NASA CR-171, 832

A Reproduced Copy

OF

NASA CR-171, 832

Reproduced for NASA

by the

NASA Scientific and Technical Information Facility

Impact of Lunar and Planetary Missions on the Space Station

(NASA-CR-171032) IMPACT OF LUNAR AND PLANETARY MISSIONS ON THE SPACE STATION Final Report (Eagle Engineering, Inc.) 141 p HC A07/MF A01 CSCL 22B
N85-16563
Unclas
G3/15 13432

FINAL REPORT
NOVEMBER 21, 1984
REPORT NO. 84-85D

ENGINEERING, INC.

CONTRACT NO. NAS9-17176

Final Report

Impact of Lunar and Planetary Missions on the Space Station

Prepared for the

Planetary Exploration Division

Johnson Space Center

by Eagle Engineering

Report Number 84-85D

Contract Number NAS9-17176

November 21, 1984

Table of Contents

List of Figures

List of Tables

Foreword

This study was conducted between June and November of 1984 by Eagle Engineering for the Planetary Exploration Division of the Johnson Space Center. The purpose of the study was to assist Space Station designers in planning for future needs, and to see what a conservative design Space Station/OTV infrastructure can do for a lunar base build-up and for advanced planetary missions. Three other interim reports were produced in this study. This report includes all the material from all three. A slide presentation and technical paper were also produced for the Symposium on Lunar Bases and Space Activities of the 21st Century, held in Washington D.C. in October, 1984.

Gus R. Babb served as the study leader for this effort. Significant contributions were also made by the following Eagle team members. Paul G. Phillips and William R. Stump made up the engineering staff for this project. R. Patrick Rawlings and Mark W. Dowman executed the airbrush art and other graphics. Eric Franklin provided graphics support. Willard Taub and Richard B. Ferguson designed the propellant storage modules. Hubert P. Davis and W. B. Evans provided technical and editorial supervision.

1.0 Executive Summary

The impacts upon the growth Space Station of several advanced planetary missions and a populated lunar base are examined. Planetary missions examined include sample returns from Mars, the Comet Kopff and the main belt asteroid Ceres, a Mercury Orbiter, and a Saturn Orbiter with multiple Titan Probes. A manned lunar base build-up scenario is defined, encompassing preliminary lunar surveys, ten years of construction, and establishment of a permanent 18 person facility with the capability to produce oxygen propellant.

The spacecraft mass departing from the Space Station, mission Delta V requirements, and scheduled departure date for each payload outbound from Low Earth Orbit (LEO) are determined for both the planetary missions and for the lunar base build-up. Large aerobraked Orbital Transfer Vehicles (OTV's) are used, similar in concept to those now being designed for geosynchronous orbit missions. Two 42 metric ton propellant capacity OTV's are required for each of the 68 lunar sorties of the base build-up scenario. The two most difficult planetary missions (Kopff and Ceres) also require two of these OTV's.

An expendable lunar lander and ascent stage and a reusable lunar lander which will use lunar produced oxygen are sized to deliver 18 metric tons to the lunar surface.

For the lunar base, the Space Station must hangar at least two non-pressurized OTV's, store 100 metric tons of cryogens, and support an average of 14 OTV launch, return, and refurbishment cycles per year. Planetary sample return missions require a dedicated Quarantine Module.

An average of 630 metric tons per year must be launched from the Kennedy Space Center (KSC) to the Space Station for lunar base support during the ten years of base construction. Approximately 70% of this cargo from Earth is OTV hydrogen/oxygen propellant. An Unmanned Launch Vehicle (ULV) capable of lifting 100 metric tons net useful payload is considered necessary to deliver this propellant. An average launch rate of one shuttle and one ULV every ten weeks to the Growth Space Station will provide the required 630 metric tons per year.

Figures 2 and 1 show the Space Station with and without impacts from the lunar and planetary missions. Figure 1 shows the Space Station without OTV hangars or propellant storage and transfer facilities. The entire OTV infrastructure should not necessarily be considered dedicated to the lunar and planetary missions. It is more likely the OTV infrastructure will be put in place earlier to support revenue-generating missions to geosynchronous orbit.

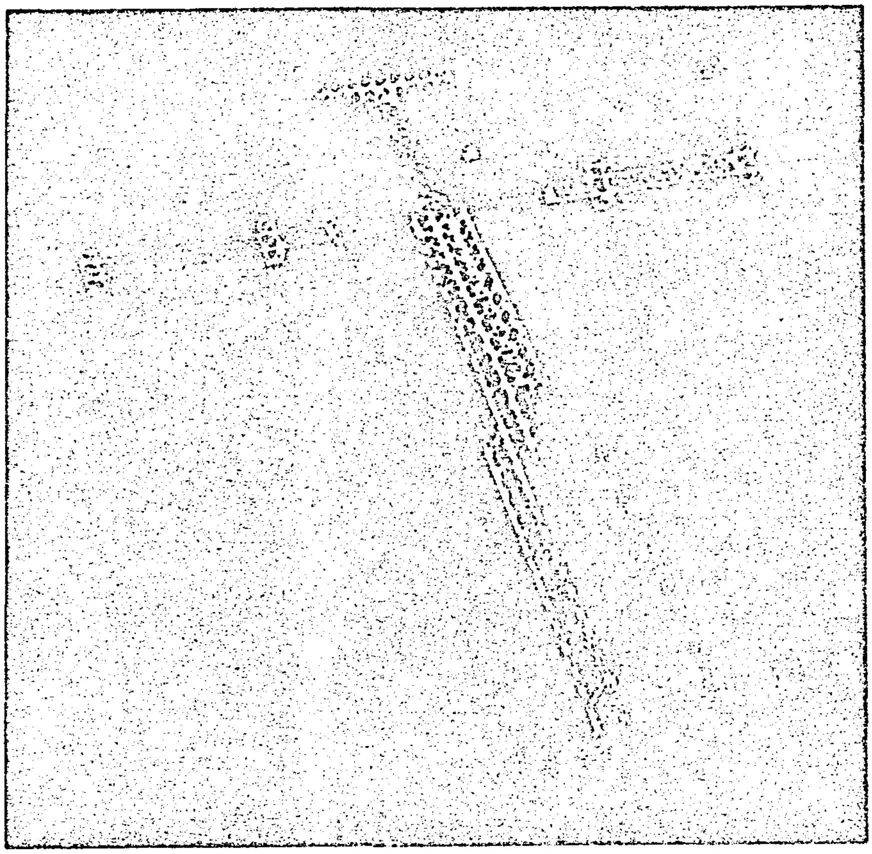


Figure 1

Space Station with No Impacts

ORIGINAL PAGE IS OF POOR QUALITY

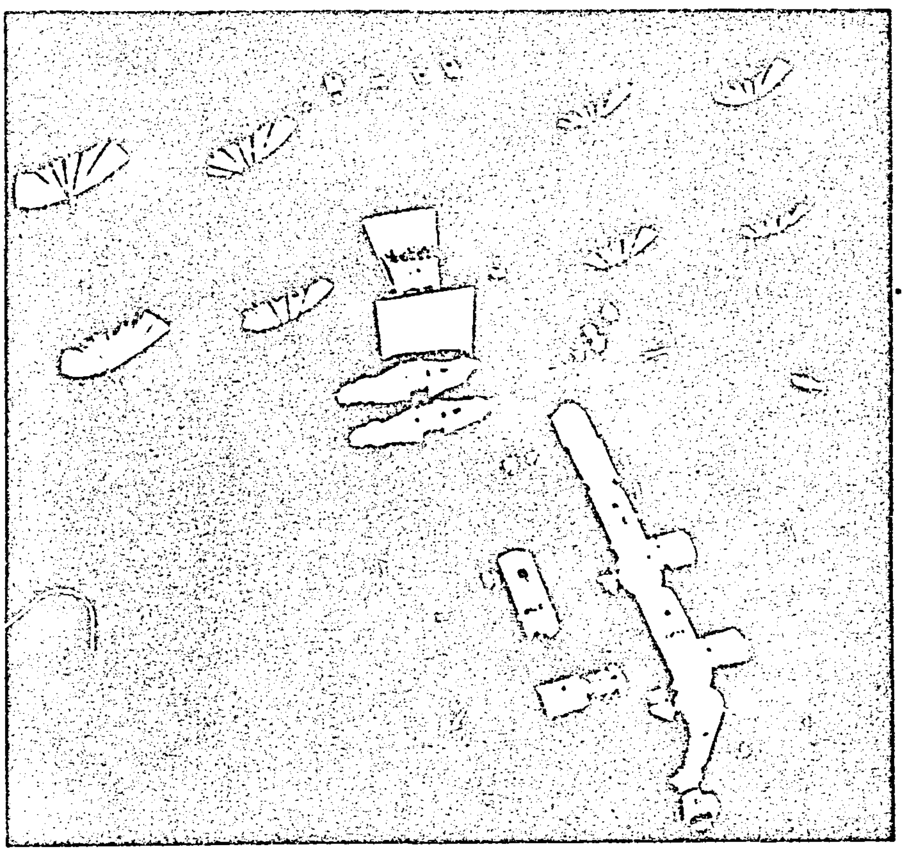


Figure 2

Space Station with Impacts

2.0 Introduction

NASA and contractors are now working on the conceptual design of the Low Earth Orbit (LEO) Space Station. The designers must include in their thinking, for the early (Initial Operational Capability, or IOC) Space Station, the requirements of the turn of the century "Growth" Space Station. This study, performed by Eagle Engineering, Inc. for the Johnson Space Center (JSC) Planetary Exploration Division, examines the impacts of advanced lunar and planetary missions upon the Growth Space Station.

Mass estimates were constructed for a science-emphasis lunar base using lunar produced oxygen, a transportation system sized to land its elements on the lunar surface. A ten year flight schedule was developed, including weights, propellants, crew size, etc. and then the impacts upon the Space Station were estimated.

In a similar manner, five advanced planetary missions were examined - three sample returns and two orbiter/probe missions. Weight statements and trajectories for each of these were tabulated. The propellant loads, configurations, and mission plans of single and two stage stacks of conceptually designed standard OTV's (Orbital Transfer Vehicles) were also developed at this time. From these requirements the impacts on the Space Station were then estimated.

3.0 Groundrules & Assumptions

The following groundrules and assumptions were used in this study:

1. The Space Station can store and transfer LO_2 and LH_2 to the Orbital Transfer Vehicle (OTV) in orbit. See section 6.2 for a discussion of the state of the art in this technology.

2. Aerobraking will be a mature technology and is incorporated in the OTV design.

3. The OTV will use LO_2/LH_2 propellant.

4. OTV Isp = 460 sec with 1% start/stop losses yielding an effective OTV Isp = 455 sec. for cryogenics (from Ref. 2).

5. Isp = 340 sec. effective for storable fuels.

6. All stages, Lunar Landers, etc., will be LO_2/LH_2 unless <u>strongly</u> contra-indicated.

   <u>Exception</u> - Expendable ascent stage will use storables.

7. Boil-off rate for cryogenic stages is 55 kg/day of LH_2 per stage. (Ref. 2)

8. Cargo units for the lunar base weigh a maximum of 17.5 metric tons. This is the estimated weight for a Space Station Common Module.

9. OTV elements can be "stacked," i.e. used as two identical stages, one staging before the other ignites.

10. Lunar surface storage, transfer (into Landers), and re-refrigeration of cryogenics, both LO_2 and LH_2, is assumed after O_2 production commences.

11. The lander can be maintained at the lunar base.

12. For the purpose of this Study: Lunar O_2 will become available after delivery of the <u>production</u> plant to lunar surface. This O_2 will be used in the reusable Lunar Lander, but delivery of Lunar O_2 to Earth orbit will not be examined in this study.

13. The OTV will be sized to perform any of three reference missions:

    A. Deliver 9 metric tons to geosynchronous orbit, returning empty using a single stage.

B. Deliver 6 metric tons round trip to geosynchronous orbit, using a single stage.

C. Deliver 17.5 metric tons payload <u>plus</u> a Lunar Lander (sized to land the payload) to lunar orbit, using two OTV stages in tandem. Both OTV stages are returned to the Space Station.

14. The same OTV's (with a kick stage where appropriate) can be used for the planetary mission. Alternate expendable stages (such as Centaur) can also be considered. Where feasible, OTV stages are recovered.

15. The Space Station altitude = 500 km (270 n mi).

16. A lunar launch window will nominally occur every nine days.

17. Lunar orbit operations will be at 200 km lunar altitude (109 naut mi.).

18. Lunar base will be near equatorial ($\pm$ 4^{o}).

19. After first stage OTV burnout, the second stage coasts around nearly to perigee before ignition to minimize g-losses (2 burn option).

20. Propellant transfer to the R-LEM takes place on the lunar surface. The H_2 Tank is landed intact and stored on the surface for refrigeration and pumping.

21. No Lunar Orbit Service Station is assumed.

22. LO_2/LH_2 mixture ratios of 7:1 are used for all lunar landers.

23. The Aft Cargo Carrier on the Shuttle External Tank is assumed available and used to carry E-Landers.

24. Shuttle Derived-Unmanned Launch Vehicles (ULV's) are needed and assumed available for propellant tankers. They are assumed to launch 100 metric tons of LO_2/LH_2 to the Space Station per flight.

25. Launch cost estimates (1984 dollars) ULV -\$133 Million/launch
STS -\$100 Million/launch

26. Shuttle is assumed capable of launching 25 m tons (55 Klb.) to the Space Station orbit. Current capability is only 19 m tons but currently funded improvements including filament wound solids and 109% SSME thrust should provide the higher 25 ton figure. However, all lunar base launch manifests were volume limited. The most massive lunar shuttle payload was 21.5 m tons.

4.0 Lunar Missions

4.1 Introduction

This section of the overall study investigates the impact on the Space Station of supporting a manned return to the lunar surface. The envisioned return entails the construction and operation of a large, permanent base designed to emphasize lunar science and lunar resource utilization.

Earlier JSC in-house studies (Ref. 1) on the "lunar initiative" have shown that a transportation system composed of a Space Station combined with Aerobraking Orbital Transfer Vehicles (AOTV's), designed for round trip delivery to geosynchronous orbit, can readily provide transportation from low Earth orbit to lunar orbit and back. What has not been previously examined is the impact upon the current space station concepts of the routine, continuing, large scale transportation needs of a serious lunar program.

This study is to assess the representative transportation requirements of such a program. To enable this, a representative lunar base "model" and build-up schedule were defined.

The mission model presented is based upon the lunar base buildup described in Reference 1, which was produced in-house at JSC. This was augmented with operations scenarios from Mr. Barney Roberts of JSC's Systems Engineering Division. The result was used as the transportation objective.

A set of necessary space transportation elements were defined and sized, including OTV elements, landers, manned modules, etc.

Vehicle inert weight scaling formulae for this exercise are taken from Reference 2, (See Table 4). Lunar Landers have an inert weight increment equal to 2% of the maximum landed mass for landing gear.

The lunar delta V budget is based upon Apollo 11 data (Reference 3) altered to reflect the different operational altitudes. Midcourse budgets were enlarged to yield plane change capability of 25^{o} at the gravitational field interface between the Earth and the Moon. The Apollo 11 mission used a fast, 2 1/2 day transit, free-return trajectory. Later Apollo missions used slower (up to 4 day) non-free-return trajectories. These yielded significant delta V reductions, particularly in the Lunar Orbit Insertion (LOI) and Trans-Earth Injection (TEI) maneuvers. The capability for the faster flight time has been built into the delta V budget for this study so that flight time can be varied as necessary to allow launch windows that are several days long at nine day intervals.

The nine day mission opportunity interval is created by the requirement to depart from the Space Station orbit. Reasonable transfer opportunities occur only when the Moon is in, or near, the plane of the Space Station orbit. This occurs every 9 days as the Moon revolves around the Earth and the Space Station orbit precesses in the opposite direction.

4.2 Lunar Base Description

The study examines the transportation requirements for the build-up and supply of a representative ambitious lunar base. The model selected for study was a permanently manned installation of from 18 to 20 personnel. The facility is heavily oriented toward lunar science but also includes limited capability for the production of lunar derived resources. The key production plant is a small lunar oxygen facility capable of producing at least 30 metric tons of oxygen per month for use at the base and as propellant for a reusable lunar lander/launcher.

Only the first ten years of base build-up was examined. At the end of ten years the base consists of:

- 5 HABITABILITY MODULES
- 5 RESEARCH UNITS
  - GEO-CHEMICAL LABORATORY
  - CHEMICAL/BIOLOGY LABORATORY
  - GEO-CHEMICAL/PETROLOGY LABORATORY
  - PARTICLE ACCELERATOR
  - RADIO TELESCOPE
- 3 PRODUCTION PLANTS (PRECEDED BY PILOT PLANTS)
  - OXYGEN PLANT
  - CERAMICS PLANT
  - METALLURGY PLANT
- 2 WORK SHOPS
- 3 POWER UNITS
- 1 EARTHMOVER/CRANE
- 3 MOBILITY UNITS W/TRAILERS
- 18 PERMANENT PERSONNEL

It is assumed that the basic elements will be constructed using the standardized Space Station "Common Module", a cylinder 4.5 meters in diameter and 11 meters long (15 ft. X 36 ft.). The weights of these elements including their contents was held to 17.5 metric tons (38,600 lbm).

Figure 3 illustrates one of these Common Modules being unloaded from an Expendable-Lander (this is prior to achievement of full O_2 production). The crane and trailer illustrated are designed to fit within the same reference envelope (Figure 4). They do not fit inside a Common Module, however. This 4.5 X 11 meter envelope will fit inside the Shuttle bay for launch from the Earth's surface. The various elements of the lunar base are shown in the background. The habitats and laboratories are interconnected and covered with lunar regolith for radiation and meteorite protection and for thermal insulation. The Common Module being unloaded will be placed in the excavated area.

Figure 4 shows one of these common modules mounted on a transport/trailer. Transport will be necessary because the landing must take place some distance from the main base. This prevents a landing accident from damaging the base. Pin-point, automated lunar landings may not yet be within the state-of-the-art in this time frame.

Figure 4 includes a sketch of the crane illustrated in the previous picture. It is one possible design approach to a crane that can be packaged to fit within the standard 4.5 X 11 meter envelope and 17.5 metric ton weight constraint. The tires are hollow metal. The crane will be required to handle items equal to or more than its own weight. The necessary strength should not be difficult to achieve, considering the low lunar gravity, but balance will be difficult. Transport using just the crane appears impractical. This gave rise to the "little red wagon" concept shown here.

In general, consideration of the details of the base elements is beyond the scope of this transportation study. The crane and wagon, however, provide the final transportation step so some thought was given to them to insure no insurmountable problems would be presented.

4.3 Lunar Base Build-up Scheme

The lunar base mission sequence begins with preliminary orbital geo-chemical mapping via a satellite placed in a low lunar polar orbit, followed by 5 years of remote "lunar rover" surface investigations and site selection. Starting in the year 2005, the actual build-up of the lunar base begins. The base is fully operational by the year 2014.

This build-up requires delivery of the following:

Major Lunar Base Elements: (17.5 metric ton cargo units)

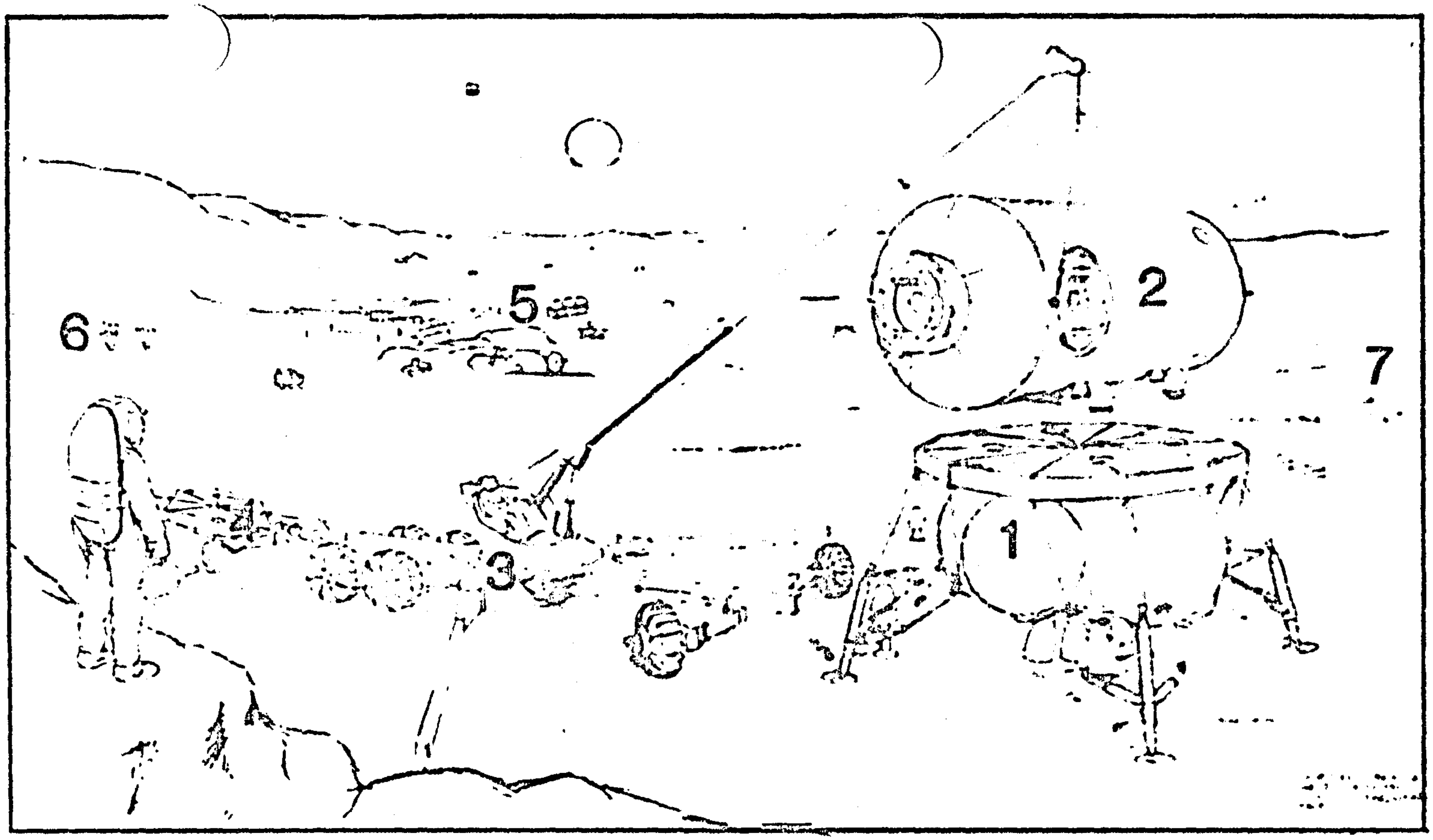
- Earthmover/Crane - 1
- Power Unit - 3
- Habitat - 5
- Lunar LO_2 Pilot Plant - 1
- Lunar LO_2 Production Plant - 2
- Unpressurized Mobility Unit & Relay Station - 1
- Pressurized Mobility Unit - 2
- Geo-Chemical Lab - 1
- Geo-Chemical - Petrology Lab/Observation Equipment -1
- Work Shop - 2
- Ceramics Pilot Plant - 1
- Metallurgy Pilot Plant -1
- Particle Accelerator - 1
- Chemical/Biology Lab - 1
- Ceramics Plant - Operational - 1
- Metallurgy Plant - Operational - 1

Plus Light Units: (9 metric ton cargo units delivered during crew rotation flights)

- Ground Relay Station - 1
- Radio Telescope - 1
- Power Converter - 1

Starting with the year 2005, some 3 to 5 major elements per year are delivered to the lunar surface; manned sorties occur every 3 to 4 months. Each delivery or manned mission requires a two-stage OTV sortie plus an expendable lander and, for the manned mission, an expendable launcher. The manned missions also require a reusable manned module to carry men on the OTV, an OTV Manned Module (OMM), and a manned module to carry men on the landers, the Lunar Lander Manned Module (LLMM). This last element may be expendable initially, but will be reused and stored at the lunar base once lunar produced oxygen and the reusable lunar lander become operational.

During 2005, the first year of base build-up, a power unit, crane, trailer, and one laboratory are delivered on unmanned flights. Two manned sorties of approximately one lunar daylight period each, 14 days, are then flown to prepare the base and



UNLOADING MODULE ON LUNAR SURFACE

1. E-LANDER
2. COMMON MODULE
3. LUNAR CRANE
4. TRAILER
5. LUNAR BASE
6. NUCLEAR POWER PLANT
7. EXPENDED E-LANDERS

FIGURE 3
LEGEND

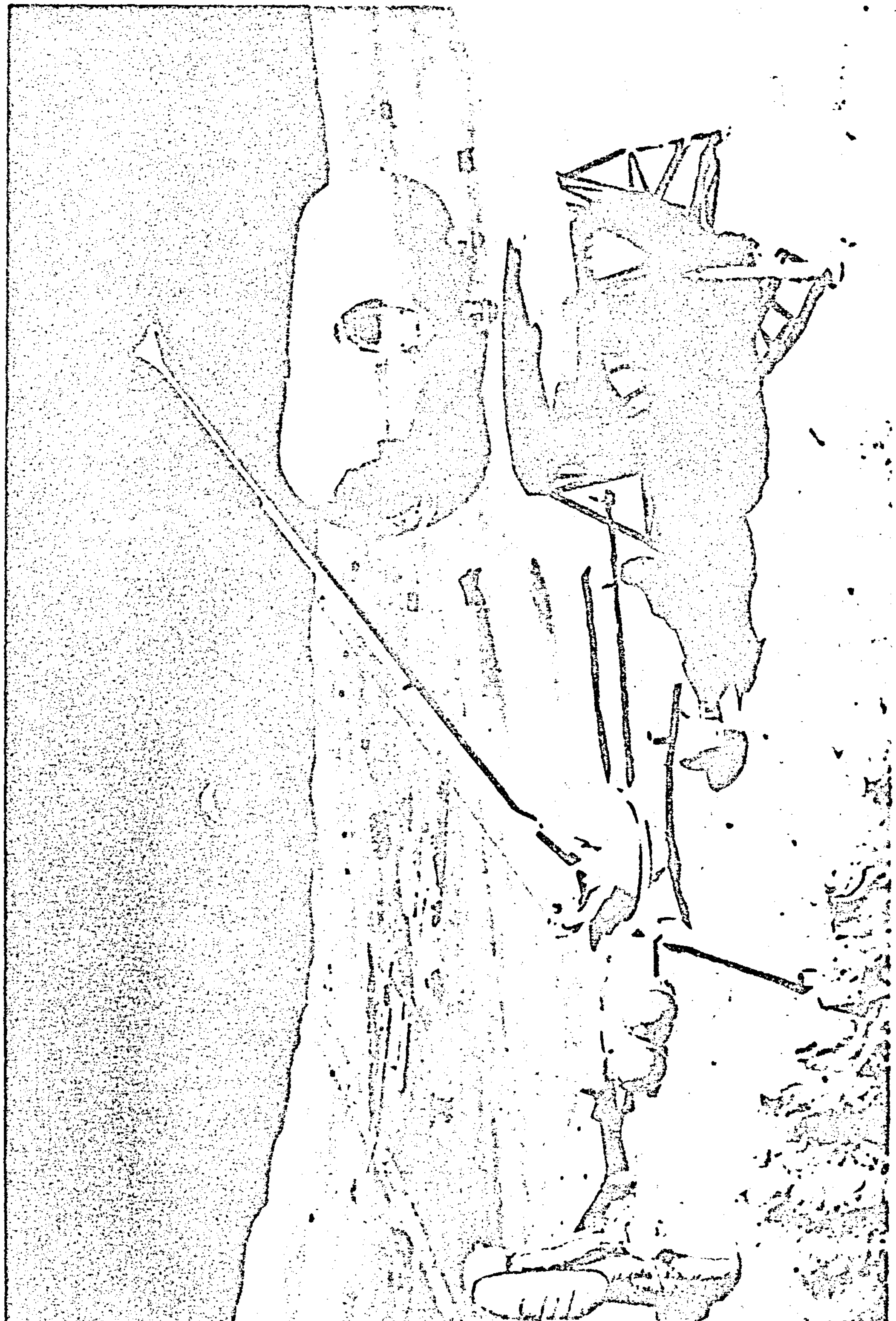
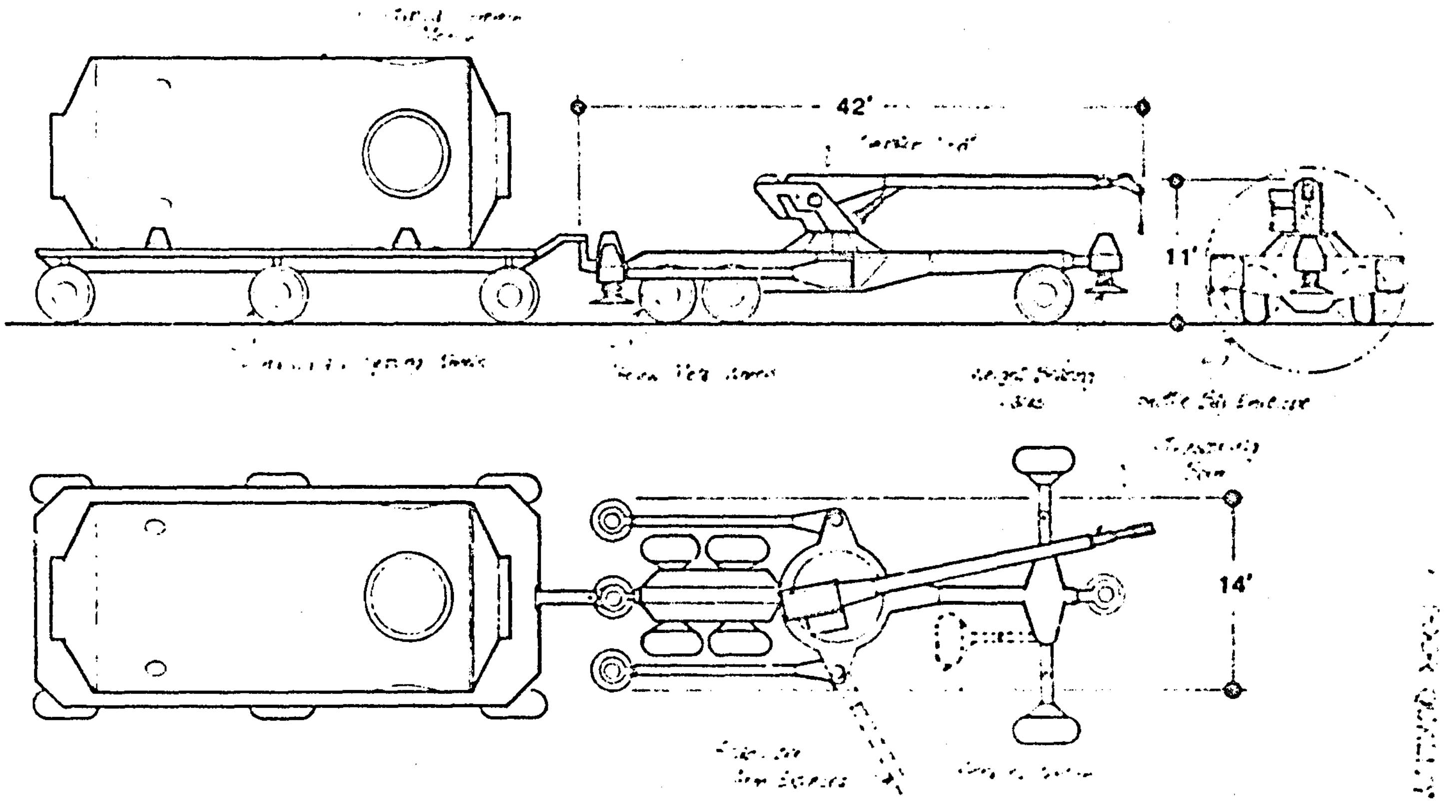


Figure 3



Lunar Crane
& Trailer with Common Module

Figure 4

commence operations. The entire crew returns to Earth each time, leaving the base unmanned between missions.

In the second year, 2006, a mobility unit and a pilot plant for oxygen production are delivered. Two more manned sorties are flown. The last crew remains, along with their launch vehicle, beginning permanent human occupancy of the lunar base.

In the third year, 2007, one more laboratory and miscellaneous equipment are delivered unmanned. Three manned sorties are flown providing crew rotation.

In the fourth year, 2008, an operational oxygen production plant is delivered (several flights): the new Reusable Lander/Launcher (R-LEM) is delivered and becomes operational. The permanent crew continues to grow in number.

In the fifth through the tenth years a heavy flight schedule delivers the remainder of base elements. This activity slacks off to six manned crew rotation sorties per year as the base approaches full growth. The "final" configuration of this study's lunar base is achieved in the tenth year, 2014. In reality, the base may continue to grow indefinitely, once this "beachhead" is established. Figure 13 graphs the material build-up.

Table 1, the Lunar Mission Sequence, gives the detailed transportation requirements for this build-up on a year-by-year basis, broken down into single mission-sized elements.

Table 2 is a manifest/schedule of Earth launches and lunar missions to achieve these requirements. It is designed to provide launches and lunar departures on flight centers as evenly scheduled as possible. Shuttle derived unmanned launch vehicles are required to launch all LO_2 and LH_2 propellant to the Space Station. This includes propellant used by the lunar landers as well as that for the OTV's. Crews and cargos will all be launched on the Space Shuttle.

Consecutive launches of the Shuttle were kept to at least 6 week centers as were those of the unmanned tanker flights. These two different vehicles will use different launch facilities, so interference is not expected to be a problem.

After the lunar oxygen and the reusable lander become available, the number of launches per lunar flight drops from two to approximately one and one third. In some of these latter cases, it is assumed that the lunar crew will be launched to the Space Station on a regularly scheduled Space Station resupply mission. Except for these crews, this schedule does not include Space Station resupply or support of any operations other than the lunar base.

The estimated manning levels for the lunar base are shown in Figure 5. This is an Eagle Engineering estimate based on the availability of housing and laboratory facilities. Even numbers are maintained so that work functions can be done in pairs for safety. For flight scheduling purposes, a six month tour of duty was assumed, and one third of the crew will be replaced at a time.

