ADVANCED CIVIL
SPACE SYSTEMS

Piloted Rover Technology
Study Task 9.1 Closing Report
NASA Contract NAS8-37857

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D615-10014

ABSTRACT

This is the May 25, 1990 summary report for Space Transfer Concepts and Analyses (STCA) Study, NASA Contract NAS8-37857, Special study Task 9.1, Piloted Rovers Technology Study. This study examined piloted rover concepts, mission scenarios, and the requirements necessary for completion of these missions resulting in the establishment of a Lunar base. These tasks were intended to lead to a logical conclusion concerning which piloted rovers technologies are needed to accomplish the various missions, along with a recommended schedule for the development of these technologies.

KEY WORDS

Piloted Rover
Lunar Roving Vehicle
Lunar Base
Straddler
LEVPU

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1.0 INTRODUCTION AND BACKGROUND

At the request of NASA Code R, Task 9.1 was closed in order to apply the remaining funds to a study specifically addressing the state of the art of Piloted, Unique, Lunar Vehicle subsystems and subsystem components. This document presents a summary of the activity from the inception of the study on December 15, 1989, through April 1990.

The Piloted Rovers Study was composed of eight tasks, as shown on Figure 1-1, Program Master Flow. Work was performed on six of these tasks, as indicated by the cross hatching of those bars impacted. A brief summary of the activities is given below. The charts presenting the results are given in Sections 3.0 to 8.0.

<u>State of the Art Survey:</u>
Library files were screened to locate documents pertaining to the Lunar Roving Vehicle (LRV) produced by Boeing under Contract NAS8-25145 to Marshall Space Flight Center. NASA files were also screened to obtain information documenting the performance of the LRV during Apollo Missions 15, 16 and 17. Copies of the pertinent documents were requested in order to identify performance areas where improvements would be required. The results of these efforts were documented in viewgraphs and presented in reviews at the Johnson Space Center on February 8 & 9 , 1990, at Marshall Space Flight Center on March 30, 1990, and at NASA Code R Headquarters in Washington D.C. on April 11, 1990.

<u>Mission Model:</u>
At the suggestions of JPL and JSC, the NASA 90-day study report was obtained and examined closely to assess its usefulness as a baseline mission model for the Piloted Vehicles Study. The decision was made to use the 90-day study as a framework from which to define the detailed rover mission requirements. It was determined that there were basically three vehicles, as follows:

1. A Light Utility Vehicle to perform in a dual mode, remotely controlled from Earth at the outset, and later on, under local control during the manned missions.
2. A Large Hauler (pressurized or unpressurized) to move larger loads and with the ability to traverse further from the Lunar Lander Site.
3. A Special Purpose Vehicle to serve as a Crane or Unloader.

The 90-day Study Report first five missions were expanded upon to define the vehicle tasks in greater detail. The results were presented to JPL and JSC personnel in a joint presentation in Houston on Feb. 8, 1990 and in the midterm report in Huntsville on March 30.1990.

Performance Operations:

Vehicle requirements were defined for Lunar Missions 0 through 4 of the 90-day study. These were considered to be baseline values to be used only to establish the vehicle set of requirements. This was assumed to be a reasonable first-cut due to the fact that the vehicles of the first five missions would be used in a dual mode (first remotely controlled and then in a manned mode). LRV experience on Apollo Missions 15, 16 and 17 was used to establish reasonable vehicle velocities and ranges, and hence, timelines to accomplish the various tasks. The conclusions at this point were quite preliminary, since detailed inquires were not completed with the current practitioners and suppliers of present day versions of the LRV subsystems and subsystem components.

Evaluation Measures:

The Evaluation Measures study effort was scheduled to begin during the final weeks of the Mission Definition, and hence was only partially completed at the time the task was reprogrammed. The early trade studies were conducted using vehicle attributes as evaluation measures with individual experience of the study team members relied upon in order to form a consensus as a measure of the ability of the various vehicle configurations to perform. The refinement of this early effort to a more rigorous set of evaluation measures was to grow out of the requirements for the vehicle performance on the early missions and an estimate of performance requirements during the subsequent operations. Characteristics being considered for evaluation measures included; weight, power requirement, drawbar pull capability, duration or range of cperation, ease of maintenance, maintenance requirements, and adaptability to the use of attachments.

Concepts Definition:

Several vehicle variations to the above configurations were examined early in the study so that mission models could be formulated. These were both the product of the Apollo mission experience as well as experience gained in various Boeing construction activities. The redirection of the contract however, precluded further concept definition and evaluation which would have led to other alternate forms or applications.

Program Master Flow

This chart presents the program schedule as was originally funded in Phase Ø1 of the Piloted Rovers Technical Needs Study.

The figures on the left show typical configurations of the major types of vehicles involved. They consist of a lifter/crane, a heavy hauler, and a light utility/astronaut support vehicle.

Piloted Rovers Technology Needs Study
Program Master Flow

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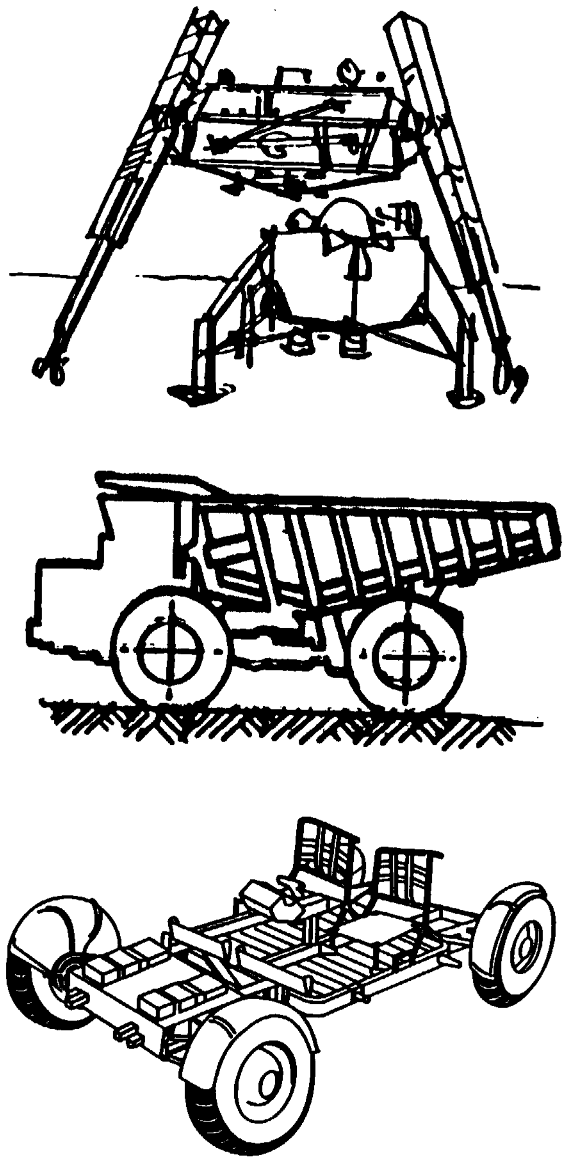
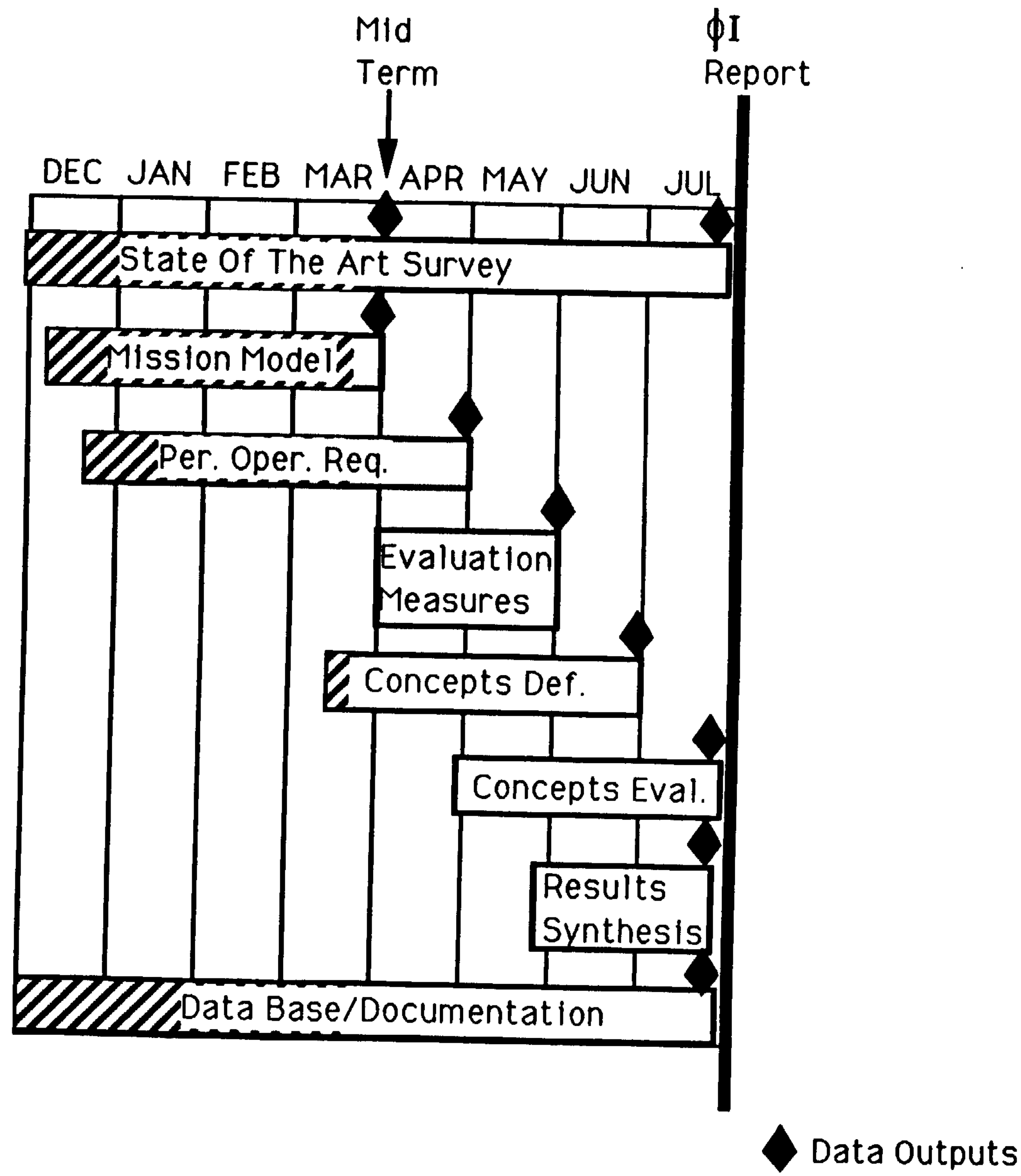
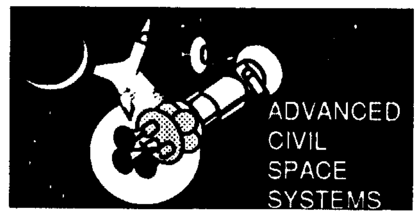




master flow-1/Task 9.1 Final Report/6-1-90/DLT

Figure 1-1

2.0 Approach Summary



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Piloted Rovers Technology Needs Study Task Logic Flow

This chart presents the interrelationship of the various tasks in performing the study.

Task Logic Flow

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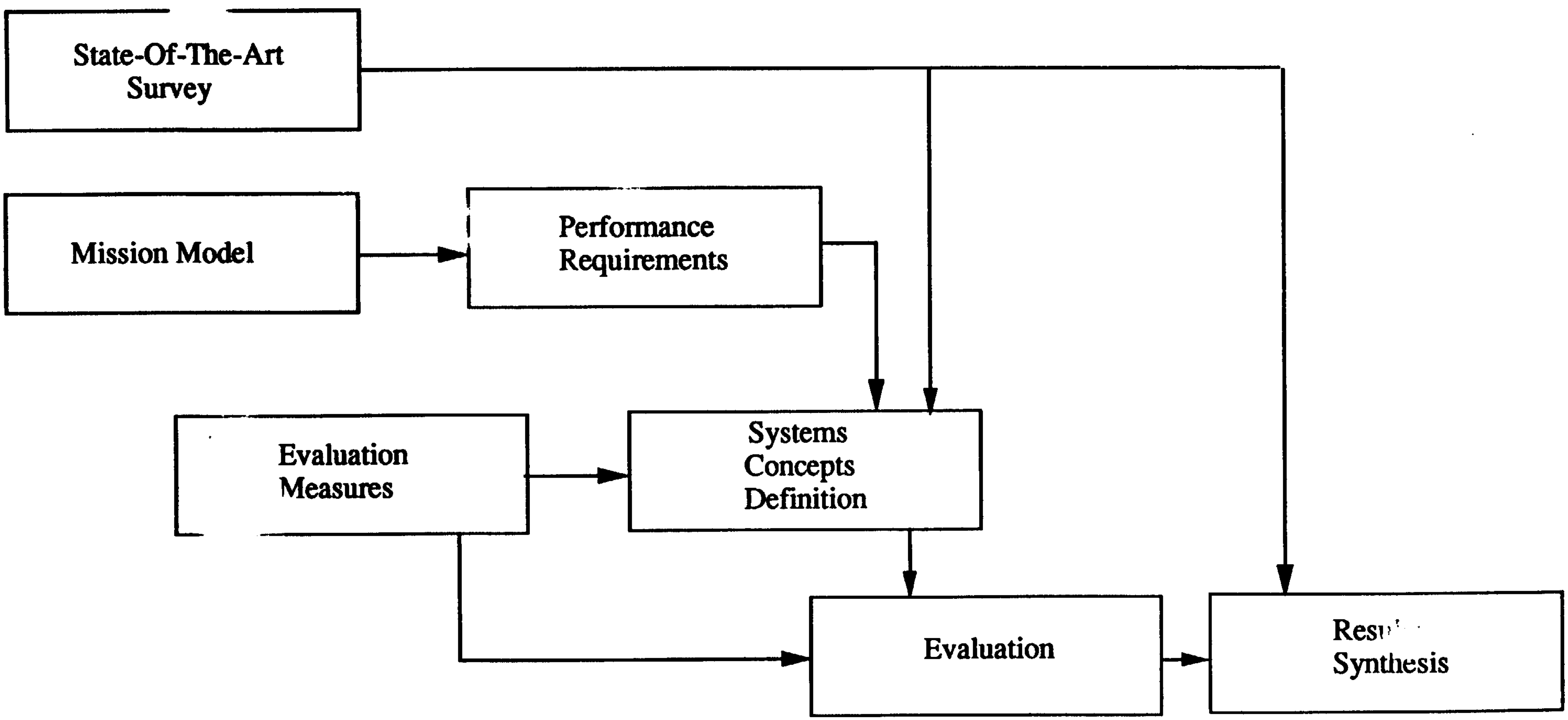

Task Logic Flow/Task 9.1 Final Report/6-4-90/DLT

re 2

Piloted Rovers Technology Needs Study Organizational Chart

This chart presents the sources of data and direction in conducting the study as well as the group of individuals within Boeing who will participate and their area of technical specialization.

Piloted Rovers Technology Needs Organization Chart

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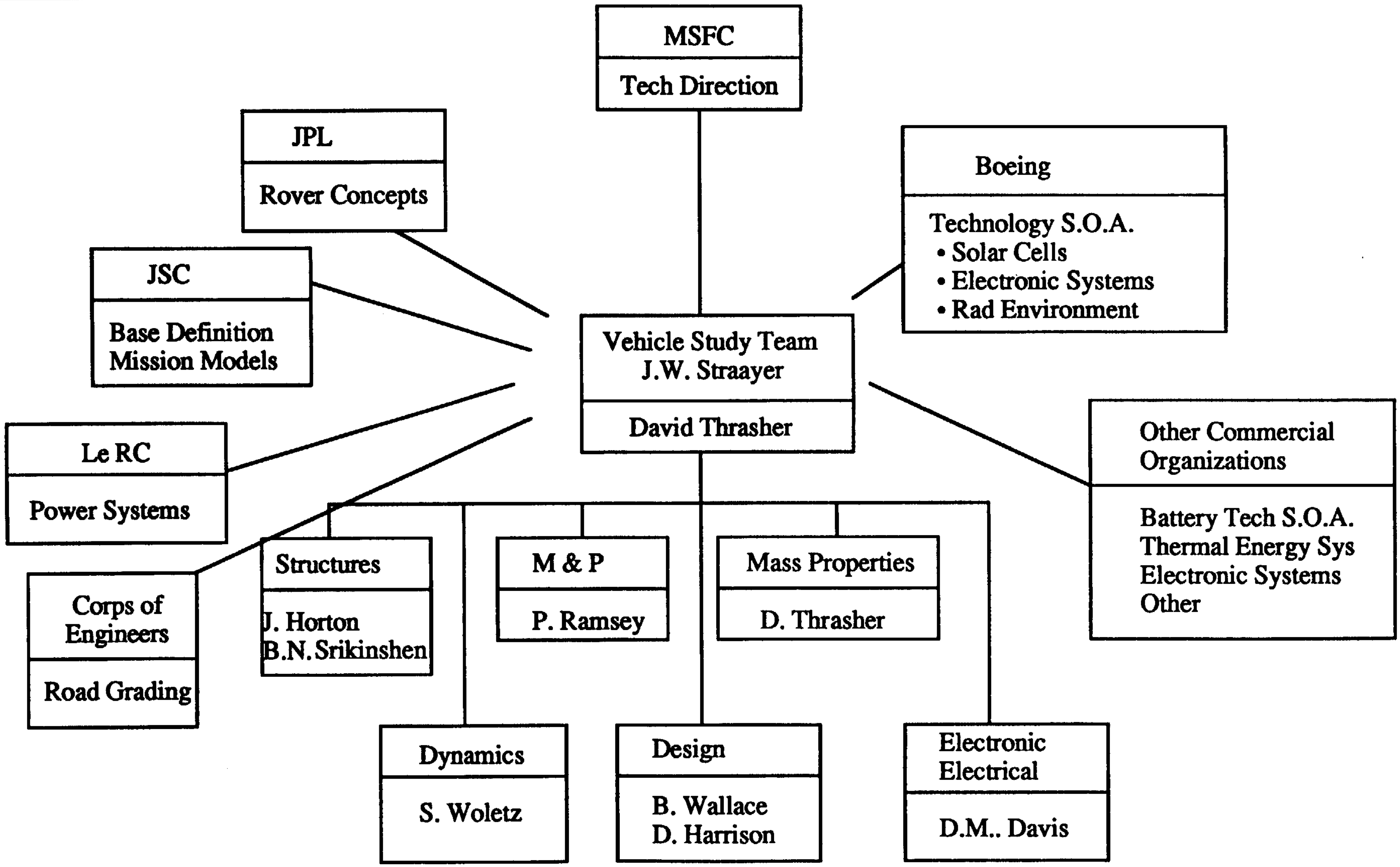

piloted rover org chart/Task 9.1 Final Report/6-4-90/DLT

Figure

Lunar Vehicle Systems

Using knowledge based on Lunar Rover design of Apollo years, areas of interest for vehicle design have been determined. This list represents systems and subsystems for design emphasis for a vehicle intended for Lunar surface operations.

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Rover Systems

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System	Subsystem
Chassis	Frame
Suspension	Arms, Springs and Seals Dampers and Seals
Steering Mechanisms (Dual Redundant)	
Traction Drive (Drive Motors & Gears)	
Wheel	Fenders and Dust Control
Drive Control	Manual Operated Steering Remote Signal Processing Common Component
Attached Mechanisms Control	Manual Controls Remote Signal Processing Common Component
Crew Station(s)	
Power	Power Storage Power Supply Thermal Control
Vehicle Navigation	
Communication	
Attached Mechanism System(s)	

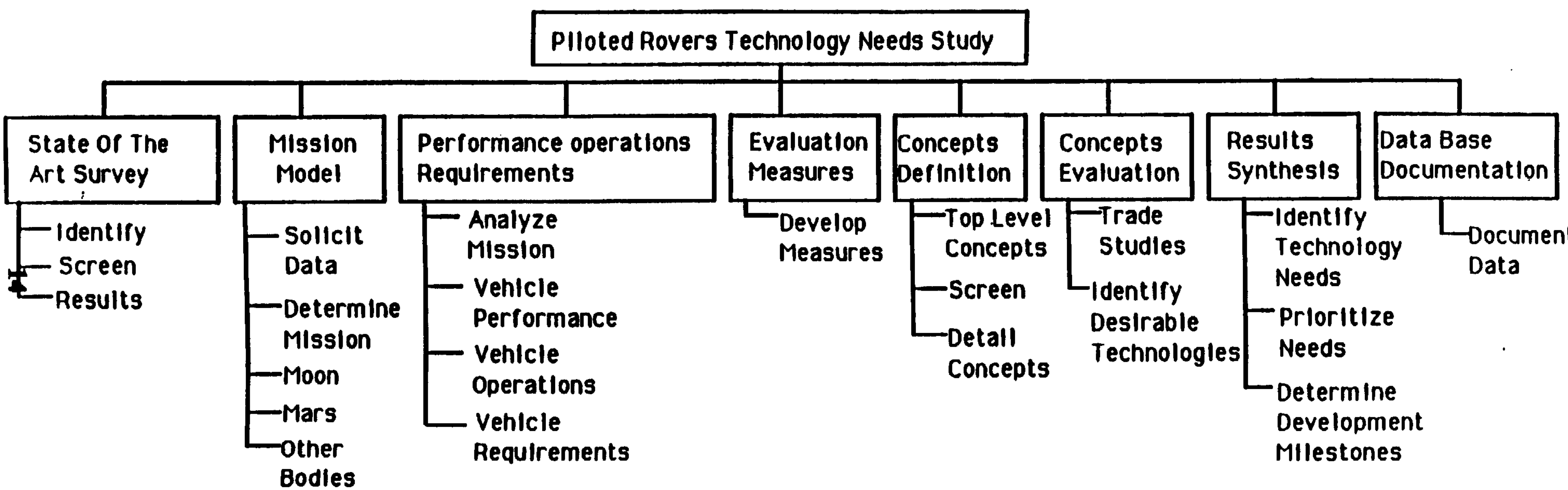
Figure 2

Piloted Rovers Technology Needs Study Work Breakdown Structure

This chart presents the Work Breakdown Structure (WBS) for the study. It also shows the elements of each task within the WBS.

This chart is intended to point out that there are indications that the Lunar/Mars Base and Rover Studies may not have defined the Rover concepts and tasks to be performed in sufficient detail to support all of the technical needs of the "Piloted Rover Technology Needs Study". Therefore, it is our intention to proceed to prepare a "Strawman" data set and transmit it to all the concerned organizations for their comments and recommendations.

Work Breakdown Structure



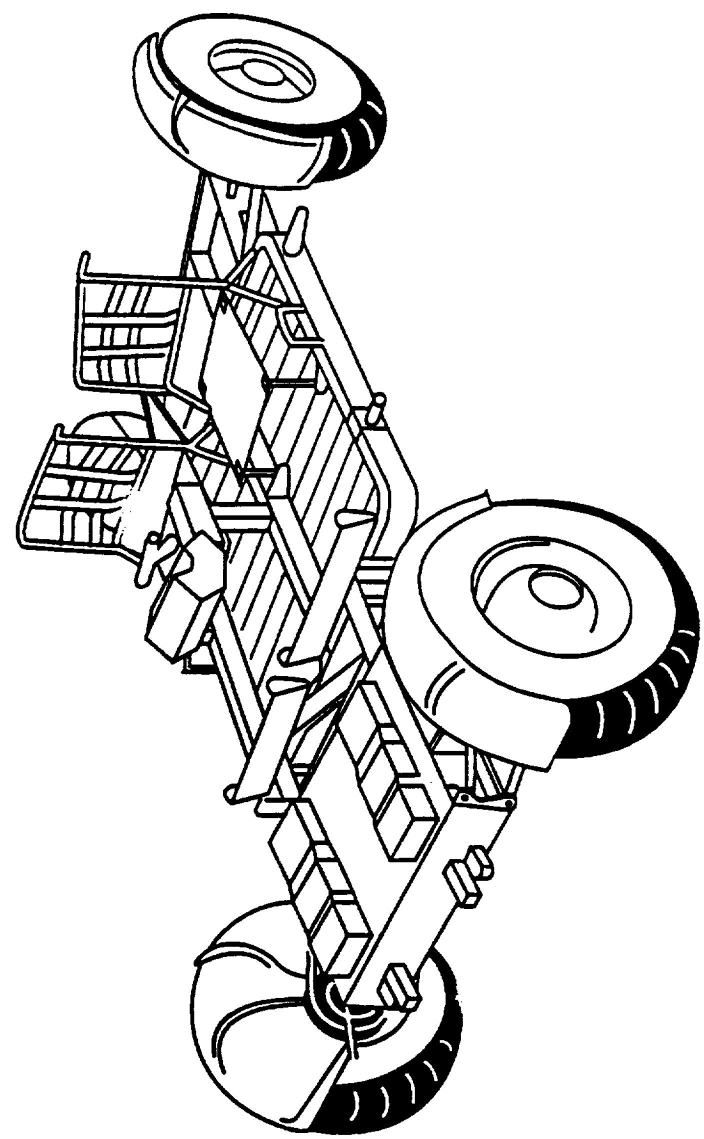
Data will be solicited from appropriate sources.
If not received within a reasonable amount of time
Boeing will develop data.

Figure 2-4

Apollo Lunar Rover

The chart below shows the Apollo Lunar Rover. This vehicle was the basis for much of the early concept and mission development.

Apollo Lunar Rover



Mission Analysis

By utilizing inputs from various sources as well as in-house data, a mission model for flights 0 to 4 has been compiled. This mission model is being used as a tool to help develop requirements which will eventually lead to vehicle conceptualization and design.

3.0 Mission Model

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Elements of Mission Definition of a Vehicle

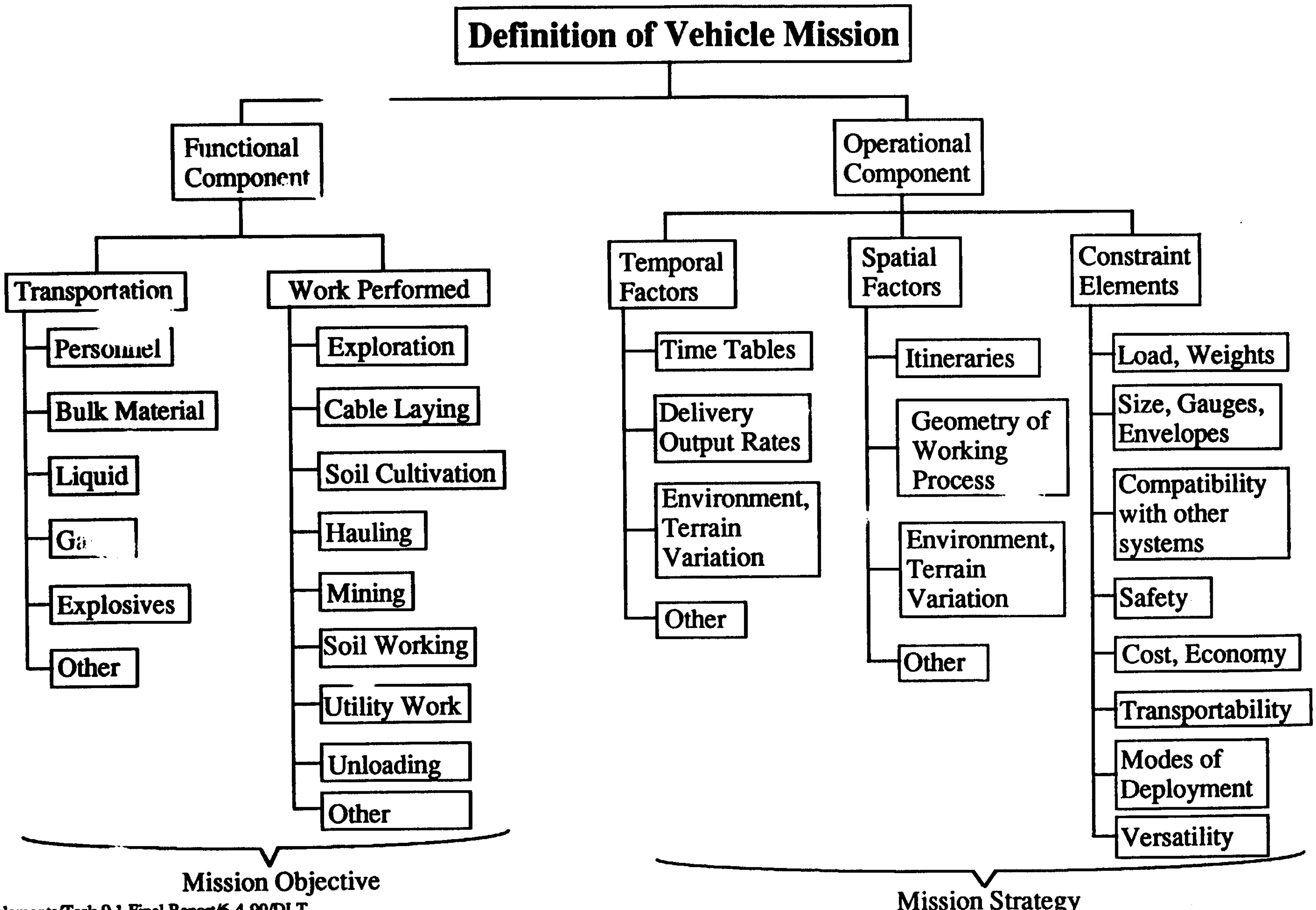
Mission definition for a vehicle is divided into two (2) categories: A vehicle functional component and an operational component.

The functional component consists of the tasks and work to be performed by the vehicle in meeting its objective.

The operational component is made up of various temporal factors (time related), those having to do with spatial factors (distance related), and the constraint factors involved in the strategies in accomplishing its objective.

Elements of Mission Definition of a Vehicle

BOEING



mission elements/Task 9.1 Final Report/6-4-90/DLT

Figure 3-1

ORIGINAL PAGE IS OF POOR QUALITY

Lunar Mission Overview

The results of the NASA 90-Day Study prepared at JSC was used as the primary source of data from which the initial mission analysis was derived.

NASA

90 Day Study

Lunar Mission Overview

Planet Surface Systems

BEAR-Borrios/WEllis/Concept D&D Rqmts/GJF-10/5/89-16

Figure 3

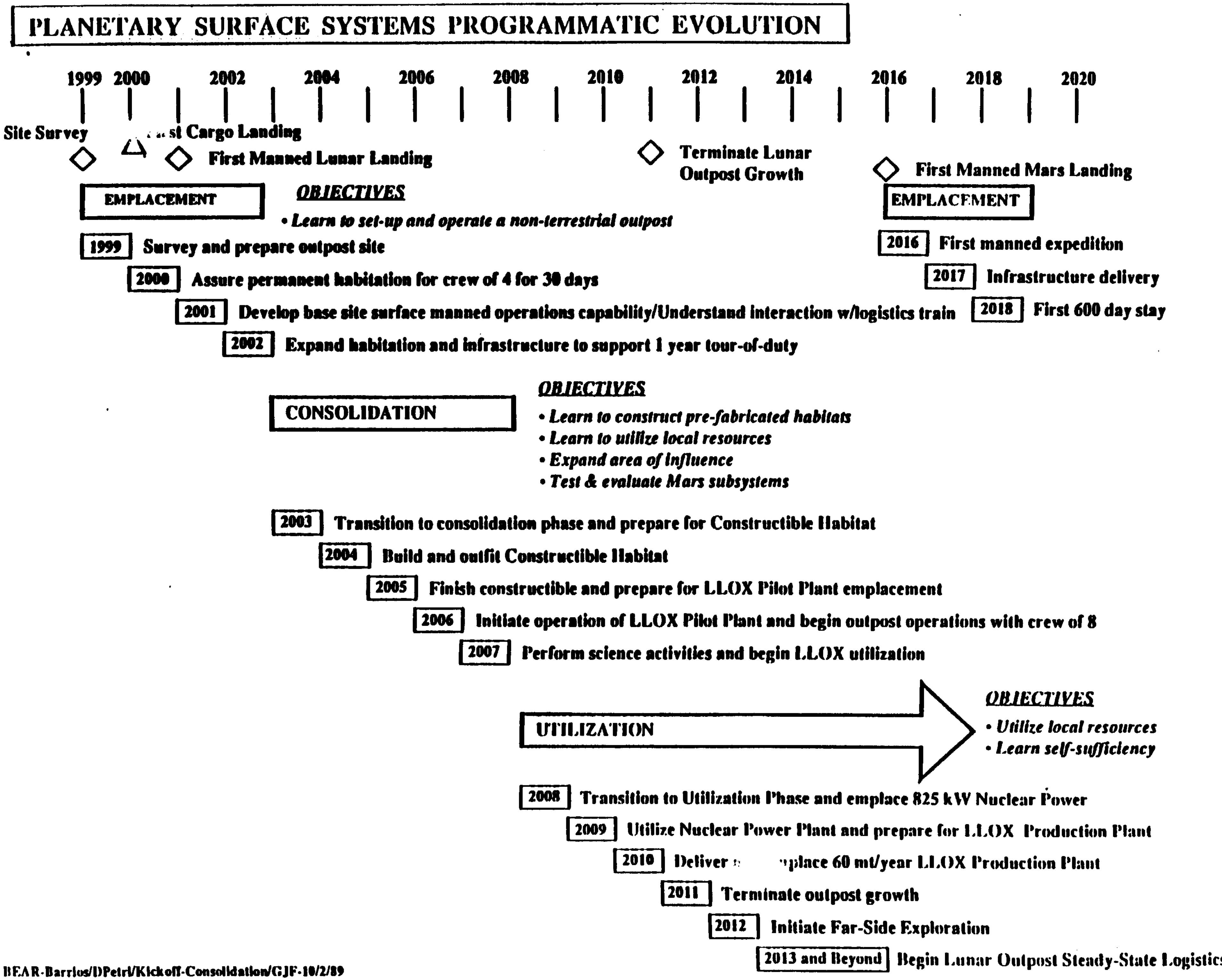
Planetary Surface Systems Programmatic Evolution

This is a chart produced by JSC during the 90 Day Study which lists all lunar flights and their associated objectives.

