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SPACE STATION ACCOMMODATIONS FOR LUNAR BASE ELEMENTS - A STUDY

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INTRODUCTION

The Space Station has been an object of considerable design, redesign, and alteration since it was originally proposed in early 1984. In the intervening years, the station has slowly evolved to a specific design that was very thoroughly reviewed by a large agency-wide Critical Evaluation Task Force (CETF). As Space Station designs evolve, studies must be conducted to determine the suitability of the current design for some of the primary purposes for which the station will be used.

This study was requested by the Office of Aeronautics and Space Technology (OAST) in NASA Headquarters to specifically evaluate the technology required for the Space Station to accommodate a phased series of missions with the expressed goal of providing and maintaining a manned lunar base. The impacts on the station were defined and the required technology needed was specified. This study is an example of the many future evaluations of the station designs and their applicability to specific purposes that will be required before the space station is accepted as a truly general purpose facility.

This report is a compilation of the final report of the study's results that was presented to NASA management on June 18, 1987, and includes all conclusions and recommendations available then.

Lunar Base Accommodation Study

FINAL REPORT

JUNE, 1987

LUNAR BASE ACCOMMODATION STUDY

PRESENTATION OUTLINE

Presentations made on the lunar base accommodations study were made in the order shown below. An introduction and overview set the stage for the entire meeting, and a complete description of the lunar missions and the vehicles was presented.
Next, the interfaces between the lunar base infrastructures and the space station were identified and discussed. A number of options were defined and compared, and the results of some initial studies were presented. Then, the support requirements from the cape were presented and lunar base assembly ops were discussed.
In the final section of the report, the technology and science effects of the lunar base were assessed, and the resource requirements were defined. All of the key results of the lunar base accommodations were summarized in the final few charts.

Lunar Base Accommodation Study

PRESENTATION OUTLINE

o INTRODUCTION	B. PRITCHARD
o STUDY OVERVIEW	R. MURRAY
o LUNAR MISSION AND VEHICLE	B. CIRILLO
o SPACE STATION INTERFACES	M. KASZUBOWSKI
o KSC SUPPORT REQUIREMENTS & STATION ASSEMBLY OPS	M. KIENLEN
o TECHNOLOGY & ORBITAL DEMON.	C. LLEWELLYN
o RESOURCE REQUIREMENTS	C. LLEWELLYN
o SCIENCE ASSESSMENT	G . LAWRENCE
o SUMMARY AND CONCLUSIONS	R. MURRAY

LUNAR BASE ACCOMMODATION STUDY

STUDY TEAM

This chart indicates the content of the team assembled to study the lunar base accommodation on the space station. The team consisted mainly of space station in-house staff from LaRC, with some of their contractor support. Two other centers also supplied needed additional support in key areas.

Lunar Base Accommodation Study

STUDY TEAM

LaRC

BOB MURRAY
BRIAN PRITCHARD
DON EIDE
JACK HALL
GEORGE LAWRENCE
BARRY MEREDITH
DEBBIE MONTOYA
DEENE WEIDMAN
KIRK AYERS
BILL CIRILLO
MARTY KASZUBOWSKI
CHARLIE LLEWELLYN
HERB KOWITZ
LAURA WATERS
PAT TROUTMAN
MIKE HECK

KSC

GARY POWERS
MIKE KIENLAN

LeRC

LARRY COOPER

LUNAR BASE ACCOMMODATION STUDY

STUDY OBJECTIVES

The Lunar Base scenario and Lunar spacecraft systems were provided by Barney Roberts and his task force at JSC. Thus the objective of this study was to establish all of the impacts on the IOC space station of accommodating the Lunar Base missions. Impacts in the listed areas were of primary importance; that is, resources required, interfaces between systems, science impacts, new technologies requiring development at the space station, and general definition of required configuration changes.

STUDY OBJECTIVES

DETERMINE LUNAR BASE MISSION IMPACTS ON THE IOC SPACE STATION

- RESOURCES
- INTERFACES
- SCIENCE
- TECHNOLOGY DDT&E
- CONFIGURATION

LUNAR BASE ACCOMMODATION STUDY

GROUND RULES

This chart shows the basic assumptions that were made in the process of assessing the impact of the lunar base on the space station. For this study, the CETF redesign of the space station (Sept. 1986) was chosen as the baseline station design. An early manned mission was also assumed as dictated by the JSC provided scenario. by this assumption. Two already planned ,unmanned precursor missions, the sample return and Rover missions, were included to finalize the Lunar Base site selection. Also the JSC study on lunar bases provided the fundamental definition of the total mass (vehicles, crew, logistics, propellant) which passes through the station as a function of time. It was also assumed that the lunar mission vehicles would be builtup, maintained and refueled at the station.The propulsion systems were assumed to be liquid H2/ O2 chemical systems. The activities of the OTV and OMV were assessed and it was decided that both vehicles needed to be man-rated and space- based to accomplish the many tasks they would be called upon to complete. An operational HLLV was also required to provide the high mass-to-orbit for lunar base support. The study considered only the early (up to 2010) time frame, since the definition of the growth lunar base has many more unknowns than the earliest possible lunar bases included.

GROUND RULES

- CETF IOC CONFIGURATION IS STUDY BASELINE
- EARLY MANNED LUNAR MISSION
- LUNAR SAMPLE RETURN AND ROVER PRECURSOR MISSIONS WITH ELVS
- JSC LUNAR BASE SCENARIO IS PRIMARY BASIS FOR SPACE STATION MASS FLOW
- LUNAR MISSION VEHICLE BUILD-UP IN LEO
- HYDROGEN/OXYGEN CHEMICAL PROPULSION SYSTEM
- OTV AND OMV MAN-RATED AND SPACE BASED
- OPERATIONAL HLLV
- STUDY DOES NOT CONSIDER POST 2010 TIME FRAME

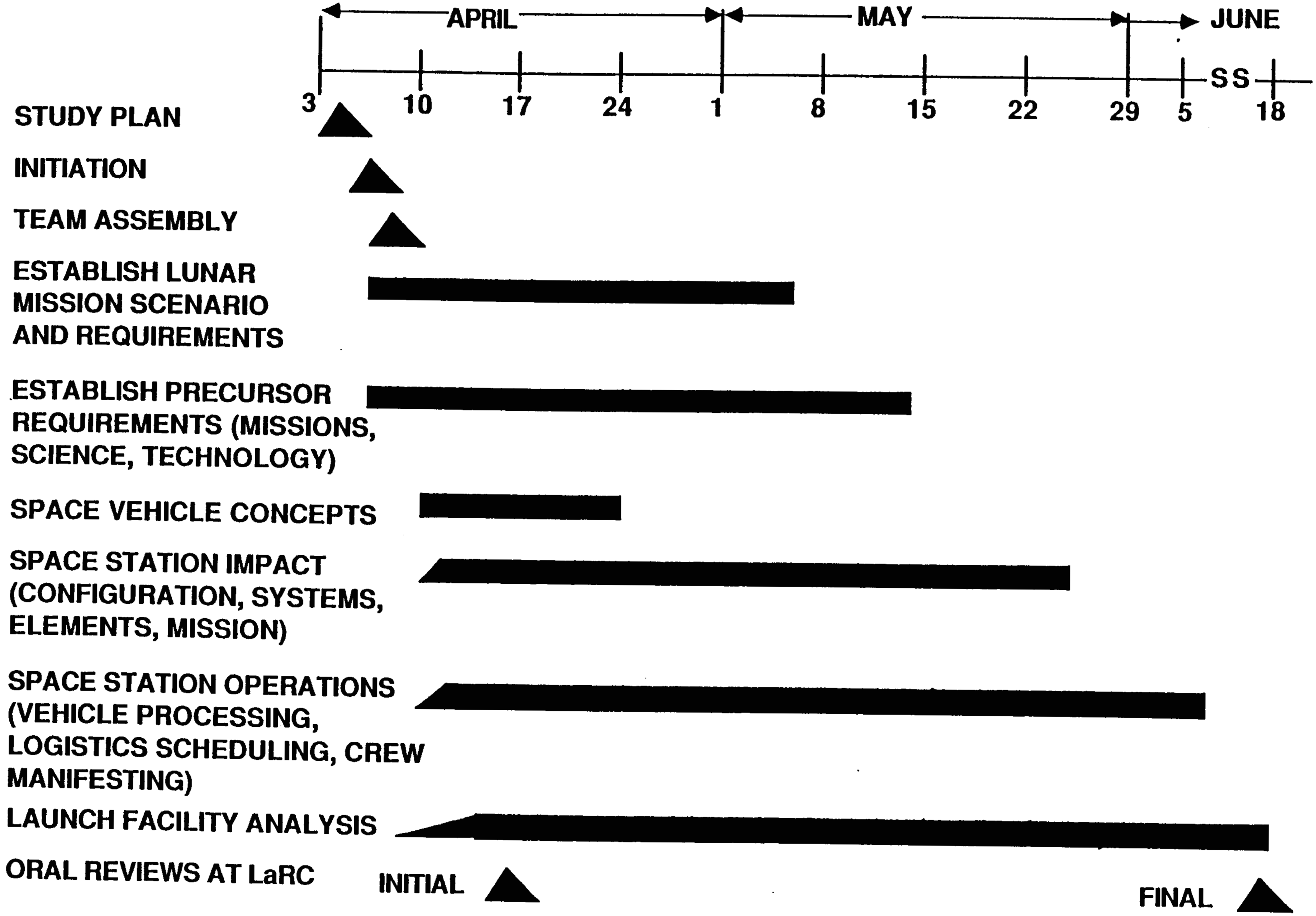
LUNAR BASE ACCOMMODATION STUDY

SCHEDULE

This chart indicates the short time available for this small group to complete the studies involved. This time line was rather strictly adhered to, and the activities were accomplished as noted. The time from the initial review to the final oral review was two months.

Lunar Base Accommodation Study

SCHEDULE

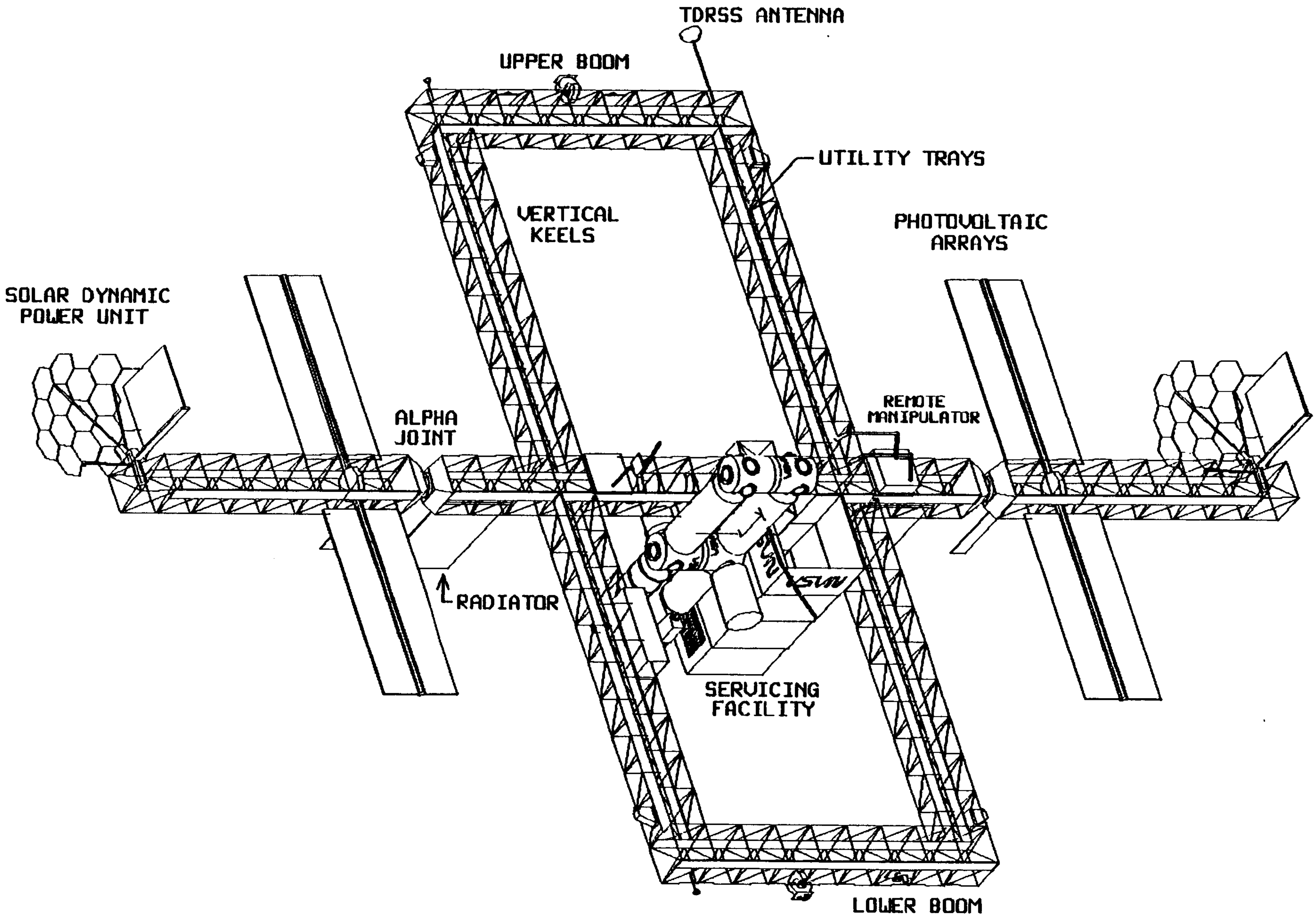


LUNAR BASE ACCOMMODATION STUDY

FINAL ASSEMBLY CONFIGURATION

This chart illustrates the initial configuration upon which the lunar base accommodation study was based , and is a picture of the CETF version of the IOC station without all the payloads.

CRITICAL EVALUATION TASK FORCE (CETF)
FINAL ASSEMBLY CONFIGURATION



LUNAR BASE ACCOMMODATION STUDY

IOC-SS SUPPORT REQUIREMENTS

This chart illustrates the primary activities required at the space station in support of the lunar base activities. The activities have been separated into two time periods; early ('97-'00), and growth ('00-'10). The early activities are devoted to the assembly and construction of lunar accommodation infrastructure at the station, development testing for key technologies, and, finally, verification testing of lunar vehicles. These activities were considered the essential ones that were required early in the development phase of the lunar base, and more detail will be presented later.
The activities considered for the "growth to full base" capability are shown in the second list, and include the requirements for providing the lunar base supporting facilities, for providing servicing to these facilities, and for providing development and verification testing for any advanced new technologies that may be defined in the interim.
These activities will be explained later.

IOC - SS SUPPORT REQUIREMENTS

TOP LEVEL

1997 - 2000

- o ON-ORBIT FACILITIES BUILD-UP
- o TECHNOLOGY DEVELOPMENT/DEMONSTRATION
- o LUNAR VEHICLE DEMONSTRATION/VERIFICATION

2000 - 2010

- o LUNAR VEHICLE SERVICING
- o LUNAR BASE MISSION SUPPORT
- o ADVANCED TECHNOLOGY DEVELOPMENT/DEMONSTRATION
- o ADVANCED LUNAR VEHICLE DEVELOPMENT/VERIFICATION

LUNAR BASE ACCOMMODATION STUDY

SIGNIFICANT ENGINEERING QUESTIONS

The key important unanswered questions that arose during this study are listed on this chart, and include some enabling technologies that were considered ESSENTIAL for a realistic lunar base to be accomplished.

Many questions still remain to be answered on the cryogenic fuel handling, including automation of the fuel transfer procedure and robotic handling of the fuel tanks themselves. The handling of the boiloff, whether through reliquification or use for reboost or attitude control, still remains an important question, and large improvements in mass-to-orbit can still be accomplished with some engineering ingenuity in fuel handling.

The methods for aerocapture and design of the aeroshell is an enabling technology for any reasonable lunar or planetary missions, and verification of the most promising designs is essential. Replacement of an aeroshell design with an all-propulsive design would cause an unacceptabl[illegible] high weight penalty, and would still need verification testing. Aeroshell design must be started early, so that other portions of the transfer vehicles can be designed around the aeroshell.

The life support systems for the lunar base will be required to operate continuously and these systems need to be defined, built, and verified long before the lunar base can become a reality. Many questions exist about the methods for recovery of O2, N2, H2O, and wastes that need to be answered before life support can even be designed. This activity must be started as soon as possible in order to answer these design questions, and much resupply savings can be accommmplished by an efficient life support system design.

The crew requirements are not well defined at present, and, while reasonable assumptions are made in this presentation, the best selection of crew size, replacement rate, crew work load, psychological and other factors still is needed.

Finally, integration of all of the elements of the lunar base infrastructure still needs to be completed in an overall design. This activity requires most decisions to be made on the other systems first, and forces the lunar base design to start soon. The question of refurbishment/maintenance appears very important, because the major impact on space station resources and science programs are associated with these functions. The aeroshells are an excellent example of the savings possible by refurbishing an existing element. Detailed analyses of the resources required to accomplish both refurbishment and maintenance are needed.

Lunar Base Accommodation Study

SIGNIFICANT ENGINEERING QUESTIONS

- CRYOGENIC FUEL HANDLING
- AEROCAPTURE
- LIFE SUPPORT
- CREW REQUIREMENTS
- VEHICLE INTEGRATION AND REFURBISHMENT

MISSION AND VEHICLE DESCRIPTIONS

BILL CIRILLO
APRIL 27, 1987

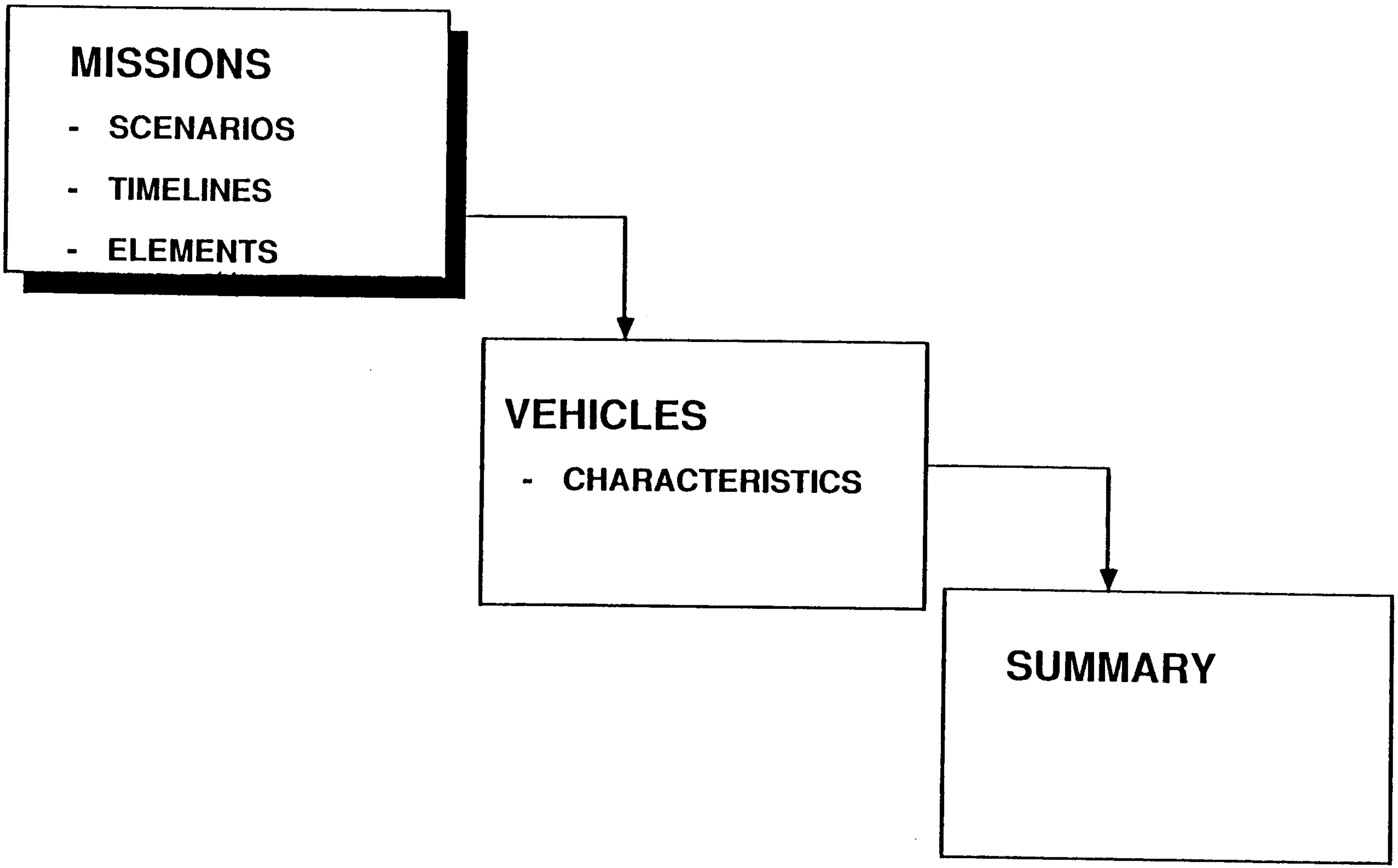
OUTLINE

The following section of the Lunar Base Accommodation Study discusses overall mission design, mission elements and desirable program timelines. The vehicles necessary to establish and support a manned lunar base are also presented.

Once the mission and vehicles are defined the impacts to the Space Station can be assessed in a practical manner.

Lunar Base Accommodation Study

OUTLINE



MISSION PHASES

This section of the report only deals with on orbit and lunar activities. Ground launch activities and schedules are dealt with in a following section.

MISSION PHASES

- o GROUND ASSEMBLY AND CHECKOUT
- o EARTH TO LEO LAUNCH
- o LEO TO LUNAR ORBIT
- o LUNAR ORBIT TO LUNAR SURFACE
- o LUNAR SURFACE TO LUNAR ORBIT
- o LUNAR ORBIT TO LEO
- o LEO TO EARTH RETURN

LUNAR BASE OBJECTIVES

There are three basic objectives in establishing a manned lunar base that are beneficial to mankind. The first objective, science, is two-fold. The moon is an ideal site for conducting various experiments including noise free radio astronomy, atmosphere free astronomical observations, and low gravity experiments. In addition to being a good platform for experimentati detailed studies of the moon will provide information on planetary geologica evolution and solar system development.

The second objective in establishing a manned lunar base would be to utilize lunar resources such as lunar produced oxygen and lunar materials for LEO an GEO shielding. If lunar oxygen can be produced in large quantities as is theorized and transported to low earth orbit, oxygen need no longer be launc from earth, reducing launch costs.

The final objective is a long term goal of establishing a permanent, self-supporting lunar colony.

This study only extends to the year 2010, and provides for a combination of t first two objectives with the potential for establishing a permanent colony the far future.

LUNAR BASE OBJECTIVES

- **SCIENCE**
  - LUNAR STRUCTURE
  - PLANETARY GEOLOGICAL EVOLUTION
  - SOLAR SYSTEM DEVELOPMENT
  - LOW GRAVITY EXPERIMENTS
  - NOISE FREE RADIO ASTRONOMY
  - ATMOSPHERE FREE ASTRONOMICAL OBSERVATION
- **LUNAR RESOURCE UTILIZATION**
  - OXYGEN FOR SPACE TRANSPORTATION SYSTEM
  - LUNAR MANUFACTURING FOR SUPPORT OF LUNAR ACTIVITIES AND LARGE SCALE SCIENCE AND ENGINEERING PROJECTS
  - MATERIALS FOR SHIELDING IN LEO OR GEO
- **COLONIZATION**
  - DEVELOPMENT OF EXTRATERRESTRIAL COLONIZATION TECHNOLOGY
  - SUPPORT HUMAN EXPANSION THROUGH THE SOLAR SYSTEM
- **COMBINATION OF THE ABOVE OPTIONS**

LUNAR BASE SCENARIO

The lunar base proposed in this study has three phases. The first phase consists of robotic exploration of the lunar surface from 1994 through 1999 in order to select an appropriate landing site. The process would begin with a lunar orbiting satellite to provide a detailed map of the entire lunar surface. This mission would be followed by several sample returns and delivery of seve unmanned lunar rovers for detailed landing area investigation. The final step in this phase could be the delivery of telerobitic or automatic construction equipment for site preparation.

The second phase (2000-2005) begins with the delivery of a small power plant, habitat, unpressurized rover, and various scientific experiments to the prepared landing site. A crew of four personnel will temporarily man the base for up to two weeks at a time the first two years. As more facilities and equipment are delivered to the moon, stay times will increase. Also during this phase a small scale mining of lunar regolith is started and the experimental production of lunar oxygen is begun.

Phase three begins in 2005 with the establishment of a permanently manned luna facility. During this phase the crew size will increase to twelve persons located in two habitats with sevaral laboratories having been established for life science and materials research. The production of lunar oxygen will be increased to the point where the transports arriving from LEO can be refueled for their return trip to earth. A lunar orbiting support facility will be developed for the storage and transfer of the lunar produced oxygen and provide a rendezvous point for crew transfer between arriving and returning lunar base vehicles.

LUNAR BASE SCENARIO

PHASE 1: PREPARATORY EXPLORATION (ROBOTIC)

- o LUNAR ORBITER EXPLORER AND MAPPER (LGO)
- o SITE SELECTION
- o POSSIBLE AUTOMATED SITE PREPARATION

PHASE 2: RESEARCH OUTPOST (0-4 PERSONNEL)

- o MAN TENDED
- o HABITAT MODULE
- o TOTAL EARTH RESUPPLY
- o SCIENCE MODULE
- o LUNAR OXYGEN PILOT PLANT
- o SURFACE MINING PILOT OPERATION
- o POWER UNIT

PHASE 3: OPERATIONAL BASE (4-12 PERSONNEL)

- o PERMANENTLY OCCUPIED FACILITY
- o ADDITIONAL/HABITATS AND LABORATORIES
- o EXPANDED MINING FACILITY
- o OXYGEN PRODUCTION PLANT
- o ADDITIONAL POWER

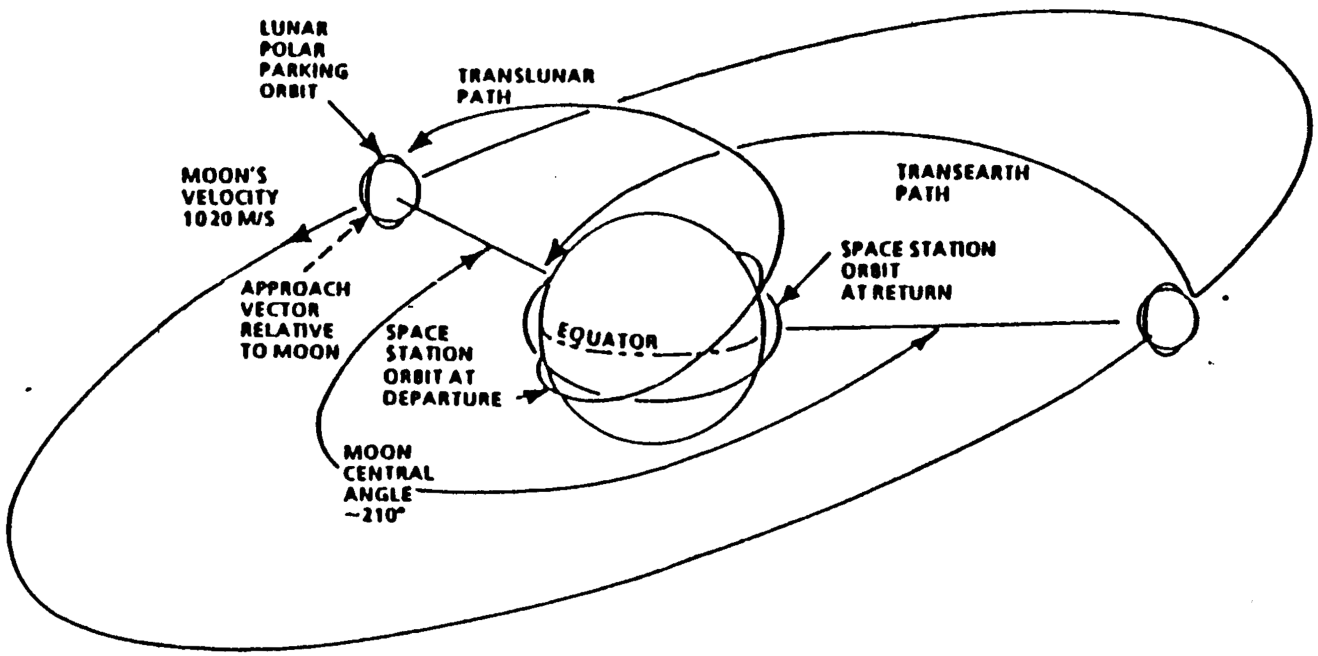
MISSION CYCLE FROM ORBITAL MECHANICS

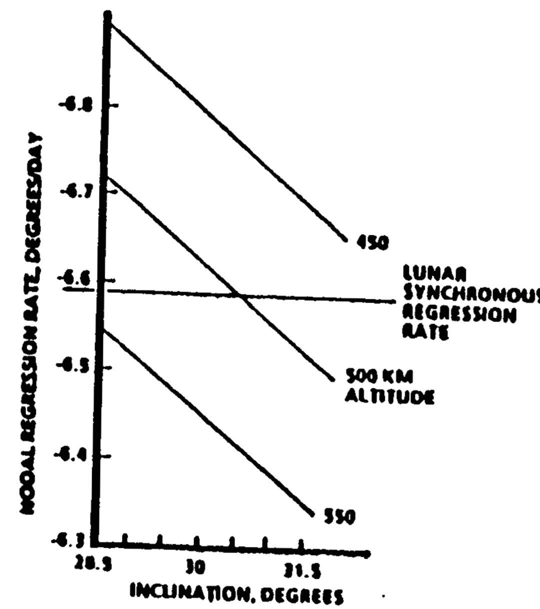
Because of orbital mechanics considerations, including the space stations inclined orbital plane and the fact that the moon revolves posigrade about the earth at approximately 13 degrees per day, an opportunity for an in-plane departure from the space station to the moon occurs every 9 days. However, if one wishes to rendezvous with a lunar polar orbiting refueling facility, such as the one proposed in this study, opportunities occurr only every 55 days. This means that beginning in 2005 with the arrival of the Lunar Orbit Support Facility (LOSF), mission opportunities only occur every 55 days instead of every 9 days.

In order to obtain regularly repeating Earth departure and lunar arrival windows, the moon's motion and the space station's orbit must be synchronized with the lunar month. This synchronization occurs at altitudes and inclinations near to the present IOC space station's orbit.

Lunar Base Accommodation Study

MISSION CYCLE FROM ORBITAL MECHANICS





- 55 DAY MISSION CYCLE TO POLAR LUNAR ORBIT

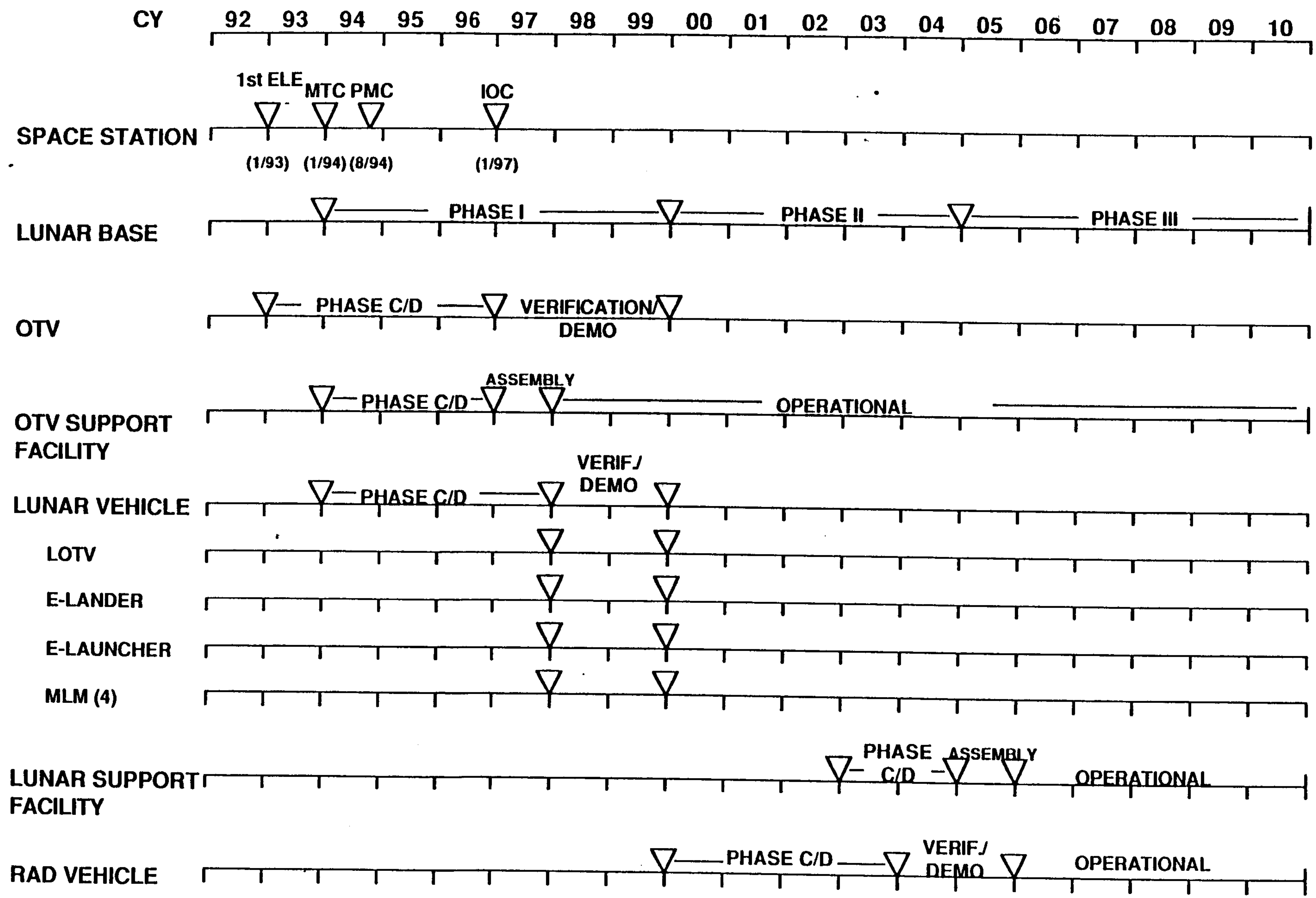
MAJOR DEVELOPMENT MILESTONES FOR LUNAR BASES AND SPACE STATION

The space station timeline shown is for the Critical Evaluation Task Force (CETF) study conducted in September, 1986. Shown below is the timeline for the vehicles and facilities necessary to establish and support a near term manned lunar base. The proposed primary lunar transfer vehicle is a mated pair of advanced Orbital Transfer Vehicles (OTVs) with the capability to deliver approximately 77,000 lbs. to lunar orbit. Of the 77,000 lbs. only 38,500 lbs. will be usable payload with the rest consisting of ascent and descent stages and their propellants.