TABLE 1
LUNAR MISSION SEQUENCE

YEAR	FLIGHT OBJECTIVES	CARGO TO LUNAR ORB M. TONS	CARGO RETURNED M. TONS	ELEMENTS TO LUNAR ORBIT	ELEMENTS TO SURFACE	ELEMENTS RETURNED
1996	DELIVER GEO-MAPPER SATELLITE	0.5	0	GEO-MAPPER SATELLITE		
1999 THROUGH 2004	DELIVER UNMANNED SURFACE EXPLORER/ ROVER 1 PER YR. NOTE: CENTAUR TYPE MISSION	4	0	SURFACE ROVER/EXPLORER-1/YR	LUNAR ROVER PLUS SMALL LANDER (ONE PER YEAR)	
START LUNAR BASE BUILDUP						
2005	UNMANNED HEAVY DELIVERIES					
	- EARTHMOVER/CRANE	35	0	E-LANDER + CRANE	CRANE	
	- POWER UNIT #1	35	0	E-LANDER + PU#1	PWR. UNIT #1	
	- HABITAT #1	35	0	E-LANDER + HM#1	MAN. HABITAT #1	
	- GEO CHEM LAB	35	0	E-LANDER + GEO CHEM LAB	GEO,CHEM LAB	
	MANNED SORTIE-BASE SET-UP	32	6	OTV-MANNED MODULE (OMM)+LUNAR LANDING MANNED MOD. (LLMM) + E-LANDER + E-ASCENT + 2 ton PL	LLMM + E-ASCENT	LLMM + LUNAR SAMPLE
	MANNED SORTIE-BASE OPS	32	6	OMM, LLMM, E-LANDER, E-ASCENT,+2T	LLMM + E-ASCENT	LLMM + LUNAR SAMPLE
2006	UNMANNED HEAVY DELIVERIES					
	- UNPRESSURIZED MOBILITY UNIT + RELAY STATION	35	0	E-LANDER + CARGO UNIT	MOBILITY UNIT	
	- LLOX PILOT PLANT	35	0	E-LANDER + CARGO UNIT	LLOX PILOT PLANT	
	MANNED SORTIE	32	6	OMM, LLMM, E-LANDER,E-ASCENT,+2T	LLMM + E-ASCENT	LLMM + LUNAR SAMPLE
	MANNED SORTIE	32	6	OMM, LLMM, E-LANDER,E-ASCENT,+2T	LLMM + E-ASCENT	LLMM + LUNAR SAMPLE
2007	PLACE L-2 RELAY SATELLITE	0.5	0	RELAY SATELLITE (TO L-2 POSITION)		
	UNMANNED HEAVY DELIVERIES					
	- GEO/CHEM PETROLOGY LAB AND SOME OBS. EQPT.	35	0	E-LANDER+CARGO ELEMENT	GEO-CHEM PETROLOGY LAB PLUS OBSERVATORY	
	- MANNED SORTIE W/NETWORK	32	6	OMM, LLMM, E-LANDER,E-ASCENT,+2T	LLMM + E-ASCENT + 2T P/L	LLMM
	- MANNED SORTIE W/NETWORK	32	6	OMM, LLMM, E-LANDER,E-ASCENT,+2T	LLMM + E-ASCENT + 2T P/L	
	- MANNED SORTIE W/NETWORK	32	6	OMM, LLMM, E-LANDER,E-ASCENT,+2T		
2008	UNMANNED HEAVY DELIVERY					
	- LUNAR ORBIT SPACE STATI	35	0	LOSS		
	- LLOX PRODUCTION UNIT #1	35	0	E-LANDER + LOX PRODUCTION PLANT	LLOX PRODUCTION PLANT + LOADING FACILITY	
	- LLOX PRODUCTION UNIT #2	35	0	E-LANDER + LOX PRODUCTION PLANT		

TABLE 1
LUNAR MISSION SEQU.

YEAR	FLIGHT OBJECTIVES	CARGO TO LUNAR ORB M. TONS	CARGO RETURNED M. TONS	ELEMENTS TO LUNAR ORBIT	ELEMENTS TO SURFACE	ELEMENTS RETURNED
	MANNED SORTIE+REUSE LUNAR LANDER (R-LEM) DELIVERY (PARTIALLY FUELED)	32	6	R-LEM, H2, OMM, REUSABLE LLMM	R-LEM, R-LLMM 4 TO 7 TONS H2	R-LLMM R-LEM
REUSABLE LEM USE WITH LUNAR O2 COMMENCES						
	MANNED SORTIE - OPS+SUPPLY	19.5	7	OMM, 5T H2 TANK, 9T CARGO	R-LEM, R-LLMM, 9T	R-LLMM, R
	MANNED SORTIE - OPS+SUPPLY	19.5	7	OMM, 5T H2 TANK, 9T CARGO	R-LEM, R-LLMM, 9T	R-LLMM, R
	MANNED SORTIE - OPS+SUPPLY	19.5	7	OMM, 5T H2 TANK, 9T CARGO	R-LEM, R-LLMM, 9T	R-LLMM, R
2009	UNMANNED HEAVY DELIVERIES					
	- POWER UNIT #2	22.5	1	POWER UNIT + H2 TANK	R-LEM - POWER UNIT	R-LEM
	- POWER UNIT #3	22.5	1	POWER UNIT + H2 TANK	R-LEM - POWER UNIT	R-LEM
	- HABITABILITY MODULE #2	22.5	1	HABITABILITY MOD + H2 TANK	R-LEM HABITABILITY MODULE	R-LEM
	- HABITABILITY MODULE #3	22.5	1	HABITABILITY MOD + H2 TANK	R-LEM HABITABILITY MODULE	R-LEM
	- HABITABILITY MODULE #4	22.5	1	HABITABILITY MOD + H2 TANK	R-LEM HABITABILITY MODULE	R-LEM
	MANNED SORTIE - OPS (+2T)	12.5	7.5	OMM, 5T H2 TANK, 2T CARGO	R-LEM, R-LLMM, 2T	R-LLMM, R-LEM
	MANNED SORTIE - OPS (+2T)	12.5	7.5	OMM, 5T H2 TANK, 2T CARGO	R-LEM, R-LLMM, 2T	R-LLMM, R-LEM
	MANNED SORTIE - OPS (+2T)	12.5	7.5	OMM, 5T H2 TANK, 2T CARGO	R-LEM, R-LLMM, 2T	R-LLMM, R-LEM
	MANNED SORTIE - OPS (+2T)	12.5	7.5	OMM, 5T H2 TANK, 2T CARGO	R-LEM, R-LLMM, 2T	R-LLMM, R-LEM
2010	UNMANNED HEAVY DELIVERIES					
	- PRESSURIZED MOBILITY UN	22.5	1	POWER UNIT + H2 TANK	R-LEM + PMU	R-LEM
	- SHOP	22.5	1	SHOP + H2 TANK	R-LEM + SHOP	R-LEM
	- CERAMICS PILOT	22.5	1	CERAMICS PILOT + H2 TANK	R-LEM + CER. PILOT	R-LEM
	- METALLURGY PILOT	22.5	1	METALLURGY PILOT + H2 TANK	R-LEM + MET. PILOT	R-LEM
	- PARTICLE ACCELERATOR	22.5	1	PARTICLE ACC. + H2 TANK	R-LEM + PARTICLE ACC.	R-LEM
	MANNED SORTIE - RESUPPLY	19.5	7.5	OMM, H2, 9T CARGO	R-LEM, R-LLMM, 9T	R-LEM, R-LLMM + 2T
	MANNED SORTIE - RESUPPLY	19.5	7.5	OMM, H2, 9T CARGO	R-LEM, R-LLMM, 9T	R-LEM, R-LLMM + 2T
	MANNED SORTIE - RESUPPLY	19.5	7.5	OMM, H2, 9T CARGO	R-LEM, R-LLMM, 9T	R-LEM, R-LLMM + 2T
	MANNED SORTIE - CREW ROT.	14.5	7.5	OMM, H2, 4T CARGO	R-LEM, R-LLMM, 4T	R-LEM, R-LLMM + 2T +O2
	MANNED SORTIE - CREW ROT.	14.5	7.5	OMM, H2, 4T CARGO	R-LEM, R-LLMM, 4T	R-LEM, R-LLMM + 2T +O2
	MANNED SORTIE - CREW ROT.	14.5	7.5	OMM, H2, 4T CARGO	R-LEM, R-LLMM, 4T	R-LEM, R-LLMM + 2T +O2
	LIGHT UNMANNED DELIVERY					
	- RELAY SATELLITE TO L-2	2	0	RELAY SATELLITE +KICK STAGE		
2011	UNMANNED HEAVY DELIVERIES					
	- CHEMICAL/BIOLOGY LAB	22.5	1	CHEM/BIOLOGY LAB +H2 TANK	R-LEM + CHEM/BIOLOGY LAB	R-LEM
	MANNED SORTIE - RESUPPLY	22	10	OMM, H2, 9T CARGO	R-LEM, R-LLMM, 9T	R-LEM, R-LLMM + 2T
	MANNED SORTIE - RESUPPLY	22	10	OMM, H2, 9T CARGO	R-LEM, R-LLMM, 9T	R-LEM, R-LLMM + 2T
	MANNED SORTIE - RESUPPLY	22	10	OMM, H2, 9T CARGO	R-LEM, R-LLMM, 9T	R-LEM, R-LLMM + 2T
	MANNED SORTIE - RESUPPLY	22	10	OMM, H2, 9T CARGO	R-LEM, R-LLMM, 9T	R-LEM, R-LLMM + 2T
2012	MANNED SORTIE - RESUPPLY	22	10	OMM, H2, 9T CARGO	R-LEM, R-LLMM, 9T	R-LEM, R-LLMM + 2T
	MANNED SORTIE - RESUPPLY	22	10	OMM, H2, 9T CARGO	R-LEM, R-LLMM, 9T	R-LEM, R-LLMM + 2T
	MANNED SORTIE - RESUPPLY	22	10	OMM, H2, 9T CARGO	R-LEM, R-LLMM, 9T	R-LEM, R-LLMM + 2T
	MANNED SORTIE - CREW ROT.	17	10	OMM, H2, 4T CARGO	R-LEM, R-LLMM, 4T	R-LEM, R-LLMM + 2T +O2

TABLE 1
LUNAR MISSION SEQUENCE

YEAR	FLIGHT OBJECTIVES	CARGO TO LUNAR ORB M. TONS	CARGO RETURNED M. TONS	ELEMENTS TO LUNAR ORBIT	ELEMENTS TO SURFACE	ELEMENTS RETURNED
	MANNED SORTIE - CREW ROT.	17	10	OTM, H2, 4T CARGO	R-LEM, R-LLEM, 4T	R-LEM, R-LLEM + 2T +O2
	MANNED SORTIE - CREW ROT.	17	10	OTM, H2, 4T CARGO	R-LEM, R-LLEM, 4T	R-LEM, R-LLEM + 2T +O2
2013	UNMANNED HEAVY DELIVERIES					
	- HABITABILITY MODULE # 5	22.5	1	HAB. MOD. #5 +H2 TANK	R-LEM + HAB. MOD.	R-LEM
	- SHOP #2	22.5	1	SHOP + H2 TANK	R-LEM +SHOP	R-LEM
	- CERAMICS PLANT , OPS.	22.5	1	CERAMIC PLANT + H2 TANK	R-LEM +CER. PLANT	R-LEM
	- METALLURGY PLANT , OPS.	22.5	1	METALLURGY PLANT + H2 TANK	R-LEM + MET. PLANT	R-LEM
	- PRESS. MOBILITY UNIT #2	22.5	1	PRESS.MOBILITY UNIT +H2 TANK	R-LEM + PRESS. MOB. UNIT	R-LEM
	MANNED SORTIE + F/R GROUND STATION	22	10	OTM,H2,+F/R GRND STATION	R-LEMM,R-LLEM,F/R GND. STA.	R-LEM, R-LLEM, + 2T
	MANNED SORTIE +RAD TELE.	22	10	OTM,H2,+RADIO TELESCOPE	R-LEM, R-LLEM, RADIO TELE.	R-LEM, R-LLEM, + 2T
	MANNED SORTIE +POWER CONVERTER FOR LDPW	22	10	OTM,H2,+POWER CONVERTER	R-LEM, R-LLEM, PWR. CONV.	R-LEM, R-LLEM, + 2T
	MANNED SORTIE - RESUPPLY	22	10	OTM, H2, 9T CARGO	R-LEM, R-LLEM, 9T	R-LEM, R-LLEM, + 2T
	MANNED SORTIE - RESUPPLY	22	10	OTM, H2, 9T CARGO	R-LEM, R-LLEM, 9T	R-LEM, R-LLEM, + 2T
	MANNED SORTIE - CREW ROT.	17	10	OTM, H2, 4T CARGO	R-LEM, R-LLEM, 4T	R-LEM, R-LLEM + 2T +O2
2014	MANNED SORTIE - RESUPPLY	22	10	OTM, H2, 9T CARGO	R-LEM, R-LLEM, 9T	R-LEM, R-LLEM, + 2T
	MANNED SORTIE - RESUPPLY	22	10	OTM, H2, 9T CARGO	R-LEM, R-LLEM, 9T	R-LEM, R-LLEM, + 2T
	MANNED SORTIE - RESUPPLY	22	10	OTM, H2, 9T CARGO	R-LEM, R-LLEM, 9T	R-LEM, R-LLEM, + 2T
	MANNED SORTIE - CREW ROT.	17	10	OTM, H2, 4T CARGO	R-LEM, R-LLEM, 4T	R-LEM, R-LLEM + 2T +O2
	MANNED SORTIE - CREW ROT.	17	10	OTM, H2, 4T CARGO	R-LEM, R-LLEM, 4T	R-LEM, R-LLEM + 2T +O2
	MANNED SORTIE - CREW ROT.	17	10	OTM, H2, 4T CARGO	R-LEM, R-LLEM, 4T	R-LEM, R-LLEM + 2T +O2

TABLE 2
DETAILED LAUNCH MANIFEST AND L[illegible]SSION SCHEDULE

MONTH	LAUNCH NO.	TYPE	CARGO MANIFEST	CARGO WT. m ton	LUNAR FLIGHT NO.	FLIGHT TYPE	SPACE STATION TASKS FOR FLIGHT	LOX/LH2 AT DEPOT m ton
			------------- YEAR 2005 --------------					
JAN	5-1	SD-ULV	LOX/LH2 PROPELLANT SUPPLY UNIT	100				100
FEB	5-2	STS-ACC	E-LANDER,+BASE ELEMENT 01	21	L5-1	UNMANNED DELIVERY	PREPARE (CHECK OUT & FUEL) 2 OTVs AND E-LANDER,CHECK OUT CARGO, & MATE STACK -(2 OTVs,E-LANDER,AND BASE ELEMENT)	0
MARCH	5-3	SD-ULV	LOX/LH2 PROPELLANT SUPPLY UNIT	100				100
APRIL	5-4	STS-ACC	E-LANDER,+BASE ELEMENT 02	21	L5-2	UNMANNED DELIVERY	PREPARE (CHECK OUT & FUEL) 2 OTVs AND E-LANDER,CHECK OUT CARGO, & MATE STACK -(2 OTVs,E-LANDER,AND BASE ELEMENT)	0
MAY	5-5	SD-ULV	LOX/LH2 PROPELLANT SUPPLY UNIT	100				100
	5-6	STS-ACC	E-LANDER,+BASE ELEMENT 03	21	L5-3	UNMANNED DELIVERY	PREPARE (CHECK OUT & FUEL) 2 OTVs AND E-LANDER,CHECK OUT CARGO, & MATE STACK -(2 OTVs,E-LANDER,AND BASE ELEMENT)	0
JULY	5-7	SD-ULV	LOX/LH2 PROPELLANT SUPPLY UNIT	100				100
AUG	5-8	STS-ACC	E-LANDER,+BASE ELEMENT 04	21	L5-4	UNMANNED DELIVERY	PREPARE (CHECK OUT & FUEL) 2 OTVs AND E-LANDER,CHECK OUT CARGO, & MATE STACK -(2 OTVs,E-LANDER,AND BASE ELEMENT)	0
SEPT	5-9	SD-ULV	LOX/LH2 PROPELLANT SUPPLY UNIT	100				100
OCT	5-10	STS-ACC	E-LANDER,+E-LLMM/ASCENT,+OMM,+4 CREW, + 2 TON PL	20	L5-5	MANNED SORTIE	PREPARE 2 OTVs AND E-LANDER, CHECK OUT OMM,E-LLMM/ASCENT, MATE STACK -(2 OTVs, OMM,E-LLMM/ASCENT,& E-LANDER),AND TRANSFER CREW TO OMM	0
NOV	5-11	SD-ULV	LOX/LH2 PROPELLANT SUPPLY UNIT	100				100
DEC	5-12	STS-ACC	E-LANDER,+E-LLMM/ASCENT,+OMM,+4 CREW + 2 TON PL	20	L5-6	MS-(4M+2t for 14 days)	PREPARE 2 OTVs AND E-LANDER, CHECK OUT OMM,E-LLMM/ASCENT, MATE STACK -(2 OTVs, OMM,E-LLMM/ASCENT,& E-LANDER);AND TRANSFER CREW TO OMM	0
			------------- YEAR 2006 --------------					
JAN	6-1	SD-ULV	LOX/LH2 PROPELLANT SUPPLY UNIT	100				100
FEB	6-2	STS-ACC	E-LANDER,+BASE ELEMENT 05	21	L6-1	UNMANNED DELIVERY	PREPARE (CHECK OUT & FUEL) 2 OTVs AND E-LANDER,CHECK OUT CARGO, & MATE STACK -(2 OTVs,E-LANDER,AND BASE ELEMENT)	0
MARCH								
APRIL	6-3	SD-ULV	LOX/LH2 PROPELLANT SUPPLY UNIT	100				100
MAY	6-4	STS-ACC	E-LANDER,+E-LLMM/ASCENT,+4 CREW,+2 ton P.L.,+ 4 ton of AOTV ELEMENTS	20	L6-2	MS-(4M+2t for 14 days)	PREPARE 2 OTVs, E-LANDER, AND OMM , CHECK OUT E-LLMM/ASCENT; MATE STACK -(2 OTVs, OMM,E-LLMM/ASCENT,& E-LANDER);AND TRANSFER CREW TO OMM	0
JUNE								
JULY	6-5	SD-ULV	LOX/LH2 PROPELLANT SUPPLY UNIT	100				100
AUG	6-6	STS-ACC	E-LANDER,+BASE ELEMENT 06	21	L6-3	UNMANNED DELIVERY	PREPARE (CHECK OUT & FUEL) 2 OTVs AND E-LANDER,CHECK OUT CARGO, & MATE STACK -(2 OTVs,E-LANDER,AND BASE ELEMENT)	0
SEPT								
OCT	6-7	SD-ULV	LOX/LH2 PROPELLANT SUPPLY UNIT	100				100
NOV	6-8	STS-ACC	E-LANDER,+E-LLMM/ASCENT,+4 CREW,+2 ton P.L.,+ 4 ton of AOTV ELEMENTS	20	L6-4	MS-(4M+2t for 14 days)	PREPARE 2 OTVs, E-LANDER, AND OMM ; CHECK OUT E-LLMM/ASCENT; MATE STACK -(2 OTVs, OMM,E-LLMM/ASCENT,& E-LANDER);AND TRANSFER CREW TO OMM	0
DEC								

TABLE
DETAILED LAUNCH MANIFEST AND MISSION SCHEDULE

MONTH	LAUNCH NO.	TYPE	CARGO MANIFEST	CARGO WT. m.ton	LUNAR FLIGHT NO.	FLIGHT TYPE	SPACE STATION TASKS FOR FLIGHT	LOX/LH2 AT DEPOT m.ton
			------------- YEAR 2007 -------------					
JAN	7-1	SD-ULV	LOX/LH2 PROPELLANT SUPPLY UNIT	100				100
FEB	7-2	STS-ACC	E-LANDER,+BASE ELEMENT #7	21	L7-1	UNMANNED DELIVERY	PREPARE (CHECK OUT & FUEL) 2 OTVs AND E-LANDER;CHECK OUT CARGO, & MATE STACK -(2 OTVs,E-LANDER,AND BASE ELEMENT)	0
MARCH								
APRIL	7-3	SD-ULV	LOX/LH2 PROPELLANT SUPPLY UNIT	100				100
MAY	7-4	STS-ACC	E-LANDER,+E-LLMM/ASCENT,+4 CREW,+2 ton P L.,+ 4 ton of AOTV ELEMENTS	20	L7-2	MS-(4M+2t)	PREPARE 2 OTVs, E-LANDER, AND OMM ; CHECK OUT E-LLMM/ASCENT; MATE STACK -(2 OTVs, OMM,E-LLMM/ASCENT,& E-LANDER);AND TRANS-FER CREW TO OMM	0
JUNE								
JULY	7-5	SD-ULV	LOX/LH2 PROPELLANT SUPPLY UNIT	100				100
AUG	7-6	STS-ACC	E-LANDER,+E-LLMM/ASCENT,+4 CREW,+2 ton P.L.,+ 4 ton of AOTV ELEMENTS	20	L7-3	MS-(4M+2t)	PREPARE 2 OTVs, E-LANDER, AND OMM ; CHECK OUT E-LLMM/ASCENT; MATE STACK -(2 OTVs, OMM,E-LLMM/ASCENT,& E-LANDER);AND TRANS-FER CREW TO OMM	0
SEPT								
OCT	7-7	SD-ULV	LOX/LH2 PROPELLANT SUPPLY UNIT	100				100
NOV	7-8	STS-ACC	E-LANDER,+E-LLMM/ASCENT,+4 CREW,+2 ton P.L.,+ R-LLMM	21	L7-4	MS-(4M+2t)	PREPARE 2 OTVs, E-LANDER, AND OMM ; CHECK OUT E-LLMM/ASCENT; MATE STACK -(2 OTVs, OMM,E-LLMM/ASCENT,& E-LANDER),AND TRANS-FER CREW TO OMM	0
DEC	7-9	STS-ACC	R-LEM ELEMENTS,+SECOND R-LLMM,+H2 TANK	10				
	7-10	SD-ULV	LOX/LH2 PROPELLANT SUPPLY UNIT	100				100
			------------- YEAR 2008 -------------					
JAN	8-1	STS-ACC	E-LANDER,+BASE ELEMENT #8	21	L8-1	UNMANNED DELIVERY	PREPARE (CHECK OUT & FUEL) 2 OTVs AND E-LANDER;CHECK OUT CARGO; & MATE STACK -(2 OTVs,E-LANDER,AND BASE ELEMENT)	0
FEB	8-2	SD-ULV	LOX/LH2 PROPELLANT SUPPLY UNIT	100				100
MARCH	8-3	STS-ACC	E-LANDER,+BASE ELEMENT #9	21	L8-2	UNMANNED DELIVERY	PREPARE (CHECK OUT & FUEL) 2 OTVs AND E-LANDER,CHECK OUT CARGO & MATE STACK -(2 OTVs,E-LANDER,AND BASE ELEMENT)	0
APRIL	8-4	SD-ULV	LOX/LH2 PROPELLANT SUPPLY UNIT	100				100
	note--- lunar crew delivered to Space Station on scheduled resupply STS launch							
MAY					L8-3	MS-(R-LEM + 4M + R-LLMM)	PREPARE 2 OTVs, R-LEM, H2 TANK, OMM, AND R-LLMM ; MATE STACK -(2 OTVs,OMM,R-LLMM, AND R-LEM), & TRANSFER CREW TO OMM	12
JUNE	8-5	SD-ULV	LOX/LH2 PROPELLANT SUPPLY UNIT	100				112
JULY	8-6	STS	2 H2 TANKS,+ 10 tons of LUNAR CARGO, + 4 CREW	21	L8-4	MS-(4M+9t)	PREPARE 2 OTVs AND H2 TANK; CHECK OUT OMM; MATE STACK (2OTVs,H2 TANK,OMM,AND 9 tons OF LUNAR CARGO); & TRANSFER CREW TO OMM	47
AUG	8-7	SD-ULV	LOX/LH2 PROPELLANT SUPPLY UNIT	100				147
			----4 crew delivered on S.S. resupply launch ----		TS launch			
SEPT					L8-5	MS-(4M+9t)	PREPARE 2 OTVs AND H2 TANK; CHECK OUT OMM; MATE STACK (2OTVs,H2 TANK,OMM,AND 9 tons OF LUNAR CARGO), & TRANSFER CREW TO OMM	82
OCT	8-8	STS	2 H2 TANKS,+ 11 tons of LUNAR CARGO, + 4 CREW	14				
NOV					L8-6	MS-(4M+9t)	PREPARE 2 OTVs AND H2 TANK; CHECK OUT OMM, MATE STACK (2OTVs,H2 TANK,OMM,AND 9 tons OF LUNAR CARGO); & TRANSFER CREW TO OMM	17
DEC								

TABLE 2
DETAILED LAUNCH MANIFEST AND LUNAR MISSION SCHEDULE

MN	LAUNCH NO	TYPE	CARGO MANIFEST	CARGO WT in ton	LUNAR FLIGHT NO	FLIGHT TYPE	SPACE STATION TASKS FOR FLIGHT	LOX/LH2 AT DEPOT in ton
			------------- YEAR 2009 --------------					
[illegible]	9-1	SD-ULV	LOX/LH2 PROPELLANT SUPPLY UNIT	100				117
			----4 crew delivered on S.S. resupply launch ----		L9-1	MS-(4M+2D)	---FOR MS (MANNED SCIENTIFIC)FLIGHTS---	67
[illegible]	9-2	STS	H2 TANK,+ BASE ELEMENT # 10	10.5	L9-2	UNMANNED DELIVERY	PREPARE 2 OTVs AND H2 TANK, CHECK OUT OCM, MATE STACK (2OTVs,H2 TANK,OCM,AND 9 tons OF LUNAR CARGO), & TRANSFER CREW TO OCM	3
[illegible]	9-3	SD-ULV	LOX/LH2 PROPELLANT SUPPLY UNIT	100				103
[illegible]	9-4	STS	3 H2 TANKS,+6 TON SUPPLIES,+4 CREW	18	L9-3	MS-(4M+2D)		53
[illegible]	9-5	SD-ULV	LOX/LH2 PROPELLANT SUPPLY UNIT	100			---FOR UNMANNED DELIVERY FLIGHTS--- PREPARE 2 OTVs AND H2 TANK, CHECK OUT BASE ELEMENT (CARGO), MATE STACK (2 OTVs H2 TANK,AND BASE ELEMENT)	153
[illegible]	9-6	STS	H2 TANK,+ BASE ELEMENT # 11	10.5	L9-4	UNMANNED DELIVERY		87
[illegible]	9-7	STS	H2 TANK,+ BASE ELEMENT # 12,+ 4 CREW	19.5	L9-5	MS-(4M+2D)		37
[illegible]	9-8	SD-ULV	LOX/LH2 PROPELLANT SUPPLY UNIT	100	L9-6	UNMANNED DELIVERY		72
[illegible]	9-9	SD-ULV	LOX/LH2 PROPELLANT SUPPLY UNIT	100				172
[illegible]	9-10	STS	H2 TANK,+ BASE ELEMENT # 13,+ 4 CREW	19.5	L9-7	MS-(4M+2D)		122
[illegible]	9-11	SD-ULV	LOX/LH2 PROPELLANT SUPPLY UNIT	100	L9-8	UNMANNED DELIVERY		133
[illegible]	9-12	STS	H2 TANK,+ BASE ELEMENT # 14	10.5	L9-9	UNMANNED DELIVERY		93
			------------- YEAR 2010 --------------					
[illegible]	10-1	STS	2 H2 TANKS, + 13 TON, + 4 CREW	16	L10-1	MS-(4M+4D)	---FOR MS (MANNED SCIENTIFIC)FLIGHTS---	35
[illegible]	10-2	SD-ULV	LOX/LH2 PROPELLANT SUPPLY UNIT	100			PREPARE 2 OTVs AND H2 TANK, CHECK OUT OCM, MATE STACK (2OTVs,H2 TANK,OCM,AND 9 tons	135
[illegible]	10-3	STS	H2 TANK,+ BASE ELEMENT # 15,+ 4 CREW	19.5	L10-2	MS-(4M+9D)	OF LUNAR CARGO), & TRANSFER CREW TO OCM	78
	10-4	SD-ULV	LOX/LH2 PROPELLANT SUPPLY UNIT	100				178
[illegible]					L10-3	UNMANNED DELIVERY		133
	10-5	STS	2 H2 TANKS, + 13 TON, + 4 CREW	16			---FOR UNMANNED DELIVERY FLIGHTS---	
[illegible]	10-6	SD-ULV	LOX/LH2 PROPELLANT SUPPLY UNIT	100	L10-4	MS-(4M+4D)	PREPARE 2 OTVs AND H2 TANK, CHECK OUT BASE ELEMENT (CARGO), MATE STACK (2 OTVs	138
[illegible]	10-7	STS	H2 TANK,+ BASE ELEMENT # 16	10.5	L10-5	UNMANNED DELIVERY	H2 TANK,AND BASE ELEMENT)	95
[illegible]	10-8	STS	H2 TANK,+ BASE ELEMENT # 17,+ 4 CREW	19.5	L10-6	MS-(4M+9D)		38
[illegible]	10-9	SD-ULV	LOX/LH2 PROPELLANT SUPPLY UNIT	100	L10-7	UNMANNED DELIVERY		65
[illegible]	10-10	STS	2 H2 TANKS, + 13 TON, + 4 CREW	16	L10-8	MS-(4M+4D)		13
	10-11	SD-ULV	LOX/LH2 PROPELLANT SUPPLY UNIT	100				113
[illegible]	10-12	STS	H2 TANK,+ BASE ELEMENT # 18,+ 4 CREW	19.5	L10-9	UNMANNED DELIVERY		63
[illegible]	10-13	SD-ULV	LOX/LH2 PROPELLANT SUPPLY UNIT	100	L10-10	MS-(4M+9D)		88
[illegible]	10-14	STS	H2 TANK,+ BASE ELEMENT # 19	10.5	L10-11	UNMANNED DELIVERY		15

TABLE 2
DETAILED LAUNCH MANIFEST AND LUNAR MISSION SCHEDULE

LAUNCH NO	TYPE	CARGO MANIFEST	CARGO WT m tons	LUNAR FLIGHT NO	FLIGHT TYPE	SPACE STATION TASKS FOR FLIGHT	LOX/LH2 AT DEPOT m tons
		------------- YEAR 2011 ---------------					
11-1	SD-ULV	LOX/LH2 PROPELLANT SUPPLY UNIT	100				115
11-2	STS-ACC	1 H2 TANK,+9 TON,+LARGE CRM,+6 CREW	18	L11-1	MS-(4M+9D)		41
						---FOR MS (MANNED SORTIE)FLIGHTS--- PREPARE 2 OTVs AND H2 TANK, CHECK OUT CRM, MATE STACK (2OTVs,H2 TANK,CRM,AND 9 tons OF LUNAR CARGO), & TRANSFER CREW TO CRM	
11-3	SD-ULV	LOX/LH2 PROPELLANT SUPPLY UNIT	100				141
11-4	STS	2 H2 TANKS,+ 18 TON,+ 6 CREW	21.5	L11-2	MS-(6M+9D)		67
						---FOR UNMANNED DELIVERY FLIGHTS--- PREPARE 2 OTVs AND H2 TANK, CHECK OUT BASE ELEMENT (CARGO), MATE STACK (2 OTVs H2 TANK,AND BASE ELEMENT)	
11-5	SD-ULV	LOX/LH2 PROPELLANT SUPPLY UNIT	100				167
11-6	STS	H2 TANK,+ BASE ELEMENT @ 20,+ 6 CREW	22	L11-3	MS-(6M+9D)		93
				L11-4	UNMANNED DELIVERY		38
11-7	SD-ULV	LOX/LH2 PROPELLANT SUPPLY UNIT	100				128
11-8	STS	1 H2 TANK,+9 TON,+LARGE CRM,+6 CREW	18	L11-5	MS-(4M+9D)		54
		------------- YEAR 2012 ---------------					
12-1	SD-ULV	LOX/LH2 PROPELLANT SUPPLY UNIT	100				154
12-2	STS-ACC	2 H2 TANKS,+15 TON,+6 CREW,+ 1/2 R-LEM	21	L12-1	MS-(4M+9D)		88
						---FOR MS (MANNED SORTIE)FLIGHTS--- PREPARE 2 OTVs AND H2 TANK, CHECK OUT CRM, MATE STACK (2OTVs,H2 TANK,CRM,AND 9 tons OF LUNAR CARGO), & TRANSFER CREW TO CRM	
		----6 crew delivered on S S resupply launch ----		L12-2	MS-(6M+6D)		13
12-3	SD-ULV	LOX/LH2 PROPELLANT SUPPLY UNIT	100				113
12-4	STS-ACC	2 H2 TANKS,+15 TON,+6 CREW,+ 1/2 R-LEM	21	L12-3	MS-(4M+9D)	---FOR UNMANNED DELIVERY FLIGHTS--- PREPARE 2 OTVs AND H2 TANK, CHECK OUT BASE ELEMENT (CARGO), MATE STACK (2 OTVs H2 TANK,AND BASE ELEMENT)	38
12-5	SD-ULV	LOX/LH2 PROPELLANT SUPPLY UNIT	100				138
		----7 crew delivered on S S resupply launch ----		L12-4	MS-(7M+6D)		69
12-6	SD-ULV	LOX/LH2 PROPELLANT SUPPLY UNIT	100				169
12-7	STS	2 H2 TANKS,+R-LLEM,+ 4 CREW,+ 9 TON	17	L12-5	MS-(4M+NEW R-LEM/R-LLEM ,SMALL CRM)		94
12-8	SD-ULV	LOX/LH2 PROPELLANT SUPPLY UNIT	100				174
		----7 crew delivered on S S resupply launch ----		L12-6	MS-(7M+9D)		188

