LUNAR ORBITAL TECHNIQUE

FOR PERFORMING

THE LUNAR MISSION

(NASA-TM-X-66758) LUNAR ORBITAL TECHNIQUE
FOR PERFORMING THE LUNAR MISSION (NASA)
61 p
LUNAR ORBITAL TECHNIQUE FOR PERFORMING THE LUNAR MISSION

PREPARED BY: MANNED SPACECRAFT CENTER Houston, Texas

APRIL, 1962
INTRODUCTION

The Apollo Spacecraft is being designed, developed and qualified for the ultimate mission of lunar landing and return. Several techniques have been investigated for performing the lunar-landing and lunar-launch phase of the mission. The Manned Spacecraft Center has studied a Lunar Excursion Module (LEM) System which is designed for direct earth-launch and a lunar orbit rendezvous technique for performing the lunar-landing and lunar-launch phase.

The lunar orbit rendezvous technique involves the injection of the complete Apollo Spacecraft into a translunar trajectory using one Saturn C-5 Launch Vehicle. The Spacecraft for this mode is composed of the Command, Service and Lunar Excursion Modules. After injection and prior to the first midcourse correction, the Lunar Excursion Module is docked to the Command Module. The Service Module propulsion system is used for performing the midcourse maneuvers and for placing the Spacecraft into a lunar orbit. In lunar orbit the Lunar Excursion Module with two crew members aboard separates from the Command Module and descends to a lunar landing. The third crew member remains in the Command Module in lunar orbit. The Lunar Excursion Module crew performs their mission goal tasks and return to lunar orbit with their records and specimens. The Lunar Excursion Module crew performs a rendezvous and docking maneuver with the Command Module. The crew and payload transfer to the Command Module and the Command Module, with or without the Lunar Excursion Module, is injected into a transearth trajectory by the Service Module propulsion system.

The following material is a summary of the study. The MIT Instrumentation Laboratory performed the Navigation and Guidance System phase of the study. The Systems Integration study was performed by NAA Space and Information Systems Division.
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COMMAND AND SERVICE MODULE
APOLLO SPACECRAFT

LAUNCH ESCAPE SYSTEM

SERVICE MODULE

COMMAND MODULE

COMMAND MODULE

NORMAL INGRESS, EGRESS

AIRLOCK CLOSED

DISPLAYS, CONTROLS

PRIMARY DUTY STATION

SLEEPING

EXTENDED AIRLOCK

WORK STATION

HEAVY EQUIPMENT THIS SIDE TO SHIFT CENTER OF GRAVITY

PRESSURE CABIN 400 CU. FT.
STRUCTURAL SYSTEM C/M
(INCLUDE THERMAL PROTECTION)

AIRLOCK STANDOFFS
-WINDOW COVERS

INNER CABIN
WELDED ALUM.
HONEYCOMB

OUTER SHELL
INCONEL HONEYCOMB

ABLATION MATERIAL
ON OUTER SHELL
CONTRACTOR—AVCO

SERVICE MODULE

REACTION CONTROL SYSTEM

COMMAND MODULE

PARABOLIC ANTENNAE
FUEL CELLS

HELIUM

RADIATORS 124"

SERVICE PROPULSION SYS.

154 D
STRUCTURAL SYSTEM, S/M

THrust Pad 6 Places
Fuel Tanks Between
Shear Webs 6 Places

Launch Loads
Fuel Tanks
Meteoroid Shield
Fuel Cells
Close-out BulkHds Each End
Continuous Skin and/or Radiators
Retention Hook 3 Places

Radar Dishes

LAUNCH ESCAPE SYSTEM

DUTIES:
Lifts C/M 5000 ft Above Pad
Separates C/M from Launch Vehicle 125 ft
In First Second at Max Q

System Description:
Solid Propellant, Regressive Thrust
Probably Post-Nozzle Injection for Control
Contractor - Lockheed
Separation Motor Contractor - Thiokol
SERVICE PROPULSION SYSTEM

DUTIES:
- Earth-orbit retrograde
- Mid-course velocity changes
- Extra atmosphere abort
- Lunar orbit (Phase B)
- Lunar launch

SYSTEM DESCRIPTION:
- Earth storable, hypergolic
- Single, gimbaled engine
- Ablation cooled
- Pressure fed
- Contractor - Aerojet

REACTION CONTROL SYSTEM

SERVICE MODULE:
- Spacecraft attitude reaction control
- Ullage duty for service prop syst.
- Minor mid-course correction
- Docking

COMMAND MODULE:
- 3-axis entry control
- Landing roll control

SYSTEM DESCRIPTION:
- Earth storable, hypergolic
- Pulse modulated, semi-radiative
- Positive expulsion
- Contractor - Marquardt
ENVIRONMENTAL CONTROL

ATMOSPHERIC COMPOSITION:

- OXYGEN-NITROGEN
- 7.0 PSIA CABIN, 3.5 PSIA SUIT
- USES FUEL CELL OXYGEN
- 3-PRESSURIZATION + 18-AIRLOCK OPER.+ LEAKAGE

TEMPERATURE AND HUMIDITY:

- SQUEEZABLE SPONGE FOR WATER SEPARATION
- WATER EVAPORATOR DURING LAUNCH, ENTRY
- VITAL EQUIPMENT USES ACTIVE COOLING

SCAVENGING:

- LITHIUM-HYDROXIDE CO$_2$ REMOVAL
- CHARCOAL AND CATALYTIC BURNER FOR NOXIOUS GASES.
- INTERMITTANT WASTE JETTISONED

COMMUNICATIONS AND INSTRUMENTATION

COMMUNICATIONS:

- TRANSMISSION OF DIGITAL PCM ON PROGRAMMED BASIS (DATA PLUS VOICE OR DATA PLUS TV)
- CONTINUOUS RECEPTION OF ANALOGUE VOICE EXCEPT ON FAR SIDE OF MOON
- VHF FOR NEAR-EARTH PHASES
- UHF/DSIF IN DEEP SPACE
- UHF COMMAND EQUIPMENT MAY BE LIMITED TO LAUNCH VEHICLE
- UHF, HF, AND VHF RECOVERY AIDS
- MAJOR CONTRACTOR – COLLINS RADIO

INSTRUMENTATIONS:

- OPERATIONAL EQUIPMENT – BY NAA
- RESEARCH AND DEVELOPMENT – BY MSC
ELECTRICAL POWER SYSTEM

REQUIREMENTS:
- NOMINAL: 2.0 KW
- EMERGENCY: 0.6 KW
- ENTRY: 1.0 KW

SYSTEM DESCRIPTION:
- OXYGEN-HYDROGEN FUEL CELLS
- 3 UNITS, SIZED FOR 2 OUT OF 3
- CONTRACTOR-PRATT & WHITNEY
- WATER-GLYCOL - RADIATOR COOLING
- WATER SAVED FOR DRINKING, COOLING
- SILVER-ZINC PRIMARY BATTERIES

EARTH LANDING SYSTEM

DUTIES:
□ STABILIZES
□ REDUCES IMPACT VELOCITY TO 30 FPS

SYSTEM DESCRIPTION:
□ FIRST RIBBON DROGUES
□ 93 FT. RINGSAIL MAIN CHUTES
□ SIMULTANEOUSLY DEPLOYED
□ SIZED FOR 2 OUT OF 3
□ CANTED C/M, ROLL ORIENTED
□ CONTRACTOR-RADIOPLANE

SPECIAL PROVISION:
□ MUST BE COMPATIBLE WITH PARAWING
MISSION AND SPACE VEHICLE CONCEPT
LAUNCH CONFIGURATION

SPACE FLIGHT CONFIGURATIONS
MISSION SEQUENCE CONFIGURATIONS

1. TRANSLUNAR INJECTION
   - EARTH ORBITAL INSERTION
   - ESCAPE TOWER JETTISON
   - 2nd STAGE IGNITION
   - 1st STAGE JETTISON
   - LAUNCH

   TURN AROUND
   - MIDCOURSE CORRECTIONS
   - SERVICE MODULE SEPARATION
   - RETRO FIRE INTO LUNAR ORBIT
   - DROGUE DEPLOY
   - LUNAR LANDING
   - MAIN CHUTE DEPLOY
   - LANDING & MAIN CHUTE RELEASE

LUNAR EXCURSION MODULE GUIDE LINES

2 MEN AND PAYLOAD LAND ON THE MOON
STAY TIME IS NOMINALLY 24 HOURS
CONTINGENCY IS 24 HOURS
EXPLORATION NEAR LANDING SITE
LAND AT VARIOUS DESIGNATED POINTS
CAPABILITY FOR ABORT TO LUNAR RENDEZVOUS
LEM. TO HAVE ONBOARD COMMAND
CABIN ENVIRONMENT TO ALLOW OPEN FACE PLATE
BASIC ATTRACTIVE FEATURES OF LUNAR RENDEZVOUS

- HIGH PAYLOAD EFFICIENCY
- MINIMUM CONSTRAINT ON DESIGN OF LUNAR LANDER
- SMALLEST SIZE FOR LUNAR LANDER
LUNAR ORBITAL OPERATIONS
LUNAR LANDING TECHNIQUE VIA EQUAL PERIOD TRANSFER

A, A' 100 N. MI. CIRCULAR

EVENT | TIME MIN. | ANGULAR POSITION, DEG. |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LUNAR LANDER</td>
<td>SPACECRAFT</td>
</tr>
<tr>
<td>A</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>B</td>
<td>29.78</td>
<td>95.07</td>
</tr>
<tr>
<td>C</td>
<td>36.62</td>
<td>107.76</td>
</tr>
<tr>
<td>D</td>
<td>41.02</td>
<td>107.76</td>
</tr>
<tr>
<td>E</td>
<td>42.95</td>
<td>110.69</td>
</tr>
<tr>
<td>F</td>
<td>101.91</td>
<td>290.69</td>
</tr>
</tbody>
</table>
TIME HISTORY FOR LUNAR LANDING

$T/W_0 = 0.4 \quad \text{isp} = 305$

VELOCITY, $(V \times 10^{-2})$, ft/sec.

ALTITUDE, $(H \times 10^3)$, ft.

RANGE, $(R)$, NM.

TIME, $(T)$, SEC.

LUNAR LANDING TIME HISTORY OF LINE OF SITE AND FLIGHT PATH ANGLE

LINE OF SIGHT ANGLE, $\gamma$, DEG.

FLIGHT PATH ANGLE, $\psi$, DEG.

LINE OF SIGHT RANGE, $R_s$, NM.
TIME HISTORY FOR LUNAR LANDING

\[ \frac{T}{W_0} = 0.4 \quad \text{isp} = 305 \]

1/2 THROTTLE AT 350 SEC.

LUNAR LANDING TIME HISTORY OF LINE OF SITE AND FLIGHT PATH ANGLE

\( \psi^\circ \quad \psi^\circ \)

\( \frac{1}{2} \) THROTTLE AT 350 sec.