All of the vehicles listed below are described in further detail later in the report.

Lunar Base Accommodation Study

MAJOR MILESTONES FOR LUNAR BASE/SS

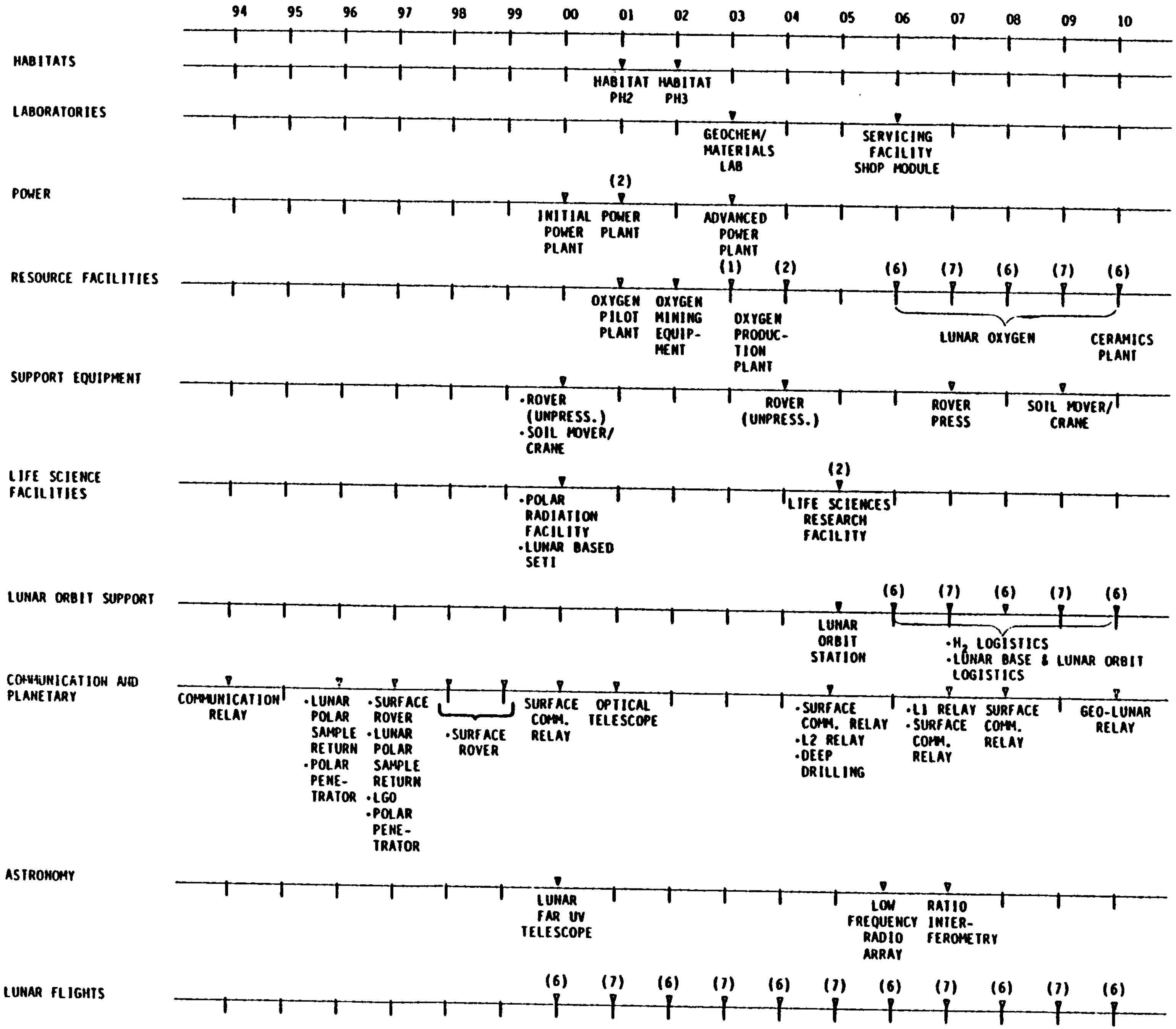


LUNAR BASE ELEMENTS

The table identifies the various elements that comprise the lunar base defined in the Civil Needs Date Base (CNDB), option 4. The superscripted numbers indicate the number of elements or flights, except in the case of the oxygen production plant, which, because of its large size, is delivered in thre flights and then assembled into one facility. The lunar flights that are displayed on the bottom line always consist of four manned flights per year with the remaining flights being payload deliveries.

Even the establishment and resupply of this small lunar base represents a dramatic increase in necessary earth launches, mandating the need for a heavy lift launch vehicle and the establishment of a highly reusable and operable transporation system.

LUNAR BASE ELEMENTS

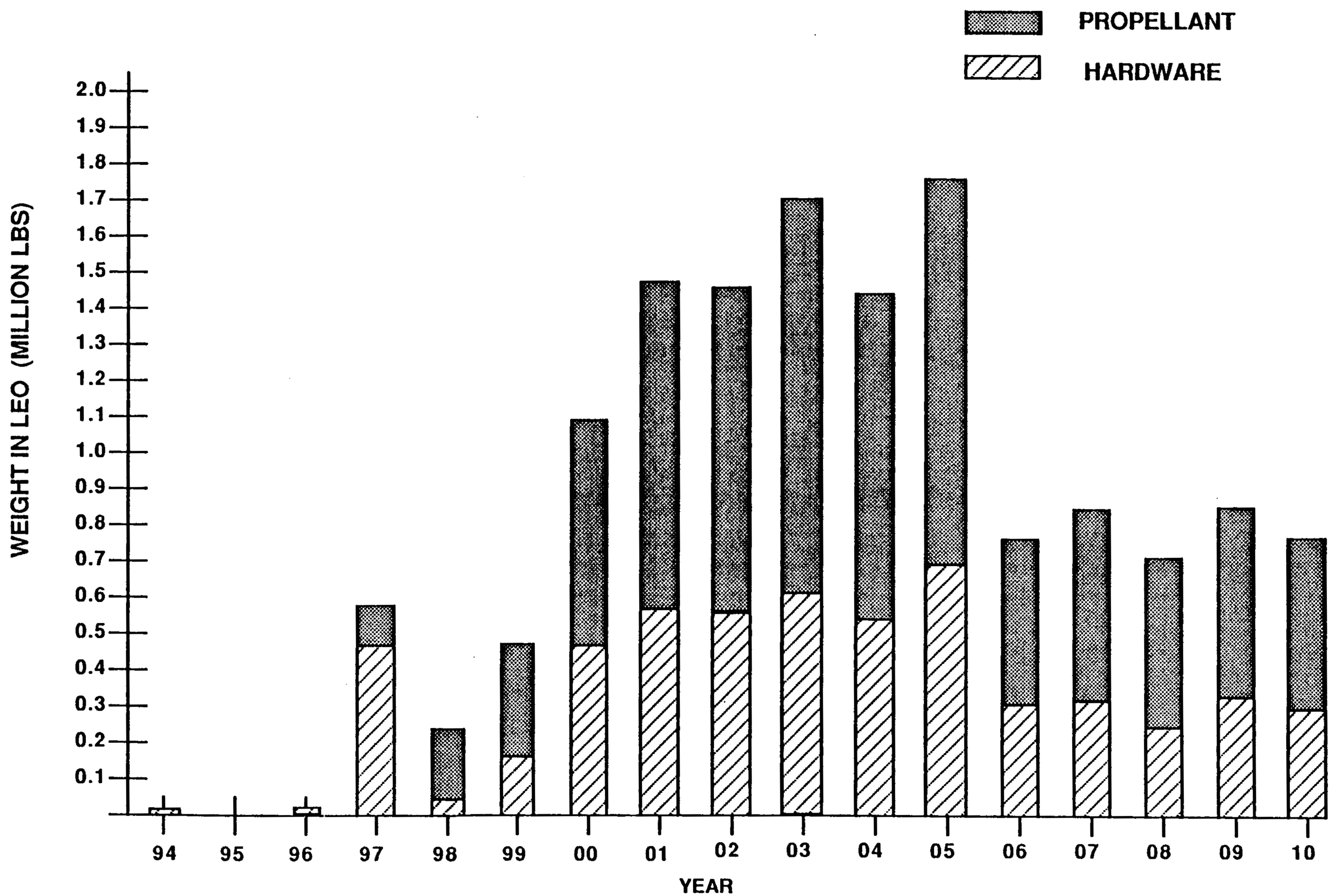


WEIGHT LAUNCHED INTO LOW EARTH ORBIT

The yearly weight that is required in Low Earth Orbit (LEO) is graphically presented. The weight includes additional space station and propellant farm structure, lunar transportation sysytem vehicles, logistics support, and propellant.

Lunar Base Accommodation Study

WEIGHT IN LOW EARTH ORBIT



MISSION SCENARIO

There are three proposed mission scenarios in this study. The first two, the manned and unmanned missions, begin in 2000 with the start of Phase 2 activities. The lunar oxygen mission scenario does not begin until the full scale production of lunar oxygen is begun in 2006.

MISSION SCENARIOS

- MANNED MISSION
  - EXPENDABLE LUNAR LANDER/LAUNCHER
  - 2 OTV'S
- UNMANNED CARGO MISSION
  - EXPENDABLE LANDER
  - 2 OTV'S
- LUNAR OXYGEN MISSION (2006)
  - REUSABLE LUNAR LANDER/LAUNCHER OTV
  - 1 OTV

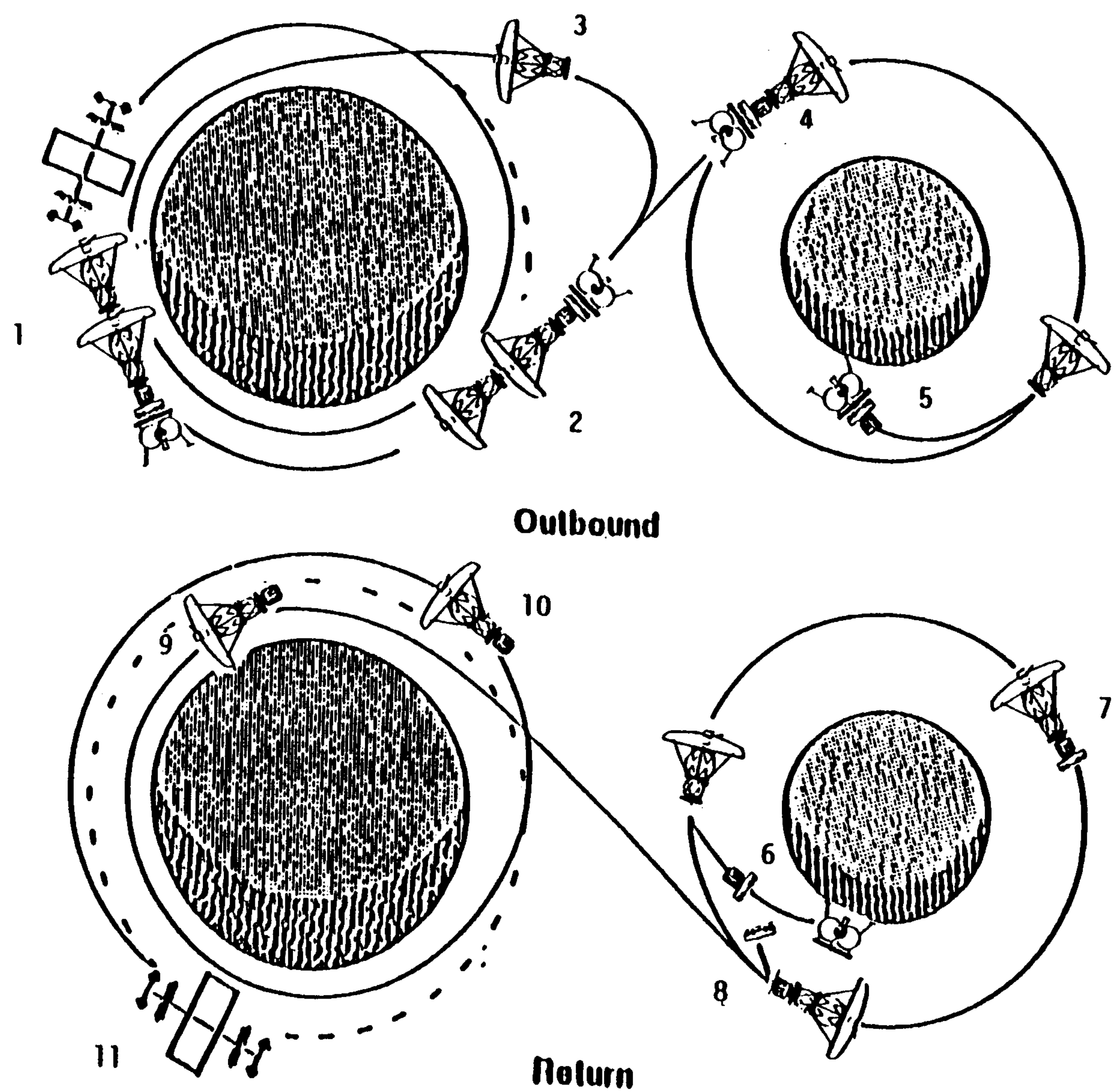
MANNED LUNAR MISSION SCENARIO

The delivery to and return of personnel from the moon is outlined and illustrated on the following two pages. The mission begins with the depature of the assembled and verified lunar vehicle from the space station. The deberthing and manuevering of the lunar vehicle away from the space station may require the assistance of a large Orbital Manuevering Vehicle (OMV). After departure the first OTV will perform the tranlunar injection (TLI) burn and then aerobrake back into LEO. The remaining OTV and manned lunar excursion module will proceed to lunar parking orbit where the crew will descend to the lunar surface and conduct their mission. Upon completion of the mission the crew will ascend and rendezvous with the orbiting OTV for return to earth. After discarding the expendable ascent stage and performing the Trans Earth Injection (TEI) burn the OTV and crew module will aerobrake into earth orbit for rendezvous with the space station.

MANNED LUNAR MISSION SCENARIO

1. STACK DEPARTS SPACE STATION
2. TRANS-LUNAR INJECTION BURN
3. FIRST OTV RETURNS TO SPACE STATION
4. SECOND OTV, LANDER/LAUNCHER, AND MANNED LUNAR MODULE (MLM) INSERT INTO LUNAR ORBIT
5. MLM, EXPENDABLE LANDER/LAUNCHER DESCEND
6. MLM WITH LAUNCHER DEPARTS LUNAR SURFACE
7. MLM AND OTV RENDEZVOUS IN LUNAR ORBIT
8. SECOND OTV RETURNS TO EARTH WITH MLM (LAUNCHER DISCARDED)
9. OTV/MLM AEROBRAKING INTO EARTH ORBIT
10. OTV/MLM CIRCULARIZATION ABOVE SPACE STATION ORBIT
11. OTV/MLM RENDEZVOUS WITH SPACE STATION USING OMV

MANNED LUNAR MISSION SCENARIO



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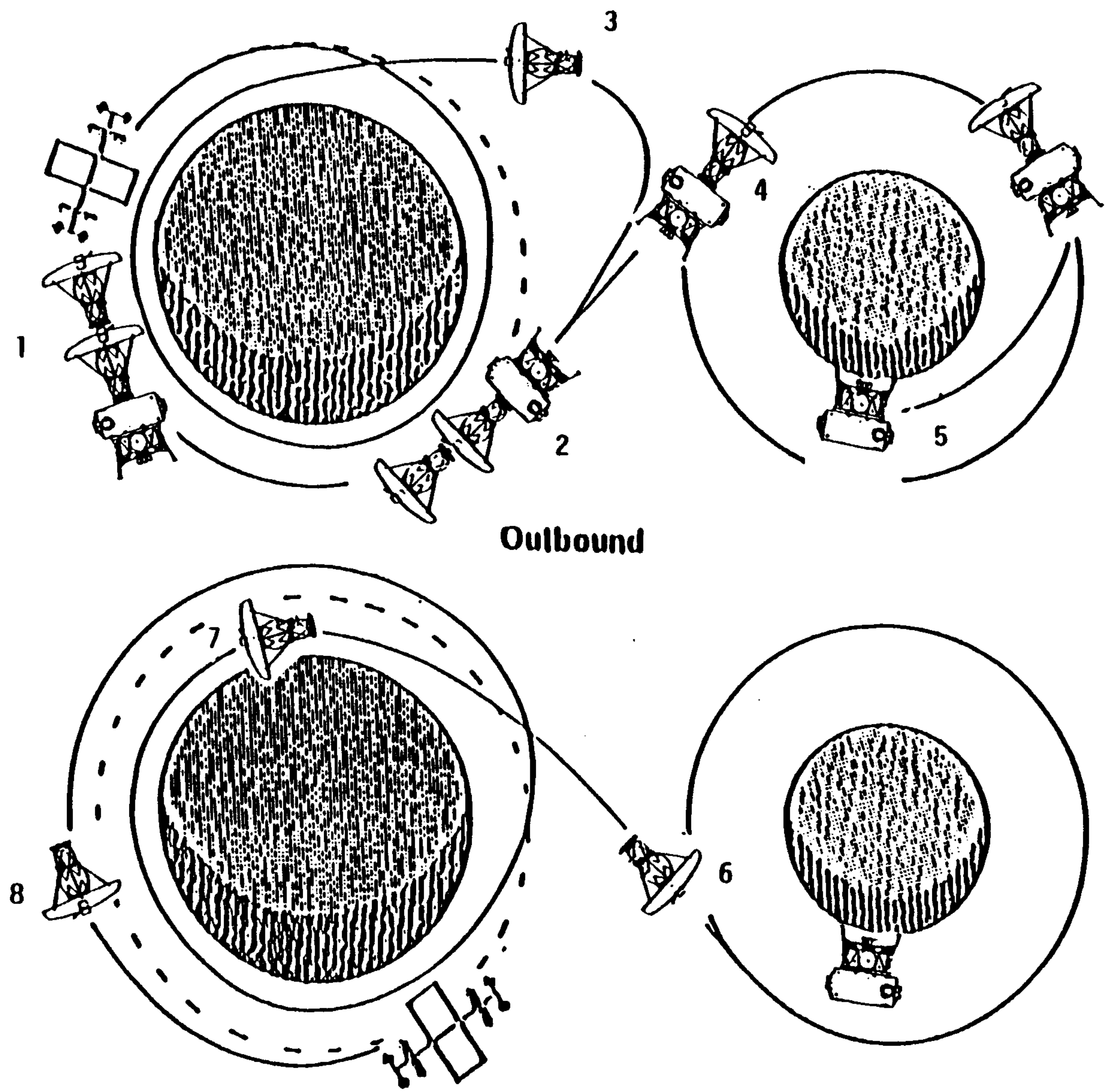
UNMANNED LUNAR MISSION SCENARIO

The delivery of unmanned cargo to the lunar surface begins the same as the manned missions with the departure from the space station after on-orbit assembly and verification. In this case, though, the vehicle is unmanned, requiring the delivery process to be either automated or controlled from ground stations. After departure, the first OTV stage will again perform the TLI burn and aerobrake back to LEO. After arrival in a lunar parking orbit, the cargo vehicle will descend to the lunar surface on an expendable descent stage and the orbiting OTV will return to earth and aerobrake back into LEO for rendezvous with the space station and eventual refurbishment for another mission.

UNMANNED LUNAR MISSION SCENARIO

1. STACK DEPARTS SPACE STATION
2. TRANS-LUNAR INJECTION BURN
3. FIRST OTV RETURNS TO SPACE STATION
4. SECOND OTV , CARGO MODULE, EXPENDABLE LANDER INSERT INTO LUNAR ORBIT
5. LANDER PLACES CARGO ON THE LUNAR SURFACE
6. SECOND OTV RETURNS TO EARTH
7. OTV AEROBRAKING FOR EARTH ORBIT INSERTION
8. OTV CIRCULARIZATION ABOVE SPACE STATION ORBIT
9. SECOND OTV RENDEZVOUS WITH SPACE STATION USING OMV

UNMANNED LUNAR MISSION SCENARIO



LUNAR OXYGEN MISSION SCENARIO

Beginning in 2006 with the production of lunar oxygen, the number of OTVs required to deliver personnel and equipment to the moon is reduced from two to one. After the lunar vehicle stack arrives in lunar orbit it will rendezvous with the Lunar Orbit Support Facility (LOSF) for resupply of lunar produced oxygen for the trip back to LEO. The lunar oxygen is delivered to the LOSF either by chemical means or by some other method such as an electro-magnetic mass accelerator. There will still be a requirement for the delivery of liquid hydrogen to the moon for use with the reusable ascent/descent (RAD) vehicle which comes on line in 2006 to replace the expendable ascent and descent stages used previously.

The use of lunar oxygen will greatly reduce the required mass in low earth orbit as shown in the previous weight in low earth orbit graph and thus reduce the number of required HLLV launches.

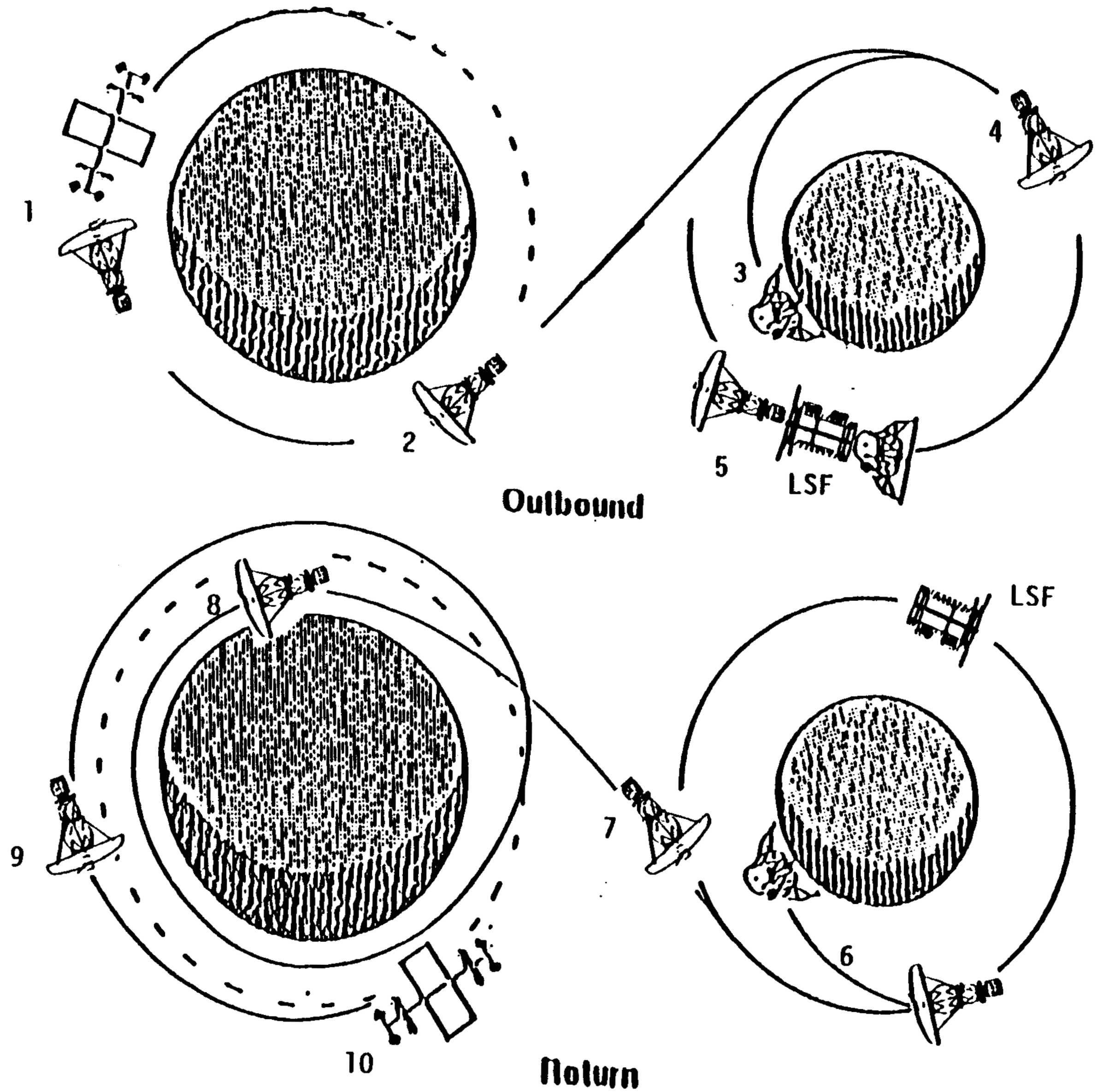
Lunar Base Accommodation Study

LUNAR OXYGEN MISSION SCENARIO

1. STACK DEPARTS SPACE STATION (1 OTV, MLM, HYDROGEN CARGO)
2. TRANS-LUNAR INJECTION BURN
3. REUSABLE LUNAR ASCENT/DESCENT STAGE ASCENDS TO LUNAR ORBIT SUPPORT FACILITY FROM LUNAR SURFACE
4. LUNAR STACK FROM EARTH INSERTS INTO LUNAR ORBIT
5. TRANSFER OF CREW AND PROPELLANT OCCURS ABOARD LUNAR ORBIT SUPPORT FACILITY
6. REUSABLE ASCENT/DESCENT STAGE RETURNS TO LUNAR SURFACE WITH NEW CREW AND HYDROGEN CARGO
7. OTV AND MLM TRANS-EARTH INJECTION BURN
8. OTV/MLM AEROBRAKE INTO EARTH ORBIT
9. OTV/MLM CIRCULARIZE ABOVE SPACE STATION ORBIT
10. OTV/MLM RENDEZVOUS WITH SPACE STATION

Lunar Base Accommodation Study

LUNAR OXYGEN MISSION SCENARIO



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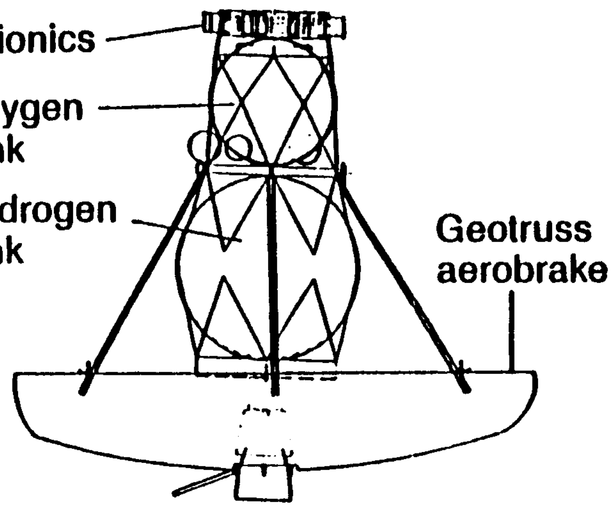
ORBITAL TRANSFER VEHICLE (OTV)

The Orbital Transfer Vehicle (OTV) shown on was sized so that a mated pair could deliver approximately 87,000 pounds to lunar orbit. The OTV pictured is based on studies conducted by Boeing Company and General Dynamics under recently completed Phase A concept studies.

The OTVs use liquid oxygen and liquid hydrogen propulsion systems with a specific impulse of 480 seconds. The OTVs are equiped with an aerobrake for atmospheric braking and the required avionics systems to complete the maneuver.

ORBITAL TRANSFER VEHICLE (OTV)



OTV

PROPELLANT WEIGHT	75,400 LBS.
DRY WEIGHT	11,500 LBS.
TOTAL WEIGHT	87,000 LBS.

I sp = 480 SEC.

MANNED LUNAR MODULE (MLM)

The Manned lunar module shown is designed to accommodate four crew personnel for transfer to the lunar surface. In the first year of operation the MLM will also be required to accommodate the lunar crew during their two week stay on the surface. The MLM is designed to be reusable from manned mission to manned mission with refurbishment and checkout occurring on-board the space station.

The MLM is based on studies conducted by Gordon Woodcock of Boeing Company and work done by Eagle Engineering.

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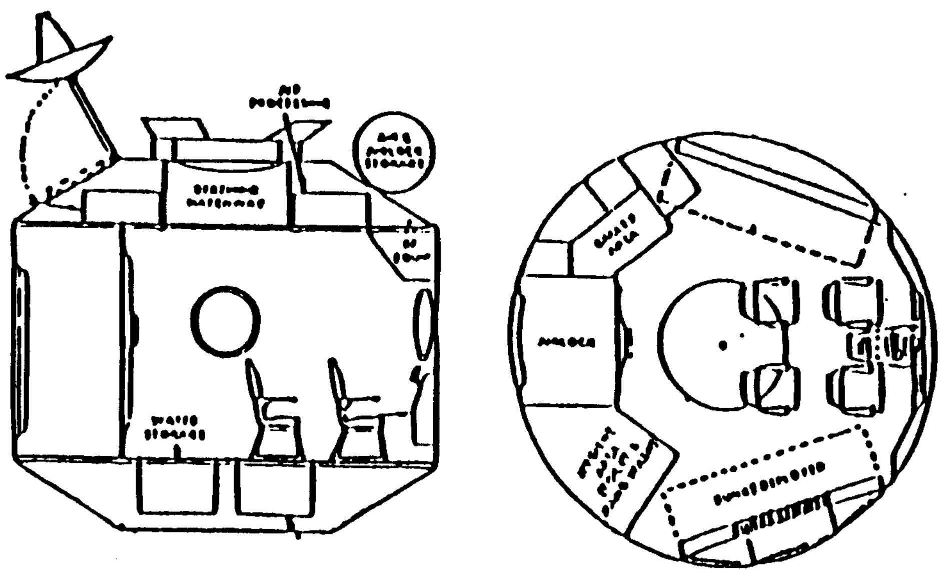
MANNED LUNAR MODULE (MLM)

MLM

TOTAL WEIGHT 13,200 LBS.

