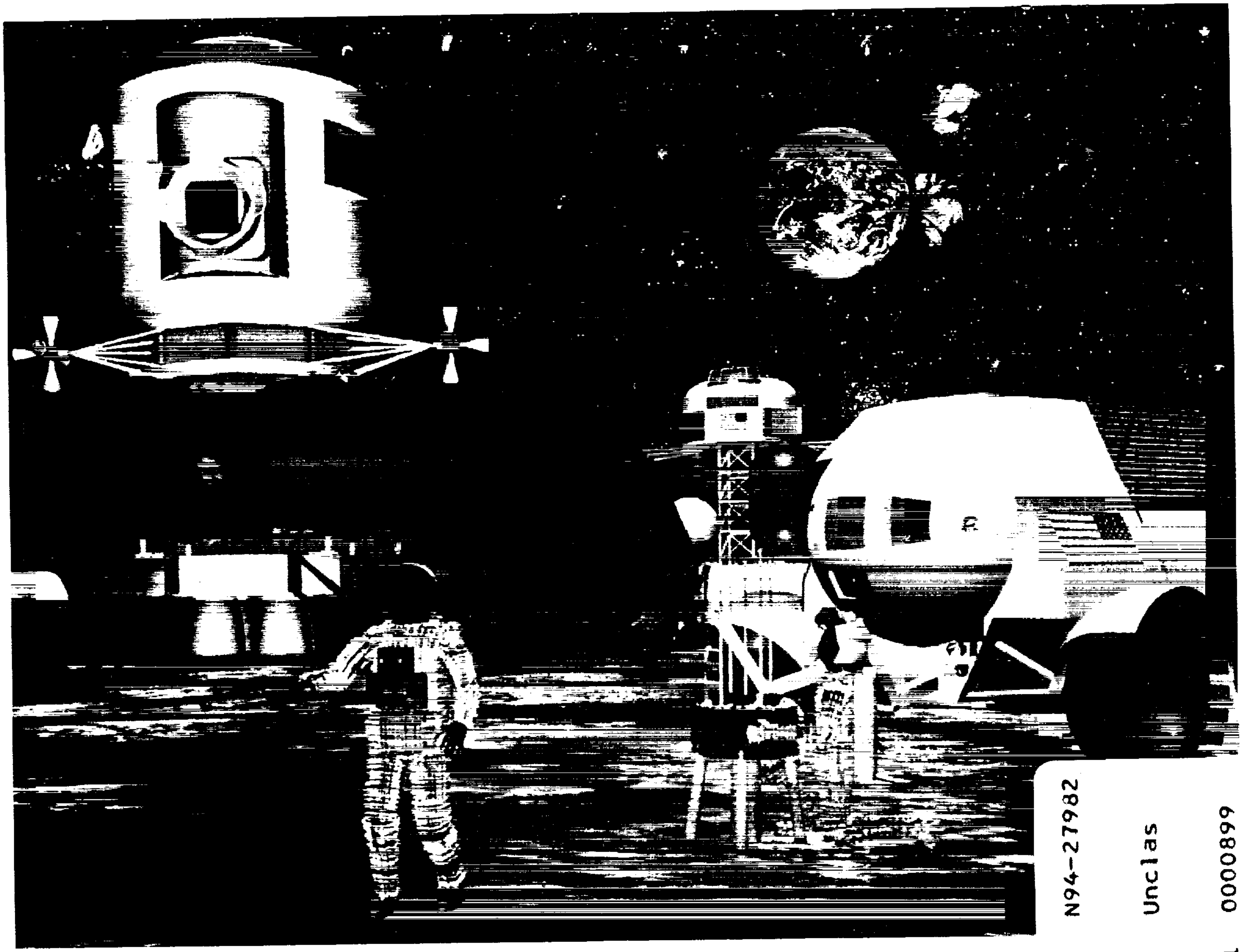

Lunar Transportation Facilities and Operations Study - Option 1

Annual Report
May 1991

McDonnell Douglas Space Systems Company
Kennedy Space Center

MCDONNELL DOUGLAS

Lunar Transportation Facilities and Operations Study
Option 1
Annual Report

prepared for

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by

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Kennedy Space Center

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Abbreviations and Acronyms

A/B	Airborne
CAD	Complete Advanced Development
CCLS	Computer Controlled Launch Set
CCVAPS	Computer Controlled Vent and Pressurization System
CEP	Circle Error of Probability
CK	Check
C/O	Checkout
DCU	Data Computer Unit
ECLS	Environmental Control and Life Support
ECLSS	Environmental Control and Life Support System
EDCAS	Equipment Design Cost Analysis
EMU	Extravehicular Mobility Unit
EVA	Extravehicular Activity
Gnd	Ground
GSE	Ground Support Equipment
HAB	Habitat
ILS	Integrated Logistics System
IMG	Inertial Measurement Group
IVA	Intravehicular Activity
JSC	Johnson Space Center
KSC	Kennedy Space Center
km	Kilometer
KMI	Kennedy Management Instruction
LaRC	Langley Research Center
lbf	Pounds force
lbs	Pounds (mass)
LEM	Lunar Excursion Module
LEV	Lunar Excursion Vehicle
LEVPU	Lunar Excursion Vehicle Payload Unloader
LH2	Liquid Hydrogen
LLOX	Lunar Liquid Oxygen
LM	Lunar Module
LMEPO	Lunar/Mars Exploration Program Office
LTFOS	Lunar Transportation Facilities and Operations Study

MASE	Mission Analysis and Systems Engineering
MDSSC-KSC	McDonnell Douglas Space Systems Company – Kennedy Space Division
MEV	Mars Excursion Vehicle
Mgt	Management
mm	Millimeter
MMH	Monomethyl Hydrazine
m/s	Meters per second
MTBF	Mean Time Between Failure
N	Newtons
N2H4	Nitrogen Tetroxide
NASA 90 Day Study	Report of the 90 Day Study on Human Exploration of the Moon and Mars
NASA KSC	National Aeronautics and Space Administration – Kennedy Space Center
NASA-KSC CP	National Aeronautics and Space Administration – Kennedy Space Center Cargo Projects
NASTRAN	NASA Structural Analysis (computer generated structural analysis model)
PCM	Pulse Compression Module
psi	Pounds per square inch
psia	Pounds per square inch absolute
PSS	Planetary Surface Systems
PUV	Pressurized Utility Vehicle
P&W	Pratt and Whitney
RCS	Reaction Control System
SCAPE	Self-Contained At[illegible]ive Ensemble
SDU Model	System Design [illegible]
SEI	Space Explora[illegible]
SSE	Surface Support Equ[illegible]
SSF	Space Station Freedom
SSFP	Space Station Freedom Program
TBD	To Be Determined
UDMH	Unsymmetrical Dimethyl Hydrazine
UPR	Unpressurized Rover
UV	Ultraviolet
WBS	Work Breakdown Structure
XDCR	Transducer

1.0 Executive Summary

Throughout the Option I period of the Lunar Transportation Facilities and Operations Study (LTFOS), McDonnell Douglas Space Systems Company - Kennedy Space Center (MDSSC-KSC) provided support to both the Planetary Surface Systems (PSS) Office at the National Aeronautics and Space Administration (NASA) at the Johnson Space Center and to the Flight and Ground Systems Projects Office (Payload Projects Management) at the Kennedy Space Center. The primary objective of the Option 1 phase of the study was to assist the above NASA centers in developing Space Exploration Initiative (SEI) concepts.

MDSSC-KSC conducted three analyses which provided launch and landing detail to the proposed exploration concepts. One analysis, the Lunar Ejecta Assessment, was conducted to determine the effects of launch and landing a vehicle in a dusty environment. Impacts to the base layout as well as the vehicle and Surface Support Equipment (SSE) were identified. It was found that the base elements of Reference Architecture Option 5A could be protected from small particles if a 1.5 meter high berm was erected at the pad perimeter. However, equipment higher than 1.5 meters and equipment located beyond 375 meters from the landing site could be struck by large particles.

A second analysis, the Thermal/Micrometeoroid Protection Trade Study, was refined to determine the impacts that Reference Architecture Option 5A would have on thermal/micrometeoroid protection approaches. It was found that the storage facility option is still the best protection option. In addition, mobilizing this facility would reduce the amount of Extravehicular Time which would make the storage facility even more attractive when compared to other protection options.

The third analysis, the Centaur Prelaunch Procedure Analysis, used a Centaur prelaunch test and checkout flow to identify key considerations that would be important if a Lunar Excursion Vehicle (LEV) was to use an expander cycle liquid oxygen-liquid hydrogen engine. This assessment indicated that the existing approaches to conducting prelaunch checkout of an expander-cycle liquid oxygen and liquid hydrogen is procedurally intensive. Lunar-based engines, which will see repeated use in a non-terrestrial environment, should be designed to minimize hands-on servicing.

Several "quick look" assessments were also conducted. Most of these were in response to requests to provide detail to the Mission Analysis and Systems Engineering trade studies. One quick look assessment, the Storable Propellant Quick Look Assessment, was conducted to identify design considerations that should be made if storable propellants were to be used instead of liquid oxygen and liquid hydrogen. This assessment indicates that the use of storable propellants will not eliminate the need for surface operations and related SSE. If the propellants are to be maintained in a liquid state and vehicle tank pressures are to remain within a reasonable range, thermal conditioning of the LEVs and Mars Excursion Vehicles (MEVs) will be required.

The LEV Servicer Maintenance Analysis, provided an early look at the effort required to maintain an LEV Servicer on the lunar surface. This analysis indicated that the reliquefaction and the communication/computer systems of the servicer would incur excessive number of failures. (Based on the reliability of similar systems) Recommendations made by this assessment are 1) explore alternatives to reliquefaction or increase the reliquefaction systems reliability to reduce the number of failures, 2) increase the reliquefaction system maintainability to reduce the overall maintenance times, and 3) increase the computer and communications systems reliability to reduce the number of failures.

Also, support was provided to the PSS Logistics Manager to develop initial LEV Servicer cost inputs. The overall PSS objective was to demonstrate the viability of using the System Design Utility Model which will be used to determine logistics support impacts on the life cycle cost of the SEI program.

Finally, consideration was given to the advanced development that must be provided to accomplish a lunar and/or Mars mission. Inputs regarding the advanced development test methods and test beds as well as the schedule, manpower, and cost associated with an advanced development program were made. If the LEV is to be maintained under planetary environmental conditions, thermal and fluid management and maintenance concepts will have to be developed.

MDSSC-KSC also provided support to both MASE and PSS by reviewing and commenting on architecture documents and concept definitions to ensure adequate considerations were given to the launch and landing function of an exploration initiative.

The Lunar Transportation Facilities and Operations Study, Option I, generated a wide array of products. These products have been attached to the report as appendices.

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2.0 Introduction

This report documents the results of the Option 1 of the Lunar Transportation Facilities and Operations Study (LTFOS) results (NAS10-11567). The Option 1 period of the LTFOS had the objectives of performing several tasks for NASA-KSC which were integrated into the ongoing Space Exploration Initiative (SEI). The tasks can be grouped into four categories - Analyses and "Quick Look" Assessments, Logistics Support, Advanced Development Planning, and Document Reviews.

A summary of the tasks performed under LTFOS Option 1 are contained in Table 2-1.

2.1 Analyses and Quick Look Assessments

The Lunar Ejecta Analysis was one of the analyses that was refined during this period. The analysis was

Table 2-1 LTFOS Option 1 Study Tasks and Products

STUDY TASKS	PRODUCTS
Lunar Ejecta Analysis	Estimates of blast damages to SSE and lunar base facilities Estimates of safe distances from launch site Recommendations for changes to base configuration and protection concepts
Thermal/Micrometeroid Protection Analysis	Thermal/micrometeroid protection for Reference Architecture Option 5A EVA Assembly Time vs mass considerations for protection Performance concerns of options considered
Analysis on the Lunar Application of Centaur Prelaunch Procedures	Identification of lunar launch and landing tasks for cryogenic engines Engine design considerations
Quick Look Assessments in Support of MASE Trade Studies	Precursor engineering data needs for lunar and Mars missions Option 5A launch and landing scenarios for manned and unmanned LEVs Launch and landing task estimates Option 5A manned and unmanned vehicles
Quick Look Assessment of MASE Surface Architectures	Launch and landing considerations for the Exploration Emphasis, Expanding Human Presence, and Evolution Emphasis Architectures
Storable Propellant Quick Look Assessment	Identification of lunar and martian environmental impacts to storing hypergolic propellants Preliminary recommendations for SSE
LEV Servicer Maintenance Analysis	Identification of reliability, supportability, and maintenance design drivers for an LEV Servicer Identification of LEV servicer maintenance support requirements
Logistics Inputs to the System Design Utility Model	LEV Servicer costs Preliminary LEV servicer MTBF data
Operations and Logistics Concept Document	Launch and landing concept descriptions LEV Servicer maintenance concept Contingency operations (launch and landing aborts)
Advanced Development Planning	LEV/MEV functional system breakdown Descriptions of advanced development test beds Test bed implementation scheule Advanced development WBS Advanced development schedule Task description sheets Advanced development cost estimates

refined to make estimates of the blast damages to SSE and lunar base facilities that could be expected from a vehicle taking off and landing on the surface. Other estimates that were made include safe distance from the launch site that are required to escape this damage. Where appropriate, recommendations for changes to the base configuration were made as well as recommendations for protection options. The description of this analysis activity and the results are contained in section 3.1.

Another analysis, The Thermal/micrometeoroid protection trade study, was also refined during this period. The description of this analysis activity and the results are contained in section 3.2.

Engines planned for the LEV are cryogenic oxygen/hydrogen engines. To gain insight into the types of tasks that will be required to ready these engines for launch from the lunar surface, existing Centaur procedures were reviewed. This review also revealed some insight into which of the procedures would have application in the lunar environment. The description of this analysis activity and the results are contained in section 3.3.

Throughout the Option 1 period Mission Analysis and System Engineering (MASE) was conducting several trade studies. To support this Level II activity, MDSSC-KSC conducted "quick look" assessments and made several inputs as requested by the Planetary Surface Systems Office (Level III). As a result, MDSSC provided inputs to assist MASE in defining precursor engineering data needs, expendable versus reusable vehicles, workload/crew size/automation, and system commonality considerations. The description of this analysis activity and the results are contained in section 3.4.

The JSC PSS Manager of the Launch and Landing Element (Mr. Joe Riccio) was responsible for conducting propellant conditioning analyses. The Thermal/Micrometeoroid Protection Trade Study supported Mr. Riccio's analysis. However, additional data was required to properly assess the appropriateness of using one type of propellant over another. MDSSC-KSC was requested to conduct a quick look assessment on storable propellant Ground Support Equipment (GSE). The Standard for the Design of Hypergolic Propellants Ground Support Equipment (KSC-STD-Z-0006A) was used as a baseline to derive appropriate design-to criteria for storable-propellant storage and conditioning systems. The description of this activity and the results are contained in section 3.5.

2.2 Logistics Support

During the Option 1 period of LTFOS, a logistics analysis effort was initiated. The top level goal of logistics in the conceptual phase is to ensure front-end consideration of the impacts logistics will have on the overall program. To satisfy this goal, a LEV Servicer maintenance analysis was performed. The objective of this analysis was to influence and impact LEV Servicer design so reliability, maintainability, and supportability are optimized to achieve the program's operational goals. The final product was the derivation of LEV Servicer maintenance support requirements. The description of this analysis and the results are contained in section 4.1.

The results of the LEV Servicer maintenance analysis were used to provide launch and landing inputs to the System Design Utility Model. This model was adopted by the PSS Office for the generation of logistics data and the eventual cost of supporting for the planetary surface infrastructure. Along with the maintenance requirements, estimates for the cost of the servicer, drawings, Mean-Time-Between-Failure (MTBF) data, and other logistical parameters were made. This effort along with the tabular results of this assessment are contained in section 4.2.

2.3 Advanced Development Planning

As the LTFOS Option 1 period progressed, greater emphasis was given to advanced development planning. This effort consisted of two tasks: the definition of advanced development test beds, and an estimation of the manpower and tasks required to develop a validation model of the LEV servicer. The results of these tasks are documented in sections 5.1 and 5.2.

2.4 Document Reviews

Periodically, MDSSC-KSC was requested to provide launch and landing inputs to documents such as plans, requirements documents, and operations concept documents.

One document was the Planet Surface Systems Operations and Logistics Concept document (JSC-24824). It defines the planetary surface operations concept and is the first of a series of documents to be developed concurrently with Space Exploration Initiative mission scenarios. The scenarios reflect how the various mission elements and supporting infrastructure will be operationally integrated and used to accomplish all requirements associated with assigned missions to a planetary surface.

During the LTFOS Option 1 period, the Planetary Surface Systems office was tasked to respond to the release of the MASE surface architecture by deriving preliminary manifests, mass estimates, surface system program development schedules, and capability comparisons for each of the architectures. MDSSC-KSC supported this effort by providing the appropriate launch and landing inputs and general review comments.

A description of this activity and the results are contained in section 6.0.

2.5 Presentation of Study Results

During the study, progress presentations were given to NASA-KSC CP and to the PSS office at JSC. The annual review presentation is contained in Appendix A.

3.0 Analyses and Quick Look Assessments

This section of the report documents the approaches, results, and conclusions of the analyses and quick look assessments that were conducted during the Option 1 period of the Lunar Transportation, Facilities and Operations Study.

All analyses and quick look assessments that were conducted under the Option 1 period were performed under the assumption that the surface architecture would be Reference Architecture Option 5A. Option 5A is a deviation to Reference Architecture Option E which was developed under the NASA 90 Day Study, but emphasizes In-Situ Resource Utilization (ISRU). Option 5 reduces the scale of lunar outpost activity by using a human-tended mode of operation and limiting the flight rate to the Moon to one mission per year.

Option 5A adds a lunar oxygen production capability of five tons per year to the Option 5. This rate is sufficient for the LEV ascent needs in view of the one flight per year rate. The emplacement phase and early consolidation phase and are basically identical to the baseline Option 5. Changes between Options 5 and 5A become evident with flight 10 in the later part of the consolidation phase, where a cargo flight to deliver power, mining, and Lunar Liquid Oxygen (LLOX) elements has been inserted. Due to space basing of the LEVs, there is a resulting five metric ton increase in cargo capacity of landers.

A summary of the activities leading to the emplacement, consolidation, and operational phases of the Option 5A approach are illustrated as a schedule in Figure 3-1.

3.1 Lunar Ejecta Analysis

The lunar surface is covered by a very fine dust, being compared to abrasive talcum powder, and has characteristics which causes it to adhere very tenaciously to surfaces such as EVA suits and spacecraft surfaces. Apollo 12 landed 160 meters from the Surveyor III, which had landed on the moon two and one-half years earlier. The engine exhaust plume from the Apollo 12 lander caused the lunar dust to be propelled radially outward from the landing site. The Apollo mission included the return of a number of samples obtained from the Surveyor III spacecraft. Among the samples retrieved were the TV camera and a 19.7 cm length of a polished aluminum tube. The tube was cut from one of the radar antenna support struts, but the exact position and orientation is unknown. Analysis of these samples showed that the Surveyor III did receive damage from micrometeoroid and/or ejecta impacts. Data regarding the analysis of particle impacts on these samples are documented in the report "Results of the Surveyor III Sample Impact Examination Conducted at the Manned Spacecraft Center" dated 30 March 1971.

3.1.1 Ejecta Analysis Paper Search

To project possible ejecta damage, MDSSC-KSC used an ejecta analysis model developed by Eagle Engineering, Inc. The model was based on data, detailed above. A paper search was conducted to obtain additional data.

3.1.1.1 Interaction of Highly Under-expanded Jets with Simulated Lunar Surfaces. The source for this data was "Interaction of Highly Under-expanded Jets with Simulated Lunar Surfaces," NASA TN D-1095, LeRC, December 1961.

This paper documents testing which used a supersonic wind tunnel (Mo = 3.5 at 300 psia) to achieve test pressures of approximately one psia on a 40 inch diameter base. Cold air at 2,000 psia was exhausted through the sting to various engine nozzle configurations with data collected at various distances from, and approach conditions to, the simulated lunar surface (a flat plate).

Throat and exit diameters were 0.5 and 2.5 inches, respectively for a 25:1 area ratio. A cluster of four nozzles with mass flow equivalent to a single nozzle (throat diameters of 0.25 inches each) was also tested.

Base pressures were measured on the thrust centerline and radially along four axes at four throat diameter (2 inch) intervals. Schlieren photographs (shadow graphs) were also taken.

The results of the test show that surface pressure distributions were dependent on: nozzle area ratio (exit area/throat areas), nozzle contour (some contours caused annular surface pressure variations, which resulted from shock waves that originated within the nozzle), and height from the surface.

Maximum pressure increased from 0.4 percent of chamber pressure at 40 throat diameters (8 exit diameters) to 6 percent of chamber pressure at 13 throat diameters (3.6 exit diameters). High surface pressure was generally contained within 16 throat diameters (3.2 exit diameters).

3.1.1.2 Plane Section of Exhaust Flow Field of a Jet. The source for this information is "Experimental Investigation of Jet Impingement on Surfaces of Fine Particles in a Vacuum" NASA TN D-2633, LaRC, February 1965.

The test on which the paper was based measured the time history of crater growth and near field visibility as a result of impingement from a single supersonic (Mach 3.36) cold gas nozzle perpendicular to a dust bed located in a 60 foot diameter vacuum sphere (starting at 0.3 millitorr, which increased after two tests to 1.0 millitorr).

Visibility through one side and both sides of the debris cloud was measured using collimated light beams and photo cells. Soil density versus time was recorded by X-ray exposure of film rotating past a

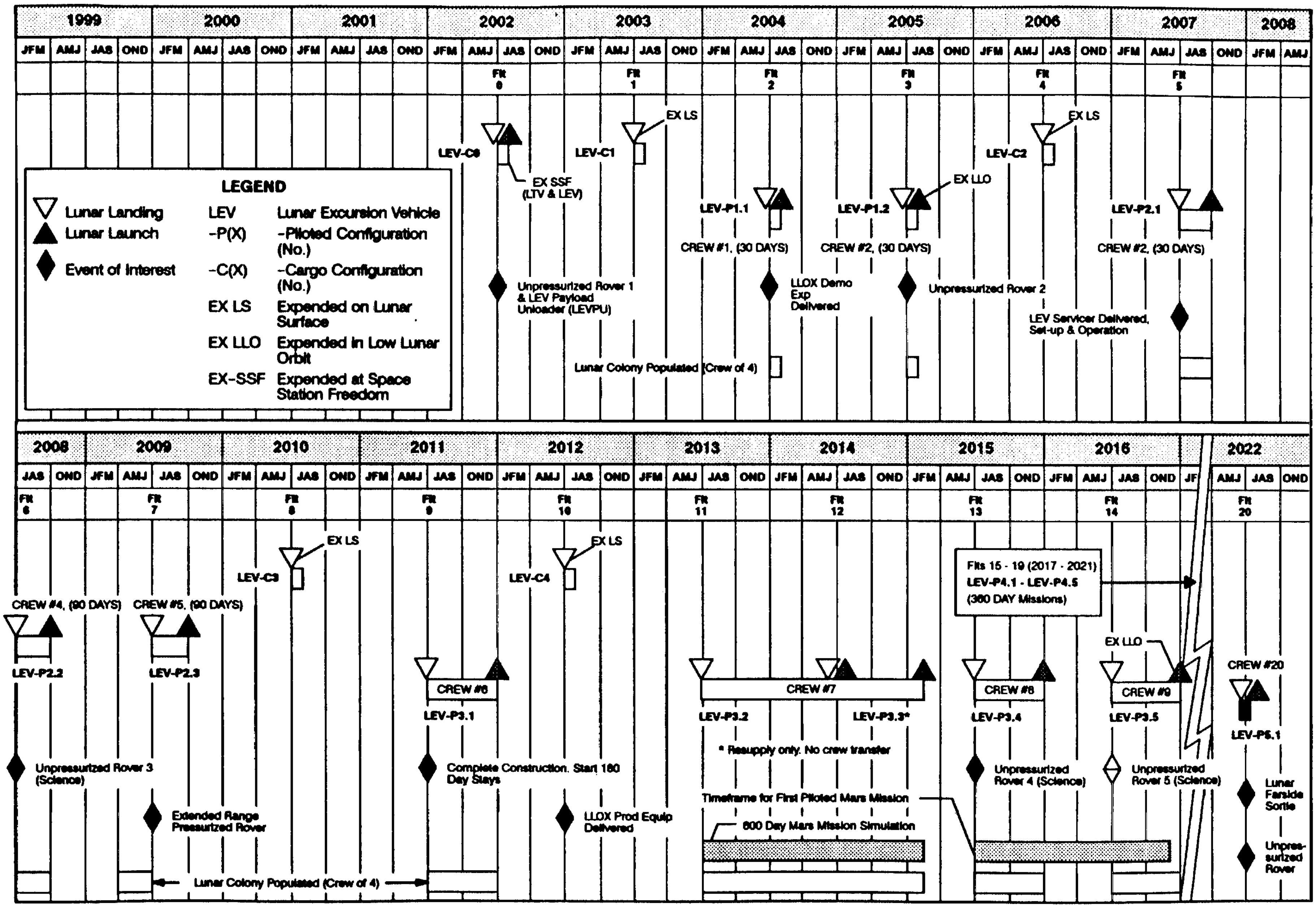

Figure 3-1 Reference Architecture Option 5A Lunar Launch and Landing Schedule

slot beneath the soil bed. High-bed motion picture and sequence camera coverage were also used.

From this source, it was found that the exhaust jet will most likely exit the engine in an under-expanded condition, and will expand and plume outward at a very large angle with respect to the jet axis as defined by the "jet boundary" as illustrated in Figure 3-2. Under these high expansions, and for a single engine, no oblique or transverse shock waves should be formed.

Just above the surface, a bowl-shaped "normal shock wave" will be formed, which will turn the flow radially outward, as indicated by the "streamline."

A stagnation condition will exist where the nozzle centerline intersects the surface. The resulting "free-stream dynamic pressure" will peak near a point directly beneath the nozzle lip, and decrease rapidly as radial distance from the stagnation point increases.

The flow just above the surface will accelerate radially from the stagnation point, reaching a supersonic speed ("sonic line") while continually decreasing in density.

Maximum surface shearing stress will likely occur at the point of maximum dynamic pressure. This explains the occurrence of initial erosion in an annular ring and the formation of central peaks. With time the erosion should extend from this annular ring both inwardly and outwardly.

The report states that "The ejection velocities may be high and it is theoretically possible for the eroded particles to reach lunar orbital conditions."

The experiment data confirmed the existence of an incipient erosion boundary based on particle size.

Craters formed at a lower nozzle height tended to have a greater depth-to-diameter ratio than those formed at a greater nozzle height. Erosion rate increased by a factor of 120 when nozzle height was decreased from 10 to 5 nozzle radii.

Outside crater walls may be at angles greater than the static angle of repose of the material, being supported by the exhaust pressure field, with inward collapse occurring when the nozzle flow ceases. With larger particles, which permitted the soil to "breathe," this collapse was a slumping action. However, with one micron particles, it appeared that gas, forced into the dust in the stagnation region, expanded explosively at flow cutoff, destroying the crater structure.

3.1.1.3 Close-Range Rocket Exhaust Impingement on Surfaces. The source for this data was Experimental Investigation of Close-Range Rocket-Exhaust Impingement on Surfaces in a Vacuum, NASA TN D-5895, LaRC, July 1970.

The test on which this paper reports used an Apollo Lunar Module (LM) attitude control engine with a simulated LM base structure to fire at flat, dished, and particulate surfaces under near-vacuum conditions. Target surface impingement pressures and heating rates, descent stage base pressures, and nozzle static pressures were measured with the engine at different thrust levels and at various altitudes from and attitudes to the surface.

For firings normal to a flat surface, surface pressures were distributed symmetrically across the surface, and for altitudes down to about one nozzle diameter, were highest at the nozzle centerline, peaking at a pressure of about 0.043 times chamber pressure at an altitude of two nozzle diameters. Below two nozzle diameters, maximum pressure began to de-

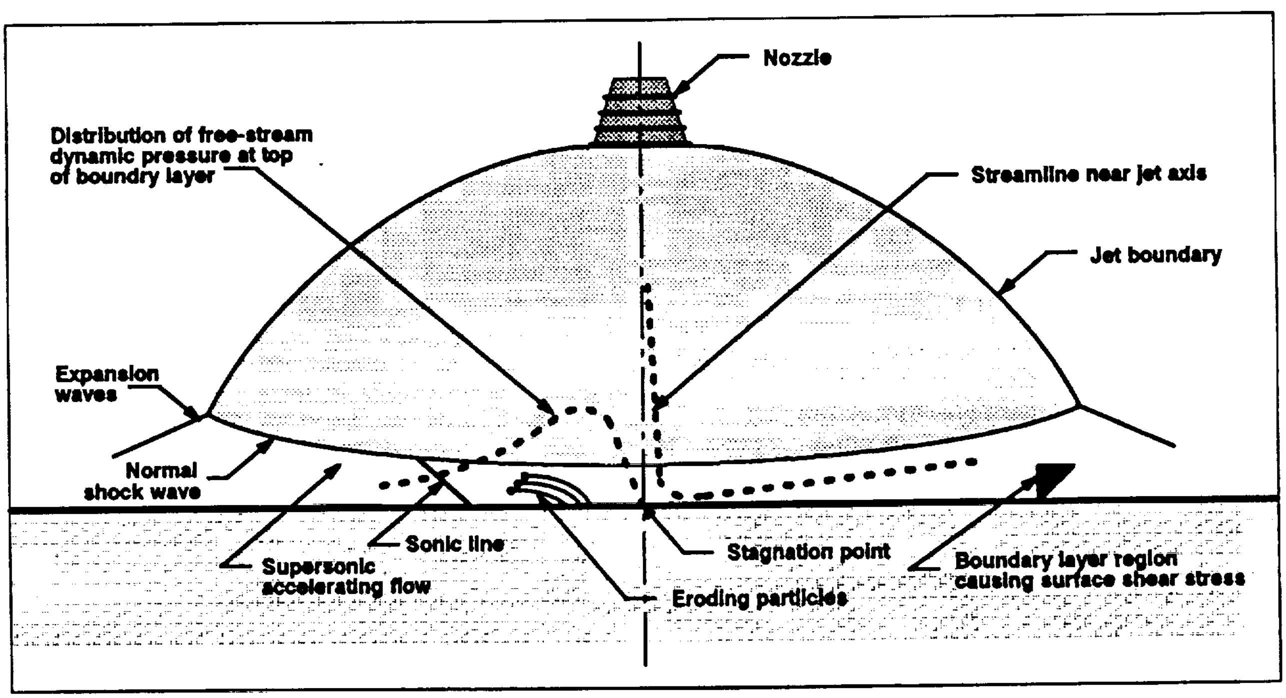

Figure 3-2 Plane Section of Exhaust Flow Field of Jet

crease and shift to a point below the nozzle edge. At an altitude of one nozzle diameter and in an area directly beneath the nozzle it was relatively constant at 0.024 times chamber pressure. At altitudes below one nozzle diameter, peak pressure was under the nozzle edge, increasing to 0.029 times chamber pressure at an altitude of 0.28 nozzle diameter (just prior to reaching choked flow).

During 0.1 second engine firings, vacuum chamber increased from 0.4 millitorr to 1.3 millitorr (the lunar surface is 1.0 millitorr).

The testing generated results which showed that space vehicle base pressures were one to two orders of magnitude less than the target-surface pressures, and were measurable only at altitudes less than two rocket exit diameters.

The onset of nozzle choking occurred when the cylindrical escape area, formed between the rocket exit and the target surface, became less than the rocket exit area (i.e., an altitude of 0.25 rocket exit diameters). The effect of nozzle choking is a significant increase in nozzle static pressures compared with unchoked values.

Surface heating increased with chamber pressure and decreasing altitude. The maximum heating rate occurred directly under the nozzle edge.

Firings off-normal to the surface increased both the pressures and heating with increasing tilt. The changes were within about 10 percent for angles of eight degrees or less and altitudes down to one nozzle diameter. At an altitude of 0.5 nozzle diameter, uphill pressure under the nozzle edge increased to about 0.056 times chamber pressure at four degrees tilt, and to 0.108 times chamber pressure at eight degrees tilt.

Firing into a concave dish had little effect on pressure levels, but the shift of the pressure peak from the centerline to nozzle edge tended to occur at a higher altitude (about 1.7 nozzle diameters).

3.1.1.4 Conclusions of the Exhaust Ejecta Paper Search. Surface pressures probably achieved during landings of the Apollo Lunar Module were estimated from test data that indicated peak pressure of 4.3 percent chamber pressure should have been achieved at an altitude of 2 nozzle exit diameters. For the 59 inch LM descent engine nozzle, operating at reduced thrust at a chamber pressure of 104 psia, yielded a maximum surface pressure of about 4.5 psia at a LM altitude of about 3 meters. At engine cutoff and an altitude of 1.3 meters, surface pressure was an estimated 2.5 psia under the nozzle edge.

A single RL10-3-3A engine, with a nozzle exit diameter of 39.5 inches and operating at a liftoff chamber pressure of 465 psia (16,500 lbs thrust), would produce at an altitude of about two meters, peak surface pressure of approximately 20 psia, over four times the surface pressure produced by the LM. Advanced engines, operating at higher chamber pressures, would result in even higher surface pressures.

A cluster of four RL10s would have an equivalent single-engine nozzle exit diameter of 79 inches. This should raise the altitude of maximum pressure to about four meters. However, depending on engine spacing, shock waves resulting from interaction of the four engine exhaust jets, would probably spread the pressure over a broader area, with a corresponding reduction in peak pressure.

One protective measure would be to compact the soil in the pad area to increase the cohesive forces that resist erosion of fine particles.

Another measure would be to pave the pad area with stones of sufficient mass to resist the aerodynamic erosion force. Surface static pressure dropped precipitously at one nozzle diameter from the center of thrust, and pavement much beyond this point should not be necessary (three to four meters beyond the landing Critical Error of Probability).

3.1.2 Ejecta Analysis Approach

A computer model was developed by Eagle Engineering, Inc. to define ejecta caused by the engine blast of a vehicle landing or launching from the surface. The model required three pieces of information; the engine thrust, the height of the nozzle above the lunar surface, and distances from the engine centerline. The outputs from the model included the velocity at which the particle impacts a target (in meters per second), the particle impact crater that the propelled particle could cause in aluminum and bullet resistant glass (crater size in millimeters), the percentage of the target's surface which is pitted by the particles in the blast plume, and particle density.

The program is based on Prandtl-Meyer expansion equations which provide a method of determining the gas velocity, flow angle, and shock angles at various points in a pressure field. (The Lunar Blast Program user guide and code is contained in Appendix B.) The Prandtl-Meyer expansion equations provide a method of determining the gas velocity, flow angle, and shock angles at various points in the pressure field. These equations depended upon the type of gas being analyzed; they were developed for a sea-level atmosphere. It is assumed that the gasses coming out of the lander engine have the same properties as a standard atmosphere. This assumption is made primarily because the gas constant for the propellant is unknown. Since the 1 atmosphere specific heat ratio (gamma) for the engine exhaust is not significantly different from a standard atmosphere, 1.3 vs 1.4, this assumption should not be in great error. The problem is that the vacuum environment causes gas rarification. The effects of rarification of the Prandtl-Meyer model are unknown.

MDSSC used this program to determine the effects of small particle ejecta for a range of engine thrust levels from 15,000 to 80,000 lbf. Engine nozzle height was held to 1.0 meter because the minimum nozzle heights varied between 1.0 and 1.28 in the Transfer Vehicle Concepts and Requirements Study, Interim Reviews. Target distances were varied from between 50 meters to 15 kilometers. The model was also used to examine large particle trajectories with the same input parameters. See Table 3-1 for a listing of the input parameters.

Table 3-1 Ejecta Analysis Input Parameters

Engine Configuration	Thrust	Nozzle Height	Target Distance
Single Engine	15,000 lbf 20,000 lbf	1 meter	50 M to 15 KM
Two Engines	30,000 lbf 40,000 lbf	1 meter	50 M to 15 KM
Three Engines	45,000 lbf 60,000 lbf	1 meter	50 M to 15 KM
Four Engines	60,000 lbf 80,000 lbf	1 meter	50 M to 15 KM

Location of the crew habitat with respect to the launch and landing area was also considered. The habitat must be close enough to the launch and landing area such that transportation time between the two is not excessive, and yet far enough away to preclude the possibility of damage from engine ejecta. Surface Support Equipment (SSE) must be close to the pads to reduce the length of interconnecting fluid lines and electrical cables. For these reasons MDSSC examined the range between 50 meters and 15 kilometers.

Two basic types of damage from ejecta were addressed, sandblasting caused by small particles (i.e., 1 mm or less in diameter), and dents or punctures caused by large particle impact (particles greater than 1mm in diameter).

Soil samples taken on the Apollo 11 mission were analyzed to determine soil particle size distributions. It was found that 90% of the soil is made up of particles less than 1mm in diameter. Figure 3-3 illustrates the lunar soil grain size versus per cent distribution.

3.1.3 Ejecta Analysis Results

This analysis showed that small particles (150 micrometers) will pass above and beyond habitat and ISRU areas, except particles propelled at low elevation angles (0.25 - 1.0 degrees). The impact velocity of the small particles will vary according to the thrust levels of the engines. A 15,000 lbf engine will propel particles at velocities of up to 329 m/s, an 80,000 lbf engine will propel particles at a velocity of 966 m/s. However, these small particles have a tendency to disperse rapidly with range and the density

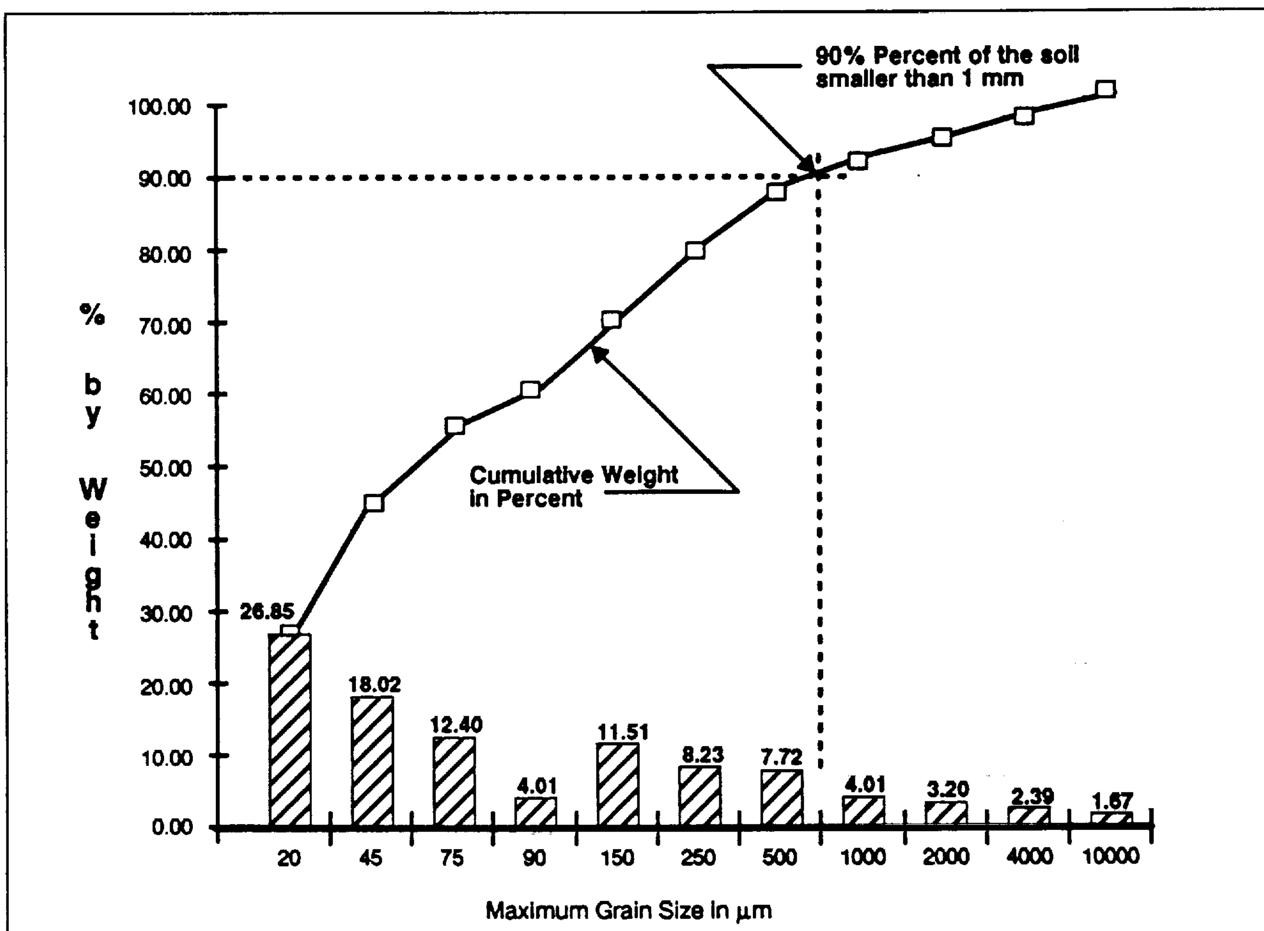

Figure 3-3 Lunar Soil Grain Size Distribution Based on Apollo 11 Soil Sample

approaches zero at 4 km when propelled by an 80,000 lbf engine. Aluminum pitting caused by small particles drops below 10% at 1 km and glass pitting from these particles drops below 10% below 2.4 km.

The results of the analysis for large particles (1mm to 10mm) indicate that an 80,000 lbf engine will propel 1mm particles to impact velocities of 370 m/s and 10 mm particles to impact velocities of 117 m/s. If it is assumed that the particles are sent out at a maximum elevation angle of 5 degrees, then 1 mm particles could be propelled as far as 15 km and 10 mm particles could be propelled as far as 1.5 km.

According to post mission reports and interviews with Mr. Pete Conrad, Apollo 12 astronaut, surface gas flows horizontal to the surface. These sources also reported that the dust which was displaced by the lander, or by the astronauts walking on the surface, had a tendency to stay relatively close to the surface. Because there is no atmosphere upon which the dust can remain suspended, the dust did not billow up as it was displaced. Therefore, a five degree maximum elevation was assumed.

3.1.4 Conclusions of the Ejecta Analysis

If Reference Architecture Option 5A is assumed and a barrier is erected between the pad and the areas to be protected (75 meters from the center of the pad), the barrier would have to be 1.5 meters high to provide protection from the blast effects of small particles being propelled from the landing site. The protection could be erected from blast shields or from surface regolith piled up as berms. The erection of the berms, or blast shields, would also provide protection for low profile equipment (less that 1.5 meters in height) from large particles as long as the equipment was located from 75 to 375 meters from the pad. The chart in Figure 3-4 illustrates the protection which could be provided by berms.

The use of a berm, 1.5 meters high, located 75 meters from the center of the pad is intended to be used as a point design. The berm should be a 120 degree arc approximately 157 meters long, requiring 353 cubic meters of regolith, or 530 tonnes (assuming 1.5 tonnes per cubic meter). Figure 3-5 illustrates this configuration. It may be possible to obtain this much regolith during the pad preparation (i.e., leveling). It may require filling "sandbags" with regolith and arranging the "sandbags" to form the berms. A loose piling of regolith could actually contribute to ejecta problems because the berm could act as a ramp to propel loose particles on its surface.

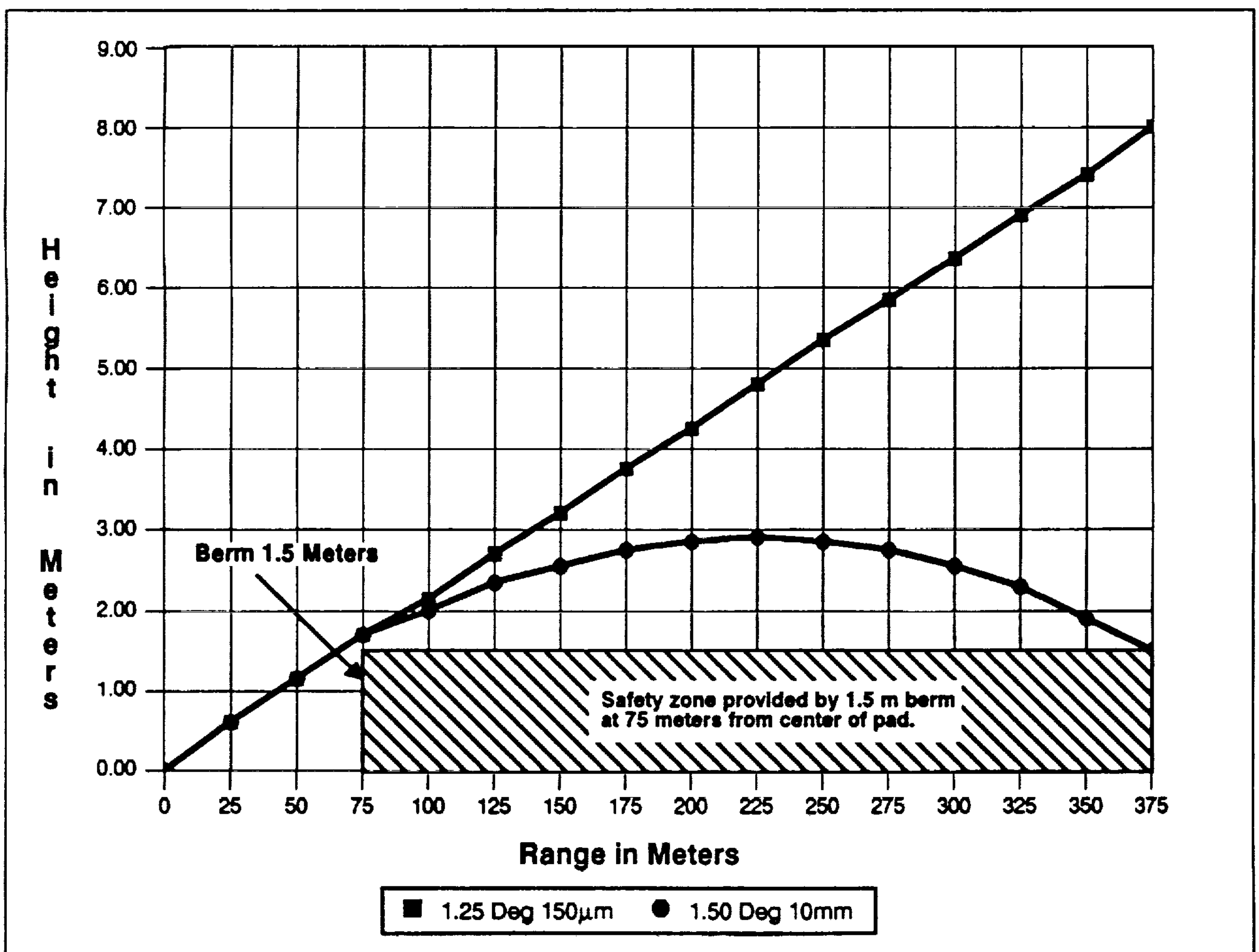

Figure 3-4 Safety Zone Provided by 1.5 Meter Berms

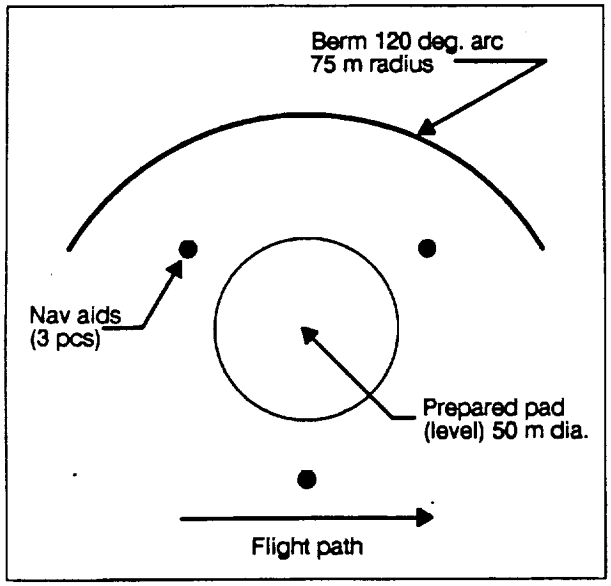

Figure 3-5 Layout of the Lunar Base Launch and Landing Site

During the course of the analysis, MDSSC-KSC was requested by Planetary Surface Systems to consider the effects of a vehicle landing 100 meters from the berm (nominal being 75 meters). Because the engine is throttled down during landing, this landing profile was not seen as a significant concern. For example, during the Apollo 12 mission the LEM engine throttle setting, under manual control, varied between 19% and 44% of maximum thrust from an altitude of 1000 feet until landing. (See Altitude/Range Profile in Figure 3-6)

However, during lift-off the throttle would probably be set at 100% for maximum thrust. Figure 3-4 (page 3-6) shows projectile trajectories for an 80,000 lbf (355858 N) engine with the berm at 75 meters for 150 micrometer and 10 mm particles. At 100 meters from the berm, 10 mm particles could strike the surface at a range of 375 meters.

In discussing the Apollo 12 mission with Astronaut Pete Conrad, he stated that dust movement was first noted at an altitude of 175 feet (thrust level was between 1990 and 4400 lbf), and the Surveyor was covered completely with very fine lunar dust to the point where it was almost impossible to see it against the lunar background after landing. At first they thought that the structure was discolored from some solar effect. The fact that it was coated as a result of

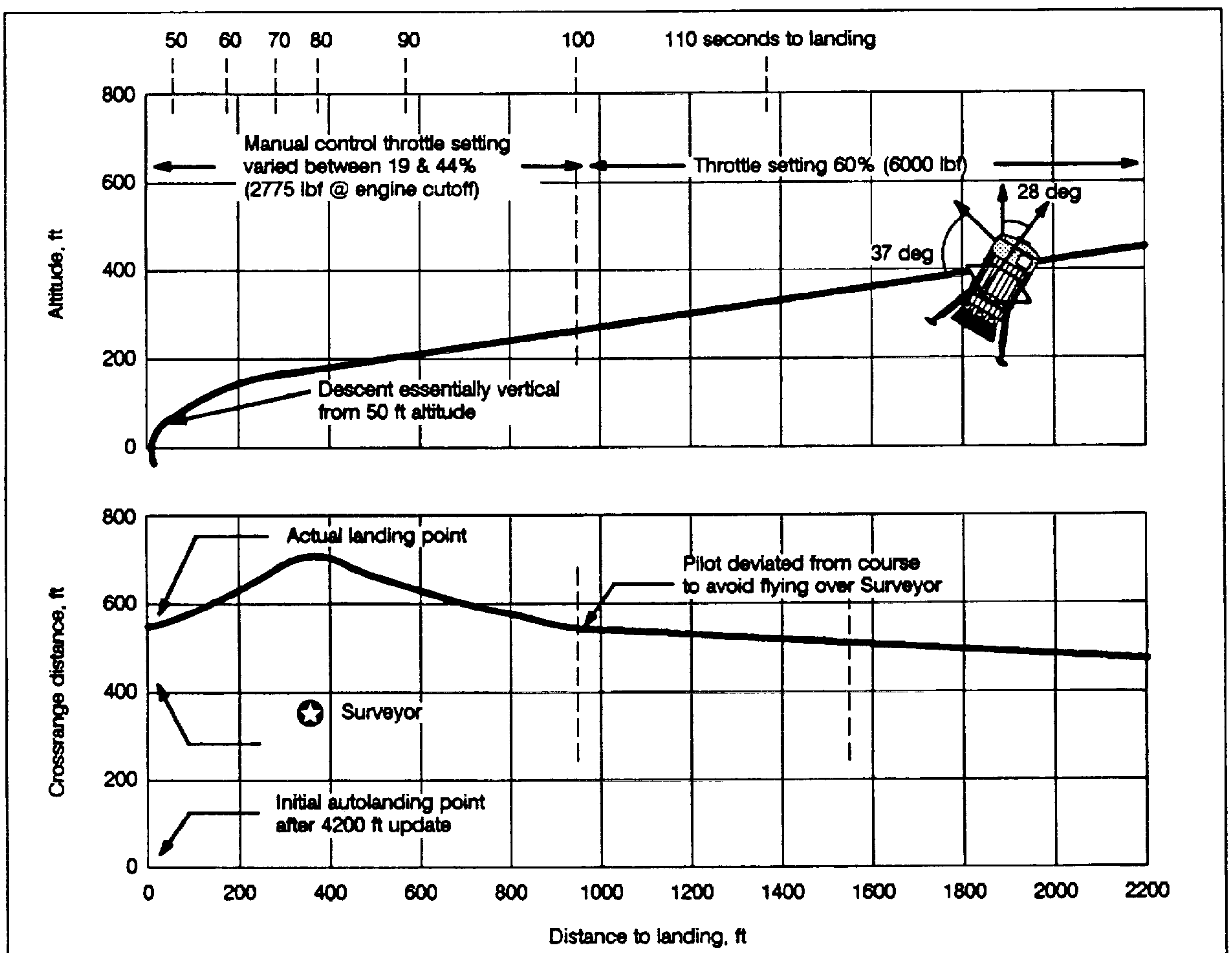

Figure 3-6 Lunar Lander Altitude and Range Profile

engine blast ejecta was not determined until they returned to earth with their samples.

While berms would provide protection from small particle strikes, the berms would not protect against large particles strikes which would follow a ballistic trajectory. Large particles could rise over the berm and on the downward flight path strike surface equipment and structures. The danger from this hazard occurs from 375 meters out to 15 km. However the probability of large particle impact damage is relatively low for two reasons. First, large particles (1 to 10 mm) constitute less than 10 percent of the lunar soil, thus reducing the probability of a large particle being contained in the ejecta. Secondly, these particles would be propelled at velocities which are relatively low (117 to 340 m/s).

3.2 Thermal/Micrometeoroid Protection Trade Study

This analysis was originally performed under the base study period of the Lunar Transportation Facilities and Operations Study. Per the request of the NASA-KSC Study Manager, Mr. J. R. Reiss, the analysis was refined to evaluate the same protection options using the PSS Reference Option 5A. After that analysis was made, the PSS Office at JSC requested MDSSC-KSC to evaluate the impacts of making the Storage Facility Option mobile. Differences between the groundrules of this analysis and the previous analysis are illustrated in Table 3-2.

3.2.1 Trade Study Approach

For this trade study, four options were analyzed. One option, the Consolidated Vehicle Option, would have the lander provide its own protection for both the space flight and the surface stay time. This protection would be similar to the Apollo Lunar Modules (LM) which carried its own thermal protection. The other three options are surface based protection systems - the A-frame Tent, the Vehicle Skirt and the Storage Facility. For this analysis it was assumed that these systems would not be constructed of lunar surface material, but would be part of the infrastructure that must be developed on earth and sent to the lunar surface.

Table 3-2 Comparison of Baseline and Option 5A Architecture Launch and Landing Groundrules

BASELINE STUDY ARCHITECTURE	OPTION 5A ARCHITECTURE
Permanent Habitation	Man-tended
Four Crew Members with Growth to Twenty	Four Crew Members
Three Vehicles on the Surface	One Vehicle on the Surface
More Than One Vehicle Flight Per Year	One Vehicle Flight Per Year
LLOX Production Plant	LLOX Production Plant
Vehicles Based on Lunar Surface with Excursions to LLO	Vehicles Based in LLO with Excursions to Surface
Vehicles to be Replaced After Five Flights	Vehicle Use Varies - No More Than Five Flights
Cargo Vehicles were Reusable	All Cargo Vehicles are Expended on Lunar Surface

In space flight, a "Barbecue Mode" of heat rejection is used in which the spacecraft is slowly rotated on an axis perpendicular to the sun so that hardware items which have accumulated heat can reject the excess heat to deep space. Obviously, this approach is not suitable for the lunar surface. The Consolidated Vehicle Option, Figure 3-7, combines the required spaceflight protection with the required surface protection into a single vehicle design. This consolidation of the requirements into a single design provides protection for both environments.

However, even with adding this protection, the engine nozzle will remain exposed to the thermal environment through reflected energy from the surface. The nozzles which are directly attached to the engines and the propellant distribution system allow a thermal short directly to the propellant tanks where unacceptable heating may occur. It should be noted that the landing pads of the vehicle will be in direct contact with the surface and will also conduct heat to the vehicle. However, protection against the conduction of heat through the pads was not considered in this analysis.

The A-Frame Tent (Figure 3-8) uses two upright poles, a ridge pole, blankets and guy wires to erect protection for the vehicle at the landing site. To construct the tent, one edge of the tent blanket would be staked to the ground, the support would be attached to two of the lander foot pads, and then the assembly would be raised over the vehicle. As the assembly is raised, the blanket would deploy along guy wires. Once vertical, the remaining half of the blanket would be deployed by lowering it along guy

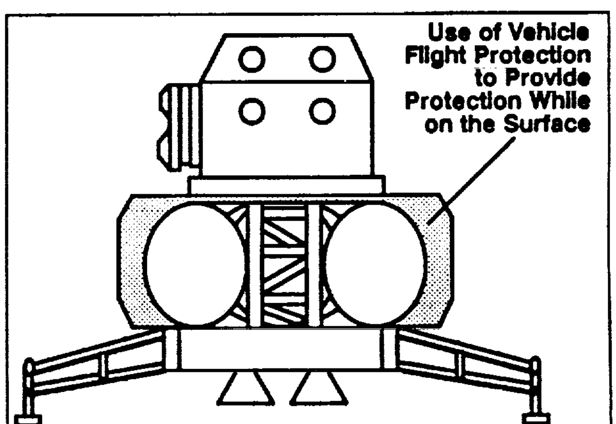

Figure 3-7 Consolidated Vehicle

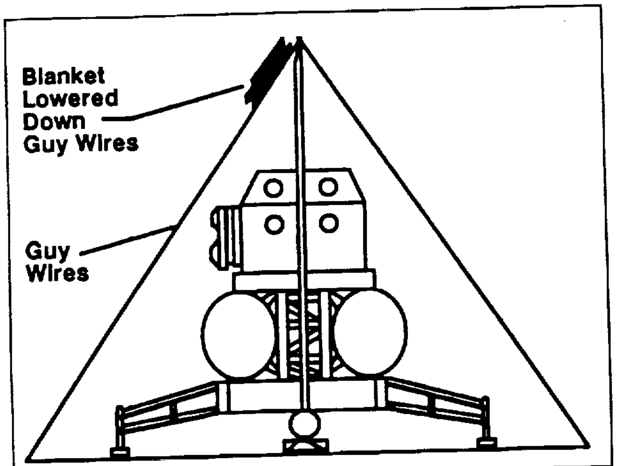

Figure 3-8 A-Frame Tent

wires. Side flaps, which would be required to protect against heat reflected by the surface, would deploy automatically with the blankets.

Another surface-based option, the Vehicle Skirt Option (Figure 3-9), is similar to the Consolidated Vehicle Option except that the required protection is added to the vehicle after landing. Following landing, crew egress, postlanding inspections and cargo removal, the crew would be required to remove blankets or "skirts" from storage and use access equipment and handling fixtures to attach the blanket to the manned module or cargo interface. The flight vehicle would have provisions for attaching the top edge of the protective blanket with the bottom edge attached to the lander legs. Since the cargo vehicles are expended on the lunar surface after a single use (Reference Architecture Option 5A), the cargo vehicles would not require protection. It should be recognized that vehicles expended on the lunar surface could be a source of spares for other vehicles, but protection of expended vehicles was not considered in this analysis.

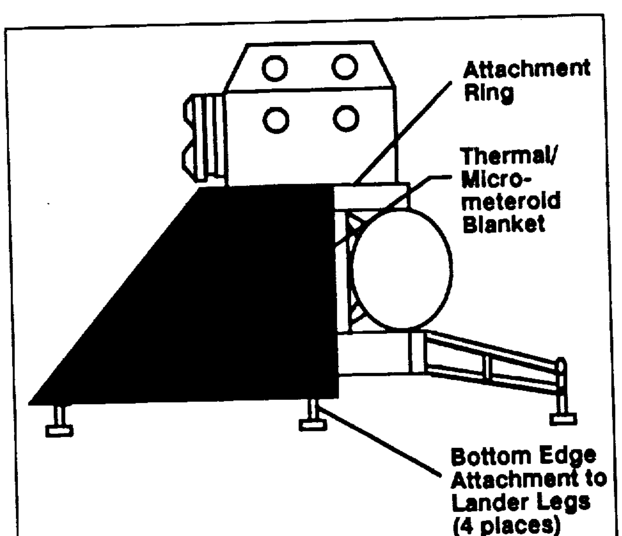

Figure 3-9 Vehicle Skirt

A final surface-based option is the Facility Storage Option (Figure 3-10). This option has a feature that the other options do not have. It can be expanded to accommodate multiple launch and landing vehicles and associated Surface Support Equipment (SSE). Following landing, the vehicle would be raised, wheel assemblies attached and then the vehicle would be towed to the storage facility. Hazardous consumables could be offloaded prior to facility entry if a propellant storage area were provided. The facility would be sized to accommodate any number of vehicles and could accommodate changes in the vehicle configuration. Since the other surface based options are meant to protect a single vehicle, this analysis used a single bay storage facility. This permits an accurate comparison of masses and EVA man-hours required to erect these protection options.

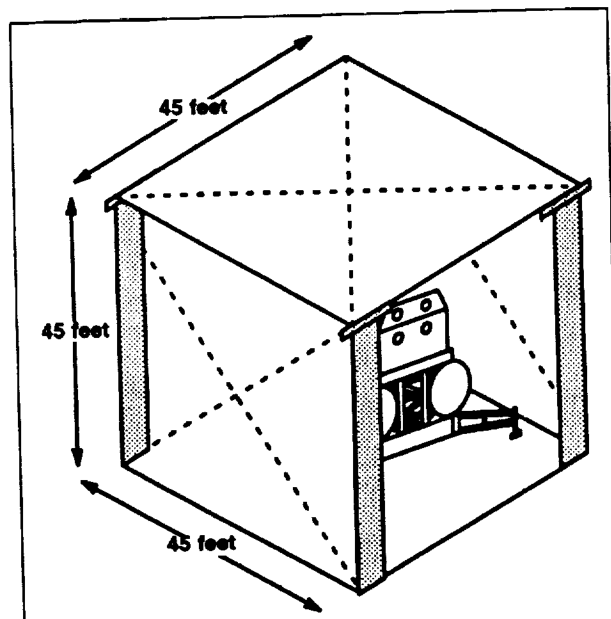

Figure 3-10 One Bay Storage Facility

3.2.2 Evaluation of the Thermal/ Micrometeoroid Options

Three primary factors were used to determine the relative merits of one lunar protection option over another. The mass required to be placed on the lunar surface was one criterion. This estimate included the mass of the protection system, but did not include the mass of the propellant that would be required to transport the protective system to the lunar surface.

Another evaluation criterion was the amount of time (EVA man-hours) that would be required to erect the protective system on the lunar surface. The estimates for these timeframes are relative at best. The estimates were made by determining which current prelaunch and postlanding operations were similar to the proposed operations and then making time projections based upon experience. In some instances existing KSC operations did not provide a credible comparison aircraft handling operations were used for comparison purposes.

The final criterion used for this evaluation was the operational characteristics of each of the options under study. Included in this criterion are such factors as safety (mission, lander, crew, surface systems), operational complexity, and durability.

3.2.2.1 Mass to Surface. The results of the mass-to-lunar comparisons are recorded in Table 3-3. As identified in this table, the least mass to the lunar surface is provided by the Vehicle Skirt Option. The next lightest form of protection is the Consolidated Vehicle Option. The heaviest protection was provided by the Storage Facility Option with 7821 pounds. However, this assumes that the storage facility is a one-bay configuration. The storage facility option has a greater mass pay-back when it is expanded to accommodate more than one vehicle. For instance, a three bay facility accommodates three vehicles with about twice the mass. The mass calculations for each of the options are contained in Appendix C.

When the operational characteristics of each of the options is taken into account, a straight forward comparison of the masses of each of the options may be misleading. The material used to provide surface protection will deteriorate from continued exposure to intense ultraviolet radiation. This causes the material to become brittle which would become a problem if the fabric is folded or unfolded repeatedly. The A-Frame and the Vehicle Skirt would call for the repeated folding and unfolding of the protection material; therefore, the A-Frame Tent and the Vehicle Skirt would have mass penalties from material replacement requirements.

Table 3-3 Mass of the Surface Protection Options

OPTION	MASS
Consolidated Vehicle Option	2,425 lbs. (each flight)
A-Frame Option	6,342 lbs. (total)
Vehicle Skirt Option	1,915 lbs. manned (total)
Storage Facility Option	7,821 lbs. (1 bay)

If it is assumed that the fabric would have to be replaced after five flights, then the mass advantage of the Vehicle Skirt diminishes. At one flight per year, this five year life is probably optimistic. After four replacements, the facility option would become the lightest surface protection. The Consolidated Vehicle Option carries its protective system on the vehicle, therefore, the mass associated with this option accumulates with each flight. The Consolidated Vehicle Option becomes the least desirable from a mass standpoint after just three flights. The graph in Figure 3-11 illustrates the resulting material replacement impacts. Based on these considerations the Storage Facility Option was considered to have the greatest mass to surface advantage.

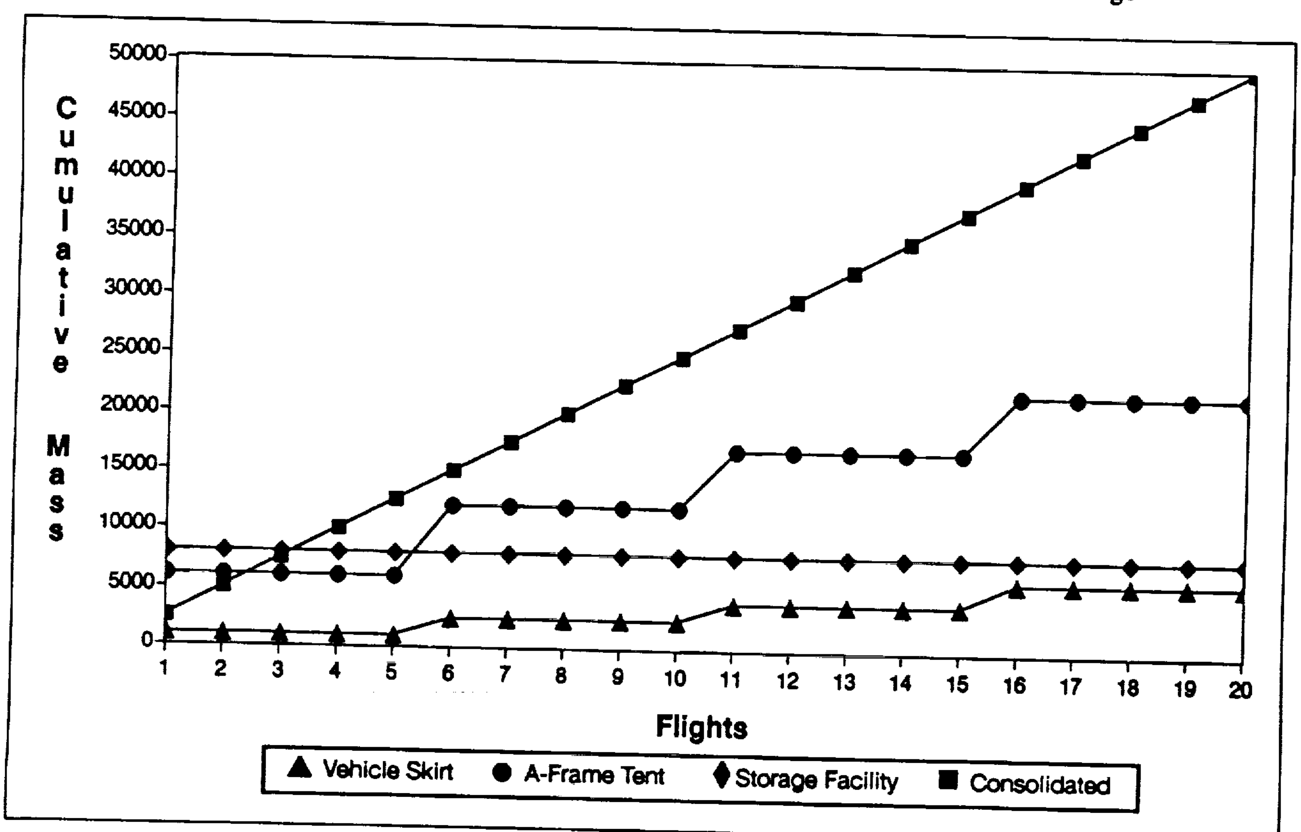

Figure 3-11 Delivered Mass of Each Option Including Material Replacement

3.2.2.2 Operational Considerations. As discussed in section 3.2.2 estimates for EVA Man-Hours are based on comparative earth bound tasks. Based on this methodology, flow charts for the tasks to establish surface protection were generated and the required times to erect each of the protection options were estimated. (The flowcharts of these tasks and the estimated times for each of the tasks are documented in Appendix D.) Table 3-4 documents the total times required for each of the options.

Since the Consolidated Vehicle Option brings its protection with it to the surface, it requires no erection time. Excluding the Consolidated Option, the table illustrates that the A-Frame Tent has the lowest single erection time. However, The A-Frame Tent and the Vehicle Skirt Option require repeated deployment for manned vehicles.

The Storage Facility Option, on the other hand, requires a the preparation of a site and the erection of the facility itself, which is a one-time event. The recurring portion, 13:50, is preparing the vehicle and transporting it to the facility.

Based on the operational considerations the Consolidated Vehicle Option is the preferred option followed by the Storage Facility, A-Frame Tent, and Vehicle Skirt options.

3.2.2.3 Summary of Results. The consolidated Vehicle Option offers advantages in that the surface operational complexities are minimized. Providing protection by using vehicle systems eliminates the need for additional prelaunch/postlanding operations and associated EVA. Another advantage is that the vehicle does not need to be moved. However, the disadvantage of this approach is that there is a cumulative mass penalty. Another disadvantage is the thermal short from the hot lunar surface to the propellant through the engines and propellant lines. The Consolidated Vehicle Option, while simplifying operational complexities, imposes a great mass penalty without providing optimum protection and is not considered a desirable option for multiple missions.

Table 3-4 EVA Manhours for Each Protection Option

OPTIONS	EVA TIME
Consolidated Vehicle	Not Applicable
A-Frame Preps & blanket installation & removal	17:40 (recurring)
Vehicle Skirt Preps & blanket installation & removal	21:20 (recurring)
Storage Facility Site preps & facility erection	18:30 (1 bay - non-recurring)
Preps & flight vehicle transportation to/from pad/storage facility	13:50 (recurring)

There are two distinct advantages to the A-Frame Tent Option. One advantage is that it offloads mass from the vehicle. Another is that the vehicle does not have to be moved to a storage site. The disadvantage of this system is that the protective system must be moved to the landing site. This entails the use of equipment or surface transportation vehicles and also adds to the complexity of the surface operations. This adds to the amount of EVA. The blanket material itself would have to be replaced because repeated erections and lowering after exposure to intense ultraviolet radiation degrades the material. There is also the potential for damage to the lander and surface support systems if the A-Frame or its blanket is dropped onto the lander.

