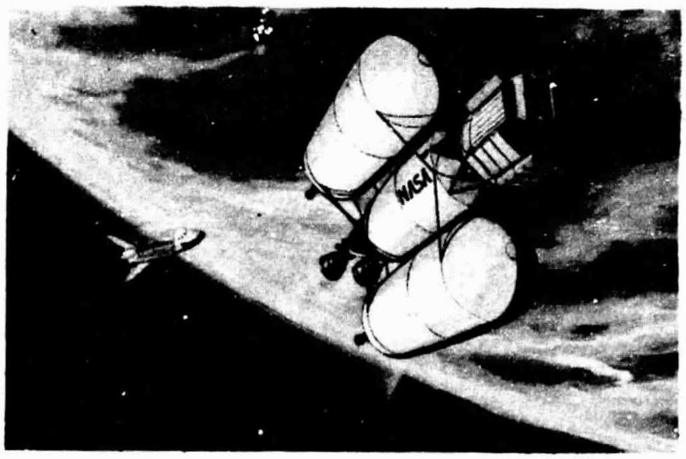
NASA CR-
160429

MANNED GEOSYNCHRONOUS MISSION REQUIREMENTS & SYSTEMS ANALYSIS STUDY

volume 1
executive summary



GRUMMAN AEROSPACE CORPORATION

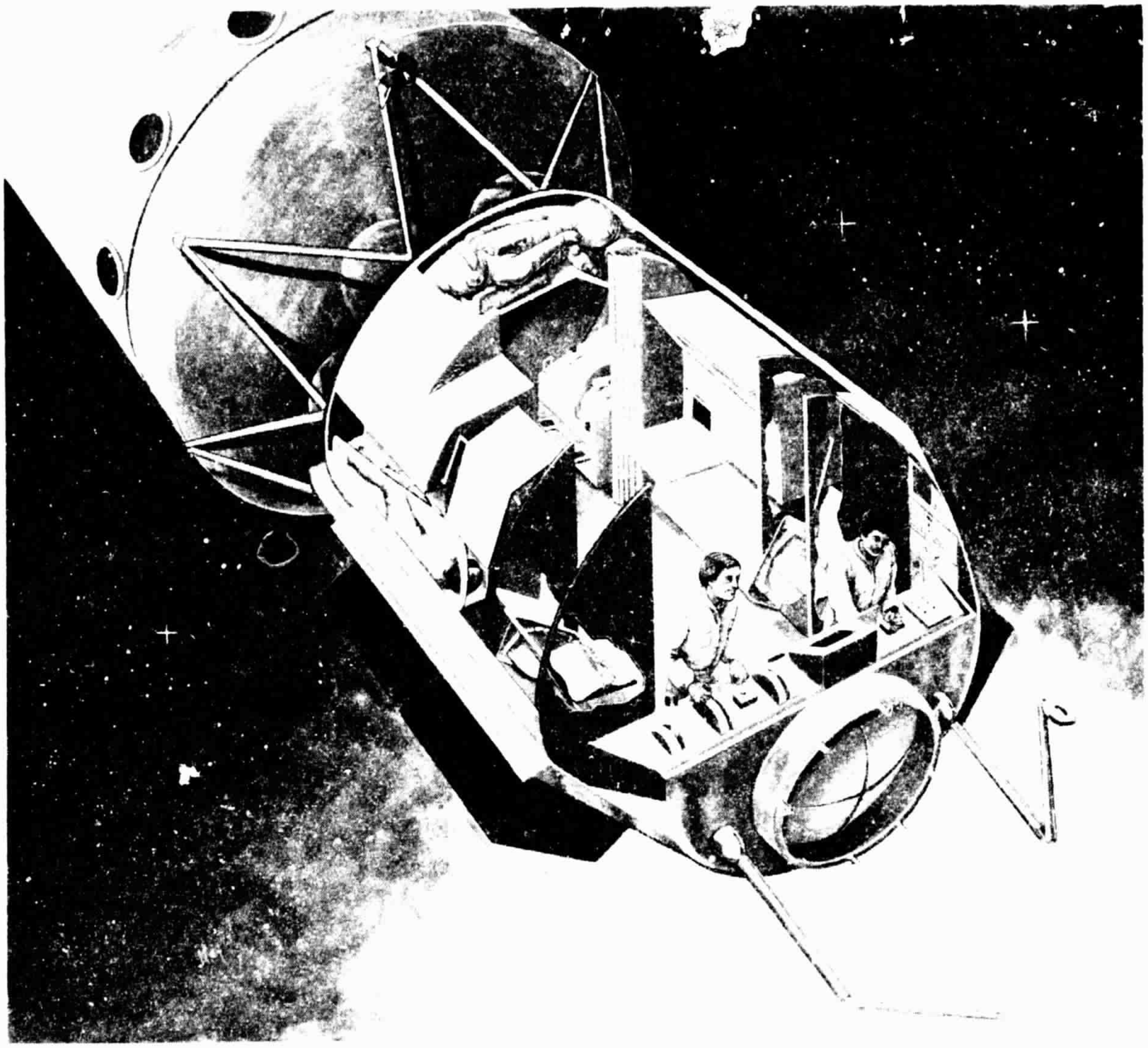
MANNED GEOSYNCHRONOUS MISSION REQUIREMENTS & SYSTEMS ANALYSIS STUDY

volume 1
executive summary

prepared for
National Aeronautics and Space Administration
Johnson Space Center
Houston, Texas

prepared by
Grumman Aerospace Corporation
Bethpage, New York 11714

November 7, 1979



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FOREWORD

This final report documents the results of a study performed under NASA Contract NAS 9-15779. The study was conducted under the technical direction of the Contracting Officer's Representative (COR), Herbert G. Patterson, Systems Design, Johnson Space Center. Mr. Lester K. Fero, NASA Headquarters, Office of Space Transportation Systems, Advanced Concepts, was the cognizant representative of that agency.

The Grumman Aerospace Corporation's study manager was Charles J. Goodwin. The major contributors and principal investigators were Ron E. Boyland, Stanley W. Sherman and Henry W. Morfin.

This final report consists of the following volumes:

- Executive Summary - Volume 1
- Mission Handbook - Volume 2
- Program Requirements Document - Volume 3
- Supporting Analysis - Volume 4
- Turnaround Analysis - Volume 5
- Five Year Program Plan - Volume 6

1 – INTRODUCTION

The first Orbiter flight will usher in a new era in which manned missions to Low Earth Orbit will become commonplace. The extension of regular manned operations to Geosynchronous and other high energy orbits, as depicted in Fig. 1-1, is the next logical extension of this capability. The objective of this 12-month study has been to determine the types of manned missions that will likely be performed in the late 1980's or early 1990's timeframe, define MOTV configurations which satisfy these mission requirements, and develop a program plan for its development.

Since the primary focus of this study was on the crew capsule, particular emphasis was given to crew accommodations, crew capsule functional requirements, subsystem interface definition between crew module and propulsion module, and man rating requirements. A brief study of competing mission modes was also incorporated in this study and covered a wide range of propulsion concepts. These included 1 stage, 1½ stage, and 2 stage concepts using either the standard STS or an augmented STS. Several de-orbit concepts were also considered, including all-propulsive modes (APOTV), direct re-entry like Apollo (AMRV), and aeromaneuvering skip-in skip-out in the upper reaches of Earth's atmosphere (AMOTV).

The study also considered various turnaround modes which compared ground turnaround to Shuttle-tended and SOC turnaround. A five year plan covering costs, schedules and critical technology issues which need early resolution completes the task requirements under this contract. All costs quoted in this report are in 1979 dollars. The sections which follow summarize the salient results of this 12-month study.

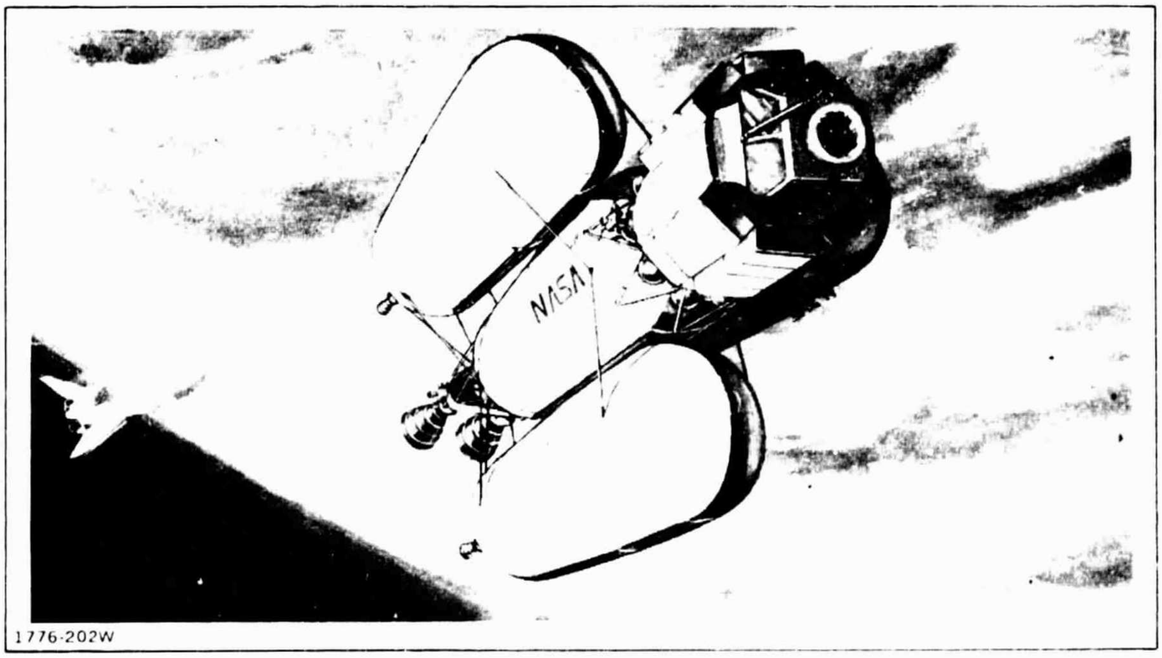

Fig. 1-1 MOTV Transfer to GEO

2 – MISSION & MISSION REQUIREMENTS

Although there are no officially sanctioned programs which depend on the early availability of an MOTV, there are over 100 proposed future space programs which could substantially benefit from an OTV and man's presence in high Earth orbit. Satellite deployment, construction, check-out and repair are some obvious uses of an MOTV. Among these many potential user programs there are several areas of overlap. There are, for example, at least seven Public Service Platform (PSP) concepts covering 24 separate Communication, Detection & Control, and Earth Observation functions. Analysis of these PSP concepts leads to the conclusion that such programs are still some distance in the future. Undoubtedly, some of these PSP's will be built, but their size and cost will likely dictate that provisions be made for maintenance, updating and growth. More than half the remaining potential user programs make use of space construction, mostly in the weight range from 15,000 Kg to 50,000 Kg. The remainder of the user programs involve crew rotation and resupply missions to space bases, and servicing, repair and retrieval of military satellites.

2.1 Generic Missions

For this study, the mission features of interest are the services that the MOTV will be called upon to provide. Based on analysis of the Potential User Programs, 20 generic MOTV missions have been defined, each providing a specific service. In order to keep these applications general, none of them are narrowly or directly related to any particular user program. Details of these 20 missions are included in the Mission Handbook, Volume 2.

The 20 generic missions are intended to give convenient, cookbook coverage for user planning, but a smaller number of these - seven - have been selected for more detailed use within this study. Figure 2-1 summarizes these two sets. The full set of 20 generic missions are grouped into four manned and one unmanned categories and cover a wide range of mission characteristics. The operational orbits are mostly geosynchronous, but with some going in 12 hour/63° inclined or deep space (400,000 n mi) orbits. The mission hardware (cargo) has a spread of nearly two orders of magnitude, while crew size varies from 2 to 3, not including passengers. Mission duration ranges from 3 to 30 days. The seven missions selected for detailed study embrace the same range of orbits, crew size and MOTV duration. The cargo weights are also typical of each class of generic mission.

These missions, both the "20," and in greater detail the "seven," have been analyzed to derive MOTV mission requirements. Their more important characteristics are reviewed under the following headings:

- Orbits and missions durations
- Crew size and IVA/EVA mix
- General Purpose Missions Equipment
- Payload Requirements.

Orbits and Mission Duration. A nominal assembly, departure and recovery altitude in Low Earth Orbit for MOTV of 370 Km (200 n mi) 28½° inclination has been chosen based on superior Shuttle performance to that orbit. From this orbit the generic missions depart for three different working orbits. Geosynchronous orbit is the most frequently used and requires a 4209 m/sec (13,810 fps) one-way delta V for the transfer (transfer time varies from about seven to 13 hours, depending on the number and duration of main engine propulsion burns). The highly elliptic 12-hour orbit, typical of lower energy orbits that are beyond the reach of the Shuttle, requires a 3344 m/sec (10,971 fps) one-way delta V, and has about the same transfer times as GEO missions. The deep space orbit, nearly twice as far out as the moon, requires 3785 m/sec (12,418 fps) one-way delta V, and a transfer time of about 14 days each way.

GENERIC MISSION		SCENARIO CHARACTERISTICS				
CATEGORY	SYMBOL	ORBIT	MISSION HDWR, Kg	CREW	DURATION, DAYS	DESCRIPTION
INSPECTION SERVICE & REPAIR	IN1	GEO	510	2	4	SCIENTIFIC SATELLITE REVISIT
	[S1]	GEO	1684	3	19	MODULAR LEVEL SERVICE
	S2	GEO	2966	3	27	COMPONENT LEVEL SERVICE & UPDATE
	S3(a)	GEO	2600	2	21	SERV & UPDATE NUCL PWRD SATS
	S3(b)	GEO	2600	2	3	REPLACE NUCL REACTOR
	ER1	GEO	453	2	4	EMERGENCY REPAIR (GEO)
	[ER2]	12 HR/63	272	2	4	EMERGENCY REPAIR (HEO)
	R1	12 HR/63	4100	3	2	FAILED SATELLITE
OPERATION OF LARGE SPACE SYSTEM	OP1	GEO	440	2	16	TENDED STD
	P1	GEO	1683	2	4	3 MAN CREW ROTATION/RESUPPLY
	[P2]	GEO	4485	2	4	10 MAN CREW ROTATION/RESUPPLY
	P3	GEO	16,819	2	4	30 MAN CREW ROTATION/RESUPPLY
	[P4]	DEEP SPACE	3364	2	30	6 MAN CREW ROTATION/RESUPPLY
DEBRIS REMOVAL	[DR1]	GEO	550	2	9	REMOVE DEBRIS FROM 45 SECTOR OF GEO
CONSTRUCTION	C1	GEO	10,000	2	3	UNFOLD WIRE WHEEL ANTENNA
	C2	GEO	16,000	3	6	UNFOLD COMMUN PLATFORM
	[C3]	GEO	17,000	3	6	PREFAB COMMUN PLATFORM
	C4	GEO	15,000	3	7	AUTOFAB COMMUN PLATFORM
	C5	GEO	110,535	3	14/5/5/5	AUTOFAB SPDA
	[C6]	GEO	–	2	17	MODULAR ASSY SPDA
UNMANNED CARGO	UC	VARIOUS	15,000 55,000	NONE		SECONDARY ROLE

SYMBOLS

- IN = INSPECTION
- S = SERVICE
- ER = EMERG REPAIR
- R = RETRIEVAL
- OP = OPER. LG SPACE SYSTEM
- P = PASS. TRANSPORT
- DR = DEBRIS REMOVAL
- C = CONST
- UC = UNMAN. CARGO

[ ] SELECTED FOR DETAILED STUDY

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Fig. 2-1 Generic Mission Summary

The 12-hour orbit and the deep space transfer orbit both present special hazards to the crew with respect to radiation: the 12-hour orbit because of repeated passages through the Van Allen Belts; the deep space transfer orbit because the crew are at long-term risk in the event of a major solar storm at mid passage. Solutions to these hazards are discussed in the Systems Requirements section.

Generic mission durations are the sum of orbit transfer times, on-orbit work time and, for some missions, the time spent phasing in orbit from work site to work site, as shown in Fig. 2-2. As previously mentioned, only the deep space crew station mission (P4) has a significant transfer time, 28 days roundtrip. On-orbit work times vary from one or two shifts, for the single satellite inspection or repair missions, up to 20 shifts for the largest construction mission. On-orbit phasing is exemplified by modular service mission (S1). Four satellites are visited in turn for servicing and updating; this involves three 90° phasing operations. Each phasing occupies four days, a duration chosen after trading the propellant weight needed for shorter times against the system cost of keeping an MOTV longer in orbit.

