AIAA
LOW COST LUNAR ACCESS CONFERENCE
ARLINGTON, VIRGINIA

AN AFFORDABLE APPROACH FOR HUMAN RETURN TO THE MOON

7 MAY 1993

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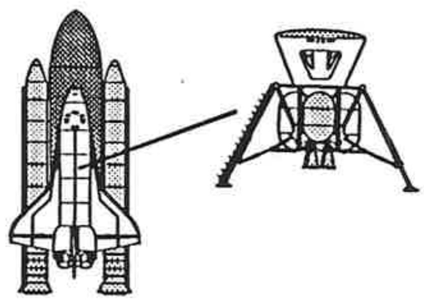
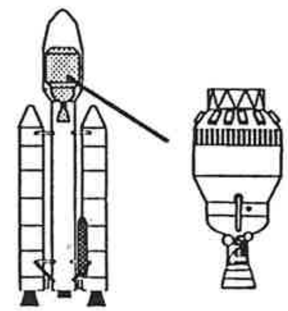
GENERAL DYNAMICS
Space Systems Division

EARLY LUNAR ACCESS: MISSION OVERVIEW



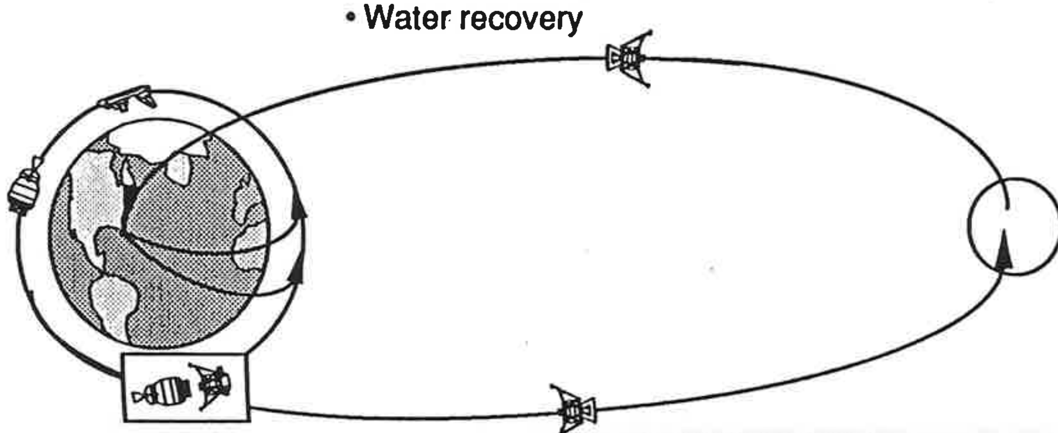
SPACE SHUTTLE DELIVERS LUNAR EXCURSION VEHICLE (LEV) AND PAYLOAD



TITAN IV DELIVERS WIDE-BODY CENTAUR

LEV RETURNS TO EARTH VIA DIRECT RE-ENTRY (PILOTED MISSIONS ONLY)

- Ballistic re-entry
- Water recovery



LEV LANDS ON MOON AFTER DIRECT DESCENT TRAJECTORY

- Initial missions: cargo only
- Piloted missions: 14-21 day crew stay time on lunar surface

CENTAUR AND LEV DOCK AND DEPART FOR MOON

LEV PERFORMS LUNAR DESCENT

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INTRODUCTION

STUDY OBJECTIVE

DETERMINE FEASIBILITY OF ACCOMPLISHING EARLY PILOTED LUNAR MISSIONS WITH EXISTING ASSETS

KEY REQUIREMENTS

- PERFORM MEANINGFUL (BEYOND APOLLO-CLASS) MISSIONS PRIOR TO ESTABLISHMENT OF FULL-SCALE FIRST LUNAR OUTPOST
- ACHIEVE FIRST PILOTED LUNAR MISSION BY 2000
- EMPLACE PERMANENT FACILITIES THAT CAN SUPPORT FIRST LUNAR OUTPOST

APPROACH

- USE EXISTING FLEET FOR EARTH-TO-ORBIT ACCESS (SHUTTLE & TITAN IV)
- USE EXISTING WIDE-BODY CENTAUR FOR TRANS-LUNAR INSERTION (TLI)
- ADAPT OTHER OPERATIONAL SYSTEMS TO FULFILL MISSION NEEDS
- INCORPORATE NEW (DOMESTIC AND FOREIGN) SYSTEMS AS THEY BECOME EFFECTIVE

EARLY LUNAR ACCESS: MISSION OBJECTIVES

HIGH PRIORITY LUNAR SCIENCE

- Characterize geology & physical properties
- Establish early astronomy outpost
- Demonstrate lunar oxygen processing pilot plant

RESEARCH AND TECHNOLOGIES FOR LIFE SUPPORT

- Assess effectiveness of EMU suits
- Determine crew capabilities for moderate (14-21 day) stay times
- Evaluate crew capabilities during lunar night

SUPPORT OF FIRST LUNAR OUTPOST

- Survey and map potential landing sites
- Emplace navigation aids, communications links
- Determine effectiveness of telerobotic rovers
- Preposition critical supplies and equipment
  - Emergency and water rations
  - Electrical power system
  - Oxygen and fuels
  - Emergency shelter
- Test materials, equipment to long duration lunar environment exposure

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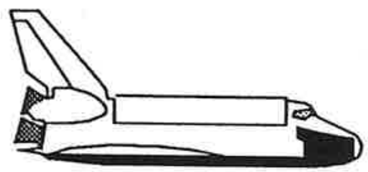
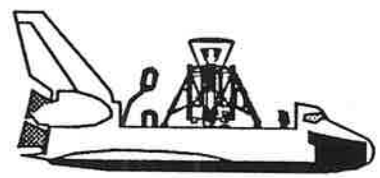
EARTH-ORBIT OPERATIONS SUMMARY

EARTH-ORBIT OPERATIONS SUMMARY



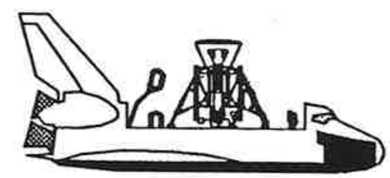
1. STS Enters Parking Orbit

0.0 days*



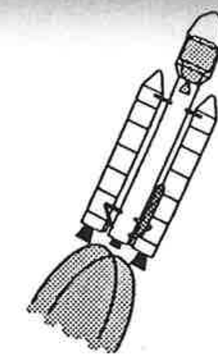
2. LEV Configured for Deployment with RMS, EVA Backup

1.0 days



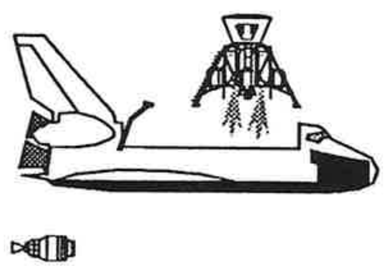
3. Checkout/verify LEV & Cargo

1.3 days



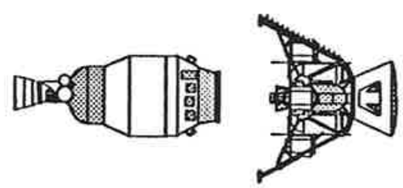
4. Titan IV/Centaur Launch, Insertion into STS co-orbit (100 nmi separation)

