Final Presentation

Results of the Engineering Feasibility Study

NASA Johnson Space Center

September 17, 1991
# Common Lunar Lander

## Engineering Study Results

17-Sep-91  
2:00 - 4:00 pm

<table>
<thead>
<tr>
<th>Time</th>
<th>Speaker</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>2:00 - 2:10</td>
<td>Bob Ried</td>
<td>Introduction</td>
</tr>
<tr>
<td>2:10 - 2:30</td>
<td>Steve Bailey</td>
<td>Project Perspective</td>
</tr>
<tr>
<td>2:30 - 2:50</td>
<td>Jonette Stecklein</td>
<td>Systems Engineering</td>
</tr>
<tr>
<td>2:50 - 2:55</td>
<td>Lynn Wagner</td>
<td>Trajectory</td>
</tr>
<tr>
<td>2:55 - 3:00</td>
<td>Ed Robertson</td>
<td>Launch Vehicles</td>
</tr>
<tr>
<td>5 min</td>
<td>Shelby Lawson</td>
<td>Configuration Design</td>
</tr>
<tr>
<td>5 min</td>
<td>George Sanger</td>
<td>Structures</td>
</tr>
<tr>
<td>5 min</td>
<td>Don Hyatt</td>
<td>Propulsion</td>
</tr>
<tr>
<td>5 min</td>
<td>Nancy Smith</td>
<td>GN&amp;C</td>
</tr>
<tr>
<td>5 min</td>
<td>Bill Culpepper</td>
<td>Tracking</td>
</tr>
<tr>
<td>5 min</td>
<td>Henry Chen</td>
<td>Communications</td>
</tr>
<tr>
<td>5 min</td>
<td>Betsy Kluksdahl</td>
<td>Power</td>
</tr>
<tr>
<td>5 min</td>
<td>Diane McLaughlin</td>
<td>Reliability</td>
</tr>
<tr>
<td>3:40 - 4:00</td>
<td>Jonette Stecklein</td>
<td>Synopsis - Engr. Product</td>
</tr>
</tbody>
</table>

Building 1, Room 945
Artemis

A Common Lunar Lander for the Space Exploration Initiative

Presentation to Aaron Cohen

September 17, 1991
## Summary of Past & Future Events

<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>June 13</td>
<td>• Initial Common Lunar Lander Presentation, Authorization to proceed with In-house study</td>
</tr>
<tr>
<td>July 1</td>
<td>• Workshop held at JSC</td>
</tr>
<tr>
<td>July 17</td>
<td>• Kickoff meeting of EA spacecraft design study team</td>
</tr>
<tr>
<td>August 23</td>
<td>• EA Senior Board Review</td>
</tr>
<tr>
<td>Sept 17</td>
<td>• Design team results presentation, distribution to payload developers, sponsors and industry</td>
</tr>
<tr>
<td>Oct 11</td>
<td>• External concept assessment complete</td>
</tr>
<tr>
<td>Oct 21</td>
<td>• Presentation of program strategy and recommendations. Procurement, Management structure, cost estimates, etc.</td>
</tr>
</tbody>
</table>
Artemis Program Rationale

- Correctly anticipates the strategy that Mike Griffin as the new AA for Exploration brings to SEI

  - Build Congressional trust by starting small and meeting cost and schedule objectives

  - Sell SEI in bite size chunks - "Buy it by the yard..."

  - Start with Robotic Missions

  - Start early with missions that are:
    - Small
    - Simple
    - Cheap
    - Quick
    - Contribute to SEI goals
Artemis Program Rationale (Cont)

- Analysis Stafford Synthesis Group Architecture Themes

  - Architecture 1, Mars Exploration - Meets the criteria of establishing a permanent presence of the moon, without committing to manned landings if Mars beckons irresistibly or if funding constrained

  - Architecture 2, Science Emphasis - Establishes "Lunar Network", also emplaces optical and radio observatories

  - Architecture 3, Moon to Stay... - Delivers rover for in-situ resource characterization and subsurface analysis prior to base selection

  - Architecture 4, Space Resource Utilization - Meets requirements to locate resource concentrations, map them and to test pilot processes, technologies, and equipment

Artemis Concept is Architecture independent - value varies with theme
Artemis Program Rationale (Cont)

- Compelling scientific rationale exist for further exploring the surface of the Moon, and for using the Moon as a platform for Space and Astrophysics observatories

- Equally compelling is the need for engineering information
  - Base-site survey
  - Resource characterization
  - Hardware test or demonstration, and technology development

- Infrastructure emplacement
  - Navigation aids
  - Caches for long traverses
  - Emergency resupply
  - Remote equipment delivery

To safely extend the reach of humans to areas on the moon that are otherwise inaccessible due to cost or risk
# Summary of Potential Payloads

<table>
<thead>
<tr>
<th>Sample Collection</th>
<th>Rover</th>
<th>ISRU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample</td>
<td>Rover</td>
<td>Cast Basalt</td>
</tr>
<tr>
<td></td>
<td>XRD/XRF</td>
<td>O2 Extraction</td>
</tr>
<tr>
<td>Geophysical Station</td>
<td>LIBS</td>
<td>Thermal Processing</td>
</tr>
<tr>
<td>Geophysical Station</td>
<td>Magnetometer</td>
<td>Magnetic Separation</td>
</tr>
<tr>
<td>Central Station</td>
<td>Gamma-Ray Spectrometer</td>
<td>Gas Analysis</td>
</tr>
<tr>
<td>RTG</td>
<td>Neutron Spectrometer</td>
<td></td>
</tr>
<tr>
<td>Broad Band Seismometer</td>
<td>Stereo-Imager</td>
<td></td>
</tr>
<tr>
<td>Heat Flow Probe</td>
<td>Mass Spectrometer</td>
<td></td>
</tr>
<tr>
<td>Long Period Seismometer</td>
<td>Visual and Near-IR</td>
<td></td>
</tr>
<tr>
<td>Solar Wind Experiment</td>
<td>Spectrometer</td>
<td></td>
</tr>
<tr>
<td>Charged Particle Experiment</td>
<td>Telescopes</td>
<td></td>
</tr>
<tr>
<td>Cosmic-Ray Experiment</td>
<td>1 m APT/UV-IR Survey/UV Spec.</td>
<td></td>
</tr>
<tr>
<td>Micro-Meteorite Experiment</td>
<td>UV Ast./Atm.</td>
<td></td>
</tr>
<tr>
<td>Mass Spectrometer</td>
<td>Lunar Transit Telescope</td>
<td></td>
</tr>
<tr>
<td>Suprathermal Ion Detector</td>
<td>Lunar Hubble Telescope</td>
<td></td>
</tr>
<tr>
<td>Cold Cathode Pressure Gage</td>
<td>Moon-Earth VLBI</td>
<td></td>
</tr>
<tr>
<td>UV Spectrometer</td>
<td>VLF Interferometer</td>
<td></td>
</tr>
<tr>
<td>Alpha Particle Spectrometer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low Frequency Magnetometer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tidal Gravimeter</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Stephen Bailey/IE3/283-5411

New Initiatives Office
Physical Characteristics of Experiments

**Mass of Individual Experiment**

- Number of Experiments vs. Mass (kg)
  - 33: 0
  - 67: 5
  - 100: 10
  - 200: 15
  - 267: 20
  - 500: 25

**Experiment Downlink Data Rates**

- Number of Experiments vs. Kilobits per Second
  - 0.1: 0
  - 0.3: 1
  - 0.7: 2
  - 1: 3
  - 3: 4
  - 7: 5
  - 30: 6

**Power Requirements for Experiment**

- Number of Experiments vs. Power (Watts)
  - 3: 2
  - 7: 3
  - 10: 4
  - 30: 5
  - 70: 6
  - 100: 7
  - 700: 8
  - 1000: 9
  - 3000: 10

**Maximum Dimension of Experiment**

- Number of Experiments vs. Maximum Dimension (Meters)
  - 0.2: 0
  - 0.4: 1
  - 0.6: 2
  - 0.8: 3
  - 1: 4
  - 1.6: 5
  - 2: 6
  - 5: 7

Stephen Bailey/IE3/283-5411
ROCK SAMPLES

SOIL SAMPLES

CORE DRILLING

SAMPLE RETURN MISSION
ISMU PILOT PLANT
ON UNMANNED
LUNAR LANDER
TETHERED MICRO-ROVERS
TransLunar Injection Capability of US Launchers as a Function of Payload Delivered to the Surface

Payload Mass (kg) vs. Total Wet Mass (kg)

Legend:
- Light Weight Lander
- Mid Weight Lander
- Heavy Weight Lander

Launchers:
- Titan III/II (10 SRMs)
- Titan III/IUS
- Delta 7925/STAR-48B
- Delta 6925/STAR-48B
- Atlas I/Centaur I
- Atlas IIA/Centaur IIA
- Atlas IIAS/Centaur IIAS
- Titan IV Type II/Centaur G
- Titan IV Type II/IUS

Stephen Bailey/IE3/283-5411

New Initiatives Office
Study Objectives

The purpose of the design study is to define what the attributes of a lander would be that rank priorities as:

- Cost (as low as possible)
- Schedule (1996 launch date)
- Performance (within reason for a potentially long lived system)
- Risk (acceptable for this mission type)

Provide crisp definition of lander concept for critical review by:
- Payload Developers
- Payload Sponsors (Codes M, R, SL, SS, SZ, SB, XE, ...)
- Industry and other Government agencies (particularly SDIO)

Demonstrate the ability of the center to quickly mobilize, with NIO leadership, and to efficiently produce quality study products
Study Products

(Complete)
- Payloads Assessment
  - Market Definition
  - Interface Requirements
- Payload Integration Analysis
- Requirements
  - Lander mission and system
  - Payload Interfaces
  - Operations
- Launch Vehicle Analysis
- Subsystem Design Concepts
- System Trade Studies

(In Work)
- Cost Analysis
  - System-level Up
  - Top Down
- Ground Operations Overview
- Mission Planning/Ops. Overview
- Program Management Plan
- Procurement Plan
- Facilities Assessment
- Development/Certification/Test Plan

Stephen Bailey/IE3/283-5411

New Initiatives Office
Conclusions

- Excellent support from the Center resulted in a well executed study

- In many ways a prototype for how similar preliminary concept studies can be performed
  - Fast paced, fixed schedule
  - NIO in project management role, ET in Systems Engineering role, EA providing discipline engineering

- Concept study will be finished by mid October
  - EA's work is finished

- Study objectives met

- Next phase of requirements assessment set to begin

- Accolades all around

Stephen Bailey/IE3/283-5411
Recommendations

- Return in mid October with Programmatics assessment
  - Strategic options and recommendations
    - Program Implementation Plan
    - Procurement Strategies
    - Project Management Strategies
    - Facilities and resource assessment

- Get a more definitive reading from our customer, Mike Griffin, on the Artemis Concept

- Conduct an assessment of where to go from here
  - Options:
    - Quit until serious indication of program interest
    - Study Common Mars Lander
    - Consider In-House skunkworks
    - Other
The Name and the Logo

- Should a project develop, we would like to suggest a name
  - Artemis
  - Reference from classical Greek mythology
  - Purposefully avoiding an acronym

- Artemis is the Greek Goddess often associated with the Moon
  - She is the twin sister of Apollo
  - The shining one, goddess of the golden arrows
  - The slender crescent of the Moon is her bow

- The logo represents the shaft of an arrow notched in the bow, with a "quiver" of payloads ready to loose
Appendix

Payload Descriptions
Payload: Sample Return

Vital Statistics
Mass: 200 kg
Power: TBD
Volume: 2m x 2m x 2m
Data Rate: TBD
No. of Missions: ~100 over 30 years
Mission Duration: Few hours on Lunar surface

Description: Collect 1 kg of 1 to 3 cm rock and soil samples. Deliver the samples to Earth via a return stage. Obtain representative samples from the numerous petrological units over the entire lunar surface.

Objective: Determine the composition, the age and developmental history of the lunar crust and mantle and the Moon itself. Find economically important resources for use on the Moon and for export to Earth.
Payload: Geophysical Station Network

Vital Statistics
Mass: 150 kg
Power: 45 w
Volume: 1.6m x 1.2m x 1.2m
Data Rate: 1.1 kbs
No. of Missions: >20
Mission Duration: >10 years

Description: Set up a global network of geophysical stations to obtain long term, seismic, heat flow, magnetic, exospheric, gravity, etc., data on the Moon.

Objective: Determine the internal structure, composition, energy budget, etc., of the Moon. Determine the composition and dynamics of the lunar atmosphere.
Payload: Teleoperated Rovers

Vital Statistics
Mass: 200 kg
Power: 300 W
Volume: 2m x 2m x 2m
Data Rate: 25 kbs
No of Missions: ~10
Mission Duration: ~1 year

Description: Obtain composition, gravity, magnetic, etc. profiling data along 100 to 1000 km traversers. Do detailed resource mapping of 1 to 10 km square areas.