CREW OF 4

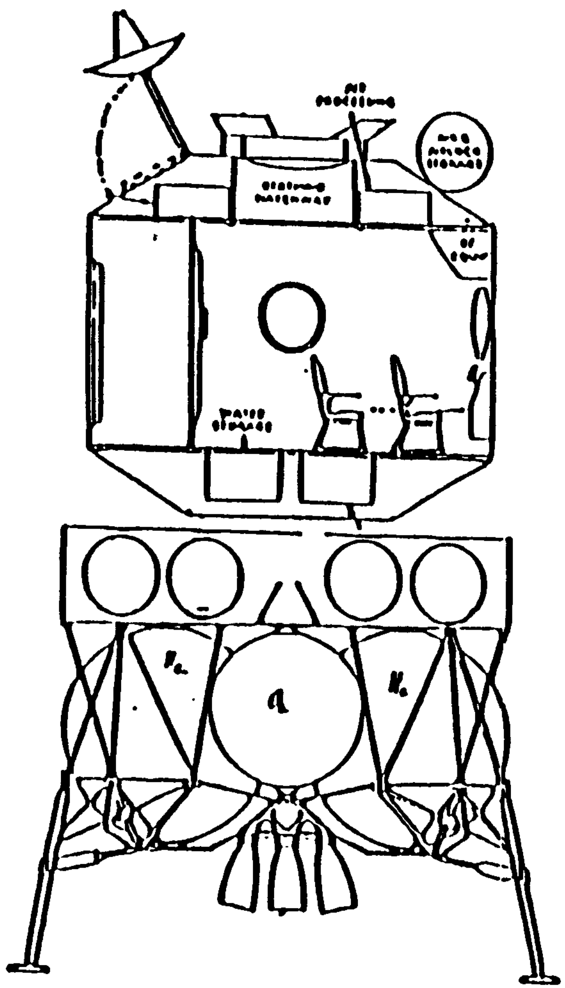


EXPENDABLE LUNAR EXCURSION MODULE (E-LEM)

The Expendable Lunar Excursion Module (E-LEM) consists of the afore mentioned Manned Lunar Module (MLM) and an expendable ascent and descent stage.

Lunar Base Accommodation Study

EXPENDABLE LUNAR EXCURSION MODULE (E-LEM)



MLM

TOTAL WEIGHT	13,200 LBS.

E-LAUNCHER

PROPELLANT WEIGHT	11,000 LBS.
DRY WEIGHT	5,720 LBS.
TOTAL WEIGHT	16,720 LBS.

E-LANDER*

PROPELLANT WEIGHT	29,920 LBS.
DRY WEIGHT	8,360 LBS.
TOTAL WEIGHT	38,280 LBS.

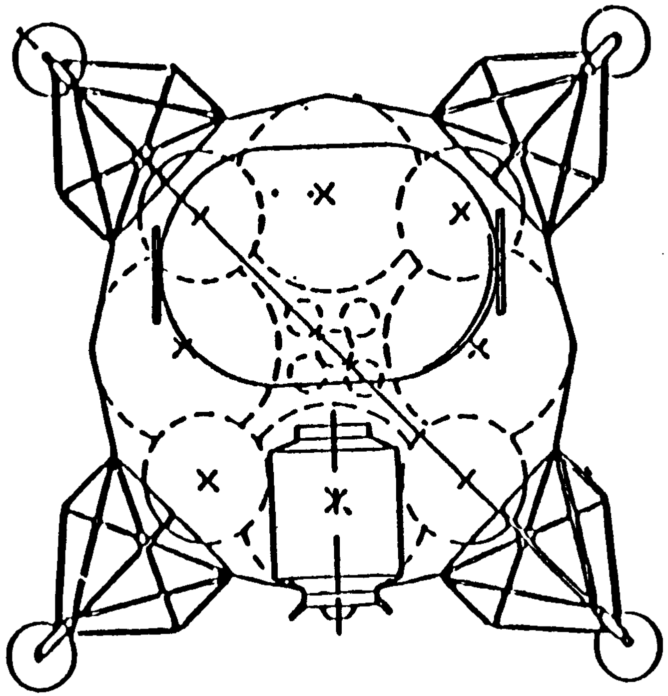
*DELIVERS 38,500 LBS. TO LUNAR SURFACE

REUSABLE ASCENT/DESCENT VEHICLE (RAD)

The Reusable Ascent/Descent (RAD) vehicle shown is based on the lunar surface, and is designed to replace the expendable ascent and descent stages used previously. The RAD will begin service in 2006 with the start of lunar oxygen production. The RAD will use the lunar produced oxygen but will require the delivery of liquid hydrogen fron earth in order to operate.

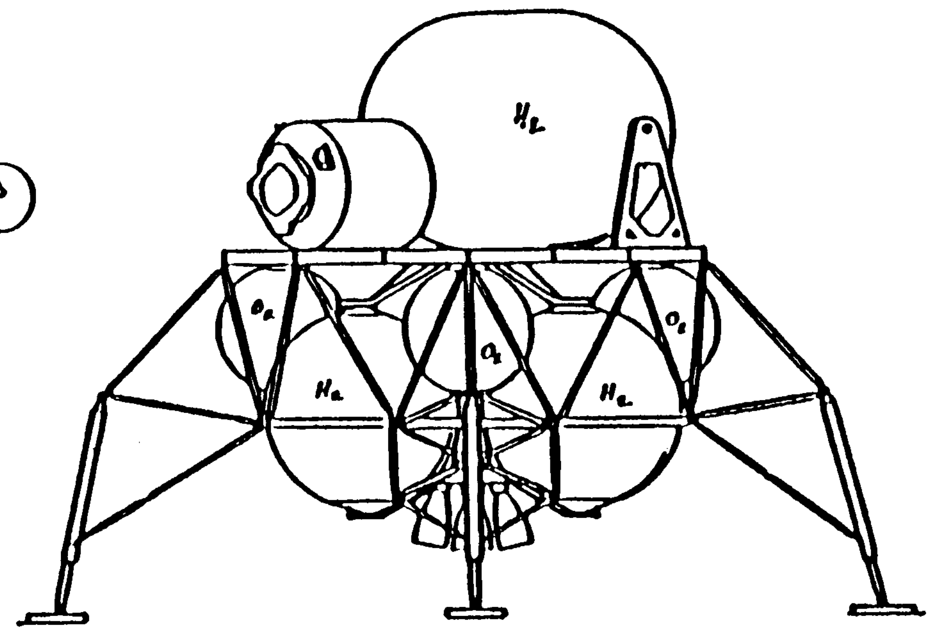
The RAD is designed to operate from the lunar surface to lunar orbit, where it will either deliver equipment arriving from earth to the lunar surface or transfer arriving and departing lunar base personnel.

REUSABLE ASCENT/DESCENT VEHICLE (RAD)



RAD

PROPELLANT WEIGHT	66,000 LBS.
DRY WEIGHT	11,440 L;BS.
TOTAL WEIGHT	77,400 LBS.

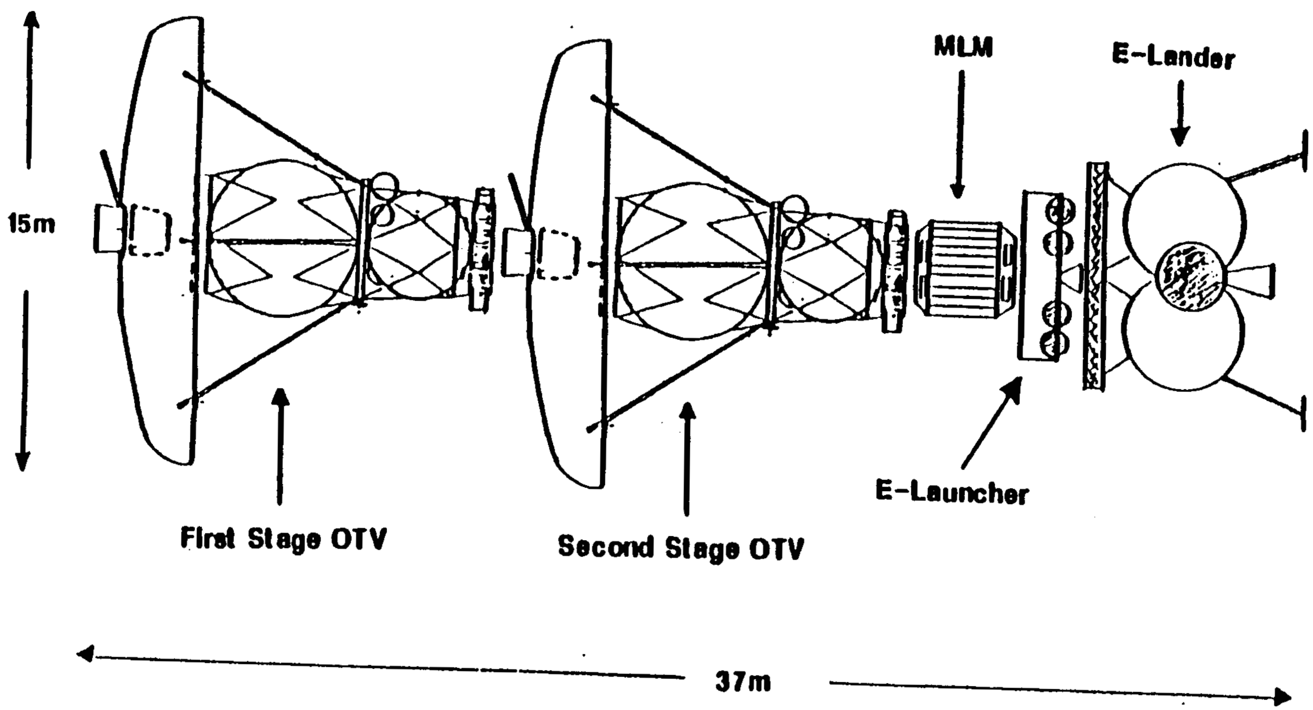


MANNED LUNAR VEHICLE STACK

The vehicle shown below is the fully assembled, manned lunar vehicle which departs the space station for trans lunar injection (TLI). The first stage OTV performs the TLI burn and then aerobrakes back into LEO for rendezvous with the space station. The second stage OTV brakes the vehicle into lunar orbit and performs the trans earth injection burn upon return. The crew is housed in the Manned Lunar Module during the trip to and from the moon.

Lunar Base Accommodation Study

LUNAR VEHICLE STACK



LUNAR VEHICLE STACK WEIGHT (LBS.)

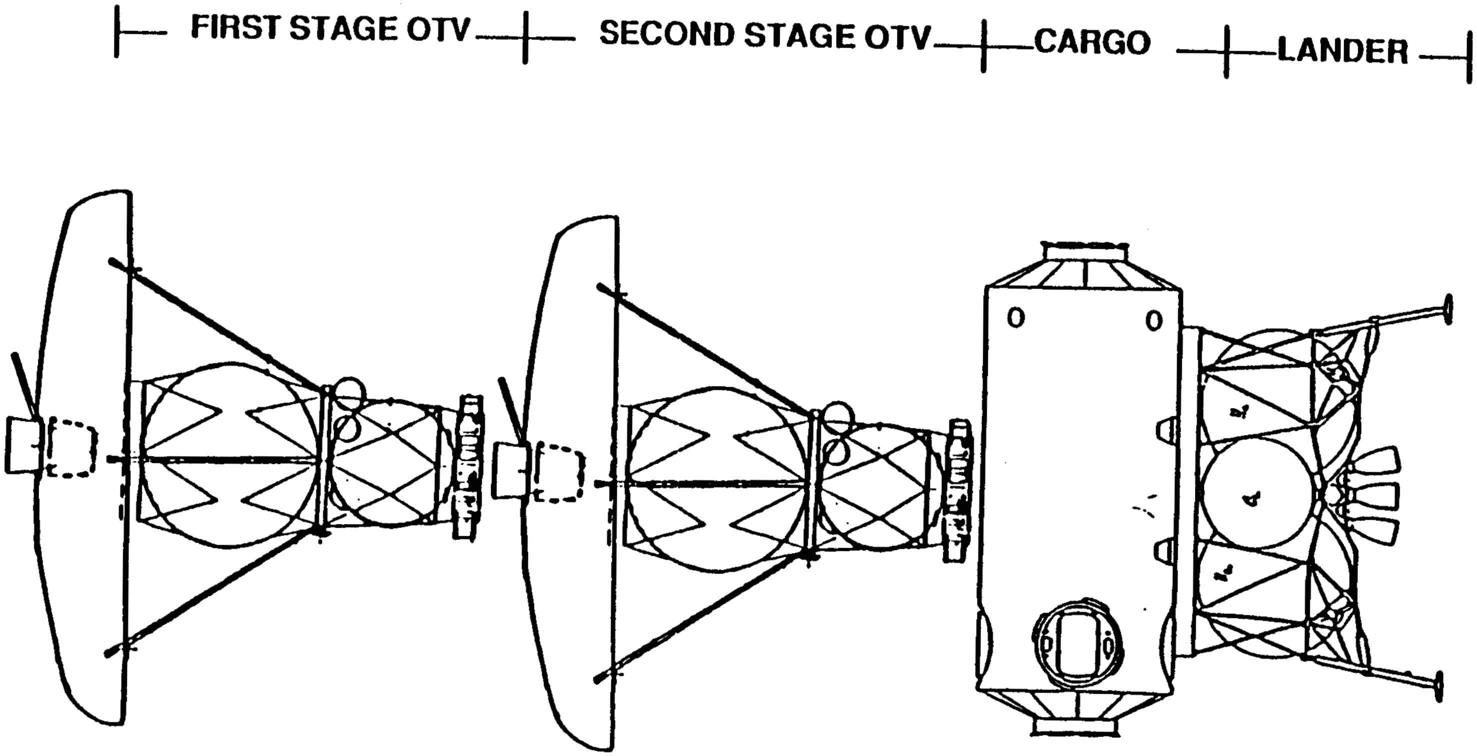
FIRST STAGE	= 87,000
SECOND STAGE	= 87,000
MLM	= 13,200
EXPENDABLE LANDER	= 38,200
EXPENDABLE LAUNCHER	= 16,720
TOTAL VEHICLE WEIGHT	= 242,200

UNMANNED LUNAR VEHICLE STACK

The complete unmanned lunar vehicle stack is designed to deliver 77,500 pounds of cargo to lunar orbit. The lunar vehicle has two OTV stages, the first being for the TLI burn and the second to park the vehicle into lunar orbit and then perform the TEI burn. The 77,500 pounds of cargo consists of a 38,500 pound expenable descent stage and 38,500 pounds of equipment.

Lunar Base Accommodation Study

UNMANNED LAUNCH STACK



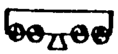
FIRST STAGE WEIGHT	87,000 LBS.
SECOND STAGE WEIGHT	87,000 LBS.
E-LANDER WEIGHT	38,280 LBS.
CARGO WEIGHT	38,500 LBS.
TOTAL WEIGHT	250,780 LBS.

LUNAR MISSION VEHICLE SUMMARY

The chart summarizes the design and performance characteristics of all of the required lunar mission vehicles.

Lunar Base Accommodation Study

LUNAR MISSION VEHICLE SUMMARY

SYMBOL	ELEMENT	TOTAL MASS	DRY MASS	PROPELLANT MASS	CAPACITY
	OTV	39,500 Kg (87,000 LBM)	5,250 Kg (11,600 LBM)	34,300 Kg (75,400 LBM)	Deliver 35000 Kg to LLO and return to LEO
	MLM	6,000 Kg (13,200 LBM)	-	-	Carry crew of 4 from LEO to Lunar Surface and back to LEO
	E-Lander	17,400 Kg (38,280 LBM)	3,800 Kg (8,360 LBM)	13,600 Kg (29,920 LBM)	Deliver 17,500 Kg to Lunar surface
	E-Launcher	7,600 Kg (16,720 LBM)	2,600 Kg (5,720 LBM)	5,000 Kg (11,000 LBM)	Carry LLMM and 500 Kg payload from Lunar surface to LLO
	RAD	35,200 Kg (77,400 LBM)	5,200 Kg (11,440 LBM)	30,000 Kg (66,000 LBM)	Deliver 17,500 Kg to surface w/no payload return, or 14,500 Kg to surface w/7000 Kg payload return
	RAD-MLM	5,000 Kg (11,000 LBM)	-	-	Holds crew of 6 (normal), 10 (max.)
	Large MLM	8,000 Kg (17,600 LBM)	-	-	Holds crew of 6 (normal), 10 (max.)
	HLLV	2,066,040 Kg (4,545,290 LBM)	:-	-	Deliver 68,000 Kg - 90,000 Kg to LEO

SUMMARY

The proposed manned lunar base program which has been outlined here is ambitious in both the amount of equipment which must be transported to the moon and the timescale in which the mission is to be conducted. In order to accomplish this scenario it is necessary that it be conducted in a safe and orderly manner. The development of highly operable transporation vehicles that can be readily refurbished for multiple missions is of extreme importance if this program is to be feasible in a reasonable manner. The vehicles, equipment, and operations must be designed and constructed to be safe and withstand the years of rugged use.

The three phase program allows for the orderly establishment of a permanent manned lunar facility with the potential for unlimited growth.

SUMMARY

- 3 PHASED LUNAR PROGRAM (PREPARATORY EXPLORATION, RESEARCH OUTPOST, OPERATIONAL BASE)
- 3 OTV'S MUST BE AVAILABLE TO INITIATE MANNED LUNAR MISSIONS
- MUST AVOID SINGLE POINT FAILURE DESIGNS AND SCENARIOS
- MUST DESIGN LUNAR VEHICLES TO BE HIGHLY OPERATIONAL AND EASY TO MAINTAIN AND REPAIR

LUNAR BASE ACCOMMODATION STUDY

SPACE STATION INTERFACES

PRESENTED BY: MARTIN KASZUBOWSKI
PRC

JUNE 18, 1987

LUNAR BASE ACCOMMODATION STUDY

OUTLINE

This chart shows the outline that will be followed in this section of the report.

Lunar Base Accommodation Study

OUTLINE

- APPROACH
- DESCRIPTION OF LUNAR VEHICLE BASING OPTIONS
- EVALUATION OF SS INTERFACES
  - CONFIGURATION ANALYSIS
  - OTHER CONSIDERATIONS
  - SUGGESTED FURTHER ANALYSIS
- CONCLUSIONS

LUNAR BASE ACCOMMODATION STUDY

ANALYSIS RATIONALE

There are three parts to this section of the study. The requirements for on-orbit support facilities were determined, a quantitative analysis of the CETF IOC station was performed with the lunar support facilities attached, and finally a system level impact analysis was performed for the CETF IOC station and alternative facilities.

LUNAR VEHICLE ACCOMMODATION ANALYSIS RATIONALE

APPROACH

- o GIVEN LUNAR MISSION AND VEHICLE REQUIREMENTS, DETERMINED ON-ORBIT FACILITY REQUIREMENTS BASED ON MASS AND SIZE OF EQUIPMENTS TO BE ACCOMMODATED

- o USING IOC - SPACE STATION AS THE BASIC ACCOMMODATION MODE, DETERMINED LOCATIONS FOR THE LUNAR VEHICLE SUPPORT FACILITIES CONSIDERING:

  - VIEWING
  - MICRO-GRAVITY
  - SAFETY
  - ACCESS (IVA & EVA)
  - GN&C
  - ORBITAL PARAMETERS

- o DEVELOPED ALTERNATIVE ACCOMMODATION MODES AND CONDUCTED CONFIGURATION/SYSTEMS ANALYSES TO DETERMINE MINIMUM IMPACTS ON IOC-SPACE STATION ACTIVITIES

LUNAR BASE ACCOMMODATION STUDY

MASS AND SIZE OF EQUIPMENT TO BE ACCOMMODATED

This chart shows the mass and size of each of the major components needed for lunar mission support. As will be shown in succeeding charts, the size, mass, and surface area of the vehicle hangar and the mass of propellant produce the most significant impacts to the station. In particular, the placement of the hangar and propellant tanks on the station greatly affects the behavior of the system in terms of static microgravity envelope, Torque Equilibrium Angles (TEA), and control system requirements.

Lunar Base Accommodation Study

MASS AND SIZE OF EQUIPMENT TO BE ACCOMMODATED

EQUIPMENT NAME	MASS	SIZE
3 OTVs (2 STACKED IN HANGAR, 1 STOWED)	5,250 KG EA.	LENGTH = 12.2 M DIAM. = 15.2 M
OTV HANGAR WITH SUPPORT EQUIPMENT	15,500 KG	LENGTH = 45 M HEIGHT = 25 M WIDTH = 20 M
4 PROPELLANT TANKS (2 FOR LO2, 2 FOR LH2)	8,850 KG EA.	LENGTH = 15 M DIAM. = 5 M
PROPELLANT MASS LO2: LH2:	 156,000 KG 26,000 KG	 ------------- -------------
ADDITIONAL CREW MODULE	31,500 KG	LENGTH = 14.8 M DIAM. = 4.4 M
PAYLOAD FOR DELIVERY TO LUNAR SURFACE	16,000 KG	LENGTH = 18 M DIAM. = 3 M
EXPENDABLE LUNAR LANDER (W/FUEL)	17,400 KG	LENGTH = 7 M DIAM. = 8.7 M
EXPENDABLE LUNAR LAUNCHER (W/FUEL)	7,600 KG	LENGTH = 2 M DIAM. = 5 M
2 MANNED LUNAR MODULES (MLM)	6,000 KG EA.	LENGTH = 3.6 M DIAM. = 4.3 M

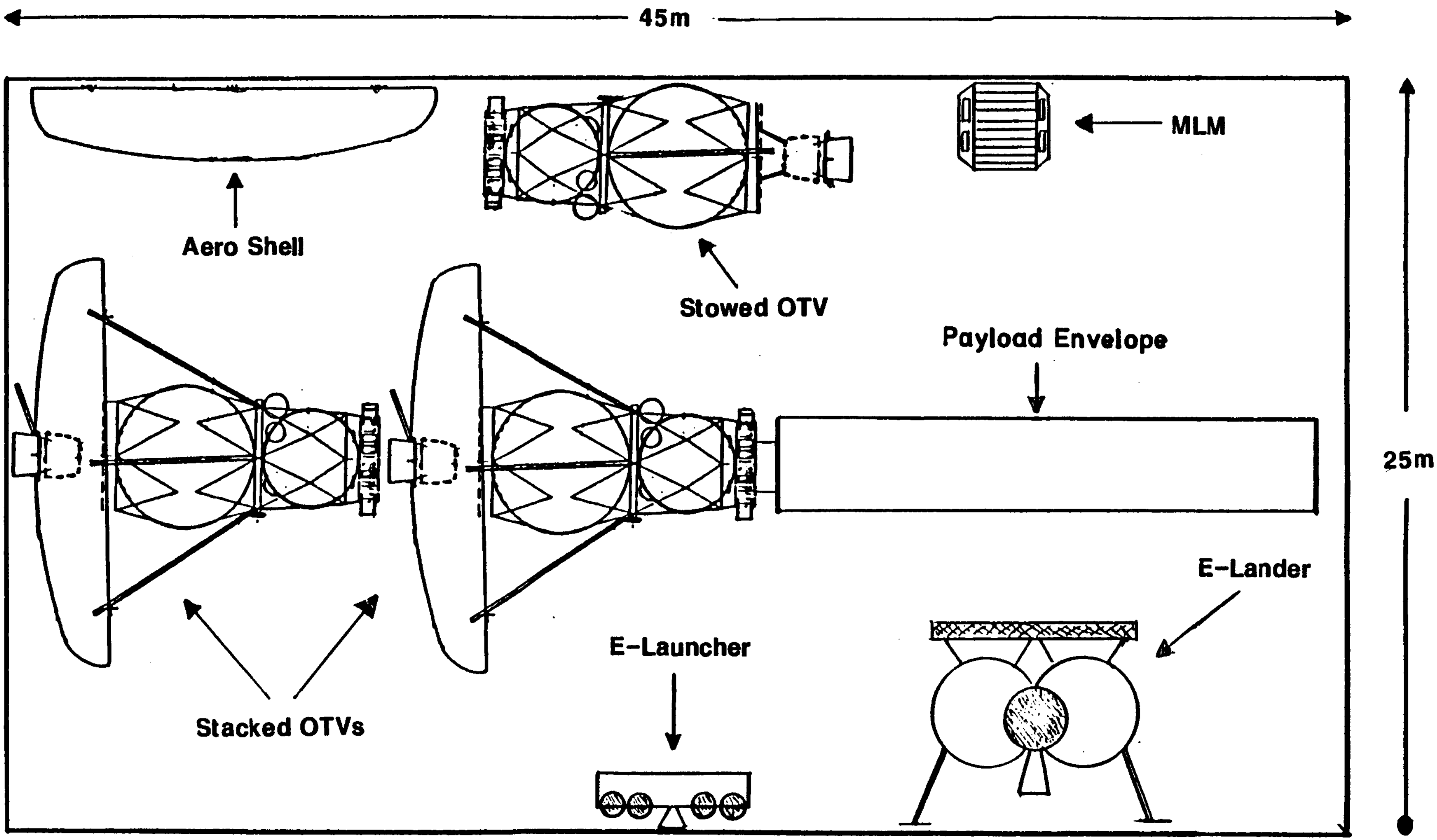
LUNAR BASE ACCOMMODATION STUDY

STATION BASED OTV HANGER

This figure shows a complete lunar vehicle stacked inside the hangar with extra equipment stowed. This shows the relative sizes of the hangar and the hardware needed to accommodate a lunar mission.

Lunar Base Accommodation Study

Station Based OTV Hanger



LUNAR VEHICLE ACCOMMODATIONS OPTIONS

The analysis of configurations for lunar vehicle preparation and maintenance facilities considered the four basic options described. Only options #1 and #2 were analyzed for their impact on the station since, by definition, options #3 and #4 produce little or no impact.

LUNAR VEHICLE ACCOMMODATION OPTIONS

- OPTIONS CONSIDERED IN THIS STUDY WERE:
  - OPTION # 1 - ALL VEHICLE ACCOMMODATIONS BASED ON STATION
  - OPTION # 2 - VEHICLE HANGAR BASED ON STATION BUT PROPELLANT LOCATED ON A CO-ORBITING FACILITY
  - OPTION # 3 - ALL VEHICLE ACCOMMODATIONS EXCEPT CREW HABITATION MODULE BASED ON A CO-ORBITING FACILITY
  - OPTION # 4 - ALL VEHICLE ACCOMMODATIONS INCLUDING CREW MODULE BASED ON A CO-ORBITING FACILITY

- OPTIONS 1 AND 2 WERE ANALYZED IN DETAIL FOR IMPACT ON IOC - SPACE STATION

LUNAR BASE ACCOMMODATION STUDY

STATION BASED (OPTION #1)

Option #1 includes all lunar vehicle preparation and maintenance facilities on the station. The four sub-options listed were analyzed and represent a wide range of the effects produced by moving the support facilities to various locations on the station. These four sub-options are described on the next four charts.

Lunar Base Accommodation Study

STATION BASED (OPTION #1)

- ALL LUNAR MISSION SUPPORT FACILITIES ON STATION:
  - OPTION 1A - HANGAR AND TANKS ON OPPOSITE SIDES OF TRANSVERSE BOOM
  - OPTION 1B - TANKS ABOVE HANGAR ON SAME SIDE OF TRANSVERSE BOOM
  - OPTION 1C - TANKS BELOW HANGAR ON SAME SIDE OF TRANSVERSE BOOM
  - OPTION 1D - TANKS AND HANGAR ALIGNED ON SAME SIDE OF TRANSVERSE BOOM

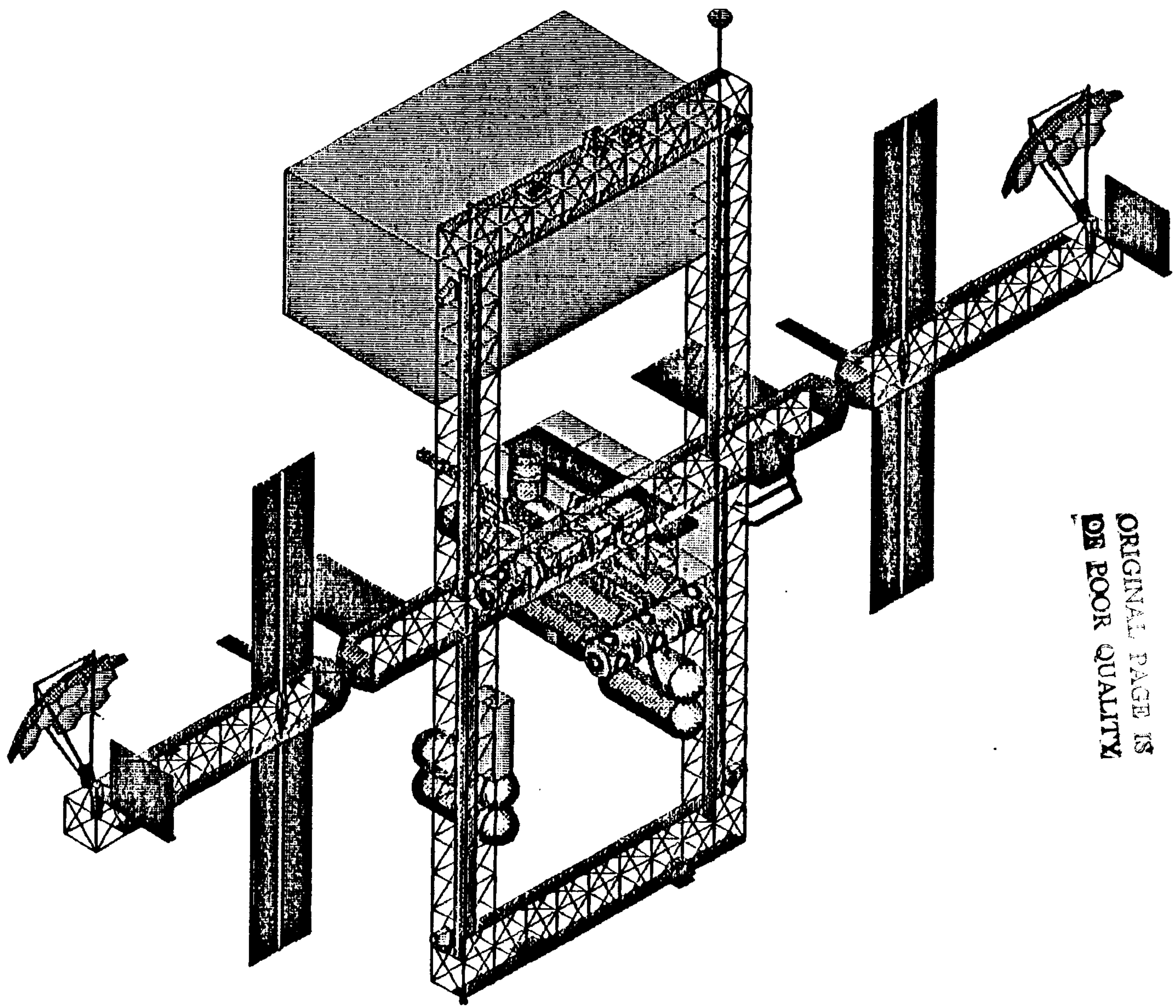
STATION CONFIGURATION (OPTION #1A)

Option #1A has the propellant tanks below the transverse boom and attached to the lower keels, while the vehicle hangar is above the boom at the top of the upper keels. This option was chosen for study because it allows the system to be balanced by strategic placement of the propellant tanks.

It is important to note that the analysis of option #1A, as well as that of each option that follows, maintained the standard cartesian coordinate system of the CETF IOC station. The center of the coordinate system is in the middle of the center bay of the transverse boom with the positive X-axis extending into the velocity vector (out of the page and to the right in the view shown). The positive Y-axis extends along the boom to the left of the picture, while the positive Z-axis points toward earth (to the bottom of the picture) through the lower boom.