2.0 days



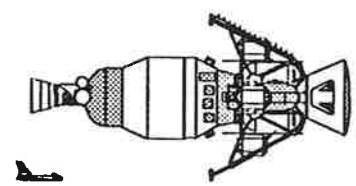
5. LEV Deployed

2.2 days



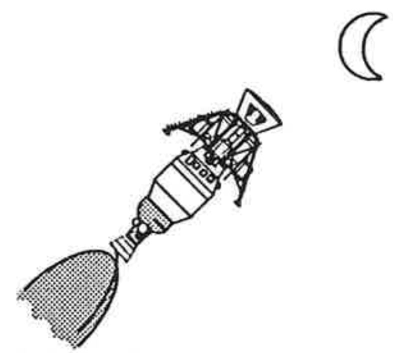
6. LEV Phases, Rendezvous, and Docks With Centaur, Orbiter in Backup Position

2.3 days



7. Integrated System Checkout

2.9 days

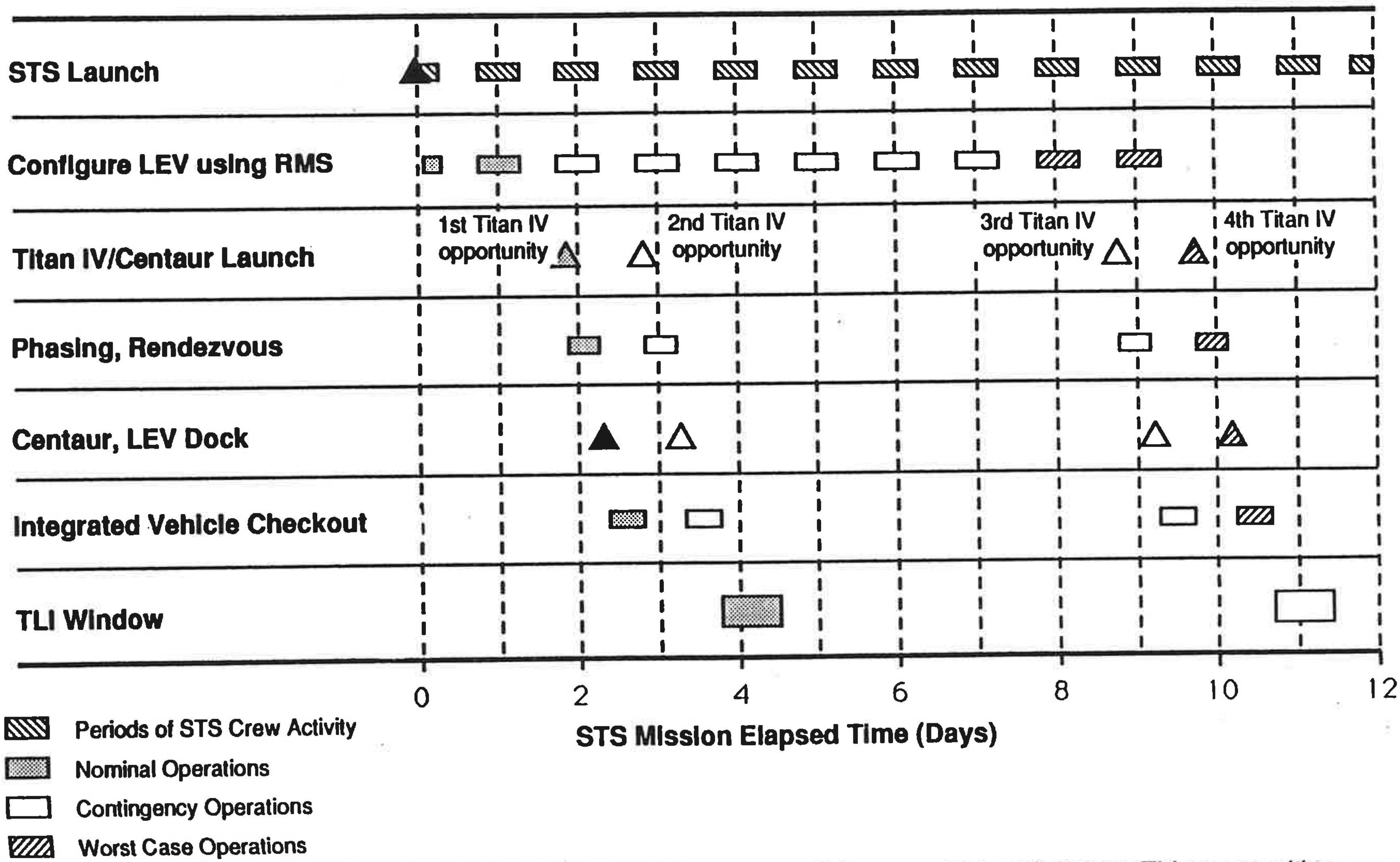


8. Hold for Launch Window/TLI

4.0 days

**** Mission Elapsed Time (MET)***

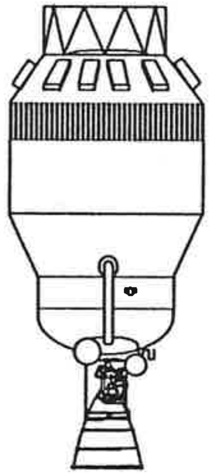
REPRESENTATIVE MISSION TIMELINE



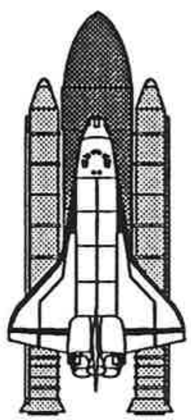
* Assumes 7 days between TLI opportunities
(actual time varies from 3-11 days)

SUMMARY OF MAJOR MISSION ELEMENTS

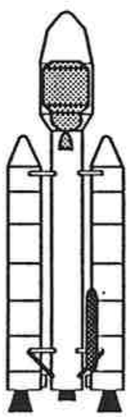
EXISTING SYSTEMS



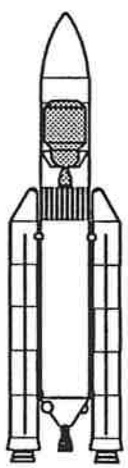
Wide-Body Centaur



Space Shuttle

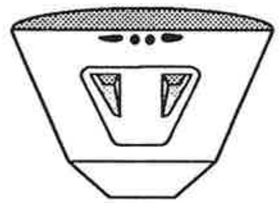


Titan IV

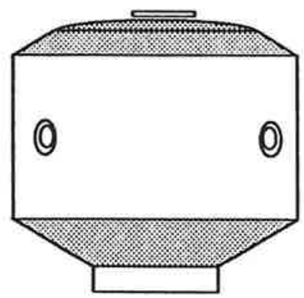


Ariane 5

DERIVATIVES OF EXISTING SYSTEMS

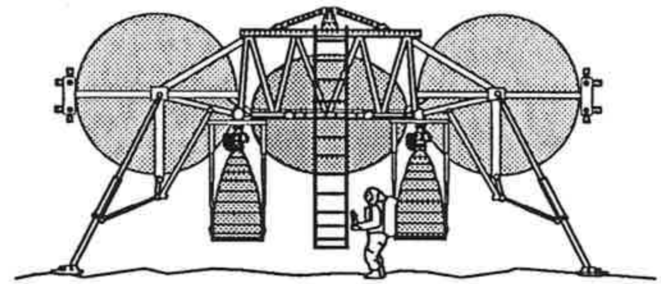


2-Man Crew Capsule Derived from Apollo Capsule

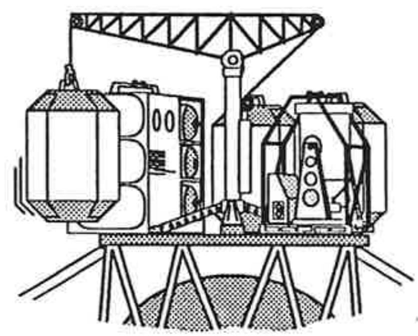


Lunar Habitat Derived from SSF Mini Pressurized Logistics Module

NEW SYSTEMS



Lunar Excursion Vehicle

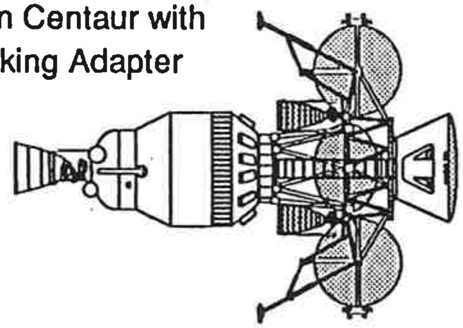


Lunar Science Equipment, Surface Elements, and Multiple Payload Adapter

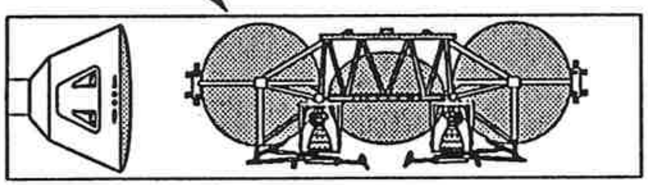
(Drawings not to scale)