Like the A-Frame Tent, the Vehicle Skirt Option off-loads mass from the vehicle and does not require the moving of the vehicle to a storage site. However, it adds greatly to operational complexity including the moving of the protective system to the landing site. This concept is dependent upon surface support equipment for access, lifting, and handling. It requires a great amount of EVA support. There is also a potential for damage to the lander and/or injury to the crew members from mishandling the skirt or handling equipment. The material itself is subject to damage from repeated deployment that must occur on every flight and would require replacement.

The Storage Facility Option offloads mass from the vehicle. Also, the characteristics of the facility provides several advantages. It can be expanded to accommodate several vehicles, which increases the operational efficiencies for multiple vehicle flows. However, placing multiple vehicles within a single facility exposes all of the vehicles to any catastrophic event. The facility can also provide protection for Surface Support Equipment and for astronauts working on the vehicles. This option also has the distinct advantage that material degradation will not occur through repeated handling and deployment. The major disadvantage to the Storage Facility Option is that it requires the moving of the vehicle to the storage facility, which adds to the complexity of prelaunch and/or postlanding operations.

3.2.2.4 Conclusions of the Thermal/Micrometeoroid Study. The comparative results of each of the options (Consolidated Vehicle, A-Frame, Vehicle Skirt, and Storage Facility options) are shown in Table 3-5. Based on these considerations, the Storage Facility Option appears to be the best current choice.

3.2.3 Mobility Analysis of the Storage Facility Option

The Storage Facility Option was originally evaluated as a stationary surface protection system. However, the PSS Office requested MDSSC-KSC to determine if there were any potential benefits associated with using a mobile facility. Therefore, MDSSC-KSC conducted a quick assessment of making the facility mobile. Two areas were addressed. First, this concept was evaluated

Table 3-5 Summary Comparison of the Protection Options

OPTION	MASS ASSESSMENT	EVA MANHOUR ASSESSMENT	OPERATIONS ASSESSMENT	PERFORMANCE ASSESSMENT
Consolidated Vehicle Option	Least Desirable	Most Desirable	Most Desirable	Inadequate
A-Frame Tent Option	Less Desirable	Less Desirable	Less Desirable	Adequate
Vehicle Skirt Option	Most Desirable	Least Desirable	Least Desirable	Adequate
Storage Facility Option	More Desirable	More Desirable	More Desirable	Adequate

to determine if the facility would need any additional stiffening of its structure. This stiffening would impose a mass penalty. Secondly, this concept was evaluated to determine if there would be any changes associated with the EVA time required to for a mobile versus a fixed protection facility.

A NASA Structural Analysis (NASTRAN) model was created by MDSSC-KSC Mechanical and Facilities Engineering to analyze the loads that might be encountered in the facility structure if it were mounted on wheels on each corner. The loads that were evaluated included the lunar gravity, the loads of the material being supported on the Storage Facility frame, and the loads which would be imparted to the structure due to the torque of the drive units. The three configurations that were evaluate are:

1. Fully closed on four sides
2. Partially opened (bottom front horizontal stabilizer removed)
3. Fully opened (bottom front horizontal stabilizer and diagonal guy wires removed to provide full frontal opening for positioning around item to be stored)

The model assumed construction with the horizontal trusses connected so that they can transmit torques and moments. It was assumed that the upright columns would be deployable masts and they take only axial loads. The model was constrained to simulate one wheel off the ground for each facility configuration. This effectively supports the structure by two opposite corners allowing it to deflect as much as it can.

For the fully closed configuration, the facility deflected 2 inches. For the partially opened configuration deflection was 30 inches, and the deflection was excessive for the fully opened configuration. (A deflection of 24 inches could be tolerated.) The NASTRAN model indicates that the facility is structurally sound and should weigh 7821 lbs.

Wheel loading for the facility drive units was briefly studied. Engineering assumptions were based on extrapolations of data found in a report titled "Lunar Surface Transportation Systems conceptual Design" which was prepared by Eagle Engineering, Inc. This study estimates that four 60 inch diameter wheels 12 inches wide could support the facility while exerting a contact pressure of 1.2 psi. (The maximum that the lunar regolith can support is 1.4 psi.) The wheel would sink about 2.5 inches.

The size of the wheel would probably dictate that mounting of the drive units would have to be to the side. Additional NASTRAN runs were made and verified that this would not have much of an effect on the structure's weight. Extrapolating weight data from the Eagle report indicates that the wheel assemblies would add another 330 lbs to make the facility mobile. The total weight of a mobile facility would be about 8151 pounds.

There would be a savings in EVA time. If the facility were mobile, there would be no need to attach jacks and raise the lander, attach wheel assemblies to the lander, and attach a tow bar to the vehicle. Deleting these three activities saves about four hours in EVA time. Total EVA time to move the facility to the landing site and provide protection for the vehicle would be about nine hours and 50 minutes.

3.3 Centaur Prelaunch Procedure Analysis

For this study, the prevailing thought was that the Lunar Excursion Vehicle would use liquid oxygen and hydrogen for propellants and expander cycle engines in the 15,000 to 20,000 lbf thrust range. The only engine in the United States inventory that uses liquid hydrogen and oxygen and an expander cycle is the RL-10 engine, which is used on the Centaur. Therefore, the Centaur offers an example of the type of prelaunch procedures that might be employed with a liquid hydrogen-oxygen lunar lander. This lead to the Centaur prelaunch procedure analysis.

3.3.1 Analysis Approach

The approach was to identify each one of the procedures which are used to ready the Centaur for launch. Each procedure was then evaluated to determine the tasks performed, resources required, and time necessary to run the procedure. The applicability of each procedure to LEV/MEV operations was assessed and relevant data was recorded in a data base.

In each data base record there are nine fields as follows:

- Sequence number (Data base entry number)
- Title

- Procedure (Centaur procedure number)
- Description (Description of the procedure)
- Remarks
- Resources
- Schedule Data
- Recommendations
- Rationale

Figure 3–12 shows a sample record.

3.3.2 Analysis Results

Forty–eight test procedures were analyzed and 28 appear to have some degree of applicability to the LEV/MEV. The flow of these procedures is illustrated in Figure 3–13 Appendix E is a printout of the data base.

3.3.3 Analysis Conclusions

Analysis of the Centaur prelaunch test flow has identified several tests that must be added to the planned LEV turnaround flow, which was prepared during the original study period. One general conclusion that can be drawn is that there are many procedures which are necessary to maintain existing engine designs and that any engine which will see repeated use in a non–terrestrial environment should be designed specifically to minimize hands–on servicing.

3.4 MDSSC–KSC Support to MASE Trade Studies

During the Option 1 period of the LTFOS, Mission Analysis and System Engineering conducted several trade studies which required inputs from the functional areas of the Planetary Surface Systems Office. This section describes the support that MDSSC–KSC provided to the PSS Office in meeting these assignments.

3.4.1 Precursor Engineering Data Needs

High resolution information and detailed soil and atmospheric data are available for the Apollo lunar landing sites, and to a lesser degree for Viking martian landing sites. A higher level of detail is required for the preliminary design phase of the equipment development program and is required eight to ten years before launch.

The approach to defining the required data was to consider launch and landing operations in the lunar and martian environments and identify those parameters that must be known to ensure that adequate equipment development and program planning can

CENTAUR TEST PROCEDURE

CTP: CCLS VALIDATION

Old CTP No: CCLS-5000 **New CTP No:** CCLS-0001

Description Verifies proper operation of the computer controlled launch set interfaces (ground equipment, computer, peripherals and digital communication landlines) through the use of tenant validation programs.

Remarks Run prior to vehicle support

AC68 RESOURCES:

Ground Power [X] **Vehicle Power** [X] **Pneumatics** [X] **CCLS** [X]

Total Personnel 3 : **Engr** 1 **Tech** 1 **Insp** 1 **Safety** ____

AC68 SCHEDULE DATA:

Start Date 05/22/89 **Shifts** 5 **Serial Operation** [X] **Parallel Operation** [X]

SPECIAL TEST EQUIPMENT

PSS RECOMMENDATION: **Retain** [ ] **Reduce** [X] **Delete** [ ]

Rationale: Run a much shorter version for PSS computer system.

Figure 3-12 Sample Record of the Centaur Procedure Analysis Database

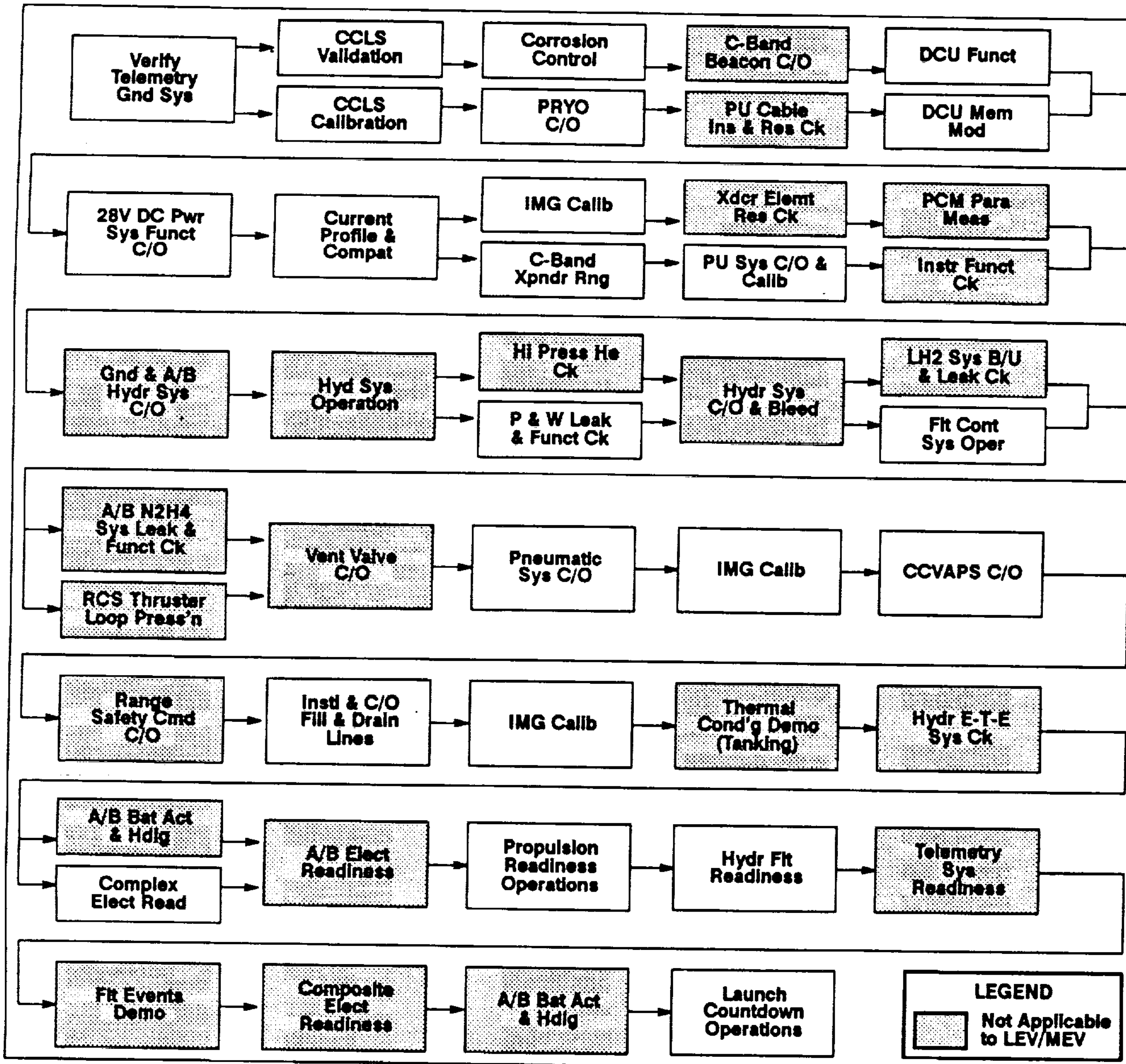

Figure 3-13 Centaur Test Flow

occur. A rationale for each required parameter and the system impacted by the parameter were also identified. A listing of the required data is contained in Appendix F.

3.4.2 Reference Architecture Option 5A Landing Assessment

The two purposes of this assignment were to 1) identify the launch and landing tasks, their durations, and the resource utilization in terms of SSE and machine time, and 2) determine which of the launch and landing tasks would be candidates for robotic applications. The outputs of this assessment were 1) a turnaround scenario for Reference Architecture Option 5A, 2) a task-duration-machine use matrix, and 3) a listing of launch and landing tasks which are candidates for robotics.

3.4.2.1 Assessment Approach. The major input to making this assessment was the Reference Architecture Description Option 5a (Option 5 with ISRU Emphasis), PSS Reference Architecture Document 90-2.

In the Reference Architecture Option 5A, the lunar base would not become permanently manned. The first human return to the moon would occur in 2004. Its man-tended crew of four would have one flight per year for one-to-twelve month tours of duty. The LEV would be stored in low lunar orbit between missions. A lunar LLOX demonstration is planned for 2011, but there will be no lunar liquid oxygen produced for export to Space Station Freedom (SSF). A LLOX production plant would become available in 2012. A direct mission to the lunar far side would be conducted in 2022. This option also features a simulated Mars mission starting in 2013 with a crew surface stay time of 600 days. Since a base crew would not be available, the launch and landing operations will have to be performed by the flight crew or the procedures automated, or done telerobotically. The profile for the missions that would be carried out under a Reference Architecture Option 5A is summarized in Appendix G.

To derive the launch and landing turnaround scenario for Option 5A several assumptions were made. These are:

- Only planetary surface launch and landing operations are considered.
- The surface base is man-tended and not permanently inhabited
- EVA operations require two surface crewmen and one Intravehicular Activity (IVA) person for support
- Cargo vehicles are expended on the planetary surface, with the exception of the first cargo vehicle (LEV-C0) which is returned to the Space Station Freedom for engineering analysis
- Expendable manned vehicles are expended in space

Based on these assumptions and the baseline turnaround flow developed under the base study period, an Option 5A Launch and Landing Turnaround Scenario for the LEV was developed. (See Appendix H.) Once the turnaround scenario for Option 5A was developed, estimates of the task durations could be made. These estimates were based on the previous estimates made for the baseline turnaround flow. Like the baseline turnaround flow, the times shown in the matrix are Earth equivalent times and do not compensate for inherent EVA inefficiencies or transmission delays associated with telerobotic operations. Also, no attempt has been made to identify the potential for parallel operations since crew size limitations may not permit them. The time estimates for the tasks associated with the manned and unmanned vehicles are contained in Appendix I.

Based on KSC experience, each launch and landing task which may require SSE was identified. (See Appendix I.) Since Reference Architecture Option 5A does not dedicate a surface crew to launch and landing operations, there are limitations as to what the crew will be available to do. When a task was found to be a candidate for robotic applications, it was identified and it is noted in Appendix I.

3.4.2.2 Results. Ten major activities, including eighty-two launch and landing tasks were identified. Fourteen types of SSE were identified that may have some application to lunar launch and landing operations under Reference Architecture Option 5A. Total time durations to accomplish this activity is slightly over 52 hours. Of these tasks, the large majority was identified as having a potential for robotics, telerobotics and/or automation applications.

3.4.2.3 Conclusions. When compared to other lunar launch and landing operation approaches, Reference Architecture Option 5A does not significantly differ in the tasks, amount of activity, and time and SSE requirements.

3.4.3 Expendable vs Reusable Vehicle Quick Look Assessment

MDSSC-KSC was requested to conduct a quick look assessment to determine which of the Reference Architecture Option 5A launch and landing tasks would be applicable to expendable and reusable vehicles.

The turnaround scenario, developed by MDSSC-KSC was used in this assessment. Generally speaking, manned vehicles were considered to be reusable. Because cargo vehicles are to be expended on the surface after a single use, they were considered to be expendable. Each vehicle was then compared to the turnaround scenario to determine the applicability of each of the launch and landing tasks identified in that scenario.

A task to vehicle applicability matrix is contained in Appendix J. Both the expendable and reusable vehicles would require tasks associated with landing and cargo removal. However, the reusable vehicle would require additional tasks associated with mating SSE interfaces, transporting crew members to habitats, post-landing inspections, thermal blanket installations, vehicle maintenance (if required), blanket removal and external closeout, launch preparations, and launch.

As the study team expected, using expendable vehicles greatly reduces the launch and landing operations. However, there are other activities that may be undertaken if expended vehicles were on the surface. These would include cannibalization of fluids and parts for reusable vehicles or other surface systems, offloading tanksets for fuel storage, and using the vehicle thermal protection for surface systems. Although these other activities are valid considerations, detailed evaluations will have to wait until the surface architecture and operations concepts are better defined.

Recognizing that there are other considerations which should be made, a recommendation to use expendable vehicles would be premature. The savings of IVA and EVA time should be traded against additional vehicles and associated vehicle processing at orbital and earth nodes.

3.5 Storable Propellant Quick Look Assessment

The objective of this quick look assessment was to determine the considerations that should be made if storable propellants were to be used instead of liquid oxygen and hydrogen.

3.5.1 Approach

The approach to this analysis was to evaluate the lunar/martian environment, compare two options for storing propellants against the environmental considerations, and identify appropriate design to criteria for SSE using KSC-STD-Z-006A,Standard for Design of Hypergolic Propellants GSE, as a reference.

It was assumed that the storable propellants must be maintained in their liquid state at 15 psia. As can be seen in Figure 3-14, at this pressure, significant

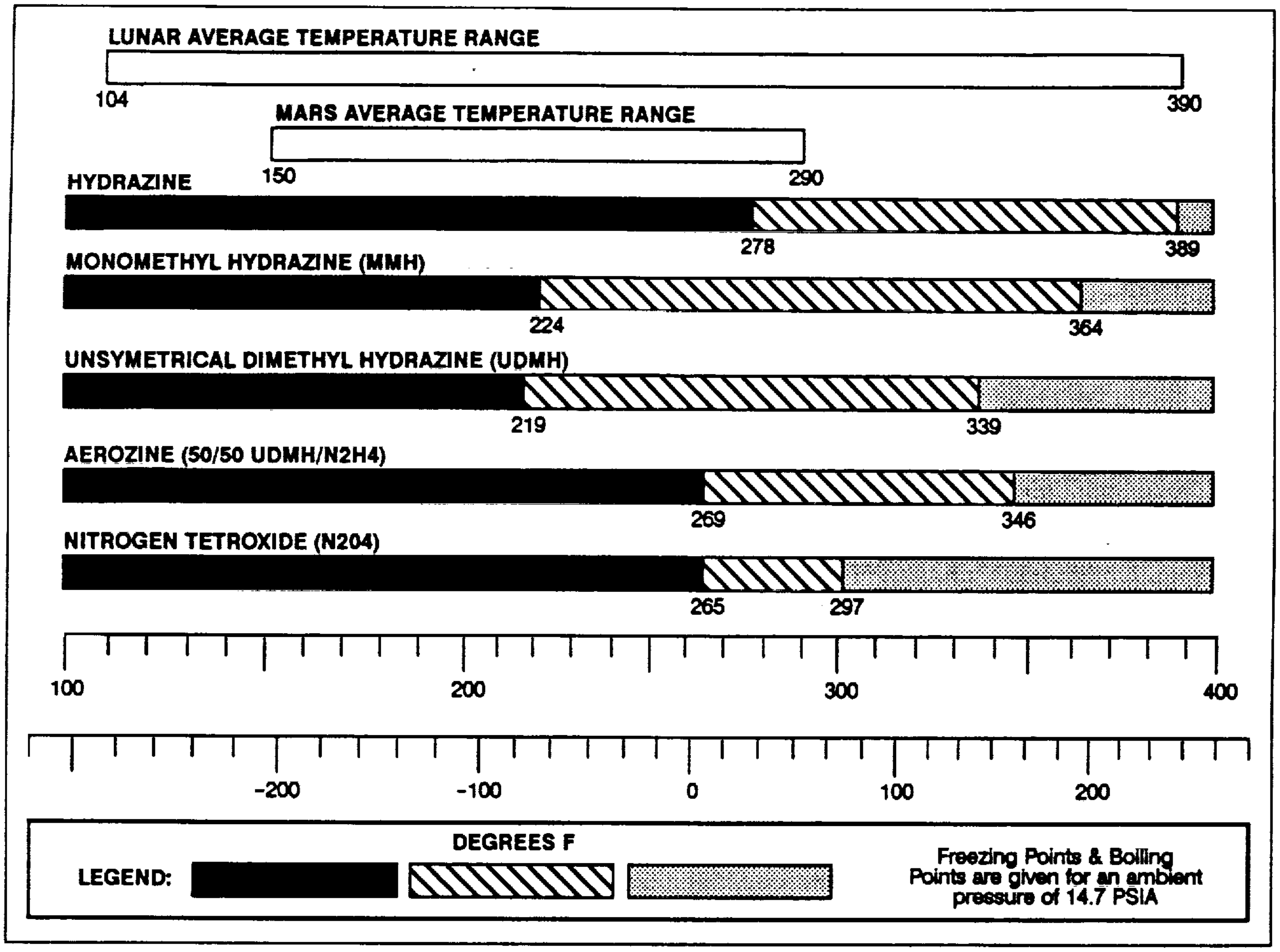

Figure 3-14 Thermal Considerations for Five Different Storable Propellants

thermal conditioning will be required by planetary SSE. Heating and cooling will be required on the moon, and heating will be required on Mars to maintain the liquid state throughout the local day-night cycle.

The capabilities of SSE are driven by which approach is taken for storing propellants. For Option 1, it was assumed that there would be no handling of storable propellants on the planetary surface, and the SSE would be required to monitor the propellant pressure and temperature, thermally condition the propellant, and capture and contain any propellant overflow due to such things as high temperature expansion or decomposition. Option 2 assumes that SSE would be used for all of Option 1 requirements and be used to transfer and scavenge propellants and top-off LEV/MEV tanks. Table 3-6 identifies the required capabilities for each of the storage options.

The design requirements for KSC hypergolic propellant GSE contained in KSC-STD-Z-0006A were then summarized and projected to the lunar and Mars surface environments to obtain a summary of PSS storage propellant SSE design requirements.

3.5.2 Results

The results of this assessment are summarized in Tables 3-7 and 3-8. Table 3-7 summarizes the requirements for equipment in general and Table 3-8 summarizes the requirements for mobile equipment.

Table 3-6 Required SSE Capabilities for Two Propellant Handling Options

REQUIRED SSE CAPABILITIES	OPTION 1	OPTION 2	
	FLIGHT VEHICLE TANKS	FLIGHT VEHICLE TANKS	AUXILIARY TANKS
Monitor Tank Pressures & Temperatures	■	■	■
Propellant Temperature Conditioning	■	■	■
Capture Overflow (Expansion or Decomposition)	■	■	■
Transfer Propellants (Auxiliary to Flight Tanks)	N/A	■	■

Table 3-7 Comparison of SSE General Design Requirements for KSC, the Moon, and Mars

	KSC	LUNAR	MARS
General			
Environment	Humid Corrosive Atmosphere 1 G	Dry, Dusty No Atmosphere 1/6 G	Dry, Dusty Minimum Atmosphere 1/3 G
Corrosion Protection	Salt Air	Dry	Dry
Design Life	20 Yrs.	30+ Yrs.	30+ Yrs.
Safety Requirements	Severe	More Severe	More Severe
Vapor Detection	Required	Doubtful	Possible
Safety Factor	"Boiler Code"	Flight Weight	Flight Weight
Operating Pressure	Earth Environment	1/6G, No Atmosphere	1/3 G, Min. Atmosphere
Quantity vs. Distance	Earth Environment	1/6 G, No Atmosphere	1/3 G, Min. Atmosphere
Fire Protection	0.5 GPM Deluge	No Area Deluge	No Area Deluge
Lightning	Protection Required	N/A	N/A
Hazard Proofing	KSC-STD-E-0002	No Atmosphere	Inert Atmosphere
Vapor Disposal	Environmental Regs.	No Purges	Purges TBD (CO2)
Connections	Within Controlled Area	No Permanent Facility	No Permanent Facility
Ecological Considerations	Earth Impact	Lunar Impact	Mars Impact
Human Engineering	SCAPE Operations	EVA Operations	EVA Operations
Reliability	KMI-1710.1	(Probably More Strict)	
Materials			
Cleaning	Per 79K11948 KSC-C-123 Level 300/300A	TBD	TBD
Pickling			
Passivation			
Welding	KSC-SPEC-Z-0003/0016	TBD (May Not Be Considered a Viable Operation)	TBD
Bonding & Grounding	KSC-STD-0012	TBD	TBD

When comparing requirements for SSE against GSE, safety requirements are one category of significant differences. These are largely related to reduced gravity, the non-availability of water, and no significant atmosphere (Mars' surface atmosphere is 95 per cent carbon dioxide and the pressure is equivalent to Earth's at 100,000 feet altitude or 1/100 the surface pressure at Earth). Other considerations include operations in EVA suits versus Self Contained Atmosphere Protective Ensemble (SCAPE) suits at KSC and the very dry conditions and low conductivity of lunar soil which may cause severe buildup of static electricity.

For mobile equipment, hose material will have to contend with intense ultraviolet radiation, near vacuum conditions, and severe contamination. Lubricants will be exposed to near vacuum and severe temperature extremes and will have to be specially formulated to preclude off-gassing of volatiles and a loss of function. The near vacuum environment will preclude the use of bubble solutions as a leak detection method. More frequent cleaning of filters may be required because of the dust environments, but these same conditions could make the task much more difficult to accomplish without introducing contamination into the system. Ullage space in pressure vessels should probably be increased because of the temperature extremes that could be encountered in the event of an Environmental Control System (ECS) failure. Because of near vacuum conditions, wind loading is of no consequence. (See Table 3-8.)

Table 3-8 Comparison of Mobile Support Equipment Design Requirements for KSC, the Moon, and Mars

	KSC	LUNAR	MARS
Mobile Equipment			
Portable Equipment	OSHA Weight Limits	1/6 G (TBD)	1/3 G (TBD)
	SCAPE Suits	EVA Suits	EVA Suits
Hoses			
Material	Polytetrafluoroethylene w/Stainless Steel Wire Wrap	UV & Vacuum Compatible	UV & Vacuum Compatible
Service Life	2 Yrs.		
Full Inspection	Prior to Use or Yearly		
Restraints	Anchors Req'd > 150 psig	(Same as KSC)	(Same as KSC)
Permeability	Through Inner Liner OK		
Valves			
Seal Material	No Metal-to-Metal Seats	TBD	TBD
Operation	Pneumatic Preffered	Electrical Preferred	
Lubricants	Krytox 240 AC	(Exposure to Lunar/Mars Atmosphere & Temperature Extremes Must Be Considered in the Design)	
	Tribolube 16, Types I & III		
	Tribolube 10, Type III		
Leak Tests	Bubble w/10% He Mixture	Mass Spectro	Mass Spectro
	Mass Spectrometer		
Filters			
Type	Tee Type Preferred	Tee Type Preferred	Tee Type Preferred
Cleaning	Periodically	TBD	TBD
Leak Test Medium	He Gas	TBD	TBD
Pressure Vessels & Supports	ASME Boiler Code	Flight Weight	Flight Weight
Corrosion Allowance	Additional 1/16" Thickness	Flight Weight	Flight Weight
Ullage	10%	(More Because, Temperature Extremes Must be Considered)	
Wind Load Allowance	2 psig	None Required	No Consequence

3.5.3 Conclusions

The results of the assessment showed that the use of storable propellants will not eliminate the need for surface operations and related SSE. If the propellants are to be maintained in a liquid state and vehicle tank pressures are to remain within a reasonable range, thermal conditioning of the LEV/MEV will be required, as a minimum.

4.0 Logistics Support

During the Option 1 Period two logistics tasks were undertaken. One task was an analysis to provide an early look at the effort required to support an LEV Servicer on the surface. The second task involved providing support to the PSS Logistics Functional Area Manager who was integrating data from all functional areas into the System Design Utility Model.

4.1 LEV Servicer Maintenance Analysis

The objective of this analysis on the LEV Servicer was two-fold. First, it was to demonstrate how early logistics involvement during the conceptual phase of a program can be effectively employed. This is very important since ninety percent of the support decisions are made prior to any hardware fabrication. The second objective, was to influence the conceptual design of the LEV servicer towards a more supportable system.

The purpose was also two-fold. First, to select or develop a comparative system that represents characteristics of the LEV servicer for projecting supportability requirements, making judgements concerning feasibility of the LEV servicer support requirements, and identifying targets for improvement. And second, to determine supportability, cost, and readiness drivers of the LEV servicer.

The approach used to conduct this analysis was a tailored MIL-STD-1388-1A "Comparative Analysis Task 203" approach. The first step was to select a candidate system for analysis; in this case the LEV servicer. Then develop, if not already available, a maintenance concept for the servicer. Next, develop ground rules and assumptions necessary to define the system and operation. Then applying the maintenance concept, develop functional flow diagrams to identify the operations and support tasks that must be performed. Then utilizing these data, select a functionally similar existing system for comparison. From the flows, compare the new systems tasks and support requirements with the existing systems tasks and support requirements and extrapolate the support requirements where necessary. Then conduct an assessment to determine the key support drivers and develop design recommendations. The detailed analysis is provided in Appendix L.

The greatest benefit of this approach is that it quickly reduces new design concepts to a quantitative measurement enabling early feasibility judgements and identification of key drivers. This allows the design function to focus on these significant drivers during the conceptual phase. This approach also enables management to focus its design efforts where there is the highest potential for improvement.

The groundrules and assumptions utilized in this study are as follows:

- The LEV servicer will operate continuously for one year
- No attempt was made to factor for the differences between SSF and lunar operating environments
- EVA overhead time (i.e., suitup, teardown, transition to work site) was not considered in the maintenance hours
- Limited life items were not included in this analysis
- The following source documents/data were utilized:
- PSS Elements Data Base for 90 Day Lunar/Mars Study (1/90)
- PSS Operations and Logistics concept, ILS Section (6/90)
- Lunar Lander Propellant Liquefaction System Study (9/89)
- External Maintenance Task Team (i.e., Fisher-Price) Report (7/90)
- Space Station Freedom Preliminary Design Data

The comparison systems selected from the Space Station Freedom are shown in Table 4-1. The SSF systems were selected because of the desire to apply the latest technology and the availability of comparison data.

After extrapolating the servicer systems support requirements from the SSFP systems, the results indicated the LEV servicer will incur approximately 46 failures per year; will require approximately 60 hours of EVA maintenance time per year, and will require 43 spares per year. The key support drivers are the reliquefaction system as well as the computer and communications systems. Together, these systems represent 81 per cent of the total servicer failures.

In addition, the analysis revealed the maintenance tasks will be conducted on hazardous systems thereby mandating special access, leak detection, and cleaning equipment.

Of note, the Fisher Price Report dated July 1990 estimates that the number of SSFP electrical power system failures will range between 93 and 153, thermal control system between 0 and 7, ECLSS between 21 and 50, and communication system failures between 127 and 262. For an overall estimate of between 241 and 472 failures per year. This coupled with the fact that no factoring for operating environment, EVA overhead, or limited life item replacement was included, tends to lead one to believe the

Table 4-1 LEV Servicer Systems Comparison

LEV SERVICER SYSTEMS	SSF SYSTEMS
Power Supply System	Power System
Thermal Rejection/ Control System	Thermal Control System
Reliquefaction System	ECLS/Thermal/ Power System
Computer/ Communication System	Data Management and Communication System

LEV Servicer estimates are low and the actual figures will end up being much higher than indicated.

The conclusions drawn from this analysis are(1) alternatives to the use of reliquefaction or an increase in the reliquefaction systems reliability are necessary to reduce the number of failures, (2) an increase in the reliquefaction systems maintainability are required to reduce the overall maintenance times, and (3) the computer and communications systems reliability needs to be increased to reduce number of failures.

4.2 Planet Surface System Logistics Modeling Support

Another area of support provided by MDSSC-KSC to the PSS Logistics Manager at Johnson Space Center was in the development of initial design cost inputs on the LEV Servicer to help test the System Design Utility (SDU) and the Equipment Design Cost Analysis (EDCAS) models. These models were being evaluated for standardization of the PSS logistics modeling effort and for use in determining logistic support impacts on system design and life cycle cost.

Each NASA functional area manager was tasked to provide the data required for the SDU model input fields. MDSSC-KSC, in support to the Launch and Landing functional area manager, used the comparative analysis on the LEV Servicer to derive the data. Comparative data were extrapolated from the Space Station Freedom preliminary design and the Spacelab program. The cost data were derived through the use of cost estimating relationships.

The results Appendix L indicated that the LEV Servicer would cost approximately nine million dollars, and once deployed, would require thirty-five hours of scheduled maintenance per year. (This is in addition to the unscheduled maintenance.) The specific inputs are provided in Appendix L. It is very important to remember these data are preliminary and were based upon a conceptual design. As the design matures, these data will also change accordingly.

5.0 Advanced Development Planning

MDSSC-KSC participated in two areas of advanced development planning. One area was to determine the types of test beds that would be required to support an advanced development program for PSS hardware. Another advanced development planning effort was undertaken to determine the requirements for technology which needed advanced development to support timely delivery of the required lunar/Mars launch and landing systems.

5.1 Test Bed Development Planning

From the PSS perspective advanced development is the transfer of technology into an approved flight project. For example, this will require the development of several subsystems such as thermal, reactor, and conversion subsystems for a power system. Concepts and operations will have to be developed through the use of models, mockups, and testbeds. Therefore, there was a need to define the types of testbeds, models and mockups that would be required for PSS developments.

The PSS Office managed this effort by requiring each of the functional areas to respond to a series of action items, each action item building upon the preceding. The first step was to develop a functional area hierarchy. For the launch and landing area the functional area system breakdown included two areas – the LEV and the SSE required to support the LEV. Each of these areas were described in general terms. Figure 5–1, shown on next page, illustrates the Launch and Landing Functional system breakdown.

Table 5-1 Test Applications of an Advanced Development Environmental Test Chamber

- Demonstrate active and passive thermal control under planetary conditions
- Demonstrate the detection/isolation/control of out-of-tolerant conditions under planetary environmental conditions
- Evaluate the use of humans, automation, robotics, and telerobotics (HART) for vehicle repair
- Test fluid transfer, conditioning, reliquefaction, and gauging techniques
- Test cryogenic storage and handling concepts

The launch and landing analysis for advanced development found that an environmental chamber could be used to support several advanced development tests and/or demonstrations. Table 5–1 lists these test applications.

Once the functional area was broken down, PSS required a description of the advanced development test beds that would be required to demonstrate or make a proof of concept for the hardware areas that required new technologies. Supporting information as to why the test bed was required was provided. After the test beds were defined, the last action item was to estimate when the test beds would be required by determining when the technology would be needed by the functional area.

The schedule for this activity is illustrated in Figure 5–2. Note that on the schedule are milestones which

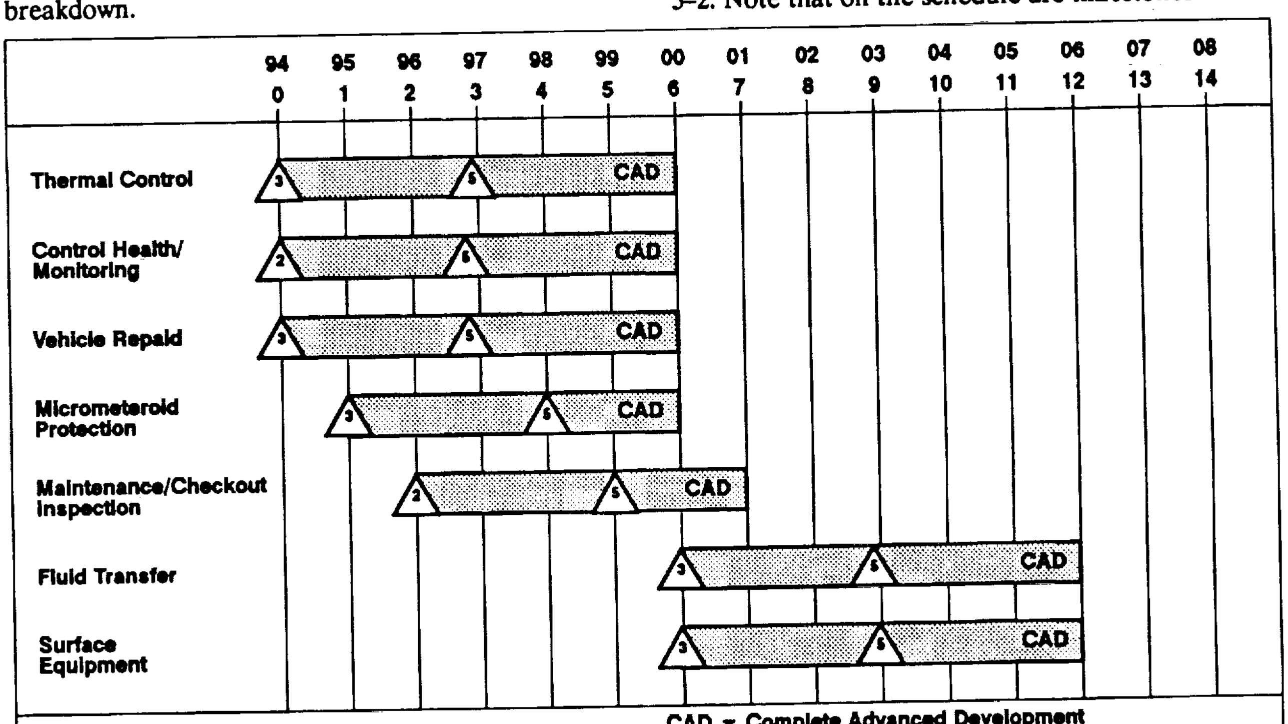

Figure 5-2 Schedule of Test Bed Activity for Launch and Landing Advanced Development

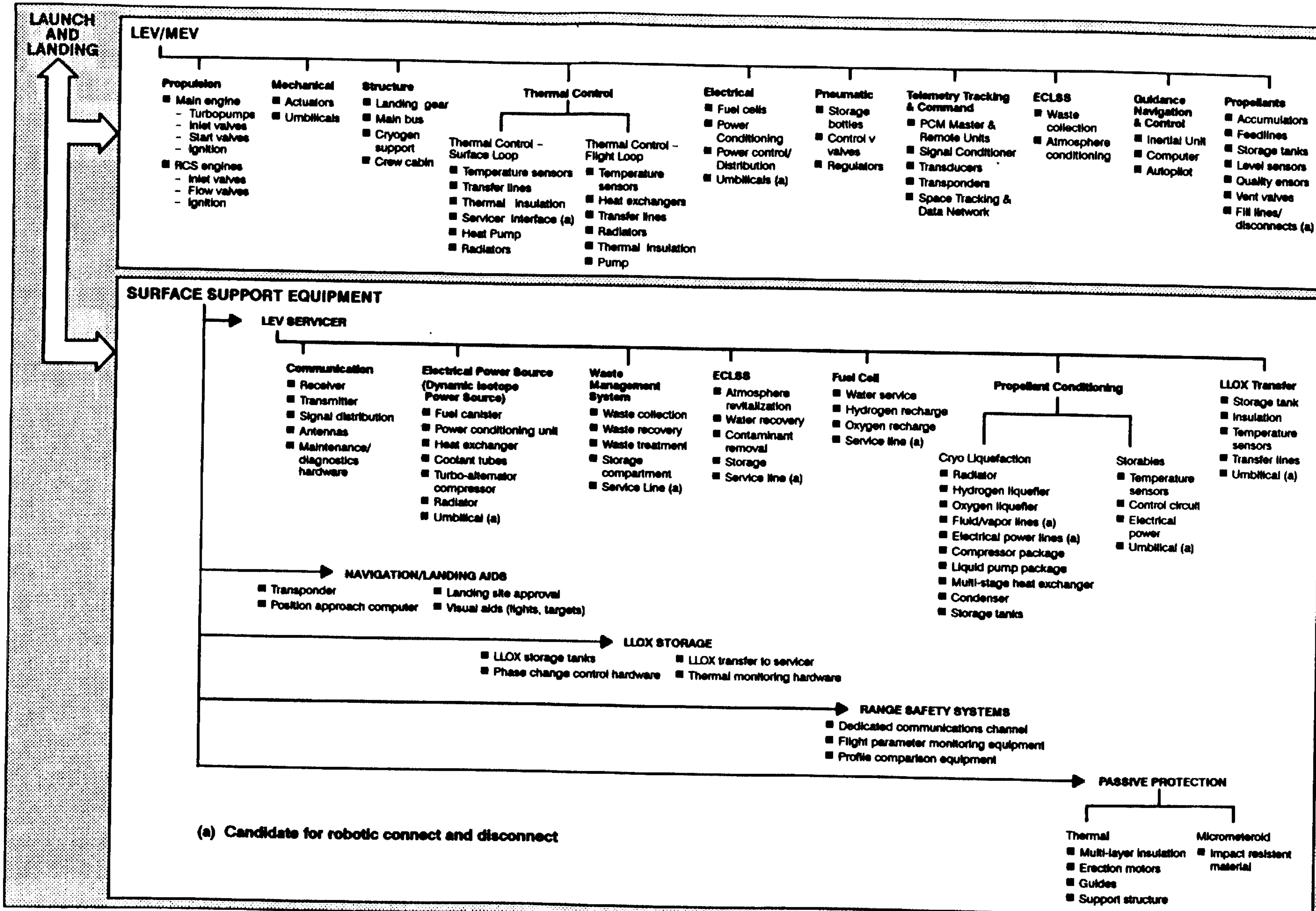

Figure 5-1 Launch and Landing Functional Area Breakdown

ample, the test activity associated with development of thermal control begins in 1994 and ends in 2000 which is six years. The technology begins with a technology readiness of 3 and ends with a technology readiness of 5. The technology readiness levels are defined in Table 5-2. Note that in the example mentioned above, the technology would progress from analytical and experimental to component and/or breadboard demonstrations.

5.2 Identification of PSS Advanced Development Tasks, Schedule and Provide Manpower Estimates

The objective of this support was to provide launch and landing inputs to the PSS Advanced Planning Effort. As a functional area of PSS, the launch and landing area was tasked with determining the requirements for technology and advanced development to support timely delivery of the required lunar/Mars launch and landing systems. Inputs required the generation of a Work Breakdown Structure (WBS) and manpower estimates.

Table 5-2 Technology Readiness Levels

READINESS	
Level 1	Basic principles observed and reported
Level 2	Technology concept and/or application formulated
Level 3	Analytical & experimental critical function/ characteristic proof of concept
Level 4	Component and/or breadboard validation in lab
Level 5	Component and/or breadboard demo in relevant environment
Level 6	System validation model demo in simulated environment
Level 7	System validation model demo in space
Level 8	Minority of drawings exist
Level 9	Roughly half of drawings exist
Level 10	Majority of drawings exist
Level 11	Predominant number of drawings exist
Level 12	Virtually 100% of drawings exist

Using the mission profile (Appendix G), a WBS was developed. The WBS is contained in Appendix M. Based on the WBS and the schedule for development of the launch and landing system, manpower estimates were was generated. The manpower estimates are contained on task description sheets which describe the WBS task. The task description sheets and the schedule are contained in Appendix N.

5.3 PSS Launch and Landing Requirements Generation

Another advanced development planning activity was the development of launch and landing requirements. The requirements were generated by reviewing the study and analysis work performed over the last year (both in support of the PSS office and NASA-KSC) and identifying those items which would become requirements for a lunar/Mars mission.

The objective was not to identify detailed design requirements (Level III or IV), but to identify broad system requirements (Level II). If this work is not undertaken there is a risk of missed opportunities to plan and execute advanced development programs in a timely manner.

Appendix O is a description of the studies and analyses that will be required to derive adequate requirements for lunar surface launch and landing operations. Each page describes the launch and landing advanced development requirement, its rationale, a description of the task associated with the development requirements (future work), and the risks associated with not pursuing the future work.

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6.0 Document and Concept Reviews

Throughout the course of the study, MDSSC-KSC was requested to provide inputs and review comments to several SEI Documents. The documents were the MASE Architecture Documents, PSS Architecture Implementation Strategy documents, and the PSS Operations and Logistics Concepts Document.

6.1 Review of the MASE Architectural Themes

During the Option 1 period of LTFOS Mission Analysis and System Engineering (MASE) developed five approaches to surface architectures. These were the Exploration Emphasis, Expanding Human Presence, Aggressive Mars, Modified Reference (later renamed as the Evolution Emphasis), and the Energy Enterprise. Of these MDSSC-KSC was tasked with reviewing the Exploration, Expanding Human Presence, and the Evolution Emphasis Architectures. Comments to these documents were submitted through the PSS Launch and Landing Functional Area Manager.

6.2 Review of the PSS Architecture Implementation Strategies

The objective of this review was to compare the PSS Implementation Strategies to the MASE Architectures. The PSS Implementation Strategies were to complement the MASE Architectures. It should be pointed out that the Research Emphasis Architecture of PSS responds to the Modified Reference (also called the Evolution Emphasis). Appendix P provides a comparison of the characterizations of each of three MASE architectures reviewed and compares the PSS Implementation Strategies to these characterizations.

6.3 Review of the Planet Surface Systems Operations and Logistics Concept Document

This document is intended to be one of a set of documents for the operations of the Planet Surface Systems (PSS) for both Lunar and Mars Exploration. The set also includes PSS Operations Plans, Requirements, Rules, Data File, Activity Ground Rules and Constraints, and Program Objectives. The purpose of this document is to capture the basic ideas which form the foundation for the subsequent documents. MDSSC-KSC was requested to provide inputs for the launch and landing section of this document and provide review comments on all of the sections. MDSSC-KSC's and NASA-KSC's comments and inputs were submitted through the PSS Launch and Landing Functional Area Manager and incorporated into the first draft copy of this document. The document was released as JSC-24824. Since this document has been released and portrays a synthesized operations concept, this report will not replicate the inputs of that document.

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7.0 Conclusions of the LTFOS Option 1 Study

The greater part of this year's study effort was spent supporting the development and definition of concepts and reference architectures, and conducting analyses and quick look assessments.

7.1 Conclusions of Analyses and Quick Look Assessments

The lunar ejecta analysis indicates that protection for a lunar base would be required either in the form of berms or paving or both. However, the results obtained from the computer-based model are preliminary and are based on soil samples taken from Apollo and damage assessments made available from samples taken from the Surveyor III spacecraft during the Apollo 12 landing. This only provides a single data point. Precursor missions may be required to obtain data which would provide a greater confidence level. This precursor requirement was provided to the MASE trade studies.

The thermal/micrometeoroid protection trade study resulted in broad conclusions. Vehicle based-protection has a mass penalty associated with it, while surface-based protection requires an increase in surface operations to provide the required protection. A surface based option which does not require assembly or disassembly tends to be the best compromise. Making such an option mobile was one of the objectives of this year's analyses. This approach tended to make the surface based option more attractive.

The analysis of the Centaur prelaunch operations procedures has identified several RL-10 engine tests that should be considered for an LEV. One general conclusion that can be drawn is that there are many procedures which are necessary to maintain existing engine designs and that any engine which will see repeated use in a non-terrestrial environment should be designed specifically to minimize hands-on servicing.

A quick look assessment to evaluate using hypergolic propellants instead of liquid hydrogen and oxygen was conducted. The assessment, which was limited to SSE considerations, indicates that the use of storable propellants will not eliminate the need for surface operations and related SSE. If the propellants are to be maintained in a liquid state and vehicle tank pressures are to remain within a reasonable range, thermal conditioning of the LEV/MEV will be required, as a minimum.

7.2 Conclusions of Logistics Support Tasks

Several conclusions can be drawn from an LEV Servicer Maintenance Analysis. The current thought is that the LEV would require reliquefaction to conserve fuel which may boil off from the vehicle. However, the analysis indicates that alternatives to the use of reliquefaction or an increase in the reliability of a reliquefaction system are necessary to reduce the number of failures. The reliquefaction system, if used, must be designed with maintainability goals in mind. Based on the analysis results, the reliquefaction system could expect as many as 19 failures per year. In a similar fashion, the computer/communications system could expect as many as 18 failures per year and must have maintainability designed into the system.

7.3 Conclusions Regarding Reference Architecture Option 5A

Evaluation of the Reference Architecture Option 5A from a launch and landing perspective indicates that the reference architecture has relatively little impact on the type or nature of launch and landing tasks that must occur. The vehicle must still be landed, safed, cargo unloaded (if applicable), serviced, maintained, readied for launch and launched.

However, the features of this reference architecture has an impact on vehicle design. The vehicle must be designed with greater autonomy in mind with regards to testing and servicing. The LEV is strictly a transportation vehicle and as such provides a service. As with any service, it must be reliable, available, and affordable.

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Appendix A

Presentation

of the

Lunar Transportation Facilities Operations Study, Option 1

Annual Report

Appendix A

Presentation of the LTFOS Option 1 Annual Report

This appendix contains the vugraphs and facing page materials provided for the study final presentation. It provides a summary, in presentation format, of the accomplishments and conclusions drawn during the past year.

Annual Review

Lunar Transportation, Facilities and Operations Study

May 1991

Prepared for

Office of Advanced Systems and Technology
NASA Kennedy Space Center

by

McDonnell Douglas Space Systems Company
Kennedy Space Center

NASA Contract Number: NAS10-11567

MDSSC-KSC

LTFOS Annual Review
Launch & Landing Functional Area
Agenda

This chart shows the agenda for today's presentation. The first item to be covered is a summary of activities from February 1990 through March 1991. This will be followed by a review of the technical results of the of the studies and analyses performed during the period.

LTFOS Annual Review
Launch & Landing Functional Area
Agenda

- ❑ Summary of Activities (2/90 - 3/91)
- ❑ Technical Results
  - Level III & IV Requirements
  - Integrated Project Plan
  - Element Description & Sizing Results
  - Results of Internal Studies & Analyses
  - Advanced Development Plan
  - Logistics Modeling Support

L&L Functional Area
Summary of Activities Feb 1990 - March 1991

The greater part of this year's study effort was spent supporting the development and definition of concepts and reference architectures, and conducting analyses and quick look assessments.

Precursor engineering data needs. - The purpose of this effort was to define those data required prior to conducting launch and landing operations in the lunar and martian environments and to identify those parameters that must be known to ensure that adequate equipment development and program planning can occur. A rationale for each required parameter and the system impacted by the parameter were also identified.

Technology needs data base. - We reviewed this data base and provided inputs related to launch and landing operations.

Advanced development. - For this task we identified initial test beds, reviewed mission profiles and factors, developed a WBS, developed a schedule, described tasks and estimated costs for LEV Servicer and MEV Servicer advanced development programs. This was one of the major efforts of this period and it will be discussed in greater detail later in the presentation.

PSS Operations and Logistics Concept Document. - This document was reviewed and L&L comments were provided in a redlined copy of the document. Additional inputs, , such as a crew emergency rescue operations concept, were provided.

MASE trade studies. - We participated in the MASE trade studies and provided inputs related to parametric sizing, conducted an analysis of expendable versus reusable vehicles with regard to the L&L operations required for each type of vehicle and identified candidate tasks for automation to reduce crew workload. We also examined balanced payloads.

L&L Function Area
Summary of Activities Feb 1990 - March 1991

- Provided reviews, comments & data in the following areas:
  - Precursor engineering data needs
  - Technology needs data base
  - Advanced development
    - Initial candidates for test beds
    - Mission profile & factors
    - Work breakdown structure (WBS)
    - Schedules
    - Cost estimates
    - Task description sheets
  - L&L input to PSS Operations & Logistics Concept Document
    - Crew emergency rescue operations concept
  - PSS communications questionnaire
  - MASE trade studies
    - Parametric sizing
    - Expendable vs. reusable vehicles
    - Balanced payloads
    - Workload/crew size/ automation

L&L Summary (Continued)

Lunar Mars Exploration Program Office (LMEPO) architectures strategies and white papers were reviewed and compared with the PSS implementation strategies and white papers. Inputs were provided related to L&L operations and inconsistencies between the LMEPO architectures strategies and the PSS implementation strategies were identified.

Ten technologies were identified as top candidates for the PSS technology project ranking effort.

In the logistics area we provided inputs to the Integrated Logistics Support Document, the Element Designer Questionnaire for the LEV Servicer, and supported the development of the System Design Utility Model.

Preliminary SRM&QA areas which must be addressed were identified.

Inputs were provided to the Activity Based Cost Analysis conducted by KDT Industries.

Data was provided for advanced development/exploration technology budget summary.

The engineering environments "design -to" database was reviewed and comments provided.

L&L Summary (Continued)

- LMEPO architecture strategies & white papers
  - -- Exploration
  - -- Expanded human Presence
  - -- Evolution
- PSS implementation strategies & white papers
  - -- Exploration
  - -- Expanded human Presence
  - -- Evolution (Research)
  - -- Human Expedition
- PSS technology project ranking (Top ten technology candidates)
- Logistics
  - -- Integrated Logistics Support Document
  - -- Element Designer Questionnaire for LEV Servicer
  - -- System Design Utility Model
- SRM&QA
  - -- Preliminary SRM&QA areas to be addressed
- Activity based cost analysis (KDT Industries)
- Advanced development/exploration technology budget summary
- Engineering environments "design-to" database

L&L Summary (Continued)

Analyses conducted during this period included LEV Servicer maintenance analysis, an analysis of the design requirements for storable propellant surface support equipment, and an applicability analysis of Centaur processing procedures to the LEV/MEV operations.

Trades conducted included a continuation of the lunar ejecta analysis and a re-examination of the thermal/micrometeoroid protection approaches for LEVs on the lunar surface.

Also, during this period the final report for the basic Lunar Transportation, Facilities and Operations Study was published.

L&L Summary (Continued)

- ❑ Conducted analyses & studies for the following:
  - LEV Servicer maintenance analysis
  - Trade studies
    - Lunar ejecta analysis
    - Thermal/micrometeoroid protection for LEVs on lunar surface
  - Storable propellant surface support equipment design requirements
  - Centaur processing procedures & applicability to the LEV/MEV
- ❑ MDSSC peculiar:
  - Published final report for basic Lunar Transportation, Facilities and Operations Study (Performed for KSC under contract NAS 10-11567)

L&L Technical Results

This chart lists the subjects to be covered during this portion of the presentation. The first topic is the Level III & IV requirements.

L&L Technical Results

- Technical Results
  - Level III & IV Requirements
  - Integrated Project Plan
  - Element Description & Sizing Results
  - Results of Internal Studies & Analyses
  - Advanced Development Plan
  - Logistics Modeling Support
  - Conclusions

Level III & IV Requirements Input
L&L Requirements

This chart lists the Level III & IV requirements for launch and landing. In all, sixteen requirements were developed which ranged from from a general requirement for the LEV to more specific requirements such as the requirement for a command and control telemetry link.

It should be pointed out that the requirement for a Data Management and Communications System, Command Control System, and a Command and Control Link may appear to be redundant requirements. However, these are three independent requirements.

The Data Management and Communications System provides for the monitoring and testing of the LEV and the LEV Servicer systems built into the LEV and the LEV Servicer.

The Command and Control System is located in a habitable area on the lunar surface and provides an automated control capability to conduct function tests, determine the status of all systems, and monitor system trends for the remote monitoring and testing of the LEV and its surface support equipment.

To reduce the work load of the lunar crew during manned missions a command and control telemetry link to/from earth will be required to conduct function tests, determine the status of all systems, and monitor system trends for the remote monitoring and testing of the LEV and its surface support equipment.

Level III & IV Requirements Input
L&L Requirements

- General LEV Requirement
- Engine Blast Protection
- Thermal/Micrometeoroid Protection
- Cryogenic Propellant Management
- Thermal Control
- Data Management & Communications
- Electrical Power
- Navigation Aids
- Access Equipment
- Auxiliary Lighting Equipment
- Waste Management System
- Fuel Cell Service System
- Command & Control System
- Command & Control Telemetry Link
- Lunar LOX Pallet
- ECLSS Service System

General Requirement for LEV

This is an example of the format that PSS requested for use in presenting requirements.

At the request of PSS, each requirement was prepared in a presentation format that provided a brief description of the requirement, the rationale for the requirement, future work needed and risk to the overall program associated with not performing the future work. Once requirements have been selected from the candidates submitted they will be included in a requirements document.

A complete set of requirements provided to PSS is contained in Appendix O of the Annual Report.

General Requirement for LEV

REQUIREMENT:

Provide the capability to protect, maintain, and service the LEV and LEV surface support equipment while on the lunar surface.

RATIONALE:

The LEV, as described in the LTFOS Final Report, April 1990, will be designed to be self sufficient for manned lunar missions with lunar surface stays lasting up to 30 days. However, for longer manned missions the LEV will require thermal protection from solar radiation; protection from micrometeoroids; data management and communication capability; and cryogenic propellant (fuel/oxidizer) management to conserve LH2 and LOX.

FUTURE WORK:

Conceptual LEV designs must be continually reviewed and surface support requirements assessed against capabilities of L&L surface support equipment as described in the PSS Element Data Base (1/12/90).

RISKS:

Risk not identifying major design drivers and missing opportunities to plan and execute advanced development programs in a timely manner.

L&L Technical Results

The next topic for discussion is the Integrated Project Plan.

L&L Technical Results

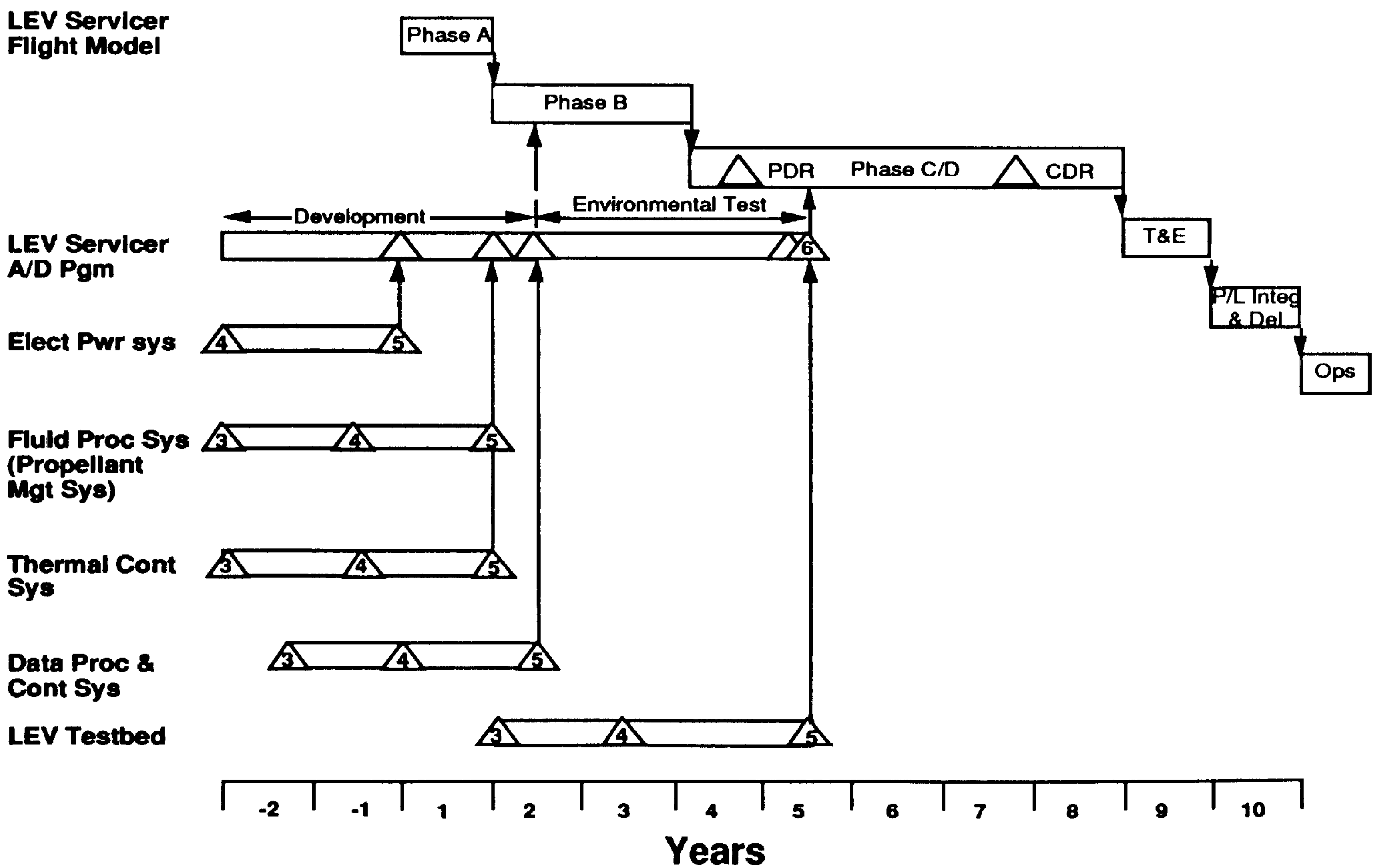
- Technical Results
  - Level III & IV Requirements
  - Integrated Project Plan
  - Element Description & Sizing Results
  - Results of Internal Studies & Analyses
  - Advanced Development Plan
  - Logistics Modeling Support
  - Conclusions

LEV Servicer

The project plan for the development of the LEV Servicer is shown on this chart. The LEV Servicer flight hardware DDT&E program developed by PSS starts with a one year Phase A effort, followed by a two year Phase B, a five year Phase C/D, one year of test and evaluation, and one year for payload integration and preparations for launch.

The advanced development phase will start two years before Phase A, and continue through the early part of Phase C/D. The object of the advanced development program is to build a model containing the necessary systems to meet the LEV support requirements. Each servicer system will be tested individually and then in combination in a simulated lunar environment. Data obtained during the advanced development phase will be fed into flight hardware development during Phase B and Phase C/D.

LEV Servicer

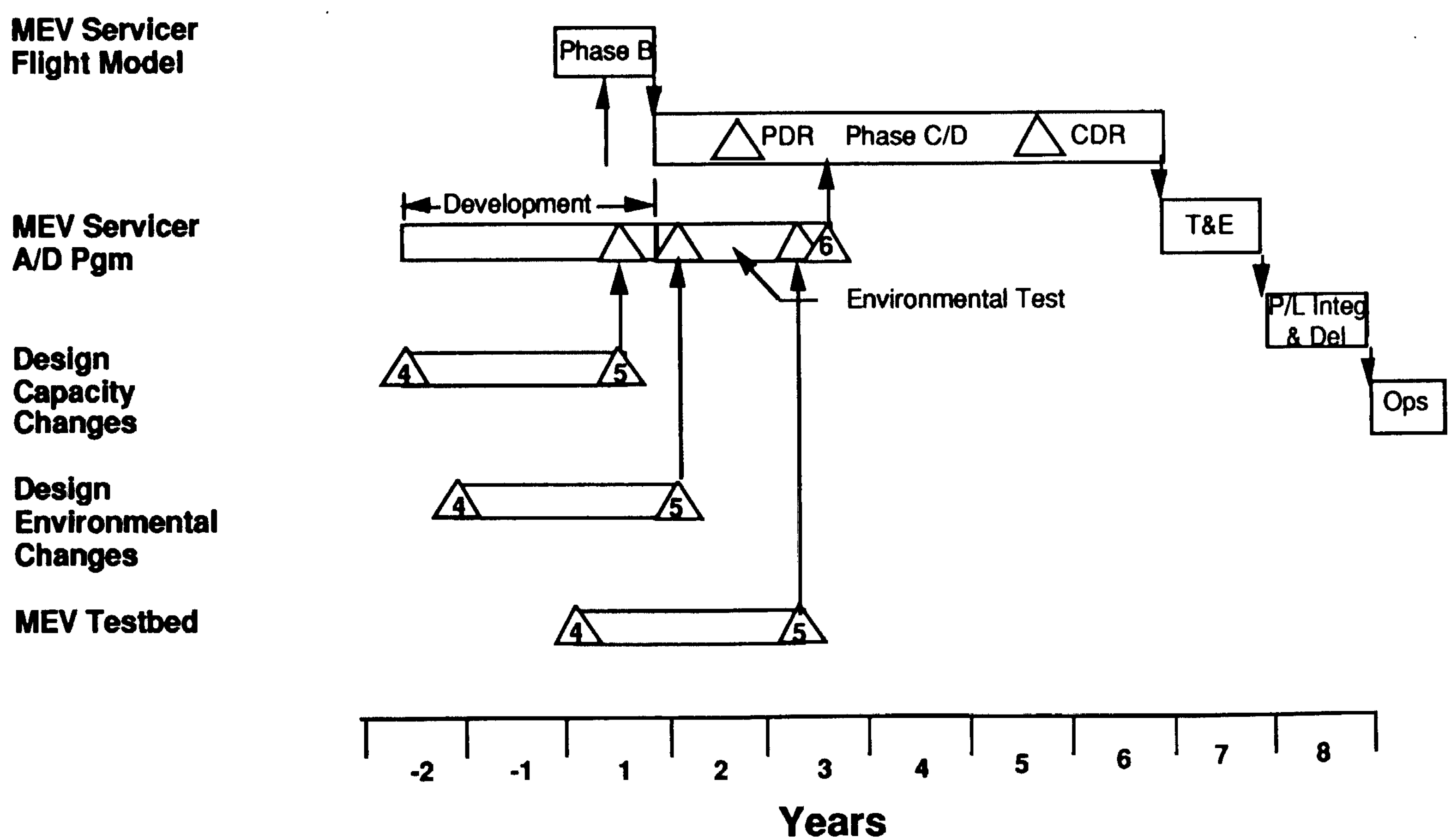


MEV Servicer

The project plan for the development of the MEV Servicer is shown on this chart. The MEV Servicer flight hardware DDT&E program developed by PSS starts with a one year Phase B effort, followed by a five year Phase C/D, one year of test and evaluation, and one year for payload integration and preparations for launch.

The advanced development phase will start one and one-half years before Phase B, and continue through the early part of Phase C/D. The object of the advanced development program is to build model with the necessary design changes to the LEV design to meet the MEV support requirements. Each servicer system will be tested individually and then in combination, in a simulated martian environment. Data obtained during the advanced development phase will be fed into flight hardware development during Phase B and Phase C/D.

MEV Servicer



L&L Technical Results

The next topic for discussion is the element description and sizing.

L&L Technical Results

- Technical Results
  - Level III & IV Requirements
  - Integrated Project Plan
  - Element Description & Sizing Results
  - Results of Internal Studies & Analyses
  - Advanced Development Plan
  - Logistics Modeling Support
  - Conclusions

LEV Servicer

The LEV Servicer description and sizing is shown on this chart. This data is included in the PSS Elements Description Data Base. The data base was was created during the basic contract period and was updated during the Option I period.

LEV Servicer

Id: lsl   Name: Lunar Excursion Vehcle Servicer

Mass	1.80 t	Day Power	9.00 kW	Volume	20.00 cu m
Supply	0.00 t/yr	Night Power	9.00 kW	Height	3.00 m
Ops Life	10.00 yr	Duty Cycle	1.00	Weight	3.00 m
				Length	2.50 m

Capabilities

Provides service for a lunar lander that stays more than 30 days on the surface.
Provides power at 9 kW avg, 12 kW peak.
Heat rejection at 3 kW avg, 5kW peak.
Reliquefacton to limit loss to < 250 kg per month.
Capability to monitor and/or inspect critical LEV subsystems.

Interfaces

Provides own power from DIPS.
Transport to LEV.
TNIM
LEV interface

Subsystems

Structure.
Power: Dynamic Isotope Power System (DIPS)
Data Management & Communication.
Liquefaction: Heyland cycle machinery.
LLOX Transfer.
Thermal Control: heat pump with unshaded composite inflatable radiators
Thermal blanket and tent structure.

Options

Individual carts for different servicers.
Integrated systems on one cart.
Full servicing from central unit.

References

e/s db

MEV Servicer

The MEV Servicer description and sizing is shown on this chart. This data is included in the PSS Elements Description Data Base. The data base was was created during the basic contract period and was updated during the Option I period.

MEV Servicer

Id	lsm		Name	Martian Excursion Vehcle Servicer				
Mass	2.00	t	Day Power	9.00	kW	Volume	20.00	cu m
Supply	0.00	t/yr	Night Power	9.00	kW	Height		m
Ops Life	10.00	yr	Duty Cycle	1.00		Weight		m
						Length		m

Capabilities

Provides service for a Martian lander that stays more than 30 days on the surface.
Provides power at 9 kW avg, 12 kW peak.
Heat rejection at 3 kW avg, 5kW peak.
Reliquefacton to limit loss to < 4% per month.
Capability to monitor and/or inspect critical MEV subsystems.

Interfaces

Provides own power from advanced DIPS.
Transport to MEV.
TNIM
MEV Interface

Subsystems

Structure
Power:
Data Management & Communications
Liquefaction: Heyland cycle machinery.
MLOX Transfer.
Thermal Control: heat pump with unshaded composite inflatable radiators
Thermal blanket and tent structure.

Options

Individual carts for different servicers.
Integrated systems on one cart.
Full servicing from central unit.

References

e/s db

L&L Technical Results

The next topic for discussion is the results of internal studies and analysis.

L&L Technical Results

- Technical Results
  - Level III & IV Requirements
  - Integrated Project Plan
  - Element Description & Sizing Results
  - Results of Internal Studies & Analyses
  - Advanced Development Plan
  - Logistics Modeling Support
  - Conclusions

Results of Internal Studies & Analyses

The LEV Servicer maintenance analysis was undertaken during the Option I period.

Results of Internal Studies & Analyses

- ❑ LEV Servicer maintenance analysis
- ❑ Lunar ejecta analysis
- ❑ Thermal/Micrometeoroid protection trade study
- ❑ Applicability of Centaur processing tasks to LEV/MEV launch operations

Goals

During the Option 1 period of LTFOS, a logistics analysis effort was initiated. The top level goal of logistics in the conceptual phase is to ensure front-end consideration of the impacts integrated logistics support will have on the overall PSS program. The specific goal of the LEV Servicer maintenance analysis was to influence and impact PSS LEV Servicer design so reliability, maintainability, and supportability are optimized to achieve the program's operational goals.

Goals

- ❑ Ensure logistics considerations are addressed in the early phases of the program

- ❑ To influence and impact PSS designs to optimize support in achieving program operational goals

Maintenance Analysis Approach

MDSSC-KSC's approach to conducting a front-end analysis was to select a candidate system for study, in this case the LEV Servicer. The final product was the derivation of LEV Servicer maintenance support requirements and recommendations. The analysis was accomplished in the sequence indicated on the facing chart.