Crew Size and IVA/EVA Considerations. Based on a preliminary analysis of the specific tasks involved in each generic mission, the minimum MOTV crew size was fixed at two. However, larger numbers might have been justified if:

- Possible cost benefits accrued from a large crew/short duration mission as compared with a smaller crew/longer duration approach
- The need arose for a greater range of skills than two can provide
- EVA safety considerations dictated.

The only missions likely to show a cost reduction for larger crews are "construction" missions where all the work is performed at one

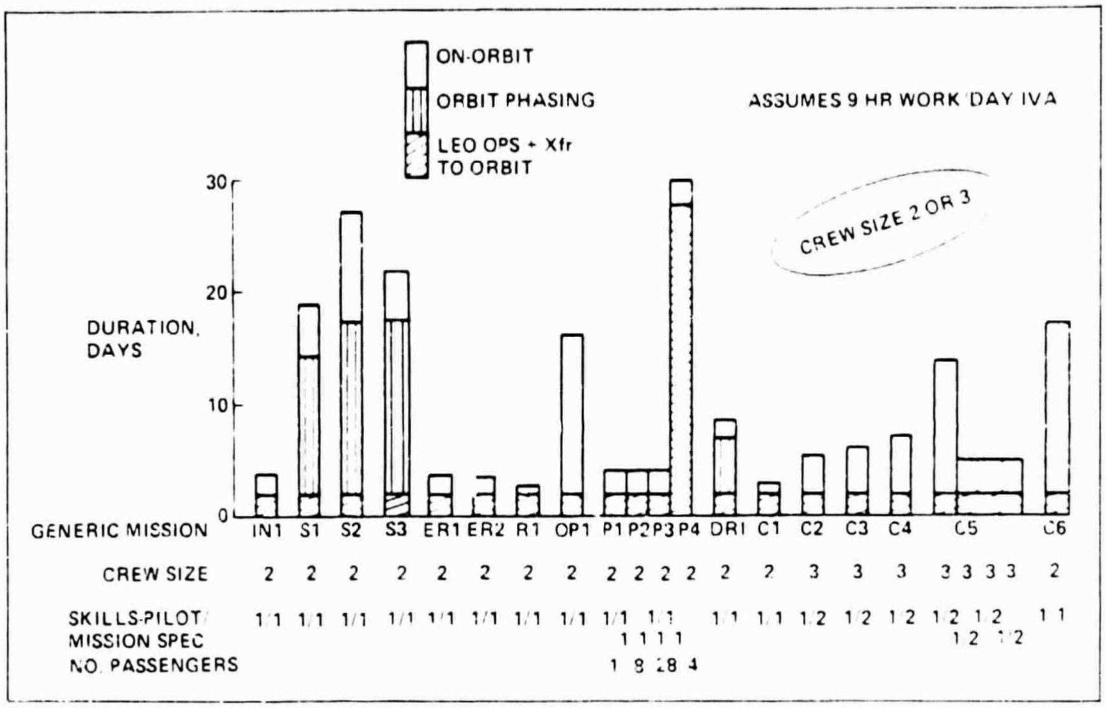

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Fig. 2-2 Generic Mission Duration, Crew Size, & Skill Requirements

site and lasts for many shifts. "Service" type missions, where a large proportion of the mission time (80 to 90%) is spent in orbit transfer or phasing operations and the work at each site frequently lasts less than a shift, are unlikely to show any cost benefit. A cost trade for a typical construction mission showed that a crew of three might start to be cost effective after 15 days of work. Since nearly all construction missions lie at or below this figure, this is not a strong motive for a crew of three or more.

Analysis of a construction and a service mission showed that the skills demanded, particularly when backed up by ground support personnel, do not appear to be excessive (consider previous manned space missions, fighter pilots, etc.). Our conclusion is that for routine missions of this sort the skills of a crew of two will usually be adequate. Occasionally, specialist expertise in scientific or defense matters is required and can be met by providing a third crew member.

A limited number of crew functions are basically concerned with "internal" tasks - navigation, piloting, remote inspection, capsule housekeeping and subsystem monitoring. Much of the productive work, however, is "external" work, i.e., construction, satellite servicing, updating, repair. These "external" tasks can be performed in an Intra-Vehicle Activity (IVA) mode, with the crew working inside the capsule controlling external dexterous manipulators, or they can be accomplished in an Extra Vehicle Activity (EVA) working mode, with the crew working outside the MOTV in space suits. For predictable, and well rehearsed external tasks where manipulator tools and adaptors have been developed, analysis shows that IVA is the more efficient mode. However, for contingency tasks which require close proximity to the work and ad-hoc workaround's, EVA is expected to be an essential ingredient. Most of the construction and service missions are expected to require EVA quite frequently. In these instances the "buddy" system is used for safety. The shorter inspection and recovery missions, as well as the crew rotation missions, will be provided with EVA capability, but are not expected to employ it with any regularity.

Thus it is assumed that every mission may involve EVA either as a normal work mode or for contingency/emergency operations. When one EVA crew member is outside, it is axiomatic that another will be suited up and ready to go out and help with a two-crew EVA task or to come to the aid of his buddy. At such times, the prospect of leaving the MOTV crew capsule untended is not a comfortable one and may lead to overhurried external work patterns. Therefore, for any mission where significant amounts of EVA are planned, a third crew member is carried as a matter of course.

General Purpose Mission Equipment. It appears that all missions require EVA suits, cabin suits, external EVA hand grips and tools and cargo mounting rails. All missions except crew rotation missions also require dexterous maniupulators and a grappler.

In the interests of economy these items are treated as General Purpose Mission Equipment - servicing virtually all missions. As may be seen in Fig. 2-3, current analysis of the seven generic missions shows that for the EVA suits, manipulators and grappler, the specifications vary from mission to mission. If the radiation protection afforded by the EVA suit is designed for the worst radiation environment, the mobility provided for other missions is impaired. Similarly, the requirements for the dexterous manipulator and grappler reaches and intertia loads are seen to vary, possibly requiring different sets of hardware instead of the more desirable common hardware. For capsule design purposes, we have selected compromise specification values for these items and believe that eventually acceptable performance levels will be established for across-the-board use.

Payload Requirements. Mission payload requirements for all generic manned OTV missions are summarized in Fig. 2-4. Here, payload is taken to mean everything forward of the propulsion module (the crew capsule, the crew and their com-

EQUIPMENT	S1	ER2	P2	P4	DR1	C3	C6
1. MANIPULATORS							
– REACH (M)	2	3	NONE	NONE	4	4	2.5
– DOF	7	7	REQD	REQD	7	7	7
– NO. REQD	2	2			2	2	2
– INERTIAL LOAD (Kg)	190	100			5500	1100	100
2. GRAPPLER							
– REACH (M)	2	2	NONE	NONE	1.5	2	2
– DOF	4	4	REQD	REQD	2	4	2
– NO. REQD	1	1			1	1	1
– INERTIAL LOAD (Kg)	6000	4100			50,000	1700	140,000
3. DOCKING			INT'L	INT'L	IVA & EVA EQUIP REQD		
– TYPE	NONE	NONE	DOCK	DOCK			NONE
– NO. REQD			(1)	(1)			
4. STOWAGE SYSTEM							
– RAIL SYSTEM	YES	YES	YES	YES			YES
– MOUNTING RACKS	YES	YES	YES	YES			YES
– OTHER RACKS	YES	YES	NO	NO			YES
5. ASSEMBLY JIG	NO	NO	NO	NO	NO	YES	NO
6. SATELLITE DEACTIVATION	YES	YES	NO	NO	YES	NO	NO
7. EVA EQUIP (SUITS, ATTACH)	YES	YES	YES	YES	YES	YES	YES

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Fig. 2-3 Generic Mission Equipment Requirements

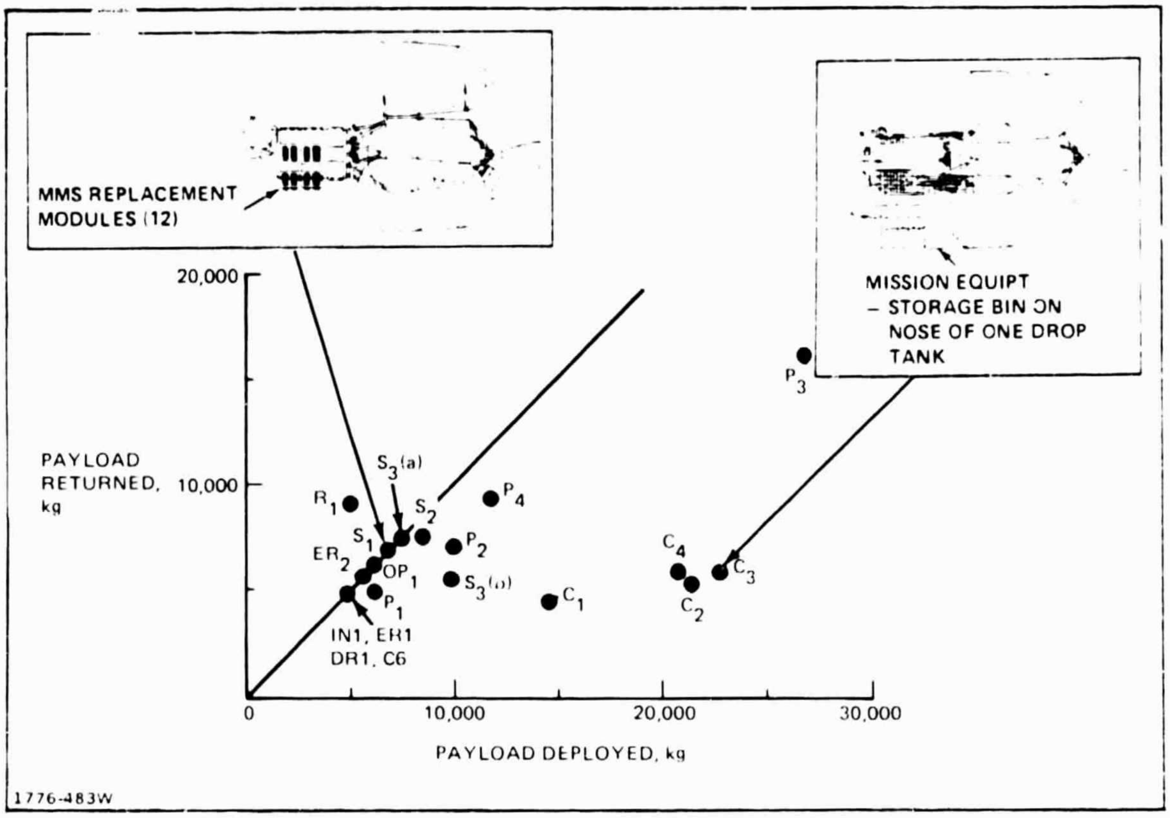


Fig. 2-4 Generic Mission Payload Requirements (25% Crew Module Weight Contingency)

mander, the general purpose equipment and any cargo). In general, the missions cluster in two categories, those which require "roundtrip" capability and those which are "mostly deploy." Most of the inspection, service, repair and passenger transport missions fall into the roundtrip category. For the construction missions, about one-fourth the amount of payload deployed is returned. These missions are the most demanding in terms of MOTV payload performance and equipment needed for their support. Generic mission P3 is not shown on the chart. This mission is a 30-man crew rotation/resupply mission to GEO requiring a deploy payload of 27,454 Kg, and a return payload of 16,119 Kg. The inset configuration pictures depict the difference in payload packaging for the two categories of generic missions.

These characteristics, the mission orbits and durations, the crew size and the interplay of IVA and EVA, the general purpose mission equipment, and the payloads, all define the mission requirement.

To permit the establishment of an MOTV point design and as a frame of reference for sensitivity analysis when comparing the manned OTV requirements of other generic missions, generic mission S1 has been selected as a Design Reference Mission (DRM).

This mission, which services four MMS-type satellites in GEO, was chosen because:

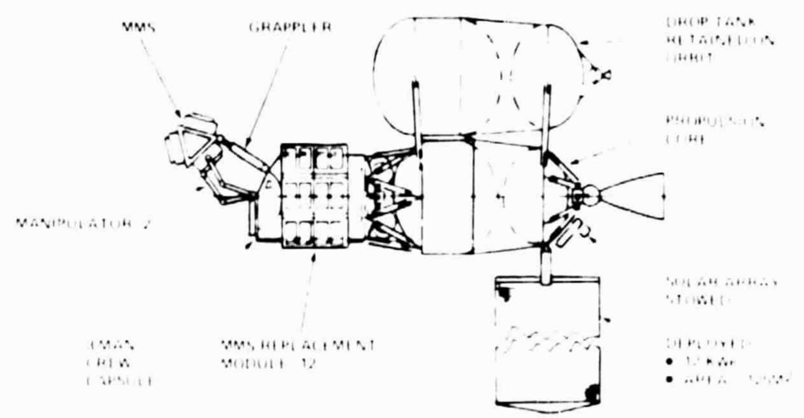
- Its functions and capabilities are typical of 95% of the generic missions
- Its payload requirements, Fig. 2-4, lie midway between the least and most ambitious manned missions
- It is a likely, cost effective, future mission showing a net cost benefit for servicing of $100M to $200M per mission.

The characteristics of this mission and the MOTV configuration which goes with it are summarized in Fig. 2-5.

This 19-day mission involves servicing and updating four communication satellites, widely separated in geosynchronous orbit. The crew capsule has mounting rails which carry the external cargo and new subsystem modules which will be exchanged for the old units on the satellites to be visited. The cabin accommodates a crew of three, and has at the front a work station/flight deck, a berthing hatch, two dexterous manipulators, and a stabilizer ("grabber") that captures and holds the satellites to be worked on.

The core propulsion module lines up behind the crew capsule and carries the two main engines, the guidance and RCS subsystems, and tanks for the cryogenic propellent that will be used at the end of the missions. The rest of the propellant is carried in drop tanks mounted around the propulsions core. The number of add-on tanks can go as high as four and is mission dependent; three are needed for S1. These drop tanks – the only expendable items on the MOTV – are provided with a disposal impulse so that, when empty, they can be de-orbited to Earth and burned up in the atmosphere; there is no space debris.