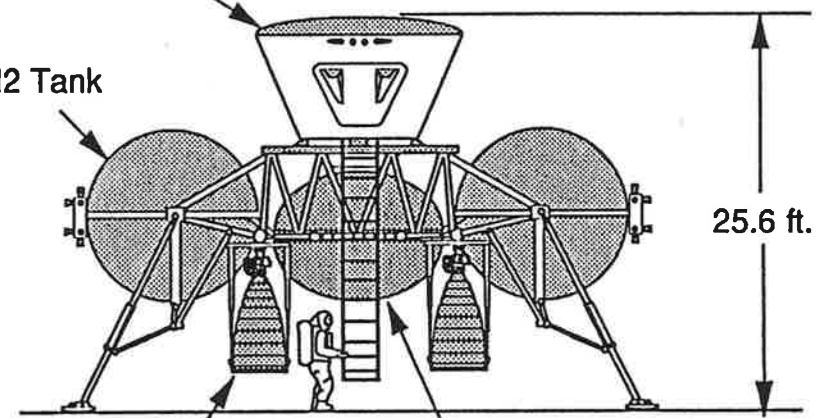
ELA CRYO LEV CONCEPT

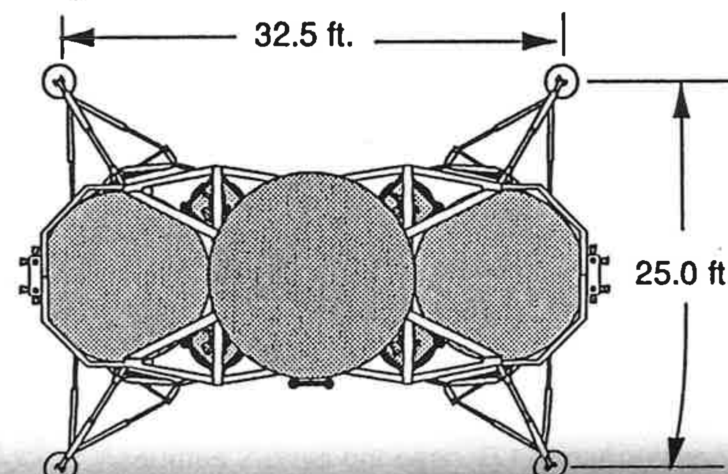
Titan Centaur with Docking Adapter



SHUTTLE BAY ENVELOPE







MANNED MISSION WEIGHT SUMMARY

LEV INERT WEIGHT	7,500 lbs
PROPELLANT	36,600 lbs
CREW CAPSULE (EMPTY)	7,100 lbs
CREW & EMU's	1,000 lbs
ASE	4,400 lbs
GROSS WEIGHT*	56,600 lbs

* Requires Shuttle upgrades

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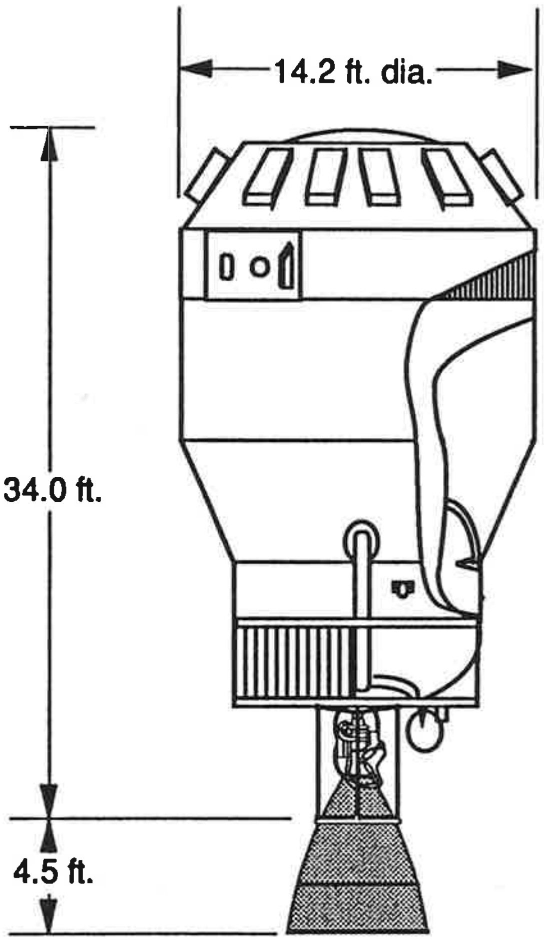
CENTAUR CONFIGURATION FOR EARLY LUNAR ACCESS



RL10 C-1 Engine
F=33,130 lbs

MODIFICATIONS TO BASELINE TITAN CENTAUR

- **STRUCTURE**
  - New Payload Adapter for LEV
  - New single engine thrust structure
  - Lengthened propellant tankage
- **AVIONICS**
  - Six 250 AH lithium batteries
  - GPS receiver to calibrate INU for MES
  - Significant software modifications
  - Rendezvous & docking hardware
  - Requalify for at least 3-day operation in park orbit
- **THERMAL MANAGEMENT**
  - Six additional MLI Insulation layers
- **PROPULSION**
  - Engine upgrade to single RL10C-1
  - Additional N2H4 bottle
  - Additional main propellant (approx. 25% increase)
- **MAN-RATING**
  - Two-fault tolerant subsystems
  - Tank strength safety factors
  - Vent, Pressurization, & other Fluid systems
  - Engine rating
  - Certified Abort capability from all flight phases

EXAMPLE EARLY LUNAR ACCESS MANIFEST
Lunar Missions 1 through 4 (Cryogenic LEV)

Mission 1: Initial Science & Exploration

Payload	mt
• Science expedition package	1.5
• Geophysical station	1.5
• Geological tools	0.2
• Optical telescope	0.9
• Unpressurized rover	0.6
• Comm. system & approach controller	1.0
• Solar arrays	0.2
• Habitat consumables	0.8
• UV telescope	0.7
• Lunar mining experiment	1.1
Total Wt.	8.5

Mission 2: Habitation System Deployment

Payload	mt
• Habitat structure	3.1
• ECLSS	1.3
• Thermal control system	1.0
• Radiator	0.2
• Crew & medical systems	0.9
• Fuel cell power sys.	1.6
• Fuel cell reactants	0.4
Total Wt.	8.5