Lunar Base Accommodation Study

STATION CONFIGURATION (OPTION 1A)



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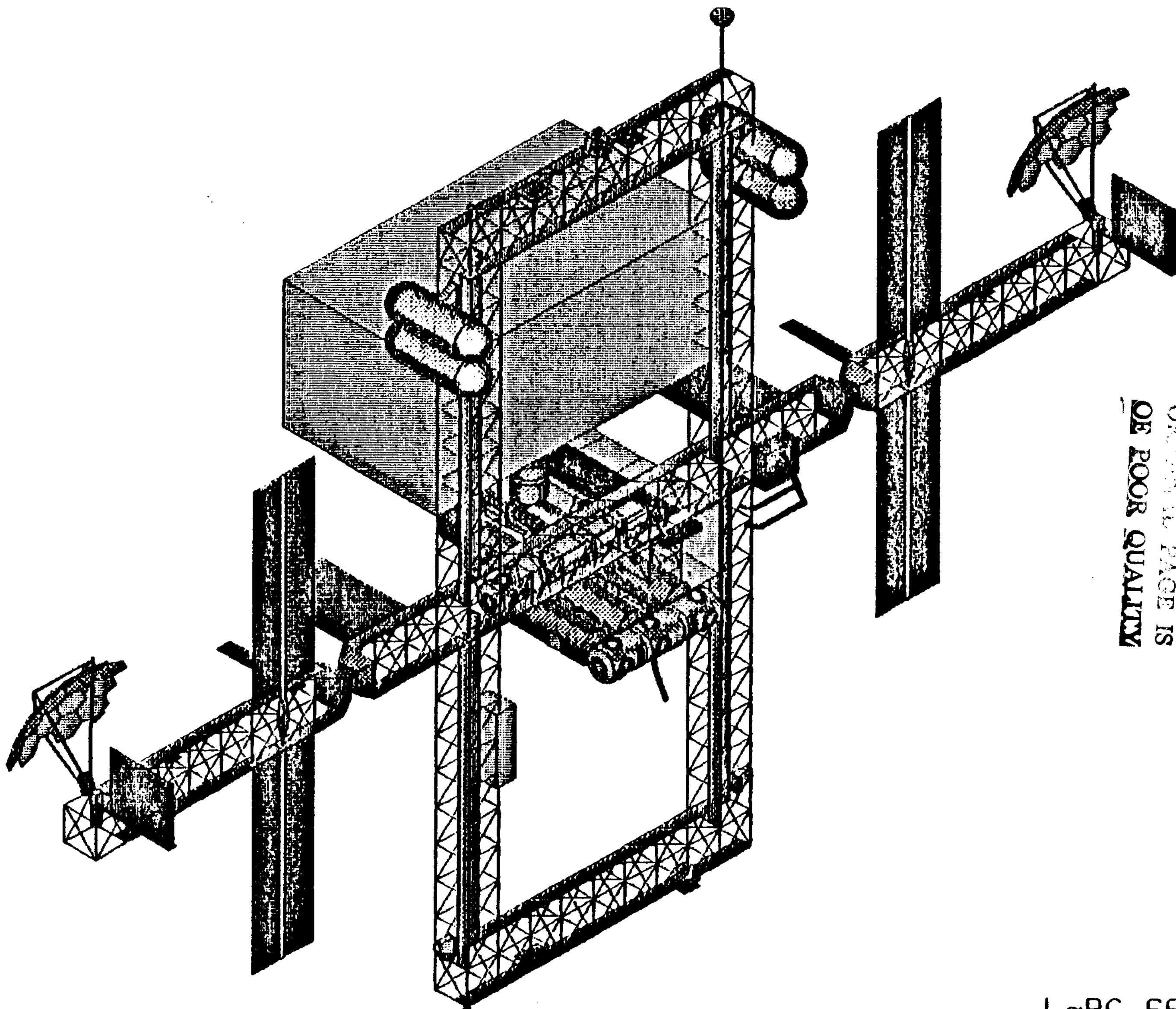
LUNAR BASE ACCOMMODATION STUDY

STATION CONFIGURATION (OPTION #1B)

Option #1B shows the tanks at the extreme top of the upper keels with the hangar just below. The next three options were studied to show the effects of varying the relative locations of the tanks and hangar.

Lunar Base Accommodation Study

STATION CONFIGURATION (OPTION 1B)



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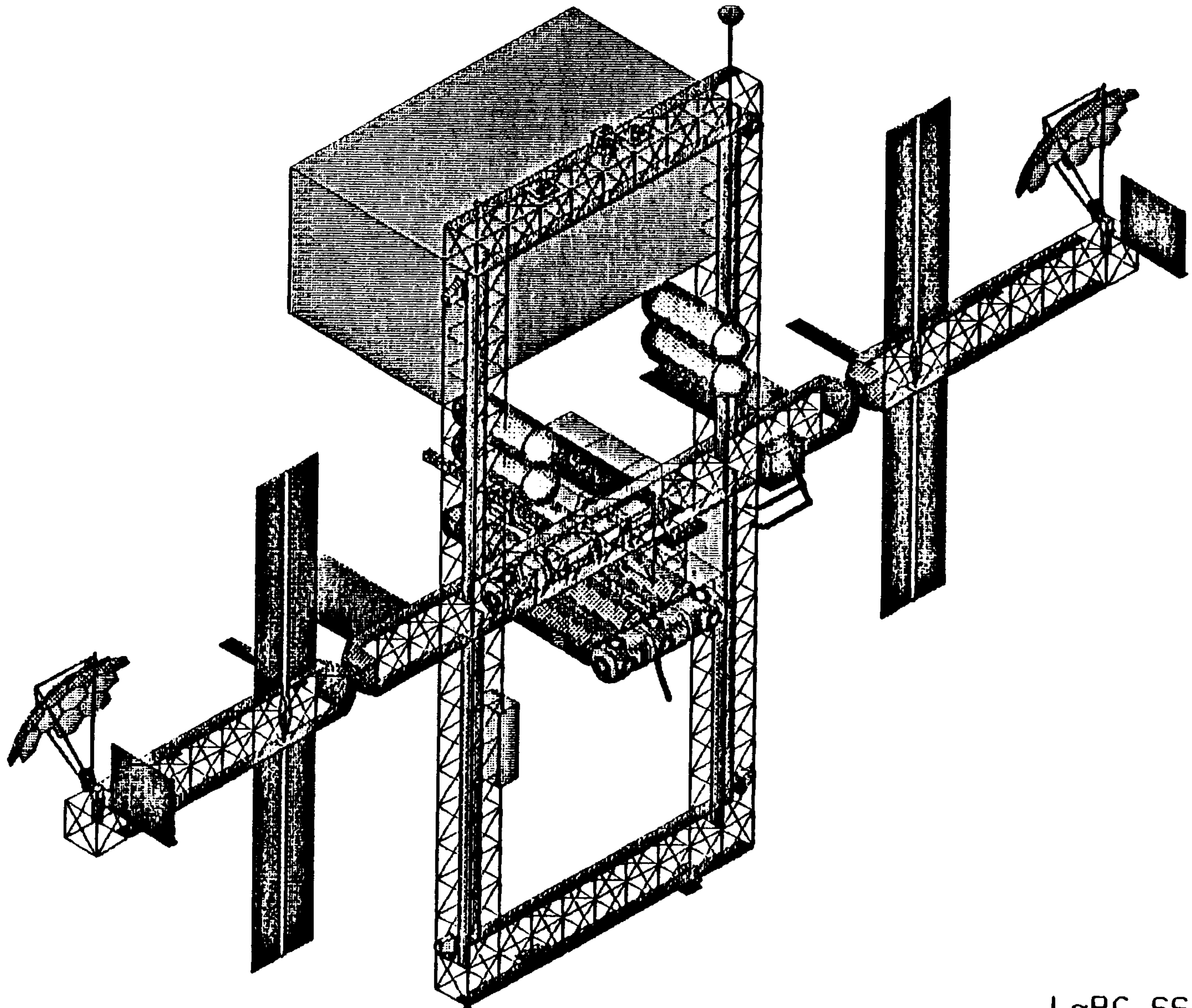
LUNAR BASE ACCOMMODATION STUDY

STATION CONFIGURATION (OPTION #1C)

Option #1C shows the hangar at the extreme top of the upper keels with the tanks just below

Lunar Base Accommodation Study

STATION CONFIGURATION (OPTION 1C)



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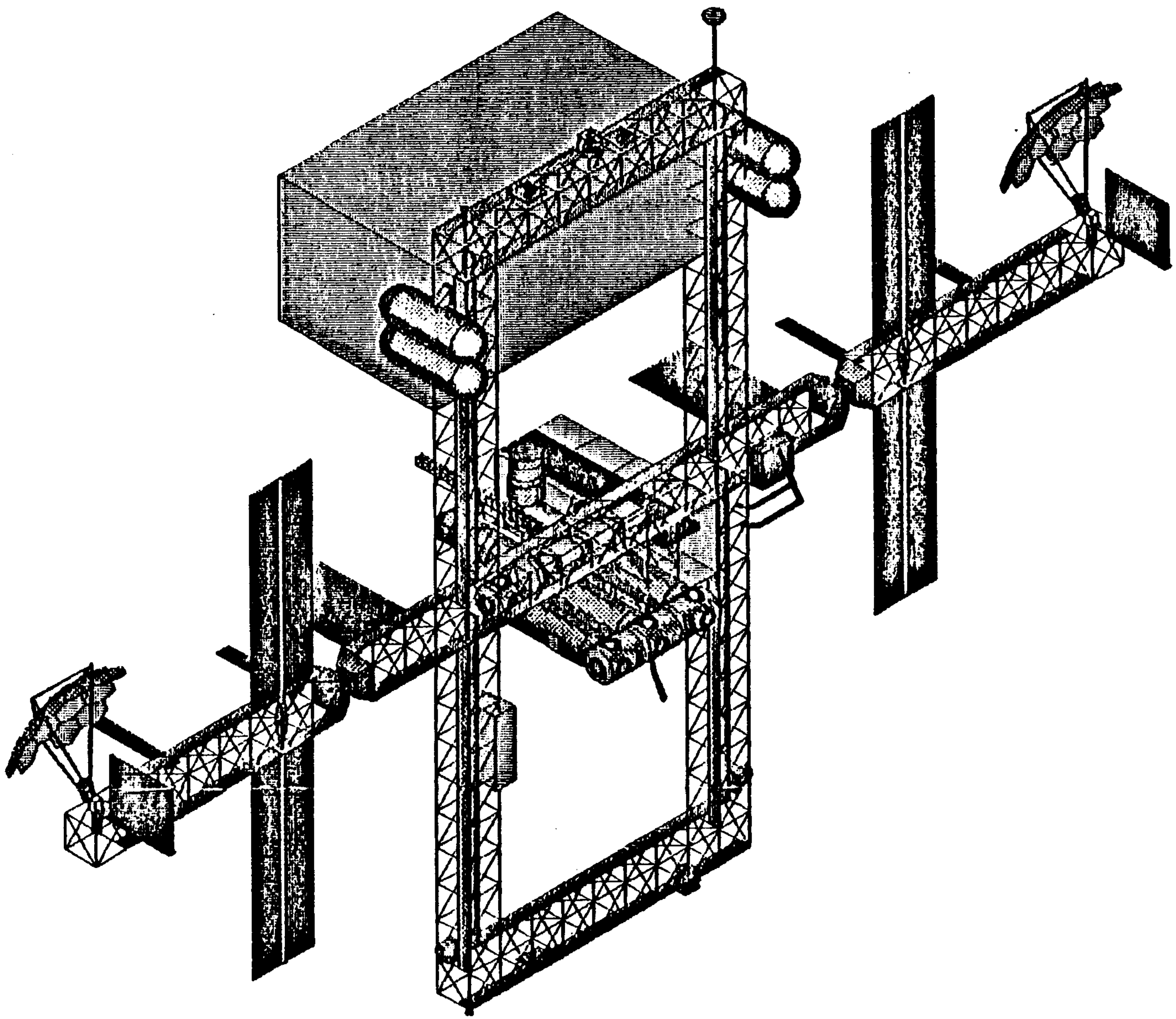
LUNAR BASE ACCOMMODATION STUDY

STATION CONFIGURATION (OPTION #1D)

Option #1D shows the hangar at the top of the upper keels and the tanks attached to the keels near the middle of the hangar.

Lunar Base Accommodation Study

STATION CONFIGURATION (OPTION 1D)



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LUNAR BASE ACCOMMODATION STUDY

STATION BASED W/PTF (OPTION #2)

Option #2 has all the support facilities, except the propellant, located on the station. In this configuration the propellant tanks are kept on a co-orbiting Propellant Tank Farm (PTF). Two sub-options are shown on the following charts.

No effort has been made to develop detailed concepts for a PTF. However, a few of the important features that this type of structure would have to incorporate are :

1. Robotic capability for maneuvering and re-positioning propellant tanks.
2. Power to support propellant pumping, robotics, and a moderately sophisticated Data Management System (DMS).
3. Docking ports for OMVs with completely assembled lunar vehicles.

STATION BASED W/PTF (OPTION # 2)

- ALL LUNAR BASE SUPPORT FACILITIES EXCEPT PROPELLANT STORAGE AND HANDLING ARE BASED ON STATION:
  - OPTION 2A - HANGAR AT TOP OF KEELS
  - OPTION 2B - HANGAR NEAR TRANSVERSE BOOM

- ALL PROPELLANT RELATED OPERATIONS ARE DONE AT A CO-ORBITING PROPELLANT TANK FARM (PTF)
  - DESIGNED FOR MINIMUM MAINTENANCE
  - EMPHASIS ON AUTOMATION AND ROBOTICS (A&R)

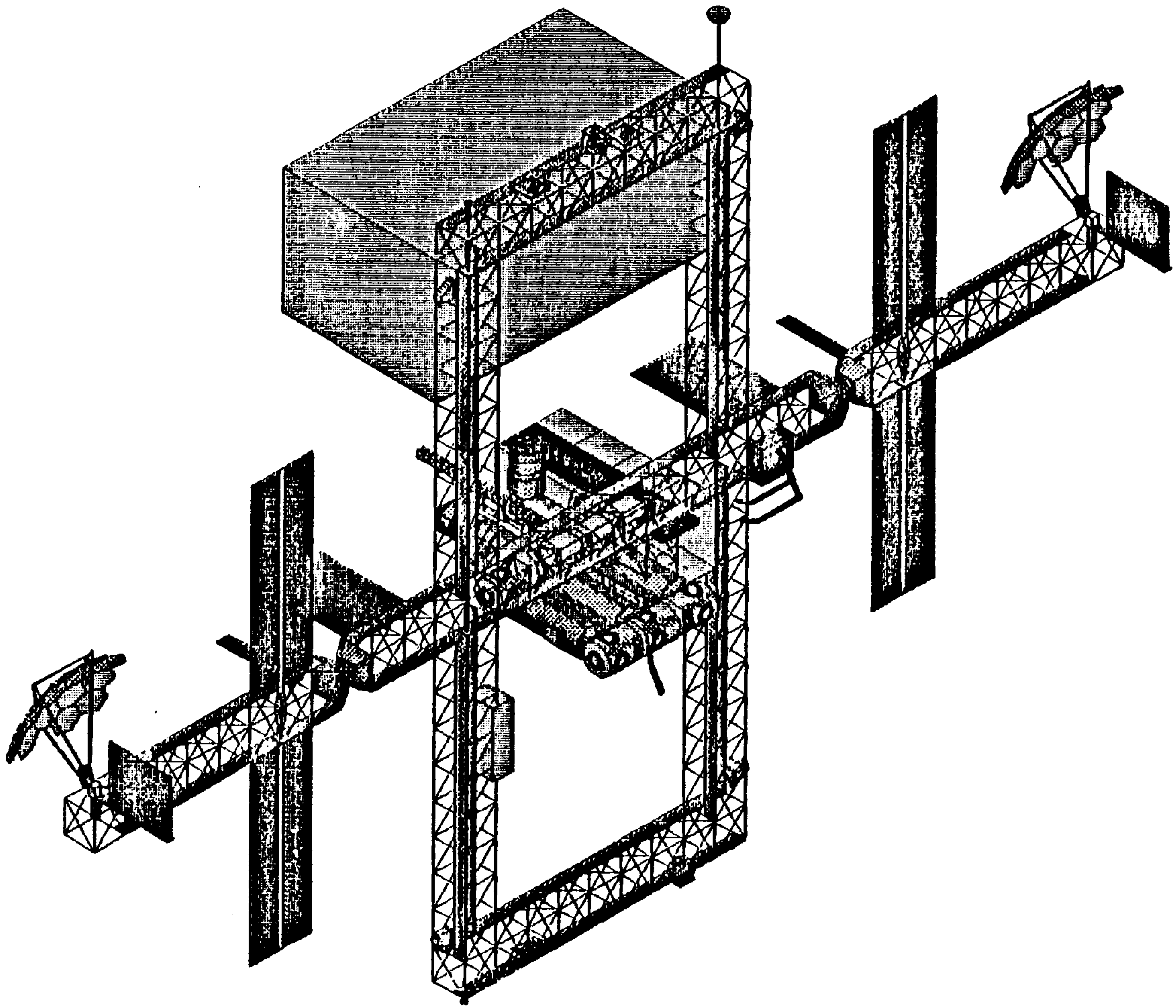
LUNAR BASE ACCOMMODATION STUDY

STATION WITH HANGAR (OPTION #2A)

Option #2A is shown with the vehicle hangar at the top of the upper keels. Options #2A and #2B were studied to determine how the performanse of the system changes with different hangar locations.

Lunar Base Accommodation Study

STATION WITH HANGAR (OPTION 2A)



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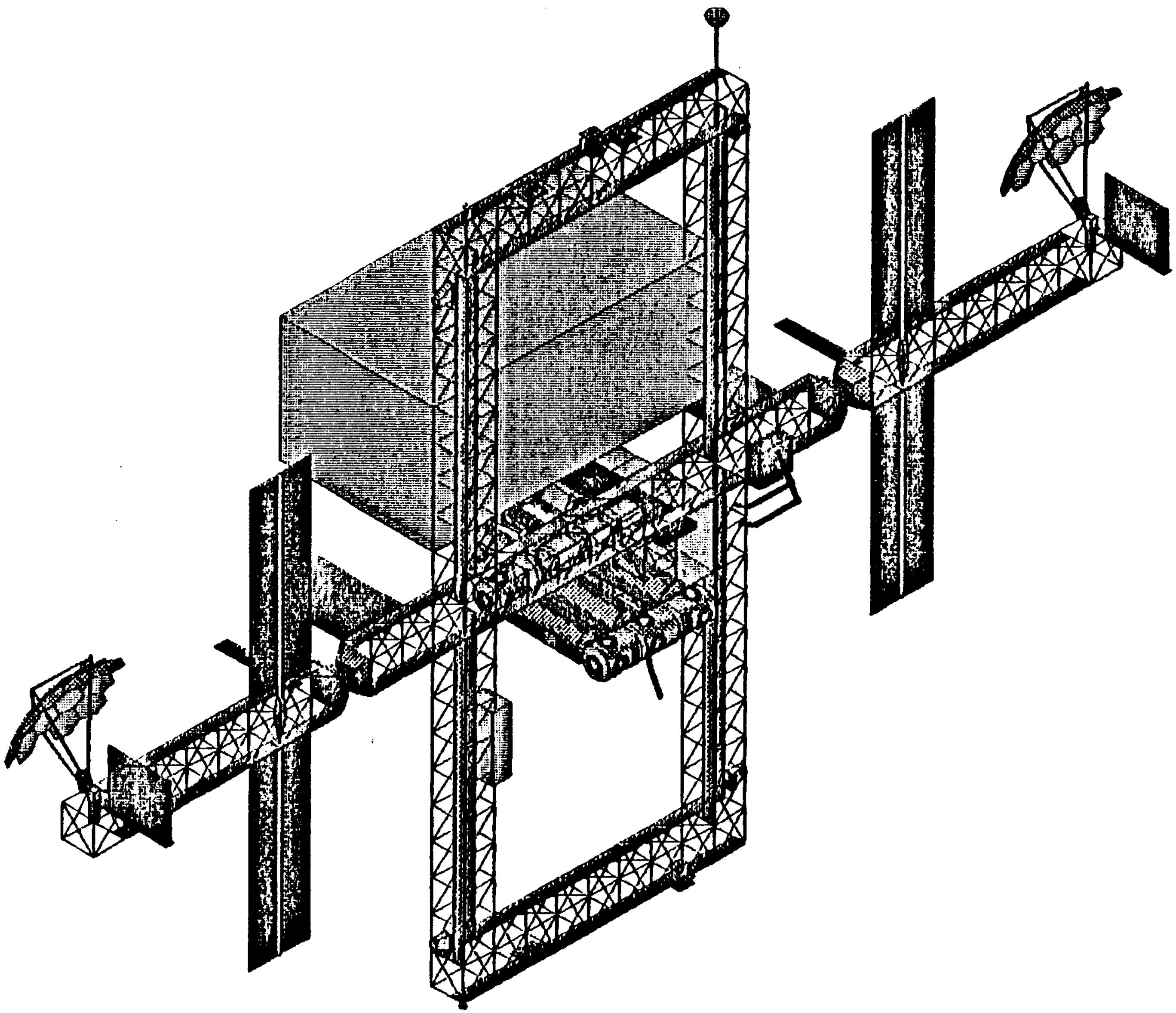
LUNAR BASE ACCOMMODATION STUDY

STATION WITH HANGAR (OPTION #2B)

Option #2B is shown with the vehicle hangar near the transverse boom.

Lunar Base Accommodation Study

STATION WITH HANGAR (OPTION 2B)



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LUNAR BASE ACCOMMODATION STUDY

CONFIGURATION ANALYSIS

The quantitative analysis of options #1 and #2 followed the approach described on this chart. Results were obtained for each of the sub-options and were compared to corresponding results for the CETF IOC station. Again, no analysis was performed for options #3 and #4 since, by definition, their impact on the station was minimal.

CONFIGURATION ANALYSIS

APPROACH:

- o FOR OPTIONS # 1 AND #2 QUANTITATIVELY EVALUATE THE FOLLOWING CHARACTERISTICS:
  - MASS PROPERTIES
  - RIGID BODY ATTITUDE/CONTROL SYSTEM SIZING
    - o ATTITUDE CONTROL ANALYSIS PERFORMED AT 250 N.M. ALTITUDE.
    - o 2 SIGMA ATMOSPHERE MODEL USED FOR ORBIT DECAY ANALYSIS - ANALYSIS STARTED AT JULY 4, 2000.
  - MICRO-GRAVITY ENVIRONMENT
  - ORBIT LIFETIME
- o NO ANALYSIS FOR OPTIONS #3 AND #4 SINCE OPERATIONS ARE PERFORMED ON A CO-ORBITING FACILITY

MASS PROPERTIES

The chart shown contains mass property data for each of the sub-options and for the CETF IOC station. Note that the placement of the hangar and tanks on option #1A maintains the location of the Center of Mass (C.M.) along the Z-axis in nearly the same location as the CETF IOC station, while for the other options the C.M. is offset significantly. This indicates that by varying the location of the hangar and tanks the system may be balanced in order to minimize the effects on the performance of the station. However, when the tanks and the hangar are seperated as great a distance as they are with option #1A, many other the problems, such as those associated with transferring propellant to the vehicle, will likely be compounded. Clearly, a trade is required to compromise between the beneficial effects of mass balancing, and the possibly detrimental effects of placing hardware and propellant were their utilization may be difficult.

MASS PROPERTIES

CONFIGURATION	MASS ($KG*10^3$)	CENTER OF MASS (M)			MOMENT OF INERTIA ($KG*M^2 x10^7$)			PRODUCT OF INERTIA ($KG*M^2 x10^6$)			PRINCIPAL TO BODY AXIS ROTATION ANGLES (DEG)		
		X	Y	Z	I_{XX}	I_{YY}	I_{ZZ}	I_{XY}	I_{XZ}	I_{YZ}	$\Psi(Z)$	$\theta(Y)$	$\phi(X)$
CETF IOC STATION	267	-3.5	-0.9	3.2	31.0	9.1	25.6	1.76	-1.54	-1.87	0.5	1.6	0.7
OPTION 1 A	517	-4.9	0.2	5.0	57.3	32.4	32.1	4.72	27.8	-1.12	1.7	-6.1	-5.8
OPTION 1 B	517	-3.6	0.2	-11.8	61.2	30.9	37.9	4.56	-1.97	0.94	0.9	0.5	-0.7
OPTION 1 C	517	-3.6	0.2	-8.5	48.6	23.8	32.4	4.58	19.9	0.53	1.1	-6.9	-0.7
OPTION 1 D	517	-3.6	0.2	-13.9	64.9	34.6	37.9	4.56	10.0	1.19	0.9	-2.1	-2.3
OPTION 2 A	378	-4.9	0.3	-4.1	42.5	20.5	28.7	4.72	27.9	-0.01	1.3	-10.9	-0.7
OPTION 2 B	378	-4.9	0.3	-0.3	35.5	13.4	28.7	4.72	13.7	-0.46	1.2	-11.1	-0.2

CONFIGURATION ANALYSIS

The most significant results of the calculation of the mass properties are summarized on this chart.

CONFIGURATION ANALYSIS

MASS PROPERTIES:

- o MICRO-GRAVITY ENVELOPE, TORQUE EQUILIBRIUM ANGLES (TEAs), AND SECULAR MOMENTUM BUILD-UP ARE HIGHLY DEPENDENT ON CENTER OF MASS (C.M.) LOCATION ALONG Z-AXIS.
  - IOC STATION HAS C.M. OFFSET OF 3.2 M IN +Z DIRECTION
  - PROP. TANKS ON OPTION 1A WERE PLACED TO MINIMIZE C.M. TRAVEL.
  - OPTIONS 1B, 1C, AND 1D EACH EXHIBIT SIGNIFICANT C.M. TRAVEL DUE TO PLACEMENT OF HANGAR AND TANKS ON SAME SIDE OF TRANSVERSE BOOM.
  - OPTIONS 2A AND 2B EXHIBIT LESS C.M. TRAVEL DUE TO ABSENCE OF TANKS.
- o PLACEMENT OF TANKS AND HANGAR ALSO PRODUCES SIGNIFICANT CHANGES IN MOMENTS OF INERTIA, PRODUCTS OF INERTIA, AND PRINCIPAL AXES.
  - AFFECTS CONTROL SYSTEM SIZING, SECULAR MOMENTUM BUILD-UP, AND TEAs FOR ALL OPTIONS
- o OPTION 1A HAS LEAST SIGNIFICANT IMPACT ON MASS PROPERTIES DUE TO BALANCING OF TANKS AND HANGAR.

LUNAR BASE ACCOMMODATION STUDY

CONTROLLABILLITY ASSESSMENT

This chart contains results obtained from the analysis of the control characteristics of each sub-option and for the CETF IOC station. Note that the CETF station flies with a pitch angle (about the Y-axis) of +3.0 degrees, while all the options #1A-#2B have negative pitch angles. This means that the CETF station "leans into" the direction of its travel but that each of the options would "lean back". The sign of the pitch angle is not a problem, however, since adequate viewing requires only that the pitch angle be between +5 and -5 degrees. The closer the angle is to zero, of course, the more favorable the viewing.

The negative pitch angles exhibited by the options is caused by the aerodynamic drag associated with the projected frontal area of the hangar. Essentially, the presence of the hangar moves the Center of Pressure (CP) of the system well above the CM, thereby creating a net negative moment about the CM. Also note that options #1B and #1D both have more favorable pitch angles than option #1A because the difference between the location of the CM and the CP is less. Clearly, placing the tanks very high on the upper keels moves the CM high enough to partially offset the effect of the drag of the hangar.

C-2

CONTROLLABILITY ASSESSMENT

CONFIGURATION	ATTITUDE (DEG)			PEAK MOMENTUM RQMT'S		SECULAR MOMENTUM PER ORBIT (N-M-S)
	ψ (Z)	θ (Y)	ϕ (X)	N-M-S	CMG's @ 3100 N-M-S	
CETF IOC STATION	0.2	3.0	0.6	3050	1	1500
OPTION 1 A	1.8	-5.0	-1.3	4400	2	2500
OPTION 1 B	0.9	-0.5	-0.7	4500	2	850
OPTION 1 C	1.1	-7.3	-0.8	4000	2	650
OPTION 1 D	0.9	-2.9	-2.0	4550	2	950
OPTION 2 A	1.5	-10.7	-0.5	3900	2	1200
OPTION 2 B	1.5	-10.7	-0.2	3550	2	1175

CONFIGURATION ANALYSIS

The most significant results of the controllability analysis are summarized on this chart.

Lunar Base Accommodation Study

CONFIGURATION ANALYSIS

RIGID BODY ATTITUDE/CONTROL SYSTEM SIZING:

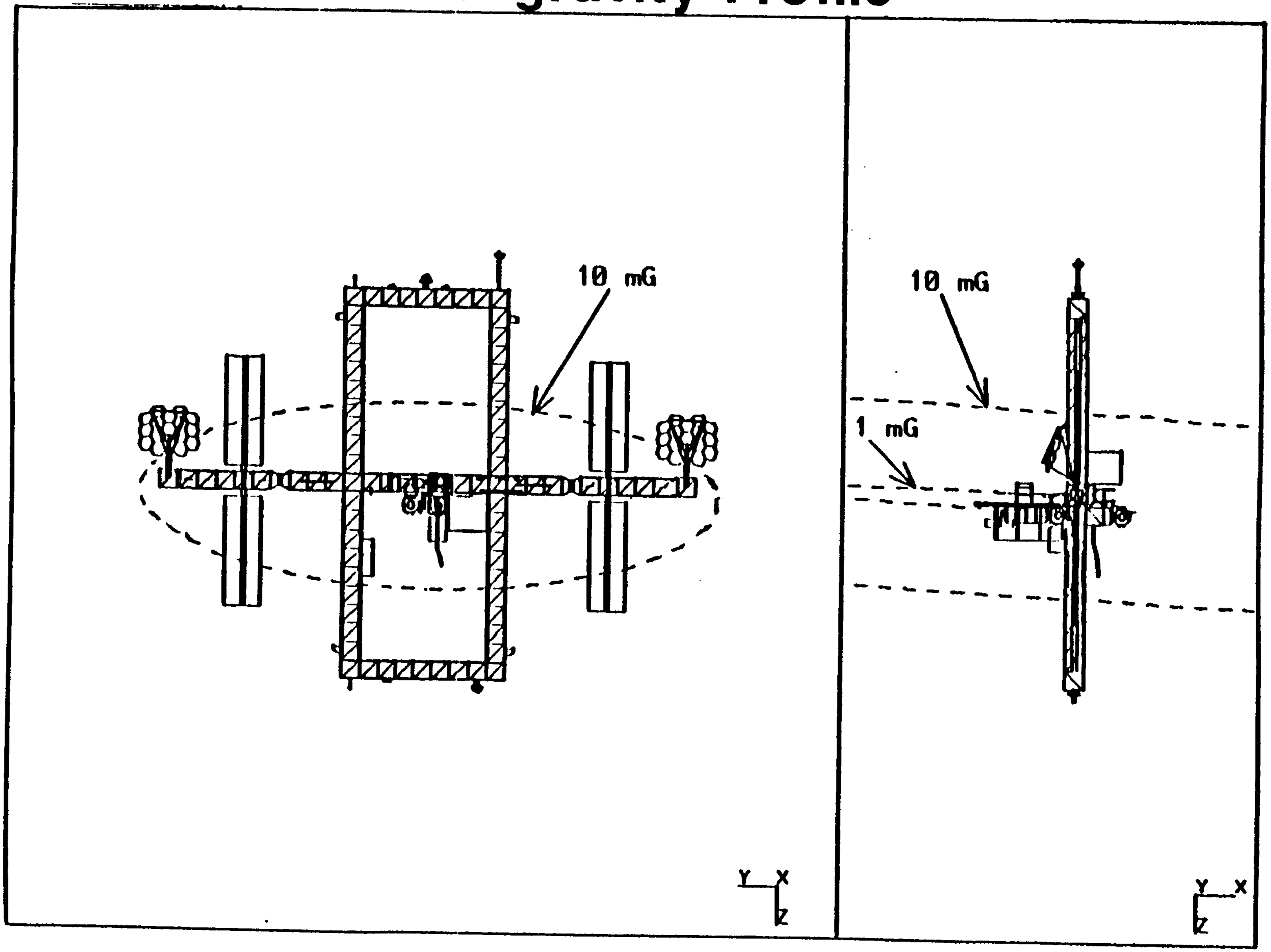
- o VIEWING REQUIREMENT FOR TEA IS +/- 5 DEGREES IN PITCH:
  - POSITION OF TANKS AND HANGAR ON OPTIONS 1A, 1B, AND 1D KEEPS PITCH TEAs BELOW 5 DEGREES
  - MOVING TANKS ABOVE HANGAR ON OPTION 1C FORCES PITCH TEA TO -7.3 DEGREES
  - OPTION 2 TEAs ARE -10.7 DEGREES SINCE BALANCING EFFECT OF PROPELLANT TANKS WAS REMOVED.
- o CURRENT STATION REQUIRES ONE 3100 NT-M-SEC CMG:
  - PEAK MOMENTUM REQUIREMENTS INCREASED UP TO 50% - ONE ADDITIONAL CMG IS REQUIRED FOR ALL CONFIGURATIONS.
  - CHANGE IN LOCATION OF TANKS ALSO AFFECTS MOMENTUM BUILD UP.
- o OPTIONS 1A, 1B, AND 1D HAVE LEAST SIGNIFICANT IMPACT ON ATTITUDE CONTROL/CMG SIZING.

LUNAR BASE ACCOMMODATION STUDY

CETF IOC STATION MICRO-GRAVITY PROFILE

This figure shows the static micro-gravity characteristics for the CETF IOC station. To interpret this picture and those which follow, note that the two ellipsoids that appear in dotted lines represent the areas in which accelerations up to 1 micro-g and 10 micro-g, respectively, can be expected. For the CETF IOC station, the 10 micro-g ellipse can be seen on the left encompassing the entire transverse boom. Within this volume, then it can be expected to find accelerations from 1 X 10**-6 g's to 1 X 10**-5 g's. The much smaller 1 micro-g ellipse can be seen on the right slicing through the module cluster. Here, the measured accelerations would appear up to 1 X 10**-6 g's. It should be kept in mind, however, that these values represent only the static behavior of the overal system; no analysis has been performed to determine the effects of the dynamic environment on the micro-gravity profile of the system. Clearly, a complete treatment of micro-gravity considerations would include such an analysis, but time constraints precluded that level of detail in this study. The following charts show the micro-gravity profiles corresponding to options #1A-#2B which should be compared with the CETF station profile shown here.