TABLE 1
DETAILED LAUNCH MANIFEST AND LUNAR MISSION SCHEDULE

MONTH	LAUNCH NO	TYPE	CARGO MANIFEST	CARGO WT m ton	LUNAR FLIGHT NO	FLIGHT TYPE	SPACE STATION TASKS FOR FLIGHT	LOX/LH2 AT DEPOT m ton
			------------- YEAR 2013 --------------					
JAN	13-1	STS-ACC	2 H2 TANKS,+F/R GND STA ,+6 CREW,+9 TON	21.5	L13-1	MS-(4M+F/R GND STA)		26
FEB	13-2	SD-ULV	LOX/LH2 PROPELLANT SUPPLY UNIT	100			---FOR MS (MANNED SORTIE)FLIGHTS--- PREPARE 2 OTVs AND H2 TANK, CHECK OUT OTM, MATE STACK (2OTVs,H2 TANK OTM,AND 9 tons OF LUNAR CARGO), & TRANSFER CREW TO OTM	126
MAR	13-3	STS	H2 TANK,+ BASE ELEMENT # 21,+ 6 CREW	28	L13-2	MS-(4M+9T)		52
APRIL	13-4	SD-ULV	LOX/LH2 PROPELLANT SUPPLY UNIT	100	L13-3	UNMANNED DELIVERY		87
MAY	13-5	STS-ACC	2 H2 TANKS,+RAD TELE ,+6 CREW,+9 TON	21.5	L13-4	MS-(4M+RAD TELE)	---FOR UNMANNED DELIVERY FLIGHTS--- PREPARE 2 OTVs AND H2 TANK, CHECK OUT BASE ELEMENT (CARGO), MATE STACK (2 OTVs H2 TANK,AND BASE ELEMENT)	13
	13-6	SD-ULV	LOX/LH2 PROPELLANT SUPPLY UNIT	100				113
JUNE	13-7	STS	H2 TANK,+ BASE ELEMENT # 22	18.5	L13-5	UNMANNED DELIVERY		48
	13-8	SD-ULV	LOX/LH2 PROPELLANT SUPPLY UNIT	100				148
JULY	13-9	STS	H2 TANK,+ BASE ELEMENT # 23,+ 6 CREW	28	L13-6	MS-(4M+9T)		76
AUG	13-10	SD-ULV	LOX/LH2 PROPELLANT SUPPLY UNIT	100	L13-7	UNMANNED DELIVERY		189
SEPT	13-11	STS-ACC	2 H2 TANKS,+PWR CONV ,+6 CREW,+4 TON	16.5	L13-8	MS-(4M+PWR CONV)		35
	13-12	SD-ULV	LOX/LH2 PROPELLANT SUPPLY UNIT	100				135
OCT	13-13	STS	H2 TANK,+ BASE ELEMENT # 24	18.5	L13-9	UNMANNED DELIVERY		78
NOV	13-14	STS	H2 TANK,+ BASE ELEMENT # 23,+ 6 CREW	20	L13-10	MS-(4M+4T)		6
DEC	13-15	SD-ULV	LOX/LH2 PROPELLANT SUPPLY UNIT	100	L13-11	UNMANNED DELIVERY		41
			------------- YEAR 2014 --------------					
JAN	14-1	SD-ULV	LOX/LH2 PROPELLANT SUPPLY UNIT	100				141
FEB	14-2	STS	2 H2 TANKS,+ 6 CREW,+ 13 TON	16.5	L14-1	MS-(4M+9T)		67
MAR								
APRIL		----6 crew delivered on S.S. resupply launch ----			L14-2	MS-(4M+4T)		3
MAY	14-3	SD-ULV	LOX/LH2 PROPELLANT SUPPLY UNIT	100				103
JUNE	14-4	STS	2 H2 TANKS,+ 6 CREW,+ 13 TON	16.5	L14-3	MS-(4M+9T)		29
JULY	14-5	SD-ULV	LOX/LH2 PROPELLANT SUPPLY UNIT	100				129
AUG		----6 crew delivered on S.S. resupply launch ----			L14-4	MS-(4M+4T)		65
SEPT								
OCT	14-6	STS	2 H2 TANKS,+ 6 CREW,+ 13 TON	16.5	L14-5	MS-(4M+4T)		8
NOV	14-7	SD-ULV	LOX/LH2 PROPELLANT SUPPLY UNIT	100				108
DEC		----6 crew delivered on S.S. resupply launch ----			L14-6	MS-(4M+9T)		26

Estimated Manning Levels of Lunar Base

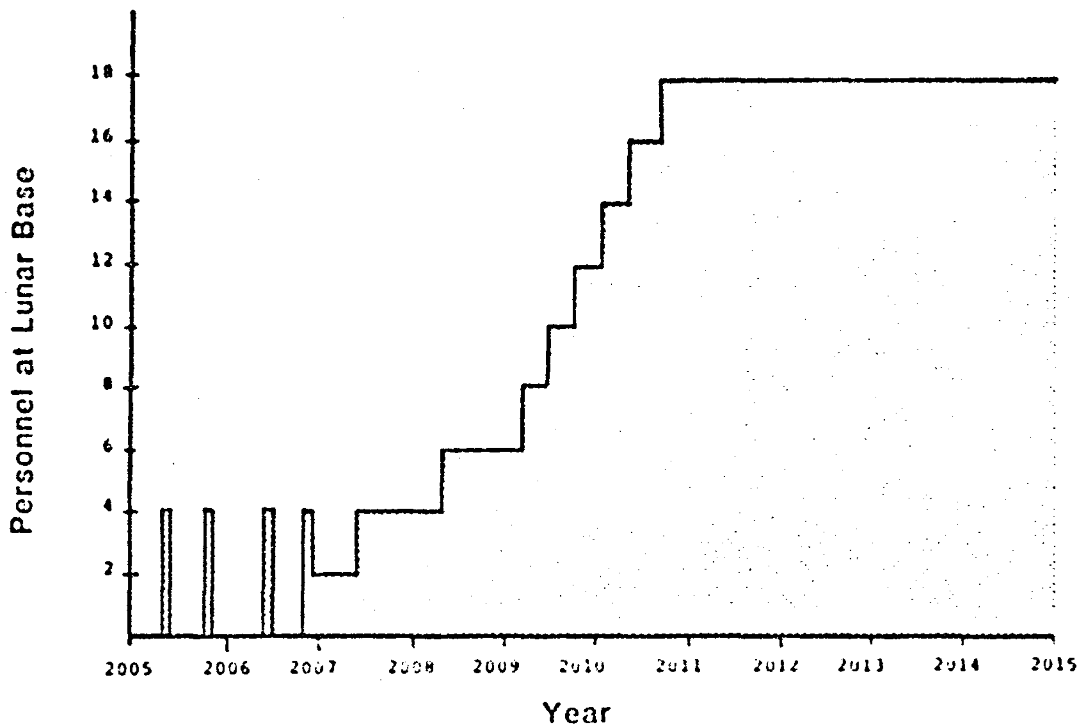


Figure 5

4.4 Lunar Space Transportation System

A set of vehicles designed to perform the lunar space transportation function was defined and sized. The elements of the system were those defined in the JSC Lunar study (Reference 1).

The system was designed to deliver a 17.5 metric ton unmanned payload module to the lunar surface, or to deliver a manned module plus an ascent vehicle to the surface. The OTV's all return to low Earth orbit. It was assumed that man-rated aerobraking orbital transfer vehicles are available.

The Delta-V budget for the sizing exercise is given in Table 3.

The scaling laws for estimating inert weights of propulsive stages are given in Table 4. These were provided by JSC (Ref. 2) as an agreed upon representative set of inert weights. In addition to the inert weights, each propulsive stage was considered to have 2.5% of its propellant weight left at burnout for reserves and residuals. This was composed of 1% of the propellant as trapped and unavailable and 1.5% as hardware reserves for such items as mixture ratio errors, Isp variation, etc. Mission reserves are included in the delta V budget.

The Expendable Lunar Lander was first sized to deliver the 17.5 metric ton base element from lunar orbit to the lunar surface. Then the AOTV's were sized to deliver the fueled lander plus payload to lunar orbit using two stages and returning empty via aerobraking. The other elements were then sized to accordingly.

The resultant set of elements of the lunar space transportation system are given in Table 5.

4.4.1 Sizing The OTV - Multi-Stage Rationale

The Aerobraking Orbital Transfer Vehicle (OTV) along with the Shuttle, the Space Station, and the small OMV will be pre-existing elements of a generalized space transportation system. The OTV's are sized initially for delivery and retrieval of satellites to Geosynchronous Earth Orbit (GEO).

Such an OTV is well suited to lunar transport since the delta V from the Space Station to GEO is almost exactly that from the Space Station to lunar orbit. Returning from the Moon with aerobraking actually takes less delta V than the same return from GEO.

Lunar operations, however, generally require payloads in lunar orbit that are several times as large as the equivalent GEO payload, because half the mass in lunar orbit is lander weight. Therefore, an OTV sized for GEO operations may be only half as large as one designed for single stage lunar operations. One solution is to use more than one OTV at a time for each lunar mission.

If the OTV's are designed to be "stacked" into a multi-stage vehicle, then almost any size payload can be delivered to almost any delta V desired (such as for high energy planetary missions)

Table 3, Lunar Operations Delta V Budget

The following is the Delta V budget for operating from a 500 km (270 n mi) Earth orbit (the Space Station orbit) to a 200 km (108 n mi) lunar orbit, with return to the original orbit via an aerobraking maneuver.

The lunar landing is made from, and at launch returns to the 200 km lunar orbit.

The return aerobraking maneuver is targeted to an apogee 150 km above the Space Station (resultant Earth orbit 25 X 650 km); the vehicle then circularizes at 650 km and waits for the correct phasing to begin the rendezvous sequence.

Budget:

Trans-Lunar Injection (TLI)	=	3155 m/sec + g-loss
Midcourse Correction	=	60 m/sec
Lunar Orbit Insertion (LOI)	=	915 m/sec
Trans-Earth Injection (TEI)	=	915 m/sec
Midcourse Correction	=	60 m/sec
Circularization after Aerobrake	=	160 m/sec
Rendezvous	=	80 m/sec
Lunar Descent	=	2165 m/sec
Lunar Ascent	=	1920 m/sec

g loss = $1635/[1-9.86\ T/W + 512\ (T/W)^2]$ for a single burn TLI and 1/3 of that for the two burn TLI option. T/W is the <u>initial</u> thrust to weight at the beginning of the trans-lunar injection.

After the trans-lunar injection maneuver g losses are not significant. The thrust to weight (T/W) is improved by a factor of 2 during TLI (more than half the weight is expended during the first maneuver) while at the same time subsequent maneuvers are much smaller, lowering post-TLI losses to an insignificant level.

This budget utilizes data from Apollo 11 (Ref. 3) augmented with in-house estimates by Eagle Engineering. The equation for g-losses was derived as part of the study.

Table 4, Space Transportation Vehicles Scaling Laws

The inert weight for the Orbital Transfer Vehicles (OTV's) and the various propulsive elements of the lunar operations transportation system are given as follows:

$$\text{Stage Inert Weight} = \frac{(A + B \cdot Wp)}{(1 - \lambda_B)} + \lambda_B \cdot PL_{aero}$$

Where

Wp = Stage Propellant Capacity (in kg).

PL_{aero} = the maximum amount of payload that will be carried through the aerobraking maneuver (in kg).

λ_B = the aerobrake mass fraction.

= .15 for this study.

and:

A = 2279 kg, B = .04545 for cryogenic stages

A = 2352 kg, B = .0228 for pump fed storable stages

A = 2454 kg, B = .04253 for pressure fed storable stages

The above are for space-based vehicles. For Lunar Landers an additional 2% of the maximum landed weight (including payload) must be added for landing gear.

These data are from Reference 2. Sections 4.6 and 5.8 examine the sensitivity of some of this study's conclusions to changes in some of these numbers, such as Isp and inert weight.

TABLE 5

LUNAR SPACE TRANSPORTATION SYSTEM

STS ELEMENTS	ELEMENT DESCRIPTION	ELEMENT FUNCTION AND DESIGN GOALS
BASE ELEMENT COMMON MODULE	Length = 11 m , Diameter = 4.6 m. Weight =17.5 m ton	COMMON LUNAR HOUSING AND/OR LABORATORY UNIT
E-LANDER	Diameter = 8.2 m. , Height = 7 m Weights Burn Out = 3.8 m ton Usable Propellant = 13.6 m ton LOX/LH2 Propellant	EXPENDABLE LUNAR LANDER DESIGNED TO DELIVER 17.5 m ton TO LUNAR SURFACE
LUNAR LANDING MANNED MODULE (LLMM)	Length = 3.6 m. , Diameter = 2.6 m Weight = 3.25 m ton (with 4 crew)	MODULE TO CARRY CREW OF 4 TO LUNAR SURFACE, AND RETURN -- LIMITED LIFE SUPPORT --NOT REUSED--
E-LAUNCHER	Diameter = 3.6 to 5 m. Height = 2 m Weights Burn Out = 2.6 m ton Usable Propellant = 5 m ton PUMP FED,STORABLE Propellant	EXPENDABLE LAUNCHER TO CARRY LLMM Plus 5 ton PAYLOAD FROM LUNAR SURFACE TO LUNAR ORBIT
OTV MANNED MODULE (OMM)	Length = 2.4 m. ; Diameter = 3 m. Diameter = 3 m Weight = 5.5 m ton (with 4 crew)	CREW MODULE FOR OTV, TO CARRY PERSONNEL FROM ORBIT TO ORBIT -SHIRT SLEEVE EVIRONMENT ---REUSABLE---
AEROBRAKING ORBITAL TRANSFER VEHICLE (AOTV)	Diameter = 12.2 m (Aero Shield) Length = 5 m. Weights : Burn Out = 7.8 m ton Usable Propellant = 42 m ton LOX/LH2 Propellant	OTV SIZED TO DELIVER 35 m ton TO LUNAR ORBIT AND RETURN EMPTY USING TWO OTVs BOTH RETURNED BY AEROBRAKING -- REUSABLE--
REUSABLE LUNAR LANDER/LAUNCHER (R - LEM)	Diameter = 10 m ; Height = 7 m. Weights: Burn Out = 5.2 m ton Usable Propellant = 38 m ton LOX/LH2 Propellant	LUNAR BASED VEHICLE FOR TRANSPORT FROM LUNAR SURFACE TO LUNAR ORBIT AND BACK - USING LUNAR PRODUCED OXYGEN DESIGNED FOR 17.5 ton PL DOWN, 0 UP -- OR -- 14 ton PL DOWN, 7 ton UP. - A 5 ton TANK OF LH2 IS ALSO CARRIED DOWN ON EACH LANDING
REUSABLE LUNAR LANDING MANNED MODULE (R - LLMM)	Length = 5 m ; Diameter = 2.6 m. Weight = 5 m ton (with 6 crew)	LUNAR BASED MANNED MODULE FOR USE WITH R-LEM; NORMAL CREW 6,MAX 10
LARGE OMM	Length = 4 m. ; Diameter = 3 m Weight = 8 m ton (with 6 crew)	LARGER OMM REPLACEMENT, FOR ORBITAL TRANSPORT OF CREWS IN MATURE LUNAR BASE OPERATIONS NORMAL CREW 6, MAX 10
H2 TRANSFER TANK	Volume = 57 cu m Weights Empty wt =1 m ton Full wt = 5 m ton	TANK OF LIQUID HYDROGEN FUEL FOR R-LEM (WITH LUNAR O2) - ONE DELIVERED TO LUNAR SURFACE STORAGE EACH FLIGHT
----------------- LAUNCH VEHICLES -----------------		
SHUTTLE (STS)	PL to Space Station = 25 m ton	REUSABLE LAUNCH VEHICLE FOR VALUABLE CARGOS AND PERSONNEL
SHUTTLE/AFT CARGO CARRIER (STS-ACC)	PL to Space Station = 22 m ton	SHUTTLE WITH A CARGO COMPARTMENT ON AFT END OF EXTERNAL TANK -FOR OVERSIZE CARGOS-
SHUTTLE DERIVED UNMANNED LAUNCH VEHICLE (SD-ULV)	Usable LOX/LH2 to Space Station = 100 m ton	UNMANNED LAUNCHER DESIGNED USING SHUTTLE ELEMENTS,--USED FOR LAUNCHING LOX/LH2 PROPELLANT TO ORBITAL STORAGE DEPOT

by simply stacking a sufficient number of stages.

Lunar base operations provide enough traffic so that some OTV resizing is justified and cost effective. The OTV's designed for GEO have tended to be sized at around 30 metric tons of propellant (LO_2/LH_2). The same basic vehicle could be sized to support the desired lunar operations in a two stage configuration simply by enlarging the propellant tanks by about 30%. This could be done for the JSC concept illustrated in this study (Fig. 6) without changing either the aeroshell or engines and with tanks that are still deliverable within the shuttle bay.

Trying to enlarge the OTV to support lunar operations with single stages would require a new design. For this size range, two stage operations appear to be more efficient than single stage.

Consequently, the AOTV was resized to perform the lunar mission model with two (tandem) stages. The result was a vehicle of 42 metric ton propellant capacity.

4.4.2 Mission Scenarios

The mission scenarios divide into two sets once lunar base construction begins. These are unmanned heavy delivery missions, and manned rotation/resupply missions. These are illustrated in Figures 7 and 8 respectively.

The unmanned heavy delivery missions (Fig. 7) deliver the major base elements to the lunar surface. Two large aerobraking reusable OTV vehicles, used in tandem as a two stage rocket deliver the 17.5 metric ton base element, mounted on an Expendable Lander, to a 200 km lunar orbit. The lander then provides transport to the lunar surface where it remains (Fig. 9). The OTV stage returns to earth at first opportunity.

For a manned mission (Fig. 8) two OTV's deliver an OTV Manned Module (OMM) containing the crew plus an Expendable Lunar Lander loaded with a Lunar Lander Manned Module and an ascent stage all to lunar orbit. The OTV and OTV Manned Module remain in orbit while the lander descends to the lunar surface carrying the Lunar Lander Manned Module with crew and the ascent stage. After the appropriate mission stay time (7 to 14 days) the ascent stage returns the Lunar Lander Manned Module to lunar orbit. The vehicle performs a rendezvous with the OTV and the crew transfers back to the OTV Manned Module for return to Earth via aerobraking. The Expendable Lunar Lander, ascent stage, and the Lunar Lander Manned Module are all discarded.

After lunar surface O_2 production has begun, one or more reusable single stage Lander/Launchers are delivered to the lunar surface. The scenario is then changed such that only the payloads and a large tank of liquid hydrogen fuel for the Lander is brought from earth orbit.

The Lander is kept on the lunar surface and provided with liquid oxygen (6/7 of the propellant weight) from the lunar oxygen plant. This reduces the trans-lunar transport requirement by nearly half. The OTV delivers the payload and a full H_2 tank to lunar orbit. The reusable Lander (R-LEM) then launches and rendezvous with the OTV. The payload, OTV and H_2 tank are transferred to the R-LEM and the OTV returns to Earth. The R-LEM lands and the H_2 tank is removed to a storage depot from where it is used to fuel the R-LEM for the next flight.

A reusable Lunar Lander Manned Module (LLMM) is kept at the lunar base. For manned missions it is mounted on the R-LEM to transport personnel to and from the lunar surface. For a manned flight the OTV delivers crew in an OMM plus an H_2 tank and any extra payload to lunar orbit. The R-LEM with LLMM aboard launches to lunar orbit carrying the crew to be rotated and rendezvous with the OTV. The crews each transfer from capsule to capsule and the payload and H_2 tank are transferred to the R-LEM. The R-LEM then lands with the replacement crew and the OTV returns to earth with the OMM and the returning personnel. An H2 tank is delivered for every R-LEM mission.

The R-LEM, LLMM, and H_2 tank are illustrated in flight configuration in Figure 10.

The OTV carrying the OMM is shown in Figure 11. Note the position of the OMM within the entry shadow of the aeroshell. All payloads and material carried through the aerobrake phase will be mounted in this position.

4.4.3 Earth Launch Requirements

Figure 12 shows the amount of material that must be delivered to the Space Station each year to support the given lunar base build-up scenario. Figure 13 shows the resultant build-up of material on the lunar surface. Note that the vast majority of the mass involved is LO_2/LH_2. This includes the propellant for the lunar lander as well as that for the OTV. Using the shuttle as a tanker to launch such massive amounts of cryogenics to orbit is neither prudent nor cost effective. At 25 metric tons per flight, 16 to 30 tanker shuttle launches a year would be required to support this effort.

An Unmanned Launch Vehicle designed using shuttle elements (a shuttle derived unmanned launch vehicle or ULV) should be developed as a tanker. Such a vehicle with a stretched External Tank and lengthened Solid Rockets Boosters should be able to deliver a propellant depot module of about 100 metric tons propellant capacity. This would reduce the lunar base Earth launch requirements by between 12 and 22 launches per year at an annual savings of from 1 to 2 billion dollars. In addition, the total launch rate is reduced to the much more manageable level of approximately one per month rather than one every two weeks.

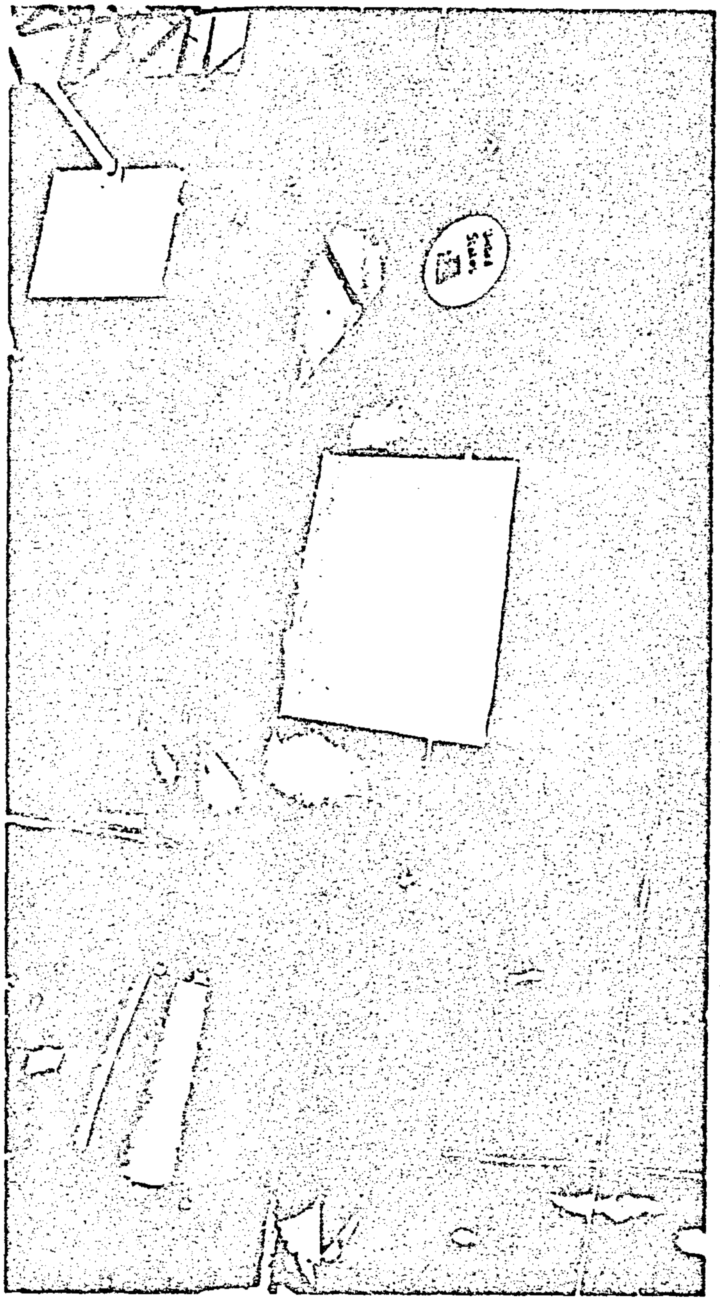


Figure 6 AOTV

UNMANNED LUNAR MISSION SCENARIO

1. STACK DEPARTS SPACE STATION
2. FIRST STAGE BURN
3. SECOND STAGE BURN
4. FIRST STAGE RETURNS TO SPACE STATION
5. CIRCULARIZED IN LUNAR ORBIT
6. EXPENDABLE LANDER PLACES COMMON MODULE ON THE LUNAR SURFACE
7. SECOND STAGE RETURNS TO EARTH
8. AEROBRAKING EARTH ORBIT INSERTION
9. CIRCULARIZED ABOVE SPACE STATION ORBIT
10. SECOND STAGE RETURNS TO SPACE STATION

FIGURE 7
LEGEND

Unmanned Lunar Mission Scenario

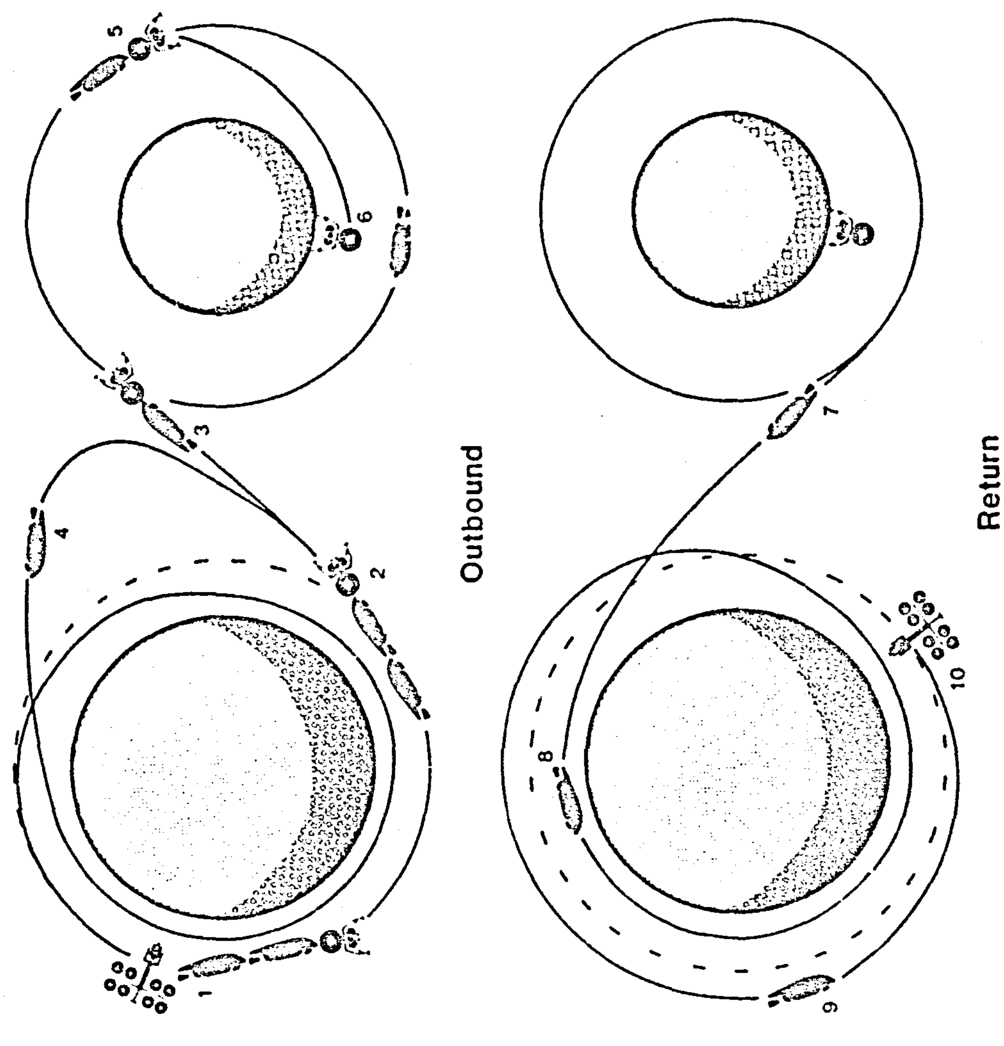


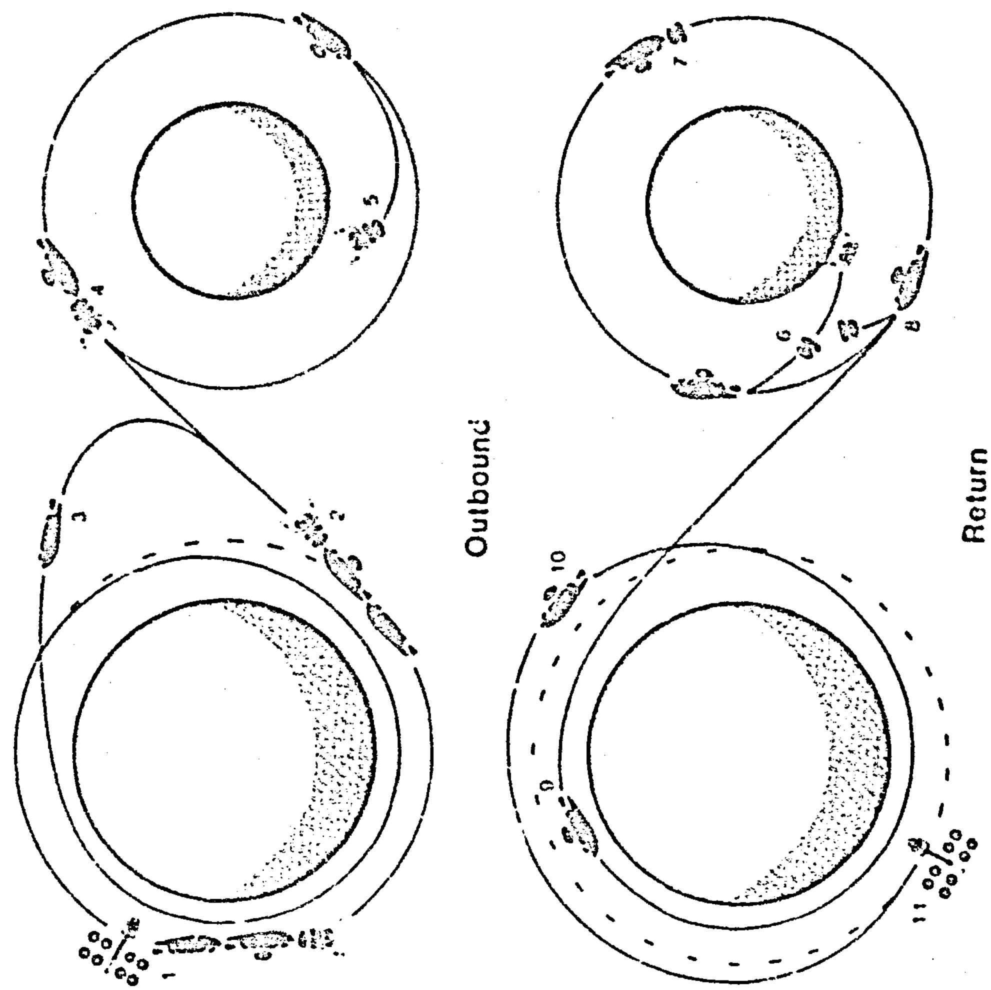
Figure 7

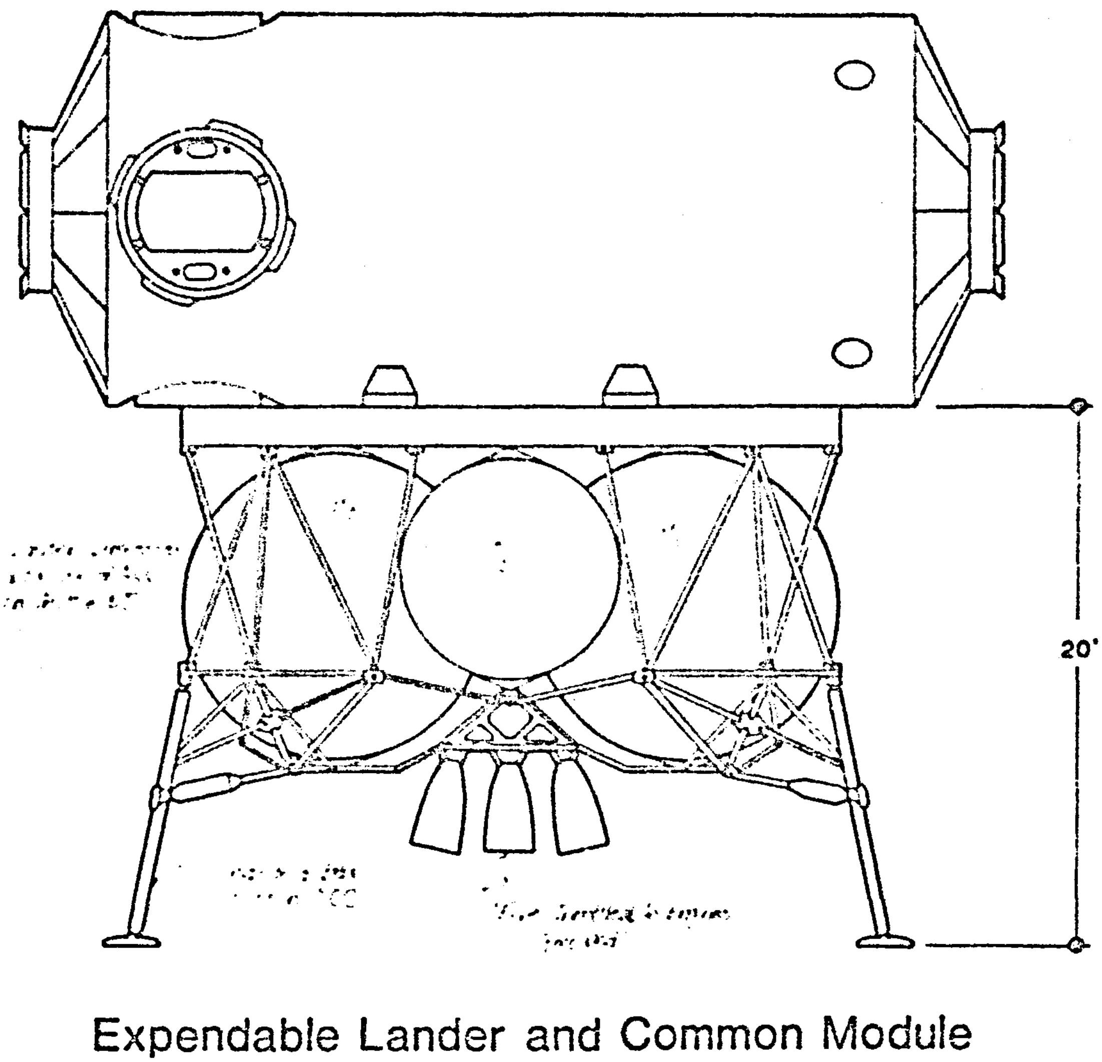
Manned Lunar Mission Scenario

1. Stack departs Space Station
2. Trans-lunar injection burn
3. First stage returns to Space Station
4. Second stage, Lander, and Manned Module insert into lunar orbit
5. Lander descends
6. Ascent stage departs lunar surface
7. Ascent module rendezvous with second stage
8. Second stage returns to earth with OMM, ascent module discarded
9. Aerobraking
10. Circularization above Space Station orbit
11. Rendezvous with Space Station