The evolution is divided into four (4) categories:

(1) Emplacement - Lunar
(2) Consolidation
(3) Utilization
(4) Emplacement - Mars

Of the flights defined in the 90 Day Study, our analysis included only the first five missions. This is due to the similarities between operations of the earlier and later flights.



PLANETARY SURFACE SYSTEMS PROGRAMMATIC EVOLUTION
1999 2000 2002 2004 2006 2008 2010 2012 2014 2016 2018 2020
Site Survey
st Cargo Landing
First Manned Lunar Landing
Terminate Lunar Outpost Growth
First Manned Mars Landing
EMPLACEMENT
OBJECTIVES
• Learn to set-up and operate a non-terrestrial outpost
1999 Survey and prepare outpost site
2000 Assure permanent habitation for crew of 4 for 30 days
2001 Develop base site surface manned operations capability/Understand interaction w/logistics train
2002 Expand habitation and infrastructure to support 1 year tour-of-duty
EMPLACEMENT
2016 First manned expedition
2017 Infrastructure delivery
2018 First 600 day stay
CONSOLIDATION
OBJECTIVES
• Learn to construct pre-fabricated habitats
• Learn to utilize local resources
• Expand area of influence
• Test & evaluate Mars subsystems
2003 Transition to consolidation phase and prepare for Constructible Habitat
2004 Build and outfit Constructible Habitat
2005 Finish constructible and prepare for LLOX Pilot Plant emplacement
2006 Initiate operation of LLOX Pilot Plant and begin outpost operations with crew of 8
2007 Perform science activities and begin LLOX utilization
UTILIZATION
OBJECTIVES
• Utilize local resources
• Learn self-sufficiency
2008 Transition to Utilization Phase and emplace 825 kW Nuclear Power
2009 Utilize Nuclear Power Plant and prepare for LLOX Production Plant
2010 Deliver place 60 mt/year LLOX Production Plant
2011 Terminate outpost growth
2012 Initiate Far-Side Exploration
2013 and Beyond Begin Lunar Outpost Steady-State Logistics
BEAR-Barrios/DPetri/Kickoff-Consolidation/GJF-10/2/89

Figure 3-2

Lunar Base Site Layout

Shown below is the reference architecture for the lunar base as defined in the 90 Day Study Results. The layout includes provisions for:

(1) a power site,

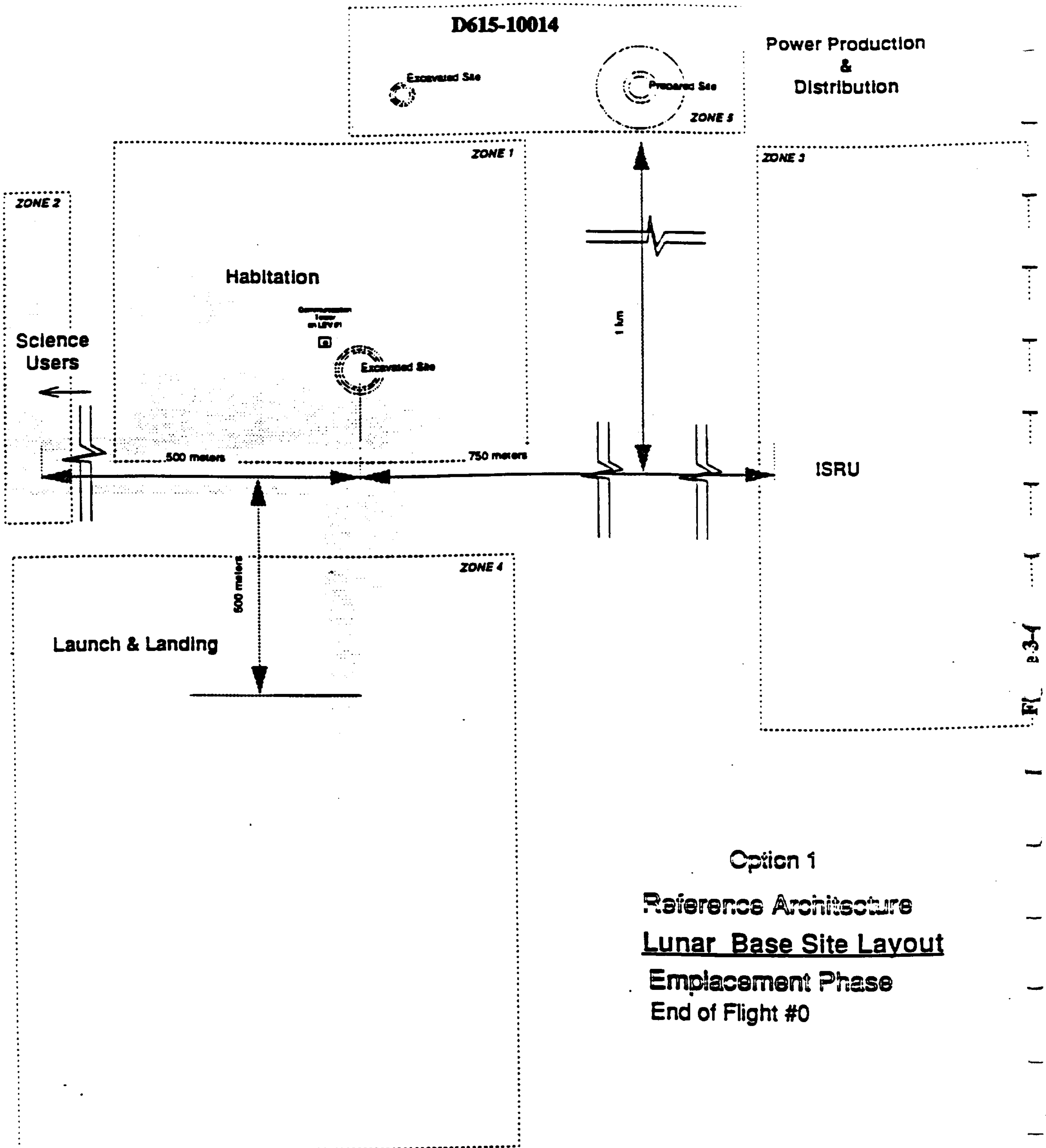
(2) Hab and Lab site,

(3) ISRU area,

(4) Science users' area,

(5) Launch and Landing area.

This layout will be used as the reference plan from which activities and operations will be analyzed.



Option 1

Reference Architecture

Lunar Base Site Layout

Emplacement Phase

End of Flight #0

NASA Lyndon B. Johnson Space Center

North

Oct 4, 1989

Planet Surface Systems

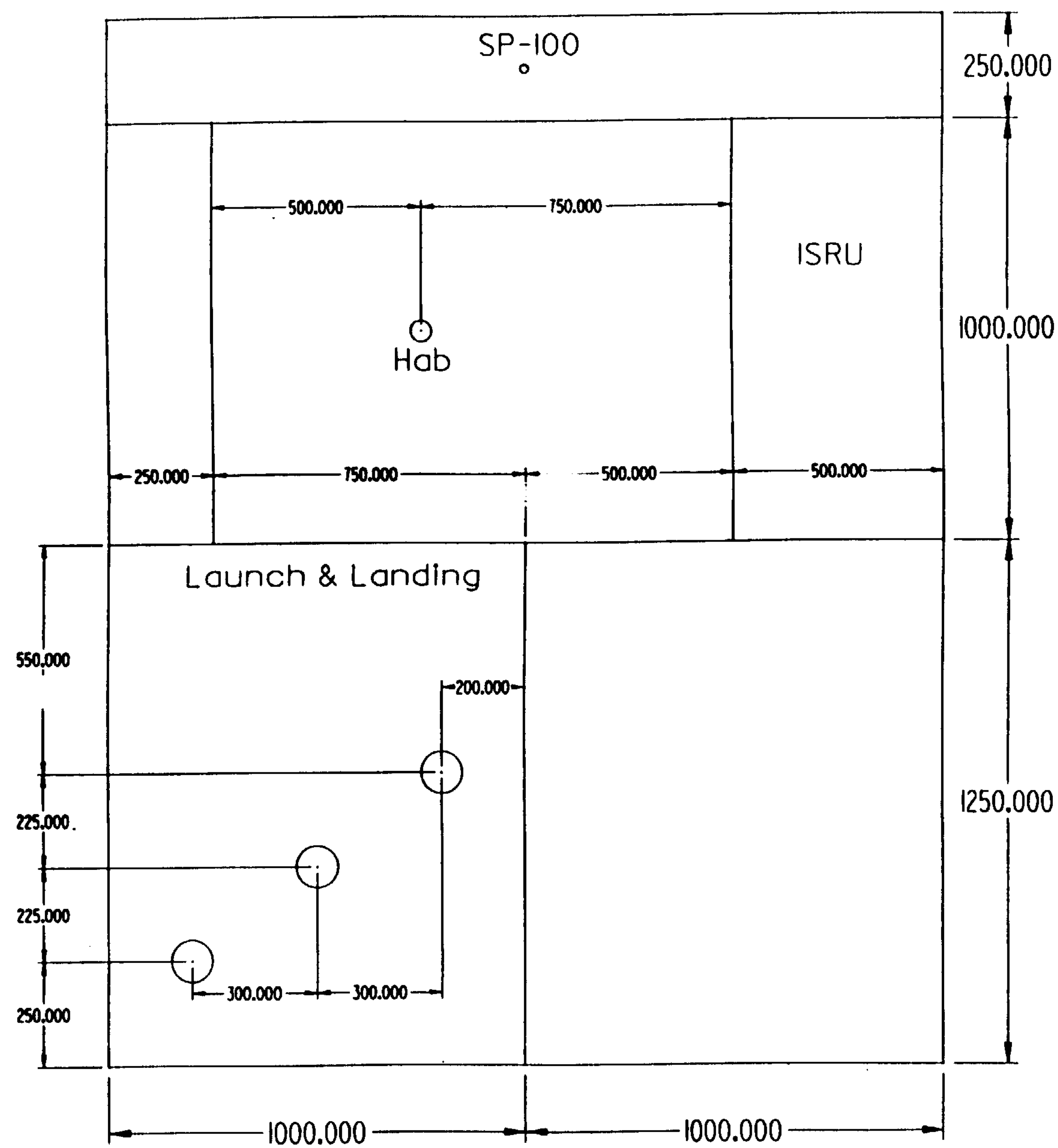
John Connolly • Larry Toups

Lunar Base Site Layout

The lunar base is a 2 X 2.5 km area. The sites will contain a Hab module, three power systems, three landing sites, a resource utilization area, and an experiment area. The layout is identical to the JSC architecture with dimensions added for detail. This layout was used in all of our missions analyses and requirements derivation.

Lunar Base Site Layout

BOEING



F---e 3-

This page from the 90 Day Study presents the first three missions to the moon, and the objectives of each. The first mission is set to launch in 1999 with a one-year gap between successive missions.

LUNAR OUTPOST – INITIAL EMPLACEMENT

2000 | 2002 | 2004 | 2006 | 2008 | 2010 | 2012 | 2014 | 2016 | 2018 | 2020

1999
▲ Flight 0

Mission Objective : Survey & verify final Outpost location.

Elements

- *LEV Payload Unloader/Attachm...*
- *Unpressurize... ...ed/Robotic Rover*
- *Navigation Aids*
- *Communication Equipment*
- *Excavation Pyrotechnics*

Mission Operations (Remote)

- *Payload Unloader deploys rover*
- *Deploy comm. system*
- *Rover verifies outpost site*
- *Rover deploys nav aids*
- *Perform site preparation (including use Pyrotechnics*

2000
▲ Flight 1 : Cargo #1

Mission Objective : Deliver, prepare & checkout human habitat module.

Elements

- *Habitat Module w/ integral thermal contr... ...irlock*
- *Deployable 25 kW/12.5 kW Power (#1)*
- *Crew consumables to support Flight #2 with contingency 6 month supply*
- *Spares*

Mission Operations (Remote)

- *Offloader unloads Hab/Airlock*
- *Offloader delivers module to pre-selected, prepared site*
- *Deploy TCS radiators & PV arrays*
- *Hook up Power to Habitat*
- *Checkout Habitat & verify habitability*
- *Cover habitat with regolith*

1st Qtr. 2001
▲ Flight 2 : Piloted #1

Mission Objective : Conduct first 4 crew / 30 day mission at initial lunar outpost.

Elements

- *EMUs*
- *25 kW/12.5 kW Power System (#2)*
- *Crew consumables*
- *O2 Demonstrator*
- *Science package*
- *Spares*

Mission Operations

- *Inspect, verify and enter Hab/airlock module*
- *Offload, deploy & integrate Power System (#2) with outpost Power System (#1)*
- *Deploy & operate science packages*
- *Emplace O2 Demo Unit and conduct experiment*
- *Prepare site for Lab/Airlock delivery on subsequent flight*
- *Close out outpost*

BEAR-Barrios/WEills/Concept D&D Rqmtsww/GJF/10/4/89

Figure 3-6

Lunar Outpost - Initial Emplacement

This page from the 90 Day Study presents the next two missions and the associated objectives of each.

LUNAR OUTPOST – INITIAL EMPLACEMENT

2000 2002 2004 2006 2008 2010 2012 2014 2016 2018 2020

2nd Qtr 2001

▲ Flight 3 : Cargo #2

Mission Objective : Upgrade habitat to provide the capability for 4 crew to live and work on the lunar surface for up to 1 year.

Elements	Mission Operations (Remote)
• *Laboratory Module w/ [illegible] & Integral Airlock* • *25 kW 12.5 kW Power System (#3)* • *Crew consumables* • *Science package* • *Spares*	• *Payload offloader unloads Lab/Airlock Module from LEV* • *Offloader delivers & docks Lab/Airlock to Hab/Airlock Module* • *Deploy & integrate Power System (#3) to outpost power system (75 kW/3[illegible] kW)* • *Check out & verify integrity of Hab/Lab Modules with 50 kW/25 kW outpost power system & thermal control system* • *Cover Lab with Regolith* • *Site prepared for first 6 month mission*

2002

▲ Flight 4 : Piloted #2

Mission Objective : Conduct first 4 crew / 6 month mission at upgraded Hab/Lab facility

Elements	Mission Operations
• *EMUs* • *LEV Servicer #1* • *Unpressurized Manned/Robotic Rover* • *Crew consumables* • *Science packages*	• *Set up LEV Servicer and begin servicing LEV* • *Offload rover* • *Offload & transfer crew consumables* • *Deploy operate science packages* • *Conduct manned rover excursions for up to 50 km* • *Close out outpost*

BEAR-Barrios/Wellis/Concept D&D Rqmtsww/GJF/10/4/89

Figure 3-6 cont.

Flight "0" Operations (Unmanned)

Trade studies have indicated a need for at least two mobile vehicle types:

1. A mobile crane to lift-translate-lower packages

2. A lunar surface roving vehicle

This chart represents the tasks assigned to the two vehicles as a baseline for a study leading to the definition of requirements and mechanisms to aid in the implementation of the task assignments.

The additional mechanisms are called out on the chart wherever their use is deemed to be required. Since the vehicles are remotely operated from the operations center on Earth, vehicle motion speeds will be slower and time requirements will include ample time for data transmission and analysis between tasks.

Flight "0" Operations (Unmanned)

0.1 Straddler deploys itself from the LEV
- 0.1.1 LEV lands 48 hrs after lunar sunrise
- 0.1.2 Straddler extends legs and lifts from mount on LEV
- 0.1.3 Straddler performs photo survey of area

0.2 Straddler unloads equipment from LEV
- 0.2.1 Straddler positions hoist mechanism and connects to rover
- 0.2.2 Straddler moves away from LEV and deploys Robotic Rover
- 0.2.3 Straddler lowers rover attachments from LEV
- 0.2.4 Checkout of Rover systems
- 0.2.5 Straddler connects to and unloads hopper(s) from LEV
- 0.2.6 Straddler offloads communications equipment from LEV and loads on Rover
- 0.2.7 Straddler offloads blast shield materials from LEV
- 0.2.8 Straddler carries blast materials to predetermined site

0.3 Rover performs site survey & deploys navigation aids and marker beacons
- 0.3.1 Rover traverses surface to verify location of outpost and perform seismic survey
- 0.3.2 Transmission and analysis of accumulated data from site survey
- 0.3.3 Rover traverses surface to verify sites and set out marker beacons
- 0.3.4 Rover traverses to site near planned landing area
- 0.3.5 Rover emplaces navigation aids
- 0.3.6 Rover returns to landing site

0.4 Rover prepares roadway surfaces on site
- 0.4.1 Rover scrapes soil to prepare surfaces for transportation
- 0.4.2 Communication equipment (used as ballast) offloaded at shelter location

0.5 Straddler deploys blast shield
- 0.5.1 Straddler deploys and assembles blast shield

0.6 Preparation of Hab site
- 0.6.1 Straddler and Rover traverse to test blast site
- 0.6.2 Rover places blast cameras
- 0.6.3 Straddler drills charge holes and places explosives
- 0.6.4 Straddler and Rover traverse back to blast shelter
- 0.6.5 Detonate charge
- 0.6.6 Analysis of test blast area (Data Transmission)
- 0.6.7 Straddler and Ro[illegible] traverse to Hab site
- 0.6.8 Straddler drills charge holes and places explosives
- 0.6.9 Rover places blast cameras
- 0.6.10 Straddler and Rover traverse back to blast shelter

Flight "0"/Task 9.1 Final Report/6-4-90/DLT

Figure 2-7

Flight "0" Operations (Unmanned)

This chart is a continuation of the Flight "0" mission analysis from the previous page.

0.6.11 Detonate charges
0.6.12 Straddler and Rover traverse to blast site and surveys blast and clear debris (Data)
0.6.13 Rover traverses to Landing Sites and clears for future landings
0.6.14 Straddler drills casting charge holes and places explosives
0.6.15 Rover traverses back to Hab site
0.6.16 Rover places blast cameras
0.6.17 Straddler and Rover traverse back to blast shelter
0.6.18 Detonate charges
0.6.19 Straddler and Rover traverse to blast site and surveys blast and clear debris (Data)
0.6.20 Straddler drills shaping charge hole and places explosives
0.6.21 Rover places blast cameras
0.6.22 Straddler and Rover traverse back to blast shelter
0.6.23 Detonate charges
0.6.24 Straddler and Rover traverse to blast site and surveys blast and clear debris (Data)

0.7 Preparation of power site
0.7.1 Straddler and Rover traverse to power site
0.7.2 Straddler drills holes for charges and places explosives
0.7.3 Rover places blast cameras
0.7.4 Straddler and Rover traverse back to blast shelter
0.7.5 Detonate charges
0.7.6 Straddler and Rover traverse to blast site and surveys blast and clear debris (Data)
0.7.7 Rover traverses to Hab/Lab site and clears area around module location
0.7.8 Straddler drills holes for fracture charges and places explosives
0.7.9 Rover places blast cameras
0.7.10 Straddler and Rover traverse back to blast shelter
0.7.11 Detonate charges
0.7.12 Straddler and Rover traverse to blast site and surveys blast and clear debris (Data)
0.7.13 Straddler and Rover traverse back to blast shelter and await next landing

Figure 3-7 cont.

Rover Operations

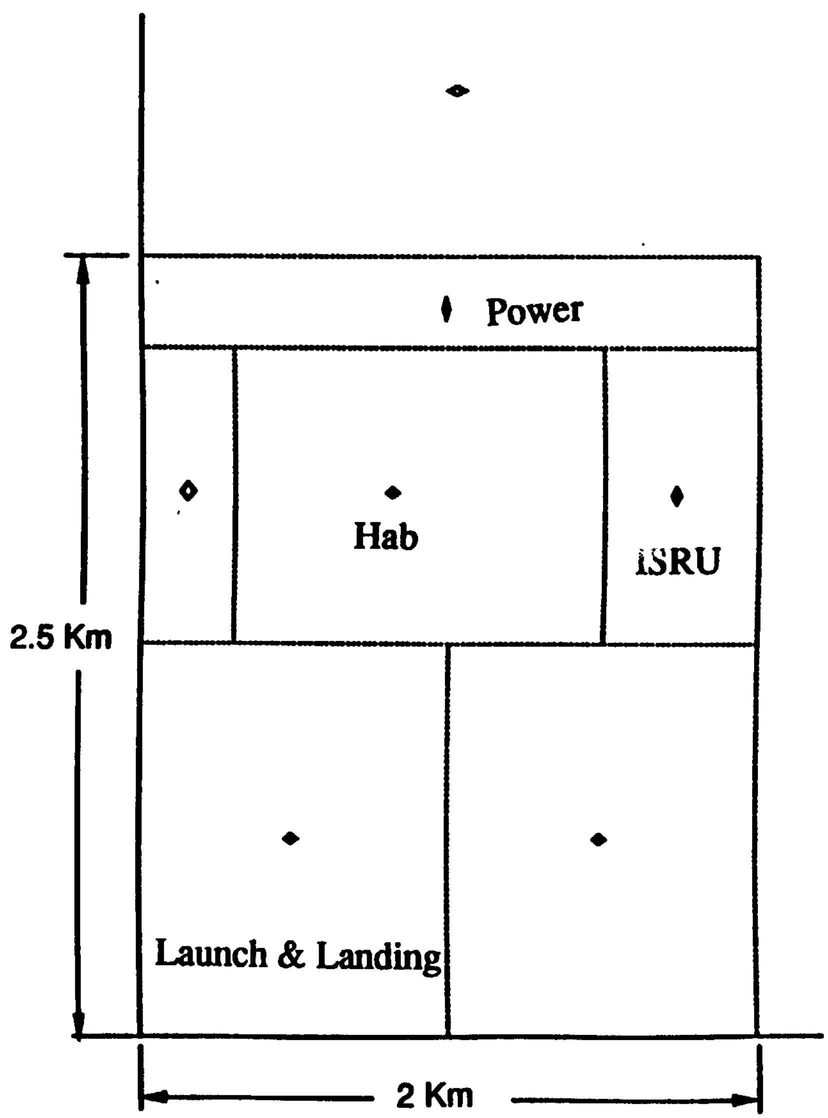
The first operation required upon arrival on the lunar surface is site survey using a camera to determine the suitability of the proposed base layout. The rover traverses to each point indicated to perform a photo survey and then transmits the accumulated data to Earth for analysis.

The path length shown below is an example of shortest path solution output from a computer program that is used to determine the cumulative distance traveled by the lunar vehicles.

Distance traveled for the vehicles is vital to wheel designs, task completion time, power required and overall vehicle life.

Rover Operations

Path for performing photo surveyal



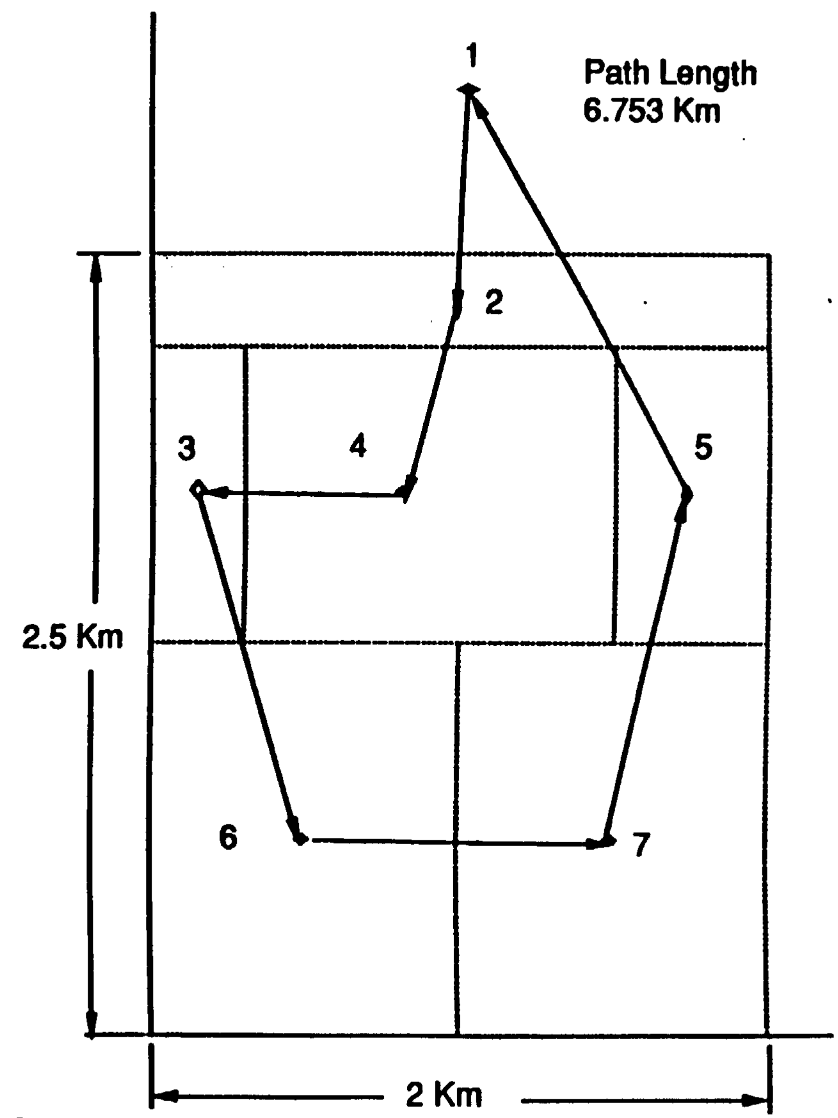


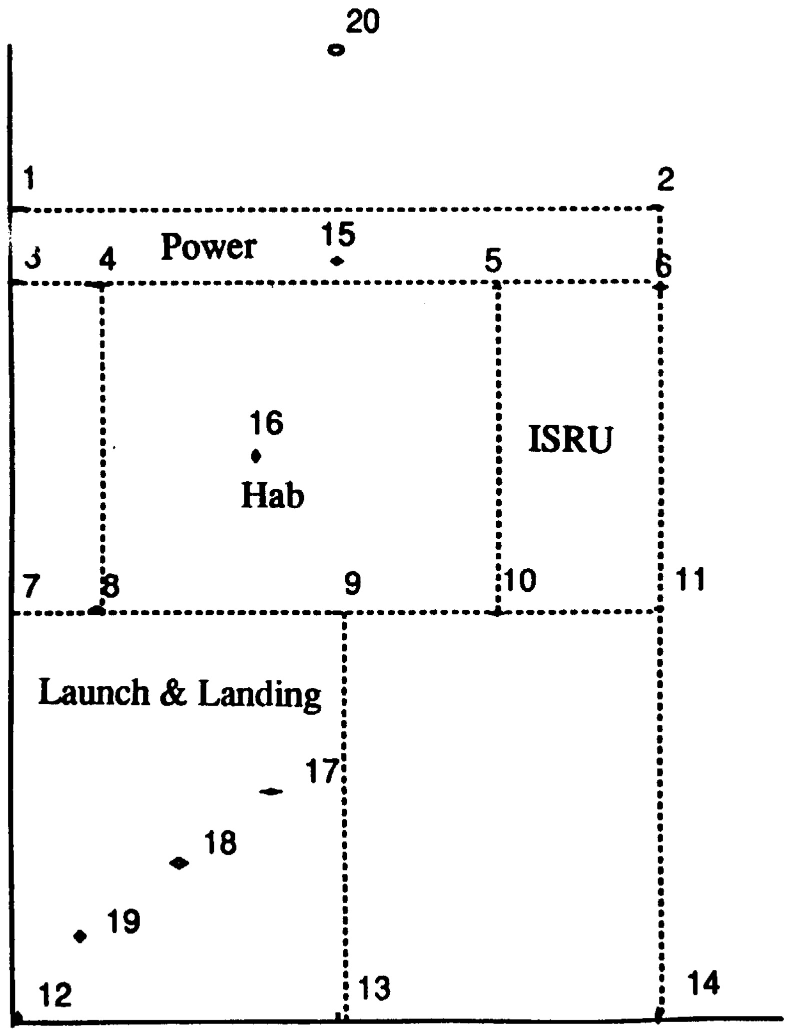
Figure 3-8

This chart shows the shortest path for deploying the navigation beacons which also affects cumulative mileage and related vehicle requirements.

The path length is shown again to present the necessity of keeping accurate mileage records for vehicles as they perform tasks on the lunar surface.

Rover Operations

Path to Deploy Navigation Beacons



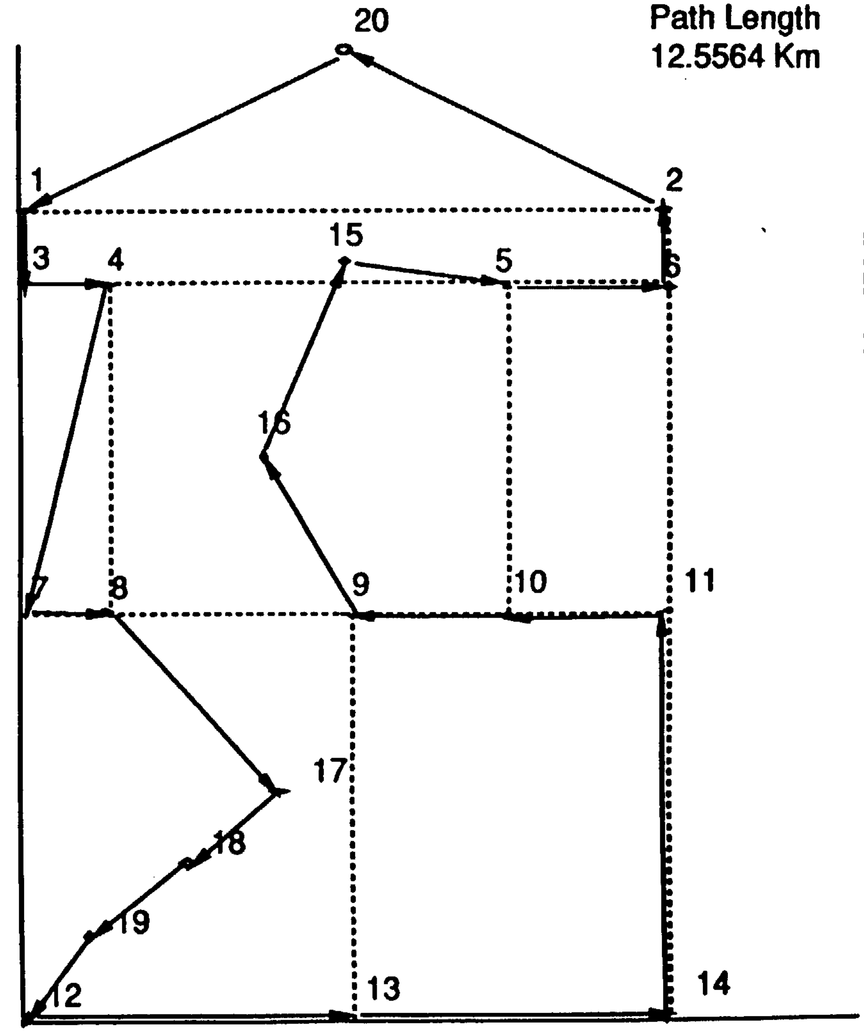


Figure 3.