Mission 3: First Crew Landing

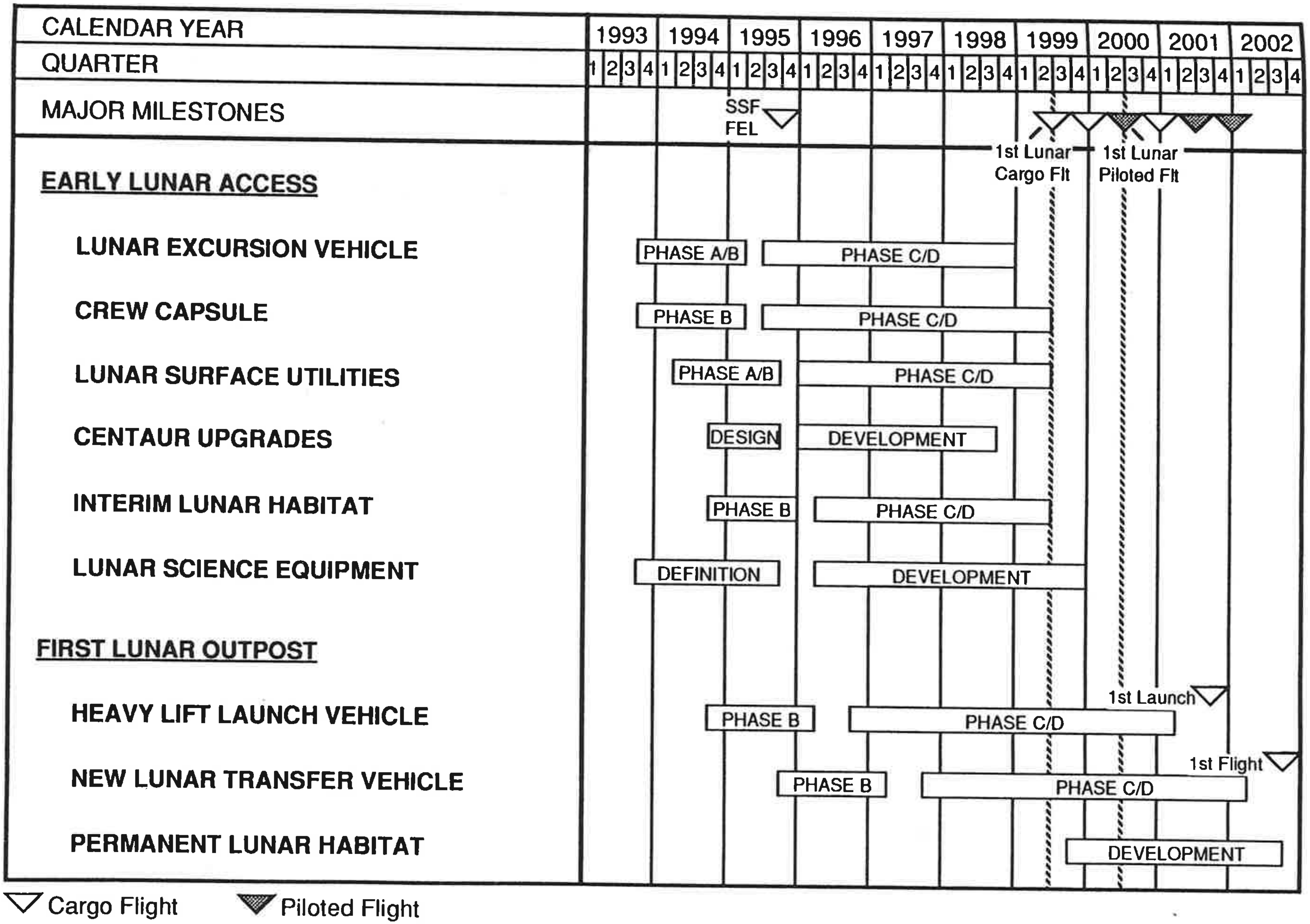
Payload	mt
• Crew capsule	3.2
• Crew & EMU's	0.5
Total payload	3.7
• Return trip propellant	4.8
Total Wt.	8.5

Mission 4: Expanded Science & Exploration

Payload	mt
• Mini-fuel cell sys	0.5
• Construction experiment	0.3
• Rollout solar array	0.2
• Spares & science resupply	1.6
• Biological lab	1.0
• 2nd optical telescope	0.9
• Gamma-ray telescope	2.8
• Consumables	1.2
Total Wt.	8.5

Following Mission 4, 2-3 piloted missions can be flown in succession to make use of the considerable infrastructure and resources already deployed on the lunar surface

EARLY LUNAR ACCESS MASTER SCHEDULE



CONCLUSIONS

THE EARLY LUNAR ACCESS CONCEPT IS FEASIBLE

- ONLY ONE NEW SYSTEM (LEV) NEEDS TO BE DEVELOPED
- NECESSARY TECHNOLOGIES ARE WELL IN HAND
- THE STRATEGY IS NOT RISK-FREE, BUT THE RISKS ARE MANAGEABLE
- FUNDING REQUIREMENTS CAN BE ACCOMMODATED WITHIN PROJECTED NASA BUDGETS

BENEFITS ARE DRAMATIC AND DEMONSTRABLE

- EARLY INVESTMENT FOCUSED ON LUNAR SCIENCE AND SURFACE ACTIVITIES — NOT ON GETTING THERE
- RETURN ON INVESTMENT IS LARGE, VISIBLE, AND BEGINS WITH THE FIRST MISSION
- INTERNATIONAL COOPERATION CAN FURTHER REDUCE U.S. INVESTMENT REQUIREMENTS AND PROMOTE COOPERATIVE OPPORTUNITIES

EARLY LUNAR ACCESS: AN AFFORDABLE APPROACH FOR HUMAN RETURN TO THE MOON

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ABSTRACT

An approach is described for the return of crews to the moon by the end of this century. It is accomplished through the use of existing transportation systems or their derivatives, e.g. Space Shuttle, Titan IV and/or Ariane V, and the Centaur stage. New developments include a new lunar excursion vehicle and a derivative of the Apollo command module, used for crew delivery and return. As the majority of the transportation infrastructure already exists, the approach offers low risk and low cost.

Also described are the scientific and technological benefits of such a program. Space operational scenarios, a critical aspect of lunar expeditions, are developed along with cargo manifests for the first three missions, the last of which is the first piloted mission, performed with a crew of two. A program schedule illustrates how the piloted mission can be achieved by the year 2000.

It is concluded that the proposed program is feasible and of considerable value. Further, it is shown that Early Lunar Access may be structured as an international venture, with the participation of several partners, mutually dependent on the others to achieve program success.

INTRODUCTION

Today, the direction that the space program is taking is unclear. However, regardless of what emerges, it appears that space exploration is not likely to be included in NASA's near term plans. This is due in no small part to the formidable costs of what had been the Space Exploration Initiative.

Nevertheless there remain compelling scientific, educational and technological reasons why the pursuit of human space exploration is important. At issue is our ability to undertake such a project in a fiscally responsible and realistic manner. We believe we can.

Within the United States, certainly within the world, exist many of the critical assets needed for a viable, affordable program to return humans to the moon. Most of these assets are within the present transportation system infrastructure; consequently new developments would be directed towards lunar surface elements and scientific packages, not on getting crews to and from the moon. Moreover, because such a program would use existing systems or their derivatives, it can be accomplished quickly and its value demonstrated to a skeptical public.

Of course simply being able to return to the moon, even at a reasonable cost, is in itself insufficient justification for doing so. We have already been there. To be successful a new lunar program must have scientific merit and must represent a major step beyond what was accomplished with Apollo.

PROGRAM OBJECTIVES

In keeping with the broadly stated objective to structure a low cost lunar program that would, at the same time, represent a major step beyond Apollo, the set of requirements (or perhaps more accurately, goals) summarized in Table 1 was developed to drive the design decisions and mission architecture.