Figure 8
Legend

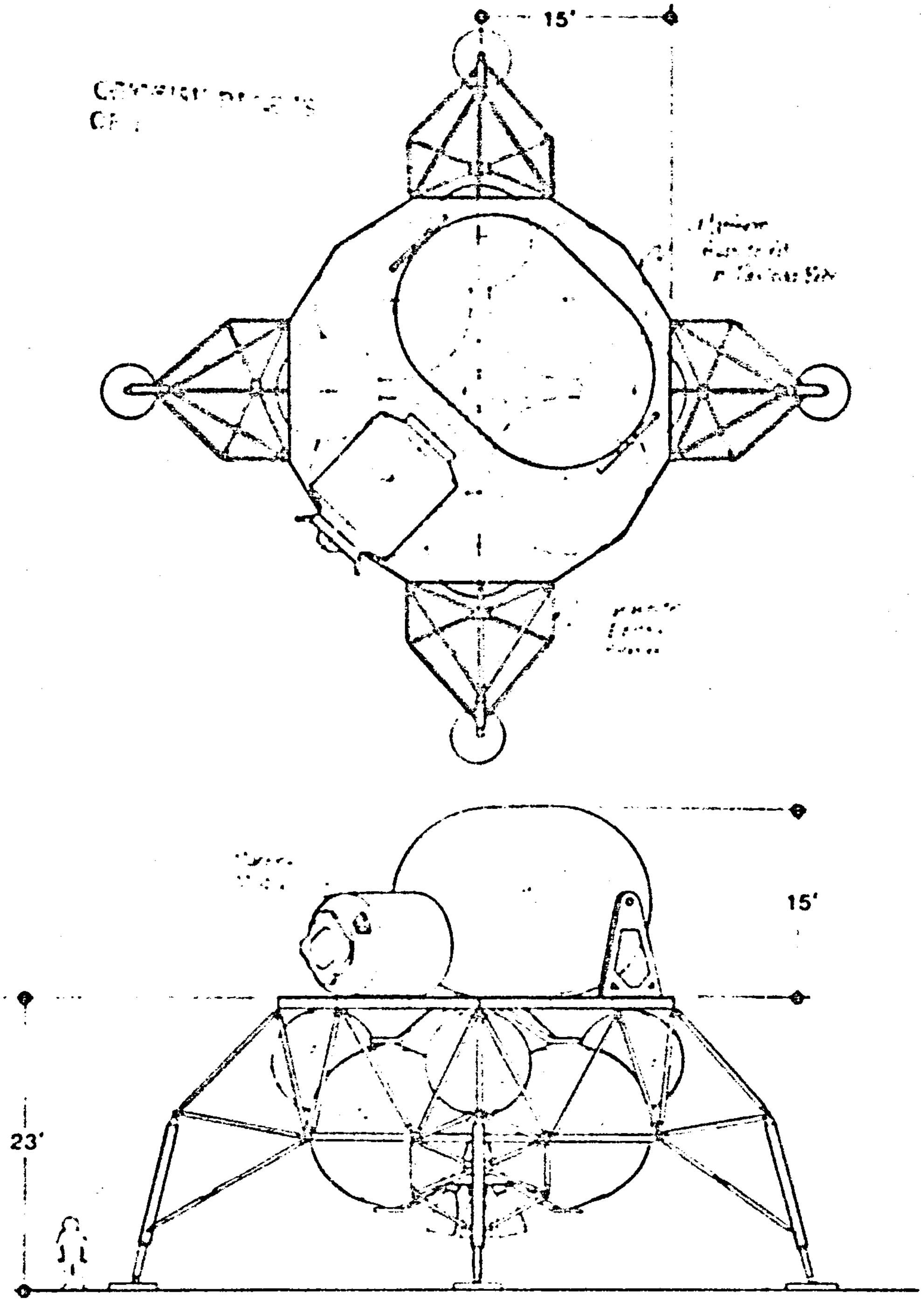
Manned Lunar Mission Scenario





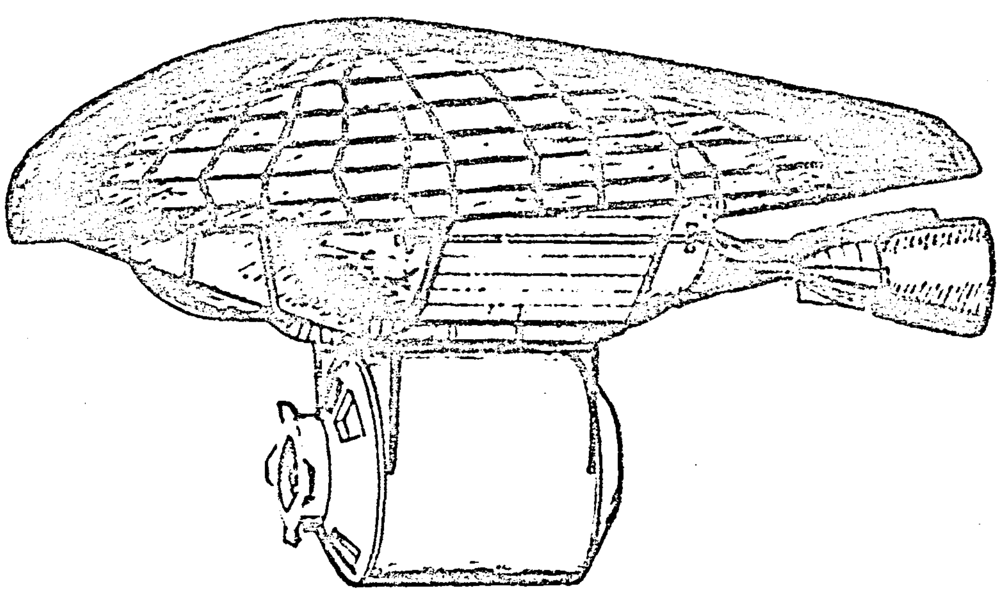
Expendable Lander and Common Module

Figure 9



R–LEM and Large H_2 Tank

Figure 10



OTV w/Manned Module

Figure 11

LUNAR BASE LAUNCH REQUIREMENTS

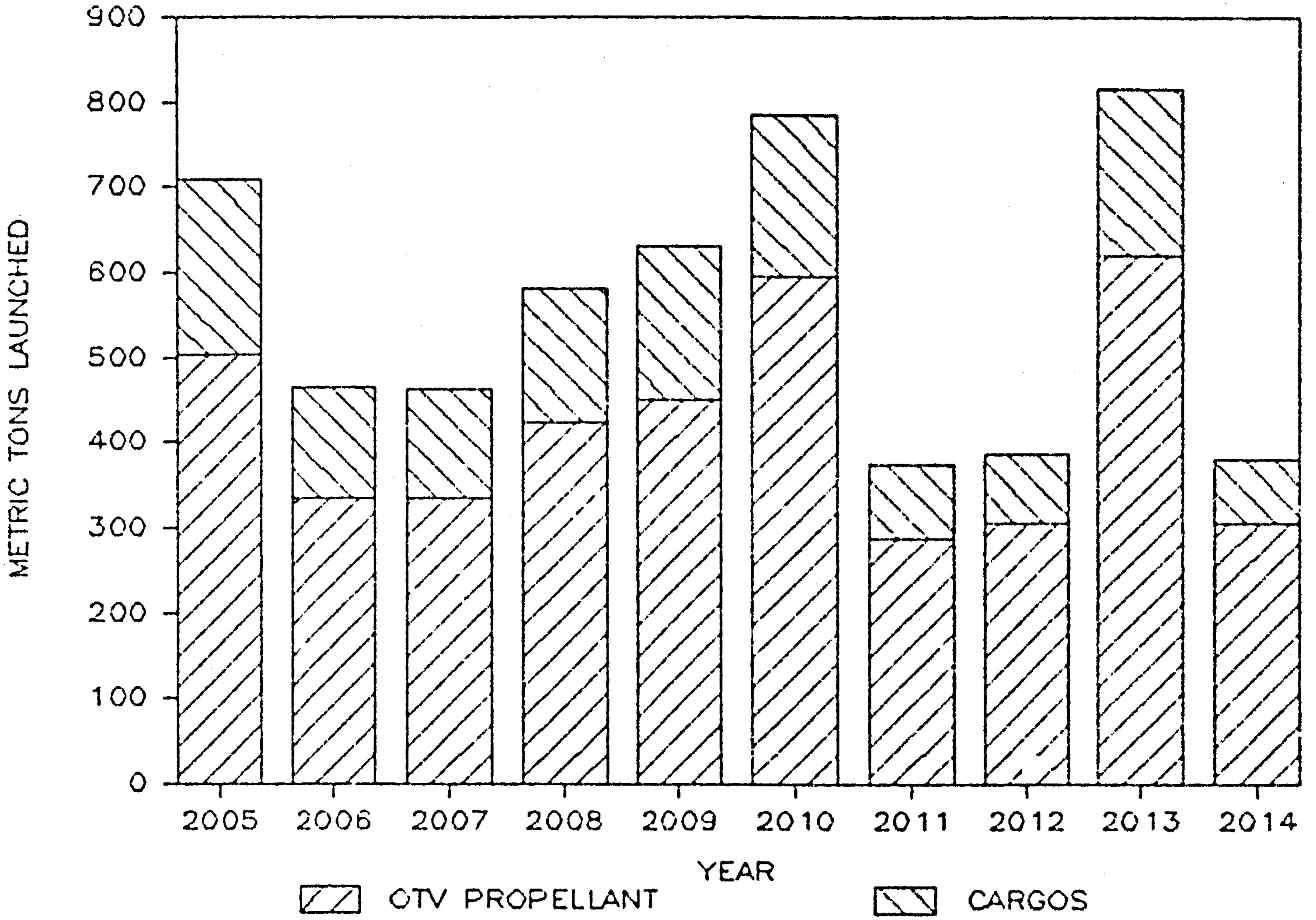


Figure 12

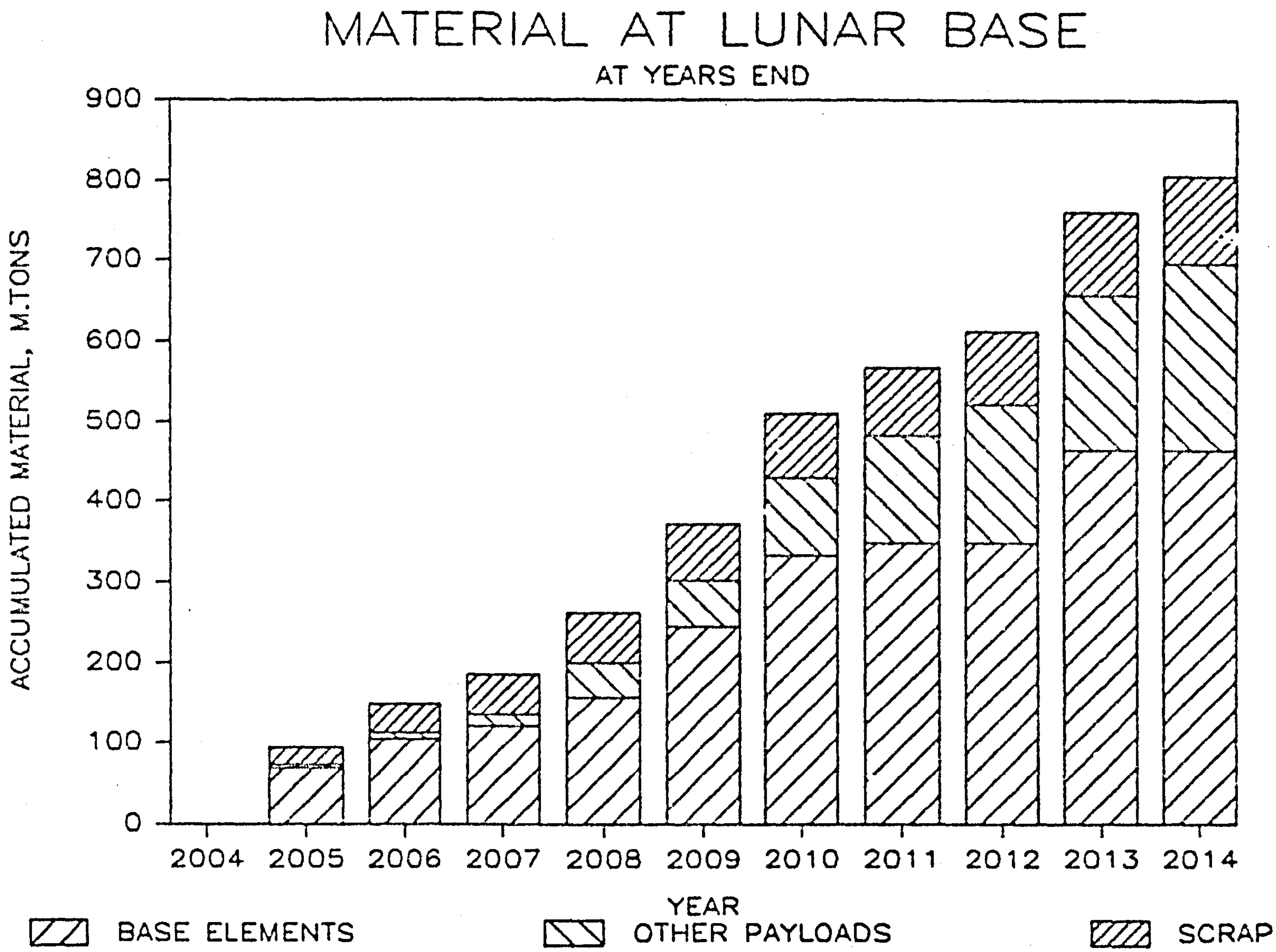

MATERIAL AT LUNAR BASE
AT YEARS END
ACCUMULATED MATERIAL, M.TONS
0
100
200
300
400
500
600
700
800
900
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
YEAR
BASE ELEMENTS
OTHER PAYLOADS
SCRAP

Figure 13

A second, but important factor is safety: the risk of many launches of a billion dollar manned Shuttle with a cargo bay full of cryogenic propellant. The loss of a ULV full of LO_2/LH_2 would be spectacular but not catastrophic.

The large 100 metric ton propellant units delivered by ULV could be plug-in-depot units so that extensive propellant transfer from the tanker to the depot would not be required. Section 6.2 discusses propellant storage and transfer in more detail.

4.4.4 External Tank - Aft Cargo Compartment (ET-ACC)

The first 16 or 17 lunar missions use an Expendable Lunar Lander that cannot readily be designed for delivery within the shuttle cargo bay. The flight frequency of those missions is high enough that assembly of the vehicle at the Space Station might produce an unreasonably heavy workload. In addition, the Shuttle payload bay threatens to become so seriously volume limited that an extra Shuttle launch per lunar mission becomes a real possibility.

Over the last several years various studies have been carried out under the guidance of Marshall Space Flight Center (MSFC) on the possibility of an External Tank Aft Cargo Carrier (ET-ACC), a cargo space attached to the rear of the Shuttle External Tank to enable delivery of oversized cargo elements. This requires that the ET be carried into a stable orbit and deorbited at a later time rather than dropped sub-orbitally as is nominally done. A pre-assembled E-Lander can thus be launched, and the payload bay is free for other cargo. There is, however, a loss in shuttle payload capability of about 3 metric tons.

The E-Lander design illustrated (Figure 9) fits within this aft cargo compartment. The number of flights (16) justifies the development cost of the ET-ACC and the savings in shuttle launches should more than pay for those development costs.

An alternate solution would be to launch the E-Lander on the ULV flights. This did not manifest as nicely but may be more cost effective.

4.5 Impact of the Lunar Missions Upon the Growth Space Station.

4.5.1 Summary

During the 10 year period of lunar operations examined the Space Station supports 68 lunar sorties, 43 of them manned, requiring:

- 102 launches - half of them Shuttles and half unmanned tanker launches.
- 136 AOTV sorties.
- 270 OMV sorties.

The Space Station must provide propellant storage and transfer facilities (propellant depot), assembly of the mission stack, payload checkout & integration into mission stacks, maintenance and checkout of vehicles stored on orbit (OTV's, OMV's, OHM's), flight control (rendezvous, proximity operations & docking), personnel billeting, and temporary payload storage.

Hardware required to be added to the growth Space Station includes:

- Permanent basing (hangars, storage and shops) for 4 OTV's, 2 OHM's and 2 OMV's.
- Gantries and docks for preparing mission stacks, up to 40 meters in length, of 2 OTV's plus a Lunar Lander, plus various manned and unmanned lunar cargo elements.
- A propellant depot for cryogenic LO_2/LH_2 propellant with capacity of at least 2 tanker units of 100 metric tons each.
- A propellant transfer capability to perform a measured propellant transfer from the depot to various vehicles in the mission stack at the assembly docks. A rate of 5 metric tons/per hour is required to complete transfer in one 24 hour period.
- Temporary storage for lunar vehicles and 20 to 30 tons of lunar payload.
- An additional habitat module as housing for the additional Space Station crew and temporary billeting for 4 to 6 transient lunar base personnel.

- An estimated 20 kw of continuous additional power with related or greater heat rejection. 10 kw depot cryogenic refrigeration, 5 kw for the extra habitat, and 5 kw or more for gantries.

Space Station identified manpower requirements are 14 manweeks per lunar sortie. This breaks down into 5 manweeks of OTV support, 5 manweeks stack assembly & fueling, 1 manweek (average) for manned vehicle (OMM) support, and 3 manweeks for flight operations and OMV support. These operations require a minimum extra crew complement of 2 persons. This could be doubled by unidentified required tasks.

4.5.2 Space Station Hardware Required.

The lunar missions require 2 OTV's per sortie while averaging one such sortie every eight weeks. A minimum of one extra OTV will be required for replacement to maintain a regular schedule. If two extras are used, two stacks could be assembled simultaneously for those periods with very compressed mission schedules. This gives rise to an operational OTV fleet size of 4. Such a fleet would also allow time for extensive scheduled maintenance and overhaul while still protecting against unscheduled flight cancellation. Schedule will be much more important in the support of a manned lunar base than in present STS operations. In addition to lunar missions, this fleet would be involved in planetary, GEO, and other missions.

Similarly, at least 2 OMM's are needed for schedule protection as well as for possible rescue operations. The small OMV units will be used up at a rapid rate and they will probably make the round trip to Earth at a fairly regular rate. However, at least 2 should be on station at all times.

Permanent basing for these vehicles should include hangar facilities for meteoroid and orbital debris protection, thermal control, and routine mission preparation. Shop and maintenance equipment for a complete overhaul of the OTV vehicles and at least routine repair of the other vehicles will be necessary. The OMM's and OMV's can be returned to earth for major repair but the OTV's would be too bulky for routine Shuttle transport.

Gantries and docks will be needed for preparing mission stacks. These stacks will typically consist of 2 OTV's, a base element and an Expendable Lunar Lander. For the manned mission the base element will be replaced by a Lunar Lander Manned Module (LLMM) on the lander and an OMM carried on the OTV. These stacks will be up to 40 meters long and when fueled mass as much as 133 metric tons.

A propellant depot for cryogenics propellant (LO_2/LH_2) will be necessary. The proposed technique is 100 metric ton depot units launched on unmanned tankers. The depot would need the capacity to handle two of these units at once, since even a half emptied unit would have to be supplemented by a second full one before a lunar sortie could be supported.

The capability to transfer a measured amount of propellant from this depot to vehicles in the mated mission stack is an absolutely necessary requirement. Two OTV's plus an Expendable Lander must be filled. Propellant transfer rates of 5 metric tons an hour are necessary in order to transfer the 98 tons in less than one day. This rate might be relaxed some if necessary, but certainly by no more than a small factor. The mechanism for this amount and type of propellant transfer is not at all understood. The first American in-orbit propellant transfer experiments have been performed in the Shuttle only within the last two months. A practical engineering solution to efficient large scale propellant transfer in orbit is crucial to the use of the Space Station as an operations base.

Temporary storage of lunar vehicles and 20 to 30 tons of lunar bound payload is necessary to allow the shuttle to be unloaded for return to Earth. Lander storage may be on the gantry arm and on the lunar bound mission stack. General lunar bound material, however, may be in storage at the Space Station for up to several months awaiting lunar transport. The high cost of Shuttle flights requires that we achieve as high a load factor as possible on each launch. This means that material manifested on several lunar flights will arrive at the Space Station at the same time. This becomes particularly true after the Reusable Lander becomes available and substantial extra payload can be carried on the manned sorties.

An additional habitat module at the Space Station will be needed. There will be 2 to 4 more permanent crew members to house, and 4 to 6 transient lunar base personnel to be billeted. Lunar crews will generally arrive at the Space Station on the same shuttle flight that delivers the various other payload elements for the scheduled mission. They will be on station during final stack assembly and checkout, a period of perhaps a week. If problems of some sort (equipment malfunctions, solar flares, etc.) should delay the lunar departure past the available launch window, an additional nine day wait will be necessary. Returning crews must wait until a regularly scheduled launch occurs. At an estimated 100 million dollars per Shuttle launch it would not pay to mount a special flight just to save a few personnel from the tedium of a few weeks in orbit. The result is that there would be transient lunar crew members at the Space Station more than half of the time.

Power modules for at least an additional 20 kw of power plus related rejection radiators are necessary to support these added elements. Eagle Engineering has estimated that from 4 to 5 kw of refrigeration at each 100 metric ton propellant depot element will reduce the cryogenic boiloff losses to a negligible amount. A total of 10 kw will be required when two units are at the depot. The extra habitat will require 5 kw and another 5 kw was allocated for cranes, gantries and shops. This latter may be underestimated especially for peak loads, but the average use is probably of this order.

4.5.3 Space Station Manpower and Functions Required.

The schedule requires a lunar sortie every eight weeks on the average. Manpower estimates per lunar sortie includes the following:

- Total OTV turnaround and maintenance of 24 man days per lunar mission.
  - OTV turnaround operation - 70 manhours per OTV.
  - OTV scheduled maintenance - 70 manhours for every 5 OTV sorties.
  - OTV unscheduled maintenance - 90 manhours for every 10 OTV sorties.
- Traffic control = 8 man days per lunar sortie - 4 major arrivals/departures requiring OMV sorties per lunar mission. Each will require 2 crew members for at least one shift or 2 man days each.
- Stack assembly - 3 or 4 days operations for 2 crew members - 8 man days.
- Propellant transfer - 24 hours for 2 crew members - 6 man days.

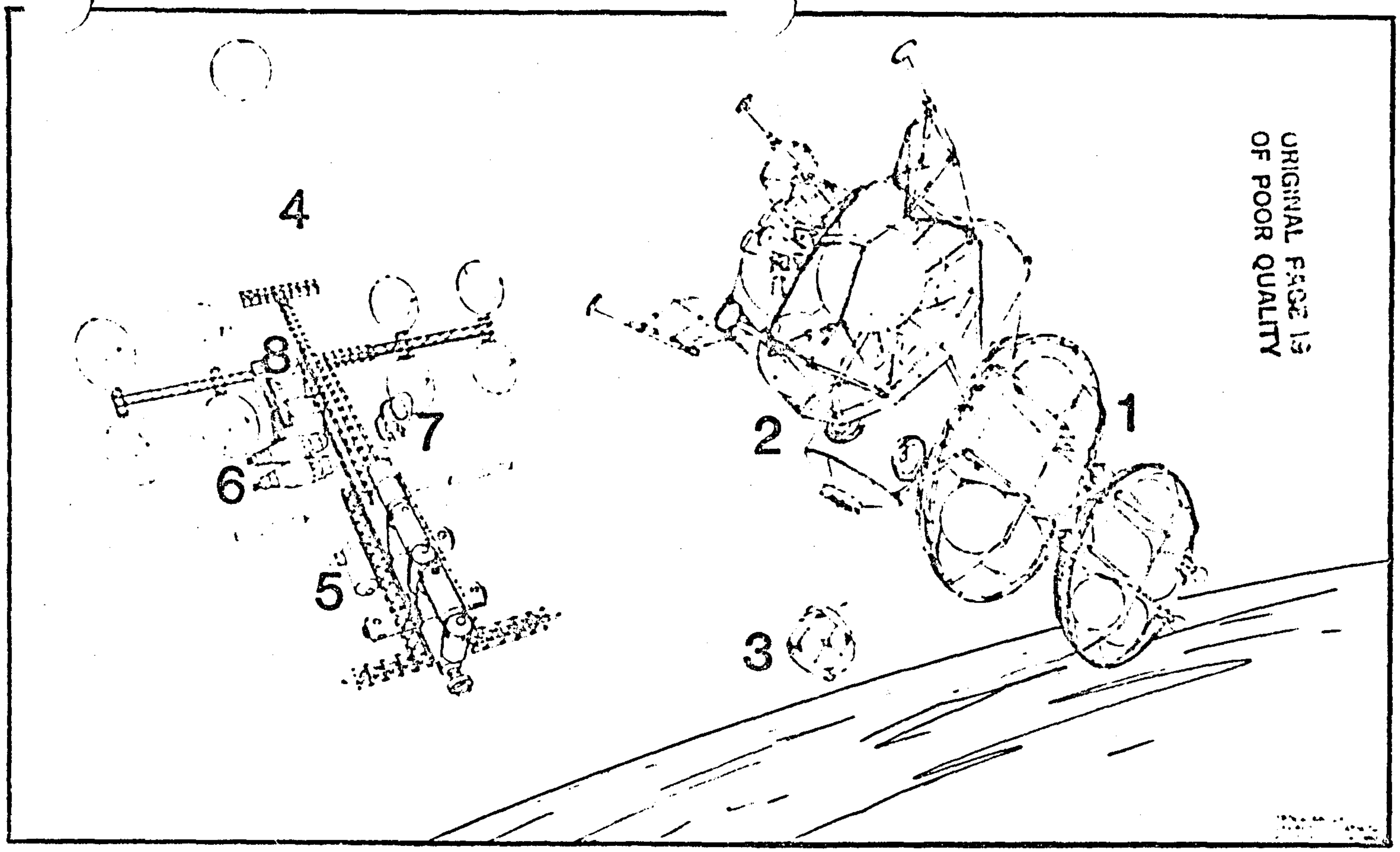
Total = 9 man weeks per 8 week period.

This requires at least 2 extra crew members for identified tasks. This will probably at least double for unidentified tasks.

4.5.4 AOTV Stack.

The stack of two AOTV's carrying an Expendable Lunar Lander and a Common Base Element is illustrated in Figure 14 departing the Space Station. Note the OMV returning to the Space Station after having maneuvered the stack to a safe distance. The AOTV illustrated is the JSC concept in which the tankage and support structure is tucked inside the aerobrake shell and the engine thrust is applied edgewise. JSC estimates that such a design would yield structure weights as low as those anticipated for the inflatable aerobrake structures, while still giving the reliability, controllability, and longer lifetime of the rigid structures.

The Space Station is shown in the background with the required hardware addition including two propellant depot elements in place.



AOTV STACK DEPARTING SPACE STATION

1. STACKED AOTVS
2. E-LANDER WITH COMMON MODULE
3. OMV
4. GROWTH SPACE STATION
5. QUARANTINE MODULE
6. OSM (PROPELLANT STORAGE MODULES)
7. OTV STACKING FACILITY
8. AOTV HANGAR

FIGURE 14
LEGEND

ORIGINAL PAGE IS
OF POOR QUALITY

Figure 14

4.5.5 Timelines for Space Station Capabilities.

No real Space Station requirements were posed by the unmanned exploration prior to the base construction start-up in 2005, so this period was not examined in detail. These early unmanned operations could be flown from the shuttle using expendable Centaur class vehicles if necessary.

The fully mature capability for lunar operations, however, needs to be in place at the beginning of the lunar base build-up in 2005. The development of these capabilities in a reasonably gradual manner needs to be addressed in the context of other scheduled developments.

Figure 8

4.6 Sensitivity Studies.

A brief analysis of the sensitivity of costs and operational requirements to changes in vehicle performance parameters (Isp, inert weights, and thrust) was performed to see if any significant changes resulted. OTV rocket engine Isp was increased from 455 sec effective to 480 sec effective. Inert weight was reduced by a third and thrust was doubled. The result, even when all three were done together, was a reduction in the number of unmanned tanker launches by a fourth (or savings of one to two launches per year), but little or no change in any of the other operations. At an estimated tanker launch cost of 133 million dollars per launch over a ten year period this amounts to an average annual savings of 173 million dollars. This is not a trivial sum and is well worth pursuing. Half of these savings can be obtained through the Isp increase to 480 seconds, an improvement considered easily achievable. However, when one considers that the total average annual launch cost is 1.17 billion dollars, and that the rest of the operations are basically unchanged, it is obvious that the scale of the operations and cost has been only moderately affected.

The same comments hold true when propellant losses and storage problems are considered. It is accepted that for vehicle and storage elements of the size considered over the periods of time involved (two or three weeks for the OTV's and two or three months for the depot), that losses can be kept to a few percent. Again such percentages, while they represent a fairly large sum of money, are not a critical percentage of the total, either in costs or in operational complexity.

4.7 Other Schemes

A conservative straight-forward approach was taken with this study. The only unconventional assumptions were the use of aerobraking and lunar produced oxygen for the Lunar Lander. This approach will support the lunar operations at an average launch cost of slightly over one billion dollars per year. No costing was performed on the other elements used for transport but it is to be expected that these launch costs will be the bulk of the actual transportation costs.

Other schemes for lunar operations have been proposed and more will undoubtedly develop in the future. Some of these may offer significant performance gains and, if they are not overly constrained operationally, may prove to be superior.

Generally, performance gains are obtained at the cost of operational flexibility, but for a large, long term project such as the lunar base it may well pay to give up some general capability and more fully optimize for the special lunar missions.

For example, Dr. Buzz Aldrin has proposed a scheme whereby the outbound vehicle rendezvous with the Lunar Lander in a free return trans-lunar orbit rather than in low lunar orbit. The principal advantage seems to be that the aerobrake does not have to brake in and out of lunar orbit. Also, such a system may have the potential of single-stage operations from the shuttle so that the Space Station assist is not required. However, balanced against this is the difficulty of performing a rendezvous in a trans-lunar orbit and the potential losses of adding one more constraint (the trans-lunar orbit) to a given flight. Such constraints usually create a performance loss.

The efficacy of many such proposals will in part depend upon which flight techniques are developed to state-of-the-art within the next twenty years.

5.0 Planetary Missions

5.1 Introduction

The five planetary missions shown in Table 6 were examined to determine their impacts on the growth Space Station. Table 7 summarizes their impacts on the Space Station. This set of missions, including three sample returns and two orbiter/probes, was chosen to show how the Space Station/Reusable-OTV infrastructure might enable more ambitious planetary exploration and also to examine how the use of this OTV infrastructure for planetary exploration would affect the growth configuration of the Space Station. This set of missions is an example set and not a proposed addition to the NASA planetary exploration program. The current core missions, proposed by the Solar System Exploration Committee of the NASA Advisory Council, (reference 7) are designed for single shuttle launch and have negligible impact on the Space Station.

The five missions studied illustrate what can be done with single and two-stage space-based OTV's designed under the groundrules of Section 3.0 and the rationale of 4.4.1.

5.2 Mission Design

Conceptual designs and in some cases detailed weight statements for all of the spacecraft and missions existed prior to this study. Delta V's were taken from previous work in some cases, and calculated in a few. Table 8 summarizes the orbital mechanics data for each of the missions. The sections on individual missions provide references and spacecraft weight statements (Tables 15 through 19).

Using the level of detail available, mass and burn histories were prepared for the individual missions. Table 9 shows the mass/burn history of each of the five missions from the trans-planetary, midcourse burn on. The midcourse mass before burn in the last part of Table 9, plus adapters and other jetsam, must be carried to the required C_3. This weight is fundamentally the planetary spacecraft that the OTV must launch.

We assume that a space-based, reusable, aerobraked-OTV system with many other users is available. Such a system would not be built only for planetary missions. A 42 metric ton propellant OTV design (see figure 6) was used. Section 4.4.1 discusses the rationale for this particular size and configuration. The desired mode of operation of this system would be a single-stage launch from LEO and an aerobraked return of the OTV to the Space Station. This mode of operation is applied to each of the five missions in Table 10. Table 10 shows that the Kopff, Ceres, and Titan missions require over 42 metric tons of propellant and therefore cannot be flown in the single-stage, aerobraked-return mode. A second set of calculations at the bottom of Table 10 shows that the Titan mission can be flown with a single, 42 metric ton stage if the aerobrake is removed and the OTV does

TABLE 6
PLANETARY MISSIONS PERFORMANCE SUMMARY

	C3	Type of OTV*	Payload out of LEO	LEO Total Departure Mass	OTV Propellant Load	Propellant + Payload (Lift Req.)
	$(km/sec)^2$		metric tons	metric tons	metric tons	metric tons
Mars Sample Return	9.0	1 Stage Reusable	8.89	44.03	27.76	36.65
Kopff Sample Return	80.7	2 Stage, 1st Stage Returns	8.38	92.49	71.51	79.89
Ceres Sample Return	9.9	2 Stage, 1st Stage Returns	43.57	131.59	75.47	119.04
Mercury Orbiter	18.7	1 Stage Reusable	5.63	41.62	28.90	34.53
Titan Probes/ Saturn Orbiter	50.5	1 Stage Expendable	6.34	53.54	41.81	48.15

* Isp = 455.4 sec., all stages have a total propellant capacity of 42 metric tons. A = 3,731 kg, B = .0785. Stages that do not return have the aerobrake removed.