LINE OF SIGHT RANGE, \( R_s \) (NM)

FLIGHT PATH ANGLE \( \psi \) (DEG.)
PERTURBATIONS OF A 10° INCLINED, 100 N.M. CIRCULAR ORBIT AFTER 12 ORBITS

<table>
<thead>
<tr>
<th></th>
<th>INCLINATION (DEG.)</th>
<th>ECCENTRICITY</th>
<th>PERICYCThON (N.M.)</th>
<th>APOCYCThON (N.M.)</th>
<th>PERIOD (HR.)</th>
<th>INERTIAL ASC.NODE (DEG.)</th>
<th>ASC. NODE MOON ROTATION (DEG.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>INITIAL VALUE</td>
<td>10.0000</td>
<td>0</td>
<td>1038.48</td>
<td>1038.48</td>
<td>2.043</td>
<td>0</td>
<td>90.0</td>
</tr>
<tr>
<td>CHANGE AFTER 12 ORBITS</td>
<td>0.0078</td>
<td>0.000048</td>
<td>-0.05</td>
<td>0.03</td>
<td>-0.0013</td>
<td>-0.685</td>
<td>-15.15</td>
</tr>
<tr>
<td>MAX. CHANGE</td>
<td>0.0078</td>
<td>0.000048</td>
<td>-0.74</td>
<td>-1.2</td>
<td>-0.0013</td>
<td>-0.685</td>
<td>-15.15</td>
</tr>
</tbody>
</table>
EARLY LAUNCH TIME WINDOW FOR LUNAR RENDEZVOUS

TIME HISTORY FOR LUNAR LAUNCH

\( \frac{T}{W_0} = 1.2 \quad \text{Isp} = 305 \)

VELOCITY, \( (V \times 10^{-2}) \), ft./sec.

ALTITUDE, \( (H \times 10^{-2}) \), ft.

RANGE, (R), NM

\( \Delta V \) TOTAL

TIME, MIN.

\( 0 \ 0 \ 2 \ 4 \ 6 \ 8 \ 10 \)

0 20 40 60 80 100 120

0 10 20 30 40 50 60

0 12.5 25 37.5
LUNAR LAUNCH TIME HISTORY
OF LINE OF SIGHT & FLIGHT PATH ANGLE
NAVIGATION AND GUIDANCE SYSTEM
DESIGN APPROACH

1. PROVIDE CAPABILITY TO LAND WITH ONLY ONBOARD SYSTEMS

2. PROVIDE CAPABILITY TO LAND WITH AIDE OF LUNAR SURFACE BEACON.

3. ATTEMPT TO IMPROVE FUEL RESERVE OR PAYLOAD CAPABILITY BY MEANS OF GUIDANCE PRECISION.

4. FAVOR USE OF EQUIPMENT INTERCHANGEABLE WITH COMMAND MODULE EQUIPMENT

5. PROVIDE ULTIMATE BACK-UP THROUGH MANUAL CONTROL USING RUDIMENTARY COMPONENTS AND ASSISTANCE FROM MOTHER SPACECRAFT

GUIDANCE EQUIPMENT

<table>
<thead>
<tr>
<th>LEM EQUIPMENT</th>
<th>WEIGHT</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMU (INERTIAL MEASUREMENT UNIT)</td>
<td>60</td>
</tr>
<tr>
<td>PSA/CDU (ELECTRONICS)</td>
<td>25</td>
</tr>
<tr>
<td>AGC (ABRIDGED COMPUTER)</td>
<td>40</td>
</tr>
<tr>
<td>RIVOTTER</td>
<td>20</td>
</tr>
<tr>
<td>ALIGNMENT TELESCOPE</td>
<td>15</td>
</tr>
<tr>
<td>TRACKING RADAR</td>
<td>55</td>
</tr>
<tr>
<td>ALTIMETER</td>
<td>10</td>
</tr>
<tr>
<td>CONTROLS &amp; DISPLAYS</td>
<td>20</td>
</tr>
<tr>
<td>BACK-UP INERTIAL COMPONENTS</td>
<td>30</td>
</tr>
<tr>
<td>CABLED</td>
<td>10</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>275</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CM EQUIPMENT</th>
<th>WEIGHT</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMU &amp; CDU</td>
<td>60</td>
</tr>
<tr>
<td>PSA/CDU</td>
<td>26</td>
</tr>
<tr>
<td>AGC</td>
<td>100</td>
</tr>
<tr>
<td>SECTOR &amp; SCANNING TELESCOPE</td>
<td>40</td>
</tr>
<tr>
<td>TRANSPONDER</td>
<td>10</td>
</tr>
<tr>
<td>CABLED</td>
<td>11</td>
</tr>
<tr>
<td>MAP &amp; VISUAL DISPLAY</td>
<td>10</td>
</tr>
<tr>
<td>DISPLAY &amp; CONTROLS</td>
<td>13</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>290</strong></td>
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</tbody>
</table>
LUNAR ORBIT INJECTION

INITIAL ERRORS (RMS)

<table>
<thead>
<tr>
<th>POSITION</th>
<th>ALTITUDE</th>
<th>DEVIATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALTITUDE</td>
<td>0.6 N.M.</td>
<td>2.5 N.M.</td>
</tr>
<tr>
<td>RANGE</td>
<td>0.4 N.M.</td>
<td>3.5 N.M.</td>
</tr>
<tr>
<td>TRACK</td>
<td>0.4 N.M.</td>
<td>0.5 N.M.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>VELOCITY</th>
<th>ALTITUDE</th>
<th>DEVIATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>RANGE</td>
<td>3 fps</td>
<td>37 fps</td>
</tr>
<tr>
<td>TRACK</td>
<td>7 fps</td>
<td>2 fps</td>
</tr>
</tbody>
</table>

CIRCULAR ORBIT DEVIATIONS (RMS)

- ALTITUDE: 0.5 N.M.
- VELOCITY: 1 fps
- TRACK: 1 fps

LUNAR ORBIT DETERMINATION

SURVEILLANCE OF LANDING SITE WITH SEXTANT

<table>
<thead>
<tr>
<th>ORBIT UNCERTAINTIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALT.</td>
</tr>
<tr>
<td>ALT.</td>
</tr>
<tr>
<td>1500</td>
</tr>
<tr>
<td>VELOCITY</td>
</tr>
<tr>
<td>2.1</td>
</tr>
</tbody>
</table>