Objective: Determine the variations in the composition and structure of the crust on the regional scale to determine its origin and evolution. Determine the extent and ore grade of lunar mining sites.
Payload: 1m Astronomical Telescopes

Vital Statistics
Mass: 200 kg
Power: TBD
Volume: 2m x 2m x 2m
Data Rate: TBD
No. of Missions: ~10
Mission Duration: >10 year

Description: Set up several 1m, automated telescopes. Obtain high quality, uninterrupted, long term, UV, visual and IR, photometric, spectral and sky survey data.

Objective: Determine the composition, structure and evolution of stars, galaxies and the universe as a whole.
Payload: Moon-Earth Radio Interferometer

Vital Statistics
Mass: 200 kg
Power: TBD
Volume: TBD
Data Rate: TBD
No. of Missions: 1
Mission Duration: > 10 years

Description: Set up a radio telescope on the Moon as part of a Moon-Earth interferometer with a 384,000 km baseline (30 x greater than possible on the Earth alone).

Objective: Obtain detailed astrometry with a resolution of 30 microarcsec (at 6 cm wavelength).
Payload: Very Low Frequency Radio Antennas

Vital Statistics
Mass: 20 kg
Power: 20 w
Volume: TBD
Data Rate: TBD
No. of Missions: > 20
Mission Duration: > 10 years

Description: Set up an array of 1 to 10 mHz antennas to obtain the low frequency radio spectra of galactic and extragalactic sources.

Objective: Determine the structure of galactic and extragalactic objects. Map the distribution of interstellar matter out to several thousand parsecs.
Payload: Lunar Polar Crater Telescope

Vital Statistics
Mass: 200 kg
Power: TBD
Volume: 2 m x 2 m x 2 m
Data Rate: TBD
No. of Missions: 1
Mission Duration: > 10 years

Description: Set up a 1 m, automated, IR telescope in a permanently shadowed, polar crater where the temperature is always < 80k.

Objective: Obtain IR data on solar system, galactic and extragalactic sources with a telescope and detector which are naturally cooled in the lunar polar environment.
Payload: Lunar Resource Utilization Experiments

Vital Statistics
Mass: 200 kg
Power: TBD
Volume: TBD
Data Rate: TBD
No. of Missions: > 10
Mission Duration: 1 year

Description: Set up laboratory scale experiments to make lunar oxygen, cast basalt, metals, ceramics, etc. from lunar resources.

Objective: Evaluate various processes proposed for obtaining useful products from lunar resources.
Payload: SEI Engineering Experiments

Vital Statistics
Mass: 200 kg
Power: TBD
Volume: TBD
Data Rate: TBD
No. of Missions: > 10
Mission Duration: 1 year

Description: Conduct engineering tests of equipment in the lunar environment.

Objective: Determine the effects on SEI critical hardware of lunar dust, 1/6g, vacuum, etc.
Payload: Biological Experiments

Vital Statistics
Mass: < 200 kg
Power: TBD
Volume: TBD
Data Rate: TBD
No. of Missions: ~ 3
Mission Duration: 1 year

Description: Set up small, automated biological experiments in the lunar environment.

Objective: Determine the effects of 1/6g, cosmic radiation, etc. on the growth and health of simple plants and animals.
Artemis

Common Lunar Lander
Engineering Study Results

Presentation to Aaron Cohen
September 17, 1991
by
Jonette Stecklein
CLL Engineering Study: Results

- CLL Engineering Study
- CLL Mission
- Options
- CLL Team & Supporters
Mission

Provide a delivery system to soft-land a 200 kg payload set at any given Lunar latitude and longitude.
CLL Engineering Study

Objective: Perform a feasibility study of the CLL concept

Approach: Point design of lunar lander + Overall system trades

Products:
- Requirements for delivery system
  (launch vehicle, lander, payload i/f, mission op.)
- Completion and documentation of major system trades
- Lunar lander conceptual design and drawings
- Subsystem design and characterization (lunar lander)
- Cost estimates at the subsystem level (lunar lander)
Common Lunar Lander Engineering Study Schedule


July 1991

21 22 23 24 25

Team Mtg

LAUNCH VEHICLE CHOSEN

PAYLOAD INTEGRATION COMPLETED

Subsystem Chosen

Power packs to Betsy

1st TEAM INPUT

Kickoff

August 1991

21 22 23 24 25

Team Mtg

Team Mtg

Team Mtg

Trip to D.C.

Senior Board Review

September 1991

21 22 23 24 25

Team Mtg

Team Mtg

Team Mtg

Team Mtg

Subsystem Charac to Jonette

Dry Run

Dry Run

1st TEAM INPUT

9 weeks from Study Kickoff

Cohen

2 - 4 pm
B.1; Rm 945
Mission Goals and Requirements

GUIDELINES
- Small, simple, cheap, & quick

SYSTEM DRIVERS
1. Cost
2. Schedule
3. Performance

Earth Launch
- Use existing launch vehicle (medium class)
- First flight: Nov. 1996
- 2 to 5 flights/year for 20 years

Lander
- Lander provides no services to the payload (other than landing)
- Lander is active until touchdown + time to telemeter landing information
- Design loads and limits are constrained by launch vehicle, not by lander system
- Budget: $30 million/each for Lander hardware (recurring cost)

Payload Imposed Requirements
- Provide unobstructed hemispherical view of the sky
- Do not preclude payload access to lunar surface OR payload dismount
- Do not preclude payload return to Earth (Sample Return Mission)

Lander Subsystems
- Emphasis on choosing existing system, rather than new design
- Strive for light weight solutions
- Avoid block redundancy when a single string system can provide adequate reliability
CLL Reference Mission

- Payload set mated to pallet. CLL spacecraft built in parallel. Payload pallet and CLL spacecraft integrated (structural i/f only).
- CLL 2 stage spacecraft is launched by ELV using an east coast launch pad.
- LV places CLL in circular Earth orbit.
- CLL remains in Earth orbit for up to 1 rev.
- CLL Transfer Stage performs TLI.
- 5 day trip to moon.
- Transfer Stage performs LOI, into circular orbit about Moon.
- Up to 14 day wait in lunar orbit.
- Transfer Stage performs deorbit burn.
- Transfer Stage separates from Lander Stage.
- Lander performs descent and landing burns, targeting for a given lunar lat/long, and landing at lunar dawn.
- Lander transmits final system performance and landing location information to Earth.
  Sized for 1 hour lifetime on lunar surface.
CLL Mission

Flexible Earth Launch Window

CLL Separation from LV, after circularization

Stage Separation, after deorbit

- Lander
- Transfer Stage
- Launch Vehicle
Launch Vehicle
- Purchase
  - medium class ELV

Options
- Delta II
- Titan II Series
- Atlas II Series

Transfer Stage
- Preliminary Sizing
  - 86.5% Mass Fraction
    - 7.6% prop. sys. (dry)
    - 5.9% structure, etc.
  - Subsystems off-loaded from Lander Stage

Lander Stage
- Designed through subsystem level
  - Subsystems designed
    - Structure
    - Propulsion
    - Power
    - GN&C
    - Communication
    - Tracking
  - Subsystems estimated
    - Thermal
    - Insulation
## Cost

<table>
<thead>
<tr>
<th>Recurring Costs</th>
<th>Non-recurring Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Launch Vehicle</td>
<td>$50 - 100 million</td>
</tr>
<tr>
<td>CLL System</td>
<td></td>
</tr>
<tr>
<td>Transfer Stage</td>
<td>$10 million</td>
</tr>
<tr>
<td>Lander Stage</td>
<td>$30 million</td>
</tr>
<tr>
<td>Payloads</td>
<td></td>
</tr>
<tr>
<td>Separate program.</td>
<td></td>
</tr>
<tr>
<td>Specific costs are payload specific.</td>
<td>$120 million</td>
</tr>
</tbody>
</table>
CLL Options

• Architectural Options
  • 1 stage CLL Vehicle (LOI, DD&L)
  • 2 stage CLL Vehicle
    • considered staging opportunities within (0 - 100% TLI, LOI, DD&L) burns

• Lower Cost Options
  • Lower Performance Launch Vehicle
  • Use of Refurbished ICBM Missiles (Titan II)

• Lower Weight Options
  • Use of SDIO Developed Hardware
  • Full Sun Trajectory during Lunar Orbit Wait
    • leads to smaller Solar Arrays
Two Stage Performance Analysis
1st Stage Mass Fraction = 0.86

Reference Design Parametrics
1st Stage Isp = 328, Mass Fraction = 86%

Current Reference Design
200 kg Payload
138 kg Subsystems

- - - 25% Margin
- - 15% Margin
----- No Margin

Jonette Stecklein/ET2/x36624/ p. 12
Systems Engineering Division
Two Stage Performance Analysis (Cont)
1st Stage Mass Fraction = 0.88

Reference Design Parametrics
1st Stage $\text{i}sp = 328$, Mass Fraction = 88%

Current Reference Design
200 kg Payload
138 kg Subsystems

- Fixed Mass on Lander (PL + Subsystems) (kg)
- Total Flight System Mass (kg)

- Titan III
- Atlas IIA
- Atlas IAS
- Atlas II
- Titan IIS
- Delta II 7920

- 25% Margin
- 15% Margin
- No Margin
Two Stage Performance Analysis (Cont)
1st Stage Mass Fraction = 0.90

Reference Design Parametrics
1st Stage Isp = 328, Mass Fraction = 90%

Current Reference Design
200 kg Payload
138 kg Subsystems

Fixed Mass on Lander (PL + Subsystems) (kg)
CLL Engineering Team

Jonette Stecklein  ET2  Lead Engineer
Shelby Lawson    Configuration Design
Ed Robertson     Launch Vehicle Assessment
Lynn Wagner      ET3  Trajectory Design
Bill Culpepper   EE6  Tracking
Henry Chen       EE7  Communications
Nancy Smith      EG2  GN&C
Don Hyatt        EP4  Propulsion
Betsy Kluksdahl  EP5  Power
George Sanger    LESC Structures
Ken Baker        ER2  Landing: Hazard Avoidance

CLL Team Supporters

John Kowal      Thermal Control
Nancy Wilks     Mission Analysis
Gerry Condon    Mission Analysis
Max Kilbourn   Mission Analysis
Rocky Duncan   Mission Analysis
D. McLain      Communication
T. Early        Communications
Zafar Taqvi    Communications
Rich Schoenberg Propulsion
Bob Hendrix     Power (EPDC)
Darin McKinnis  Power (Pyrotechnics)
Shannan Fisher  Power (Solar Arrays)
Don Allison     Power (Solar Arrays)
Bob Bragg       Power (Batteries)
Fred Abolfathi  Structures
Rick Deppisch   GN&C

Paul Phillips  Programmatic
Steve Hoffman  Cost Estimation
Gail Boyes     Procurement
Alan Binder    Payloads/Science
W. Holdenbach  Payloads Assessment
Jim Engler     GN&C
D. McSweeny    Operations
D. McLaughlin  SR&QA
Edmund Hack    Landing

Jonette Stecklein/ET2/x36624/ p. 15
Systems Engineering Division
Two Stage Performance Analysis (Cont)

1st Stage Mass Fraction = 0.9, 850 kg Reference Lander

Lightweight (850 kg) Lander Parametrics
Lander Isp = 310, 15% Improved Propulsion & Structural Factor
1st Stage Isp = 328, Mass Fraction = 90%

Current Reference Design
200 kg Payload
138 kg Subsystems

Fixed mass reductions possible from lighter weight avionics, etc.
(30% reduction shown)

Fixed Mass on Lander (PL + Subsystems) (kg)

Titan IIL
Atlas IIAS
Atlas IIA
Atlas II
Titan II
Delta II 7920

--- 25% Margin
--- 15% Margin
--- No Margin

Jonette Stecklein/ET2/x36624/ p. 16

Systems Engineering Division
COMMON LUNAR LANDER TRAJECTORY ANALYSIS

Lynn A. Wagner, Jr.
Nancy A. Wilks
Mission Definition Branch/ ET3
September 17, 1991

Lynn Wagner/ET3/x33816

Systems Engineering Division
COMMON LUNAR LANDER
TRAJECTORY REQUIREMENTS

- Earth launch flexibility
  - 14-day launch window to be achieved by variable loiter time in lunar parking orbit
- Land at any specified lunar latitude and longitude
- Land at any specified time in the lunar day/night cycle
- Program will operate during the entire 18.6 year lunar cycle
COMMON LUNAR LANDER TRAJECTORY CHARACTERISTICS