The stack weight of the MOTV for this particular mission is 99,091 Kg and its main elements are summarized in Fig. 2-6. Four standard capacity Shuttle flights suffice to lift the MOTV and its propellant (84% of the total) into LEO for assembly. The sequence is shown in Fig. 2-7; the first flight launches the crew capsule, cargo, propulsion module and its propellant. Flights 2,



A DESIGN REFERENCE MISSION HAS BEEN ESTABLISHED BETWEEN NASA/JSC & GRUMMAN WHICH HAS THE FOLLOWING CHARACTERISTICS:

• MISSION OBJECTIVE	SERVICE 4 MMS SATS 90 APART
• CREW SIZE	3
• MISSION DURATION	19 DAYS
• PAYLOAD DEPLOYED	6883 Kg
RETURNED	6883 Kg
• ORBIT	GEO
• NO STS FLTS FOR MOTV ASSY	4
• TOTAL VELOCITY INCREMENT	29,849 FT/SEC
• START BURN WT IN LEO	99091 Kg
• COST PER MISSION	$118 M

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Fig. 2-5 Characteristics of MOTV for Design Reference Mission

	CREW CAPSULE	PROP'LS'N CORE	DROP TANKS (3)	MISSION EQUIP'T GENERAL PURPOSE	MISSION EQUIP'T DEDICATED
DRY WEIGHT	3951	3328	4725	773	120
CREW/CONSUMABLES	577	51			
RESERVES/RESIDS		296	705		
BURNOUT WEIGHT	4528	3675	5430	773	120
[illegible] IN PROP – (CAPACITY)		(17,500)	(81,810)		
– LOADING		13,404	66,762		
ACPS PROP		2570			
MISC		145			1684
MOTV WEIGHT	4528	19,794	72,192	773	1804
TOTAL MOTV WEIGHT	← 99,091 →				

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Fig. 2-6 S1 Summary Weight Statement, Kg

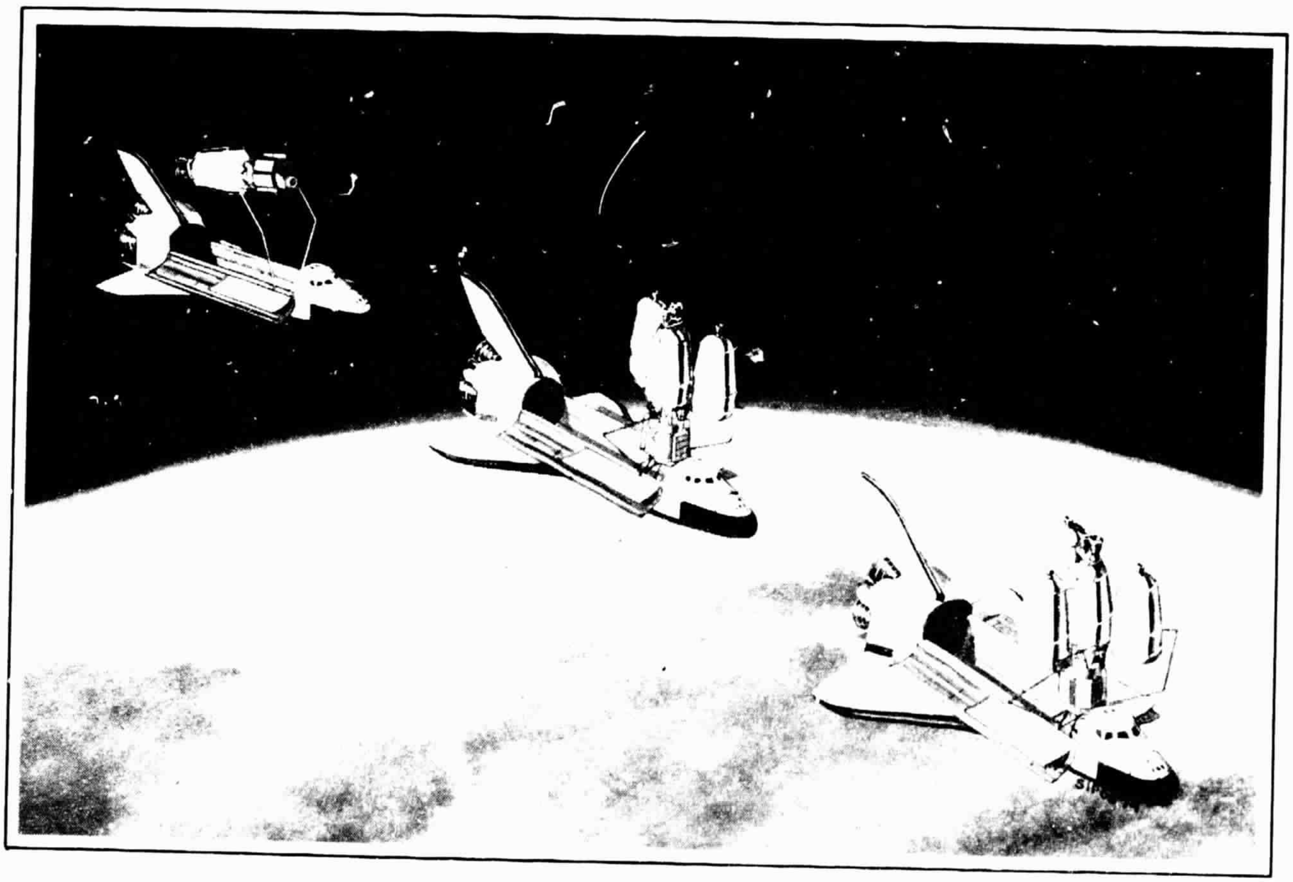

Fig. 2-7 MOTV Assembly Sequence

3, and 4 bring up the drop tanks for assembly to the core – each full drop tank constitutes a totally loaded STS. The MOTV crew arrive in LEO on the fourth flight, fly the MOTV phase of the mission and return after 19 days, rejoining the Shuttle that brought them up. The whole mission, from the first Shuttle launch to final Earth return, is supported by one Shuttle and takes a total of 71 days.

The geosynchronous part of the mission includes the phasing operations when the servicing/updating MOTV moves from satellite to satellite. Each phasing covers 90° of orbit and takes four days; this constitutes a compromise between the weight of on-orbit propellant used and the cost of extra mission days. Because of the modular nature of the MMS change-out units, the work to be done at each satellite is estimated to take only one shift.

Although mission cost/benefit analysis has not been part of this study, it is worth noting that while the recurring cost of this mission is $118M (93% of which is attributable to the Shuttle), the benefit, based on the replacement value of these satellites, ranges from $120M to $200M – compared to the cost of servicing.

3 -- SYSTEM REQUIREMENTS & MAN RATING

The first and most important system requirement is that the MOTV perform the generic missions. The current concept vehicle performs them all, with the exception of P3, which involves the rotation of 30 people to and from a geosynchronous station. The MOTV could transport the weight and a special passenger capsule could be provided, but handling 30 people in Low Earth Orbit will require a modified Shuttle or a Space Station, neither of which is part of the present MOTV total system.

A related general requirement calls for non-recurring costs and recurring costs to be minimized. With no established traffic model the MOTV concept tends to emphasize development, rather than operating, economies. At present, the most cost effective way of reducing MOTV operating costs would be the development of a higher Shuttle payload capability.

After mission performance, the most important system requirements are those imposed by man rating. In this area, crew safety is the major concern, and it has several aspects.

Reliability, Safety and Mission Success. Both safety (man rating) and mission success involve reliability requirements, but from different points of view.

Safety is chiefly concerned with only those system capabilities that are needed to get a crew back to Earth unharmed. These fail-safe capabilities, which may be degraded from nominal, must have as a minimum an overall reliability level at which astronauts, program management and, ultimately, public opinion are prepared to see manned MOTV missions flown on a routine basis.

Mission success, as distinguished from crew safety, is chiefly concerned with money. The benefits of a higher probability of mission success are traded against the cost of the increased reliability needed to achieve that success. All the system capabilities needed for a particular mission are involved, not just those necessary for crew survival.

From an analysis point of view, these two approaches are separate, but the design and development of each subsystem must take account of both.

Safety (Man Rating). To establish a frame of reference, the likelihood of commercial airline pilots, policemen, firemen or underground miners losing their lives in job-related incidents, in the course of their whole careers, varies between one chance in 120 and one chance in 10. The safety level of the MOTV/STS combination should be such that an MOTV space crew member will have a comparable chance of surviving his career number of MOTV missions.

The figures proposed for early MOTV operations are:

- MOTV crew member career risk = 1 in 50 (i.e., crew career survival rate = 0.980)
- Assumed number of missions per crew member = 10
- Hence, crew mission survival rate = 0.998 (1 failure in 500).

This per mission survival figure has to be allocated between the STS and MOTV phases. Making an arbitrary even division, we have:

- survival rate for STS phase of mission = 0.999 (1 failure in 1000)
- survival rate for MOTV phase of mission = 0.999 (1 failure in 1000)

The initial crew member career risk of one chance in 50 was selected, bearing in mind that the safety record of transport systems improves with time when developed diligently (typically, experiencing a halving of risk with 20 years of use). The program risk - one mission catastrophe in 500 - translates, at six missions per year, into one mission lost in about 80 years.

Turning now to the Man Rating of the MOTV, the overall catastrophic failure probability for the MOTV part of the mission is the sum of the failure probabilities of those particular subsystems that assure safe return of the space crew (not those needed for mission success). "Failure" means that the subsystem performance, together with any alternate capability, has fallen below the minimum needed to get home.

Future feasibility and cost studies, together with component development work, will establish the approximate distribution of overall failure probability among these critical subsystems. In the meantime, as a guide to current studies, a first cut allocation of this distribution is given in Fig. 3-1. The percentage column shows the proportion of catastrophic failures "allowed" for each subsystem. The final column shows the same distribution in terms of the mean number of missions between fatal failures scaled to match the previously discussed overall safety level of one fatal MOTV failure in 1000 missions.

Fail-Safe Engineering Considerations. To achieve a fail-safe standard demands attention to one prime design goal, and to several detail requirements. The design goal – to minimize single point failures – is usually met by appropriate levels of duplication, but it cannot be made absolute. For instance, the present MOTV has a double-walled pressure cabin and two main engines; but cabins can develop dormant leaks, and one engine – in failing – might damage another. Meeting this design goal economically will be a major challenge for all working on the MOTV.

CRITICAL SUB-SYSTEM	% ALLOCATION	MISSIONS PER CATAST FAILURE
MAIN PROPULSION	50	2,000
RCS	7	14,000
EPS	8	12,000
AVIONICS	10	10,000
ECLS	10	10,000
RADIATION PROTECTION	12	8,000
CREW TRANSFER	3	30,000
FOOD/WATER	0	∞
OVERALL STRUCTURE	0	∞
1776-190W		

Fig. 3-1 Preliminary Allocation of Catastrophic Failures

The detail requirements are more readily met and are incorporated in the present MOTV concept. Firstly, the concept affords ground and on-orbit monitoring of crew health, subsystems "health" and radiation levels (as discussed later). Secondly, the concept carries reserves – main and RCS propellant, power and atmosphere make-up and food and drinking water (the quantities vary from mission to mission). Thirdly, it has provisions for EVA by two of the crew. Fourthly, it has the ability to abort (the abort trajectories are dependent on the mission phase, and in some cases are different for different abort causes).

Radiation Protection. The allowable radiation doses for the MOTV crew are the same as for the Shuttle crew. For a typical mission in geosynchronous orbit under "normal" conditions, the protection against electrons provided by the crew capsule and EVA suits permits about 30 missions each of 20 days duration before a crew member's carreer limit is approached.

From time to time "solar events" appear which, for a few days, subject any object in geosynchronous orbit or beyond to high energy proton fluxes. If a solar event occurs during a mission, the operational response will depend on its severity. The flux build-up will be monitored and if the total flux threatens to rise above a threshold figure – tentatively set at 10^8 p per cm^2 for protons charged above 30 MEV – then the mission will be cut short and the MOTV will retreat to below the protective shield of the Van Allen Belt. A safety margin is built into the accuracy of the flux forecast because the capsule can protect the crew against a flux an order of magnitude bigger than the threshold figure. It is interesting to note that present forecasting methods differ in predicted dose rates by factors of as much as 30. This uncertainty is unacceptable, and must be greatly reduced before MOTV crew safety can be adequately assured. It is a critical MOTV technology requirement that this real-time flux forecast capability be available in time for the first MOTV flight. These protective measures are summarized in Fig. 3-2.

This during-the-event forecast is for safety. In addition, in the interest of economy it is an MOTV system goal that presolar-event forecasting technology continues to be developed so that mission timing can be adjusted to avoid major solar events completely.

Missions using other orbits can present special problems. Working in the 12-hour highly elliptic orbit involves passing four times a day through the highly radiative Van Allen Belts, rather than the customary twice per mission. At present, missions using this orbit are of short duration; a longer one could turn out to be a radiation protection worst-case. In the P4 crew mission, the MOTV moves deep into space taking 14 days for each leg of the journey. In such orbits escape from a massive solar event is not feasible and a solar storm shelter must be taken along. This shelter, a mission peculiar add-on to the crew capsule, has thick walls and, during normal transfer, provides sleeping accommodations for two of the crew. In an emergency all six crew members can shelter in it until radiation falls or safety is reached.

Capsule Volume. Adequate cabin volume is a prominent man rating requirement not directly related to safety. Ideally the cabin size should represent a cost effective balance between crew productivity and morale on the one hand and weight penalties on the other. The minimum free volume per crew member guide that we are using is shown in Fig. 3-3. This is taken from a study by Frazer, one of several that are available. In applying this or any other guide there are some features of MOTV operations that need to be remembered.

Firstly, the MOTV crew mission duration has one or two days of Shuttle time added at each end of the LEO-to-LEO phase.

Secondly, switching from the Shuttle to the

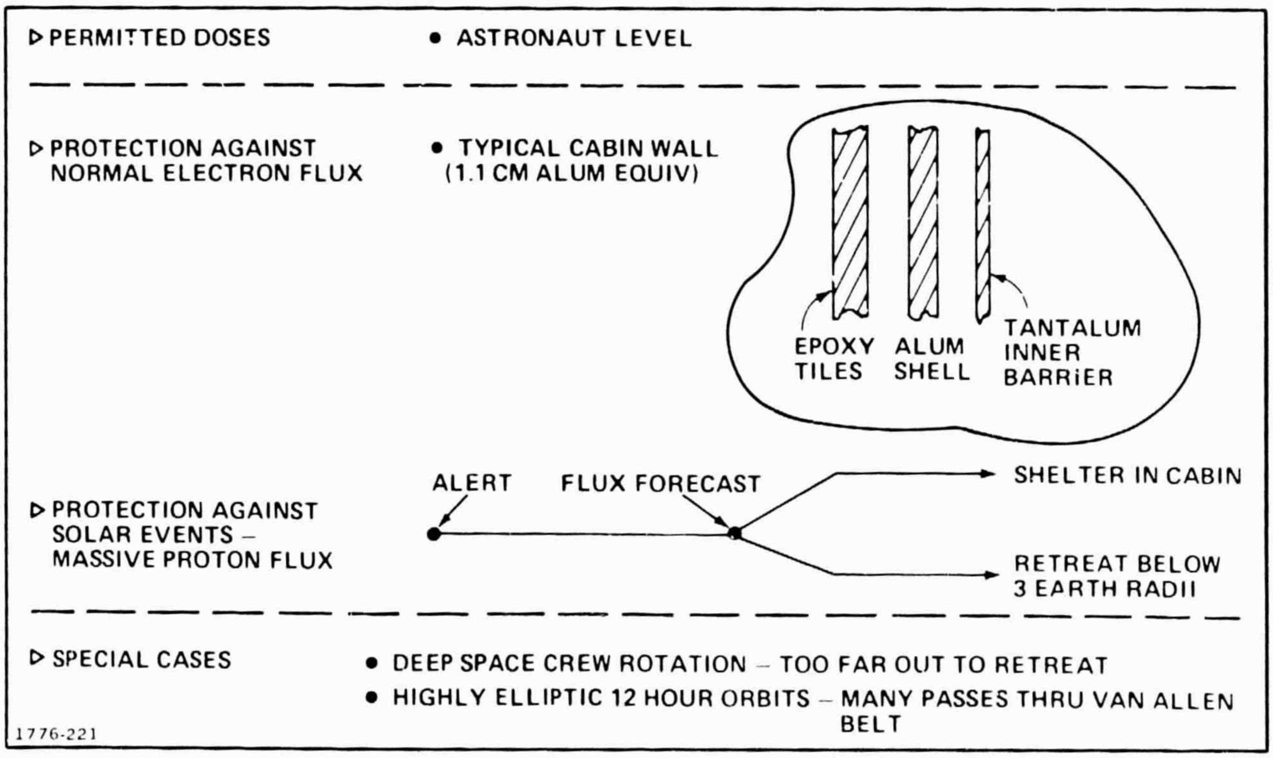

Fig. 3-2 MOTV Measures Against Radiation

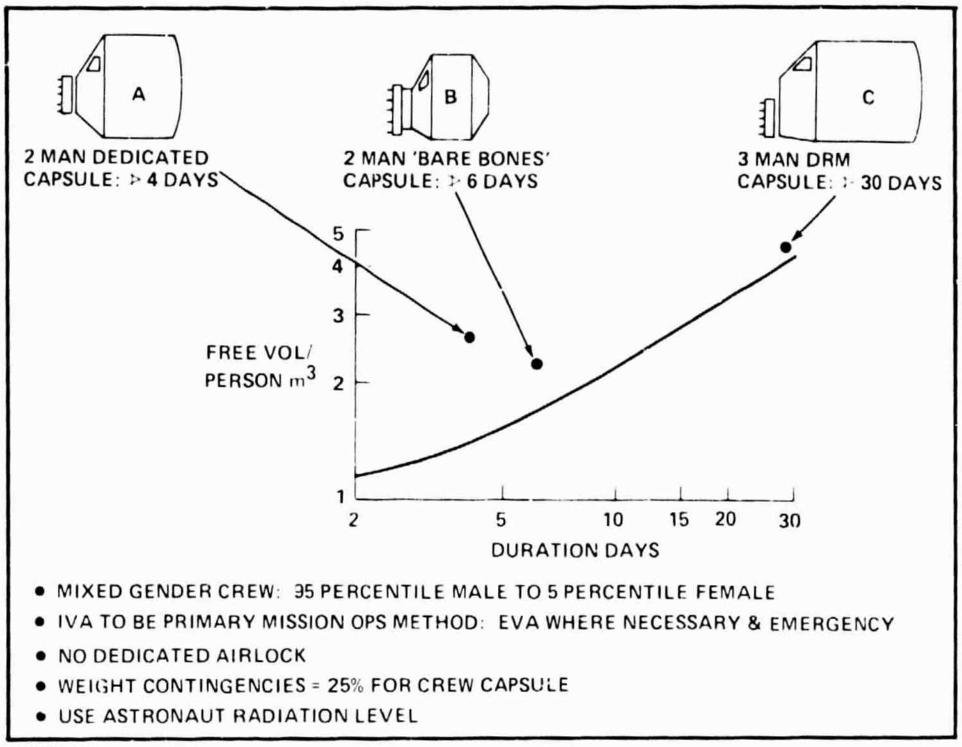

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Fig. 3-3 Minimum Free Volume per Crew Member

MOTV and back, some possible EVA time and the view of space from windows in the work station may ameliorate the effect of cramped quarters.