DE-BOOST TO LUNAR ORBIT

TRACK TWO STARS

TRACK ORBIT FOR ALTITUDE CHECK

1 DEG BOOST TO LUNAR ORBIT
L.E.M. DE-BOOST AND COAST TO PERILUNE

DE-BOOST MANEUVER

DE-BOOST UNCERTAINTIES (RMS) RELATIVE TO LUNAR ORBIT

<table>
<thead>
<tr>
<th>POSITION</th>
<th>VELOCITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>RANGE</td>
<td>&lt; 50 ft</td>
</tr>
<tr>
<td>ALTITUDE</td>
<td>&lt; 50 ft</td>
</tr>
<tr>
<td>TRACK</td>
<td>&lt; 50 ft</td>
</tr>
</tbody>
</table>

ABORT RENDEZVOUS UNCERTAINTIES (RMS) RELATIVE TO LUNAR ORBIT

<table>
<thead>
<tr>
<th>POSITION</th>
<th>VELOCITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>RANGE</td>
<td>1.5 N.M.</td>
</tr>
<tr>
<td>ALTITUDE</td>
<td>0.15 N.M.</td>
</tr>
<tr>
<td>TRACK</td>
<td>0</td>
</tr>
</tbody>
</table>

LANDING MANEUVER

\[ \text{T/W} = 4 \]
\[ l_1 = 305 \]
\[ A_1 = 12 \]

\[ t = 0 \]
\[ a = 12.8 \]

\[ t = 50 \]
\[ a = 12.8 \]

\[ t = 100 \]
\[ a = 14.8 \]

\[ t = 160 \text{ sec.} \]
\[ a = 16.3 \]

\[ t = 200 \]
\[ a = 17.3 \]

\[ t = 250 \]
\[ a = 19.1 \]

\[ t = 900 \text{ fps} \]

\[ 39,000' \]

\[ 400' \]

\[ A_1 = 14^\circ \]

\[ A_2 = 36^\circ \]

\[ A_3 = 36^\circ \]

\[ a = 15 \]

\[ \text{ELEVATION TO SCALE} \]
FLARE OUT TRAJECTORIES

PHASE 1
\[ \begin{align*}
A_T &= 36^\circ \\
a &= 15 \text{ fps}^2
\end{align*} \]

PHASE 2
\[ \begin{align*}
A_T &= 41^\circ \\
a &= 6.6 \text{ fps}^2
\end{align*} \]

LANDING SITE SENSING

ALTIMETER BEAM
RETICLE SIGHT LINE
RADAR TRACK LINE
SURFACE OPERATION

L.E.M. LAUNCH TRAJECTORY

IMU CUT-OFF UNCERTAINTIES (RMS)

<table>
<thead>
<tr>
<th>ALT.</th>
<th>RANGE</th>
<th>TRACK</th>
</tr>
</thead>
<tbody>
<tr>
<td>POSITION</td>
<td>100°</td>
<td>70°</td>
</tr>
<tr>
<td>VELOCITY</td>
<td>1.5fps</td>
<td>1.0fps</td>
</tr>
</tbody>
</table>

CUT-OFF CONDITIONS

\[ V_{co} = 5607 \text{ fps} \]
\[ \alpha \approx 0 \]
\[ t = 137 \text{ sec} \]

ALT. = 50,000 FT.

57 N.M.

135 N.M.

190 N.M.
L.E.M. ASCENT TRAJECTORIES

INITIAL CLOSING VEL \( \approx 400 \text{ fps} \)

INITIAL CLOSING VEL \( \approx 200 \text{ fps} \)

S.M. TRACKING RADAR BACK-UP
BLINKER

LE M OPTICAL TRACKING
SCANNING TELESCOPE
ORIENTATION LIGHTS

RENE closest PHASE

L.E.M. TRACKING RADAR
RENDEZVOUS TRAJECTORY—HORIZONTAL
PLANE PROJECTION

UNTREATED MISS DISTANCE
TERMINAL VELOCITY CORRECTION
(INTERMITTENT THRUST MANEUVER
USING ATTITUDE CONTROL JETS)

TERMINAL MANEUVER
MAX THRUST LEVEL (8000 LBS)
TIME = 5.7 SEC.
R_o = 1200 FT.

MIN THRUST LEVEL (1000 LBS)
TIME = 46 SEC.
R_o = 9600 FT.

COLLISION COURSE CORRECTION
(INTERMITTENT THRUST MANEUVER
USING ATTITUDE CONTROL JETS)

R_o = 400 FT.
LUNAR EXCURSION MODULE
CONFIGURATION, SYSTEMS
AND WEIGHTS
LUNAR EXCURSION MODULE
DESIGN CRITERIA

LUNAR SURFACE MODEL:
CHOSEN AS A COMPROMISE BETWEEN LANDING SYSTEM REQUIREMENTS AND RECONNAISSANCE CAPABILITIES.

MICROMETEOROID ACTIVITY:
DESIGN FOR SPORADIC MICROMETEOROID FLUX AS GIVEN BY WHIPPLE - 1957.

RADIATION FROM MAJOR PROTON EVENTS:
PROTECTION SCHEME DESIGNED TO PERMIT OPERATIONS TO CONTINUE WITH CERTAIN LIMITATIONS ON ACTIVITIES.

SOLAR INSOLATION:
ATTENUATION OF SOLAR ENERGY FOR LUNAR SURFACE OPERATIONS PROVIDED ACCORDING TO MISSION REQUIREMENTS.

LUNAR EXCURSION MODULE
DESIGN CRITERIA (CONT’D)

PROPULSION:
LEM. PROPULSION USED FOR OPERATIONS FROM LUNAR ORBIT TO LUNAR SURFACE AND BACK TO LUNAR ORBIT RENDEZVOUS.

PROPELLANTS ARE SAME AS THOSE IN SERVICE MODULE.

SYSTEMS ARE REDUNDANT AND FAIL-SAFE WHERE ADVANTAGEOUS EXCEPT FOR MAIN THRUST CHAMBER AND INJECTOR.