TABLE 7
PLANETARY MISSIONS IMPACTS ON THE SPACE STATION

Requirements	Mars Sample Return	Kopff Sample Return	Ceres Sample Return	Mercury Orbiter	Titan Probes/ Saturn Orbiter
o Space Station Hardware Req.					
No. of OTV's Expended (not returned)	0	1	1	0	1
No. of OTV Refurb. Kits	1	2	2	1	1
Gantry to stack two stages		yes	yes		
Checkout equip. for two stage stack		yes	yes		
Quarantine Module	yes	yes	yes		
Additional power, KW	5	5	5		
Additional thermal control, no. of standard modules	1	1	1		
o Space Station Manhours Req.					
OTV Refurbishment	52	103	103	52	52
Aerobrake Removal		21	21		21
OTV/Payload Integration & C/O	11	21	21	11	11
Fuel, Release, and Launch	24	36	36	24	24
Rendez/Retrieve OTV using OMV	12	12	12	12	
Shuttle Rendez/Payload Removal	3	2	12	2	2
ULV Fuel Delivery	7	17	18	7	10
Sample Retrieval using OMV	8	8	8		
Sample Analysis & Shipment	24	16	16		
Total Mission Manhours	138	236	247	106	119

TABLE 8
Summary of Delta V/C_3 Requirements

Mission	C_3 $(km/sec)^2$	V Infinity km/sec	Burn from 200nm LEO km/sec	Launch Date	Time Enroute days	Decl. launch deg.	Rend. Delta V km/sec	Mid-Crs Correctn km/sec	Earth Return km/sec	Earth Insertion km/sec
1. Mars sample return Nominal case	9	3	3.59	11/18/96	304 Out 401 Stay 326 Return	30.58	0.125	0.2	2.027	1.929
2. Mars sample return Worst case	10	3.16	3.63	11/1/96			0.125	0.2	2.2	1.929
3. Kopff sample return	80.662	8.98	6.41	7/12/03	1,298 Out 50 Stay 854 Return	5.27	1.651		3.047	0.213
4. Mercury orbiter Best case	18.7	4.32	4.01	6/30/94	859 Out	18	3.38	0.15	-	-
5. Mercury orbiter Worst case	27.4	5.23	4.38	11/18/94	900 Out	28	3.96	0.15	-	-
6. Ceres sample return with Mars assist	9.859	3.14	3.63	10/29/94	1,654 Out 30 Stay 375 Return	31.734	3.829	0.481	5.292	0.213
7. Titan Probe/ Saturn Orbiter DVEGA Traj.	50.537	7.11	5.30	4/29/93	2,666 Out	-18.005	2	0.773	-	-

TABLE 9
MASS HISTORY AFTER OTV SEPARATION

Mission	Mars Sample Return Nominal	Mars Sample Return Worst	Kopff Sample Return	Mercury Orbiter Best Case	Mercury Orbiter Worst Case	Ceres Sample Return	Titan Probe/ Saturn Orbiter
o Earth Orbit Insertion							
Delta V, km/sec	1.929	1.929	0.213	-	-	0.213	-
Isp, sec	290	290	230	-	-	230	-
Lambda	0.82	0.82	0.9	-	-	0.9	-
Mass before burn, kg	125.02	125.02	102.22	-	-	102.22	-
Propellant used, kg	61.51	61.51	9.20	-	-	9.20	-
Mass after burn, kg	63.50	63.50	93.02	-	-	93.02	-
o Trans-Earth Injection							
Delta V, km/sec	2.027	2.2	3.047	-	-	5.292	-
Isp, sec	290	290	298	-	-	310	-
Lambda	0.87	0.87	0.85	-	-	0.97	-
Mass before burn, kg	722	785	3,993	-	-	7,241	-
Propellant used, kg	368	422	2,584	-	-	5,968	-
Mass after burn, kg	354	362	1,410	-	-	1,273	-

TABLE 9 (Continued)
MASS HISTORY AFTER OTV SEPARATION

Mission	Mars Sample Return Nominal	Mars Sample Return Worst	Kopff Sample Return	Mercury Orbiter Best Case	Mercury Orbiter Worst Case	Ceres Sample Return	Titan Probe/ Saturn Orbiter
o Planetary Rendezvous/ Insertion							
Delta V, km/sec	0.125	0.125	1.651	3.38	3.96	3.829	2.00
Isp, sec	310	310	298	298	298	310	298
Lambda	0.82	0.82	0.87	0.87	0.87	0.9	0.87
Mass before burn, kg	8,204	8,270	8,376	5,306	7,647	36,494	4,515
Propellant used, kg	330	333	3,612	3,634	5,671	26,120	2,236
Mass after burn, kg	7,874	7,937	4,765	1,672	1,976	10,374	2,280
o Midcourse Burn(s)							
Delta V, km/sec	0.2	0.2	0	0.15	0.15	0.481	0.773
Isp, sec	310	310	298	298	298	310	298
Lambda	0.82	0.82	0.87	0.87	0.87	0.9	0.87
Mass before burn, kg	8,894	9,635	8,376	5,629	8,112	43,570	6,344

TABLE 10
SINGLE STAGE OTV's

Mission	Mars Sample Return Nominal	Mars Sample Return Worst	Kopff Sample Return	Mercury Orbiter Best Case	Mercury Orbiter Worst Case	Ceres Sample Return	Titan Probe/ Saturn Orbiter
o LEO Departure, 42 metric ton max propellant single stage OTV with aerobrake *Any of these stages showing more than 42,000 kg of propellant will require a 2nd stage and the numbers here should be disregarded							
Delta V, km/sec	3.59	3.63	6.41	4.01	4.38	3.63	5.30
Finite burn loss, km/sec	0.1	0.1	1.4	0.06	0.07	0.35	1.4
Tot. Delta V, km/sec	3.69	3.73	7.81	4.07	4.45	3.98	6.70
Return Delta V, km/sec	1.45	1.50	6.19	1.89	2.32	1.78	4.91
Isp, sec	455.4	455.4	455.4	455.4	455.4	455.4	455.4
Mass at return burn, kg	9,712	9,823	28,045	10,715	11,803	10,459	21,070
Return Prop., kg	2,684	2,795	21,017	3,687	4,775	3,431	14,042
Outbound Mass before burn, kg	44,031	46,466	214,204	41,619	55,116	133,702	125,755
Propellant used, kg	24,398	25,941	* 173,304	24,512	34,195	* 77,634	* 95,799
Mass after burn, kg	19,634	20,524	40,900	17,107	20,921	56,068	29,956
o LEO Departure, 42 metric ton max propellant single stage OTV, no aerobrake no return, delta Vs and other parameters the same as returned vehicles							
Inert OTV mass, kg	5,243	5,243	5,243	5,243	5,243	5,243	5,243
Outbound Mass before burn, kg	33,687	35,757	80,636	27,811	37,096	120,818	53,541
Propellant used, kg	18,666	19,963	65,240	16,380	23,016	70,153	40,787
Mass after burn, kgms	15,021	15,794	15,397	11,432	14,081	50,665	12,754

not return. More calculation has also shown that this Titan mission can be flown with a 42 metric ton OTV with the aerobrake on, if no OTV return is required.

The Kopff and Ceres missions still require too much propellant and must either use additional propellant tanks, with total capacity in the 70 metric ton range, on a single stage or a second stage. Table 11 shows the mass breakdown for the two stage LEO launch of the Kopff and Ceres missions. Both OTV stages retain their aerobrakes, but only the first stage returns. Return of the second stages requires over 42 metric tons of propellant in each case. OTV's at or near the end of their useful life could be used for the second stages on these missions and for the single stage of the Titan mission.

Table 12 shows the mass breakdown for a single-stage expendable "rubber" OTV. These OTV's, though not really options, give an idea of the mass of a design optimized for a single given mission. A small kick stage would probably be used to further reduce launch mass on the Kopff and Ceres missions.

Table 13 summarizes the Earth launch requirements for each mission in terms of Shuttle and ULV loads required. The hardware required for each mission, except for the Ceres sample return, is in the range of 20 to 40 % of a shuttle load to the Space Station orbit. The number of Shuttles required to carry hardware only, and propellant only, and the number of ULV's required to carry propellant only are all tabulated. Figure 15 is a bar chart of the Earth launch requirements for payloads and propellants. This is shown for shuttle only missions because the number of missions required to support planetary flights do not justify the development of ULV. It is likely however, that if the OTV infrastructure postulated exists, a ULV to fuel the OTV will also exist, paid for by some program other than the planetary.

Table 14 shows all the constants used to size the planetary mission OTV's. These come from reference 2 and Eagle Engineering estimates.

TABLE 11
TWO STAGE OTV's

Mission	Mars Sample Return Nominal	Mars Sample Return Worst	Kopff Sample Return	Mercury Orbiter Best Case	Mercury Orbiter Worst Case	Ceres Sample Return	Titan Probe/ Saturn Orbiter
o LEO Departure, two stage OTV, each with 42,000 kg prop. capacity and an aerobrake. Only the 1st stage returns.							
2nd Stage							
Delta V, km/sec	n/a	n/a	6.17	n/a	n/a	2.72	n/a
Isp, sec			455.4			455.4	
Tanks,& engines, kg			5,243			5,243	
Mass before burn, kg			55,739			90,885	
Propellant used, kg			40,950			40,950	
Mass after burn, kg			14,789			49,935	
1st Stage							
Delta V, km/sec			1.64			1.26	
Return Delta V, km/sec			0.365			0.365	
Isp, sec			455.4			455.4	
Mass at return burn, kg			7,626			7,626	
Return prop., kg			598			598	
Mass before burn, kg			92,489			131,591	
Propellant used, kg			28,218			32,079	
Mass after burn, kg			64,270			99,512	
Total OTV Prop. loaded, 1st & 2nd stages, kg			71,510			75,467	

TABLE 12
SINGLE STAGE "RUBBER" OTV

Mission	Mars Sample Return Nominal	Mars Sample Return Worst	Kopff Sample Return	Mercury Orbiter Best Case	Mercury Orbiter Worst Case	Ceres Sample Return	Titan Probe/ Saturn Orbiter
o LEO Departure No aerobrake, no stage return single stage rubber OTV							
Delta V, km/sec	3.59	3.63	6.41	4.01	4.38	3.63	5.30
Isp, sec	455.4	455.4	455.4	455.4	455.4	455.4	455.4
Lambda	0.86	0.86	0.86	0.86	0.86	0.86	0.86
Mass before burn, kg	25,997	28,473	74,574	18,568	30,156	123,438	33,722
Propellant used, kg	14,350	15,842	56,804	10,998	18,829	68,602	23,418
Mass after burn, kg	11,648	12,631	17,770	7,570	11,328	54,836	10,304

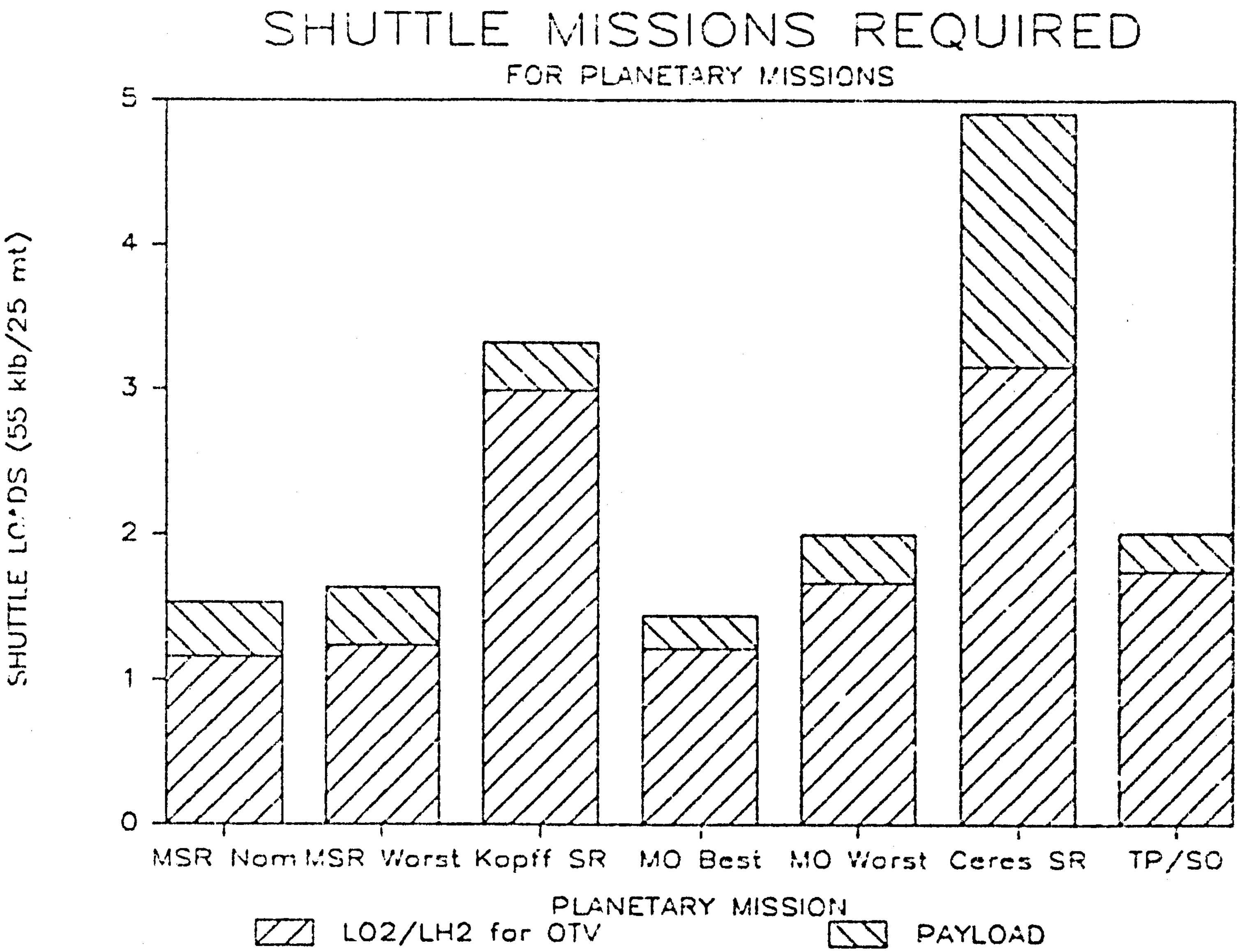
TABLE 13
LAUNCH REQUIREMENTS

Mission	Mars Sample Return Nominal	Mars Sample Return Worst	Kopff Sample Return	Mercury Orbiter Best Case	Mercury Orbiter Worst Case	Ceres Sample Return	Titan Probe/ Saturn Orbiter
o Summary of Launch Requirements, from the surface							
Shuttle only scenario							
Shuttle capacity, less ASE, kg	25,000	25,000 (55,000 lbs)	25,000	25,000	25,000	25,000	25,000
* Total hardware to be launched, kg	9,312	10,052	8,523	5,779	8,262	43,668	6,492
No. of Shuttles req. for hardware	0.37	0.40	0.34	0.23	0.33	1.75	0.26
Total LO2/H2 to be launched, kg	27,759 Reusable 1 stage	29,455 Reusable 1 stage	71,510 2 Stage	28,904 Reusable 1 stage	39,945 Reusable 1 stage	75,467 2 Stage	41,807 Non-reuse. 1 stage
Tankage for LO2/H2, kg	1,262	1,339	3,250	1,314	1,815	3,430	1,900
No. of Shuttles req. for LO2/H2	1.16	1.23	2.99	1.21	1.67	3.16	1.75
Total No. of Shuttles req.	1.53	1.63	3.33	1.44	2.00	4.90	2.01
Shuttle Derived Vehicle (ULV) Available to carry LOX/H2							
Capacity of ULV, kg	113,636 (250,000 lbs)	113,636	113,636	113,636	113,636	113,636	113,636
No. of ULV's req. for LO2/H2	0.24	0.26	0.63	0.25	0.35	0.66	0.37

* This includes all propellants for the planetary spacecraft and launch adapters. It does not include the OTVs which are assumed to be space based.

TABLE 14
OTV CONSTANTS

Mission	Mars Sample Return Nominal	Mars Sample Return Worst	Kopff Sample Return	Mercury Orbiter Best Case	Mercury Orbiter Worst Case	Ceres Sample Return	Titan Probe/ Saturn Orbiter
o OTV Constraints, Total dry mass = A + B*(Propellant Weight) A = A1 + A2, B = B1 + B2 + B3 + B4							
A1, Basic, kg	2,284	2,284	2,284	2,284	2,284	2,284	2,284
A2, Aerobrake, kg	1,447	1,447	1,447	1,447	1,447	1,447	1,447
A, Total, kg	3,731	3,731	3,731	3,731	3,731	3,731	3,731
B1, Basic	0.04545	0.04545	0.04545	0.04545	0.04545	0.04545	0.04545
B2, Aerobrake	0.00805	0.00805	0.00805	0.00805	0.00805	0.00805	0.00805
B3, Residuals	0.01	0.01	0.01	0.01	0.01	0.01	0.01
B4, Mixture ratio & Isp variation	0.015	0.015	0.015	0.015	0.015	0.015	0.015
B, Total	0.0785	0.0785	0.0785	0.0785	0.0785	0.0785	0.0785
Max allowable propellant,kg	42,000	42,000	42,000	42,000	42,000	42,000	42,000


SHUTTLE MISSIONS REQUIRED
FOR PLANETARY MISSIONS
SHUTTLE LOADS (55 klb/25 mt)
0
1
2
3
4
5
MSR Nom
MSR Worst
Kopff SR
MO Best
MO Worst
Ceres SR
TP/SO
PLANETARY MISSION
LO2/LH2 for OTV
PAYLOAD

5.3 Mars Sample Return

5.3.1 General Description

The Mars Sample Return Mission (November, 1996 launch) will provide detailed post-Viking exploration of Mars--including interior, surface, and atmospheric studies. In addition, it will provide intensive study of local areas and return unsterilized Martian samples to Earth orbit for analysis. The samples will be selected based on local studies and will require a "rover" for actual sampling. Specific objectives are:

- o Return samples for analysis of chronology, elemental and isotopic chemistry, mineralogy and petrology and the search for current and fossil life.
- o Intensive local studies to determine mineralogy, petrology, chemistry of materials, chronology of geologic processes, distribution and abundances of volatiles and surface interaction with atmosphere and radiation.
- o Study of the structure and circulation of the Martian atmosphere.
- o Study of the structures and dynamics of the Martian interior.
- o Mapping the global chemical and physical characteristics.
- o Investigate magnetic fields and solar wind interactions.

Figure 16 shows the mission scenario and Table 6 shows the Earth departure/OTV weights. The Mars Sample Return spacecraft consists basically of an Orbiter and a Lander. Upon arrival at Mars, the Lander and the Orbiter, which are connected, use aerobraking and a periapsis burn to insert into an elliptical orbit. After orbit insertion, the Lander separates from the Orbiter to deorbit while the Orbiter circularizes at 560 KM.

The Lander consists of a Mars Lander Module (MLM) carrying the Mars Rendezvous Vehicle (MRV), which will later carry the sample back to the Orbiter, with its Mars Ascent Boost Module (MABM), and the Mars Rover, which will collect the samples to be returned. After landing, the MLM deploys the Rover which is guided from Earth in its search for samples. The Rover deposits the sample in the Sample Canister Assembly (SCA) which will eventually be returned to Earth orbit.

After the Rover has collected the samples it returns to the MLM. The SCA with its 5 kg sample is then transferred to the MRV with a crane-like mechanism on the MLM. The sterilized solid rockets on the MRV and MASM booster are used for launch into Mars orbit. Once the MRV achieves orbit the Mars Orbiter Vehicle (MOV) maneuvers to rendezvous with it.

The Orbiter, known as the Mars Orbit Vehicle (MOV) contains the Earth Return Vehicle (ERV). The ERV in turn houses the Earth Orbit Capsule (EOC) which orbits Earth waiting to be picked up for processing at the Space Station.

After the docking in Mars orbit of the MOV with the MRV, the Sample Canister is placed into the Earth Orbit Capsule. This is its final position for return to the Earth Space Station. When this transfer has been completed, the Earth Return Vehicle, detaches from the MRV and MOV. The ERV protects the EOC with the SCA during the trans-Earth voyage and is jettisoned just before arrival. The EOC first inserts into Earth orbit, and then carries and protects the SCA and sample while they are waiting to be picked up by an OTV (Orbit Transfer Vehicle) or OMV (Orbit Maneuvering Vehicle). This general description was derived from references 4 and 5.

5.3.2 Spacecraft Mass Estimates

As described previously, the Mars Sample Return spacecraft consists of several discrete modules. The weights of these modules are given in Table 15. The summary separates the spacecraft into three systems: Earth Return System; Lander/ Rendezvous System and Orbiter/Earth Departure Systems.

The Earth Return System includes the Sample Canister, Earth Orbit Capsule and the Earth Return Vehicle. The Lander/Rendezvous Vehicle includes the Mars Lander Module and the Mars Rendezvous Vehicle along with the MABM booster. The Orbiter/Earth Departure System is the Mars Orbit Vehicle which serves as the Earth Departure System as well.

A separate section is included for miscellaneous adapters which includes the departure bioshield and the adapter for the Orbital Transfer Vehicle for insertion into trans-Mars orbit from Low Earth Orbit.

This mass properties information was derived from Reference 5.

5.3.3 Delta V's

The Delta V's used for the Mars sample return mission also come from reference 5. The baseline trajectory includes an aerocapture into Mars orbit, a perigee raising maneuver, a lander deployment, a circularization maneuver, a Mars orbit rendezvous with the sample carrying ascent stage, trans-Earth injection of the sample and carrier, and propulsive earth orbit insertion into an orbit from which the Space Station can capture the sample with the OMV or OTV. The sample is inserted into a 280 km perigee, Mars Sample Return Scenario

1. Stack leaves Space Station
2. Trans-Mars Injection
3. First stage returns
4. Trans-Mars voyage
5. Aerocapture and Mars Orbit Insertion
6. Jettison MOV aeroshell
7. Lander and orbiter separate
8. Lander enters Mars atmosphere
9. Landing on martian surface
10. Collect samples
11. Launch from Mars
12. Mars Rendezvous Vehicle injection into Mars orbit
13. Mars Orbiter Vehicle manuevers to rendezvous with MRV
14. Trans-Earth injection
15. Trans-Earth voyage
16. Earth Orbit Capsule insertion into Earth orbit
17. OMV rendzvous with EOC
18. OMV returns EOC with sample to Space Station Quarantine Module

Figure 16
Legend

ORIGINAL PAGE IS
OF POOR QUALITY

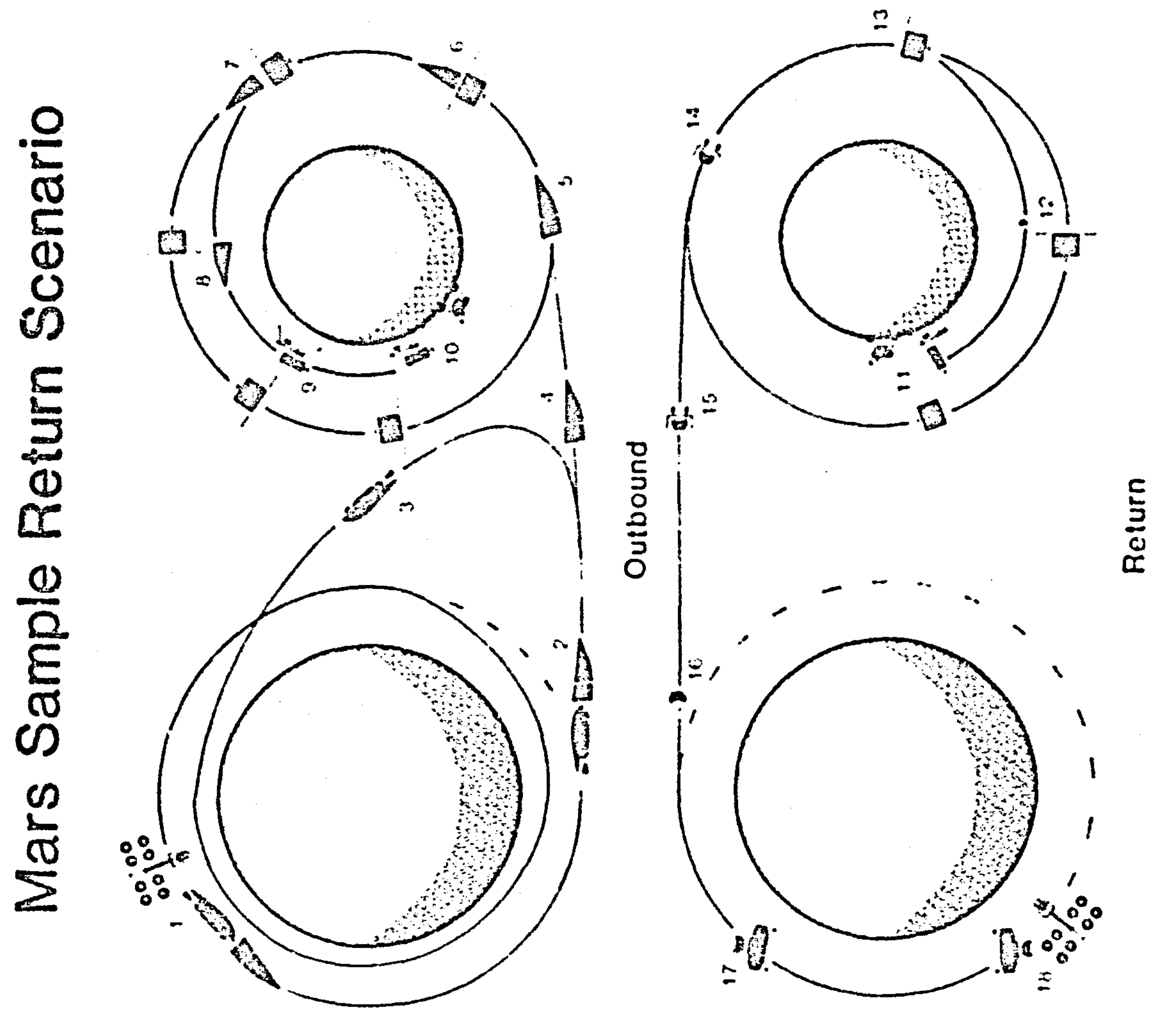


Figure 16

12 hour period orbit. The Mars departure date can be picked so that the arrival plane coincides with any desired node. The arrival can thus be planned for the desired Space Station node biased for nodal regression during the rendezvous sequence. The worst case Mars departure delta V penalty for achieving the desired node is approximately 10% (ref. 4).

References 4 and 6 discuss the window and delta V ranges associated with Space Station OTV departure and Earth orbit arrival. Two opportunities for in plane departure occur every 50 days due to nodal regression of the Space Station plane. The worst departure delta V penalty from the Space Station orbit is less than 2% of the minimum delta V for the 1996 mission opportunity (ref. 4).

Table 8 shows the delta V's of interest for Space Station impact purposes. Table 8 delta V's and spacecraft weights feed into Table 9 where the LEO departure weight is determined. There are some delta V's in the Mars mission, such as lander deorbit, landing, and ascent burns, and Mars orbiter circularization and rendezvous maneuvers that are book-kept in the weight statements.

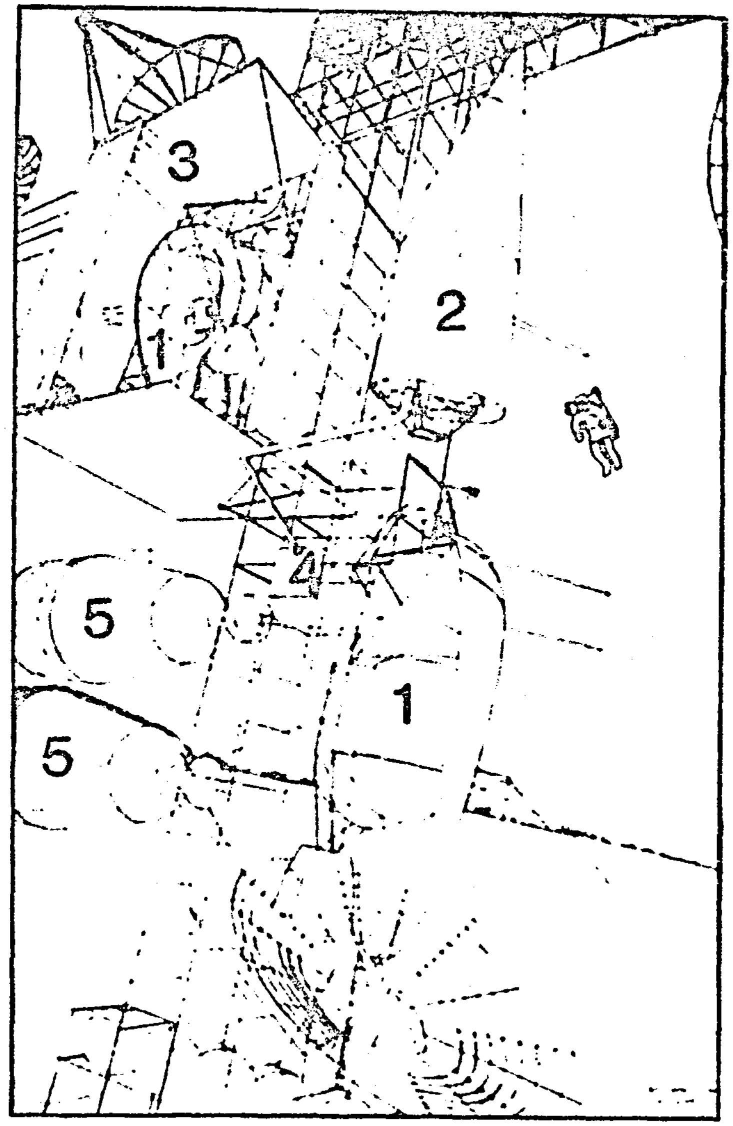
The Mars Sample Return Mission has been well studied and good orbital mechanics data is available. Several trade studies of various mission scenarios have also been conducted and are in process as of this date.

5.3.4 Space Station Impacts

Figure 17 shows a Mars Sample Return Vehicle being mated to an OTV at the Space Station. Table 7 summarizes the impacts. The major impact on the Space Station of mission departure is the OTV turnaround and payload integration. An OTV must be refurbished, the payload mated, the stack must be checked out, fueled, released, and launched. The returning OTV must be retrieved. A tanker must be docked to replenish fuel supplies. Table 7 shows an estimate of manhours on-orbit required to do all this. Sections 6.2, 6.3, and 6.5 provide more information on these impacts.

Retrieval of the returned sample will cause the greatest impact on the station. A Biological Quarantine Module will be added to the Station to handle and repackage the returned sample for shipment to Earth on a shuttle. The Quarantine Module is an environmentally isolated module in which the sample can be packaged in a biologically disaster-proof container for shipment. Some minimal testing can also be done in the Quarantine Module. Section 6.4 discusses the Quarantine Module in more detail.

THIS PAGE
INTENTIONALLY
LEFT
BLANK



MARS SAMPLE RETURN SPACECRAFT - OTV MATING

1. AOTV
2. MARS SAMPLE RETURN SPACECRAFT (INSIDE AEROSHELL)
3. OTV HANGAR
4. MOBILE RMS
5. OSM (PROPELLANT STORAGE MODULES)

FIGURE 17
LEGEND

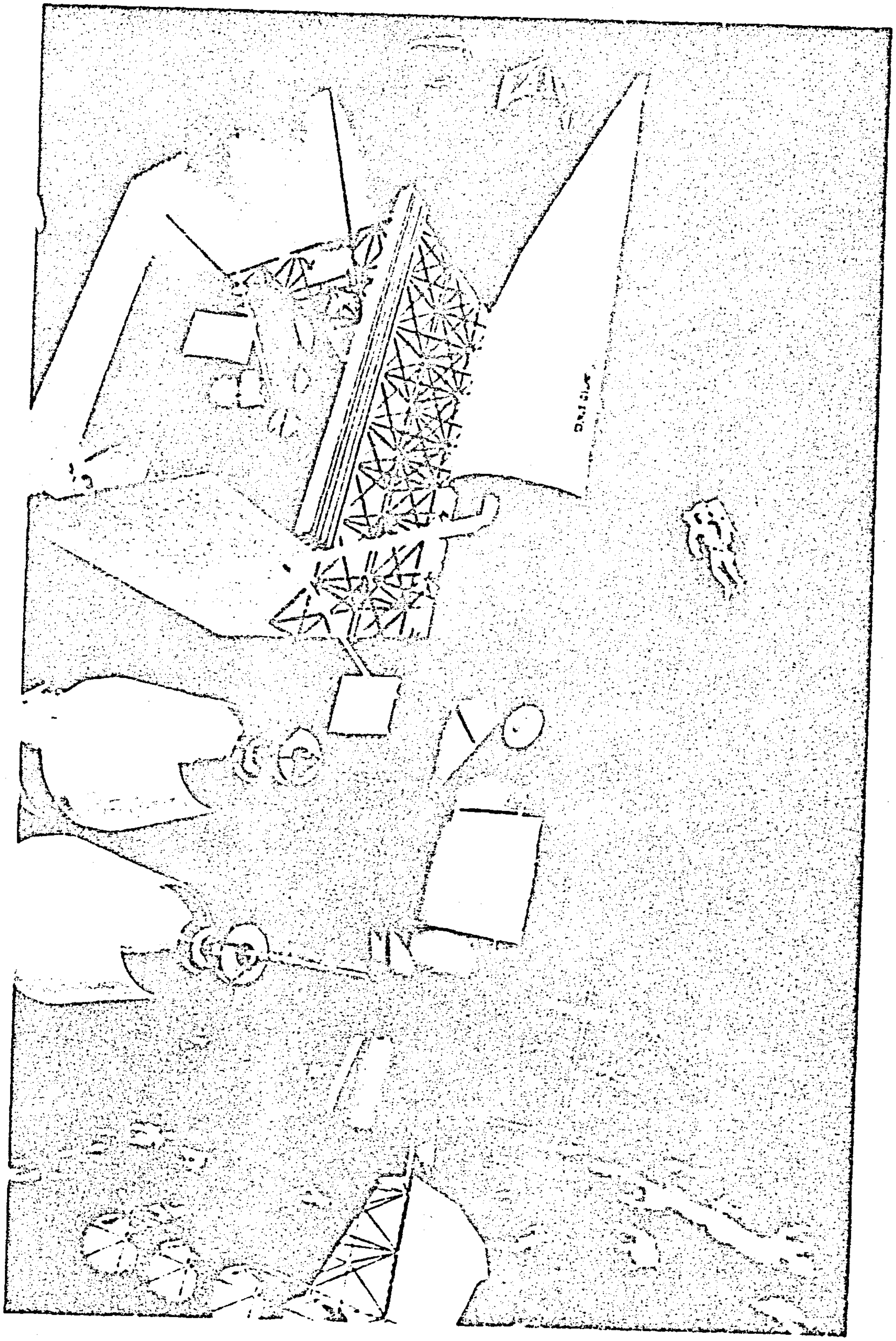


Figure 17

TABLE 15 Mars Sample Return Mission Weight Statement

Description	Item (kg)	Totals (kg)	
EARTH RETURN SYSTEMS			
SAMPLE CANISTER ASSEMBLY			
SCA	15.0		
SAMPLE	5.0		
TOTAL SCA		20.0	
EARTH ORBIT CAPSULE			
COMMUNICATIONS	1.6		
POWER ASSEMBLY	3.8		
THERMAL CONTROL	3.0		
SRM IGNITER ASSEMBLY	0.3		
GRAPPLING & RECOVERY	1.2		
SCA MONITOR TO CONTACT ASSEMBLY	1.4		
BUS STRUCTURE	10.2		
COVER ASSEMBLY	2.4		
MECHANISMS (MISC.)	0.7		
RETENTION PINS	0.6		
SUBTOTAL		25.2	
CONTINGENCY	4.8		
VEH. TOTAL (DRY)		30.0	
+ SCA	20.0		
TOTAL		50.0	
EARTH ORBIT INSERTION PROP.:			
SRM PROPELLANT (3 SRMS)	61.5		290 Isp
SRM STRUCTURE	13.5		
TOTAL EOC		125.0	

TABLE 15 Mars Sample Return Mission Weight Statement
(Continued)