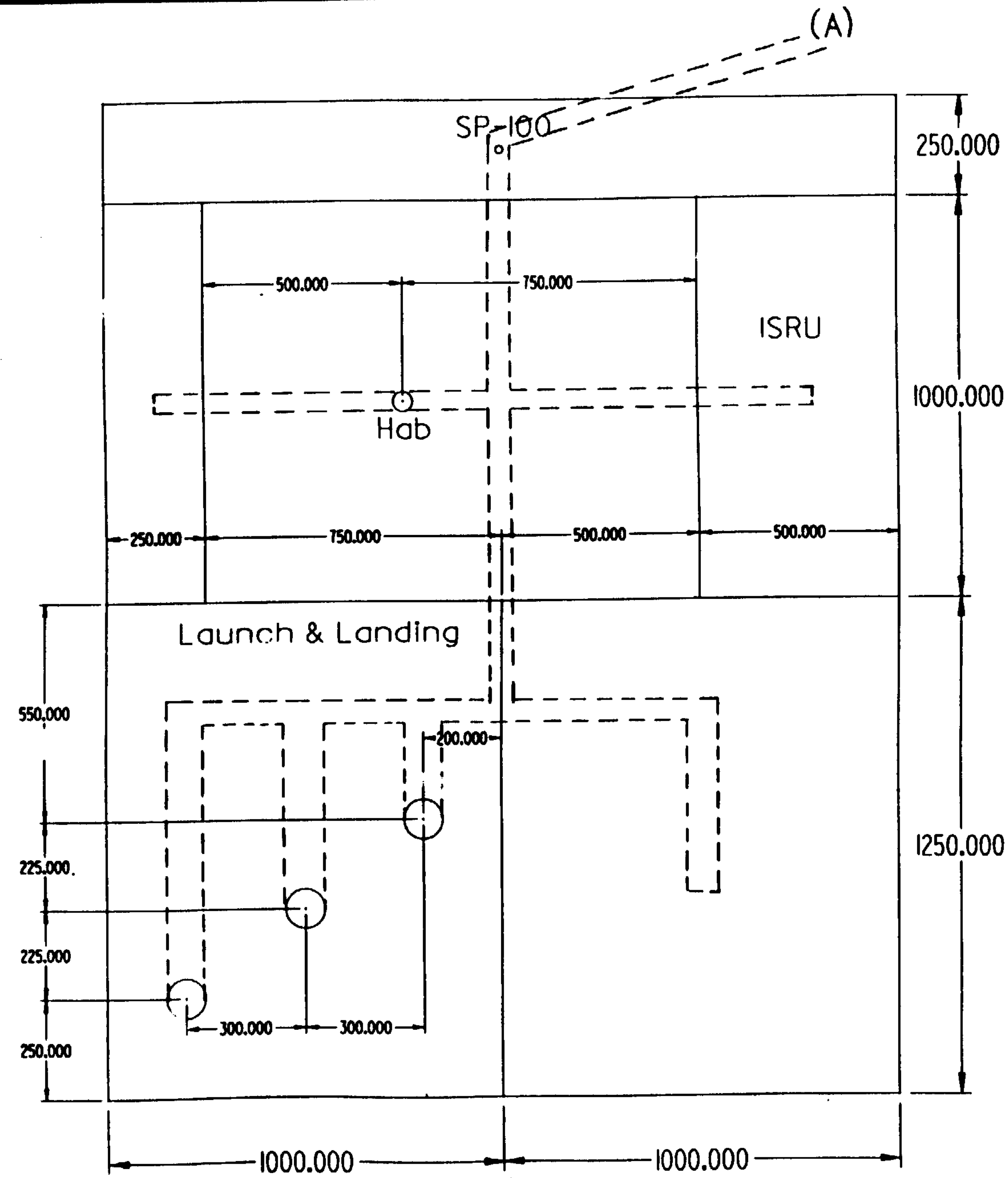
Lunar Base Site Layout

The lunar base shown below presents the improved surface pathways created by the rover. These pathways are prepared on Flight "0".

It is necessary to prepare road surfaces as best as possible to aid in more efficient speed of the vehicles and also less wear.

Lunar Base Site Layout

BOEING



Legend:

==========	Prepared Road Surface
(A)	Blast & Debris Shelter

Figure 10

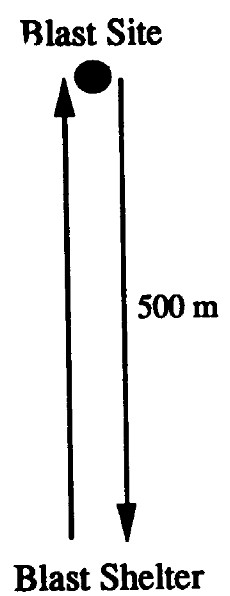
Rover Operations

Because of the uncertainty related to Lunar surface blasting effects, we anticipate a need for a test blast to be performed prior to the actual site preparation blasting. The test blast site is undetermined but could possibly be the SP-100 site. After the test blast results are analyzed, the actual site blasting takes place.

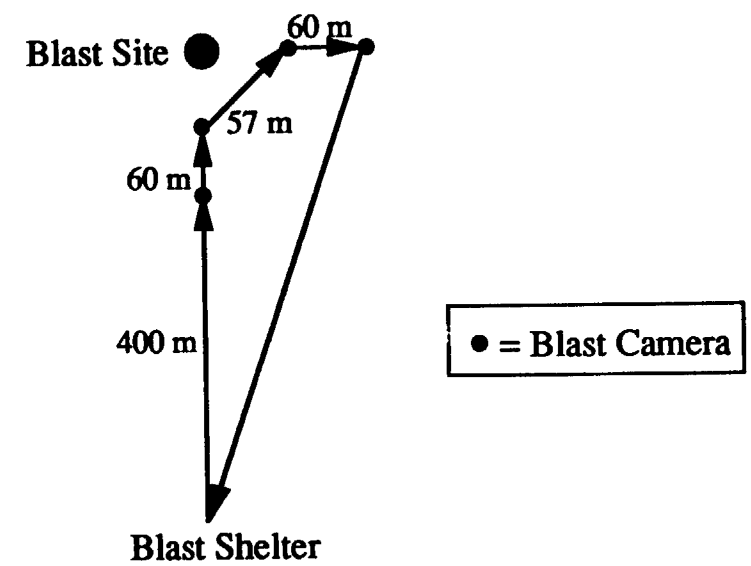
Rover Operations

BOEING

Precursor Blast Operations



Straddler Places Charges

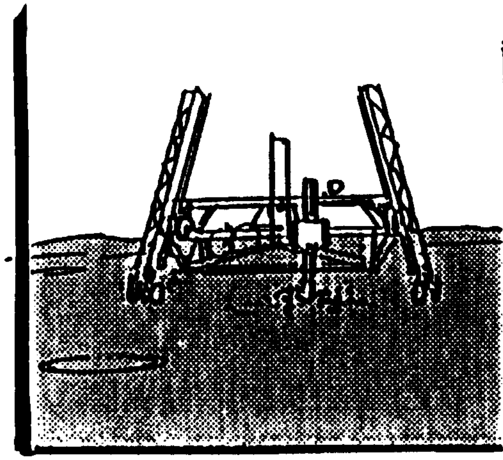


Rover Sets Out Cameras

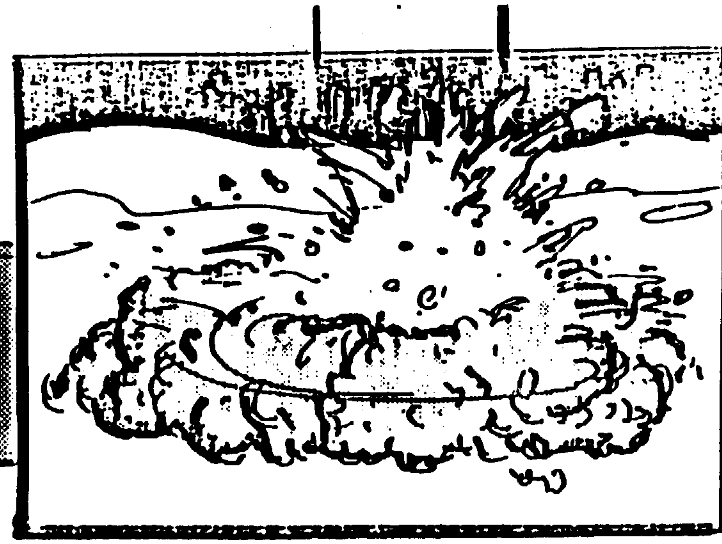
Habitat Robotic Pyrotechnic Excavation

This is a chart from the NASA 90-Day Study Results. Shown in the storyboard is an LEVPU with a drilling attachment (preliminary studies have indicated that a drill attachment on the LEVPU may not be the optimum method for charge placement).

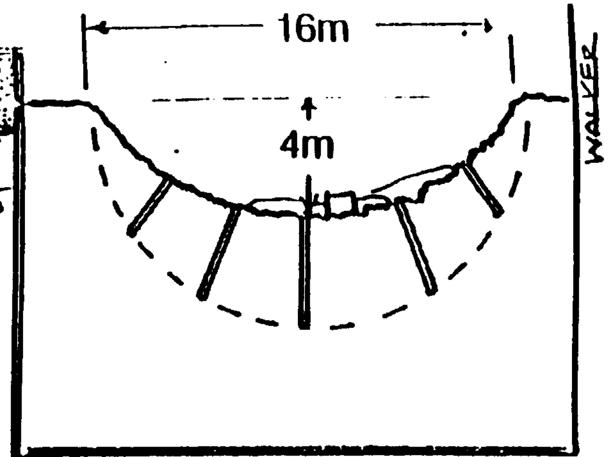
Also shown are the three blasting operations required to prepare the site for the Habitat module. Studies are in progress that look at the best method of excavating, blasting, and preparing various module sites.



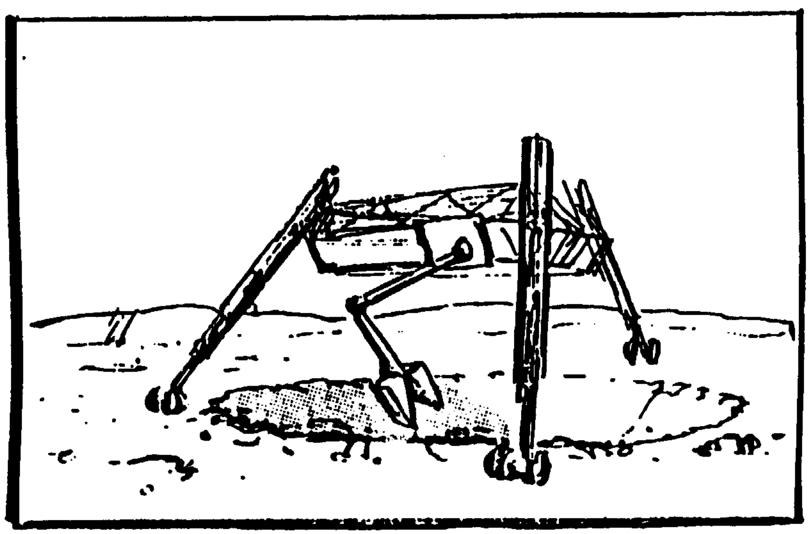
(1) LEVPU with drill attachment drills charge into site.



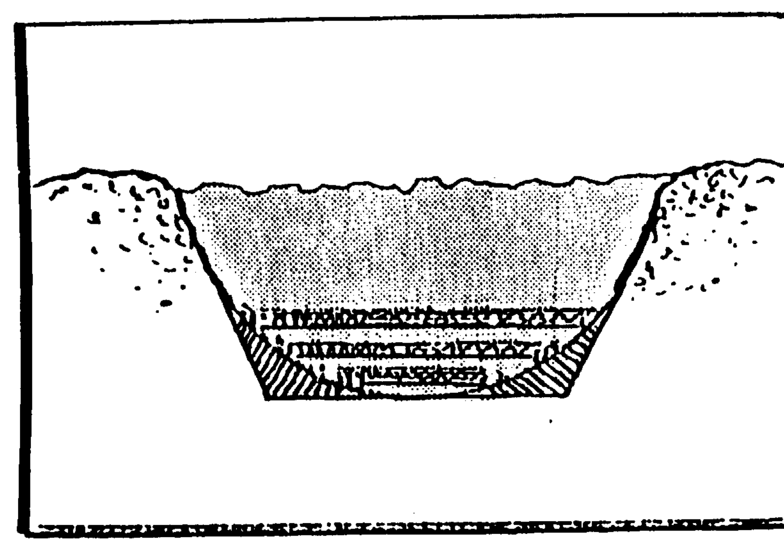
(2) Initial charge detonated.



(3) Casting charges placed by LEVPU to refine shape.



(4) Rubble from casting charge is removed by LEVPU with shovel attachment.



5 Final shaping charges create a flat bottom.

Flight 0 Constructible

Habitat Robotic Pyrotechnic Excavation

Reference Mission Storyboard

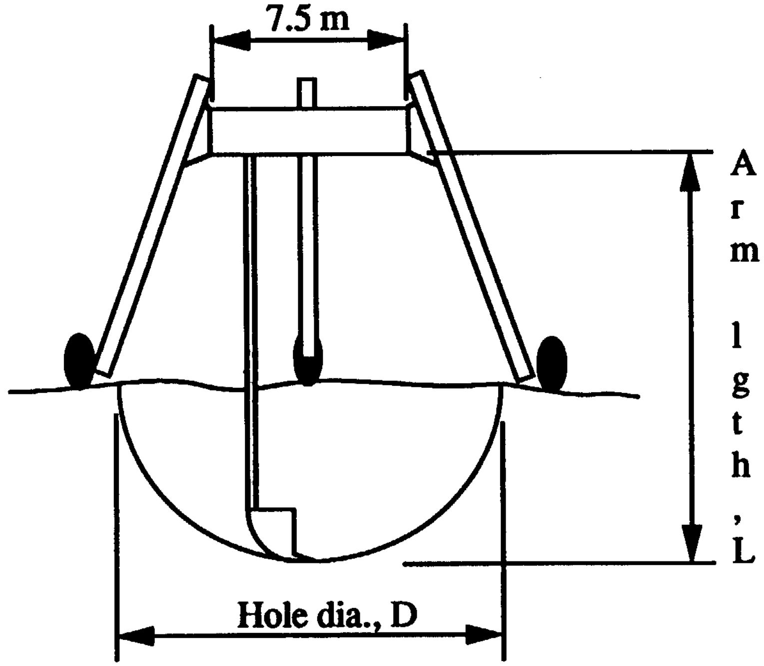
NASA 90 Day Lunar/Mars Study

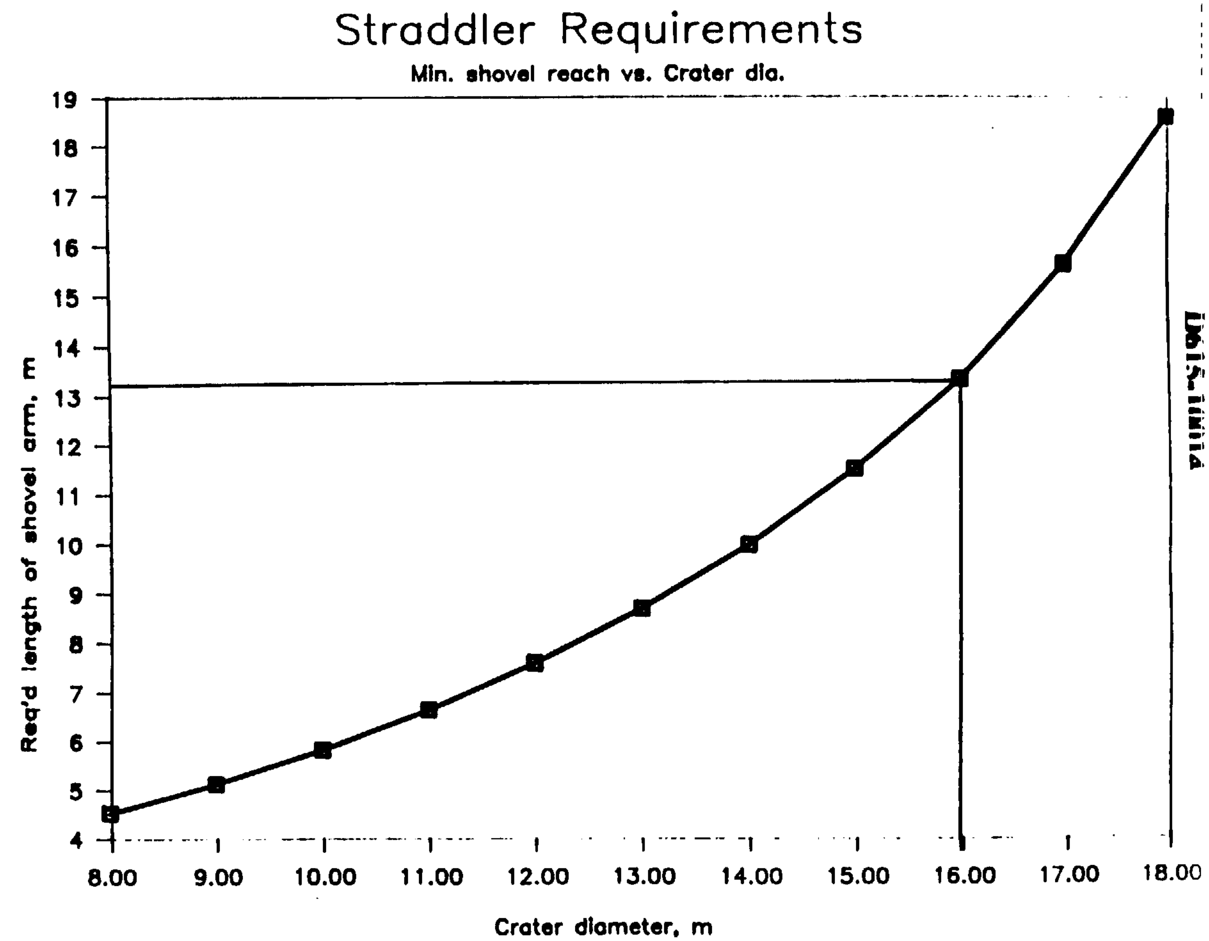
Straddler Requirements/Limitations

If a straddler is the vehicle chosen to perform blasting and digging operations, its dimensions may be dictated by crater size. Current crater concepts require a crater of 16m diameter. Although the straddler concept will accommodate such a crater, it would require a shovel arm of over 13m length as a minimum. This would make the shovel very heavy which suggests the need to study and develop alternative cratering operations, using a different vehicle for the digging task. Note that the dimensions shown on the facing chart are based on geometrical considerations. The straddler size will be dictated by launch vehicle shroud diameter (assumed here to be 7.5m).

Straddler Requirements/Limitations

BOEING





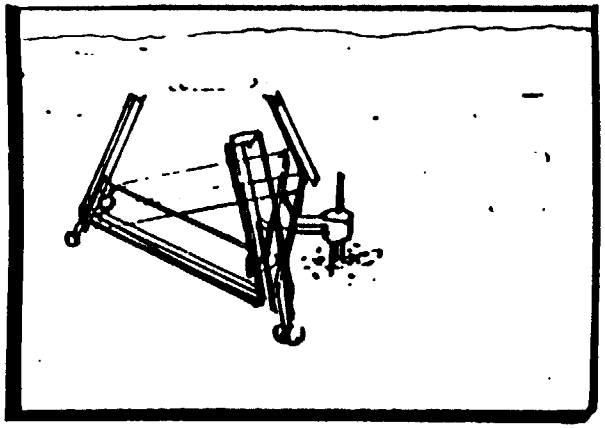
straddling/Task 9.1 Final Report/6-4-90/DLT

Fig 3-13

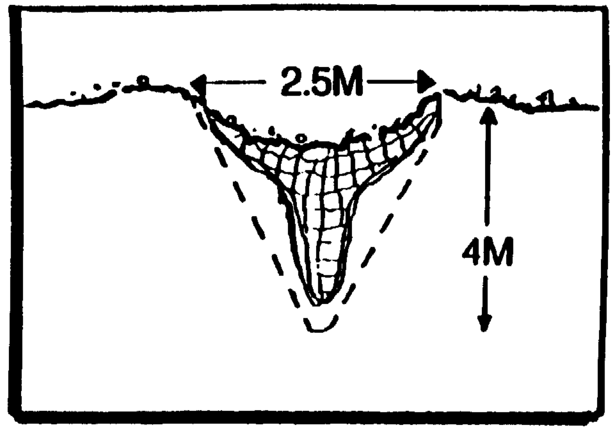
Power Module Robotic Crater Preparation

This is a chart from the NASA 90 Day Study Results. Shown in the storyboard is conceptual drilling and blasting operations for preparing the nuclear power module.

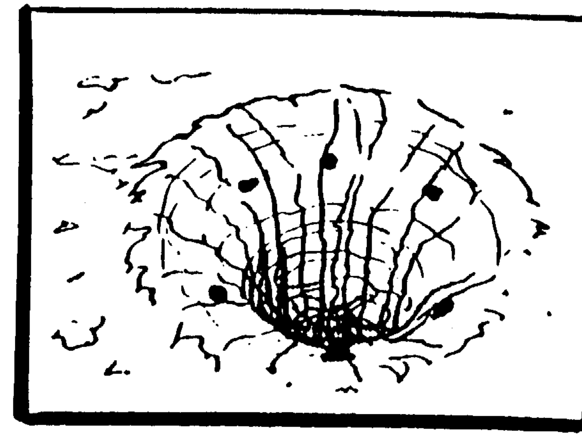
FP power crater prep/Task 9.1 Final Report/6-1-90/DLT



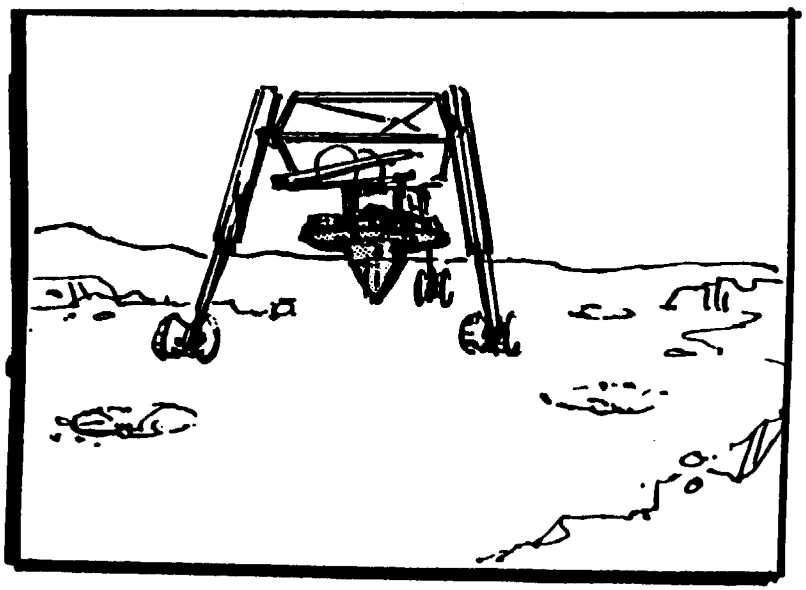
(1) LEVPU drills hole and sets fracturing charge.



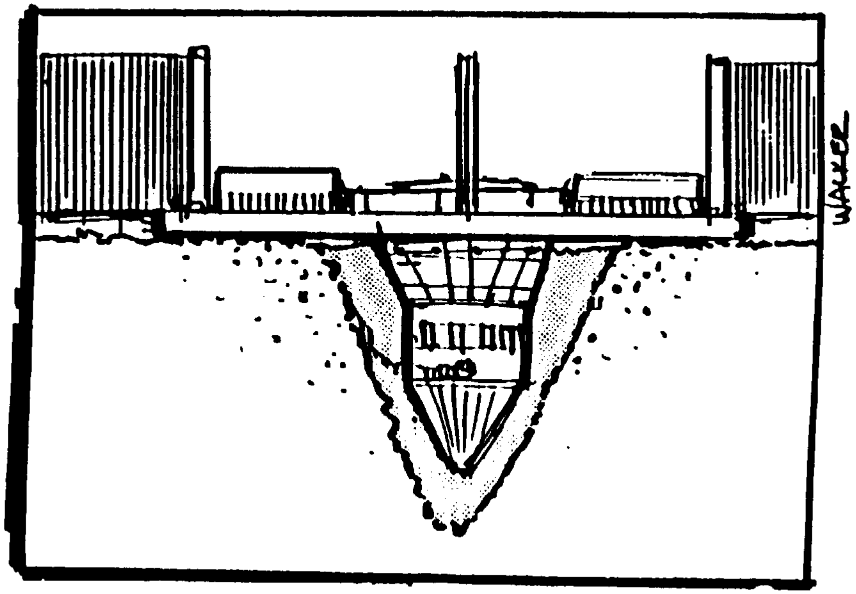
(2) Rubble to be removed by LEVPU.



(3) 6 fracturing charge "pipes" set in ring.



(4) In later flight, LEVPU will move power module to hole.



(5) Power module will be placed in hole and deployed in a later flight.

Reference Mission Storyboard

Flight 0
Power Module Robotic Crater Preparation

NASA 90 Day Lunar/Mars Study

Figure 3-14

Flight "0" Operations (Unmanned)

This chart shows the estimated timeline for the initial operations, separated by vehicle.

Because the Straddler performs most site preparation operations during this mission, it is the longest mission of the first five flights, lasting over four Earth months. The timeline suggests that further mission analysis may be necessary to uncover more efficient uses of the vehicles available, relieeving the burden on the large, slow Straddler thereby shortening the mission duration and costs. It further suggests that the Straddler, which is configured mainly to satisfy unloading requirements, is not the ideal vehicle to use for surface preparation and construction tasks.

Flight "0" Operations

BOEING

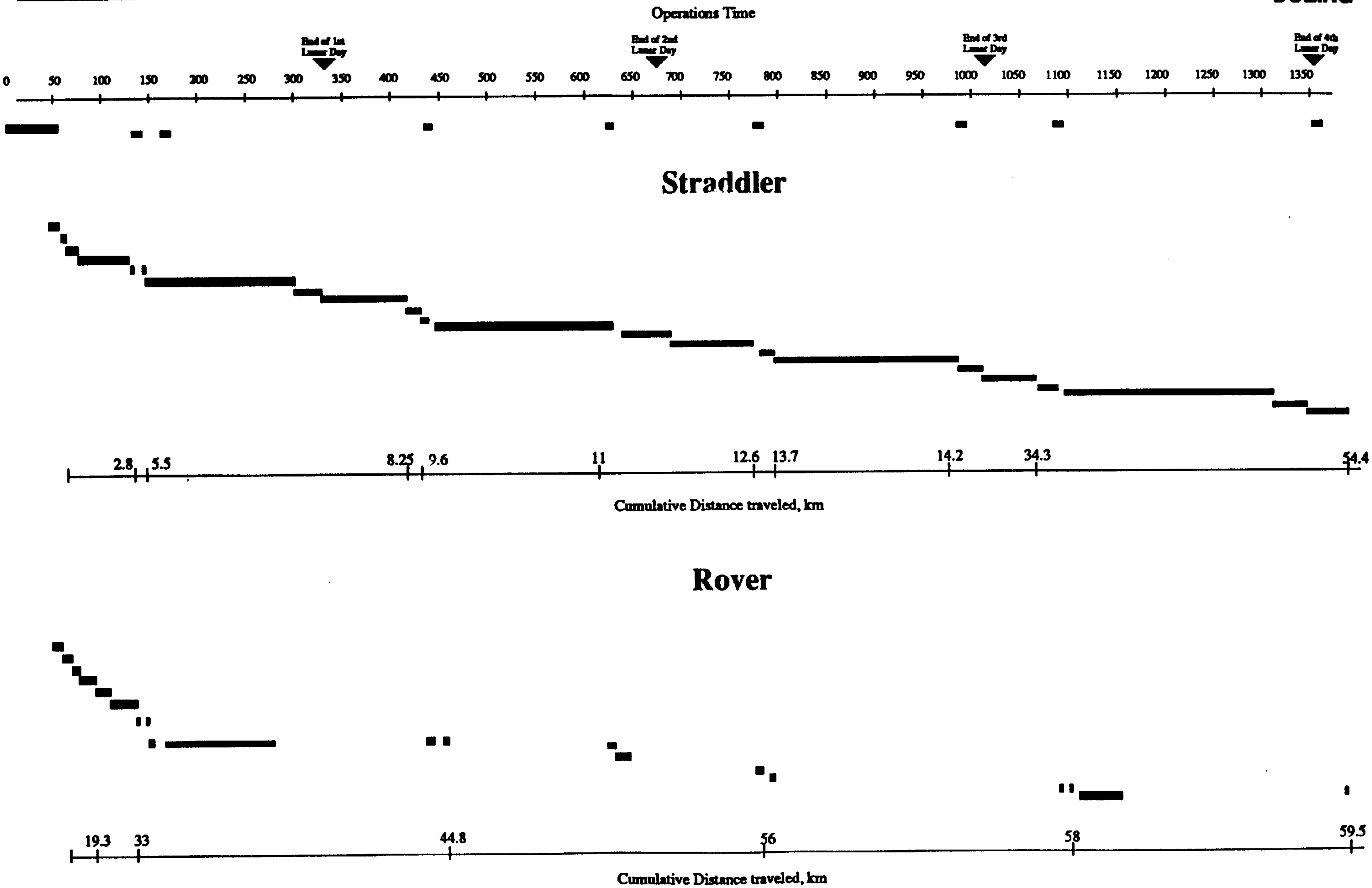


Figure ? 15

Flight "1" Operations (Unmanned)

Flight "1" is identified as the "first cargo landing". Its objective is to land the equipment and supplies required for the first manned 30-day mission to the Moon.

The elements delivered to the Moon are as follows:

1. The Habitat Module with integrated Airlock and thermal control system

2. A deployable 25kw/12.5kw power supply system

3. Crew consumables to support a crew of four (4) for seven months (30 days plus contingency stay of 6 months)

The Rover and Straddler will be required to perform the tasks shown on the following chart prior to the manned landing.

Flight "1" Operations (Unmanned)

1.1 Straddler offloads and deploys Hab/Airlock
- 1.1.1 LEV landing 48 hrs after lunar sunrise
- 1.1.2 Straddler traverses to landing site
- 1.1.3 Straddler positions over, attaches to, and lifts Hab/Airlock
- 1.1.4 Straddler traverses to prepared Hab site
- 1.1.5 Straddler lowers and levels Hab

1.2 Straddler deploys TCS radiators on Hab

1.3 Rover prepares PVA array area
- 1.3.1 Rover traverses to power site ahead of Straddler
- 1.3.2 Rover does light scraping of area and moves small obstacles

1.4 Straddler deploys regolith bags on Hab
- 1.4.1 Straddler traverses to Hab site

1.5 Straddler fills bags with regolith
- 1.5.1 Straddler moves to regolith site located at Hab site
- 1.5.2 Straddler fills hoppers with regolith
- 1.5.3 Straddler transports full hoppers to Hab site
- 1.5.4 Straddler empties each hopper into bags
- 1.5.5 Straddler and Rover return to blast shelter

1.6 Straddler offloads and delivers power system
- 1.6.1 Straddler moves to LEV and offloads power system
- 1.6.2 Straddler traverses to power site prepared by Rover and deploys power system
- 1.6.3 Checkout of power hardware (Data Transmission)

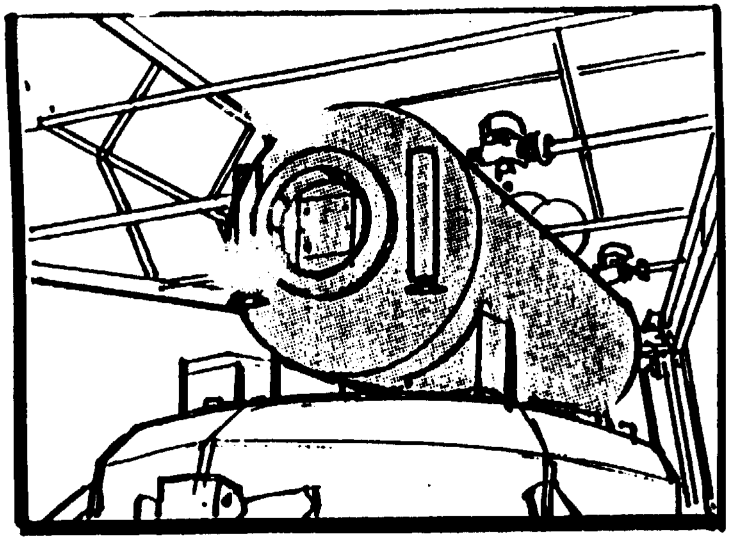
1.7 Rover emplaces cable from power site to Hab
- 1.7.1 Rover attaches to cable
- 1.7.2 Rover simultaneously digs small trench and places cable during power system
- 1.7.3 System checkout and data transmission

Flight "1"/Task 9.1 Final Report/6-4-90/DLT

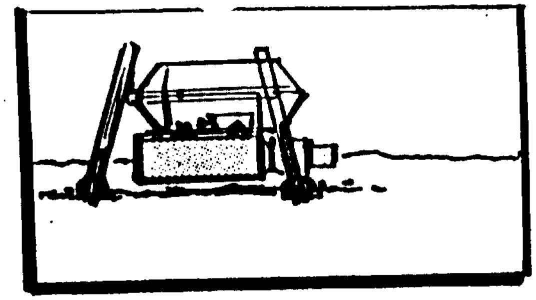
Figure 3-16

Robotic Offloading and Deployment

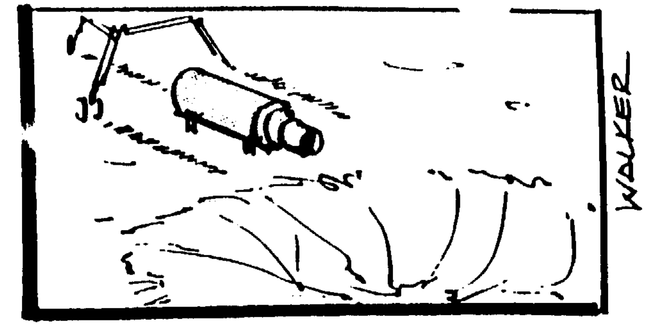
This is a chart from the NASA 90 Day Study Results. Shown below is a storyboard representing the deployment of the Hab module from the LEV and the placement of the module at the pre-prepared site.