GROWTH CONTINGENCY:
SIZING OF TANKAGE AND SIMILAR FACTORS ADJUSTED TO ALLOW UTILIZATION OF FULL SATURN C-5 CAPABILITY.

NON PROPULSIVE PAYLOADS CONSIDERED TO GROW 25% OVER THE PRESENT BEST ESTIMATES.

VELOCITY RESERVES PROVIDED ARE 5% IN EXCESS OF THE BEST CHARACTERISTIC VELOCITY ESTIMATES.
STRUCTURAL DESIGN:
BASED ON NORMAL AND EMERGENCY MISSION PROFILES AND ENVIRONMENTS.
CABIN SHALL BE PRESSURE VESSEL PERMITTING SHIRT-SLEEVE HABITABILITY IN TRANSLUNAR FLIGHT.

LEM INTEGRATION WITH SPACE VEHICLE:
STOWED BEHIND SERVICE MODULE FOR LAUNCH AND INJECTION.
HARD-DOCKED ON COMMAND-MODULE AIRLOCK DURING MID-COURSE.

COMMUNICATION:
DIRECT COMMUNICATION LINKS BETWEEN LEM CM. AND EARTH.
EACH MAY PERFORM RELAY FUNCTION EXCEPT AS LIMITED BY LUNAR SHIELDING.

GUIDANCE:
REDUNDANT GUIDANCE AND CONTROL CAPABILITY FOR LUNAR LANDING AND RETURN TO ORBIT THROUGH INDEPENDENT OVERLAPPING MODES.

LUNAR EXCURSION MODULE CONFIGURATION
LUNAR EXCURSION MODULE
INBOARD PROFILE AND GEOMETRY

DISPLAYS
SC. PAYLOAD (RETURN)

RCS
G & C
RADAR
ANTENNA
COMM. EQUIP.

276"

36.0" DIA.

ECS
POWER SUPPLY
OXIDIZER
FUEL
HELIXM (6)

212"

30.0"

CREW POSN. FOR DOCKING
OXIDIZER
FUEL
HELIXM (2)

ECS, BATT, T.V., SC. PAYLOAD

LUNAR EXCURSION MODULE
STAGING AT LIFT-OFF OR ABORT
CREW DESCRIPTION
LUNAR EXCURSION MODULE

COMMANDER PILOT:
EXERCISES ONBOARD COMMAND.
CONTROLS SELECTION OF SYSTEM MODES.
CLOSES OUTER LOOP IN PILOTING ACTIVITY.

CO-PILOT - SYSTEMS MANAGER:
MONITORS ON BOARD SYSTEMS.
ASSISTS IN SELECTION OF SYSTEM MODES.
TAKES OVER PILOTING AS REQUIRED.

CREW EQUIPMENT
LUNAR EXCURSION MODULE

SPACE SUIT:
PERMITS PILOTING, MAINTENANCE, GENERAL MOBILITY,
AND DEXTERITY.
FACE PLATE MAY BE OPEN IN CABIN ENVIRONMENT.
NORMALLY USED IN AIRLOCK AND LUNAR EXCURSION
MODULE OPERATIONS.
PRIMARY EXTRAVEHICULAR PROTECTION FOR EARLY
MISSION.

SUPPORT AND RESTRAINT:
NORMALLY SPINE ALIGNED WITH THRUST.
CREW MAY ALTER ORIENTATION AND GEOMETRY
ACCORDING TO OPERATIONAL REQUIREMENTS.
STRUCTURAL SYSTEM
LUNAR EXCURSION MODULE

ATTACH TO ADAPTER AT MULTIPLE DISCRETE POINTS.

LANDING GEAR UTILIZES ATTACHMENT STRUCTURE.

BUMPER - INSULATION COMBINATION UTILIZED FOR MICROMETEOROID ATTENUATION.

TRANSPARENT AREAS TO BE COVERED EXCEPT FOR OPERATIONAL USE.

CABIN SUPPORT, DOCKING, AND THRUST STRUCTURES ARE INTEGRATED.

STAGING DISCONNECTS ARE DISCRETE AT EXISTING HARD POINTS.

LUNAR EXCURSION MODULE
COMMUNICATIONS BLOCK DIAGRAM
LUNAR EXCURSION MODULE
ENVIRONMENTAL CONTROL

LUNAR EXCURSION MODULE
ELECTRICAL SYSTEM POWER PROFILE
LUNAR EXCURSION MODULE
REACTION CONTROL SYSTEM

LATCH-TYPE
SOLENOID VALVE

FUEL

OXIDIZER

LATCH-TYPE
SOLENOID VALVE

CONNECTED TO
MAIN PROPULSION
SYSTEM

TO DUPLICATE SYSTEM
BI-PROPELLANT
SOLENOID VALVES

20 LB 20 20 20 100 100 100 100
C.W.R. C.W.R. C.W.R. C.W.R.
PU. PD YR. Y.L.

LUNAR EXCURSION MODULE
SCIENTIFIC PAYLOAD (NOMINAL MISSION)