Maintenance Analysis Approach

- Identify candidate for analysis (i.e., LEV Servicer)
- Develop ground rules and assumptions
- Develop maintenance concept
- Select comparison system
- Develop functional flow diagrams
- Conduct systems comparison
- Extrapolate maintenance support requirements
- Develop recommendations

LEV General Description

This chart summarizes the purpose, general parameters and lists the major subsystems of the LEV Servicer.

LEV Servicer General Description

- ❑ Purpose is to provide power, thermal control, and reliquefaction of oxygen (O2) and hydrogen (H2) propellants for lunar landers as needed to maintain them in an operational state.
- ❑ Weight 1.8 metric tons (4,032 lbs)
- ❑ Dimensions: height - 3.0 meters (10 ft), length - 2.5 meters (8 ft), depth - 3.0 meters (10 ft).
- ❑ Major systems:
  - Power Supply Unit
  - Thermal Rejection and Control System
  - Reliquefaction Unit
  - Computer and Communications System

Comparison System Selected

The comparison systems selected from the Space Station Freedom are shown this this chart. These systems were selected because of the desire to apply the latest technology and because of the availability of comparison data.

Comparison System Selection

LEV Servicer	SSFP
❑ Power Supply System	❑ Power System
❑ Thermal Rejection/ Control System	❑ Thermal Control System
❑ Reliquefaction System	❑ ECLSS/Thermal/Power System
❑ Computer/Comm System	❑ Data Mgmt and Comm Systems

LEV Servicer Maintenance Summary

After extrapolating the servicer's systems support requirements from the SSFP systems, the results indicated the LEV servicer will incur approximately 46 failures per year; will require approximately 60 hours of EVA maintenance time per year, and will require 43 spares per year. The key support drivers are the reliquefaction system as well as the computer and communications systems. Together, these systems represent 81 per cent of the total servicer failures.

In addition, the analysis revealed the maintenance tasks will be conducted on hazardous systems thereby mandating special access, leak detection, an cleaning equipment.

LEV Servicer Maintenance Support Summary

- ❑ Estimated equipment failures total per year = 45.73
  - Reliquefaction and Computer/Communications Systems = 81 % of total
- ❑ EVA maintenance hours total per year = 59.87
  - This does not include factoring for lunar surface nor does it include EVA overhead time (i.e., setup, teardown, and translation Times)
- ❑ Estimated spares required total per year = 43
- ❑ EVA maintenance tasks require special access, leak detection, and cleaning equipment
- ❑ EVA maintenance required on hazardous propellant systems
- ❑ Increased number of spares and special equipment dictate additional storage facilities

LEV Servicer Maintenance Conclusions

The conclusions drawn from this analysis are (1) alternatives to the use of reliquefaction or an increase in the reliquefaction system's reliability is necessary to reduce the number of failures, (2) an increase in the maintainability of the reliquefaction system is required to reduce the overall maintenance times, and (3) the computer and communications systems' reliability needs to be increased to reduce the number of failures.

LEV Servicer Maintenance Conclusions

- Explore alternatives or increase reliability of the Reliquefaction System
- Increase Reliquefaction System maintainability
- Increase both reliability and maintainability of the Computer and Communications System

LEV Servicer Maintenance Recommendations

Recommendations for future maintenance analyses are listed in the facing chart.

LEV Servicer Maintenance Recommendations

- ❑ Continue to utilize comparative analysis during Phase A/B and apply to other PSS system
- ❑ Select and employ an automated tool to conducting of life cycle cost analyses
- ❑ Commence life cycle cost analyses
- ❑ As program progresses, expand analyses to provide a greater level of detail

Results of Internal Studies & Analyses

The lunar ejecta analysis was continued during the Option I period.

Results of Internal Studies & Analyses

- ❑ LEV Servicer maintenance analysis
- ❑ Lunar ejecta analysis
- ❑ Thermal/Micrometeoroid protection trade study
- ❑ Applicability of Centaur processing tasks to LEV/MEV launch operations

Lunar Ejecta Analysis
Small Particles

Two basic types of damage from ejecta were addressed, sandblasting caused by small particles (i.e., 1 mm or less in diameter), and dents or punctures caused by large particle impact (particles greater than 1 mm in diameter).

This chart summarizes the results obtained for small particles during the analysis.

Lunar Ejecta Analysis
Small Particles

- ❑ Small particle trajectories (1mm and Finer)
  - Small particles will pass above and beyond habitat and ISRU areas, except particles propelled at low elevation angles (0.25 - 1.0 degrees)*
  - Small particle impact velocities vary between 329 - 966 m/s for 15K - 80K thrust values* *
- ❑ Small particles disperse rapidly with range and approach zero at 4 kilometers even with the most powerful engine being considered
- ❑ Aluminum pitting drops below 10% at 1 kilometer
- ❑ Glass pitting drops below 10% at 2.4 kilometers

* 150 μm Particles

** The muzzle velocity of 12 gauge shotgun pellets (#6 shot) are approximately 394 m/s

Lunar Ejecta Analysis
Large Particles

This chart summarizes the results obtained for large particles during the analysis.

Lunar Ejecta Analysis
Large Particles

- ❑ A vehicle with a total thrust of 80,000 lbf will propel
  - 1 mm particles to an impact velocity of 370 m/s
  - 10 mm particles to an impact velocity of 117 m/s
- ❑ Assuming a maximum elevation angle of 5 degrees
  - 1 mm particles could be propelled as far as 15 kilometers
  - 10 mm particles could be propelled as far as 1.5 kilometers

Lunar Ejecta Analysis
Berm Protection

Berms will provide protection against small particle sandblast damage and large particle impact damage for low profile equipment (1.5 m) in a zone between 75 and 375 m from the pad.

Berms will not provide protection against large particle damage in a danger zone between 375 m to 15 km. However, the probability of large particle damage is relatively low due to low particle density and low impact velocity.

Lunar Ejecta Analysis
Berm Protection

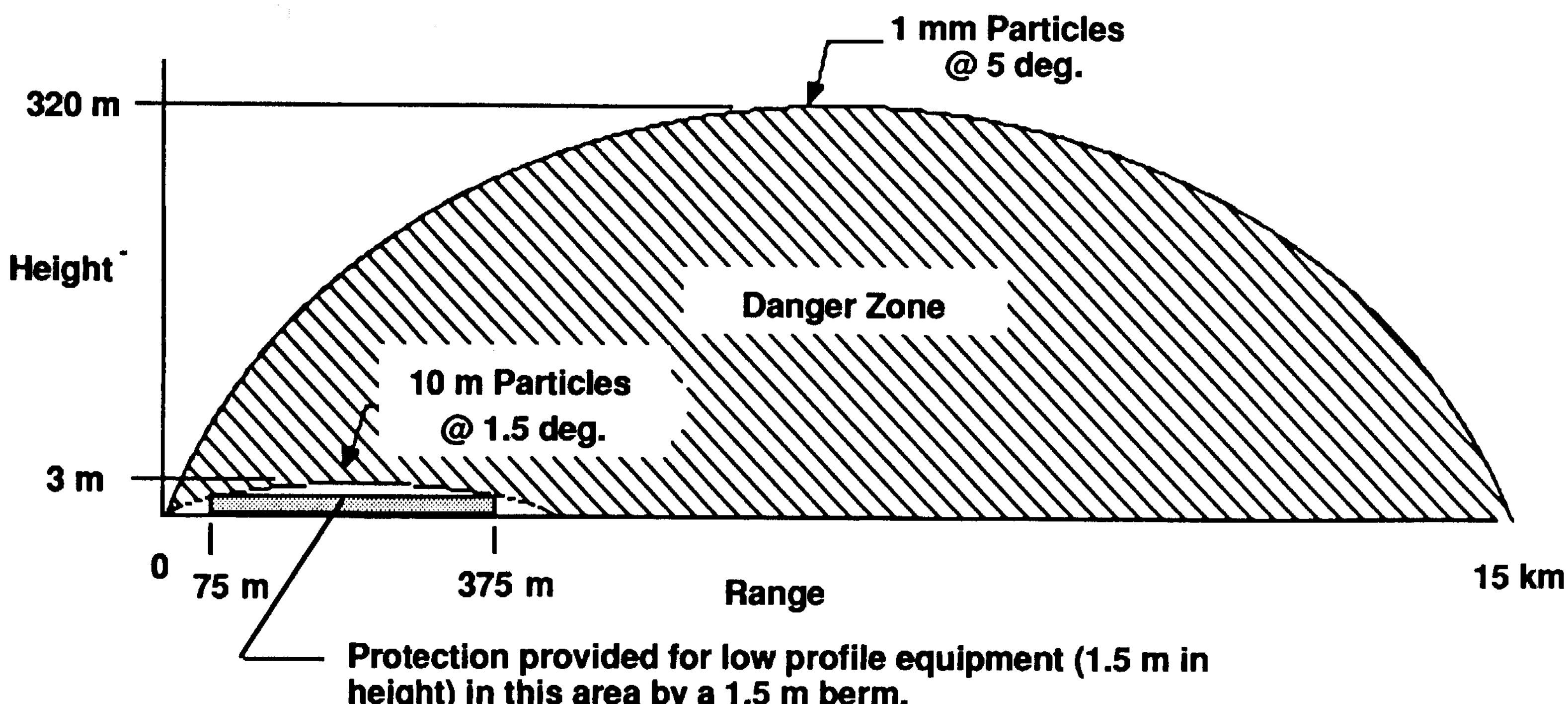
- ❑ Berms will provide protection against
  - Small particle sandblast damage
  - Large particle impact damage for low profile equipment (1.5 m) in a zone between 75 and 375 m from the pad
- ❑ Berms will not provide protection against
  - Large particle damage in a danger zone between 375 m to 15 km
- ❑ Probability of large particle damage is low due to
  - Low large particle density
  - Low impact velocity

Lunar Ejecta Analysis
Large Particle Danger Zone

This chart illustrates a danger zone created by large particles where berms will not provide protection.

Lunar Ejecta Analysis
Large Particle Danger Zone

- ❑ Large particle trajectories (1 mm to 10 mm)



Lunar Ejecta Analysis
Paper Search

The lunar ejecta analysis indicates that protection for a lunar base would be required either in the form of berms and/or paving. However, the results obtained from the computer-based model are preliminary and are based on soil samples taken from Apollo II and damage assessments made available from samples taken from the Surveyor III spacecraft during the Apollo 12 landing. This only provides a single data point for calibrating and validating the model. In an attempt to find additional reference points for the model validation, or any other significant information, three NASA Technical Notes, listed below, were reviewed.

- NASA TN D-2633, Interaction of Highly Underexpanded Jets with Simulated Lunar Surfaces, LeRC, December 1961
- NASA TN D-1095, Experimental Investigation of Jet Impingement on Surfaces of Fine Particles in a Vacuum, LaRC, February 1965
- NASA TN D-5895, Experimental Investigation of Close Range Rocket Exhaust Impingement on Surfaces of Fine Particles in a Vacuum, LaRC, July 1970

Lunar Ejecta Analysis
Paper Search

- Reviewed three NASA Technical Notes
  - NASA TN D-2633, Interaction of Highly Underexpanded Jets with Simulated Lunar Surfaces, LeRC, December 1961
  - NASA TN D-1095, Experimental Investigation of Jet Impingement on Surfaces of Fine Particles in a Vacuum, LaRC, February 1965
  - NASA TN D-5895, Experimental Investigation of Close Range Rocket Exhaust Impingement on Surfaces of Fine Particles in a Vacuum, LaRC, July 1970
- Purpose of these experiments
  - Investigate erosion effects of rocket exhaust impingement on the lunar surface during the Apollo lunar module landing
- Purpose of the review
  - Find additional reference points for model validation
  - Find any other significant information

C-2

Lunar Ejecta Analysis
TN D-1095

This paper documents testing which used a supersonic wind tunnel (Mo = 3.5 at 300 psia) to achieve test pressures of approximately one psia on a 40 inch diameter base. Cold air at 2,000 psia was exhausted through the sting to various engine nozzle configurations with data collected at various distances from, and approach conditions to, the simulated lunar surface (a flat plate).

Throat and exit diameters were 0.5 and 2.5 inches, respectively for a 25:1 area ratio. A cluster of four nozzles with mass flow equivalent to a single nozzle (throat diameters of 0.25 inches each) was also tested.

Base pressures were measured on the thrust centerline and radially along four axes at four throat diameter (2 inch) intervals. Schlieren photographs (shadow graphs) were also taken.

The results of the test show that surface pressure distributions were dependent on: nozzle area ratio (exit area/throat area, nozzle contour (some contours caused annular surface pressure variations, which resulted from shock waves that originated within the nozzle), and height from the surface.

Maximum pressure increased from 0.4 percent of chamber pressure at 40 throat diameters (8 exit diameters) to 6 percent of chamber pressure at 13 throat diameters (3.6 exit diameters). High surface pressure was generally contained within 16 throat diameters (3.2 exit diameters).

Lunar Ejecta Analysis
TN D-1095

- ❑ Observed effects of cold-gas jets on simulated lunar surfaces (hard and soft) at various nozzle heights, nozzle configurations and pressure ratios.
- ❑ Results significant to the ejecta analysis:
  - Surface pressure distributions are a function of
    - Nozzle area ratio
    - Nozzle contour
    - Nozzle height
  - Pressure detected (0.4% of Chamber Pressure) at a height of 8 exit diameters
  - Pressure increased (6% Pc) at a height of 3.6 exit diameters
  - Clustered nozzles produced shock waves which caused annular pressure variations
  - Erosion craters had central peaks

Lunar Ejecta Analysis
TN D-2633

The test on which the paper was based measured the time history of crater growth and near field visibility as a result of impingement from a single supersonic (Mach 3.36) cold gas nozzle perpendicular to a dust bed located in a 60 foot diameter vacuum sphere (starting at 0.3 millitorr, which increased after two tests to 1.0 millitorr).

Visibility through one side and both sides of the debris cloud was measured using collimated light beams and photo cells.

Soil density versus time was recorded by X-ray exposure of film rotating past a slot beneath the soil bed.

High-speed motion picture and sequence camera coverage were also used.

The experiment data confirmed the existence of an incipient erosion boundary based on particle size.

Craters formed at a lower nozzle height tended to have a greater depth-to-diameter ratio than those formed at a greater nozzle height.

Erosion rate increased by a factor of 120 when nozzle height was decreased from 10 to 5 nozzle radii.

Outside crater walls may be at angles greater than the static angle of repose of the material, being supported by the exhaust pressure field, with inward collapse occurring when the nozzle flow ceases. With larger particles, which permitted the soil to "breathe," this collapse was a slumping action. However, with one micron particles, it appeared that gas, forced into the dust in the stagnation region, expended explosively at flow cutoff, destroying the crater structure.

Lunar Ejecta Analysis
TN D-2633

- Measured the time history of crater growth and near field visibility resulting from a cold-gas nozzle perpendicular to simulated lunar surfaces.
- Results significant to the ejecta analysis:
  - Surface erosion was a function of
    - Particle size and compaction
    - Nozzle height
  - Lower nozzles produced
    - Deeper craters (larger depth-to-diameter ratios)
  - Erosion started in a annular ring
    - Expanded inward
    - Expanded outward
  - Cohesion forces
    - Extremely important effect on fine particle behavior
    - Little information on lunar soil cohesion available at the time

Lunar Ejecta Analysis
TN D-2633 (Continued)

Information from NASA TN D-2633, indicates that the jet will most likely exit the engine in an under-expanded condition, and will expand and plume outward at a very large angle with respect to the jet axis as defined by the "jet boundary" as illustrated in this chart

Just above the surface, a bowl-shaped "normal shock wave" will be formed, which will turn the flow radially outward, as indicated by the "streamline."

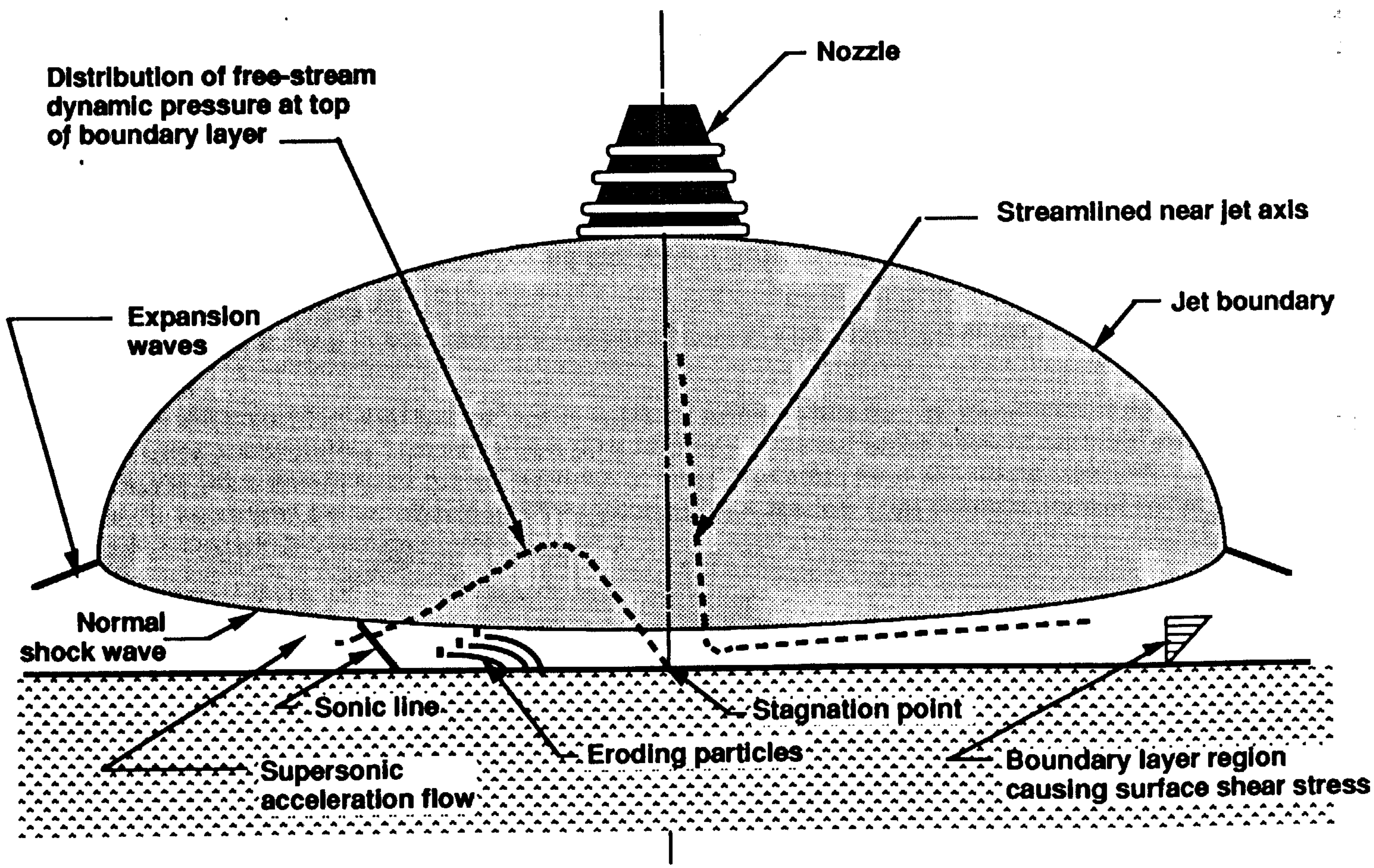
A stagnation condition will exist where the nozzle centerline intersects the surface. The resulting "free-stream dynamic pressure" will peak near a point directly beneath the nozzle lip, and decrease rapidly as radial distance from the stagnation point increases.

The flow just above the surface will accelerate radially from the stagnation point, reaching a supersonic speed ("sonic line") while continually decreasing in density.

Maximum surface shearing stress will likely occur at the point of maximum dynamic pressure. This explains the occurrence of initial erosion in an annular ring and the formation of central peaks. With time the erosion should extend from this annular ring both inwardly and outwardly.

Lunar Ejecta Analysis
TN D-2633 (Continued)

Plane Section of Exhaust Flow Field of Jet



Lunar Ejecta Analysis
TN D-5895

The test on which this paper reports used an Apollo Lunar Module (LM) attitude control engine with a simulated LM base structure to fire at flat, dished, and particulate surfaces under near-vacuum conditions. Target surface impingement pressures and heating rates, descent stage base pressures, and nozzle static pressures were measured with the engine at different thrust levels and at various altitudes from and attitudes to the surface.

During 0.1 second engine firings, vacuum chamber pressure increased from .04 millitorr to 1.3 millitorr (the lunar surface is 1.0 millitorr).

The testing generated results which showed that lander base pressures were one to two orders of magnitude less than the target-surface pressures, and were measurable only at altitudes less than two rocket exit diameters.

For firings normal to a flat surface, surface pressures were distributed symmetrically across the surface, and for altitudes down to about one nozzle diameter, were highest at the nozzle centerline, peaking at a pressure of about 0.043 times chamber pressure at an altitude of two nozzle diameters. Below two nozzle diameters, maximum pressure began to decrease and begin a shift to a point below the nozzle edge. At an altitude of one nozzle diameter and in an area directly beneath the nozzle it was relatively constant at 0.024 times chamber pressure. At altitudes below one nozzle diameter peak pressure was under the nozzle edge, increasing to 0.029 times chamber pressure at an altitude of 0.28 nozzle diameter (just prior to reaching choked flow).

The onset of nozzle choking occurred when the cylindrical escape area, formed between the rocket exit and the target surface, became less than the rocket exit area (i.e., an altitude of 0.25 rocket exit diameters). The effect of nozzle choking is a significant increase in nozzle static pressures compared with unchoked values.

Lunar Ejecta Analysis
TN D-5895

- An Apollo lunar module retrorocket was fired at flat, dished and perpendicular surfaces in a near vacuum conditions.
- Results significant to the ejecta analysis:
  - At altitudes above 2 nozzle diameters static surface pressure
    - Increases as altitude decreases
    - Reaches maximum values at an altitude of approximately 2 nozzle diameters
    - Is maximum at the thrust centerline
  - At altitudes between 1 and 2 nozzle diameters static pressure
    - Decreases as altitude decreases
    - Is distributed in a circular pattern with the maximum point at the center of thrust, but moving outward toward the nozzle edge
  - At altitudes between 1 and 0.25 nozzle diameters static pressure (start of choked flow)
    - Increases with altitude decreases
    - Is distributed in an annular pattern with maximum static pressure under the nozzle edge

Lunar Ejecta Analysis
TN D-5895 (Continued)

Surface heating increased with chamber pressure and decreasing altitude. The maximum heating rate occurred directly under the nozzle edge.

Firings off-normal to the surface increased both the pressures and heating with increasing tilt. The changes were within about 10 percent for angles of eight degrees or less and altitudes down to one nozzle diameter. At an altitude of 0.5 nozzle diameter, uphill pressure under the nozzle edge increased to about 0.056 times chamber pressure at four degrees tilt, and to 0.108 times chamber pressure at eight degrees tilt.

Firing into a concave dish had little effect on pressure levels, but the shift of the pressure peak from the centerline to nozzle edge tended to occur at a higher altitude (about 1.7 nozzle diameters).

Lunar Ejecta Analysis
TN D-5895 (Continued)

- Surface heating
  - -- Increases with increased chamber pressure
  - -- Increases with decreasing altitude
  - -- Peaks beneath the nozzle edge
- Firings off-normal to the surface caused changes of less than 10% for angles of 8 degrees or less and altitudes down to 1 nozzle diameter.
- Firings into a concave dished caused little more than the pressure peak to shift from the centerline of thrust to the edge of the nozzle at a higher altitude.

Lunar Ejecta Analysis
Paper Search Summary

A summary of findings from the technical notes is present in the next two charts.

Lunar Ejecta Analysis
Paper Search Summary

❑ Surface Static Pressure

- Distribution is a function of
  - Nozzle area ratio (Expansion ratio)
  - Nozzle contour
  - Nozzle height
- Reaches a maximum at an altitude of 2 nozzle diameters, on the thrust centerline
- Maximum pressure peak moves outward as altitude decreases, peaking at the nozzle edge at an altitudes less than 1 nozzle diameter
- Onset of nozzle choking occurs at altitude of approximately 0.25 nozzles diameters*

* The effect of nozzle choking is a significant increase in nozzle static pressure compared to unchoked values.

Lunar Ejecta Analysis
Paper Search Summary (Continued)

A summary of findings from the technical notes continued.

Lunar Ejecta Analysis
Paper Search Summary (Continued)

- ❑ Surface erosion
  - Was a function of nozzle height, particle size and cohesion
  - Started in a ring the same diameter as the nozzle and expanded outward as well as inward
  - Observation on the lunar surface indicate little cratering apparently due to the cohesive nature of the particles and low LM chamber pressure at landing.
- ❑ Clustered nozzles (with the equivalent weight flow as a single nozzle) generally had slightly lower peak pressures.
- ❑ Surface heating
  - Increased with increased chamber pressure
  - Increased as altitude decreased
  - Maximum heating occurred at the nozzle edge

Lunar Ejecta Analysis
Paper Search Results

Calculations based on data obtained from the NASA Technical Notes were made to determined the maximum surface pressure and the altitude at which the maximum pressure occurs for the Apollo descent engine, one RL10A-3 and a cluster of four RL10A-3s. The results are shown on the facing chart.

Lunar Ejecta Analysis
Paper Search Results

- Calculations based on data obtained from the NASA Technical Notes

	Nozzle Diameter (meters)	Chamber Pressure (psia)	Max Surface Pressure (psia)	Altitude at Max Pressure (meters)
Apollo LM (descent engine)	1.50	104.00	4.47	3.00
Single RL10A-3	1.00	465.00	20.00	2.00
Four RL10A-3s	* 2.01	465.00	20.00	4.01

* Equivalent Diameter

- Protection measures
  - Surface compaction to increase cohesion
  - Paving with stones (3 to 4 meters beyond landing CEP)
- The technical notes review did not yield data that could be used to validate the BLAST computer model
- Surface cratering effects predicted by the experiments did not occur during actual lunar landings.

Results of Internal Studies & Analyses

The thermal/micrometeoroid protection trade study was revisited during the Option I period.

Results of Internal Studies & Analyses

- ❑ LEV Servicer maintenance analysis
- ❑ Lunar ejecta analysis
- ❑ Thermal/Micrometeoroid protection trade study
- ❑ Applicability of Centaur processing tasks to LEV/MEV launch operations

Thermal/Micrometeoroid Protection

This assessment was originally performed under the base period of the Lunar Transportation Facilities and Operations Study. Per the request of the NASA-KSC Study Manager, Mr. J. R. Reiss, the trade study was refined to evaluate the same protection options using the PSS Reference Option 5A. After that assessment was made, the PSS Office at JSC requested MDSSC-KSC to evaluate the impacts of making the Storage Facility Option mobile.

For this trade study, four options were studied. The Consolidated Vehicle Option would have the lander provide its own protection for both the space flight and the surface stay time . This protection would be similar to the Apollo landers which depended on its own thermal protection to shield sensitive components from heat. The other three options, the A-frame Tent, the Vehicle Skirt and the Storage Facility, are surface based protection systems. For this analysis it is assumed that these systems would not be constructed of lunar surface material, but would be part of the infrastructure that must be developed on earth and sent to the lunar surface.

Evaluation criteria used were performance, mass to the lunar surface, EVA man-hours and the effect on launch and landing operations. The consolidated vehicle option has the advantage that no EVA is required and it simplifies launch and landing operations. However, there is a mass penalty associated with this option, because the mass of the protection material reduces the payload mass that can be transported. Also, a thermal short to the propellant tanks, caused by reflected heat being radiated to the engine nozzle, may make the performance of this option inadequate for long duration surface stays.

Surface based options provide adequate performance and provide a mass payback, but require increased launch and landing operations and EVA.

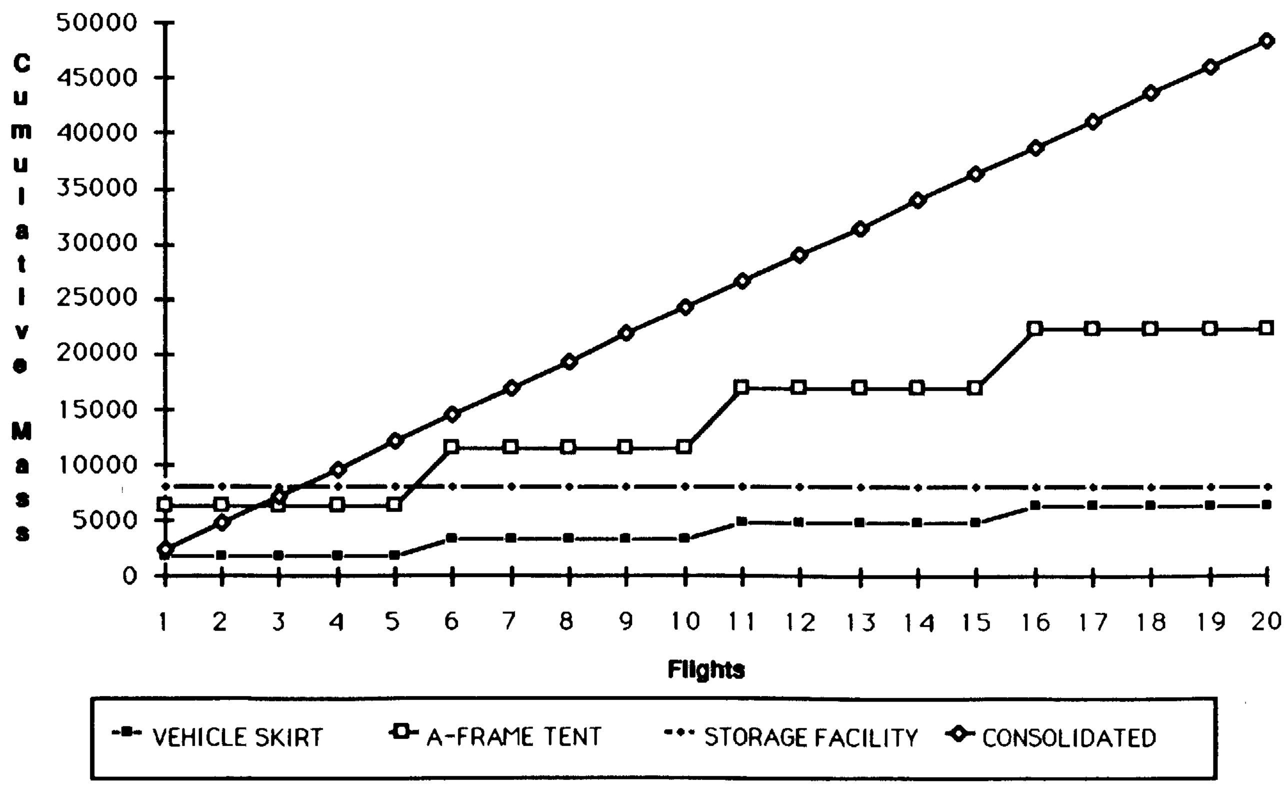
Thermal/Micrometeoroid Protection

- Two basic approaches
  - Vehicle based (Consolidated Vehicle)
  - Surface Based (A-Frame Tent, Vehicle Skirt, and Storage Facility)
- Vehicle based.
  - No requirements for EVA
  - Simplifies launch and landing operations
  - Mass penalty
  - Inadequate performance (thermal short to propellant tank)
- Surface based
  - Mass payback
  - Adequate performance
  - EVA requirements
  - Increased launch and landing operations

Mass Comparisons Considering Material Replacements

This chart shows the cumulative mass versus the number of flights for the approaches considered. The cumulative mass for the A-Frame Tent and the Vehicle Skirt include the mass associated with replacing the protective cover.

Mass Comparisons Considering Material Replacements



Thermal/Micrometeoroid Protection
Update Analysis

In updating this analysis special attention was paid to structural considerations regarding adequacy of structure to support protection material, as well as structural considerations associated with a mobile storage facility.

Thermal/Micrometeoroid Protection Update Analysis

- ❑ Structural Considerations
  - Adequacy of structure to support protective material
- ❑ Mobility considerations for the Storage Facility Option
  - Flex and torsional problems associated with the facility
  - Mass penalty associated with stiffening structure
  - Mass penalty associated with mobility equipment
  - Changes in the EVA estimates for mobilizing the facility

Results of Stability/Structural Analysis of the Storage Facility

Deployable mast required additional stiffening. Stiffened masts would weigh 119 lbs each and there are four required for a total of 476 lbs. The mass estimate for the original mast concept was 46 lbs each, or 184 lbs total.

Alignment/compression bars required replacement by trusses, however, there was no mass penalty associated with this change.

The original protective material selected was found to be inadequate. Estimated mass for proper material is 5715 lbs. The total mass of a structurally sound non-mobile storage facility is 7821 lbs.

Results of Stability/Structural Analysis of the Storage Facility

- Deployable mast required additional stiffening
  - Stiffened masts would weigh 119 lbs
  - Original mast concept weighed 46 lbs
  - Mass of deployable mast increases to 476 lbs
- Alignment/compression bars required replacement by trusses
  - No mass penalty associated with change
- Original protective material was found to be inadequate
  - Mass of proper material is 5715 lbs
- Total mass of structurally sound storage facility is 7821 lbs
- Total mass is for a non-mobile storage facility

Mobility Analysis on the Storage Facility

The Storage Facility Option was originally evaluated as a stationary surface protection system. However, the PSS Office requested MDSSC-KSC to determine if there were any potential benefits associated with using a mobile facility. Therefore, MDSSC-KSC conducted a quick assessment of making the facility mobile. A NASA Structural Analysis (NASTRAN) model was created by MDSSC-KSC Mechanical and Facilities Engineering to analyze the loads that might be encountered in the facility structure if it were mounted on wheels on each corner. The loads that were evaluated included the lunar gravity, the loads of the material being supported on the Storage Facility frame, and the loads which would be imparted to the structure due to the torque of the drive units. The three configurations that were evaluate are shown in the facing chart.

Mobility Analysis on the Storage Facility

- ❑ MDSSC-KSC was requested to evaluate a mobile Storage Facility Concept
- ❑ NASTRAN was used to model 3 configurations of the Storage Facility
- \- Configuration A: Truss and guy wires are used and placed across the entrance during transport.
- \- Configuration B: Horizontal trusses are removed from entrance
- \- Configuration C: Both trusses and guy wires are removed from entrance

Mobility Analysis on the Storage Facility (Continued)

The NASTRAN model assumed construction with the horizontal trusses connected so that they can transmit torques and moments, guy wires (1/8") are pre-loaded to 150 lbs. It was assumed that the upright columns would be deployable masts and they take only axial loads. The model was constrained to simulate one wheel off the ground for each facility configuration. This effectively supports the structure by two opposite corners allowing it to deflect as much as it can.

No consideration was given going up or down slopes, acceleration/deceleration, or dynamic loads.

For configuration A, the facility deflected 2 inches. For configuration B deflection was 30 inches (a deflection of 24 inches could be tolerated). For configuration C the deflection was excessive.

Mobility Analysis on the Storage Facility (continued)

- ❑ NASTRAN constraints
  - Trusses connected so torques and moments can be transmitted
  - Guy wires (1/8") pre-loaded to 150 lbs
  - One wheel off ground to simulate worst case deflection
  - Did not consider going up/down slopes, acceleration/deceleration, or dynamic loads
- ❑ Deflection estimates
  - Configuration A showed a deflection of 2 inches.
  - Configuration B showed a deflection of 30 inches (Structural damage)
  - Configuration C showed a deflection which was too excessive

Mobility Analysis on the Storage Facility
Mass Impacts

Configuration A is an 7821 lb structurally sound facility which requires no additional mass for stiffening.

Assuming that mobility can be obtained through the use of wheels and drive motors, the mass penalty is estimated at 330 lbs. This is based on using wheels similar to those developed for the Apollo 14 Modular Equipment Transport.

Mobility Analysis on the Storage Facility
Mass Impacts

- Mass penalties

- Configuration A incurs no mass penalty due to stiffening requirements
- Mobility requires addition of wheels which incurs a mass penalty
- Assuming Apollo 14 Modular Equipment Transport similarities a mass penalty of 330 lbs would be incurred to mobilize the Storage Facility

Mobility Analysis on the Storage Facility
EVA Impacts

There would be a savings in EVA time if the facility were mobile, there would be no need to attach jacks and raise the lander, attach wheel assemblies to the lander, and attach a tow bar to the vehicle. Deleting these three activities saves about four hours in EVA time. This saving is based on the following assumptions:

- Wheel assemblies are permanently attached to the facility
- Trusses must be removed prior to placing the facility over the vehicle
- The time to transfer the facility to the vehicle is equal to the time to transfer the vehicle to the facility

Total EVA time to move the facility to the landing site and provide protection for the vehicle would be about nine hours and 50 minutes.

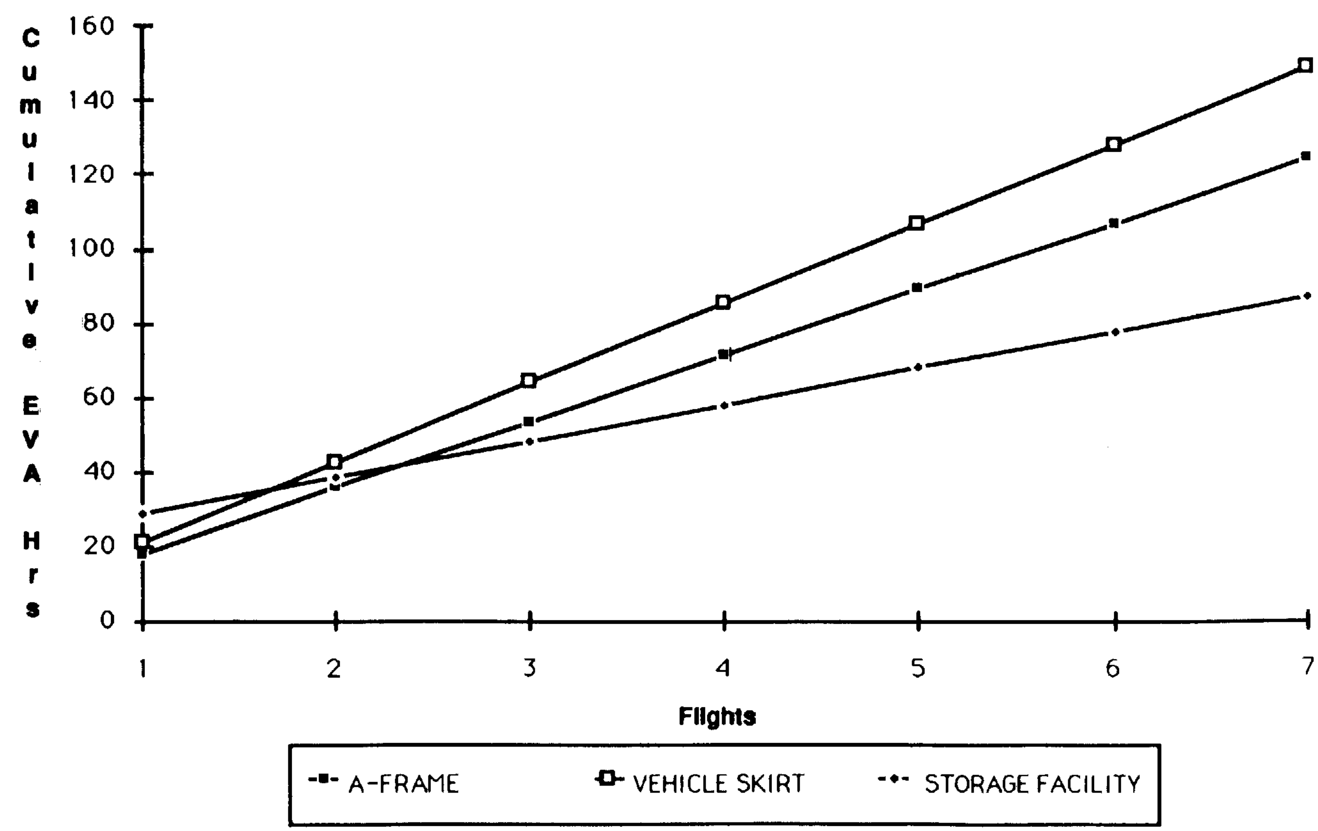
Mobility Analysis on the Storage Facility
EVA Impacts

- ❑ EVA assessment
  - Assume
    - -- Wheel assemblies are permanently attached to facility
    - -- Trusses must be removed prior to placing the storage facility over the vehicle
    - -- Time to transfer facility is equal to the time to transfer a vehicle to a fixed facility
- Approximate time to move facility and place over vehicle is 9:50 hrs

EVA Comparisons of the Mobile Storage Facility with the other Options

This chart shows the cumulative EVA hours versus the number of flights for the approaches considered. The the storage facility would require less cumulative EVA hours after three flights.

EVA Comparisons of the Mobile Storage Facility with the other Options



Mobility Analysis on the Storage Facility
Conclusions

A non-mobile structurally sound storage facility would weigh about 7821 lbs. The compression trusses and cables used in the original design must be retained for structural stability.

The storage facility can be made mobile if wheels and drive motors are added. Adding wheels and drive motors would increase the mass by 330 lbs. The total mass of the facility would be 8151 lbs.

A mobile version of the facility is more attractive than a fixed facility from the standpoint of EVA hours, and is more attractive than the A-Frame Tent or the Vehicle Skirt in all aspects.

Mobility Analysis on the Storage Facility Conclusions

- Conclusions
  - A non-mobile storage facility would weigh about 7821 lbs
  - The compression trusses and cables used in the original design must be retained for structural stability
  - The storage facility can be made mobile if wheels and drive motors are added
  - A mobile version of the facility would weigh about 8151 lbs
  - A mobile version of the facility is more attractive than a fixed facility from the standpoint of EVA hours
  - More attractive than the A-Frame Tent and the Vehicle Skirt in all aspects

Thermal/Micrometeoroid Protection Results

This chart shows the relative merits of each of the approaches in regard to the evaluation criteria.

Thermal/Micrometeoroid Protection Results

OPTION	MASS ASSESSMENT	EVA MANHOUR ASSESSMENT	OPERATIONS ASSESSMENT	PERFORMANCE ASSESSMENT
CONSOLIDATED VEHICLE OPTION	LEAST DESIRABLE	MOST DESIRABLE	MOST DESIRABLE	INADEQUATE
A-FRAME TENT OPTION	LESS DESIRABLE	LESS DESIRABLE	LEAST DESIRABLE	ADEQUATE
VEHICLE SKIRT OPTION	MORE DESIRABLE	LEAST DESIRABLE	LESS DESIRABLE	ADEQUATE
STORAGE FACILITY OPTION (Fixed or Mobile)	MOST DESIRABLE	MORE DESIRABLE	MORE DESIRABLE	ADEQUATE

Results of Internal Studies & Analyses

A review of Centaur processing task to determine applicability to LEV/MEV launch operations was continued during the Option I period.

Results of Internal Studies & Analyses

- LEV Servicer maintenance analysis
- Impact of maintaining LH2 on planetary surfaces
- Lunar ejecta analysis
- Thermal/Micrometeoroid protection trade study
- **Applicability of Centaur processing tasks to LEV/MEV launch operations**

Applicability of Centaur Processing Tasks to LEV/MEV Launch Operations

The objectives of this review were to assess Atlas/Centaur prelaunch processing tasks for applicability to LEV/MEV launch operations and for applicable tasks, recommend areas that would be candidates for automation.

The technique used to perform this assessment was to review the list of Atlas/Centaur Test Procedures (CTP), and select candidate CTPs for detailed review, perform the detail review and develop database with a data sheet for each CTP. Task summary data charts were developed from the a database which outlined areas of applicability and recommended portions that were candidates for automation.

Applicability of Centaur Processing Tasks to LEV/MEV Launch Operations

- ❑ Objectives
  - Assess Atlas/Centaur prelaunch processing tasks for applicability to LEV/MEV launch operations
  - Recommend task areas that would be candidates for automation
- ❑ Techniques
  - Review Atlas/Centaur Test Procedures (CTP) list
  - Select candidate CTPs for detailed review
  - Perform detail review
  - Develop database with data sheet for each CTP
  - Develop task summary data chart
    - Outline applicability
    - Recommend automated portions

Applicability of Centaur Processing Tasks (Continued)

Lunar and Mars excursion vehicles are baselined to use LOX & LH2. Centaur is the only high energy (LOX & LH2) upper stage in the U.S. launch vehicle fleet (has been in operation since 1962).

Prelaunch testing of the Atlas/Centaur is complex. There are 104 tests performed on Centaur alone and all tests are considered necessary to assure successful launch from this planet.

It seems reasonable to assume that some similar type of testing will be required for successful launch of similar vehicles from another planet.

Due to the unavailability of large surface crews to perform tasks manually, the LEV /MEV testing will require a high degree automation and built-in functional test capability, which can be initiated from within the vehicle, from a habitable area on the lunar or martian surface, or from Earth.

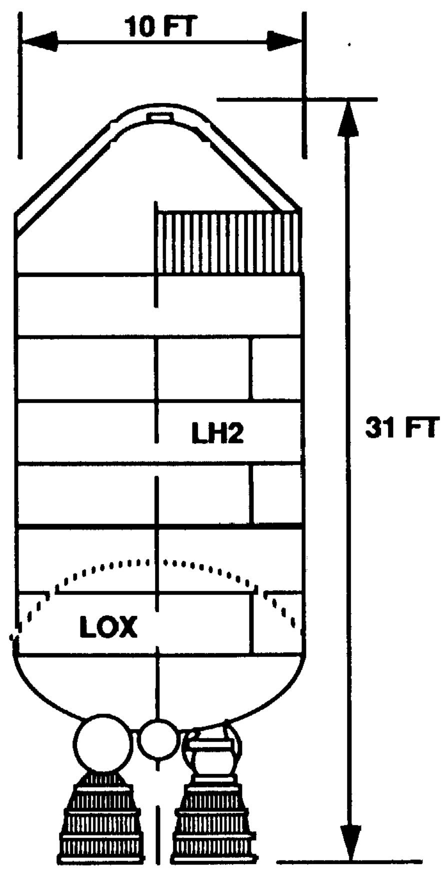
Applicability of Centaur Processing Tasks
(Continued)

- Rationale
  - Lunar and Mars excursion vehicles baselined to use LOX & LH2
  - Centaur is the only high energy (LOX & LH2) upper stage in the U.S. launch vehicle fleet (has been in operation since 1962)
  - Prelaunch testing is complex and active
    - 104 tests performed on Centaur alone
  - All tests are considered necessary to assure successful launch from this planet
  - Reasonable to assume that some similar type of testing will be required for successful launch of similar vehicles from another planet
    - The LEV /MEV testing will require a high degree automation and built-in test capability

Applicability of Centaur Processing Tasks (Continued)

The facing chart provides an overview of the Centaur and the RL10 engine.

Applicability of Centaur Processing Tasks (Continued)



- Centaur Overview
  - High energy upper stage
  - Pressure stabilized vehicle (Common bulkhead)
  - Guidance ---------------------------- Inertial
  - Main propellants
    - Oxidizer (LOX) ----------------- 25,000 LBS
    - Fuel (LH2) ----------------------- 5,000 LBS
  - RCS propellant -------- Storable propellant (N2H4)
  - Tank pressurized & purged with GHe
    - Autogenous system used during burn
  - Main engines
    - Pratt & Whitney dual RL10A-3 or RL10A-4
  - Thrust -- RL10A-3 -------------- 33,000 LBS
    - -- RL10A-4 -------------- 40,500 LBS
  - Isp ------------------------------------ 446 SEC
  - Dry Weight -------------------------- 3,800 LBS

Applicability of Centaur Processing Tasks
(Continued)

In all there is a total of 266 Atlas/Centaur procedures. Of that number 106 are related to facilities and GSE, 56 are related to the Atlas and 104 to the Centaur.

The number of candidate Centaur tasks screened for LEV/MEV relevancy was 48. Of the 48, 20 were not applicable and 28 were applicable to LEV/MEV prelaunch processing.

Applicability of Centaur Processing Tasks
(Continued)

- Total number of Atlas/Centaur procedures - 266
  - Facilities/GSE -------------- 106
  - Atlas -------------------------- 56
  - Centaur --------------------- 104
- Candidate Centaur tasks screened for LEV/MEV relevancy - 48
- Summary evaluation
  - Retain ------------------------ 28
  - Not applicable -------------- 20

Applicability of Centaur Processing Tasks (Continued)

This chart shows a sample summary chart developed from the data base. Each record (Centaur Test Procedure) provides the CTP number, the title and brief description of the task, the resources required (i. e., number of shifts, total crew and special test equipment) and comments regarding the applicability to to LEV/MEV.

Applicability of Centaur Processing Tasks (Continued)

Old CTP No.	Title/Description	Shifts	Total Crew	Special Test Equip	LEV/MEV
PROP-3131N	CENTAUR PRATT & WHITNEY ENGINE LEAL & FUNCTIONAL CHECK Performs transducer calibrations and leak and functional checks of engines and associated hardware	11	6	Portable Pneumatic Checkout Panel Flow Meters Flex Hoses Pressure Test Plates & Fixtures Propulsion Checkout Panel Leakage Detector Fixture	Develop a condensed version that uses special built in capabilities of the LEV/MEV engines.
PROP-3133	CENTAUR PROPULSION FLIGHT READINESS OPERATIONS Propulsion components are functionally checked for flight and the propulsion system is partially configured for flight such as turbopump torque checks, final leak checks, and preliminary blowdowns are accomplished. Both the LH2/LO2 and N2H4 systems are checked	7	5	Backup Engine Purge Panel Panel Flow Meters Flex Hoses Portable Pneumatic Checkout Panel Propulsion Checkout Panel Purge manifold	A shortened version would be required on planetary surface; increased use of built in test is required to reduce EVA for these checks
PROP-3156	AIRBOURNE N2H4 SYSTEM LEAK & FUNCTIONAL Performs hydrazine RCS engine functional checks, valve leak checks, N2H4 bottle leak checks, thruster loop leak checks, and RCS line heater checks.	6	5	Hydrazine Service Panel & Vacuum Pump N4H4 RCS GSE Test Kit N2H4 Mass Spectrometer Fill &	Develop a condensed version that uses LEV/MEV Built-in-Test capability for leak and functional tests.

L&L Technical Results

The next topic for discussion is the advanced development plan.

L&L Technical Results

- Technical Results
  - Level III & IV Requirements
  - Integrated Project Plan
  - Element Description & Sizing Results
  - Results of Internal Studies & Analyses
  - Advanced Development Plan
  - Logistics Modeling Support
  - Conclusions

Advanced Development Plan

The areas to be discussed during this presentation of the Advanced Development Plan are listed in the facing chart.

Advanced Development Plan

- ❑ Advanced Development Plan
  - Reference Architecture 5a L&L Schedule
  - Mission Profile
  - Mission factors
  - WBS
  - L&L System Advanced Development Schedule
  - L&L System Advanced Development Manloading
  - L&L System Advanced Development Development Cost

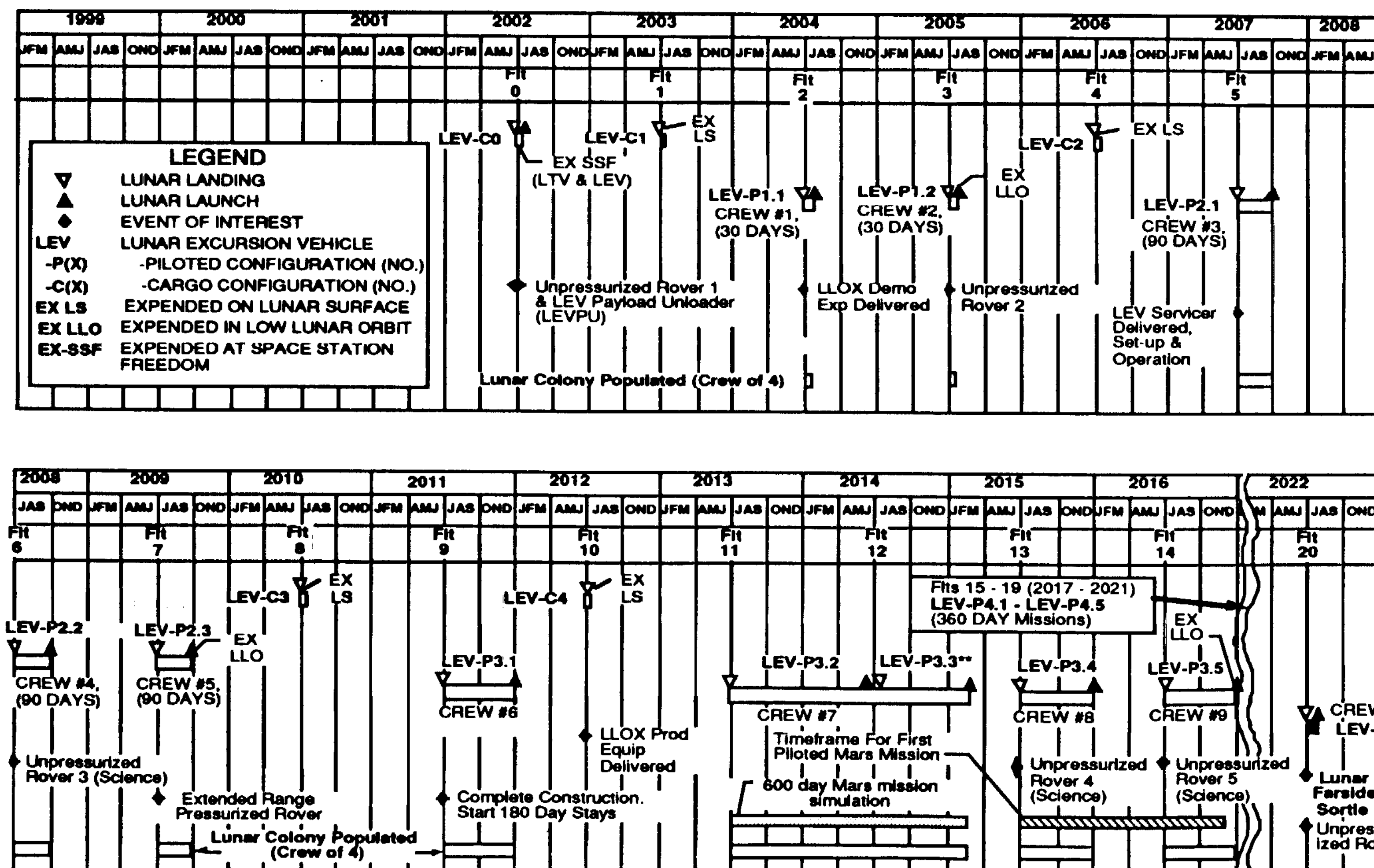
Reference Architecture 5a L&L Schedule

The first step in the advanced development planning process was to establish a Launch and Landing schedule for Reference Architecture 5a, based on the manifest provided with the May 22, 1990 version of the architecture. This was necessary to determine when specific operation capabilities were to be in place.

As shown in the schedule the longer lunar surface stays start in 2007 with a 90 day mission. This requires the LEV Servicer and other Surface Support Equipment (SSE) to be delivered, set-up and operational at this time.

This establishes an overall time frame in which the advanced development, DDT&E, payload integration and payload delivery (to the lunar surface) must be completed.

Reference Architecture 5a L&L Schedule*



* Reference Architecture Option 5a manifest, 22 MAY 1990

** Resupply only. No crew transfer

WBS for Vehicle Processing Advanced Development Plan

The next step in the advanced development planning process was to develop a Work Breakdown Structure (WBS). This was necessary to identify specific tasks and assign responsibilities. The WBS for vehicle processing is shown in the facing chart.

WBS 8.4.2.2.2.2.6 Vehicle Processing Advanced Development Plan

- 1.0 System Development
  - 1.1 Lunar Deliverables
    - 1.1.1 LEV Servicer
      - 1.1.1.1 Fluid Processing System
      - 1.1.1.2 Electrical Power & Data Processing
      - 1.1.1.3 LEV Thermal Control
      - 1.1.1.4 Transportation, Storage & Control
    - 1.1.2 Thermal/Micrometeoroid Protection
      - 1.1.2.1 Fabric/Cover
      - 1.1.2.2 Support Structure & Deployment Mech
      - 1.1.2.3 Transportation & Storage System
    - 1.1.3 Engine Ejecta Protection
      - 1.1.3.1 Berm/Blast Fence Construction
      - 1.1.3.2 Pad Surface Paving
      - 1.1.3.3 Protective Covers/Structures
    - 1.1.4 Launch & Landing SSE
      - 1.1.4.1 Landing/Navigation Aids
      - 1.1.4.2 Auxiliary Lighting Kit
      - 1.1.4.3 L&L Access Equipment
      - 1.1.4.4 L&L Tools & Test Equipment
      - 1.1.4.5 LLOX Pallet
      - 1.1.4.6 Life Support Servicer
      - 1.1.4.7 Fuel Cell Servicer
      - 1.1.4.8 Waste Management System Servicer
      - 1.1.4.9 Range Safety Systems

- 1.0 System Development (cont'd)
  - 1.2 Mars Deliverables
    - 1.2.1 MEV Servicer Design Changes
      - 1.2.1.1 Capacity Changes
      - 1.2.1.2 Environmental Changes
    - 1.2.2 Thermal/Micrometeoroid Protection Design Changes
      - 1.2.2.1 Lower Thermal & Micrometeoroid Load
      - 1.2.2.2 Consider Wind Load
      - 1.2.2.3 Dust Storm Proof Fabric Joints & Access Openings
    - 1.2.3 Engine Ejecta Protection Design Changes
      - 1.2.3.1 Effect of Higher Thrust & Atmosphere on Ejecta Trajectories
      - 1.2.3.2 Effect of Different Soil Characteristics on Berm Construction
      - 1.2.3.3 Availability of ISRU Paving Materials
    - 1.2.4 Launch & Landing SSE Design Changes
      - 1.2.4.1 Changes Driven by LEV-MEV Differences
      - 1.2.4.2 Changes Driven by Differences in Other SSE

- 2.0 System Integration
  - 2.1 Simulation & Modeling
  - 2.2 Testbeds
    - 2.2.1 LEV/MEV Servicer Testbed
    - 2.2.2 ISRU/LEV/MEV Fluid Transfer Testbed
    - 2.2.3 LEV/MEV Mockups
    - 2.2.4 Surface Equipment Life Test Testbed
  - 2.3 Cross-Cutting Analyses
    - 2.3.1 Operations
    - 2.3.2 Logistics
    - 2.3.3 Automation
    - 2.3.4 Robotics/Telerobotics
    - 2.3.5 Human Factors
    - 2.3.6 Safety, Reliability, Main & Quality Assurance
  - 2.4 Interfaces with Other Systems

- 3.0 Program Management

- 4.0 Procurement

- 5.0 Facilities Development

L&L System Advanced Development
Task Description Sheets

A Task Description Sheet (TDS) was prepared for each item in the WBS on a form developed for this purpose by PSS. The LTFOS Study team prepared TDSs for each vehicle processing WBS item. After completion these forms were returned to PSS electronically using the NASAMAIL system. Updates were also sent to PSS electronically using the NASAMAIL system. A sample TDS is shown in the facing chart. Manloading was added to the TDS after the schedule was developed.

Task Description Sheets

WBS#: 1.1.1.1 | Activity: L&L Advanced Development Plan | Date: 1/24/91

Integration Agent: | Contact Person: | NASAMail ID: | Mail Code:

Title: LEV Servicer/Fluid Processing System | Phone: | Fax:

Task Objective: Develop a fluid processing system that will conserve LEV propellants through reliquefaction.

Task Description/Approach: Design, construct and test dual reliquefaction devices that will collect, compress and liquify GO_2 and GH_2 boiloff gases from the LEV propellant tanks. The Servicer will have the capability to transfer liquid propellants to the LEV tanks.

Products/Milestones/Schedule:

Resources Summary:

Real Year $

FY	95	96	97	98	99	00	01
Obls. ($K)							
Costs($K)							

Manpower Summary:

FY	95	96	97	98	99	00	01
Civil Service EP:							
Prime Contract EP:	1	4.5	6	4.5			
Supp. Contract EP:	0.2	0.7	0.9	0.7			

C of F Requirements:

FY	95	96	97	98	99	00	01
$K							

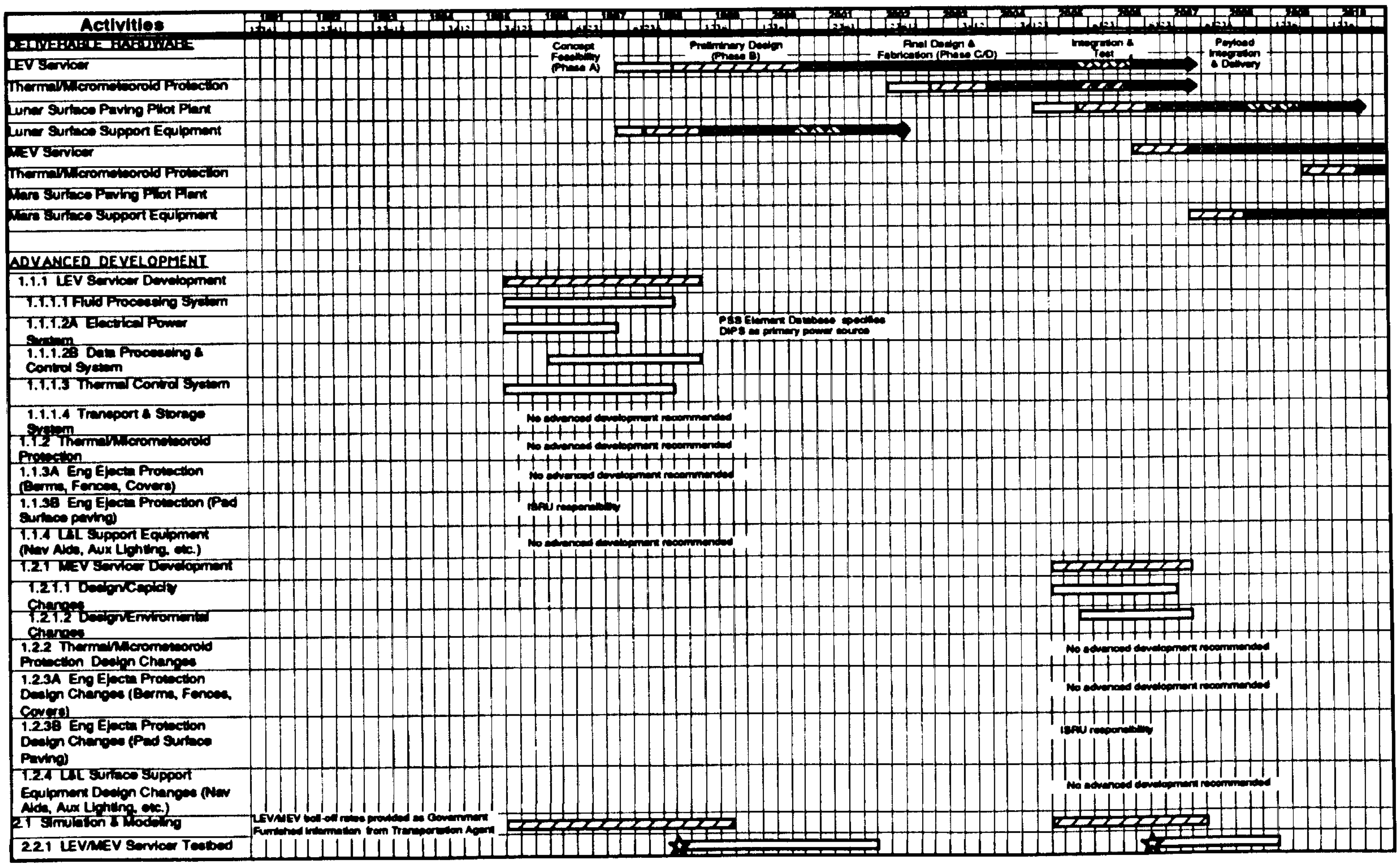
Materials and Equipment

FY	95	96	97	98	99	00	01
$K		483	967				

L&L System Advanced Development Schedule

Following the development of the Work Breakdown Structure (WBS) and TDSs an overall schedule for the advanced development of the LEV Servicer and the MEV Servicer. This schedule, which covers the years 1991 through 2010 is shown in the next two charts. The facing chart shows WBS numbers 1.1.1 through 2.2.1.

L&L System Advanced Development Schedule

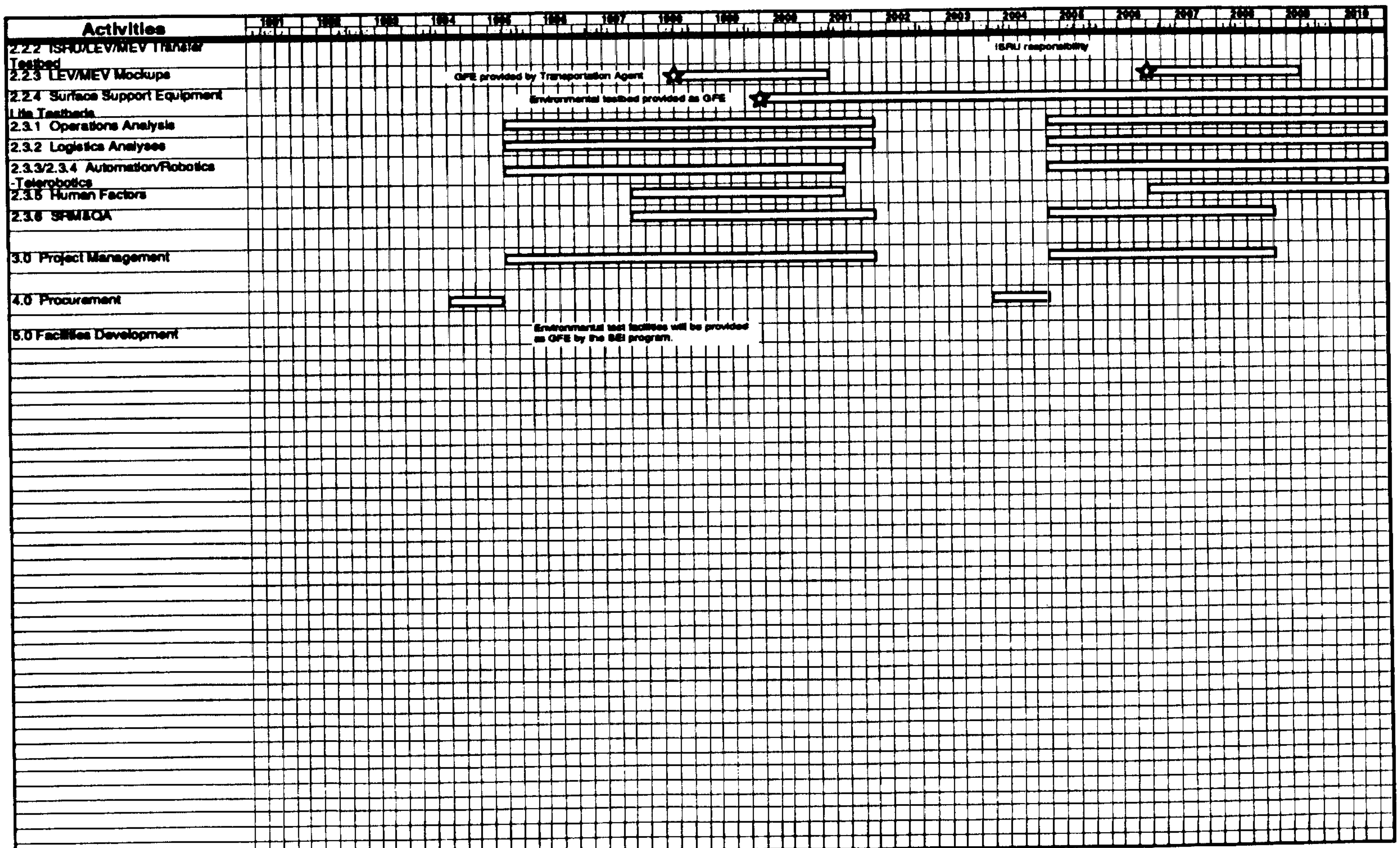


L&L Advanced Development Plan, Rev 4, 1/17/91

L&L System Advanced Development Schedule (Cont'd)

The facing chart shows WBS numbers 2.2.2 through 5.0.

L&L System Advanced Development Schedule(Cont'd)



L&L Advanced Development Plan, Rev 4, 1/17/91

L&L System Advanced Development Cost

The LTFOS Study Team was requested to estimate the manpower and material cost for the L&L advanced development plan for the period 1994 through 2001. The facing chart is a summary of this costing exercise.

L&L System Advanced Development Cost

	FY	95	96	97	98	99	00	01	TOTAL
1.1.1.1 FLUID SYS See Notes 1 & 2	$K		1852.7	3705.3					5558
1.1.1.2A ELECTRIC PWR (2) See Note 3	$K		325.0	650.0					975
1.1.1.2B DATA PROC See Note 1	$K			1191.7	2383.3				3575
1.1.1.3 THERMAL See Note 1	$K		433.3	866.7					1300
SUBTOTAL		0.0	2611.0	6413.7	2383.3	0.0	0.0	0.0	11408
2.2.1 LEV/MEV SERV TESTBED	$K*				0.7	2.8	2.8	2.8	9
3.0 PROGRAM MANAGEMENT	$K*	0.7	2.8	2.8	2.8	2.8	2.8	2.8	18
TOTAL	$K*	0.7	2613.8	6416.5	2386.8	5.6	5.6	5.6	11435

Manpower costs at $100K per man year	$19,080
Grand Total	$30,515

* Includes one (1) three (3) day trip per quarter @ $700.00 per trip.

Notes:

1. Hardware material costs are based on an engineering estimate by Jeff Traylor, times a 1.3 complexity factor.

2. Fluid system cost breakdown

Low pressure He liquifier (Jeff Traylor's est. for H system)	$2,900	K
Plus:		
Compressor	$250	K
Motor	$250	K
3 Heat Exchangers	$375	K
2 Expanders	$500	K
Subtotal	$4,275	K
Total including 1.3 complexity factor	$5,558	K

3. Electrical Power System based on LeRC providing the DIPS and L&L proving the rectifier/regulator and distribution portion.

L&L Technical Results

The next topic for discussion is the logistics modeling support provided to PSS.

L&L Technical Results

- Technical Results
  - Level III & IV Requirements
  - Integrated Project Plan
  - Element Description & Sizing Results
  - Results of Internal Studies & Analyses
  - Advanced Development Plan
  - Logistics Modeling Support
  - Conclusions

Logistics Modeling Support

During this reporting period MDSSC-KSC provided extensive logistics modeling support to PSS. The facing chart is a sample input sheet for the System Design Utility (SDU) Model. The SDU Model is a tool to analyze, identify logistics considerations in the early stages of the program, and tracking logistics requirements throughout the life of the program.