- Earth Parking Orbit (185 km circular orbit)
  - Due east launch from ETR into a 28.45 deg inclination
  - Standard circular orbit for the launch vehicles examined
- Minimum Energy Trajectories
  - 5 day transfer time
  - Near Hohmann transfers
- Lunar Parking Orbit (122 km circular orbit)
  - Minimizes deorbit, descent, and landing delta-V cost
  - Inclination and Ascending Node defined for each specific landing site and lunar loiter time
- All lunar landing sites are accessible
COMMON LUNAR LANDER TRAJECTORY

LUNAR ORBIT INSERTION (LOI)

LOW LUNAR ORBIT (LLO)

LOW EARTH ORBIT (LEO) AT TIME OF INJECTION

MOON AT LUNAR ARRIVAL

~13°/DAY

TRANS Lunar TRAJECTORY

MOON AT TRANS Lunar INJECTION

Drawing not to scale

Lynn Wagner/ET3/x33816

Systems Engineering Division
COMMON LUNAR LANDER TRAJECTORY

- Earth Orbit (LEO)
- Translunar Injection (TLI)
- Ascent
- Translunar Trajectory
- Low Lunar Orbit (LLO)
- Lunar Orbit Insertion (LOI)
- Descent and Landing
- Deorbit Burn

Drawing not to scale
<table>
<thead>
<tr>
<th>Trajectory Event</th>
<th>Duration</th>
<th>ALLOCATED DELTA-V*</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Launch</td>
<td>20-30 min</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Earth Parking Orbit Coast</td>
<td>0-90 min</td>
<td></td>
<td>185 km Circular Orbit</td>
</tr>
<tr>
<td>Translunar Injection</td>
<td></td>
<td>3200 m/s</td>
<td></td>
</tr>
<tr>
<td>Translunar Coast</td>
<td>5 days</td>
<td>30 m/s</td>
<td>Midcourse correction (100% lighting)</td>
</tr>
<tr>
<td>Lunar Orbit Insertion</td>
<td></td>
<td>840 m/s</td>
<td></td>
</tr>
<tr>
<td>Lunar Parking Orbit Coast</td>
<td>0-14 days</td>
<td></td>
<td>122 km Circular Orbit (Minimum of 61% lighting)</td>
</tr>
<tr>
<td>Deorbit Maneuver</td>
<td></td>
<td>30 m/s</td>
<td></td>
</tr>
<tr>
<td>Deorbit Coast</td>
<td>51 min</td>
<td></td>
<td>122 x 15 km Orbit</td>
</tr>
<tr>
<td>Descent and Landing</td>
<td>9 min</td>
<td>1820 m/s</td>
<td></td>
</tr>
</tbody>
</table>

* Does not include provisions for dispersions and performance reserves
COMMON LUNAR LANDER
ALTERNATE TRAJECTORY

SCENARIO

- 90° Inclination Orbital Plane required
- 122 km. Circular Orbit
- Approximately 90° or -90° Ascending Node location at LOI

ADVANTAGES

- 100% light during entire lunar orbit
- Minimum batteries needed during lunar orbit coast

DISADVANTAGES

- Solar Panel shadowing may occur during translunar coast and maneuver/IMU realignments
- Launch Windows occur once or twice a month
  - The landing site determines which opportunity is valid based on the maximum lunar orbit loiter time
  - The lighting constraints allowable are sunrise and sunset
- Launch Window duration is estimated at 2-3 days at most
COMMON LUNAR LANDER ALTERNATE TRAJECTORY

Moon

Lunar Parking Orbit

Earth

↑ Sun ↑

Drawing not to scale
Introduction

Baseline Mission Profile:
ELV injection to a 185 km circular LEO
Two-stage lunar stack consisting of a transfer vehicle and lander

Baseline ELVs:
Delta II 7920
Titan IIS SLV

Optional Mission Profile:
ELV performs TLI burn
Single-stage lander injected

Optional ELVs:
Atlas II, IIA, IIAS
Titan IIL SLV
McDonnell Douglas 7920

Description of Delta II Series ELVs:

LOX/RP-1 first stage, RS-270/B or RS-270/C main engine.  
N2O4/Aerozine-50 second stage, AJ10-118K, avionics for first two stages.  
Delta II 7920 has 9 GEM strap-ons, 7925 has a STAR-48B upper stage.

Availability:

Production Plans: Phase out from 69xx to 79xx series complete by 1992.
Delta II 792X Configurations

Graphite Epoxy Motors (GEMs)

Delta 7925

2.9
5.5

8.5
27.8

38.2
125.2

Delta 7925 - 10

3.0
10

7.9
25

37.6
123.4

12:1 Main Engine Expansion Ratio

 Delta II 792X Configurations

Graphite Epoxy Motors (GEMs)

Delta 7925

2.9
5.5

8.5
27.8

38.2
125.2

Delta 7925 - 10

3.0
10

7.9
25

37.6
123.4

12:1 Main Engine Expansion Ratio
Delta II Payload Fairings (PAFs)

Note: All Station Numbers are in inches.

1. All Station Numbers are in inches.
2. Station Numbers with an asterisk (*) indicate outside stations.

Projections of spacecraft appendages below the spacecraft separation plane may be permitted but must be coordinated with the Delta Program Office.

Systems Engineering Division
Description of Titan II SLV Series derived from ex-ICBMs:

Two stage Titan II booster configuration using N2O4/Aerozine-50

IIG  = No booster thrust augmentation, 3.0 meter Delta II PLF

IIS  = 2 to 10 strap-on Graphite Epoxy Motors (GEMs)

III  = Parallel configuration of two baseline boosters (1st stage only)
    attached to a baseline core (stages 1 & 2), 3.0 meter Delta II PLF

IIIIL = Parallel configuration of two baseline boosters (1st stage only)
    attached to a Titan III (Commercial Titan) core using Titan II
    stage 1 & 2 engines, 13.1' x 34' PLF (4.0 x 10.4 meter PLF)

Availability:

Number Remaining          41 (out of 55) unrefurbished, unmodified ICBMs
Expected Prod Run          Refurbish remainder of ICBM stock
                          Plans to produce revisions of the Titan II series
Titan II Series Configurations

TITAN FAMILY

Basic
No Thrust Augmented
Solid Thrust Augmented
Liquid Thrust Augmented
Solid Thrust Augmented

4,200 lbs Polar
4,200 lbs Polar
7,800 lbs Polar
15,500 lbs Polar
24,000 lbs Polar

TII B
TII G
TII S
TII L/TII L
TIIII

Systems Engineering Division
Titan II Payload Fairings (PAFs)

<table>
<thead>
<tr>
<th>Dimension, In.</th>
<th>Weight, Lb</th>
</tr>
</thead>
<tbody>
<tr>
<td>L, FT</td>
<td>L</td>
</tr>
<tr>
<td>20</td>
<td>240</td>
</tr>
<tr>
<td>25</td>
<td>300</td>
</tr>
<tr>
<td>30</td>
<td>360</td>
</tr>
</tbody>
</table>

*Weight Excludes Exterior Insulation, Acoustic Blankets and Standard Access Doors (Preliminary).*
General Dynamics Atlas Series

Description of Atlas Series ELVs:

LOX/RP-1 booster, one sustainer and two booster engines, 1.5 stage.
LOX/LH2 Centaur upper stage, two P&W RL-10 series engines, avionics.

Atlas II has longer tanks & more booster thrust. Atlas IIA has upgraded Centaur. Atlas IIAS has four Castor IVA solid rockets strapped to booster.

Availability:

<table>
<thead>
<tr>
<th>ELV</th>
<th>Year</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atlas I</td>
<td>1990</td>
<td>7 remaining (committed)</td>
</tr>
<tr>
<td>Atlas II</td>
<td>1991</td>
<td></td>
</tr>
<tr>
<td>Atlas IIA</td>
<td>1991</td>
<td></td>
</tr>
<tr>
<td>Atlas IIAS</td>
<td>1993</td>
<td></td>
</tr>
</tbody>
</table>
Atlas II Series Configurations

ATLAS LAUNCH VEHICLE

Characteristics
• 2 1/2 stages
• Pressure-stabilized tanks
• 42.7 to 47.2m (140 to 155 ft) long
• 3.05m (10 ft) diameter tanks
• 4.2m or 3.3m (14 or 11 ft) diameter fairing
Atlas II Payload Fairings (PAFs)

LPF
14-FT FAIRING
(4.2M)

MPF
11-FT FAIRING
(3.3M)

208.5 IN.
(5296 mm)

147.7 IN.
(3752 mm)

143.7 IN.
DIA
(3650 MM)

154.0 IN.
DIA
(3912 MM)

165.0 IN.
(4191 MM)

115.0 IN.
(2921 MM)
### Payload Performance to LEO

<table>
<thead>
<tr>
<th>PSW Performance (kg):</th>
<th>Delta II 7920</th>
<th>Titan IIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>185 km/28.7/ESMC</td>
<td>5,040*</td>
<td>5,430</td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td><strong>$55 M</strong></td>
<td><strong>$35 M</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PSW Performance (kg):</th>
<th>Atlas II/IIA/IIAS</th>
<th>Titan III</th>
</tr>
</thead>
<tbody>
<tr>
<td>185 km/28.5/ESMC</td>
<td>6,600/7,050/8,600***</td>
<td>9,060</td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td><strong>$85/90/120 M</strong></td>
<td><strong>$47 M</strong></td>
</tr>
</tbody>
</table>

* 2.9m PLF  
** W/O integration costs  
*** 4.2m (large) PLF
Common Lunar Lander (CLL)

Conceptual Design &
Mass Properties
CLL Preliminary Conceptual Design

- Lander sized to fit within Delta payload shroud
  - 3-lander legs stowed during flight
  - 5 S-band omni antennas
  - Landing radar underneath lander structure
  - 6 VTE bi-propellant engines for lunar descent and landing
  - 12 RCS engines for attitude control

- Crushable honeycomb legs deploy during lunar descent
  (dimensions are to be updated by George Sanger & Fred Abolfathi)
  - 4.0 meter footprint
  - 2.25 meter diameter lander base

- Transfer stage performs TLI, midcourse, LOI and lunar deorbit burns
  - 2 solar arrays and rechargeable batteries
  - 1 Transtar bi-propellant engine
CLL Schematic

Guidance, Navigation & Control System
- Inertial Measurement Unit
- Star Tracker
- Sensors
- VTE Jet Drivers

Propulsion System
- Reaction Control System
- Descent System

Data Management System
- Multiplexer Demultiplexer (MDM)

Instrumentation

Power System
- Power Distribution System
- Pyros
- Power

Communications & Tracking
- S-Band

Landing Radar System

TRANSFER STAGE
- Power System - batteries
- - solar array
- Communications - antenna

Shelby Lawson, ET2, x36611  September 17, 1991

Systems Engineering Division
### DESIGN MASS SUMMARY

**Common Lunar Lander (CLL)**

<table>
<thead>
<tr>
<th>FUNCTIONAL SUBSYSTEM CODE</th>
<th>Lander</th>
<th>Transfer Stage</th>
<th>CLL Launch Adapter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0 STRUCTURE</td>
<td>27</td>
<td>300</td>
<td>255</td>
</tr>
<tr>
<td>2.0 PROTECTION</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.0 PROPULSION</td>
<td>94</td>
<td>282</td>
<td></td>
</tr>
<tr>
<td>4.0 POWER</td>
<td>39</td>
<td>93</td>
<td></td>
</tr>
<tr>
<td>5.0 CONTROL</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>6.0 AVIONICS</td>
<td>91</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>7.0 ENVIRONMENT</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8.0 OTHER</td>
<td>24</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>9.0 GROWTH</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>DRY MASS</strong></td>
<td>280</td>
<td>679</td>
<td>255</td>
</tr>
<tr>
<td>10.0 NON-CARGO</td>
<td>11</td>
<td>104</td>
<td></td>
</tr>
<tr>
<td>11.0 CARGO</td>
<td>200</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td><strong>INERT MASS</strong></td>
<td>491</td>
<td>784</td>
<td>255</td>
</tr>
<tr>
<td>12.0 NON-PROPELLANT</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>13.0 PROPELLANT</td>
<td>426</td>
<td>4,410</td>
<td></td>
</tr>
<tr>
<td><strong>GROSS MASS</strong></td>
<td>917</td>
<td>5,193</td>
<td>255</td>
</tr>
</tbody>
</table>

**NOTE:** Single string systems. Selective redundancy.

Lander: 5.8 m dia legs deployed, 2.75 m dia lander structure
Payload: 1.5 x 1.5 x 1.5 meter cube represented, 200 kg.