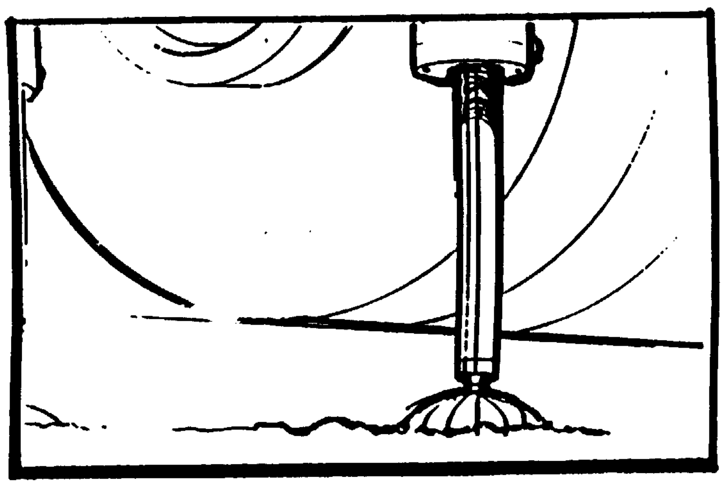
(1) LEV   loads Habitation/Airlock module.



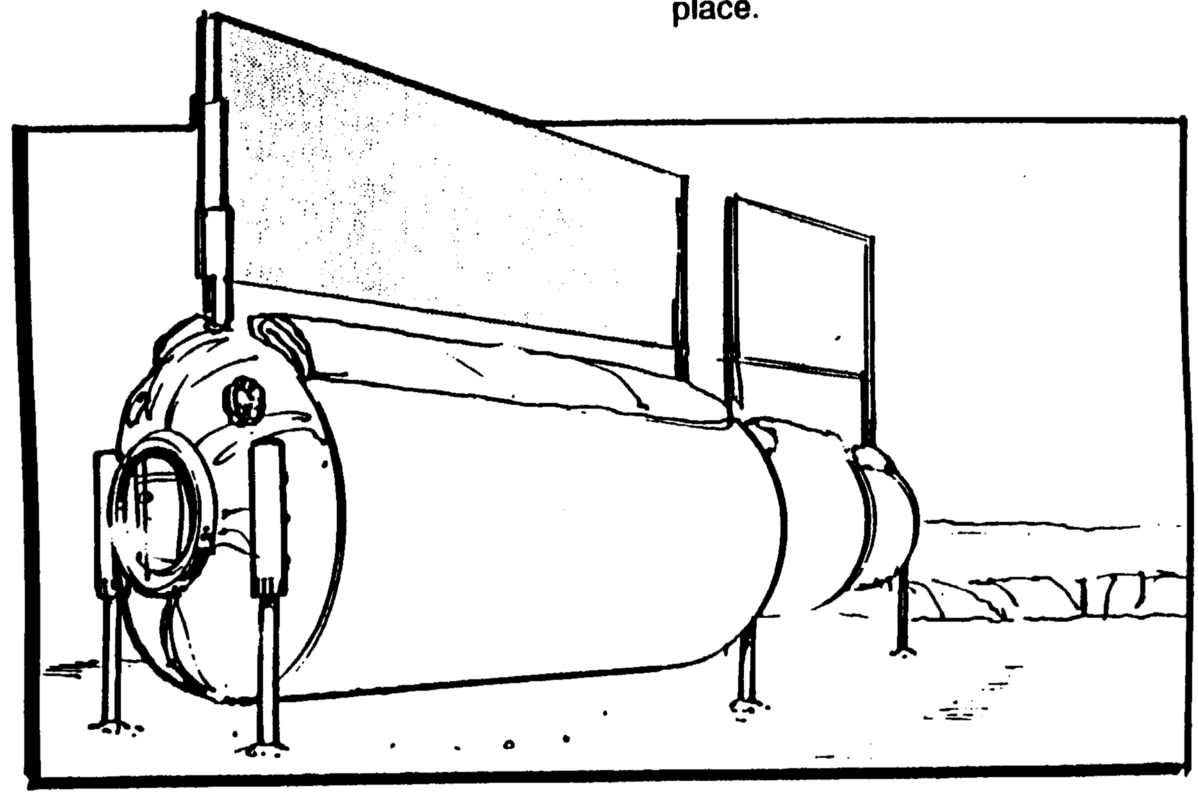
(2) HAB/Al is transported to emplacement site.



(3) HAB/AL is oriented and lowered into place.



(4) Module is leveled.



(5) The TCS radiators are deployed.

Reference Mission Storyboard

Flight 1 Initial Outpost
Robotic Offloading and Deployment

NASA 90 Day Lunar/Mars Study

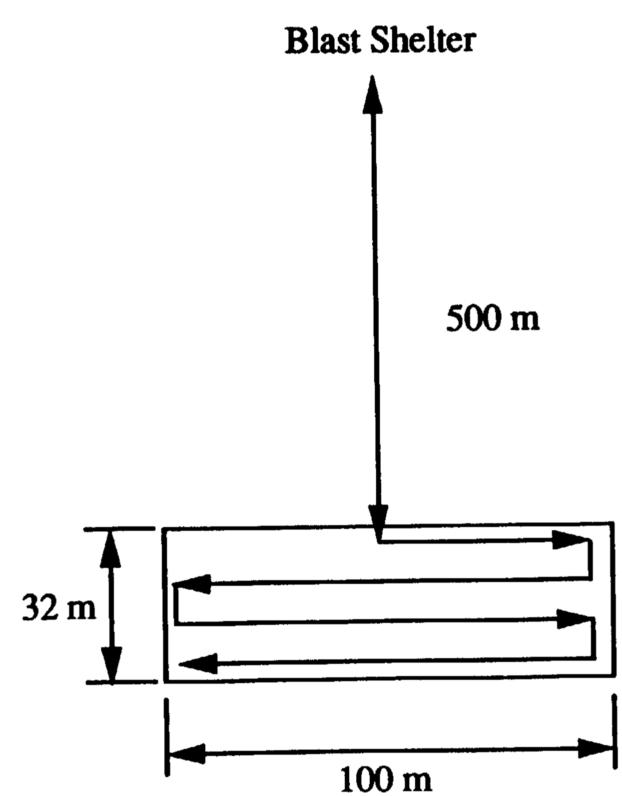
Rover Operations

PVA site preparation is necessary so that a smooth surface exists for deployment of the arrays.

The chart below presents the traverse requirements for preparing the Photovoltaic array area. This will affect rover usage timelines and distance relationships.

Rover Operations

PVA Site Preparation



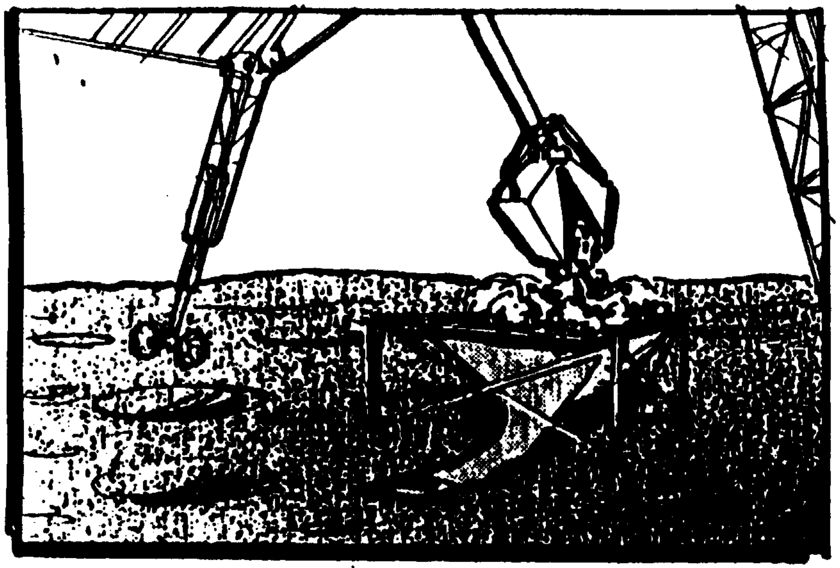
Grade Depth = 15 cm

Rover makes 3 passes at 5 cm

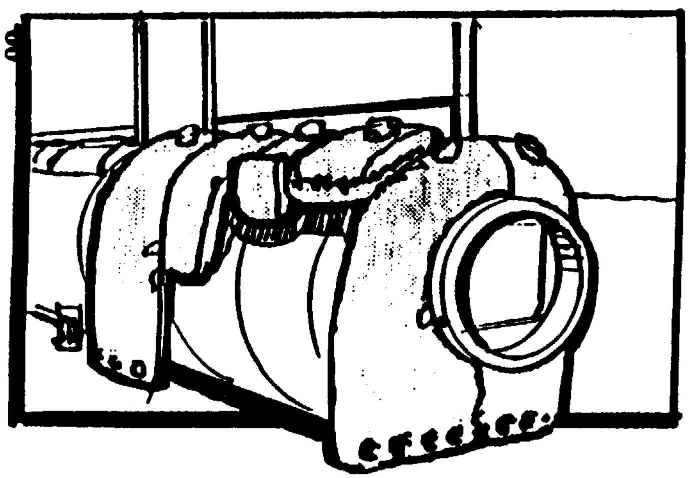
0.3 m wide pass

Regolith Shroud Deployed and Filled

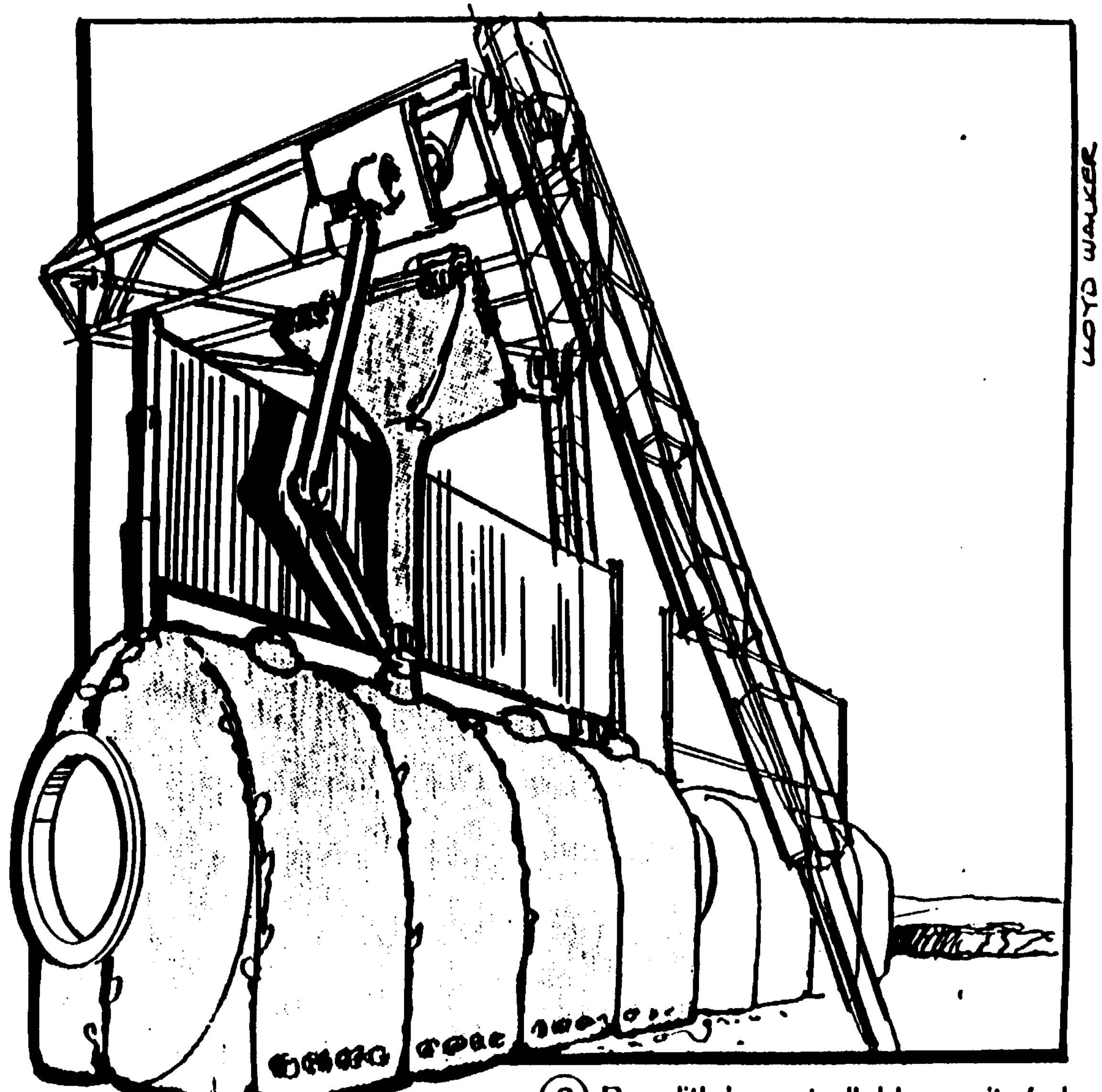
This is a chart from the NASA 90 Day Study Results. Shown below is a storyboard which represents the method of filling bags on the Hab module with regolith to provide radiation protection. The methodology of performing this task is currently being traded to determine the most efficient method.



(1) LEVPU loads regolith into hopper.



(2) Regolith Shroud bags are deployed on Hab module.



(3) Regolith is controllably gravity fed by LEVPU into Shroud bags.

Reference Mission Storyboard

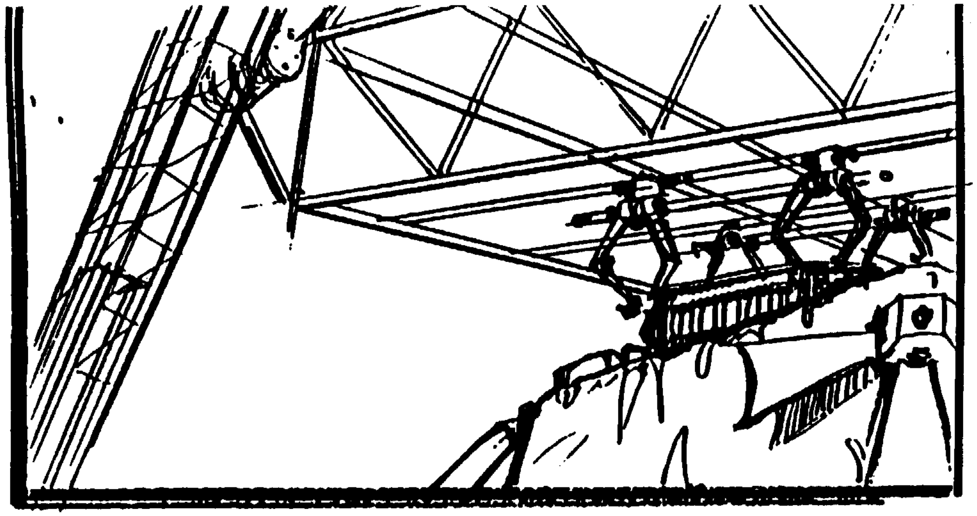
Flight 1 Regolith Shroud deployed and robotically filled

NASA 90 Day Lunar/Mars Study

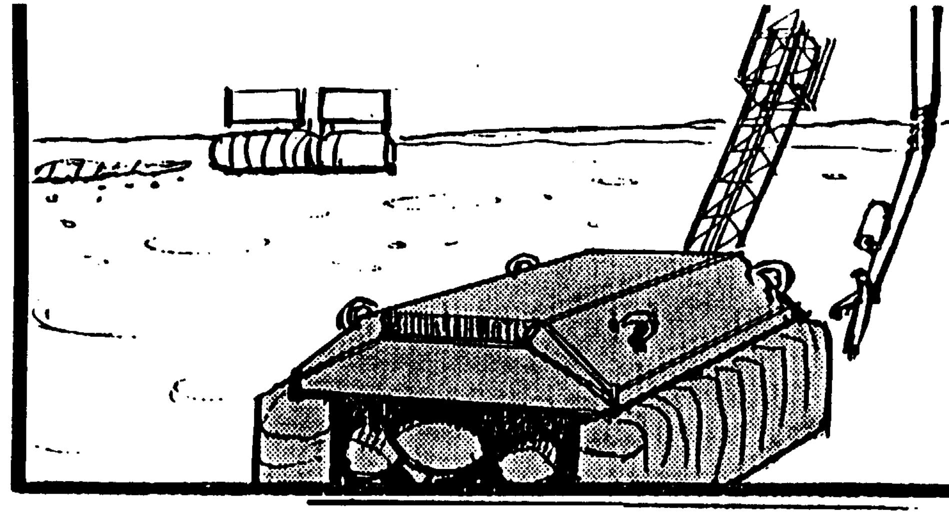
Figure 3-10

Initial Outpost Power System Offloading and Deployment

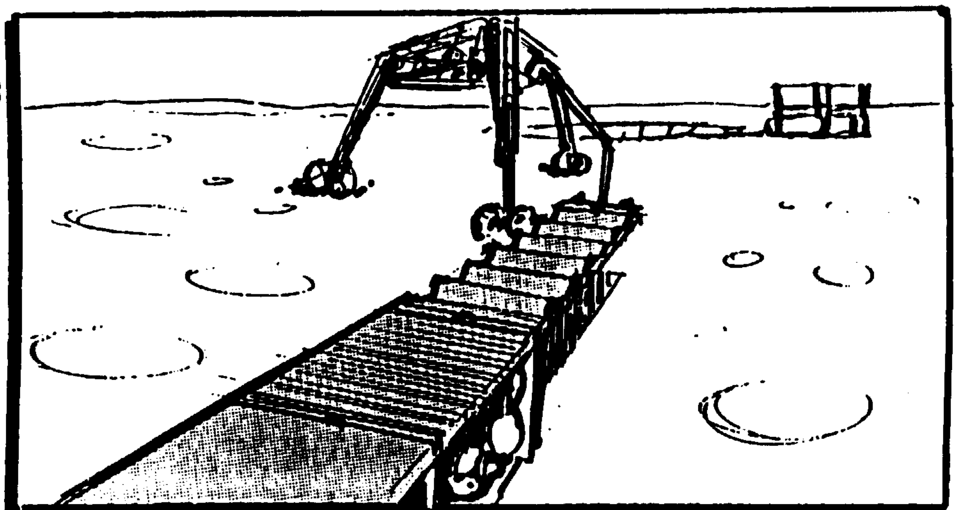
This is a chart from the NASA 90 Day Study Results. Shown below is a storyboard which represents the offloading, deployment, and hookup of the power system. In order to lay the cables from the power system to the Hab, a cable laying device will be necessary.



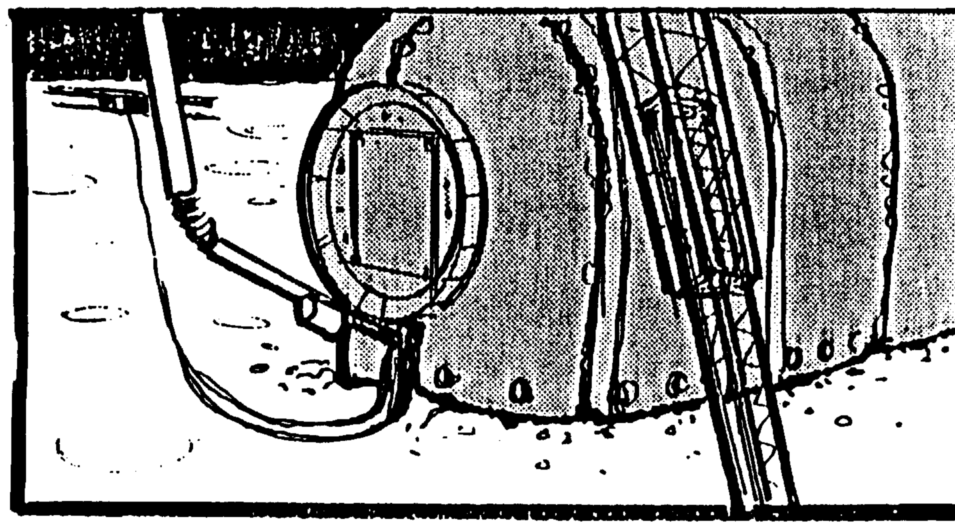
(1) Power System offloading by LEVPU.



(2) Power System is oriented at site.



(3) Power System deployed.



(4) Electrical power connected to HAB.

Reference Mission Storyboard

Flight 1 Initial Outpost Power Systen
robotic offloading and deploymen

NASA 90 Day Lunar/Mars Study

John Frassanito & Associate:

Figure 3-20

Flight "1" Operations

This chart shows the estimated timeline for the second unmanned lunar flight.

This mission is much shorter than the first mission, due mainly to the use of the smaller, quicker rover for the tasks other than unloading equipment from the lander. Because the Straddler is limited to unloading and carrying large payloads, this timeline represents a more efficient use of the two vehicles than the previous flights.

Flight "1" Operations

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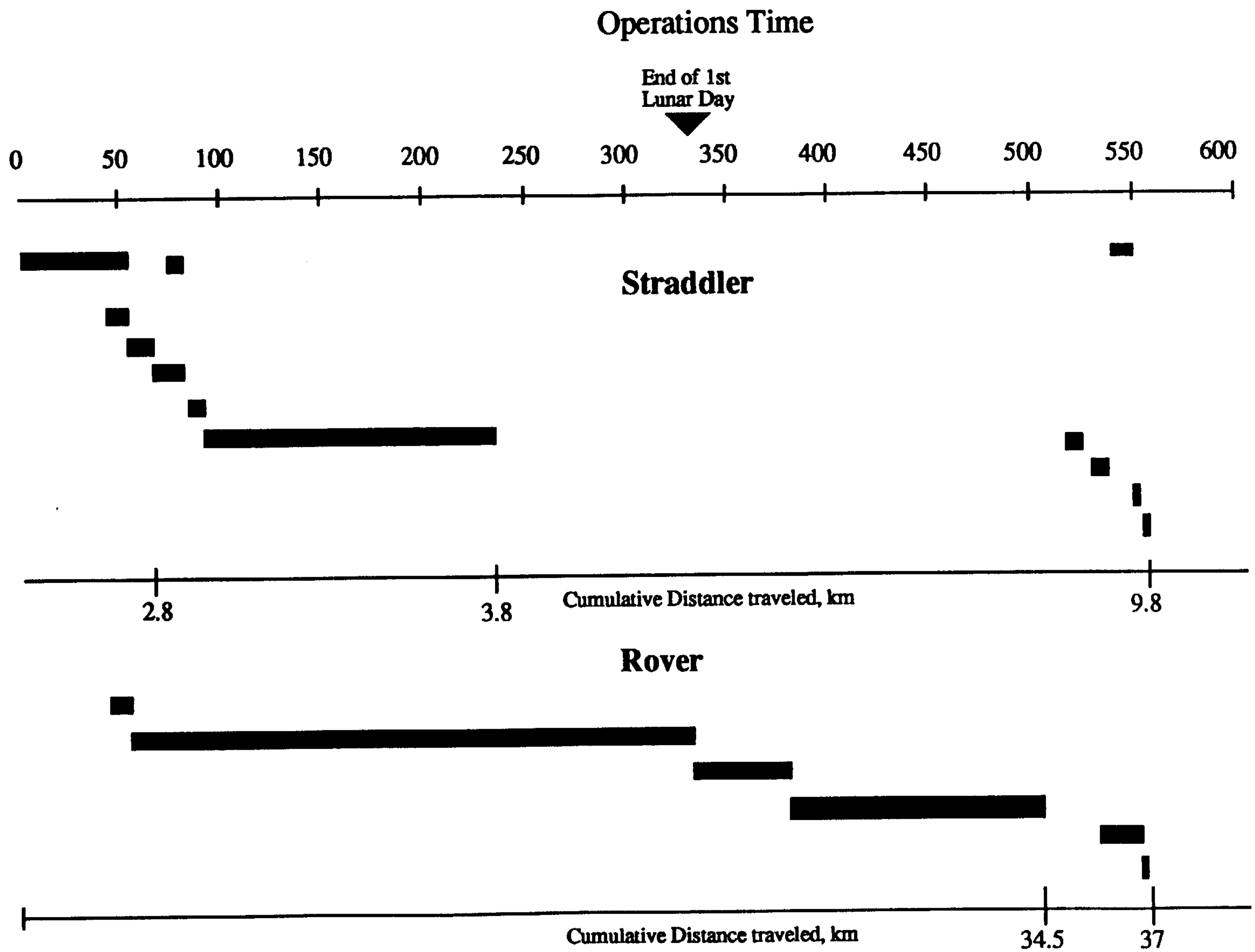


timeline1/Task 9.1 Final Report/6-4-90/DLT

Flight "2" Operations (Manned)

Flight "2" is the first manned mission to the lunar outpost. The crew of four (4) conducts a 30 day mission during their stay.

The primary function of this mission is to perform scientific experiments which are necessary for future long-term habitation. The crew engages an oxygen demonstration experiment to obtain data vital to establishing an oxygen producing facility. The crew also integrates the second power system which will run the Lab/Airlock which arrives on a later flight.

Flight "2" Operations (Manned)

2.1 Straddler & Rover traverse to LEV
- 2.1.1 LEV lands 48 hrs after lunar sunrise
- 2.1.2 Straddler and Rover traverse to landing site

2.2 Straddler offloads and deploys power system (PV)
- 2.2.1 Straddler extends grapple fixture and grapples power system
- 2.2.2 Straddler offloads power system (PV) from LEV
- 2.2.3 Crew transfers EVA to Rover
- 2.2.4 Crew checks Rover and subsystems
- 2.2.5 Crew traverses to power site (PV) and verifies
- 2.2.6 Straddler traverses to power site and deploys (PV) power system
- 2.2.7 Straddler integrates power systems #1 & #2 (installation and deployment)
- 2.2.8 Crew traverses to Hab via Rover
- 2.2.9 Crew checks out Hab (Data transmission)

2.3 Crew conducts local science mission
- 2.3.1 Crew loads,boards, and checks out Rover
- 2.3.2 Crew traverses to science site via Rover
- 2.3.3 Crew unloads science equipment and engages experiments

2.4 Crew closes out Hab
- 2.4.1 Crew traverses to Hab
- 2.4.2 Crew loads Rover with necessary equipment
- 2.4.3 Crew close out Hab

2.5 Crew traverses via Rover to LEV
- 2.5.1 Crew traverses to LEV via Rover
- 2.5.2 Crew unloads Rover and enables robotic operations
- 2.5.3 Crew boards LEV
- 2.5.4 Straddler disposes of LEV equipment
- 2.5.5 Straddler and Rover traverse to blast shelter

Fi---- 3-2?

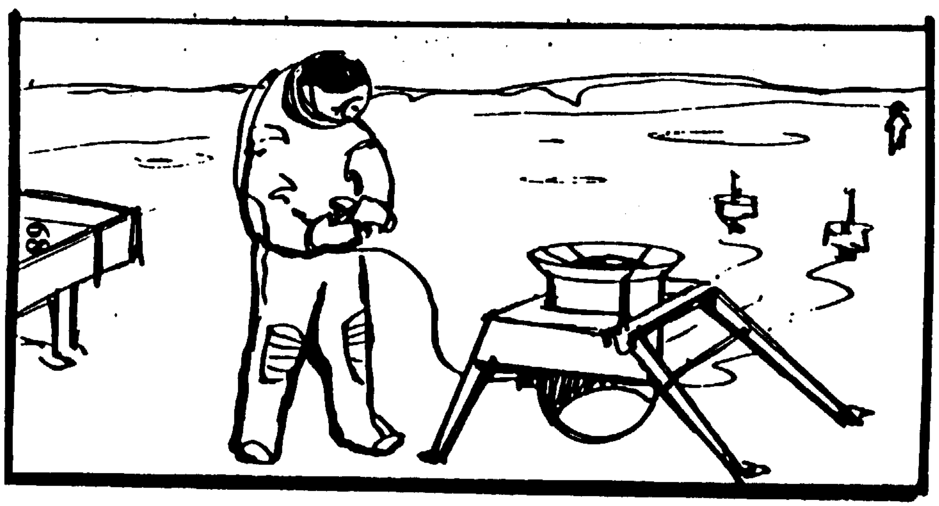
EVA Planning Comparisons

This chart shows how Apollo data can be used to estimate local science mission timelines.

A key portion of determining rover requirements will be estimating the rover driving time and distance traveled relationship, affecting the vehicle speed , power, and navigation requirements. Our missions analysis used this Apollo data for determining the rover usage and range requirements during local science missions.

The distance/time values shown correspond to a speed of around 8 kph. This speed was limited by the crew safety and endurance on the rough lunar terrain. For this reason, it is questionable whether traverse speeds for future science excursions will be substantially different.

EVA Planning Comparisons



	EVA Duration (Hr:min)		Traverse Distance (Km)	
	Plan	Actual	Plan	Actual
EVA I				
Apollo 15	7:00	6:32	8.2	10.3
Apollo 16	7:00	7:11	3.2	4.2
Apollo 17	7:00	7:12	3.2	3.3
EVA II				
Apollo 15	7:00	7:12	14.3	12.5
Apollo 16	7:00	7:23	9.5	11.5
Apollo 17	7:00	7:34	17.5	18.9
EVA III				
Apollo 15	6:00	4:49	10.5	5.1
Apollo 16	7:00	5:40	12.6	11.4
Apollo 17	7:00	7:15	12.6	11.6
Totals				
Apollo 15	20:00	18:33	33.0	27.9
Apollo 16	21:00	20:14	25.2	27.1
Apollo 17	21:00	22:05	33.3	33.8
Driving Time:				
Apollo 15		3:08		
Apollo 16		3:17		
Apollo 17		4:15		

Figure 3-23

Local Science Missions

The NASA 90 Day Study included a requirement for the capability to perform traverses up to 50 km away from the base, or 100 km round trip. Based on an EVA limit of 8 hrs and an average traverse speed of 8 kph (see previous page), this is not possible. A 30 km traverse (15 km away from the base) would leave approximately 4 hours for science experiments. This time is consistent with the data of Apollo missions 15, 16, and 17 shown on the previous page. A 64 km traverse (32 km away from the base) is a desirable maximum. Note again that the rover traverse speed is not limited by rover capabilities, but by crew safety and endurance considerations.

Local Science Missions

BOEING

Traverse vs. Science Time
Assume 8 hours EVA

Round Trip Distance, km	Traverse Time @ 8 KPH, hrs	Time Available for Science, hrs
30	3.75	4.25
50	6.25	1.75
64	8.0	0.0
100	12.50*	-

* - Requires Pressurized Rover

traverse requirements/Task 9.1 Final Report/6-4-90/DLT

Figure 3-24

Local Science Excursions

The requirements discussed on the previous page were formulated under the assumption of normal conditions. The chart on the facing page represents an analysis of contingency conditions (a rover failure on the excursion). The chart shows separate excursion requirements for cases where a rescue rover is available as well as where the astronaut would need to walk back to the base. Based on an EVA contingency limit of 10 hours, the excursion could be up to 27 km away from the base (54 km round trip). If an excursion of more than this distance is desired, space suit technology advancements would need to be made and the astronauts' comfort would be compromised.