Logistics Modeling Support

Input Sheet For System Design Utility (SDU) Model — PRELIMINARY - FOR INFORMATION PURPOSES ONLY

System WBS/ SDU Inputs	Unit Cost ($K)	Lot Size (#)	MT to Fail (Yrs)	MT to Repair (Hrs)	Supp Eqt Cost ($K)	Diag SW Cost ($K)	Repair Doc (Pgs)	Repair Train (Hrs)	Repair Mat Cost ($K)	Condemn Rate (Dec)	Sched Maint (Hrs)	Maint Training (Hrs)	Total Weight (Lbs)	Contain Cost ($K)	Tech Draw (Pgs)
LEV Servicer	**9000.0**	**1.0**			**3825.0**	**6120.0**	**1900.0**	**52.5**	**2295.0**	**1.0**	**35.0**	**525.0**	**3462.0**	**70.6**	**316.0**
Pwr Supply Unit	**2350.0**	**1.0**			**1175.0**	**1880.0**	**775.0**	**10.0**	**705.0**	**1.0**	**9.0**	**100.0**	**2205.0**		**124.0**
Fuel Cell	2000.0	3.0	3.9	1.0	500.0	800.0	25.0	8.0	300.0	1.0	8.0	80.0	1500.0		64.0
Regulator	250.0	3.0	3.9	1.0	62.5	100.0	25.0		37.5	1.0					4.0
Pump Assbly	250.0	3.0	4.4	1.0	62.5	100.0	50.0		37.5	1.0					4.0
Motor	250.0	3.0	19.0	1.0	62.5	100.0	50.0		37.5	1.0					4.0
Condenser	250.0	3.0	64.3	1.0	62.5	100.0	50.0		37.5	1.0					4.0
Coolant Valve	50.0	6.0	11.4	1.0	12.5	20.0	50.0		7.5	1.0					4.0
Heater	100.0	6.0	2.2	1.0	25.0	40.0	50.0		15.0	1.0					4.0
Purge Valve	50.0	6.0	11.4	1.0	12.5	20.0	50.0		7.5	1.0					4.0
Elect Unit	750.0	3.0	20.0	1.0	187.5	300.0	50.0		112.5	1.0					4.0
Press Xducer	20.0	6.0	34.2	1.0	5.0	8.0	50.0		3.0	1.0					4.0
Temp Xducer	20.0	6.0	34.2	1.0	5.0	8.0	50.0		3.0	1.0					4.0
QD's	10.0	12.0	415.0	1.0	2.5	4.0	50.0		1.5	1.0					4.0
Tank Assembly	350.0	3.0	30.8	1.0	87.5	140.0	25.0	2.0	52.5	1.0	1.0	20.0	705.0		4.0
O2 Tank	100.0	6.0	30.8	1.0	25.0	40.0	50.0		15.0	1.0					4.0
H2 Tank	100.0	6.0	30.8	1.0	25.0	40.0	50.0		15.0	1.0					4.0
H2O Tank	100.0	6.0	30.8	1.0	25.0	40.0	50.0		15.0	1.0					4.0
Lines	50.0	50.0	71.7	1.0	12.5	20.0	50.0		7.5	1.0					4.0
Thermal/Control	**1000.0**	**1.0**			**250.0**	**400.0**	**75.0**	**8.0**	**150.0**	**1.0**	**2.0**	**80.0**	**441.0**		**92.0**
Control System	500.0	2.0	27.0	1.0	125.0	200.0	25.0	6.0	75.0	1.0	1.0	60.0	200.0		4.0
Heat Pump	250.0	2.0	10.0	1.0	62.5	100.0	25.0	1.0	37.5	1.0	0.5	10.0	200.0		4.0
Radiator	250.0	2.0	29.4	1.0	62.5	100.0	25.0	1.0	37.5	1.0	0.5	10.0	41.0		4.0

Logistics Modeling Groundrules/Assumptions

Shown in the facing chart is the groundrules and assumptions used in developing the inputs for the System Design Utility (SDU) Model.

Logistics Modeling Groundrules/Assumptions

LUNAR EXCURSION VEHICLE (LEV) SERVICER SYSTEM DESIGN UTILITY INPUTS

CATEGORY	GROUNDRULE/ASSUMPTION
UNIT COST	ESTIMATE BASED UPON EXTRAPOLATION OF REPLACEMENT COSTS AND DOES NOT TAKE INTO CONSIDERATION ANY FACTORING FOR LUNAR OPERATIONS
LOT SIZE	ENGINEERING ESTIMATE OF "POPULATION" NOT PRODUCTION RUN
MT TO FAIL	MTBF EXTRAPOLATED FROM SSFP FISHER PRICE REPORT TABLE 5-1. CONVERTED HOURS TO YEARS USING 8760 HOURS PER YEAR
MT TO REPAIR	ENGINEERING ESTIMATE OF SUGGESTED MTTR GOALS FOR LUNAR CREWMEN
SUPPORT EQUIPMENT COST	DERIVED FROM UNIT COST. ENGINEERING ESTIMATE 25% OF UNIT COST.
DIAG S/W COST	DERIVED FROM UNIT COST. ENGINEERING ESTIMATE 40% OF UNIT COST.
REPAIR DOC	ORGANIZATIONAL LEVEL REPAIR MANUALS AVERAGES 25 PAGES INTERMEDIATE/DEPOT LEVEL REPAIR MANUALS AVERAGES 50 PAGES
REPAIR TRAINING	ENGINEERING ESTIMATE OF SUGGESTED LUNAR CREW TRAINING FOR ORGANIZATIONAL LEVEL REPAIR ACTIVITIES
REPAIR MATERIAL COST	MAINTENANCE SUPPORT EQUIPMENT DERIVED FROM UNIT COST. ENGINEERING ESTIMATE 15% OF UNIT COST.
CONDEMNATION RATE	ENGINEERING ESTIMATE OF 1% OF ORU'S
SCHED MAINTENANCE	ENGINEERING ESTIMATE OF SUGGESTED PREVENTIVE MAINTENANCE

Logistics Modeling Groundrules/Assumptions (Cont'd)

This chart is a continuation of the groundrules and assumptions used in developing the inputs for the System Design Utility (SDU) Model.

Logistics Modeling Groundrules/Assumptions (Cont'd)

LUNAR EXCURSION VEHICLE (LEV) SERVICER SYSTEM DESIGN UTILITY INPUTS

CATEGORY	GROUNDRULE/ASSUMPTION
MAINT TRAINING	ENGINEERING ESTIMATE. 10 TIMES CREW REPAIR TRAINING
TOTAL WEIGHT	EXTRAPOLATED FROM PSS ELEMENTS DATA BASE FIR 90 DAY LUNAR/MARS STUDY DATED 1/12/90
CONTAINER COST	DERIVED FROM LEV SERVICER TOTAL VOLUME (REF PSS ELEMENTS DATA BASE) AND FACTOR OF \$100 PER CUBIC FT (20 CU METERS x 35.31 x \$100)
TECH DRAWINGS	ENGINEERING ESTIMATE DETERMINED BY TYPE OF EQUIPMENT MECHANICAL, ELECTRICAL, ELECTRONIC, ELECTRO-MECH 1 PAGE/TYPE

L&L Technical Results

The final subject is overall conclusions of the LTFOS Option 1 Study.

L&L Technical Results

- ❑ Technical Results
  - Level III & IV Requirements
  - Integrated Project Plan
  - Element Description & Sizing Results
  - Results of Internal Studies & Analyses
  - Advanced Development Plan
  - Logistics Modeling Support
  - Conclusions

Conclusions

Conclusions of the LTFOS Option 1 Study

The greater part of this year's study effort was spent supporting the development and definition of concepts and reference architectures, and conducting analyses and quick look assessments.

Conclusions Regarding Reference Architectures

Evaluation of this Reference Architecture Option 5A from a launch and landing perspective indicates that the reference architecture has relatively little impact on the type or nature of launch and landing tasks that must occur. The vehicle must still be landed, safed, cargo unloaded (if applicable), serviced, readied for launch and launched.

However, the features of this reference architecture has an impact on vehicle design. The vehicle must be designed with greater autonomy in mind with regards to testing and servicing. The LEV is strictly a transportation vehicle and as such provides a service. As with any service, it must be reliable, available, and affordable.

Conclusions

- ❑ Conclusions of the LTFOS Option 1 Study
  - Supported the development and definition of concepts and reference architectures
  - Conducted analyses and quick look assessments
- ❑ Conclusions Regarding Reference Architecture 5A
  - Reference Architecture 5A has relatively little impact on the type or nature of launch and landing tasks
    - -- The vehicle must still be landed, safed, cargo unloaded (if applicable), serviced, readied for launch and launched
  - Features of this architecture impact vehicle design
    - -- The vehicle must be designed with greater autonomy for testing and servicing
    - -- The LEV is strictly a transportation vehicle and as such provides a service. As with any service, it must be reliable, available, and affordable.

Conclusions (Continued)

The lunar ejecta analysis indicates that protection for a lunar base would be required either in the form of berms and/or paving. However, the results obtained from the computer-based model are preliminary and are based on soil samples taken from Apollo and damage assessments made available from samples taken from the Surveyor III spacecraft during the Apollo 12 landing. This only provides a single data point. Precursor missions may be required to obtain data which would provide a greater confidence level. This precursor requirement was provided to the MASE trade studies.

The thermal/micrometeoroid protection trade studies resulted in broad conclusions. Vehicle based-protection has a mass penalty associated with it, while surface-based protection requires an increase in surface operations to provide the required protection. A surface based option which does not require assembly or disassembly tends to be the best compromise. Making such an option mobile was one of the objectives of this year's trade studies. A mobile storage facility is more attractive than the A-Frame Tent and the Vehicle Skirt in all aspects. This approach tended to make the surface based option more attractive from an operational standpoint, but was not quite as attractive from the EVA standpoint as an option which is inherent to the design of the vehicle.

Conclusions (Continued)

- Conclusions of Analyses and Quick Look Assessments
  - Ejecta Analysis
    - Protection (berms or paving) will be required
    - Results are preliminary
    - Obtained from the computer model based on a single data point (samples from Surveyor III spacecraft during Apollo 12)
    - Precursor missions required to provide a greater confidence level
    - Precursor requirement was identified in the MASE trade studies.
  - Thermal/Micrometeoroid Protection Trade Studies
    - Vehicle based-protection has an associated mass penalty
    - Surface-based protection increased surface operations and are not as attractive as Vehicle based-protection from the EVA standpoint
    - A surface based option which does not require assembly or disassembly tends to be the best compromise
    - A mobile storage facility is more attractive than the A-Frame Tent and the Vehicle Skirt in all aspects

Conclusions (Continued)

Conclusions of Analyses and Quick Look Assessments

The study of the RL10 engine (Centaur) for lunar prelaunch operations has identified several tests that should be considered for an LEV. One general conclusion that can be drawn is that there are many procedures which are necessary to maintain existing engine design and that any engine which will see repeated in a non-terrestrial envirnoment use should be designed specifically to minimize hands-on servicing.

Several conclusions can be drawn from an LEV Servicer Maintenance Analysis. The current thought is that the LEV would require reliquefaction to conserve propellant which may boil off from the vehicle. However, comparisons with similar technologies indicates that alternatives to the use of reliquefaction or an increase in the reliability of a reliquefaction system are necessary to reduce the number of failures, Secondly, the reliquefaction system, if used, must be designed with maintainability goals in mind. Based on the analysis results, the reliquefaction system could expect as many as 19 failures per year. The communications systems must also be designed with maintainability in mind, as it could expect as many as 18 failures per year and this drives the third conclusions which is to design.

Conclusions (Continued)

- Conclusions of Analyses and Quick Look Assessments
  - Applicability of Centaur Processing Tasks
    - Identified several tasks that should be considered for LEV/MEV L&L operations
    - RL10 engine testing is particularly applicable
    - Engines designed for repeated reuse should be designed specifically to minimize hands-on servicing
  - LEV Servicer Maintenance Analysis
    - Reliquefaction to conserve propellant may not be the best approach without increased system reliability
    - Based on the analysis the reliquefaction system could expect as many as 19 failures per year
    - The communications system associated with the Servicer could expect as many as 18 failures per year
    - Communications systems must be designed with maintainability in mind

Appendix B

Lunar Blast Program

Appendix B

Lunar Blast Program

This appendix contains a description of the Lunar Blast Program. The program was developed by Eagle Engineering, Inc. to assist MDSSC-KSC in conducting its lunar blast ejecta analysis. The attached document describes the theory and assumptions on which the lunar blast program is based. The blast program code is also attached as an appendix to the program theory and description.

Lunar BLAST Program

Prepared for McDonnell Douglas Space Systems Co.
Eagle Engineering, Inc. Report No. 91-8910
April 30, 1991

EAGLE

BLAST Theory and Assumptions

The BLAST program is intended to be a "quick-look" predictor of damage due to lunar ejecta from launch and landing events at a future lunar base.

The basis for the progam is the calculation of the exhaust plume flowfield from the vehicle motor. This calculation is made utilizing the Prandtl-Meyer expansion equations. These equations provide a method of determining the gas velocity, flow angle, and shock angles at various points in the pressure field. These equations depended upon the type of gas being analyzed; they were developed for a sea-level atmosphere. It is assumed that the gases coming out of the lander engine have the same properties as a standard atmosphere. This assumption is made primarily because the gas constant for the propellant is unknown. Future literature searches may provide a value, and hence a more accurate solution. Since the one atmosphere specific heat ratio (gamma) for the engine exhaust is not significantly different from a standard atmosphere, 1.3 vs 1.4, this assumption should not be in great error. The problem is that the vacuum environment causes gas rarification. The effects of rarification on the Prandtl-Meyer model are unknown.

The engine model is that of a Lunar Excursion Module (LEM) descent engine. It is a pressure fed, monomethyl-hydrozene/nitrogen-tetroxide (MMH and N_2O_4, respectively), radiativelly cooled engine. The coefficients used for calculating the throat gas density and total temperature are based upon MMH.

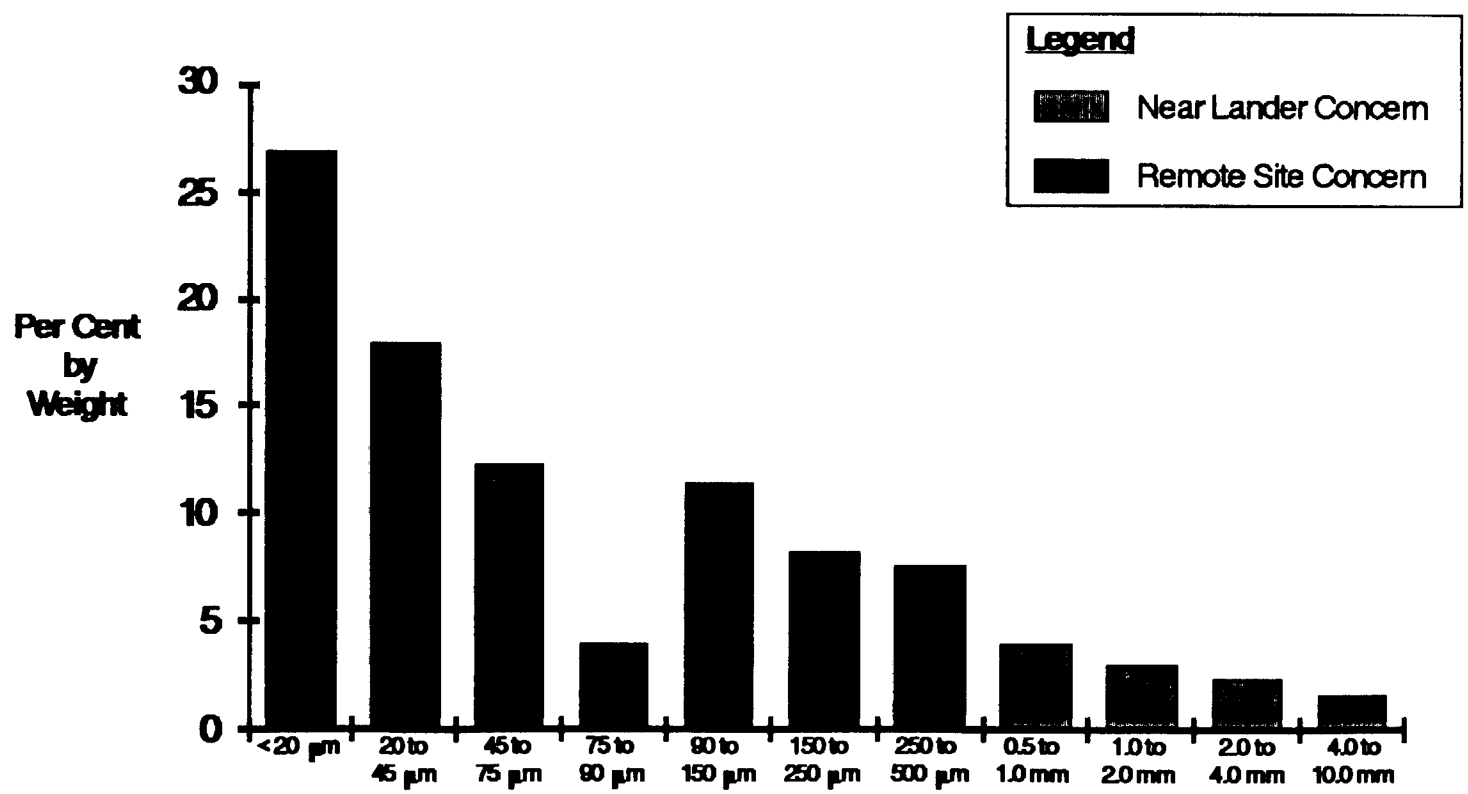
The gas flow is blocked and redirected by the presence of the lunar surface. Prandtl-Meyer theory for a gas leaving the exit surface of a rocket nozzle makes no allowances for gas flow redirection due to external blockages. To account for this problem, a pseudoexit surface is envisioned. The pseudoexit surface is a the vertical cylinder below the nozzle. It has a diameter equal to that of the nozzle exit, and a length which is equal to the nozzle height. This surface is the gas exit surface which is used in the Prandtl-Meyer model. This also requires that the model be modified for the radial expansion effects of the circular exit surface.

In order to calibrate the model to fit the Surveyor damage estimates, the initial position of the particle is chosen to be 17.1 nozzle exit radii from the nozzle centerline. The damage is more sensitive to the particle's initial position than the obscuration factor.

There is a particle "spreading effect" which occurs as the lander approaches the lunar surface. The smaller particles are moved first, when the lander is high. As the lander gets closer to the ground, progressively larger particles are moved, and the smaller particles which have already been moved are pushed farther from the landing site. For the Apollo 11 landing site, a comparison of the particulate size versus percent (by weight) of the lunar regolith is shown in Figure 1.

The BLAST model selects six particulate sizes representing the most damaging to objects far from the landing site. Damage is estimated using artillery models

Figure 1
Lunar Soil Particle Distribution



developed by the Army. A weighted average of the effects of each particle size is used to calculate total damage. The particle sizes and their corresponding weights are shown in Figure 2.

One of the ultimate goals of this activity is to determine the mean particle size as a function distance from the lander. This is a landing trajectory problem which is presently not treated in this model.

The particle's position and velocity are integrated until the gas density is less than .00001 lbs/ft^3. Prandtl-Meyer theory expects the gas to expand to some static atmospheric pressure. The extreme case in which the gas is expanded to a vacuum is not modelled well under this theory. The gas density tends to asymptotically approach a lower limit which is not zero. To handle for this problem, the gas density is adjusted with a correction factor (cf). The correction factor is a weighted function of distance from the nozzle. If the particle is close to the (<10 nozzle radii), then the cf is inversely proportional to the ratio of the distance. Beyond 10 nozzle radii, it is inversely proportional to the ratio of the square of the distance. This means that the gas is expanded radially when it is near the nozzle, and as a source flow when it is far from the nozzle.

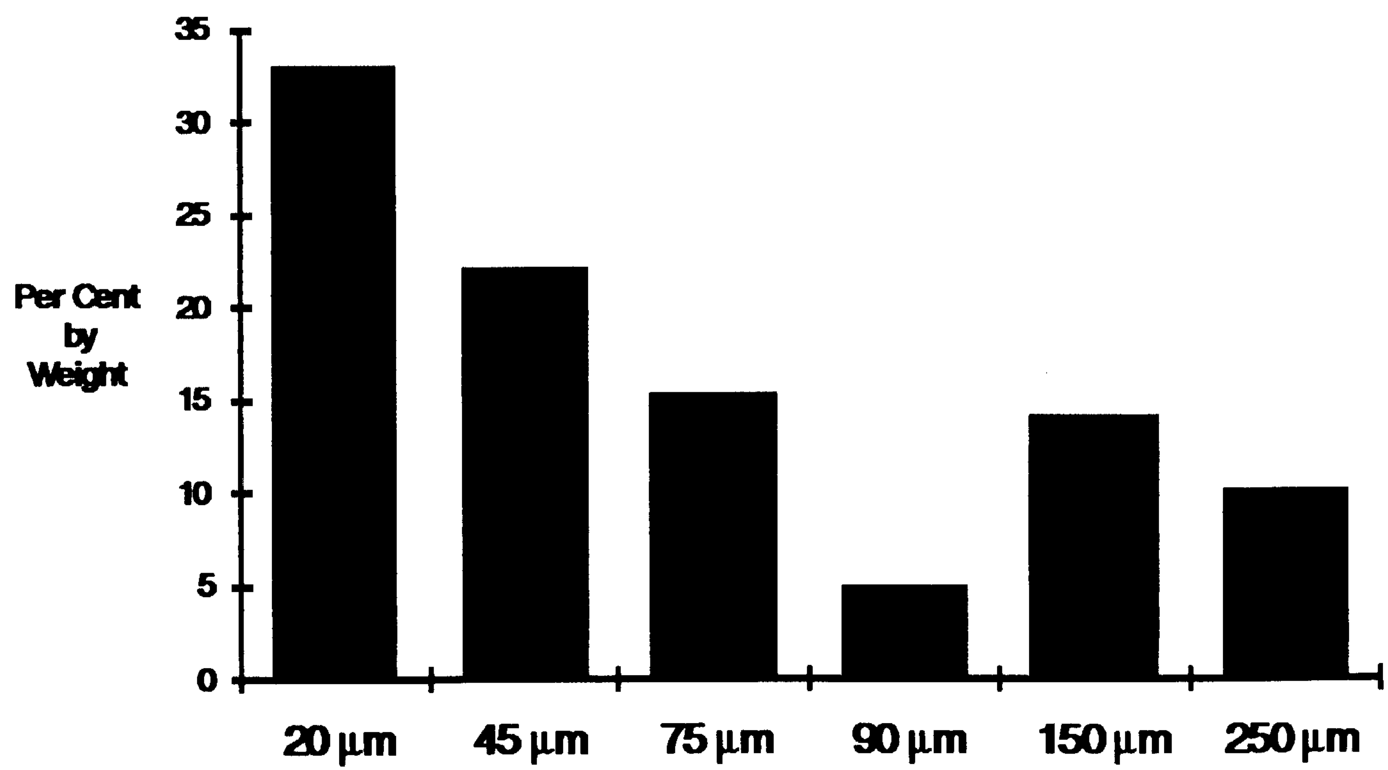
A one dimensional integration of the horizontal velocity is performed. The maximum distance the particle may travel can be approximated by completing a ballistic analysis of a 45° lob using the horizontal velocity.

The astronauts commented that lunar dust had obscured visibility during the landing process. Apollo 15 reported dust movement at an altitude of 45 m. Total obscuration was normal at the time of landing. The "obscuration factor" is the primary method by which BLAST defines the particle flux. This factor is selected to be 50%.

The obscuration is defined to be the loss of visibility through a cubic 1 meter of dust. It should be noted that the astronauts were reporting obscuration of the lunar surface. These obscuration reports are depend upon the thickness of the dust cloud, or – if the lander is in the dust cloud – the height of the lander. Therefore, 100% obscuration simply means that the astronaut could not recognize the surface. The altitude of the lander or the thickness of the dust cloud must be known at the instant in which "100% obscured" is first reported in order to accurately calculate the particle flux. However, the astronauts did not report the first observance of "100% obscured". It must also be understood that recognition and seeing are not the same. An astronaut may be able to see the surface; but since he can not recognize it, he will report "100% obscured". Obviously there are many problems with using obscuration as the defining parameter for flux. Unfortunately, it is the only parameter that we have.

The flux reduces at a rate proportional to the square of the distance from the point at which it is measured. It is assumed that the obscuration measurement is made at a location which is 5 meters from the nozzle center line.

Figure 2
BLAST Particle Distribution



Descent profile for Lunar Lander Blast Program

BLAST is equipped with a trajectory of an Apollo lander, if so desired by the user. The following description covers the lessons of the Apollo flights regarding ejecta as well as the trajectory itself.

Apollos 12 and 15 reported total obscuration during the descent. Apollo 15 observed dust movement at 45 m above the surface, and reported total loss of visibility at 18 m. This was not the general case, however. Apollo 14 observed that the dust was a sheet less than 6" deep moving along the surface; and though which, surface features were always visible. Apollo 11 transcripts indicate the appearance of a "faint shadow" just prior to landing. Apollos 16 and 17, which descended more rapidly, reported first dust movement at altitudes much lower then the previous lunar missions. In Apollo 17, the dust never totally obscured the view of the surface, but was seen to be moving when the lander was at 15 m. Table 1 gives an overview of the dust observations for the various Apollo missions.

Table 1: Apollo Dust Reports

Apollo 11	Location:	South Plain of the Sea of Tranquility	
	Dust	"Kicking up some dust"	30 ft
		"Faint shadow"	Landing
	Descent	2 to 3 ft/s	
Apollo 12	Location:	South-east Plain of the Sea of Storms	
	Dust	Dust Movement	175 ft
		Totally Obscured	50 ft
	Descent	2 to 6 ft/s	
Apollo 14	Location:	Fra Mauro Highlands	
		North of the Sea of Clouds	
	Dust	Dust Movement (6" sheet)	110 ft
		Never Totally Occurred	
	Descent	3 ft/s	
Apollo 15	Location:	Hadley Rille Plain	
		South-east Section of the Sea of Rains	
		(Apennine Mountain)	
	Dust	First Dust	130 ft
		Totally Obscured	60 ft
Apollo 16	Location:	Descartes Highlands	
		Mountains West of the Sea of Nectar	
	Dust	First Dust	80 ft
		Never Totally Obscured	
	Descent	11 to 5 ft/s	

Apollo 17	Location:	Taurus-Littrow Valley	
		South-eastern Edge of the Sea of Serenity	
	Dust	Dust Movement	50 ft
		Never Totally Obscured	

The amount of dust and blown particles is heavily dependent upon the location. It is possible that descent rate could also be a key factor, but the connection is not obvious. If the number of particles is dependent upon location, it is logical to conclude that the blast damage is also location dependent. This means that future modifications to the lunar blast model should have some technique for adjusting the bed dynamics for different soil characteristics.

Figure 3 is a graphical illustration of the vertical descent profiles for Apollos 14, 15, and 17. Apollo 17 appears to have a median trajectory. Therefore, the Apollo 17 trajectory has been selected to be the baseline descent trajectory for the Lunar Blast Model.

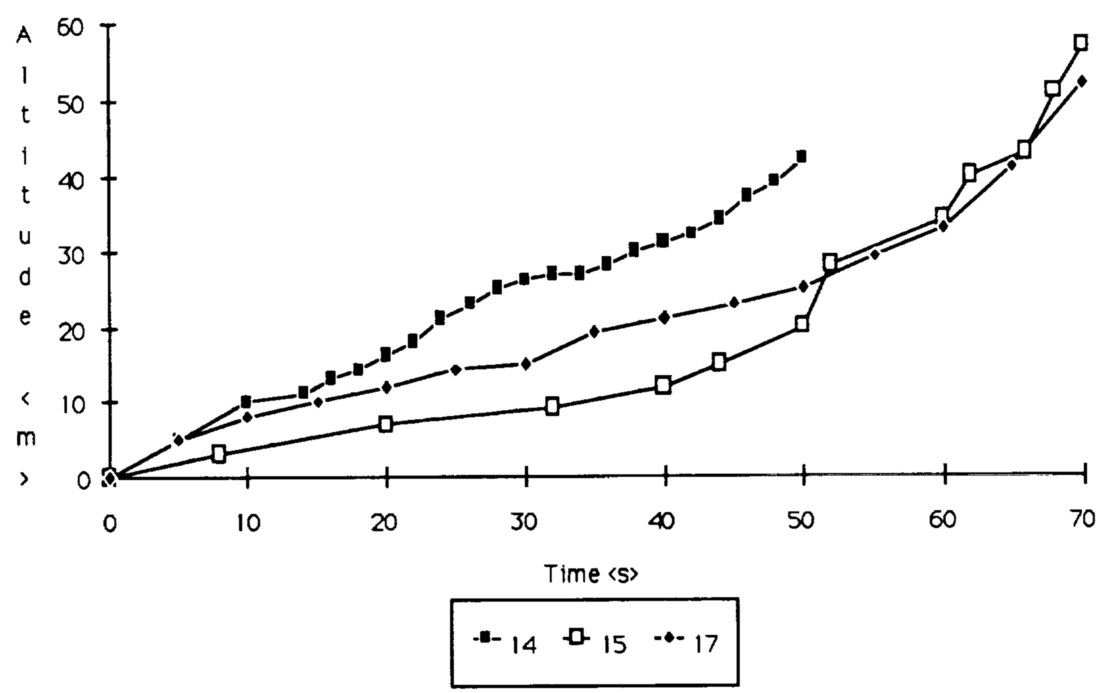


Figure 3: Vertical Descent Profiles

The chosen trajectory is detailed in Table 1.

Table 1 - Altitude versus Time for Apollo 17 Descent

Time <s>	Alt <m>
0	0
5	5
10	8
15	10
20	12
25	14
30	15
35	19
40	21
45	23
50	25
55	29
60	33
65	41
70	52

APPENDIX A

Lunar Trajectory Data

		Apollo						
Number	**Time <s>**	**14**	**15**	**17**	**y**	**yt**	**t^2**	**yt^2**
1	0	0			0	0	0	0
2	5	5			5	25	25	125
3	10	10			10	100	100	1000
4	14	11			11	154	196	2156
5	16	13			13	208	256	3328
6	18	14			14	252	324	4536
7	20	16			16	320	400	6400
8	22	18			18	396	484	8712
9	24	21			21	504	576	12096
10	26	23			23	598	676	15548
11	28	25			25	700	784	19600
12	30	26			26	780	900	23400
13	32	27			27	864	1024	27648
14	34	27			27	918	1156	31212
15	36	28			28	1008	1296	36288
16	38	30			30	1140	1444	43320
17	40	31			31	1240	1600	49600
18	42	32			32	1344	1764	56448
19	44	34			34	1496	1936	65824
20	46	37			37	1702	2116	78292
21	48	39			39	1872	2304	89856
22	50	42			42	2100	2500	105000
23	0		0		0	0	0	0
24	8		3		3	24	64	192
25	20		7		7	140	400	2800
26	32		9		9	288	1024	9216

27	40	12		12	480	1600	19200
28	44	15		15	660	1936	29040
29	50	20		20	1000	2500	50000
30	52	28		28	1456	2704	75712
31	60	34		34	2040	3600	122400
32	62	40		40	2480	3844	153760
33	66	43		43	2838	4356	187308
34	68	51		51	3468	4624	235824
35	70	57		57	3990	4900	279300
36	0		0	0	0	0	0
37	5		5	5	25	25	125
38	10		8	8	80	100	800
39	15		10	10	150	225	2250
40	20		12	12	240	400	4800
41	25		14	14	350	625	8750
42	30		15	15	450	900	13500
43	35		19	19	665	1225	23275
44	40		21	21	840	1600	33600
45	45		23	23	1035	2025	46575
46	50		25	25	1250	2500	62500
47	55		29	29	1595	3025	87725
48	60		33	33	1980	3600	118800
49	65		41	41	2665	4225	173225
50	70		52	52	3640	4900	254800
Sum	1720			1135	51550	78788	2675866

C-3.

BLAST Particle Distribution and Comparisons

Particle Diameter	Initial Position	Obscuration Factor	Al Damage	Glass Damage	Raw Weights	Normalized Weights
20	14.72	0.5	0.61	14	26.85	33.14
45	14.55	0.6	0.64	15	18.02	22.24
75	14.25	0.6	0.56	13	12.4	15.30
90	14.15	0.6	0.55	13	4.01	4.95
150	13.75	0.5	0.62	14	11.51	14.21
250	13.05	0.45	0.64	14	8.23	10.16
				Sum	81.02	100
		Average	0.61	14		

APPENDIX B

BLAST Program Listing

```
1000   DIM C(3, 101), nut(4, 360)
1010 'Constants
1020 pi = 4 * ATN(1)
1030 DTIME = .001                    'Time Step <s>
1040 ROL = 1600                      'Soil Density <kg/m^3>
1070 GL = 1.62                       'Lunar G <m/s^2>
1080 CD = 4                          'Coefficient of Drag
1090 OBS = .5                        'Obscuring Factor
1100 PD = .00015                     'Particle Diameter <m>
1120 BD = 5                          'Blast Duration <s>
1130 CLS
1135 '
1140 'Create the Mach Parameters Table (Mach vs Turning Ang, Mach Ang,
Area Ratio)
1145 '
1150 FOR i = 1 TO 300
1155   mach = 1 + i / 100
1160 ' Calculate the turning angle for Std. air
1165   nu = (2.45 * ATN((.167 * (mach ^ 2 - 1)) ^ .5) - ATN((mach ^ 2 -
1) ^ .5)) * 180 / pi
1170   mu = ATN(1 / (mach ^ 2 - 1) ^ .5) * 180 / pi
1175   Aet = ((1 + .2 * mach ^ 2) / 1.2) ^ 3 / mach
1180   nut(1, i) = mach
1185   nut(2, i) = nu
1190   nut(3, i) = mu
1195   nut(4, i) = Aet
1200 NEXT i
1205 FOR i = 1 TO 30
1210   mach = 4 + i / 10
1215 ' Calculate the turning angle for Std. air
1220   nu = (2.45 * ATN((.167 * (mach ^ 2 - 1)) ^ .5) - ATN((mach ^ 2 -
1) ^ .5)) * 180 / pi
1225   mu = ATN(1 / (mach ^ 2 - 1) ^ .5) * 180 / pi
1230   Aet = ((1 + .2 * mach ^ 2) / 1.2) ^ 3 / mach
1235   nut(1, 300 + i) = mach
1240   nut(2, 300 + i) = nu
1245   nut(3, 300 + i) = mu
1250   nut(4, 300 + i) = Aet
1255 NEXT i
1260 FOR i = 1 TO 6
1265   mach = 7 + i / 2
1270 ' Calculate the turning angle for Std. air
1275   nu = (2.45 * ATN((.167 * (mach ^ 2 - 1)) ^ .5) - ATN((mach ^ 2 -
1) ^ .5)) * 180 / pi
1280   mu = ATN(1 / (mach ^ 2 - 1) ^ .5) * 180 / pi
1285   Aet = ((1 + .2 * mach ^ 2) / 1.2) ^ 3 / mach
1290   nut(1, 330 + i) = mach
1295   nut(2, 330 + i) = nu
1300   nut(3, 330 + i) = mu
1310   nut(4, 330 + i) = Aet
1315 NEXT i
1320 FOR i = 1 TO 10
1325   mach = 10 + i
```

```
1330 ' Calculate the turning angle for Std. air
1335   nu = (2.45 * ATN((.167 * (mach ^ 2 - 1)) ^ .5) - ATN((mach ^ 2 -
1) ^ .5)) * 180 / pi
1340   mu = ATN(1 / (mach ^ 2 - 1) ^ .5) * 180 / pi
1350   Aet = ((1 + .2 * mach ^ 2) / 1.2) ^ 3 / mach
1355   nut(1, 336 + i) = mach
1360   nut(2, 336 + i) = nu
1365   nut(3, 336 + i) = mu
1370   nut(4, 336 + i) = Aet
1375 NEXT i
1380 FOR i = 1 TO 6
1385   mach = 20 + 5 * i
1390 ' Calculate the turning angle for Std. air
1395   nu = (2.45 * ATN((.167 * (mach ^ 2 - 1)) ^ .5) - ATN((mach ^ 2 -
1) ^ .5)) * 180 / pi
1400   mu = ATN(1 / (mach ^ 2 - 1) ^ .5) * 180 / pi
1405   Aet = ((1 + .2 * mach ^ 2) / 1.2) ^ 3 / mach
1410   nut(1, 346 + i) = mach
1415   nut(2, 346 + i) = nu
1420   nut(3, 346 + i) = mu
1425   nut(4, 346 + i) = Aet
1430 NEXT i
1435 FOR i = 1 TO 5
1440   mach = 50 + 10 * i
1445 ' Calculate the turning angle for Std. air
1450   nu = (2.45 * ATN((.167 * (mach ^ 2 - 1)) ^ .5) - ATN((mach ^ 2 -
1) ^ .5)) * 180 / pi
1452   mu = ATN(1 / (mach ^ 2 - 1) ^ .5) * 180 / pi
1454   Aet = ((1 + .2 * mach ^ 2) / 1.2) ^ 3 / mach
1456   nut(1, 352 + i) = mach
1458   nut(2, 352 + i) = nu
1460   nut(3, 352 + i) = mu
1462   nut(4, 352 + i) = Aet
1464 NEXT i
1466 mach = 1000
1468 'Calculate the turning angle for Std. air
1470 nu = (2.45 * ATN((.167 * (mach ^ 2 - 1)) ^ .5) - ATN((mach ^ 2 -
1) ^ .5)) * 180 / pi
1472 mu = ATN(1 / (mach ^ 2 - 1)) * 180 / pi
1474 Aet = ((1 + .2 * mach ^ 2) / 1.2) ^ 3 / mach
1476 nut(1, 358) = mach
1478 nut(2, 358) = nu
1480 nut(3, 358) = mu
1482 nut(4, 358) = Aet
1484 mach = 10000
1486 'Calculate the turning angle for Std. air
1488 nu = (2.45 * ATN((.167 * (mach ^ 2 - 1)) ^ .5) - ATN((mach ^ 2 -
1) ^ .5)) * 180 / pi
1490 mu = ATN(1 / (mach ^ 2 - 1) ^ .5) * 180 / pi
1492 Aet = ((1 + .2 * mach ^ 2) / 1.2) ^ 3 / mach
1494 nut(1, 359) = mach
1496 nut(2, 359) = nu
1498 nut(3, 359) = mu
```

```
1500 nut(4, 359) = Aet
1502 mach = 100000
1504 'Calculate the turning angle for Std. air
1506 nu = (2.45 * ATN((.167 * (mach ^ 2 - 1)) ^ .5) - ATN((mach ^ 2 -
1) ^ .5)) * 180 / pi
1508 mu = ATN(1 / (mach ^ 2 - 1) ^ .5) * 180 / pi
1510 Aet = ((1 + .2 * mach ^ 2) / 1.2) ^ 3 / mach
1512 nut(1, 360) = mach
1514 nut(2, 360) = nu
1516 nut(3, 360) = mu
1518 nut(4, 360) = Aet
1520 'User Inputs
1530 INPUT "Engine Thrust <n>                          = "; TR
1540 INPUT "Nozzle Height <m>                          = "; NH
1550 INPUT "Object's Distance from the Landing Site <m>= "; DLS
1560 thrst = TR / 4.4482                  'Thrust (lbs)
1570 isp = 302                           'Specific impulse
1580 ER = 43                             'Expansion Ratio
1590 p0 = 102 * 144                       'Chamber Pressure = 102 psia
1600 t0 = 5350                           'Chamber Temp. -- H2O4/MMH (R)
1610 RC = 53.3                            'Gas Constant (Std. Air)
1620 dens0 = p0 / RC / t0                 'Chamber Density-Approx.(lb/ft^3)
1630 denst = .63394 * dens0               'Throat Density (lb/ft^3)
1640 wdot = thrst / isp                   'Weight Flow Rate (lb/s)
1650 tt = .83611 * t0                     'Throat Temperature (R)
1660 sost = (1.4 * RC * 32.174 * tt) ^ .5      'Throat Speed of Sound (ft/s)
1670 At = wdot / dens0 / sost             'Throat Area (ft)
1680 re = (At * ER / pi) ^ .5             'Nozzle Exit Radius (ft)
1690 Aes = 2 * pi * re * NH * .3048              'Pseudoexit Surface Area (ft)
1700 '
1710 'Determine the pseudoexit surface mach number.  If the area of the
exit
1720 'surface is less than the throat area, then the exit surface mach
number
1730 'is 1.  1.000001 is used to prevent mathematical division errors.
1740 '
1750 maches = 1.000001
1760 IF Aes / At < 1 THEN 1800
1770   FOR i = 1 TO 359
1780     IF Aes / At > nut(4, i) THEN maches = (nut(1, i + 1) - nut(1, i)) /
(nut(4, i + 1) - (nut(4, i)) * (Aes / At - nut(4, i))) + nut(1, i)
1790   NEXT i
1800 'END IF
1810 '
1820 'Compute the pseudoexit surface turning angle (deg)
1830 '
1840 nues = (2.45 * ATN((.167 * (maches ^ 2 - 1)) ^ .5) - ATN((maches
^ 2 - 1) ^ .5)) * 180 / pi
1850 '
1860 'Compute the surface location of the mach line if it contacts the
ground
1870 'the nozzle bell (turning angle is less than 85 degrees)
1880 '
```

```
1890 xml = 0
1900 IF nues >= 85 THEN 1920
1910   xml = re - NH * .3048 * TAN(nues * pi / 180)
1920 'END IF
1925 '
1930 'Calculations
1935 '
1950 RA = pi * PD ^ 2 / 4              'Ref. Area <m^2>
1960 PV = pi * PD ^ 3 / 6              'Particle Volume <m^3>
1970 PM = ROL * PV            'Particle Mass <kg>
1980 PRINT : PRINT : PRINT "Calculating Velocity of 150 Micron
Particles": PRINT
1985 PRINT "Percent Complete", "Velocity <m/s>"
1990 GOSUB 10010              'Particle Impact Velocity
2000 LOCATE 5, 1
2010 PRINT USING "& ####"; "150 Micron Particle Impact Velocity
<m/s> ="; XD
2020 GOSUB 14010              'Particle Damage
2030 PRINT USING "& ##.#^^^^"; "Particle Crater Diameter - Al 2024T3
<mm> : "; PCDA
2040 PRINT USING "& ##.#^^^^"; "Particle Crater Diameter - Glass Blt
<mm> : "; PCDG
2050 GOSUB 16010              'Particle Flux
2060 PRINT USING "& ######"; "Particle Flux <#/cm^2/s>
="; PFX
2070 DAMA = PFX * BD * pi * (PCDA / 10) ^ 2 / 4
2080 IF DAMA > 1 THEN DAMA = 1
2090 DAMG = PFX * BD * pi * (PCDG / 10) ^ 2 / 4
2100 IF DAMG > 1 THEN DAMG = 1
2110 PRINT : PRINT "For a 5 second exposure at "; DLS; "meters:"
2120 PRINT USING "###.#  &"; DAMA * 100; " Percent of an Aluminum
Surface is Pitted"
2130 PRINT USING "###    &"; DAMG * 100; " Percent of a Glass
Surface is Pitted"
2140 END
10000 ' -------------------------------------------------------------
10010 '|              Particle Impact Velocity                      |
10020 ' -------------------------------------------------------------
10030 x = (re * 17.1) * .3048          'Initial conditions
10050 XD = 0
10070 TIME = 0
10120 GOSUB 11020                      'gas density and velocity
10130 'Impulsive Force
10140 FIMP = .5 * DENS * 16.02 * (VELO * .3048) ^ 2 * RA * CD
10150 'Acceleration (question the Absolute)
10160 XDD = FIMP / PM
10180 'Local particle Gs
10190 GP = FIMP / PM / GL
10200 'PRINT "time  x   y  r  t   xd  yd  xdd  ydd  fimp  rog  vg
gp"
10210 'PRINT USING "#.## ###.# ###.# ##.# ##.## ###.# ##.# ####
###.# #^^^^ #^^^^ #### ###.#"; time; x; y; r; t; xd; yd; xdd; ydd; Fimp;
ROg; Vg; Gp
```

```
10220 IF DENS < .00001 THEN 10260
10230   GOSUB 13010                    'Integrate
10240 ' PRINT USING "#.## ###.# ###.# ##.# ##.## ###.# ##.# ####
###.##^^^^ #^^^^ #### ###.#"; time; x; y; r; t; xd; yd; xdd; ydd; Fimp;
ROg; Vg; Gp
10250   GOTO 10220
10260 'END IF
10270 RETURN
11000 ' ----------------------------------------------------------------
11010 '|                 Gas Density and Velocity                  |
11020 ' ----------------------------------------------------------------
11030 '
11040 'If the particle's position is inside the mach line, then assume that
11050 'the gas flow is choked; the mach number is 1.  Otherwise Expand
the
11060 'flow with the assumptions of Prandtl-Meyer theory.
11070 '
11080 IF x / .3048 < xml THEN
11090   mach = 1
11100   DENS = denst
11110   temp = tt
11120   VELO = sost
11130   theta = 0
11140 ELSE
11150 '
11160 ' Calculate the expansion wave surface angle (deg)
11170 '
11180   NUMOR = NH / .3048: DENOM = x / .3048 - re: GOSUB 17000
'ArcTan 360
11190   theta = angle * 180 / pi
11200 '
11210 ' Determine the local mach number
11220 '
11230   FOR i = 1 TO 359
11240     mtheta = nut(3, i) - nut(2, i) + nues
11250     mthetap1 = nut(3, i + 1) - nut(2, i + 1) + nues
11260     IF theta < mtheta THEN mach = (nut(1, i + 1) - nut(1, i)) /
(mthetap1 - mtheta) * (theta - mtheta) + nut(1, i)
11270   NEXT i
11280   dl0 = (1 / (1 + .2 * mach ^ 2)) ^ 2.5         'Gas Density Ratio
11290 '
11300 ' If the particle is far from the nozzle (i.e. >10*re) then expand the
11310 ' source flow two dimensionally, otherwise expand Prandtl-Meyer
radially.
11320 '
11330   r = (NH ^ 2 + x ^ 2) ^ .5 / .3048          'Distance in ft
11340   IF r > 100 * re THEN PRINT "Negative Weighting Being Com-
puted!"
11350   w2 = LOG(r / re) / LOG(10) / 2
11360   w1 = 1 - w2
11370   cf = w1 * (re / r) + w2 * (re / r) ^ 2
11380   dc0 = cf * dl0                          'Corrected Gas Density Ratio
11390   machc = ((1 / dc0 ^ (1 / 2.5) - 1) / .2) ^ .5          'Corrected Mach
Number
```

```
11400   DENS = dens0 * dc0                      'Local Gas Density (lb/ft^3)
11410   temp = t0 / (1 + .2 * machc ^ 2)              'Local Gas Temperature
(R)
11420   sos = (1.4 * 53.3 * 32.174 * temp) ^ .5            'Local Speed of
Sound (ft/s)
11430   VELO = machc * sos                      'Local Gas Velocity (ft/s)
11440 END IF
11450 RETURN
13000 ' ------------------------------------------------------------------
13010 '|                    Integrate                            |
13020 ' ------------------------------------------------------------------
13025 LOCATE 10, 1: PRINT LOG(DENS) / LOG(.00001) * 100, , XD
13030 x = x + XD * DTIME + .5 * XDD * DTIME ^ 2
13050 XD = XD + XDD * DTIME
13070 TIME = TIME + DTIME
13120 GOSUB 11020                    'gas density and velocity
13130 'Impulsive Force
13140 FIMP = .5 * DENS * 16.02 * (VELO * .3048) ^ 2 * RA * CD
13150 'Acceleration (question the Absolute)
13160 XDD = FIMP / PM
13180 'Local particle Gs
13190 GP = FIMP / PM / GL
13200 RETURN
14000 ' ------------------------------------------------------------------
14010 '|                    Particle Damage                      |
14020 ' ------------------------------------------------------------------
14030 TRA = (pi * PD ^ 3 / 6) ^ (2 / 3)             'THOR Ref. Area
<m^2>
14040 TRA = TRA / .3048 ^ 2 * 12 ^ 2                '           <in^2>
14050 ROP = 3.34 * 100 ^ 3                          'Projectile Density
<g/m^3>
14060 TPM = pi * PD ^ 3 / 6 * ROP                   'Projectile Mass <g>
14070 TPM = TPM / 453.6 * 7000                '          <grains>
14080 TV = SQR(XD ^ 2 + YD ^ 2) / .3048  'THOR Velocity <ft/s>
14090 IA = 0                                        'Impact Angle <rad>
14100 'THOR Coefficients for Aluminum 2024-T3
14110 C1 = 6.185: ALPHA1 = .903: BETA1 = -.941: GAMMA1 = 1.098
14120 GOSUB 15010                                   'THOR Equations
14130 PCDA = PDI
14140 'THOR Coefficients for Bullet Resistant Glass
14150 C1 = 6.991: ALPHA1 = 1.316: BETA1 = -1.351: GAMMA1 =
1.289
14160 GOSUB 15010                                   'THOR Equations
14170 PCDG = PDI
14180 RETURN
15000 ' ------------------------------------------------------------------
15010 '|                    THOR Equations                       |
15020 ' ------------------------------------------------------------------
15030 PDE = ((TV / (10 ^ C1 * TPM ^ BETA1 * (1 / COS(IA)) ^ GAM-
MA1)) ^ (1 / ALPHA1)) / TRA
15040 PDI = PDE * 2.5                'Crater Diameter = 2.5 * Penetration
Depth
15050 PDI = PDI * 25.4               'Crater Diameter <mm>
```

```
15060 RETURN
16000 ' ---------------------------------------------------------------
16010 '|                      Particle Flux                            |
16020 ' ---------------------------------------------------------------
16030  NOP = OBS / RA                                    'Number of Particles
<#/m^2>
16040 'Assume that the obscuring applies to a 1 meter depth
16050  NOP = NOP * 1                                     'Number of Particles
<#/m^3>
16060  PFXI = NOP * SQR(XD ^ 2 + YD ^ 2)                 'Initial Particle Flux
<#/m^2/s>
16070 'Initial distance from the landing site for 1 cubic meter volume <m>.
16080  DI = 5
16090  PFX = PFXI * (DI / DLS) ^ 2                       'Final Particle Flux
<#/m^2/s>
16100  PFX = PFX * .0001                                 'Particle Flux
<#/cm^2/s>
16110 RETURN
17000 ' ---------------------------------------------------------------
17010 '|                      ArcTan360                                |
17020 ' ---------------------------------------------------------------
17030 '
17040  IF NUMOR > 0 AND DENOM = 0 THEN 17050 ELSE 17070
17050    angle = pi / 2
17060    GOTO 17240
17070 'ELSE
17080    IF DENOM = 0 THEN 17090 ELSE 17110
17090      angle = 3 * pi / 2
17100      GOTO 17230
17110 '  ELSE
17120      IF (NUMOR > 0 OR NUMOR = 0) AND DENOM > 0 THEN
17130 ELSE 17150
17130        angle = ATN(NUMOR / DENOM)
17140        GOTO 17220
17150 '    ELSE
17160        IF NUMOR < 0 AND DENOM > 0 THEN 17170 ELSE 17190
17170          angle = 2 * pi + ATN(NUMOR / DENOM)
17180          GOTO 17210
17190 '      ELSE
17200          angle = pi + ATN(NUMOR / DENOM)
17210 '      ENDIF
17220 '    ENDIF
17230 '  ENDIF
17240 'ENDIF
17250  RETURN
```

Appendix C

Data and Calculations

Supporting the Thermal/Micrometeoroid Protection Trade Study

Mass Estimates

Appendix C

Data and Calculations

Supporting the Thermal/Micrometeoroid Protection Trade Study

Mass Estimates

This appendix contains the data and calculations which were used in the Thermal/Micrometeoroid Protection Trade Study to make mass estimates of each of the four protection options. The data is presented in a spreadsheet fashion.

VEHICLE SELF-PROTECTION

Assume the need to protect from the cargo interface to the engine bell exit:

Height: 17 ft.
Radius: 13 ft.
Fabric mass 2.12 lb/yd^2 (Assume 1/3 PSS mass added to existing insulation)

Cylinder surface = (pi)(R^2)(h)
= 3.1416*13^2*17 = 9025.816 sq.ft.
Engine area cover = pi(R^2) = 3.1416*13^2 = 530.9304

Total cover area = 9556.747 sq.ft.

Cover Area (sq.ft.)	9,557
(sq.yd.)	1,062
Fabric Mass (lbs.)	2,251
(kg)	1,023
Support/Deployment Hardware (lbs)	174
(kg)	79
Total mass (lbs)	2,425
(kg)	1,102

THERMAL BLANKET AND A-FRAME TENT

Aluminum poles: 6 inch dia with 1/8" wall, 3/16" wall, or 1/4" wall

1/8" wall thickness:

circumference = 3.14 (6) = 18.84 inches

in^3/ft of pole: 18.84(0.125)(12) = 28.26 in^3

mass/ft of pole (@ 0.098lbs/in^3): 28.26(0.098) = 2.76948

3/16" wall thickness:

(1.5 times 1/8 wall)

1.5(2.76948) = 4.15422 lbs/ft

1/4" wall thickness:

(2 times 1/8 wall)

2(2.76948) = 5.53896 lbs/ft

	Wall Thickness 1/8"	3/16"	1/4"
60 ft vertical pole (ea):	166.17	249.25	332.34
40 ft ridge pole:	110.78	166.17	221.56
Hyp = (60^2+20^2)^0.5 =	63.24555		
Total pole mass (lbs):	443.12	664.68	886.23

Thermal blanket (Orcofilm AN-22 or SSF MLI):

Top Area = 64*40*2 =	5,120 ft^2 =	569 yd^2
End Area = 60*40*0.5*2 =	2,400 ft^2 =	267 yd^2
Total Area =	7,520	836 yd^2
Fabric Mass @ 6.35lb/yd^2	5,306 lbs	2,412 kg

Drive mechanism (2 ea):	50	100	100
Misc attach hardware:	25	50	50
Total misc:	75	150	150
TOTAL MASS (lbs)	5,824	6,120	6,342
(kg)	2,647	2,782	2,883

LANDER SKIRT

Height:	20 ft.
Top radius:	13 ft.
Bottom radius:	19.5 ft.
Fabric mass	6.35 lb/yd^2

Conical surface = (pi)(R)(R^2 + h^2)^0.5

Total cone =	3.1416*19.5*(19.5^2+60^2)^0.5 =	3864.921
Truncated part =	3.1416*13*(13^2+40^2)^0.5 =	1717.742

Truncated cone (manned vehicle) =		2147.178 sq.ft.
Top cover = pi(R^2) = 3.1416*13^2 =		530.9304

Truncated cone + cover (unmanned vehicle) =		2678.108 sq.ft.

	Unmanned Vehicle	Manned Vehicle
Cover Area (sq.ft.)	2,678	2,147
(sq.yd.)	298	239
Fabric Mass (lbs.)	1,890	1,515
(kg)	859	689
Hoisting Hardware (lbs)	400	400
(kg)	182	182
Total mass (lbs)	2,290	1,915
(kg)	1,041	870

ERECTABLE STORAGE FACILITY

Each Bay: 45 ft deep x 45 ft high x 45 ft wide
Errectable Trusses: 119 lbs each
Truss plates: 28 lbs each (top and bottom of each truss)
Alignment-Compression Bars: 3.38 lb/ft
Tension Cross Braces: 0.03 lb/ft
Deployment mechanism 170 lbs
Cover Fabric: 6.35 lb/yd^2

		One Bay	Two Bays	Three Bays
Errectable Trusses:	(No.)	4	6	8
	(lbs)	476	714	952
	(kg)	216	325	433
Truss Plates:	(No.)	8	12	16
	(lbs)	224	336	448
	(kg)	102	153	204
Alignment-Compression Trusses				
	(linear feet)	360	630	900
	(lbs)	1,217	2,129	3,042
	(kg)	553	968	1,383
Tension Cross Braces				
	(linear feet)	640	1024	1408
	(lbs)	19	31	42
	(kg)	9	14	19
Deployment Mechanism	(No.)	1	1	1
	(lbs)	170	170	170
	(kg)	77	77	77
Fabric Cover	(sq.ft.)	8,100	12,150	16,200
	(sq.yd.)	900	1,350	1,800
	(lbs)	5,715	8,573	11,430
	(kg)	2,598	3,897	5,195
TOTAL FACILITY	(lbs)	7,821	11,953	16,084
	(kg)	3,555	5,433	7,311

Appendix D

Assumptions, Data, and Flowcharts

Supporting EVA Man-hour Estimates

for the

Thermal/Micrometeoroid Protection Trade Study

Appendix D

Assumptions, Data, and Flowcharts

Supporting EVA Man-hour Estimates

for the

Thermal/Micrometeoroid Protection
Trade Study

Contained is a description of the the operations that would be required to implement the three surface-based protection options. From this description, flowcharts were generated. The flow charts illustrate the flow of tasks to use the three surface-based protection options. Associated with each of the tasks is a timeline which was generated by using equivalent KSC operations to make time estimates. These time estimates were used in the trade study to make a comparative analyses of each of the protection options.

EVA-MANHOUR ESTIMATES FOR THE LUNAR THERMAL/MICROMETEOROID OPTIONS

The following discussion explains the scenarios associated with the erection of three protection options - the storage facility, the vehicle skirt, and the A-frame options.

The scenarios assume that there are two astronauts performing the assembly steps. They are performing simultaneous tasks in close proximity. However, one is not acting as an observer for the other. The man-hour estimates are based on similar earth tasks and do not take into account the complexities or limiting factors on the lunar surface.

STORAGE FACILITY ERECTION SCENARIO

Prior to beginning the erection of the storage facility, the site would have to be prepared. Surveying can be done using precursor space craft which would survey the lunar surface, looking for suitable sites for establishing a lunar base. Even though a site is suitable for a base, it may still require grading and other regolith moving activities. For this reason the site preparations are not included in the EVA man-hour estimates for the erection of a storage facility. (They are not included in the other protection options either.)

The activities which are included in the scenario for storage facility erection are illustrated in figure A-1. This scenario begins with the facility preparations. The facility kit is removed from the lander, transported to the erection site and unpacked.

Once the facility kit is at the erection site, the trusses, along with the spacing/alignment bars will be removed from the containers. The trusses and the spacing alignment bars will be positioned and connected.

Then the roofing system and its bracing will be installed. This activity will require the erection and position of fabric support stands which will be use to deploy and attach the roofing and sides. Once the roofing is installed the sides will be positioned and attached to the truss structures.

Once all the protection material is attached to the trusses, the trusses will be raised and the tension cables will be tightened to rigidize the structure. Then the fabric support stands will be stored.

The storage facility does not require repetitive erection. The only tasks that will be repetitive will be the moving of the vehicle to the storage facility. This activity adds 13:50 hours to the EVA man-hours associated with protecting the vehicle and preparing it for each flight.

The preparation and the moving of the vehicle into storage is depicted in figure A-1A. The storage facility has a distinct advantage of permitting the storage of several vehicles and associated equipment under the same protective system if sized for more than one vehicle. This maximizes commonality and minimizes the total required protective system mass. The vehicle, once it lands will have fuel and oxidizer onboard. The presence of these commodities in proximity on the vehicle poses a hazard. This hazard is compounded if several vehicles are close to each other. A catastrophic event may cause the loss of several vehicles and pieces of support equipment. For this reason, removal of either the fuel or the oxidizer would reduce the hazard level.

The vehicle must be raised, either by using jacks or a hoisting mechanism. After raising the vehicle, either wheel assemblies will be attached or a wheeled dolly will be positioned under the vehicle and the vehicle will be lowered. The tow bar will be attached and then the vehicle will be transferred to the storage facility. It will be positioned and the vehicle and handling equipment will be secured.

A-FRAME ERECTION SCENARIO

The A-frame tent option requires the removal of the tent from storage and its erection around the vehicle at its landing site which should also be a prepared site. However, the tent does require erection tasks that will be repetitive from mission to mission. The scenario associated with this task is illustrated in figure A-2.

To provide protection using the A-frame tent, the tent will have to be removed from storage and taken to the the landing site. The assembly of the A-frame involves using truss-like structures for two 60 foot vertical poles and one 40 foot ridge pole. The blanket support frame will be assembled, positioned on the surface, attached to opposite flight vehicle lander legs, and the erection drive mechanism will be attached. The near-side edge of the blanket will be secured to the surface by stakes or weights, and the far-side will be attached to the frame guy wires. The frame will be erected to an upright position, deploying the near-side half of the blanket and its guy wires in the process. The far guy wires will be extended to form an A-frame the surface; and then the far-side edge of the blanket will be lowered to the surface and secured.

The A-frame also requires a disassembly scenario which is the reverse of the erection scenario and includes dispatching the crew to the pad to remove the blankets, unstake the guy wires, lower the support frame, remove the blankets form the frame and stowing them, disassembling the frame and returning the disassembled A-frame tent to storage.

LANDER SKIRT OPTION

The scenario associated with this option is illustrated in figure A-3. The lander skirt is similar to the A-frame tent in concept. The skirt would have to be removed from storage and taken to the landing site where it would be attached to the side of the lander.

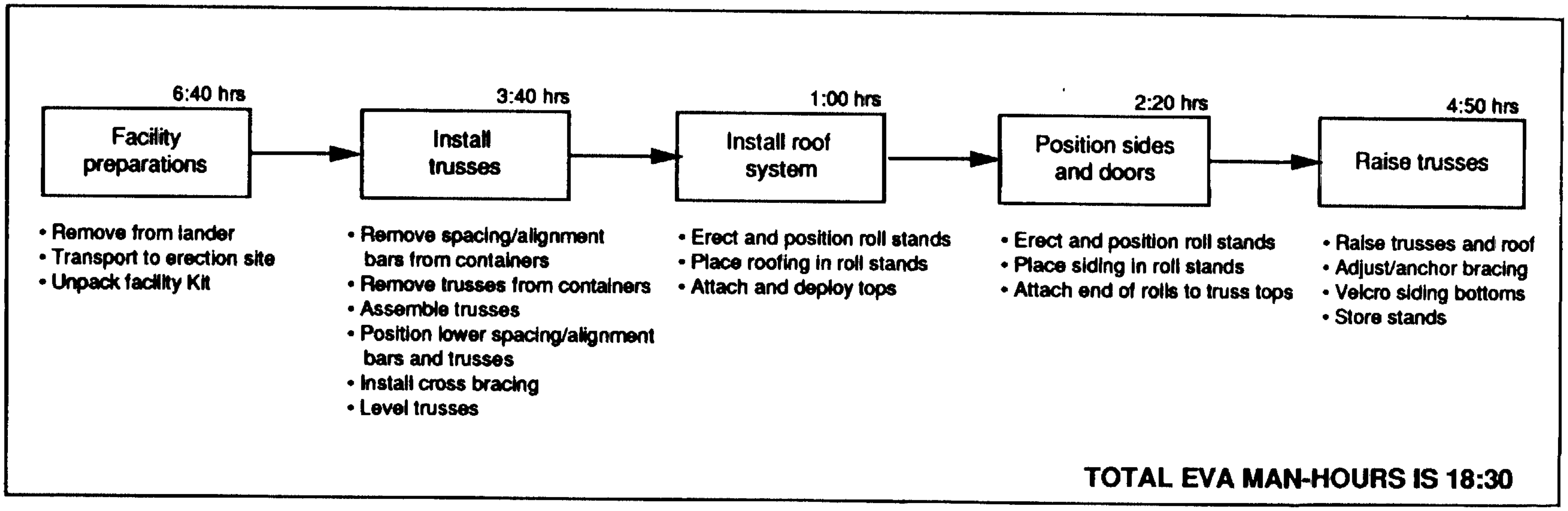
However, unlike the A-frame, the skirt concept depends upon the lander to provide the frame to which the skirt could be attached. It also requires considerable handling equipment because the skirts would have to be hoisted and suspended while EVA crewmembers make the final attachment.

This concept requires the assembly of a hoisting mechanism, attaching the blankets to the hoisting mechanism and raising the blankets to the location on the vehicle to where they will be attached. Once the blankets are attached the hoisting mechanism will have to be disassembled and returned to storage.

To prepare the vehicle for launch, the removal of the skirt would require the reverse of the assembly steps. These tasks are repetitive for each vehicle and for each flight.

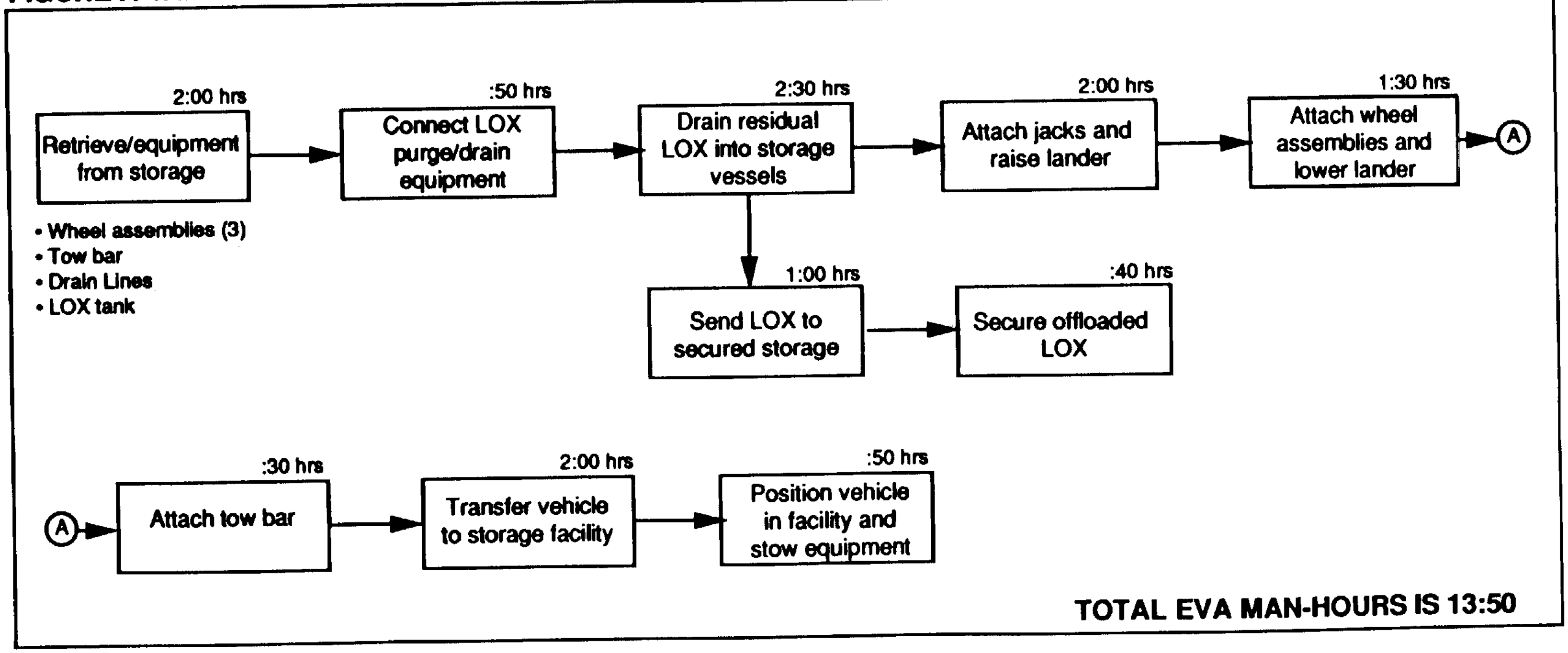
SCENARIO DEPICTING THE ACTIVITIES ASSOCIATED WITH THE ERECTION OF THE STORAGE FACILITY

FIGURE A-1. STORAGE FACILITY ERECTION



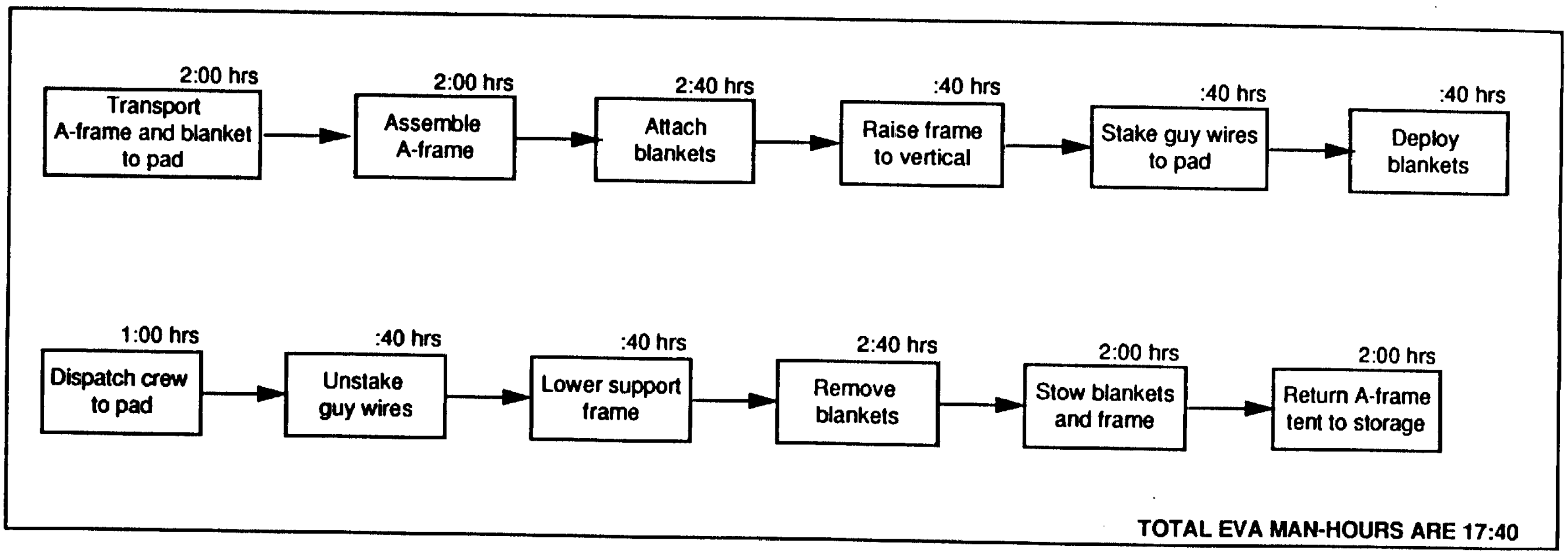
SCENARIO DEPICTING THE ACTIVITIES ASSOCIATED WITH PLACING VEHICLES IN THE STORAGE FACILITY

FIGURE A-1A. PREPARATION OF LANDERS FOR THE STORAGE FACILITY



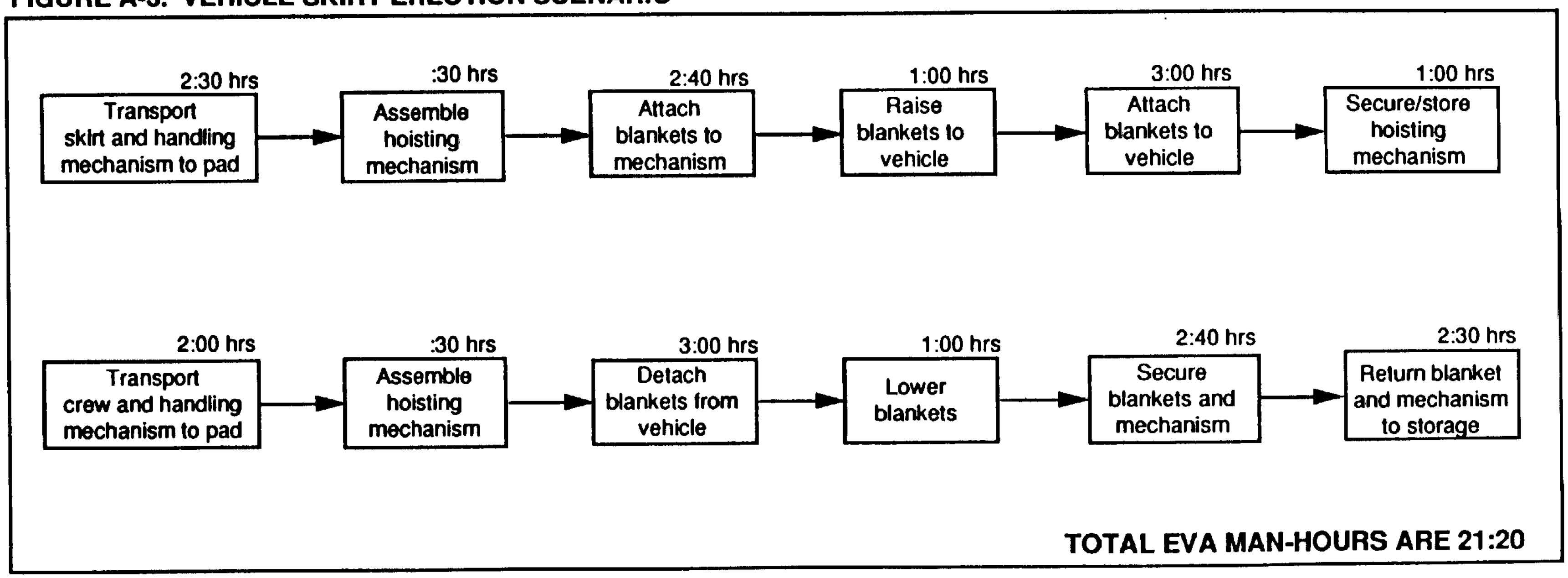
SCENARIO DEPICTING THE ACTIVITIES ASSOCIATED WITH THE ERECTION OF THE A-FRAME TENT

FIGURE A-2. A-FRAME TENT ERECTION



SCENARIO DEPICTING THE ACTIVITIES ASSOCIATED WITH THE VEHICLE SKIRT OPTION

FIGURE A-3. VEHICLE SKIRT ERECTION SCENARIO



Appendix E

Database Records

Of

Centaur Test Procedure Analysis

Appendix E

Database Records

Of

Centaur Test Procedure Analysis

This appendix contains a printout of the database that was compiled by conducting an analysis of Centaur prelaunch test procedures. The analysis was conducted to identify possible prelaunch tests that would be required if using a liquid oxygen and liquid hydrogen expansion cycle engine on a Lunar Excursion Vehicle. The basis of the analysis was the Pratt and Whittney RL-10 engine. Database fields include the Centaur Test Procedure number, a description f the test, remarks, resources required for the test, schedule data, special test equipment, and a recommendation of whether the test should be retained, reduced in some manner, or deleted, for Planetary Surface Systems launch and landing operations.