Adapter, Support Equipment:

Launch mass = 6,365 kg

**NOTE:** All dimensions are in meters.
## DESIGN MASS SUMMARY

### Common Lunar Lander (CLL)

<table>
<thead>
<tr>
<th>FUNCTIONAL SUBSYSTEM CODE</th>
<th>Lander</th>
<th>Transfer Stage</th>
<th>CLL Launch Adapter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0 STRUCTURE</td>
<td>27</td>
<td>300</td>
<td>270</td>
</tr>
<tr>
<td>2.0 PROTECTION</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.0 PROPULSION</td>
<td>96</td>
<td>291</td>
<td></td>
</tr>
<tr>
<td>4.0 POWER</td>
<td>39</td>
<td>93</td>
<td></td>
</tr>
<tr>
<td>5.0 CONTROL</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>6.0 AVIONICS</td>
<td>91</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>7.0 ENVIRONMENT</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8.0 OTHER</td>
<td>24</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>9.0 GROWTH (15%)</td>
<td>42</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**DRY MASS**
- 325 + 689 = 1014 kg
- 270 kg

**INERTIA MASS**
- 537 + 799 = 1336 kg
- 270 kg

**NON-CARGO**
- 12 kg
- 111 kg

**CARGO**
- 200 kg

**NON-PROPELLANT**
- 0 kg
- 0 kg

**PROPELLANT**
- 465 kg
- 4,671 kg

**GROSS MASS**
- 1,002 kg
- 5,470 kg
- 270 kg

**NOTE:** All dimensions are in meters.

**NOTE:** Single string systems. Selective redundancy.

Lander: 4.0 m dia legs deployed, 2.25 m dia lander structure
Payload: 1.5 x 1.5 x 0.6 meter Rover & instruments, 200 kg.
Transfer Stage: 87% Mass Fraction
Adapter, Support Equipment: 4% of CLL & Transfer Stage.

Launch mass = 6,742 kg
<table>
<thead>
<tr>
<th>CLL Lander</th>
<th>Ti. Mass</th>
<th>Ti. Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1.0 Structure</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Space Frame Assembly</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>- CLL / Transfer Stage Adapter</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>- Mounting Structure (info)</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td><strong>2.0 Protection</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Insulation</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td><strong>3.0 Propulsion</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Integrated Propulsion System</td>
<td>96</td>
<td></td>
</tr>
<tr>
<td><strong>4.0 Power</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Generation</td>
<td>39</td>
<td></td>
</tr>
<tr>
<td>- Electrical Pwr Dist. &amp; Control (EPDC)</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>- Wiring</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td><strong>6.0 Avionics</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Guidance, Navigation &amp; Control (GNC)</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>- Data Management System (DMS)</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>- Instrumentation</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>- Communications &amp; Tracking (C&amp;T)</td>
<td>53</td>
<td></td>
</tr>
<tr>
<td><strong>7.0 Environment</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Environment Control System (ECS)</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td><strong>8.0 Other</strong></td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>- Landing System</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td>- Pyrotechnics</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>- Miscellaneous Mechanisms</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td><strong>9.0 Growth</strong></td>
<td>42</td>
<td></td>
</tr>
<tr>
<td><strong>10.0 Non-Cargo</strong></td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>- Reserve and Residual Fluids</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td><strong>11.0 Cargo</strong></td>
<td>200</td>
<td></td>
</tr>
<tr>
<td><strong>12.0 Non-Propellant (Consummables)</strong></td>
<td>0</td>
<td></td>
</tr>
<tr>
<td><strong>13.0 Propellant</strong></td>
<td>465</td>
<td></td>
</tr>
<tr>
<td><strong>14.0 Other</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Landing System</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>- Pyrotechnics</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>- Miscellaneous Mechanisms</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td><strong>15.0 Growth</strong></td>
<td>42</td>
<td></td>
</tr>
<tr>
<td><strong>16.0 Non-Cargo</strong></td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>- Reserve and Residual Fluids</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td><strong>17.0 Cargo</strong></td>
<td>200</td>
<td></td>
</tr>
<tr>
<td><strong>18.0 Non-Propellant (Consummables)</strong></td>
<td>0</td>
<td></td>
</tr>
<tr>
<td><strong>19.0 Propellant</strong></td>
<td>465</td>
<td></td>
</tr>
</tbody>
</table>

**CLL Lander Dry Mass** = 325 KG

**CLL Lander Inert Mass** = 537 KG

**CLL Lander Gross Mass** = 1,002 KG
### Common Lunar Lander Mass Properties

#### CLL Transfer Stage

<table>
<thead>
<tr>
<th>Component</th>
<th>Ti. Mass</th>
<th>Kg</th>
<th>Component</th>
<th>Ti. Mass</th>
<th>Kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0 Structure</td>
<td>300</td>
<td></td>
<td>8.0 Other</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>- Primary Body Structure</td>
<td>300</td>
<td></td>
<td>- Miscellaneous Mechanisms</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>2.0 Protection</td>
<td></td>
<td></td>
<td>9.0 Growth</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>- Insulation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.0 Propulsion</td>
<td>291</td>
<td></td>
<td>10.0 Non-Cargo</td>
<td>111</td>
<td></td>
</tr>
<tr>
<td>- Integrated Propulsion System</td>
<td>291</td>
<td></td>
<td>- Reserve and Residual Fluids</td>
<td>111</td>
<td></td>
</tr>
<tr>
<td>4.0 Power</td>
<td>93</td>
<td></td>
<td>11.0 Cargo</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>- Generation</td>
<td>47</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Electrical Pwr Dist. &amp; Control (EPDC)</td>
<td>27</td>
<td></td>
<td>12.0 Non-Propellant (Consummables)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>- Wiring</td>
<td>18</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.0 Avionics</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Instrumentation</td>
<td>1</td>
<td></td>
<td>13.0 Propellant</td>
<td>4,671</td>
<td></td>
</tr>
<tr>
<td>7.0 Environment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Environment Control System (ECS)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Launch Adapter & Support

<table>
<thead>
<tr>
<th>Component</th>
<th>Ti. Mass</th>
<th>Kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Launch Adapter &amp; Support</td>
<td>270</td>
<td>Used on launch from ELV, Estimate.</td>
</tr>
</tbody>
</table>

#### Total Launch Mass

<table>
<thead>
<tr>
<th>Component</th>
<th>Ti. Mass</th>
<th>Kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Launch Mass</td>
<td>6,742</td>
<td></td>
</tr>
<tr>
<td>CLL: LANDER SUBSYSTEM:</td>
<td>Ti. Mass (KG)</td>
<td>No</td>
</tr>
<tr>
<td>------------------------</td>
<td>--------------</td>
<td>----</td>
</tr>
<tr>
<td>1.0 Structure:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Space Frame Assembly</td>
<td>27.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>19.2</td>
<td></td>
</tr>
<tr>
<td>CLL / Transfer Stage Adapter</td>
<td>8.0</td>
<td></td>
</tr>
<tr>
<td>Subsystem Mounting (info only)</td>
<td>20.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.0 Protection:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Insulation</td>
<td>3.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.0</td>
<td></td>
</tr>
</tbody>
</table>

Contact George Sanger or Fred Abolfathi, LESC, 333-7254.
Contact Steve Bailey, 283-5411. Estimated.
### Common Lunar Lander Mass Properties

<table>
<thead>
<tr>
<th>CLL: LANDER SUBSYSTEM:</th>
<th>Tl. Mass (KG)</th>
<th>No</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>3.0 Propulsion:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Integrated Propulsion System</td>
<td>96.0</td>
<td></td>
<td>Contact Don Hyatt, x39019. Performs descent &amp; landing burns.</td>
</tr>
<tr>
<td>Fuel Tanks</td>
<td>7.2</td>
<td>2</td>
<td>Spherical, 59 cm dia.</td>
</tr>
<tr>
<td>Oxidizer Tanks</td>
<td>7.2</td>
<td>2</td>
<td>Spherical, 59 cm dia.</td>
</tr>
<tr>
<td>Pressurant Tanks</td>
<td>12.3</td>
<td>4</td>
<td>Spherical, 30 cm dia.</td>
</tr>
<tr>
<td>RCS Engines</td>
<td>12.6</td>
<td>12</td>
<td>Marquardt R-6C</td>
</tr>
<tr>
<td>Descent Lander Engines</td>
<td>46.3</td>
<td>6</td>
<td>TRW VTE engines, lsp=300 sec.</td>
</tr>
<tr>
<td>Lines, Valves &amp; Insulation</td>
<td>8.7</td>
<td></td>
<td>Historical estimate.</td>
</tr>
<tr>
<td>Mounting Structure</td>
<td>1.7</td>
<td></td>
<td>Historical estimate.</td>
</tr>
</tbody>
</table>

### CLL: LANDER SUBSYSTEM:

<table>
<thead>
<tr>
<th>Tl. Mass (KG)</th>
<th>No</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>4.0 Power:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Generation</td>
<td>13.1</td>
<td>Contact Betsy Kluksdahl, x36484.</td>
</tr>
<tr>
<td>Primary Batteries</td>
<td>11.3</td>
<td>Structure factor of 15.6% supplied by George Sanger, 333-7254.</td>
</tr>
<tr>
<td>Mounting Structure</td>
<td>1.8</td>
<td></td>
</tr>
<tr>
<td>Electrical Pwr Dist. &amp; Control (EPDC)</td>
<td>15.7</td>
<td>Contact Betsy Kluksdahl, x36484. Preliminary estimate.</td>
</tr>
<tr>
<td>Bus Controller</td>
<td>13.6</td>
<td>38.1x38.1x15.2 cm</td>
</tr>
<tr>
<td>Mounting Structure</td>
<td>2.1</td>
<td>Structure factor of 15.6% supplied by George Sanger, 333-7254.</td>
</tr>
<tr>
<td>Wiring</td>
<td>10.5</td>
<td>Contact Betsy Kluksdahl, x36484. Estimate based on ACRV</td>
</tr>
<tr>
<td>Cable</td>
<td>9.1</td>
<td>Includes connectors, 25.9K cm3</td>
</tr>
<tr>
<td>Mounting Structure</td>
<td>1.4</td>
<td>Structure factor of 15.6% supplied by George Sanger, 333-7254.</td>
</tr>
</tbody>
</table>
## Common Lunar Lander Mass Properties

<table>
<thead>
<tr>
<th>CLL: LANDER</th>
<th>Subsystem</th>
<th>Ti. Mass (KG)</th>
<th>No</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.0 Avionics:</td>
<td>Guidance, Navigation and Control (GNC)</td>
<td>91.2</td>
<td>9.2</td>
<td>Contact Nancy Smith, x38275. Features integrated DMS system. Honeywell-764. 17.7x17.7x22.9 cm, 7200 cm³, 40W.</td>
</tr>
<tr>
<td>Inertial Measurement Unit (IMU)</td>
<td></td>
<td>7.3</td>
<td>1</td>
<td>Lawrence Livermore. 18x18x25 cm, 8100 cm³, 8W. Structure factor of 10.8% supplied by George Sanger, 333-7254.</td>
</tr>
<tr>
<td>Star Tracker</td>
<td></td>
<td>1.0</td>
<td>1</td>
<td>Structure factor of 14.5% supplied by George Sanger, 333-7254.</td>
</tr>
<tr>
<td>Mounting Structure</td>
<td></td>
<td>0.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data Management System (DMS)</td>
<td></td>
<td>22.9</td>
<td></td>
<td>Contact Nancy Smith, x38275. Honeywell, similar to SSF, contains RJD functions. 37x23x34 cm, 29K cm³, 100W.</td>
</tr>
<tr>
<td>Multiplexer/DeMultiplexer (MDM)</td>
<td></td>
<td>20.0</td>
<td>2.9</td>
<td></td>
</tr>
<tr>
<td>Mounting Structure</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Instrumentation</td>
<td></td>
<td>5.8</td>
<td></td>
<td>Contact S. Lawson, x36611. Based on historical data. Dist. among subsystems. Structure factor of 16.6% supplied by George Sanger, 333-7254.</td>
</tr>
<tr>
<td>Sensors</td>
<td></td>
<td>3.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Signal Conditioners</td>
<td></td>
<td>1.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mounting Structure</td>
<td></td>
<td>0.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Communications &amp; Tracking (C&amp;T)</td>
<td></td>
<td>53.3</td>
<td></td>
<td>Contact Henry Chen, x30128, Zafar Taqvi, 333-6544. 8/16/91. Uses DSN 34 subnet, for telemetry, ranging and command.</td>
</tr>
<tr>
<td>- S-Band System</td>
<td></td>
<td>23.9</td>
<td></td>
<td>Motorola, inc. Cmd detector. 16x20x11 cm, 3500 cm³, 8W avg, 17.5W peak.</td>
</tr>
<tr>
<td>Transponder</td>
<td></td>
<td>3.3</td>
<td>1</td>
<td>New; 16x20x3824 cm, 7800 cm³, 18.8W avg., 71W peak.</td>
</tr>
<tr>
<td>RF Assembly</td>
<td></td>
<td>7.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Processing Module</td>
<td></td>
<td>3.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Antenna</td>
<td></td>
<td>4.6</td>
<td>1</td>
<td>TRW, Log conical spiral. 12.5 cm dia x 30 cm h, 3300 cm³, 0W.</td>
</tr>
<tr>
<td>Coaxial Cable</td>
<td></td>
<td>2.4</td>
<td>1</td>
<td>Gore, 900 cm³, dependent on communication equipment placement. Structure factor of 15.6% supplied by George Sanger, 333-7254.</td>
</tr>
<tr>
<td>Mounting Structure</td>
<td></td>
<td>3.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Tracking</td>
<td></td>
<td>29.4</td>
<td></td>
<td>Contact Bill Culpepper, x31479. Viking Heritage, Teledyne Ryan Co.</td>
</tr>
<tr>
<td>Landing Radar</td>
<td></td>
<td>22.1</td>
<td>1</td>
<td>Antenna on surface, 76.2x76.2x8.26 cm, 68W</td>
</tr>
<tr>
<td>Altimeter</td>
<td></td>
<td>5.1</td>
<td>1</td>
<td>23.4x14.7x20.1 cm, 28.5W</td>
</tr>
<tr>
<td>Altimeter Antenna</td>
<td></td>
<td>0.7</td>
<td>1</td>
<td>Cone shaped, 1721 cm³</td>
</tr>
<tr>
<td>Coax cable</td>
<td></td>
<td>0.1</td>
<td></td>
<td>Connection between altimeter and antenna. Estimate. Structure factor of 5.0% supplied by George Sanger, 333-7254.</td>
</tr>
<tr>
<td>Mounting Structure</td>
<td></td>
<td>1.4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Common Lunar Lander Mass Properties