Thirdly, the mixed crew concept will also help crew morale.

Even after a total free volume is chosen, allocation must still be made between functional zones – work station, hygiene area, personal quarters, and a common cabin. The arrangement finally adopted will go beyond simple requirements. It will, like good architecture, represent a subjective solution.

4 — CONCEPT DEFINITION

The MOTV concept for the Design Reference Mission is described and illustrated in section 2 of this report and in Fig. 4-1. The vehicle comprises a crew capsule, which houses the crew and mounts external cargo and mission equipments, and a propulsion module. This section describes some of the logic behind these components.

4.1 Crew Capsule

Mission requirements and systems requirements, from sections 2 and 3, are the point of departure for the crew capsule design. It is sized for the basic crew of three who may be male and/or female. The total internal volume is 25 cubic meters: this provides 13 cubic meters of unrestricted free volume — a little more generous than the requirements demand — plus room for subsystems, lines runs, and internal structure.

Figure 4-2 shows the capsule layout; a single deck arrangement with a common floor that encourages a sense of spaciousness. This layout was chosen after comparison with others using transverse decks because, among other reasons, it provided maximum length vistas at eye level for most areas of the capsule. The single deck arrangement,

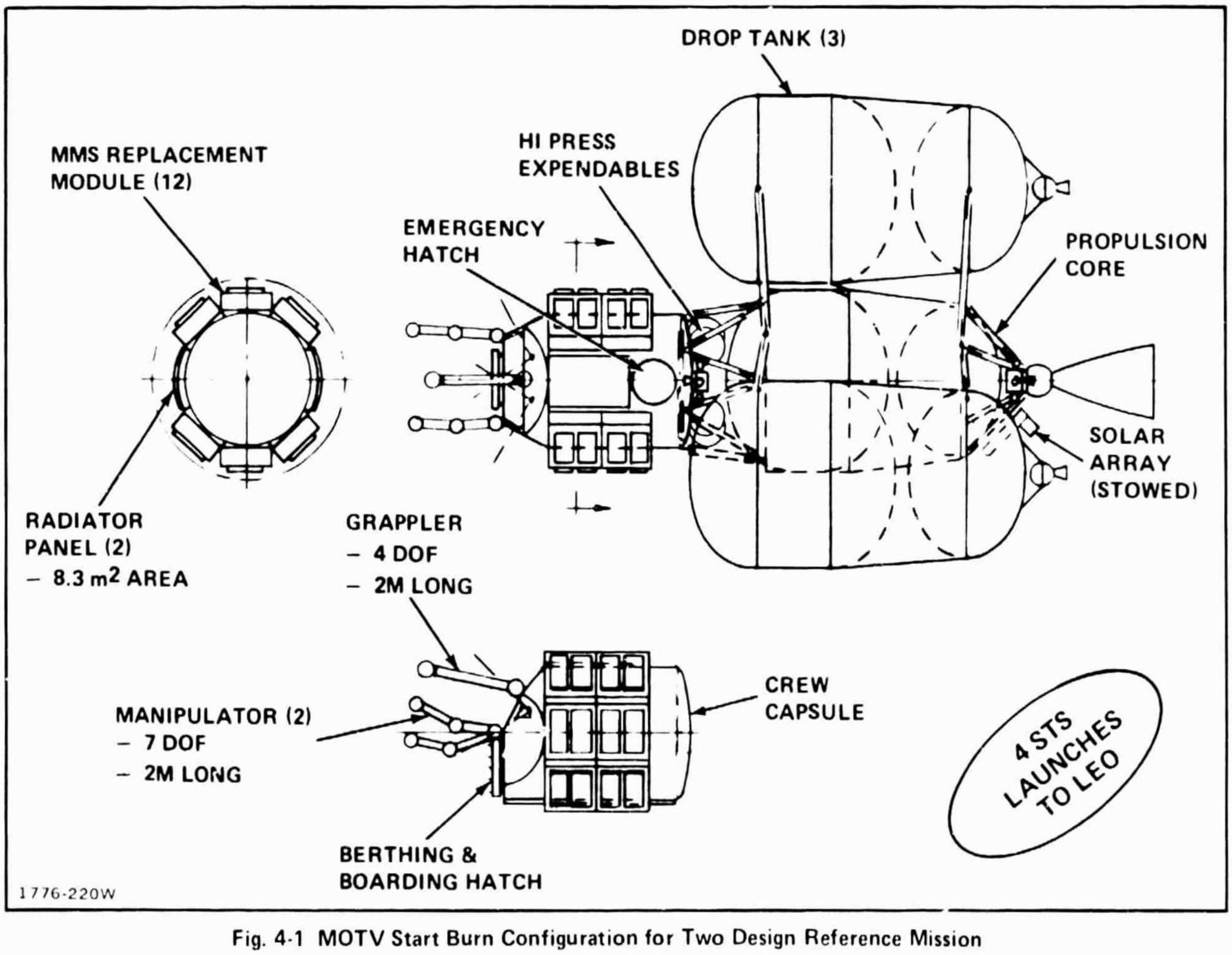

Fig. 4-1 MOTV Start Burn Configuration for Two Design Reference Mission

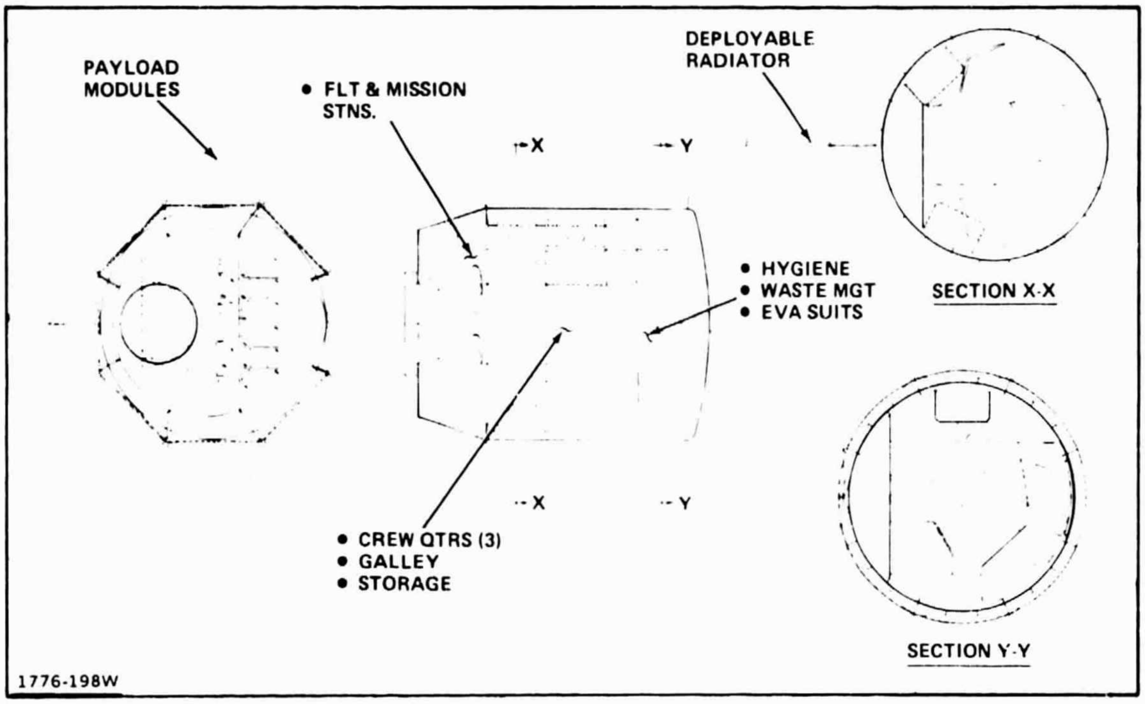

Fig. 4-2 Three-Man Crew Capsule: Design Reference Mission

combined with a 3-meter outside diameter, avoids the short-fat look and allows for the mounting of external cargo.

The interior accommodation has three functional areas. The work station at the front has large forward looking windows, control consoles, and room for two operators side by side. One position has the flight station controls and doubles for grappler operation; the other has the controls for the dexterous manipulators. Low down on the center line, between the two operators, is the berthing hatch normally used for shirtsleeve transfer. This work station configuration and the nose shape were selected after studying several alternatives. The choice was made on the basis of controller envelopes, access to the external work sites,view fields, interaction of the operators and display panel geometry.

The center of the capsule is occupied by the main cabin with two individual crew quarters on the righthand side and one on the left. Each crew member has s horizontal fore and aft berth, stowage for his clothes and gear, a recreation/resting position where he can eat, read, write, listen, or converse with his or her companions. The quarters can be open to the main cabin or closed with curtains. The central cabin area is used for food preparation, exercise, circulation, all to provide as much "roominess" as possible. The galley and food storage centers are on the left side, towards the back of the cabin

Separated from the cabin by folded doors, a combined personal hygiene and waste management compartment occupies the aft end of the capsule. The two GEO EVA suits are stowed here, and the compartment has the necessary room for donning them. A second hatch in the aft compartment roof is normally used for EVA exit and return.

4.2 Subsystems

In this study Subsystems have been defined to the level necessary to determine weights, as summarized below, and costs as listed in section 7 of this report. Another area of primary interest is those subsystems which have a gross impact on configuration. Electrical power (EPS), with its possible solar array requirements and its fuel cell reactant storage, and environmental control (ECLS), with its radiator requirements, impose such limitations. Also cf interest is the distribution of subsystems throughout the MOTV. Figure 4-3 shows the present locations of the subsystems, bearing in mind c.g. requirements, safety, access for maintainability and on-orbit repair, and the desire to minimize relocation when flying unmanned without the crew capsule. Thus, the basic electric power supply and the remote controlled guidance subsystem are with the propulsion module. The ECLS subsystem is on the crew capsule.

For the Electrical Power Subsystems, energy requirements for the 20 generic missions vary from 280 to 2970 KW hours, including in most cases a four-day reserve. The variations are pri marily due to different mission durations and crew sizes.

Viable power source options are either all fuel cells, or fuel cells with solar array recharging. A weight trade showed that, in general, missions requiring less than 800 Kw hours should use only fuel cells. This all fuel cell system utilizes cryogenic reactants and, in addition to electrical output, provides potable water for the crew capsule. The solar array recharging option, used for power hungry missions, stores water and electrolyzes it to form gaseous hydrogen and oxygen for the cells. Fuel cells are located in the propulsion module, and the solar cell array, when carried, is mounted on the core thrust structure.

ECLS design philosophy is fail-safe with a 96-hour contingency. For short-duration missions, fuel cells supply drinking water and carry breathing oxygen. Longer missions, however, cannot get water from the EPS and must recycle waste water. Two options were considered: one, to use this water for all purposes and carry gaseous oxygen; and two, to use re-

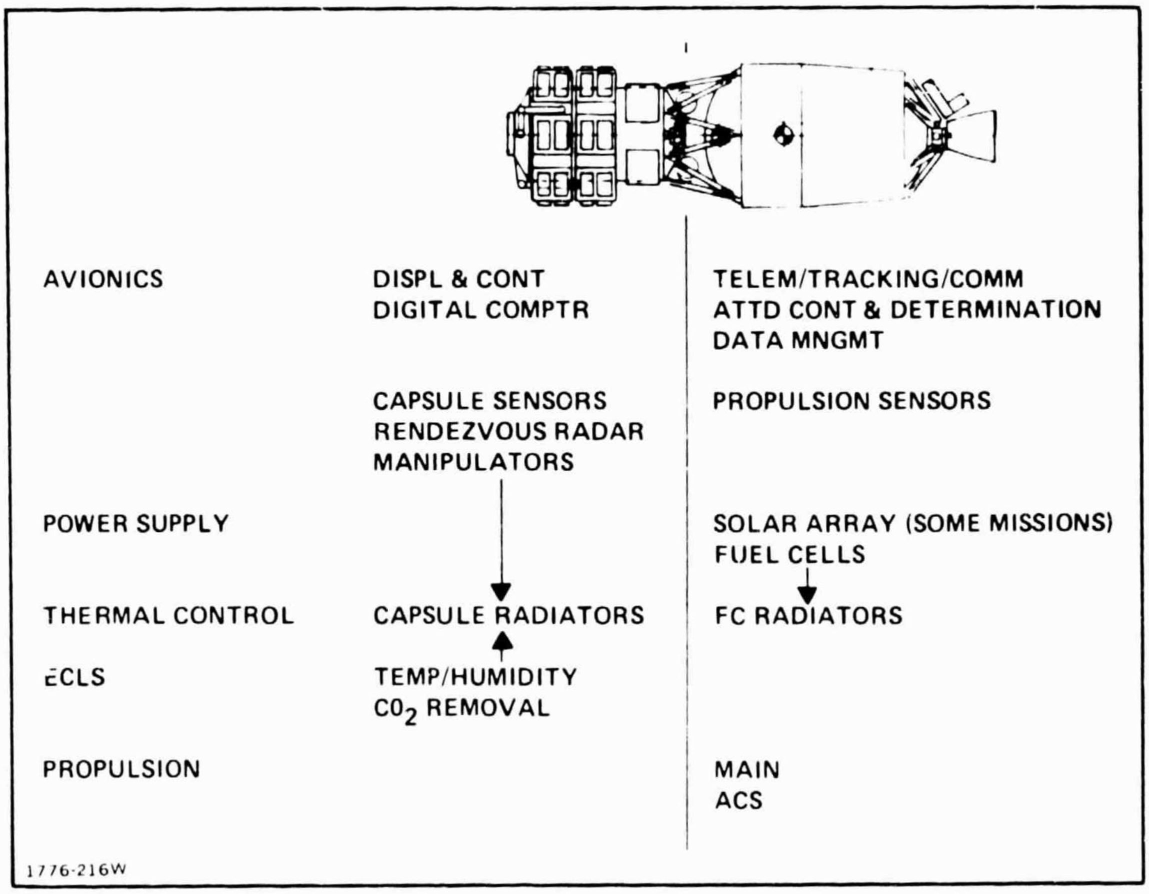

Fig. 4-3 MOTV Subsystems – Assumed Locations

cycled water for everything except drinking, carry potable water and use electrolysis for O_2 generation. The latter option was selected since drinking reclaimed water is not fully accepted and requires sterilization and monitoring of its quality. Both regenerable solid amine and the classic LiOH expendable system have been considered for CO_2 removal. For most of the missions, the solid amine appears to have the weight advantage, and it is currently the baseline.

4.3 Mission Equipment – Capsule Mounted

Dedicated mission equipment (cargo) is located external to the capsule. In the case of the DRM, the cargo is Multi-Mission Subsystem modules carried on standard mounting rails on the cylindrical shell as shown in Fig. 4-1. Also shown in that figure is General Purpose Mission Equipments. An external grappler to berth the MOTV to the workpiece satellite is mounted to the forward end of the capsule. This grappler can also move the MOTV relative to the satellite to improve the operator's view and to locate the satellite in the work envelope of the pair of manipulators. These dexterous manipulators have 7 degrees of freedom and are a bilateral force reflecting type that are presently being investigated in MRWS studies. The manipulators are operated from within the crew capsule by a master/slave system.

4.4 Crew Capsule Weight

When performing the DRM, for example, the total weight of the crew capsule together with some closely related items in the propulsion core is 6148 Kg plus 1684 Kg of cargo.

The make-up of this sum is given in Fig. 4-4 under several headings. Firstly, the capsule proper has a dry weight of 3951 Kg., the major subsystem being structure. Secondly, for reasons previously given, most of the MOTV EPS and some of its Avionics are located in the propulsion core. The EPS weight is mission dependent; for the DRM these remote items contribute 898 Kg. Thirdly, mission equipment mounted on the outside of the capsule comprises general purpose manipulators and a grappler amounting to 551 Kg; and the dedicated equipment – 1684 Kg of DRM cargo and 120 Kg for cargo support.