Description	Item (kg)	Totals (kg)	
EARTH RETURN VEHICLE			
TELECOM	18.5		
POWER	20.4		
COMMAND & DATA HANDLING	14.0		
ATTITUDE & POINTING CTRL	13.7		
EOC LATCH/UNLATCH	2.8		
EOC SEP SPRINGS	1.0		
SRM SAFE/ARM BOX	2.2		
PYRO UNITS (2) & SQUIBS	1.8		
BUS AND SUPPORT STRUCTURE	27.0		
TEMP CONTROL	8.9		
CABLING	11.0		
SUBTOTAL		121.3	
CONTINGENCY	11.2		
TOTAL (DRY)		132.5	
RCS: INERTS	10.0		
SUPPORTS	1.2		
PROPELLANT (H2N4)	30.6		
VEHICLE TOTAL		174.3	
TOTAL INCL ERV+EOC		299.3	
TRANS EARTH INSERTION PROP.:			
SRM PROP	367.6		290 Isp
SRM STRUCTURES	54.9		
TOTAL INCL. ERV+TEI PROP		596.8	
TOTAL EARTH RETURN SYSTEM (ERV+TEI PROP+EOC)		721.8	

TABLE 15 Mars Sample Return Mission Weight Statement
(Continued)

Description	Item (kg)	Totals (kg)
RENDEZVOUS/LANDING SYSTEMS		
MARS RENDEZVOUS VEHICLE		
TELECOM	18.5	
POWER	24.2	
COMMAND & DATA HANDLING	14.0	
ATTITUDE & POINTING CTRL	33.4	
MRV/MLM ANT SWITCH	0.3	
PRYO UNIT (2) & SQUIBS (30)	4.2	
TEMP. CONTROL	12.0	
DEVICE: ASCENT		
ASCENT SHROUD SEPARATION EQPT.	4.2	
HGA LATCH	1.8	
SOLAR PANEL DEPLOY	3.0	
SCA LATCH/RELEASE	1.8	
SCA TO EOC TRANSFER MECHANISM	6.4	
STAGE 1&2 SAFE/ARM BOX	2.2	
CABLING	12.0	
SCA MONITOR CONTACT ASSY.	1.4	
BUS ASSEMBLY	32.0	
EQUIPMENT SUPPORTS, BRACKETS	7.0	
HGA SOLAR PANEL LAUNCH SUPPORTS	4.0	
SCA SUPPORTS	1.4	
ASCENT SHROUD	9.1	
DOCKING DROGUE ASSY.	2.6	
RETROREFLECTORS	0.8	
SOLAR PANEL OUTRIGGERS	6.4	
SUBTOTAL		202.7
CONTINGENCY	23.2	
TOTAL (DRY)		225.9
TOTAL (MRV DRY+SCA)		245.9
RCS: INERTS	31.4	
SUPPORTS	2.0	
PROPELLANTS	19.3	
VEHICLE TOTAL (MRV WET+SCA)		298.6

TABLE 15 Mars Sample Return Mission Weight Statement
(Continued)

Description	Item (kg)	Totals (kg)	
STAGE 2			
PROPULSION:			
SRM PROPELLANT	228.5		280 Isp
SRM BURNOUT MASS	31.5		
SRM SUPPORT	7.3		
TOTAL STAGE 2		267.3	
VEHICLE TOTAL (MRV+SCA+PROP STAGE 2)		565.9	
STAGE 1			
INTERSTAGE ADPTR	30.2		
SEPARATION DEVICES	4.0		
CABLING	2.0		
PROPULSION:			
SRM PROPELLANT	1142.7		280 Isp
SRM BURNOUT MASS	138.8		
SRM SUPPORT	32.0		
TOTAL STAGE 1		1349.8	
CUMULATIVE WEIGHT (MRV + SCA + STAGE 2 + STAGE 1)		1915.7	
MARS ASCENT BOOST MODULE			
SUPPORT TRUSS	58.4		
SAFE/ARM BOX	2.2		
SEPARATION DEVICES	9.0		
MLM RELEASE MECH	2.8		
CABLING	3.6		
HEAT+PLUME SHIELDS	8.5		
TOTAL (DRY)		84.5	
PROPULSION:			
SRM PROPELLANTS	515.4		280 Isp
SRM BURNOUT MASS	76.8		
SRM SUPPORTS	17.7		
TOTAL MABM		694.4	
CUMULATIVE TOTAL WEIGHT (MRV + SCA + STAGE 1 + STAGE 2 + MABM)		2610.1	

TABLE 15 Mars Sample Return Mission Weight Statement
(Continued)

Description	Item (kg)	Totals (kg)
MARS LANDER MODULE		
TLCM:HGA+LGA+COAX	1.9	
WAVEGUIDE, ROT JOINT	1.8	
POWER: RTG	14.9	
SHUNT REG.	3.2	
SHUNT RAD.	4.9	
CTL./DIST.	7.8	
CDH: REMOTE UNIT	6.0	
APC: RADAR ALT+TDLR	31.6	
PENDULOUS SENSR	1.8	
ANTENNA ACT.	3.6	
PYRO UNIT (2), SQUIBS (40)	4.4	
SAFE/ARM BOX	2.2	
THERMAL CONTROL	7.0	
PLUME DEFLECTORS	2.8	
RTG COOLING SYS.	12.0	
CABLING	16.0	
DEVICES:		
MRV RELEASE	1.8	
AEROSHELL RELEASE	1.6	
ANT. BOOM RELEASE	0.6	
PARACHUTE RELEASE	1.2	
LAND. LEG RELEASE	3.6	
ROVER RELEASE	4.8	
MISC. RELEASE	3.0	
MRV UMBIL. SEP.	3.8	
ROVER UMB. SEP	2.4	
ROVER DEPLOYMENT	18.0	
ANT.BOOM CAN+MAST	4.7	
SCA XFER, DEV. CAN + MAST	7.4	
MRV EREC. DRIVE	22.0	
MRV ROTATN DRIVE	8.2	
FWD. TIEDOWN, LATCH/RELEASE	2.6	
VERTICAL PHASE CABLE RELEASE	1.8	
LANDING LEG DEPLOY/ADJUST	15.0	

TABLE 15 Mars Sample Return Mission Weight Statement
(Continued)

Description	Item (kg)	Totals (kg)
POWER:		
SOLAR PANELS WITH SUBSTRATE	17.8	
BATTERIES	25.2	
BATTERY CHARGER	3.4	
CONDITIONING CONTROL	7.6	
DISTRIBUTION	3.8	
ATTITUDE TO POINTING CONTROL:		
SUN SENSOR (2)	1.0	
STAR SENSOR (2)	5.4	
IRU (2)	6.4	
ACCELEROMETER	0.7	
ACCELEROMETER ELECT	2.3	
ANTENNA ACTUATORS (2)	3.6	
	3.2	
TV CAMERA ACTUATORS	2.5	
ATT. CTL ELECTRONICS	14.0	
COMMAND+DATA HANDLING:		
CDH MAIN UNIT (2)	11.6	
DATA STORAGE (2)	2.4	
TV CAMERA W/ELECTRONICS	3.0	
TEMPERATURE CONTROL:		
INSULATION	7.6	
LOUVERS	6.8	
HEATERS	1.8	
PYRO UNIT(2), SQUIBS(20)	4.0	
RENDEZVOUS+DOCKING GUIDE. EQPT.	12.0	
SPIN TABLE W.DRIVE	10.4	
MECHANICAL DEVICES:		
SOLAR PANEL DEPLMT.	4.2	
SOLAR PANEL+HGA DAMPERS	3.4	
HGA BOOM LATCH/RELEASE	2.2	
TV CAMERA BOOM LATCH/RELEASE	1.0	
MEC RELEASE/SEPAR.	4.2	
BIOSHIELD RELEASE	3.8	
ERV UMBIL. RETRACT	1.2	
ERV RELEASE/SEP	4.2	
DOCKING CONE RELEASE	2.0	
CABLING	16.0	

TABLE 15 Mars Sample Return Mission Weight Statement
(Continued)

Description	Item (kg)	Totals (kg)	
STRUCTURES:			
ANTENNA SUPPORTS	5.2		
EQPT SUPTS+BRACKETS	13.6		
HGA BOOM	3.6		
TV CAMERA BOOM	2.4		
SOLAR PANEL OUTRIGGERS	4.8		
DOCKING CONE W/SPTS	9.5		
RENDEZVOUS/DOCKING SUPPORT RING	3.6		
MAV SUPPORTS AND GUIDES	16.4		
BUS	58.0		
MEC&BIOSHIELD SUPTS	104.6		
SUBTOTAL		453.9	
CONTINGENCY	44.3		
TOTAL MOV (DRY)		498.2	
MOV AEROSHELL	617.2		
PROPULSION (MTO/MOI):			
STRUCTURE AND SUPPORTS	176.6		
PROPELLANT-TCM	565.5		310 Isp
PROPELLANT-MOI	330.0		310 Isp
PROPELLANT-ORBIT CIRC.	116.9		310 Isp
SUBTOTAL PROPELLANTS		1012.5	
TOTAL TRANS-MARS (WET)		2304.5	
CUMULATIVE TOTAL (ALL SYSTEMS)		8893.7	
ADAPTERS/MISCELLANEOUS EQUIPMENT			
BIOSHIELD	146.7		2.5% OF LANDING VEHICLE MASS
TOTAL INJECTED MASS		9040.4	
CENTAUR ADAPTER	271.2		3.0% OF INJECTED MASS
TOTAL LAUNCH MASS		9311.6	

5.4 Comet Kopff Nucleus Sample Return

5.4.1 General Description

The Comet Kopff Nucleus Sample return scheduled for launch in July, 2003, will be a follow-on to previous comet flyby and rendezvous missions. The return of a comet nucleus sample will enable detailed studies of what are probably the most chemically primitive bodies in the solar system. The mission will utilize information from the previous missions for preliminary sample site selection and Sampler configuration selection.

The specific objectives of this mission are similar to those of a comet rendezvous mission with one notable exception:

- o Return of samples for analysis of molecular and elemental abundances, concentrations of water and carbon dioxide ices, physical state of surface material, local inhomogeneity, and critical isotopic ratios.
- o Produce high level topographic map of nucleus.
- o Characterize change in nucleus, coma and tail through perihelion passage from both the nucleus surface and from orbit around the nucleus.
- o Study in detail the size, mass, shape, and rotation of the nucleus.
- o Study in detail the hydrodynamics of gas and dust flow.
- o Study in detail chemical kinetics of parent and daughter molecules in the coma.
- o Study in detail the solar wind interactions.

To accomplish many of the detailed characterizations, a long duration Lander will be required in addition to the Samplers. Two Samplers will be used, one with a Lander, which will stay on the nucleus and one without a Lander. The configuration for the ice surface shown in reference 8 is the heaviest and will be used as a baseline.

Figure 18 illustrates the scenario for both the Kopff and Ceres Sample Return Missions. A stack of two 42 metric ton propellant capacity OTV's departs the Space Station. Table 6 summarizes the mass breakdown and Table 11 provides detail. The second stage does not return and its aerobrake is removed prior to launch.

CERES OR KOPFF SAMPLE RETURN SCENARIO

1. STACK DEPARTS SPACE STATION
2. FIRST STAGE BURN, SEPARATION AND RETURN TO SPACE STATION
3. SECOND STAGE BURN, TRANS-CERES/KOPFF VOYAGE
4. SPACECRAFT RENDEZVOUS AND ASTEROID/COMET SURVEY
5. LANDER ON SURFACE, SPACECRAFT IN ORBIT
6. SPACECRAFT RECOVERS SAMPLERS AND DEPARTS FOR EARTH
7. TRANS-EARTH VOYAGE
8. CARRIER AND EARTH ORBIT CAPSULE SEPARATE
9. EOC AEROCAPTURE FOR EARTH ORBIT INSERTION
10. CIRCULARIZATION ABOVE SPACE STATION ORBIT
11. OMV RENDEZVOUS WITH EOC AND RETURN TO SPACE STATION QUARATINE MODULE

FIGURE 18
LEGEND

ORIGINAL PAGE IS
OF POOR QUALITY

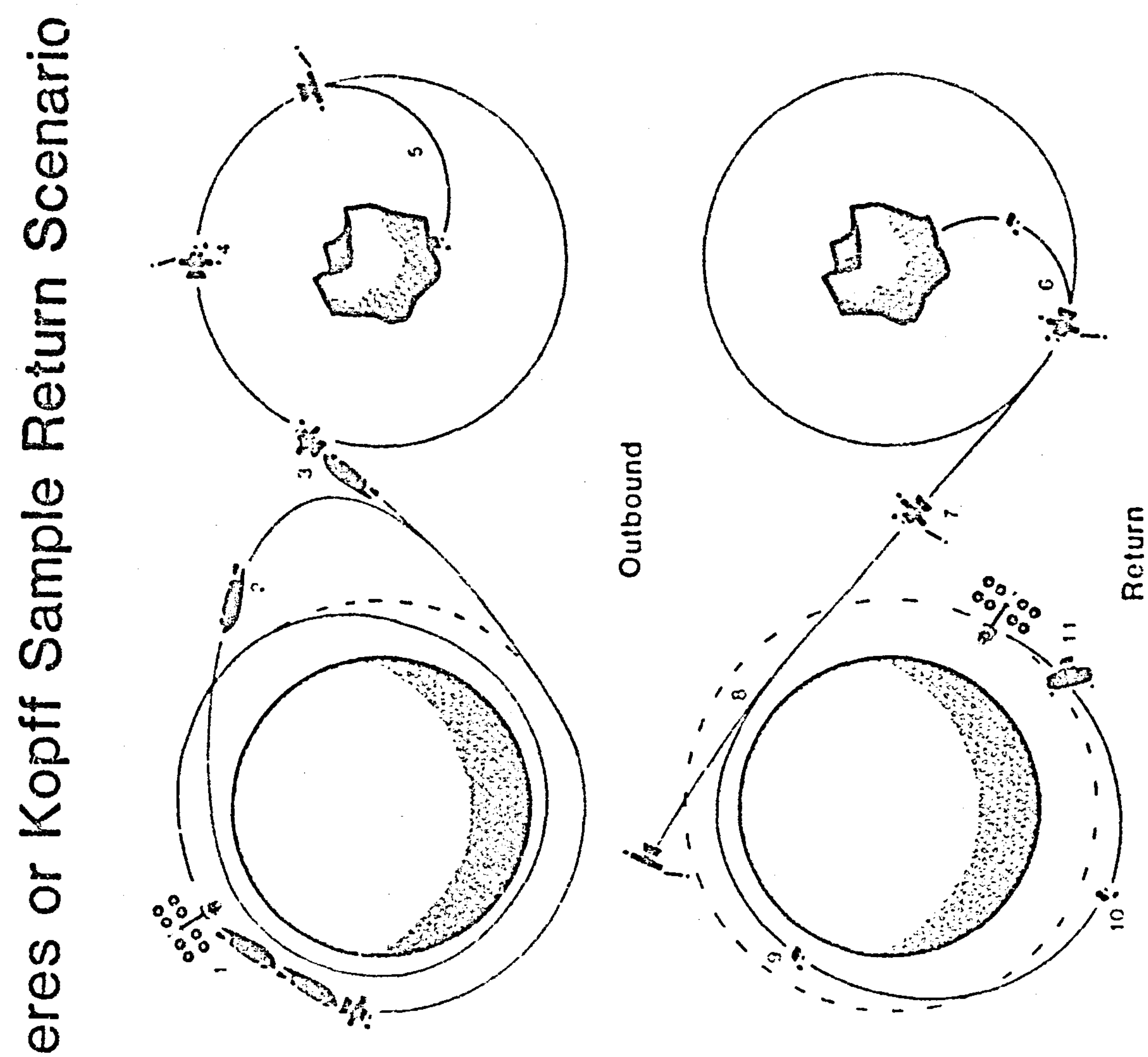


Figure 18

The spacecraft will rendezvous with the comet and select sampling sites for undisturbed subsurface material. After sample site selection the Sampler/Lander is deployed. An additional site is then selected for the second Sampler and it is deployed. Once a sample has been taken, the sample return vehicle returns to the Orbiter leaving the Lander or landing gear on the nucleus. The Lander continues to function as a weather station on the comet.

The spacecraft will provide thermal and environmental protection for the samples during the trans-Earth voyage and as in the Mars Sample Return mission, it will be jettisoned prior to Earth orbit insertion leaving only a sample assembly in the Earth Orbit Capsule. The Earth Orbit Capsule aerobrakes into Earth orbit and is retrieved to the Space Station with an OMV and placed in the Quarantine Module.

The general description of this mission comes from reference 8.

5.4.2 Spacecraft Mass Estimates

The mass statements for this mission are found in Table 16. As with the Mars Sample Return Mission, the masses are broken down into systems:

- Earth Return System is the Earth Orbit Capsule (Ref. 17).
- Lander/Rendezvous Systems include the Nucleus Lander and Samplers (Ref. 8).
- Orbiter/Earth Departure System includes a Mariner Mark II Spacecraft configured for a comet rendezvous mission (reference 9) and adapted for the Samplers and Lander. This is a round trip spacecraft as it will also serve as the Earth Return Vehicle.

5.4.3 Delta V's

The delta V's used for the Kopff sample return were provided by Alan Friedlander of Science Applications. The Kopff sample return mission has not been extensively studied. As a result no window data is available. Window data from reference 6 indicates a variation of 10% in total delta V required over a 20 day Space Station launch window for a 1994 Tempel/2 rendezvous. Variation in total delta V over 360 degrees of possible station nodal locations was 3%, assuming best date launch.

Table 8 shows the Delta V's required. This is a ballistic trajectory. Aerocapture into Earth orbit with a circularization burn is used on the return. Kopff has a period of 6.4 years. A rendezvous mission to Kopff on its orbit prior to this one, launching in July 1990, has been studied.

5.4.4 Space Station Impacts

Two OTV's must be stacked, integrated, checked out, and fueled for this mission. The aerobrake must also be removed from the second stage, which does not return. Table 7 summarizes the impacts and the on-orbit manhours. Sections 6.2, 6.3, and 6.5 provide more information on some of these operations.

As with the Mars Sample return mission, the Quarantine Module causes the biggest impact on the Space Station. The environmentally isolated Quarantine Module will be added to the Station to handle and repackage the returned sample in a biologically disaster-proof container for shipment. Section 6.4 provides more information on the Quarantine Module.

Table 16, Kopff Nucleus Sample Return Weight Statement

Description	Item (kg)	Totals (kg)	
EARTH RETURN SYSTEM			
EARTH ORBIT CAPSULE			
SAMPLE CANISTER ASSEMBLY	60.0		
INCLUDES 10 KG SAMPLE			
AEROBRAKE SHIELD	28.0		
TOTAL		88.0	
CONTINGENCY	4.0		
TOTAL (DRY)		92.0	
PROPULSION:			
STRUCTURE	1.0		
PROPELLANT	9.2		230 Isp
TOTAL EARTH ORBIT CAPSULE		102.2	
RENDEZVOUS/LANDING SYSTEM			
DRILLING SAMPLER			
SCIENCE	0.0		
COMMAND AND DATA HANDLING	1.5		
TELECOMMUNICATION	1.2		
AACS	1.6		
REACTION CONTROL SYSTEM	2.4		
POWER/PYRO	3.8		
STRUCTURE	13.0		
THERMAL CONTROL	2.5		
CABLING	0.5		
DEVICES	5.8		
SUBTOTAL		32.3	
NITROGEN PROPELLANT	0.9		
CONTINGENCY (30%)	9.7		
TOTAL SAMPLER		42.9	
DRILLING SAMPLER/LANDER			
SCIENCE	14		
COMMAND AND DATA HANDLING	16		
TELECOMMUNICATION	11.2		
AACS	0		
REACTION CONTROL SYSTEM	0		
POWER/PYRO	30		
STRUCTURE	42.5		
THERMAL CONTROL	9.6		
CABLING	5		
DEVICES	10.5		

Table 16, Kopff Nucleus Sample Return Weight Statement
(Continued)

Description	Item (kg)	Totals (kg)	
SUBTOTAL		138.8	
CONTINGENCY (15%)	20.82		
DRILL/RETURN VEHICLE	29.1		
TOTAL SAMPLER/LANDER		188.72	
ORBITER/EARTH DEPARTURE SYSTEM			
MARINER MARK II SPACECRAFT (MMII)			
SCIENCE EQUIPMENT SUBSYSTEM			CRAF MISSION
SSI NA CAMERA+ELECTRON	21.40		
SSI WA CAMERA (SHO ELE	9.60		
IMAGING VISUAL AND IR SPECTROMETER	12.00		
GAMMA RAY PENETRATOR	19.90		
GRS ANTENNA/RECEIVER/ SUPPORT	6.00		
NEUTRAL MASS SPECTROME	13.00		
ION MASS SPECTROMETER	9.00		
DUST COUNTER	5.10		
DUST ANALYZER, PARTICL	12.00		
DUST ANALYZER, BULK	11.00		
MAGNETOMETER	2.50		
CALIBRATION COIL	0.50		
PLASMA WAVE SPECTROMET	4.70		
SCIENCE CALIBRATION TA	3.00		
SUBTOTAL		129.7	
ENGINEERING SUBSYSTEMS			
STRUCTURE SUBSYSTEM	177.1		
RADIO FREQUENCY SUBSYS	24.5		
POWER/PYRO SUBSYSTEM	102.6		
COMMAND+DATA HANDLING SUBSYSTEM	23.8		
ATTITUDE+ARTICULATION CONTROL	85.4		
CABLING	51.0		
THERMAL CONTROL SUBSYS	58.0		
DEVICES SUBSYSTEM	25.3		
DATA STORAGE	8.9		
SUBTOTAL		556.6	
SUBTOTAL		686.3	
CONTINGENCY	115.3		
TOTAL MMII (DRY)		801.6	

Table 16, Kopff Nucleus Sample Return Weight Statement
(Continued)

Description	Item (kg)	Totals (kg)	
PROPULSION:			
PROPULSION STRUCTURE	995.6		
RCS PROPELLANT	50.0		
DELTA V PROPELLANT	6195.3		298 Isp
TOTAL MMII (WET)		8042.5	
TOTAL INJECTED WEIGHT		8376.4	
ADAPTERS/MISCELLANEOUS EQUIPMENT			
LAUNCH VEHICLE ADAPTER	146.3		
TOTAL OTV SEPARATION WEIGHT		8522.7	

5.5 Ceres Rendezvous/Sample Return

5.5.1 General Description

The Ceres Rendezvous/Sample Return Mission (October, 1994 launch) may be ambitious for 1994, but is included here to demonstrate capability. Although their origins may be different, asteroids, like comets, represent relatively primitive bodies. A sample return will allow detailed analysis which should provide insight into solar system evolution.

The specific objectives of this mission are as follows:

- Return samples for analysis of molecular and elemental abundances, concentrations of ices, physical state of surface material, local homogeneity, and critical isotopic ratios.

- Produce high resolution topographic map.

- Characterize the asteroid including size, rotation, albedo, mass, density, magnetic field, and solar wind interaction.

This mission, including samplers and carrier spacecraft, will be the same as a Comet Kopff Sample Return Mission, except the carrier will be configured for an asteroid. Figure 18 shows the scenario. Table 6 summarizes the OTV/launch weight breakdown. More details are found in Table 11. Sampler details are found in reference 8 and MMII Carrier details in reference 9.

5.5.2 Spacecraft Mass Estimates

The spacecraft is similar to the Kopff sample return spacecraft except that the Mariner Mark II is configured for asteroid rendezvous instead of comet rendezvous. Table 17 is the spacecraft weight summary.

- Earth Return Systems are the same as Comet Earth Return System described previously and in Reference 17.

- Rendezvous/Landing Systems again are the same as the Comet missions. (Reference 8)

- Orbiter/Earth Departure System is the Mariner Mark II spacecraft configured for main belt asteroid observation as described in reference 9. This system is also the Earth Return Vehicle.

5.5.3 Delta V's

Ceres trajectory information was provided by Science Applications, Inc. (SAI). A study of outbound trajectories was available off the shelf, but the return trajectory had to be run. Ceres outbound ballistic trajectories with no Mars gravity assist typically required 5 to 7 km/sec delta V's to rendezvous with Ceres as well as initial C_3's of 40 to 164. The best no-Mars-assist trajectory required a total delta V of 10 km/sec. These high delta V requirements, along with a sample return, produced unreasonably large vehicles, so the double-Mars-gravity-assist trajectory which has a much lower total outbound delta V requirement was chosen. Return trajectories using single and dual Mars swingbys were searched but the best trajectory found was only around 200 m/sec better than the optimum direct return, at the expense of 700 days added trip time. The departure date for a Mars assist return for the given outbound leg is in July 2000, meaning a 1.2 year stay time. We therefore chose a direct return. Mars gravity assist trajectories exist for Ceres return legs, but not for our given outbound leg (ref. 10). More analysis might uncover a mission with practical outbound and return Mars gravity assist trajectories.

Earth orbit insertion will use aerocapture with a circularization burn and Space Station or Shuttle rendezvous. An OTV or OMV would bring the sample to the Space Station. Return launch date would be adjusted to insert the sample into the Space Station plane.

5.5.4 Space Station Impacts

This mission requires a two stage stack and is very similar to the Kopff mission in terms of its' impacts on the Space Station. Table 7 summarizes the impacts. As with the other two sample return missions, the two OTV's must be retrieved, refurbished, stacked, integrated, checked out, fueled, and launched. The aerobrake must be removed from the second stage OTV, which will not return. Sections 6.2, 6.3, and 6.5 discuss these operations in more detail.

The returned sample will be retrieved to a Quarantine Module as discussed in the previous missions. Section 6.4 discusses the Quarantine Module.

Table 17, Ceres Sample Return Weight Statement

Description	Item (kg)	Totals (kg)	
EARTH RETURN SYSTEM			
EARTH ORBIT CAPSULE			
SAMPLE CANISTER ASSEMBLY	60.0		
INCLUDES 10 KG SAMPLE			
AEROBRAKE SHIELD	28.0		
TOTAL		88.0	
CONTINGENCY	4.0		
TOTAL (DRY)		92.0	
PROPULSION:			
STRUCTURE	1.0		
PROPELLANT	9.2		230 Isp
TOTAL EARTH ORBIT CAPSULE		102.2	
RENDEZVOUS/LANDING SYSTEM			
DRILLING SAMPLER			
SCIENCE	0.0		
COMMAND AND DATA HANDLING	1.5		
TELECOMMUNICATION	1.2		
AACS	1.6		
REACTION CONTROL SYSTEM	2.4		
POWER/PYRO	3.8		
STRUCTURE	13.0		
THERMAL CONTROL	2.5		
CABLING	0.5		
DEVICES	5.8		
SUBTOTAL		32.3	
NITROGEN PROPELLANT	0.9		
CONTINGENCY (30%)	9.7		
TOTAL SAMPLER		42.9	

Table 17, Ceres Sample Return Weight Statement
(Continued)

Description	Item (kg)	Totals (kg)
DRILLING SAMPLER/LANDER		
SCIENCE	14.0	
COMMAND AND DATA HANDLING	16.0	
TELECOMMUNICATION	11.2	
AACS	0.0	
REACTION CONTROL SYSTEM	0.0	
POWER/PYRO	30.0	
STRUCTURE	42.5	
THERMAL CONTROL	9.6	
CABLING	5.0	
DEVICES	10.5	
SUBTOTAL		138.8
CONTINGENCY (15%)	20.8	
DRILL/RETURN VEHICLE	29.1	
TOTAL SAMPLER/LANDER		188.7
ORBITER/EARTH DEPARTURE SYSTEM		
MARINER MARK II SPACECRAFT (MMII)------------MBAR MISSION		
SCIENCE EQUIPMENT SUBSYSTEM		
SSI NA CAMERA+ELECTRONICS	21.40	
INFRARED REFLECTANCE SPECTRAL MAPPER	18.00	
X-RAY SPECTROMETER	14.00	
GAMMA RAY SPECTROMETER	14.00	
RTG SHIELD	19.00	
ACTIVE SHIELD	10.00	
MAGNETOMETER	6.00	
CALIBRATION COIL	0.45	
SCIENCE CALIBRATION TARGET	2.10	
SCIENCE SUBTOTAL		105.0

Table 17, Ceres Sample Return Weight Statement
(Continued)

Description	Item (kg)	Totals (kg)	
ENGINEERING SUBSYSTEMS			
STRUCTURE SUBSYSTEM	277.9		
RADIO FREQUENCY SUBSYSTEM	24.5		
POWER/PYRO SUBSYSTEM	111.8		
COMMAND+DATA HANDLING SUBSYSTEM	23.8		
ATTITUDE+ARTICULATION CONTROL	82.5		
CABLING	51.0		
THERMAL CONTROL SUBSYSTEM	69.9		
DEVICES SUBSYSTEM	36.6		
DATA STORAGE	8.9		
ENGINEERING SUBTOTAL		686.9	
PROBE			
NOT APPLICABLE			
VEHICLE SUBTOTAL		791.9	
CONTINGENCY	144.3		
TOTAL MMII (DRY)		936.2	
PROPULSION:			
STRUCTURE	4087.7		
RCS PROPELLANT	50.0		
DELTA V PROPELLANT	38785.84		310 Isp
TOTAL MMII (WET)		43859.7	
TOTAL INJECTED WEIGHT		44193.5	
ADAPTERS/MISCELLANEOUS EQUIPMENT			
LAUNCH VEHICLE ADAPTER	98.3 MBAR MISSION		
TOTAL OTV SEPARATION WEIGHT		44291.8	

5.6 Mercury Orbiter

5.6.1 General Description

The Mercury Orbiter mission (June 1994 launch) is a follow-on mission to the Mariner 10 flybys in 1974. An orbiting spacecraft allows close study of Mercury's topology, morphology, mineralogy, and magnetic field and its interaction with the solar wind. A detailed surface map can also be produced.

No references were located providing specific scientific objectives for a Mercury Orbiter mission.

Figure 19 shows the mission scenario. The mission can be flown with one OTV which returns.

5.6.2 Spacecraft Mass Estimates

The weight statement for the Mercury Orbiter is contained in Table 18. Again the masses are divided into systems. There is no Earth Return or Rendezvous/Landing System for this mission. The Orbiter/Earth Departure System is a Mariner Mark II spacecraft. Since there are no detailed scientific objectives, no specific instrumentation has been selected. The weight summary includes all of the instrumentation shown in reference 9.

5.6.3 Delta V's

The Delta V's used for the Mercury Orbiter mission come from reference 6. Window data from reference 6 allows us to select a worst case. The worst case chosen assumes launch at the worst possible station nodal location, but at the optimal launch date. Table 8 shows the nominal and worst case delta V's.

5.6.4 Space Station Impacts

The only impact of this mission on the Space Station is the effort (shown in Table 7) required to refurbish, integrate, checkout, fuel, launch, and retrieve one OTV. This makes the Mercury Orbiter mission virtually the same as any Geosynchronous OTV mission. Sections 6.2, 6.3, and 6.5 discuss these operations in more detail.

PRECEDING PAGE BLANK NOT FILMED

MERCURY ORBITER SCENARIO

1. STACK DEPARTS SPACE STATION
2. TRANS-MERCURY INJECTION
3. OTV RETURNS TO SPACE STATION
4. TRANS-MERCURY VOYAGE
5. MERCURY ORBIT INSERTION
6. DATA COLLECTION

FIGURE 19
LEGEND

Mercury Orbiter Scenario

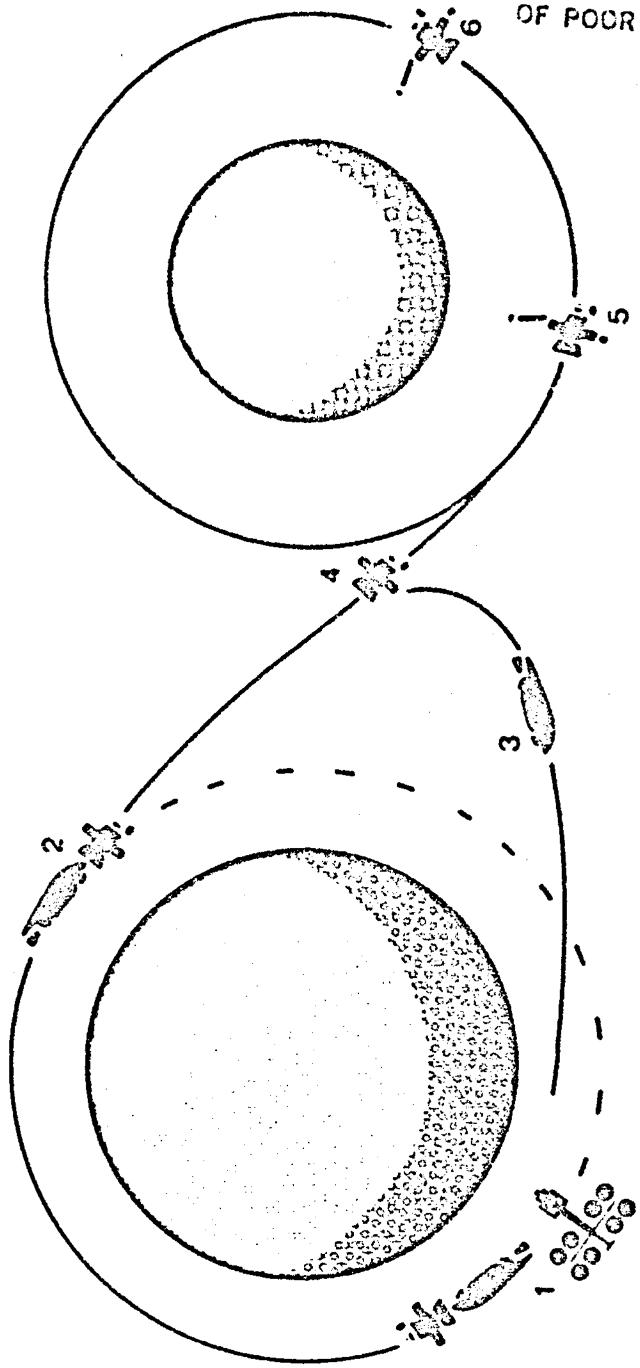


Figure 19

Table 18, Mercury Orbiter Weight Statement

Description	Item (kg)	Totals (kg)
EARTH RETURN SYSTEM		
NOT APPLICABLE		
RENDEZVOUS/LANDING SYSTEM		
MARINER MARK II SPACECRAFT (MMII)		
SCIENCE EQUIPMENT SUBSYSTEM		
SSI NA CAMERA+ELECTRONICS	21.40	
SSI WA CAMERA (W/O ELECT)	9.60	
IMAGING VISUAL AND IR SPECTROMETER	12.00	
INFRARED REFLECTANCE SPECTRAL MAPPER	18.00	
THERMAL IR SPECTRAL RADIOMETER	8.00	
X-RAY SPECTROMETER	14.00	
GAMMA RAY SPECTROMETER	14.00	
RTG SHIELD	19.00	
ACTIVE SHIELD	10.00	
GAMMA RAY PENETRATOR	19.90	
GRS ANTENNA/RECEIVER/ SUPPORT	6.00	
NEUTRAL MASS SPECTROMETER	13.00	
ION MASS SPECTROMETER	9.00	
DUST COUNTER	5.10	
DUST ANALYZER, PARTICLE	12.00	
DUST ANALYZER, BULK	11.00	
DUST DETECTOR	5.00	
ENERGETIC PARTICLE DETECTOR	9.00	
MAGNETOMETER	6.00	
MAGNETOMETER	2.50	
CALIBRATION COIL	0.45	
PLASMA WAVE SPECTROMETER	4.70	
PLASMA ANALYZER	10.00	
PLASMA WAVE ANALYZER	6.00	
PHOTOMETER	5.00	
RADAR MAPPER	28.00	
RADIO SCIENCE	5.00	
SCIENCE CALIBRATION TARGET	2.10	

Table 18, Mercury Orbiter Weight Statement
(Continued)

Description	Item (kg)	Totals (kg)	
SCIENCE CALIBRATION TARGET	3.00		
SCIENCE CALIBRATION TARGET	3.20		
RADIO RELAY HARDWARE RECEIVER	20.08		
RADIO RELAY HARDWARE ANTENNA	3.06		
SCIENCE SUBTOTAL		315.1	
ENGINEERING SUBSYSTEMS			
STRUCTURE SUBSYSTEM	207.7	SOTP MISSION	
RADIO FREQUENCY SUBSYSTEM	20.0	SOTP MISSION	
POWER/PYRO SUBSYSTEM	102.6	CRAF MISSION	
COMMAND+DATA HANDLING SUBSYSTEM	23.8	GENERAL	
ATTITUDE+ARTICULATION CONTROL	85.4	CRAF MISSION (WC)	
CABLING	52.0	SOTP MISSION (WC)	
THERMAL CONTROL SUBSYSTEM	76.5	UFUP MISSION (WC)	
DEVICES SUBSYSTEM	36.6	MRAF MISSION (WC)	
DATA STORAGE	8.9	GENERAL	
ENGINEERING SUBTOTAL		613.5	
PROBE			
NOT APPLICABLE			
VEHICLE SUBTOTAL		928.6	
CONTINGENCY	150.0	(ASSUMED)	
TOTAL MMII (DRY)		1078.6	
PROPULSION:			
STRUCTURE	585.1		
RCS PROPELLANT	50.0		
DELTA V PROPELLANT	3915.6		298 Isp
TOTAL MMII (WET)		5629.2	
ORBITER/EARTH DEPARTURE SYSTEM			
SEE RENDEZVOUS/LANDING SYSTEM ABOVE			

Table 18, Mercury Orbiter Weight Statement
(Continued)

Description	Item (kg)	Totals (kg)
ADAPTERS/MISCELLANEOUS EQUIPMENT		
LAUNCH VEHICLE ADAPTER	150.0 (ASSUMED)	
TOTAL OTV SEPARATION WEIGHT		5779.244

5.7 Saturn Orbiter/Multiple Titan Probes

5.7.1 General Description

The Saturn Orbiter/Multiple Titan Probes mission (April 1993 launch) will provide detailed information on both Satur and Titan. The Saturn Orbiter portion of this mission wil help us better understand this assembly of satellites, fiel phenomena, rings, and giant planet.