CENTAUR TEST PROCEDURE

CTP: CCLS VALIDATION

Old CTP No. CCLS-5000 **New CTP No.** CCLS-0001

Description Verifies proper operation of the computer controlled launch set interfaces (ground equipment, computer, peripherals and digital communication landlines) through the use of tenant validation programs.

Remarks Run prior to vehicle support

AC68 RESOURCES:

Ground Power [X] **Vehicle Power** [ ] **Pneumatics** [ ] **CCLS** [X]

Total Personnel 3 : **Engr** 1 **Tech** 1 **Insp** 1 **Safety** ____

AC68 SCHEDULE DATA:

Start Date 05/22/89 **Shifts** 5 **Serial Operation** [X] **Parallel Operation** [ ]

SPECIAL TEST EQUIPMENT

PSS RECOMMENDATION: **Retain** [ ] **Reduce** [X] **Delete** [ ]

Rationale: Run a much shorter version for PSS computer system.

CENTAUR TEST PROCEDURE

CTP: CCLS CALIBRATION

Old CTP No. CCLS-5002 **New CTP No.** CCLS-0002

Description Procedure for calibrating CCLS analog system, CCLS power supplies and digital interface frequency generators.

Remarks

AC68 RESOURCES:

Ground Power ☐ Vehicle Power ☐ Pneumatics ☐ CCLS ☐

Total Personnel 3 : Engr ___ Tech ___ Insp ___ Safety ___

AC68 SCHEDULE DATA:

Start Date Shifts 3 Serial Operation ☐ Parallel Operation ☐

SPECIAL TEST EQUIPMENT Voltmeter
Special Receivers

PSS RECOMMENDATION: Retain ☐ Reduce ☒ Delete ☐

Rationale: Reduce scope and modify for PSS computer system.

CENTAUR TEST PROCEDURE

CTP: DCU FUNCTIONAL

Old CTP No. DCU-5000T **New CTP No.**

Description The vehicle flight computer (DCU) is subjected to a series of tests involving the memory, sum and instruction tasks, constants loading, and interupt-clock-communications tests.

Remarks

AC68 RESOURCES:

Ground Power ☐ Vehicle Power ☐ Pneumatics ☐ CCLS ☐

Total Personnel 2 : Engr ___ Tech ___ Insp ___ Safety ___

AC68 SCHEDULE DATA:

Start Date Shifts 2 Serial Operation ☐ Parallel Operation ☒

SPECIAL TEST EQUIPMENT

PSS RECOMMENDATION: Retain ☒ Reduce ☐ Delete ☐

Rationale: Retain and adapt to LEV/MEV computer.

CENTAUR TEST PROCEDURE

CTP: DCU PERMANENT MEMORY MODIFICATION

Old CTP No. DCU-5001B **New CTP No.**

Description Provides instructions to alter the DCU permanent memory either on a single cell or 12K memory load by special options. Post modification validation tests are performed.

Remarks

AC68 RESOURCES:

Ground Power ☐ Vehicle Power ☐ Pneumatics ☐ CCLS ☐

Total Personnel 2 : Engr ____ Tech ____ Insp ____ Safety ____

AC68 SCHEDULE DATA:

Start Date Shifts 1 Serial Operation ☐ Parallel Operation ☒

SPECIAL TEST EQUIPMENT

PSS RECOMMENDATION: Retain ☒ Reduce ☐ Delete ☐

Rationale: Retain for contingency only.

CENTAUR TEST PROCEDURE

CTP: FLIGHT CONTROL SYSTEMS OPERATION

Old CTP No. FC-5001 **New CTP No.** FC-0001

Description An automated procedure to apply, remove and control Centaur and/or Atlas vehicle power, control RF systems, control N2H4 engine solenoids, support Atlas propulsion testing, support vent and pressurization system calibration, and hydraulic testing.

Remarks Provides CCLS support to mechanical and propulsion system which require vehicle power and have an interface with Flight Control.

AC68 RESOURCES:

Ground Power [X] Vehicle Power [X] Pneumatics [X] CCLS [X]

Total Personnel 7 : Engr 4 Tech 2 Insp 1 Safety ____

AC68 SCHEDULE DATA:

Start Date 07/10/89 Shifts 2.5 Serial Operation [X] Parallel Operation [ ]

SPECIAL TEST EQUIPMENT

PSS RECOMMENDATION: Retain [ ] Reduce [X] Delete [ ]

Rationale: A shorter version of this automated procedure could be used for preflight (or post landing) checks for a Lunar/Mars vehicle.

CENTAUR TEST PROCEDURE

CTP: FLIGHT CONTROL READINESS TEST

Old CTP No. FC-5002 **New CTP No.** FC-1002

Description Provides a series of tests to assure that the flight control system operates within design parameter limits. The test are performed under CCLS software control and consist of: Sequence Control Unit functional; Servo Inverter Unit functional; Optical alignment test; Engine Frequency Response tests in pitch and yaw; and Engine end-to-end test.

Remarks

AC68 RESOURCES:

Ground Power ☐ Vehicle Power ☐ Pneumatics ☐ CCLS ☒

Total Personnel 7 : Engr ____ Tech ____ Insp ____ Safety ____

AC68 SCHEDULE DATA:

Start Date Shifts 2.5 Serial Operation ☐ Parallel Operation ☐

SPECIAL TEST EQUIPMENT Ground Hydraulic Supply
Optical Alignment Tool

PSS RECOMMENDATION: Retain ☐ Reduce ☒ Delete ☐

Rationale: Retain and modify for LEV/MEV Flight control system.

CTP: CENTAUR GROUND AND AIRBORNE HYDRAULIC SYSTEM CHECKOUT

Old CTP No. HYD-3130G **New CTP No.** HYD-0030

Description Performs fill, flush, bleed, leak check and engine gimballing and alignment checks.

Remarks Requires ground and vehicle electrical power, ground hydraulic servicer, and ground pneumatics for blown downs

AC68 RESOURCES:

Ground Power [X] Vehicle Power [X] Pneumatics [X] CCLS [ ]

Total Personnel 4 : Engr 1 Tech 1 Insp 1 Safety 1

AC68 SCHEDULE DATA:

Start Date 06/22/89 Shifts 12 Serial Operation [X] Parallel Operation [ ]

SPECIAL TEST EQUIPMENT Ground Hydraulic Power Unit
Hydraulic Sampling Kit

PSS RECOMMENDATION: Retain [ ] Reduce [ ] Delete [X]

Rationale: Delete for standard Lunar/Mars operations. Not practical for hydraulic actuators and unnecessary for elector-mechanical actuators.

CTP: CENTAUR HYDRAULIC SYSTEM OPERATION

Old CTP No. HYD-3131 **New CTP No.** HYD-0031

Description Provides instructions for the use of the HPS ground supply with other procedures, validation of replacement units, and performance of engine gimbal tests in pitch and yaw. Provides detailed instructions for step-by-step replacement of actuators and specifies technique for drying hydraulic fluid.

Remarks

AC68 RESOURCES:

Ground Power ☐ Vehicle Power ☐ Pneumatics ☐ CCLS ☐

Total Personnel 4 : Engr ____ Tech ____ Insp ____ Safety ____

AC68 SCHEDULE DATA:

Start Date Shifts ? Serial Operation ☐ Parallel Operation ☐

SPECIAL TEST EQUIPMENT Dipstick Indicator Guide
Hydraulic Power Supply (HPS)
Flex Hoses
Hydraulic Drying Apparatus
Hydraulic Sampling Kit

PSS RECOMMENDATION: Retain ☐ Reduce ☒ Delete ☐

Rationale: Retain portion dealing with contingency actuator replacement. Remainder not practical for hydraulic actuators and unneccessary for elecro-mechanical actuators.

CENTAUR TEST PROCEDURE

CTP: CENTAUR HYDRAULIC END-TO-END SYSTEM TEST

Old CTP No. HYD-3132 **New CTP No.** HYD-0032

Description Functionally checks the Centaur hydraulic power packs including a fill and bleed of the hydraulic checkout unit, followed by performance tests of the main hydraulic pumps and recirculation system. Tests the electrical hydraulic circulation motors and establishes a current profile. Checks torque on hydraulic power package drive coupling.

Remarks Ground and vehicle electrical power, instrumentation, and hydraulic pumps are required

AC68 RESOURCES:

Ground Power [X] Vehicle Power [X] Pneumatics [ ] CCLS [ ]

Total Personnel 8 : Engr 2 Tech 4 Insp 2 Safety ____

AC68 SCHEDULE DATA:

Start Date 08/28/89 Shifts 3 Serial Operation [X] Parallel Operation [ ]

SPECIAL TEST EQUIPMENT Hydraulic Checkout Unit
Flex Hoses
Electrical Cables
Dipstick Indicator Guide

PSS RECOMMENDATION: Retain [ ] Reduce [ ] Delete [X]

Rationale: Delete for standard lunar/Mars operations. Not practical for hydraulic actuators and unneccessary for elecro-mechanical actuators.

CENTAUR TEST PROCEDURE

CTP: CENTAUR HYDRAUDLIC FLIGHT READINESS OPERATIONS

Old CTP No. HYD-3133 **New CTP No.** HYD-1033

Description Centaur airborne hydraulic systems are checked for proper bleed, a system fitting torque check is performed, and flight fluid sampling is accomplished. Ground hydraulic pressure is applied to the airborne system and the engines are moved in pitch and yaw with Flight Control system.

Remarks

AC68 RESOURCES:

Ground Power [X] Vehicle Power [X] Pneumatics [ ] CCLS [ ]

Total Personnel 5 : Engr 1 Tech 2 Insp 1 Safety 1

AC68 SCHEDULE DATA:

Start Date 09/12/89 Shifts 3 Serial Operation [ ] Parallel Operation [X]

SPECIAL TEST EQUIPMENT Dipstick Indicator Guides
Hydraulic System Service Panel (HSSP)
Hydraulic Power Supply (HPS)
Hydraulic Sampler Kit

PSS RECOMMENDATION: Retain [ ] Reduce [X] Delete [ ]

Rationale: Delete portions dealing with fluid sampling and bleed checks for hydraulic actuators. Modify tests to provide a pre-flight end-to-end test under command of the flight control system for either type of actuator.

CENTAUR TEST PROCEDURE

CTP: IMG CALIBRATION

Old CTP No. IMG-5000T **New CTP No.** IMG-1001

Description Provides checkout, calibration, and alignment of the Centaur Inertial Measurement Group (IMG) using the computer controlled launch set (CCLS) including options for an IMG calibration, IMG gimbal slew test, clock frequency test, steering chain test, navigation test, and earth spin test.

Remarks The Earth spin test is run during each integrated test containing a plus count demonstration

AC68 RESOURCES:

Ground Power [X] Vehicle Power [X] Pneumatics [ ] CCLS [X]

Total Personnel 3 : Engr 1 Tech 1 Insp 1 Safety ____

AC68 SCHEDULE DATA:

Start Date 06/21/89 Shifts 6 Serial Operation [X] Parallel Operation [ ]

SPECIAL TEST EQUIPMENT

PSS RECOMMENDATION: Retain [ ] Reduce [X] Delete [ ]

Rationale: A portion of this automated test could be performed as a pre-flight guidance system checkout on the planetary surface.

CENTAUR TEST PROCEDURE

CTP: LAUNCH COUNTDOWN OPERATIONS

Old CTP No. INT-XX00 **New CTP No.** INT-XXOO

Description Performs final preparations and launch for the for Atlas Centaur vehicle.

Remarks Vehicle and support equipment are in a flight (launch ready) configuration

AC68 RESOURCES:

Ground Power [X] Vehicle Power [X] Pneumatics [X] CCLS [X]

Total Personnel 80 : Engr 10 Tech 50 Insp 15 Safety 5

AC68 SCHEDULE DATA:

Start Date 09/21/89 Shifts 2 Serial Operation [ ] Parallel Operation [ ]

SPECIAL TEST EQUIPMENT

PSS RECOMMENDATION: Retain [X] Reduce [ ] Delete [ ]

Rationale: Required for planetary launch. Ground control functions to be reallocated to the LEV/MEV for launch operations. Automate and customize.

CENTAUR TEST PROCEDURE

CTP: COMPOSITE ELECTRICAL READINESS TEST

Old CTP No. INT-XX01 **New CTP No.** WT-XX01

Description Demonstrates the vehicle with associated GSE on an integrated basis, the operation of all airborne electrical systems (except range safety controller) during a simulated flight with guidance in inertial mode and using telemetry and the gantry test rack for events. monitoring

Remarks Uses test batteries for internal power

AC68 RESOURCES:

Ground Power [X] Vehicle Power [X] Pneumatics [ ] CCLS [X]

Total Personnel 51 : Engr 29 Tech 19 Insp 3 Safety AR

AC68 SCHEDULE DATA:

Start Date 09/14/89 Shifts 1 Serial Operation [X] Parallel Operation [ ]

SPECIAL TEST EQUIPMENT

PSS RECOMMENDATION: Retain [ ] Reduce [ ] Delete [X]

Rationale: Delete demonstration test for planetary surface operations. Readiness to be verified during actual countdown.

CENTAUR TEST PROCEDURE

CTP: FLIGHT EVENTS DEMONSTRATION

Old CTP No. INT-XX02 **New CTP No.**

Description 1. Demonstrates the Test Conductor ready and launch ladders will function properly for an automatic release, including ordnance functions. 2. Demonstrates operation of the airborne electrical system during a simulated flight with guidance in inertial mode after umbilical ejection.

Remarks Part 1 is performed with umbilicals in, part 2 includes umbilical ejection. Both parts are performed using test batteries for internal power

AC68 RESOURCES:

Ground Power [X] Vehicle Power [X] Pneumatics [X] CCLS [X]

Total Personnel 46 : Engr 29 Tech 14 Insp 3 Safety AR

AC68 SCHEDULE DATA:

Start Date 09/07/89 Shifts 1 Serial Operation [ ] Parallel Operation [ ]

SPECIAL TEST EQUIPMENT

PSS RECOMMENDATION: Retain [ ] Reduce [ ] Delete [X]

Rationale: Delete for planetary surface operations. Prelaunch portion to be included in launch countdown.

CENTAUR TEST PROCEDURE

CTP: TERMINAL COUNTDOWN DEMOSTRATION

Old CTP No. INT-XX03 **New CTP No.** INT-0003

Description Complete tanking test in a simulated countdown.

Remarks

AC68 RESOURCES:

Ground Power ☐ Vehicle Power ☐ Pneumatics ☐ CCLS ☐

Total Personnel 80 : Engr ____ Tech ____ Insp ____ Safety ____

AC68 SCHEDULE DATA:

Start Date Shifts 2 Serial Operation ☐ Parallel Operation ☐

SPECIAL TEST EQUIPMENT

PSS RECOMMENDATION: Retain ☐ Reduce ☐ Delete ☒

Rationale: Delete.

CENTAUR TEST PROCEDURE

CTP: LANDLINE MULTIPLEXER OPERATION & PROGRAMING

Old CTP No. LL-3008 **New CTP No.** LL-1009

Description Power up, programing and program verification, and functional operation of the landline instrumentation system multiplexer.

Remarks

AC68 RESOURCES:

Ground Power ☐ Vehicle Power ☐ Pneumatics ☐ CCLS ☐

Total Personnel 3 : Engr ___ Tech ___ Insp ___ Safety ___

AC68 SCHEDULE DATA:

Start Date Shifts 2 Serial Operation ☐ Parallel Operation ☐

SPECIAL TEST EQUIPMENT Computer
Keyboard & Video Displays
Tape Recorder

PSS RECOMMENDATION: Retain ☐ Reduce ☐ Delete ☒

Rationale: This is a verification of landline and mutiplexer system and is part of the ground station verification exercise. It is not part of the actual Centaur processing.

CENTAUR TEST PROCEDURE

CTP: ATLAS/CENTAUR CORROSION CONTROL

Old CTP No. MECH-3009A **New CTP No.** MECH-0008

Description Cleans, inspects for, removes, and applies corrosion protection on a periodic basis to the exposed vehicle surfaces.

Remarks Specific tasks allocated to area purges, surface cleaning and coating on an annual, 60 day, 30 day, weekly, 3 per week, or one per flow basis. Uses GN2 for purges

AC68 RESOURCES:

Ground Power ☐ Vehicle Power ☐ Pneumatics ☐ CCLS ☐

Total Personnel 4 : Engr ____ Tech 3 Insp 1 Safety ____

AC68 SCHEDULE DATA:

Start Date 06/05/89 Shifts 5 Serial Operation ☐ Parallel Operation ☒

SPECIAL TEST EQUIPMENT

PSS RECOMMENDATION: Retain ☒ Reduce ☐ Delete ☐

Rationale: Planetary surface environmental conditions, vehicle, and surface equipment design will determine associated contamination control requirements for LEV/MEV.

CENTAUR TEST PROCEDURE

CTP: COMPLEX ELECTRICAL READINESS TEST

Old CTP No. NET-1002 **New CTP No.** NET-0002

Description Installs or verifies proper electrical support equipment/cable connections are in place for vehicle errection, periodic once-a-week checks, TCD-3 day preps, and launch preps for ground launch control systems.

Remarks

AC68 RESOURCES:

Ground Power ☐ Vehicle Power ☐ Pneumatics ☐ CCLS ☐

Total Personnel 3 : Engr 1 Tech 1 Insp 1 Safety ___

AC68 SCHEDULE DATA:

Start Date 09/08/89 Shifts 6 Serial Operation ☒ Parallel Operation ☐

SPECIAL TEST EQUIPMENT

PSS RECOMMENDATION: Retain ☐ Reduce ☒ Delete ☐

Rationale: A similar but shorter version would be applicable for SSE to LEV/MEV verification or for initial use. Performance would be accomplished prior to interconnection of SSE with LEV/MEV.

CENTAUR TEST PROCEDURE

CTP: FUNCTIONAL CHECKOUT OF 28V DC POWER SUPPLY

Old CTP No. NET-3019 **New CTP No.** NET-1023

Description Verifies the operation of the Atlas/Centaur 28 volt ground power supplies conform to vehicle test requirements including over-voltage protection and over-voltage turn-off operations. Power supply calibration included.

Remarks Performs loads tests with vehicle and block house loads disconnected, sets over-voltage protection adjustments

AC68 RESOURCES:

Ground Power [X] Vehicle Power [ ] Pneumatics [ ] CCLS [ ]

Total Personnel 3 : Engr 1 Tech 1 Insp 1 Safety ____

AC68 SCHEDULE DATA:

Start Date 04/20/89 Shifts 5 Serial Operation [X] Parallel Operation [ ]

SPECIAL TEST EQUIPMENT Voltmeter

PSS RECOMMENDATION: Retain [X] Reduce [ ] Delete [ ]

Rationale: Perform for initial validation of LEV/MEV Servicer Power Subsystem and only repeat for maintenance or repairs.

CENTAUR TEST PROCEDURE

CTP: ALTAS/CENTAUR AIRBORNE ELECTRICAL READINESS

Old CTP No. NET-3066 **New CTP No.** NET-1032

Description Performs final closeout of vehicle electrical quick disconnects and snap lock connectors, attaching hardware and enclosures.

Remarks Applicable sections of procedure are performed to secure or verify approximately 200 items prior to launch -2 days, launch -1 day, and launch day

AC68 RESOURCES:

Ground Power ☐ Vehicle Power ☐ Pneumatics ☐ CCLS ☐

Total Personnel 4 : Engr 1 Tech 2 Insp 1 Safety ___

AC68 SCHEDULE DATA:

Start Date 09/08/89 Shifts 6 Serial Operation ☐ Parallel Operation ☒

SPECIAL TEST EQUIPMENT

PSS RECOMMENDATION: Retain ☐ Reduce ☐ Delete ☒

Rationale: Delete, except when connectors are disturbed due to modifications or replacement.

CENTAUR TEST PROCEDURE

CTP: CENTAUR MAIN BATTERY ACTIVATION & HANDLING

Old CTP No. NET-3071 **New CTP No.** NET-1035

Description Performs handling, activation, recharging, load testing, storing, checkout and discharging of the Centaur main battery.

Remarks Also used to prepare non-flight test batteries.

AC68 RESOURCES:

Ground Power [X] Vehicle Power [ ] Pneumatics [ ] CCLS [ ]

Total Personnel 3 : Engr 1 Tech 1 Insp 1 Safety ____

AC68 SCHEDULE DATA:

Start Date 09/02/89 Shifts 4 Serial Operation [ ] Parallel Operation [X]

SPECIAL TEST EQUIPMENT Battery Activation Stand
Vacuum Pump
Strip Chart Recorder with Multiple Channel Recorders

PSS RECOMMENDATION: Retain [ ] Reduce [ ] Delete [X]

Rationale: Delete. Fuel cells baselined for primary power.

CENTAUR TEST PROCEDURE

CTP: AIRBORNE BATTERY ACTIVATION & HANDLING

Old CTP No. NET-3072 **New CTP No.** NET-1036

Description Performs handling, activation, recharging, load testing, storing, checkout and discharging of flight termination system batteries.

Remarks

AC68 RESOURCES:

Ground Power ☐ Vehicle Power ☐ Pneumatics ☐ CCLS ☐

Total Personnel 3 : Engr 1 Tech 1 Insp 1 Safety ____

AC68 SCHEDULE DATA:

Start Date 9/12/89 Shifts 4 Serial Operation ☐ Parallel Operation ☒

SPECIAL TEST EQUIPMENT Battery Activation Stand
Vacuum Pump
Strip Chart Recorder

PSS RECOMMENDATION: Retain ☐ Reduce ☐ Delete ☒

Rationale: Delete. Fuel cells baselined for primary power.

CTP: PURGE AND PRESSURIZATION OF FLIGHT CONTROL UNITS

Old CTP No. NET-3075 **New CTP No.** NET-0039

Description Performs pressure and leak test on the airborne flight control Sequence Control Unit, and the Servo Inverter Unit.

Remarks

AC68 RESOURCES:

Ground Power ☐ Vehicle Power ☐ Pneumatics ☐ CCLS ☐

Total Personnel 3 : Engr ____ Tech ____ Insp ____ Safety ____

AC68 SCHEDULE DATA:

Start Date Shifts 1 Serial Operation ☐ Parallel Operation ☐

SPECIAL TEST EQUIPMENT Portable Suitcase with Pneumatic Attachments & Hoses
GN2 Bottle & Pressure Regulator

PSS RECOMMENDATION: Retain ☐ Reduce ☐ Delete ☒

Rationale: Delete.

CENTAUR TEST PROCEDURE

CTP: INSTALLATION/REMOVAL OF SIU/SCU/RGU

Old CTP No. NET-3081 **New CTP No.** NET-0044

Description Describes the methods for installing and removing the Servo Inverter Unit, Sequence Control Unit, and Rate Gyro Unit.

Remarks

AC68 RESOURCES:

Ground Power ☐ Vehicle Power ☐ Pneumatics ☐ CCLS ☐

Total Personnel 3 : Engr ____ Tech ____ Insp ____ Safety ____

AC68 SCHEDULE DATA:

Start Date Shifts 1 Serial Operation ☐ Parallel Operation ☐

SPECIAL TEST EQUIPMENT

PSS RECOMMENDATION: Retain ☒ Reduce ☐ Delete ☐

Rationale: Retain for post maintenance/replacement function.

CENTAUR TEST PROCEDURE

CTP: INITIAL CURRENT PROFILE AND COMPATIBILITY TEST

Old CTP No. NET-3082 **New CTP No.** NET-0045

Description Applies initial vehicle power, checks external/internal operation, and obtains reference current profiles. Verifies compatibility of propulsion, RF, and engine circulation pump systems with electrical power system. Simulated countdown under ground computer (CCLS) control and simmulated flight sequence under airborne computer software performed.

Remarks

AC68 RESOURCES:

Ground Power [X] Vehicle Power [X] Pneumatics [X] CCLS [X]

Total Personnel 23 : Engr 8 Tech 10 Insp 5 Safety ____

AC68 SCHEDULE DATA:

Start Date 6/20/89 Shifts 1 Serial Operation [X] Parallel Operation [ ]

SPECIAL TEST EQUIPMENT Battery Simulator Supply
Battery Interrupt Boxes (BIB)
BIB Interconnect Cables

PSS RECOMMENDATION: Retain [ ] Reduce [X] Delete [ ]

Rationale: Reduce to an automated systems check, enabling direct operation from the LEV, or remotely from the Lunar /Earth base ground computer.

CENTAUR TEST PROCEDURE

CTP: PYRO CHECKOUT

Old CTP No. ORD-3000A **New CTP No.** ORD-0001

Description Provides checkout of pyrotechnic devices prior to assigning and installing them on the flight vehicle. Provides fit and operational tests.

Remarks Performs isolation and resistance checks of rocket motors, destruct units, squibs, igniters, detonators, safe and arm switches. Also, provides fit checks and operational tests.

AC68 RESOURCES:

Ground Power ☐ Vehicle Power ☐ Pneumatics ☐ CCLS ☐

Total Personnel 4 : Engr 1 Tech 2 Insp 1 Safety ___

AC68 SCHEDULE DATA:

Start Date 06/07/89 Shifts 4 Serial Operation ☐ Parallel Operation ☒

SPECIAL TEST EQUIPMENT Megohmmeters
Low Resistance Ohmmeters
Timer Units
Breakout Boxes

PSS RECOMMENDATION: Retain ☐ Reduce ☒ Delete ☐

Rationale: Preform isolation resistance tests prior to earth and/or SSF departure. Use automated capability of Pyro Initiator Controller (PIC) for functional tests.

CTP: INSTALLATION AND CHECKOUT OF CENTAUR FILL AND DRAIN VALVES

Old CTP No. PLS-1005 **New CTP No.** PLS-0002

Description Installs and tests Centaur fill and drain valves, including leak tests, dew point verification of transfer lines, connects ground fill and drain valves to airborne fill and drain valves and verifies proper operation of valves and indications.

Remarks Requires ground and vehicle power, GN2 (GHE for LH2) for blow down purges, and a halogen (or equivalent leak detector)

AC68 RESOURCES:

Ground Power [X] Vehicle Power [X] Pneumatics [X] CCLS [ ]

Total Personnel 7 : Engr 2 Tech 3 Insp 2 Safety ____

AC68 SCHEDULE DATA:

Start Date 08/24/89 Shifts 5 Serial Operation [X] Parallel Operation [ ]

SPECIAL TEST EQUIPMENT Guide Studs

PSS RECOMMENDATION: Retain [X] Reduce [ ] Delete [ ]

Rationale: A similar operation will be required for planetary surface operations if surface storage tanks, reliquifaction, or other propellant transfer operations are planned.

CENTAUR TEST PROCEDURE

CTP: CENTAUR VENT VALVE CHECKOUT

Old CTP No. PNEU-3019 **New CTP No.** PNEU-0026

Description Verifies proper opening and closing of the LH2 and LOX tank vent valves. Opening and closing pressures are determined.

Remarks Requires tanks be raised above their fragmentation and normal operation levels and is therefore a hazardous test

AC68 RESOURCES:

Ground Power [X] Vehicle Power [X] Pneumatics [X] CCLS [ ]

Total Personnel 10 : Engr 1 Tech 5 Insp 2 Safety 2

AC68 SCHEDULE DATA:

Start Date 07/18/89 Shifts 1 Serial Operation [X] Parallel Operation [ ]

SPECIAL TEST EQUIPMENT

PSS RECOMMENDATION: Retain [ ] Reduce [ ] Delete [X]

Rationale: Delete for planetary surface operations/check for last time on earth.

CTP: CENTAUR AIRBORNE HIGH PRESSURE HELIUM STORAGE CHECKS

Old CTP No. PNEU-3021 **New CTP No.** PNEU-0027

Description Verifies the structural integrity of the airborne helium storage system including remote pressurization of storage bottles to flight pressures, a five minute lockup, a leak check at lower pressures and purge system. checks

Remarks

AC68 RESOURCES:

Ground Power [X] Vehicle Power [X] Pneumatics [X] CCLS [ ]

Total Personnel 10 : Engr 1 Tech 5 Insp 1 Safety 3

AC68 SCHEDULE DATA:

Start Date 06/27/89 Shifts 5 Serial Operation [ ] Parallel Operation [X]

SPECIAL TEST EQUIPMENT Helium Bottle Charge Panel

PSS RECOMMENDATION: Retain [X] Reduce [ ] Delete [ ]

Rationale: All pressurized systems on the LEV/MEV should be designed such that all leak and pressure testing can be accomplished using BIT/BITE.

CENTAUR TEST PROCEDURE

CTP: LH2 VENT SYSTEM LEAK CHECK

Old CTP No. PNEU-3022 **New CTP No.** PNEU-0028

Description Performs leak checks of the Centaur airborne LH2 vent system on a step-by-step basis as ducting is assembled.

Remarks Uses ground supply of helium for pressurization and leak tests

AC68 RESOURCES:

Ground Power [X] Vehicle Power [X] Pneumatics [X] CCLS [ ]

Total Personnel 5 : Engr 1 Tech 3 Insp 1 Safety ___

AC68 SCHEDULE DATA:

Start Date 07/10/89 Shifts 15 Serial Operation [ ] Parallel Operation [X]

SPECIAL TEST EQUIPMENT

PSS RECOMMENDATION: Retain [ ] Reduce [ ] Delete [X]

Rationale: Delete. Ducting is pecular to Centaur design as an upper stage of an ELV.

CTP: CENTAUR CCVAPS SYSTEM CHECKOUT

Old CTP No. PNEU-3025 **New CTP No.** PNEU-0032

Description Applies pressure to the computer controlled venting and pressurization system transducers and tank pressure transducers for performing an end-to-end calibration and leak checks.

Remarks

AC68 RESOURCES:

Ground Power [X] Vehicle Power [X] Pneumatics [X] CCLS [X]

Total Personnel 6 : Engr 2 Tech 3 Insp 1 Safety ____

AC68 SCHEDULE DATA:

Start Date 08/04/89 Shifts 2 Serial Operation [X] Parallel Operation [ ]

SPECIAL TEST EQUIPMENT CCVAPS Pressure Control Panel
Calibrated Gage
Flex Hoses
Filter

PSS RECOMMENDATION: Retain [ ] Reduce [X] Delete [ ]

Rationale: Delete transducer calibration test for planetary surface operations except for mandatory repairs/replacements or pre Earth launch verification. Substitude prelaunch functional test with special software routine.

CENTAUR TEST PROCEDURE

CTP: CENTAUR AIRBORNE PNEUMATIC SYSTEM CHECKOUT

Old CTP No. PNEU-3026 **New CTP No.** PNEU-0031

Description Performs operational and leak checks of airborne pneumatic system valves and components including a remote high pressure helium storage cycle. The gaseous helium bottles are pressurized to flight pressures and pressurization and control valves are retested for leaks. The autogenous (GH2 bleed system) pressurization lines, valves, orifices are tested.

Remarks

AC68 RESOURCES:

Ground Power [X] Vehicle Power [X] Pneumatics [X] CCLS [ ]

Total Personnel 8 : Engr 1 Tech 3 Insp 2 Safety 2

AC68 SCHEDULE DATA:

Start Date 07/19/89 Shifts 6 Serial Operation [X] Parallel Operation [ ]

SPECIAL TEST EQUIPMENT Helium Bottle Charge Panel
Flex Hoses
Flow Meters

PSS RECOMMENDATION: Retain [ ] Reduce [X] Delete [ ]

Rationale: Reduce for planetary operations to functional tests of components using BIT/BITE, and leak checking for repair or replacement only.

CENTAUR TEST PROCEDURE

CTP: CENTAUR PRATT & WHITNEY ENGINE LEAK & FUNCTIONAL CHECK

Old CTP No. PROP-3131N **New CTP No.** PROP-0036

Description Performs transducer calibrations and leak and functional checks of engines and associated hardware.

Remarks Uses fixed and portable ground support equipment

AC68 RESOURCES:

Ground Power [X] Vehicle Power [X] Pneumatics [X] CCLS [X]

Total Personnel 6 : Engr 1 Tech 3 Insp 1 Safety 1

AC68 SCHEDULE DATA:

Start Date 06/28/89 Shifts 11 Serial Operation [X] Parallel Operation [ ]

SPECIAL TEST EQUIPMENT

Portable Pneumatic Checkout Panel
Flow Meters
Flex Hoses
Pressure Test Plates & Fixtures
Propulsion Checkout Panel
Leakage Detector Fixture

PSS RECOMMENDATION: Retain [ ] Reduce [X] Delete [ ]

Rationale: Develop a condensed version that uses special built in test capabilities of the LEV/MEV engines.

CTP: CENTAUR PROPULSION FLIGHT READINESS OPERATIONS

Old CTP No. PROP-3133 **New CTP No.** PROP-0040

Description Propulsion components are functionally checked for flight and the propulsion system is partially configured for flight such as turbopump torque checks, final leak checks, and preliminary blowdowns are accomplished. Both the LH2/LO2 and N2H4 systems are checked.

Remarks Blowdowns and leak checks are performed using GN2 and GHe

AC68 RESOURCES:

Ground Power [X] Vehicle Power [X] Pneumatics [X] CCLS [ ]

Total Personnel 5 : Engr 1 Tech 2 Insp 1 Safety 1

AC68 SCHEDULE DATA:

Start Date 09/08/89 Shifts 7 Serial Operation [ ] Parallel Operation [X]

SPECIAL TEST EQUIPMENT
Backup Engine Purge Panel
Flow Meters
Flex Hoses
Portable Pneumatic Checkout Panel
Propulsion System Checkout Panel
Purge Manifold

PSS RECOMMENDATION: Retain [ ] Reduce [X] Delete [ ]

Rationale: A shortened version would be required on the planetary surface; increased use of built in test is required to reduce EVA for these checks.

CTP: AIRBORNE N2H4 SYSTEM LEAK & FUNCTIONAL

Old CTP No. PROP-3156 **New CTP No.** PROP-0037

Description Performs hydrazine RCS engine functional checks, valve leak checks, N2H4 bottle leak checks, thruster loop leak checks, and RCS line heater checks.

Remarks High pressure helium gas is used to perform tests, not hydrazine. Thruster loop is leak checked with a Mass Spectrometer.

AC68 RESOURCES:

Ground Power [X] Vehicle Power [X] Pneumatics [X] CCLS [ ]

Total Personnel 5 : Engr 1 Tech 2 Insp 1 Safety 1

AC68 SCHEDULE DATA:

Start Date 10/12/89 Shifts 6 Serial Operation [X] Parallel Operation [ ]

SPECIAL TEST EQUIPMENT
Hydrazine Service Panel & Vacuum Pump
N2H4 RCS GSE Test Kit
N2H4 Mass Spectrometer Fill & Sample Kit
Valve & Filter Assembly (for Mass Spectrometer Kit)
Mass Spectrometer

PSS RECOMMENDATION: Retain [ ] Reduce [X] Delete [ ]

Rationale: Develop a condensed version that uses LEV/MEV Built-inTest capability for leak and functional tests.

CENTAUR TEST PROCEDURE

CTP: RCS THRUSTER LOOP PRESSURIZATION

Old CTP No. PROP-3158 **New CTP No.** PROP-0033

Description N2H4 RCS thruster loop is pressurized periodically to support thruster engine cycling during major tests.

Remarks

AC68 RESOURCES:

Ground Power ☐ Vehicle Power ☐ Pneumatics ☐ CCLS ☐

Total Personnel 4 : Engr ____ Tech ____ Insp ____ Safety ____

AC68 SCHEDULE DATA:

Start Date Shifts 1 Serial Operation ☐ Parallel Operation ☐

SPECIAL TEST EQUIPMENT Hydrazine Service Panel & Vacuum Pump
N2H4 RCS GSE Test Kit

PSS RECOMMENDATION: Retain ☐ Reduce ☐ Delete ☒

Rationale: Delete. RCs manifold will be filled with flight propellant.

CENTAUR TEST PROCEDURE

CTP: CENTAUR PU SYSTEM CHECKOUT & CALIB

Old CTP No. PU-5000 **New CTP No.** PU-1005

Description Performs checkout and calibration of the propellant utilization system prior to flight. This includes the servo positioner limit checks and valve angles with PU associated errors.

Remarks Options are provided to perform calibrations, data printout, load flight constants, perform functional checks and load the ground computer (CCLS)

AC68 RESOURCES:

Ground Power [X] Vehicle Power [X] Pneumatics [ ] CCLS [X]

Total Personnel 3 : Engr 1 Tech 1 Insp 1 Safety ___

AC68 SCHEDULE DATA:

Start Date 06/22/89 Shifts 2 Serial Operation [ ] Parallel Operation [ ]

SPECIAL TEST EQUIPMENT

PSS RECOMMENDATION: Retain [ ] Reduce [X] Delete [ ]

Rationale: Reduce to automated functional check for planetary surface use. Most options call for leaving propellants on board, or refilling, without emptying tanks. Ulimate use will depend upon if a PU system is incorporated into the LEV/MEVdesign.

CENTAUR TEST PROCEDURE

CTP: LO2 & LH2 PU CABLES & PROBE INSULATION RESISTANCE CHECKS

Old CTP No. PU-5001 **New CTP No.** PU-1006

Description Performs insulation resistance checks of the LO2 and LOX propellant utilization system cables, connectors, and probes.

Remarks Requires vehicle power off; breaks into PU probe interfaces to perform megger tests

AC68 RESOURCES:

Ground Power ☐ Vehicle Power ☐ Pneumatics ☐ CCLS ☐

Total Personnel 3 : Engr 1 Tech 1 Insp 1 Safety ___

AC68 SCHEDULE DATA:

Start Date 06/19/89 Shifts 2 Serial Operation ☐ Parallel Operation ☒

SPECIAL TEST EQUIPMENT Breakout Boxes
Megohmmeters

PSS RECOMMENDATION: Retain ☐ Reduce ☐ Delete ☒

Rationale: Delete as standard test on Lunar/Mars surface, would invalidate system with propellants on board. Perform prior to earth and/or SSF departure.

CENTAUR TEST PROCEDURE

CTP: C-BAND BEACON PRESSURIZATION AND LEAK TEST

Old CTP No. RF-3002 **New CTP No.** RF-0001

Description Performs pressurization and leak test on the airborne and back-up C-Band transponders.

Remarks

AC68 RESOURCES:

Ground Power ☐ **Vehicle Power** ☐ **Pneumatics** ☐ **CCLS** ☐

Total Personnel 3 : **Engr** ____ **Tech** ____ **Insp** ____ **Safety** ____

AC68 SCHEDULE DATA:

Start Date **Shifts** 1 **Serial Operation** ☐ **Parallel Operation** ☐

SPECIAL TEST EQUIPMENT Suitcase with Pressure Fittings & Hoses
GN2 Source & Regulator

PSS RECOMMENDATION: **Retain** ☐ **Reduce** ☐ **Delete** ☒

Rationale: Delete.

CTP: C-BAND BEACON SYSTEM CHECKOUT

Old CTP No. RF-3005 **New CTP No.** RF-0002

Description Provides system level checkout of the C-Band transponder. Parameters tested are sensitivity, bandwidth, frequency, delay, decoder limits, interrogation rate, and power output.

Remarks Utilizes several items of portable ground support equipment to perform a vehicle subsystem test. An option allows either vehicle power or ground power

AC68 RESOURCES:

Ground Power [X] Vehicle Power [X] Pneumatics [ ] CCLS [ ]

Total Personnel 3 : Engr 1 Tech 1 Insp 1 Safety ____

AC68 SCHEDULE DATA:

Start Date 06/16/89 Shifts 1 Serial Operation [X] Parallel Operation [ ]

SPECIAL TEST EQUIPMENT C-Band Transpoonder Test Set
Coaxial Cables

PSS RECOMMENDATION: Retain [ ] Reduce [ ] Delete [X]

Rationale: Delete for Lunar/Mars surface use, replace with a functional demonstration of beacon system.

CENTAUR TEST PROCEDURE

CTP: C-BAND XPONDER RANGE READOUT

Old CTP No. RF-3008 **New CTP No.** RF-1005

Description Operates the airborne C-Band transponder system to enable range control to verify proper operation of receivers, transmitters, and decoders. Transponder frequency, sensitivity, pulse width, pulse jitter, power, delay and decoder limits are changed.

Remarks

AC68 RESOURCES:

Ground Power [X] Vehicle Power [X] Pneumatics [ ] CCLS [ ]

Total Personnel 2 : Engr 2 Tech ___ Insp ___ Safety ___

AC68 SCHEDULE DATA:

Start Date 06/21/89 Shifts 1 Serial Operation [ ] Parallel Operation [X]

SPECIAL TEST EQUIPMENT

PSS RECOMMENDATION: Retain [X] Reduce [ ] Delete [ ]

Rationale: A similar test would most likely be performed from the earth or a planetary surface control station prior to launch. Also a function of whether it is incorporated into the LEV/MEVdesign.

CENTAUR TEST PROCEDURE

CTP: RF PACKAGE REPLACEMENT (C-BAND AND/OR S-BAND)

Old CTP No. RF-3009 **New CTP No.** RF-0006

Description Provides instructions for the removal of the C-band transponder, and the S-Band transmitter.

Remarks

AC68 RESOURCES:

Ground Power ☐ Vehicle Power ☐ Pneumatics ☐ CCLS ☐

Total Personnel 3 : Engr ___ Tech ___ Insp ___ Safety ___

AC68 SCHEDULE DATA:

Start Date Shifts 1 Serial Operation ☐ Parallel Operation ☐

SPECIAL TEST EQUIPMENT

PSS RECOMMENDATION: Retain [X] Reduce ☐ Delete ☐

Rationale: Retain for post maintenance/replacement function.

CENTAUR TEST PROCEDURE

CTP: CENTAUR SPACECRAFT RANGE SAFETY COMMAND CHECKOUT

Old CTP No. RSC-3007 **New CTP No.** RSC-1004

Description Performs a functional checkout of the Centaur/Spacecraft range safety command system in closed loop configuration with the Centaur insulation panels installed. Test include sys response, immunity, telemetry verification, stray voltage, and receiver performance measurements.

Remarks Procedure also used for replacement receiver testing or retesting within 90 days of launch

AC68 RESOURCES:

Ground Power [X] Vehicle Power [X] Pneumatics [ ] CCLS [X]

Total Personnel 5 : Engr 1 Tech 2 Insp 2 Safety ____

AC68 SCHEDULE DATA:

Start Date 08/07/89 Shifts 2 Serial Operation [ ] Parallel Operation [ ]

SPECIAL TEST EQUIPMENT
- RSC Test Set
- Dummy Destruct Unit (Green Box)
- Squid Simulator
- Power Meter
- Coax Cable Adapter
- Attenuator
- Frequency Counter
- Special Test Plug

PSS RECOMMENDATION: Retain [ ] Reduce [ ] Delete [X]

Rationale: Delete: Range safety system not required; planetary base not manned for Option 5 launch or landing operations.

CENTAUR TEST PROCEDURE

CTP: REPETITIVE PARAMETER MEASURMENTS PCM

Old CTP No. TLM-3001 **New CTP No.** TLM-1001

Description Repeats telemetry parameter measurement verification due to system tests, major integrated tests, replacement of components affecting a parameter, or an engineering decision.

Remarks Performs telemetry system power on and off checks including PCM bit rate, hardline output voltage, carrier deviation, antenna coupler output, and carrier frequency

AC68 RESOURCES:

Ground Power [X] Vehicle Power [X] Pneumatics [X] CCLS [X]

Total Personnel 4 : Engr 1 Tech 2 Insp 1 Safety ____

AC68 SCHEDULE DATA:

Start Date 06/22/89 , Shifts 28 Serial Operation [ ] Parallel Operation [X]

SPECIAL TEST EQUIPMENT Digital Voltmeter
RF Power Meter
Strip Chart Recorders
Coax Cables & Coupler Hat

PSS RECOMMENDATION: Retain [ ] Reduce [X] Delete [ ]

Rationale: Measurements should be used to validate a Lunar/Mars vehicle and only repeated if trouble is suspected or indicated, or components have been repaired/replaced.

CENTAUR TEST PROCEDURE

CTP: TRANSDUCER ELEMENT RESISTANCE CHECKS

Old CTP No. TLM-3003A **New CTP No.** TLM-1002

Description Performs element resistance checks/simulations of P&W engine Atlas/Centaur cryogenic temperature transducers. Resistance tests are done at ambient temperature only for a single data point and a resistance excursion test is performed with an aerosol spray.

Remarks Requires vehicle power off, disconnection and removal of transducer connectors and mounting hardware to apply thermal conduction compound and installation of breakout boxes. Power on simulations are performed

AC68 RESOURCES:

Ground Power ☐ Vehicle Power ☐ Pneumatics ☐ CCLS ☐

Total Personnel 5 : Engr 1 Tech 3 Insp 1 Safety ___

AC68 SCHEDULE DATA:

Start Date 06/22/89 Shifts 5 Serial Operation ☒ Parallel Operation ☒

SPECIAL TEST EQUIPMENT Ohmmeter
Breakout Boxes

PSS RECOMMENDATION: Retain ☐ Reduce ☐ Delete ☒

Rationale: Delete from Lunar/Mars surface operations. Propellants remain on board and configuration should not be broken. Perform on Earth and/or SSF prior to departure for the Moon.

CENTAUR TEST PROCEDURE

CTP: INSTRUMENTATION FUNCTIONAL CHECKS

Old CTP No. TLM-3004A **New CTP No.** TLM-1003

Description Performs measurement verification using temperature and pressure stimulation, functional verification and performs preflight close out inspections of instrumentation flight boxes.

Remarks Requires flight hardware disconnects and openings to accomplish tests, requires telemetry ground station and flight vehicle power up

AC68 RESOURCES:

Ground Power [X] Vehicle Power [X] Pneumatics [ ] CCLS [X]

Total Personnel 5 : Engr 1 Tech 3 Insp 1 Safety ___

AC68 SCHEDULE DATA:

Start Date 06/22/89 Shifts 15 Serial Operation [ ] Parallel Operation [X]

SPECIAL TEST EQUIPMENT Ohmmeter
Breakout Boxes
Pressurization Equipment with Gaging
Leak Detector Kit (Cryo)

PSS RECOMMENDATION: Retain [ ] Reduce [ ] Delete [X]

Rationale: Delete for planned Lunar/Mars surface operations. Use system until it indicates maint, repair, calibration are required. Perform on Earth and/or SSF prior to departure for the Moon.

CENTAUR TEST PROCEDURE

CTP: TELEMETRY SYSTEM READINESS

Old CTP No. TLM-3008 **New CTP No.** TLM-1006

Description Verifies proper telemetry system and airborne instrumentation configuration for flight. Verifies protective covers, interface connectors, lanyards, cables, and telemetry ground station are configured for launch.

Remarks Totally manual operation, no ground or vehicle power required

AC68 RESOURCES:

Ground Power ☐ Vehicle Power ☐ Pneumatics ☐ CCLS ☐

Total Personnel 3 : Engr 1 Tech 1 Insp 1 Safety ____

AC68 SCHEDULE DATA:

Start Date 09/15/89 Shifts 3 Serial Operation ☐ Parallel Operation [X]

SPECIAL TEST EQUIPMENT

PSS RECOMMENDATION: Retain ☐ Reduce ☐ Delete [X]

Rationale: Delete except for post maintenance/replacement verification. Proper operation should be verified by functional tests performed by BITE/BITE.

CENTAUR TEST PROCEDURE

CTP: PCM DOWNLINK LSB/TGS SIGNAL CONDITIONING CHECKOUT

Old CTP No. TLM-3014 **New CTP No.** TLM-1008

Description Performs checkout of the PCM downlink launch service building (LSB) interface monitor panel (IMP) to the telemetry ground station (TGS), IMP coaxial links and electronics, transmission of decommutator simulators to LSB and return to TGS, and TGS S-Band receivers to Decom functional test.

Remarks Verifies telemetry ground system and PCM downlink prior to flight vehicle checkout

AC68 RESOURCES:

Ground Power [X] Vehicle Power [ ] Pneumatics [ ] CCLS [ ]

Total Personnel 3 : Engr 1 Tech 2 Insp ___ Safety ___

AC68 SCHEDULE DATA:

Start Date 05/17/89 Shifts 2 Serial Operation [X] Parallel Operation [ ]

SPECIAL TEST EQUIPMENT Oscilloscapes
Digtal Voltmeters
FM Signal Generator
Frequency Synthesizer
Electronic Counter

PSS RECOMMENDATION: Retain [X] Reduce [ ] Delete [ ]

Rationale: Perform an automated version following initial deployment of planetary surface support equipment and then only repeat portions as required for maintenance and repairs.

Appendix F

Planetary Surface Systems Input Forms

Containing Launch and Landing Precursor Engineering Data Needs for Lunar and Mars Missions

Appendix F

Planetary Surface Systems
Input Forms

Containing Launch and Landing
Precursor Engineering Data Needs
for Lunar and Mars Missions

This appendix contains the parameters that must be known before any lunar or martian missions can be undertaken from a launch and landing perspective. The input forms were developed by the Planetary Surface Systems Office. Input Form 1 records the parameter or requirement, the systems impacted by the parameter, and the rationale for obtaining this data. Input Form 2, records the precision to which the parameter must be known, and the consequences of not obtaining the required parameter or requirement prior to conducting a lunar or martian mission.

Input Form 1

Precursor Engineering Data Needs

Lunar Data

Parameter or Requirement	Systems Impacted	Rationale for Need
Site Characteristics (Grain size)	Surface Support Equipment (SSE) and flight hardware	Protection of SSE from LEV exhaust blast effects
Temperature - extreme ranges	SSE/LEV	SSE/LEV environmental design
Heat Transmission	SSE/LEV	SSE/LEV environmental design
Solar Flux	SSE/LEV	SSE/LEV environmental design
Meteroid Flux	SSE/LEV	Design protection for SSE/LEV
Electromagnetic Radiation	Electrical, pyrotechnical, and fuel systems.	Prevent unacceptable damage or disruption of operability
Ionizing/Nonionizing Radiation	Personnel	Protect surface crewmembers from the harmful effects of these energy sources
Soil Density	Personnel, electrical, and structural systems	Radiation protection (shielding)
Illuminance	Monitoring systems and teleoperated systems	Establishes the lighting energy that may have to be provided to makeup for inadequate natural sources.

Input Form 2

Precursor Engineering Data Needs

Lunar Data

Parameter or Requirement	Precision Required	Consequences of Degraded or No data, Possible Workarounds
Site Characteristics (Grain size)	+/- 10%. Need range of grain sizes and percent of weight for each size for proposed launch and landing sites	Unacceptable damage to hardware. Design to Apollo data in the absence of certified data.
Temperature - extreme ranges	+/- 30 Kelvin. Need temperature gradient as a function of time. (Based on rotation or eclipse.)	Adverse material wear due to thermal cycling. Design to earth based astronomical measurements.
Heat Transmission	+/- 10%	Design to Earth based astronomical measurements
Solar Flux	+/- 20%.	Design to Earth based astronomical measurements
Meteroid Flux	Requires a range of particle sizes and associated worst case flux	Damage from particle impact. Design to Apollo/Earth orbital data.
Electromagnetic Radiation	mW. Design parameters require isolation/protection of susceptible systems to the mW range.	Disrutpion of system effectiveness

Input Form 2

Precursor Engineering Data Needs

Lunar Data

Parameter or Requirement	Precision Required	Consequences of Degraded or No data, Possible Workarounds
Ionizing/Nonionizing radiation	mREM. Must able to measure induced and natural background radiation levels and distinguish them.	Failure to provide workable environment for surface crewmembers
Soil Density	Milli-gram per cubic centimeter	Failure to adequately use ISRU soil to shield sensitive systems and humans. Use available Apollo data.
Illuminance	Lumens or candela. Must be able to determine acceptable contrast and illumination levels for point task operations and control.	Failure to detect aberrations in terrain and failed structures, and inadequate light for observation monitoring systems. Use Apollo data where conditions and locations are alike.

Input Form 1

Precursor Engineering Data Needs

Mars Data

Parameter or Requirement	Systems Impacted	Rationale for Need
Temperature Extreme Ranges	Surface Support Equipment (SSE)/MEV	SSE/MEV environmental design
Pressure	SSE/MEV	SSE/MEV environmental design for themal conduction factors
Wind/Storms/Dust	SSE/MEV	SSE/MEV environmental design/equipment protection/MEV exhaust blast effects
Corrosives	SSE/MEV	SSE/MEV environmental design
Heat Transmission	SSE/MEV	SSE/MEV environmental design
Solar Flux	SSE/MEV	SSE/MEV environmental design
Meteroid Flux	SSE/MEV	Design protection for SSE/MEV
ElectromagneticRadiation	Electrical, pyrotechnical, and fuel systems.	Prevent unacceptable damage or disrutpion of operability
Ionizing/Nonionizing radiation	Personnel	Protect surface crewmembers from biologically harmful effects from these energy sources.
Soil Density	Personnel, electrical, and structural systems	Radiation protection (shielding)
Illuminance	Monitoring systems and teleoperated systems	Establishes the lighting energy that may have to be provided to makeup for inadequate natural sources.

Input Form 2

Precursor Engineering Data Needs

Mars Data

Parameter or Requirement	Precision Required	Consequences of Degraded or No data, Possible Workarounds
Temperature Extreme Ranges	+/- 30 Kelvin. Need temperature gradient as a function of time. (Based on rotation)	Design to Earth based astronomical measurements
Pressure	+/- 50%	Design to earth based astronomical measurements.
Wind/Storms/Dust	TBD	Design to Earth based astronomical measurements.
Corrosives	TBD	Design to best estimate of soil/air/chemical compounds
Heat Transmission	TBD	Design to Earth based astronomical measurements
Solar Flux	+/- 20%	Design to earth based astronomical measurements
Meteroid Flux	Requires range of particle sizes and worst case flux.	Design to Apollo/Earth orbital data
Electromagnetic Radiation	mW. Design parameters require isolation/protection of susceptible systems to the mW range	Disruption of system effectiveness

Input Form 2

Precursor Engineering Data Needs

Mars Data

Parameter or Requirement	Precision Required	Consequences of Degraded or No data, Possible Workarounds
Ionizing/Nonionizing radiation	mREM. Must be able to measure induced and natural background radiation levels and distinguish them.	Failure to provide workable environment for surface crewmembers
Soil Density	Milli-gram per cubic centimeter	Failure to adequately use ISRU soil to shield sensitive systems and humans. Use data from Viking probes.
Illuminance	Lumens or candela. Must be able to determine acceptable contrast and illumination levels for point task operations and control.	Failure to detect aberrations in terrain, failed structures, and inadequate observation monitoring systems. Use Viking data where conditions and locations are alike.

Appendix G

Mission Profile

for

Reference Architecture Option 5A

Appendix G

Mission Profile

for

Reference Architecture Option 5A

The mission profile was developed using the data as provided the PSS Reference Architecture Document 90-2, "Reference Architecture Description Option 5A." The profile was developed to assist the MDSSC-KSC office in developing launch and landing scenarios, based on the Reference Architecture Option 5A. Significant launch and landing parameters are given on a flight-by-flight basis as well as the year in which the flight will occur. This data was used to develop inputs to the Planetary Surface Systems Office for the advanced development planning which occurred in the winter of 1990.

MISSION PROFILE*
LAUNCH AND LANDING FUNCTIONAL AREA
ADVANCED DEVELOPMENT PLANNING

PARAMETER	YEAR
Payload requirements determined for cargo vehicle	1994
Vehicle design determined	1995
Flight 0 (Cargo flight) • Unpressurized rover delivered • TNIM (landing aids) • Payload unloader • Excavation pyrotechnics	2002
Flight 1 (Cargo flight) • Initial Hab module • Airlock #1 w/Dustoff • SP 100 power module • Vehicle is expended on lunar surface	2003
Flight 2 (Manned vehicle) • Crew of 4 • Crew stay time of 30 days • LLOX demonstration • EMUs delivered	2004
Launch and landing and ejecta protection required for first manned landing	2004
Flight 3 (Manned vehicle) • Crew of 4 • Crew stay time of 30 days • EMUs • Unpressurized manned/robotic rover • Vehicle is expended in LLO after 2nd manned mission	2005
Flight 4 (Cargo flight) • Lab module • Airlock #2 • Vehicle is expended on the lunar surface	2006
Flight 5 (Manned vehicle) • Crew of 4 • Crew stay time of 90 days • LEV servicer • EMUs	2007
Thermal protection required	2007

PARAMETER	YEAR
Flight 6 (Manned vehicle) • Crew of 4 • Crew stay time of 90 days • Unpressurized rover	2008
Flight 7 (Manned vehicle) • Crew of 4 • Crew stay time of 90 days • Pressurized manned rover - extended range • Vehicle is expended in LLO after 3 manned missions	2009
Flight 8 (Cargo vehicle) • Constructible Hab and associated subsystems • Airlock #3 • Constructible logistics module • Vehicle is expended on the lunar surface	2010
Flight 9 (Manned vehicle) • Crew of 4 • Crew stay time of 180 days • Complete constructible Hab module	2011
Flight 10 (Cargo vehicle) • 550 kW nuclear power plant • LLOX production plant • LLOX fueling pallet • Mining excavator/loader • Regolith hauler • Vehicle is expended on the lunar surface	2012
Flight 11 (Manned vehicle) • Crew of 4 • Crew stay time of 360 days • Mars simulation mission begins • Flight 11 vehicle is launched after landing of of flight 12	2013
Flight 12 (Manned vehicle) • Crew of 4 • Crew stay time of 240 days • Complete 600 day Mars mission simulation	2014
First flight to Mars • Mission time of 600 days • Crew size of 12 • No resupply support • No use ISRU products for this mission • 20 kW power available for mission	2014

PARAMETER	YEAR
Flight 13 (Manned vehicle) • Crew of 4 • Crew stay time of 180 days • Unpressurized manned rover • Begin usage of LLOX	2015
Flight 14 (Manned vehicle) • Crew of 4 • Crew stay time of 180 days • Pressurized transport module • Unpressurized manned rover • Vehicle is expended in LLO after 5 manned missions	2016
Flight 15 (Manned vehicle) • Crew of 4 • Crew stay time of 360 days • Unpressurized manned rover	2017
Flight 16 (Manned vehicle) • Crew of 4 • Crew stay time of 360 days	2018
Flight 17 (Manned vehicle) • Crew of 4 • Crew stay time of 360 days	2019
Flight 18 (Manned vehicle) • Crew of 4 • Crew stay time of 360 days • Deliver last identified science payload	2020
Flight 19 (Manned vehicle) • Crew of 4 • Crew stay time of 360 days • Vehicle is expended in LLO after 5 manned missions	2021
Flight 20 (Manned vehicle) • Crew of 4 • Crew stay time of 30 days • Lunar far-side sortie (30 days) • Unpressurized manned rover	2022

* Profile based on "Reference Architecture Description Option 5a." PSS Reference Architecture Document 90-2. Planet Surface Systems Office, NASA. Interim Review May 22-24.

Appendix H

Launch and Landing Turnaround Scenarios

for

Reference Architecture Option 5A

Appendix H

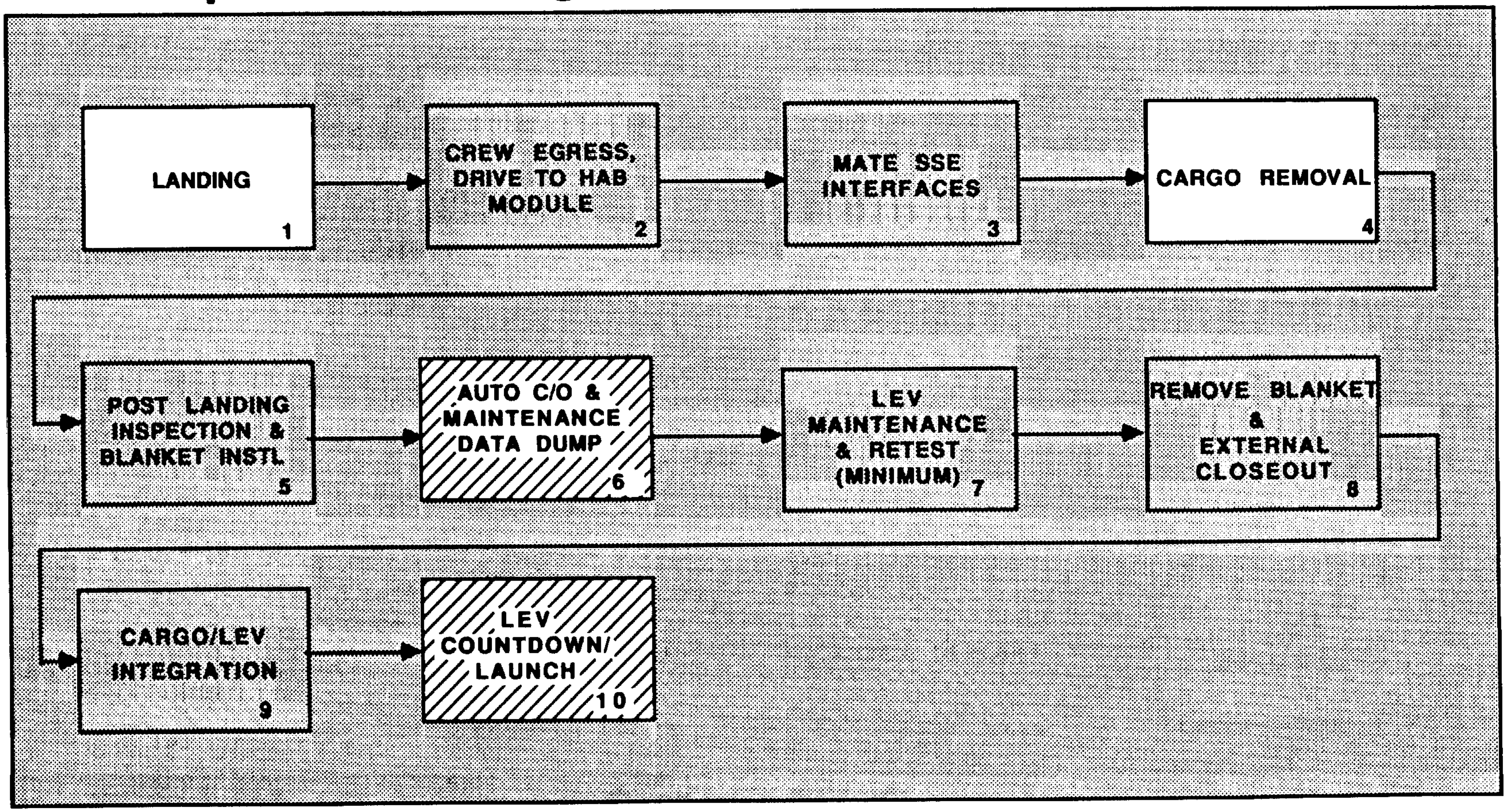
Launch and Landing Turnaround Scenarios

for

Reference Architecture Option 5A

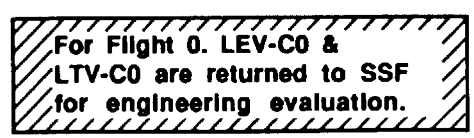
The launch and landing scenarios in this appendix were developed using the baseline turnaround scenario which was developed under the base period of the Lunar Transportation Facilities and Operations Study as well as the mission profile contained in Appendix G. Two mission mission turnaround scenarios are contained in this appendix. A turnaround scenario for a cargo vehicle (unmanned) can be found on page H-1, while the launch and landing turnaround scenario for the manned vehicle begins on H-6.