Local Science Excursions

Contingency Ops. Rescue vs. Walk-Back

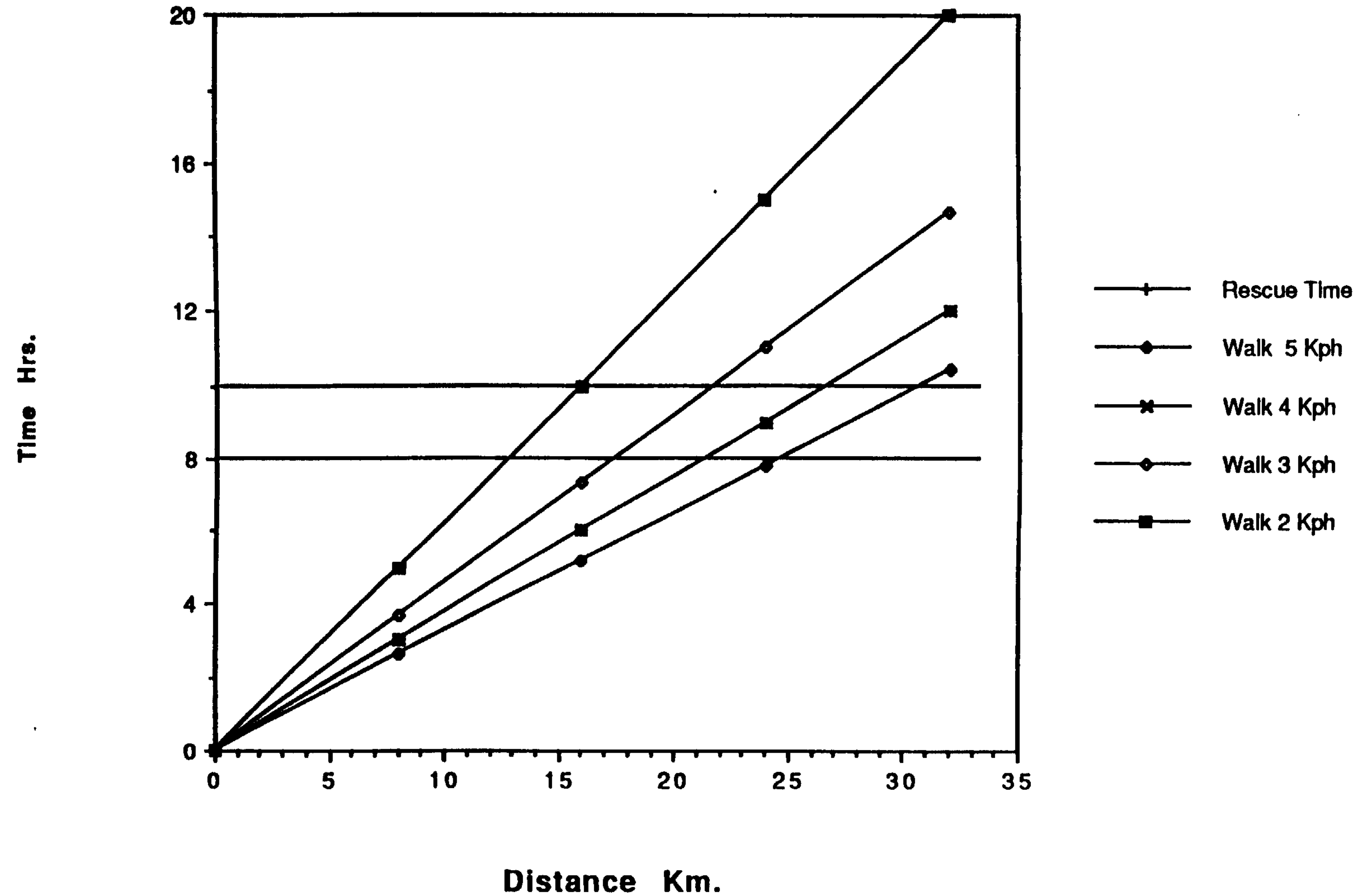


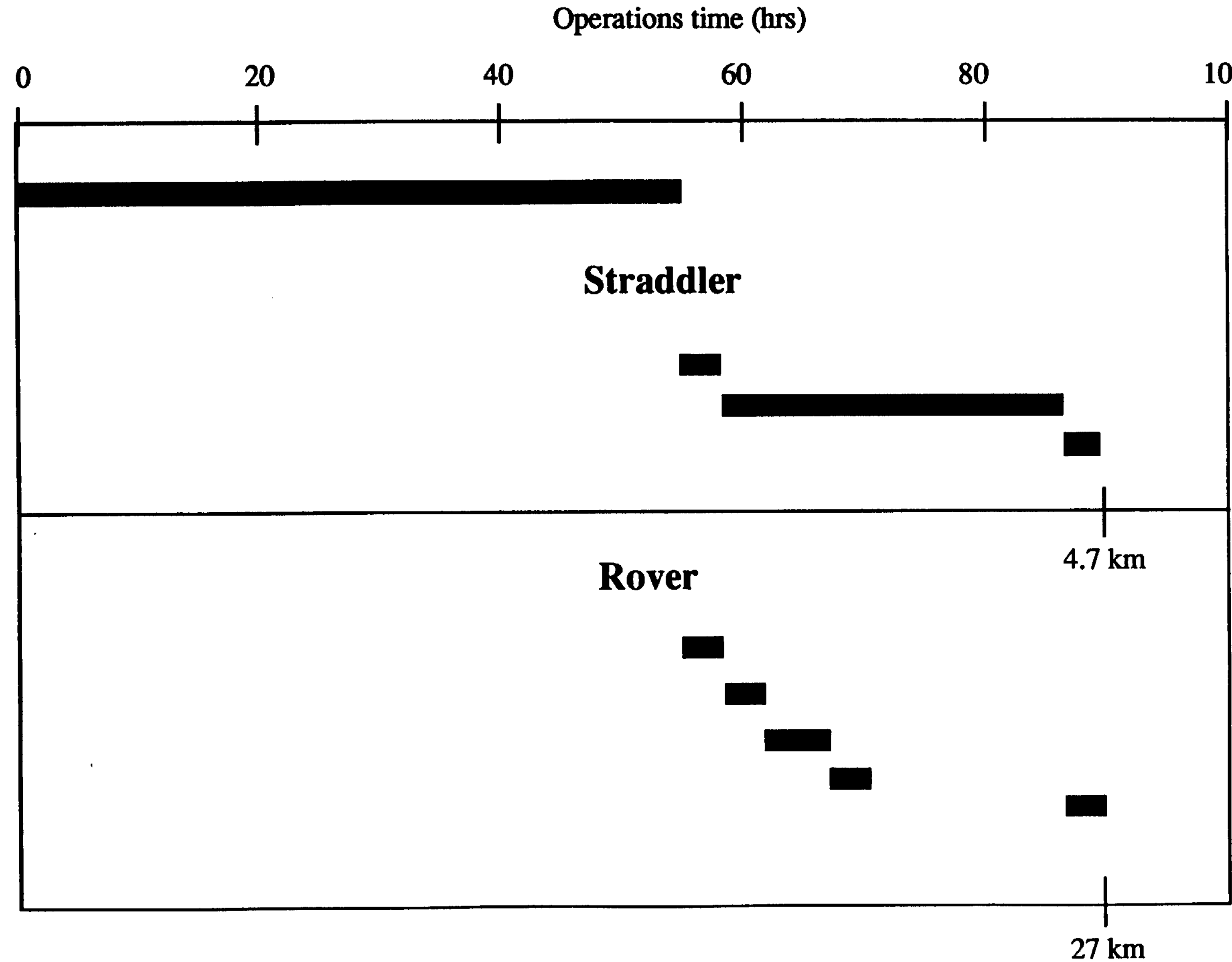
Figure 3-25

Flight "2" Operations

This chart shows the estimated timeline for the third lunar flight mission, separated by surface vehicle.

From a vehicle use standpoint, this mission has the shortest duration of the first five flights. The straddler is used sparingly while the rover is used mainly for crew transport and traverses for local science missions. It, therefore, compiles a fairly high mileage total compared to its actual useage (time in operation).

Flight "2" Operations



timeline2/Task 9.1 Final Report/6-4-90/DLT

Figure 3-26

Flight "3" Operations (Unmanned)

Flight "3" is an unmanned mission whose objective is to upgrade the habitat to provide the capability for a crew of four (4) to live and work on the lunar surface for up to one (1) year.

This flight involves tasks which repeat those of earlier flights. However, the Lab/AL unloading task may dictate the unloader payload capacity requirement due to the Lab's size and weight.

Flight "3" Operations (Unmanned)

3.1 Straddler offloads and deploys Lab/Airlock
- 3.1.1 LEV lands 48 hrs after lunar sunrise
- 3.1.2 Straddler traverses to LEV and offloads Lab/Airlock
- 3.1.3 Straddler traverses to Lab site

3.2 Straddler deploys Lab TCS radiators
- 3.2.1 Ground control integrates and checks out

3.3 Straddler deploys regolith bags on Lab

3.4 Straddler fills shroud bags with regolith
- 3.4.1 Straddler traverses to site and fills hoppers
- 3.4.2 Straddler lifts each hopper, positions over bag and empties into shroud bags

3.5 Straddler offloads and deploys power system #3
- 3.5.1 Straddler traverses to LEV and offloads power system #3 (installation and deployment)
- 3.5.2 Straddler traverses to power site
- 3.5.3 Straddler deploys and integrates power systems

3.6 Straddler moves LEV equipment to disposal area
- 3.6.1 Straddler traverses to LEV site and lifts equipment
- 3.6.2 Straddler traverses to disposal site and unloads equipment
- 3.6.3 Straddler returns to shelter

Flight "3"/Task 9.1 Final Report/6-4-90/DLT

Figure 3-27

Flight "3" Operations

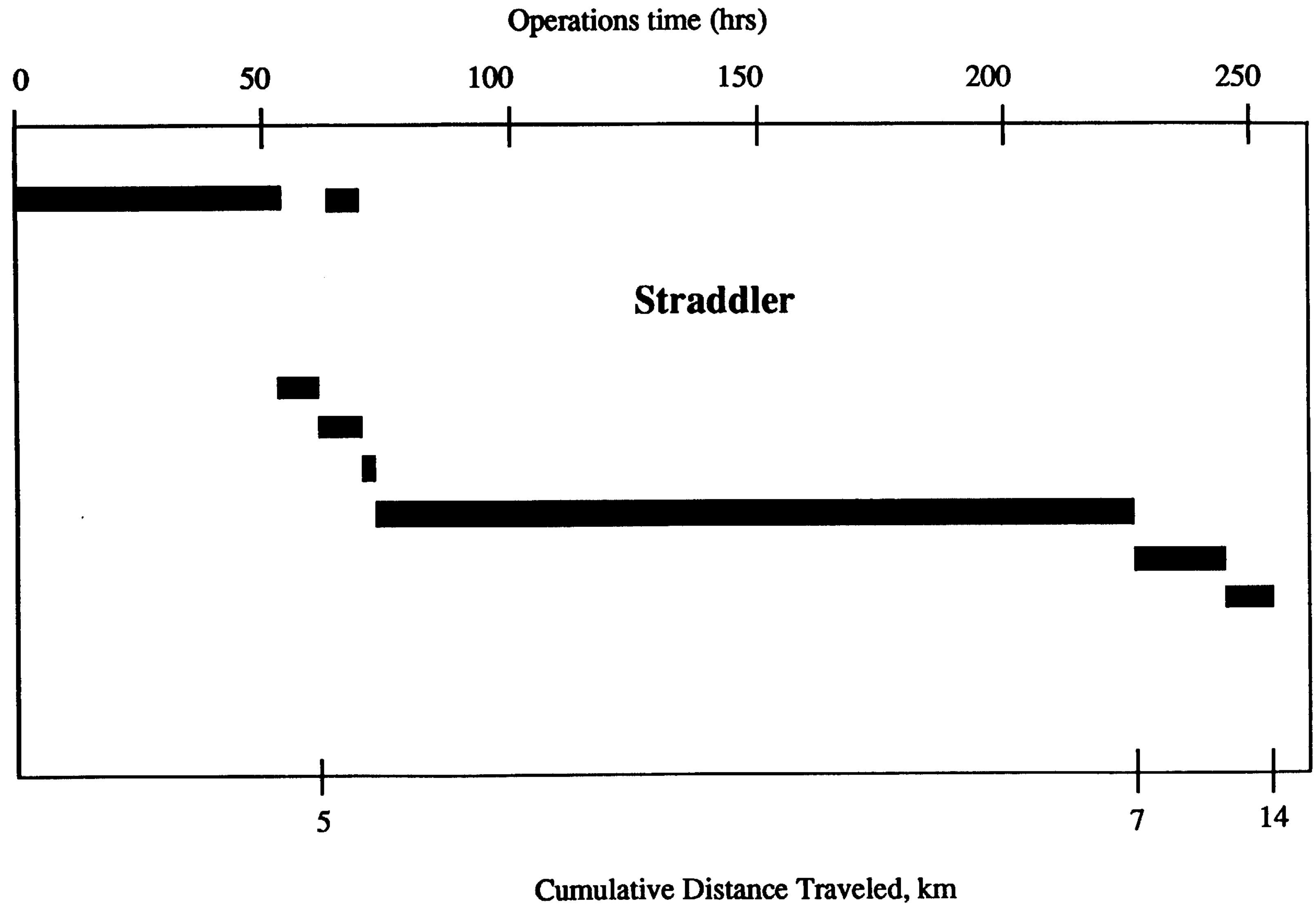
This chart shows the estimated timeline for the fourth lunar flight mission, separated by surface vehicle.

This mission includes only operations which are best suited for the straddler. The rover is not used.

If future missions show lengthy rover operations, this flight is a potential time to ease those burdens.

Flight "3" Operations

BOEING



timeline3/Task 9.1 Final Report/6-4-90/DLT

Figure 3 28

Flight "4" Operations (Manned)

Flight "4" is a manned mission whose primary objective is to conduct the first four (4) crew/six (6) month mission at upgraded Hab/Lab facility.

In this mission the crew begins to make extended excursions in the Rover. This mission is primarily for performance of scientific experiments and checkout of existing equipment and facilities.

Because of the mission's long duration nature, the Rover may be required to repeat several trips in the consumables transfer task. Due to an EVA limit and high payload requirements, the payload capacity requirement for the Rover could be dictated by this mission.

Flight "4" operations (Manned)

4.1 Straddler offloads LEV Servicer
- 4.1.1 LEV lands 48 hrs after lunar sunrise
- 4.1.2 Straddler positions over LEV and attaches to LEV Servicer
- 4.1.3 Straddler extends and lifts LEV Servicer & support equipment
- 4.1.4 Straddler moves to position and lowers LEV Servicer

4.2 Straddler deploys thermal tent over LEV

4.3 Crew connects umbilical to LEV using power
- 4.3.1 Crew calls Rover to position from position in shelter
- 4.3.2 Crew transfers EVA to Rover
- 4.3.3 Crew traverses to LEV Servicer site
- 4.3.4 Crew connects umbilical on Servicer

4.4 Crew transfers consumables to Hab
- 4.4.1 Crew loads Rover with consumables
- 4.4.2 Crew traverses to Hab via Rover
- 4.4.3 Crew unloads Rover and places consumables in Hab

4.5 Crew conducts surface science
- 4.5.1 Crew checks out Rover systems
- 4.5.2 Crew loads science equipment onto manned Rover
- 4.5.3 Crew traverses to science site
- 4.5.4 Crew unloads Rover and engages experiments
- 4.5.5 Crew loads Rover and traverses to Hab

4.6 Crew closes out outpost
- 4.6.1 Crew unloads and loads Rover
- 4.6.2 Crew closes Hab

4.7 Crew transfers to LEV via Rover
- 4.7.1 Crew unloads and laods Rover with necessary equipment
- 4.7.2 Crew boards Rover and traverses to Hab
- 4.7.3 Crew transfers any equipment from Rover to LEV
- 4.7.4 Crew enables Robotic Rover systems
- 4.7.5 Rover moves to shelter

4.8 Straddler moves LEV equipment to disposal area
- 4.8.1 Straddler traverses to LEV area and lifts equipment
- 4.8.2 Straddler traverses to disposal area and lowers LEV equipment
- 4.8.3 Straddler traverses to shelter

Flight "4"/Task 9.1 Final Report/6-4-90/DLT

Figure 3-29

Flight "4" Operations

This chart shows the estimated timeline for the first long duration stay, separated by vehicle.

Because this mission is the first 6 month stay at the lunar base, it is the least defined in terms of vehicle usage.

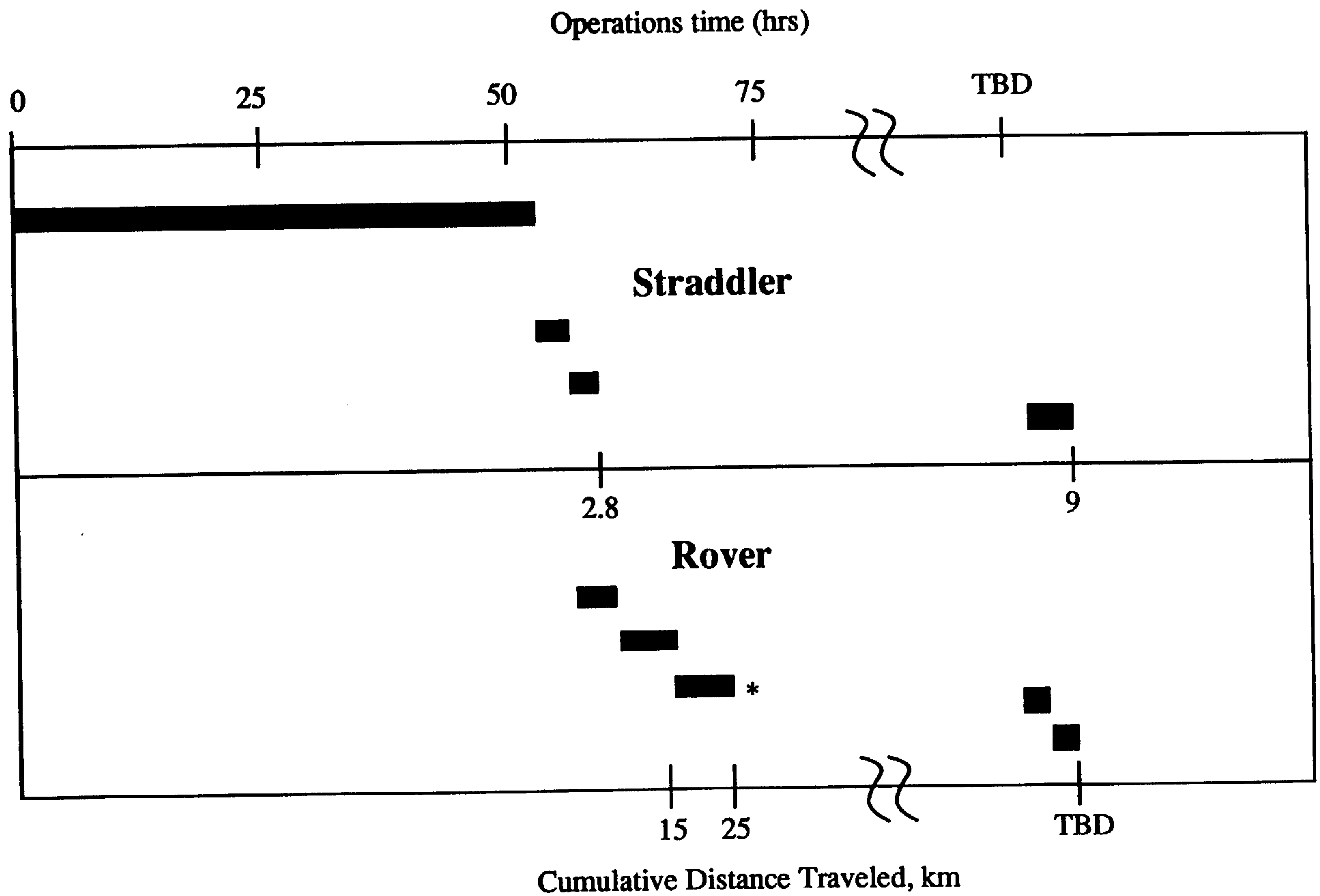
It is anticipated that the rover will perform several local science missions during the stay. Since the number and frequency fo these EVA missions are undefined, an accurateprofile of vehicle usage is difficult to estimate.

This timeline presents a need for a hard requirement on the maximum distances involved in these initial traverses. Because there is no rescue capability (an additional rover) available, it is assumed that the traverses will be limited to walk-back ranges, or approximately 10 km. This maximum traverse distance will affect the required vehicle speed and power.

The vehicle use depicted on the chart is an estimate based on EVA missions of Apollo 15, 16, and 17.

Flight "4" Operations

BOEING



* - This operation may be repeated several times over the 6 month stay

timeline4/Task 9.1 Final Report/6-4-90/DLT

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Scheduled Vehicle Usage

Scheduled vehicle usage is important for several reasons including life and fatigue analysis of vehicles and components and timeline analysis. The chart below shows vehicle usage through the first five flights in terms of hours used. As would intuitively be expected, the straddler is used more on the unmanned flights while the rover is used extensively on manned missions. Values for flights 2 and 4 may be greater depending on the frerquency and number of local science excursions on those flights.

ADVANCED CIVIL SPACE SYSTEMS

Scheduled Vehicle Usage

BOEING

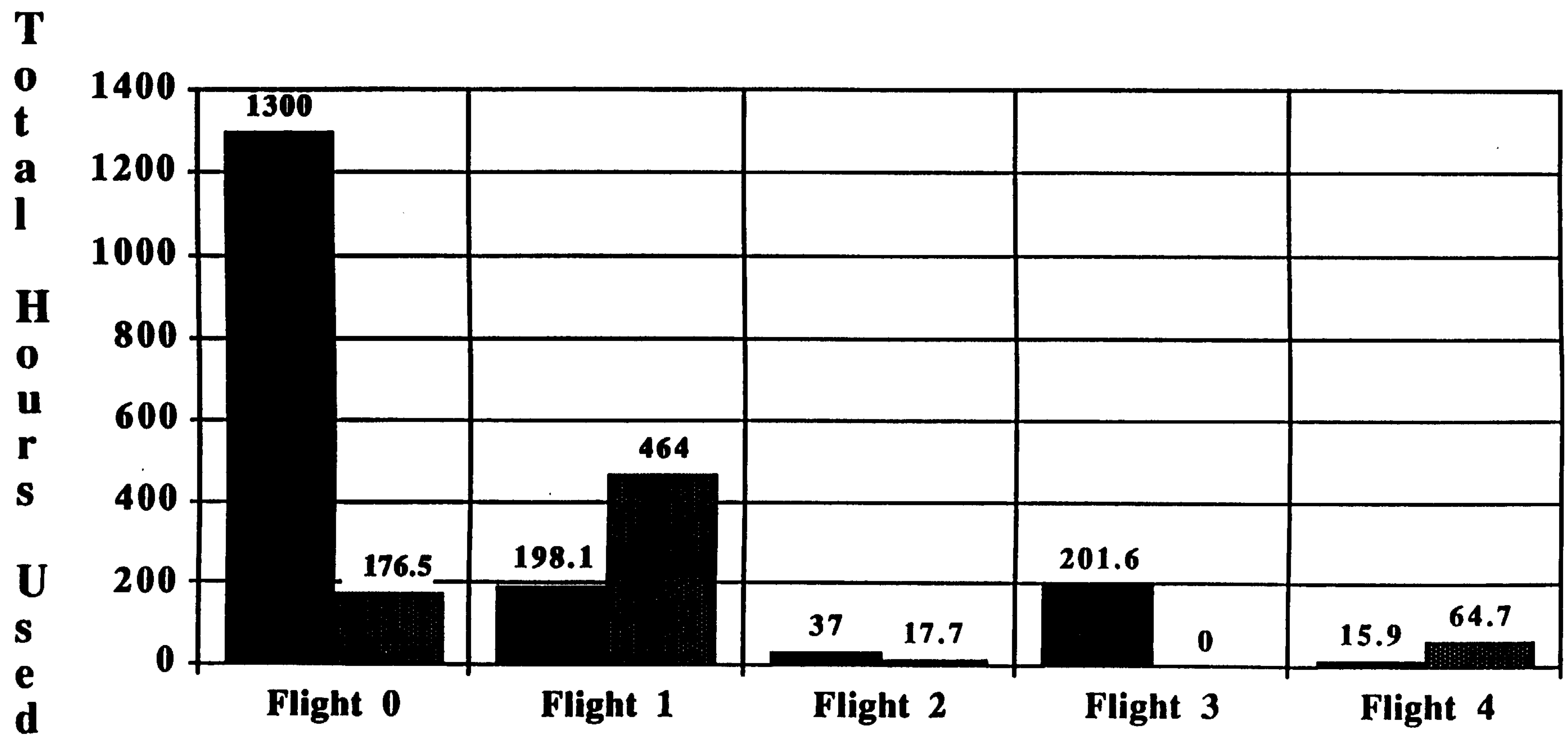


Figure 3-31

Cumulative Vehicle Usage

The chart below shows cumulative vehicle usage through the first five flights in terms of hours used.

ADVANCED CIVIL SPACE SYSTEMS

Cumulative Vehicle Usage

BOEING

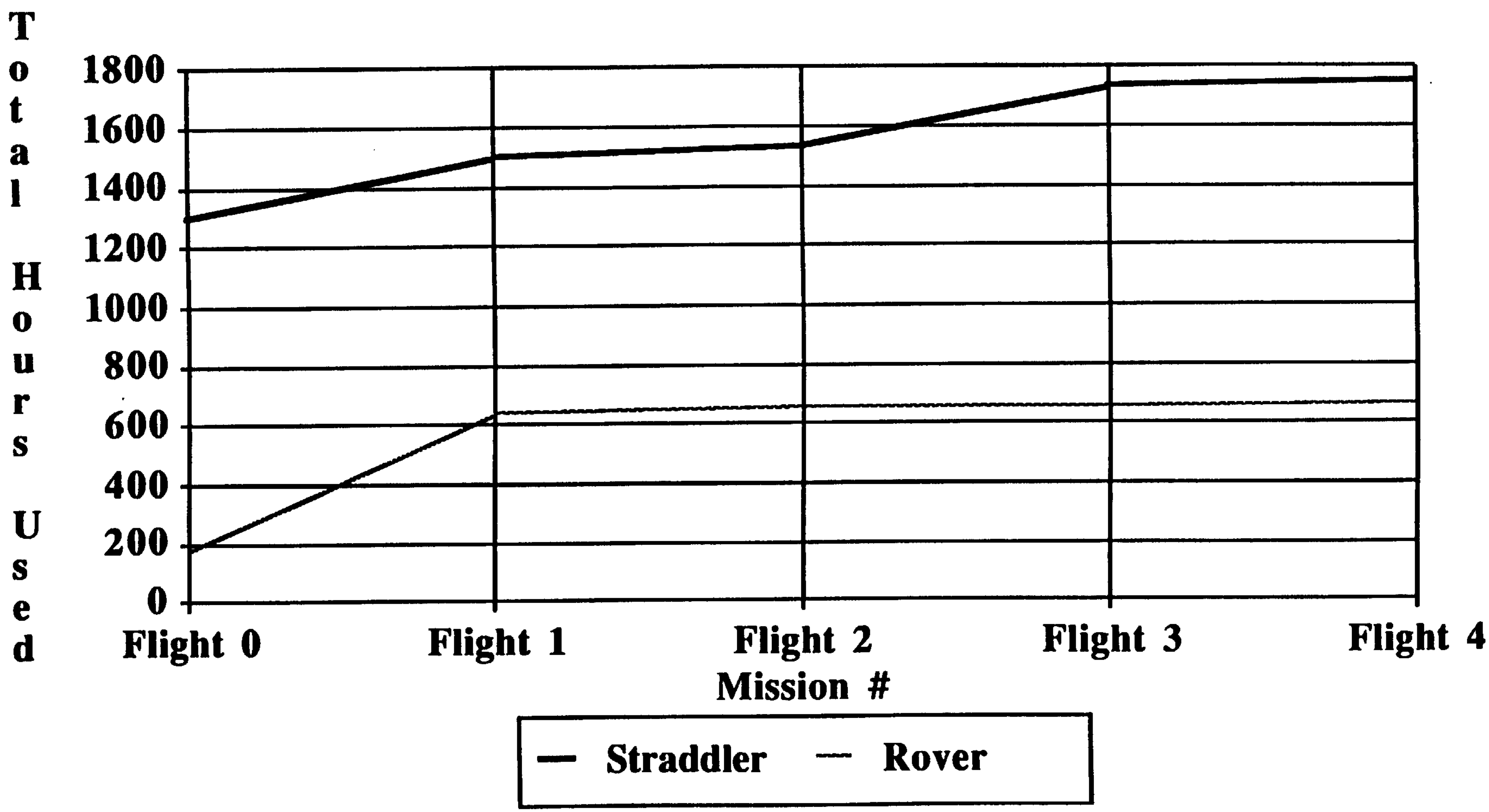


Fig 3-3

Scheduled Vehicle Usage

The chart below shows vehicle usage for each of the first five flights in terms of kilometers traveled. As expected, the rover is almost exclusively used for travelling operations due to the straddler's relatively slow traverse speed.

Scheduled Vehicle Usage

BOEING

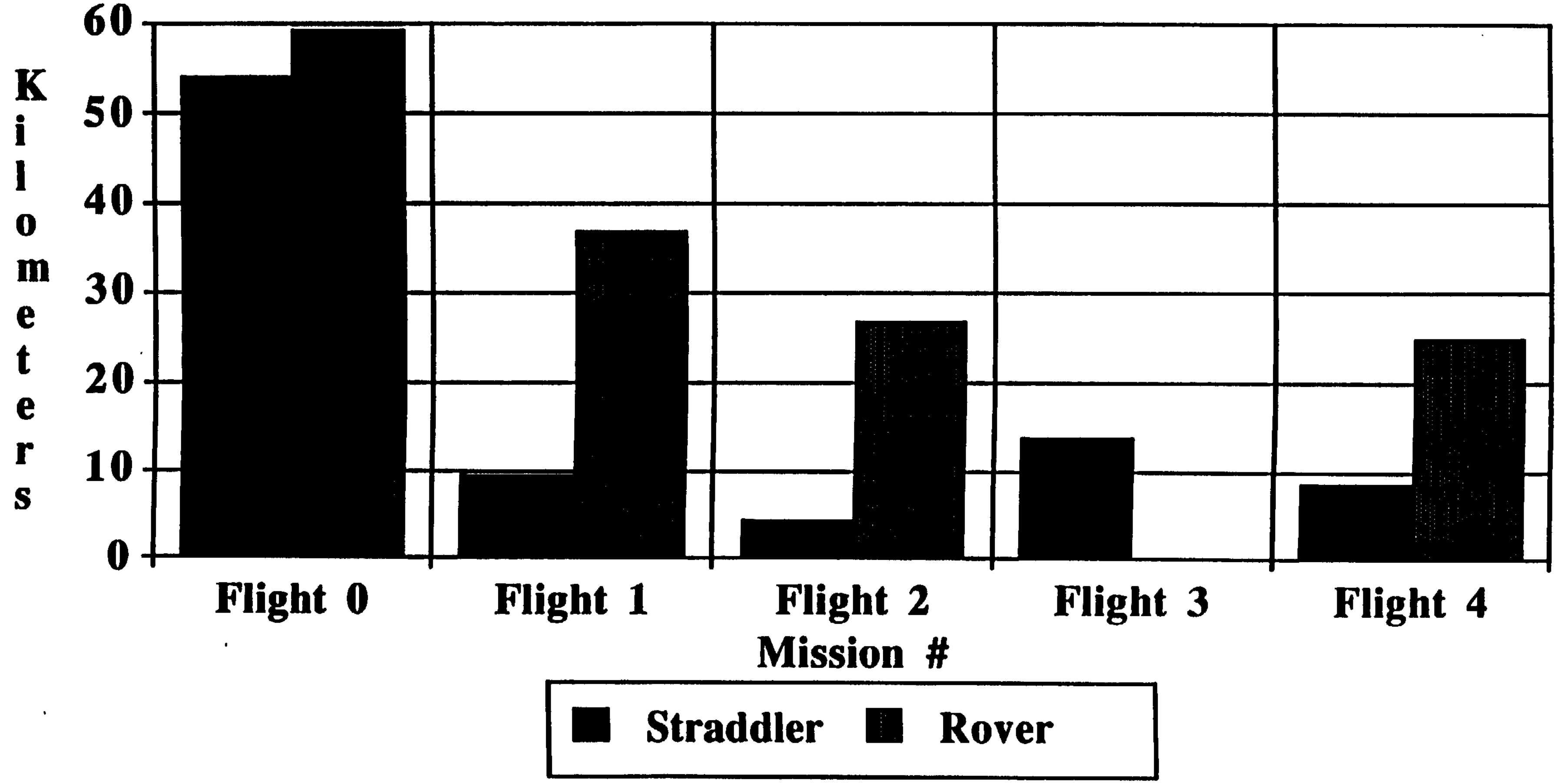


Figure 3-33

duled Vehicle Usage

The chart below shows cumulative vehicle usage through the first five flights in terms of kilometers traveled.