Table 1. System Requirements

- *Maximize use of existing systems and subsystems or their derivatives*
- *Achieve first piloted lunar mission by 2000*
- *Provide capability for crew stay times for up to three weeks on the moon*
- *Provide shirtsleeve environment for IVA functions*
- *Emplace permanent facilities that can support expansion to larger base operations*

Of equal or greater importance is the justification for why such a venture should be undertaken at all. It is necessary to establish not only the benefits of lunar based science and applications, but the need for human participation as well. Fundamental to this argument is the question of whether we intend to ever conduct a program involving human exploration of our solar system. If the answer is yes, many synergistic benefits will accrue through the conduct of scientific, technology development, and human behavioral experiments. Some examples are presented in Table 2.

SYSTEM ARCHITECTURE

A transportation architecture was developed, responsive to the system requirements, based upon the use of the Space Shuttle, an ELV (either Titan IV or Ariane V), and a wide-body Centaur stage. An overview of a typical mission is illustrated in Figure 1. In essence, a mission begins with a Shuttle launch to LEO of a Lunar Excursion Vehicle (LEV) with its payload, either cargo for permanent lunar placement or a crew of two and their crew capsule. Subsequently, the

Table 2. Mission Objectives

High Priority Lunar Science
- *Characterize geology and physical properties*
- *Establish early astronomy outpost*
- *Demonstrate lunar oxygen processing pilot plant*

Human Life Support Technologies
- *Assess effectiveness of EMU suits*
- *Evaluate crew capabilities for moderate (14-21 day) stay times*
- *Determine crew effectiveness during lunar night*

Support of First Lunar Outpost
- *Survey and map potential landing sites*
- *Emplace navigation aids, communication links*
- *Determine effectiveness of telerobotic rovers*
- *Test materials, equipment exposed to long duration lunar environment*
- *Preposition critical supplies and equipment*

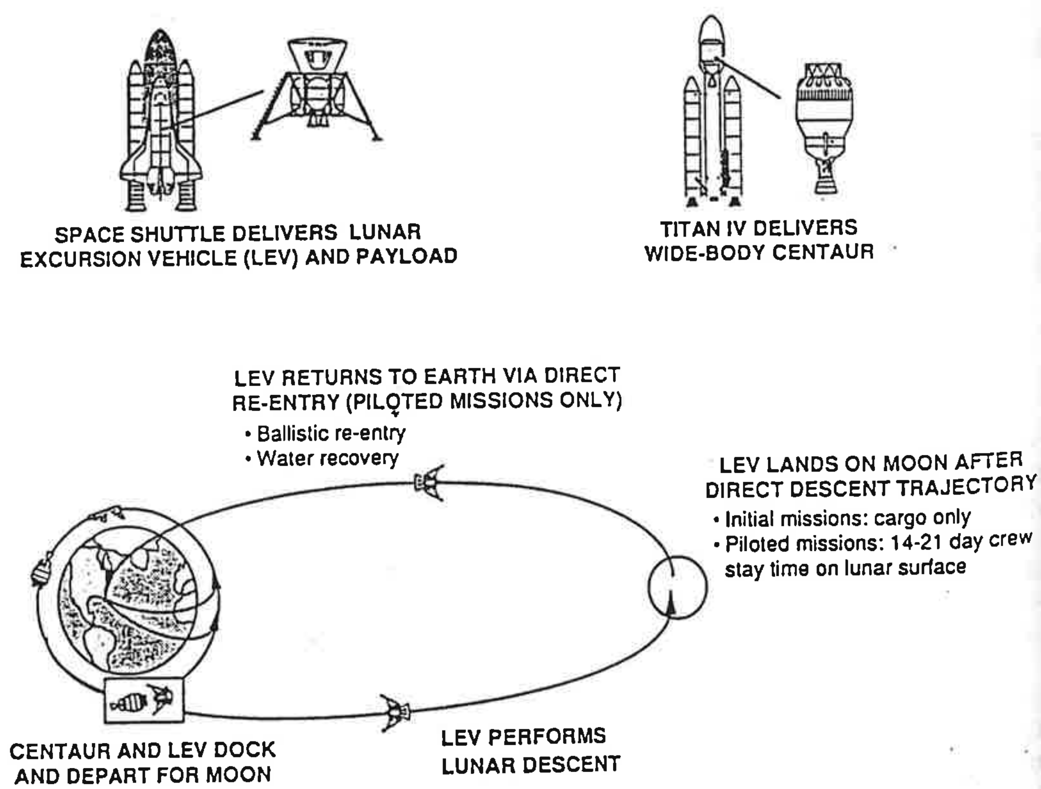


Figure 1. Mission Overview

ELV deploys a fully fueled Centaur to co-orbit with the Shuttle, after which the Centaur and LEV dock. When the launch window for lunar departure opens, the Centaur provides the propulsive impulse for trans-lunar injection then separates and, upon approaching the moon, the LEV performs the propulsive braking for lunar descent and landing. For cargo missions the LEV burns to depletion for landing; for piloted missions it retains sufficient propellant to perform a later Earth ascent burn to return the crew.

The crew capsule is derived from the Apollo command module design but scaled down, to support a crew of two instead of three, and further lightened through the use of modern materials and construction methods. It does, however, retain the external shape of the Apollo capsule to take advantage of the extensive aero- and thermodynamic data bases developed during that program. As with Apollo, the ELA capsule returns to Earth with aerodynamic braking and an ocean spash-down.

The architectural elements that comprise the Early Lunar Access missions are illustrated in Figure 2.

In addition to those already discussed is a lunar habitat, providing a shirt sleeve environment for the crews during their three week stays, and the complement of lunar science and support equipment. The lunar habitat may be derived from the mini -pressurized logistics module being developed for Space Station Freedom by Alenia, or from a scaled down version of a space station habitation module. It would be used for sleeping and personal hygiene, monitoring and control functions, and communications.

The major new element is the LEV, a high performance LO2/LH2 system with advanced engines that throttle to enable soft landings on the lunar surface. The cluster of four engines are designed to offer fail-safe operation through the capability to shut down a diametrically opposed pair in the event of a failure. It is the combined mass of the LEV and the crew capsule that is most critical for mission planning as the Shuttle is limited in its weight carrying capacity. Their system weights are summarized in Table 3; also included is the airborne support equipment (ASE), that equipment used to integrate the flight elements into the Shuttle.