The specific objectives include:

- o Determine three-dimensional ring structure.
- o Characterize satellite compositions.
- o Measure three-dimensional magnetosphere structure.
- o Study the behavior of Saturn's atmosphere at the cloud level.
- o Detailed studies of some of the satellites including regional mapping of Titan's surface.

The Titan probes will be used to study the atmosphere o Titan at various locations. This atmosphere is believed t resemble the pre-life Earth atmosphere.

The specific objectives of each probe include:

- o Determine the structure and chemical compositior of the atmosphere.
- o Study the exchange and deposition of energy with the atmosphere.
- o Characterize the surface morphology on a local basis.

References 9 and 11 contain details of the science objectives Figure 20 shows the mission scenario and Table 6 shows the OTV/launc weight breakdown.

5.7.2 Spacecraft Mass Estimates

Again, a Mariner Mark II spacecraft will be used. Referenc 9 shows the configuration of the spacecraft and reference 1 provides the details of the first probe. The additional probe will be the same except that they will have the propulsion require for deorbit. Table 19 contains the spacecraft weight breakdown The Earth Return System is not used for this mission. The Rendez vous/Landing System includes the probes, and the Orbiter/Eart Departure System is the MMII spacecraft.

SATURN ORBITER / TITAN PROBES SCENARIO

1. STACK DEPARTS SPACE STATION
2. TRANS-SATURN INJECTION AND OTV SEPARATION
3. TRANS-SATURN TRANSFER VOYAGE
4. RELEASE OF FIRST PROBE FOR DIRECT ENTRY
5. SATURN ORBIT INSERTION AND ENTRY OF FIRST TITAN PROBE
6. ORBIT SATURN
7. RELEASE SUBSEQUENT TITAN PROBE

FIGURE 26
LEGEND

Saturn Orbiter / Titan Probes Scenario

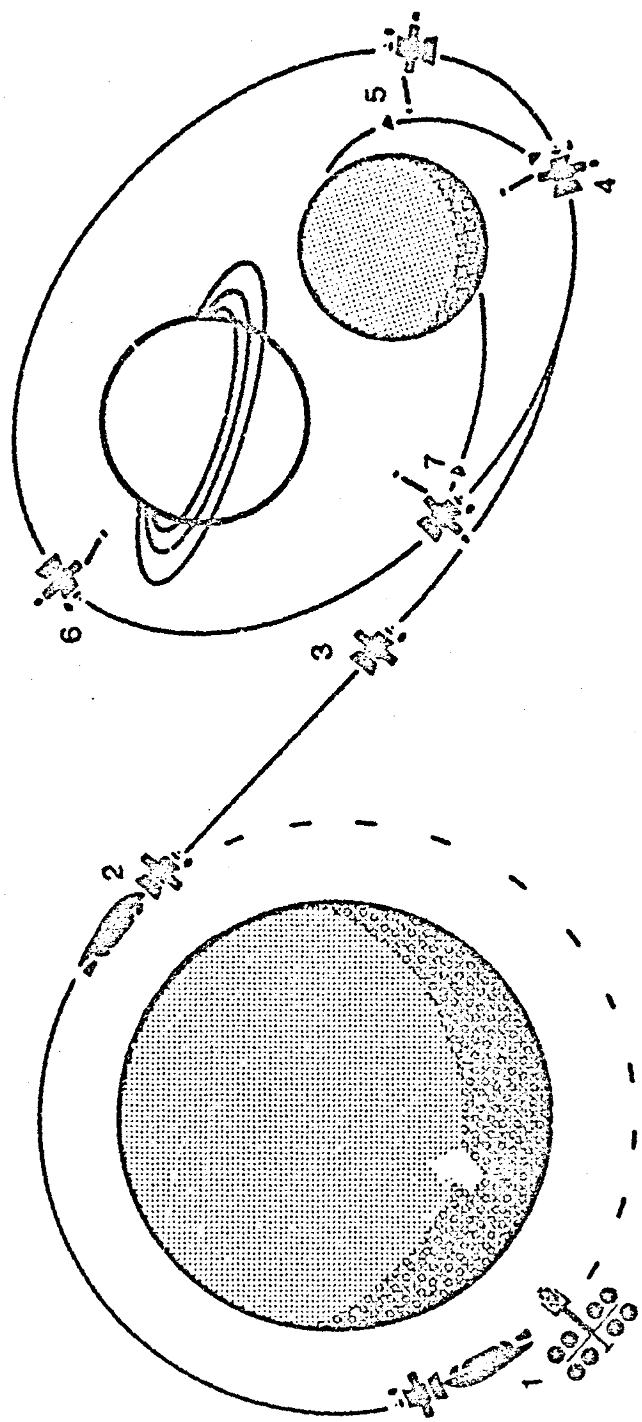


Figure 20

5.7.3 Delta V's

Titan Probe/Saturn Orbiter trajectory information was supplied by SAI. No window data was available. Reference 12 contains other potential mission dates.

The Saturn Orbiter was placed in a 1.51×10^5 by 24.4×10^5 km orbit around Saturn with a periapsis burn. More study of this arrival is required to insure the timing will work out. 1.51×10^5 km is 2.5 x the radius of Saturn. 24.4×10^5 km is the orbital altitude of Titan. Insertions into circular orbits at these two altitudes were also considered but required much higher delta V's.

5.7.4 Space Station Impacts

The aerobrake of the single, one-way OTV boosting this mission must be removed. The mission can also be flown with the aerobrake on with some payload penalty. The OTV must also be refurbished, stacked, integrated with the payload, checked out, fueled, and launched. More discussion of these impacts is found in sections 6.2, 6.3, and 6.5. Since the OTV does not return, another must be launched and assembled. This last operation should not be charged entirely to this mission however, since the reusable OTV's can only be used a limited number of times, and will have to be disposed of at the end of their lifetime.

Table 19, Saturn Orbiter/Multiple Titan Probes Weight Statement

Description	Item (kg)	Totals (kg)
EARTH RETURN SYSTEM		
NO EARTH RETURN		
RENDEZVOUS/LANDING SYSTEM		
PRE-INSERTION PROBE (1)		
SCIENCE EQUIPMENT SUBSYSTEM:		
ATMOSPHERE STRUCTURE INST	3.80	
NEUTRAL MASS SPECTROMETER	12.30	
GAS CHROMATOGRAPH	3.70	
NEPHELOMETER	4.40	
NET FLUX RADIOMETER / DESCENT IMAGER	3.00	
SUBTOTAL		27.2
COMMUNICATION	7.20	
DATA HANDLING	14.20	
POWER	8.40	
STRUCTURE	16.70	
HARNESS	8.90	
LARGE PARACHUTE	8.10	
JETTISON HARDWARE	7.70	
SMALL PARACHUTE	5.00	
SUBTOTAL- MISCELLANEOUS SUBSYSTEMS		76.2
DECELERATION MODULE:		
DECELERATOR	26.0	
ABLATION NOSECAP	6.9	
SUBTOTAL		32.9
TOTAL		136.3
POST-INSERTION PROBES (2 THROUGH 5)		
SCIENCE EQUIPMENT SUBSYSTEM:		
ATMOSPHERE STRUCTURE INST	3.80	
NEUTRAL MASS SPECTROMETER	12.30	
GAS CHROMATOGRAPH	3.70	
NEPHELOMETER	4.40	
NET FLUX RADIOMETER / DESCENT IMAGER	3.00	

Table 19, Saturn Orbiter/Multiple Titan Probes Weight Statement
(Continued)

Description	Item (kg)	Totals (kg)
SUBTOTAL		27.2
COMMUNICATION	7.20	
DATA HANDLING	14.20	
POWER	8.40	
STRUCTURE	16.70	
HARNESS	8.90	
LARGE PARACHUTE	8.10	
JETTISON HARDWARE	7.70	
SMALL PARACHUTE	5.00	
SUBTOTAL- MISCELLANEOUS SUBSYSTEMS		76.2
DECELERATION MODULE:		
DECELERATOR	26.0	
ABLATION NOSECAP	6.9	
SUBTOTAL		32.9
DEORBIT PROPULSION SUBTOTAL (BUDGET 100% OF INERT WEIGHT)		136.3
TOTAL		272.6
TOTAL OF 4 POST-INSERTION PROBES		1090.4
ORBITER/EARTH DEPARTURE SYSTEM		
MARINER MARK II		
SCIENCE EQUIPMENT SUBSYSTEMS		
SSI NA CAMERA+ELECTRONICS	21.40	
THERMAL IR SPECTRAL RADIOMETER	8.00	
DUST DETECTOR	5.00	
ENERGETIC PARTICLE DETECTOR	9.00	
MAGNETOMETER	6.00	
CALIBRATION COIL	0.45	
PLASMA ANALYZER	10.00	
PLASMA WAVE ANALYZER	6.00	
PHOTOMETER	5.00	
RADAR MAPPER	28.00	
RADIO SCIENCE	5.00	

Table 19, Saturn Orbiter/Multiple Titan Probes Weight Statement
(Continued)

Description	Item (kg)	Totals (kg)	
SCIENCE CALIBRATION TARGET	3.00		
RADIO RELAY HARDWARE RECEIVER	20.08		
SCIENCE SUBTOTAL		126.9	
ENGINEERING SUBSYSTEMS			
STRUCTURE SUBSYSTEM	207.7		
RADIO FREQUENCY SUBSYSTEM	20.0		
POWER/PYRO SUBSYSTEM	172.3		
COMMAND+DATA HANDLING SUBSYSTEM	23.8		
ATTITUDE+ARTICULATION CONTROL	80.8		
CABLING	52.0		
THERMAL CONTROL SUBSYSTEM	61.0		
DEVICES SUBSYSTEM	25.8		
DATA STORAGE	8.9		
ENGINEERING SUBTOTAL		652.3	
VEHICLE SUBTOTAL		779.2	
CONTINGENCY	162.2		
TOTAL MMII (DRY)		941.4	
PROPULSION:			
STRUCTURE	417.8		
RCS PROPELLANT	50.0		
DELTA V PROPELLANT	3708.3		298 Isp
TOTAL MMII (WET)		5117.6	
TOTAL INJECTED WEIGHT		6344.3	
ADAPTERS/MISCELLANEOUS EQUIPMENT			
LAUNCH VEHICLE ADAPTER	147.3		
TOTAL OTV SEPARATION WEIGHT		6491.6	

5.8 Sensitivity Studies

The sensitivity of the Earth launch weight for each of the five best case planetary missions to Isp, inert weight, and propellant capacity was examined. Earth launch costs are the largest number in many overall systems of this nature and their relationship to other parameters in the upper stages of the system is a good first-cut indication of the dollar value of development work.

The baseline Isp used for the OTV LO2/H2 engines in this study was a conservative 455 seconds (from Ref. 2). Raising this Isp to 480 seconds reduced the total average Earth launch requirement for all five missions by 5.4%. The total average propellant load for the five missions that could be launched by a ULV drops by 9.4%. The missions with the highest C_3's, the Kopff and Titan missions, were affected the most, with propellant load reductions of 11.3 and 10.5 % respectively. These propellant reductions do not significantly affect the overall scenario or its impact on the Space Station. The number of stages, their approximate size, and the operations that must be done remain the same.

The total propellant required for all five missions was 221.1 metric tons. Given a ULV capable of launching 100 metric tons of propellant and costing 133 million dollars per launch, the cost to launch 221.1 metric tons of propellant is 294 million dollars. An increase in OTV Isp to 480 seconds would reduce this 9.4 % for these five missions, saving 27.6 million dollars, which could be used for engine development. The same calculations using only the Shuttle for transport result in a 75 million dollar savings. The much more numerous OTV missions to GEO and the Moon will produce other savings from Isp increase, which will be the dominant numbers.

An "Inert Weight = A + B*(Propellant Weight)" equation from reference 2 was used to determine inert weight for the OTV's. The A term includes the weight of the aerobrake, engines, and other non-propellant-dependent structure. The B term accounts for the tanks and other propellant-dependent structure. To check the sensitivity of Earth-launch weight to OTV inert weight, the A number was reduced by 1/3 from 3,731 kg's to 2,487 kg's. The average total-Earth-launch weight for all five missions went down 7.1 %. In terms of cost benefits this reduction is similar to the previously discussed Isp reduction. The launch weight reductions for the individual missions were MSR - 7.6 %, Kopff - 9.6 %, Ceres - 2.1 %, Mercury - 10.4 %, and Titan - 5.7 %. As with the Isp change, this inert weight reduction did not change the Space Station impacts.

The baseline OTV propellant capacity was 40 metric tons when this sensitivity study was done. Later in the study the baseline was changed to 42 metric tons as the vehicles were refined. All the tables and figures now reflect this change to 42 metric tons, but the sensitivity numbers do not. Since the change from 40 to 42 metric tons makes no significant difference in any of the conclusions drawn in this section it was not necessary to rerun the numbers.

To determine the effect of a significant change in propellant capacity, the planetary mission numbers were rerun with a 30 metric ton propellant capacity OTV. This change made a significant difference. The Kopff and Ceres Sample Return Missions both required three stages instead of two, and the Titan Probes/-Saturn Orbiter Mission required two stages instead of one. Since the increased complexity of this arrangement was perceived as undesirable, the stack design was not pursued. Approximate total Earth launch weight reductions (payload and propellant only) were, however, calculated in the range of 3%.

5.9 Planetary Missions from Lunar Orbit

It is a widely held belief that there are substantial performance benefits associated with departing from the Moon using lunar produced propellant to perform planetary exploration due to the shallow lunar gravity well. This is not necessarily true for the case where the fuel (H_2) must be brought from Earth. Consider the following:

1) The most efficient regular departure mode for transfer from lunar orbit to an interplanetary C_3 is via low Earth orbit flyby with a minimum delta V lunar to Earth transfer and a burn from a parabolic to hyperbolic Earth orbit at perigee. This yields a total departure delta V from the Moon a constant 2 km/sec below that from low circular Earth orbit (where the transfer is from the circle onto the same hyperbola).

2) To depart from lunar orbit, however, one must first get there and that takes a total of 4 km/sec. In fact, for a cargo originating at Earth, a C_3 of 30 km^2/sec^2 can be reached for the same delta V as going to lunar orbit.

3) If lunar oxygen is available for propellant with terrestrial hydrogen fuel at a 7/1 mixture ratio, it takes approximately 3/4 of a kg of propellant in low Earth orbit to provide the fuel (hydrogen) portion of one kg of propellant in lunar orbit. This is composed of the hydrogen used in launching the lunar O_2, the H_2 to be burned with the lunar O_2 to depart from lunar orbit, and the LO_2/LH_2 propellant to transport that hydrogen to the Moon.

4) Because more total delta V is needed if interplanetary departure of an Earth-supplied payload is made via the Moon, and because lunar derived propellant expended in lunar orbit requires 3/4ths as much propellant to be expended in low Earth orbit, all of the unmanned missions examined in this study required more total propellant expended in low Earth orbit if lunar departure was used than for direct departure from LEO.

   This proves true for any Earth supplied cargo until C_3 is at least above 80 $(km/sec)^2$. There is a theoretical breakeven point for "rubber" stages at a C_3 of between 80 and 100 where the mass in LEO becomes less for lunar departure. This C_3 range is above the energy of the missions of this study.

5) This does not discount the possibility of supplying

lunar O_2 to low Earth orbit. This option may be attractive to reduce the mass required to be launched from the Earth's surface.

6) Only if a significant percentage of the interplanetary cargo itself is lunar-produced does any advantage appear. This now appears to be the case only for spacecraft utilizing LO_2/LH_2 propellant for post insertion manuevers.

An example of this is the case of a 150 metric ton manned Mars mission module proposed by Gordon Woodcock as an element in one proposed Mars mission scenario. If that weight included sufficient cryogenics for Mars orbit insertion and trans-Earth injection, then 3/4 of the mass might be propellant with 65%, or 96 metric tons being oxygen. If the vehicle departed from Earth, a total of 360 metric tons (including payload) are needed in low Earth orbit.

If the same vehicle departs from lunar orbit via Earth flyby trajectory and uses lunar produced O_2 for the 96 tons as well as for interplanetary injection, then only 276 metric tons are needed in Earth orbit including the H_2 shipped to the Moon for the lunar launcher, etc. The savings is 90 metric tons in Earth orbit, or slightly over 25%. To achieve this, a total of 230 metric tons of lunar O_2 must be produced and used and 5 sorties of the reusable lunar lander flown to deliver the 140 tons of lunar oxygen to lunar orbit.

Whether it is possible to produce 230 tons of O_2 on the Moon and fly 5 sorties of the lunar launch vehicle less expensively than producing 90 tons of O_2 on Earth and launching one unmanned launch vehicle tanker is an unanswered question.

There may be some cost advantage to lunar operations in this instance but it is certainly not overwhelming.

If a suitable lunar fuel can be developed to go with the lunar O_2, then this relationship may change sharply. A lower Isp might be acceptable if all of the propellant could be produced from lunar resources, but this possibility requires further study.

If a source of lunar hydrogen, such as the postulated lunar pole "cold traps" can be located, the need to transport hydrogen from Earth to support lunar and planetary mission operations can be eliminated. In this case, the use of lunar-produced O_2/H_2 propellants becomes a very attractive option.

6.0 Discussion of Individual Impacts

The major impacts of lunar and planetary missions on the Space Station can be described as relatively discrete elements and effects. Although many of these impacts have been described previously, several require further discussion, specifically: the OTV hangar and maintenance facility, the propellant storage and transfer facility, the OTV mating and stacking gantry, the Quarantine Module, and OTV maintenance and refurbishment operations. The following paragraphs describe each of these.

The OTV infrastructure in its entirety should not be considered an impact on the Station. The space based, reusable OTV system may well be put in place first to service geosynchronous orbit missions. The lunar base may strongly influence the way the system is built, but will hopefully not have to pay for it all or even the majority of it.

6.1 OTV Hangars

An OTV hangar is shown in Figure 22. The main truss, shelter, and shelter structure are clearly visible. A OMM is seen in the lower left portion of the hangar and the Remote Workstation is in use performing a visual inspection. The OTV Hangar is perhaps the most visible of all the impacts on the Space Station. This facility is assumed to be located on the Space Station keel just below the transverse boom consistent with the JSC "reference" Growth Space Station. It is attached to the starboard side of the keel to allow full mobility of the Space Station Mobile RMS. The hangar itself is really not an impact of lunar and planetary missions, but its ability to accommodate two OTV's is required by these missions. For that reason the hangar is described here in its entirety.

The hangar has several major features including the main truss, the shelter, spares storage capabilities, and maintenance control station capabilities.

The main truss structure is connected to the Space Station keel and is constructed of the same material and with the same basic configuration as the Space Station truss structure. The hangar main truss is attached to the keel in two locations, spaced approximately 15 meters, the length of one OTV, apart. From the attach points, the trusses extend away from the keel approximately 15 meters or sufficient distance to accommodate two OTV's. The ends of the two trusses are connected by another truss making the hangar main truss structure "U" shaped.

ORIGINAL PAGE IS
OF POOR QUALITY

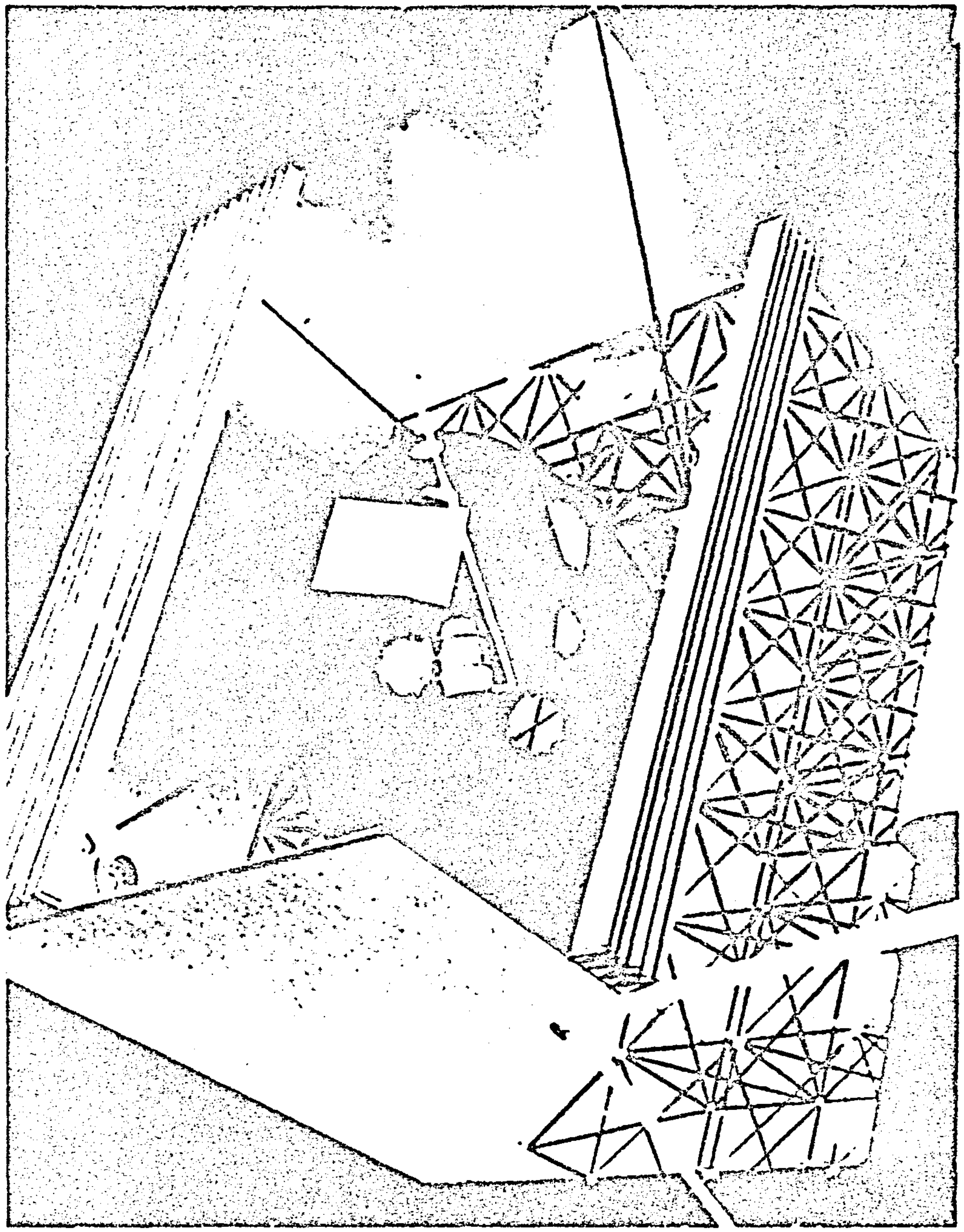


Figure 22 AOTV Hangar

The purpose of the hangar main truss is for berthing during long-term storage for turnaround and maintenance. The inside faces of the truss are fitted with two sets of OTV berthing interface and attachment devices. These interface devices provide mechanical, electrical, and data connections between the OTV's and the Space Station. The sides of the main truss provide the same capabilities for the Hangar Mobile RMS as do the front and back of the Space Station keel for the Space Station Mobile RMS. Finally, the main truss will provide some support for the hangar shelter (figure 22).

The shelter is required to provide the OTV hangar with passive thermal control and some degree of micrometeoroid and orbital debris protection. It extends 15 meters from the keel, runs 18 meters along the keel, and is 17 meters wide. The shelter has an independent structural system with attach points to both the Space Station keel and the hangar main truss. Each side of the shelter is independently retractable for OTV berthing access and for removal with minimum environmental exposure to personnel and equipment within the hangar. Each side retracts in an accordion-like fashion and is driven by retraction/extension motors. The shelter structure is fitted with area lighting for maintenance activity and fittings for connection of spare parts.

Spare parts and some OTV fittings will be required during maintenance and refurbishment. The OTV Manned Modules (OMM's) are stored in the corners of the hangar where they do not interfere with operations. The OMM is the largest of the storage items. Other items requiring storage are Attitude Control System modules for replacement and refurbishment after each mission, avionics Orbital Replacement Units and spare OTV engines. These are all stored within the shelter for easy access and maintenance, and for protection from environmental conditions.

Hangar control, maintenance operations, and refurbishment operations can all be accomplished from several locations. First, these functions can be performed from any of the Habitation or Laboratory Module Control Stations. It is intended that normal turnaround operations for an OTV be accomplished from one of these locations. A pressurized Manned Remote Workstation is provided for extended capabilities and is designed for connection to the Hangar MRMS. All of the hangar functions can be controlled from this workstation, with the added advantage of line of sight work. This enables normal turnaround and both scheduled and unscheduled maintenance operations. Although, many operations can be accomplished from this workstation, EVA activities will be required in some cases.

Note that the hangar requires a dedicated RMS.

6.2 Propellant Storage and Transfer

The Space Station must be able to store and transfer large quantities of cryogenic propellants to support ambitious lunar and planetary missions. The lunar missions discussed in previous sections require a Propellant Storage and Transfer Facility. Our conceptual design for this facility consists of two Orbital Storage Modules (OSM's) and two Cryogenic Liquefaction and Transfer Units (CLTU's). The Orbital Storage Modules are brought to the Space Station full and are disposed of after use. On the other hand the CLTU's are permanently attached to the Space Station and are not discarded. The CLTU also serves as the attachment interface for the OSM.

The CLTU's can transfer propellants into and out of the OTV's. During propellant loading the CLTU's should be capable of a transfer rate of 5 metric tons per hour. This allows fueling of an 84 metric ton propellant stack, typical of a lunar sortie, in an 18 hour period. Following OTV berthing, after mission completion, the CLTU can off-load and liquify residual OTV propellants and return them to the Orbital Storage Modules. The CLTU can both pump and liquify. The liquifying system not only provides liquefaction for off-loaded, gaseous propellants but also cooling required to maintain the OSM at cryogenic temperatures. The CLTU liquefaction system provides this service only during periods of exposure to sunlight. A preliminary design has not been performed on the CLTU, however, several options are available for the liquefaction system. For example, a mechanical refrigeration system may be used. A mechanical refrigeration system would require 3.9 kw of electrical power for each CLTU. In addition, a corresponding load would be imposed on the Space Station heat rejection subsystem. Another option would be to use the hydride sorption refrigeration system currently under development at JPL. This system is likely to be more reliable as it requires no rotating equipment and in addition, only thermal energy is required to drive the compressor (Ref. 19).

The Orbital Storage Module is designed to be launched within an unmanned shuttle derived launch vehicle with the payload positioned vertically above the external tank. The OSM has the capacity to store 100 metric tons of usable liquid hydrogen and liquid oxygen propellants. It contains one 23 metric ton hydrogen tank and one 85 metric ton oxygen tank each covered by approximately 45 layers of MLI. For orbital injection the OSM is fitted with either a Trans-Stage Upper Stage or an upper stage using existing Shuttle OMS engines. The OSM inert mass is approximately 12.4 metric tons dry and is deorbited after use.

Figure 23 shows several tentative designs for this propellant storage module with the liquid hydrogen tanks forward of the oxygen tank. The modules indicated in Figure 17 have the oxygen tanks forward. As shown in Figure 17, these modules are attached to the Space Station keel on the starboard side just above the keel extension.

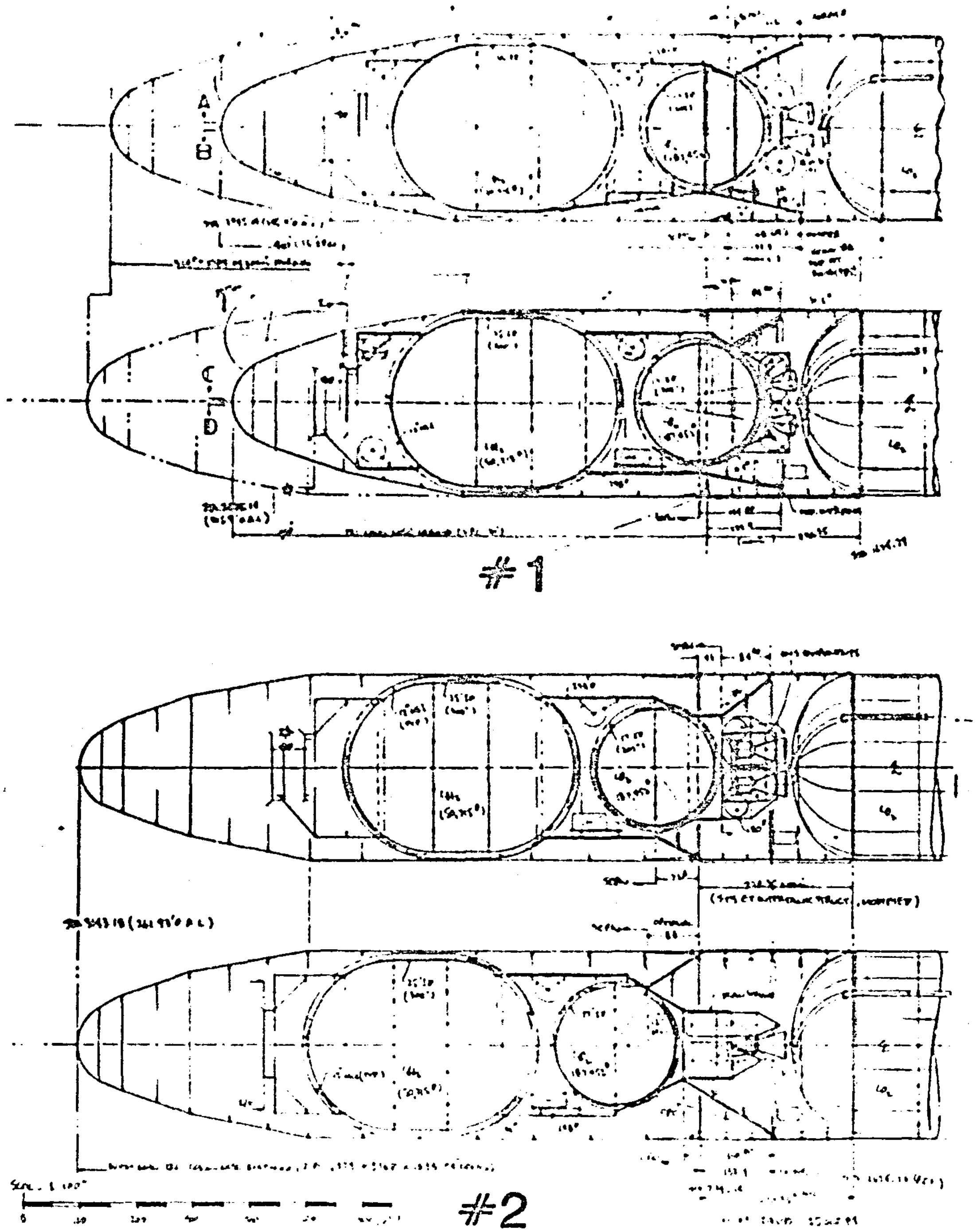


Figure 23 Orbital Storage Module

A flight experiment regarding on-orbit hydrogen storage and transfer is currently in preparation at Lewis Research Center. This experiment, scheduled for 1988, will transfer 100 lb. of liquid hydrogen. The results of this experiment are likely to be a strong influence on the methods of on-orbit cryogenic propellant storage and transfer.