	CREW CAPSULE	ASSOCIATED SUBSYSTEM IN CORE	MISSION EQUIPT ON CAPSULE: GENRL PURPOSE	MISSION EQUIPT ON CAPSULE: DEDICATED
STRUCTURE	1515			
THERMAL PROTECTION	48			
EPS				
• FUEL CELLS/TANKS/LINES		306		
• SOLAR ARRAY		193		
• CONVERSION/DISTRIB	25	166		
AVIONICS	149	116		
ECLS	524			
CREW ACCOMMODATION	894			
PROPULSION CONTROLS	6			
MANIPULATORS (2)			356	
GRAPPLER, TOOLS			85	
MMS MODULES (12)				1684
SUPPORTS				96
CONTINGENCIES	(25%) 790	(15%) 117	(25%) 110	(25%) 24
DRY WEIGHT	3951	898	551	1804
CREW (3)	245			
CREW CONSUMABLES	332			
FUEL CELL REACTANTS		51		
BURNOUT WEIGHT	4528	949	551	1804

1776-219W

Fig. 4-4 Weight Summary (Kg) for Capsule Related Items (S1 Mission)

The crew of three weigh 245 Kg, their consumables 332 Kg and the fuel cell reactants 51 Kg. The total capsule, therefore, together with its remote subsystems, adds up to the aforementioned 6148 Kg, plus mission cargo. Note that the dry weight contingencies are 25%, except for the propulsion core which carries 15%.

4.5 Crew Capsule Modularity

The Design Reference Mission (S1) crew capsule lends itself to the concept of modular changes to satisfy changing requirements. With this three-man capsule as the departure point, Fig. 4-5 shows changes to accommodate two, four, six, and eight men or women for specific generic missions. For the two-man capsule, one crew quarter is deleted and may be replaced by equipment; externally there is no change. The four-man capsule is also unchanged externally but, internally, a crew quarter is added as shown. This same four-man capsule is used for the six-man, P4 mission to deep space. The remaining two men are accommodated in a storm shelter, which provides an emergency haven for the six-man crew in the event of an unpredicted solar flare occurring during the 14-day, one-way trip. The storm shelter mates to the aft external hatch provided in the baseline capsule. P2 mission transports eight men to GEO. The trip is analogous to a one-day coachttrip and calls for that type of facilities. Two of the crew are pilot and co-pilot, leaving six to be seated, as shown, in the center section of the capsule. Externally, the capsule shell is unchanged

Most of the generic mission require two or three crew members. They are listed under the appropriate crew number.

As other missions evolve, they may demand an airlock for multiple EVA operations or the MRWS as a positionable, shirtsleeve, work sta-

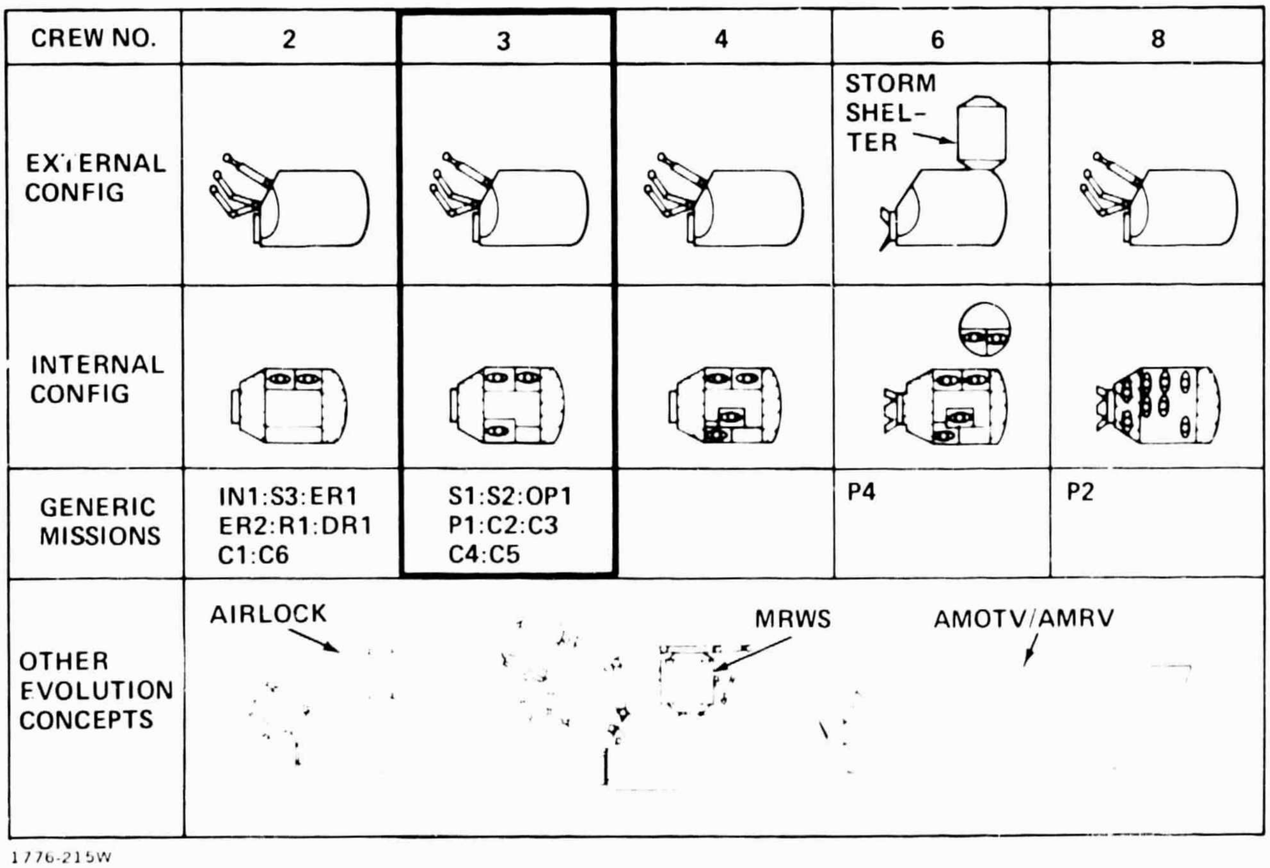

Fig. 4-5 Crew Capsule Modularity

tion. As indicated, they can be accommodated with little impact on the capsule. If evolving to an AMOTV, as illustrated, the crew capsule is of a diameter that will fit readily inside a heat shield structure designed to fit within the shuttle cargo bay.

4.6 Propulsion

By a selection process described in section 5, the MOTV has a 1½ stage propulsion system, using its main engines for all orbit transfers. Figure 4-1 shows how its propulsion comprises a core and three drop tanks. Other provisions require from one to four drop tanks.

The propulsion core is common for all missions; it has two RL 10 CAT 11B engines and a cryogenic propellant capacity of 17,500 Kg.

The drop tanks are standard for all missions and each has a cryogenic propellant capacity of 27,270 Kg. When fully loaded, the drop tank absorbs the launch capability of a standard Shuttle. Useful propellant loading of each tank is mission dependent, but the launch capacity diminishes with boil-off as the tank remains in LEO, waiting for the assembly of the drop tanks to propulsion core. When empty the tank is disposed of by a motor mounted to the LO_2 tank, which de-orbits it to burn up in the Earth's atmosphere.

5 MISSION MODES & COSTS PER MISSION

The choice of mission mode impacts the overall MOTV system, its costs, its operations, the man rating requirements and the crew capsule design. Two areas of interest have been explored.

Firstly, what propulsion system modularity and which method of returning from high energy orbits should be used?

Secondly, a narrower question. Given a short-duration geosynchronous mission (say five days) with a crew of two in a Spartan capsule with minimum equipment and cargo, is it possible to launch the necessary MOTV to Low Earth Orbit with one Shuttle flight? If such a "bare-bones" mission can be flown without on-orbit assembly or propellant transfer, operations will be simplified and a valuable minimum cost concept will have been identified.

A third area of interest, whether the MOTV should be turned around on the ground or in Low Earth Orbit, is discussed in section 6 Turnaround Analysis.

On the first, more general, issue, a matrix of eight concepts, using multiple standard Shuttle launches, was analyzed. The matrix covered 1 stage, 1½ stage, and 2 stage (common) MOTV configurations; and three orbit return methods, viz:

- All Propulsive Orbit Transfer Vehicle (APOTV), using its main propulsion both for de-orbit and for circularization at the Low Earth Orbit rendezvous
- Air Maneuvering Orbit Transfer Vehicle (AMOTV), employing main propulsion for de-orbit, followed at perigee by a series of aerodynamic braking incursions into the upper atmosphere that result in circularization
- Air Maneuvering Return Vehicle (AMRV), which again uses its main propulsion for de-orbit. The ballistic crew capsule, which is shaped for re-entry and has thermal protection, guidance and landing subsystems, separates from the propulsion module and returns the crew directly to Earth. In the simplest version of this concept the propulsion module is expended.

With regard to the choice of staging strategies, the lessons learned in the necessarily high thrust-to-weight launcher field are not directly transferable to lower thrust-to-weight orbit transfer craft. Thus, Fig. 5-1 compares three APOTV staging arrangements, with performance plotted against cost per mission. Whether two, three, four or five Shuttle launches per mission are used to assemble the MOTV and fill its tanks, the 1½ stage configuration is the clear winner. The two-stage configuration (each stage being volume-limited by the Shuttle cargo bay) cannot use more than four Shuttle launches per mission, and when less than three launches are employed it deteriorates to a virtual single-stage mode with very low performance/cost characteristics.

For the 1½ stage arrangement, the maximum roundtrip cargo weight with five Shuttle launches is 13,000 Kg. The same MOTV configuration will deploy a cargo of 38,000 Kg, and if the cargo is already in Low Earth Orbit, the five launch MOTV can deploy a weight of 54,000 Kg. With these performance levels achievable as and when needed, all 10 of the generic MOTV missions can be undertaken.

The general superiority of the 1½ stage mission mode in this APOTV example, is repeated in the AMOTV and AMRV cases. In view of this, it was thought desirable to eliminate the one disadvantage of the mode, namely, drop tanks left in space. Each drop tank is therefore provided with spin-up gear, dampers, and a small de-orbit motor which is fired after separation to ensure re-entry and burn-up in the Earth's atmosphere. All the 1½ stage performances and costs allow for this feature and the

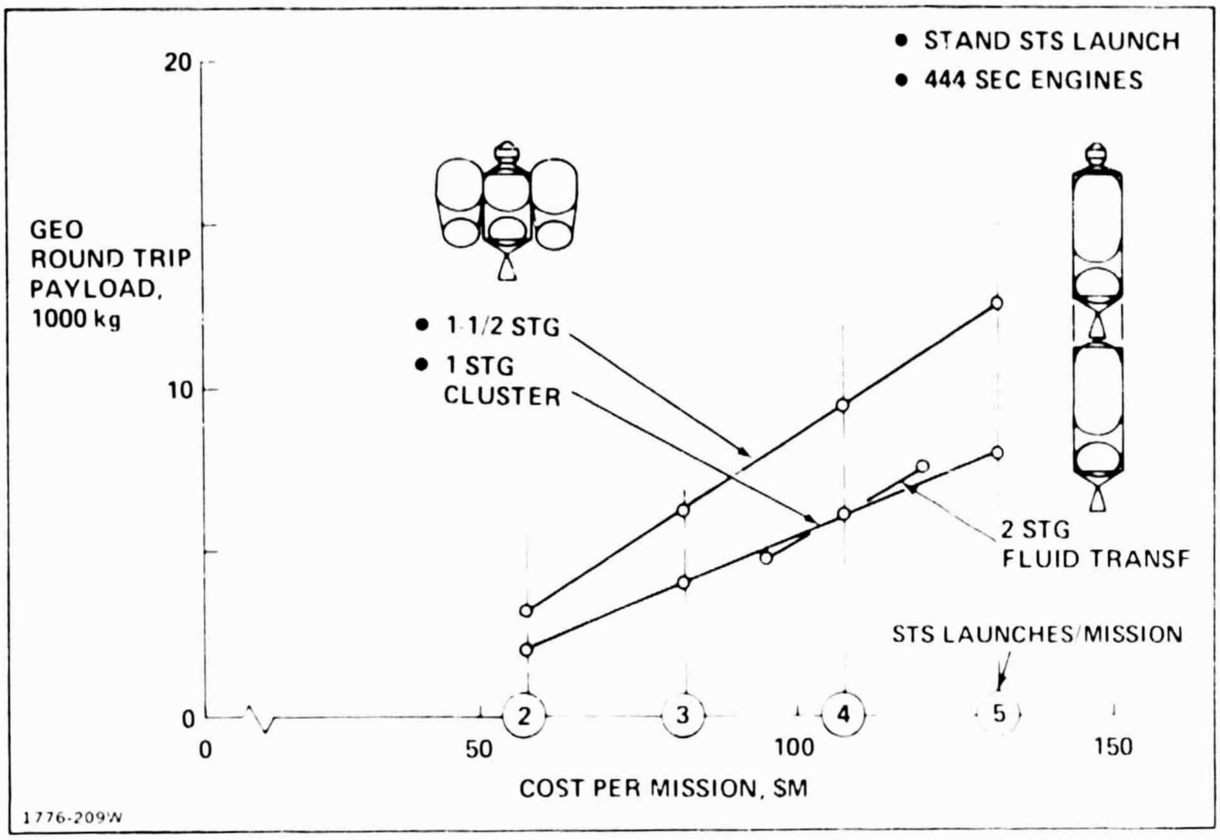

Fig. 5-1 Three APOTV Staging Arrangements Compared

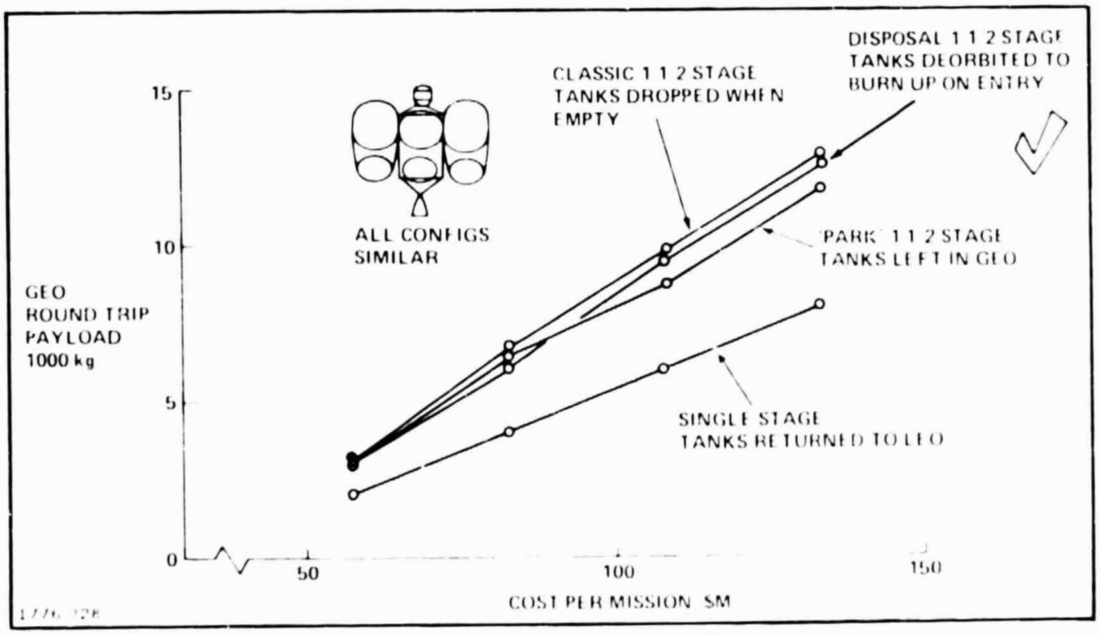

Fig. 5-2 Effect of Tank Disposition on APOTV Performance

performance penalty, as seen in Fig. 5-2, is small.

The choice between rival return methods – APOTV, AMOTV, AMRV – is less easily made. Preliminary analysis showed that the AMOTV concept had performance advantages over the other two: considerable advantages for the heavier roundtrip cargoes; and, less marked for lighter roundtrip and deploy-only cargoes.