<table>
<thead>
<tr>
<th>CLL: LANDER SUBSYSTEM:</th>
<th>Tt. Mass (KG)</th>
<th>No</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.0 Environment:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Environment Control System (ECS)</td>
<td>2.1</td>
<td></td>
<td>Contact Steve Bailey, 283-5411. Estimated.</td>
</tr>
<tr>
<td>Heaters</td>
<td>2.0</td>
<td></td>
<td>Estimate. Used to keep engines, tanks and subsystems warm.</td>
</tr>
<tr>
<td>Mounting Structure</td>
<td>0.1</td>
<td></td>
<td>Structure factor of 5.6% supplied by George Sanger, 333-7254.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CLL: LANDER SUBSYSTEM:</th>
<th>Tt. Mass (KG)</th>
<th>No</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.0 Other:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lander Legs</td>
<td>18.0</td>
<td>3</td>
<td>Alum. honeycomb.</td>
</tr>
<tr>
<td>Mounting Structure</td>
<td>3.9</td>
<td></td>
<td>Structure factor of 21.6% supplied by George Sanger, 333-7254.</td>
</tr>
<tr>
<td>Pyrotechnics System</td>
<td>1.8</td>
<td></td>
<td>Contact Betsy Kluksdahl, x36484.</td>
</tr>
<tr>
<td>N/C Pyrovalve</td>
<td>0.6</td>
<td>4</td>
<td>RCS Isolate, Unidynamics (P/N 51-1630) 8x5x5 cm, 200 cm3, 5A @ 30 mSec peak pwr.</td>
</tr>
<tr>
<td>Uplock Cutter</td>
<td>0.8</td>
<td>3</td>
<td>Lander Leg deploy, Apollo, 16x12x5 cm, 960 cm3, 5A @ 30 mSec peak pwr.</td>
</tr>
<tr>
<td>Mounting Structure</td>
<td>0.5</td>
<td></td>
<td>Structure factor of 38.5% supplied by George Sanger, 333-7254.</td>
</tr>
</tbody>
</table>
### Common Lunar Lander Mass Properties

<table>
<thead>
<tr>
<th>CLL: LANDER \ SUBSYSTEM:</th>
<th>Ti. Mass (KG)</th>
<th>No</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.0 Growth:</td>
<td>42.4</td>
<td></td>
<td>15% of all subsystems.</td>
</tr>
</tbody>
</table>

#### CLL Lander DRY MASS

325

#### CLL: LANDER \ SUBSYSTEM:

<table>
<thead>
<tr>
<th>Ti. Mass (KG)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.0</td>
<td></td>
</tr>
</tbody>
</table>

#### 10.0 Non-Cargo Reserve and Residual Fluids

| IPS Fuel Reserves | 0.0 | 0% reserves, D. Hyatt. |
| IPS Fuel Residuals | 3.6 | 2% residuals, Monomethylhydrazine (MMH), Contact D. Hyatt. |
| IPS Oxidizer Reserves | 0.0 | 0% reserves, D. Hyatt. |
| IPS Oxidizer Residuals | 5.9 | 2% residuals, Nitrogen Tetroxide (NTO), Contact D. Hyatt. |
| IPS Pressurant | 2.5 | Helium, D. Hyatt. |

#### 11.0 Cargo

| Scientific Payloads | 200.0 | Contact Alan Binder, 283-5849. |
| Rover + Instruments | 200.0 | 150 kg rover + 50 kg instruments; 1.5x1.5x1.5 m box dimensions assumed |

#### CLL Lander INERT MASS

537
## Common Lunar Lander Mass Properties

<table>
<thead>
<tr>
<th>SUBSYSTEM:</th>
<th>Ti. Mass (KG)</th>
<th>No.</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.0 Non-Propellant (Consummables)</td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13.0 Propellant</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel</td>
<td>465.1</td>
<td>1</td>
<td>Delta V = 1820 m/s</td>
</tr>
<tr>
<td>Oxidizer</td>
<td>176.2</td>
<td>2</td>
<td>Monomethylhydrazine (MMH)</td>
</tr>
<tr>
<td></td>
<td>288.9</td>
<td>2</td>
<td>Nitrogen Tetroxide (NTO)</td>
</tr>
</tbody>
</table>

**CLL Lander GROSS MASS**

1,002
### CLL: TRANSFER STAGE

<table>
<thead>
<tr>
<th>SUBSYSTEM:</th>
<th>Tl. Mass (KG)</th>
<th>No</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0 Structure:</td>
<td>300.0</td>
<td></td>
<td>Contact Steve Bailey, 283-5411. Assume 5% of t.s. gross mass. Includes all subsystem mass except power &amp; mechanisms.</td>
</tr>
<tr>
<td>Primary Body Structure</td>
<td>300.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SUBSYSTEM:</th>
<th>Tl. Mass (KG)</th>
<th>No</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0 Protection:</td>
<td>0.0</td>
<td></td>
<td>Contact Steve Bailey, 283-5411. Included in structure mass.</td>
</tr>
<tr>
<td>Insulation</td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SUBSYSTEM:</th>
<th>Tl. Mass (KG)</th>
<th>No</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.0 Propulsion:</td>
<td>291.4</td>
<td></td>
<td>Contact Don Hyatt, x39019. Performs RCS, TLI, LOI &amp; deorbit burns Bipropellant RCS and Primary Engine System, Delta V=4100 m/s.</td>
</tr>
<tr>
<td>Integrated Propulsion System</td>
<td>291.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel Tanks</td>
<td>40.1</td>
<td>4</td>
<td>Spherical, 99 cm dia.</td>
</tr>
<tr>
<td>Oxidizer Tanks</td>
<td>42.8</td>
<td>4</td>
<td>Spherical, 102 cm dia.</td>
</tr>
<tr>
<td>Pressurant Tanks</td>
<td>77.0</td>
<td>4</td>
<td>Spherical, 55 cm dia.</td>
</tr>
<tr>
<td>RCS Engines</td>
<td>26.8</td>
<td>12</td>
<td>Marquardt R-IE, 25 lbs thrust</td>
</tr>
<tr>
<td>Transfer Stage Engine</td>
<td>66.7</td>
<td>1</td>
<td>Transtar engine, lsp=328 sec.</td>
</tr>
<tr>
<td>Lines, Valves &amp; Insulation</td>
<td>31.6</td>
<td></td>
<td>Historical estimate.</td>
</tr>
<tr>
<td>Mounting Structure</td>
<td>6.3</td>
<td></td>
<td>Historical estimate.</td>
</tr>
</tbody>
</table>
# Common Lunar Lander Mass Properties

**CLL: TRANSFER STAGE**

<table>
<thead>
<tr>
<th>SUBSYSTEM:</th>
<th>Tl. Mass (KG)</th>
<th>No</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.0 Power: Generation</td>
<td>92.6</td>
<td></td>
<td>Contact Betsy Kluksdahl, x36484.</td>
</tr>
<tr>
<td>4.0 Rechargeable Batteries</td>
<td>11.3</td>
<td></td>
<td>Silver-Zinc chemistry (Zn-AgO), 3 modules, 0.01 M3, jettison prior to deorbit</td>
</tr>
<tr>
<td>4.0 Solar Arrays</td>
<td>36.0</td>
<td>2</td>
<td>Silicon cells, accordion-style, 1.33 w x 4.0 h m ea.</td>
</tr>
<tr>
<td>4.0 Mounting Structure</td>
<td>0.0</td>
<td></td>
<td>Included in structure mass.</td>
</tr>
<tr>
<td><strong>Electrical Pwr Dist. &amp; Control (EPDC)</strong></td>
<td>27.2</td>
<td></td>
<td>Contact Betsy Kluksdahl, x36484. Preliminary estimate.</td>
</tr>
<tr>
<td>Solar Array Controller</td>
<td>9.1</td>
<td>1</td>
<td>25.4x38.1x15.2 cm</td>
</tr>
<tr>
<td>Battery Charger</td>
<td>9.1</td>
<td>1</td>
<td>25.4x30.5x12.7 cm</td>
</tr>
<tr>
<td>Bus Controller</td>
<td>9.1</td>
<td>1</td>
<td>38.1x38.1x15.2 cm</td>
</tr>
<tr>
<td>Mounting Structure</td>
<td>0.0</td>
<td></td>
<td>Included in structure mass.</td>
</tr>
<tr>
<td><strong>Wiring</strong></td>
<td>18.1</td>
<td></td>
<td>Contact Betsy Kluksdahl, x36484. Estimate based on ACRV</td>
</tr>
<tr>
<td>Cable</td>
<td>18.1</td>
<td></td>
<td>Includes connectors, 25.9K cm3</td>
</tr>
<tr>
<td>Mounting Structure</td>
<td>0.0</td>
<td></td>
<td>Included in structure mass.</td>
</tr>
</tbody>
</table>

**CLL: TRANSFER STAGE**

<table>
<thead>
<tr>
<th>SUBSYSTEM:</th>
<th>Tl. Mass (KG)</th>
<th>No</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.0 Avionics: Communications</td>
<td>1.0</td>
<td></td>
<td>TRW, Log conical spiral. 12.5 cm dia x 30 cm h, 3300 cm3, 0W.</td>
</tr>
<tr>
<td>Antenna</td>
<td>1.0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Mounting Structure</td>
<td>0.0</td>
<td></td>
<td>Included in structure estimate</td>
</tr>
</tbody>
</table>

**CLL: TRANSFER STAGE**

<table>
<thead>
<tr>
<th>SUBSYSTEM:</th>
<th>Tl. Mass (KG)</th>
<th>No</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.0 Environment:</td>
<td>0.0</td>
<td></td>
<td>Contact Steve Bailey, 283-5411. Included in structure estimate.</td>
</tr>
<tr>
<td>Subsystem</td>
<td>Mass (kg)</td>
<td>No</td>
<td>Comments</td>
</tr>
<tr>
<td>---------------------------------</td>
<td>-----------</td>
<td>----</td>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td>8.0 Other:</td>
<td>3.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mechanisms</td>
<td>3.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solar Array Deployment &amp; Tracking</td>
<td>3.6</td>
<td>2</td>
<td>Contact George Sanger, 333-7254.</td>
</tr>
<tr>
<td>Mounting Structure</td>
<td>0.0</td>
<td></td>
<td>Included in structure mass.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Mass (kg)</th>
<th>No</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.0 Growth:</td>
<td>0.0</td>
<td></td>
<td>No growth or contingency mass calculated.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Using mass fraction.</td>
</tr>
</tbody>
</table>