<table>
<thead>
<tr>
<th></th>
<th>LANDING</th>
<th></th>
<th>LIFT OFF</th>
</tr>
</thead>
<tbody>
<tr>
<td>RADIOACTIVITY</td>
<td>POUNDS</td>
<td>CUBIC FEET</td>
<td>POUNDS</td>
</tr>
<tr>
<td>TEMPERATURE</td>
<td>10</td>
<td>.15</td>
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</tr>
<tr>
<td>SURFACE DETAIL</td>
<td>6</td>
<td>.1</td>
<td></td>
</tr>
<tr>
<td>ROCK SURVEY</td>
<td>15</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>COMMUNICATION</td>
<td>1</td>
<td>.01</td>
<td></td>
</tr>
<tr>
<td>SOIL ANALYSIS</td>
<td>10</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>FRICTION</td>
<td>10</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>DENSITY SURVEY</td>
<td>4</td>
<td>.15</td>
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</tr>
<tr>
<td>CORE SAMPLE</td>
<td>5</td>
<td>.08</td>
<td></td>
</tr>
<tr>
<td>SEISMOMETER</td>
<td>25</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>ATMOSPHERE</td>
<td>40</td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td>GRAVITY</td>
<td>27</td>
<td>1.9</td>
<td></td>
</tr>
<tr>
<td>MAGNETIC FIELD</td>
<td>5</td>
<td>.15</td>
<td></td>
</tr>
<tr>
<td>SAMPLE CONTAINERS</td>
<td>7</td>
<td>.4</td>
<td></td>
</tr>
<tr>
<td>SAMPLES</td>
<td>10</td>
<td>1.5</td>
<td>10.</td>
</tr>
<tr>
<td>RECORDS &amp; PHOTOGRAPHS</td>
<td>20</td>
<td>1.5</td>
<td>20.</td>
</tr>
<tr>
<td>FILM PROCESSING</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CAMERA</td>
<td>10</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>215</td>
<td>13.44</td>
<td>80.</td>
</tr>
</tbody>
</table>
LUNAR EXCURSION MODULE
LANDING STABILITY DESIGN CONDITIONS

LUNAR EXCURSION MODULE
PROPULSION SYSTEM

- VARIABLE AREA INJECTOR
- QUAD CHECK VALVE NOZZLE
- PRESSURE REGULATOR
- BURST DISC

Legend:
- N.O. Normally Open
- N.C. Normally Closed
- Squib Valve
- Pressure
- Temperature
- Explosive Disconnect
- Filter
- Quad Check Valve
- Relief Valve
- Hand Valve
- Cap
- Dual Propellant Valve
- Variable Area Injector
- Nozzle

N.O. Normally Open
N.C. Normally Closed
NON PROPULSIVE PAYLOAD FOR LUNAR EXCURSION MODULE

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>LANDING Weight (lbs.)</th>
<th>LIFTOFF Weight (lbs.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CREW and EQUIPMENT</td>
<td>455</td>
<td>455</td>
</tr>
<tr>
<td>STRUCTURE</td>
<td>396</td>
<td>396</td>
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<tr>
<td>GUIDANCE and CONTROL</td>
<td>287</td>
<td>287</td>
</tr>
<tr>
<td>COMMUNICATIONS</td>
<td>193</td>
<td>133</td>
</tr>
<tr>
<td>ENVIRONMENTAL CONTROL SYSTEM</td>
<td>468</td>
<td>302</td>
</tr>
<tr>
<td>ELECTRICAL POWER SYSTEM</td>
<td>463</td>
<td>197</td>
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<tr>
<td>REACTION CONTROL SYSTEM</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>INSTRUMENT PANEL</td>
<td>80</td>
<td>80</td>
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<tr>
<td>SCIENTIFIC PAYLOAD</td>
<td>215</td>
<td>80</td>
</tr>
<tr>
<td>TOTAL PAYLOAD WEIGHT (No Growth)</td>
<td>2707</td>
<td>2080</td>
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<tr>
<td>CONTINGENCY (25 percent)</td>
<td>677</td>
<td>520</td>
</tr>
<tr>
<td>TOTAL PAYLOAD WEIGHT (With Growth)</td>
<td>3384</td>
<td>2600</td>
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</table>

LUNAR EXCURSION MODULE DESIGN VELOCITY INCREMENTS

<table>
<thead>
<tr>
<th>PHASE OF MISSION</th>
<th>VELOCITY FT/SEC</th>
<th>VELOCITY +5% FT/SEC</th>
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</thead>
<tbody>
<tr>
<td>CIRCULAR TO ELLIPTIC ORBIT</td>
<td>120</td>
<td></td>
</tr>
<tr>
<td>BRAKE TO ZERO—NEAR SURFACE</td>
<td>5924</td>
<td></td>
</tr>
<tr>
<td>HOVER, TRANSLATION, TOUCHDOWN</td>
<td>800</td>
<td></td>
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<tr>
<td>LEM LANDING STAGE</td>
<td>6844</td>
<td>7186</td>
</tr>
<tr>
<td>ASCEND TO ELLIPTIC ORBIT (T/W = .4)</td>
<td>6000</td>
<td></td>
</tr>
<tr>
<td>ELLIPTIC TO CIRCULAR ORBIT</td>
<td>120</td>
<td></td>
</tr>
<tr>
<td>RENDEZVOUS IN LUNAR ORBIT</td>
<td>600</td>
<td></td>
</tr>
<tr>
<td>LEM LAUNCH STAGE</td>
<td>6720</td>
<td>7056</td>
</tr>
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</table>
### LUNAR EXCURSION MODULE
#### SUMMARY WEIGHT STATEMENT (25% GROWTH)

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>SEPARATION</th>
<th>LANDING</th>
<th>LIFTOFF</th>
<th>BURNOUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAYLOAD (25% GROWTH)</td>
<td>2600</td>
<td>2600</td>
<td>2600</td>
<td>2600</td>
</tr>
<tr>
<td>LAUNCH INERT PROPULSION</td>
<td>850</td>
<td>850</td>
<td>850</td>
<td>850</td>
</tr>
<tr>
<td>LAUNCH PROPELLANT</td>
<td>3625</td>
<td>3625</td>
<td>3625</td>
<td></td>
</tr>
<tr>
<td>LANDING INERT PROPULSION</td>
<td>1520</td>
<td>1520</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LANDING PROPELLANT</td>
<td>10473</td>
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<td></td>
<td></td>
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<tr>
<td>LANDING GEAR</td>
<td>414</td>
<td>414</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LANDING AIDS</td>
<td>22</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PAYLOAD LEFT ON LUNAR SURFACE</td>
<td>784</td>
<td>784</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL WEIGHT</strong></td>
<td><strong>20288</strong></td>
<td><strong>9793</strong></td>
<td><strong>7075</strong></td>
<td><strong>3450</strong></td>
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</table>