CETF IOC Station
Micro-gravity Profile



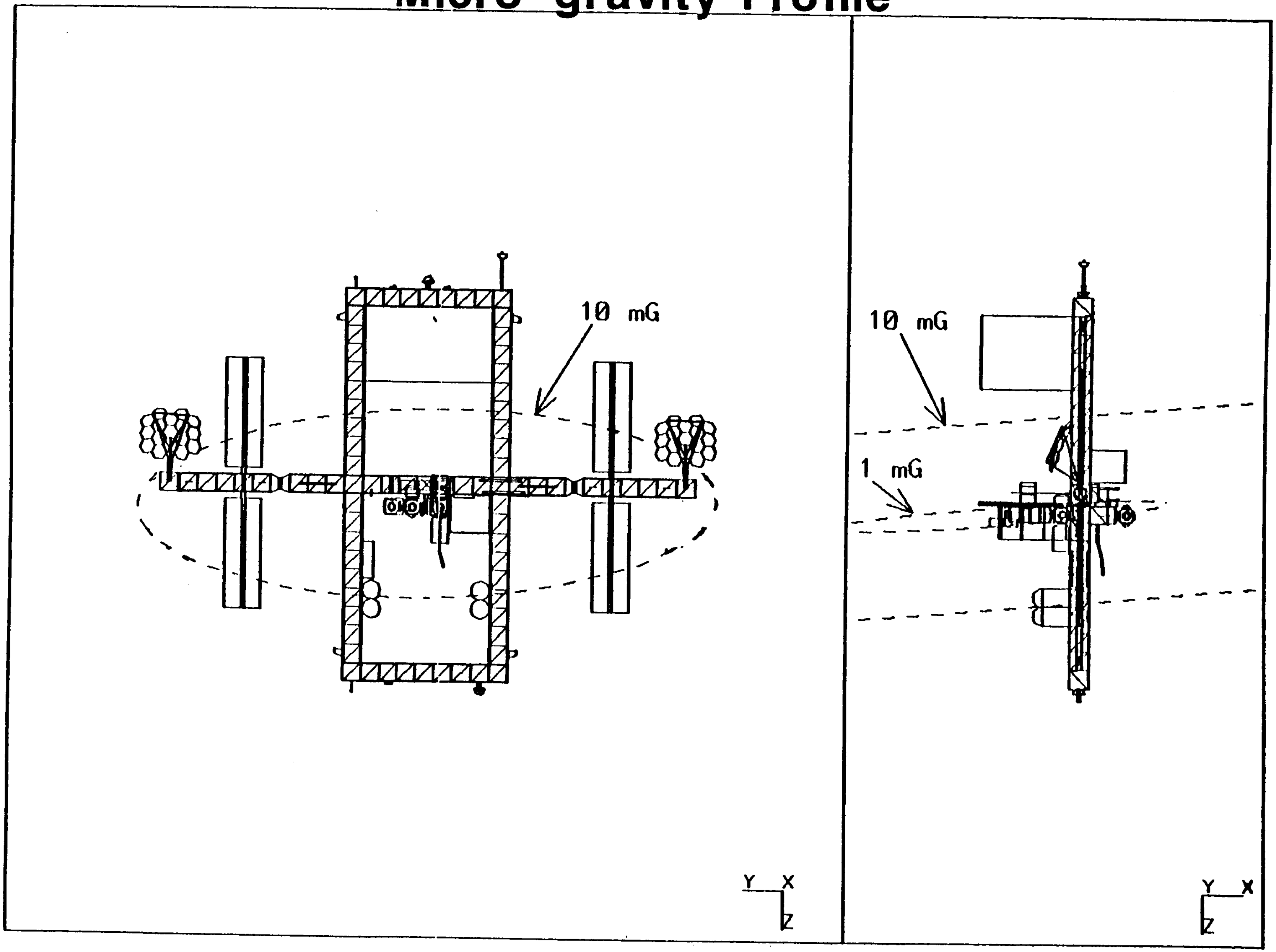
LUNAR BASE ACCOMMODATION STUDY

STATION CONFIGURATION (OPTION #1A)
MICRO-GRAVITY PROFILE

This figure shows the static micro-gravity characteristics for option #1A. The micro-g profile of this option is very similar to that of the IOC station because the hangar and propellant tanks were located in a position which minimzed the change in the position of the Center of Mass (C.M.) in an effort to leave the 1 and 10 micro-g ellipses as undisturbed as possible. As will be seen in the following profiles, and in the summary of the micro-gravity analysis, the position of the C.M. is the most significant factor in the position of the micro-g ellipses.

Lunar Base Accommodation Study

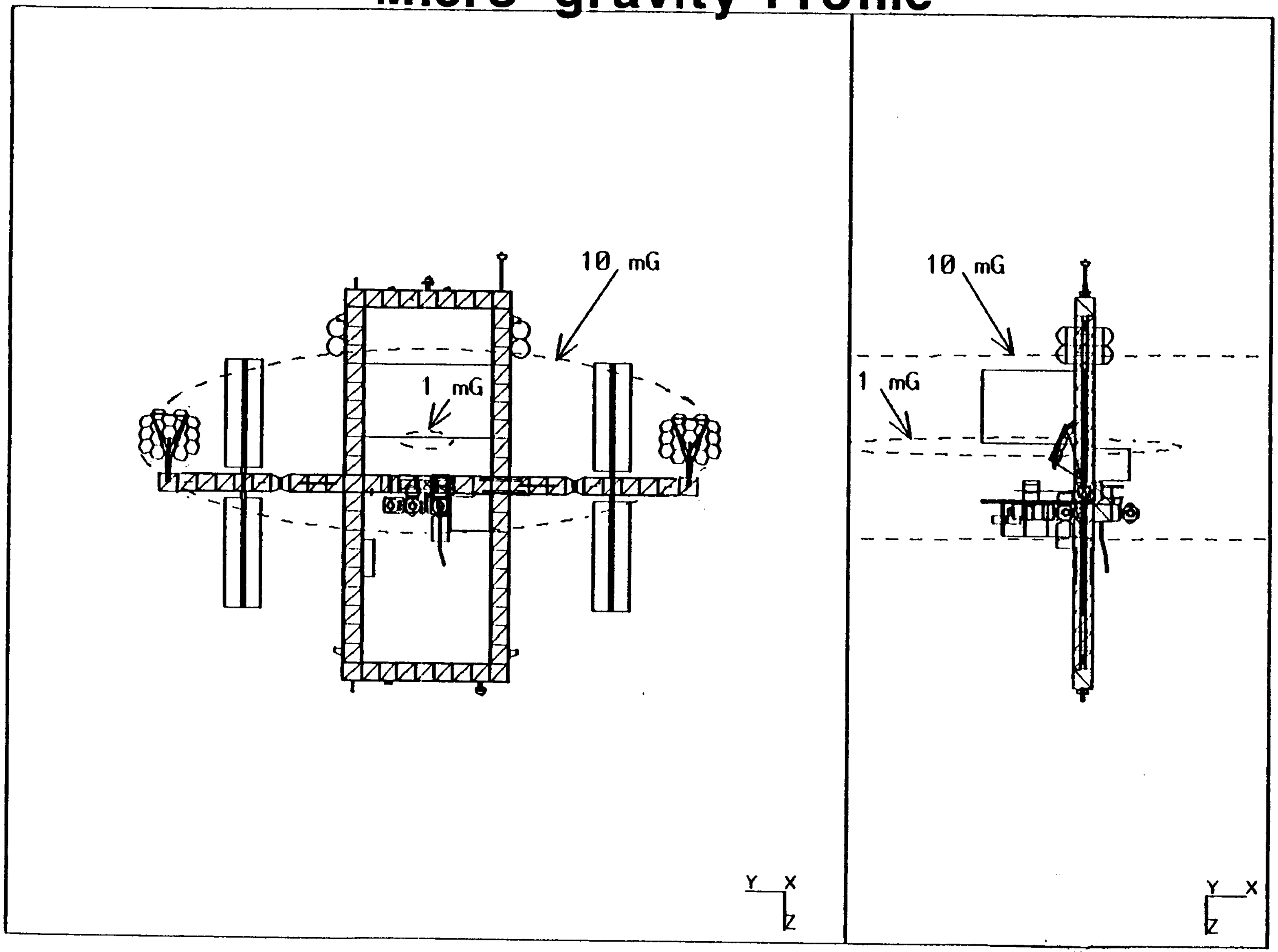
Station Configuration (Option 1A)
Micro-gravity Profile



STATION CONFIGURATION (OPTION #1B)
MICRO-GRAVITY PROFILE

This figure shows the static micro-gravity characteristics for option #1B. By placing both the hangar and tanks above the transverse boom, the C.M. and, thus, the center of the micro-g ellipses were offset well above the boom and, more importatly, well outside the module cluster. The implication, of course, is that science or materials payload requirements for a static 1 mG acceleration will not be met inside the Laboratory or Habitation modules.

Station Configuration (Option 1B)
Micro-gravity Profile

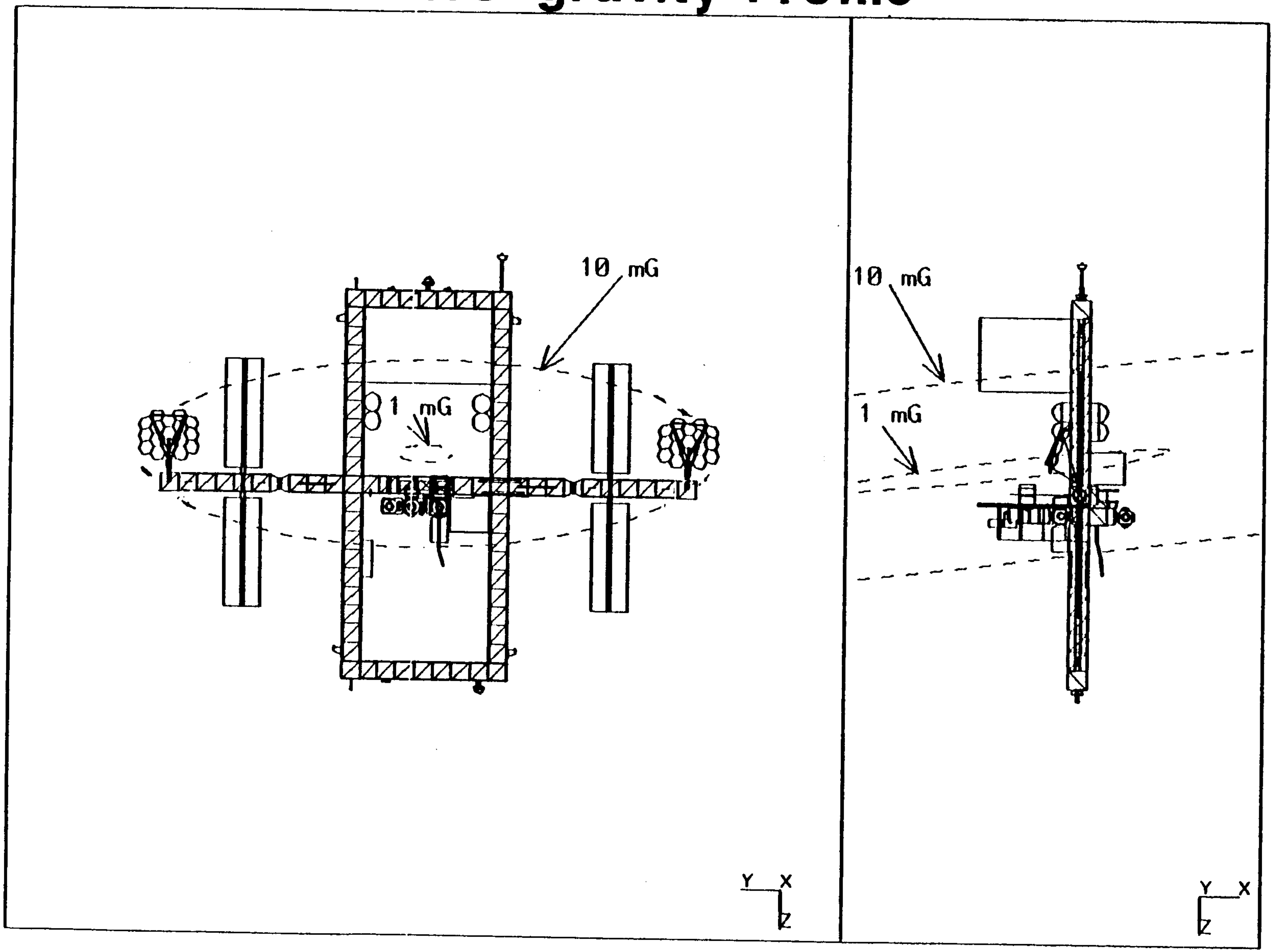


LUNAR BASE ACCOMMODATION STUDY

STATION CONFIGURATION (OPTION #1C)
MICRO-GRAVITY PROFILE

This figure shows the static micro-gravity characteristics for option #1C. As with option #1B, the placement of the hangar and tanks moved the C.M. and the center of the micro-g ellipses well above the transverse boom.

Station Configuration (Option 1C)
Micro-gravity Profile



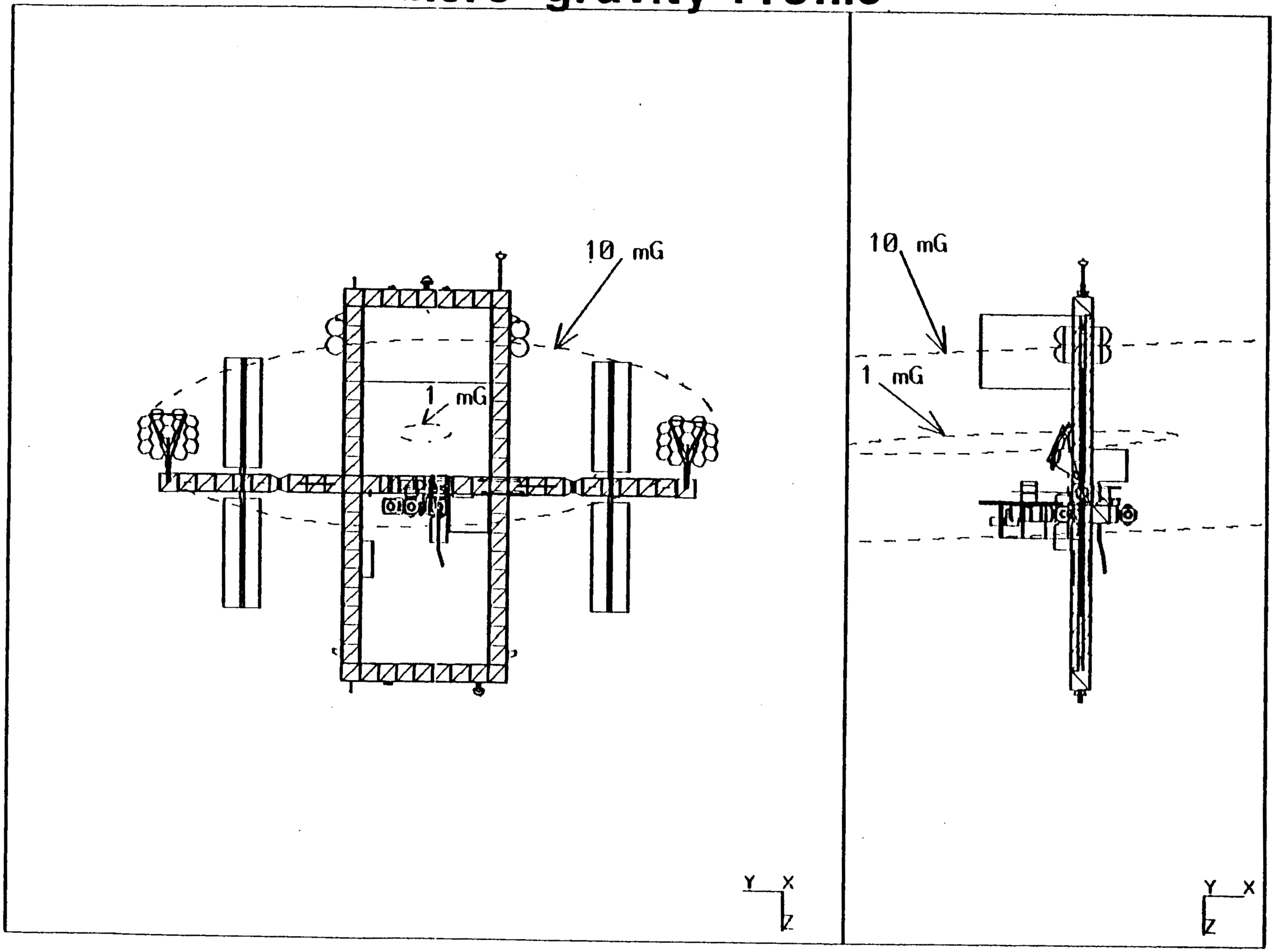
LUNAR BASE ACCOMMODATION STUDY

STATION CONFIGURATION (OPTION #1D)
MICRO-GRAVITY PROFILE

This figure shows the static micro-gravity characteristics for option #1D. As with options #1B and #1C, the placement of the hangar and tanks moved the C.M. and the center of the micro-g ellipses well above the transverse boom.

Lunar Base Accommodation Study

Station Configuration (Option 1D)
Micro-gravity Profile

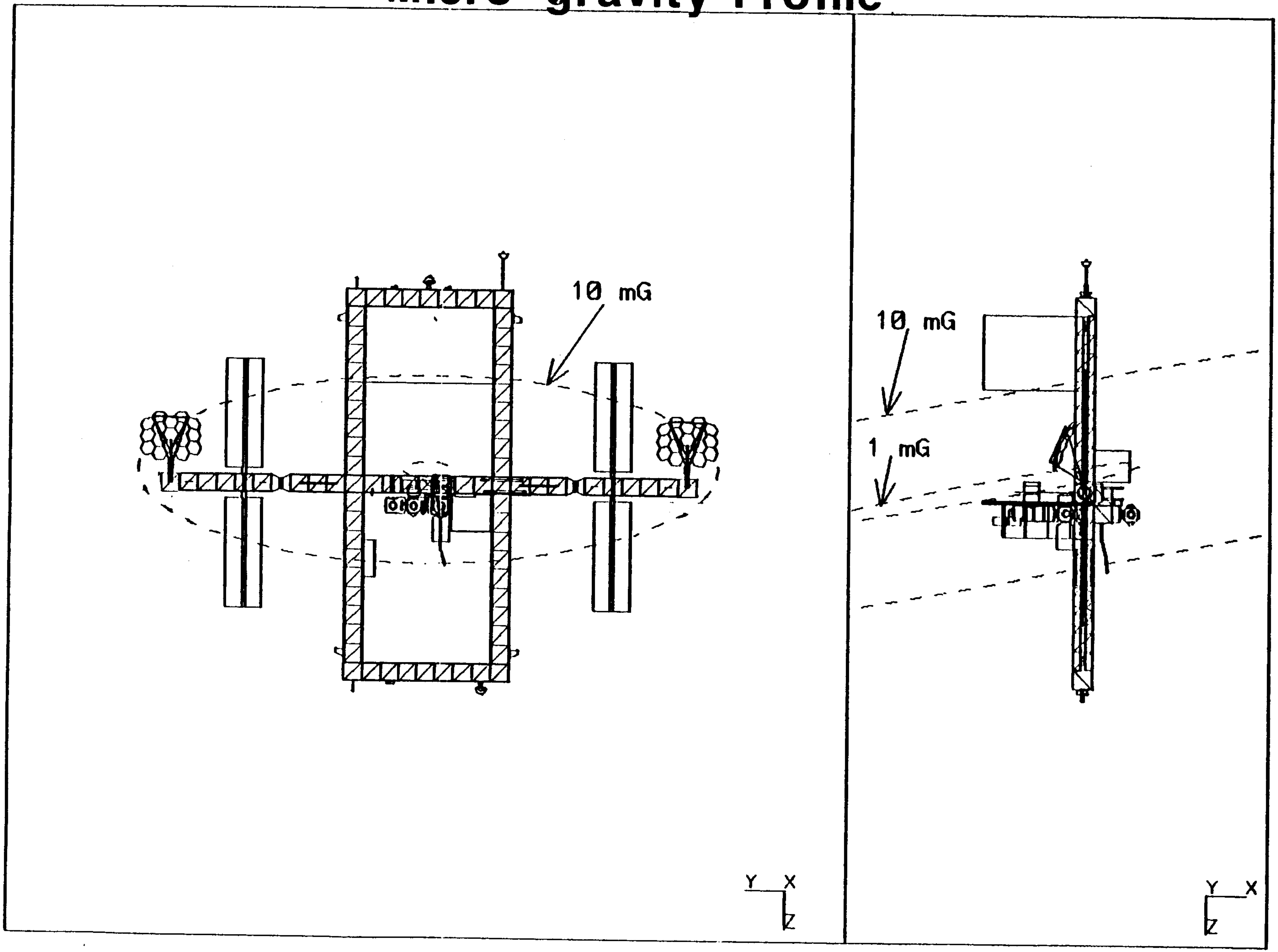


LUNAR BASE ACCOMMODATION STUDY

STATION WITH HANGAR (OPTION #2A)
MICRO-GRAVITY PROFILE

This figure shows the static micro-gravity characteristics for option #2A. By moving the massive propellant tanks off the station, the C.M., and the center of the micro-gravity ellipses, remains nearer the transverse boom. In this option the hangar is at the top of the upper keels and the 1 micro-g ellipse is offset only a few meters from the boom.

Station With Hangar (Option 2A)
Micro-gravity Profile

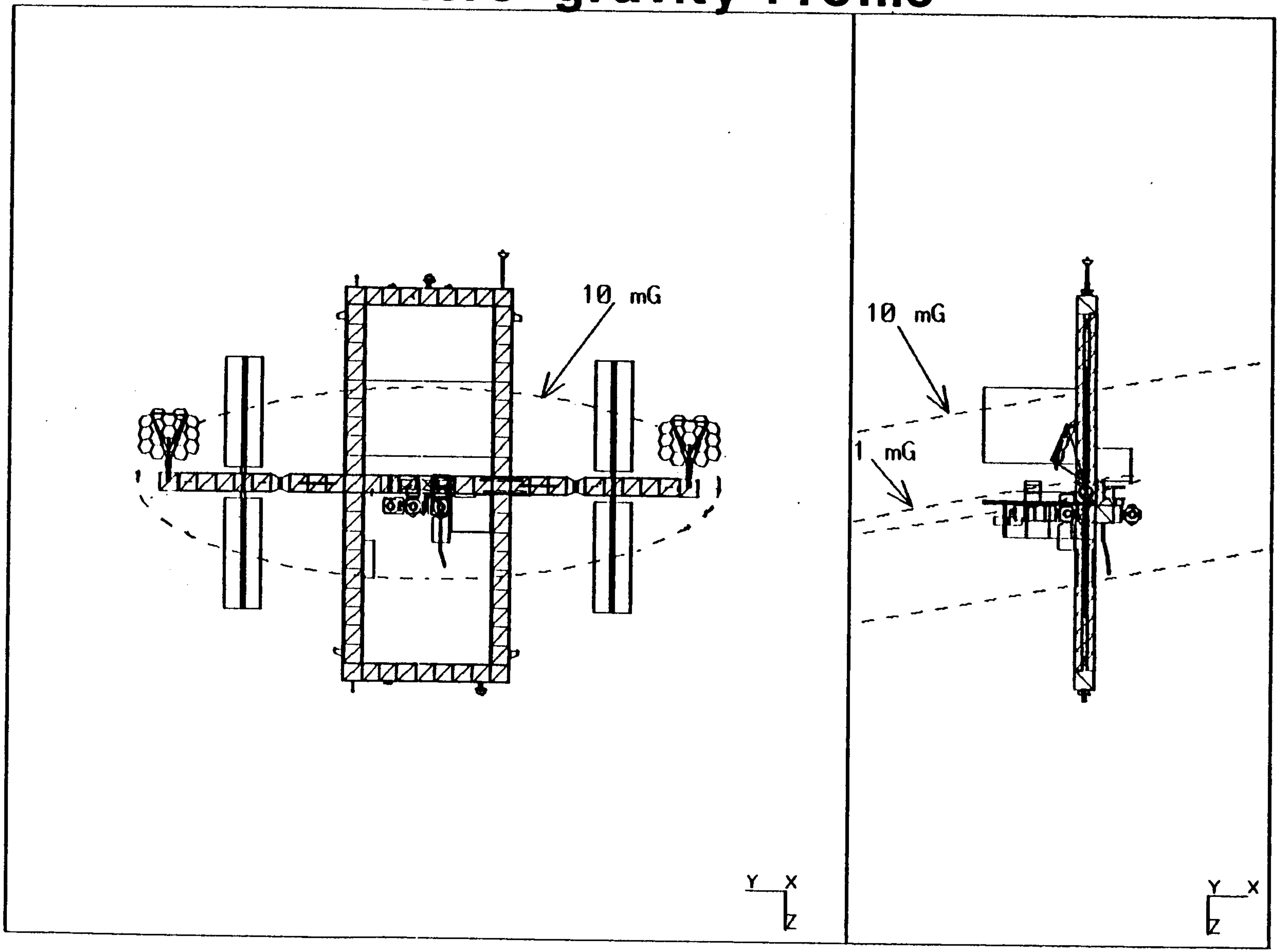


LUNAR BASE ACCOMMODATION STUDY

STATION WITH HANGAR (OPTION #2B)
MICRO-GRAVITY PROFILE

This figure shows the static micro-gravity characteristics for option #2B. Here the hangar was placed much nearer the the transverse boom and the center of the 1 micro-g ellipse is very near that of the CETF IOC station.

Station With Hangar (Option 2B)
Micro-gravity Profile



LUNAR BASE ACCOMMODATION STUDY

CONFIGURATION ANALYSIS

This chart summarizes the results obtained from the static micro-gravity analysis performed for options #1A-#2B.

CONFIGURATION ANALYSIS

MICRO-GRAVITY ENVELOPE (STATIC):

- o ANALYSIS OF THE STATIC MICR0-G ENVELOPE SHOWED A MINOR IMPACT FOR OPTIONS 1 AND 2
  - ALL MODULES REMAIN WITHIN THE 10 MICRO-G ENVELOPE
  - PROPELLANT TANKS FOR OPTION 1A WERE PLACED SPECIFICALLY TO MAINTAIN 1 MICRO-G VOLUME WITHIN MODULES.
  - 1 MICRO-G VOLUME IS SHIFTED OUTSIDE THE MODULES FOR ALL CONFIGURATIONS EXCEPT OPTION 1A.

LUNAR BASE ACCOMMODATION STUDY

ORBIT LIFETIME CHARACTERISTICS

This chart contains results obtained from the analysis of the orbit lifetime characteristics of each sub-option and for the CETF IOC station. The orbit lifetime of an object in space is dependent on the ratio of total projected area in the direction of the velocity vector to the total mass of the object. This ratio is called the ballistic coefficient. It can be seen from the chart that options #2A and #2B have considerably smaller ballistic coefficients (and correspondinly shorter orbit lifetimes) than options #1A-#1D, but that all the options have a smaller coefficient and higher lifetime than the CETF IOC station. This is due to the fact that the added mass of the hangar, (on options #1A-#2B), and that of the propellant tanks (on options #1A-#1D), is enough to offset the considerable increase in projected area. The other side of the story, of course, is that even though the orbits of each option take longer to decay, their considerably higher total mass requires more propellant to perform a reboost maneuver. Luckily, the additional reboost propellant which is required is negligible when compared to the total mass of the lunar vehicle accommodations, and so should not be considered a problem.

ORBIT LIFETIME CHARACTERISTICS

CONFIGURATION	MASS ($KG*10^3$)	AREA (M^2)	BALLISTIC COEFF. (KG/M^2)	ORBIT DECAY TIME (DAYS) 250-150 (NM)	ORBIT DECAY TIME (DAYS) 150-0 (NM)	90^o ORBIT REBOOST PROPELLANT RQMT AT ISP=380 ; H=250 NM (KG)
CETF IOC STATION	267	3070	37.8	302	9	570
OPTION 1 A	517	4200	53.6	408	14	742
OPTION 1 B	517	4050	55.6	423	13	715
OPTION 1 C	517	4260	52.8	407	13	740
OPTION 1 D	517	4120	54.6	415	14	745
OPTION 2 A	378	4290	38.3	306	9	780
OPTION 2 B	378	4260	38.5	306	11	775

CONFIGURATION ANALYSIS

The most significant results of the orbit lifetime analysis are summarized on this chart.

CONFIGURATION ANALYSIS

ORBIT LIFETIME:

- ANALYSIS SHOWS THAT THE ORBITAL LIFETIME OF OPTION 1 IS HIGHER THAN THAT OF BOTH OPTION 2 AND THE IOC STATION
  - OTV HANGAR HAS A MINIMAL IMPACT ON BALLISTIC COEFFICIENT (2%) AND ORBITAL LIFETIME (1.3%).
  - HIGH MASS AND LOW PROJECTED SURFACE AREA OF TANKS IN YZ PLANE INCREASES BALLISTIC COEFFICIENT BY 47% AND ORBITAL LIFETIME BY 40%.
  - ADDED MASS INCREASES REBOOST PROPELLANT REQUIREMENTS BY APPROXIMATELY 30% FOR OPTIONS 1A-1D, AND 36% FOR OPTIONS 2A AND 2B.

OTHER CONSIDERATIONS

This chart lists the key concerns and results obtained from a qualitative consideration of the necessary robotic support for the lunar mission. It is clear that a high level of automation in the assembly and verification of the vehicle stacks, and in the routine replenishment of propellant stores will be required to effectively support a lunar base.

OTHER CONSIDERATIONS

ROBOTIC ARMS:

- THE VEHICLE HANGAR WILL HAVE ITS OWN ROBOTICS SYSTEM AND SO WILL NOT IMPACT CURRENT RMS
- STATION RMS MASS HANDLING CAPABILITIES WILL HAVE TO BE INCREASED TO HANDLE PROPELLANT AND TANKS
- OPTION 2 WOULD REQUIRE SEPARATE RMS SYSTEMS AT THE PTF
- MUST ASSIGN A COST TO UP-GRADING CURRENT SYSTEM VERSUS DEVELOPING NEW SYSTEMS

OTHER CONSIDERATIONS

This chart shows the key concerns and results obtained from a qualitative consideration of the OMV traffic and of the viewing problems asscociated with lunar mission support. Related results appear later in this report during the discussions of science impacts and space station traffic.

OTHER CONSIDERATIONS

OMV USE:

- OMV CAPABILITIES MUST BE INCREASED TO:
  - CAPTURE AND STOW NEW PROPELLANT TANKS
  - CAPTURE AND PLACE OTVs IN HANGAR
  - MOVE COMPLETED LUNAR VEHICLE TO STAGING AREA
- OPTION 2 REQUIRES AN ADDITIONAL STOP AT THE PTF BEFORE MOVING TO THE STAGING AREA.

VIEWING AT STATION:

- OPTION 1 HAS BLOCKAGE FROM THE VEHICLE HANGAR AND FROM PROPELLANT BOIL-OFF CONTAMINATION.
- OPTION 2 ALSO HAS BLOCKAGE FROM HANGAR, BUT ALLEVIATES THE CONTAMINATION PROBLEM BY MOVING PROPELLANT TANKS TO THE PTF.

LUNAR BASE ACCOMMODATION STUDY

ORBITING SUPPORT FACILITY (OSF)

Although this study concentrated on determining impacts to the current station design, it was helpful to develop concepts for a co-orbiting platform for support of lunar vehicles (options #3 and #4). No attempt was made to analyze these concepts as was done for options #1A-#2B, but the important features that such a facility would be required to provide are shown on the facing page.