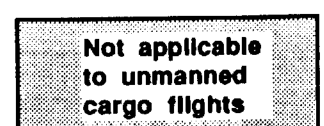
Option 5a
Expendable Cargo LEV Turnaround Scenario*



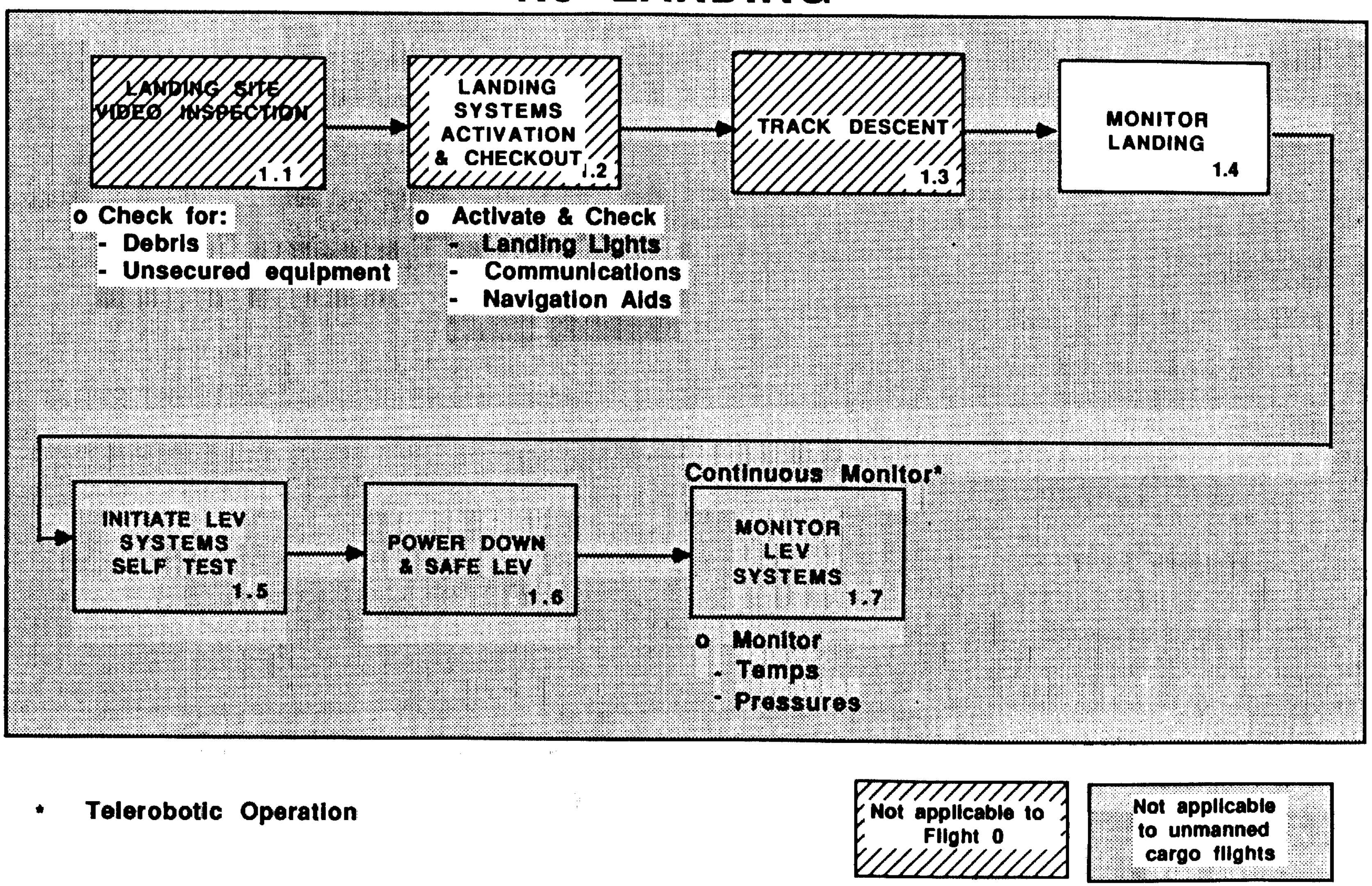
*Applicable to all unmanned cargo flights

Reference Approach 5a, Manifest, 22 May 1990



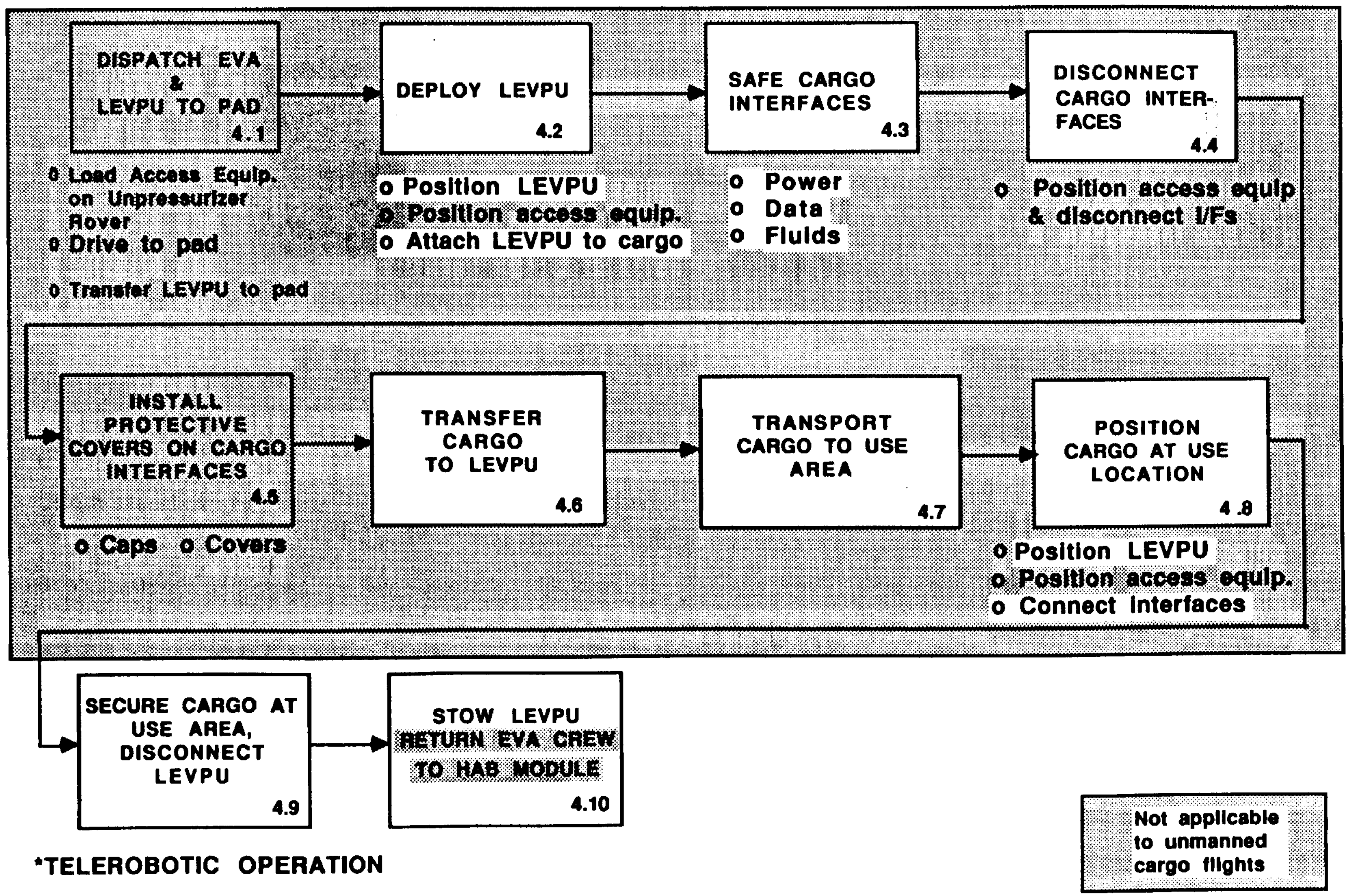


1.0 LANDING*



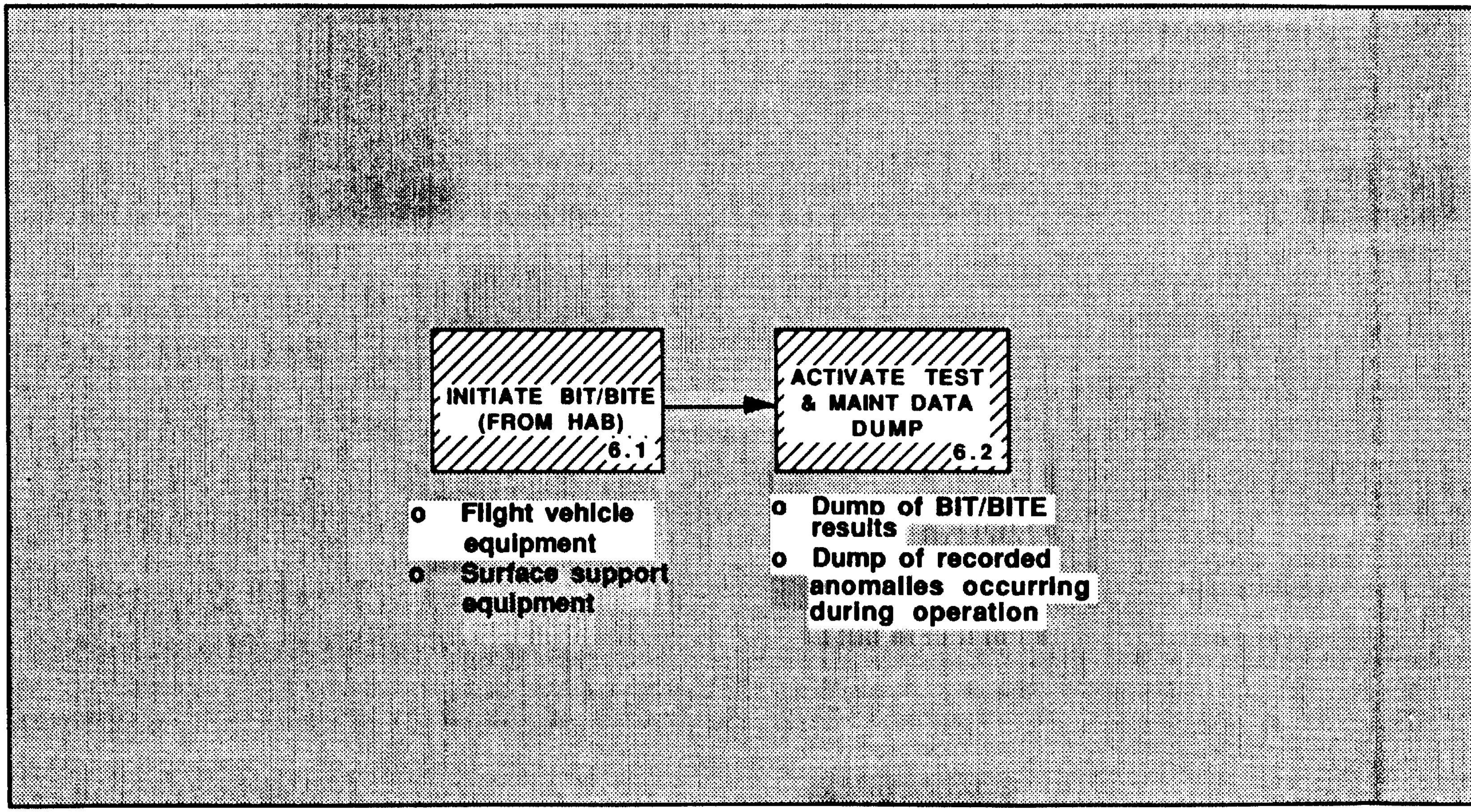
* Telerobotic Operation

4.0 CARGO REMOVAL*



*TELEROBOTIC OPERATION

6.0 AUTOMATIC CHECKOUT & MAINTENANCE DATA DUMP*

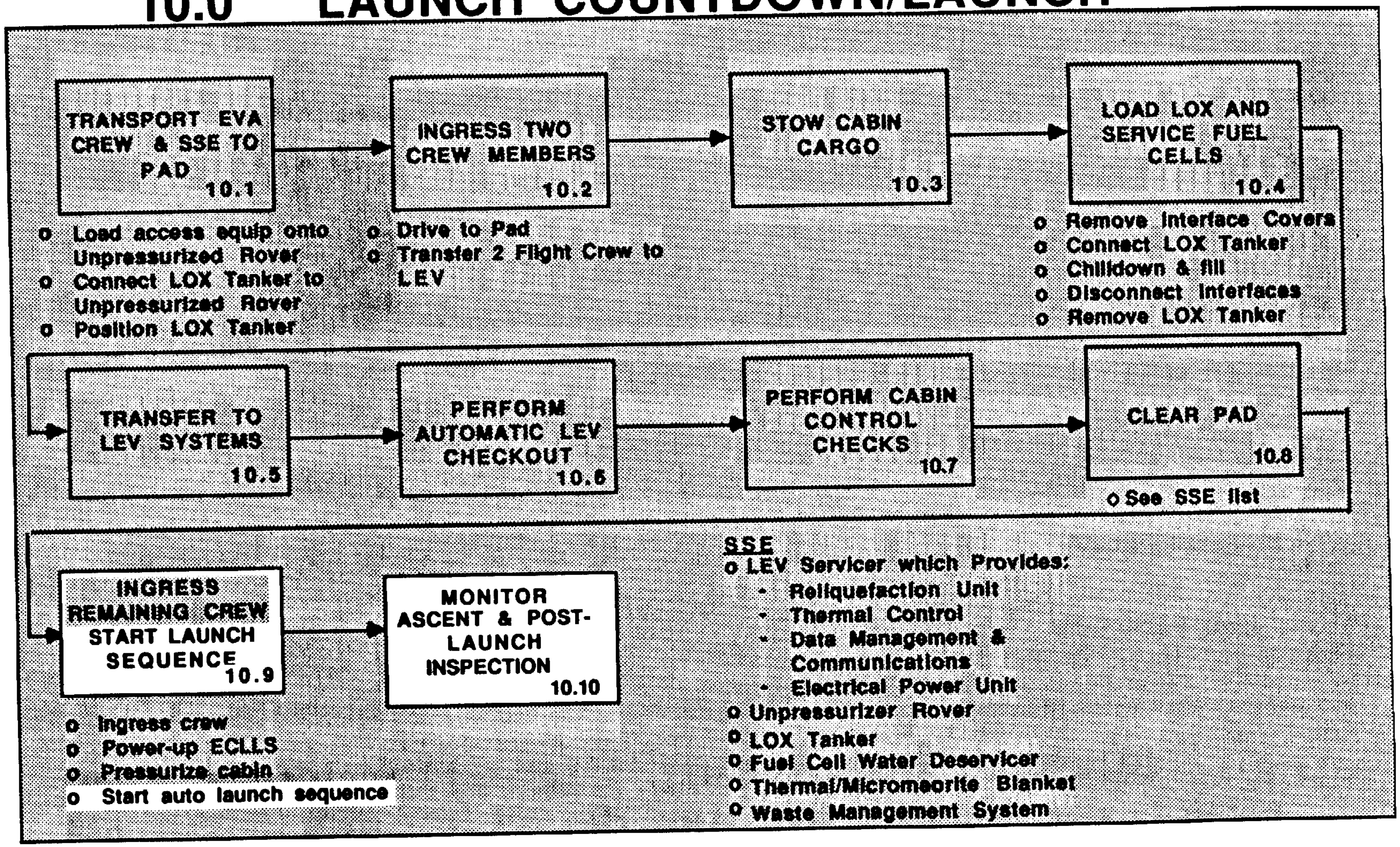


*Telerobotic Operation from Earth and/or Lunar Surface

For Flight 0. LEV-C0 & LTV-C0 are returned to SSF for engineering evaluation.

NOT APPLICABLE TO THIS FLIGHT

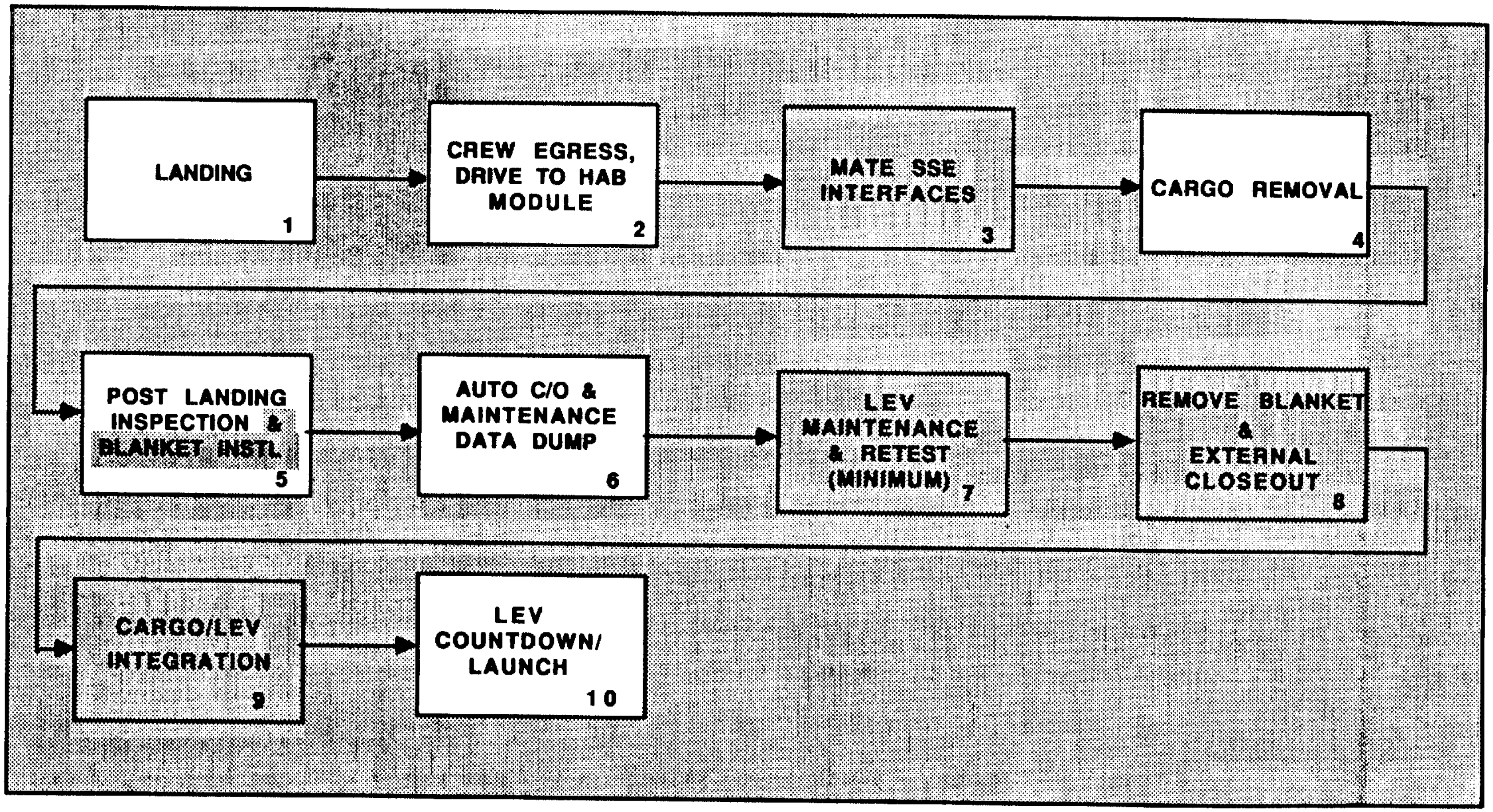
10.0 LAUNCH COUNTDOWN/LAUNCH*



Not applicable to unmanned cargo flights

* Applicable to Flight 0 only.
Telerobotic Operation from Earth.

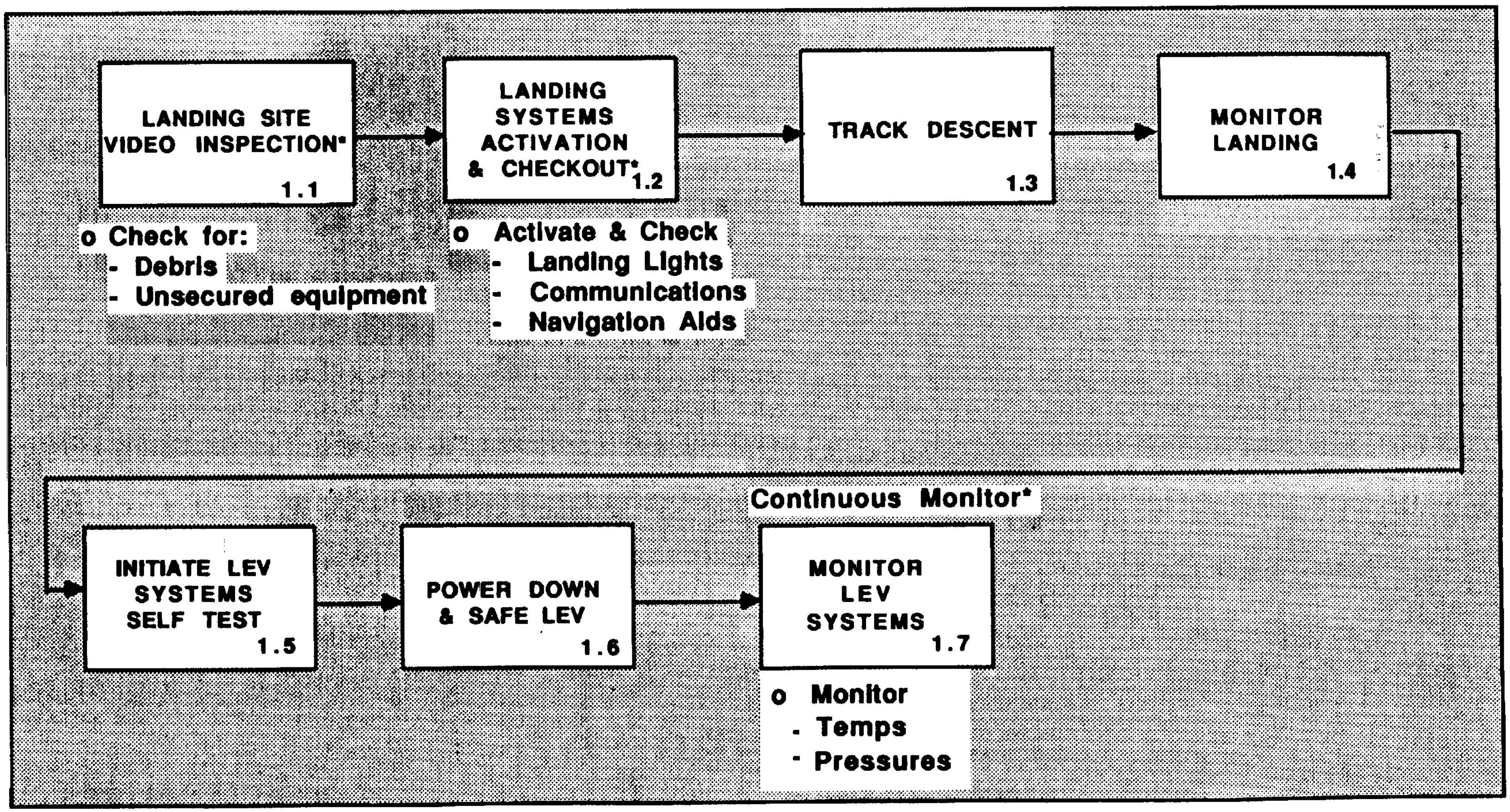
Option 5a
Flight 2 LEV-P1.1 Turnaround scenario



* ALSO APPLICABLE TO FLIGHTS 3 (LEV-P1.2) & 20 (LEV-P5.1 FAR SIDE DIRECT FLIGHT)
Referance Approach 5a, Manifest, 22 May 1990.

NOT APPLICABLE TO THIS FLIGHT

Flight 2 LEV-P1.1
1.0 LANDING

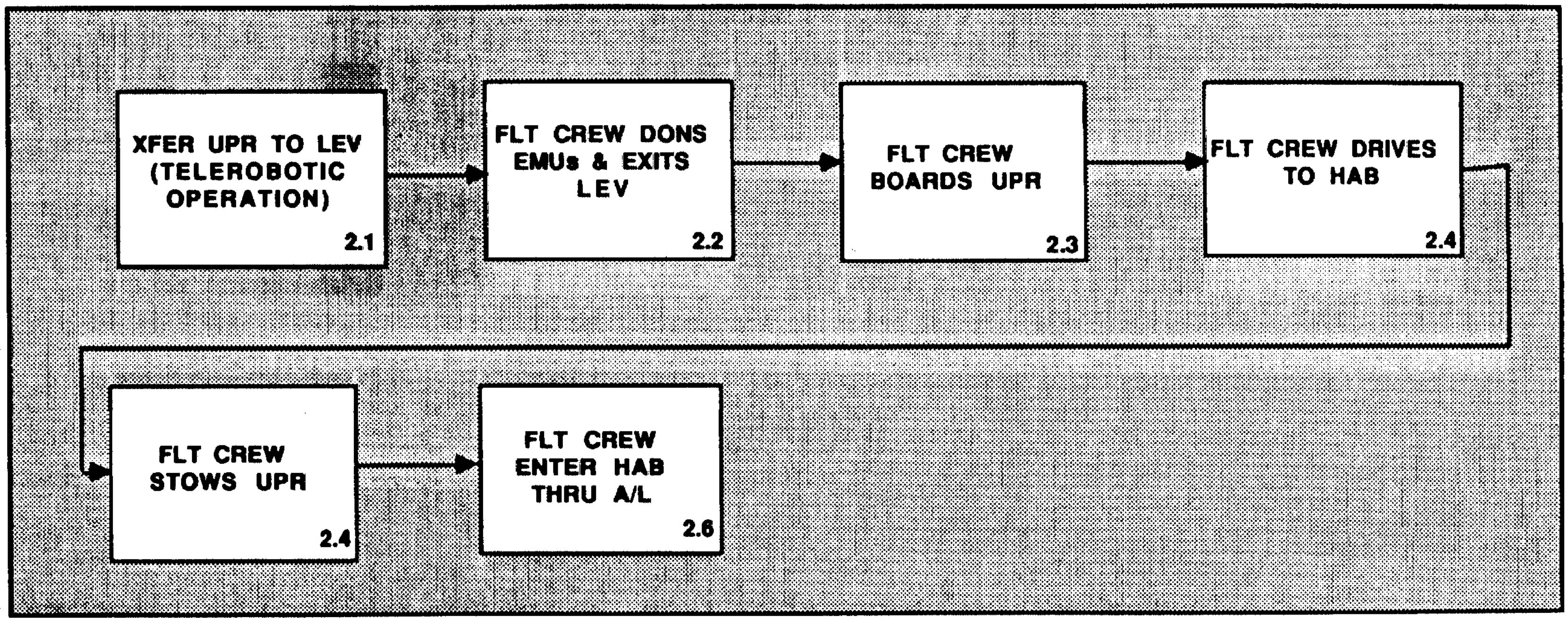


* Telerobotic Operation from Earth and/or Lunar Flight Crew

** Continuous Computer Monitoring with C&W Alarms to Alert Earth Crew of Out-of-Tolerance Conditions.

NOT APPLICABLE TO THIS FLIGHT

Flight 2 LEV-P1.1
2.0 CREW EGRESS

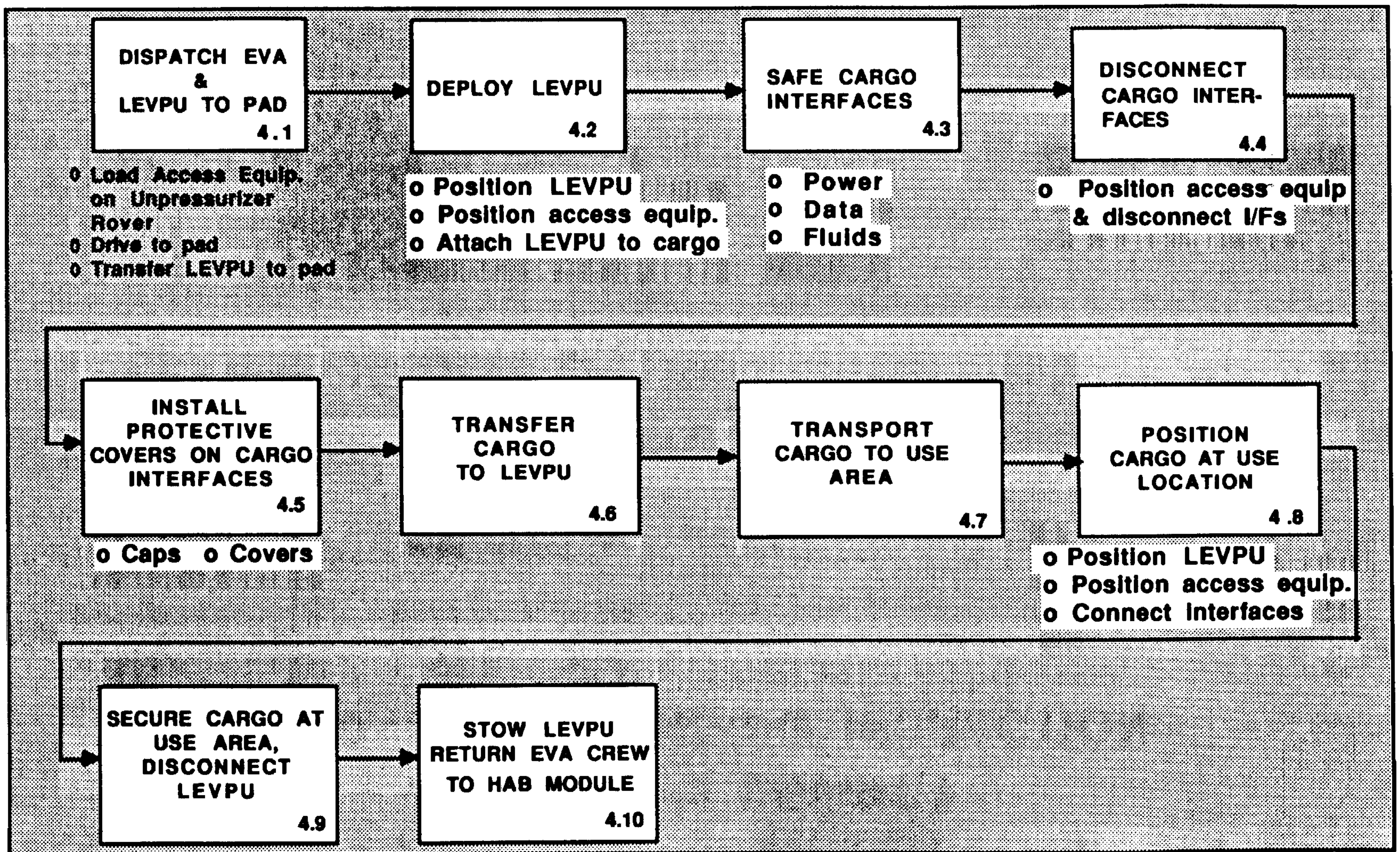


* Rover transported to LEV from parking area Telerobotically by Earth and/or Lunar Flight Crew

NOT APPLICABLE TO THIS FLIGHT

a-4.

Flight 2 LEV-P1.1
4.0 CARGO REMOVAL*

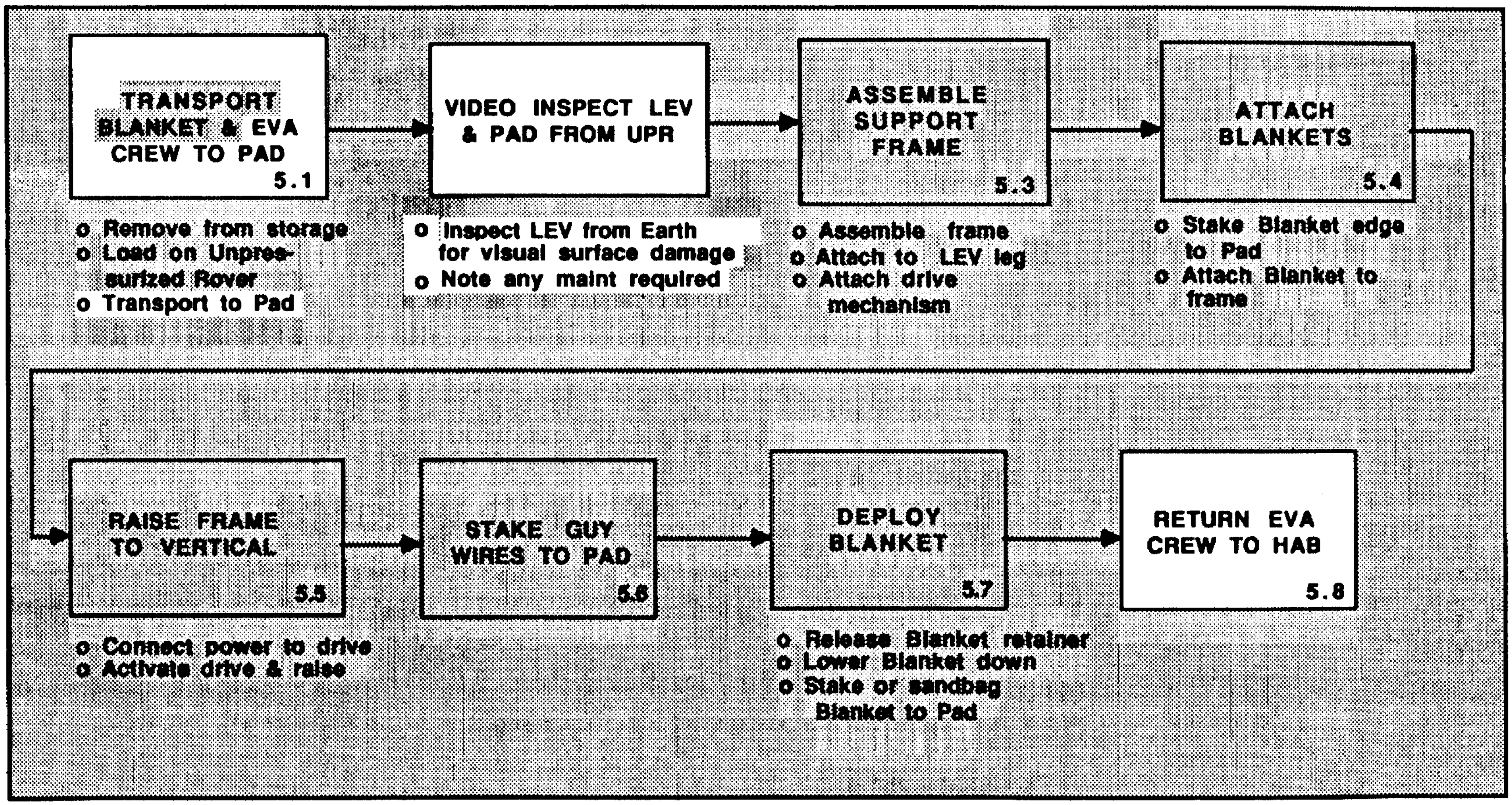


*Telerobotic Operation from Earth and/or Lunar Surface

NOT APPLICABLE TO THIS FLIGHT

Flight 2 LEV-P1.1

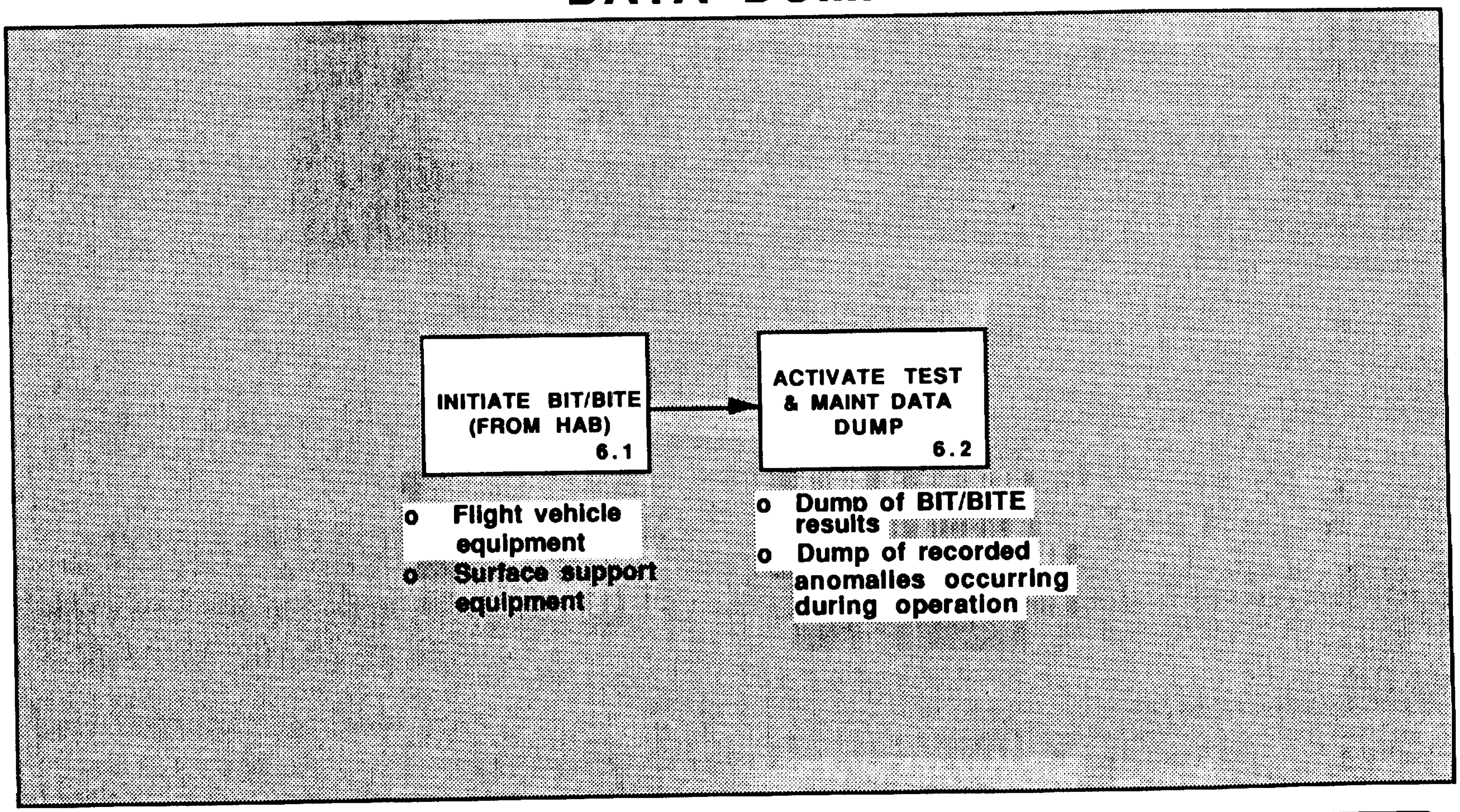
5.0 POST LANDING INSPECTION



*Telerobotic Operation from Earth and/or Lunar Surface

NOT APPLICABLE TO THIS FLIGHT

Flight 2 LEV-P1.1
6.0 AUTOMATIC CHECKOUT & MAINTENANCE DATA DUMP*

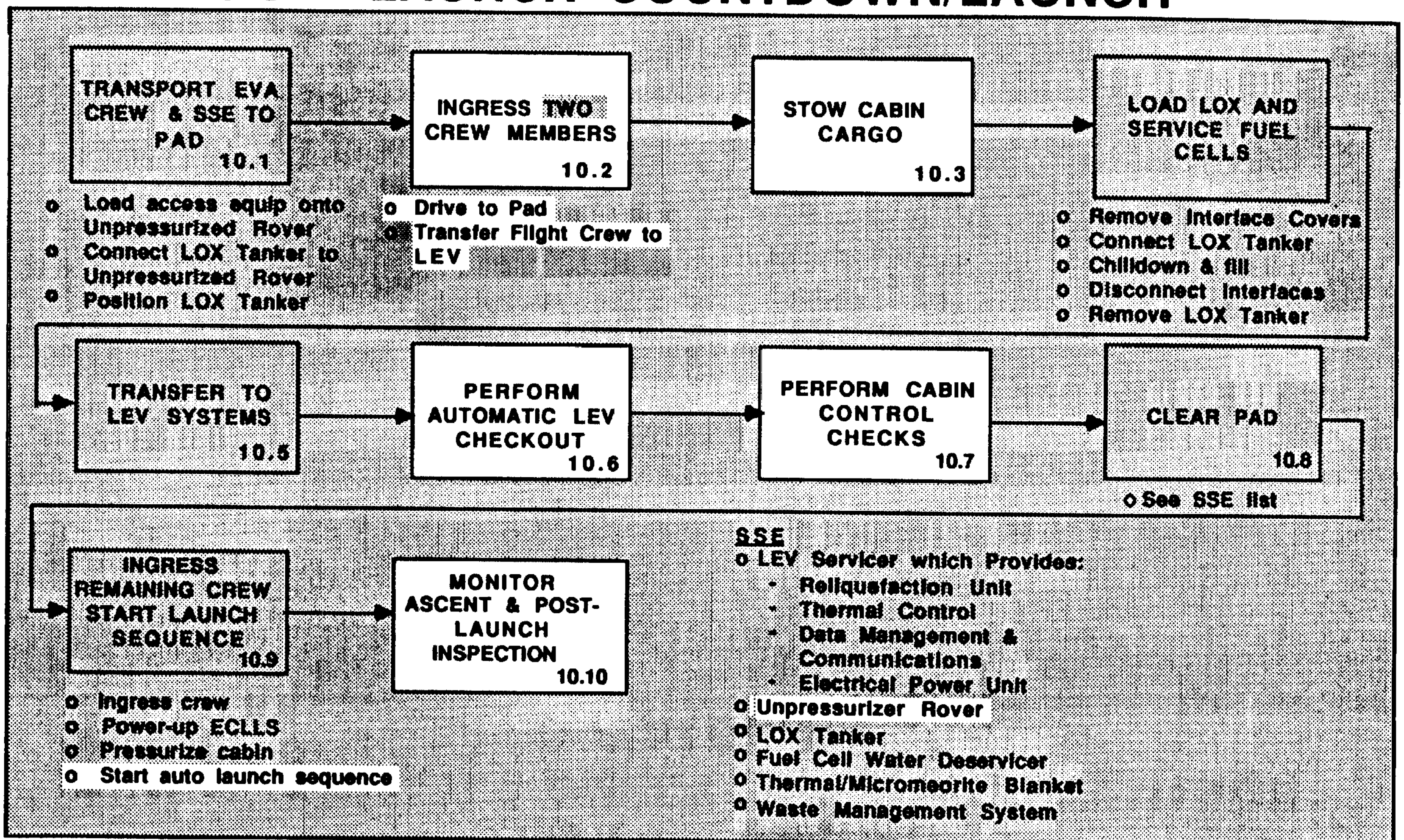


NOT APPLICABLE TO THIS FLIGHT

*Telerobotic Operation from Earth and/or Lunar Surface

Flight 2 LEV-P1.1

10.0 LAUNCH COUNTDOWN/LAUNCH

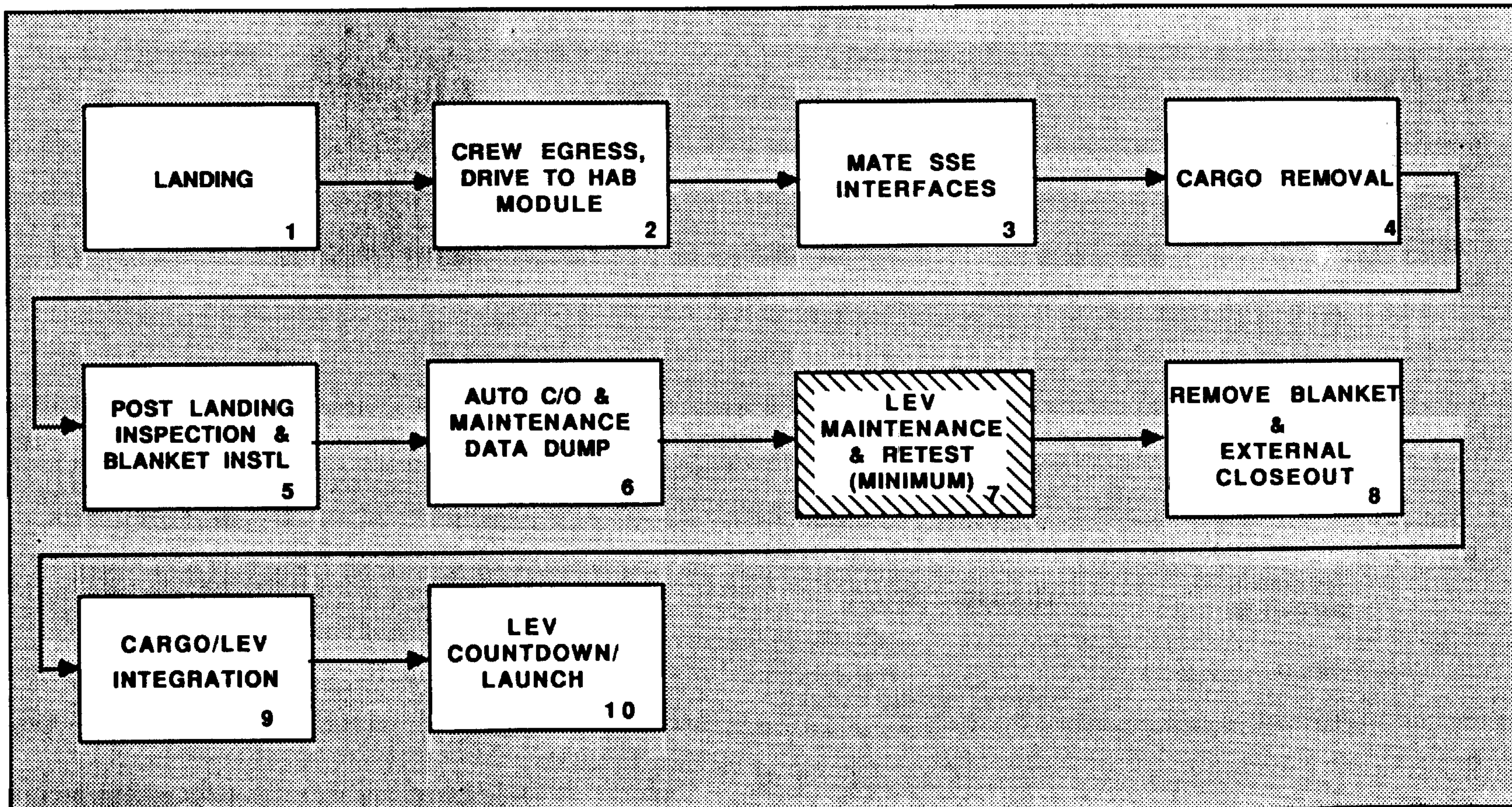


* Telerobotic Operation from Earth and/or Lunar Flight Crew

NOT APPLICABLE TO THIS FLIGHT

Option 5a
Manned LEV Turnaround Scenario*

LEV Servicer is delivered & used on this & subsequent reusable LEV flights



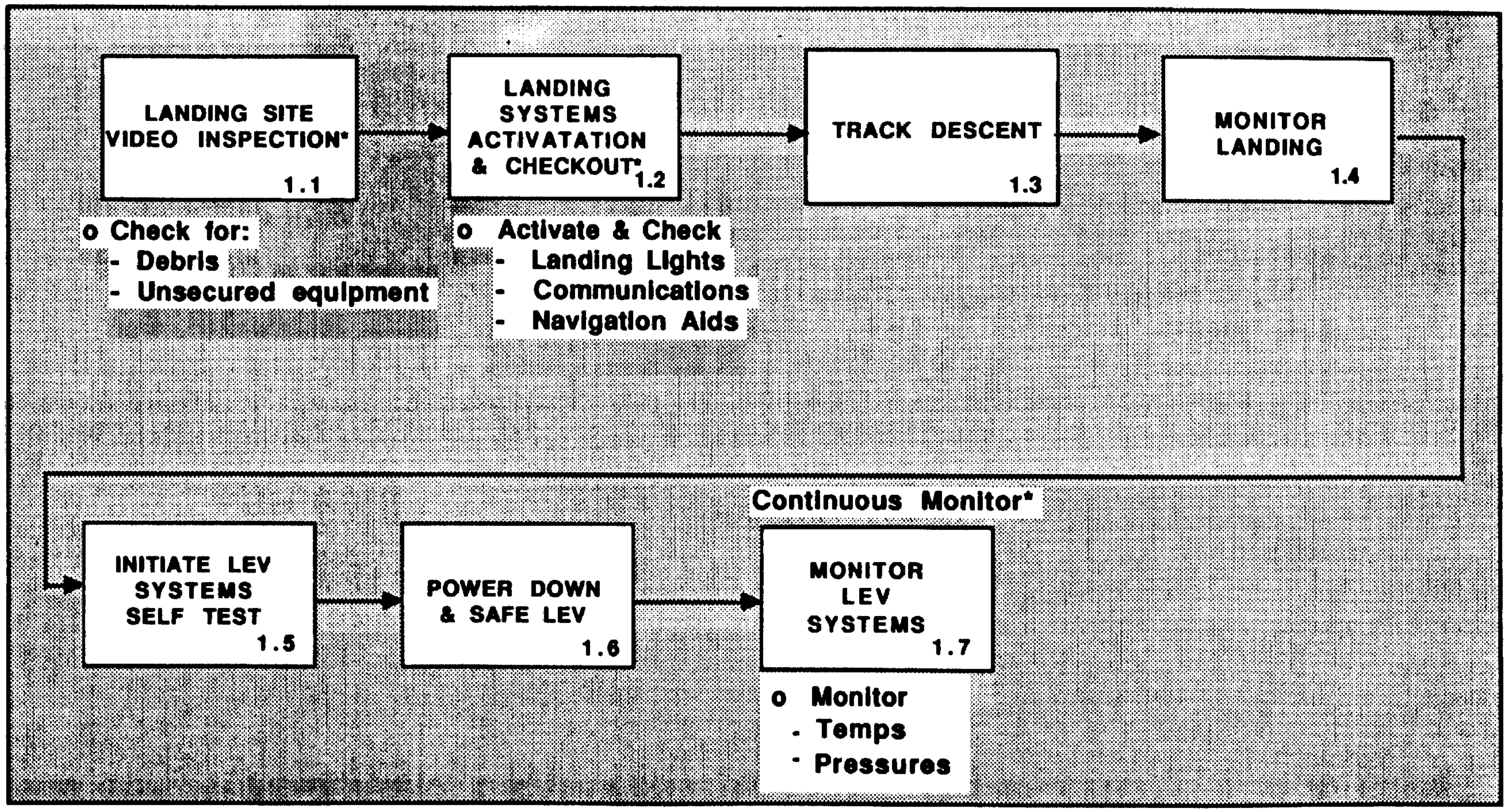
Applicable to Flight 5 (LEV-P2.1) and all subsequent flights except * the Mars simulation mission flight 11 (LEV-P3.2) and far side direct mission flight 20 (LEV-P5.1)

Referance 5a Manifest, 22 May 1990

Capabilities Provided for Minor Remove/Replace Tasks Only

NOT APPLICABLE TO THIS FLIGHT

Flight 5 LEV-P2.1
1.0 LANDING

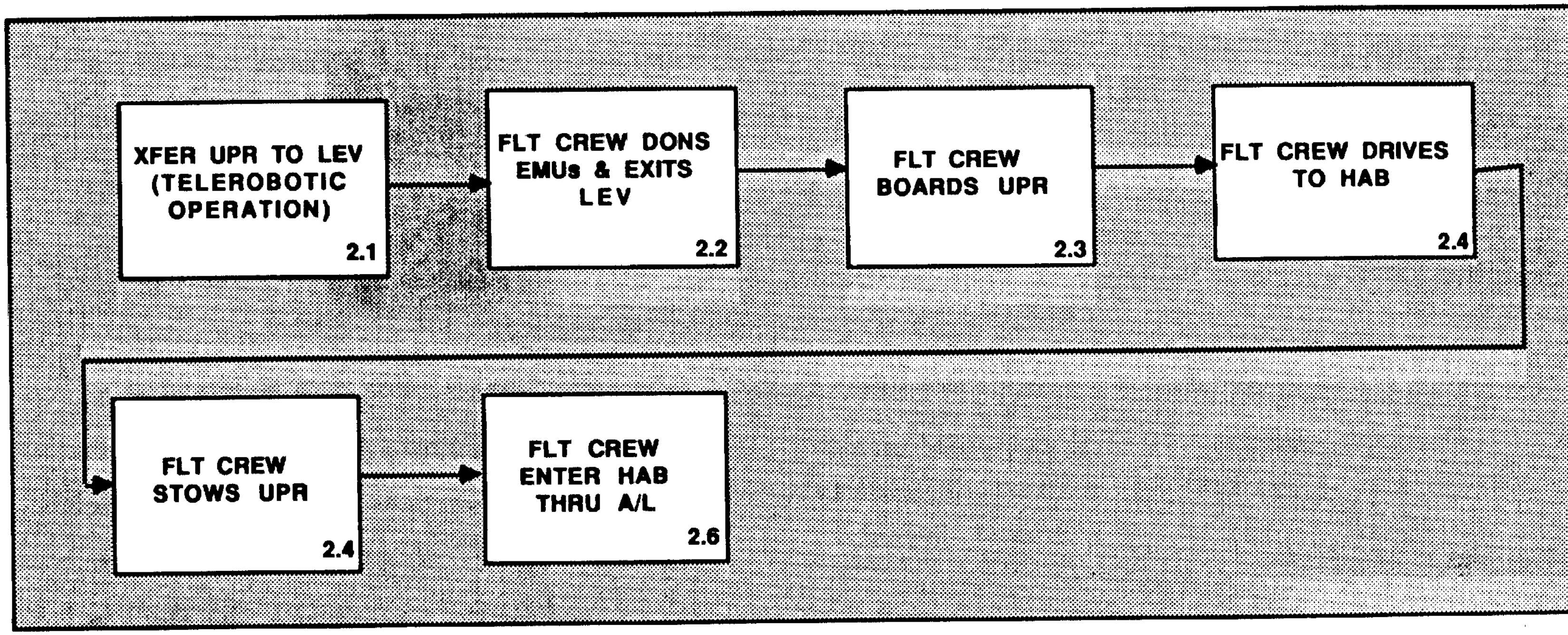


* Telerobotic Operation from Earth and/or Lunar Flight Crew

** Continuous Computer Monitoring with C&W Alarms to Alert Earth Crew of Out-of-Tolerance Conditions.

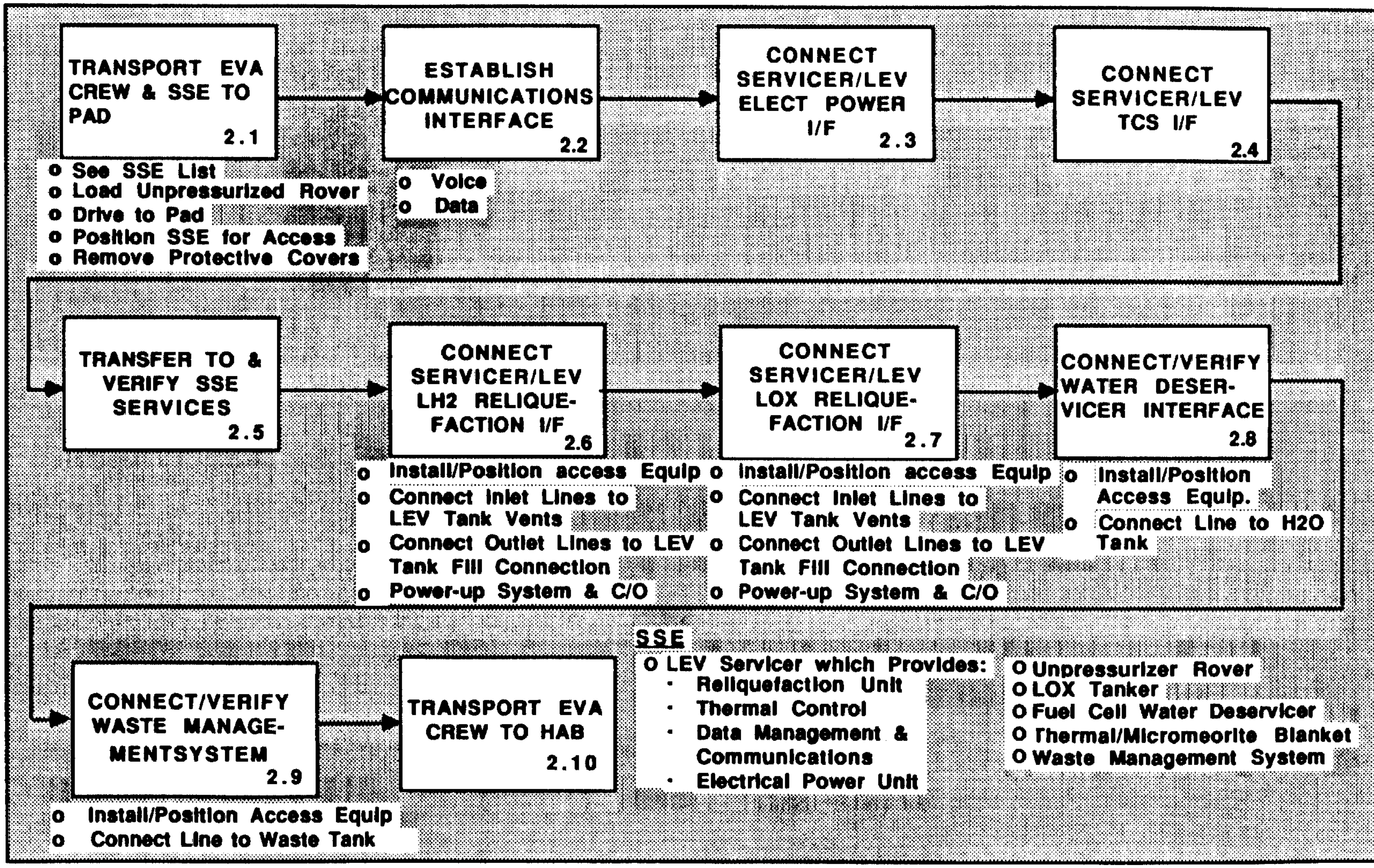
NOT APPLICABLE TO THIS FLIGHT

Flight 5 LEV-P2.1
2.0 CREW EGRESS



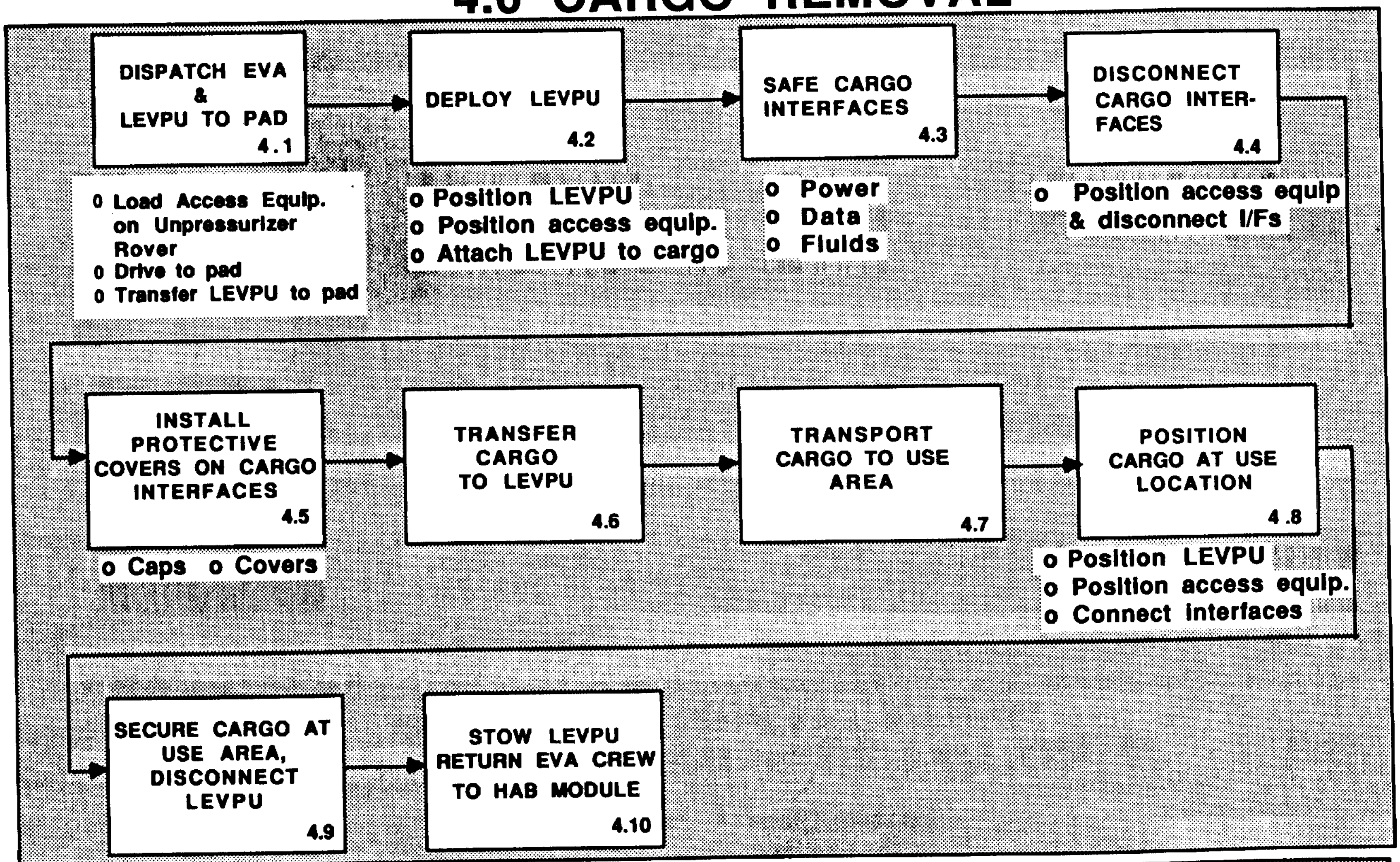
* Rover transported to LEV from parking area Telerobotically by Earth and/or Lunar Flight Crew

Flight 5 LEV-P2.1
3.0 MATE SSE INTERFACES



NOT APPLICABLE TO THIS FLIGHT

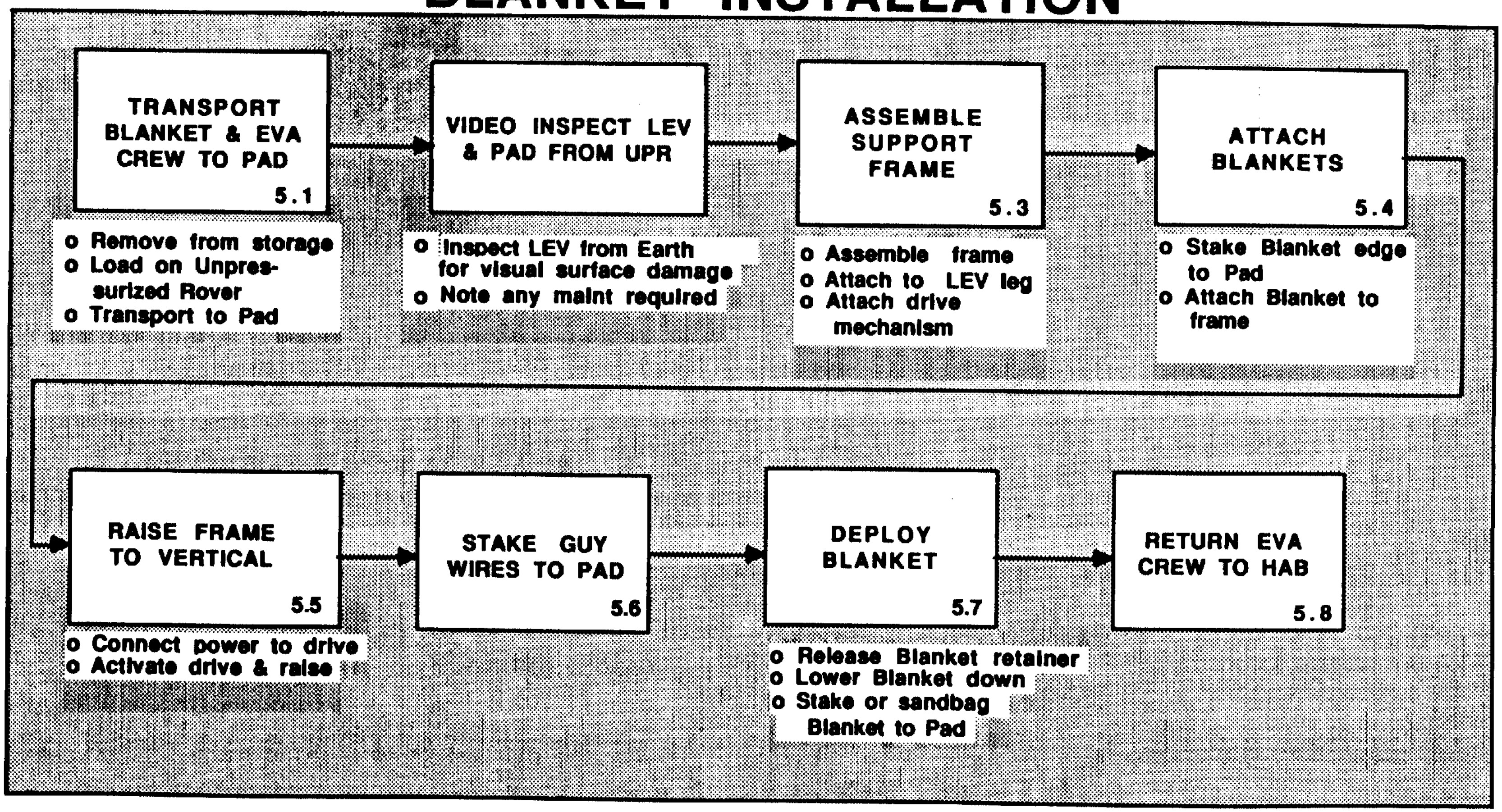
Flight 5 LEV-P2.1
4.0 CARGO REMOVAL*



*Telerobotic Operation from Earth and/or Lunar Surface

NOT APPLICABLE TO THIS FLIGHT

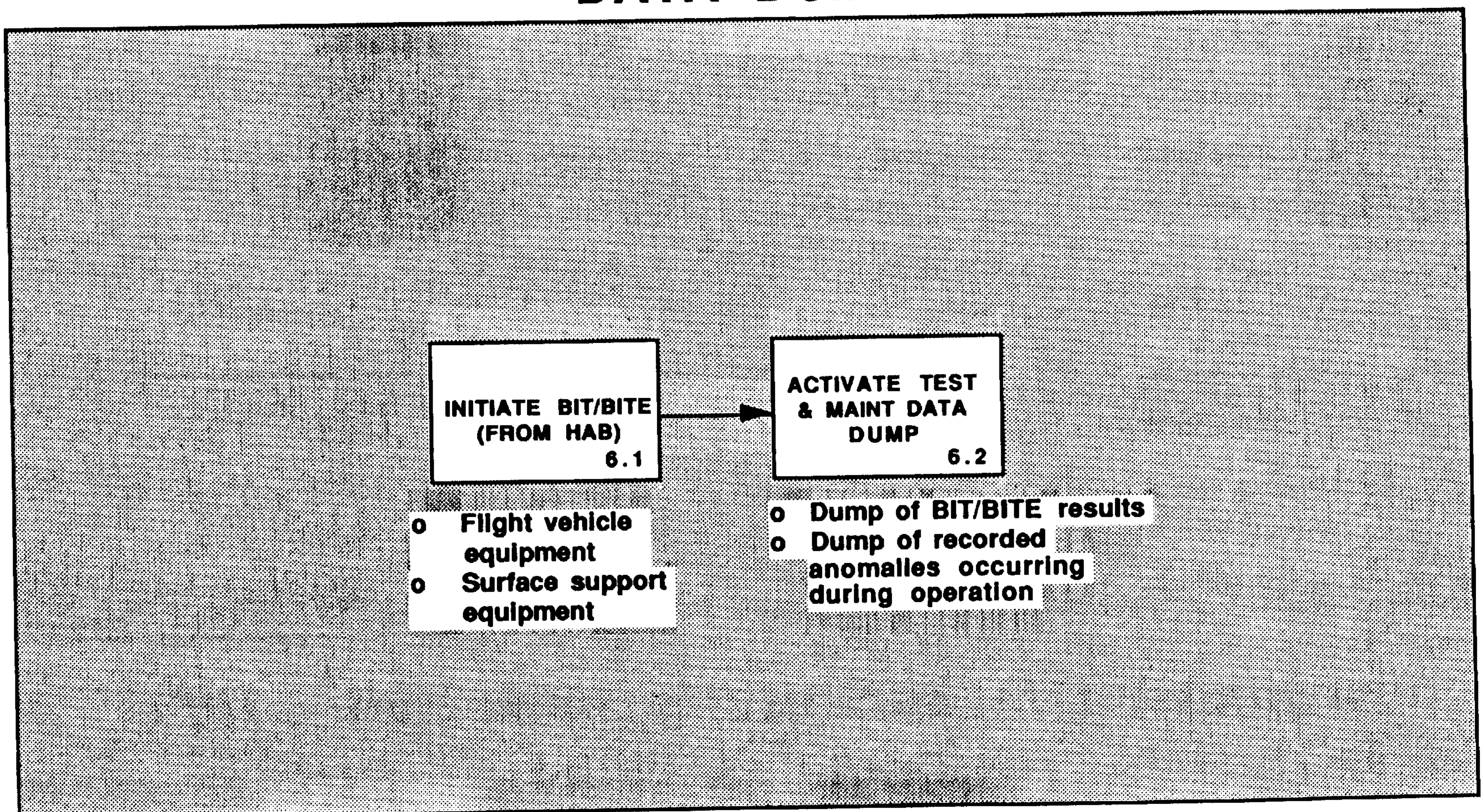
Flight 5 LEV-P2.1
5.0 POST LANDING INSPECTION & BLANKET INSTALLATION



*Telerobotic Operation from Earth and/or Lunar Surface

NOT APPLICABLE TO THIS FLIGHT

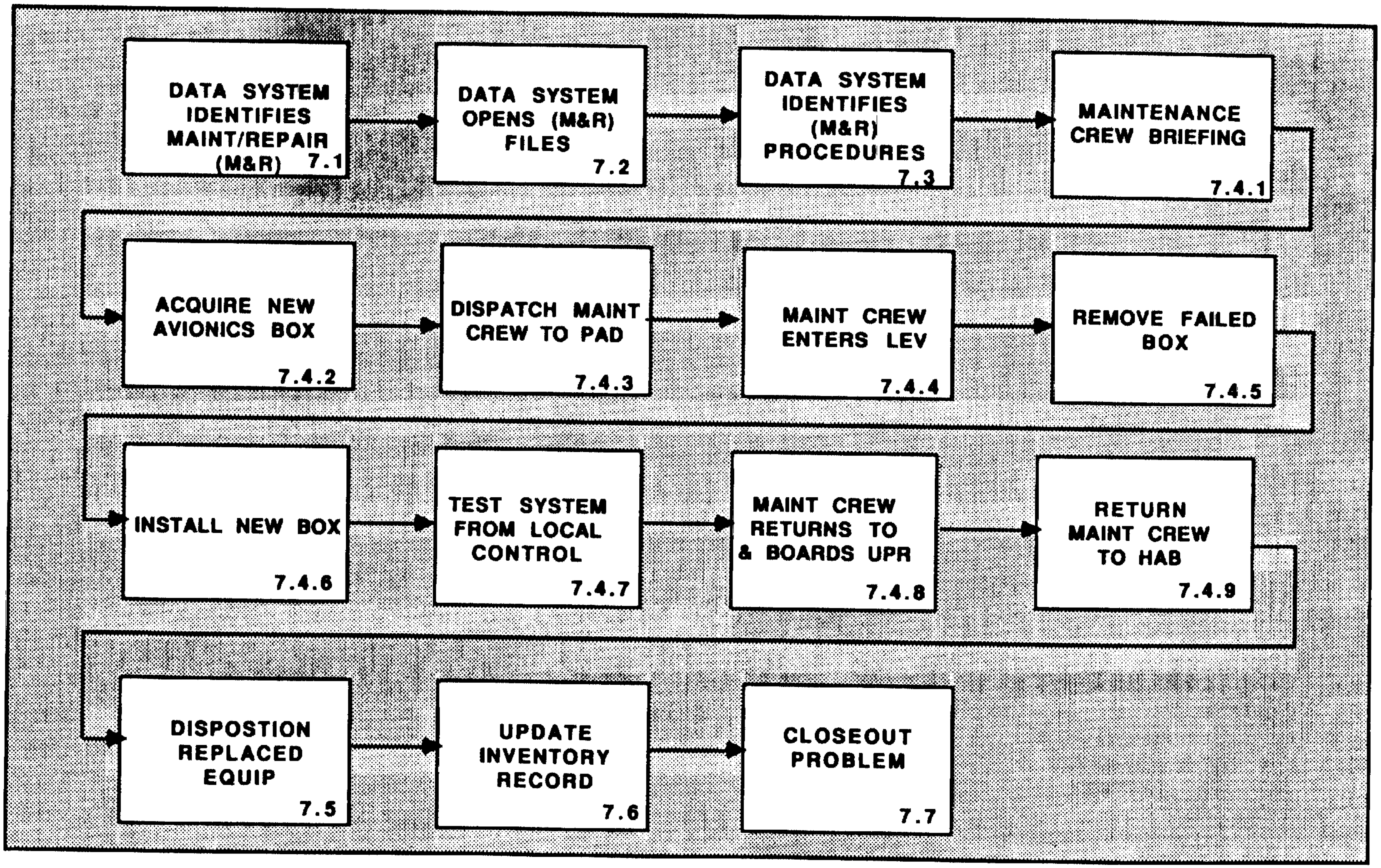
Flight 5 LEV-P2.1
6.0 AUTOMATIC CHECKOUT & MAINTENANCE DATA DUMP*