### MISSION WEIGHT HISTORY

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>NOMINAL</th>
<th>25% GROWTH</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAUNCH ESCAPE SYSTEM (4%)</td>
<td>250</td>
<td>250</td>
</tr>
<tr>
<td>COMMAND MODULE (TOTAL)</td>
<td>8,500</td>
<td>10,625</td>
</tr>
<tr>
<td>SERVICE MODULE</td>
<td>36,004</td>
<td>41,042</td>
</tr>
<tr>
<td>ADAPTER</td>
<td>1,450</td>
<td>1,450</td>
</tr>
<tr>
<td>LEM. (LESS CREW)</td>
<td>17,302</td>
<td>19,818</td>
</tr>
<tr>
<td>EARTH ESCAPE</td>
<td>63,506</td>
<td>73,185</td>
</tr>
<tr>
<td>IN LUNAR ORBIT</td>
<td>42,053</td>
<td>48,626</td>
</tr>
<tr>
<td>LEM. SEPARATION</td>
<td>17,772</td>
<td>20,288</td>
</tr>
<tr>
<td>LEM. LANDING</td>
<td>8,574</td>
<td>9,793</td>
</tr>
<tr>
<td>TOTAL LEFT ON MOON</td>
<td>2,561</td>
<td>2,718</td>
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<tr>
<td>PAYLOAD LEFT ON MOON</td>
<td>627</td>
<td>784</td>
</tr>
<tr>
<td>LEM. LIFT OFF</td>
<td>6,013</td>
<td>7,075</td>
</tr>
<tr>
<td>LEM. BURNOUT</td>
<td>2,930</td>
<td>3,450</td>
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<tr>
<td>ORBIT-DOCKED</td>
<td>27,681</td>
<td>32,258</td>
</tr>
<tr>
<td>PRIOR TO TRANS EARTH</td>
<td>24,751</td>
<td>28,808</td>
</tr>
<tr>
<td>PRIOR TO REENTRY</td>
<td>16,684</td>
<td>19,434</td>
</tr>
</tbody>
</table>
SATURN C-5 LAUNCH VEHICLE
PERFORMANCE MARGINS

CM/SM + ADAPTER
+LES EFFECTIVE WT
MAX 54,000
NOM 46,500
MIN GUARANTEED 90,000
PAYLOAD
MAX REQ 74,000
NOM REQ 64,000
% MIN MARGIN 22
% NOM MARGIN 40

LUNAR EXCURSION MODULE
MAX 20,000
NOM 17,500

USABLE PROPELLANT
(INCLUDES FPR 20,000)
216,000*
25,000*

BURN-OUT WEIGHT

MIN GUARANTEED 90,000
MAX REQUIRED 74,000
% MIN MARGIN 8
% NOM MARGIN 25

C-5 STAGED IN ORBIT
MIN GUARANTEED 80,000
MAX REQUIRED 74,000
% MIN MARGIN 8
% NOM MARGIN 25

USABLE PROPELLANT
4,320,000*
403,000*

BURN-OUT WEIGHT

SAT C-5
DESIGN FOR ESCAPE
RESTART IN ORBIT

SAT C-5
PERFORMANCE MARGINS

CM/SM + ADAPTER
+LES EFFECTIVE WT
MAX 54,000
NOM 46,500
MIN GUARANTEED 90,000
PAYLOAD
MAX REQ 74,000
NOM REQ 64,000
% MIN MARGIN 22
% NOM MARGIN 40

LUNAR EXCURSION MODULE
MAX 20,000
NOM 17,500

USABLE PROPELLANT
(INCLUDES FPR 20,000)
216,000*
25,000*

BURN-OUT WEIGHT

MIN GUARANTEED 90,000
MAX REQUIRED 74,000
% MIN MARGIN 8
% NOM MARGIN 25

C-5 STAGED IN ORBIT
MIN GUARANTEED 80,000
MAX REQUIRED 74,000
% MIN MARGIN 8
% NOM MARGIN 25

USABLE PROPELLANT
4,320,000*
403,000*

BURN-OUT WEIGHT

SAT C-5
DESIGN FOR ESCAPE
RESTART IN ORBIT
LUNAR EXCURSION MODULE
PROPULSION
FLIGHT RELIABILITY HISTORY
OF TITAN, ATLAS, THOR, REDSTONE, JUPITER

<table>
<thead>
<tr>
<th>COMPONENT OR SUBSYSTEM</th>
<th>% TOTAL FAILURES</th>
</tr>
</thead>
<tbody>
<tr>
<td>TURBOPUMP</td>
<td>15</td>
</tr>
<tr>
<td>ENGINE VALVES AND REGULATORS</td>
<td>15</td>
</tr>
<tr>
<td>THRUST CHAMBERS (ROUGH COMBUSTION)</td>
<td>3</td>
</tr>
<tr>
<td>TANKS AND LINES</td>
<td>6</td>
</tr>
<tr>
<td>PROPELLANT SLOSH</td>
<td>3</td>
</tr>
<tr>
<td>PROPELLANT UTILIZATION</td>
<td>5</td>
</tr>
<tr>
<td>PRESSURIZATION SYSTEMS</td>
<td>8</td>
</tr>
<tr>
<td>THRUST VECTOR CONTROL &amp; HYDRAULICS</td>
<td>6</td>
</tr>
<tr>
<td>ELECTRICAL POWER &amp; DISTRIBUTION</td>
<td>14</td>
</tr>
<tr>
<td>FLIGHT CONTROLS</td>
<td>12</td>
</tr>
<tr>
<td>GUIDANCE</td>
<td>9</td>
</tr>
<tr>
<td>STRUCTURES</td>
<td>4</td>
</tr>
</tbody>
</table>