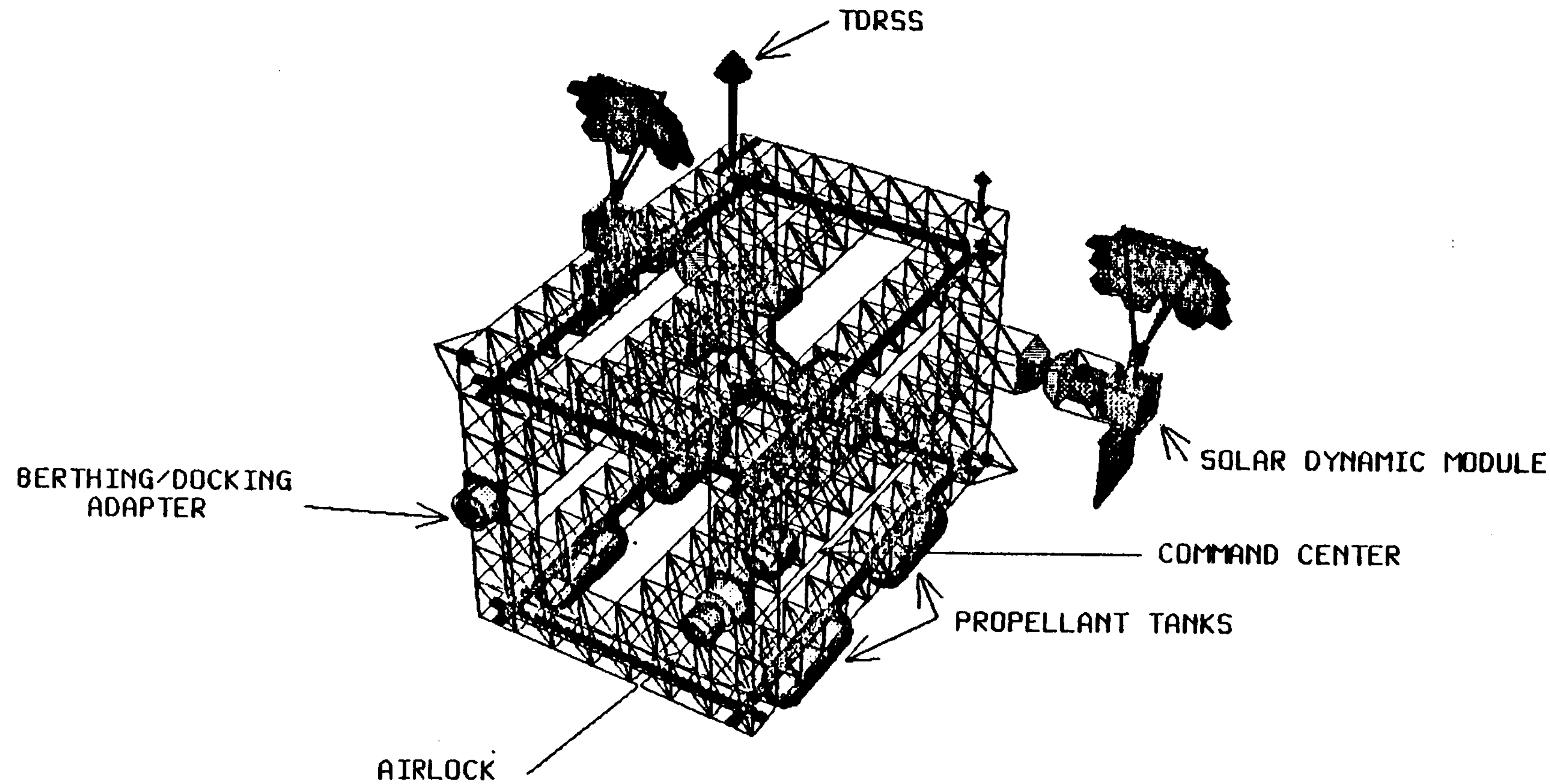
ORBITING SUPPORT FACILITY (OSF)

- DESIGN TAILORED FOR TRANSPORTATION NEEDS:
  - LUNAR MISSIONS
  - GEO MISSIONS
  - PLANETARY MISSIONS
- LESS STRINGENT REQUIREMENTS ON:
  - POINTING
  - VIEWING
  - MICRO-GRAVITY ENVELOPE
- EMPHASIS ON A&R - 360 DEGREE CIRCUMFRENTIAL ACCESS
- SPACE STATION DERIVED HARDWARE
- POWER, DMS, GN&C, ETC. TO SUPPORT TRANSPORTATION NEEDS

ORBITING SUPPORT FACILITY (OSF)

An Orbiting Support Facility (OSF) concept (options #3 and #4) is illustrated by the structure shown. Features include areas for OMV and shuttle docking, propellant tanks conveniently located for vehicle fueling, storage areas in the corners of the structure, access routes for movement of robotic arms, and room for a crew module or command center. As previously stated, several similar concepts have been developed with the same features to provide appropriate support for transportation needs in LEO. These concepts included an open box similar to but larger than the one shown, a dual keel derived platform, and a prism shaped platform.

ORBITING SUPPORT FACILITY



LUNAR BASE ACCOMMODATION STUDY

RECOMMENDED FURTHER ANALYSIS

The analyses described in this section of the report have led to the identification of several studies which would fill out and complete the outstanding issues mentioned. Particularily, a comprehensive analysis of the dynamic environment induced by lunar mission support, and its effect on the space station structure and on planned science activities, would add considerably to a complete understanding of the appropriateness of options #1 and #2. Similarily, a quantitative analysis of the propellant related issues listed, and of the risk associated with the increased LEO traffic would better establish the viability of each basing option.

RECOMMENDED FURTHER ANALYSIS

- DYNAMIC RESPONSE:
  - FREQUENCY DEPENDENT MICRO-G EFFECTS
  - POINTING DISTURBANCES
  - STRUCTURAL LOADS
  - STRUCTURES/CONTROL SYSTEM INTERACTIONS
- CONTAMINATION RISK, BOIL-OFF LEVELS
- RISK FROM PROPELLANT EXPLOSION
- TRAFFIC DENSITY RISK

LUNAR BASE ACCOMMODATION STUDY

CONCLUSIONS

The conclusions drawn from the analyses described in this section of the report are listed on this chart.

CONCLUSIONS

- CHOICE OF A PARTICULAR OPTION IS A COMPROMISE BETWEEN THE PRIORITIES OF AFFECTED SCIENCE USERS AND CONFLICTING TRANSPORTATION NEEDS:
  - IT IS POSSIBLE TO ACCOMMODATE THE ASSEMBLY AND REFURBISHMENT OF LUNAR VEHICLES ON THE IOC SPACE STATION
  - A CO-ORBITING PTF REDUCES CONTAMINATION LEVELS BUT DOES NOT APPRECIABLY ENHANCE FOV, MICRO-G ENVELOPE AND POINTING PARAMETERS
  - PRESENTLY DEFINED CAPABILITIES OF RMS, DMS, AND OMV SHOULD BE FURTHER EXAMINED TO DETERMINE THEIR ABILITY (CAPABILITY/PERFORMANCE) TO SUPPORT LUNAR ACTIVITIES

SPACE STATION ASSEMBLY OPERATION AND KSC SUPPORT REQUIREMENT

E. MICHAEL KIENLEN, JR.

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LUNAR BASE ACCOMMODATION STUDY

OUTLINE

The purpose of this portion of the presentation is to develop the Kennedy Space Center (KSC) requirements to support a lunar mission scenario. To do this, the basic mission parameters, such as weight to Leo,lunar launch rate, and crew requirements, are defined and a launch rate out of KSC is established to support these parameters. The first part of this presentation is the establishment of the mission parameters and the second part is the support required through KSC to accomplish the mission.

OUTLINE

- EARTH TO LEO REQUIREMENTS
  - PROPELLANT WEIGHT TO LEO
  - PAYLOAD WEIGHT TO LEO
  - THE NEED FOR A HLLV
- ON ORBIT PROCESSING
  - SERIAL FLOW SCHEDULE
  - CREW REQUIREMENTS
- POSSIBLE MIX FLEET LAUNCH MANIFESTS
- KSC SUPPORT REQUIREMENTS

LUNAR BASE ACCOMMODATION STUDY

PROPELLANT WEIGHT TO LEO

This chart indicates the assumptions made on propellant needs for the lunar missions, and is based on the mission elements as defined under the lunar vehicle and space station presentations already given. The number of total missions could be either 6 or 7 per year and are carried as two possibilities. Also, several types of fuel were assummed to be needed.

PROPELLENT WEIGHT TO LEO

o BASELINE (lbs)

- 200K OF PROPELLANT PER MISSION
- 7/6 TOTAL MISION PER YEAR
- 1400/1200K OF PROPELLANT PER YEAR

o ON STATION REQUIREMENTS

- 200K FOR A MISSION
- 200K FOR A RESCUE MISSION
- 400K ON ORBIT AT ANY ONE TIME

o TYPES OF PROPELLANT

- LH2, LO2, LN2, HYDRAZINE

LUNAR BASE ACCOMMODATION STUDY

PAYLOAD WEIGHT TO LEO

The baseline values shown here include all of the lunar delivery material other than propellant, and includes the astronauts and their support needs. With the two possible mission numbers per year, the total deliverable mass has been determined.

PAYLOAD WEIGHT TO LEO

- o BASELINE (LBS)
  - 80K OF PAYLOAD PER MISSION
  - 7/6 MISSION PER YEAR

  - 560/480K OF PAYLOAD REQUIRED PER YEAR

LUNAR BASE ACCOMMODATION STUDY

THE NEED FOR A HLLV

The purpose of this chart is to show the magnitude of mass to Leo required to support the lunar activity on a yearly basis. The total mass is larger than the STS can support on its own, and in fact it requires the support of a large (200 k lbs.payload to space station orbit) Heavy Lift Launch Vehicle (HLLV) to meet the mission requirements.This mission profile could not be supported realistically even with an 85 k lbs. HLLV, because it would require more than 23 HLLV launches per year plus the STS launches or a total of more than 30 launches oer year out of KSC. This is an unrealistic and unachievable launch rate.

THE NEED FOR A HLLV

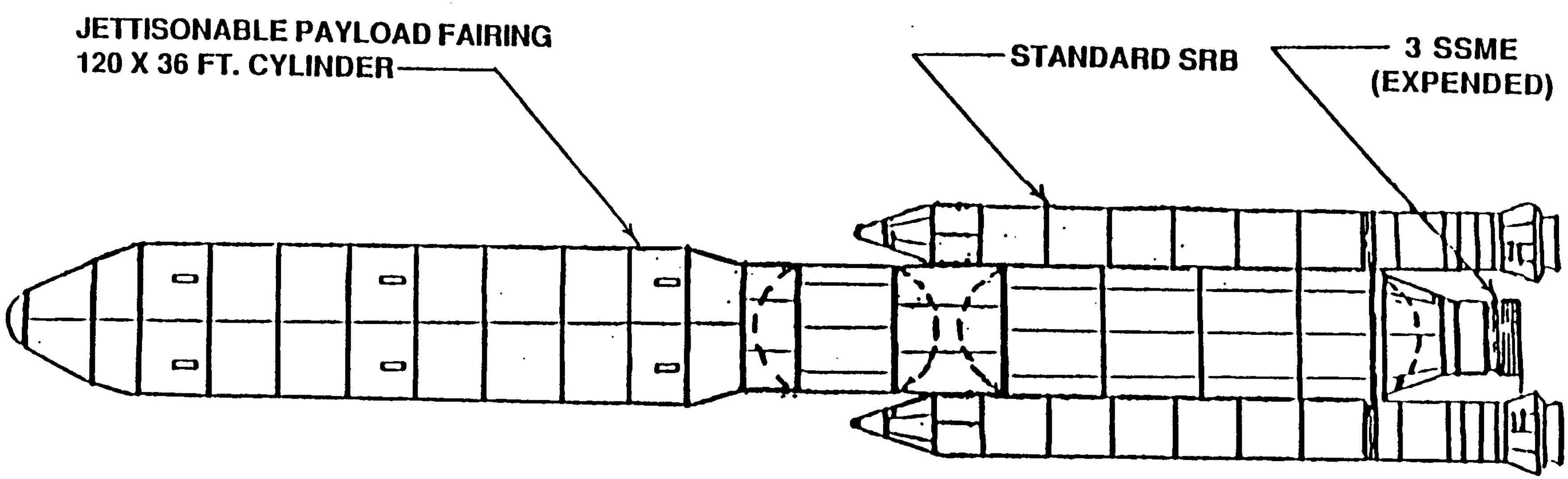
- 1400 K (LBS) OF PROPELLANT PER YEAR
- 560 K (LBS) OF PAYLOAD PER YEAR
- 1960 K (LBS) REQUIRE TRANSFER TO LEO PER YEAR
- IF ALL THIS IS CARRIED ON STS
  - 50 STS FLIGHT PER YEAR AT 39530 LBS EACH
- IF CARRIED ON HLLV MINUS CREW
  - 10 HLLV PER YEAR AT 160-200 K (LBS) EACH

LUNAR BASE ACCOMMODATION STUDY

HEAVY LIFT LAUNCH VEHICLE CONCEPT

The chart is intended to show the size and configuration of a typical HLLV as proposed. This vehicle weighs 4.5 M lbs. and carries a payload of 150-200 k lbs. to the space station orbit.

HEAVY LIFT LAUNCH VEHICLE CONCEPT



GROSS WEIGHT - 4,545,290 LB
PAYLOAD - 150,000-200,000 LB
104% POWER LEVEL
30° INCLININATION, 220 NMI

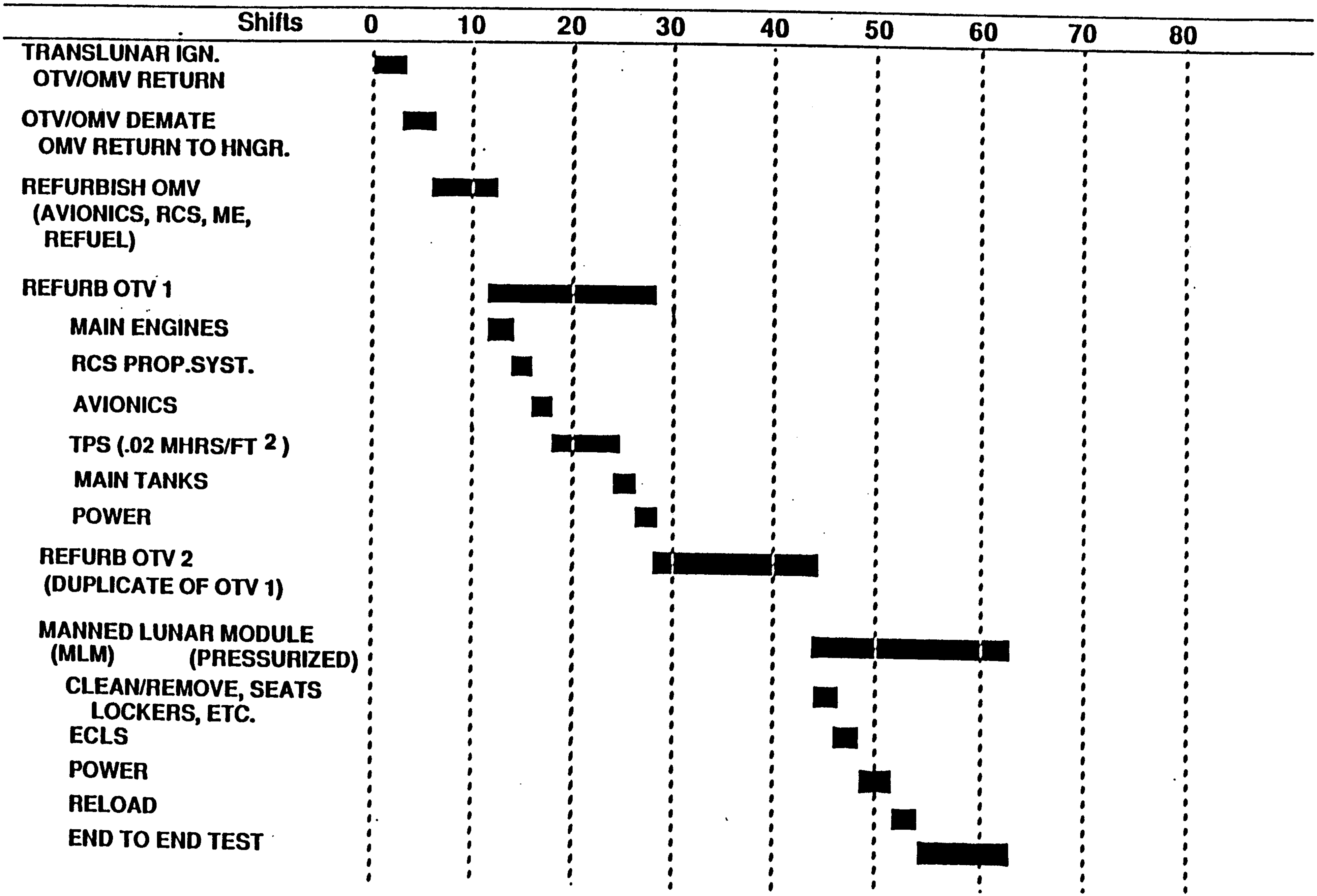
LUNAR BASE ACCOMMODATION STUDY

SINGLE SITE SERIAL SERVICING

Lunar vehicle servicing in LEO is constrained by many factors which are not related to the vehicle itself. Primarily because of manpower, facility, and equipment constraints, all servicing must be done consecutively at a single location, called single site serial servicing. This procedure is the only realistic operating mode, since the capacity on orbit to process two vehicles at the same time is not planned. Secondly, with a 55-day launch cycle, this serial processing must be accomplished within this 55-day window.

On the next two consecutive charts, a listing of the servicing tasks needed for a single lunar mission are listed, and a time line defined for serial processing of the servicing activities. This time line is in units of shifts, which each consist of the entire workday for a crew of three, which is the minimum crew when EVA tasks are included.

SINGLE SITE SERIAL SERVICING



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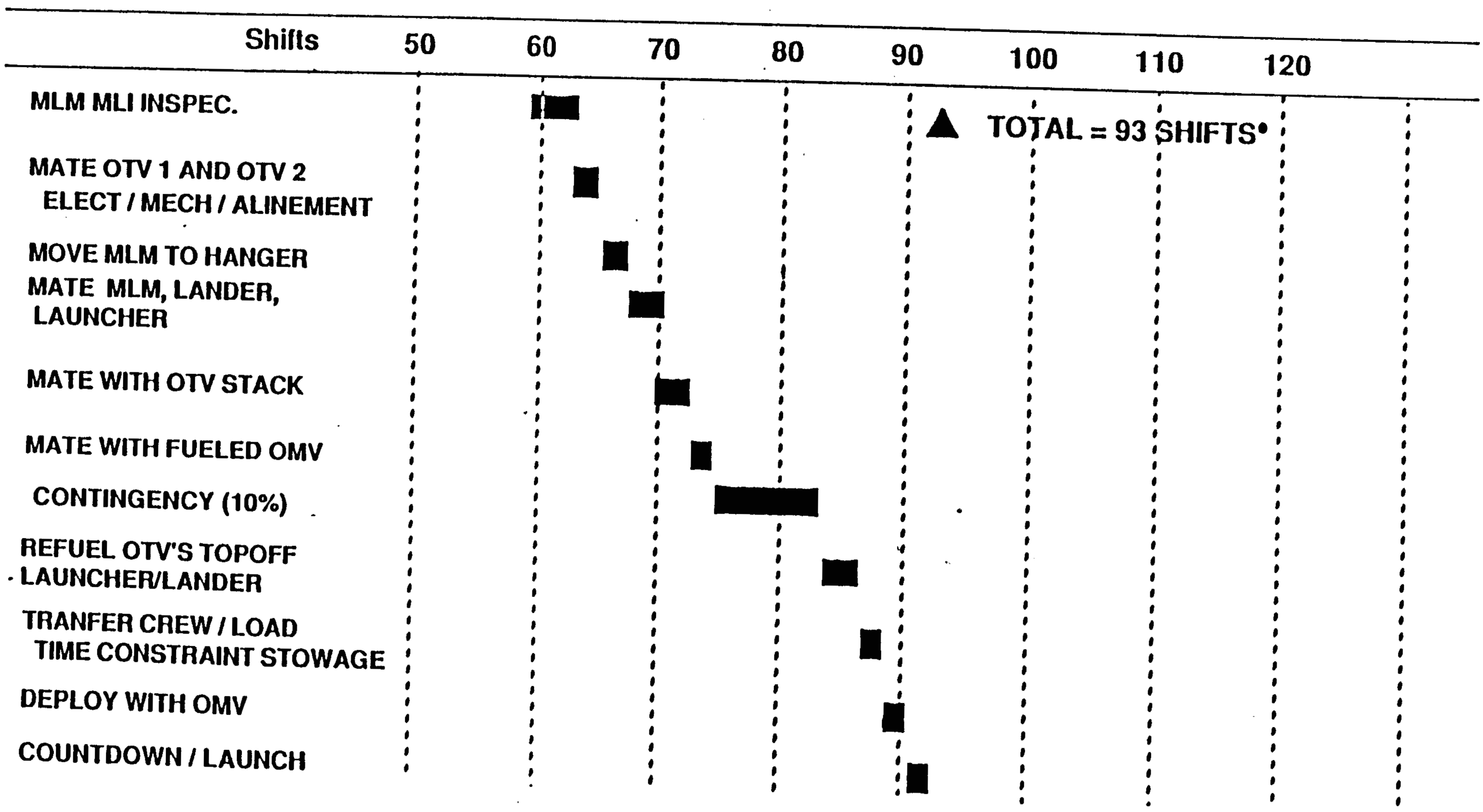
LUNAR BASE ACCOMMODATION STUDY

S S S S CONTINUED

These charts are not an engineering evaluation of the lunar vehicle itself, but are a lunar vehicle turnaround scenario based on the given set of parameters. In short, what these charts show is if you want the vehicle processed in 55 days this is the type and rate of processing that would be required. The total activity would require 93 shifts of work to be accomplished. Now, the actual crew size can be determined from these shift requirements.

SINGLE SITE SERIAL SERVICING CONTINUED



* SHIFTS EQUALS A WORKING DAY FOR A TEAM OF 3 CREW

LUNAR BASE ACCOMMODATION STUDY

CREW SIZE REQUIRED

Based on the space station crew working limit of six days per week, the 93 shift work load would take one team 109 calendar days to complete. With twice as many teams, the servicing workload would be completed in half the time, or 55 days.

Therefore, to support a 55 day lunar mission turn around time, two teams working serially would be sufficient, providing no unexpected delays occur during this servicing. In addition, the 4-man mission crew would also be needed, bring the total space population to 10 crew.

CREW SIZE REQUIRED

- WITH ONE TEAM (3 PEOPLE)
  - 93 SHIFTS EQUALS 109 CALENDAR DAYS OF SERIAL PROCESSING

- WITH 2 TEAMS (6 PEOPLE)
  - 93 SHIFTS EQUALS 55 CALENDAR DAYS OF DUAL SHIFT SERIAL PROCESSING

- TO SUPPORT A 55 DAY LUNAR MISSION CYCLE TOTAL CREW SIZE IS 2 TEAMS PLUS 4 MAN MISSION CREW * OR 10 PEOPLE

* THE LUNAR MISSION CREW ARE ASSUMED TO BE MISSION SPECIALISTS AND ARE NOT LUNAR VEHICLE EXPERTS

LUNAR BASE ACCOMMODATION STUDY

CREW SIZE REQUIRED IN SPACE

This chart represents the crew required in space in support of lunar and space station activities for the first 16 years after IOC, including 1996-2011. The crew scale is listed on the left side of the chart, with the un-noted black triangles indicating manned and the "um" triangles indicating unmanned lunar launches.In the year 1996, there is shown the IOC Space Station with its 8 crew which increases to 12 in the year 1997 to support the lunar base precursor activities. This crew increase is space station crew actively building the associated facilities for the future lunar accommodations.

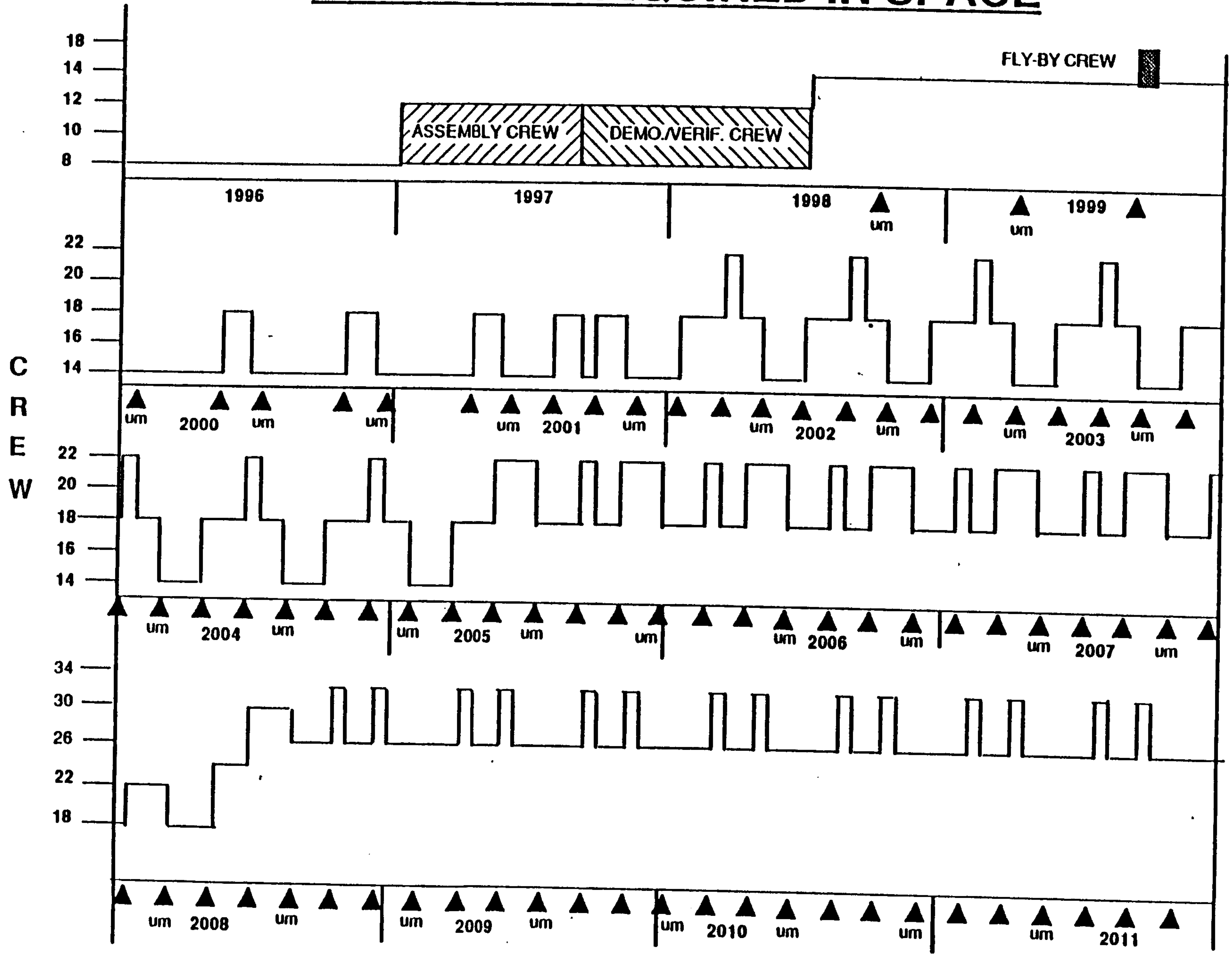
In the year 1998, the verification crew returns to earth and the lunar support crew of 6 arrives. This crew is dedicated to lunar missions support, and increases the space total to 14 crew.- There is also shown a lunar fly-by mission in late 1999.

In the year 2000, phase II or manned missions to the moon's surface begin, and on station there is the 8 man IOC crew, 6 man lunar support crew, and the 4 man lunar mission crew. When the flight crew returns to earth, the total crew compliment drops to 14 again. In the early part of phase 11, the lunar mission crew are on three week duration missions until 2002 when the stay time is increased to 55 days. The spikes shown during this phase are the 4 man replacement crew in space and changing out with the mission crew on the moon. These 4 crewmen spikes continue thereafter indicative of the lunar mission.

In the year 2005, the permanently man tended lunar base starts, where the lunar stay times have been increased to 110 days. Starting in the year 2008, the 6 man MLM is on line so the lunar crew size is increased to 12 or the total crew in space totals 32 crewmen. This crew is distributed as follows: 8 crew IOC station, 6 crew lunar support, 12 crew lunar missions and 6 new lunar mission crew for changeout on the moon.

Lunar Base Accommodation Study

CREW SIZE REQUIRED IN SPACE



LUNAR BASE ACCOMMODATION STUDY

110 DAY CREW CYCLE/18 CREW TOTAL ON ORBIT

This chart describes the form and content of the following several charts, which contain the data needed to define a launch scenario for KSC. The charts define a mixed fleet launch schedule above a heavy dark line in the middle of the page and shows both the STS and HLLV launches for a typical 12 month period. The STS launches are categorized into either space station or lunar base launches, and the HLLV launches are defined as either propellant or payload launches. The total KSC launch rate is 26 launches per year or once every 14 days.

This chart defines the assumptions and definitions for the various quantities on the following charts, and are essentially self-descriptive.
There is also indicated on the bottom of the chart a typical lunar mission schedule to indicate the serial processing required to accommplish each mission. This format for the missions is shown on the bottom of the actual mission schedules that follow.

110 DAY CREW CYCLE / 18 CREW TOTAL ON ORBIT

o CHART DESCRIPTION

- o STS SS LAUNCHES ARE TO SUPPORT IOC SPACE STATION AND ITS 8 CREW
- o STS LUNAR LAUNCHES ARE TO SUPPORT THE 10 LUNAR CREW, BOTH MISSION AND SUPPORT, ALONG WITH THEIR SPACE STATION LOGISTICAL REQUIREMENTS
- o HLLV IS A 200K LBS EARTH TO LEO VEHICLE WHICH SUPPLIES ALL FUEL, PAYLOAD, LUNAR VEHICLES AND LOGISTICS FOR LUNAR OPERATION
- o MISSION CREW ARE PILOTS, MISSION AND PAYLOAD SPECIALISTS
- o SUPPORT CREW ARE LUNAR VEHICLE MECHANICS WITH EXPERTISE ON OMV, OTV, MLM, LAUNCHER, LANDER, TANK FARM, LUNAR LEO FACILITY AND LUNAR VEHICLE MGSE/EGSE
- o STS CREW CYCLE MUST BE IN SYNCH WITH LUNAR CYCLE TO MAXIMIZE CREW EFFICIENCY
- o 5 CREW TRANSFERED ON EACH STS LUNAR LAUNCH

o DEFINITION OF LUNAR MISSION SCHEDULE

- MAINTENANCE AND REFURBISHMENT
- INTEGRATION AND TEST OF LUNAR VEHICLE
- CONTINGENCY (10%)
- PROPELLANT LOAD, CREW LOAD, COUNTDOWN AND LAUNCH TO MOON
- MISSION
- POST MISSION

LUNAR BASE ACCOMMODATION STUDY

18 CREW TOTAL ON ORBIT

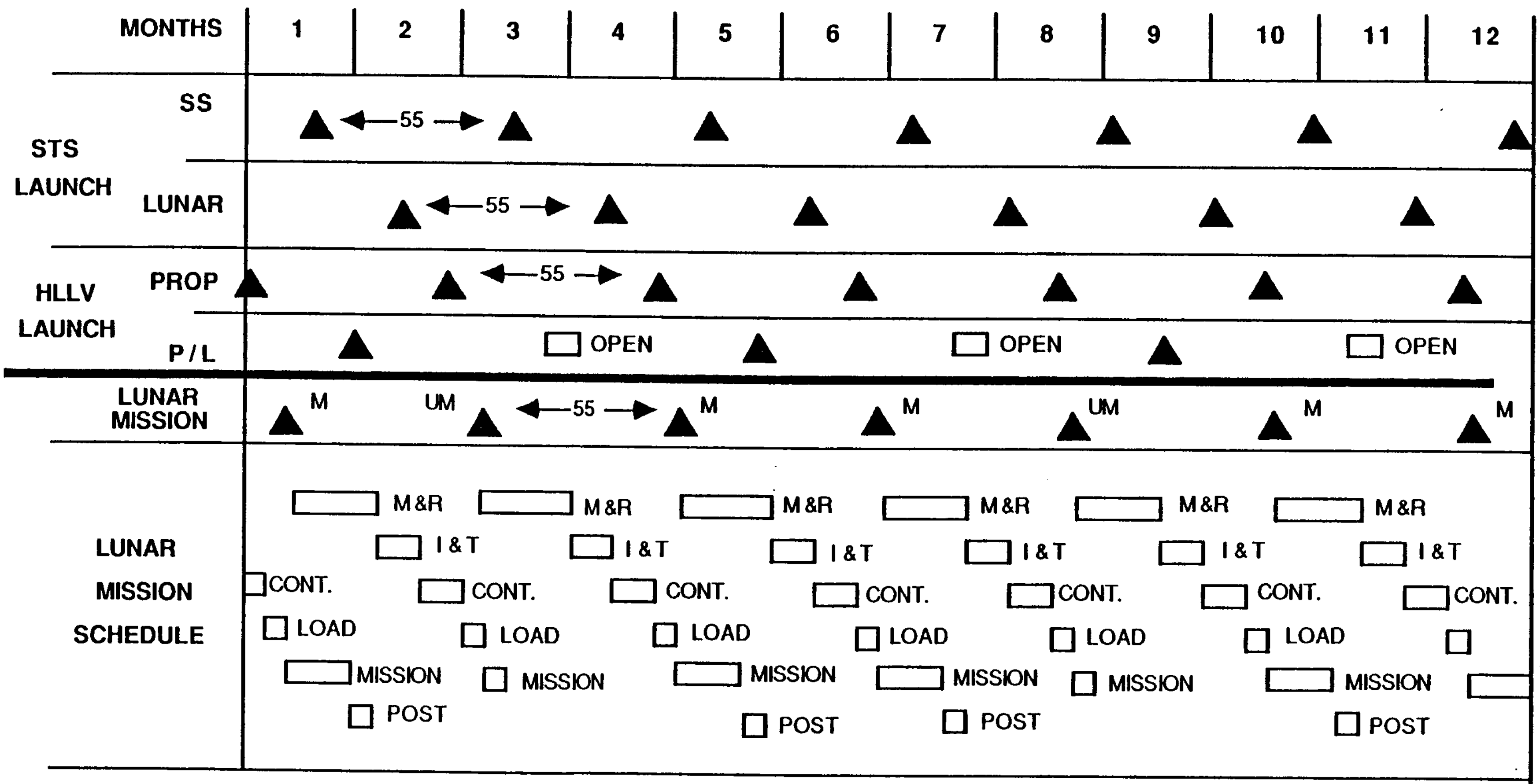
LUNAR MISSION SCHEDULE

The purpose of the next few charts is to establish a mixed fleet launch manifest that meets both crew and logistical requirements for the lunar missions. Because the station lunar vehicle build-up and test activity is a constant from lunar launch to lunar launch, the lunar vehicle logistical delivery schedule will also become a constant from launch to launch. Crew delivery on orbit also follows this pattern: If a certain type of crewman is required x number of days before launch, then the next mission will also require that type crewman x days before launch. If the lunar launch rate is on 55 day centers then the STS and HLLV will also be required to launch on 55 day cycles.