*Telerobotic Operation from Earth and/or Lunar Surface

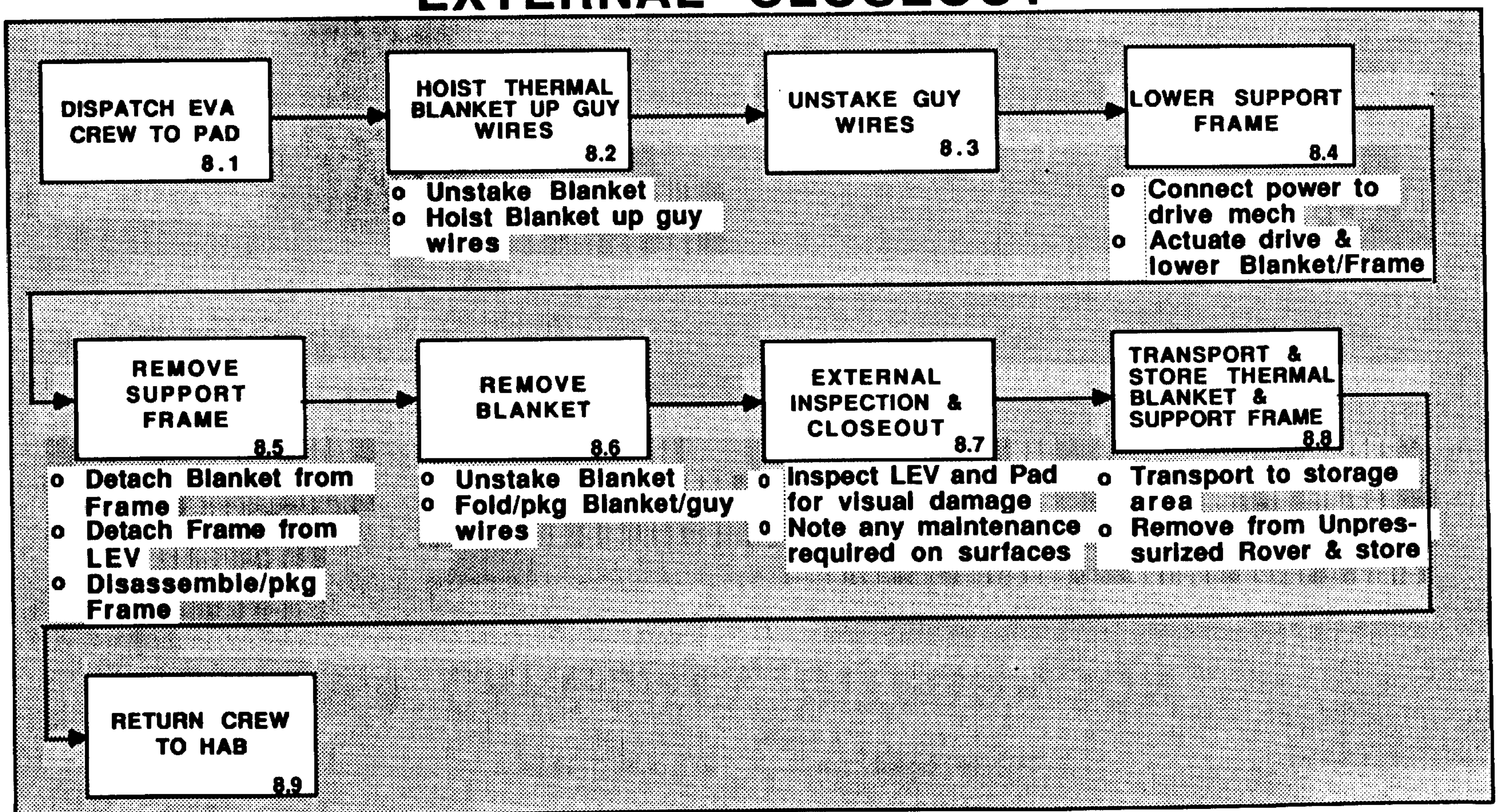
NOT APPLICABLE TO THIS FLIGHT

Flight 5 LEV-P2.1
7.0A LEV MAINTENANCE/RETEST (MINIMUM)



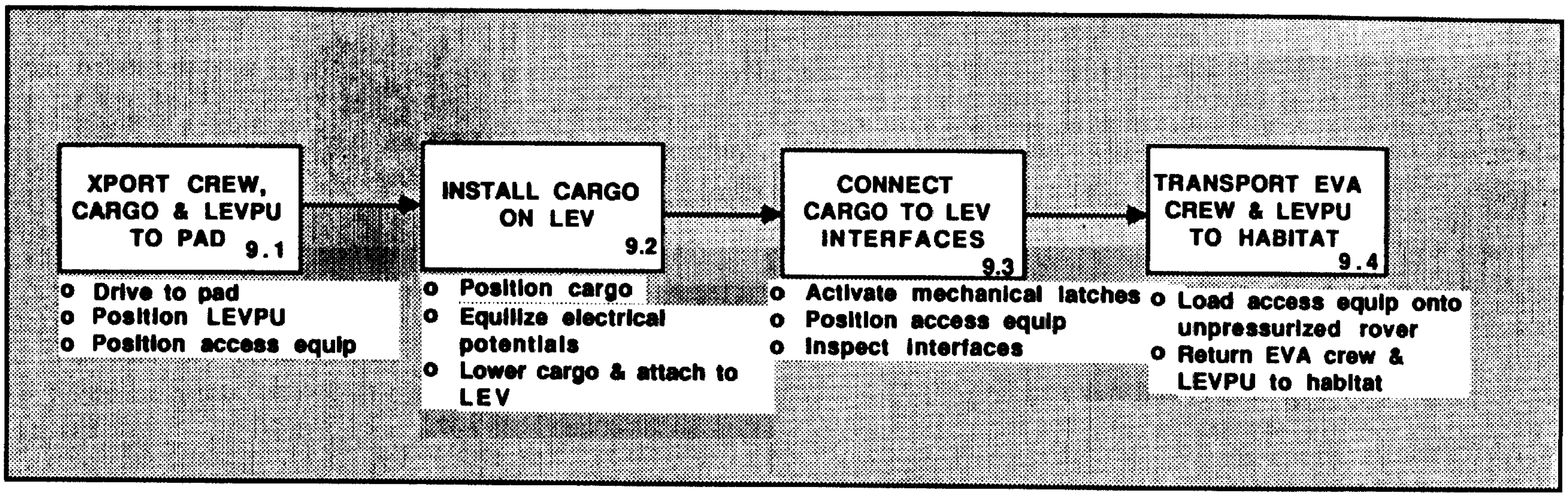
Flight 5 LEV-P2.1

8.0 REMOVE THERMAL/MICROMEORITE BLANKET & EXTERNAL CLOSEOUT



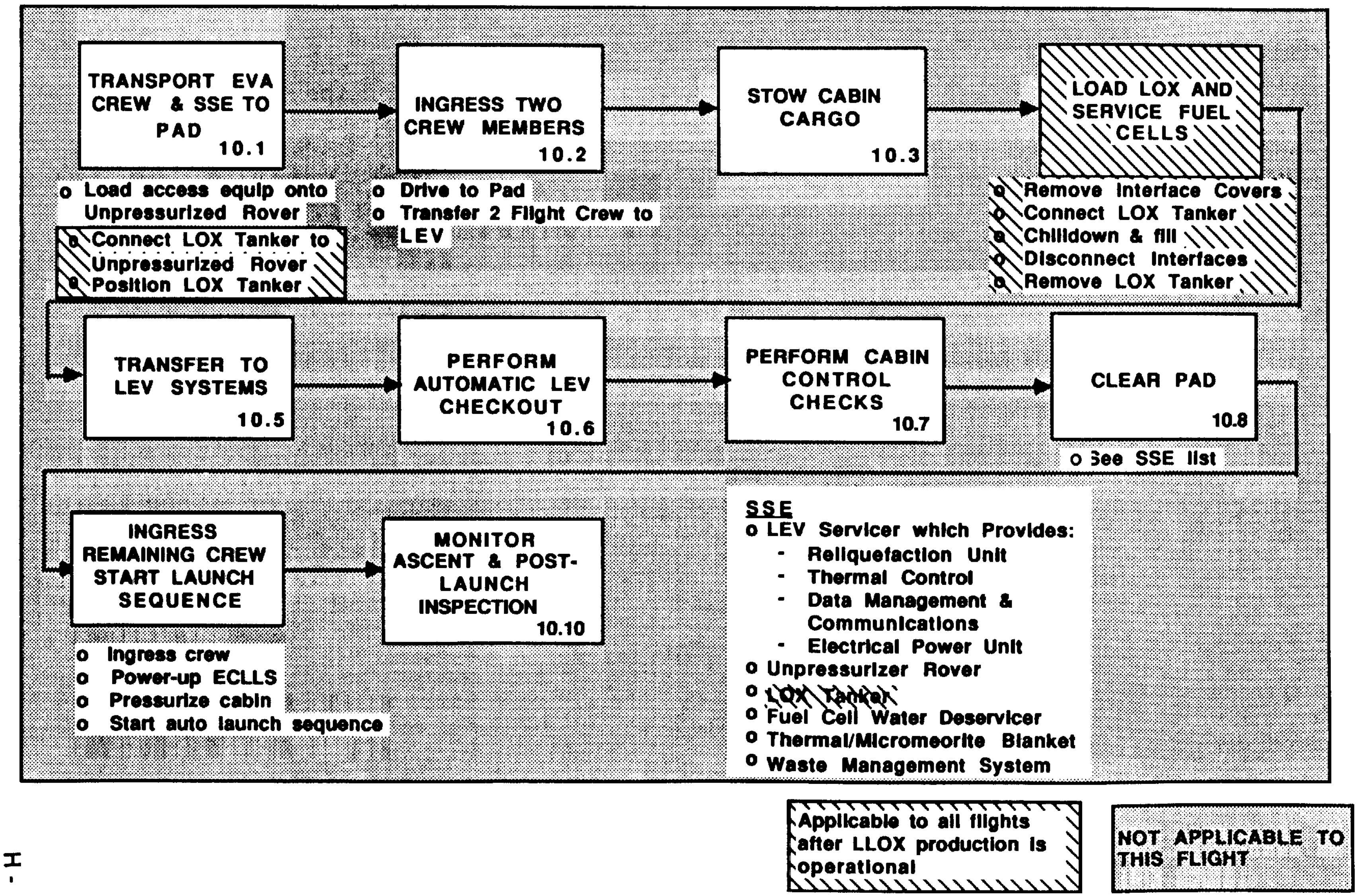
NOT APPLICABLE TO THIS FLIGHT

Flight 5 LEV-P2.1
9.0 CARGO/LEV INTEGRATION



NOT APPLICABLE TO THIS FLIGHT

Flight 5 LEV-P2.1
10.0 LAUNCH COUNTDOWN/LAUNCH



Appendix I

Tasks, Durations, SSE and Potential Robotic Applications

for

Manned and Unmanned Vehicle Launch and Landing Operations

Appendix I

Tasks, Durations, SSE and Potential Robotic Applications

for

Manned and Unmanned Vehicle Launch and Landing Operations

Based on the launch and landing turnaround scenario for Reference Architecture Option 5A, the data in this appendix was generated. Along with the timeline estimates, potential Surface Support Equipment was defined as well as which of the launch and landing tasks could be automated through the use of robotics. The data for unmanned/cargo vehicle can be found on page I-1 and the data for manned vehicles begins on page I-3.

UNMANNED/CARGO VEHICLES
TASKS, DURATIONS, SSE and ROBOTIC APPLICATIONS

Task	Duration	IVA Manhours*	SSE	Candidate for Robotics
Landing site video inspection (1.1)	0:15	**	Comm and T&V systems	Yes
Landing system activation and checkout (1.2)	1:30	**	Comm systems	Yes
Track LEV descent (1.3)	1:00	**	Landing aids	Yes
Monitor landing (1.4)	0:30	**	N/A	Yes
Power down and safe LEV (1.6)	1:00	**	N/A	N/A
Monitor LEV systems (1.7)***	Continuous	**	N/A	N/A
Dispatch LEVPU & EVA crew to pad (4.1)	0:30	**	LEVPU	Yes
Deploy, attach handling equip (4.2)	1:30	**	LEVPU	Yes
Safe cargo I/Fs (4.3)	0:15	**	N/A	Yes
Disconnect cargo I/Fs (4.4)	0:30	**	LEVPU	Yes
Transfer cargo to LEVPU (4.6)	2:00	**	LEVPU	Yes
Xport payload to use area (4.7)	0:30	**	LEVPU	Yes
Position payload at use location & disct LEVPU (4.8)	1:00	**	LEVPU	Yes
Secure payload at use area (4.9)	1:00	**	LEVPU	Yes

* Manhour estimates are based on Earth equivalent task times and do not include a lunar complexity factor.
** Telerobotic operations from earth and/or lunar flight crew.
*** Applicable to LEV C-0 only. LEV C-0 is returned to SSF for engineering evualuation.

UNMANNED/CARGO VEHICLES

TASKS, DURATIONS, SSE and ROBOTIC APPLICATIONS

Task	Duration	IVA Manhours*	SSE	Candidate for Robotics
Stow LEVPU & return storage (4.10)	1:00	* *	LEVPU	Yes
Perform automated LEV C/O (10.6)	0:25	* *	N/A	Yes
Start Launch Sequence (10.9)***	0:15	* *	N/A	Yes
Monitor ascent & post-launch inspect (10.10)***	0:15	* *	N/A	Yes

* Manhour estimates are based on Earth equivalent task times an[illegible] not include a lunar complexity factor.
** Telerobotic operations from earth and/or lunar flight crew.
*** Applicable to LEV C-0 only. LEV C-0 is returned to SSF for engineering evualuation.

MANNED VEHICLE
TASKS, DURATIONS, SSE, and ROBOTIC APPLICATIONS

Task	Duration	Manhours* EVA	Manhours* IVA	SSE	Candidate for Robotics
Landing site video inspection (1.1)	0:15	0	**	Comm and T& V Systems	Yes
Landing system activation & checkout (1.2)	1:30	0:00	**	Comm systems	Yes
Track LEV descent (1.3)	1:00	0:00	**	Landing aids	Yes
Monitor landing (1.4)	0:30	0:00	**	Blast protection	Yes
Power down & safe LEV (1.6)	1:00	0:00	**	N/A	N/A
Initiate LEV Self Test (1.5)	N/A	0:00	**	LEV BIT/BITE	N/A
Monitor vehicle systems (1.7)	Continuous	0:00	**	Communication system	Yes
Xfer unpress'd rover toLEV (for crew) (2.1)	0:20	0:00	0:20	Unpressurized rover	Yes
Flt crew dons EMUs & exits LEV (2.2)	1:00	4:00	0:00	Unpressurized rover	No
Flt crew boards unpress'd rover (2.3)	0:10	0:40	0:00	Unpressurized rover	No
Drive to hab (2.4)	0:30	2:00	0:00	Unpressurized rover	No
Flt crew stows unpress'd rover (2.5)	0:20	1:20	0:00	Unpressurized rover	Yes
Flt crew enters hab thru A/L (2.6)	0:05	0:20	0:00	N/A	No
Xport EVA crew & SSE to Pad (3.1)	1:00	2:00	0:00	Unpressurized rover	Yes
Establish Communications I/F (3.2)	0:20	0:40	0:00	Communications system (Servicer)	Yes
Connect Servicer/LEV power I/F (3.3)	0:20	0:40	0:00	Pwr system (Servicer)	Yes
Connect Servicer/LEV TCS I/F (3.4)	0:20	0:40	0:00	Cooling system (Servicer)	Yes

* Manhour estimates are based on Earth equivalent task times and do not include a lunar complexity factor.

** Telerobotic operations from earth and/or lunar flight crew.

*** Timelines are not provided for contingency operations.

MANNED VEHICLE
TASKS, DURATIONS, SSE, and ROBOTIC APPLICATIONS

Task	Duration	Manhours* EVA	Manhours* IVA	SSE	Candidate for Robotics
Transfer to/Verify SSE Services (3.5)	0:15	0:00	0:15	Servicer	Yes
Connect/Verify Servicer/LEV LH2 I/Fs (3.6)	1:15	2:30	1:15	H2 & O2 reliquefaction (Servicer)	Yes
Install/Connect/Verify Servicer/LEV LOX I/F (3.7)	0:35	1:10	0:00	LOX tank vent system	yes
Connect/Verify water servicer I/Fs (3.8)	0:40	1:20	0:00	H20 servicer system	Yes
Connect/Verify waste management system (3.9)	0:40	1:20	0:00	Waste mgt servicer	Yes
Return EVA crew to Hab (3.10)	0:20	0:40	0:00	Unpressurized rover	Yes
Dispatch EVA crew & LEVPU to pad (4.1)	0:30	1:00	0:30	Rover, LEVPU	Yes
Deploy LEVPU (4.2)	1:30	3:00	1:30	LEVPU	Yes
Safe cargo I/Fs (4.3)	0:15	0:00	0:15	Surface monitoring systems	Yes
Disconnect cargo I/Fs (4.4)	0:30	1:00	0:30	N/A	Yes
Install protective covers on cargo I/Fs (4.5)	0:05	0:10	0:05	N/A	Yes
Xfer cargo to LEVPU (4.6)	2:00	4:00	2:00	LEVPU	Yes
Xport payload to use area (4.7)	0:30	1:00	0:30	LEVPU	Yes
Position cargo at use location (4.8)	1:30	3:00	1:30	LEVPU	Yes
Secure cargo at use location, disct LEVPU (4.9)	1:00	2:00	1:00	LEVPU	Yes
Secure payload at use area (4.10)	1:00	2:00	1:00	LEVPU	Yes
Stow LEVPU & return EVA crew to hab (4.10)	1:00	2:00	1:00	LEVPU	Yes

* Manhour estimates are based on Earth equivalent task times and do not include a lunar complexity factor.

** Telerobotic operations from earth and/or lunar flight crew.

*** Timelines are not provided for contingency operations.

MANNED VEHICLE
TASKS, DURATIONS, SSE, and ROBOTIC APPLICATIONS

Task	Duration	Manhours* EVA	Manhours* IVA	SSE	Candidate for Robotics
Xport EVA crew and blanket to pad (5.1)	1:00	2:00	0:00	Unpressurized rover	Yes
Video inspect LEV & pad (5.2)	2:30	5:00	2:30	Unpressurized rover	Yes
Erect and cover vehicle with blanket (5.3 - 5.7)	3:20	6:40	3:20	Erection equipment	Yes
Return to Hab module (5.8)	0:20	0:40	0:20	Rover	Yes
Initiate BIT/BITE (6.1)	0:30	0:00	0:30	Test station hardware	Yes
Activate Test & Maint Data Dump (6.2)	0:30	0:00	0:30	Test station/BITE	Yes
LEV maintenance/retest (minimum) (7.1 -7.7)	***	***	***	Rover, EVA handtools, LEVPU	No
Dispatch crew to pad (8.1)	0:30	1:00	0:00	Unpressurized rover	No
Lower/remove blanket (8.2 - 8.6)	3:20	6:40	3:20	Erection equipment	Yes
External inspect'n and pad closeout (8.7)	2:30	5:00	2:30	Unpressurized rover	Yes
Xport & store blanket & frame (8.8)	1:00	2:00	0:00	Unpressurized rover	Yes
Return crew to hab (8.9)					
Dispatch EVA crew, cargo & LEVPU to pad (9.1)	1:00	2:00	1:00	Rover, LEVPU	Yes
Install cargo on LEV (9.2)	1:00	2:00	1:00	LEVPU	Yes
Connect cargo to LEV I/Fs (9.3)	1:15	2:30	1:15	LEVPU	Yes
Return EVA crew & LEVPU to hab (9.4)	1:00	2:00	1:00	Unpress rover, LEVPU	Yes
Xport EVA crew and SSE to pad (10.1)	1:00	2:00	0:00	Unpressurized rover	No

* Manhour estimates are based on Earth equivalent task times and do not include a lunar complexity factor.

** Telerobotic operations from earth and/or lunar flight crew.

*** Timelines are not provided for contingency operations.

MANNED VEHICLE
TASKS, DURATIONS, SSE, and ROBOTIC APPLICATIONS

Task	Duration	Manhours* EVA	Manhours* IVA	SSE	Candidate for Robotics
Ingress 2 flight crew members (10.2)***	1:30	3:00	0:00	Unpressurized rover	No
Stow cabin cargo (10.3)	0:15	0:30	0:00	N/A	No
Load LLOX and service fuel cells (10.4)	1:00	2:00	1:00	LOX Tanker	
Transfer to LEV systems (10.5)	0:15	0:00	0:00	N/A	No
Perform automated LEV C/O (10.6)	0:25	0:00	0:00	N/A	No
Perform cabin control checks (10.7)	0:30	0:00	0:00	N/A	No
Clear pad (10.8)	3:15	2:00	0:00	N/A	Yes
Ingress crew, start launch sequence (10.9)***	1:00	4:00	0:00	N/A	No
Monitor ascent & post-launch inspection (10.10)**	0:15	0:00	0:15	N/A	No

* Manhour estimates are based on Earth equivalent task times and do not include a lunar complexity factor.

** Telerobotic operations from earth and/or lunar flight crew.

*** Timelines are not provided for contingency operations.

Appendix J

Launch and Landing Task Applicability

to

Reusable and Expendable Vehicles

Appendix J

Launch and Landing Task Applicability

to

Reusable and Expendable Vehicles

To compare which of the tasks of the Reference Architecture Option 5A launch and landing tasks would be applicable to either a reusable or an expendable vehicle a tasks-by-task comparison was made. The results are documented in this appendix.

TASK APPLICABILITY FOR LUNAR AND MARS EXPENDABLE AND REUSABLE VEHICLES

Task	Lunar Cargo Expendables	Lunar Manned Expendable*/Reusable	Mars Cargo Expendables	Mars Manned Expendable*/Reusable
Landing site video inspection (1.1)	Yes	Yes	Yes	Yes
Landing system activation & checkout (1.2)	Yes	Yes	Yes	Yes
Track LEV descent (1.3)	Yes	Yes	Yes	Yes
Monitor landing (1.4)	Yes	Yes	Yes	Yes
Initiate LEV system self test (1.5)	No**	Yes	No	Yes
Power down & safe LEV (1.6)	Yes	Yes	Yes	Yes
Monitor LEV systems (1.7)	No**	Yes	No	Yes
X-fer Unpress'd rover to LEV (2.1)	No	Yes	No	Yes
Flt crew dons EMUs & exits LEV (2.2)	No	Yes	No	Yes
Flt crew boards unpress'd rover (2.3)	No	Yes	No	Yes
Flt crew drives to hab (2.4)	No	Yes	No	Yes
Flt crew stows unpress'd rover (2.5)	No	Yes	No	Yes
Flt crew enters hab thru A/L (2.6)	No	Yes	No	Yes
X-port EVA crew & SSE to Pad (3.1)	No	Yes	No	Yes
Establish Communications I/F (3.2)	No	Yes	No	Yes
Connect Servicer/LEV power I/F (3.3)	No	Yes	No	Yes
Connect Servicer/LEV TCS I/F (3.4)	No	Yes	No	Yes

* Manned expendables are expended in space

** Applicable to LEV C-0

*** Crew ingress applicable to manned vehicles only

TASK APPLICABILITY FOR LUNAR AND MARS EXPENDABLE AND REUSABLE VEHICLES

Task	Lunar Cargo Expendables	Lunar Manned Expendable*/Reusable	Mars Cargo Expendables	Mars Manned Expendable*/Reusable
Transfer to/verify SSE Services (3.5)	No	Yes	No	Yes
Connect/Verify Servicer/LEV LH2 I/F (3.6)	No	Yes	No	Yes
Connect/Verify Servicer/LEV LOX I/F (3.7)	No	Yes	No	Yes
Connect/Verify water servicer I/Fs (3.8)	No	Yes	No	Yes
Connect/waste management servicer (3.9)	No	Yes	No	Yes
Return EVA crew to hab (3.10)	No	Yes	No	Yes
Dispatch EVA crew & LEVPU to pad (4.1)	Yes	Yes	Yes	Yes
Deploy LEVPU (4.2)	Yes	Yes	Yes	Yes
Safe cargo I/Fs (4.3)	Yes	Yes	Yes	Yes
Disconnect cargo I/Fs (4.4)	Yes	Yes	Yes	Yes
Install protective covers on cargo I/Fs (4.5)	No	Yes	No	Yes
X-fer LEVPU cargo to LEVPU (4.6)	Yes	Yes	Yes	Yes
X-port cargo to use area (4.7)	Yes	Yes	Yes	Yes
Position cargo at use location (4.8)	No	Yes	No	Yes
Secure cargo use location & disct LEVPU (4.9)	Yes	Yes	Yes	Yes
Stow LEVPU &return EVA crew to hab (4.10)	Yes	Yes	Yes	Yes
X-port blanket & EVA crew to pad (5.1)	No	Yes	No	Yes

* Manned expendables are expended in space

** Applicable to LEV C-0

*** Crew ingress applicable to manned vehicles only

TASK APPLICABILITY FOR LUNAR AND MARS EXPENDABLE AND REUSABLE VEHICLES

Task	Lunar Cargo Expendables	Lunar Manned Expendable*/Reusable	Mars Cargo Expendables	Mars Manned Expendable*/Reusable
Video Inspect LEV & pad (5.2)	No	Yes	No	Yes
Erect and cover vehicle with blanket (5.3 - 5.7)	No	Yes	No	Yes
Return to EVA crew to hab (5.8)	No	Yes	No	Yes
Initiate BIT/BITE (6.1)	No	Yes	No	Yes
Activate Test & Maint Data Dump (6.2)	No	Yes	No	No
LEV Maintenance/retest (7.1 -7.9)	No	Yes	No	Yes
Dispatch crew to pad (8.1)	No	No	No	No
Lower/remove blanket (8.2 - 8.6)	No	Yes	No	Yes
External inspect'n & closeout (8.7)	No	Yes	No	Yes
X-Port & store blanket & frame (8.8)	No	Yes	No	Yes
Return crew to hab (8.9)	No	Yes	No	Yes
Dispatch EVA crew, cargo & LEVPU to pad (9.1)	No	Yes	No	Yes
Install cargo on LEV (9.2)	No	Yes	No	Yes
Connect cargo to LEV I/Fs (9.3)	No	Yes	No	Yes
Return EVA crew &LEVPU to hab (9.4)	No	Yes	No	Yes
X-port EVA crew and SSE to Pad (10.1)	No	Yes	No	Yes
Ingress 2 flight crew members (10.2)***	No	Yes	No	Yes

* Manned expendables are expended in space

** Applicable to LEV C-0

*** Crew ingress applicable to manned vehicles only

TASK APPLICABILITY FOR LUNAR AND MARS EXPENDABLE AND REUSABLE VEHICLES

Task	Lunar Cargo Expendables	Lunar Manned Expendable*/Reusable	Mars Cargo Expendables	Mars Manned Expendable*/Reusable
Stow cabin cargo (10.3)	No	Yes	No	Yes
Load LOX and service fuel cells (10.4)	No	Yes	No	No
Verify Interior Configuration (10.5)	No	Yes	No	Yes
Transfer LEV systems (10.5)	No	Yes	No	Yes
Perform automated LEV C/O (10.6)	No**	Yes	No	Yes
Perform cabin control checks (10.7)	No	Yes	No	Yes
Clear pad (10.8)	No	Yes	No	Yes
Ingress rest of crew & start launch (10.9)	No	Yes	No	Yes
Monitor ascent and post-launch inspect (10.10) **	No**	Yes	No	Yes

* Manned expendables are expended in space

** Applicable to LEV C-0

*** Crew ingress applicable to manned vehicles only

Appendix K

Lunar Excursion Vehicle (LEV) Servicer Maintenance Analysis

Appendix K

Lunar Excursion Vehicle (LEV)
Servicer Maintenance Analysis

This appendix contains a vuchart documentation of the Servicer Maintenance Analysis that was performed by MDSSC-KSC. The analysis was a front-end analysis which selected a candidate system for analysis. A maintenance concept for the servicer was developed along with groundrules and assumptions necessary to define the system and its operation. An existing system was selected for comparison purposes. Then, the operations and support tasks that must be performed were identified. From this analysis, conceptual system support requirements were identified.

Lunar Excursion Vehicle Servicer Maintenance Analysis

Agenda

- LEV Servicer Maintenance
  - Introduction
    -- Goals
    -- Problem
    -- Approach
  - LEV Servicer Description
  - Maintenance Concept
  - Functional Analyses
  - Maintenance Analysis
  - Recommendations

Goal Of Logistics In The Conceptual Phase

The top level goal of logistics in the conceptual phase of any program is to ensure front-end consideration of the impacts integrated logistics support will have on the overall program. And in this case , the impacts logistics will have on the overall Planetary Surface Systems (PSS) Program.

The immediate goal is to influence and impact PSS designs so reliability, maintainability, and supportability are optimized to achieve the programs operational goals.

Goals

- ❑ Ensure logistics considerations are addressed in the early phases of the program

- ❑ To influence and impact PSS designs to optimize support in achieving program operational goals

Conceptual Phase Analysis Problem

The traditional problem exists today as it did yesterday. In order to design, analysis is required. This in turn requires data, which is only created through design.

To counter this, you can capitalize on past experience and programs, by using comparison systems for the data needed. This front-end analysis enables early identification of key support drivers which in turn permits the conceptual effort to focus on and thereby work toward reducing them

Conceptual Phase Analysis Problem

- Good design begins with analysis
- Analysis requires data
- Data is created by design

Solution...."Front-End Analysis"

Front-End Analysis Approach

The approach to conducting a front-end analysis is to first select a candidate system for analysis. Then develop, if not already available, a maintenance concept for the candidate system. Next develop ground rules and assumptions necessary to define the system and operation. Then utilizing data, select a functionally similar existing system for comparison.

Utilizing the maintenance concept, develop functional flow diagrams to identify the operations and support tasks that must be performed. From these flows, compare the candidate system tasks with the existing system tasks and support requirements to derive the conceptual systems support requirements.

Once these requirements are known, conduct an assessment to determine the key support drivers and develop design recommendations.

This approach reduces new design concepts to a quantitative measurement quickly, thereby enabling design to focus on the significant drivers during the conceptual phase. This also enables logistics to focus it's efforts where there is the highest potential for improvement.

Front-End Analysis Approach

- ❑ Identify Candidate For Analysis
- ❑ Develop Ground Rules And Assumptions
- ❑ Develop Maintenance Concept
- ❑ Select Comparison System
- ❑ Develop Functional Flow Diagram/s
- ❑ Conduct Systems Comparison
- ❑ Derive Maintenance Support Requirements
- ❑ Develop Recommendations

LEV Servicer General Description

The candidate system selected for front-end analysis is the LEV servicer. The purpose is to provide power, thermal control, and reliquefaction of oxygen (O_2) and hydrogen (H_2) propellants for lunar landers as needed to maintain them in a re-usable state. The system is required for the servicer which remains on the lunar surface longer than thirty days. Mobility is provided by payload unloader.

The overall weight of the servicer is estimated at 1.8 metric tons (4,032 lbs) and it's dimensions are: height - 2.5 meters (8 ft), width - 3 meters (10 ft), depth - 3 meters (10 ft).

The servicer is comprised of four major systems.

The Power Supply Unit supplies the power to the LEV. This may vary from 173 to 11,285 watts.

The next system is the Thermal Rejection and Control System. This system contains the heat pump and low mass radiators.

Then comes the Reliquefaction Unit which is comprised of radiators, oxygen and hydrogen liquefiers, fluid and vapor lines, and power lines.

The last system is the Computer and Communications System. This system provides the computer facilities and communications equipment which is used to monitor the LEV.

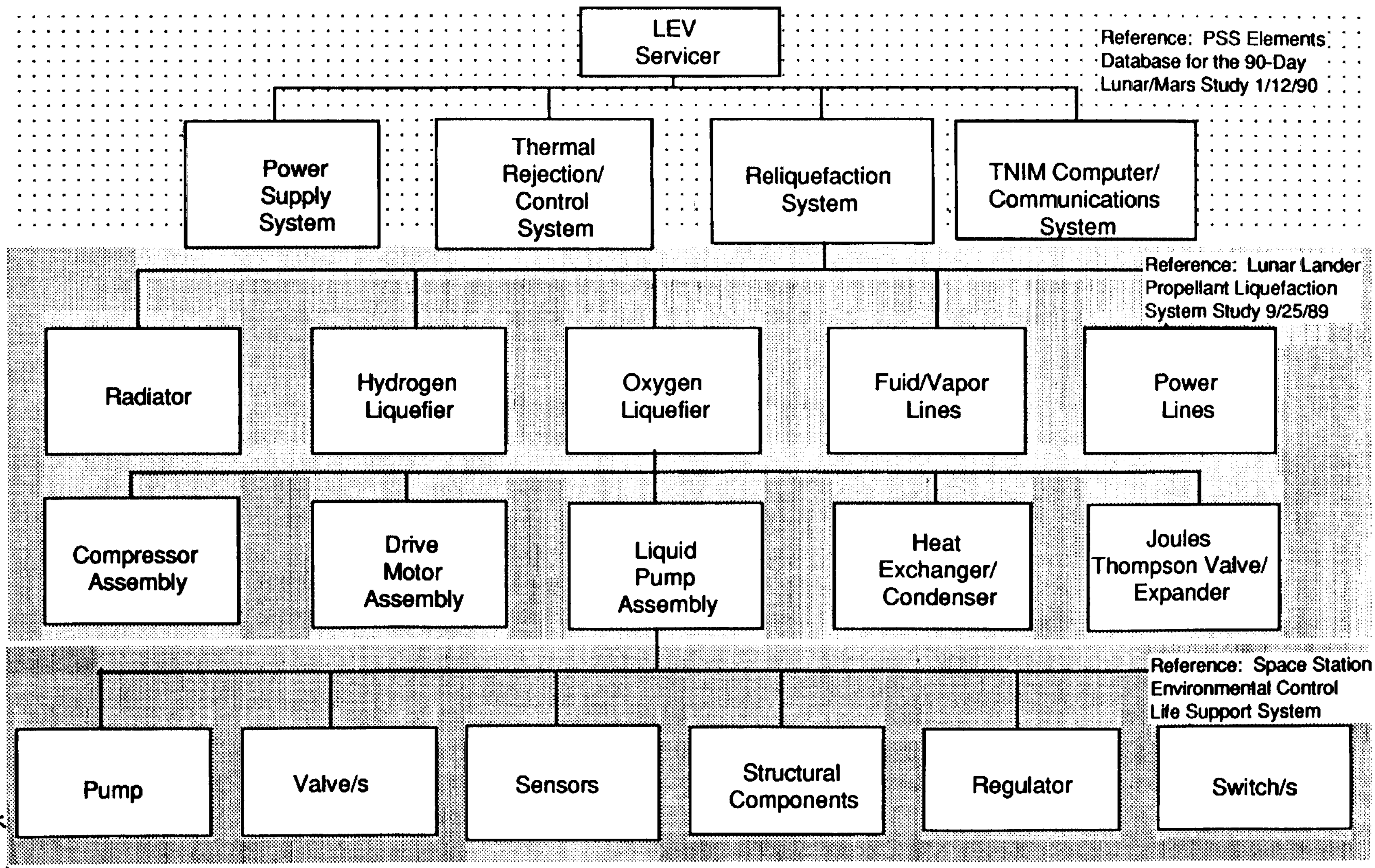
Lunar Excursion Vehicle (LEV) Servicer General Description

- Purpose is to provide power, thermal control, and reliquefaction of oxygen (O_2) and hydrogen (H_2) propellants for lunar landers as needed to maintain them in a re-usable state.
- Weight 1.8 metric tons (4,032 lbs)
- Dimensions: height - 2.5 meters (8 ft), width - 3 meters (10 ft), depth - 3 meters (10 ft).
- Major systems:
  - Power Supply Unit
  - Thermal Rejection and Control System
  - Reliquefaction Unit
  - Computer and Communications System

LEV Servicer Equipment Breakdown Structure

This drawing depicts an example of the LEV Servicer's systems, subsystems, assemblies, and components. As you can see that by using comparison data, analyst are able to define the system to it's lowest level. For a front-end analysis, the level at which you define the system is dependent entirely upon the level of conceptual data available and time. These analyses generally are conducted as quickly as possible in order to influence design, recognizing that a detailed analysis will be conducted later.

LEV Servicer Equipment Breakdown Structure



LEV Servicer Ground Rules And Assumptions

These are the ground rules and assumptions utilized in conducting the front-end analysis.

LEV Servicer Ground Rules And Assumptions

- ❑ LEV servicer operates continuously for a minimum of one year.
- ❑ No factoring for differences between SSF and Lunar environments.
- ❑ EVA overhead time not considered in maintenance hours.
- ❑ Limited life items not addressed.
- ❑ Following source documents/data were utilized:
  - PSS Elements Data Base For 90 Day Lunar/Mars Study (1/12/90)
  - PSS Operations and Logistics Concept, ILS Section (6/90)
  - Lunar Lander Propellant Liquefaction System Study (9/25/89)
  - External Maintenance Task Team (i.e., Fisher Price) Report (7/90)
  - Space Station Preliminary Design Data

LEV Servicer Maintenance Concept

The LEV servicer maintenance concept consists of two types of maintenance (i.e., scheduled or preventive and unscheduled or corrective) and three levels of maintenance (i.e., organizational, intermediate, and depot).

The primary method of maintenance on the Planetary Surface Systems will be to remove and replace to the line replaceable unit (LRU) level either on a scheduled basis as determined from design characteristics or on an unscheduled basis as determined from a malfunction.

Hazardous maintenance operations will be conducted by robots.

On-condition monitoring will be performed on the liquefaction systems rotating machinery LRUs (i.e., liquid pump packages and drive motor packages).

This chart illustrates the levels of maintenance, locations, and types of maintenance tasks performed at each. Organizational level maintenance is defined as routine maintenance, either scheduled or unscheduled, (most likely scheduled), performed by operator personnel utilizing remove and replace techniques at the equipment location.

The intermediate level maintenance supplements and supports the organizational level maintenance effort through more extensive repair capabilities and responsibilities. The work effort is usually performed at a maintenance workstation, and is either preventive or corrective. At this level, end items may be repaired by the removal and replacement of major modules, assemblies, or piece parts.

The depot level maintenance is the level of maintenance performing the most complex maintenance actions. This level often requires designated facilities, sophisticated support and test equipment, and personnel with specialized training and experience. Depot maintenance includes the complete overhauling, rebuilding, and calibration of equipment as well as the performance of highly complex maintenance actions requiring resources and facilities on Earth.

LEV Servicer Maintenance Concept

Maintenance Levels	Location		Who Does It	Type Of Maintenance Performed	
Organizational	Lunar Surface	On-Line	Flight Crew	Lubricate/Calibrate Adjust/Service Clean/Inspect Housekeeping	Preventive
				Test/Verify Fault Detect/Isolate Remove/Replace Funct Reverify/Reset	Corrective
	Ground	On-Line	Maint. Personnel	Lubricate/Calibrate Adjust/Service Clean/Inspect	Preventive
				Test/Verify Fault Detect/Isolate Remove/Replace Funct Reverify/Recal	Corrective
Intermediate	Lunar Surface	Off-Line	Flight Crew	Fault Diagnose Repair/Retest	Limited Corrective
	Ground	Off-Line	Maint. Personnel	Fault Detect/Isolate Calibrate/Lubricate Adjust/Service Remove/Replace	Corrective
Depot	Ground	Off-Line	Repair Personnel	Fault Detect/Isolate Modify/Overhaul Calibrate/Lubricate Adjust/Service Manufacture/Rebuild Failure Analysis	Corrective

Comparison System Selection

This chart illustrates the SSFP systems selected to be used in the comparison process. This selection was based upon similiar functions. Utilizing these comparison systems, logistics support tasks and requirements are extrapolated for the LEV Servicer.

Comparison System Selection

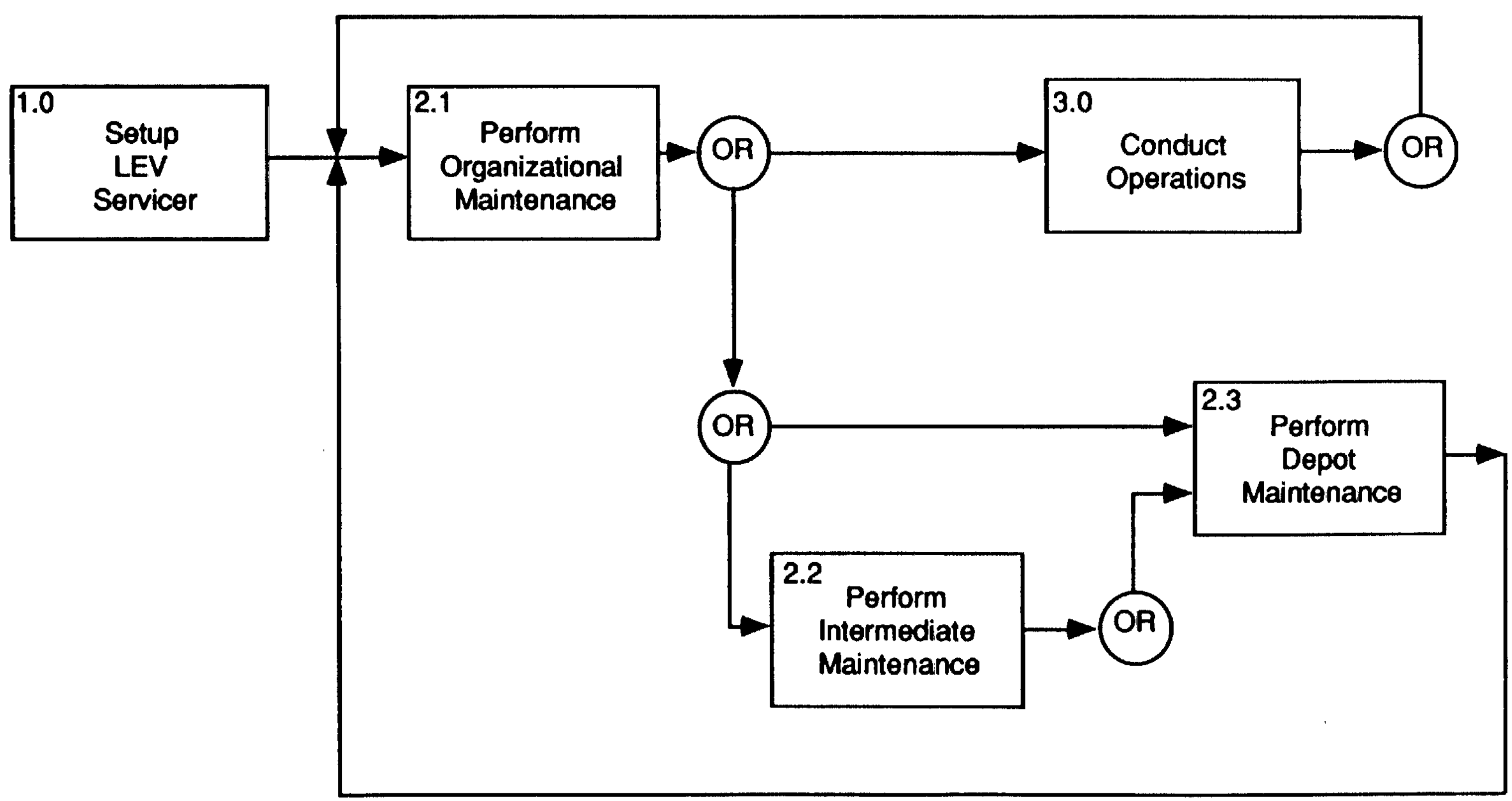
LEV Servicer	SSFP
❑ Power Supply System	❑ Power System
❑ Thermal Rejection/ Control System	❑ Thermal Control System
❑ Reliquefaction System	❑ ECLS/Thermal/Power System
❑ Computer/Comm System	❑ Data Mgmt and Comm Systems

1st Level Functional Flow Diagram

This chart depicts the top level LEV Servicer functional flow diagram and the tasks performed. For the front-end analysis, these tasks are expanded to the level at which conceptual data is available. This is illustrated in the following charts. Then from these functional analyses, quantitative and qualitative support requirements can be derived, utilizing the comparison system data, to influence system or subsystem design.

Generally, for the conceptual phase of a program, this level is defined as the organizational level. For the purposes of this study, I've included the intermediate and depot levels for information only. The analysis, however, was conducted only to the organizational level.

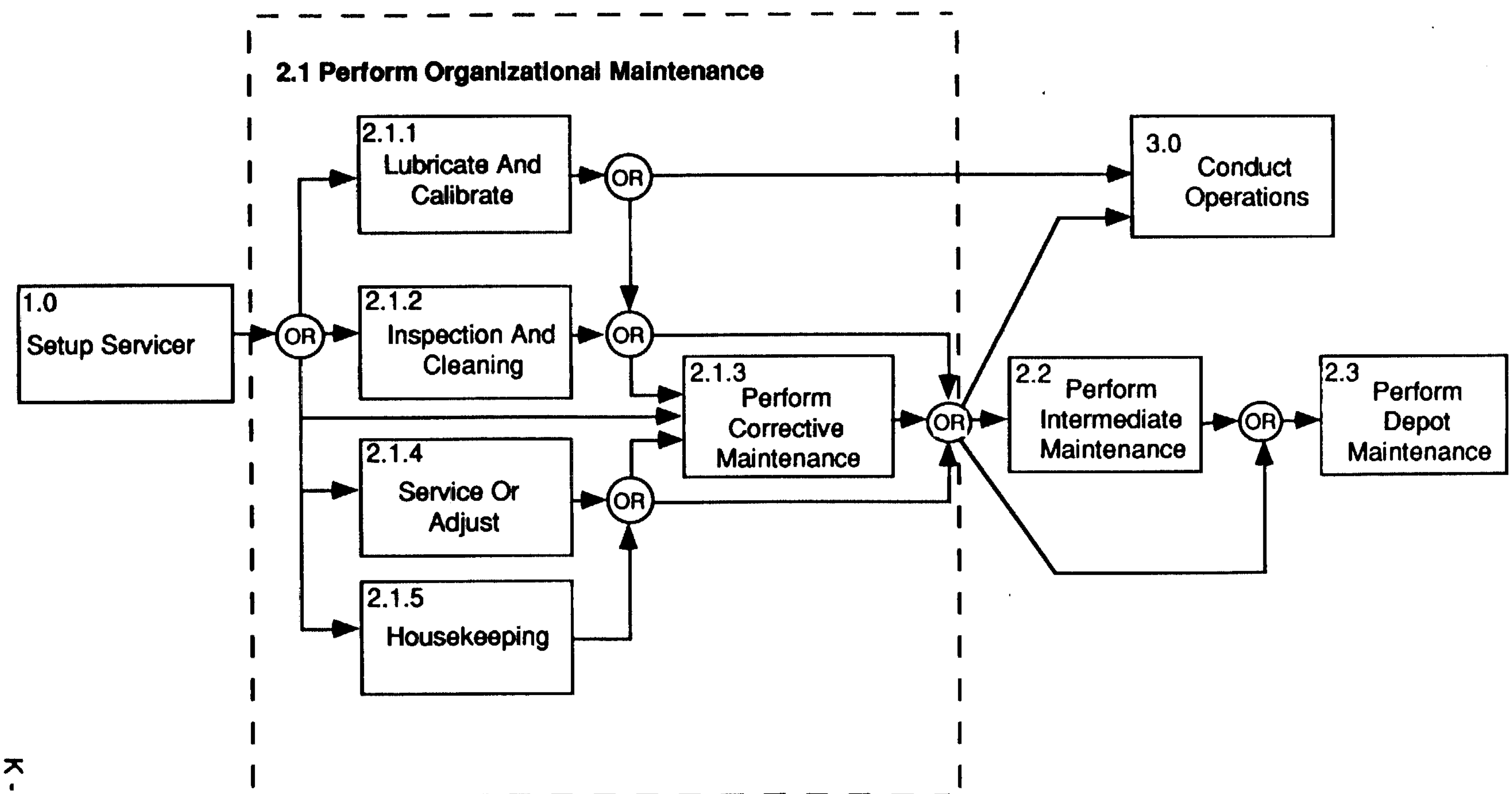
1st Level Functional Flow Diagram



2nd Level Functional Flow Diagram

This chart is an expansion of the 1st level functional flow diagram "Perform Organizational Maintenance" block 2.1. It depicts the major tasks performed at this level and is used to derive the organizational level maintenance support requirements.

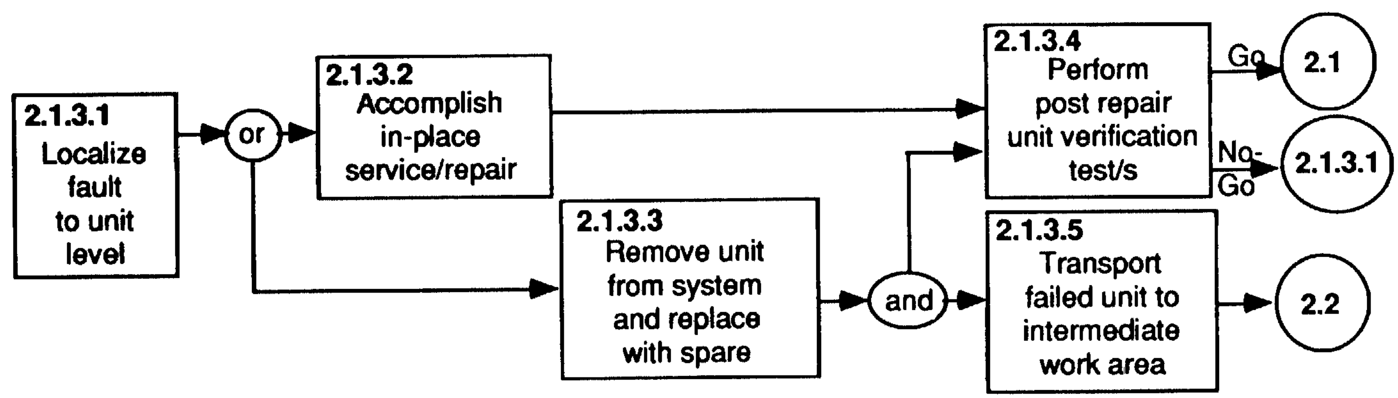
2nd Level Functional Flow Diagram



3rd Level Functional Flow Diagram
(Organizational Level)

This chart is an expansion of the 2nd level functional flow diagram "Perform Corrective Maintenance" block 2.1.3. It depicts the major tasks performed at this level and is used to derive the organizational level corrective maintenance support requirements.

3rd Level Functional Flow Diagram (Organizational Level Corrective Maintenance)



LEV Servicer Maintenance Support Requirements

This chart summarizes the LEV Servicers maintenance support requirements as extrapolated from the SSFP systems. These requirements were derived based on the LEV Servicer operating continuously for one year.

As you can see, the computer and communications system and the reliquefaction system both require considerable maintenance time and spares. The reliquefaction system has been expanded on the next chart to try to narrow down the support drivers.

LEV Servicer Maintenance Support Requirements

System Name	Failures Per Year (1)	Maint (Hrs/Yr) (2)	Spares (#/Yr) (1)	Maintenance Personnel Skills	Tools and Test Equipment	Facility	Remarks
Power Supply Unit	2.67	2.67	3	Electrical/ Electronic Engineer/Tech	Standard EVA Tools	Test Equipment, Tools, and Cleaning Equipment Storage Spare and Repair Materials Storage Portable Access Equipment Storage	Estimates Based Upon: (1) SSFP Preliminary Design Data (2) Engineering Estimates (# Failures X MTTR *) * Fisher Price Report Vol 1 Part 2 Appendix C No Factoring, EVA Overhead or Limited Life Included
Thermal Rejection/ Control System	6	6	6	Electrical/ Mechanical Engineer/Tech	Standard EVA Tools		
Reliquefaction System	19.06	33.2	16	Electrical/ Mechanical Engineer/Tech Trained and Certified in Hazardous EVA Maintenance.	Standard EVA Mechanical/ Electrical Tools / Test Equipment Leak Detection Equipment Portable Access Equipment Special Cleaning Equipment		
Computer/ Communications System	18	18	18	Electrical/ Electronic Engineer/Tech			

Reliquefaction System Maintenance Support Requirements

This chart is a further expansion of the LEV Servicer's Reliquefaction System maintenance support requirements as derived from the SSFP Environmental Control Life Support System (ECLS) comparison data. As shown, the key support drivers are the pump, heat exchanger/condenser, and the Expander/Joules Thompson valve.

Reliquefaction System Maintenance Support Requirements

System Name	Failures Per Year (1)	Maint (Hrs/Yr) (2)	Spares (#/yr) (1)	Maintenance Personnel Skills	Tools and Test Equipment	Facility	Remarks
Reliquefaction System (Total)	19.06	33.2	16	Electrical/Mechanical Engineer/Tech Trained and Certified in Hazardous EVA Maintenance	Standard EVA Mechanical/Electrical Tools and Test Equipment. Leak Detection Equipment Portable Access Equipment Special Cleaning Equipment	Portable Access Equipment Storage Test Equipment, Tools, and Cleaning Equipment Storage Spare and Repair Materials Storage	**No Factoring, EVA Overhead or Limited Life Included** (1) SSFP Preliminary Design Data (2) Engineering Judgement (# Failure X MTTR*) *Fisher Price Report Appendix C (3) SSFP ECLS Data (4) For purposes of this analysis, this system is considered the same as the oxygen liquefier system Note 1: No designated spares will be carried, only repair materials
0 Radiator	2.2	3.3	1				
0 Oxygen Liquefier (3)	8.42	14.95	7				
- Compressor	.08	.12	1				
- Drive Motor	.42	.42	1				
- Pump	2.13	3.2	1				
- Heat Exchanger Condenser	3.68	8	2				
- Expander/Joules Thompson Valve	2.11	3.17	2				
0 Hydrogen Liquefier (4)	8.42	14.95	7				
0 Fluid/Vapor Lines	.01	.02	Note #1				
0 Power Lines	.014	.02	1				

Maintenance Support Requirements Summary

In summary, the LEV servicer will incur an estimated 45.73 failures per year; require an estimated 59.87 hours of EVA maintenance time, and require 43 spares. The key maintenance drivers are the reliquefaction and the computer/communications systems. They represent 81 per cent of the total servicers failures.

In addition, the maintenance tasks will be conducted on hazardous propellant systems and will require special access, leak detection, and cleaning equipment.

This comparison data does not include any factoring or adjustments associated with the differences between lunar surface and the Space Station Freedom. Nor does this data take into account the time associated with EVA setup, teardown, or translation to the maintenance site.

Note: The Fisher Price report dated July 1990 estimates SSFP Electrical Power System failures between 93 and 153, Thermal Control System between 0 and 7, ECLS between 21 and 50, and Communications between 127 and 262. For an estimate of between 241 and 472 failures per year. So these estimates may be higher than indicated after factoring and adjusting.

LEV Servicer Maintenance Support Summary

- ❑ Estimated Equipment Failures Total Per Year = 45.73
  - Reliquefaction and Computer/Communications Systems = 81%
- ❑ EVA Maintenance Hours Total Per Year = 59.87
  - This Does Not Include Factoring For Lunar Surface Nor Does it Include EVA Overhead Time (i.e., Setup, Teardown, and Translation Times)
- ❑ Estimated Spares Required Total Per Year = 43
- ❑ EVA Maintenance Tasks Requires Special Access, Leak Detection, and Cleaning Equipment
- ❑ EVA Maintenance Required on Hazardous Propellant Systems
- ❑ Increased No. of Spares and Special Equipment Dictate Additional Storage Facilities

Conclusions

As shown from the analysis, alternatives to the use of reliquefaction or an increase in the reliability goals is necessary to reduce the number of failures.

In addition, an increase in the reliquefaction systems maintainability is required to reduce the maintenance time.

And lastly, the computer and communications system reliability needs to be increased to reduce it's number of failures.

As a follow-on task, periodic re-evaluation of these systems should conducted, as necessary, to ensure achievement of the goals.

Conclusions

- ❑ Explore Alternatives Or Increase Reliability Of The Reliquefaction System
- ❑ Increase Reliquefaction System Maintainability Goals
- ❑ Increase Both Reliability and Maintainability For The Computer And Communications System

Recommendations

Also recommend expanding this analysis approach to include other systems to first identify the key support drivers and then feedback to design in order to help eliminate or reduce them.

Recommend selecting and employing an automated tool for conducting logistics analyses, life cycle costing, and building a common requirements database. This will reduce the assessment time and enable assessing life cycle cost impacts resulting from design changes.

Then, as the program progresses, expand the analyses to provide a greater level of detail.

Recommendations

- ❑ Continue to Utilize Comparative Analysis During Phase A/B and Apply to Other PSS Systems
- ❑ Select and Employ An Automated Tool For Utilization and Conducting of Life Cycle Cost Analyses
- ❑ Commence Life Cycle Cost Analyses
- ❑ As Program Progresses, Expand Analyses to Provide a Greater Level Of Detail

Appendix L

Planet Surface System Logistics Modeling Support Inputs

Appendix L

Planet Surface System Logistics Modeling Support Inputs

Support was provided to the PSS Logistics Manager at JSC in the development of initial design cost inputs on the Lunar Excursion Vehicle Servicer to help test the System Design Utility (SDU) and the Equipment Design Cost Analysis models. These models were being evaluated for standardization of the PSS logistics modeling effort and for use in determining logistic support impacts on system design and life cycle cost. The inputs provided by MDSSC-KSC are contained in this appendix.

LUNAR EXCURSION VEHICLE SERVICER

Input Sheet For System Design Utility (SDU) Model							PRELIMINARY - FOR INFORMATION PURPOSES ONLY								
System WBS/ SDU Inputs	Unit Cost ($K)	Lot Size (#)	MT to Fail (Yrs)	MT to Repair (Hrs)	Supp Eqt Cost ($K)	Diag SW Cost ($K)	Repair Doc (Pgs)	Repair Train (Hrs)	Repair Mat Cost ($K)	Condemn Rate (Dec)	Sched Maint (Hrs)	Maint Training (Hrs)	Total Weight (Lbs)	Contain Cost ($K)	Tech Draw (Pgs)
LEV Servicer	**9000.0**	**1.0**			**3825.0**	**6120.0**	**1900.0**	**52.5**	**2295.0**	**1.0**	**35.0**	**525.0**	**3462.0**	**70.6**	**316.0**
Pwr Supply Unit	**2350.0**	**1.0**			**1175.0**	**1880.0**	**775.0**	**10.0**	**705.0**	**1.0**	**9.0**	**100.0**	**2205.0**		**124.0**
Fuel Cell	2000.0	3.0	3.9	1.0	500.0	800.0	25.0	8.0	300.0	1.0	8.0	80.0	1500.0		64.0
Regulator	250.0	3.0	3.9	1.0	62.5	100.0	25.0		37.5	1.0					4.0
Pump Assbly	250.0	3.0	4.4	1.0	62.5	100.0	50.0		37.5	1.0					4.0
Motor	250.0	3.0	19.0	1.0	62.5	100.0	50.0		37.5	1.0					4.0
Condenser	250.0	3.0	64.3	1.0	62.5	100.0	50.0		37.5	1.0					4.0
Coolant Valve	50.0	6.0	11.4	1.0	12.5	20.0	50.0		7.5	1.0					4.0
Heater	100.0	6.0	2.2	1.0	25.0	40.0	50.0		15.0	1.0					4.0
Purge Valve	50.0	6.0	11.4	1.0	12.5	20.0	50.0		7.5	1.0					4.0
Elect Unit	750.0	3.0	20.0	1.0	187.5	300.0	50.0		112.5	1.0					4.0
Press Xducer	20.0	6.0	34.2	1.0	5.0	8.0	50.0		3.0	1.0					4.0
Temp Xducer	20.0	6.0	34.2	1.0	5.0	8.0	50.0		3.0	1.0					4.0
QD's	10.0	12.0	415.0	1.0	2.5	4.0	50.0		1.5	1.0					4.0
Tank Assembly	350.0	3.0	30.8	1.0	87.5	140.0	25.0	2.0	52.5	1.0	1.0	20.0	705.0		4.0
O2 Tank	100.0	6.0	30.8	1.0	25.0	40.0	50.0		15.0	1.0					4.0
H2 Tank	100.0	6.0	30.8	1.0	25.0	40.0	50.0		15.0	1.0					4.0
H2O Tank	100.0	6.0	30.8	1.0	25.0	40.0	50.0		15.0	1.0					4.0
Lines	50.0	50.0	71.7	1.0	12.5	20.0	50.0		7.5	1.0					4.0
Thermal/Control	**1000.0**	**1.0**			**250.0**	**400.0**	**75.0**	**8.0**	**150.0**	**1.0**	**2.0**	**80.0**	**441.0**		**92.0**
Control System	500.0	2.0	27.0	1.0	125.0	200.0	25.0	6.0	75.0	1.0	1.0	60.0	200.0		4.0
Heat Pump	250.0	2.0	10.0	1.0	62.5	100.0	25.0	1.0	37.5	1.0	0.5	10.0	200.0		4.0
Radiator	250.0	2.0	29.4	1.0	62.5	100.0	25.0	1.0	37.5	1.0	0.5	10.0	41.0		4.0

LUNAR EXCURSION VEHICLE SERVICER

Input Sheet For System Design Utility (SDU) Model							PRELIMINARY - FOR INFORMATION PURPOSES ONLY									
System WBS/ SDU Inputs	Unit Cost ($K)	Lot Size (#)	MT to Fail (Yrs)	MT to Repair (Hrs)	Supp Eqt Cost ($K)	Diag SW Cost ($K)	Repair Doc (Pgs)	Repair Train (Hrs)	Repair Mat Cost ($K)	Condemn Rate (Dec)	Sched Maint (Hrs)	Maint Training (Hrs)	Total Weight (Lbs)	Contain Cost ($K)	Tech Draw (Pgs)
Liquefaction Sy	**2900.0**	**1.0**			**1337.5**	**2140.0**	**750.0**	**18.5**	**802.5**	**1.0**	**8.0**	**185.0**	**441.0**		**72.0**
Radiator	250.0	2.0	29.4	1.0	62.5	100.0	25.0	1.0	37.5	1.0	0.5	10.0	41.0		4.0
Hyd Liquefier	1225.0	2.0	2.7	1.0	306.3	490.0	25.0	8.0	183.8	1.0	3.0	80.0	175.0		4.0
Compressor	250.0	2.0	2.7	1.0	62.5	100.0	50.0		37.5	1.0					4.0
Motor	250.0	2.0	19.0	1.0	62.5	100.0	50.0		37.5	1.0					4.0
Pump	250.0	2.0	10.0	1.0	62.5	100.0	50.0		37.5	1.0					4.0
Heat Xchanger	125.0	2.0	17.1	1.0	31.3	50.0	50.0		18.8	1.0					4.0
Condenser	250.0	2.0	64.3	1.0	62.5	100.0	50.0		37.5	1.0					4.0
Storage Tank	100.0	2.0	30.8	1.0	25.0	40.0	50.0		15.0	1.0					4.0
Oxy Liquefier	1225.0	2.0	2.7	1.0	306.3	490.0	25.0	8.0	183.8	1.0	3.0	80.0	175.0		4.0
Compressor	250.0	2.0	2.7	1.0	62.5	100.0	50.0		37.5	1.0					4.0
Motor	250.0	2.0	19.0	1.0	62.5	100.0	50.0		37.5	1.0					4.0
Pump	250.0	2.0	10.0	1.0	62.5	100.0	50.0		37.5	1.0					4.0
Heat Xchanger	125.0	2.0	17.1	1.0	31.3	50.0	50.0		18.8	1.0					4.0
Condenser	250.0	2.0	64.3	1.0	62.5	100.0	50.0		37.5	1.0					4.0
Storage Tank	100.0	2.0	30.8	1.0	25.0	40.0	50.0		15.0	1.0					4.0
Fluid/Vapor Lines	75.0	50.0	155.4	1.0	18.8	30.0	25.0	0.5	11.3	1.0	0.5	5.0	20.0		4.0
Power Lines	75.0	50.0	71.7	1.0	18.8	30.0	25.0	0.5	11.3	1.0	0.5	5.0	20.0		4.0
Sensors	50.0	25.0	11.4	1.0	12.5	20.0	25.0	0.5	7.5	1.0	0.5	5.0	10.0		4.0
Comp/Comm Sys	**2750.0**	**1.0**			**1062.5**	**1700.0**	**300.0**	**16.0**	**637.5**	**1.0**	**16.0**	**160.0**	**375.0**		**28.0**
Computer	1500.0	3.0	5.7	1.0	375.0	600.0	25.0	8.0	225.0	1.0	8.0	80.0	175.0		4.0
Comm Subsys	1250.0	3.0	2.9	1.0	312.5	500.0	25.0	8.0	187.5	1.0	8.0	80.0	200.0		4.0
Transmitter	500.0	3.0	2.9	1.0	125.0	200.0	50.0		75.0	1.0					4.0
Receiver	500.0	3.0	2.9	1.0	125.0	200.0	50.0		75.0	1.0					4.0
Antenna	250.0	6.0	9.5	1.0	62.5	100.0	50.0		37.5	1.0					4.0
UHF	125.0	3.0	22.8	1.0	31.3	50.0	50.0		18.8	1.0					4.0
Omni	125.0	3.0	9.5	1.0	31.3	0	50.0		18.8	1.0					4.0

LUNAR EXCURSION VEHICLE (LEV) SERVICER SYSTEM DESIGN UTILITY INPUTS

CATEGORY	GROUNDRULE/ASSUMPTION
UNIT COST	ESTIMATE BASED UPON EXTRAPOLATION OF REPLACEMENT COSTS AND DOES NOT TAKE INTO CONSIDERATION ANY FACTORING FOR LUNAR OPERATIONS
LOT SIZE	ENGINEERING ESTIMATE OF "POPULATION" NOT PRODUCTION RUN
MT TO FAIL	MTBF EXTRAPOLATED FROM SSFP FISHER PRICE REPORT TABLE 5-1. CONVERTED HOURS TO YEARS USING 8760 HOURS PER YEAR
MT TO REPAIR	ENGINEERING ESTIMATE OF SUGGESTED MTTR GOALS FOR LUNAR CREWMEN
SUPPORT EQUIPMENT COST	DERIVED FROM UNIT COST. ENGINEERING ESTIMATE 25% OF UNIT COST.
DIAG S/W COST	DERIVED FROM UNIT COST. ENGINEERING ESTIMATE 40% OF UNIT COST.
REPAIR DOC	ORGANIZATIONAL LEVEL REPAIR MANUALS AVERAGES 25 PAGES INTERMEDIATE/DEPOT LEVEL REPAIR MANUALS AVERAGES 50 PAGES
REPAIR TRAINING	ENGINEERING ESTIMATE OF SUGGESTED LUNAR CREW TRAINING FOR ORGANIZATIONAL LEVEL REPAIR ACTIVITIES
REPAIR MATERIAL COST	MAINTENANCE SUPPORT EQUIPMENT DERIVED FROM UNIT COST. ENGINEERING ESTIMATE 15% OF UNIT COST.
CONDEMNATION RATE	ENGINEERING ESTIMATE OF 1% OF ORU'S
SCHED MAINTENANCE	ENGINEERING ESTIMATE OF SUGGESTED PREVENTIVE MAINTENANCE

LUNAR EXCURSION VEHICLE (LEV) SERVICER SYSTEM DESIGN UTILITY INPUTS

CATEGORY	GROUNDRULE/ASSUMPTION
MAINT TRAINING	ENGINEERING ESTIMATE. 10 TIMES CREW REPAIR TRAINING
TOTAL WEIGHT	EXTRAPOLATED FROM PSS ELEMENTS DATA BASE FIR 90 DAY LUNAR/MARS STUDY DATED 1/12/90
CONTAINER COST	DERIVED FROM LEV SERVICER TOTAL VOLUME (REF PSS ELEMENTS DATA BASE) AND FACTOR OF $100 PER CUBIC FT (20 CU METERS x 35.31 x $100)
TECH DRAWINGS	ENGINEERING ESTIMATE DETERMINED BY TYPE OF EQUIPMENT MECHANICAL, ELECTRICAL, ELECTRONIC, ELECTRO-MECH 1 PAGE/TYPE

Appendix M

Vehicle Servicing and Processing Work Breakdown Structure

Appendix M

Vehicle Servicing and Processing Work Breakdown Structure

MDSSC-KSC provided support to the Planetary Surface Systems Office in the planning of advanced development activities. One of the firsts inputs was the submittal of a Work Breakdown Structure (WBS). The WBS was based on the Mission Profile and the Turnaround Scenarios contained in Appendices G and H.

1.0 SYSTEM DEVELOPMENT

1.1 Lunar Deliverables

1.1.1 LEV Servicer
1.1.1.1 Fluid Processing System
(Reliquefaction/Refrigeration, Collection & Storage, Heat Transfer, Propellant Transfer, Process Control)
1.1.1.2 Electrical Power and Data Processing
(Power Generation, Storage, & Control, Instrumentation, Communication, Test & Checkout)
1.1.1.3 LEV Thermal Control
1.1.1.4 Transportation & Storage System (No Advanced Development)
(Movement to and from a protected environment between missions.)