Cumulative Vehicle Usage

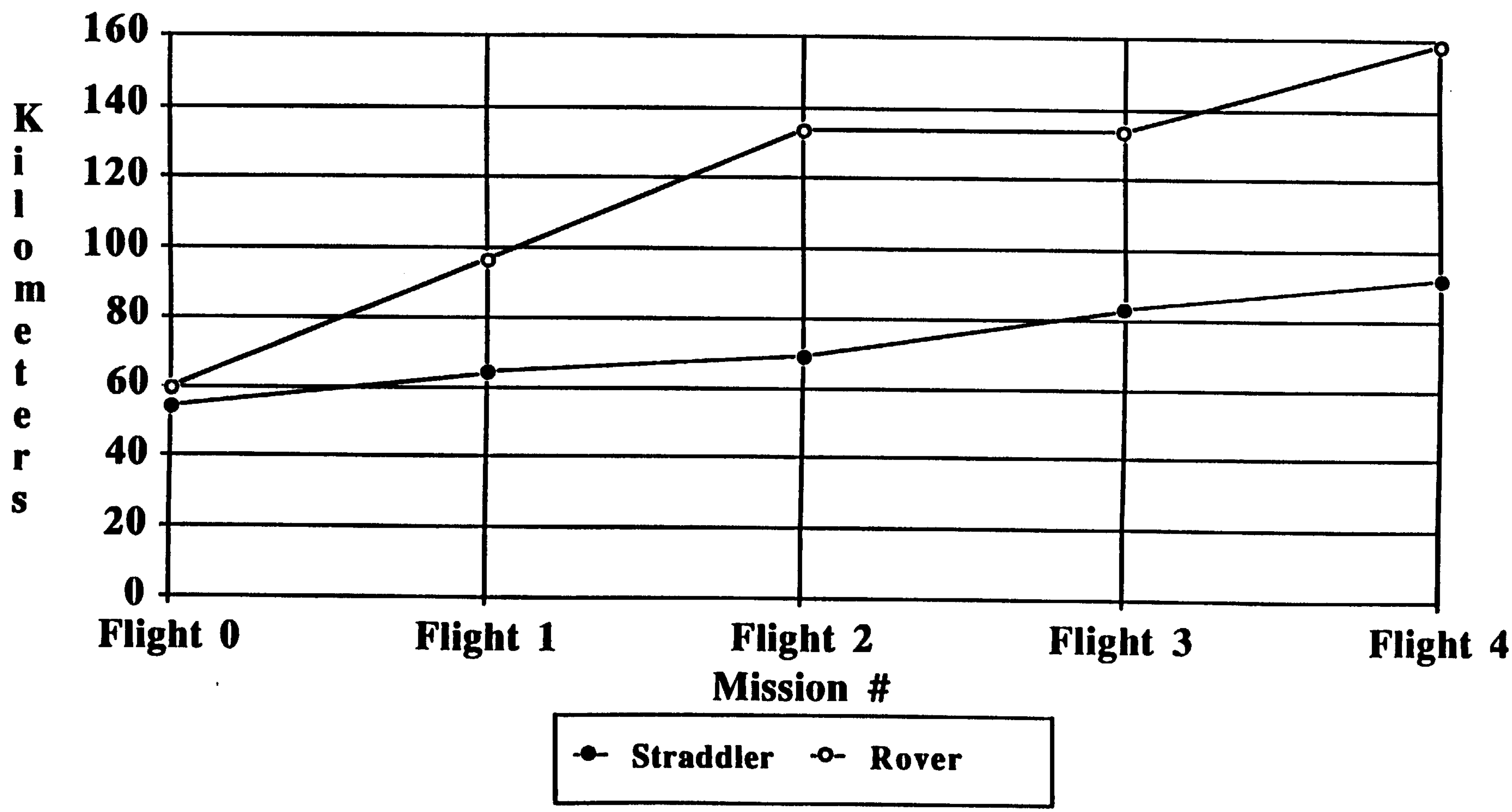
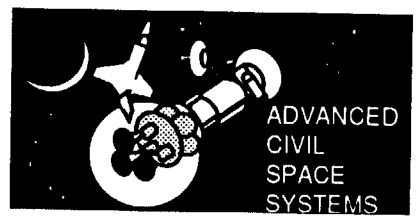


Figure 2-24

4.0 Perfromance / Operations Requirements



BOEING

Preliminary Vehicle Requirements

This chart is intended to represent two aspects of vehicle definition and development:

First, capabilities of several of the vehicles we anticipate for the early lunar base build-up are compared against the Apollo Lunar Roving Vehicle and MOLAB capabilities. This gives a rough estimate of the overall problems which are new or compounded in the lunar base vehicles, providing a basis for initial concept and technology development needs. These needs should be addressed and evaluated before any vehicle system requirements or concepts can be accurately formulated.

Secondly, the chart represents some requirements and some vehicle attributes to accomplish the base build-up as it is currently envisioned in the most reasonable, efficient manner. For example, the ability to drill 8m is considered necessary for some surface prep or blasting operations, but the rate of drilling is dependent on the vehicle design and mission time constraints. The rate, therefore, is considered a vehicle attribute rather than a requirement and is is assumed for purposes of formulating efficient mission timelines.

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Preliminary Vehicle Requirements/Attributes

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Requirement Categories

Vehicle Description	Uses	Operation Mode(s)	Rates	Payload Capacity	Weight (Mass)	Size Envelope	Power Reqmt's	Range	Oper. Lifetime
Straddler	Unloading LEV	Tele-oper	.33 - 1 kph	25 mt	10 mt	TBD	10 kw peak	TBD	300 hrs
Drill	Deploy pyro		4 m/hr	N/A	TBD	10 cm dia.	TBD	N/A	N/A
Scraper	Surface prep		.33 kph	TBD	TBD	1 cu. m.	N/A	N/A	N/A
Hoist	Load/unload		20 m/hr	25 mt	TBD	TBD	10 kW peak	N/A	N/A
Shovel	soil extraction		3.4 cu. m/hr	TBD	TBD	1 cu. m.	TBD	N/A	N/A
Unpress Rover	Transfers	Manned and/or tele-oper	.25 - 17 kph	**2,000 #	1,600 #	TBD	3 kw peak	1000 km	300 hrs
Drill	Deploy beacons		2 m/hr	N/A	TBD	8 m length	TBD	N/A	N/A
Scraper	Lt surface prep		.4 kph	TBD	TBD	.3 cu. m.	N/A	N/A	N/A
Brush	Lt surface prep		TBD	N/A	TBD	TBD	TBD	N/A	N/A
Pressurized Rover	Sci excursions	Manned	TBD	TBD	4.5 mt	100 cu m.	12 kw peak	500 km	TBD
Drill	geolog. sample		4 m/hr	N/A	TBD	10 m length	TBD	N/A	N/A
High Reach Manipulator Truck	Straddler support Con. Hab assy	Manned	TBD	TBD	TBD	TBD	TBD	TBD	N/A
Apollo LRV*	Transfers	Manned	14 kph max.	**1,140 #	462 #	3.1 x 1.83m	2 @ 36V 115 A-hrs	92 km	78 hrs
MOLAB*	Sci. excursions	Manned	NA	**1,750#	6,500#	200 cu. ft.	NA	400 km	336 hrs

* Boeing designs, included for comparison purposes
** Includes approximate weight of two Astronauts

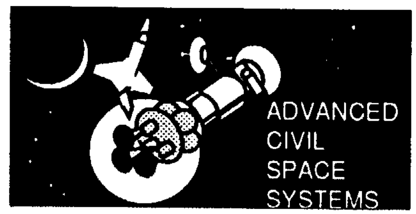
vehicle requirements/Task 9.1 Final Report/6-4-90/DLT

Figure 4-1

Key Performance Parameters

Requirements which affect several of the evaluation measures - and therefore the sensitivity of the study results - are denoted key performance parameters. The chart below shows a preliminary attempt to determine these parameters. They will be the emphasis of mission and vehicle concept analyses.

5.0 Concepts Definition



BOEING

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Modular Structure Tractor Concept

Shown below is a modularized vehicle concept. The vehicle consists of four (4) sections which are interchangeable based on what function the overall vehicle is serving.

The intent of the chart is to stress the importance of vehicle component arrangement. Many tasks can be done with the same basic components. Different arrangements, however, are optimum for different tasks.

Modular Structure Tractor Concept

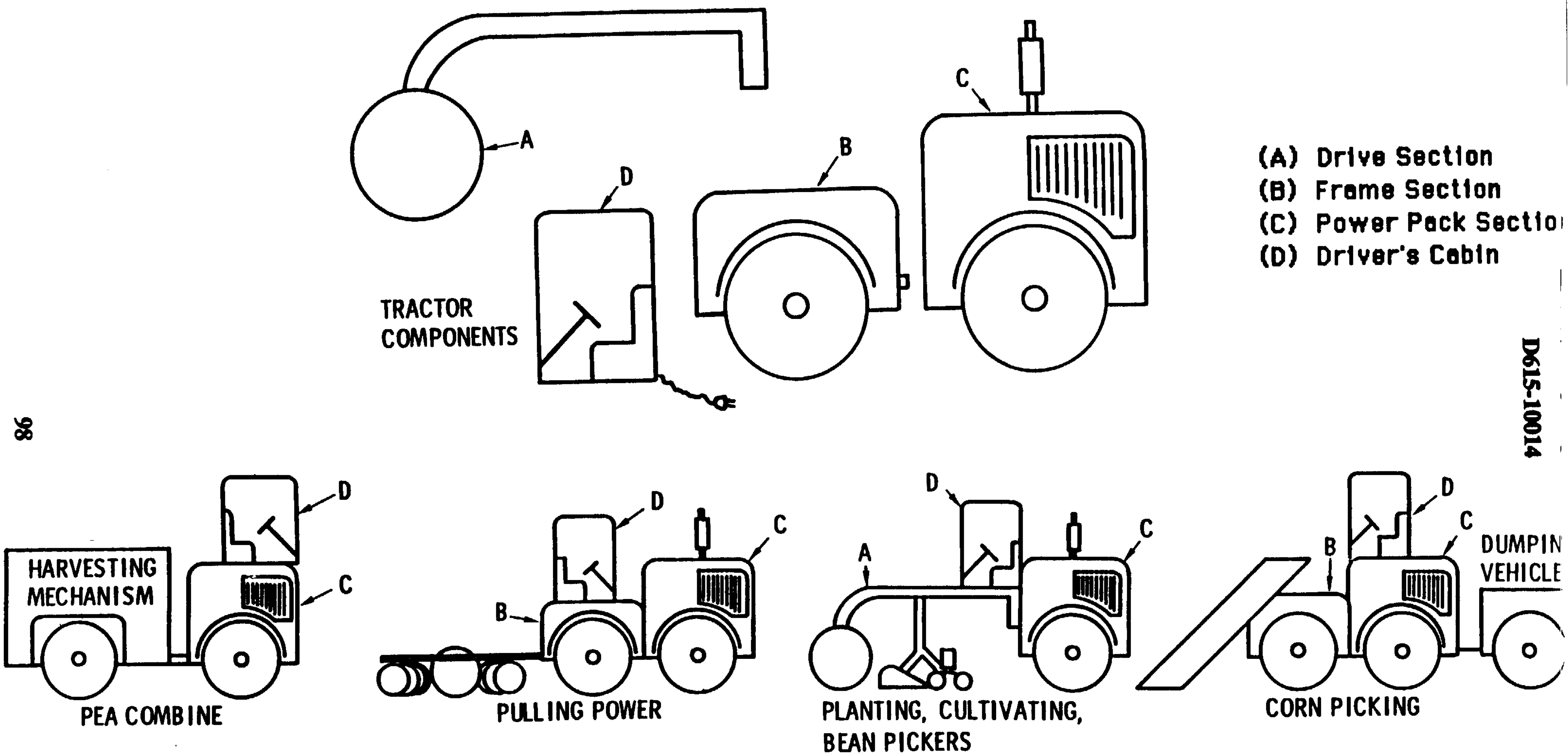

Figure 5

Three-Unit Articulated Vehicle

Shown below is a concept of how to perform multiple tasks without using multiple vehicles. A multiple function vehicle would be very beneficial in the lunar environment due to the extreme limitations put on launch weight, and also for the variety of tasks carried out in a single lunar mission.

ADVANCED CIVIL SPACE SYSTEMS

Three-Unit Articulated Vehicle

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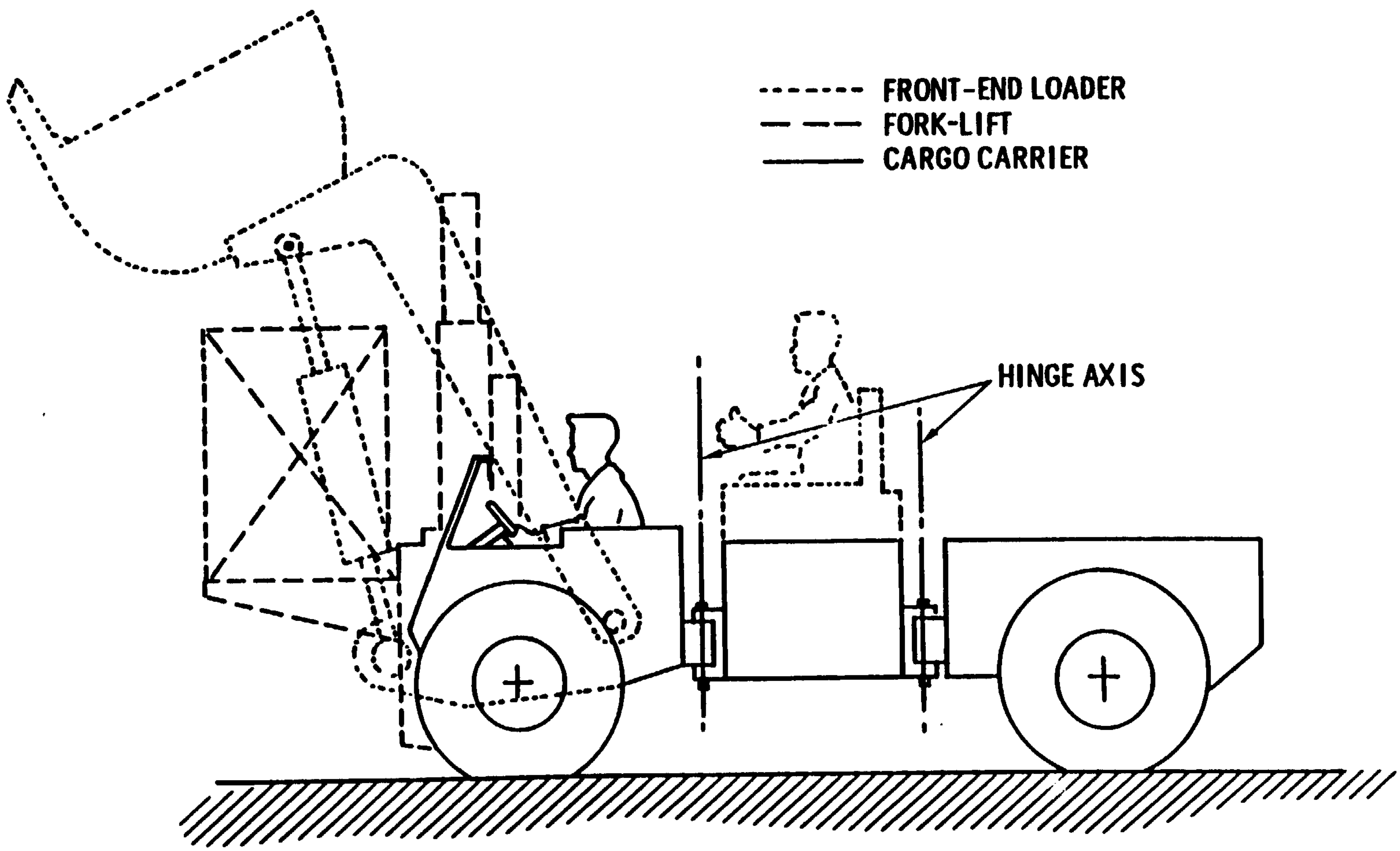


F_ e 5

Common Component Dump Trucks

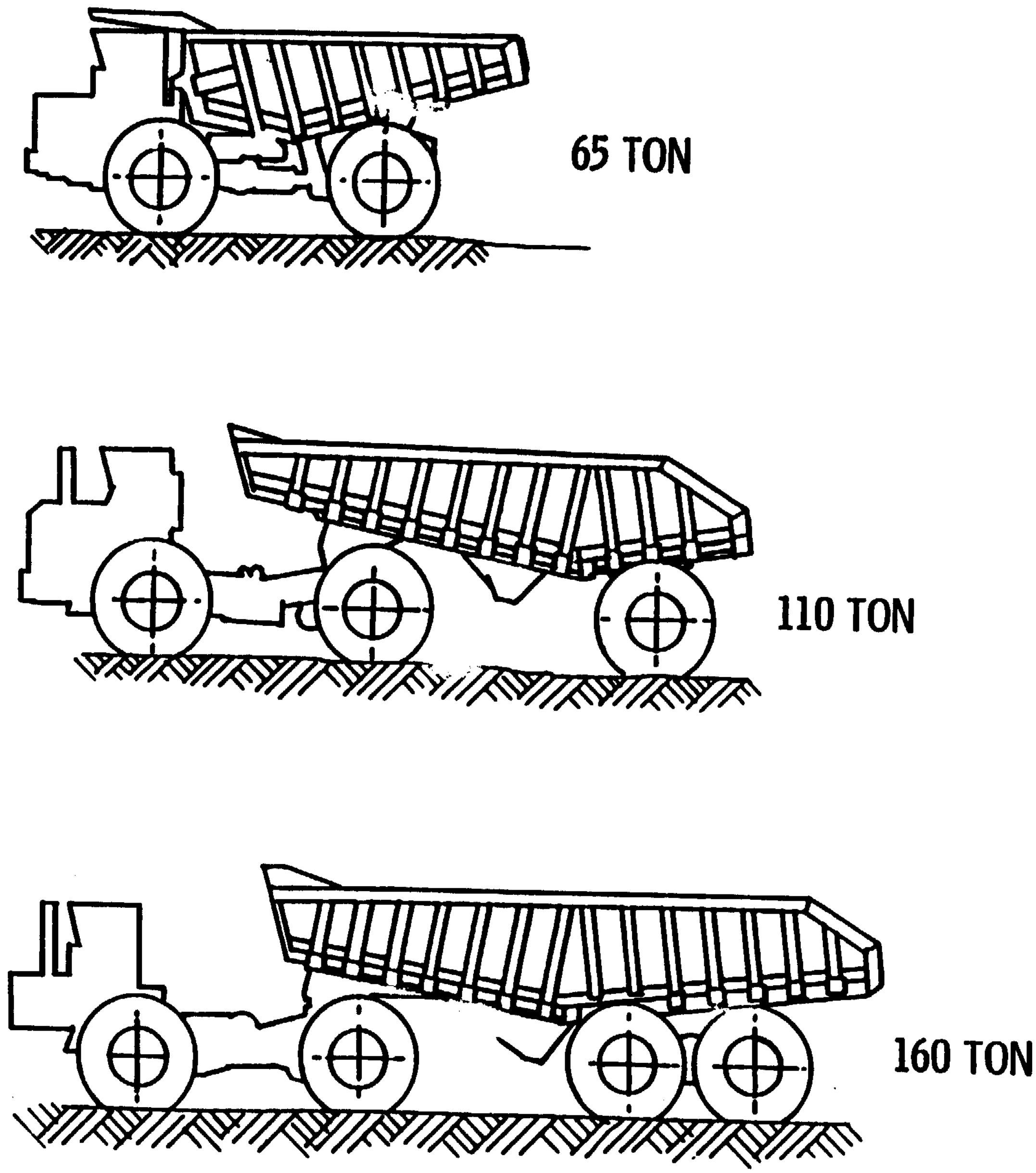
Mission scenarios have shown that a need exists for a large hauling vehicle, but the size needs to be determined by study.

This concept is shown below as applied in earth construction. The concept has a cab, transmission, and a box to carry the load. The trade study examines the variations resulting from a range of vehicle payloads. The final vehicle is then selected on the basis of the output of the base to meet its overall mission objective.

ADVANCED CIVIL SPACE SYSTEMS

Common Component Dump Trucks

BOEING



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Unloading Vehicle Options

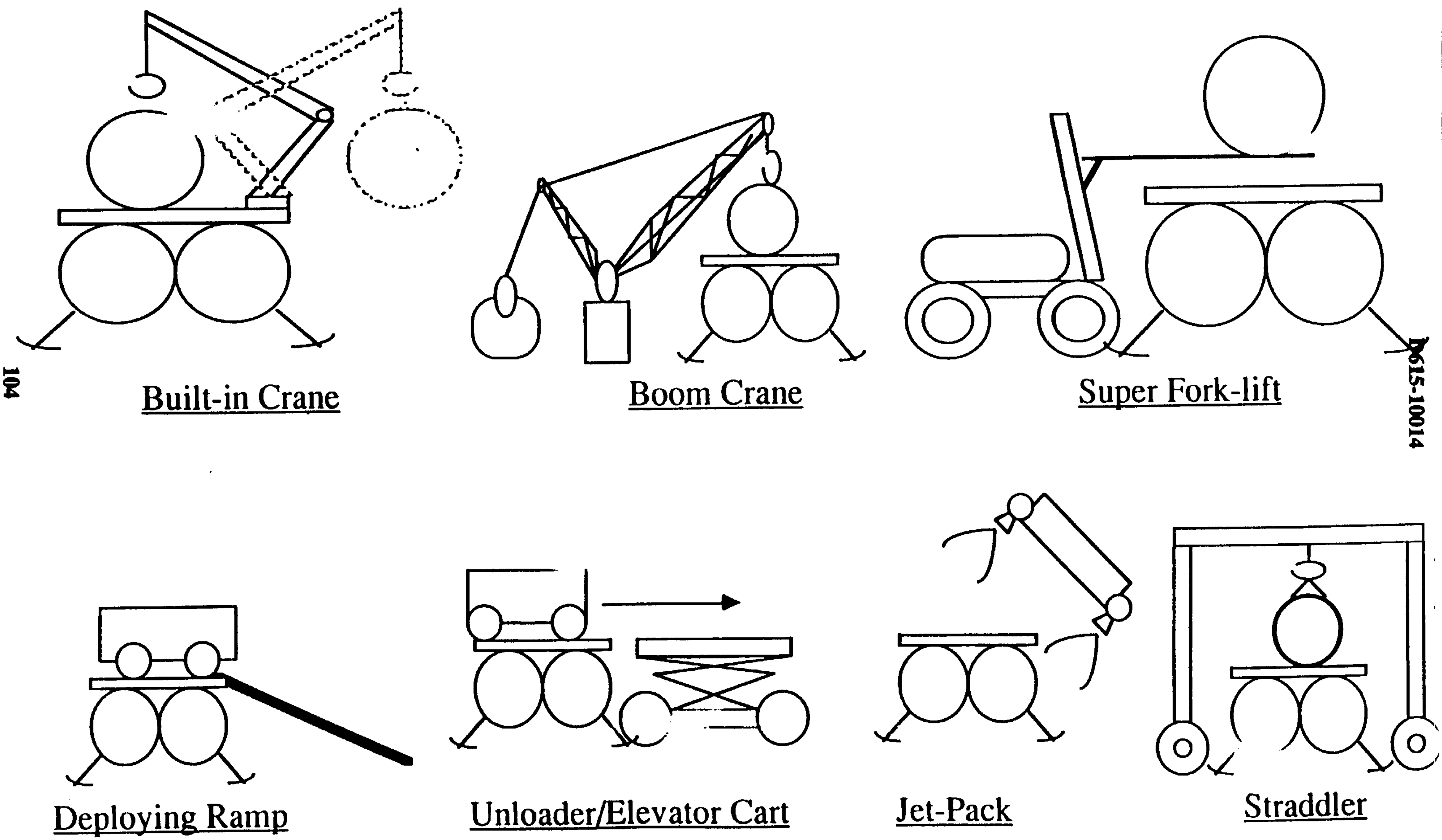
A trade study was conducted that defines a concept for a lunar vehicle to be used for unloading and transporting equipment.

Seven (7) basic vehicle configurations (shown below) were considered which represent various methods of unloading and transporting equipment.

The analysis factors used in this trade study are shown on the following chart.

The trade study was necessary to define a best unloading vehicle for preliminary missions and operations analysis. This trade study was also necessary to verify the use of the concept described for unloading in the NASA 90 Day Study.

Unloading Vehicle Options



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Unloader Trade Study

Nine (9) attributes were selected as critical parameters in the unloader study. The performance of each concept was rated as to its design, performance and relative capability (performance rating) to meet the objective.

The boxes highlighted identify those that rate superior in that particular category. Note that "high" is not always the optimum rating. For instance, high weight is undesireable while high reach capability is desired.

ADVANCED CIVIL SPACE SYSTEMS

Unloader Trade Study

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Vehicle Description	Weight (Mass)	Risk (Payload)	Power Reqmt's	Lift Capacity	Reach	Stability	Manu.	Addit. Equip. Reqmt's	Assembly Required
	FACTORS								
Built-In-Crane	Moderate	Low	Moderate	Moderate	Moderate	Moderate	Low	High	Low
Boom Crane	Low	Moderate	Moderate	High	Moderate	Moderate	Low	High	High
Sup[illegible]k Lift	High	Moderate	Moderate	Moderate	Moderate	Moderate	High	Low	Moderate
Deploying Ramp	Low	High	Low	High	Low	Moderate	Low	Moderate	Low
Unloader/Elev Cart	Moderate	[illegible]	Moderate	Moderate	Low	High	Moderate	High	Moderate
Jet-Pack	Moderate	High	High	Low	High	Low	High	Moderate	Moderate
Straddler*	High	Low	High	High	High	High	Moderate	Low	Moderate

* Successful Trade Study Candidate

Figure 5-5

Vehicle Concept Trades
Unloader Configuration Trade

Of the seven (7) vehicles considered, the Straddler scored the highest total score based on the nine (9) factors analyzed.

The Straddler had the lowest risk, highest lift capacity, highest reach, highest stability and lowest additional equipment requirements of the vehicles considered.

This conclusion was also consistent with 90-Day Study vehicle uses.

The Boeing version "Straddler" name is synonomous with the LEVPU name used in the JSC 90 Day Study.

Vehicle Concept Trades
Unloader Configuration Trade

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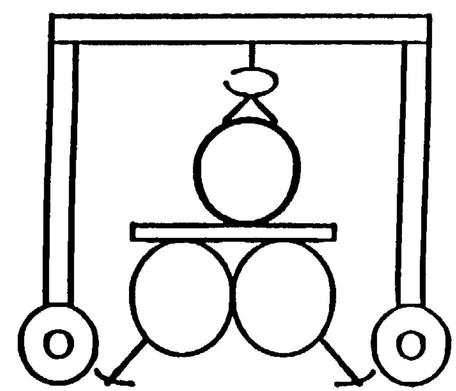
- Built in Crane
- Boom Crane
- Super Fork Lift
- Deploying Ramp
- Elevator Cart
- Jet Pack
- Straddler

Straddler (or LEVPU)

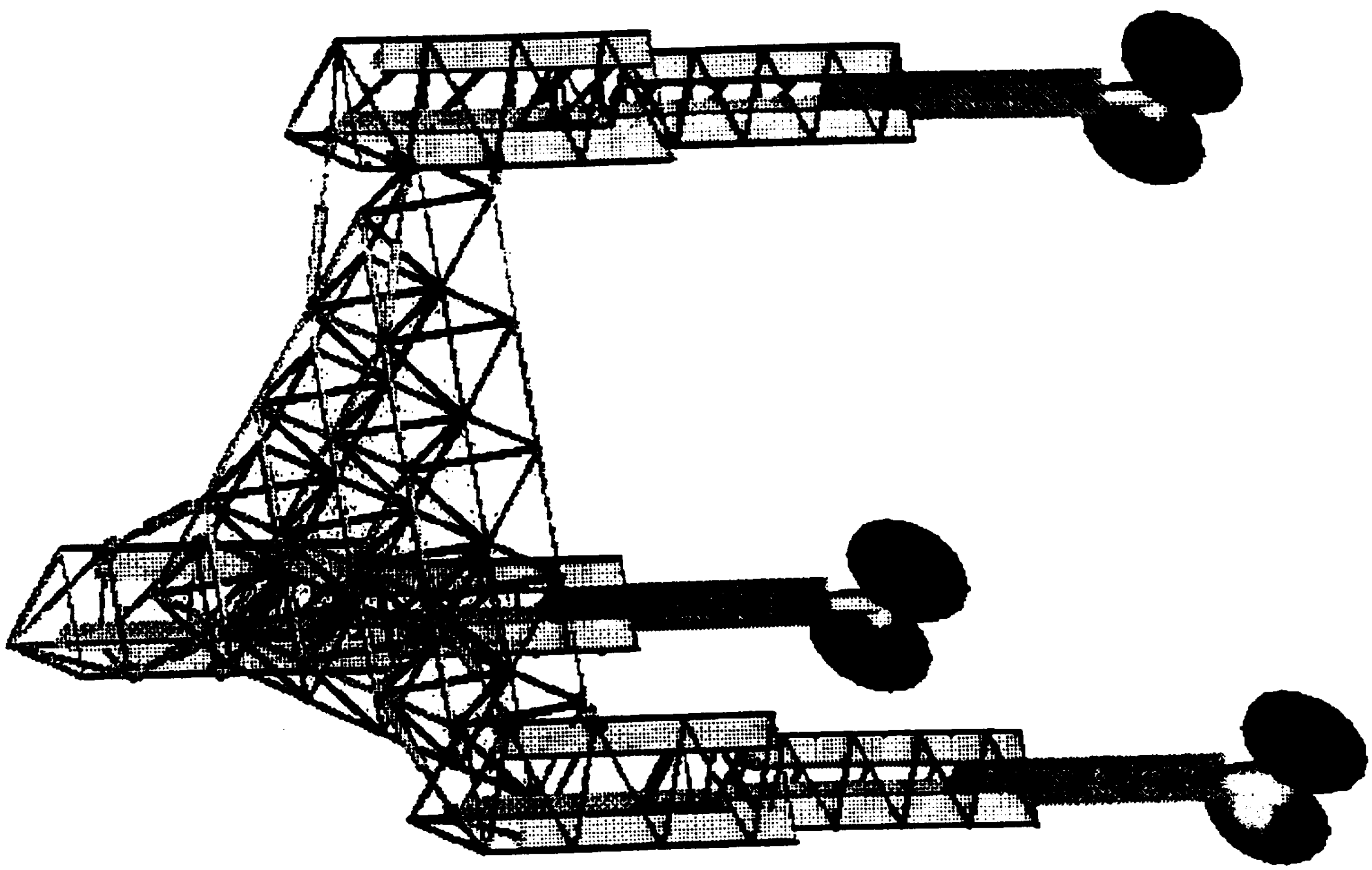


unloaders/Task 9.1 Final Report/6-4-90/DLT

Figure 5-6

Straddler Concept

Shown below is an isometric view of the Straddler. The dimensions used were taken from the NASA 90 Day Study.



F e 5-

Straddler Concept

This chart represents the actuator mechanisms at the top of the legs of the straddler to allow for tripod motion of the legs.

FP Straddler concept 2/Task 9.1 Final Report/6-4-90/DLT

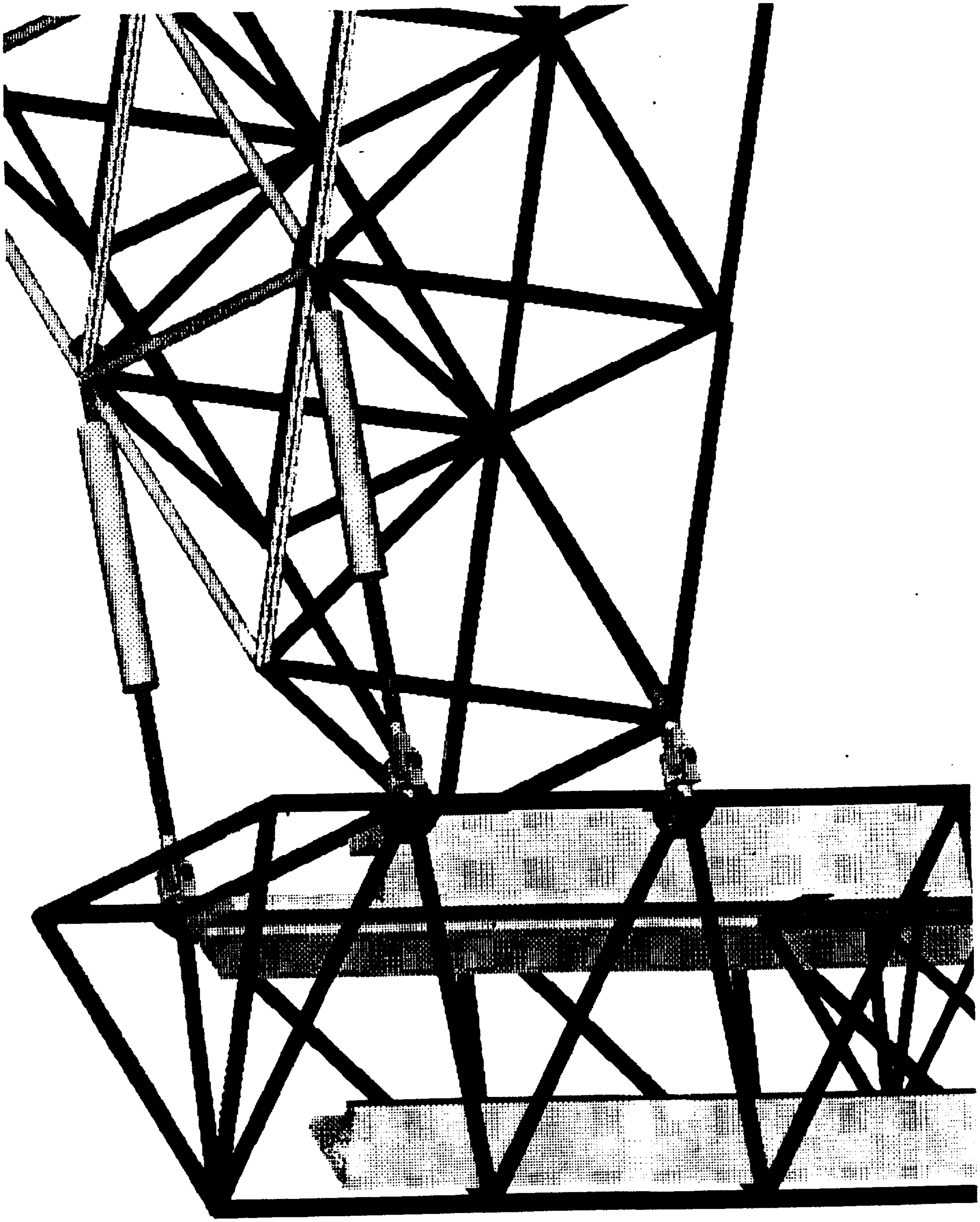


Figure 5-7 cont.