6.3 Stacking Gantry

The OTV Stacking Gantry is a facility located on the lower keel just above the keel extension. This facility is used during normal flight preparation to mate payloads with OTV's and to mate OTV's when a two stage mission is in preparation.

Each gantry arm extends from the Space Station lower keel and attaches to the OTV at the front or back. The facility can handle two, two stage OTV stacks including the payloads. The two stacks will be held in parallel along the keel while being processed.

Propellant loading and off-loading is accomplished when the OTV is berthed at this facility.

In addition to processing, the Stacking Gantry can provide short-term OTV storage in the event the OTV hangar is fully occupied. For protection against the space environment, a cover may be deployed over the underside of the OTV.

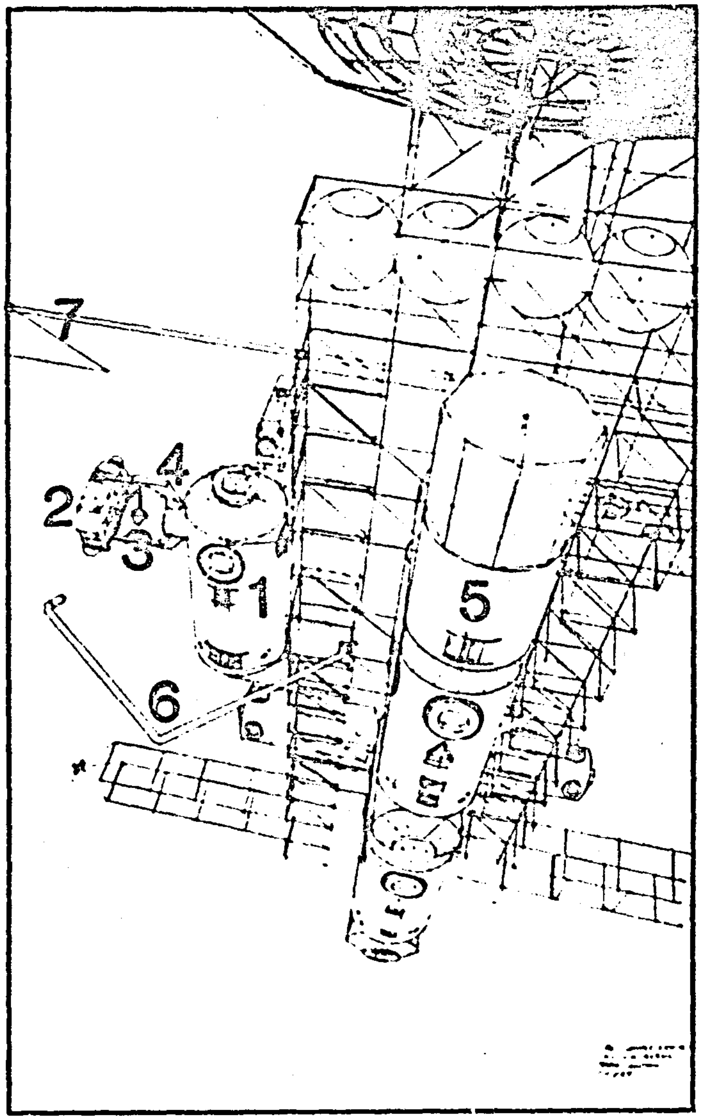
Figure 17 shows an OTV berthed in the Stacking Gantry and the Mars Sample Return mission spacecraft being mated to it.

6.4 Space Station Planetary Sample Quarantine Facility

Proposals for the quarantine of samples returned by unmanned probes from Mars and other bodies in the solar system range from direct entry into the Earth's atmosphere (no quarantine in space), which has some performance advantages, to a billion-dollar mini-space station quarantine facility entirely separate from any other space station. A middle ground option might use one module of the proposed NASA Space Station to serve as a quarantine facility for planetary samples in addition to other duties. This module would have its own life support system, but use Space Station power and thermal control. It would not be connected via any pressurized pathway to the rest of the station. In Figure 21 an OMV delivers a returned sample to this single module.

The selection of overall approach to the quarantine problem is directly influenced by the real probability of returning some sort of replicating organism. A careful assessment of this probability in light of recent data, and for the comets and asteroids as well as Mars and the Moon is required prior to making the final decision and is beyond the scope of this study. It now appears however, as though the probability of finding life in returned samples is low. Some risk, however, does exist and life that could exist in the temperature, pressure, and radiation extremes of the Martian surface or in the interior of a comet might be difficult to control. A degree of caution is therefore required. Reference 13 provides a preliminary design of a separate space station designed especially for sample quarantine that might be appropriate if the probability of finding life was thought to be significant. Figure 24 shows the whole facility and a weight statement. The power requirement of this configuration is estimated to be 25 to 35 kw (Ref. 13). Figure 25 shows the interior of the Laboratory Module for this design. Both figures were taken from reference 13.

A scaled down, simplified version of the laboratory module in reference 13, attached structurally, but not environmentally to the current NASA baseline Space Station, may be the most cost effective solution. This Quarantine Module would be more of a way station than a major laboratory, though emergency equipment to isolate the module and one or more crewman for long periods of time would be available should the improbable occur. Figure 21 shows a conceptual Quarantine Module and its' mounting and operation on the NASA baseline space station.



OMV Delivers Sample to Quarantine Module

1. Quarantine Module
2. OMV
3. Returned planetary sample
4. Airlock/OMV hard dock
5. Other modules of growth Space Station
6. Mobile RMS
7. Radiators

Figure 21
Legend

ORIGINAL PAGE IS
OF POOR QUALITY

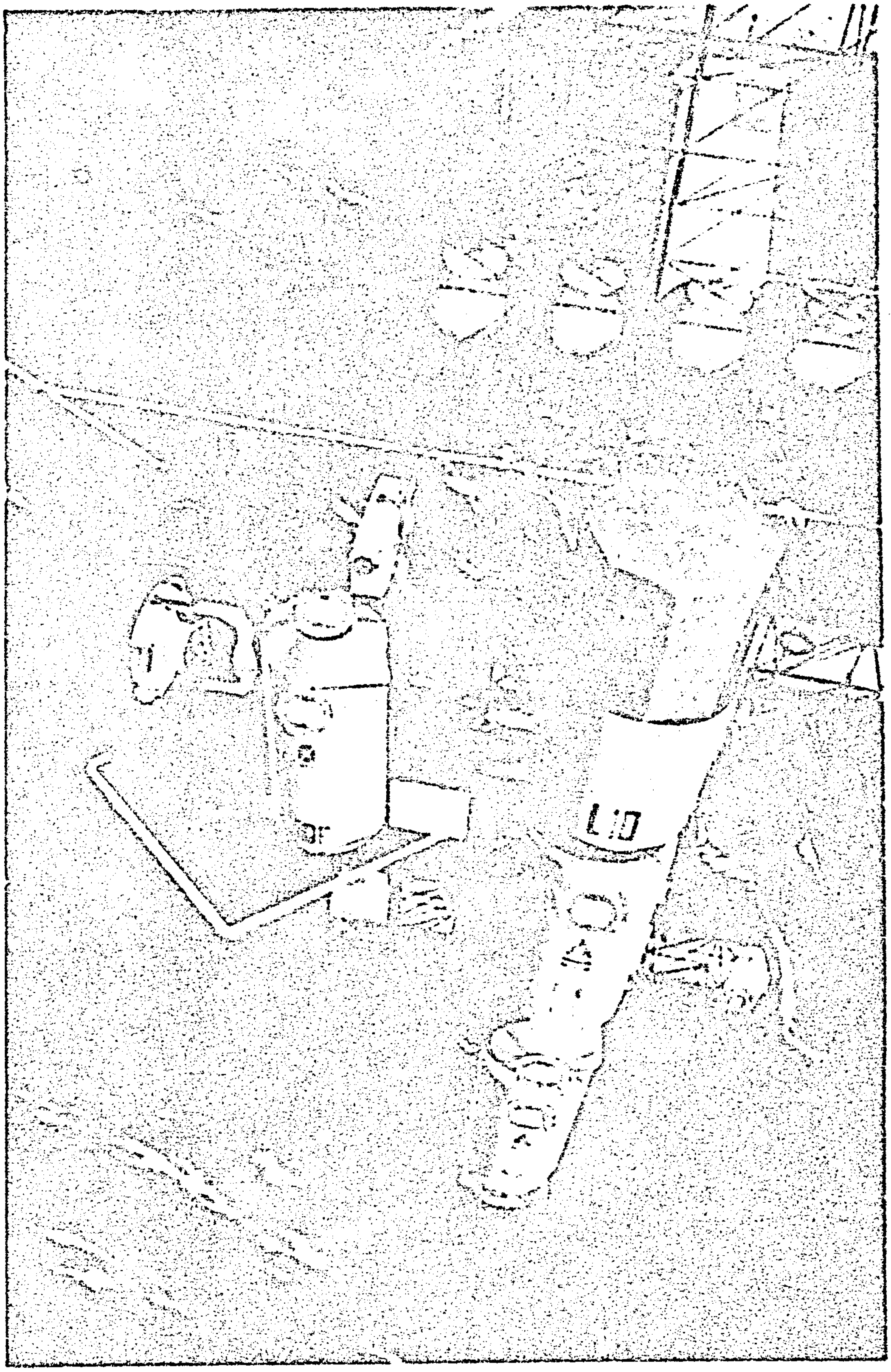
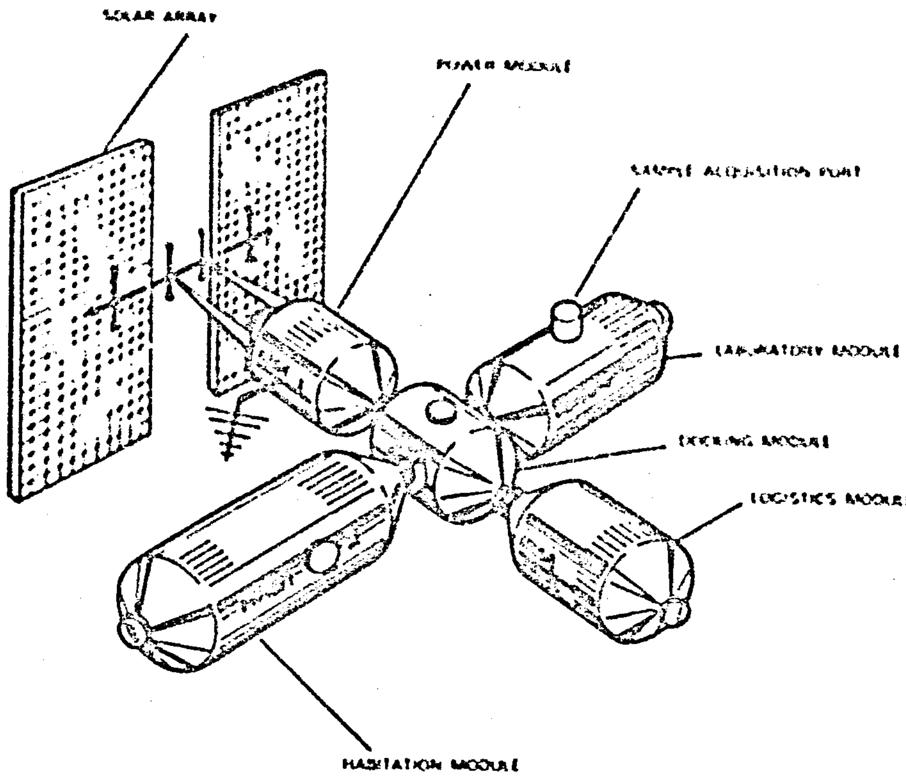


Figure 21



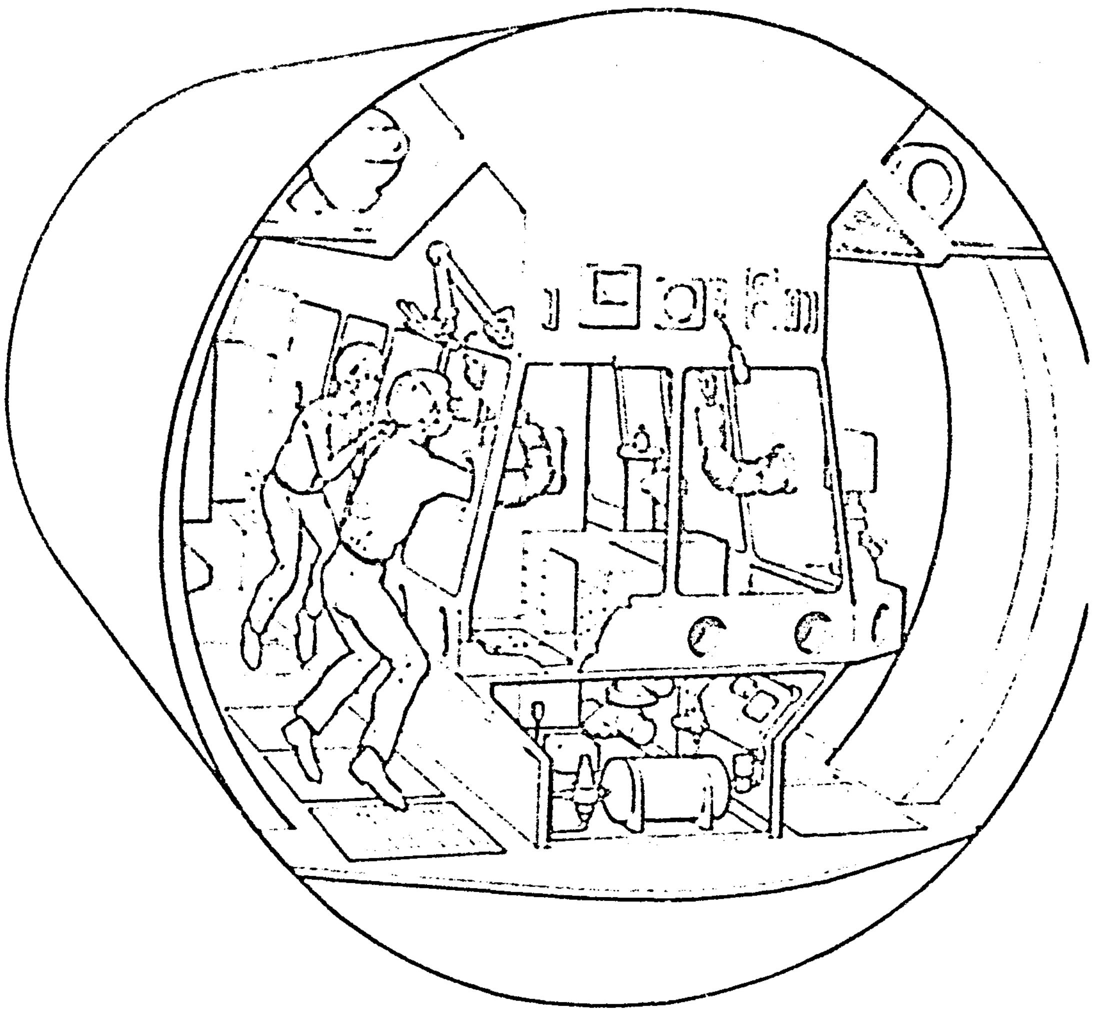
Orbiting Quarantine Facility
(from Ref. 13)

ESTIMATED MASS OF THE OQF COMPONENTS

Module	*Mass*
Laboratory	13 600 kg*
Habitation	13 600 kg
Power	13 600 kg
Docking	2300 kg
Logistics	4500 kg
Large Motor IUS (1st stage)	11 400 kg
Large Motor IUS (2nd stage)	11 400 kg
Small Motor IUS	3100 kg

*13 600 kg = 30 000 lb.

Figure 24



Interior of Laboratory Module

(from Ref. 13)

Figure 25

A standard, 11 meter (36 ft) long module, such as is currently envisioned for the Life Sciences Laboratory in recent NASA Space Station studies (ref. 18) is the best model available. The Life Sciences Lab, shown in figure 26 (taken from ref. 18), uses approximately 25 kw of electrical power, requires 30 kw of heat rejection, and has a volume of 3,704 cubic feet. As envisioned in reference 18, this module has an internal "safe haven" that will support two men for twenty-two days, isolated from the rest of the station. The final design of the Quarantine module would probably not require as much continuous power and heat rejection as the Life Sciences Lab, which has a sealed animal research area with its' own environmental control and life support system (ECLSS). If the final configuration includes just a large glove box, and an independent ECLSS capable of supporting two individuals for several months under emergency conditions, the power requirement might go down as low as 5 kw.

Individual radiators on each module are now planned, with a "thermal bus", using ammonia as the working fluid, interconnecting all the modules. Though isolation of environmental and life support functions may be required, the Quarantine module could probably still be linked to the other modules with the ammonia thermal bus, and the electrical power and data lines.

The Quarantine Module would be designed to accommodate automated docking of the OMV carrying the sample to an airlock attached to a glove box. Upon arrival of a sample, a biologist would use the glove box to remove a small sample that would then be examined quickly for any signs of life, or "sterilized" by some means and sent to Earth. The main sample would be sealed in a "super box", with the desired environmental control to await conclusions from the small sample. Given no signs of life or other dangers in the small sample, the main sample could then be shipped to Earth for further examination in a laboratory similar the Center for Disease Control (CDC) high-hazard containment facility. Another method for dealing with the sample would be to seal the entire sample in a "super box" upon arrival at the Quarantine Module and ship it to Earth in this secure container to be examined in a CDC type facility.

The "super box" would be a rugged container capable of withstanding a Shuttle crash without rupture. Thermal control for the sample would be required. A Mars sample might require maintenance of -40 degrees C. Reference 14 indicates passive thermal control (insulation) can be used to keep the Mars sample cold while in Earth orbit. A comet nucleus sample might be kept at a temperature as low as 100 degrees Kelvin (-173 degrees C).

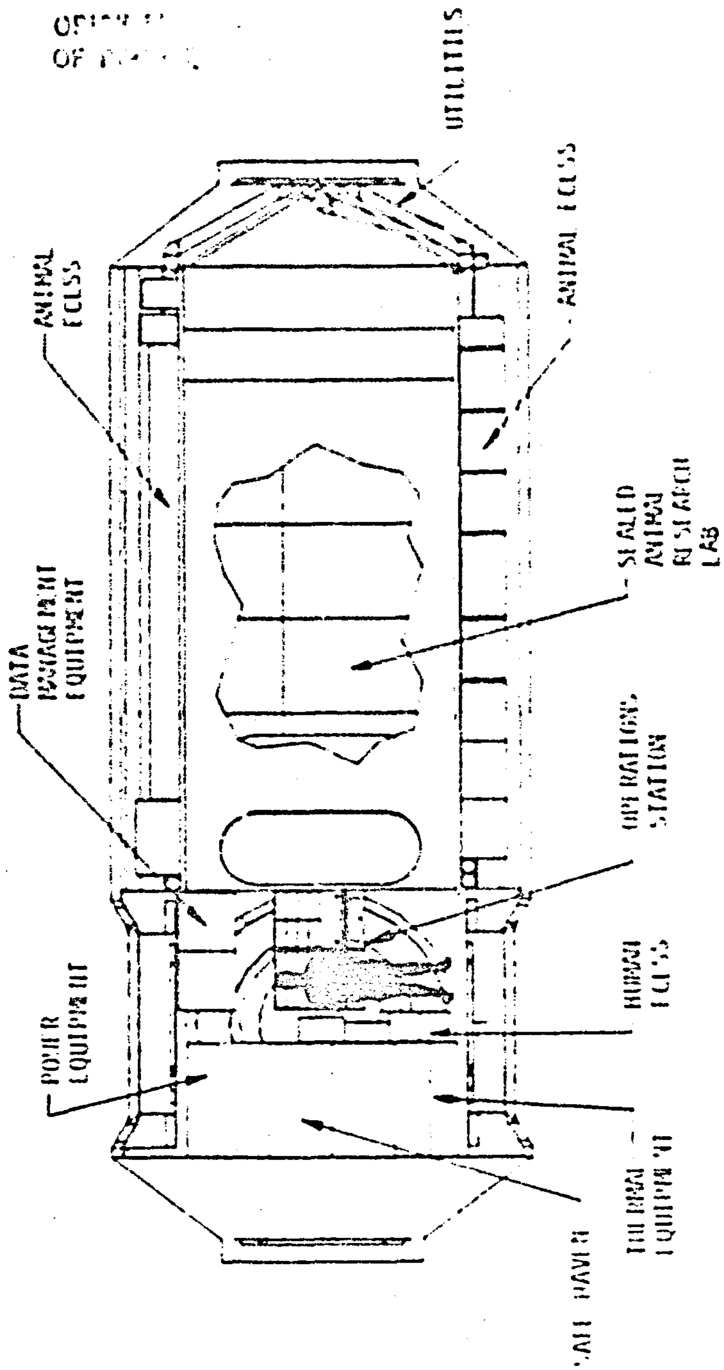


Figure 26, Life Sciences Lab Module

(from Ref. 13)

The impact to the Space Station would therefore consist of accommodating one module designed for sample reception and quarantine. Due to its physical isolation from the rest of the Station it might not be of much use for other tasks. EVA would be required to enter it. The requirement to sustain one or more individuals in emergency isolation for long periods might make the Quarantine Module useful as a backup system or lifeboat, or as part of the station medical facilities. A sick individual could be effectively quarantined. Provisions could also be made to attach it via a pressurized passageway to the rest of the station during the expected long periods between sample handling and required quarantine. This would significantly increase its utility.

The Mars sample will be either aerobraked or propulsively inserted into low Earth orbit with solid rockets. Mars launch will be timed to place the sample in the Space Station plane at the time of rendezvous. References 14 and 15 suggest a 870 km (470 nm) circular orbit as the final destination. Reference 16 indicates the OMV can easily retrieve the entire 63.6 kg (140 lb) Earth orbit Capsule from orbital altitudes as high as 2,777 km (1,500 nm) circular, or can accommodate retrieval with a small plane change from lower altitudes.

The Kopff and Ceres sample return missions both aerobrake into LEO. Reference 5 suggests the aerobraked samples can be circularized at 370 km (200nm) in the Space Station plane if desired. Recent Space Station designs use a 463 km (250) to 500 km (270 nm) altitude. The samples could also be aerobraked and circularized into 870 km (470 nm) in-plane orbits as with the Mars Sample return Vehicle. Only the 93 kg (205 lb) Earth Orbit Capsules are aerobraked into Earth orbit. The Mariner Mark II spacecraft also return to the vicinity of Earth but fly by after releasing their Earth Orbit Capsules.

6.5 OTV Maintenance and Refurbishment Operations

OTV maintenance and refurbishment operations at the Space Station consist of several classifications of work. These include Normal Turnaround, Scheduled and Unscheduled Maintenance and Refurbishment, and Secondary Support Activities. Table 7 lists the Space Station crew manhour requirements for these activities as they relate to Planetary missions. The classifications mentioned above have become somewhat mixed in this table as each mission has been charged with prorated shares of the manhour requirements for scheduled maintenance operations.

Normal OTV turnaround is defined as the operations surrounding checkout, integration, and launch and retrieval. This is distinct from maintenance operations which can be either scheduled preventive maintenance or unscheduled repair of faulty components. Table 7 lists four separate operations which are classified as Normal turnaround operations. These are as follows:

- OTV Refurbishment

- OTV/Payload Integration and Checkout
- Fuel, Release and Launch
- Rendezvous and Retrieve OTV using OMV

OTV refurbishment includes the normal turnaround operation of visual inspection, removal and replacement of ACS modules and a system test. Also, part of the manhours required fo: scheduled maintenance has been charged to each mission. I(is assumed that scheduled maintenance will be performed on a: OTV after five missions. Because of this, one fifth of th(manhcur requirements have been included. Normal turnaroun(requires two crew members for execution while some of the maintenanc(operations require four. For a single stage OTV mission, this operations phase requires approximately 52 manhours, half of which are the result of maintenance work.

OTV to payload integration and checkout involves the transfer of the OTV from the hangar to the stacking facility, the transfer of the payload from its holding location to the stacking facility, the mating of the OTV and the payload, and finally the integrated system test. This phase includes only normal turnaround operations and no maintenance operations. The integrated test is anticipated to be accomplished with OTV and payload self test capabilities and will consequently not require a significant number of manhours. This operational phase requires two crew members and approximately 11 manhours.

The fuel, release and launch phase includes OTV fueling, release from the stacking gantry, transfer by the Space Station RMS to the launch location, mating with the OMV, and launch. This phase also includes only normal OTV turnaround operations and requires two crew members. The manhour requirements for a one stage mission are approximately 24 manhours, while a two stage mission requires about 36 manhours. The two stage mission does not require twice the crew manhours since prelaunch and launch operations are not performed twice for the mission while the fueling operations are.

Rendezvous and retrieval operations involve deployment of the OMV, rendezvous of the OMV and OTV, berthing, and safing of the OTV. Again, this phase includes only normal operations. Two crew members are required and a total of about 12 manhours will be expended.

Table 7 also lists various Secondary Support Activities and approximate manhour requirements for each. The removal of an aerobrake has been included for missions that have an expended OTV. Shuttle rendezvous and payload removal represents the delivery of a mission payload or planetary spacecraft. ULV propellant delivery involves the arrival and replacement of one of the Orbital Storage Modules. The manhour requirements given for the propellant operations are prorated to the amount of propellant used for each mission. The sample retrieval operations listed apply only to the three sample return missions listed.

In addition to normal turnaround operations and secondary support activities, maintenance operations are included, as discussed previously, in Table 7. OTV maintenance can be divided into three basic levels. Level 1 maintenance involves both scheduled and unscheduled functions that take place on the vehicle as it is berthed in the Space Station sheltered maintenance facility. Level 2 maintenance is repair of replaceable OTV parts at the Space Station or on Earth if test equipment, spares availability, and economic constraints dictate. Level 3 maintenance includes Earth based repair of OTV components. For the purposes of this study, only Level 1 scheduled maintenance is considered.

Two specific operations are included in OTV refurbishment. The first is the removal and replacement of a fuel cell and battery. This operation requires two crew members and approximately 5 manhours. Second is the removal and replacement of two OTV engines. This operation requires four crew members working a total of 65 hours per engine. It is most likely that EVA activity will be required for these unscheduled operations.

These manhour and operations requirements were derived from reference 20. This reference also provides additional details on scheduled and unscheduled maintenance operations, and initial delivery operations.

7.0 Conclusions and Recommendations

An Operational Space Station with large high energy (cryogenic propellant) orbital transfer vehicles can support an extremely wide range of space transportation options. The following conclusions and recommendations outline some of the areas requiring significant additional study:

1) The Space Station must include a cryogenic propellant depot with large scale (hundreds of metric tons) on-orbit propellant transfer capability. This is central to any large space transportation operations. The ability to transfer and store cryogenic propellants in these quantities must be developed.

2) The OTV vehicles must be "stackable" to provide multi-stage capability. With this capability a larger payload or a high delta V can always be accommodated by adding another propulsion stage (although eventually this becomes impractical). Without this capability, the system is constrained to the performance envelope of a single OTV.

3) For practical high density round trip operation to Lunar Orbit (and Geosynchronous orbits) aerobraking is required of the OTV's. Development of aerobraking technology should be undertaken.

4) In order to support the high flight rate lunar program a large shuttle derived-unmanned launch vehicle with payload in the 100 metric ton class should be developed as a cryogenic propellant tanker vehicle. Such a vehicle would reduce the average launch rate for lunar support from 25 shuttle launches a year (one every two weeks) to 10 a year (one every 5 weeks). The average annual savings in launch costs alone should be around 1.4 billion dollars, enough to recover development costs in the first two years.

5) The External Tank, Aft-Cargo Compartment proposed by Marshall Space Flight Center for use on shuttle launches should be developed for carrying the Expendable Lunar Lander. With at least 16 launches required in the first four years of heavy lunar traffic, this could also be easily amortized.

6) For lunar base support, the Space Station must be capable of substantial operational support such as flight control, storage and preparation of payloads and mission stacks, propellant transfer operations, and routine OTV checkout and maintenance. This means

the basic Space Station operations will be shifted toward support of transportation. This will require some enlargement of the Space Station.

This emphasis, however, does not preclude heavy utilization of the Space Station as a scientific research and facilities base. Even with the lunar base, large traffic arrivals or departures only occur approximately once every two weeks.

7) Interplanetary departure from lunar orbit using only lunar derived O_2 for propellant does not appear to be significantly advantageous as long as all lunar fuel (H_2) must be brought from Earth. No advantage was found if the total outbound cargo must come from Earth. The case using lunar derived fuel, as well as lunar oxygen should be studied.

8) The economics of lunar surface to lunar orbit ferry operations with a reusable lander should be studied to determine approximately what it costs to fly such a mission with and without lunar produced propellants. This cost number is needed to assess the economics of a number of schemes using lunar resources. The general economics of a round-trip two-stage OTV sortie from LEO to lunar orbit also needs to be determined.

9) Any exploration, research, or engineering development that might result in a source of lunar hydrogen should be pursued.

10) The requirements that manned Mars, Mars moon, or asteroid missions would impose on the Space Station should be determined. Rumors of Russian efforts exist. Such a program might occur sometime during the Space Station's lifetime.

11) The design of and rationale for the Quarantine Module require more definition. A sample return mission is quite likely to occur during the lifetime of the Space Station and the IOC design should take this into account. As a part of this effort, special attention needs to be paid to the sample return container, particularly its environmental control system and packaging for Earth return.

8.0 Definitions of Terms and Acronyms

Aerobrake	The portion of a stage that creates drag when the atmosphere is used to slow the stage down
CLTU	Cryogenic Liquefaction and Transfer Unit
Delta V	Change in velocity required
E-Ascent	Expendable Ascent Stage, propulsion stage to return personnel from lunar surface
ECLSS	Environmental Control and Life Support System
E-Lander	Expendable Lander, large one way lunar lander
EOC	Earth Orbit Capsule
ERV	Earth Return Vehicle
ET	External Tank
ET-ACC	External Tank - Aft Cargo Compartment
Free Return Trajectory	Earth to Moon orbit that loops around the moon and returns to earth without any rocket firings
Geosynchronous Orbit	An equatorial orbit at the altitude (35,810 km) at which the satellites revolution and the earth's rotation are the same so the satellite appears to remain stationary over fixed point on the earth
g losses	Difference between theoretical and actual space maneuver requirements due to altitude changes during the time the rocket is firing
Isp	Specific impulse - measure of engine performance
JSC	Johnson Space Center
LEO	Low Earth Orbit
LH_2	Liquid Hydrogen
LLMM	Lunar Landing Manned Module - to be carried on E-Lander and E-Ascent
LOI	Lunar Orbit Injection
LOSS	Lunar Orbit Service Station

LOX	Liquid Oxygen
MABM	Mars Ascent Boost Module
MLM	Mars Lander Module
MRV	Mars Rendezvous Vehicle
OMM	OTV manned module - manned module to be mated to OTV
OMV	Orbit Maneuvering Vehicle
OSM	Orbital Storage Module
OTV	Orbit Transfer Vehicle
PL	Payload
PLaero	Payload carried through an aerobrake maneuver
R-LEM	Reusable Lunar Excursion Module - single stage lunar lander/launch vehicle - reusable
R-LLEM	Reusable Lunar Landing Manned Module
SCA	Sample Canister Assembly
TLI	Trans-Lunar Injection
T/W	Thrust to weight ratio
ULV	Unmanned Launch Vehicle
Wp	Propellant weight (capacity of a stage)

9.0 References

1. Lunar Surface Return Report - In-house JSC study, presente March 1984.

2. Roberts, Barney B., OTV Weight Estimates, JSC Memorandu ET4/8401-11L.

3. Apollo 11 Mission Report, prepared by the Mission Evaluatio Team, NASA Report No. N71-25042.

4. Bourke, Blanchard, and DeVries, Mars Sample Return Mission FY 84 Study Report to OSSA, JSC and JPL, July 26, 1984

5. Bourke, Friedlander, DeVries, Norton, and Blanchard, Complet Report, Advanced Planetary Studies, Mars Sample Return Quarterly Review, FY 1984, May 15, 1984.

6. Friedlander, Soldner, and Niehoff, Performance Assessmen of Planetary Missions as Launched from an Orbiting Spac Station, Science Applications, Inc. Report No. SAI 1-120 340-T19, September, 1982.

7. Planetary Exploration Through Year 2000, A Core Program Executive Summary, Part One of a report by the Solar Syste Exploration Committee of the NASA Advisory Council, Gov. Printing Office, Washington D.C., 1983.

8. Comet Nucleus Sample Return Mission, Science Application Report No. 83/1152, Presentation to Solar System Exploratio Committee Summer Study, Snowmass, Colorado, August 2, 1983.

9. Draper, R. F., The Mariner Mark II Program, AIAA-84-0214 presented at the AIAA 22nd Aerospace Sciences Meeting January 9-12, 1984/Reno, Nevada.

10. Private communication from John Soldner, SAI.

11. Swenson, Mascy, and Edsinger, A New System Concept fo a Titan Atmospheric Probe, NASA Ames, AIAA-84-0456, AIA 22nd Aerospace Sciences Meeting, January 9-12, Reno, Nevada.

12. Calendar of Planetary Mission Opportunities, SAI

13. DeVincenzi, Donald L., Bagby, John R., Orbiting Quarantine Facility, NASA SP-454, NASA Scientific and Technical Informatio Branch, Washington, D. C., 1981.

14. Presentation Package from Joint JSC-JPL-SAI Meeting o Mars Sample Return, March 27, 1984.

15. Bourke, R. D., Blanchard, D., and DeVries, J. P., Mars Sample Return Mission (Presentation Material), FY 84 Study Report to OSSA, JPL D-1698, July 26, 1984.

16. Teleoperator Maneuvering System Study, Mission Requirements and System Definition, Study Review, Prepared by Vought Corp. for the NASA Marshall Space Flight Center, December 16, 1982.

17. Comet Nucleus Sample Return with Aerocapture, Presentation Package, no date, Science Applications Inc.

18. Space Station Reference Configuration Description, Systems Engineering and Integration, Space Station Program Office, JSC-19989, NASA Johnson Space Center, Houston, Texas, August, 1984.

19. Advanced Thermal Control Technology for Cryogenic Propellant Storage, NASA-OAST Final Report F.Y., Gail Klein, 1983.

20. Definition of Technology Development Missions for Early Space Station's Orbit Transfer Vehicle Servicing. Phase III, Task 1 Space Station. Support of Operational OTV Servicing, Contract No. NAS8-35039, General Dynamics, December 1983, Report No. GDC-SP-83-067.

End of Document