Below the heavy black bar on this chart, the lunar missions for a typical year are shown launched to the moon on 55 day centers, with two manned launches for every unmanned. The lowest part of the chart shows the activities that are required for each of these lunar launches, with the mission bar starting at the same time as the lunar mission triangle indicates. Activities for two crews working serially have been included, and show that all activity required can be accomplished.

110 DAY CREW CYCLE / 18 CREW TOTAL ON ORBIT

(KSC LAUNCH RATE ON 14 DAY CENTERS/26 PER YEAR)



LUNAR BASE ACCOMMODATION STUDY

18 CREW TOTAL ON ORBIT

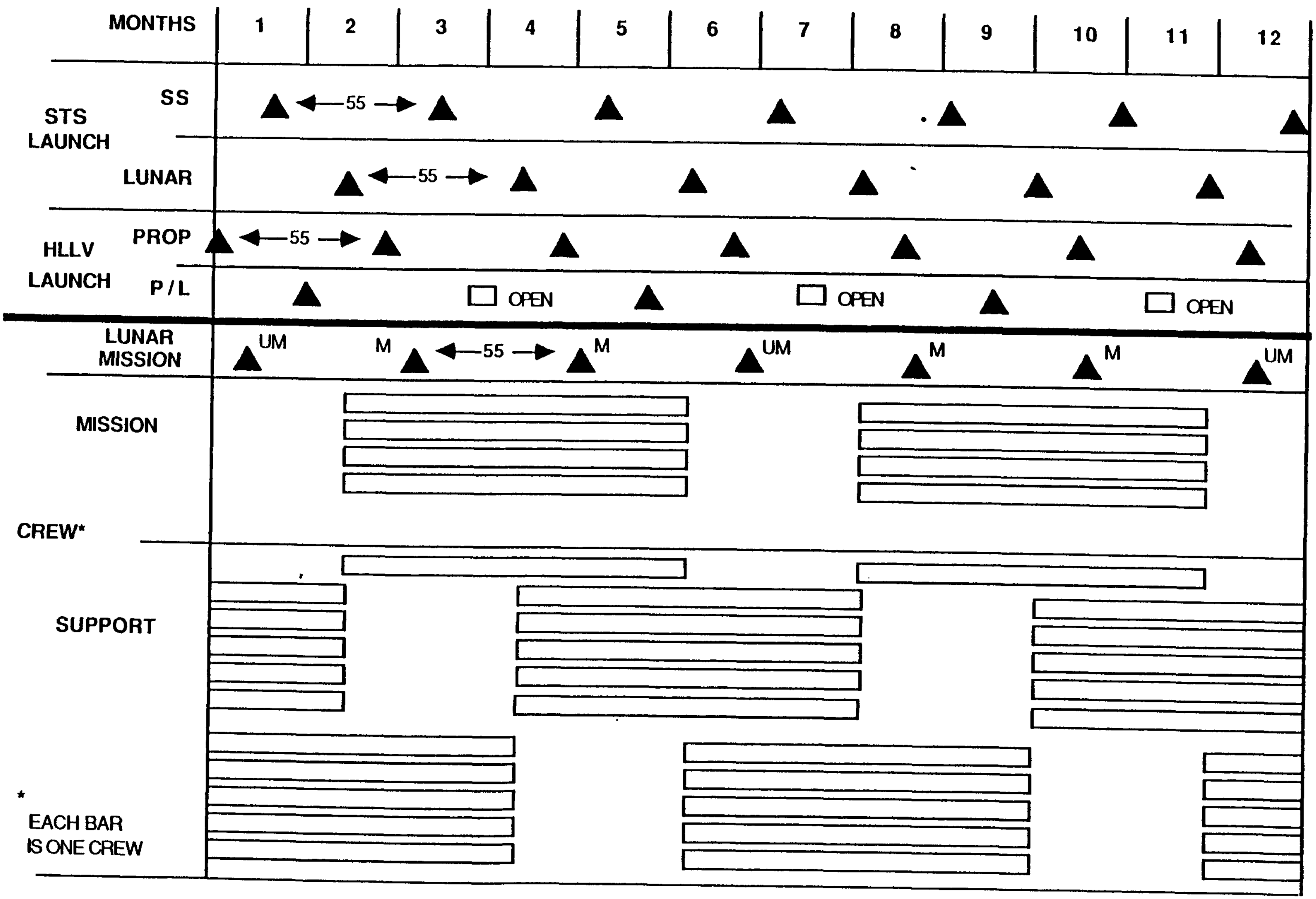
LUNAR CREW MANIFESTING

This chart shows the same yearly launches as the previous charts above the heavy black line. Below the line are shown the lunar missions for a different calendar year than previously illustrated, but still indicating the typical crew requirements for these missions. The lunar crew required are separated into two categories, mission crew and support crew. Since the STS is defined to carry 5 crew and the lunar missions have only 4 crew, then 1 of these crewmen is shifted to support as shown, and there are either 10 or 6 crewmen supplying support services at any given time. Crew changes coincide with the lunar STS launches as indicated above. - Results from these comparisons are noted on the next chart.

Lunar Base Accommodation Study

110 DAY CREW CYCLE / 18 CREW TOTAL ON ORBIT

(KSC LAUNCH RATE ON 14 DAY CENTERS)



LUNAR BASE ACCOMMODATION STUDY

18 CREW TOTAL ON ORBIT

NOTES

This chart summarizes the results of the comparisons from the previous charts on the support of the lunar base. Key items are as follows:

1. All of the launches must be synchronized with the lunar missions, and this approach does not allow for any delays in any flights. P-racticallity dictates that some allowances should be made for contingencies in some flights.

2. Contingency allowance should be made in the lunar mission schedules and has not been included herein.

3. Payload storage on orbit can be as long as three months and is unacceptable for the propulsion flights (with boiloff problems, controlability, etc.) The schedules should be adjusted to account for keeping payloads only for relatively short times before they are needed for a lunar launch. The nominal mission needs do not allocate any time for major system improvements or replacement even though there might be many major improvements developed before the lunar flights become routine.

110 DAY CREW CYCLE / 18 CREW TOTAL ON ORBIT

- NOTES
  - STS LUNAR AND HLLV LAUNCHES MUST BY IN SYNCH WITH LUNAR MISSION CYCLE TO MAXIMIZE CREW EFFICIENY AND HARDWARE UTILIZATION
  - VERY HIGH INTEGRATED DEPENDENCE BUILT INTO ENTIRE NASA OPERATION
  - NEED USABLE CONTINGENCY IN LUNAR MISSION SCHEDULE TO PREVENT A WATERFALL OF DELAYS (LAUNCH TO MOON IS END ITEM IN FLOW)
  - PAYLOAD STORAGE TIME ON ORBIT IS AS LONG AS 3 MONTHS
  - THESE NOMINAL FLOWS DO NOT ALLOCATE TIME OR SPACE FOR MAJOR SYSTEM REPLACEMENT / ENHANCEMENTS
  - THE MAXIMUM CREW TRANSFER REQUIREMENT AT ANY GIVEN TIME IS THIRTEEN (4 SPACE STATION, 3 LUNAR SUPPORT AND 6 LUNAR MISSION CREW)

LUNAR BASE ACCOMMODATION STUDY

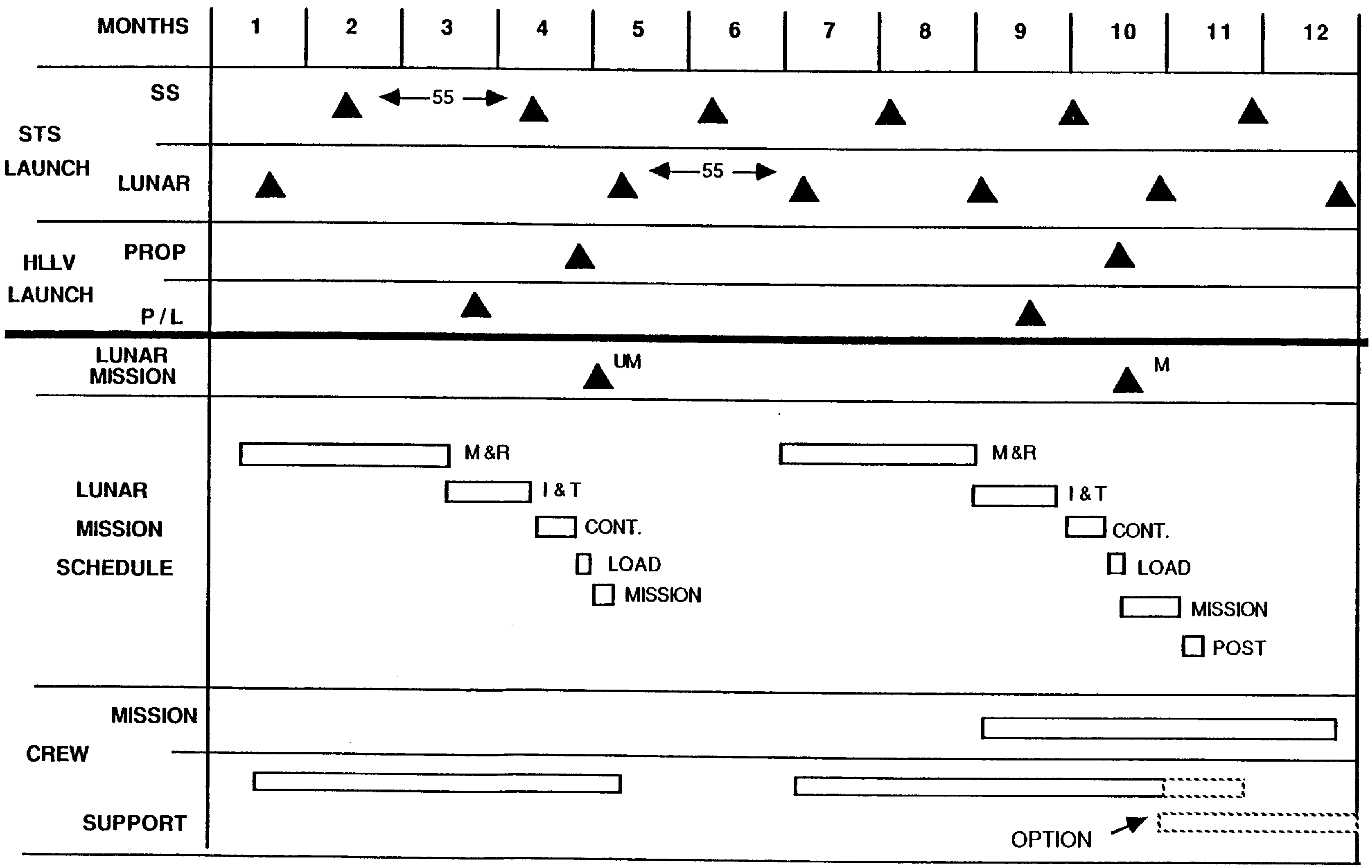
15 CREW MAX ON ORBIT

This chart shows the effect of reducing the number of lunar missions from the previous seven per year to only two missions per year. The number of STS flights per year is only reduced from 13 to 12 during the year, saving only one STS lunar support launch. Therefore, the STS launch limitations remain as a major bottleneck for the support of the lunar base missions. The major reduction in launch activity is the saving of six HLLV flights, primarily for propellant.

The crew requirements are also shown at the bottom of the chart, where the mission crew line refers to the entire four man mission crew and the support crew line refers to all three of the support crew. The option noted at the bottom of the chart indicates the possibility of having two support crews with overlapping activities, thereby increasing the crew on orbit to 18.

110 DAY CREW CYCLE / 15 CREW MAX ON ORBIT

(2 LUNAR MISSIONS PER YEAR / SINGLE SHIFT OPERATIONS)



LUNAR BASE ACCOMMODATION STUDY

ETR FACILITY REQUIREMENTS

This chart indicates the changes that need to be made at KSC to support the required lunar mission launch rates of 26 flights per year. Changes are defined in three categories; mods to existing facilities, entirely new facilities, and new equipment.

Mods to the existing facilities include improving both pads A&B and all four high bays of the Vehicle Assembly Building, reconfiguring the LCC and increasing the SSHAZ facility. Most of these changes would be to accommodate the required HLLVs.

The new facilities required are listed on the chart and are self descriptive.

The new equipment required includes two mobile launch platforms and a payload transporter for the HLLV.

These HLLV additions would be required for nearly any extended future missions, whether they were for lunar base accommodation or manned Mars missions, or any other missions. They allow the launch of 200 k lbs. of mass each flight, and this size allows many advanced missions.

ETR, STS/HLLV FACILITY REQUIREMENTS

o 26 FLIGHT/YEAR

- EXISTING STS FACILITIES WITH MODES
  - o PADS A&B MODED TO SUPPORT HLLV
  - o VAB - HIGH BAYS 1 & 3, NEW WORK PLATFORMS FOR HLLV
    - HIGH BAYS 2 & 4, ONE NEW ET TEST/STORAGE CELL EACH
  - o LCC - CONFIGURE FOR HLLV, (FR 1, 2 & 3 WILL SUPPORT VAB TO PAD FLOWS)
  - o SSHAZ FACILITY MOD FOR HLLV PAYLOAD ENTRY

- NEW FACILITIES
  - o 2 SRB STACK FACILITIES
  - o 1 RPSF (1 ROTATION AND 2 SURGE)
  - o CONTROL ROOMS TO SUPPORT POWER UP IN OPF BAYS 1, 2, & 3 AND SOFTWARE DEVELOPMENT
  - o HLLV PAYLOAD INTEGRATION CELL
  - o HLLV PAYLOAD ROTATION CELL
  - o PAYLOAD PROCESSING FACILITY

- NEW EQUIPMENT
  - o 2 HLLV MOBILE LAUNCH PLATFORMS
  - o 1 HLLV PAYLOAD TRANSPORTER

LUNAR BASE ACCOMMODATION STUDY

KSC PROCESSING

This presentation was based on a nominal flow and using the present philosophy of "launch when everything is right". This lunar operation requires a launch-on-demand philosophy which can be very inefficient in terms of our present operation mode. Once this program has started, the ability to recover from problems and meet the scheduled launch dates is imperative , and this is what requires the new philosophy.

With this launch-on-demand philosophy NASA will be required to have the vehicle ready to launch when the schedule calls and every time the schedule calls . To do this, the agency needs to be able to operate at less than it's maximum capacity to meet the nominal flows and use that remaining capability to recover from problems and still meet the scheduled launch dates. Using this remaining capability to recover from problems requires not only scheduled contingency time, but also additional shuttles, launch pads, and HLLVs.

Lunar Base Accommodation Study

KSC PROCESSING

- o THEORY
  - THIS NOMINAL REQUIREMENT FOR 26 MISSIONS PER YEAR CAN BE DONE WITH THE HARDWARE AND FACILITIES LISTED
- o REALITY
  - A 10 PLUS YEAR PROGRAM IS NOT "NOMINAL"
  - OTHER NASA AND MILITARY MISSIONS HAVE NOT BEEN FACTORED IN
  - THERE IS AN EXTREMELY HIGH LAUNCH ON DEMAND REQUIREMENT
- o CONCLUSION
  - KSC NEEDS A HIGHER FLIGHT RATE THAN 26 PER YEAR
  - KSC NEEDS TO ADD SOME FLEXIBILITY TO IT PROCESSING
  - AN ADDITIONAL ORBITER AND LAUNCH PAD IS REQUIRED

LUNAR MISSION TECHNOLOGY ISSUES AND ON-ORBIT DEMONSTRATION REQUIREMENTS

C.P. LLEWELLYN
JUNE 18, 1987

LUNAR BASE ACCOMMODATION STUDY

LUNAR BASE TECHNOLOGY ISSUES

TOP LEVEL

This set of two charts identifies the top level technology issues that must be addressed in order to establish a permanently manned presence on the moon . These technologies are "across the board" or generic in nature and are required to support the evolutionary lunar base progra discussed in this report. These technologies were not priortized or time-phased but did serve as a basis for a point of departure in the study to determine areas of specific emphasis for the IOC space station support. For example, the structures, automation and robotics, and life support technologies developed under the space station program are directly transferable to lunar base applications.

Lunar Base Accommodation Study

LUNAR BASE TECHNOLOGY ISSUES TOP LEVEL

ADVANCED ECLSS

- AIR, WATER, WASTE MANAGEMENT, FOOD PRODUCTION

CREW SYSTEMS

- ADVANCED EVA SUITS
- HABITABILITY CONSIDERATIONS
- HEALTH CARE AND MAINTENANCE CONSIDERATIONS

SURFACE TRANSPORTATION

- ROVERS (MANNED, UNMANNED)
- MOBILE IVA WORK STATIONS/HABITATS

AUTOMATION AND ROBOTICS

- CARGO HANDLING
- ASSEMBLY
- MINING
- REMOTE SITE EXPLORATION

LUNAR BASE ACCOMMODATION STUDY

TOP LEVEL TECHNOLOGY ISSUES

(CONTINUED)

It should be pointed out that in this study only those technologies that needed the space station for direct support were considered in any depth. Areas such as surface transportation, power generation, and thermal protection, for example, could be done best on the ground, with prototype and final hardware demonstration and verification being done on the lunar surface.

LUNAR BASE TECHNOLOGY ISSUES

TOP LEVEL (CONTINUED)

STRUCTURES

- MANUFACTURING
- ASSEMBLY/HANDLING

POWER/THERMAL

- SOLAR
- NUCLEAR
- CHEMICAL

LONG-TERM PASSIVE STORAGE OF LUNAR BASE SYSTEMS

- RADIATION EFFECTS
- TEMPERATURE EFFECTS
- PROPELLENT STORAGE
- MAINTENANCE

LUNAR BASE ACCOMMODATION STUDY

TECHNOLOGY ISSUES-SPACE STATION FOCUSED

The first five technology issues shown in this chart depict those technologies that this study identified as needed early in the program. These techologies are identifed as "Accelerated Emphasis", and may be considered as enabling technologies, whereas the technologies under "Space Station Supporting" could be considered as "enhancing" technologies and will be accommodated by the space station in any event.

TECHNOLOGY ISSUES - SPACE STATION FOCUSED

ACCELERATED EMPHASIS

- AUTOMATION/ROBOTICS
- AEROBRAKING
- AUTOMATED RENDEZVOUS AND DOCKING
- SPACE PROPULSION SYSTEMS
- SPACE CRYOGENICS

SPACE STATION SUPPORTING TECHNOLOGY AND DEVELOPMENT

- ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEMS (ECLSS)
- GUIDANCE, NAVIGATION AND CONTROL (GN&C)
- COMMUNICATIONS AND TRACKING (C&T)
- EXTRA VEHICULAR ACTIVITY (EVA)
- DATA MANAGEMENT SYSTEM (DMS)

LUNAR BASE ACCOMMODATION STUDY

DETAILED TECHNOLOGY ISSUES

The next two charts show the technology issues just defined with a brief statement as to their application to the lunar base program. In most cases, the applications are shown as near-term and long-term requirements. For example, the automation/robotics technology, while key to the success of the lunar vehicle on-orbit servicing/refurbishment requirements, is also an essential technology necessary to support lunar base surface operations. This is equally true for the automated rendezvous-/docking issue where sophisticated systems are required to support the numerous LEO and lunar orbital operations that will be required.

TECHNOLOGY ISSUES - SPACE STATION FOCUSED CONTINUED

AUTOMATION/ROBOTICS

- LUNAR VEHICLE PREPARATION/SERVICING IN LEO
- LUNAR BASE SURFACE OPERATIONS

AEROBRAKING

- OTV LEO OPERATIONS

AUTOMATED RENDEZVOUS/DOCKING

- OTV, OMV, HLLV, LEO OPERATIONS
- LUNAR VEHICLE LUNAR ORBIT OPERATIONS

SPACE PROPULSION SYSTEMS

- OTV, E-LANDER, E-LAUNCHER ENGINE DEVELOPMENT
- OTV, OMV PROPULSION SYSTEMS REUSABILITY, MAINTAINABILITY, REFURBISHMENT

SPACE CRYOGENICS

- PROPELLANT TRANSFER AND STORAGE

ECLSS

- MANNED LUNAR MODULE (MLM)
- LEO/LO SUPPORT OPERATIONS
- LUNAR BASE OPERATIONS

LUNAR BASE ACCOMMODATION STUDY

DETAILED TECHNOLOGY ISSUES

Guidance, navigation , and control and communication and tracking are also key technology issues, especially when the extensive traffic expecte in the space station vicinity is considered. In the EVA area, lighter more rugged suits with increased mobility will be required to support both LEO and Lunar surface operations.

TECHNOLOGY ISSUES - SPACE STATION FOCUSED CONTINUED

GN&C

- TRAFFIC CONTROL IN LEO
- OMV, OTV LEO OPERATIONS
- LUNAR VEHICLE TRANSLUNAR AND LUNAR ORBIT OPERATIONS
- LUNAR ORBIT SYSTEM

COMM/TRACKING

- TRAFFIC CONTROL IN LEO
- OMV, OTV LEO OPERATIONS
- LUNAR VEHICLE TRANSLUNAR AND LUNAR ORBIT OPERATIONS
- LUNAR ORBIT SYSTEMS

EVA SYSTEMS

- LUNAR SURFACE OPERATIONS
- LEO SUPPORT OPERATIONS

DMS

- LEO SUPPORT OPERATIONS
- LUNAR BASE SUPPORT
- MLM SUPPORT

LUNAR BASE ACCOMMODATION STUDY

TECHNOLOGY ISSUES

PROPELLANT DEPOT/TANK FARM

As mentioned earlier, the handling of the cryogenic propellants at the propellant depot/tank farm needs early emphasis, since the transfer and storage of propellants is critical to the mission"s success and performance. This becomes even more apparent later in the program when lunar oxygen production bscomes a reality. The successful solutions to the issues raised here are also keyed to the supporting automation/-robotics and the automated rendezvousand docking technologies.

TECHNOLOGY ISSUES

PROPELLENT DEPOT/TANK FARM

FUEL TRANSFER

- TANK TO TANK
- TANK TO VEHICLE

FUEL STORAGE/BOIL OFF

ON-ORBIT TANK HANDLING

- AUTOMATED RENDEZVOUS/DOCKING
- OMV CAPABILITIES

ROBOTIC/TELEOPERATOR SERVICING/OPERATIONS

LUNAR BASE ACCOMMODATION STUDY

TECHNOLOGY ISSUES

IN-SPACE PROCESSING/OPERATIONS

The technology issues on this chart evolved from the analysis of the lunar vehicle in-space processing and turnaround requirements.The spacebased diagnostics/prognostics issue is key to successfully meeting the rigid turaround schedule used in the study and for establishing the high degree of confidence required for safe system operations. The degree of modularity, the level of component changeout and replacement engine/tank reusability, spares inventory, etc. will be a real challenge for the designers to provide "serviceability" to the lunar vehicle systems.

It should be noted that LeRC is proposing studies on reuseable space propulsion systems that should be directly applicable to any in-space vehicle processing, especially in the area of expert systems for monitoring, diagnostics, and control.

The issue of on-orbit processing of hazardous (wet) systems and the transfer of crewmen in pressurized modules to fueled space vehicles will also require new and inovative "operational philosophies" and engineering ingenuity in order to provide timely and safe solution to these problems.

TECHNOLOGY ISSUES SPACE STATION FOCUSED IN-SPACE VEHICLE PROCESSING/OPERATIONS

SPACE BASED DIAGNOSTICS/PROGNOSTICS

- IN-SPACE SYSTEMS CHECKOUT
- ON-BOARD/ORBIT DECISION MAKING FOR SAFE SYSTEMS OPERATIONS
- SYSTEMS HEALTH PREDICTION/

IN-SPACE SHELF LIFE OF LUNAR BASE HARDWARE/SPARES INVENTORY IN LEO, LUNAR VICINITY

IN-SPACE PROCESSING OF HAZARDOUS (WET) SYSTEMS

PRESSURIZED TRANSFER OF CREW TO FUELED LUNAR VEHICLE

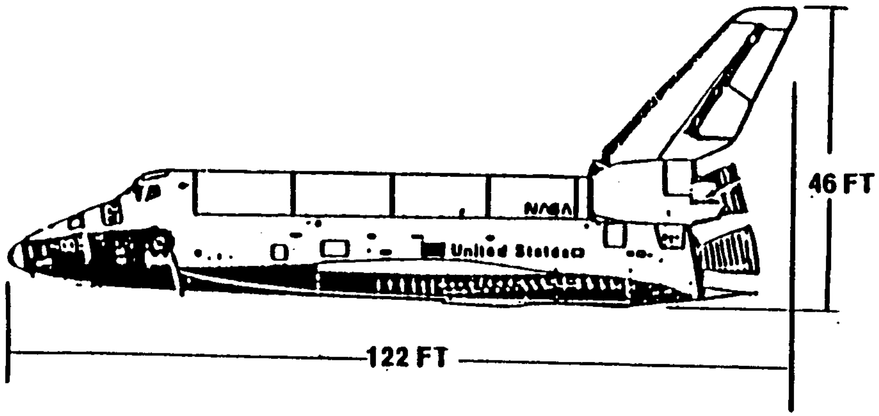
LUNAR BASE ACCOMMODATION STUDY

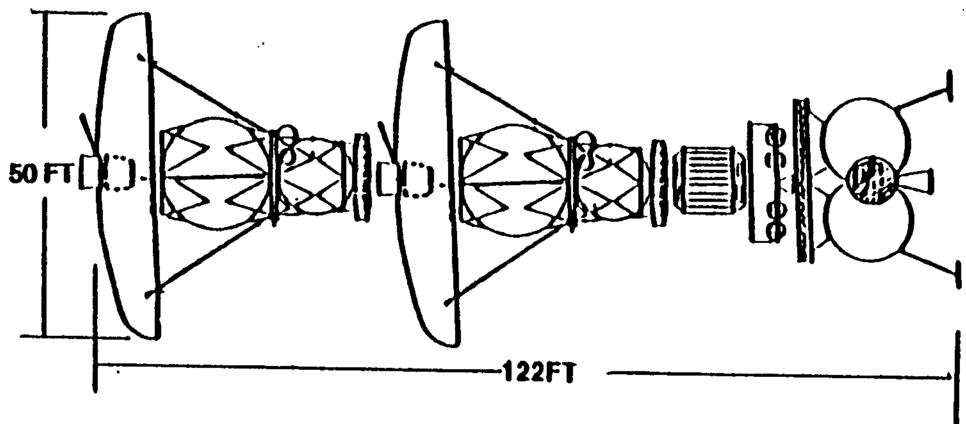
VEHICLE COMPARISON

This chart shows the magnitude of some of the challenges associated with on-orbit vehicle processing and refurbishment. The chart shows the space shuttle and the manned lunar vehicle used in this study to the same scale. Not only is the lunar vehicle as big as the shuttle, but it is at least as complex. It has more engine systems and more vehicle elements that must be serviced, integrated, and checked out- all on-orbit and with a crew of six on a two-shift operation! Even if the flight rates and the turnaround times assumed in this study were relaxed, considering what it takes now to process the shuttle in terms of people, time, operations, etc., it will be a real challenge to accommodate the lunar vehicle operations on-orbit.

Lunar Base Accommodation Study

VEHICLE COMPARISON





SPACE SHUTTLE	
LENGTH	122 FT
WIDTH	78 FT
HEIGHT	46 FT
DRY WEIGHT	165 K#'S
ON-ORBIT WEIGHT	230 K#'S
ENGINE SYS'S	
SSME	LOX/LH
OMS	MMH/NTO
RCS	MMH/NTO
SUBSYSTEMS	
ECLSS	
GN&C	
C&T	
EMP	
DMS	
EVA	

MANNED LUNAR VEHICLE	
LENGTH	122FT
WIDTH	50 FT
DRY WEIGHT	56 K#'S
EARTH DEP. WEIGHT	248 K#'S
ENGINE SYS'S	
SPACE PROP. SYS	LOX/LH
RCS	MMH/NTO
E-LANDER	LOX/LH
E-LAUNCHER	MMH/NTO
SUBSYSTEMS	
ECLSS	
GN&C	
C&T	
EPS	
DMS	
EVA	

LUNAR BASE ACCOMMODATION STUDY

TECHNOLOGY ISSUES- SYSTEMS LEVEL

The next three charts present the systems level technology issues for the major flight hardware elements of the lunar vehicles. Each of the new development items that make up the lunar vehicle is listed along with the major subsystems/functions that comprise that element. In an attempt to define the technology readiness of the flight hardware, an overall assessment of the availability of the technology is shown in the first two columns. These technology requirements were identified as being space station derived, new technology, or some combination of both. As can be seen, over half of those identified were found to be highly dependent on space station heritage.

The applicability of using the shuttle and/or space station experience (or test bed capabilities) for the on-orbit development and testing for lunar base elements is indicated in the last two columns of the charts.

TECHNOLOGY ISSUES - SYSTEMS LEVEL

ELEMENT/FUNCTION	SS - DERIVED	NEW	LEO DEV. TEST	
			STS	SS
MANNED LUNAR MODULE				
ECLSS	YES	SOME	NO	YES
EPS	NO	NO	NO	YES
GN&C	YES	YES	YES	YES
COMM/TRACKING	YES	YES	YES	YES
EVA SYSTEMS	YES	YES	SOME	YES
DMS	YES	NO	NO	YES
COMMAND/CONTROL INTERFACE	SOME	YES	YES	YES

LUNAR BASE ACCOMMODATION STUDY

TECHNOLOGY ISSUES-SYSTEMS LEVEL

OTV SYSTEMS

This chart indicates the technologies needed for the OTV. The OTV main engine is an excellent example of capitalizing on the experience base accumulated on the shuttle main engines (SSME's). This base, along with the proposed LeRC efforts on reusable space propulsion systems, will be invaluable in finding solutions to the challenges of on-orbit vehicle processing/refurbishment.

Lunar Base Accommodation Study

TECHNOLOGY ISSUES - SYSTEMS LEVEL CONTINUED

			LEO DEVELOPMENT TEST	
ELEMENT/FUNCTION	SS DERIVED	NEW	STS	SS
OTV				
AUTOMATED REND./DOCKING	YES	YES	YES	YES
ACS	YES	NO	NO	YES
GN&C	YES	YES	YES	YES
C&T	YES	YES	YES	YES
PROPULSION SYSTEM	NO	SOME	YES	YES
(REUSABILITY TECH)	NO	YES	YES	YES
AEROBRAKE/AEROSHELL	YES	YES	YES	YES
COMMAND/CONTROL INTERFACE	SOME	YES	YES	YES

LUNAR BASE ACCOMMODATION STUDY

TECHNOLOGY ISSUES- SYSTEMS LEVEL

EXPENDABLE ELEMENTS

From this systems level analysis, the single common thread that ran through all of the systems elements was the command and control interface function. This requirement was due primarily to the "man-in-the-loop", and must be an integral part of all vehicle systems with which he will interface. No matter how sophisticated the automated rendezvous /docking systems become, the crewman must have the capability to monitor, assess, and intervene if necessary, to take active, real-time control of any vehicle or situation of which he is part.