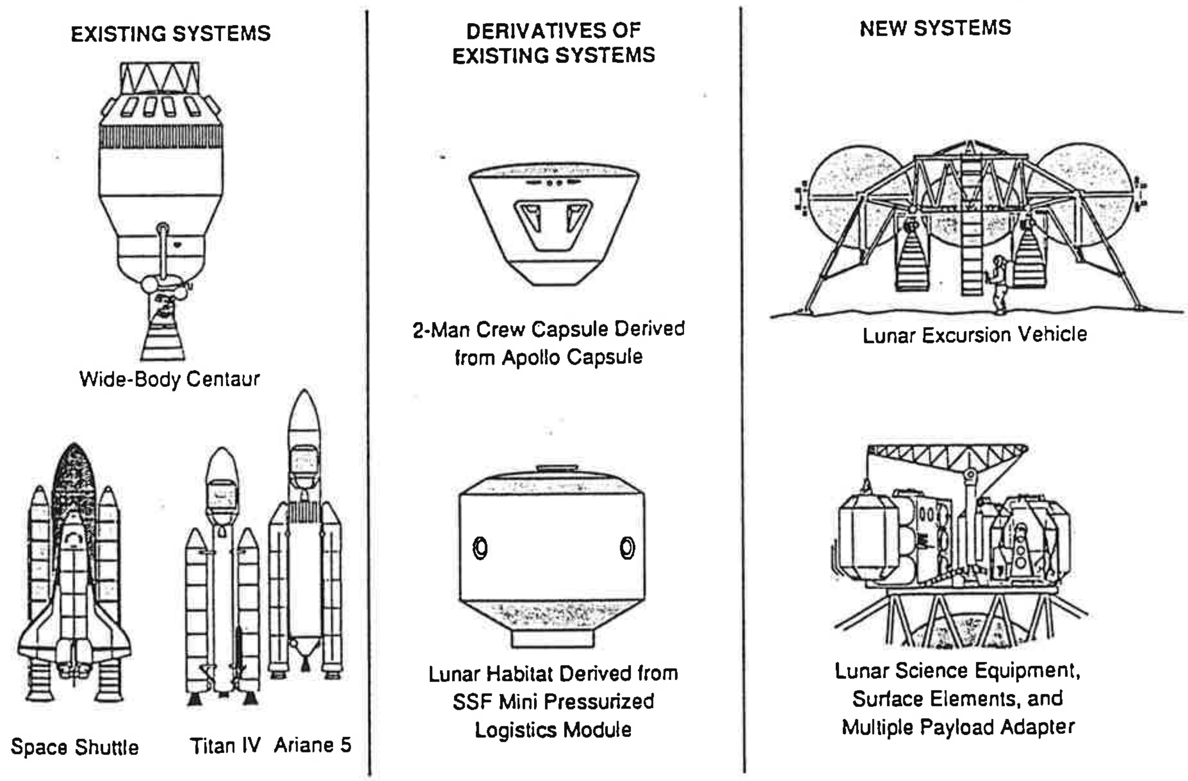


Figure 2. Major Mission Elements

Table 3. Weight Summary

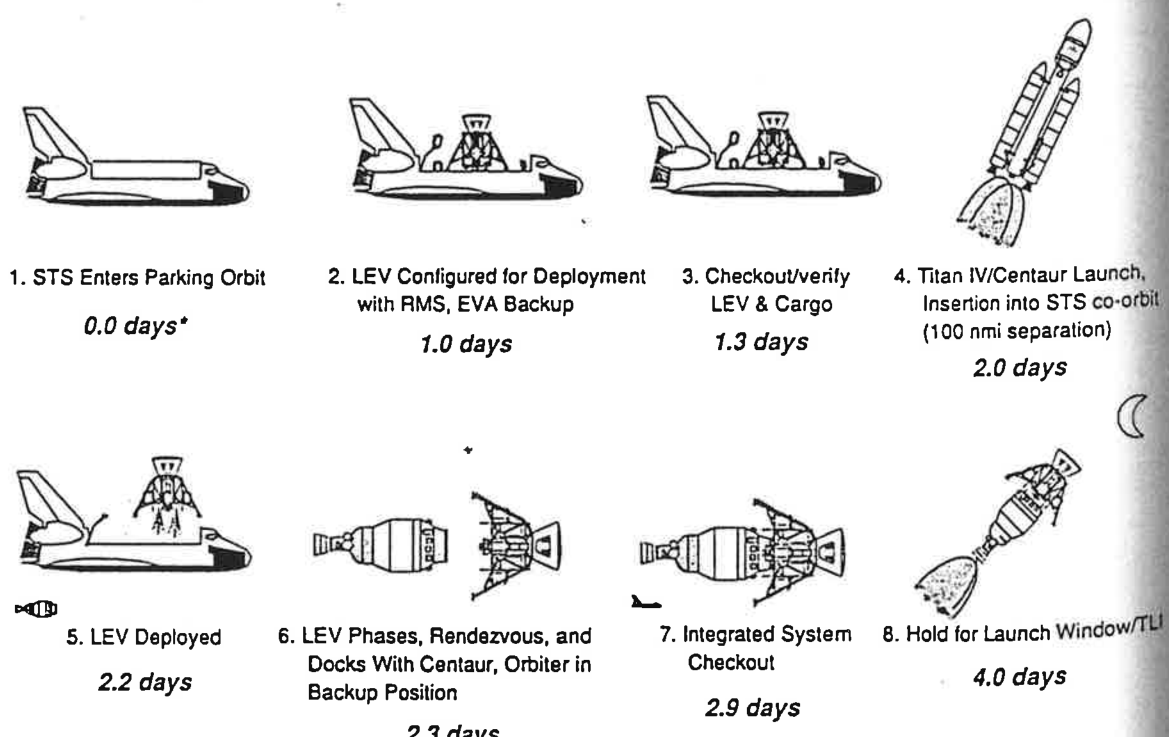
Crew Capsule		*8130 lb*
Dry weight	*6770*	
Fluids	*310*	
Crew and Crew Support	*1050*	
Lunar Excursion vehicle		*44180*
Dry Weight	*5840*	
Non propulsive fluids	*1720*	
Main propellant	*36620*	
ASE		*4400*
Total weight in Shuttle		*56710 lb*

Some upgrade to the Shuttle will be necessary to enable it to deliver such a mass to LEO. Options include incorporation of the ASRMs, currently under development, or replacement of the external tank with a new, light weight version, now being considered, that is built from a higher strength Al Li alloy. Either of these systems can be operational within the time frame of the ELA program needs.

Modifications to other systems include human rating and propulsion improvements to the Centaur, and performance upgrades to the ELV.

SPACE OPERATIONS

Space operations are built around planning to comply with critical launch window opportunities and, within that framework, incorporating sufficient margins to accommodate anomalous conditions. A nominal mission sequence is shown in Figure 3. After the Shuttle reaches orbit the payload is attached to the LEV and all systems checked out. Should a problem arise that cannot be fixed in orbit, the systems will be safed, repackaged in the Orbiter, and returned to Earth prior to commitment to launch the ELV. Under normal conditions, however, an ELV would then be launched and the Centaur placed in a co-orbit with the Shuttle. During the rendezvous and docking operations the Shuttle would remain in a safe orbit to provide back-up or retrieval capabilities should the need arise. At this point the Centaur/LEV/payload system, again checked out, is prepared for lunar orbit insertion and awaits the opening of its launch window.