1.1.2 Thermal/Micrometeoroid Protection (No Advanced Development)
1.1.2.1 Fabric/Cover
1.1.2.2 Support Structure & Deployment Mechanisms
1.1.2.3 Transportation & Storage System

1.1.3 Engine Ejecta Protection (No Advanced Development)
1.1.3.1 Berm/Blast Fence Construction
1.1.3.2 Pad Surface Paving
1.1.3.3 Protective Covers/Structures

1.1.4 Launch & Landing SSE (No Advanced Development)
1.1.4.1 Landing/Navigation Aids
1.1.4.2 Auxiliary Lighting Kit
1.1.4.3 L&L Access Equipment
1.1.4.4 L&L Tools & Test Equipment Kit
1.1.4.5 LLOX Pallet
1.1.4.6 Life Support Servicer (Not required for Option 5A)
1.1.4.7 Fuel Cell Servicer (Not required for Option 5A)
1.1.4.8 Waste Management System Servicer (Not required for Option 5A)
1.1.4.9 Range Safety Systems (Not required for Option 5A)

NOTES:
- Cargo Unloader & Transporter - Assumed to be provided by Construction & Mining
- Rovers for crew & equipment transfer - Assumed to be provided by Surface Transportation

1.2 Mars Deliverables

1.2.1 MEV Servicer Design Changes
1.2.1.1 Capacity Changes (MEV Propellant Load, Lower Boiloff Rate Changes)
1.2.1.2 Environmental Changes (Lower Temperature Extremes, Possible Liquid "Air"/Dry Ice Formation, Airborne Dust, Radiator Wind Loads, Atmospheric Convection Losses)

1.2.2 Thermal/Micrometeoroid Protection Design Changes (No Advanced Development)
1.2.2.1 Lower Thermal & Micrometeoroid Load
1.2.2.2 Consider Wind Loading
1.2.2.3 Dust Storm Proof the Fabric Joints & Access Openings

1.2.3	Engine Ejecta Protection Design (No Advanced Development)
1.2.3.1	Effect of Higher Thrust & Atmosphere on Eject Trajectories
1.2.3.2	Effect of Different Soil Characteristics on Berm Construction
1.2.3.3	Availability of ISRU Paving Materials
1.2.4	Launch & Landing SSE Design Changes (No Advanced Development)
1.2.4.1	Changes Driven by LEV-MEV Differences (Tools & Test Equipment, Access Equipment)
1.2.4.2	Changes Driven by Differences in Other SSE (Tools & Test Equipment)
2.0	SYSTEM INTEGRATION
2.1	Simulation & Modeling
2.2	Testbeds
2.2.1	LEV/MEV Servicer Testbed
2.2.1.1.	Performance Verification (Fluid Transfer, Reliquefaction, Conditioning, Gaging; Thermal control; Health Monitoring and Control)
2.2.1.2	Reliability Testing
2.2.1.3	Maintainability Verification
2.2.2	ISRU/LEV/MEV Fluid Transfer Testbed NOTE: Testbed is assumed to be provided by ISRU
2.2.2.1	Performance Verification (Fluid Transfer, Reliquefaction, Conditioning, Gaging; Thermal Control; Health Monitoring and Control)
2.2.2.2	1/6-G simulation
2.2.2.3	1/3-G Simulation
2.2.3	LEV/MEV Mockups NOTE: Testbed is assumed to be provided by STV
2.2.3.1	LEV/MEV to SSE Interface/Compatibility Verification
2.2.3.2	LEV/MEV O&M Procedure/Application Software Validation (O&M, Health Monitoring and Control)
2.2.3.3	LEV/MEV O&M Emphasizing PSS Access, Repair, & Maintainability Verification
2.2.4	Surface Equipment Life Test Testbed NOTE: Testbed is assumed to be provided by PSS
2.2.4.1	SSE Service Life & Reliability Testing (Cryo Storage, Cryo Materials, Fluid Connections)
2.2.4.2	SSE Access & Maintainability Verification
2.3	Cross-Cutting Analysis
2.3.1	Operations
2.3.2	Logistics
2.3.3	Automation
2.3.4	Robotics/Telerobotics
2.3.5	Human Factors
2.3.6	Safety, Reliability, Maintenance & Quality Assurance
2.4	Interfaces with Other Systems
2.4.1	LEV/MEV (Service Requirements & Interface Definition)

2.4.2 ISRU (Propellant Reliquefaction & Storage)
2.4.3 Construction & Mining (Cargo Unloading & Transportation, LEV/MEV Servicer Prime Mover & Power Recharge)
2.4.4 Surface Transportation (Crew & Equipment)
2.4.5 Command & Data Systems (LEV/MEV/SSE O&M)
2.4.6 Power (LEV/MEV/SSE Power)
2.4.7 Processing Robotics (LEV/MEV/SSE O&M)
2.4.8 Operations & Logistics (Spares & Consumables, Expendable LEV/MEV Cannibalization)

3.0 PROGRAM MANAGEMENT

3.1 System Development
3.1.1 Lunar Deliverables
3.1.2 Mars Deliverables

3.2 System Integration

4.0 PROCUREMENT

4.1 Lunar Deliverables
4.1.1 LEV Servicer
4.1.2 Thermal/Micrometeoroid Protection
4.1.3 Engine Ejecta Protection
4.1.4 Launch & Landing SSE

4.2 Mars Deliverables
4.2.1 LEV Servicer
4.2.2 Thermal/Micrometeoroid Protection
4.2.3 Engine Ejecta Protection
4.2.4 Launch & Landing SSE

5.0 FACILITIES DEVELOPMENT

5.1 LEV/MEV Servicer Testbed

Appendix N

Advanced Development Schedule

and

Task Description Sheets

Appendix N

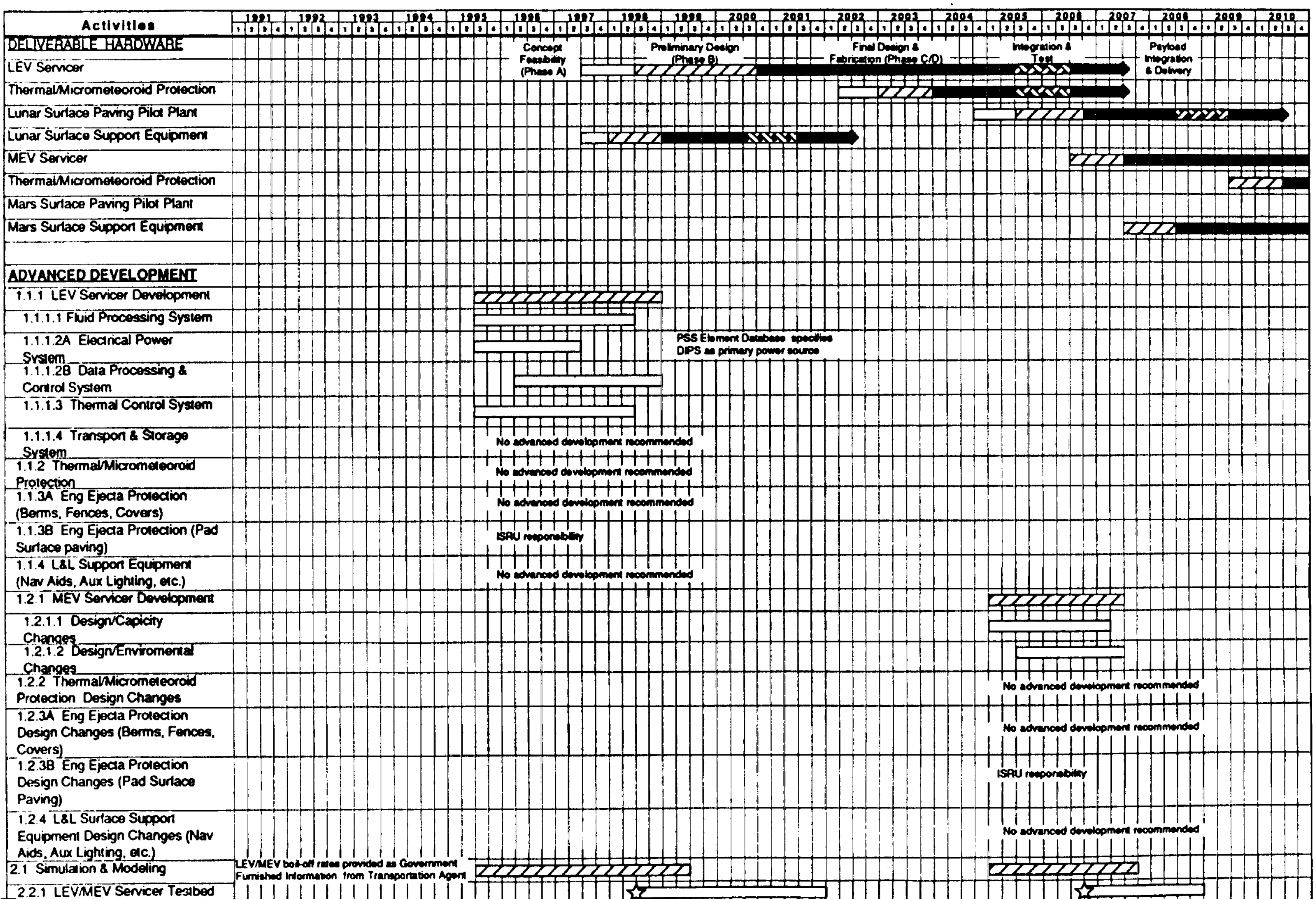
Advanced Development Schedule

and

Task Description Sheets

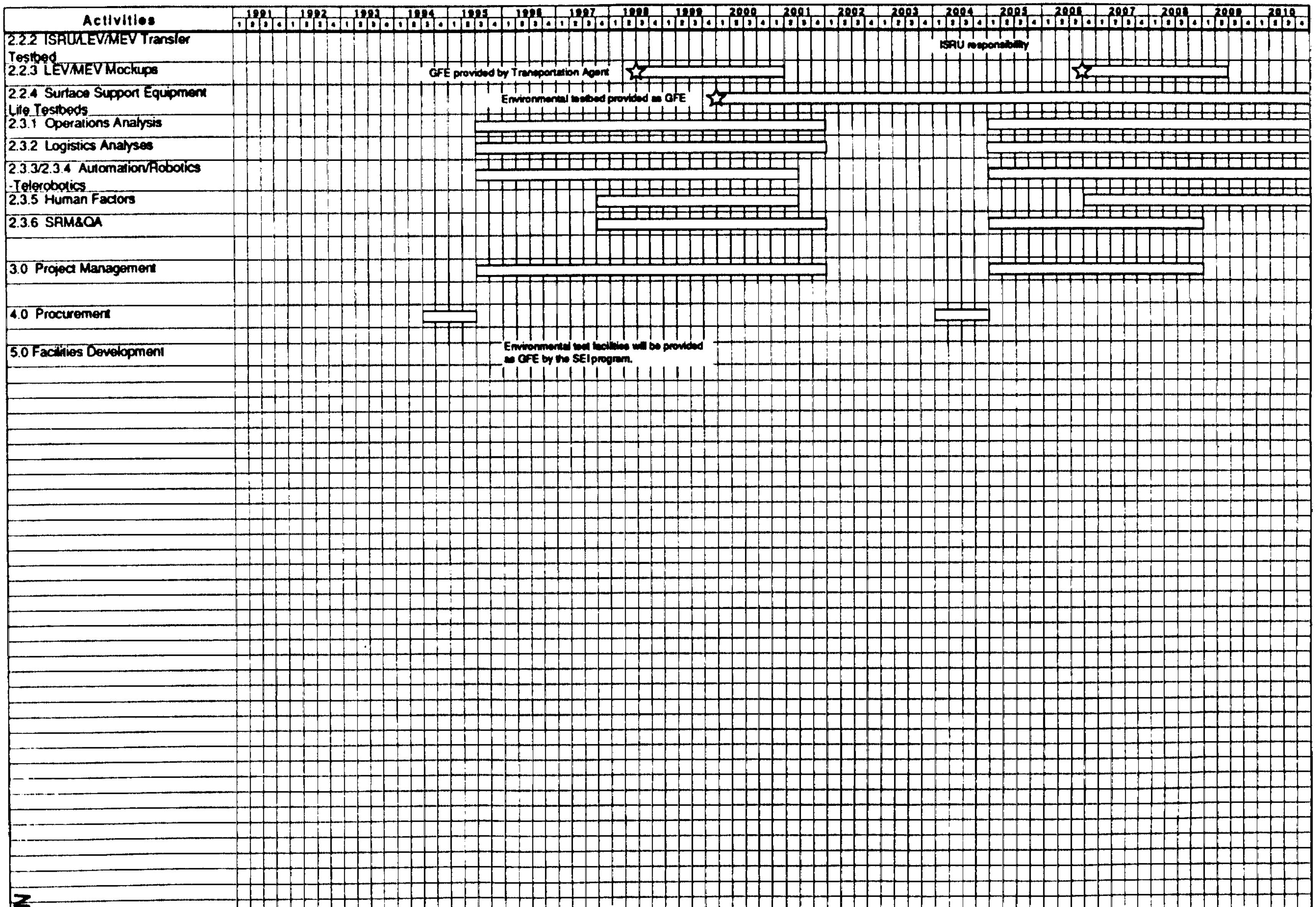
Based on the mission profile and the work breakdown structure developed as inputs to the Planetary Surface Systems advanced development planning, tasks required to develop launch and landing hardware were identified. Using these tasks a schedule was developed. This schedule is contained in this appendix on page N-1. A description of what these tasks are and the estimation of the manpower required to work these tasks were also defined. The spreadsheets containing this information begins on page N-3.

LAUNCH AND LANDING SYSTEM ADVANCED DEVELOPMENT SCHEDULE



L&L Avanced Development Plan, Rev 4, 1/17/91

LAUNCH AND LANDING SYSTEM ADVANCED DEVELOPMENT SCHEDULE



LAUNCH AND LANDING SYSTEM ADVANCED DEVELOPMENT

WBS#: 1.1.1.1	Activity: L&L Advanced Development Plan		Date: 1/24/91
Integration Agent:	Contact Person:	NASAMail ID:	Mail Code:
Title: LEV Servicer/Fluid Processing System	Phone:	Fax:	

Task Objective: Develop a fluid processing system that will conserve LEV propellants through reliquefaction.

Task Description/Approach: Design, construct and test dual reliquefaction devices that will collect, compress and liquify GO2 and GH2 boiloff gases from the LEV propellant tanks. The Servicer will have the capability to transfer liquid propellants to the LEV tanks.

Products/Milestones/Schedule:

Resources Summary:

Real Year $

FY	95	96	97	98	99	00	01
Obls. ($K)							
Costs($K)							

Manpower Summary:

FY	95	96	97	98	99	00	01
Civil Service EP:							
Prime Contract EP:	1	4.5	6	4.5			
Supp. Contract EP:	0.2	0.7	0.9	0.7			

C of F Requirements:

FY	95	96	97	98	99	00	01
$K							

Materials and Equipment

FY	95	96	97	98	99	00	01
$K		483	967				

LAUNCH AND LANDING SYSTEM ADVANCED DEVELOPMENT

WBS#: 1.1.1.2A	Activity: L&L Advanced Development Plan		Date: 1/24/91
Integration Agent:	Contact Person:	NASAMail ID:	Mail Code:
Title: LEV Servicer/Electrical Power	Phone:	Fax:	

Task Objective: Condition electrical power to run the LEV Servicer internal functions and operate the LEV electrical systems.

Task Description/Approach: Design, construct and test the power conditioning unit under various LEV and LEV Servicer electrical load conditions.
Note: PSS Element Data Base (1/12/90) Specifies DIPS as primary power source.

Products/Milestones/Schedule:

Resources Summary:

Real Year $

FY	95	96	97	98	99	00	01
Obls. ($K)							
Costs($K)							

Manpower Summary:

FY	95	96	97	98	99	00	01
Civil Service EP:							
Prime Contract EP:	0.5	2.5	2.25				
Supp. Contract EP:	0.1	0.4	0.3				

C of F Requirements:

FY	95	96	97	98	99	00	01
$K							

Materials and Equipment

FY	95	96	97	98	99	00	01
$K		392	783				

LAUNCH AND LANDING SYSTEM ADVANCED DEVELOPMENT

WBS#: 1.1.1.2B	Activity: L&L Advanced Development Plan		Date: 1/24/91
Integration Agent:	Contact Person:	NASAMail ID:	Mail Code:
Title: LEV Servicer/Data Processing & Control	Phone:	Fax:	

Task Objective: Provide automated control of the servicer thermal, electrical power and reliquefaction functions.

Task Description/Approach: Design, cosntruct, and test a servicer automated control sytem that utilizes data collection, data processing and computer programming.

Products/Milestones/Schedule:

Resources Summary:

Real Year $

FY	95	96	97	98	99	00	01
Obls. ($K)							
Costs($K)							

Manpower Summary:

FY	95	96	97	98	99	00	01
Civil Service EP:							
Prime Contract EP:		2	5	6	1.5		
Supp. Contract EP:		0.3	0.8	0.9	0.2		

C of F Requirements:

FY	95	96	97	98	99	00	01
$K							

Materials and Equipment

FY	95	96	97	98	99	00	01
$K			459	916			

LAUNCH AND LANDING SYSTEM ADVANCED DEVELOPMENT

WBS#: 1.1.1.3	Activity: L&L Advanced Development Plan		Date: 1/24/91
Integration Agent:	Contact Person:	NASAMail ID:	Mail Code:
Title: LEV Servicer/Thermal control	Phone:	Fax:	

Task Objective: Provide thermal control of the LEV avionics and electrical system.

Task Description/Approach: Design, construct, and test a fluid thermal loop system that will reject heat through a radiator device.

Products/Milestones/Schedule:

Resources Summary:

Real Year $

FY	95	96	97	98	99	00	01
Obls. ($K)							
Costs($K)							

Manpower Summary:

FY	95	96	97	98	99	00	01
Civil Service EP:							
Prime Contract EP:	0.5	2.25	3	2.25			
Supp. Contract EP:	0.1	0.3	0.5	0.3			

C of F Requirements:

FY	95	96	97	98	99	00	.01
$K							

Materials and Equipment

FY	95	96	97	98	99	00	01
$K		167	333				

LAUNCH AND LANDING SYSTEM ADVANCED DEVELOPMENT

WBS#: 1.1.1.4	Activity: L&L Advanced Development Plan		Date: 12/19/90
Integration Agent:	Contact Person:	NASAMail ID:	Mail Code:
Title: LEV Servicer/Transportation & Storage System	Phone:	Fax:	

Task Objective: Develop a technique to transport the servicer to and from a remote LEV storage system.

Task Description/Approach: No advanced development recommended.

Products/Milestones/Schedule:

Resources Summary:

Real Year $

FY	95	96	97	98	99	00	01
Obls. ($K)							
Costs($K)							

Manpower Summary:

FY	95	96	97	98	99	00	01
Civil Service EP:							
Prime Contract EP:							
Supp. Contract EP:							

C of F Requirements:

FY	95	96	97	98	99	00	01
$K							

Materials and Equipment

FY	95	96	97	98	99	00	01
$K							

LAUNCH AND LANDING SYSTEM ADVANCED DEVELOPMENT

WBS#: 1.1.2	Activity: L&L Advanced Development Plan		Date: 12/19/90
Integration Agent:	Contact Person:	NASAMail ID:	Mail Code:
Title: Thermal/Micormeteoroid Protection	Phone:	Fax:	

Task Objective: Develop techniques to provide thermal and micrometeoroid protection for the LEV.

Task Description/Approach: No advanced development recommended.

Products/Milestones/Schedule:

Resources Summary:

Real Year $

FY	95	96	97	98	99	00	01
Obls. ($K)							
Costs($K)							

Manpower Summary:

FY	95	96	97	98	99	00	01
Civil Service EP:							
Prime Contract EP:							
Supp. Contract EP:							

C of F Requirements:

FY	95	96	97	98	99	00	01
$K							

Materials and Equipment

FY	95	96	97	98	99	00	01
$K							

LAUNCH AND LANDING SYSTEM ADVANCED DEVELOPMENT

WBS#: 1.1.3A	Activity: L&L Advanced Development Plan		Date: 12/19/90
Integration Agent:	Contact Person:	NASAMail ID:	Mail Code:
Title: Engine Ejecta Protection/Berms, Fences, Covers	Phone:		Fax:

Task Objective: Develop techniques to provide protection from engine surface dust ejecta during landings and liftoff.

Task Description/Approach: No advanced development recommended.

Products/Milestones/Schedule:

Resources Summary:

Real Year $

FY	95	96	97	98	99	00	01
Obls. ($K)							
Costs($K)							

Manpower Summary:

FY	95	96	97	98	99	00	01
Civil Service EP:							
Prime Contract EP:							
Supp. Contract EP:							

C of F Requirements:

FY	95	96	97	98	99	00	01
$K							

Materials and Equipment

FY	95	96	97	98	99	00	01
$K							

LAUNCH AND LANDING SYSTEM ADVANCED DEVELOPMENT

WBS#: 1.1.3B	Activity: L&L Advanced Development Plan		Date: 1/3/91
Integration Agent:	Contact Person:	NASAMail ID:	Mail Code:
Title: Engine Ejecta Protection/Pad Surface Paving	Phone:		Fax:

Task Objective: Develop a technique that uses lunar surface materials to pave the landing area.

Task Description/Approach: Develop and test a pilot plant process that will utilize lunar soil to produce paving bricks or other paving materials. (ISRU responsibility)

Products/Milestones/Schedule:

Resources Summary:

Real Year $

FY	95	96	97	98	99	00	01
Obls. ($K)							
Costs($K)							

Manpower Summary:

FY	95	96	97	98	99	00	01
Civil Service EP:							
Prime Contract EP:							
Supp. Contract EP:							

C of F Requirements:

FY	95	96	97	98	99	00	01
$K							

Materials and Equipment

FY	95	96	97	98	99	00	01
$K							

LAUNCH AND LANDING SYSTEM ADVANCED DEVELOPMENT

WBS#: 1.1.4	Activity: L&L Advanced Development Plan		Date: 12/19/90
Integration Agent:	Contact Person:	NASAMail ID:	Mail Code:
Title: Launch and Landing Surface Support Equipment	Phone:		Fax:

Task Objective: Design and develop additional support equipment such as landing and navigation aids, auxiliary lighting, access equipment, tools and test equipment, and LLOX pallet.

Task Description/Approach: No advanced development recommended.

Products/Milestones/Schedule:

Resources Summary:

Real Year $

FY	95	96	97	98	99	00	01
Obls. ($K)							
Costs($K)							

Manpower Summary:

FY	95	96	97	98	99	00	01
Civil Service EP:							
Prime Contract EP:							
Supp. Contract EP:							

C of F Requirements:

FY	95	96	97	98	99	00	01
$K							

Materials and Equipment

FY	95	96	97	98	99	00	01
$K							

LAUNCH AND LANDING SYSTEM ADVANCED DEVELOPMENT

WBS#: 1.2.1.1		Activity: L&L Advanced Development Plan		Date: 1/3/91
Integration Agent:		Contact Person:	NASAMail ID:	Mail Code:
Title: MEV Servicer Design Changes/Capacity Changes		Phone:	Fax:	

Task Objective: Assess the MEV Design Changes that would impact the LEV servicer fluid processing, electrical power, thermal control, and data processing control functions.

Task Description/Approach: Incorporate the MEV impact design changes into all the affected servicer functions and retest to validate the modified design.

Products/Milestones/Schedule:

Resources Summary:

Real Year $

FY	95	96	97	98	99	00	01
Obls. ($K)							
Costs($K)							

Manpower Summary:

FY	95	96	97	98	99	00	01
Civil Service EP:							
Prime Contract EP:							
Supp. Contract EP:							

C of F Requirements:

FY	95	96	97	98	99	00	01
$K							

Materials and Equipment

FY	95	96	97	98	99	00	01
$K							

WBS#: 1.2.1.2	Activity: L&L Advanced Development Plan			Date: 12/19/90	
Integration Agent:	Contact Person:	NASAMail ID:		Mail Code:	
Title: MEV Servicer Design/Environmental Changes	Phone:		Fax:		

Task Objective: Assess the Martian environmental differences and their impact on the LEV servicer fluid processing, electrical power, thermal control and data processing and control functions.

Task Description/Approach: Incorporate the Martian environmental impact design changes into all the affected servicer functions and retest to validate the modified design.

Products/Milestones/Schedule:

Resources Summary:

Real Year $

FY	95	96	97	98	99	00	01
Obls. ($K)							
Costs($K)							

Manpower Summary:

FY	95	96	97	98	99	00	01
Civil Service EP:							
Prime Contract EP:							
Supp. Contract EP:							

C of F Requirements:

FY	95	96	97	98	99	00	01
$K							

Materials and Equipment

FY	95	96	97	98	99	00	01
$K							

LAUNCH LANDING SYSTEM ADVANCED DEVELOPMENT

WBS#:	1.2.2	Activity:	L&L Advanced Development Plan	Date:	12/19/90
Integration Agent:		Contact Person:	NASAMail ID:	Mail Code:	
Title:	Thermal/Micrometeoroid Protection Design Change	Phone:		Fax:	

Task Objective: Assess the Martian environmental differences and their impact on the protection devices developed for the LEV. Modify the designs as necessary.

Task Description/Approach: No advanced development recommended.

Products/Milestones/Schedule:

Resources Summary:

Real Year $

FY	95	96	97	98	99	00	01
Obls. ($K)							
Costs($K)							

Manpower Summary:

FY	95	96	97	98	99	00	01
Civil Service EP:							
Prime Contract EP:							
Supp. Contract EP:							

C of F Requirements:

FY	95	96	97	98	99	00	01
$K							

Materials and Equipment

FY	95	96	97	98	99	00	01
$K							

LAUNCH LANDING SYSTEM ADVANCED DEVELOPMENT

WBS#: 1.2.3A	Activity: L&L Advanced Development Plan		Date: 12/19/90
Integration Agent:	Contact Person:	NASAMail ID:	Mail Code:
Title: Eng Ejecta Protection Design Changes/Berms, etc.	Phone:		Fax:

Task Objective: Assess the impact of MEV higher thrust levels, atmosphere and soil characteristics on the protective berms, fences, covers, etc. Modify the designs as necessary.

Task Description/Approach: No advanced development recommended.

Products/Milestones/Schedule:

Resources Summary:

Real Year $

FY	95	96	97	98	99	00	01
Obls. ($K)							
Costs($K)							

Manpower Summary:

FY	95	96	97	98	99	00	01
Civil Service EP:							
Prime Contract EP:							
Supp. Contract EP:							

C of F Requirements:

FY	95	96	97	98	99	00	01
$K							

Materials and Equipment

FY	95	96	97	98	99	00	01
$K							

LAUNCH LANDING SYSTEM ADVANCED DEVELOPMENT

WBS#: 1.2.3B	Activity: L&L Advanced Development Plan		Date: 12/19/90
Integration Agent:	Contact Person:	NASAMail ID:	Mail Code:
Title: Eng Ejecta Protection Design Changes/Pad Paving	Phone:	Fax:	

Task Objective: Determine the soil characteristic differences for Martian soil and the impact on the capability to produce paving material.

Task Description/Approach: Develop and test a pilot plant process that will produce paving material from martian soil. (ISRU responsibility)

Products/Milestones/Schedule:

Resources Summary:

Real Year $

FY	95	96	97	98	99	00	01
Obls. ($K)							
Costs($K)							

Manpower Summary:

FY	95	96	97	98	99	00	01
Civil Service EP:							
Prime Contract EP:							
Supp. Contract EP:							

C of F Requirements:

FY	95	96	97	98	99	00	01
$K							

Materials and Equipment

FY	95	96	97	98	99	00	01
$K							

LAUNCH AND LANDING SYSTEM ADVANCED DEVELOPMENT

WBS#: 1.2.4	Activity: L&L Advanced Development Plan		Date: 12/19/90
Integration Agent:	Contact Person:	NASAMail ID:	Mail Code:
Title: Launch and Landing SSE Design Changes	Phone:	Fax:	

Task Objective: Assess the impact of MEV and martian environmental factors on the Surface Support Equipment and modify the designs as necessary.

Task Description/Approach: No advanced development recommended.

Products/Milestones/Schedule:

Resources Summary:

Real Year $

FY	95	96	97	98	99	00	01
Obls. ($K)							
Costs($K)							

Manpower Summary:

FY	95	96	97	98	99	00	01
Civil Service EP:							
Prime Contract EP:							
Supp. Contract EP:							

C of F Requirements:

FY	95	96	97	98	99	00	01
$K							

Materials and Equipment

FY	95	96	97	98	99	00	01
$K							

LAUNCH AND LANDING SYSTEM ADVANCED DEVELOPMENT

WBS#: 2.1	Activity: L&L Advanced Development Plan		Date: 1/24/91
Integration Agent:	Contact Person:	NASAMail ID:	Mail Code:
Title: Simulation and Modeling	Phone:		Fax:

Task Objective: Develop computerized models of the LEV/MEV Servicer reliquefaction and thermal control fluid systems.

Task Description/Approach: Develop and utilize Servicer fluid system models to perfect reliquefaction and thermal dissipation capabilities under the planetary environmental conditions. Note: LEV/MEV tank boil-off rates are GFI (Government Furnished Information) from the Transportation Agent

Products/Milestones/Schedule:

Resources Summary:

Real Year $

FY	95	96	97	98	99	00	01
Obls. ($K)							
Costs($K)							

Manpower Summary:

FY	95	96	97	98	99	00	01
Civil Service EP:							
Prime Contract EP:	1	3.75	2.75	1.75	0.75		
Supp. Contract EP:	0.2	0.6	0.4	0.3	0.1		

C of F Requirements:

FY	95	96	97	98	99	00	01
$K							

Materials and Equipment

FY	95	96	97	98	99	00	01
$K							

LAUNCH AND LANDING SYSTM ADVANCED DEVELOPMENT

WBS#: 2.2.1	Activity: L&L Advanced Development Plan		Date: 1/28/90
Integration Agent:	Contact Person:	NASAMail ID:	Mail Code:
Title: LEV/MEV Servicer Testbed	Phone:	Fax:	

Task Objective: Develop a Servicer testbed that can verify the reliquefaction, thermal control and electrical power functions under simulated planetary environmental test conditions

Task Description/Approach: Subject the Servicer testbed to planetary environmental conditions and the LEV/MEV variable boil off rates, thermal loads, and electrical power demands to observe fluid conditioning, reliquefaction, transfer, and gaging capabilities, as well, as thermal control, electrical power regulation, and Servicer automated control and health monitoring function. Perform tests to determine reliability and maintainability. The environmental test chamber, and required support services (i.e., transportation, storage, handling, etc.) are provided as GFE.

Products/Milestones/Schedule:

Resources Summary:

Real Year $

FY	95	96	97	98	99	00	01
Obls. ($K)							
Costs($K)							

Manpower Summary:

FY	95	96	97	98	99	00	01
Civil Service EP:							
Prime Contract EP:				1.5	8.5	8.75	6.5
Supp. Contract EP:				0.2	1.3	1.3	1.0

C of F Requirements:

FY	95	96	97	98	99	00	01
$K							

Materials and Equipment

FY	95	96	97	98	99	00	01
$K*				0.7	2.8	2.8	2.8

* Includes one (1) three (3) day trip per quarter @ $700.00 per trip.

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LAUNCH AND LANDING SYSTEM ADVANCED DEVELOPMENT

WBS#: 2.2.2	Activity: L&L Advanced Development Plan		Date: 1/24/91
Integration Agent:	Contact Person:	NASAMail ID:	Mail Code:
Title: ISRU/LEV/MEV Fluid Transfer Testbed	Phone:	Fax:	

Task Objective: Develop an ISRU Fluid Transfer Testbed that can verify LLOX storage, and line chilldown and transfer capabilites to load the LEV/MEV LO2 storage tanks under simulated planetary environmental test conditions.

Task Description/Approach: Subject the ISRU Fluid Testbed to the planetary environmental conditions, to determine the capability transfer LLOX to the vehicle flight LO2 storage tanks. Note: Testbed is GFE to be provided by ISRU.

Products/Milestones/Schedule:

Resources Summary:

Real Year $

FY	95	96	97	98	99	00	01
Obls. ($K)							
Costs($K)							

Manpower Summary:

FY	95	96	97	98	99	00	01
Civil Service EP:							
Prime Contract EP:							
Supp. Contract EP:							

C of F Requirements:

FY	95	96	97	98	99	00	01
$K							

Materials and Equipment

FY	95	96	97	98	99	00	01
$K							

LAUNCH AND LANDING SYSTEM ADVANCED DEVELOPMENT

WBS#: 2.2.3	Activity: L&L Advanced Development Plan		Date: 1/24/91	
Integration Agent:	Contact Person:	NASAMail ID:	Mail Code:	
Title: LEV/MEV Mockups	Phone:	Fax:		

Task Objective: Fabricate LEV/MEV flight vehicle mockups to verify SSE functional interfaces, operation and maintenance procedures, automated health monitoring and control and ground computer interfaces.

Task Description/Approach: Subject the flight vehicle mockups to the SSE fluid processing, thermal control and electrical power services to verify functional capabilities. Verify health monitoring and control software by simulating out-of-tolerance conditions to test detection, safing and built-in-test capabilities. In conjunction with this, verify ground computer and monitoring software/hardware interfaces. Verify access capability for periodic maintenance and repair activity. Note: LEV/MEV mockups are GFE provided by the transporation agent.

Products/Milestones/Schedule:

Resources Summary:

Real Year $

FY	95	96	97	98	99		01
Obls. ($K)							
Costs($K)							

Manpower Summary:

FY	95	96	97	98	99		01
Civil Service EP:							
Prime Contract EP:				0.5	2.25	5	5.5
Supp. Contract EP:				0.1	0.3	0.8	0.8

C of F Requirements:

FY	95	96	97	98	99		01
$K							

Materials and Equipment

FY	95	96	97	98	99		01
$K							

LAUNCH AND LANDING SYSTEM ADVANCED DEVELOPMENT

WBS#: 2.2.4	Activity: L&L Advanced Development Plan		Date: 1/28/91
Integration Agent:	Contact Person:	NASAMail ID:	Mail Code:
Title: Surface Equipment Life Testbeds	Phone:		Fax:

Task Objective: Develop a test plan to determine planetary environmental impact on LEV/MEV SSE and ISRU equipment reliability, maintainability and life expectancy.

Task Description/Approach: Subject the ISRU and LEV/MEV support equipment to long duration planetary environments, including cyclic factors, to determine their impact particularly on cryo storage, cryo materials and fluid connector.
Note: The environmental test chamber, and required support services (i.e., transportation, storage, handling, etc.) are provided as GFE.

Products/Milestones/Schedule:

Resources Summary:

Real Year $

FY	95	96	97	98	99	00	01
Obls. ($K)							
Costs($K)							

Manpower Summary:

FY	95	96	97	98	99	00	01
Civil Service EP:							
Prime Contract EP:						2	2
Supp. Contract EP:						0.3	0.3

C of F Requirements:

FY	95	96	97	98	99	00	01
$K							

Materials and Equipment

FY	95	96	97	98	99	00	01
$K							

LAUNCH AND LANDING SYSTEM ADVANCED DEVELOPMENT

WBS#: 2.3.1	Activity: L&L Advanced Development Plan		Date: 1/28/91
Integration Agent:	Contact Person:	NASAMail ID:	Mail Code:
Title: Operations Analysis	Phone:	Fax:	

Task Objective:
Provide supporting analyses to Vehicle Servicing and Processing for Advanced Development

Task Description/Approach:
Operations assessments will include the following:
1. Evaluate SSE design for compatibility with anticipated operational scenarios.
2. Develop initial timelines for equipment setup, interface connections and preoperational checkout.
3. Develop procedure (OMI) requirements.

Products/Milestones/Schedule:

Resources Summary:

Real Year $

FY	95	96	97	98	99	00	01
Obls. ($K)							
Costs($K)							

Manpower Summary:

FY	95	96	97	98	99	00	01
Civil Service EP:							
Prime Contract EP:	0.25	1.25	1.75	0.88	0.44	0.25	0.25
Supp. Contract EP:	0	0.2	0.3	0.1	0.1	0.0	0.0

C of F Requirements:

FY	95	96	97	98	99	00	01
$K							

Materials and Equipment

FY	95	96	97	98	99	00	01
$K							

LAUNCH AND LANADING ADVANCED DEVELOPMENT

WBS#: 2.3.2	Activity: L&L Advanced Development Plan			Date: 1/28/91	
Integration Agent:	Contact Person:	NASAMail ID:		Mail Code:	
Title: Logistics Analyses		Phone:	Fax:		

Task Objective: Provide supporting analyses to vehicle servicing & processing for advanced development.

Task Description/Approach: Logistics assessments will include the following:

1. Evaluate SSE designs for accessibility, supportability and maintainability from an organizational level basis.
2. Correlate predicted failure rates with actual.
3. Develop maintenance procedures.
4. Develop integrated logistics support requirements.

Products/Milestones/Schedule: NOTE: The environmental test chamber, and required support services (I.e., transportation, storage, handling, etc.) required during test of the LEV Servicer testbed are provided as GFE.

Resources Summary:

Real Year $

FY	95	96	97	98	99	00	01
Obls. ($K)							
Costs($K)							

Manpower Summary:

FY	95	96	97	98	99	00	01
Civil Service EP:							
Prime Contract EP:	0.5	3	3.75	2	0.75	0.38	0.25
Supp. Contract EP:	0.1	0.5	0.6	0.3	0.1	0.1	0.0

C of F Requirements:

FY	95	96	97	98	99	00	01
$K							

Materials and Equipment

FY	95	96	97	98	99	00	01
$K							

LAUNCH AND LANDING SYSTEM ADVANCED DEVELOPMENT

WBS#: 2.3.3/2.3.4	Activity: L&L Advanced Development Plan		Date: 1/28/91
Integration Agent:	Contact Person:	NASAMail ID:	Mail Code:
Title: Automation/Robotics-Telerobotics	Phone:	Fax:	

Task Objective: Provide supporting analyses to Vehicle Servicing & Processing for Advanced Development.

Task Description/Approach: Robotics - Telerobotics assessments will include the following:

1. Evaluate the LEV/MEV Servicer Data Processing and Control for proper automated design and operation.
2. Evaluate the LEV/MEV Mockup Health Monitor and Control hardware/software for proper automated design and operation.
3. Evaluate the ISRU Fluid Storage and Transfer system for proper automated design and operation.
4. Assess the SSE for potential phase-in of telerobotics and robotics.

Products/Milestones/Schedule:

Resources Summary:

Real Year $

FY	95	96	97	98	99	00	01
Obls. ($K)							
Costs($K)							

Manpower Summary:

FY	95	96	97	98	99	00	01
Civil Service EP:							
Prime Contract EP:	0.75	2.75	1.75	0.88	0.5	0.5	0.38
Supp. Contract EP:	0.1	0.4	0.3	0.1	0.1	0.1	0.1

C of F Requirements:

FY	95	96	97	98	99	00	01
$K							

Materials and Equipment

FY	95	96	97	98	99	00	01
$K							

LAUNCH AND LANDING SYSTEM ADVANCED DEVELOPMENT

WBS#: 2.3.5	Activity: L&L Advanced Development Plan		Date: 1/28/91
Integration Agent:	Contact Person:	NASAMail ID:	Mail Code:
Title: Human Factors	Phone:	Fax:	

Task Objective: Provide supporting analyses to Vehicle Servicing & Processing for Advanced Development.

Task Description/Approach: Evaluate the SSE designs and operational usage to assure that human factors have been incorporated.

Products/Milestones/Schedule:

Resources Summary:

Real Year $

FY	95	96	97	98	99	00	01
Obls. ($K)							
Costs($K)							

Manpower Summary:

FY	95	96	97	98	99	00	01
Civil Service EP:							
Prime Contract EP:				0.9	0.5	0.4	0.2
Supp. Contract EP:				0.1	0.1	0.1	0

C of F Requirements:

FY	95	96	97	98	99	00	01
$K							

Materials and Equipment

FY	95	96	97	98	99	00	01
$K							

LAUNCH AND LANDING ADVANCED DEVELOPMENT

WBS#: 2.3.6	Activity: L&L Advanced Development Plan		Date: 1/28/91
Integration Agent:	Contact Person:	NASAMail ID:	Mail Code:
Title: SRM & QA	Phone:	Fax:	

Task Objective: Provide supporting analyses to Vehicle Servicing & Processing for Advanced Development.

Task Description/Approach: Perform Saftey, Reliiability, Maintainability & Quality Assurance (SRM & QA) assessments on the SSE, concentrating on the LEV/MEV Servicer as follows:

1. Perform Hazard Analyses on system designs.
2. Perform Failure Mode and Effects Analyses (FMEA).
3. Identify Critical Single Failure Points (CSFP) and assign appropriate criticality designation.

Products/Milestones/Schedule:

Resources Summary:

Real Year $

FY	95	96	97	98	99	00	01
Obls. ($K)							
Costs($K)							

Manpower Summary:

FY	95	96	97	98	99	00	01
Civil Service EP:							
Prime Contract EP:				3.75	2.5	1.5	1
Supp. Contract EP:				0.6	0.4	0.2	0.2

C of F Requirements:

FY	95	96	97	98	99	00	01
$K							

Materials and Equipment

FY	95	96	97	98	99	00	01
$K							

LAUNCH AND LANDING SYSTEM ADVANCED DEVELOPMENT

WBS#: 3.0	Activity: L&L Advanced Development Plan		Date: 1/28/91
Integration Agent:	Contact Person:	NASAMail ID:	Mail Code:
Title: Project management	Phone:	Fax:	

Task Objective: Provide project management for direction and control of LEV/MEV Servicer advanced development.

Task Description/Approach: Provide oversight for work carried out under all Launch and Landing System advanced development WBS including:

1. Verify development and test activity is consistent with program objectives.
2. Ensure development is carried out in accordance with the timelines of the program schedules.
3. Ensure proper manloading and accounting.
4. Ensure proper engineering skill mix.

Products/Milestones/Schedule:

Resources Summary:

Real Year $

FY	95	96	97	98	99	00	01
Obls. ($K)							
Costs($K)							

Manpower Summary:

FY	95	96	97	98	99	00	01
Civil Service EP:	1	4	4	4	4	4	4
Prime Contract EP:	0.2	1.1	1.3	1.2	0.9	0.9	0.8
Supp. Contract EP:	0.2	0.6	0.6	0.6	0.6	0.6	0.6

C of F Requirements:

FY	95	96	97	98	99	00	01
$K							

Materials and Equipment

FY	95	96	97	98	99	00	01
$K*	0.70	2.80	2.80	2.80	2.80	2.80	2.80

*Includes one (1) three (3) day trip per quarter @ $700.00 per trip.

LAUNCH AND LANDING SYSTEM ADVANCED DEVELOPMENT

WBS#: 4.0	Activity: L&L Advanced Development Plan		Date: 1/24/91
Integration Agent:	Contact Person:	NASAMail ID:	Mail Code:
Title: Procurement	Phone:	Fax:	

Task Objective: Provide the support required for the procurement of the LEV/MEV Servicer advanced development.

Task Description/Approach: Provide the necessary documentation (i.e., SOW, RFP, etc.) for the procurement of the LEV/MEV Servicer advanced development program. Provide support for the receipt and evaluation of the proposals.

Products/Milestones/Schedule:

Resources Summary:

Real Year $

FY	94	95	96	97	98	99	00
Obls. ($K)							
Costs($K)							

Manpower Summary:

FY	94	95	96	97	98	99	00
Civil Service EP:	1.3	3.8					
Prime Contract EP:							
Supp. Contract EP:	0.2	0.6					

C of F Requirements:

FY	94	95	96	97	98	99	00
$K							

Materials and Equipment

FY	94	95	96	97	98	99	00
$K							

L and L Hardware Cost Breakdown Rev 1

	FY	95.0	96.0	97.0	98.0	99.0	0.0	1.0	TOTAL
1.1.1.1 FLUID SYS	$K		1852.7	3705.3					5558
See Notes 1 & 2									
1.1.1.2A ELECTRIC PWR (2)	$K		325.0	650.0					975
See Note 3									
1.1.1.2B DATA PROC	$K			1191.7	2383.3				3575
See Note 1									
1.1.1.3 THERMAL	$K		433.3	866.7					1300
See Note 1									
SUBTOTAL		0.0	2611.0	6413.7	2383.3	0.0	0.0	0.0	11408
2.2.1 LEV/MEV SERV TESTBED	$K*				0.7	2.8	2.8	2.8	9
3.0 PROGRAM MANAGEMENT	$K*	0.7	2.8	2.8	2.8	2.8	2.8	2.8	18
TOTAL	$K*	0.7	2613.8	6416.5	2386.8	5.6	5.6	5.6	11435

Manpower costs at $100K per man year $19,080

Grand Total $30,515

* Includes one (1) three (3) day trip per quarter @ $700.00 per trip.

Notes:

1. Hardware material costs are based on an engineering estimate by Jeff Traylor, times a 1.3 complexity factor.

2. Fluid system cost breakdown

Low pressure He liquifier (Jeff Traylor's est. for H system)	$2,900	K
Plus:		
Compressor	$250	K
Motor	$250	K
3 Heat Exchangers	$375	K
2 Expanders	$500	K
Subtotal	$4,275	K
Total including 1.3 complexity factor	$5,558	K

3. Electrical Power System based on LeRC providing the DIPS and L&L proving the rectifier/regulator and distribution portion.

1.1.1.1 FLUID PROCESSING SYSTEM

FY	95				96				97				98				99								01			
	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS
Civil Service EP																												
Prime Contractor EP				4	4	4	4	6	6	6	6	6	6	6	6													
Supp. Contractor EP @ 15%				0.6	0.6	0.6	0.6	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9													

	95	96	97	98	99	Total
Prime Contractor EP MY	1	4.5	6	4.5		16.0
Supp. Contractor EP MY	0.2	0.7	0.9	0.7		2.4

1.1.1.2A ELECTRICAL POWER

0.88

FY	95				96				97				98				99								01			
	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS
Civil Service EP																												
Prime Contractor EP				2	2	2	3	3	3	3	3																	
Supp. Contractor EP @ 15%				0.3	0.3	0.3	0.5	0.5	0.5	0.5	0.5																	

	95	96	97	98	99	Total
Prime Contractor EP MY	0.5	2.5	2.25			5.3
Supp. Contractor EP MY	0.1	0.4	0.3			0.8

1.1.1.2B DATA PROCESSING

FY	95				96				97				98				99								01			
	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS
Civil Service EP																												
Prime Contractor EP							4	4	4	4	6	6	6	6	6	6	6											
Supp. Contractor EP @ 15%							0.6	0.6	0.6	0.6	0.9	0.9	0.9	0.9	0.9	0.9	0.9											

	95	96	97	98	99	Total
Prime Contractor EP MY		2	5	6	1.5	14.5
Supp. Contractor EP MY		0.3	0.8	0.9	0.2	2.2

1.1.1.3 THERMAL

FY	95				96				97				98				99								01			
	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS
Civil Service EP																												
Prime Contractor EP				2	2	2	2	3	3	3	3	3	3	3	3													
Supp. Contractor EP @ 15%				0.3	0.3	0.3	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5													

	95	96	97	98	99	Total
Prime Contractor EP MY	0.5	2.25	3	2.25		8.0
Supp. Contractor EP MY	0.1	0.3	0.5	0.3		1.2

2.1 SIMULATION & MODELING

FY	95				96				97				98				99								01			
	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS
Civil Service EP																												
Prime Contractor EP				4	4	4	4	3	3	3	3	2	2	2	2	1	1	1	1									
Supp. Contractor EP @ 15%				0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2									

	95	96	97	98	99	Total
Prime Contractor EP MY	1	3.75	2.75	1.75	0.75	10.0
Supp. Contractor EP MY	0.2	0.6	0.4	0.3	0.1	1.5

2.2.1 LEV/MEV SERVICER TESTBED

FY	95				96				97				98				99								01				
	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	
Civil Service EP																													
Prime Contractor EP																6	7	8	9	10	10	9	8	8	7	7	6	6	
Supp. Contractor EP @ 15%																0.9	1.1	1.2	1.4	1.5	1.5	1.4	1.2	1.2	1.1	1.1	0.9	0.9	Total
Prime Contractor EP MY													1.5				8.5				8.75				6.5				25.3
Supp. Contractor EP MY													0.2				1.3				1.3				1.0				3.8

2.2.3 LEV/MEV MOCKUPS

FY	95				96				97				98				99								01				
	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	
Civil Service EP																													
Prime Contractor EP																2	2	2	2	3	3	9	4	4	5	5	6	6	
Supp. Contractor EP @ 15%																0.3	0.3	0.3	0.3	0.5	0.5	1.4	0.6	0.6	0.8	0.8	0.9	0.9	Total
Prime Contractor EP MY													0.5				2.25				5				5.5				13.3
Supp. Contractor EP MY													0.1				0.3				0.8				0.8				2.0

2.2.4 SSE LIFE TESTBED

FY	95				96				97				98				99								01				
	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	
Civil Service EP																													
Prime Contractor EP																					2	2	2	2	2	2	2	2	
Supp. Contractor EP @ 15%																					0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	Total
Prime Contractor EP MY																					2				2				4.0
Supp. Contractor EP MY																					0.3				0.3				0.6

2.3.1 OPERATIONAL ANALYSIS

FY	95				96				97				98				99								01				
	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	
Civil Service EP																													
Prime Contractor EP				1	1	1	1	2	2	2	2	1	1	1	1	0.5	0.5	0.5	0.5	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	
Supp. Contractor EP @ 15%				0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Total
Prime Contractor EP MY	0.25				1.25				1.75				0.88				0.44				0.25				0.25				5.1
Supp. Contractor EP MY	0.0				0.2				0.3				0.1				0.1				0.0				0.0				0.8

2.3.2 LOGISTICS ANALYSIS

FY	95				96				97				98				99								01				
	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	
Civil Service EP																													
Prime Contractor EP				2	2	3	3	4	4	4	4	3	3	2	2	1	1	1	0.5	0.5	0.5	0.5	0.25	0.25	0.25	0.25	0.25	0.25	
Supp. Contractor EP @ 15%				0.3	0.3	0.5	0.5	0.6	0.6	0.6	0.6	0.5	0.5	0.3	0.3	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	Total
Prime Contractor EP MY	0.5				3				3.75				2				0.75				0.38				0.25				10.6
Supp. Contractor EP MY	0.1				0.5				0.6				0.3				0.1				0.1				0.0				1.6

2.3.3/2.3.4 AUTOMATION/ROBOTICS - TELEROBOTICS

FY	95				96				97				98				99								01			
	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS
Civil Service EP																												
Prime Contractor EP				3	3	3	3	2	2	2	2	1	1	1	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	
Supp. Contractor EP @ 15%				0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	

	95	96	97	98	99		01	Total
Prime Contractor EP MY	0.75	2.75	1.75	0.88	0.5	0.5	0.38	7.5
Supp. Contractor EP MY	0.1	0.4	0.3	0.1	0.1	0.1	0.1	1.1

2.3.5 HUMAN FACTORS

FY	95				96				97				98				99								01			
	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS
Civil Service EP																												
Prime Contractor EP													1.0	1.0	1.0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	
Supp. Contractor EP @ 15%													0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	

	95	96	97	98	99		01	Total
Prime Contractor EP MY				0.9	0.5	0.4	0.2	1.9
Supp. Contractor EP MY				0.1	0.1	0.1	0.0	0.3

2.3.6 SRM&QA

FY	95				96				97				98				99				98				99			
	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS
Civil Service EP																												
Prime Contractor EP													4	4	4	3	3	3	2	2	2	2	1	1	1	1	1	1
Supp. Contractor EP @ 15%													0.6	0.6	0.6	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2

	95	96	97	98	99	98	99
Prime Contractor EP MY				3.75	2.5	1.5	1
Supp. Contractor EP MY				0.6	0.4	0.2	0.2

3.0 PROGRAM MANAGEMENT

FY	95				96				97				98				99								01			
	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS
Civil Service EP				4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Prime Contractor EP @ 5%				0.9	0.9	1.0	1.2	1.4	1.4	1.4	1.5	1.1	1.4	1.3	1.3	1.0	1.1	0.8	0.8	0.8	0.9	1.2	0.8	0.8	0.8	0.8	0.8	0.8
Supp. Contractor EP @ 15%				0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6

	95	96	97	98	99		01	Total
Civil Service EP MY	1	4	4	4	4	4	4	25.0
Prime Contractor MY	0.2	1.1	1.3	1.2	0.9	0.9	0.8	6.5
Supp. Contractor EP MY	0.2	0.6	0.6	0.6	0.6	0.6	0.6	3.8

4.0 PROCUREMENT

FY	94				95				96				97				98				99							
	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ	JAS
Civil Service EP				5	5	5	5																					
Prime Contractor EP																												
Supp. Contractor EP @ 15%				0.8	0.8	0.8	0.8																					

	94	95	Total
Civil Service EP MY	1.3	3.8	5.0
Supp. Contractor EP MY	0.2	0.6	0.8

FY	94	95	96	97	98	99		01	
Civil Service EP MY	1.3	4.8	4.0	4.0	4.0	4.0	4.0	4.0	30.0
Prime Contractor EP MY		4.7	23.1	27.6	28.1	18.6	19.7	16.9	136.6
Supp. Contractor EP MY	0.2	1.6	3.9	4.5	4.3	3.3	3.4	3.0	24.2
TOTAL	1.4	11.1	31.0	36.1	34.5	25.8	27.1	23.9	190.8

Appendix O

Description of Future Analysis Work to Derive Launch and Landing Requirements

Appendix O

Description of Future Analysis
Work to Derive Launch and Landing Requirements

Another advanced development planning activity was the development of launch and landing requirements. The requirements were generated by reviewing the study and analysis work performed over the last year (both in support of the PSS office and NASA-KSC) and identifying those items which would become requirements for a lunar/Mars mission. The requirements were to be broad system requirements (Level II). This appendix is a description of the studies and analyses that will be required to derive adequate requirements for lunar surface launch and landing operations. Each page describes the launch and landing advanced development requirement, its rationale, a description of the task associated with the development requirements (future work), and the risks associated with not pursuing the future work.

General Requirement for LEV

REQUIREMENT:

Provide the capability to protect, maintain, and service the LEV and LEV surface support equipment while on the lunar surface.

RATIONALE:

The LEV, as described in the LTFOS Final Report, April 1990, will be designed to be self sufficient for manned lunar missions with lunar surface stays lasting up to 30 days. However, for longer manned missions the LEV will require thermal protection from solar radiation; protection from micrometeoroids; data management and Communication capability; and cryogenic propellant (fuel/oxidizer) management to conserve LH2 and LOX.

FUTURE WORK:

Conceptual LEV designs must be continually reviewed and surface support requirements assessed against capabilities of L&L surface support equipment as described in the PSS Element Data Base (1/12/90).

RISKS:

Risk not identifying major design drivers and missing opportunities to plan and execute advanced development programs in a timely manner.

Engine Blast Ejecta Protection

REQUIREMENT:

Protect surface equipment and habitat areas to prevent damage from ejecta resulting from LEV/MEV engine blast effects during launch and landing operations

RATIONALE:

Initial studies documented in LTFOS Final Report, May 1991, indicate that small ejecta particles can cause glass and aluminium pitting.

Surface equipment and habitats will require protection in the form of berms, protective covers, and/or paved pad surfaces.

In addition, experiments, conducted in the 1960's and 1970's indicate that jet exhaust will cause surface soil erosion and crater formation on unprepared simulated lunar surfaces.

FUTURE WORK:

Additional studies are required to determine the most cost effective method of providing protection and/or preventing ejecta formation.

RISKS:

Failure to fully understand the engine blast ejecta will require over design of protective systems

Thermal/Micrometeoroid Protection

REQUIREMENT:

Provide thermal and micrometeoroid protection for the LEV while on the lunar surface.

RATIONALE:

The LEV will require thermal protection from solar radiation, and reflected radiant heating to minimize propellant boil-off, and protect sensitive avionic equipment.

The LEV will also require protection from micrometeoroids.

FUTURE WORK:

Additional studies are required to determine the exact nature of the lunar thermal and micrometeoroid environment and the most cost effective method of providing LEV protection.

RISKS:

Failure to fully understand the thermal and micrometeoroid problem and protection methods may lead to over/under design of the LEV and/or surface protective systems.

Cryogenic Propellant Management

REQUIREMENT:

Provide a cryogenic propellant (fuel/oxidizer) management system for the LEV while on the lunar surface to conserve LH2 and LOX.

RATIONALE:

The LEV, as described in the LTFOS Final Report, April 1990, will be designed to be self sufficient for manned lunar missions with lunar surface stays lasting up to 30 days. However, for longer manned missions the LEV will require surface support equipment in the form of a cryogenic propellant (fuel/oxidizer) management system to conserve LH2 and LOX.

FUTURE WORK:

Conceptual LEV designs must be continually reviewed and surface support requirements assessed to determine the most effective propellant management scheme (e.g., reliquefaction or refrigeration).

Keep abreast of ISRU developments for requirements commonality.

RISKS:

Risk not identifying major design drivers and missing opportunities to plan and execute advanced development programs in a timely manner.

Thermal Control

REQUIREMENT:

Provide a thermal control system for the LEV and LEV Servicer while on the lunar surface to provide cooling for internal equipment.

RATIONALE:

The LEV, as described in the LTFOS Final Report, April 1990, will be designed to be self sufficient for manned lunar missions with lunar surface stays lasting up to 30 days. However, for longer manned missions the LEV will require surface support equipment to provide thermal control and dissipate waste heat from internal equipment.

FUTURE WORK:

Conceptual LEV designs must be continually reviewed and surface support requirements assessed against capabilities of L&L surface support equipment baselined in the PSS Element Data Base (1/12/90).

RISKS:

Risk not identifying major design drivers and missing opportunities to plan and execute advanced development programs in a timely manner.

Data Management & Communications

REQUIREMENT:

Provide a data management and communications system for the control, monitoring and testing of the LEV and the LEV Servicer systems on the lunar surface.

RATIONALE:

For manned missions greater than 30 days the LEV will require surface support equipment to provide an automated control capability for the remote monitoring and testing of the LEV on the lunar surface.

The LEV servicer will also require local, remote, automated and manual monitoring and control.

FUTURE WORK:

Conceptual LEV designs must be continually reviewed and surface support requirements assessed against capabilities of L&L surface support equipment baselined in the PSS Element Data Base (1/12/90).

RISKS:

Risk not identifying major design drivers and missing opportunities to plan and execute advanced development programs in a timely manner.

Electrical Power

REQUIREMENT:

Provide an external electrical power source to permit the remote monitoring and testing of the LEV on the lunar surface.

RATIONALE:

For manned missions greater than 30 days the LEV will require surface support equipment to provide electrical power for automated control, remote monitoring and testing of the LEV on the lunar surface.

FUTURE WORK:

Conceptual LEV designs must be continually reviewed and surface support requirements assessed against capabilities of L&L surface support equipment baselined in the PSS Element Data Base (1/12/90).

RISKS:

Risk not identifying major design drivers and missing opportunities to plan and execute advanced development programs in a timely manner.

Navigation Aids

REQUIREMENT:

Provide electronic and/or visual navigation aids on the lunar surface to facilitate LEV landing operations.

RATIONALE:

For unmanned and manned missions navigational aids will be required to support automated or manual LEV flight control during descent.

FUTURE WORK:

Conceptual LEV designs must be continually reviewed and surface support requirements assessed against capabilities of L&L surface support equipment baselined in the PSS Element Data Base (1/12/90).

RISKS:

Risk not identifying major design drivers and missing opportunities to plan and execute advanced development programs in a timely manner.

Access Equipment

REQUIREMENT:

Provide the capability to access all quadrants, levels and components of the LEV and LEV surface support equipment on the lunar surface.

RATIONALE:

For long duration manned missions, surface support access equipment will be required to facilitate LEV and LEV Servicer inspection and/or maintenance.

FUTURE WORK:

Conceptual LEV designs must be continually reviewed and surface support requirements assessed against capabilities of L&L surface support equipment baselined in the PSS Element Data Base (1/12/90).

Assess other areas for common access requirements.

RISKS:

Risk not identifying major design drivers and missing opportunities to plan and execute advanced development programs in a timely manner.

Auxiliary Lighting Equipment

REQUIREMENT:

Provide the capability for auxiliary lighting to illuminate all quadrants and levels of the LEV on the lunar surface.

RATIONALE:

For long duration manned missions surface support portable lighting equipment will be required to facilitate LEV and LEV Servicer inspection and/or maintenance.

FUTURE WORK:

Conceptual LEV designs must be continually reviewed and surface support requirements assessed against capabilities of L&L surface support equipment baselined in the PSS Element Data Base (1/12/90).

Review requirements of other PSS areas (i.e., construction, ISRU, etc.) for common access requirements.

RISKS:

Risk reduced capability for performing LEV operations on the lunar surface.

Waste Management Service System

REQUIREMENT:

Provide a waste management servicing system to service the LEV waste management system on the lunar surface.

RATIONALE:

The LEV, as described in the LTFOS Final Report, April 1990, will be designed for use as a habitat for periods of up to 48 hours, and will require a waste management system. This system will require servicing on the lunar surface.

FUTURE WORK:

Conceptual LEV designs must be continually reviewed and surface support requirements assessed against capabilities of L&L surface support equipment baselined in the PSS Element Data Base (1/12/90).

Habitat designs must be reviewed for compatibility/commonality of servicing equipment for the LEV.

RISKS:

Risk not identifying major design drivers and missing opportunities to plan and execute advanced development programs in a timely manner.

Fuel Cell Service System

REQUIREMENT:

Provide a fuel cell servicing system to service the LEV fuel cell power system on the lunar surface.

RATIONALE:

The LEV, as described in the LTFOS Final Report, April 1990, uses fuel cells for electrical power generation. A fuel cell servicing system will be required to remove water produced by the fuel cells.

FUTURE WORK:

Conceptual LEV designs must be continually reviewed and surface support requirements assessed against capabilities of L&L surface support equipment baselined in the PSS Element Data Base (1/12/90).

Review requirements of other PSS areas that may require fuel cells (i.e., construction, ISRU, etc.) for commonality of requirements.

RISKS:

Non availability of a servicer may impair LEV power generation.

Command and Control System

REQUIREMENT:

Provide a command and control system in the habitable volume for the remote power up, control, monitoring and testing of the LEV and surface support equipment on the lunar surface.

RATIONALE:

For manned missions greater than 30 days will require an automated control capability to conduct function tests, determine the status of all systems, and monitor system trends for the remote monitoring and testing of the LEV and its surface support equipment.

FUTURE WORK:

Conceptual LEV designs must be continually reviewed and surface support requirements assessed against capabilities of L&L surface support equipment baselined in the PSS Element Data Base (1/12/90).

Review requirements of other PSS areas (i.e., construction, ISRU, etc.) for commonality of requirements.

RISKS:

Non availability of capability will require this function to performed from Earth and may result in delayed detection of LEV anomalies/failure, with possible lunar aborts/delays.

Command and Control Telemetry Link

REQUIREMENT:

Provide a command and control telemetry link to/from earth for the remote power up, control, monitoring and testing of the LEV and LEV surface support equipment on the lunar surface.

RATIONALE:

To reduce the work load of the lunar crew during manned missions a command and control telemetry link to/from earth will be required to conduct function tests, determine the status of all systems, and monitor system trends for the remote monitoring and testing of the LEV and its surface support equipment.

FUTURE WORK:

Conceptual LEV designs must be continually reviewed and surface support requirements assessed against capabilities of L&L surface support equipment baselined in the PSS Element Data Base (1/12/90).

Review requirements of other PSS areas (i.e., construction, ISRU, etc.) for commonality of requirements.

RISKS:

Non availability of a data link will increase lunar crew workload and may result in delayed detection of LEV anomalies/failure, with possible lunar aborts/delays.

Lunar LOX Fueling Pallet

REQUIREMENT:

Provide a Lunar LOX Fueling Pallet for the transfer of lunar LOX from the ISRU area to the LEV.

RATIONALE:

Reference Approach 5a calls for the delivery of lunar LOX production equipment in 2012. Once this capability is available a means to transport the LOX from the production/storage facility to the LEV is required.

FUTURE WORK:

Trade studies are required to determine the most cost effective method of transferring lunar LOX from one point to another (e.g., tankers, surface piping, subsurface piping, portable tanks, etc.)

Review requirements of other PSS areas that use oxygen (e.g., habitat. pressurized rover, etc.) for commonality of requirements.

RISKS:

Risk not identifying major design drivers and missing opportunities to plan and execute advanced development programs in a timely manner.

ECLSS Service System

REQUIREMENT:

Provide the capability to test and service the ECLSS Systems of the LEV, pressurized rover and habitat modules. This includes the requirement to transport consumables, operating fluids and by-products.

RATIONALE:

The ECLSS Systems of the LEV, pressurized rover and habitat modules will require periodic maintenance in the form of servicing, deservicing, testing and filtering of various fluids used in these systems.

FUTURE WORK:

Conceptual LEV designs must be continually reviewed and surface support requirements assessed against capabilities of L&L surface support equipment baselined in the PSS Element Data Base (1/12/90).

Review requirements of other PSS areas (e.g., habitat. pressurized rover, etc.) for commonality of requirements.

RISKS:

Risk not identifying major design drivers and missing opportunities to plan and execute advanced development programs in a timely manner.

Appendix P

Comparison of the MASE Architectures with the PSS Implementation Strategies for

- Exploration Emphasis
- Expanding Human Presence
- Evolution Emphasis (Modified or Research Emphasis)

Appendix P

Comparison of the MASE Architectures with the PSS Implementation Strategies for

- Exploration Emphasis
- Expanding Human Presence
- Evolution Emphasis (Modified or Research Emphasis)

This appendix provides a comparison of the characteristics of the MASE architectures with the implementation strategies of the Planetary Surface Systems Office.

Exploration Emphasis Architecture Comparison

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	MASE PLANETARY SURFACE CHARACTERIZATION LUNAR PHASE	PSS STRATEGIES
HUMAN SYSTEMS HABITATS	LANDER ONLY	ACRV → EXPENDABLE CREW CAB → REUSABLE CREW CAB → OUTPOST VIA CABS → ISRU HABITAT
ISRU	DEMO ONLY	SAMPLES DEMOS, EXPERIMENTS → PILOT PLANTS BUILDING MTR'LS LLOX → PRODUCTION PLANTS BUILDING MAT'LS LLOX OUTPOST SUPPLY
SURFACE VEHICLES	LOCAL	UNPRESSURIZED ROVER WITH TELEROBOTIC ABILITY → CONSTRUCTION MACHINERY MINING MACHINERY PRESSURIZED ROVER

Exploration Emphasis Architecture Comparison

Page 2 of 2

	MASE PLANETARY SURFACE CHARACTERIZATION LUNAR PHASE	PSS STRATEGIES
SUPPORT & UTILITIES		
POWER	POWER BEAMING	BEAMED (PVA/RFC BACKUP) → BEAMED ? NUCLEAR ?
COMM	ASSUMED LANDER	LANDER, ROVER TO EARTH (DIRECT or RELAY) → LOCAL COMM SYSTEM
LAUNCH & LANDING	MINIMAL	NO SERVICE → MONITORING → REFUEL → MAINTENANCE & SERVICE LAUNCH & LANDING CONTROL
OPERATIONS & LOGISTICS		
OPERATIONS	CONTINUAL CONTROL	EARTH BASED PLANNING DETAILED SCRIPTING → EARTH BASED OBJECTIVES OUTPOST PLANNING & SCHEDULING
LOGISTICS	ASSUMED EARTH DEPENDENT	EARTH DEPENDENT → REDUCED EARTH DEPENDENT → SELF SUFFICIENCY

Expanding Human Presence Architecture Comparison

Page 1 of 2

	MASE PLANETARY SURFACE CHARACTERIZATION LUNAR PHASE	PSS STRATEGIES
HUMAN SYSTEMS HABITATS	INITIALLY AN EMPLACED MODULE, LATER MODULE CONSTRUCTED FROM LOCAL RESOURCES	INITIAL MODULE ↓ MULTI-MODULE OUTPOST → ISRU DERIVED HAB & FAC DEMO → ISRU DERIVED OUTPOST
ISRU	LIFE SUPPORT MAKEUP, PROPELLENTS, AND FABRICATION/ MANUFACTURING	EXPERIMENTS - VOLATILE RECOVERY -REGOLITH PROCESSING - REGOLITH MANIPULATION - SIICATE, GLASS, AND METAL RECOVERY → DEMONSTRATIONS - PRESS STRUCTURES - CONSTRUCTION MAT'LS - PROPELLENT RECOVERY - CERTIFY OUTPOST EXPANSION VIA ISRU → PRODUCTION - PROPELLENT - STRUCTURAL MAT'LS - LIFE SUPPORT GASES - OTHER PRODUCTS
SURFACE VEHICLES	LOCAL EVOLVING TO GOBAL	TELEROBOTIC ROVERS → SMALL SCALE MINING, CONSTRUCTION, AND PERSONNEL TRANSPORTATION → ENHANCED MINING, CONSTRUCTION, AND LONG-RANGE PERSONNEL TRANSPORTATION

Expanding Human Presence Architecture Comparison

	MASE PLANETARY SURFACE CHARACTERIZATION LUNAR PHASE	PSS STRATEGIES
SUPPORT & UTILITIES		
POWER	NUCLEAR	PVA/RFC → NUCLEAR - SP-100 - PVA/RFC BACKUP → SELF SUFFICIENT POWER - SOLAR, NUCLEAR, OTHER
COMM		DIRECT EARTH LINK AND LOCAL COMM SYSTEM
LAUNCH & LANDING	HEALTH CONDITIONING EVOLVING TO VEHICLE PROCESSING	NO SERVICES → L&L PADS; NAVIGATIONAL SUPPORT → MONITORING & CONDITIONING; MAINTENANCE; REFUELING
OPERATIONS & LOGISTICS		
OPERATIONS	MODERATE INTERVENTION EVOLVING TO MINIMAL	EARTH BASED PLANNING DETAILED SCRIPTING → EARTH BASED OBJECTIVES DEFINITION; OUTPOST PLANNING AND SCHEDULING
LOGISTICS	ASSUMED EARTH DEPENDENT	EARTH DEPENDENT → SELF SUFFICIENCY

Modified Reference Architecture (Research Emphasis) Comparison

Page 1 of 2

		MASE PLANETARY SURFACE CHARACTERIZATION LUNAR PHASE	PSS STRATEGIES
HUMAN SYSTEMS	HABITATS	LANDER AND EMPLACED MODULE	SSF MODULE → HAB & LAB MODULES → PREFAB CONSTRUCTIBLE SSF LIFE SUPPORT $\xrightarrow{\text{TECHNOLOGY DEVELOPMENT}}$
ISRU		NONE	SAMPLES DEMOS, EXPERIMENTS → SMALL PLANTS ASCENT LLOX VOLATILES BY PRODUCTS → PRODUCTION PLANTS LLOX VOLATILES BY PRODUCTS
SURFACE VEHICLES		LOCAL EVOLVING TO REGIONAL	UNPRESSURIZED /TELEROBOTIC ROVER → MINING PRESSURIZED SURFACE TRANSPORT CONSTRUCTION LIFTING/EMPLACEMENT REGOLITH MOVEMENT/EXCAVATION

Modified Reference Architecture (Research Emphasis) Comparison

Page 2 of 2

		MASE PLANETARY SURFACE CHARACTERIZATION LUNAR PHASE	PSS STRATEGIES
SUPPORT & UTILITIES			
	POWER	PVA/RFC OR NUCLEAR	DEPLOYABLE NUCLEAR MODULE (PVA/RFC B/U) → CONSTRUCTED NUCLEAR PLANT
	COMM	ASSUMED LANDER OR LOCAL COMM SYSTEM	LOCAL COMM SYSTEM → OUTPOST PROVIDES UTILITIES FOR USERS
LAUNCH & LANDING		HEALTH CONDITIONING	MONITORING & CONDITIONING NO SERVICE → LAUNCH & LANDING CONTROL → ASCENT REFUEL → LANDER LLOX PAD AREAS
OPERATIONS & LOGISTICS			
	OPERATIONS	CONTINUAL CONTROL	EARTH BASED PLANNING DETAILED SCRIPTING → EARTH BASED OBJECTIVES OUTPOST PLANNING & SCHEDULING
	LOGISTICS	ASSUMED EARTH DEPENDENT	EARTH DEPENDENT → REDUCED EARTH DEPENDENCY → SELF SUFFICIENCY