These performance advantages are, however, accompanied by significant technical and operational risks. To keep the thermal protection lightweight, there must be several sequential incursions into the upper atmosphere. To avoid dangerous overshoots and achieve rendezvous with the recovery Orbiter imposes challenging requirements on the guidance. Compounding these are the daily, hourly and local variations in the density of the upper atmosphere where (in contrast to conventional Earth return) all the energy dissipation must take place. In addition, the AMOTV has a generic crew capsule configuration problem. The smooth contoured thermal protection shell, if kept simple, will limit external cargo stowage, manipulator arm envelopes, crew vision zones and EVA access corridors. A complex alternative requires that the TPS be divided into panels and hinged out of the way during on-orbit work. In light of these considerations, it was decided that for this study the AMOTV concept should be treated as a potential evolutionary goal, whose additional development costs might well be justified with increasing MOTV activity.

The remaining APOTV and AMRV concepts have no such troublesome technology features, and their performance levels are close to one another. Detailed analysis of the two concepts does reveal discriminators, however, and these are summarized in Fig. 5-3; some comments are in order.

The ballistic re-entry requirement of the AMRV does not penalize the crew's living quarters, but it does cramp and inhibit the layout of the flight deck and IVA work station. The higher stack weight is at first sight surprising; our initial estimates had suggested a lower weight because of the reduced propulsion task (no final circularization burn). However, when the orbital mechanics of the return trajectories of the APOTV and the AMRV were developed, it became ap-

	APOTV	AMRV
• CREW CAPSULE		LESS ROOM IN FLIGHT DECK & MANIPULATOR WORK STATION
• PERFORMANCE		GENERALLY 6% HIGHER STACK WEIGHT
• RETURN FLIGHT OPERATIONS		MORE COMPLEX HIGHER ENTRY 'G'
	12/24 HR TO GROUND	7 HR TO GROUND
• DEVELOPMENT COST		15% HIGHER
• COST PER MISSION		10% HIGHER

APOTV MODE SELECTED FOR PHASE 2 OF STUDY

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Fig. 5-3 APOTV vs AMRV Discriminators

parent that the AMRV has an advantage only so long as the capsule returns to Earth at the equator. By the time that normal return to KSC and some provisions for emergency return have been factored in, the propulsion performance advantage has shrunk to the point where the additional TPS and recovery subsystem weights swing the stack weight. The same orbital mechanics analysis shows the AMRV return flight operations to be more complex and the entry deceleration, at about 8 g, is higher.

Development costs of the AMRV crew capsule are higher than those of the APOTV, not just because of the TPS and recovery subsystems (high g couches, parachutes, retro-rockets, landing provisions), but there are also added capsule items in the areas of electrical power, guidance, environmental control and attitude control.

The one clear advantage of the AMRV over its rival is a two- to three-times quicker return to Earth in an emergency. Though this is valuable, it was not considered uniquely strong enough to override the other discriminators.

So the baseline MOTV propulsion system emerging from this study is a 1½ stage APOTV launched by a standard STS. With this arrangement, the cost per mission is crucially dependent on the number of launches needed, which in turn is driven by the stack weight. Figure 5-4 shows this relationship for the seven missions used for detail study. The only other, and less powerful, cost driver is mission duration.

As will be seen, the cost per mission for the seven shown ranges from $57M to $131M. About 90% of this figure consists of Shuttle charges, which at $23.6M per launch completely dominate the operations costs. This is shown in greater detail in Fig. 5-5, which takes the DRM at $118M from the previous figure and shows how

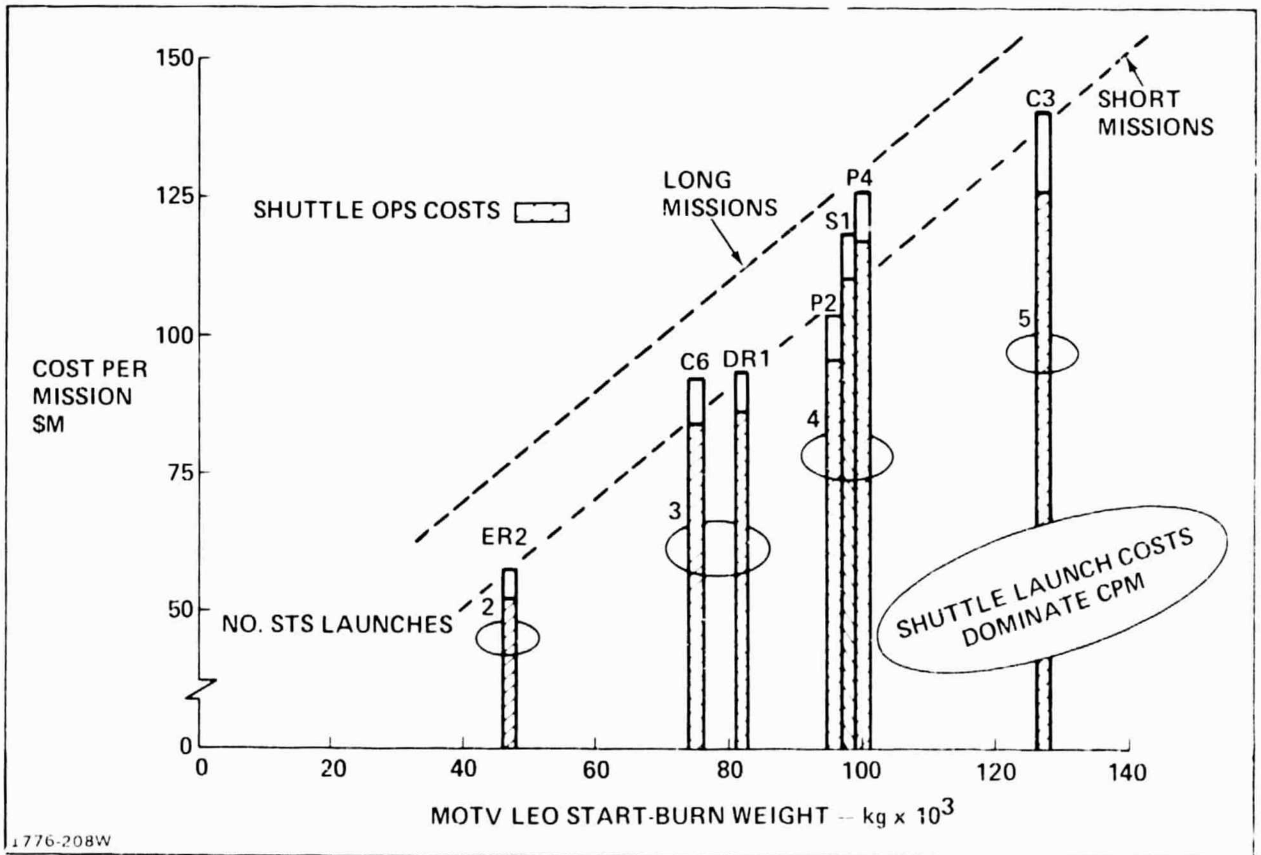

Fig. 5-4 Cost per Mission vs LEO Start Burn Weight

	CREW CAPSULE	PROPULSION CORE	DROP TANKS (3)	TOTALS
MANAGEMENT				0.42
CREW PROVISIONS	0.06			0.06
TURNAROUND			–	2.20
FUEL		0.02	0.09	0.11
DROP TANKS			3.45	3.45
MISSION OPS				1.80
STS OPS				110.10
TOTAL				118.14

1776-489W

Fig. 5-5 Typical Cost per Mission ~ Service Mission SI (Constant '79 $ M)

it is made up. After the Shuttle charges, the remaining $8M has only two items of any size: $2.2M for the crew capsule and propulsion core turnaround, and $3.45M for the only expendable hardware, the three drop tanks. These are priced for the 20th MOTV mission, assuming an 85% learning curve.

Returning to the second-narrower-mission mode question, "Can a single Shuttle launch support a minimum 'bare-bones' MOTV mission?" This was addressed independently with a matrix of five candidate concepts. APOTV, AMOTV and AMRV return methods were included, employing 1 stage and 1½ stage examples; because of the volume limitations of a single Shuttle launch cargo bay, 2 stage examples were not attempted.

To give each candidate a chance of achieving the "bare-bones" mission, Shuttle launch capability was treated as an optional parametric variable, ranging from a launch capability of 29,000 Kg at $23.6M per launch and no additional development cost for the standard Shuttle, to a launch capabil-

5 CONCEPTS		PARALLEL DEVMTS REQUIRED		TECHNICAL EVALUATION		
		AUGMNT. STS	NEW ENGINE	• COMPLEX • TECHN RISK	• DEAD ENDED GEOMETRY	• LOW PERF MARGIN
APOTV	1 STG	X	X			X
	1½ STG	X	X	X	X	
AMOTV	1 STG	X	X	X		
	1½ STG		X	X X	X	
AMRV	1 STG	X	X			X

1776-217W

Fig. 5-6 Single Launch Concepts Performing 'Bare-Bones' Missions

ity of 40,000 Kg at $29.6M per launch and $190M added development cost for a fully augmented Shuttle. The standard Shuttle cargo bay size was unchanged throughout. Also available as an optional variable was higher MOTV engine performance; ranging from a low of 444 seconds, I_{SP} to a high of 473 seconds I_{SP} at an incremented development cost of about $5M per second of I_{SP}.

As analyzed, all five candidates were able to perform the "bare-bones" mission, but in each case with some negative features. All the candidates demanded the development of the Advanced Space Engine, four of them required significant Shuttle augmentation, and all of them had one or more undesirable technical features, as summarized in Fig. 5-6.

Since all the concepts are technically flawed (either over complex and risky, or dead-ended in geometry, or lacking performance margin), and involve considerable parallel development expense, and since the "bare-bones" mission is typical of only the lower end of the MOTV missions spectrum, none of these concepts have been pursued. Nevertheless, if it were decided to initiate an MOTV program with only modest performance, and if the augmented Shuttle were available, then the single-stage APOTV concept would be a respectable candidate. It has the virtues of simplicity and the ability to evolve to much higher performance by the addition of drop tanks.

If this path were taken, it would have the effect of eventually merging a "bare-bones" approach with the baseline 1½ stage APOTV multi-launch mode.

6 – TURNAROUND ANALYSIS

The primary objective of the MOTV turnaround analysis task is to determine the process necessary to check, restore, assemble and prepare the returning MOTV for its next mission, and to define the support requirements to implement the turnaround process. A preliminary baseline was developed for ground-based turnaround utilizing existing KSC facilities. Shuttle-tended and SOC turnaround were also investigated. Early results indicated that maintenance was the prime requirement driver and was very sensitive to maintenance approach and location of the turnaround base.

Figure 6-1 illustrates the reduction in manpower requirements accruing from an approach which stresses use of flight data and inspections for determining hardware status, and incorporates MOTV maintainability features to facilitate maintenance. This basic approach reflects the current wide-bodied jet commercial experience with "condition monitoring."

A preliminary set of support data was also generated for LEO STS-tended turnaround. It indicated that manpower and support equipment increased significantly with no apparent advantage to STS-tended over ground turnaround.

During phase 2 of the study, NASA extended the MGMRSAS contract to include Space Operations Center (SOC) turnaround in LEO. A new set of SOC-oriented groundrules was generated, a conceptual design was developed (see Fig. 6-2) and a complete set of support requirements for SOC turnaround was identified. This included an analysis of split operations with the propulsion core being serviced at SOC and the Crew Module being returned to the ground.

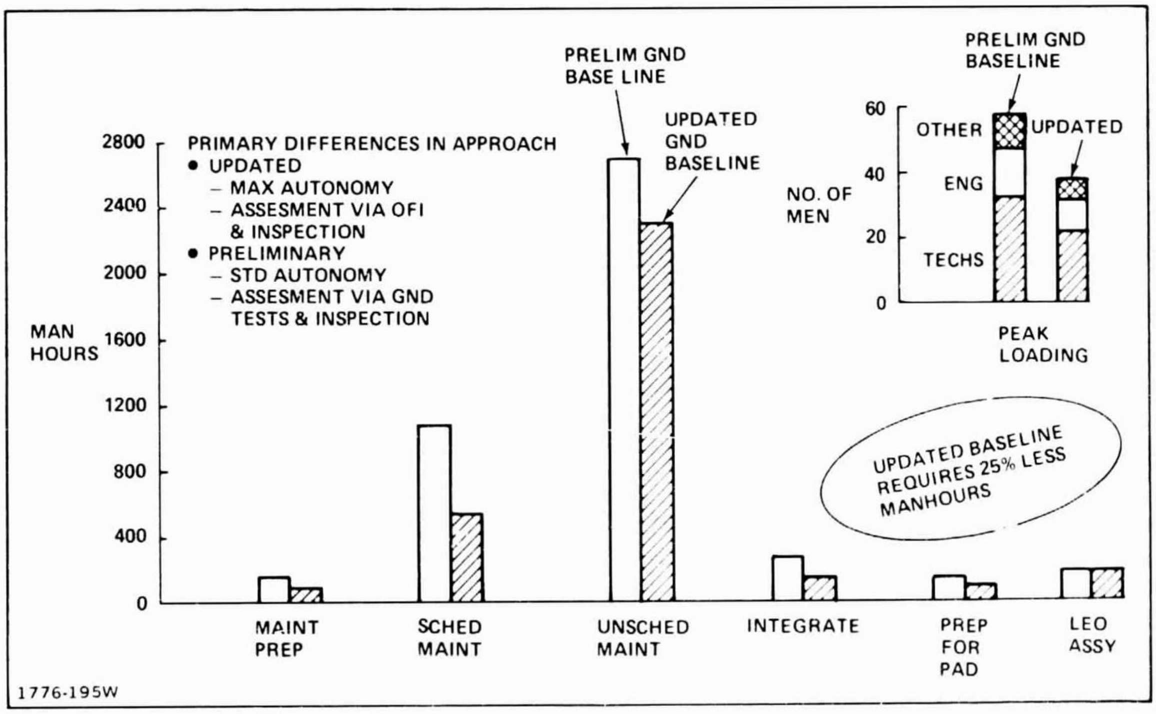

Fig. 6-1 Manpower Sensitivity to Change in Ground Turnaround Approach

6.1 Turnaround Location Comparison

Turnaround location has the greatest impact on support requirements and overall program implications. The following paragraphs compare the sensitivity of support requirements to turnaround location.

Overall Turnaround Scenarios. Figure 6-3 compares turnaround scenarios, ground, STS-tended, and SOC for the DRM. It shows the number of flights and turnaround schedules for each of the options. A single STS is assumed available to support MOTV missions.

The ground turnaround option shown is for the decoupled mode where each mission is considered indeptendent of the next one. In particular, the returning MOTV is retrieved by the "Loiter Shuttle" and the next mission begins after an indefinite period of time, indicated by X in the figure. The ground portion of the turnaround is also shown decoupled from the preparation of the next flight. With two MOTV's in the inventory, one is always taken out of storage in time for a new mission startup and the returning MOTV is secured, put into storage, and then prepared on a timetable consistent with the mission schedule. Since the MOTV ground turnaround falls well within the time needed for Shuttle ground turnaround, this decoupled mode poses no problems.