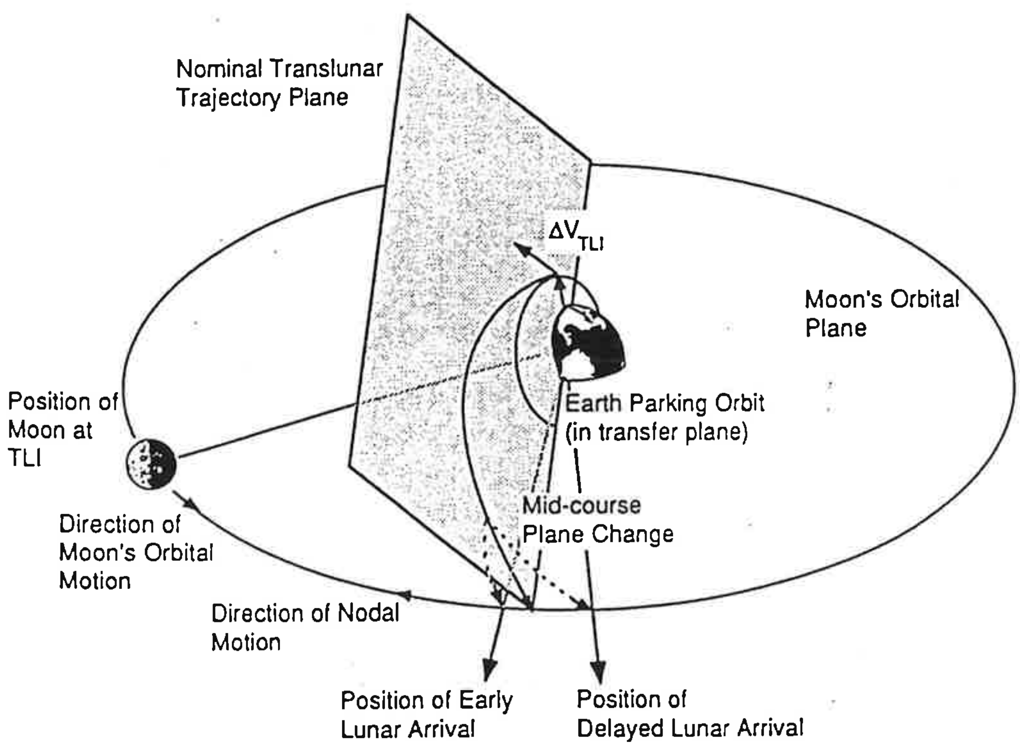
** Mission Elapsed Time (MET)*

Figure 3. Low Earth Orbit Operations Summary

Lunar transfers from low Earth orbit have more restrictive departure opportunities than do those from the Earth's surface. A transfer system circling the Earth every 90 minutes would have to depart within a launch window of only a minute or so to place itself on a lunar transfer orbit that will intercept the moons orbit so that both arrive at the same point together. This is illustrated in Figure 4. Delays in departing from LEO will postpone the next opportunity another 90 minutes, when the one minute window again opens. The 90 minute delay, however, will place the transfer system in an off-optimum trajectory, requiring a later midcourse correction to enable the spacecraft to arrive at the moon at the proper time. Midcourse corrections of course require additional energy, or propellant, that can be used just as effectively for an early departure as a late one. As mass is a critical parameter for high energy missions, it is of interest to determine how much midcourse propellant is needed.

Figure 5 relates the midcourse incremental velocity requirement as a function of the number of orbits off-nominal at which the transfer system departs. It is shown that, if an additional 2% propellant is carried, LEO departure opportunities open to 13 orbits, or a period of 18 hours in LEO for troubleshooting and corrective actions, if necessary.

After taking such factors into account a representative mission timeline is developed, as shown in Figure 6. The nominal sequence of mission operations, as was described in the Earth-orbit operations summary of Figure 3, is represented by the lightly shaded bars and milestones. Provisions are also made for contingencies. For example, if the ELV is unable to launch on schedule, perhaps due to adverse weather or anomalous conditions, the mission plan can accommodate alternative launch opportunities. Note that the worst case scenario spans 11 1/2 days, which requires that an extended duration Orbiter be included in the infrastructure.