Multipurpose Light Utility Vehicle Options

A trade study was performed that attempts to select an optimum concept for a multipurpose light utility vehicle.

Four (4) vehicle task requirements (shown below) were considered to represent the various tasks this vehicle is expected to perform.

The analysis factors used in this trade study are shown in the following chart.

The trade study was necessary to define a "best" vehicle to perform the tasks described.

Multipurpose Light Utility Vehicle Options

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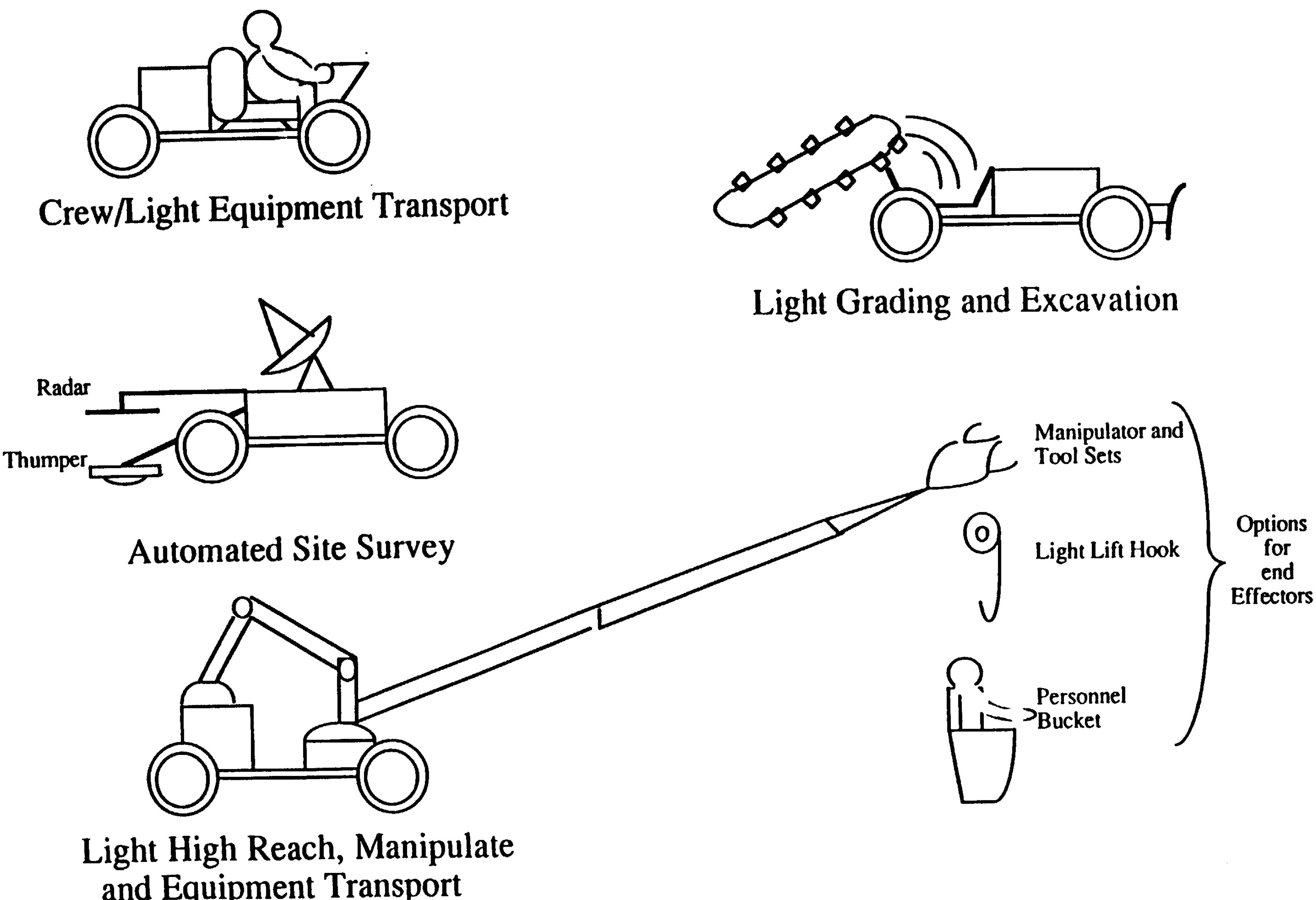

Figure 5-9

Multipurpose Light Utility Vehicle

Nine (9) attributes were selected to describe factors that relate to utility vehicle design and performance. Each vehicle concept was given a rating of low, medium or high based on its relative capability to meet the objective.

The boxes highlighted are the ones that rate highest in that particular category.

Note that high is not always the optimum rating. For instance, high weight is undesireable while high reach is desired.

Multipurpose Light Utility Vehicle

Vehicle Description	Weight (Mass)	Lift Capacity	Reach	Ease of Maint.	Versatility	Power Reqmt's	Adapt. for Manned Operations	Req. for Prepared Surface	Traverse Speed
	FACTORS								
Crew/Light Equipment Transport*	Low	Low	Low	Moderate	Moderate	Low	High	Moderate	High
Light Grading & Excavating**	Moderate	Moderate	Low	Moderate	Low	Moderate	Moderate	Low	Moderate
Automated Site Survey*	Low	Low	Moderate	High	High	Moderate	Moderate	Moderate	Moderate
Light High Reach, Manipulate & Equip Transport**	High	High	High	Moderate	Moderate	High	Moderate	Moderate	Low

* Tied for Successful Trade Study Candidate.
** Tied for Second Most Successful Trade Study Candidate.

Figure 5-9

Vehicle Concepts Trade
Multipurpose Vehicle Configuration Trade

Of the four (4) vehicles concepts considered, the scoring indicated equal values for the crew/light equipment transport and the automated site survey. Also equal scores were attained for the light grading/excavator and the light high reach manipulate & equipment transport.

Based on these findings, a need for two (2) types of utility vehicles seems to be the best solution. A revised concept sketch is shown below.

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Vehicle Concept Trades
Multipurpose Vehicle Configuration Trade

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Crew/Light Equipment Transport

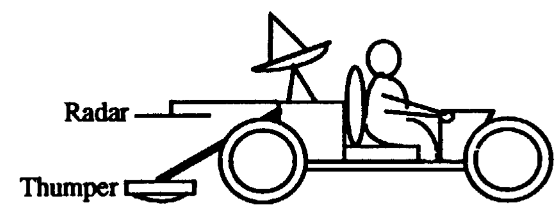
Light Grading and Excavating

Automated Site Survey

Light High Reach, Manipulate & Equipment Transport

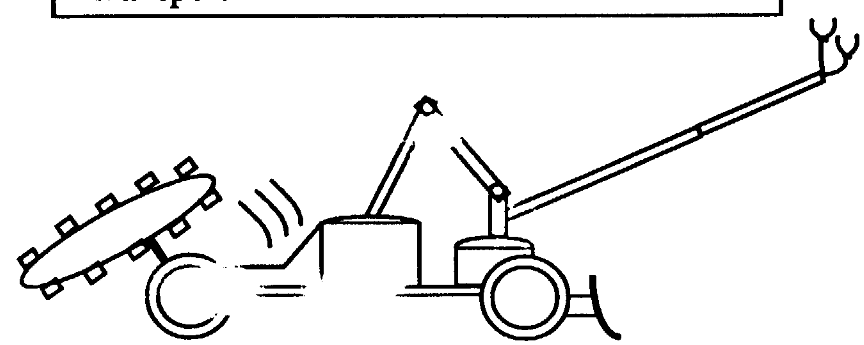
1st

Crew/ Light Equipment Transport
Automated Site Survey



2nd

Light Grading & Excavating
Light High Reach Manipulate & Equipment Transport



Trade study results indicate a need for two multipurpose vehic'

multipurpose/Task 9.1 Final Report/6-4-90/DLT

Figure 5-1(

Rover Concept

Shown below is a concept for the unpressurized rover. The trailer can be used for carrying additional power supplies if an extended traverse is expected. Otherwise, the rover can use the space for payloads or other equipment.

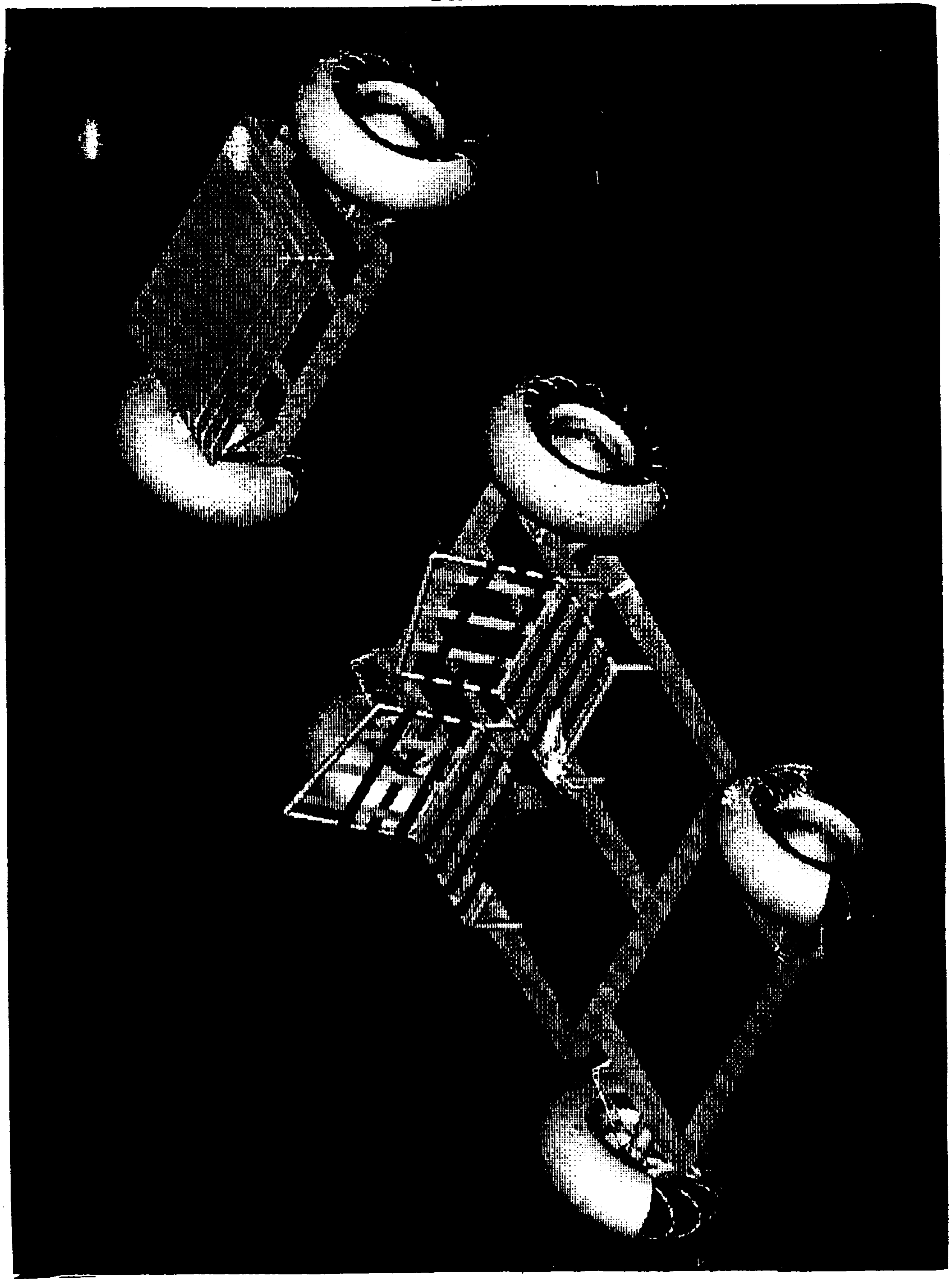
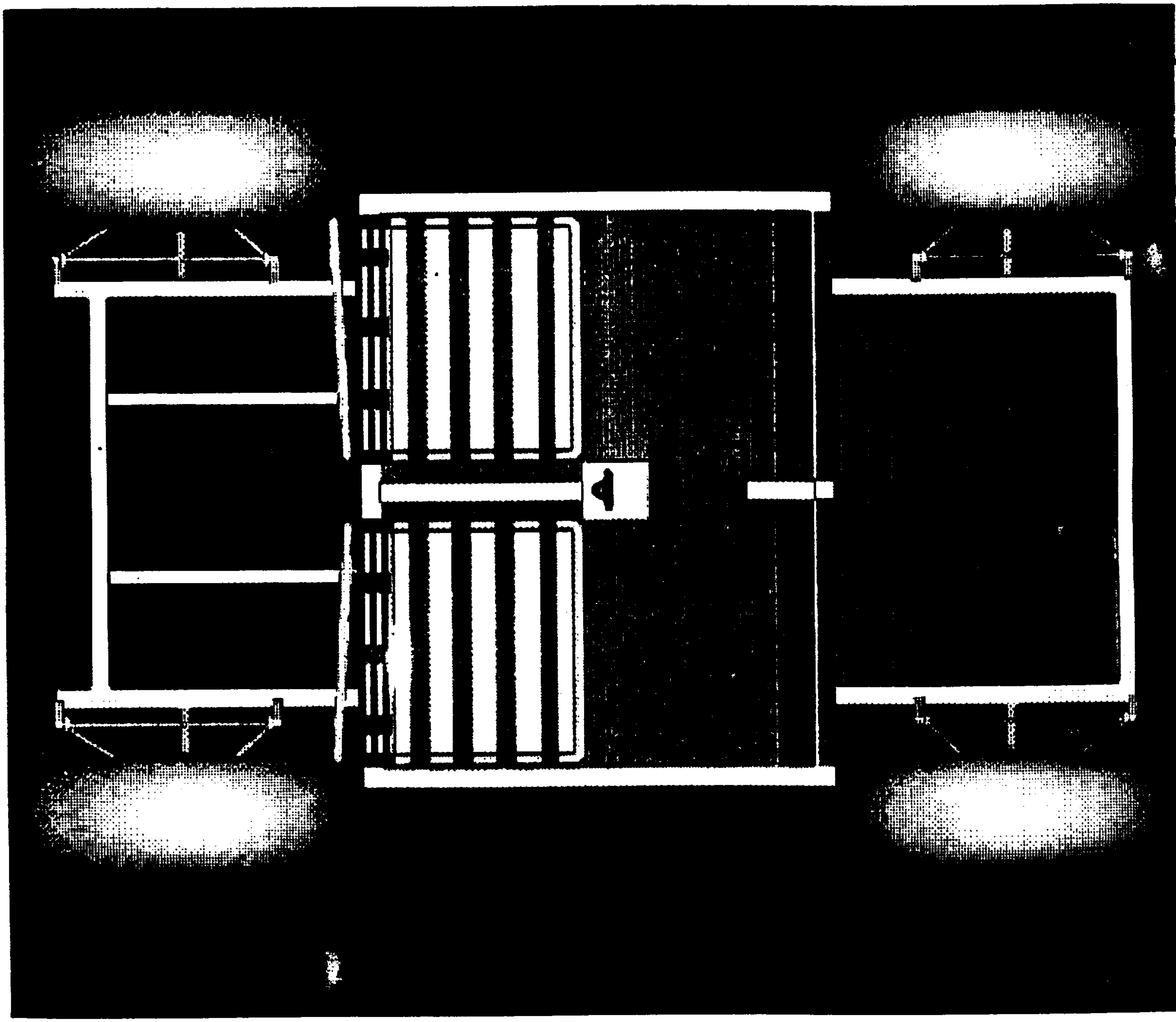


Figure 5-11

This is a top view of a typical rover frame.



Rover Concepts

The sketch on the facing page shows a concept for laying power cables using the rover. The attachment will make the cable laying operations of trenching and laying simultaneous, reducing the rover burden for this task. A backfill operation would be required to cover the cable.

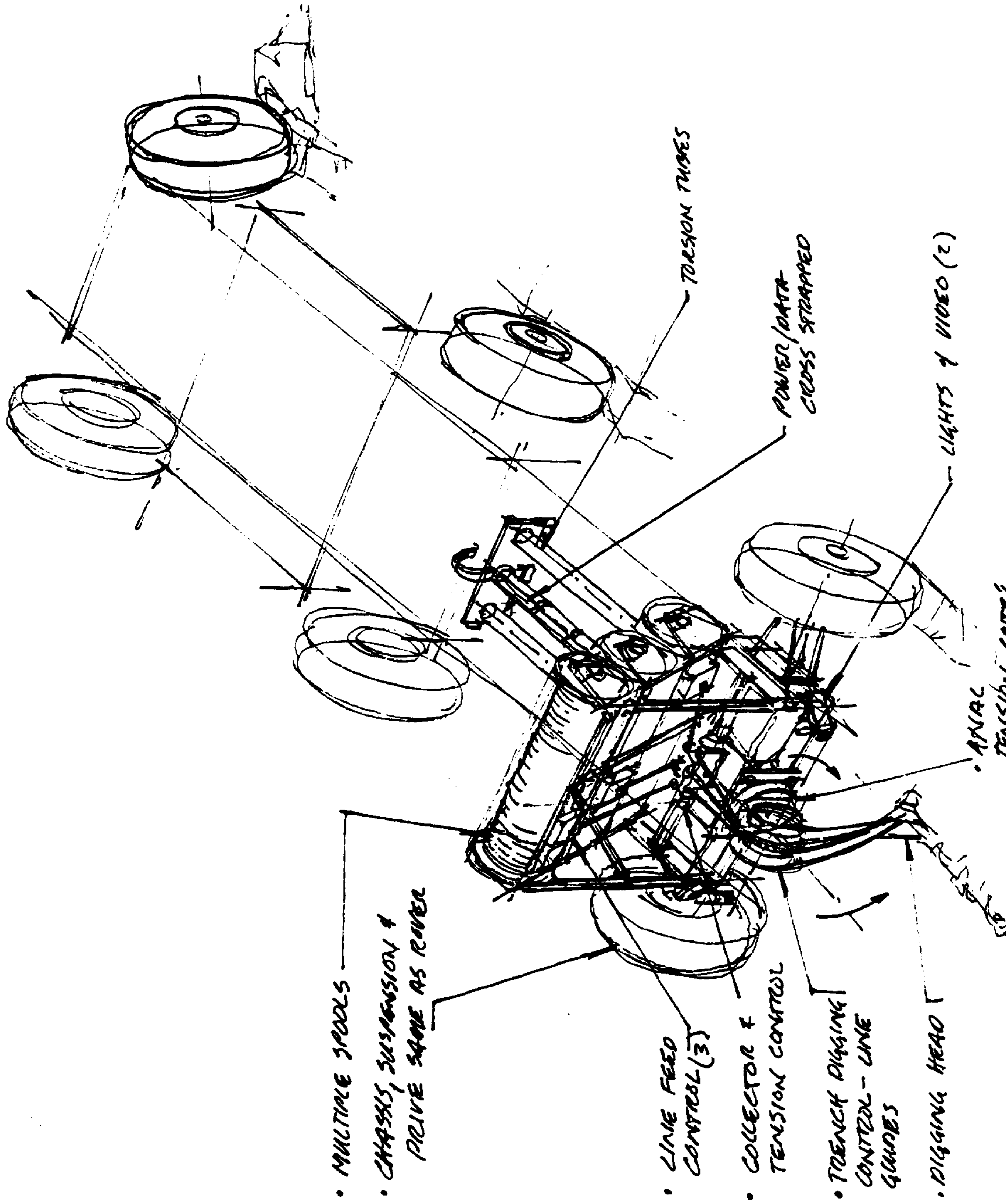

TORSION TUBES
POWER/DATA CROSS STRAPPED
LIGHTS & VIDEO (2)
AXIAL TENSION CNTRL
MULTIPLE SPOOLS
CHASSIS, SUSPENSION & DRIVE SAME AS ROVER
LINE FEED CONTROL (3)
COLLECTOR & TENSION CONTROL
TRENCH DIGGING CONTROL - LINE GUIDES
DIGGING HEAD

Figure 5-12

6.0 Evaluation Measures

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Sets of Evaluation Measures

This chart shows a standard set of evaluation measures.

This set was used for trade studies on several programs, past and present, including the current NASA MSFC/ Boeing Space Station Freedom contract.

These measures will be optimized, expanded, or reduced to best suit rover evaluations.

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Sets of Evaluation Measures

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Risks
- Performance, Schedule or Cost

Vehicle Availability
- Replacement Parts
- Mean Time to Repair
- Mean Time Between Failure

Costs
- Design, Development, Test and Evaluation
- Manufacturing
- Checkout prior to Launch
- Transit to Operations Site

Energy Required to Operated
- Type
- Amount

Safety and Reliability

Others Derived from Emerging Technology Requirements

Evaluation Measure/Task 9.1 Final Report/6-4-90/DLT

Figure 6-1

7.0 State of the Art Survey

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State-of-the-Art Survey/Technology Assessment

Shown below are the groundrules for establishing a state-of-the-art survey for piloted rovers.

State-of-the-Art Survey/Technology Assessment

BOEING

Purpose: Conduct a continuous, systematic assessment of state-of-the-art technologies related to piloted rover vehicles and associated surface systems. Identify key technology requirements, document current status, and project needed development efforts in a manner consistent with the reporting requirements of the STCAEM contract (NAS8-37857).

Background: Design of Lunar/Mars surface systems requires special consideration due to: (1) the high cost of delivering payload to planet surfaces; (2) the unique features of surface environments; and (3) the intended 15 year service life of hardware systems.

Baseline: Technology needs for this assessment are based on mission architectures and assumptions set fourth in the Report of the 90-Day Study on Human Exploration of the Moon and Mars (Nov. 89) and related government and industry research.

Sheet 1/Task 9.1 Final Report/6-4-90/DLT

Piloted Rover Vehicles Technology Assessment

There is an estimated 7-10 year lag in transferring a technology into flight hardware. For example, the Space Shuttle which first flew in 1980 is constructed with early 70's technology. The lag is due to the level of maturity required for a technology to be suitable for consideration in major development programs (Phases B & C/D).

Unless otherwise justified, all identified technologies are required to be developed to Level 3 (see facing page) prior to construction in Phase A. Insight and understanding at this level permits engineering application of the technology in conceptual design. A minimum readiness level of 5 is required for Phase B design, and a level of 6-7 is needed by the beginning of Phase C/D.

State-of-the-Art Survey/Technology Assessment

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Technology Maturation Milestones (from NASA Office of Exploration)

LEVEL 1	Basic principles observed and reported,	Ground Lab
LEVEL 2	Technology concept/application formulated.	Ground Lab
LEVEL 3	Analytical and experimental critical function and/or characteristic proof-of-concept. Required for phase A.	Ground Lab
LEVEL 4	Component and/or breadboard validation in lab.	Ground Lab
LEVEL 5	Component and/or breadboard demonstration in relevant environment. Required for phase B.	Ground Lab
LEVEL 6	System validaton model demonstrated in relevant/ simulated environment. Required for phase C/D.	Ground Lab; Flight Experiment
LEVEL 7	System validation model demonstrated in actual environment	Flight Experiment

Sheet 2/Task 9.1 Final Report/6-4-90/DLT

Figure 7-2

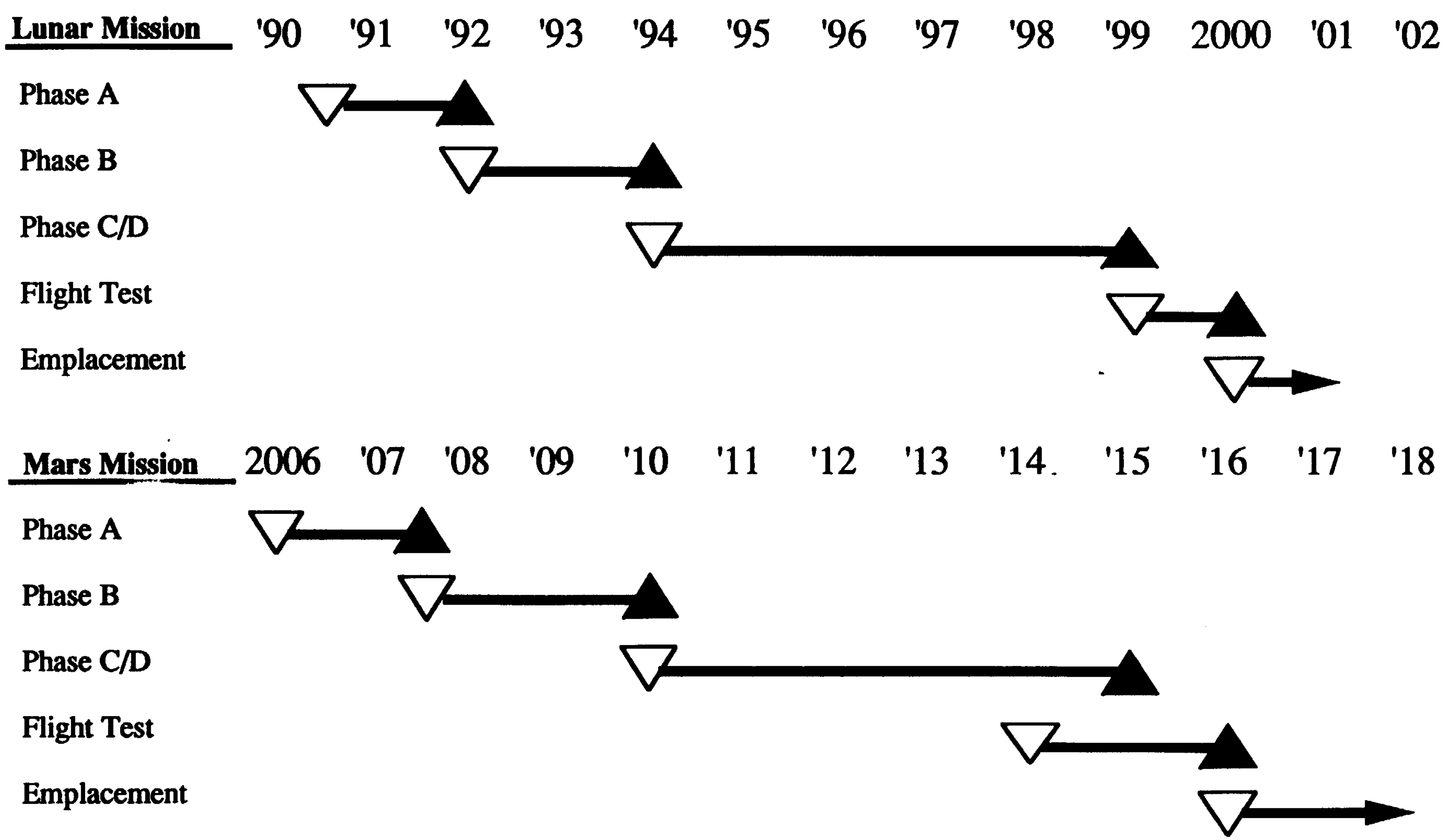
Piloted Rover Vehicles Technology Assessment

As indicated by the baseline time-tables on the facing page, technology for initial deployment of Lunar Vehicles and surface equipment would be essentially "locked in" to technology options which have attained a maturity level of 5 by 1992. Several advances cannot support this schedule. Therefore, *for the special case of technology advances needed for Lunar Outpost systems which begin Phase B in 1993 or before, it is assumed that technology developments will be performed concurrently with Phase B, unless the technology issues are currently addressed by existing technology development programs*. (Ref. Human Exploration Study Requirements Document. Sept. 89)

State-of-the-Art Survey/Technology Assessment

BOEING

Technology and Program Planning Baseline



Sheet 3/Task 9.1 Final Report/6-4-90/DLT

Figure 7-3

Piloted Rover Vehicles Technology Assessment

Technologies for Mars surface vehicles and equipment must be firm (level 5 or higher) by the 2007-2008 time frame. The Mars Sample Return precursor (with autonomous local rover) will be constructed with technology which has reached a maturity level of at least 5 by 1993. Development of Mars rovers will be largely synergistic with lunar vehicles and equipment, with modifications to accommodate the Martian atmosphere, potentially reactive elements in the soil, and the effects of high velocity dust storms. Earth based simulations of the Martian and Lunar environments must suffice for Level 5/6 technology demonstrations. Improvements to this simulation technology are needed in the near future (1990-1992).

Structures and materials technologies are expected to progress steadily from 1993-2008 based on the existence of infrastructure and facilities to support Lunar Outpost growth and advanced development of surface systems.

State-of-the-Art Survey/Technology Assessment

BOEING

Vehicle Systems/Subsystems Technology Matrix

Technology Area / Surface System	Mechanical drives, seals, and lubricants	High performance structure	Wheel design	Surface contamin. control	Passive thermal & vibr. control	Radiation protection methods	In-Space assy. & mainten.	Navigation, power, & control syst.
Mars Sample Return/Local Rover	●	○	●	○	○	○	N/A	●
Manned/Robotic Rover (unpress.)	●	○	●	○	○	○	●	●
Manned/Robotic Rover (pressur.)	●	○	●	○	○	○	●	●
Straddler	●	○	●	○	○	○	●	●
Equip. Hauler	●	○	●	○	○	○	○	●
Regolith Hauler	●	○	●	○	○	○	○	●
Excavator/Loader	●	○	●	○	○	○	○	●
Hopper Assy.	○	○	N/A	○	○	N/A	○	N/A
Grader/Scraper	●	○	●	○	○	○	○	●

Key: ● - Technology Advances Required (Enabling)
○ - Technology Advances Desirable (Enhancing)
N/A - Not Applicable

Sheet 4/Task 9.1 Final Report/6-4-90/DLT

F re 7

This chart shows the preliminary conclusions and recommendations of our analysis.

State-of-the-Art Survey/Technology Assessment

BOEING

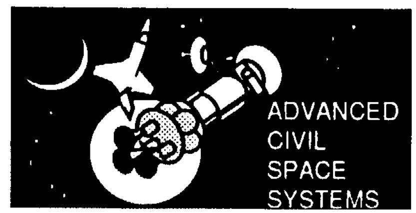
Technology Assessment Interim Conclusions/Recommendations:

- Improvements are needed in ground-based simulation and test capability.
- For some systems, trade studies are needed to determine if it is prudent to design for maintenance or replacement, rather than 15 year life.
- Technology advances are required in the following areas to support early (1993 or before) Phase B development programs.
    - mechanical drive, friction, and wear components
    - wheel design for high [illegible], long life
    - in-space assembly and maintenance concepts
    - electrical systems (especially navigation & autonomous control)
- Implementation of existing technology in structures, contamination control, and radiation protection should not be taken for granted.
- Operations (e.g. blasting & construction methods) will affect vehicle designs, and therefore technologies.

Sheet 7/Task 9.1 Final Report/6-4-90/DLT

Figure 7-f

8.0 Results and Recommendations



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State-of-the-Art Survey/Technology Assessment

Shown below are some technology areas of interest, their level of readiness, system requirements, and the urgency for their development.