TECHNOLOGY ISSUES - SYSTEMS LEVEL CONTINUED

ELEMENT/FUNCTION	SS DERIVED	NEW	LEO DEVELOP. TESTS	
			STS	SS
E-LANDER				
GN&C	YES	YES	YES	YES
C&T	YES	YES	YES	YES
ACS	YES	NO	NO	YES
PROPULSION	NO	YES	NO	NO
COMMAND/CONTROL INTERFACE	NO	SOME	YES	YES
ROVER	NO	YES	NO	NO
E-LAUNCHER				
GN&C	YES	YES	YES	YES
C&T	YES	YES	YES	YES
ACS	YES	NO	NO	YES
PROPULSION	NO	SOME	NO	NO
COMMAND/CONTROL INTERFACE	SOME	YES	YES	YES

LUNAR BASE ACCOMMODATION STUDY

ON-ORBIT DEMONSTRATION PROGRAM CONSIDERATIONS

The next two charts address the on-orbit demonstration program. The lunar vehicle system elements are shown, with the testing and verification requirements listed for each of these major flight hardware items. In addition to those listed, there will be end-to-end testing and all-up mission simulations required with the totally integrated lunar vehicle configuration.

ON-ORBIT DEMONSTRATION PROGRAM CONSIDERATIONS

TESTING/VERIFICATION

OTV

- RENDEZVOUS/DOCKING WITH OMV
- RENDEZVOUS/DOCKING WITH MLM
- SEPARATION TEST - OMV, MLM, CARGO MODULE
- SERVICEABILITY/TURNAROUND PROCEDURES
- FUELING
- AEROSHELL PERFORMANCE

OMV

- REND/DOCK WITH HLLV
- REND/DOCK WITH LUNAR VEHICLE (OTV/ MLM, OTV/CARGO)
- SERVICEABILITY/TURNAROUND PROCEDURES
- FUELING

LUNAR BASE ACCOMMODATION STUDY

ON-ORBIT DEMONSTRATION PROGRAM CONSIDERATIONS

CONTINUED

The single common thread shown throughout these charts was the importance of demonstrating and validating the "Servicability" feature of each of the lunar vehicle elements. As has been noted, being able to process the vehicle on-orbit in a timely and efficient manner with the high degree of confidence required for safe operations and mission success is going to be a real challenge to both designers and crew alike.

ON-ORBIT DEMONSTRATION PROGRAM CONSIDERATIONS (CONTINUED)

MANNED LUNAR MODULE (MLM)

- SUBSYSTEMS VERIFICATION
- COMMAND/CONTROL INTERFACE VERIFICATION
- SERVICEABILITY, MAINTENANCE
- MISSION SIMULATIONS
- CREW TRANSFER, PREMISSION/POST MISSION C/O PROCEDURES

E-LANDER/LAUNCHER

- SEPARATION, RENDEZVOUS AND DOCKING DEMONSTRATION
- LANDING AND ASCENT DEMONSTRATION
- MISSION SIMULATION (MANNED, UNMANNED)
- FUELING

AEROBRAKE/AEROSHELL

- ASSEMBLY
- SERVICEABILITY/REFURBISHMENT PROCEDURES

LUNAR BASE ACCOMMODATION STUDY

ON-ORBIT SUPPORT AND DEMONSTRATION PROGRAM

CREW AND VOLUME REQUIREMENTS

The following two charts show the crew and volume requirements necessary to support the on-orbit demonstration program discussed earlier. The numbers shown for crew requirements in the years indicated are in manyear equivalents, and for this analysis it was assumed that one on-orbit manyear was equivalent to 2808 manhours. These manhour estimates were derived primarily from analysis of the technology development data base (TDMX) payloads as described in the space station MRDB, and include both IVA and EVA tasks.

For the specific tasks listed on this chart, no internal or pressurized space station volumes were required.

C-3

C-3

ON-ORBIT SUPPORT AND DEMONSTRATION PROGRAM CREW AND VOLUME REQUIREMENTS

MISSION ELEMENT/FUNCTION TESTS	1997	1998	1999	VOLUME
OTV				
RENDEZVOUS/DOCKING	.02	.07	.06	
SERVICING/REFURB.	.04	.06	.06	
FUELING	.05	.02	.02	
AEROSHELL	.05	.05	.02	
E-LANDER/LAUNCHER				
LANDING/ASCENT		.03	.02	EXTERNAL
FUELING		.02	.02	
OMV				
RENDEZVOUS/DOCKING	.02	.03	.03	
SERVICING/REFURB.	.01	.02	.02	
FUELING	.05	.02	.02	

LUNAR BASE ACCOMMODATION STUDY

ON-ORBIT SUPPORT AND DEMONSTRATION PROGRAM

CREW AND VOLUME (CONTINUED)

On this chart, rather large manhour requirements are shown in the areas of lunar vehicle subsystems, systems monitoring, and orbital support facilities (OSF). Lunar vehicle subsystems monitoring requires rather routine but continuous activity from the crew. Systems monitoring, on the other hand, requires an intense manpower involvement while tests of the rendezvous/docking, fueling, landing/ascent demonstrations, vehicle assembly, space cryogenics, etc. are in progress.

The relatively high manloading shown for OSF activities includes the work required for the facility construction/assembly in 1997, and the manpower required to develop, test, and validate the vehicle processing and turnaround qperational procedural requirements during the two years prior to phase two initiation.

The volume requirements shown here are in terms of station double rack equivalents and represent the pressurized/internal volumes needed to accommodate the monitoring and command/control functions associated with the indicated testing/verification support demands.

ON-ORBIT SUPPORT AND DEMONSTRATION PROGRAM

CREW & VOLUME REQUIREMENTS (CONTINUED)

MISSION ELEMENT/FUNCTION TESTS	1997	1998	1999	VOLUME (DOUBLE RACK EQUIV.)
MLM				
SERVICING/REFURB.		.05	.05	EXTERNAL
MISSION SIMULATIONS			.10	
LUNAR VEHICLE SUBSYSTEMS AND SYSTEMS MONITORING	1.25	1.25	1.50	5
OSF				
VEHICLE ASSEMBLY/SERVICING	2.0	2.0	3.0	2
TOTAL	3.49	3.62	4.72	7

LUNAR BASE ACCOMMODATION STUDY

ON-ORBIT SUPPORT AND DEMONSTRATION PROGRAM

POWER REQUIREMENTS

This chart summarizes the average power requirements used during this on-orbit demonstration phase. The power usages in the lunar vehicle subsystems and systems monitoring entries represent the basic load requirements necessary to sustain these test functions and includes an allowance to support the command/control functions from the station. In the OSF case, the requirement includes the manipulators, the A&R support, the service bay facilities, monitoring, etc.. If option 3 is selected as the preferred operating mode, this power load disappears as far as the space station is concerned.

The power shown for space cryogenics comes from a TDMX in the MRDB, and includes the power necessary to support the technologies associated with storage, refrigeration, reliquefication, and transfer techniques.

ON-ORBIT SUPPORT AND DEMONSTRATION PROGRAM POWER REQUIREMENTS (KW)

MISSION ELEMENT/FUNCTIONS TESTS		1997	1998	1999
LUNAR VEHICLE SUBSYSTEMS AND SYSTEMS MONITORING		3	3	4
***OSF**				
VEHICLE ASSEMBLY/SERVICING		4	5	5
SPACE CRYOGENICS				
STORAGE/TRANSFER		2.5	2.5	2.5
TOTALS	* OPTION 1	9.5	10.5	11.5
	OPTION 3	5.5	5.5	6.5

LUNQR BASE ACCOMMODATION STUDY

ON-ORBIT PROGRAM SUMMARY

The space station resource requirements (crew, power, volume) are summarized on this chart. The average crew requirement is four manyears/-year, with an average annual power requirement of from six to eleven kilowatts depending upon the lunar vehicle basing option selected.

A peak requirement of eight crew is shown and is due to an increased crew complement needed during OSF build-up in 1997, and the additional crew required to support the lunar mission simulations in 1999. A peak power demand of 15-20 KW results from requirements associated with space cryogenic development and demonstration testing.

ON-ORBIT PROGRAM SUMMARY

SPACE STATION RESOURCE REQUIREMENTS

AVERAGE (PER YEAR)

CREW	4 MAN YEARS
POWER	6-11 KW
VOLUME	7 DOUBLE RACKS

PEAK

CREW	8
POWER	15 - 20 KW

Lunar Base Accommodation Study

SPACE STATION TRAFFIC

C. P. LLEWELLYN
JUNE 18, 1987

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LUNAR BASE ACCOMMODATION STUDY

TRAFFIC EVENTS AT SPACE STATION

One of the stated objectives of this study was to determine lunar base mission impacts on the IOC space station. This chart presents the results of a traffic assessment conducted to quantify disturbances to the station resulting from the vehicular activity required to support the lunar mission.

The results summarized here show the total number of traffic events expected at the station for both the manned lunar missions and the unmanned cargo missions during the 55-day turnaround cycle. The results are shown for three of the lunar vehicle basing options used in the study. In this analysis, it was assumed that, for the options considered, the OMV was station based.

The differences between the traffic on the station for options one and two were insignificant. The differences were due to the transfer of the lunar vehicle stack to the co-orbiting propellant tank farm (PTF) for fueling in the cargo missions and having an additional trip to the PTF to transfer the mission crew to the lunar vehicle in the manned case.

In option three. the high traffic rate results from transporting the double shift lunar support crew between the station and the Orbital Support Facility (OSF) in order to meet the 55-day turnaround cycle discussed earlier. In this option, the OMV utilization accounted for nearly all of the traffic events.

TOTAL TRAFFIC EVENTS AT SPACE STATION

55-DAY VEHICLE TURNAROUND CYCLE

	OPTION 1	OPTION 2	OPTION 3
MANNED MISSION	20	21	202
CARGO MISSION	20	19	200

NOTE:
- EVENTS ARE ANY ARRIVALS/DEPARTURES AT THE SPACE STATION AND INCLUDE THE STS, HLLV'S, LUNAR VEHICLE ELEMENTS AND OMV TRAFFIC
- OMV IS STATION BASED

LUNAR BASE ACCOMMODATION STUDY

OMV UTILIZATION- 55 DAY TURNAROUND

This chart shows the OMV utilization for the three lunar vehicle basing options for both the manned and unmanned (cargo) missions. All of the events shown here are due to the OMV utilization. Although implimentation of option three creates the most potential traffic density risks in the station vicinity, this option probably has the least effect on the space station/micro "g" environment due to disturbances.

In options 1 & 2, rather large masses (HLLV's and lunar vehicles) are being moved to and from the station, and hence the potential disturbances are of considerably greater magnitude than those in option 3, where only crew is being transported back and forth.

Further studies are needed, however, before a final decision on any option can be made. These studies should include:

- dynamic response analyses
- contamination analyses, including cryo boil-off, RCS effects
- propellant explosion, traffic density risks
- OMV requirements analysis,including minimizing transport time between station and OSF (less than 2 hrs. per trip), vehicle control authority to handle over 150klbs., pressurized transfer of up to six crew, etc.

OMV UTILIZATION - 55 DAY TURNAROUND

ACTIVITY	OPTION 1		OPTION 2		OPTION 3	
	CARGO	MANNED	CARGO	MANNED	CARGO	MANNED
HLLV						
REND/DOCK	2	2	2	2	2	2
OTV_1						
FUELING			1	1		
DEPART	1	1	1	1	1	1
RETURN	1	1	1	1	1	1
OTV_2 /CARGO						
DEPART						
RETURN	1		1		1	
OTV_2 /MLM						
DEPART						
RETURN		1		1		1
CREW TRANS. TO PTF & COF				1		1
LUNAR VEHICLE SERV. SHUTTLE					93	93
TOTAL ROUND TRIPS	5	5	6	7	98	99

LUNAR BASE ACCOMMODATION STUDY

CONCLUDING REMARKS/OBSERVATIONS

The key conclusions drawn from this section of the report are restated here. The first three remarks are directed toward the OMV-type capability that is needed to support the lunar base initiative.

From the documentation available to the study, the OMV's being considered in the IOC space station time frame do not appear adequate to fully support the orbital activities required by the lunar missions. Studies are needed to define the requirements for an OMV-type vehicle that is specifically tailored to satisfy the broad range of tasks necessary to support this program.

The success of the lunar base missions depends primarily on the ability to meet the rigid turnaround schedules established in this study and to find solutions to the space storable cryogenics issues. Automated rendezvous and docking is also critical to mission success when the complexity of performing this function with man in the loop is considered and in both LEO and Lunar orbits.

Practical solutions to all of these issues will present real challenges to planners. designers, and operators alike in carrying out such an ambitious program.

CONCLUDING REMARKS/OBSERVATIONS

- CREW TRANSIT TIME BETWEEN STATION AND CO-ORBITING FACILITIES SHOULD BE TWO HOURS OR LESS

- MOMV SHOULD BE CAPABLE OF HANDLING MASSES IN EXCESS OF 250 K LBS - (ALTERNATIVE IS TO USE LUNAR VEHICLE RCS FOR MANEUVERING IN SPACE STATION VICINITY)

- MOMV SHOULD BE CAPABLE OF PRESSURIZED TRANSFER OF UP TO SIX CREWMEN

- ON-ORBIT SERVICING/REFURBISHMENT, SPACE STORABLE CRYOGENICS, AND AUTOMATED RENDEZVOUS/DOCKING TECHNOLOGIES SHOULD BE ACCELERATED

SCIENCE IMPACT / CONSIDERATIONS

GEORGE LAWRENCE

LUNAR BASE ACCOMMODATION STUDY

SCIENCE IMPACT DEFINITION

This chart simply makes the point that some planned science payloads on the station will not be compatible with the lunar base needs, and the objective of the science impact studies is to define which science experiments are effected.

SCIENCE IMPACT DEFINITION

IDENTIFIES STATION SCIENCE PAYLOADS THAT ARE COMPATIBLE WITH LUNAR BASE ACCOMMODATION OPTIONS AND THOSE SCIENCE PAYLOADS WHICH ARE NOT COMPATIBLE.

LUNAR BASE ACCOMMODATION STUDY

KEY GROUNDRULES AND ASSUMPTIONS

This chart indicates that the mission model used was derived from the CNDB using constrained option 1. Also total resource requirements are presented for the three primary resources.

KEY GROUNDRULES AND ASSUMPTIONS

- MISSION MODEL DERIVED FROM CIVIL NEEDS DATA BASE (CONSTRAINED OPTION, # 1)

- LUNAR BASE RESOURCE REQUIREMENTS ARE ADDED TO SPACE STATION'S (CREW, POWER, LAB/HAB VOLUME)

LUNAR BASE ACCOMMODATION STUDY

MISSIONS ON STATION AT IOC

This chart lists and defines the experiments from the CNDB that have been defined as IOC experiments. They are of all types: technology, science, international, etc. and are the subset of experiments that should be evaluated for lunar base implications.

MISSIONS ON STATION AT IOC

COMM 1201	MICROGRAVITY & MATERIALS PROCESSING
COMM 1202	EOS PRODUCTION UNITS
M-001	MATERIAL SCIENCE EXPERIMENT
M-002	SPACE PROCESSING FOR ADVANCED MATERIALS
MAT110	MATERIALS SCIENCE RESEARCH LAB
MAT130	AUTOMATED MATERIALS PROCESSING
TDMX4001	MATERIALS LABORATORY
L-001	BIOLOGY AND MEDICINE
L-002	SPACE MEDICINE
L-003	CELSS
L-004	BIOTECHNOLOGY
SAAX307	LIFE SCIENCES LAB
LIF111	GENERAL PURPOSE LIFE SCIENCES RESEARCH FACILITY
TDMX2441	MICROELECTRONICS DATA EXPERIMENT
TDMX2442	TRANSIENT UPSET PHENOMENA - VLSI
TDMX2443	VHSIC FAULT TOLERANT PROCESSOR
TDMX4002	SENSOR
TDMX2011	SPACECRAFT MATERIALS & COATINGS
TDMX2132	ADVANCED RADIATOR CONCEPTS
SAAX4002	POLCATS
SAAX250	HITCHHIKER 4-EARTH RADIATION
SAAX207	SOLAR-TERRESTRIAL OBSERVATORY
SAAX012	HST SERVICING
SAAX251	TROPICAL RAIN

LUNAR BASE ACCOMMODATION STUDY

SPACE STATION SCIENCE SUMMARY

This chart summarizes the payloads categorized by the four types of science, and defines the resources needed and the type of environment each payload requires.

The material processing activities include crystal growth type experiments, for example, which require a micro-g environment and high power heaters with heavy crew involvement.

Applying the expected lunar base activity to the environments shown in the table allows a quick assessment of the possible impacts from lunar base on the space station science.

SPACE STATION SCIENCE SUMMARY

SCIENCE PAYLOAD GROUPS	RESOURCE REQUIREMENTS (DRIVERS)	STATION ENVIRONMENT (DESIRED)
MATERIAL PROCESSING	o HIGH CREW o HIGH POWER o HIGH LOGISTICS	o QUIET PLATFORM o STABLE MICRO-GRAVITY
LIFE SCIENCES	o HIGH CREW o HIGH POWER	o MODERATE ZERO-G REQUIREMENTS
ASTROPHYSICS EARTH OBS.	o SERVICE FREE-FLYERS o SERVICE ATT. PAYLOADS o MOD. CREW	o PRECISE POINTING o FOV o LOW CONTAMINATION
TECHNOLOGY	o MOD. POWER o HIGH CREW (EVA)	o MODERATE CONTAMINATION

LUNAR BASE ACCOMMODATION STUDY

LUNAR BASE EFFECTS ON STATION SCIENCE

This chart identifies the effects of the four study options on station science activities. These options range from everything for the lunar missions being done on the station, to everything being done on an accompanying free-flyer.The column on changes in station environment describes the lunar base elements and activities that would effect the station, and the final column describes the station environmental changes caused by the lunar elements. For example, the lunar vehicle hangar would cause reduced field of view for the outward and inward viewing science experiments depending on the hangar's location.

As more of the activity is moved off of the station the effects on station science activities is reduced, until finally the effects become negligible.

Lunar Base Accommodation Study

EFFECTS OF LUNAR BASE OPTIONS ON STATION SCIENCE

SS/LUNAR BASE CONFIG.	CHANGES IN STATION ENVIRONMENT	ENVIRONMENTAL EFFECTS ON STATION SCIENCE ACCOMMODATIONS
OPTION 1 (EVERYTHING ON STATION)	o LUNAR VEHICLE ASSBLY HANGAR o PROPELLANT TANK FARM CONTAMINATION o INCREASE NUMBER OF STS/HLV DOCKINGS o LARGE MASS VARIATIONS ON A 55 DAY LUNAR LAUNCH CYCLE	o ADVERSE EFFECTS FOV/ASTROPHYSIC EARTH OBS. o OPTICAL CONTAMINATION - EFFECTS ON ASTROPHYSICS/EARTH OBS. AND TECHNOLOGY o MASS TRANSIENTS AND PROPELLANT EXHAUST ON μ-G AND EARTH OBS. (POINTING) o LARGE CENTER-GRAVITY EXCURSIONS AFFECTS μ-G AND EARTH OBS. (POINTING)
OPTION 2 - ASSEMBLY ON STATION - CO-ORBITING PTF PLATFORM	o ASSEMBLY HANGAR o LARGE MASS VARIATIONS ON A 55 DAY LUN. LAUNCH CYCLE	o ADVERSE FOV/ASTROPHYSICS - EARTH OBS. o LARGE CENTER - GRAVITY EXCURSIONS AFFECTS μ-G AND EARTH OBS
OPTION 3 - CREW ON STATION - VEHICLE ASSEMBLY AND PROPELLANT ON CO-ORBITING PLATFORM	o SIGNIFICANT INCREASE IN OMV TRAFFIC	o NO SIGNIFICANT EFFECTS ON STATION SCIENCE
OPTION 4	NULL	NULL

LUNAR BASE ACCOMMODATION STUDY

ENVIRONMENTAL/RESOURCE EFFECTS ON SCIENCE

This chart indicates where lunar base activity has the most effects. The payloads are divided into nine categories as shown, and the areas of concern are divided into seven categories: The torque equilibrium angle, the field of view, the micro-gravity environment, contamination possibilities, crew motion, control and pointing, and stability of the center of gravity. An X is placed in those locations where a change in area of concern has an effect on any of the payload groups. Two X's indicates a serious or major effect that could stop the experiment. For example, material processing activities (like crystal growth) require a steady, low g level and a serious change to the g level would stop crystal growth activity until stabilized. Therefore, a double X occurs in that location in the chart.

This table addresses options 1 and 2 only, since the effects of options 3 and 4 on the science experiments are minimal and impact only a small subset of the experiments.

Lunar Base Accommodation Study

ENVIRONMENTAL/RESOURCE EFFECTS ON STATION SCIENCE ACCOMMODATIONS

(OPTION 1 AND 2)

PAYLOAD GROUPS	TEA	FOV	μ- G	CONTAMINATION	CREW	POINTING	C.G. STABILITY
MATERIAL PROCESS.	X		XX		XX		XX
LIFE SC.					X		X
ASTRO.	X	XX		XX	X	X	
EARTH OBS.	XX	XX		XX	X	XX	
TECHNOLOGY							
LARGE STR.					X		
ELECT.					X		
VIEWING	X	X			X	X	
ADV. POW.					X		

LUNAR BASE ACCOMMODATION STUDY

CONCLUDING REMARKS

This chart shows the basic effects of lunar base on station science. The major science experiments adversely effected by lunar activity are the material processing missions where micro-g may be destroyed for large periods of time and the observational experiments where the large facilities for lunar base cause field of view reductions.

The technology and life science missions are least effected by the lunar base accommodations, and can continue unaltered except for scheduling of the astronauts IVA/EVA work time.

The shifting of a significant amount of the lunar element assembly/ servicing activity away from the station causes the least disruption of station science activities and is the most logical step to take for science mission accomplishment.

CONCLUDING REMARKS

- MATERIAL PROCESSING AND ASTROPHYSICS/EARTH OBS. (ATTACHED) MISSIONS ARE MOST SENSITIVE (ADVERSELY) TO A LUNAR BASE ACCOMMODATION
- TECHNOLOGY AND LIFE SCIENCE MISSIONS CO-EXIST BEST WITH LUNAR BASE ACCOMMODATION SCENARIOS
- A PROPELLANT FARM/VEHICLE ASSEMBLY, CO-ORBITING PLATFORM (LUNAR BASE, OPTION 3) PERTURBATES SPACE STATION SCIENCE LEAST AND IS A LOGICAL STEP ONCE PHASE 2 OF THE LUNAR PROGRAM IS REACHED

Lunar Base Accommodation Study

SUMMARY AND CONCLUSIONS

BOB MURRAY
JUNE 18, 1987

LUNAR BASE ACCOMMODATION STUDY

SPACE STATION STUDIES COMPARISON

There has been some interest expressed in a comparison of the results from the lunar base accomodation (LBAS) on the space station and the previous study conducted here in the space station office on the impact of a manned Mars mission (M3) on the space station. These two studies addressed completely different objectives; the M3 study considered a manned large vehicle flying from the station to Mars and return one time, whereas LBAS considered a short shuttling of astronauts back and forth to a nearby site for a permanent manned base. With such vastly different objectives, it is not surprising that the technology needs for the two missions are different.

This chart compares the two studies and explains their differences. The objectives were as noted. The background knowledge upon which these studies were based is extensive in both cases, and have no experiments common to both studies. The mission lengths and stay times are also shown, for M3 for the total mission and for LBAS for each crew trip of which there will be many. The primary concern for LBAS is the resupply of the crew on the lunar surface, while for M3 it is getting the crew there and back safely and well.

SPACE STATION STUDIES COMPARISON

	LUNAR BASE	MANNED MARS
OBJECTIVE	BUILDUP AND SUPPORT OF PERMANENT MANNED LUNAR BASE	BUILDUP AND SUPPORT OF MANNED MARS MISSION
KNOWLEDGE BASE	RANGERS SURVEYERS ORBITERS APOLLO LUNAR GEO OBSERVATORY SAMPLE RETURN	MARINERS VIKING SAMPLE RETURN
MISSION PARAMETERS FLIGHT TIME STAY TIME	 3 DAYS ~90 DAYS	 ~ 650 DAYS ~ 60 DAYS
PRIMARY CONCERN:	LONG TERM SUPPORT REQUIREMENT - FLIGHT FREQUENCY - LOGISTICS	LIFE SCIENCE FOR LONG MISSION - RADIATION - ZERO G - MEDICAL CARE

LUNAR BASE ACCOMMODATION STUDY

MAJOR STUDY ACCOMPLISHMENTS

This chart lists the activities that were undertaken during the lunar base study. Some of these activities were completed and reported in this presentation, while a few of the activities were only addressed in a summary fashion and still remain to be fully evaluated at a later date. All of these studies need to be readdressed in greater detail when the lunar base phase A/B activity begins. Also, the lunar base infrastructure still needs to be completely defined, and it is entirely possible that new technology developed in the future will cause some of the basic assumptions of this study to be changed. However, the topics addressed here are those of primary concern and should remain so.

Lunar Base Accommodation Study

MAJOR STUDY ACCOMPLISHMENTS

- o MISSION AND MISSION VEHICLES DEFINED
- o DETAILED OPERATIONS ANLAYSIS CONCLUDED
- o STRAWMAN KSC FLIGHT SCHEDULE DEVELOPED
- o SS ACCOMMODATION OPTIONS IDENTIFIED AND ANALYZED
- o STATION SCIENCE EFFECTS ANALYZED
- o TECHNOLOGY REQUIREMENTS FOR LUNAR BASE SUPPORT EXAMINED
- o ON-ORBIT DEVELOPMENT PROGRAM REQUIREMENTS DEVELOPED

LUNAR BASE ACCOMMODATION STUDY

SUMMARY

This chart synopsizes the facts learned from the entire lunar base study. These results are supported by the facts presented in the previous charts and are consistent with the data developed.

The lunar base and its support missions can be characterized as long duration and operations intensive, with much flight activity needed on a continuing basis. Lunar base requires a very ambitious flight schedule from the cape, and would swamp the current NSTS capability. Long leadtime items, like the expansion of the cape launch capability, must be started well in advance of the lunar base elements themselves. Automation and robotics must also be applied as much as practical, to increase safety and increase efficiency. A&R studies still remain to be completed.

Increased Earth-to-orbit mass transfer was also noted as an important need to support the lunar base. Data was included to verify the need for HLLV to transport lunar hardware, and the need for a new crew transport vehicle was identified. Even the extra crew support for assembly and manning the lunar elements would strain the STS fleet.

The focus of the station activities in support of the Lunar Base missions is initially on hardware technology development , testing for verification and some orbital demonstration experiments, but no significant lunarrequired science experiments. This period would be followed by significant lunar element assembly activity and maintenance tasks.

These assembly/maintenance tasks require significant station interfaces, such as a large assembly hangar attached to the station. The OMV and OTV must be redesigned to handle these heavy elements and must be man-rated and increased in number. In fact, the much increased traffic around the station raises the need for a traffic control system for the station and its free-flyers. It was also noted that contamination would become a large problem considering all the station traffic involved, and the sensitive observational instruments would necessitate a contamination control system and procedure.

SUMMARY

- THE LUNAR MISSION
  - LONG DURATION-REPETITIVE REQUIREMENT
  - OPERATIONS INTENSIVE
  - AMBITIOUS LUNAR FLIGHT SCHEDULE
  - SIGNIFICANT A&R UTILIZATION

- EARTH TO LEO TRANSPORTATION
  - HLLV REQUIRED FOR EFFICIENT DELIVERY OF LUNAR BASE ELEMENTS
  - ADDED LUNAR CREW INCREASES STS FLEET REQUIREMENT BEYOND POINT OF REASONABLE PERFORMANCE
  - CREW CARRIER (10-13 CREW)

- STATION FOCUS
  - VEHICLE TECHNOLOGY DEVELOPMENT AND ORBITAL DEMONSTRATIONS
  - LUNAR VEHICLE ASSEMBLY AND MAINTENANCE
  - NO SIGNIFICANT LUNAR DIRECTED SCIENCE OR RESEARCH

- STATION INTERFACES/ELEMENTS
  - LARGE ASSEMBLY HANGAR REQUIRED (22,500 M^3)
  - ENHANCED PERFORMANCE OMV'S AND OTV'S REQUIRED
  - CONTROL OF TRAFFIC TO/FROM STATION IS REQUIRED
  - CONTAMINANT CONTROL IS REQUIRED FOR SATISFACTORY OBSERVATORY INSTRUMENT MEASUREMENTS

LUNAR BASE ACCOMMODATION STUDY

CONCLUSIONS

These are the key conclusions derived from this study, and are supported by the data on the previous charts.

The CETF configuration was found to be capable of supporting the lunar base missions, with an average yearly mass earth-to-orbit of 1,500,000 lbs..To support such a continuous launch load, an HLLV (200,000 lbs. minimum capacity) is essential, with attendant cape expansion as well. The large crew requirements, including assembly, maintenance, and lunar crews, indicates the need for a new crew transport vehicle.

The lunar vehicles are large and complex systems and require a great deal of crew time for assembly and maintenance. This same activity is handled on the ground by a 300 man team, and a similar activity must be accomplished on-orbit by a crew of three. Therefore, the lunar elements must be designed with modular, self testing/repairing components having increased reliability and robotics. This study concluded that Automation and Robotics must be applied throughout the operations disciplines for productivity and efficiency.

Lunar Base Accommodation Study

CONCLUSIONS

- THE CETF SPACE STATION CONFIGURATION WILL ACCOMMODATE THE LUNAR MISSION
- AVERAGE YEARLY MASS TO LEO OF 1.5 M LBS DICTATES USE OF A HLLV WITH 200 KLBS CAPABILITY
- CREW REQUIREMENTS POINT TO NEED FOR CREW CARRIER
- THE LUNAR VEHICLE SIZE, COMPLEXITY AND ALLOCATED IN-SPACE PROCESSING TIME REQUIRES IT TO BE OF MODULAR DESIGN WITH HIGH RELIABILITY AND ROBOTIC INTERFACES
- APPLICATION OF AUTOMATION AND ROBOTICS PRINCIPLES IS REQUIRED TO IMPROVE PRODUCTIVITY AND INCREASE EFFICIENCY OF THE OPERATIONS DISCIPLINE

LUNAR BASE ACCOMMODATION STUDY

ADDITIONAL QUESTIONS FOR SPACE STATION

This chart indicates the additional and more detailed study efforts required to finalize the lunar base mission impacts on the station. The resource requirements must be defined in some detail for the lunar base, including assembly at the space station and launching into orbit for all of the many required components that end up in lunar orbit or on the surface. This activity must be defined over an extended period of time since the lunar missions will be continuous after the first permanent human habitation. The resources include power, crew, and volume as well as many other logistic resupplies.

The influence of lunar base accommodation on the space station science experiments is expected to be large and extended, and all planned experiments will need to be reviewed as lunar technology tests are added to the space station science experiments. The three areas of curent station technology are listed and should be assessed separately.

There are also some unanswered questions on the influence of the lunar assembly and technologies on the primary environments of the station. That is, definition of the changes to the micro-g environment caused by the presence of the lunar base components must be defined (some information on this is presented later) and the blockage of experiment viewing by large lunar base supporting elements must be evaluated. The increase in station-based crew and crew activities is expected to cause a large increase in the dynamic loads on the station, and these loads might have a significant effect on any "quiet" experiments and activities.

Another important factor to evaluate is the compatability of the lunar base elements with the station. The station must accommodate all lunar elements with adequate well-defined interfaces and still remain controllable under all situations. These types of studies and evaluations still remain to be completed after the detailed design of the lunar elements is done. The effects of the assembly and handling of these large elements must be evaluated and is often overlooked. One possible saving feature that has not been completely assessed as yet is the influence of Automation and Robotics. Many of the difficult tasks could be automated and done robotically more efficiently than humanly possible, reducing some of these effects to tolerable levels.

Finally, the shifting of some of the more difficult operations from the space station to co-orbiting facilities should be assessed. Such a shift of activities would lessen the impact on the station and provide an expandable facility to accommodate any lunar activities. The propellant tank farm has been recommended before and has been addressed, and the provision of a special free-flying assembly "hanger" may be a convenient means for space construction of all types, particularly for the many-element lunar base.

MUST ADDRESS ADDITIONAL QUESTIONS UNIQUE TO USE OF SPACE STATION

- **RESOURCES**
  - POWER, CREW, VOLUME REQUIRED
- **SCIENCE**
  - SPACE SCIENCE
  - MATERIALS PROCESSING
  - LIFE SCIENCE
- **ENVIRONMENT**
  - MICRO-G
  - VIEWING
  - DYNAMICS
- **COMPATABILITY**
  - ACCOMMODATIONS
  - CONTROLLABILITY
  - INTERFACES
  - ASSEMBLY & HANDLING
  - A&R AUGMENTATION
- **CO-ORBITING (?)**
  - PROPELLANT STORAGE
  - ASSEMBLY HANGER

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16. Abstract

This report documents the results of a study conducted at NASA-LaRC to assess the impacts on the Space Station of accommodating a Manned Lunar Base. Included in the study are assembly activities for all infrastructure components, resupply and operations support for lunar base elements, crew activity requirements, impacts of lunar activities on Cape Kennedy operations, and impacts on Space Station science missions. Technology needs to prepare for such missions are also defined.

Results of the study indicate that the Space Station can support the manned lunar base missions with the addition of a Fuel Depot Facility and require a HLLV for supporting the large launch requirements.

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