Performance Reserve Determines Magnitude of Allowable Midcourse Plane Change

Figure 4. Geometry of Lunar Transfers with Midcourse Plane Changes

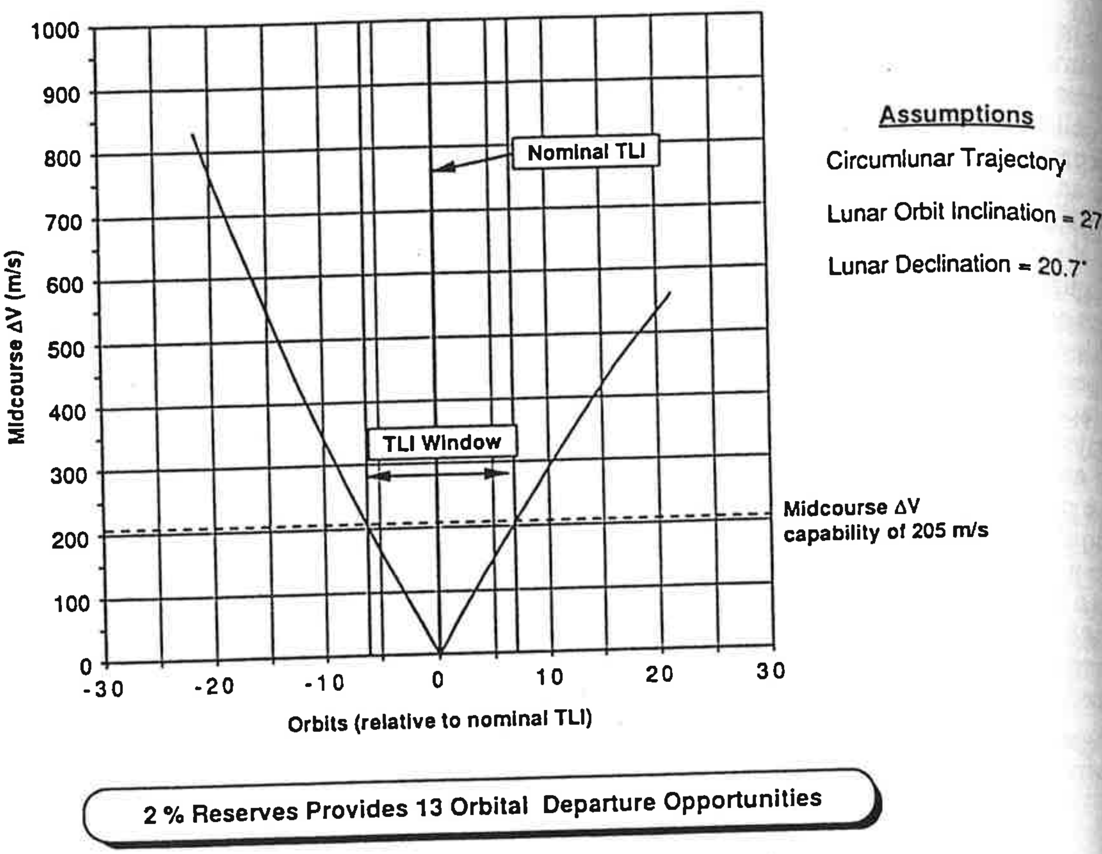


Figure 5. Midcourse Plane Change Requirements

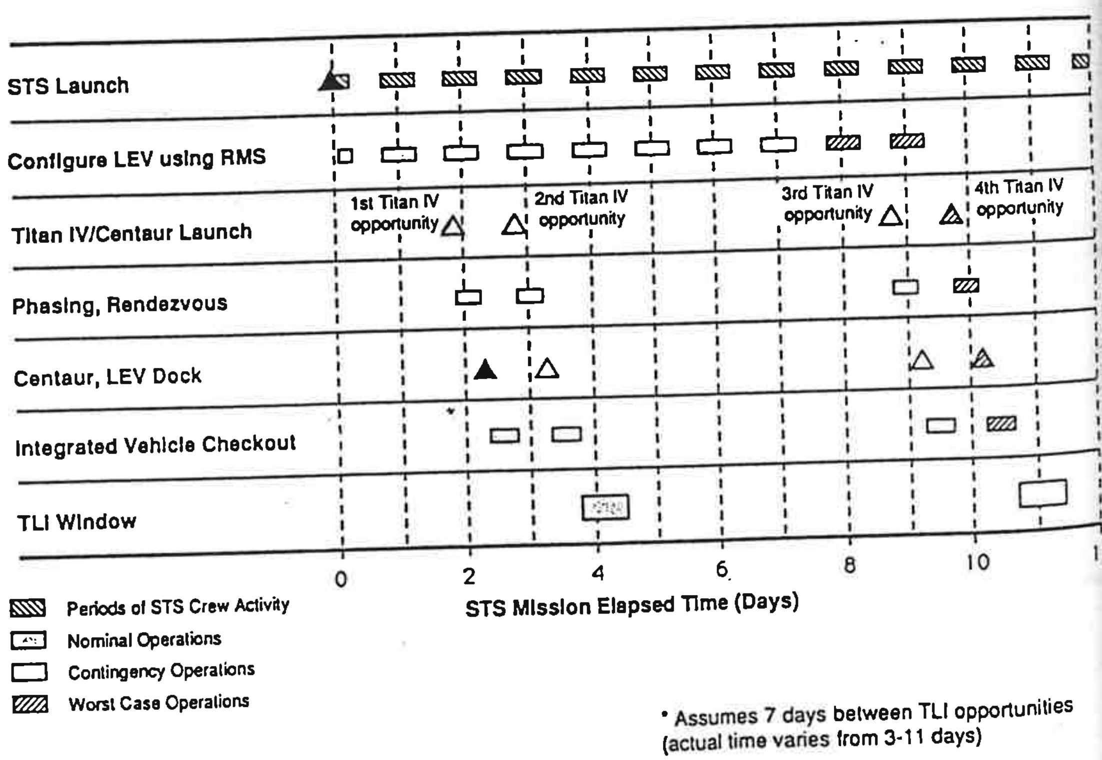


Figure 6. Representative Mission Timeline

PROGRAMMATICS SUMMARY

A typical mission manifest was assembled for the first three missions which culminate with the first piloted mission, as described in Figure 7. Mission 1 is primarily science oriented, intended to offer early returns beginning with the first mission. It is intentionally planned to be a cargo mission to demonstrate the flight systems and gain confidence in their operation. Mission 2, also a cargo mission, is for deployment of the crew habitation systems and their verification. The first piloted mission then occurs with Mission 3. It is seen that the delivery capability for the one-way, cargo missions is about 8.5 metric tonnes, but is considerably less for the round trip, piloted missions. Manifesting was not rigorously developed for Missions 4 and beyond but it is anticipated that more extensive scientific emplacements will take place, perhaps followed by expanded base facilities or in preparation for the First Lunar Outpost.

A program schedule was created, shown in Figure 8, to better understand the system development periods, their phasing and the mission opportunities. It was tailored about an assumed FY94 start. That year would be devoted mostly to definition studies, with the hardware development beginning in FY95. This should lead to the first flight taking place in mid-1999. It was further assumed that missions would take place approximately on 6 month centers, judging that two Shuttle plus two ELV flights a year would be the most that might reasonably be expected. This could allow the first piloted mission to be flown in the year 2000, in keeping with our stated program objective.

Also shown in the figure is a notional representation of the beginnings of the development for the First Lunar Outpost, should it be decided to proceed with it within that time frame.

Mission 1: Initial Science & Exploration		Mission 2: Habitation System Deployment		Mission 3: First Crew Landing		Mission 4: Expanded Science & Exploration	
Payload	mt	Payload	mt	Payload	mt	Payload	mt
• Science expedition package	1.5	• Habitat structure	3.1	• Crew capsule	3.2	• Mini-fuel cell sys	0.5
• Geophysical station	1.5	• ECLSS	1.3	• Crew & EMU's	0.5	• Construction experiment	0.3
• Geological tools	0.2	• Thermal control system	1.0	Total payload	3.7	• Rollout solar array	0.2
• Optical telescope	0.9	• Radiator	0.2	• Return trip propellant	4.8	• Spares & science resupply	1.6
• Unpressurized rover	0.6	• Crew & medical systems	0.9			• Biological lab	1.0
• Comm. system & approach controller	1.0	• Fuel cell power sys.	1.6			• 2nd optical telescope	0.9
• Solar arrays	0.2	• Fuel cell reactants	0.4			• Gamma-ray telescope	2.8
• Habitat consumables	0.8					• Consumables	1.2
• UV telescope	0.7						
• Lunar mining experiment	1.1						
Total Wt.	8.5	Total Wt.	8.5	Total Wt.	8.5	Total Wt.	8.5

Following Mission 4, 2-3 piloted missions can be flown in succession to make use of the considerable infrastructure and resources already deployed on the lunar surface

Figure 7. Example Manifest for Early Missions

CONCLUSIONS

It has been shown that a program to return people to the moon by the year 2000 is feasible, that it can produce substantial scientific and technological benefits, and that it can be done for the most part with systems that we already have, keeping costs within reasonable levels. Basically one major new system needs to be developed, the lunar excursion module, and for it the necessary technologies are well in hand.

The value in proceeding with such a program are dramatic and demonstrable. Much of the early investment is applied to lunar science and surface activities -- not on the systems to get us there. The return on that investment is great, highly visible to the public, and begins with the first mission.

Moreover, Early Lunar Access affords us an opportunity to involve international members of the space community, not as adjuncts but as equal partners. In a sense, the concept begs the question: Why have we waited so long?

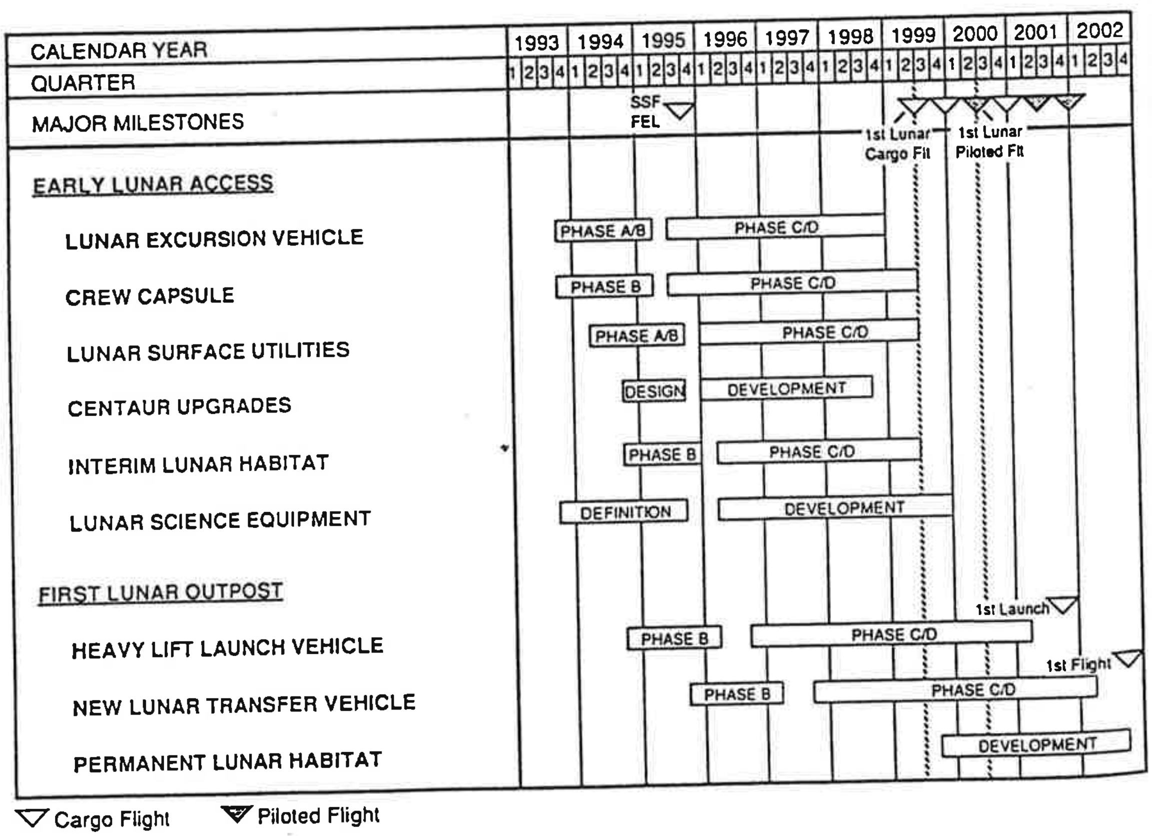


Figure 8. Program Schedule