ADVANCED CIVIL SPACE SYSTEMS

State-of-the-Art Survey/Technology Assessment

BOEING

Technology Area (Vehicle Systems)	Current Status Level/Year	System Requirement/Driver	Description and Urgency Assessment
Mechanical drives, seals, and lubricants	4/'90 (derived from industrual concepts and Apollo experience)	15 year life reliable machine systems needed. Abrasive soil elements and environment impair performance.	Apollo systems inadequate for heavy duty. Design concepts must be developed and verified in simulated environment.
High performance structure	5/'90 (advanced composite mat'l/ advanced process technologies)	High cost of transport suggests use of high strength/low mass mat'l.	Current technologies must be shown cost effective for use in specific applications.
Wheel design	3/'90 (derived from Apollo experience)	Wheels must provide long life/high load capability to minimize required maintenance.	New design must be developed for rover and construction vehicles based on Apollo lessons learned.
Surface contamination control	5/'90 (state-of-the-art technology combined with Apollo experience)	Dust impairs function of vehicles and equipment.	Problems observed on Apollo must be resolved using intelligent design, modeling, and simulation methods.
Passive thermal control and vibration damping systems	5/'90 (state-of-the-art technologies)	Induced thermal and vibration environments could cause early failure of system components.	Suitability of new passive control systems (coatings, etc.) and passive damping methods must be demonstrated in relevant simulated environment.

Sheet 5/Task 9.1 Final Report/6-4-90/DLT

Figure 8-1

This chart is a continuation of the previous chart.

ADVANCED CIVIL SPACE SYSTEMS

State-of-the-Art Survey/Technology Assessment

BOEING

Technology Area (Vehicle Systems)	Current Status Level/Year	System Requirement/Driver	Description and Urgency Assessment
Radiation protection methods	5/'90 (manned space exper. and current research develop.)	Design and performance of critical systems is determined by radiation effects.	Shielding concepts must be incorporated into design and analytically verified. Radiation effects on some materials and electronic systems not quantified.
In-Space assembly and maintenance	6/'90 (truss structure); 3/'90 (other concepts)	Deployment, assembly, reconfiguration, repair, and /or maintenance of vehicles may be required.	Assembly/maintenance concepts have not been analyzed or demonstrated. Automated and manual processes, including verification testing, must be evaluated.
Navigation, power, and control systems	3-4/'90 (independent research and development)	Advanced concepts for autonomous and telerobotic navigation are required. Application of state-of-the-art concepts in power and control technology must be adapted for rover designs.	Design and integration of vehicle electrical systems needs to be investigated. Navigation avionics based on Apollo as well as earthbound systems are probably inadequate for propose surface operations.

Sheet 6/Task 9.1 Final Report/6-4-90/DLT

Figure 8-1 cont.

Vehicle Systems

This chart presents the systems and subsystems that are typical of each of the vehicles. The columns on the right entitled Technology Assessment shows that each of the Technology Assessment charts to follow, generally apply to two or more of the systems.

ADVANCED CIVIL SPACE SYSTEMS

Vehicle Systems

BOEING

System	Subsystem	Technology Assessment #															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Chassis	Frame			X	X						X	X	X		X		X
Suspension	Arms, Springs and Seals Dampers and Seals			X	X						X		X	X	X		X
Steering Mechanisms (Dual Redundant)			X	X	X			X						X	X	X	X
Traction Drive (Drive Motors & Gears)		X	X		X			X			X			X	X		X
Wheel	Fenders and Dust Control	X		X	X						X			X	X		X
Drive Control	Manual Operated Steering Remote Signal Processing Common Component		X		X	X		X	X		X	X			X	X	X
Attached Mechanisms	Manual Controls Remote Signal Processing Common Component		X	X	X			X	X	X	X	X	X	X	X	X	X
Crew Station(s)					X		X	X	X		X	X		X	X	X	
Power	Power Storage Power Supply Thermal Control							X	X		X	X			X	X	X
Vehicle Navigation						X		X							X	X	
Communication							X	X	X						X	X	
Attached Mechanism System(s)			X	X	X			X	X	X	X	X	X	X	X	X	X

Vehicle Systems Chart/Task 9.1 Final Report/6-4-90/DLT

Figure 8-2

State of the Art Survey - Wheel Design

The Technology Assessment charts that follow are divided into three categories:

1. Piloted Rover Vehicle Must-Have Technologies (Must be at or brought to readiness level 5 by 1993)

2. Vehicle-Related "Must Have" Technologies (Not a rover task, but required for efficient piloted operations)

3. Piloted Rover Vehicles "Enhancing" Technologies (Of a lower priority, but would improve piloted operations efficiencies)

The "current status" is the concensus of the study team at this time. For the wheel design, the driving requirement stems from the Apollo wheel fatigue tests which indicate a fatigue life of approximately 250 km, far short of the current needs for a base support vehicle.

The remainder of the chart is self explanatory.

ADVANCED CIVIL SPACE SYSTEMS

State-of-the-Art Survey/Technology Assessment
Piloted Rover Vehicle "Must Have" Technologies

BOEING

Technology Area:	**WHEEL DESIGN**
Current Status: (Level/Year)	**3/'90 - Based on Apollo experience plus current developments projected to the end of FY90.**
Driving Requirement:	**Wheel designs must be provided for long life/high load capability.**
Assessment:	**Fatigue life, dust control, and friction loss are key issues. Based on function, multiple design concepts may be required. Potential solutions may involve consolidation of designs into a single wheel concept, with specific design parameters scaled as appropriate for various applications.**
New Facilities Required:	**Wheel Fatigue Test Equipment, Soil Test Bin**

Wheel Design/Task 9.1 Final Report/6-4-90/DLT

Figure 8-3

Technology Assessment #1

State of the Art Survey - Mechanical Drive Systems

The Apollo experience indicates thart the lunar surface roughness imposes a severe loading condition on the wheels and mechanical drive systems that will result in early fatigue failures unless very rugged designs are provided. This is a routine engineering task, but a high priority is assigned to it due to the time required to design, develop, and test wheel and mechanical drive systems that will result in the lowest operations costs. 15-Year-Lifetimes vs. maintenance and safety considerations of failures in the field are questions that must be addressed.

ADVANCED CIVIL SPACE SYSTEMS

State-of-the-Art Survey/Technology Assessment

Piloted Rover Vehicle "Must Have" Technologies

BOEING

Technology Area: MECHANICAL DRIVE SYSTEMS

Current Status: (Level/Year) 4/'90 - Based on Apollo experience plus current developments in materials and equipment for the aerospace, mining, and toolmaking industries.

Driving Requirement: 15-year life with minimum maintenance required for machine systems (e.g. drive motors, pullies, gearboxes, etc.)

Assessment: Abrasive soil elements and other surface environments are detrimental to mechanical system performance. Possible solutions include hermetic seals, protective shields, and abrasion resistant materials and designs. Drive motors and other machine systems must be developed to provide improved efficiency and low sensitivity to surface environments.

New Facilities Required: Dust Simulation/Mechanical Abrasion Test Facility

Mech Drive Sys/Task 9.1 Final Report/6-4-90/DLT

Figure 8-4

Technology Assessment #2

The cohesiveness of the lunar soil and the need for a dust-control shield results in the wheel and drive systems being bathed in a shower of dust very similar to earth operation in very dry dusty soil. This coupled with the extreme temperature variations of lunar and Mars surface environments will require an early start to design, development, and testing of wheel and mechanical drives.

ADVANCED CIVIL SPACE SYSTEMS

State-of-the-Art Survey/Technology Assessment

Piloted Rover Vehicle "Must Have" Technologies

BOEING

Technology Area:	**LUBRICANTS AND SEALS**
Current Status: (Level/Year)	**4/'90 - Concepts derived from existing government and industry programs associated with similar applications in space environments.**
Driving Requirement:	**15 year life with minimum maintenance required for machine systems. Apollo technologies inadequate for heavy duty, long life.**
Assessment:	**Applications for conventional (organic) lubricants and seals are highly restricted because of inherent problems with thermal vacuum stability and other environment-related failure mechanisms. Potential solutions which must be investigated include: Metallic seals, hard-facing materials, solid-state inorganic lubricants, ceramic and carbon composites, and alloys offering high inherent lubricity.**
New Facilities Required:	**Dust Simulation/Mechanical Abrasion Test Facility**

Lub & Seals/Task 9.1 Final Report/6-4-90/DLT

Figure 8-5

Technology Assessment #3

State of the Art Survey - Mobility System Shock Damper

This technology is assigned a readiness level 2 due solely to the fact that Lunar day/night operation must be considered. The conventional earth-vehicle hydraulic damper concepts are limited by the temperature range of operation of the fluids available. The use of properly designed "coulomb" (dry friction) dampers is one alternative that could be tested and and compared to the hydraulic damper for lunar operations. The technology is available, but the lead time to bring it to suitable proof-of-concept indicates that an early start is desirable.

State-of-the-Art Survey/Technology Assessment

Piloted Rover Vehicle "Must Have" Technologies

BOEING

Technology Area:	**MOBILITY SUBSYSTEM SHOCK DAMPER**
Current Status: (Level/Year)	**2/'90 - very similar to earth based systems. Lunar daytime operation but lunar night operation and/or storage will require improved designs.**
Driving Requirement:	**Vehicles require shock absorption similar to Earth-based automobiles, except adapted to lunar surface environment.**
Assessment:	**Initiate program to obtain candidate test articles for testing under lunar day/night operations. Low temperature effects or viscous dampers may require equivalent Coulomb damper be substituted.**
New Facilities Required:	**Load/Stroke Tester (capable of testing and recording data over a range of velocities and test article temperatures)**

Mobility Subsystems/Task 9.1 Final Report/6-4-90/DLT

Figure 8-6

Technology Assessment #4

State of the Art Survey - Autonomous Navigation

Apollo Rover operation on the moon resulted in the vehicle being out of sight of the LM. This dictated a requirement for an inertial guidance system to provide the astronaut with a direction bearing to the LM at all times. These added considerable cost to the vehicle for a provision that can now be provided electronically at a much lower overall cost. Our recommendation is to initiate a study by a provider of similar electronic earth-based vehicle tracking and base coordination systems leading to the selection of one for lunar vehicle operations.

State-of-the-Art Survey/Technology Assessment

Piloted Rover Vehicle "Must Have" Technologies

Technology Area: AUTONOMOUS NAVIGATION

Current Status: (Level/Year) 3/'90 - pieces of technology present in Autonomous Land Vehicle, in numerous spacecraft, and in military avionics programs.

Driving Requirement: Autonomous surface navigation over large distances.

Assessment: Requires integration of obstacle avoidance methods from ALV, star tracking from current spacecraft, inertial navigation from aircraft or missile systems, and real-time route planning from Pilot's Associate or Advanced Tactical Fighter. Alternatively, requires ALV methods plus GPS-like lunar satellite system.

Facilities Required: Improvements to ALV or similar testbed.

Figure 8-7

State of the Art Survey - Communication/Data Relay

Early operation of the lunar vehicles in an unmanned mode will require a high bandwidth communication link. Vehicle operation at a relatively low speed will permit the use of an earth tracking system for use with the vehicle antenna. A design of a gyro-stabilizer system of this type was investigated for Apollo use but not implemented due to the high cost (at that time) of the system. The payoff of the unmanned rovers and the subsequent application to the exploration class of vehicles indicates that a study should be undertaken at this time to determine the validity of this or a related concept and the applicable desired start time.

State-of-the-Art Survey/Technology Assessment

Piloted Rover Vehicle "Must Have" Technologies

BOEING

Technology Area: COMMUNICATION / DATA RELAY

Current Status: (Level/Year) 3/'90 - Military radar systems are partly similar.

Driving Requirement: Continuous tracking of Earth, relay satellite, or stationary beacon by high-gain antenna while moving over rough terrain.

Assessment: Builds on military experience. Frequency, environment, and maintenance requirements differ. Potential solution: phased array antenna. Alternative: omnidirectional antenna on rover with powerful directional antennae on Earth.

Facilities Required: None

Communication/Task 9.1 Final Report/6-4-90/DLT

Figure 8-8

Technology Assessment #6

State of the Art Survey - Power Storage

The Apollo rovers used a pair of 36 Volt primary storage batteries to provide a dual redundant power supply. A rechargeable power supply system is clearly a requirement for the lunar base vehicles. The readiness level of this technology is 5 at this time, but trade studies need to be conducted to select the optimum overall power supply system for the base and base vehicles.

State-of-the-Art Survey/Technology Assessment

Piloted Rover Vehicle "Must Have" Technologies

BOEING

ADVANCED CIVIL SPACE SYSTEMS

Technology Area: POWER STORAGE

Current Status: (Level/Year) 5/'90 - Largely similar to other space systems, e.g. SSF., and systems for Earth-bound electric cars.

Driving Requirement: Durability with good energy density.

Assessment: No serious obstacles. Prefer, but do not require, durability comparable to automobile battery, i.e. many cycles, many miles, several years, with energy density comparable to current aerospace batteries. Current research and development on electric cars is producing appropriate systems. Alternatives: fuel cells, dynamic isotope power systems (DIPS).

Facilities Required: None

Power/Task 9.1 Final Report/6-4-90/DLT

Figure 8-9

Technology Assessment #7

State of the Art Survey - Modified/Improved Space Suits

This is one of the vehicle-related "must have" technologies, and as such, constitutes a recommendation for work outside of the areas within our current assignment. Boeing has an ongoing contract to JSC to aid in the refurbishment of space suits currently in use on Shuttle. It is that activity plus the astronaut experience on Apollo that leads us to conclude that lunar or Mars surface operations will require a space suit specifically designed to support the tasks assigned, and tools to be used by the astronauts.

ADVANCED CIVIL SPACE SYSTEMS

State-of-the-Art Survey/Technology Assessment
Vehicle Related "Must Have" Technologies

BOEING

Technology Area:	**MODIFIED/IMPROVED SPACE SUITS**
Current Status: (Level/Year)	**4,5/'90 - Current astronaut space suits severly limit astronaut mobility and performance.**
Driving Requirement:	**Communication, mobility and duration.**
Assessment:	**Improvements in all three areas are required in order to achieve minimum base implementation and erection costs. Alternate suit configuration studies should be initiated and test articles prepared for evaluation.**
New Facilities Required:	**None**

Figure 8-10

State of the Art Survey - Lunar Surface Blasting

This is also a vehicle-related technology. Our concerns are based on Boeing experience and our concurrence that blasting is one of the preferred methods for loosening the regolith and dispersing it prior to final shaping of the pits for Habitation and Nuclear Power modules.

State-of-the-Art Survey/Technology Assessment

Vehicle-Related "Must Have" Technologies

BOEING

Technology Area:	**LUNAR SURFACE BLASTING**
Current Status: (Level/Year)	**2/'90 - Concepts formulated after earth-based explosive technologies for mining and civil engineering.**
Driving Requirement:	**Cost and time effective means of removing lunar regoligh for emplacement of habitation, laboratory, and power modules.**
Assessment:	**Explosives technology for earth-based blasting is well known. However, extensive test and analysis would be required for extension to lunar environment. Technical issues include: prediction of debris trajectories, charge shape and intensity, geological survey analysis, handling and placement, risk assessment, contingency planning, and alternative procedures.**
New Facilities Required:	**Lunar Surface Blast Simulation & Test Facility**

Lunar Blasting/Task 9.1 Final Report/6-4-90/DLT

Figure 8-11

Technology Assessment #9

State of the Art Survey - Telerobotic Construction Equipment

This area will impact vehicle design and trade studies to be performed. Our principle concern is the wisdom of performing many of the required tasks by a telerobotic mode. The value of an astronaut on-site for a "one-time-only" task appears to currently outweigh the benefits of telerobotic operations. For this reason, further studies regarding the use of telerobotic equipment for construction tasks should be performed.

ADVANCED CIVIL SPACE SYSTEMS

State-of-the-Art Survey/Technology Assessment

Vehicle-Related "Must Have" Technologies

BOEING

Technology Area: TELEROBOTIC CONSTRUCTION EQUIPMENT

Current Status: (Level/Year) 4/'90 - Similar to telerobots for fires and nuclear accidents, but requires re-engineering for lunar environment and self-repair.

Driving Requirement: Reliability.

Assessment: Robots break down. Robots on the Moon must either be able to repair themselves or not break down: both are beyond state of the art. Telerobotic self-repair will be very difficult to achieve, so extreme durability is the preferred solution.

New Facilities Required: Vehicle Operation, Training & Screening Facility.

Figure 8-12

State of the Art Survey - Robotic Systems Interfaces

This relates to the previous chart but adds the complexity of interchanging end-effectors. Additional study by individuals skilled in the design and implementation is warranted prior to arriving at the firm decision of the task allocation to a specific mission out of the suite of base establishment missions.

ADVANCED CIVIL SPACE SYSTEMS

State-of-the-Art Survey/Technology Assessment

Vehicle-Related "Must Have" Technologies

BOEING

Technology Area:	**ROBOTIC SYSTEMS INTERFACES**
Current Status: (Level/Year)	**4/'90 - Some robots use multiple end-effectors.**
Driving Requirement:	**Reconfigure with various regolith moving equipment.**
Assessment:	**Need to demonstrate functionality of various equipment with standard interfaces. Evolution to more complex manipulation tasks using end effectors, dextrous manipulators, etc.**
New Facilities Required:	**Vehicle Operation, Training & Screening Facility.**

Reconfiguration/Task 9.1 Final Report/6-4-90/DLT

Figure 8-13

Technology Assessment #11

State of the Art Survey - High Performance Structure

This technology area is one which will enhance the rover capabilities, but is not considered essential to their performance. The trade-off here is in the reduction of launch and transportation costs vs. the cost involved in developing and testing the new materials to be used in the vehicle systems.

State-of-the-Art Survey/Technology Assessment

Piloted Rover Vehicle "Enhancing" Technologies

BOEING

Technology Area:	**HIGH PERFORMANCE STRUCTURE**
Current Status: (Level/Year)	**5/'90 - Based on state-of-the-art composite materials and advanced fabrication technologies.**
Driving Requirement:	**High cost of transport suggests use of high strength-to-weight ratio, and high stiffness-to-weight ratio materials.**
Assessment:	**Current developments in such areas as metal matrix composites, superplastic forming, and advanced alloys must be shown to be cost effective for specific applications based on trade studies and analysis. Reduction of weight from vehicle systems, (e.g. robotics, electronic assemblies) as well as primary and secondary structure may be achieved.**
New Facilities Required:	**None**

Hi PERFORMANCE STRUCTURE/TASK 9.1 FINAL REPORT/6-4-90/DLT

Figure 8-14

Technology Assessment #12

State of the Art Survey - Surface Contamination Control

The Apollo Lunar Rover designs were more concerned with weight reductions and vehicle stowage requirements during transit to the moon, and in addition, the cohesiveness of the lunar dust was not known. Careful vehicle design of wheel running surfaces and fenders should accomplish the bulk of the surface contamination control required. This should be accomplished in concert with the designs of the wheel and mechanical drive system. Soil bin tests should be conducted on wheels provided with alternate running surfaces to reduce the dust pickup.

State-of-the-Art Survey/Technology Assessment

Piloted Rover Vehicle "Enhancing" Technologies

Technology Area:	**SURFACE CONTAMINATION CONTROL**
Current Status: (Level/Year)	**5/'90 - State-of-the-art analysis methods combined with experience from Apollo LRV activities.**
Driving Requirement:	**Dust impairs function of vehicles and equipment.**
Assessment:	**Problems observed during Apollo LRV activities included abrasive friction, contamination of photographic lenses and thermal control surfaces, electrostatic build-up, and respiratory irritation. Possible control measures may include use of electrostatic precipitators or other devices to minimize detrimental effects.**
New Facilities Required:	**None**

Figure 8-15

State of the Art Survey - Thermal/ Vibration Control

The Apollo Lunar Rover used passive thermal control and depended on short traverses with ample time between traverses for battery cooling. The vibration environment was assumed to be comparable to off-the-road operation on Earth. Extended duration lunar and Mars operations will involve more reactions to evolving situations and therefore will dictate an increased requirement for active thermal control and component vibration control of remote-control equipment as well as vehicle systems.

ADVANCED CIVIL SPACE SYSTEMS

State-of-the-Art Survey/Technology Assessment

Piloted Rover Vehicle "Enhancing" Technologies

BOEING

Technology Area:	**THERMAL/VIBRATION CONTROL**
Current Status: (Level/Year)	**5/'90 - Based on state-of-the-art technologies.**
Driving Requirement:	**Natural and induced thermal and vibration environments could cause premature failure of system components.**
Assessment:	**Suitability of new and existing passive themal control coatings and vibration damping materials and techniques must be demonstrated in a simulated space environment.**
New Facilities Required:	**None**

Thermal/Vibration Control/Task 9.1 Final Report/6-4-90/DLT

Figure 8-16

Technology Assessment #14

State of the Art Survey - Radiation Protection Methods

Little consideration was given to this requirement on the Apollo Lunar Rover operations. The lunar orbiter sensors had indicated acceptable levels of radiatiion for the duration of anticipated exposure on the Moon. The situation will be quite different in the planned Lunar Bas· ·ctivities and Mars missions. Therefore, acceptable levels of exposure must be established and each mission task reviewed to ensure protection to crew and system components and materials. Provisions should also be available in the event of solar flares, etc.

ADVANCED CIVIL SPACE SYSTEMS

State-of-the-Art Survey/Technology Assessment

Piloted Rover Vehicle "Enhancing" Technologies

BOEING

Technology Area:	**RADIATION PROTECTION METHODS**
Current Status: (Level/Year)	**5/'90 - Based on current manned and unmanned spacecraft design experience.**
Driving Requirement:	**Design and performance of critical space systems is determined by radiation effects on crew, materials, and electronics.**
Assessment:	**Shielding concepts must be incorporated into design and analytically verified. Radiation effects on some materials and electronic systems has not been quantified.**
New Facilities Required:	**None**

Radiation Protection/Task 9.1 Final Report/6-4-90/DLT

Figure 8-17

Technology Assessment #15

The Apollo LRV was provided the capabilities to work around several situations that might occur. These included dual steering - the front and rear wheels had the capability to be independently steered or steered simultaneously. Any wheel drive could be disengaged if the drive system were to seize and prevent wheel rotation. The lunar base vehicle operations plans must include a maintenance and repair provision that provides the minimum life-cost operation consistent with the maximum vehicle readiness. The chart presents our recommendations for obtaining that plan.

State-of-the-Art Survey/Technology Assessment

Piloted Rover Vehicle "Enhancing" Technologies

ADVANCED CIVIL SPACE SYSTEMS — BOEING

Technology Area:	IN-SPACE ASSEMBLY & MAINTENANCE
Current Status: (Level/Year)	3/'90 - Minimum cost vehicle maintenance trade study data does not exist.
Driving Requirement:	Vehicle operational safety, reliability, and minimum maintenance required over 15-year expected vehicle life.
Assessment:	Limited vehicle maintenance was provided on a contingency basis only to Apollo lunar vehicles. Data defining optimum maintenance provisions to achieve minimum life cost is not available. Trade study must be initiated to obtain this data. Test articles and mockups for simulated vehicle operations must be fabricated and time and motion tests carried out to obtain data.
New Facilities Required:	Vehicle Operation, Training, Screening Facility

In-Space Assy/Maint/Task 9.1 Final Report/6-4-90/DLT

Figure 8-18

Technology Assessment #16

ADVANCED CIVIL SPACE SYSTEMS

Technology Assessment Summary

BOEING

Piloted Rover "Must Have" Technologies	Piloted Rover "Enhancing" Technologies	Vehicle-Related "Must Have" Technologies	New Facilities Required
Wheel Design	High Performance Structure	Modified/Improved Space Suit(s)	Wheel Fatigue Test Equipment
Mechanical Drive Systems	Surface Contamination Control	Lunar Surface Blasting	Soil Test Bin
Lubricants and Seals	Thermal/Vibration Control	Telerobotic Construction Equipment	Dust Simulation/ Mechanical Abrasion Test Facility
Mobility Subsystem Damper	Radiation Protection	Robotic Systems Interfaces	Improved ALV Testbed
Autonomous Navigation	In-Space Assembly and Maintenance		Lunar Surface Blast Simulation & Test Facility
Communication/Data Relay			Load/Stroke Tester
Power Storage			Vehicle Operation, Training & Screening Facility

tech dev summary/Task 9.1 Final Report/6-4-90/DLT

Figure 8-19

LRV M/4 Tests

This figure from the LRV test series shows the type of fixture required to perform a fatigue test of a wheel, drive system, and suspension system that will be required for the Lunar base support vehicles.

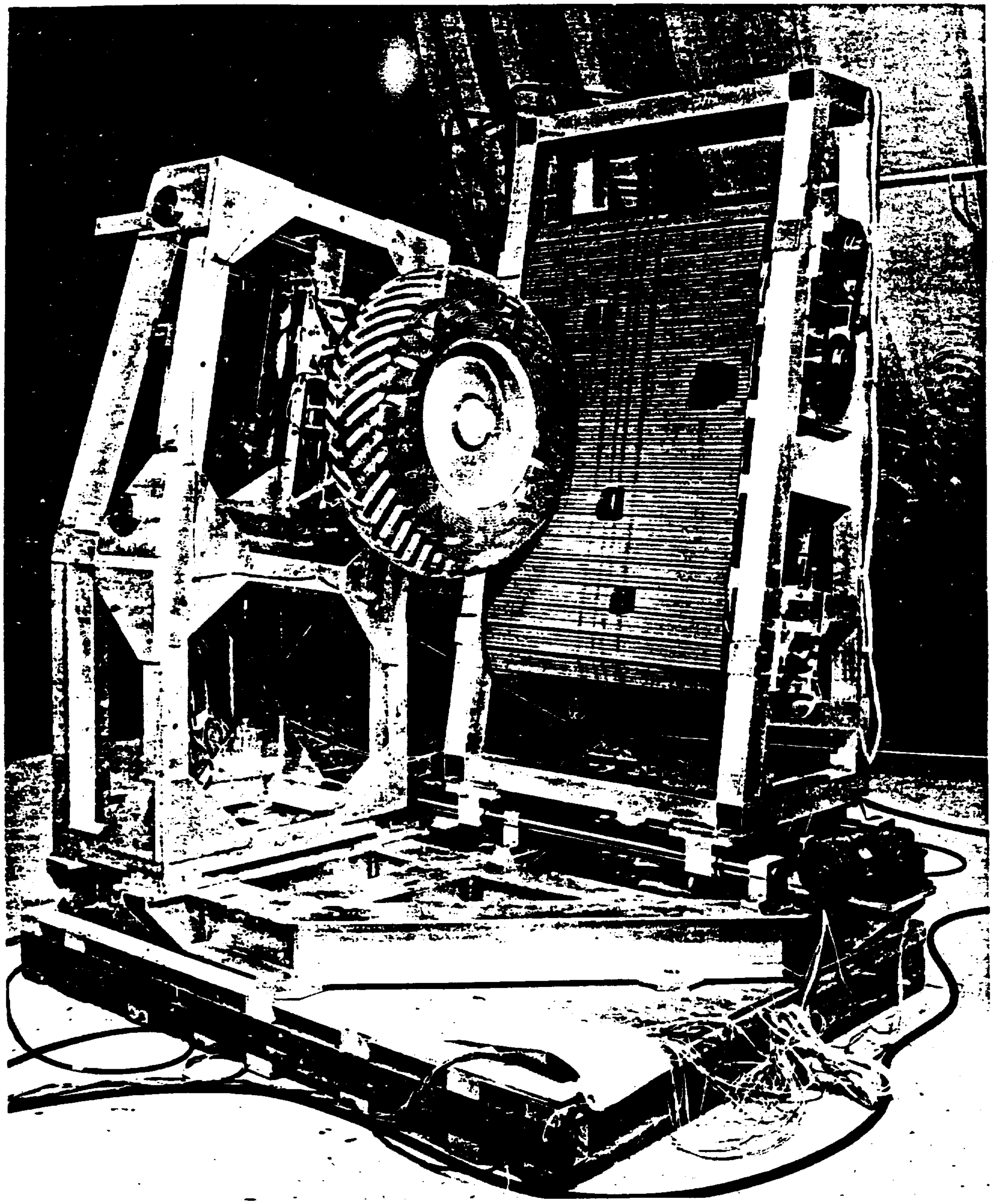

Figure 1: LRV M/4 TEST ASSEMBLY/ROLLING ROAD TEST FIXTURE (OBLIQUE VIEW)

Figure 8-20

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This figure presents more detail on the steering components and the suspension system.

Figure 8-20 cont.

Figure 2: LRV M/4 TEST ASSEMBLY/ROLL..NG ROAD TEST FIXTURE (DIRECT VIEW)

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LRV M/4 Tests

This figure shows the LRV wheel, drive, and suspension system being prepared for Thermal Vacuum Bag testing. It indicates the relative simplicity of this type of test. With proper precautions, the systems could be tested to near-lunar operation conditions (dust, vacuum, and thermal).

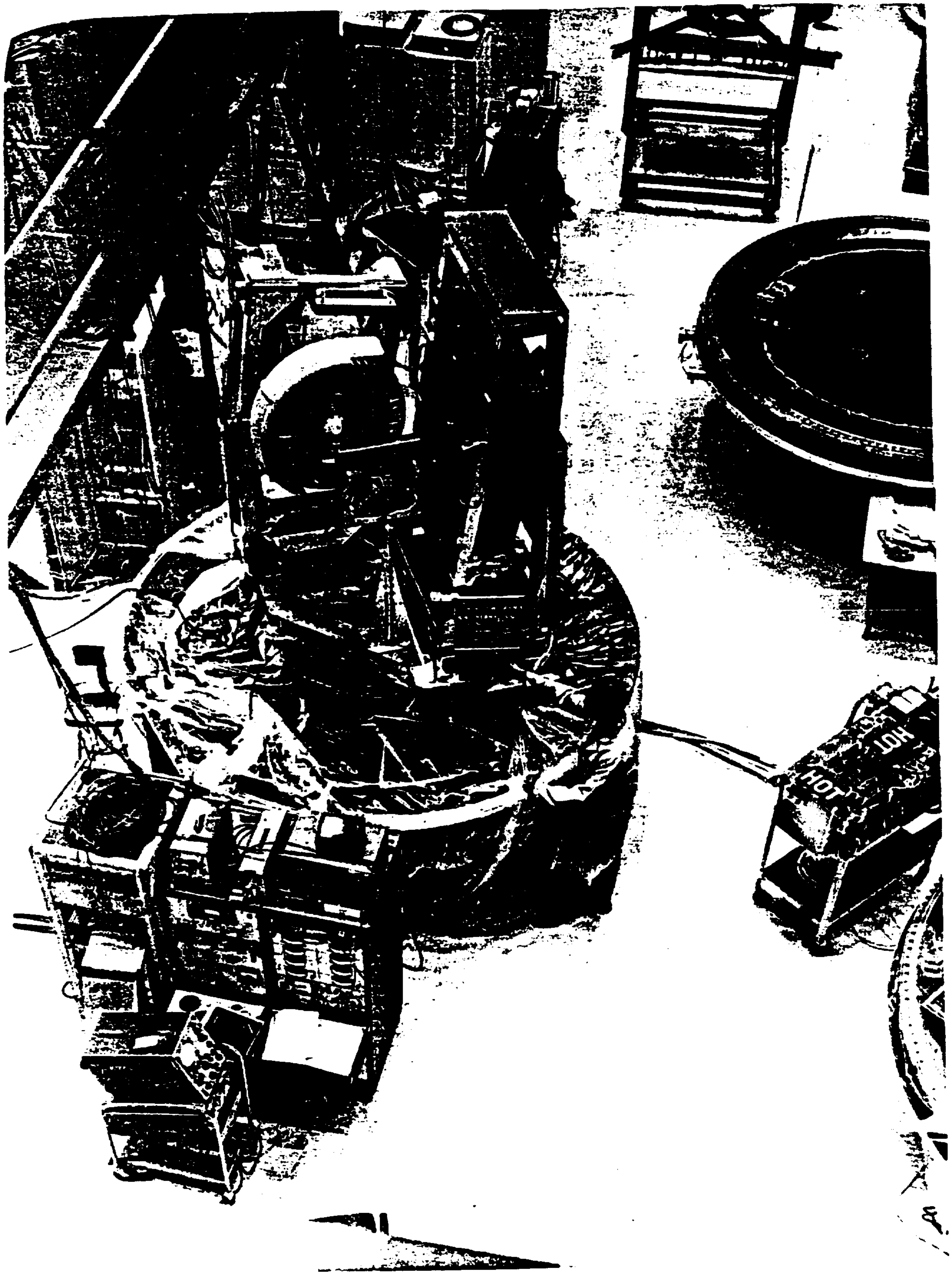

Figure 8-21

Figure 6: SET-UP FOR M/4 THERMAL VACUUM TEST (ES 10243)

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16. Abstract

This is the May 25, 1990 summary report for Space Transfer Concepts and Analyses (STCA) Study, NASA Contract NAS8-37857, Special Study Task 9.1, Piloted Rovers Technology Study. This study examined piloted rover concepts, mission scenarios, and the requirements necessary for completion of these missions resulting in the establishment of a Lunar Base. These tasks were intended to lead to a logical conclusion concerning which piloted rovers technologies are needed to accomplish the various missions, along with a recommended schedule for the development of these technologies.

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