**CLL Transfer Stage DRY MASS**

689
### Table 1: Common Lunar Lander Mass Properties

**CLL: TRANSFER STAGE**

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Tl. Mass (KG)</th>
<th>No</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.0 Non-Cargo Reserve and Residual Fluids</td>
<td>110.7</td>
<td></td>
<td>0% reserves, D. Hyatt.</td>
</tr>
<tr>
<td>IPS Fuel Reserves</td>
<td>0.0</td>
<td></td>
<td>2% residuals, Monomethylhydrazine (MMH), Contact D. Hyatt.</td>
</tr>
<tr>
<td>IPS Fuel Residuals</td>
<td>34.1</td>
<td></td>
<td>0% reserves, D. Hyatt.</td>
</tr>
<tr>
<td>IPS Oxidizer Reserves</td>
<td>0.0</td>
<td></td>
<td>2% residuals, Nitrogen Tetroxide (NTO), Contact D. Hyatt.</td>
</tr>
<tr>
<td>IPS Oxidizer Residuals</td>
<td>61.3</td>
<td></td>
<td>Helium, D. Hyatt.</td>
</tr>
<tr>
<td>IPS Pressurant</td>
<td>15.4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**CLL: TRANSFER STAGE**

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Tl. Mass (KG)</th>
<th>No</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.0 Cargo</td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 2: CLL Transfer Stage INERT MASS

<table>
<thead>
<tr>
<th>Mass Property</th>
<th>Tl. Mass (KG)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLL Transfer Stage INERT MASS</td>
<td>799</td>
</tr>
</tbody>
</table>

### Table 3: CLL: TRANSFER STAGE

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Tl. Mass (KG)</th>
<th>No</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.0 Non-Propellant (Consumables)</td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 4: CLL: TRANSFER STAGE

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Tl. Mass (KG)</th>
<th>No</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.0 Propellant</td>
<td>4,671.1</td>
<td></td>
<td>3200 m/s TLI, 30 m/s midcourse, 840 m/s LOI, 30 m/s deorbit</td>
</tr>
<tr>
<td>Fuel</td>
<td>1,668.3</td>
<td></td>
<td>Monomethylhydrazine (MMH)</td>
</tr>
<tr>
<td>Oxidizer</td>
<td>3,002.9</td>
<td></td>
<td>Nitrogen Tetroxide (NTO)</td>
</tr>
</tbody>
</table>

**CLL Transfer Stage GROSS MASS**

<table>
<thead>
<tr>
<th>Mass Property</th>
<th>Tl. Mass (KG)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLL Transfer Stage GROSS MASS</td>
<td>5,470</td>
</tr>
</tbody>
</table>
## CLL: Launch Adapter & Support Equipment

<table>
<thead>
<tr>
<th>SUBSYSTEM</th>
<th>Ti. Mass (KG)</th>
<th>No.</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0 Structure</td>
<td>269.7</td>
<td></td>
<td>Includes ground support equipment, cables, pyros.</td>
</tr>
<tr>
<td>8.0 Other</td>
<td>0.0</td>
<td></td>
<td>INCLUDED in structure.</td>
</tr>
<tr>
<td>9.0 Growth</td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Launch Adapter & Support: 270 1 Used on launch from ELV.

## CLL Mission Mass Summary

<table>
<thead>
<tr>
<th>Mass Summary</th>
<th>Ti. Mass (KG)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Launch Mass</td>
<td>6742</td>
<td>CLL Gross Mass + Transfer Stage Gross Mass + Launch Adapter Gross Mass</td>
</tr>
<tr>
<td>Prior to leaving Earth Orbit</td>
<td>6472</td>
<td>Launch Mass - Launch Adapter</td>
</tr>
<tr>
<td>5 day Moon trip</td>
<td>?</td>
<td>Prior to leaving Earth Orbit - TLI burn propellant</td>
</tr>
<tr>
<td>14 day Lunar orbit wait</td>
<td>?</td>
<td>5 day moon trip - LOI burn propellant</td>
</tr>
<tr>
<td>Lunar deorbit</td>
<td>?</td>
<td>14 day lunar orbit wait - Deorbit burn propellant</td>
</tr>
<tr>
<td>Prior to descent burn</td>
<td>1002</td>
<td>Lunar deorbit - Transfer Stage Inert Mass</td>
</tr>
<tr>
<td>Landed Vehicle</td>
<td>537</td>
<td>Prior to descent burn - Descent burn propellant</td>
</tr>
<tr>
<td>Scientific Payload</td>
<td>200</td>
<td>Landed Vehicle - CLL Inert Mass + Payload</td>
</tr>
</tbody>
</table>

## Other Design Information

<table>
<thead>
<tr>
<th>Mass Information</th>
<th>Ti Mass-kg</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLL Payload</td>
<td>200</td>
<td>Primary, Without dry propulsion system.</td>
</tr>
<tr>
<td>CLL Structure</td>
<td>27</td>
<td>Primary, Secondary and Mounting Structure</td>
</tr>
<tr>
<td>CLL Subsystems</td>
<td>202</td>
<td>Without dry propulsion system.</td>
</tr>
<tr>
<td>Transfer Stage Structure</td>
<td>300</td>
<td>CLL Gross Mass</td>
</tr>
<tr>
<td>Transfer Stage Subsystems</td>
<td>97</td>
<td>Primary, Without dry propulsion system.</td>
</tr>
<tr>
<td>Transfer Stage &quot;Payload&quot;</td>
<td>1002</td>
<td>razy, Mouning Structure</td>
</tr>
</tbody>
</table>
## Structure and Mechanics

### Primary Structure
- Space Frame Assembly: 19 kg
- CLL / Transfer Stage Adapter Ring: 8 kg
- Lander Legs: 22 kg
- Mounting Structure: 21 kg

Total: 70 kg

Structure Factor: 70 kg / 917 kg = 0.076

### Secondary Structure

<table>
<thead>
<tr>
<th>Component</th>
<th>Structure Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propulsion</td>
<td>0.185</td>
</tr>
<tr>
<td>Power</td>
<td>0.156</td>
</tr>
<tr>
<td>GNC</td>
<td>0.108</td>
</tr>
<tr>
<td>DMS</td>
<td>0.145</td>
</tr>
<tr>
<td>Instrumentation</td>
<td>0.166</td>
</tr>
<tr>
<td>Communications</td>
<td>0.156</td>
</tr>
<tr>
<td>Tracking</td>
<td>0.050</td>
</tr>
<tr>
<td>Active Thermal</td>
<td>0.056</td>
</tr>
<tr>
<td>Landing Legs</td>
<td>0.216</td>
</tr>
<tr>
<td>Pyros</td>
<td>0.385</td>
</tr>
</tbody>
</table>

- The mounting structure masses are incorporated in the design mass statement.

George Sanger/LESC/333-7254

Lockheed Engineering & Sciences Company
Note: 1. All Station Numbers Are in Inches
2. Station Numbers With an Asterisk (*) Indicate Outside Stations
Common Lunar Lander Propulsion System

System Characteristics

- Two-stage pressure-fed storable bipropellant (MMH/NTO)
- Lander stage
  - Six main engines - TRW Variable Thrust Engines (VTE)
    - Originally baselined for OMV
    - 10:1 throttling capability from 58 - 580 N (13 - 130 lbf)
    - Throttling required for landing
- Transfer stage
  - Aerojet Transtar engine - 16731 N (3750 lbf)
  - Twelve attitude control engines for each stage
    - Marquardt R6-C's (lander) and R-1E's (transfer)
      - 22 N (5 lbf) and 110 N (25 lbf) respectively
    - Extensive flight history
    - Arranged in quads: two 4-engine clusters and two 2-engine clusters
    - Provide 3-axis stabilization
COMMON LUNAR LANDER PROPULSION SYSTEM

Note: Each thruster has sensors for chamber pressure, injector temperature, and fuel and oxidizer valve position indication.
Common Lunar Lander Propulsion System

Point Design Output

- Dry propulsion system mass breakdown:

<table>
<thead>
<tr>
<th>Component</th>
<th>Lander Stage</th>
<th>Transfer Stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel tanks</td>
<td>6.7 kg</td>
<td>38.6 kg</td>
</tr>
<tr>
<td>Oxidizer tanks</td>
<td>6.7</td>
<td>41.0</td>
</tr>
<tr>
<td>Pressurant tanks</td>
<td>11.3</td>
<td>72.7</td>
</tr>
<tr>
<td>Engines (includes controllers)</td>
<td>58.8</td>
<td>93.4</td>
</tr>
<tr>
<td>Lines/Valves/Thermal</td>
<td>8.4</td>
<td>30.1</td>
</tr>
<tr>
<td>Mounting hardware</td>
<td>1.7</td>
<td>6.0</td>
</tr>
<tr>
<td>Pressurant</td>
<td>2.2</td>
<td>4.5</td>
</tr>
<tr>
<td>Residual fuel</td>
<td>3.3</td>
<td>32.2</td>
</tr>
<tr>
<td>Residual oxidizer</td>
<td>5.4</td>
<td>57.9</td>
</tr>
<tr>
<td><strong>Total dry system mass</strong></td>
<td><strong>104.5 kg</strong></td>
<td><strong>386.4 kg</strong></td>
</tr>
</tbody>
</table>

- Wet propulsion system includes above plus usable propellant

<table>
<thead>
<tr>
<th>Component</th>
<th>Lander Stage</th>
<th>Transfer Stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Usable fuel</td>
<td>161.2 kg</td>
<td>1574.9 kg</td>
</tr>
<tr>
<td>Usable oxidizer</td>
<td>264.4</td>
<td>2834.8</td>
</tr>
<tr>
<td><strong>Total usable propellant</strong></td>
<td><strong>425.6 kg</strong></td>
<td><strong>4409.7 kg</strong></td>
</tr>
</tbody>
</table>

**Total wet propulsion system mass**

<table>
<thead>
<tr>
<th>Mass</th>
<th>Lander Stage</th>
<th>Transfer Stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total dry system mass</td>
<td>530.1 kg</td>
<td>4796.1 kg</td>
</tr>
</tbody>
</table>
Common Lunar Lander Propulsion System

System Mission Requirements
- Provide propulsive maneuvers and attitude control from LEO through landing
  - TLI: 3200 m/sec
  - MCC's: 30 m/sec
  - LOI: 840 m/sec
  - D/O: 30 m/sec
  - TD&L: 1820 m/sec

Key Drivers to Subsystem Selection
- Multiple restart ==> liquid propellants
- Simplicity, orbital stay time, packaging ==> storable propellants
- Landing ==> throttling engines

System Readiness Level
- All elements are flight proven except:
  - VTE: Complete development program then proceed into qualification
  - Transtar: Flight weight engine developed, ready for qualification
  - Tanks: Custom sized for propellant/pressurant load, industry survey required
Avionics Subsystem

Subsystem Requirements:
- Guidance, navigation and control of the spacecraft
- Central computer for all subsystems
- Data storage for all subsystems for telemetry purposes
## Avionics Subsystem

<table>
<thead>
<tr>
<th>Unit</th>
<th>Cost $</th>
<th>Mass kg</th>
<th>Vol. cm$^3$</th>
<th>Size cm</th>
<th>Power W</th>
<th>Description</th>
<th>Rqmts</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMU</td>
<td>275K/1</td>
<td>7.3</td>
<td>7200</td>
<td>17.7x</td>
<td>40</td>
<td>- Honeywell H-764</td>
<td>alignment every 12 hrs &amp; prior to major burns</td>
</tr>
<tr>
<td></td>
<td>(TBD NRE: nav. algorithm)</td>
<td></td>
<td></td>
<td>17.7x</td>
<td></td>
<td>- available 92</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>22.9</td>
<td></td>
<td>- 3 RLGs, 3 accel.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- 2 CPUs</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- MTBF &gt; 4000 hrs</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- Contact: L. Brown (813) 539-5814</td>
<td></td>
</tr>
<tr>
<td>Star Tracker</td>
<td>500K/1</td>
<td>1</td>
<td>8100</td>
<td>18x</td>
<td>8</td>
<td>- Lawrence Livermore</td>
<td>access to stars</td>
</tr>
<tr>
<td></td>
<td>3M/10</td>
<td></td>
<td></td>
<td>18x</td>
<td></td>
<td>- Space Cert. in 92</td>
<td>cold plate</td>
</tr>
<tr>
<td></td>
<td>(TBD NRE: quaternion algorithm &amp; processor)</td>
<td>25</td>
<td></td>
<td></td>
<td></td>
<td>- available 1/93</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- converts 28V to $\pm 5, \pm 15$ V</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- contact: I. Lewis (415) 294-6531</td>
<td></td>
</tr>
<tr>
<td>GPC</td>
<td>inc.</td>
<td>inc.</td>
<td>inc.</td>
<td>inc.</td>
<td></td>
<td>- in MDM</td>
<td>n/a</td>
</tr>
<tr>
<td>Data Mem.</td>
<td>inc.</td>
<td>inc.</td>
<td>inc.</td>
<td>inc.</td>
<td></td>
<td>- in MDM</td>
<td>n/a</td>
</tr>
<tr>
<td>MDM</td>
<td>450K/1</td>
<td>20</td>
<td>29000</td>
<td>37x</td>
<td>50</td>
<td>- Honeywell Space Station MDM</td>
<td>access to all systems by cable</td>
</tr>
<tr>
<td></td>
<td>(&lt; 600K NRE: 28V power supply)</td>
<td></td>
<td></td>
<td>23x</td>
<td></td>
<td>- available 2 Qtr 92</td>
<td>cold plate, passively cooled</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>34</td>
<td></td>
<td>- interfaces for all subsystems</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- reconfigured by changing cards</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- programming, debugging &amp; hardware integration testing with workstations</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- contact: L. Brown (813) 539-5814</td>
<td></td>
</tr>
<tr>
<td>RCS RJD</td>
<td>inc.</td>
<td>inc.</td>
<td>inc.</td>
<td>inc.</td>
<td>3</td>
<td>- Solenoid Driver output card in MDM</td>
<td></td>
</tr>
<tr>
<td>Avionics</td>
<td>1.225M/1</td>
<td>28.3</td>
<td>44300</td>
<td>98 nom</td>
<td></td>
<td>- Nancy C. Smith/EG23/x38275  Navigation Control and Aeronautics Division</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10.25M/10</td>
<td></td>
<td></td>
<td>148 pk</td>
<td></td>
<td>- section: Nancy C. Smith/EG23/x38275  Navigation Control and Aeronautics Division</td>
<td></td>
</tr>
</tbody>
</table>
**Avionics Subsystem**