Some specific observations to be drawn from these scenarios are:

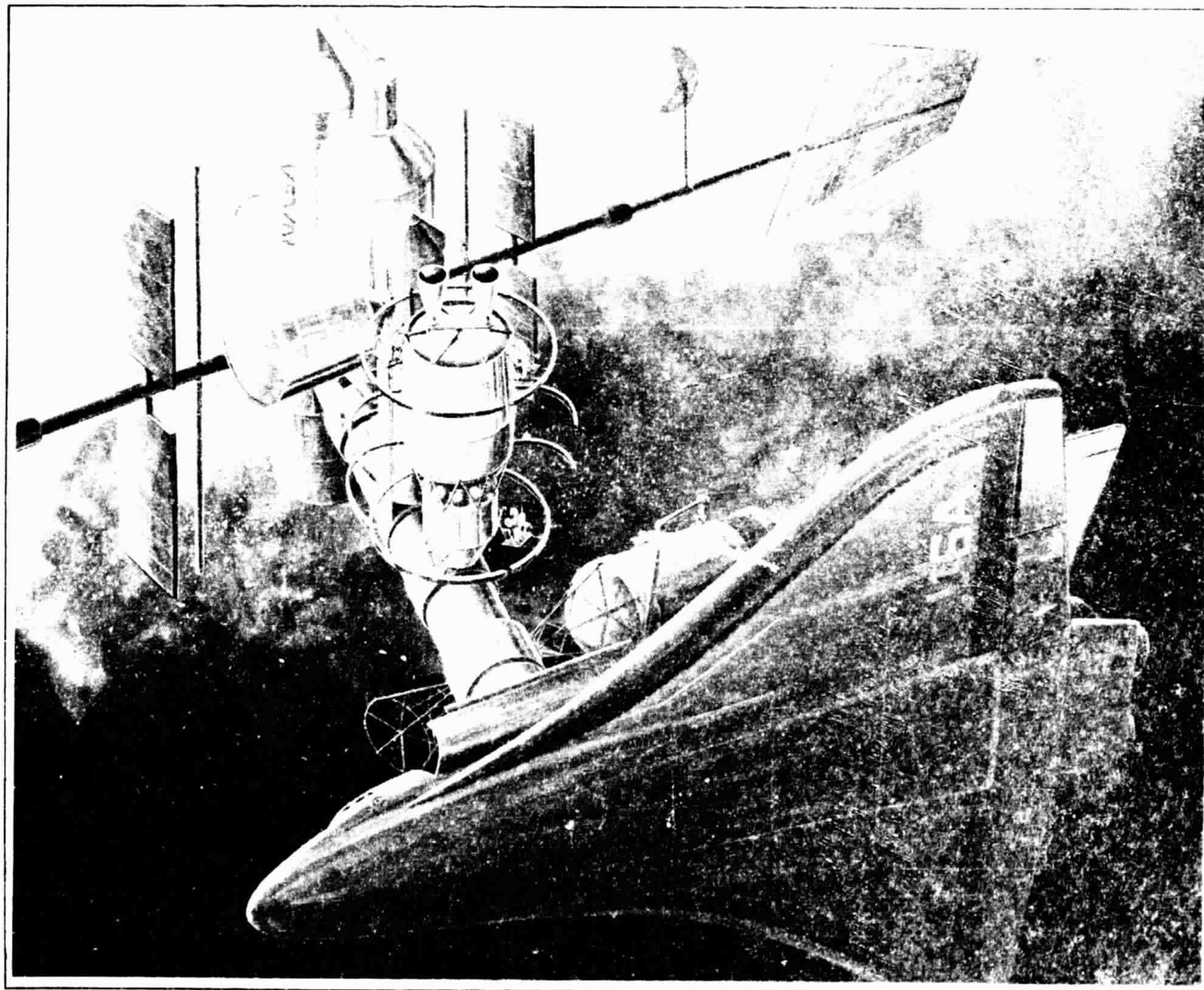

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Fig. 6-2 Turnaround Concept

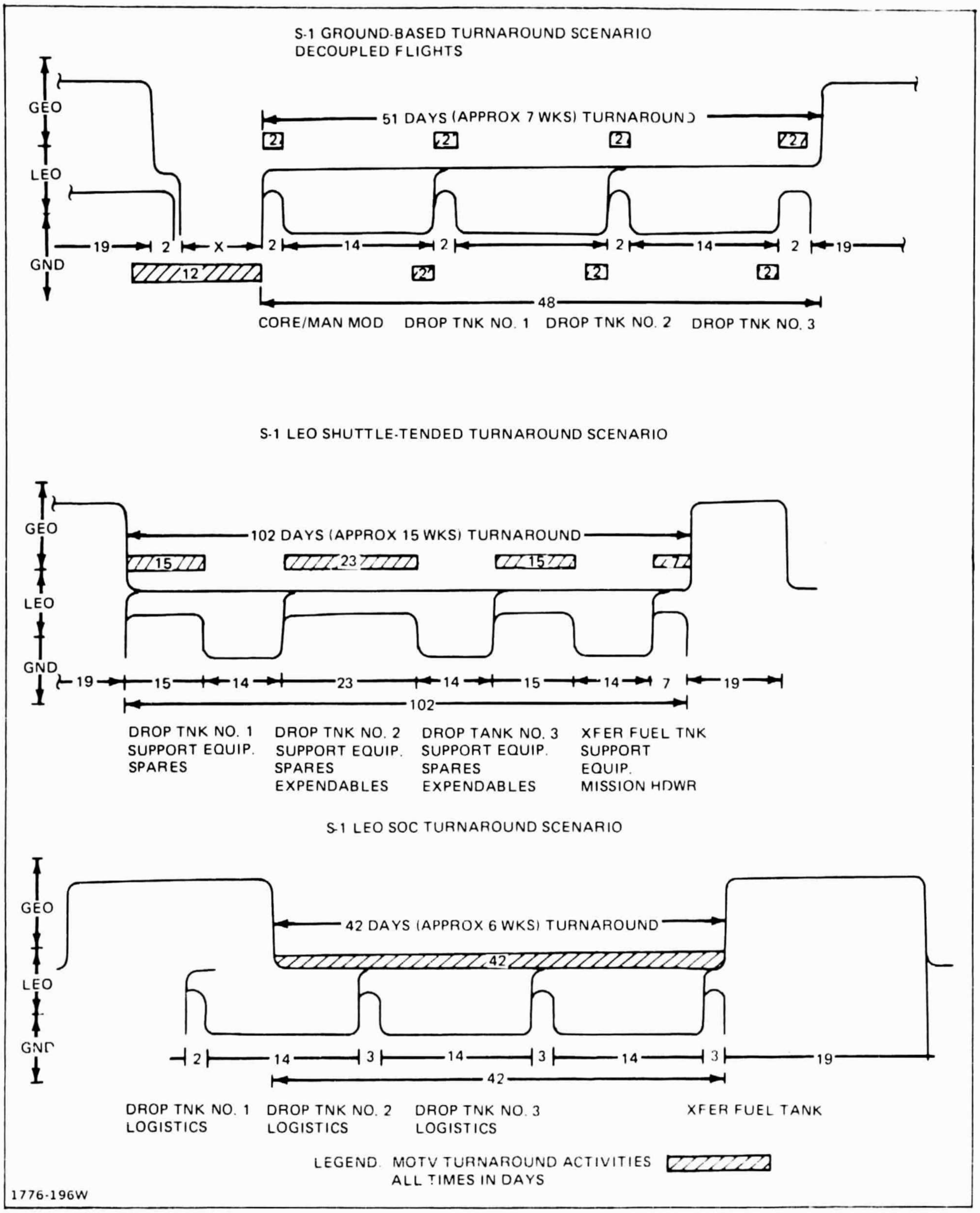

Fig. 6-3 Overall Turnaround Scenarios

- Ground and SOC mission turnaround schedules are established by the dedicated Shuttle turnaround schedule and not by the MOTV activities.
- For both ground and SOC options, decreasing the actual MOTV turnaround maintenance activities will not affect the overall S1 turnaround schedule.
- The STS-tended turnaround schedule is constrained by the MOTV activities, and reducing them would shorten the MOTV turnaround. For example, if unscheduled maintenance were not required between flights because all systems were "go," the overall turnaround schedule could be reduced from approximately 102 to approximately 64 days.
- SOC does minimize the mission turnaround time from 48 hours for ground-based to 42 hours.

Manpower Sensitivity. Figure 6-4 shows the manpower sensitivity to turnaround location. It compares the manpower requirements for ground turnaround and for SOC turnaround when each design is optimized for its turnaround location. SOC turnaround is more time consuming than ground turnaround, requiring a total of 4011 manhours compared to 2108 manhours.

Cost Per Mission. Figure 6-5 shows turnaround transportation costs for two variants of each of the three main options. Costs include charges for installing fuel cell reactant kits to extend Shuttle flight durations and the flight duration charges themselves. Also included are the OMS kit

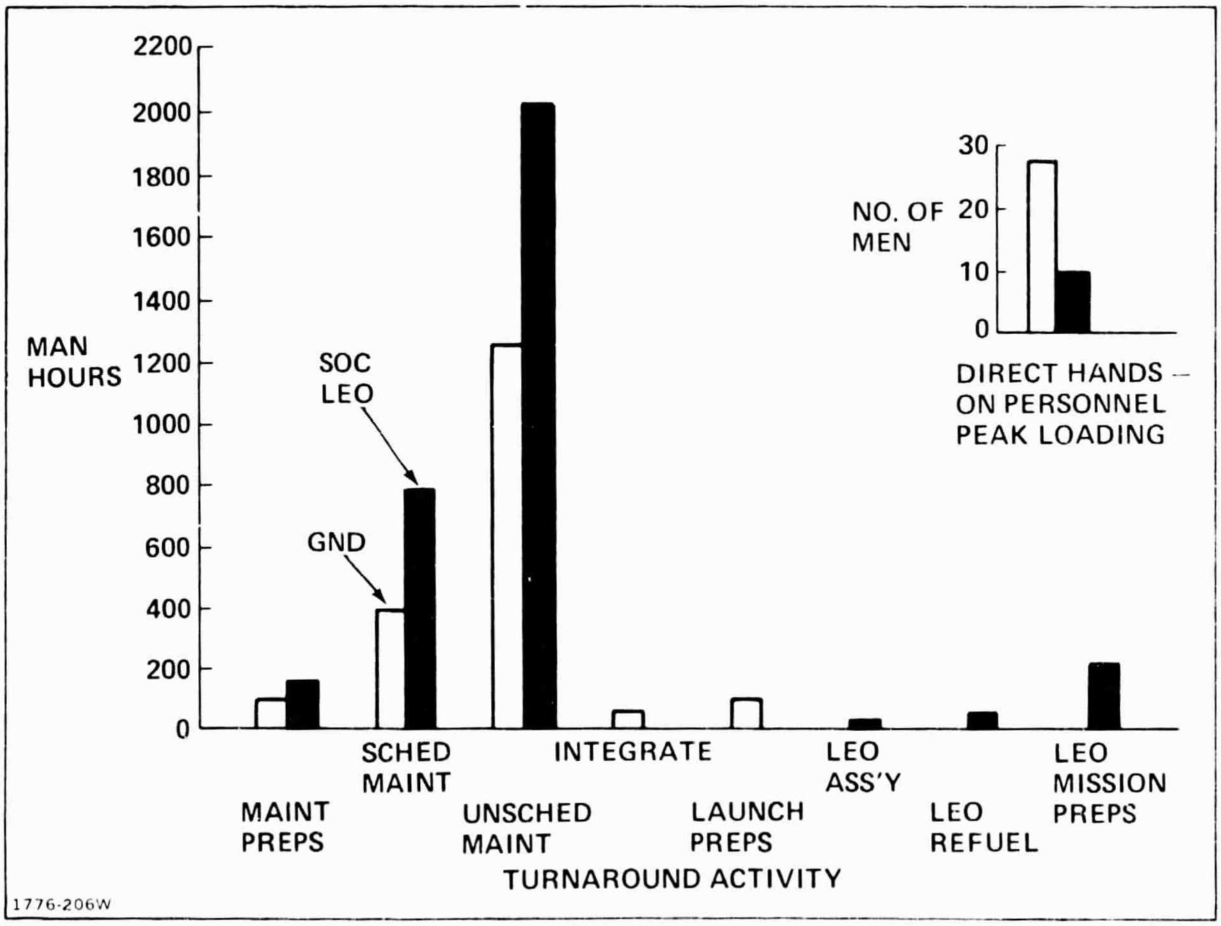

Fig. 6-4 Manpower Sensitivity to Turnaround Location

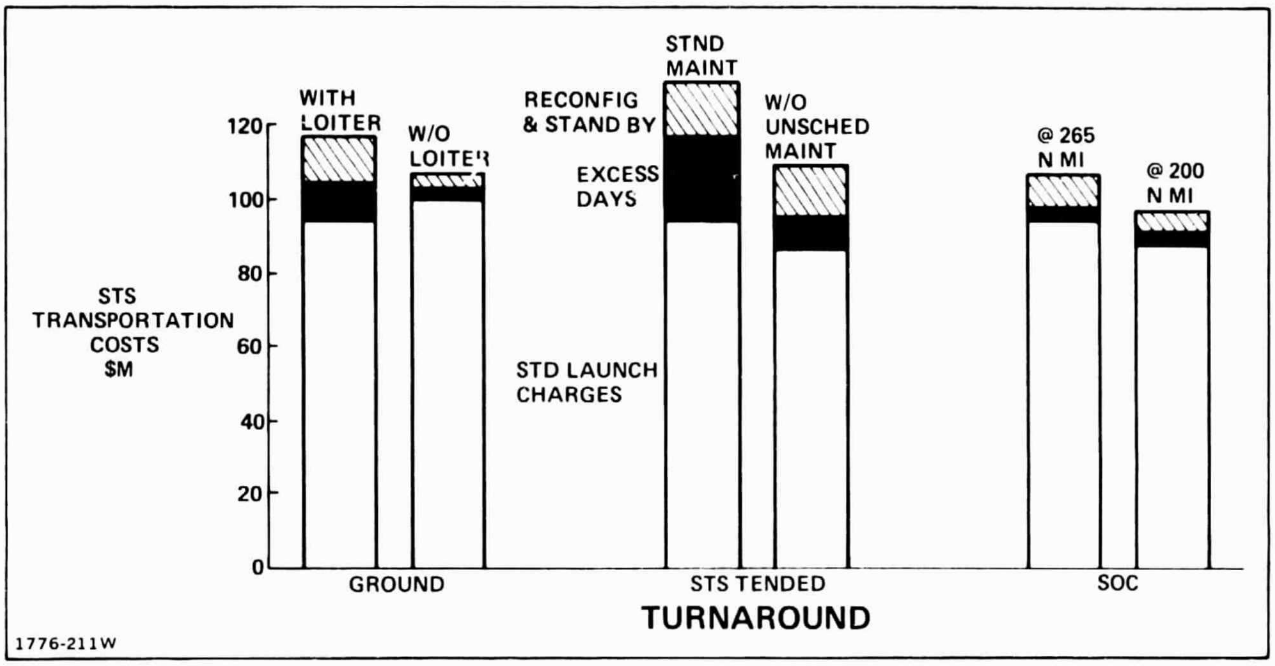

Fig. 6-5 Turnaround Transportation Costs per Mission

	MAN HRs	TURNAROUND TASK SERIAL TIME DAYS	TURNAROUND OVERALL SCHEDULE DAYS	STS FLIGHTS & LOADING	DESIGN IMPACT	SUPPORT EQUIP M $	INITIAL INVEST & PAYBACK	COST/FLT XPORTATION M $
GROUND BASED KSC	2100	14	51	3 FLTS @ 29,000 kg PLUS 2 PARTIAL FLTS	APPROX 3%	3.5	3.5	108
LEO SOC	4000	42	42	*3 FLTS @ 29,000 kg PLUS 1 FLT @ 15,000 kg	5 TO 20%	13	*330 M 15 YR PAYBACK	*97
LEO STS TENDED	5700	60	102	4 FLTS @ 29,000 kg	5 TO 20%	13		131

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*BASED ON SOC @ 200 N MI

Fig. 6-6 Turnaround Options Relative Rating Summary

installation costs, needed to reach the 490 Km (265 n mi) altitude, rather than 370 Km (200 n mi).

The first pair of variants compares ground turnaround using a Loiter Shuttle or one using a separate Shuttle to pick up the returning MOTV. The "no loiter" option is $10M less expensive.

The second pair of variants compares Shuttle-tended turnaround costs depending on whether the returning MOTV requires unscheduled maintenance or not. If on-board flight instrumentation (OFI) indicates that all is well with the MOTV and no unscheduled maintenance is required, a $22M cost savings could be achieved. It would be reasonable to assume at this juncture that this minimum maintenance flight could be achieved once every three to five flights.

The third pair of variants compares SOC turnaround transportation costs for SOC in either a 265 or 200 n mi orbit. The 200 n mi orbit is 10% lower in cost than the lowest ("no loiter") ground turnaround option and is $10M lower than the 265 n mi option.

6.2 Conclusions and Recommendations

Figure 6-6 summarizes the comparison of ground, STS-tended and SOC turnaround options relative to manhours, turnaround schedules, etc. It shows that the ground-based option requires less manhours and serial time for the activities. It should have less impact on the design and requires less GSE and facility dollars. On the other hand, the SOC turnaround schedule is less; it requires 3½ STS flights compared to three plus two partial flights for ground turnaround, and provides the lowest transportation costs per flight. However, an investment of $330M is required for this option, and the payback period of 15 years on this initial investment is not too attractive unless the facility cost can be shared with other programs. The STS-tended flight does not have any advantages over the other two modes.

Hence it is recommended that ground turnaround continue to be baselined because of its inherent low startup costs and flexibility. The SOC option should also be retained until such issues as its operational orbit (200 n mi vs 265 n mi) and how its initial investment costs are amortized are resolved.