- **Inertial Measurement Unit**
  - 1750A G&C CPU
  - 1750A Nav. CPU
  - Gyro/Accel Elex
  - 3 Bell XI-32 Accel
  - 3 HI GG1320 RLG

- **RCS Jets**
  - 12 R-1E (251bf)
  - 12 R-6C (51bf)

- **Other Subsystems**

**Specifications**

- **Mass:** 28.3 kg
- **Power:** 148 W (peak)
- **Volume:** 44300 cm³

---

Nancy C. Smith/EG23/x38275

Navigation Control and Aeronautics Division
Avionics Subsystem

Trade Studies Performed:
- IMU
- Star Tracker vs. Horizon Sensor & Sun Sensor
- RJDs vs Solenoid Driver Cards
- MDM vs GPC, Data Storage & Standard Bus

Programs Studied:
- ACRV  
- AFE  
- Apollo  
- Lifesat  
- MRSR  
- OMV  
- Shuttle  
- Surveyor  
- Viking

Companies & Agencies Contacted:
- Ball Aerospace  
- Bell Lab  
- Bendix  
- Draper Lab  
- Delco Systems  
- Gulton  
- Honeywell  
- Kearfott G&N Corp.  
- Litton G&N Systems  
- Livermore Lab  
- Lockheed  
- Marquardt  
- Martin Marietta  
- Microcosm  
- Motorola  
- Northrop  
- Optics Corp of Amer.  
- Orbital Sciences Co.  
- Radstone  
- Rockwell Int.  
- Teledyne Systems  
- Textron  
- TRW  
- GSFC  
- JPL  
- LaRC  
- MSFC  

Discriminators Considered:
- Cost  
- Schedule  
- Performance  
- Mass  
- Power  
- MTBF  
- Certification  
- Operating Temp.
TRACKING SYSTEMS TO SUPPORT

THE

COMMON LUNAR LANDER

SEPTEMBER 17, 1991
MISSION PHASES REQUIRING TRACKING INSTRUMENTATION

○ IN TRANSIT TRACKING FOR STATE INFORMATION (DSN AND/OR TDRSS)
  ○ ACCOMPLISHED IN THE COMMUNICATIONS EQUIPMENT

○ SURFACE RELATIVE TRACKING TO SUPPORT LANDING
  ○ TOPIC OF THIS PRESENTATION
MAJOR DRIVERS FOR TRACKING SYSTEM DEFINITION

○ TRACKING SUBSYSTEM FLIGHT HARDWARE DUE OCTOBER, 1993

○ PERFORMANCE REQUIREMENTS/COMPLEXITY EQUIVALENT TO SURVEYOR
  ○ MAXIMUM RANGE: 16 Km
  ○ VELOCITY ACCURACY: 30 cm/sec + 2% of TOTAL VELOCITY (V< 200 m/s)
    30 cm/sec + 3% of TOTAL VELOCITY (V>200 m/s)
  ○ RANGE ACCURACY: 9 m + 5% RANGE (R>300 m)
    1.3 m + 5% RANGE (R<300 m)
RESULTS OF VENDOR SURVEY

- NO LANDING SYSTEM EXISTS OFF-THE-SHELF
- NEW TECHNOLOGIES, SPECIFICALLY DOD, ARE PROMISING
  - NOT DEVELOPED FOR DE-ORBIT TO LANDING
  - NOT DEVELOPED FOR SPACE
  - EXCITING FOR THE NEXT GENERATION INSTRUMENTATION
- SURVEYOR/APOLLO/VIKING APPROACHES AVAILABLE
  - KNOWLEDGE/EXPERTISE STILL AVAILABLE
  - UPGRADE TO TODAY'S TECHNOLOGY REASONABLE AND FEASIBLE
  - HISTORICALLY PROVEN
SELECTED BASELINE

THE RECOMMENDED SYSTEM APPROACH FOR THE INITIAL BASELINE FOLLOWS THE VIKING HARDWARE DESIGN UPGRADED TO TODAY'S TECHNOLOGY.

BASIC DESCRIPTION

- ALTIMETER: PULSE SYSTEM
- FOUR BEAM VELOCITY SENSING RADAR

BASELINE SYSTEM PROPERTIES

- LANDING RADAR
  - SIZE: 76.2 cm X 76.2 cm X 8.26 cm
  - WEIGHT: 22.1 Kg; POWER: 68 W
  - ANTENNA: INCORPORATED ON 76.2X76.2 SURFACE

- ALTIMETER
  - SIZE: 23.4 cm X 14.7 cm X 20.1 cm
  - WEIGHT: 5.1 Kg; POWER: 28.5 W

- ALTIMETER ANTENNA (CONICAL HORN)
  - WEIGHT: 0.7 Kg; DIAMETER: 15.25 cm; LENGTH: 15.25 cm
LANDING INSTRUMENTATION CONCEPT
PROGRAMMATIC CONSIDERATIONS

○ SCHEDULE (ASSUMING JANUARY 1992 START)
  ○ FLIGHT HARDWARE DELIVERY JUNE 1, 1994

○ COSTING
  ○ ALTIMETER $875K/COPY
  ○ RADAR $675K/COPY
  ○ NON-RECURRING COSTS: ALTIMETER - $2.2M; RADAR - $1.8M
  ○ PRICING ESTIMATED FROM VIKING BUT IN TODAY’S DOLLARS

○ CAVEATS
  ○ PARTS TO BE SPACE QUALIFIED WHERE AVAILABLE, MIL SPEC OTHERWISE
  ○ MATERIAL SELECTION AND HANDLING TO BE MIL STANDARD AT TELEDYNE RYAN
  ○ MANUFACTURING, FAB AND PROCESSING TO BE MIL STANDARD AT TELEDYNE RYAN
  ○ DOCUMENTATION TO MIL STANDARDS
  ○ WORK DONE TO VIKING CLEAN ROOM STANDARDS
  ○ ENVIRONMENTAL QUALIFICATION TO NASA STANDARDS
## INITIAL HARDWARE DEVELOPMENT SCHEDULE

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>CONTRACT AWARD</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EVALUATION, ANALYSIS, SPECIFICATION</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DESIGN REVIEW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PARTS OBSOLESCENCE REVIEW/DESIGN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BENCH TEST/B/B'S W/ CORRECTIONS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ORDER/PRODUCE THE NO CHANGE PARTS/MATERIALS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DESIGN REVIEW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ORDER/PRODUCE NEW PARTS/MATERIALS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MECH, DESIGN, DRAFTING FOR CHANGED ASSYS'</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RELEASE, MFG/FAB/BUILD OF NO CHANGE ASSYS'</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FAI'TEST NEW ASSYS'</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>INTEGRATE &amp; TEST UNCHANGED AND NEW ASSYS'</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SYSTEM INTEGRATE/TEST NEW ASSYS'</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>QUAL TESTS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>INITIAL FLT TESTS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FINAL FLT TESTS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ATP, FLT HDW DELIVER</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Project: CUI, LANDING INSTRU
Date: 9/16/91

Critical Noncritical Progress Summary

William X. Culpepper/EB6/x31479  Tracking and Communications Division
TRACKING SYSTEMS

BACKGROUND MATERIAL

FOR THE

COMMON LUNAR LANDER
HISTORICAL PERSPECTIVE

- THREE SPACE PROGRAMS HAVE ACCOMPLISHED PLANETARY LANDINGS
  - SURVEYOR
  - APOLLO
  - VIKING

- ALL THREE USED THE SAME BASIC TECHNIQUE
  - ALTIMETER FOR RANGE TO THE SURFACE
  - VELOCITY SENSING RADAR FOR MAJOR AXES VELOCITY MEASUREMENTS

ALL THREE SYSTEMS WERE SUCCESSFUL
SOLUTION OPTIONS

○ OFF THE SHELF HARDWARE
  ○ SOME EXISTING ALTIMETERS MAY BE CLOSE
  ○ NO RADARS ARE KNOWN TO EXIST

○ VENDOR SURVEY
  ○ WHAT APPROACH AND TECHNOLOGY THEY RECOMMEND
  ○ SYSTEMS THEY MIGHT HAVE THAT ARE APPLICABLE
  ○ ESTIMATES OF SIZE, Weight, POWER, AND SCHEDULE
INDUSTRY CONTACTS

○ INITIAL INDUSTRY CONTACTS
  ○ TELEDYNE RYAN
  ○ GENERAL DYNAMICS
  ○ HUGHES AIRCRAFT COMPANY
  ○ LORAL DEFENSE SYSTEMS
  ○ MOTOROLA
  ○ MC DONNELL DOUGLAS
  ○ MARTIN MARIETTA

A PACKET OF INFO WAS MAILED TO SIX OF THE SEVEN COMPANIES. TWO COMPANIES CHOSE NOT TO RESPOND.

○ RESPONDING COMPANIES WERE
  ○ TELEDYNE RYAN
  ○ GENERAL DYNAMICS
  ○ HUGHES AIRCRAFT COMPANY
  ○ LORAL DEFENSE SYSTEMS
RESPONSE CONTENT

TWO COMPANIES RESPONDED WITH DESIGNS BASED ON EXPERIENCE WITH SURVEYOR AND VIKING

○ HUGHES AIRCRAFT WITH AN UPDATE OF THE SURVEYOR SYSTEM
  ○ DESIGN UPGRADED WITH TODAY'S MIMIC TECHNOLOGY
  ○ CHALLENGES ARE ANTENNA AND COMPRESSED SCHEDULE
  ○ SCHEDULE ESTIMATE IS 2 YEARS AND 9 MONTHS FOR FIRST FLIGHT UNIT
  ○ NO COSTING

○ TELEDYNE RYAN PREFERENCES THE BASIC VIKING APPROACH
  ○ RADAR WAS FOUR BEAM WHICH YIELDS REDUNDANCY
  ○ RADAR RECEIVER UPGRADE FROM 14 dB NF TO 5 dB NF WILL COVER 15Km REQUIREMENT
  ○ ASSUMING JANUARY 1992 START, DELIVERY IS JUNE 1, 1994
  ○ COST ESTIMATE IS $1.5M/COPY FOR BOTH ALTIMETER AND RADAR
  ○ NON-RECURRING COST IS $4M TOTAL FOR BOTH ALTIMETER AND RADAR
  ○ COST ESTIMATE BASED ON VIKING COSTS IN TODAY'S DOLLARS
RESPONSE CONTENT (CONTINUED)

TWO COMPANIES RESPONDED WITH DIFFERENT APPROACHES FROM SURVEYOR/VIKING

○ GENERAL DYNAMICS RESPONDED WITH TECHNOLOGY FROM DOD APPLICATIONS
  ○ DATA IS PROPRIETARY
  ○ APPROACH INCLUDES SOME PIECES THAT EXIST TODAY AND SOME TO BE DEVELOPED
  ○ NONE WERE DEVELOPED FOR THIS APPLICATION
  ○ NONE HAVE BEEN SEASONED IN THE WORLD OF SPACE

○ LORAL DEFENSE SYSTEMS RESPONDED WITH TECHNOLOGY BEING DEVELOPED BY THE ARMY
  ○ CONCEPT, THOUGH PROMISING, IS IMMATURE
  ○ DATA IS PROPRIETARY
PERPECTIVE ON THE RESPONSES