7 – PROGRAMMATICS

Programmatics in the context of this study cover MOTV program planning, including scheduling and costing for all critical technology issues resolved by Supporting Research and Technology (SR&T): phase B studies for each MOTV element (e.g., Crew Module, Propulsion Module, OTV Engine); and phase C/D hardware development and production.

The programmatics activity, planned in conformance with Directive A 109, has shown that it is feasible to achieve an MOTV IOC in 1988, as established by NASA for a study guideline. Achievement of this guideline, however, requires a properly phased development program involving phase B studies, phase C/D hardware and SR&T activity for the major MOTV modules. The phase B studies must be initiated in the 1981-1982 time frame to permit phase C/D go-aheads in the 1983-1984 time frame, which lead to the 1988 MOTV IOC. To support this schedule, the critical technology issues must be resolved in the 1980-1983 time frame.

Cost estimates have been prepared and iterated for the MOTV program as configuration changes and refined cost methodology so warranted. Although the MOTV program as defined does require significant expenditures over the program life, the early year funding requirements (1980-1983) are less than $10M in any calendar year. Furthermore, the peak annual funding does not occur until 1986.

The formal purpose of the program planning was to develop a Five Year Program Plan. However, to keep the planning logical and compatible with the NASA study guideline of an MOTV IOC in 1988, an overall plan covering the nine-year span between 1980 and 1989 was formulated. The detailed schedule resulting from this planning is included in the Five Year Program Plan Document, and is shown in summary form in Fig. 7-1. Major program milestones are shown together with the phasing for the study, phase C/D hardware and SR&T activities. The study and Phase C/D hardware activities are shown for each major module.

It is apparent that unmanned missions using MOTV elements may be performed in advance of manned missions and, once the MOTV is available, occasional unmanned missions will be flown. Hence, Propulsion Module autonomy to permit initial unmanned OTV capability appears reasonable and is reflected in our program plan. This approach, building on the studies currently under contract, produces an orderly, logical program leading to the 1988 IOC.

The phased MOTV development builds on the Propulsion Module and System/Crew Module studies currently in progress and planned for completion in 1981 and 1980, respectively. These studies are followed by competitive phase B studies which, in conjunction with competitive engine phase B studies, provide the phase C/D proposals and ultimately the contractors for the phase C/D hardware. The phase B study completions and phase C/D go-aheads are geared to an MOTV program approval in 1983, with approval of the elements needed for unmanned missions forthcoming in 1982.

Implementation and execution of the MOTV program as planned requires the resolution of a number of issues. These program issues, as shown in Fig. 7-2, include critical technology issues and major cost impact issues. The SR&T program required to resolve these critical technology issues has been developed and is presented in Fig. 7-3. This program for the critical technology issues is given in order of priority and, for each issue, the time phasing, basic purpose and output utilization are identified. The major cost impact issues of Fig. 7-2 require further effort in the area of cost trades and analysis, and may at this time be considered as potentially critical issues.

The MOTV program costs cover the early

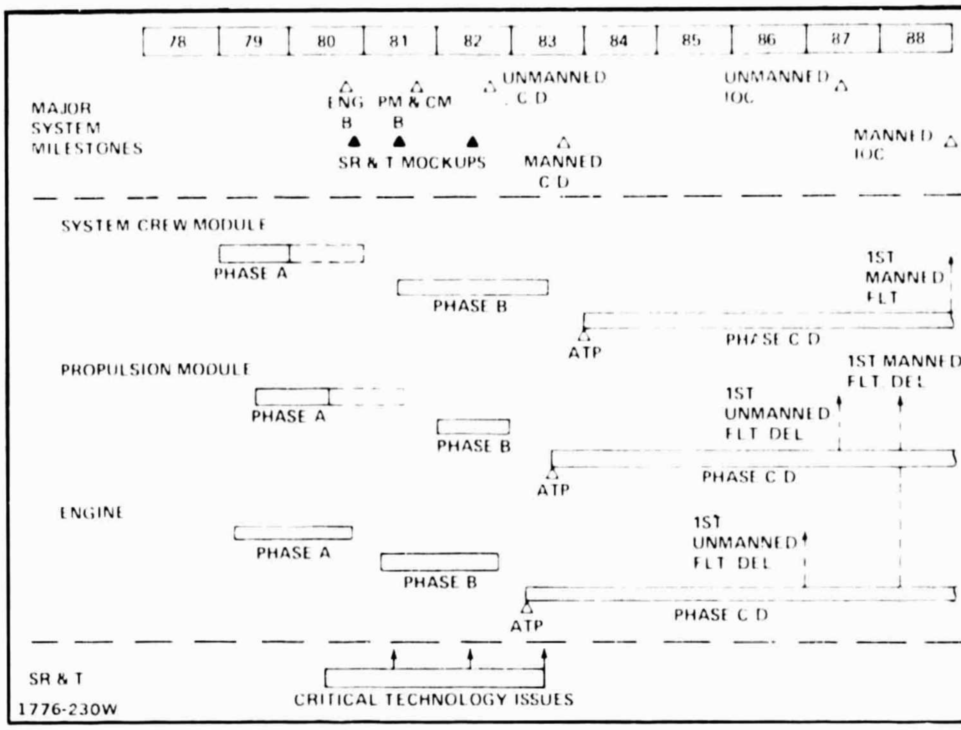

Fig. 7-1 MOTV Phased Development Program Plan, Summary Schedule

studies, the SR&T and the phase C/D hardware activities. The cost estimates were developed by the Grumman Computerized Cost Model. This cost model develops cost estimates utilizing available CER's or cost throughputs, as appropriate. It permits hardware replication, complexity and development status to be reflected in the cost estimates. The estimates produced by the cost model were verified as to validity by comparison to benchmark costs from other programs adjusted for program differences and historical inflation effects.

As for the program cost elements, the study costs, exclusive of contracts currently in progress, are estimated at $7.4M in 1979 dollars. The SR&T program is estimated at $14.9M over three years. The SR&T costs do not include time-sharing costs such as for the STS and Spacelab, or NASA facility costs which in themselves may be significant. The MOTV development/production costs are summarized in Fig. 7-4. This figure presents the MOTV costs by major hardware element or function and by program phase, i.e., DDT&E and Production. The MOTV development and production costs are $1.469 billion and $254 million, respectively. The production costs include the hardware for two vehicles. The Crew Module, or Crew Capsule as it is entitled interchangeably, accounts for approximately 33% of the MOTV program costs. The breakdown of the Crew Capsule costs is given in Fig. 7-5. The Crew Capsule development and production costs are $502 million and $115 million, respectively. Two subsystems, Structure and ECLS, drive the Crew Module cost, although a third subsystem, Avionics, is also a major program cost. The Avionics costs are less of a driver to the Crew Module since this subsystem function is split between the Crew and Propulsion Modules with approximately 55% of the cost attributable to the Crew Module.

The MOTV costed in this study is based on the DRM mission S1. The applicability of this cost estimate is not as narrow as it appears from the preceding statement. The MOTV costed herein satisfies 17 of the 20 generic missions formulated by this study, i.e., all but mission P2, 3 and 4. Missions P2, 3 and 4 require ad-

- CRITICAL TECHNOLOGY
  - SOLAR FLARE PREDICTION
  - FLT STATION SIMULATION
  - ON ORBIT ASSY SIMULATION
  - GEO SUIT DEV
  - MAIN ENGINE LIFE & RELIABILITY
  - PROP. MODULE RELIABILITY
  - SOC TURNAROUND SIMULATION
- MAJOR COST IMPACT (POTENTIAL CRITICAL TECHNOLOGY)
  - STS PERFORMANCE & COST PER LAUNCH
  - MAIN OTV ENGINE PERFORMANCE
  - SUPER LIGHT WEIGHT COMPONENT DEV
  - CRYO BOILOFF MINIMIZATION
  - CRYO RCS DEV

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Fig. 7-2 Program Issues

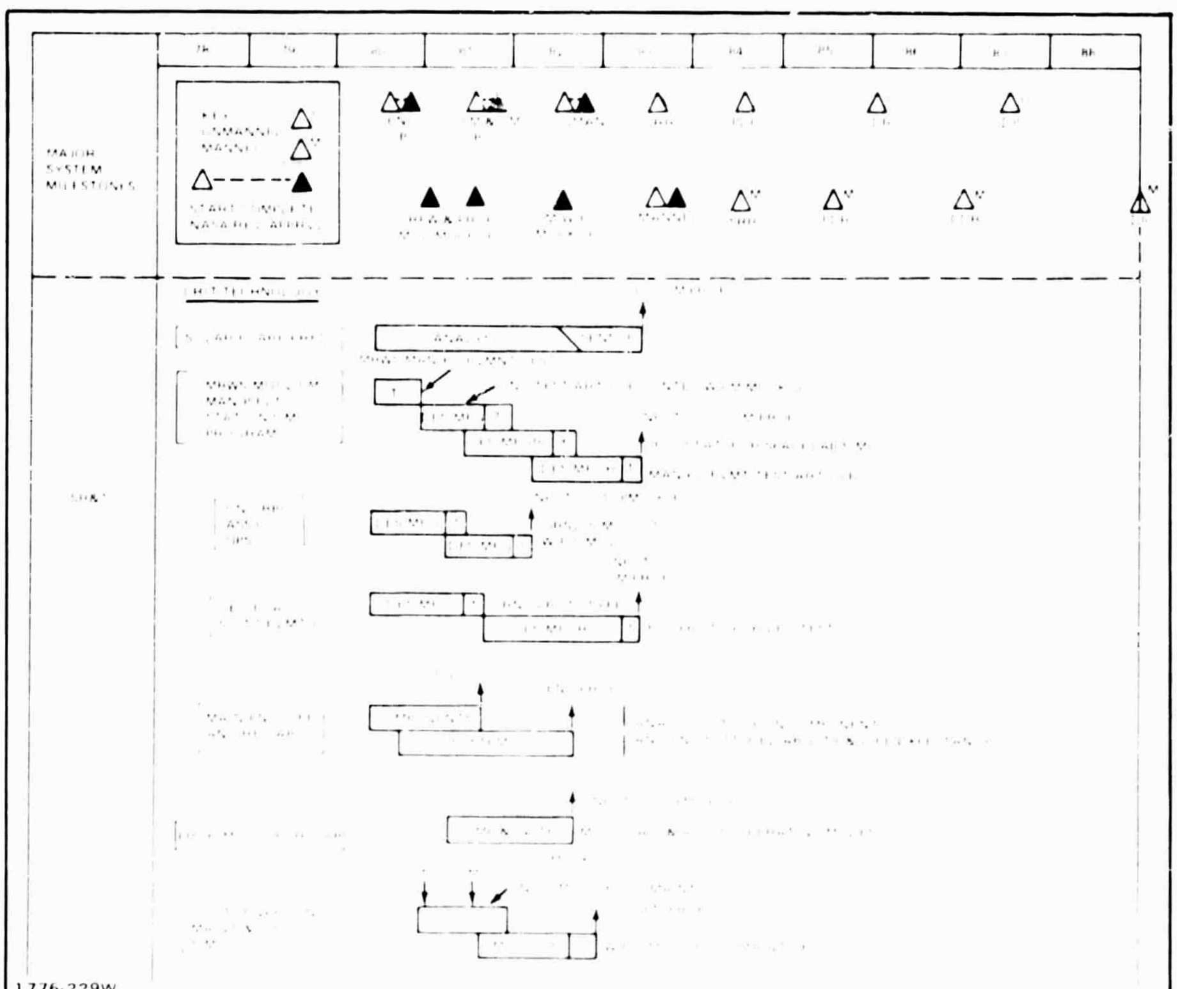

Fig. 7-3 MOTV Phased Development Program Plan, Master Schedule

	DDT&E	PRODUCTION (2 VEHICLES)	TOTAL
PROJECT MANAGEMENT	51	16	67
SE & I	71		71
SPACE VEHICLE	1028	196	1224
CREW CAPSULE	502	115	617
PROPULSION CORE	391	69	460
DROP TANKS	135	12	147
GROUND SUPPORT SYS	166	–	166
OPERATIONS	13		13
FLT SUPPORT EQUIP	47	2	49
SPACE TRANSPORT	71		71
INST ASSY CHECKOUT		40	40
SYS TEST & EVAL	22		22
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Fig. 7-4 MOTV Development/Production Cost Summary – Mission S1 (25% Weight Contingency Reflected -- Constant 1979 $ M)

	DDT&E	PROD (2)	TOTAL	
PROJECT MANAGEMENT	40	8	48	
SE & I	33	–	33	
STRUCTURE	101	16	117	
INSULATION	6	1	7	
MECHANISMS	23	13	36	
EPS	2	1	3	SUBSYSTEMS SPLIT BETWEEN
AVIONICS	66	13	79	CAPSULE & PROPULSION CORE
GN/C	44	7	51	
COMM/DATA HNDLG	5	3	8	
CONT & DISPLAYS	17	3	20	
ECLS	140	30	170	
CREW ACCOM	76	16	92	
O/B SOFTWARE	4		4	
SYS TEST & EVAL	11		11	
INST ASSY CHECKOUT		17	17	
	502	115	617	

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Fig. 7-5 Crew Capsule Development/Production Cost – Mission S1 (Constant 1979 $ M)

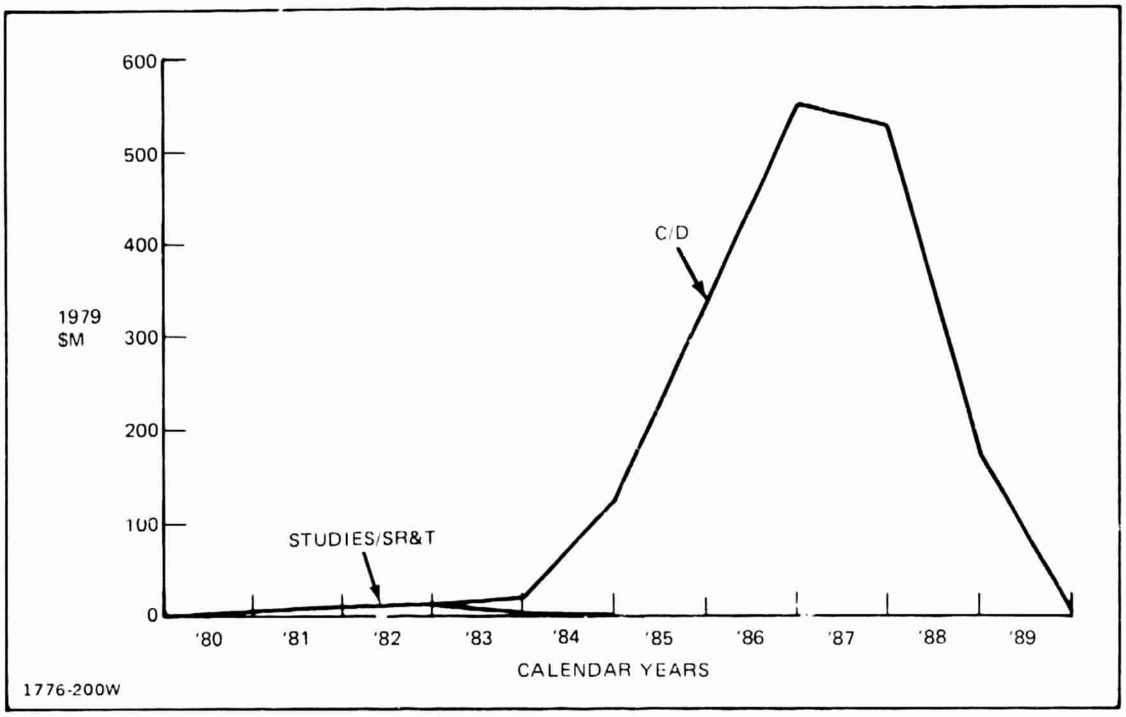

Fig. 7-6 Annual MOTV Program Funding Requirements

ditional passenger capability and mission-peculiar software. The operational costs of the generic missions also vary but are not included in these costs since they are presented and discussed in the mission mode section of this report.

The funding requirements for the MOTV program consistent with the schedule (Fig. 7-1) and cost summary (Fig. 7-4), are shown in Fig. 7-6. This figure breaks out the funding requirements by study, SR&T and phase C/D activity. The peak annual function requirements for the program and Crew Module are approximately $575M and $200M, respectively, with both peaks occurring in 1986. The funding schedule confirms the feasibility of a 1988 MOTV IOC without excessively early year funding requirements.