○ WHAT THE RESPONSES ARE NOT
  ○ REPRESENTATIVE OF A COMPLETE COMMERCIAL SURVEY
  ○ A STUDY EFFORT
  ○ A SYSTEM DESIGN

○ WHAT THE RESPONSES ARE
  ○ A CURSORY LOOK REQUESTED ON 8/2 AND COMPLETED BY 8/12
  ○ BEST GUESSES
  ○ A COURTESY PARTICIPATION

○ WHAT THE RESPONSES COST
  ○ ZERO
RATIONALE FOR SELECTION

- SHORT TIME SCHEDULE REQUIRES USE OF PROVEN TECHNIQUES
- THE SURVEYOR/VIKING/APOLLO APPROACHES WORKED
- NEW APPROACHES REQUIRE TECHNOLOGY INCORPORATION AND DEVELOPMENT TEST
- HISTORICAL DATA PROVIDE REALISM IN ESTIMATES FOR SIZE, WEIGHT, POWER, DELIVERY AND COST
- THE VIKING RADAR HAS A FOURTH SENSING BEAM WHICH OFFERS REDUNDANCY SINCE ONLY THREE ARE NEEDED
COMMON LUNAR LANDER COMMUNICATION SUBSYSTEM DESIGN
FINAL PRESENTATION

BY

TRACKING AND COMMUNICATION DIVISION
HENRY CHEN/EE7

SEPT. 17, 1991
I. Introduction
II. Trade Studies
III. Baseline Design
IV. Power, Weight, Size and Cost
V. Appendix
   A. Detailed Block Diagrams
   B. Antenna Considerations
   C. Future Studies

Tracking and Communications Division

Henry Chen/EE7/x30128
INTRODUCTION

A Division Team effort

EE2/ Richard Sinderson, K.D. Mcclain
EE3/ Tim Early
EE7/ Henry Chen
LESC/ Dr. Zafar Taqvi, Phil Lipoma

The communication subsystem is required to provide downlink for telemetry data and uplink for command data. It also provides Doppler/Ranging for the state-vector generation.

Detailed trades, system designs and requirements analysis were performed to provide the most realistic estimates for the project.
TRADE STUDIES

Data rate considerations
- Based on Lifesat and Surveyor designs
- 11.6Kbps was selected to size the communication subsystem
- Multiple data rates option was provided (500bps, 2.5Kbps, 11.6Kbps and 40Kbps)

Deep Space Network (DSN) subnet selection
- 70m vs. 34m vs. 26m subnet
- DSN 34m subnet was selected due to its scheduling and performance advantage

Frequency Trade
- L-band vs. S-band vs. X-band
- S band was selected because of hardware availability

Motorola transponders
- NASA Standard Near Earth Transponder was selected for its simplicity and availability
- Minimum amount of modification is required
TRADE STUDIES (CONT.)

Antenna selection

- Omni antennas were proposed to provide near spherical coverage and to avoid complicated support and pointing mechanisms

Circuit margin and system level trade studies were completed

- 18 different configurations were evaluated

Companies/organizations consulted

- TRW, Watkin-Johnson, M-A Comm., Motorola, Teledyne, Gore, Loral Videospection, JPL, GSFC

Programs studied

- Space Shuttle, Space Station Freedom, Surveyor, Viking, LifeSat
- SMEX, CRAF, CASSINI, GRO, HEAO, FLTSATCOM, Solar Max, COBE, OMV
Current baseline design

- S-band system using Deep Space Network (DSN) 34m subnet
- Motorola DSN Near Earth transponder
- 10W solid state power amplifier
- (2,7) convolutional coder
- PCM/PSK/PM modulation scheme
- Multiple data rates
- Log conical spiral antennas for near spherical coverage

Hardware information

- All modules have at least 2000 hrs. MTBF
- Single string implementation was selected
- Temperature range: -20 to 60 degrees C in avionics bay and -55 to 155 degrees C for externally mounted components
To MDM via 1553B bus
(Comm subsystem cmd & status)

TRANSPONDER

DOWNLINK

UPLINK

 status control

RF ASSEMBLY

SIGNAL PROCESSOR

XMIT

RCV.

COMMON LUNAR LANDER RF COMMUNICATION SUBSYSTEM

OMNI ANTENNA ASSEMBLY

TRANSMITTER STAGE

CALL TOP

CALL SIDES
(4)

Tracking and Communications Division
# POWER, WEIGHT, SIZE AND COST

<table>
<thead>
<tr>
<th>UNIT</th>
<th>WEIGHT</th>
<th>VOLUME</th>
<th>POWER</th>
<th>COST</th>
<th>#</th>
<th>VENDOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>RF assembly</td>
<td>7.4Kg</td>
<td>7800cc</td>
<td>71W (p)</td>
<td>0.65M</td>
<td>1</td>
<td>custom**</td>
</tr>
<tr>
<td>Qualification in 24 month</td>
<td>16x20x24</td>
<td>18.8W (a)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transponder</td>
<td>3.3Kg</td>
<td>3500cc</td>
<td>17.5W (p)</td>
<td>1.1M</td>
<td>1</td>
<td>Motorola</td>
</tr>
<tr>
<td>Qualification in 24 months</td>
<td>16x20x11</td>
<td>8.0 (a)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Antennas</td>
<td>5.5Kg</td>
<td>8640cc</td>
<td>0</td>
<td>0.39M</td>
<td>6</td>
<td>W-J</td>
</tr>
<tr>
<td>Qualification in 20 months</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cable</td>
<td>2.4Kg</td>
<td>900cc</td>
<td>0</td>
<td>0.03M</td>
<td>1</td>
<td>GORE set</td>
</tr>
<tr>
<td>Qualification in 6 months</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Signal Proc.</td>
<td>3.0Kg</td>
<td>4800cc</td>
<td>27W</td>
<td>1.0M</td>
<td>1</td>
<td>custom**</td>
</tr>
<tr>
<td>Qualification in 6 months</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>** TOTAL**</td>
<td>21.6Kg</td>
<td>23,400cc</td>
<td>115.5/ ***</td>
<td>3.2M*</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>53.8W</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Cost does not include integration and system testing
** Equipment built from components with established track record
*** 115.5W during operating mode and 53.8W during standby mode
APPENDIX
* Control performs two functions: (1) switches between stand-by and operation modes and (2) select multi-data rate modes.
# ANTENNA SELECTION

## Proposed antenna usage

<table>
<thead>
<tr>
<th>Phase</th>
<th>Primary</th>
<th>Secondary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Translunar stage</td>
<td>1 antenna</td>
<td>4 antenna</td>
</tr>
<tr>
<td></td>
<td>on transfer stage</td>
<td>on CLL sides</td>
</tr>
<tr>
<td>Lunar orbit</td>
<td>4 antennas</td>
<td>1 antenna</td>
</tr>
<tr>
<td></td>
<td>on CLL sides</td>
<td>on CLL top</td>
</tr>
<tr>
<td>Lunar landing</td>
<td>1 antenna</td>
<td>4 antennas</td>
</tr>
<tr>
<td></td>
<td>on CLL top</td>
<td>on CLL sides</td>
</tr>
</tbody>
</table>

The log conical spiral antennas are built by Watkins-Johnson. They were flown on Solar Max. They are 9cm tall and 10cm in diameter. The antennas are mounted on standoffs to achieve a more preferred orientation.

The antenna switching uses a passive algorithm. Signals from all antennas are sampled. The detector then picks the antenna which provides the strongest signal.
FUTURE STUDIES

Design and analyze CLL communication subsystem during the next phase of design activity.

Evaluate possible approaches for reduction in power, weight, size and cost:
- Given trajectory, vehicle configuration, DSN schedule, etc., we can perform antenna coverage analysis to possibly reduce the number of antennas.
- Integrate 3 distinct modules into 1 assembly.
- Integrate functions into chip sets using VLSI technology.
- Continuing trade studies for other critical areas.

Evaluate the application of low data rate/analog video to facilitate payload checkout.
POWER SUBSYSTEM

- Energy Storage and Power Generation
- Electrical Power Distribution and Control
- Pyrotechnics

SUBSYSTEM DESIGN

- Input from other subsystems
- Design refinement following vehicle integration
- All selected technology is available for a 1996 launch target
SOLAR ARRAY EXAMPLE

OUTBOARD STOWAGE PLATE

SILICON SOLAR CELLS

STOWAGE COMPARTMENT

TELESCOPIC MAST

50 μM KAPTON SUBSTRATE

HONEYCOMB CROSS-MEMBER

25 μM KAPTON INTERLEAVES
ENERGY STORAGE AND POWER GENERATION

- **Transfer Stage**  47.3 kg
  - Silver Zinc Rechargeable Batteries, 3 modules, 11.3 kg total
  - Silicon Solar Array, 2 arrays 1.3 m wide x 4 m long, 18 kg each
- **Design Drivers**
  - Batteries sized by Launch to Post-TLI requirement of 570.83 Wh
  - Solar array sized by Lunar Orbit power requirement of 769 W
    - Power requirement of deorbit prep. larger, but desire to keep solar arrays as small as possible; supplement by using batteries and solar arrays during light since nearing end of transfer stage battery use
    - If 100% sunlight in lunar orbit, 24 kg solar array for 527 W
- **Lander Stage**  11.3 kg
  - Silver Zinc Batteries, 3 modules
  - **Design Drivers**
    - Same battery design as for transfer stage except not recharged
    - Use of Silver Zinc provides better match to energy requirements than a specific primary battery, such as lithium thionyl chloride, which requires extra cells in order to meet the peak power current requirement
ELECTRICAL POWER DISTRIBUTION AND CONTROL

- 28 Vdc ± 4 Vdc bus
- Transfer Stage  45.3 kg
  - Transfer Stage Bus Control, Battery Charger, Solar Array Control, Wiring, Connectors, and Installation Hardware
- Lander Stage  22.8 kg
  - Bus Control, Wiring, Connectors, and Installation Hardware

PYROTECHNICS

- Transfer Stage  2.49 kg
  - 4 Pyro Valves for RCS isolation for propulsion subsystem
  - 2 Pin Pullers for solar array deployment
  - 1 Guillotine for severing electric wire bundle prior to stage separation
  - 4 Explosive Bolts for stage separation
- Lander Stage  1.32 kg
  - 4 Pyro Valves for RCS isolation for propulsion subsystem
  - 3 Uplock Cutters for landing strut deployment
PRODUCT ASSURANCE TARGETED TO MEET MISSION OBJECTIVES

- DEMONSTRATED CAPABILITY FOR:
  - HIGH PROBABILITY OF SUCCESS
  - PAYLOAD CUSTOMER CONFIDENCE

PRODUCT ASSURANCE LEVEL OF EFFORT

COST EFFECTIVE OBJECTIVE

SYSTEM RELIABILITY
PRODUCT ASSURANCE BASED ON "VALUE ADDED" STRATEGIC APPROACH

PRODUCT ASSURANCE TOOLS AND SUPPORT

- RELIABILITY BLOCK DIAGRAM ANALYSIS
  - EVALUATION OF PROBABILITY OF SUCCESS
  - SELECTIVE REDUNDANCY RECOMMENDATIONS
  - DESIGN EVALUATION
- MTBF REVIEW
- FAILURE HISTORY AND TRENDING
- OFF-THE-SHELF VENDOR MATRICES
  - MANUFACTURING PROCESS CONTROL
  - CERTIFICATION TEST REVIEW
  - INSPECTION ADEQUACY

PROJECT GOALS

- DEMONSTRATED PROBABILITY OF SUCCESS
- HARDWARE OPTIMIZATION
- COST AND SCHEDULE EFFICIENCY
PRODUCT ASSURANCE STRUCTURED FOR OPTIMAL PAYBACK

TASKS:
- CONTINUED SUPPORT OF ENGINEERING STUDY GROUP
- RELIABILITY ANALYSIS FOR CHOSEN EQUIPMENT
  - RELIABILITY BLOCK DIAGRAM ANALYSIS (RBDA) - MODELING TO VERIFY SYSTEM PERFORMANCE
- FAULT TOLERANCE ANALYSIS
- MTBF VERIFICATION
- FAILURE HISTORY REVIEW
- RELIABILITY IMPROVEMENT RECOMMENDATIONS
- VENDOR REVIEW
  - ASSURING GOOD PROCESS CONTROLS
  - TEST COMPARISON MATRIX
- SYSTEM INTEGRATION SUPPORT
  - RBDA - MODELING TO VERIFY INTEGRATED PERFORMANCE
  - SUPPORT IN DEVELOPMENT OF INTEGRATED TEST PLANS

GOAL: OPTIMAL PERFORMANCE AND RELIABILITY WITH COST AND SCHEDULE EFFICIENCY