HIGH RELIABILITY REQUIRES

- OPERATION UNDER AN EXTREME RANGE OF OFF-DESIGN CONDITIONS AND ENVIRONMENT.
- SYSTEM OPERATION INDEPENDENT OF SINGLE COMPONENT FAILURES.
- REDUNDANT COMPONENTS LINKED SUCH THAT ADDITIONAL COMPONENTS DO NOT HAVE TO FUNCTION TO SENSE AND INITIATE REDUNDANT OPERATIONAL MODE.
- MINIMUM OF COMPONENTS, LINES, FITTINGS, CIRCUITRY.
- SIMPLE CHECK OUT AND OPERATIONAL TEST.
### REDUNDANT ENGINES

<table>
<thead>
<tr>
<th>ADVANTAGES</th>
<th>DISADVANTAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>• REDUNDANT VALVES AND VALVE ACTUATORS.</td>
<td>• MALFUNCTION DETECTION AND SWITCHING SYSTEM REQUIRED FOR PROPELLANTS AND THRUST VECTOR CONTROL SYSTEM.</td>
</tr>
<tr>
<td>• REDUNDANT THRUST CHAMBERS.</td>
<td>• CATASTROPHIC MALFUNCTION PROBABILITY INCREASED.</td>
</tr>
<tr>
<td>• REDUNDANT THRUST-VECTOR CONTROL.</td>
<td>• COMPlicATES CONTROL ELECTRONICS.</td>
</tr>
<tr>
<td></td>
<td>• PROPELLANT FEED LINES, VALVES, FITTINGS INCREASE POTENTIAL LEAK POINTS AND HUMAN ERROR POINTS.</td>
</tr>
<tr>
<td></td>
<td>• PROPELLANT DEPLETION DESIGN COMPLICATED DUE TO MULTIPLE ATTITUDE AT DEPLETION.</td>
</tr>
<tr>
<td></td>
<td>• CREW VISIBILITY AND MANUAL CONTROL COMPLICATED.</td>
</tr>
<tr>
<td></td>
<td>• STABILITY AND CONTROL COMPLICATED BY ENGINE FAILURE.</td>
</tr>
</tbody>
</table>

### SINGLE ENGINE WITH REDUNDANT VALVES & THRUST VECTOR CONTROL

<table>
<thead>
<tr>
<th>ADVANTAGES</th>
<th>DISADVANTAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>• REDUNDANT VALVES &amp; ACTUATORS.</td>
<td>• THRUST CHAMBER NOT REDUNDANT</td>
</tr>
<tr>
<td>• REDUNDANT THRUST VECTOR CONTROL.</td>
<td></td>
</tr>
<tr>
<td>• NO MALFUNCTION DETECTION &amp; SWITCHING CIRCUITS.</td>
<td></td>
</tr>
<tr>
<td>• LESS PROBABILITY OF CATASTROPHIC MALFUNCTION.</td>
<td></td>
</tr>
<tr>
<td>• SINGLE ATTITUDE FOR LANDING.</td>
<td></td>
</tr>
<tr>
<td>• NO COMPLEXITIES ADDED TO ANY OTHER SYSTEM.</td>
<td></td>
</tr>
</tbody>
</table>

REDUNDANCY IN ONE OF THE MOST RELIABLE SYSTEMS OF THE VEHICLE HAS BEEN SACRIFICED TO AVOID COMPLICATIONS OF RELATIVELY UNRELIABLE ELECTRICAL NETWORKS AND FLIGHT CONTROLS.
SINGLE THRUST-CHAMBER SPECIAL
DESIGN FEATURES

- LARGE FLOW PASSAGE; SCREENED INJECTOR MANIFOLDS.
- BAFFLED COMBUSTION CHAMBER STABLE FOR ANY INJECTOR FLOW OR PRESSURE ADEQUATE FOR MISSION T/W.
- COMBUSTION CHAMBER DESIGN TOLERABLE TO ANY MAL-FORMED INJECTOR PATTERN OR OFF-DESIGN O/F RATIO ALLOWING MISSION COMPLETION.
- EXTREMELY RUGGED MECHANICAL CONSTRUCTION INSENSITIVE TO TEMPERATURE VARIATION, METEORITES, OPERATIONAL HAZARDS.
- ABLATIVE CHAMBER DESIGN.

CHOICE OF PROPELLANTS

LAUNCH-VEHICLE PERFORMANCE & PAYLOAD REQUIREMENT ALLOWS UNCOMPROMIZED CHOICE FOR RELIABILITY & OPERATIONAL CONSIDERATIONS.

CHARACTERISTICS OF MON/MMH -
- EASY TROTTLING - HYPERGOLIC STARTS - SIMPLE SYSTEM.
- LOW THERMAL DISTORTION OF MECHANICAL PARTS.
- COUNTDOWN AND CHECKOUT PROBLEMS MINIMIZED.
- SMALL VEHICLE HAS OPERATIONAL ADVANTAGES FOR:
  (A) VISIBILITY & MANEUVERABILITY DURING LANDING
  (B) CREW TRAINING OPERATIONS & SYSTEMS DEVELOPMENT
  (C) PACKAGING IN LAUNCH VEHICLE
### CONSIDERATIONS FOR STAGED VS PARTIAL-STAGED LEM PROPULSION

<table>
<thead>
<tr>
<th>STAGED</th>
<th>PARTIAL STAGED</th>
<th>UNSTAGED</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ADVANTAGES</strong></td>
<td><strong>DISADVANTAGES</strong></td>
<td><strong>ADVANTAGES</strong></td>
</tr>
<tr>
<td><em>Separate well-protected abort engine not subjected to mechanical hazards of landing.</em></td>
<td><em>Longer vehicle requires more landing legs and more C-5 adapter length.</em></td>
<td><em>Separate well-protected abort engine.</em></td>
</tr>
<tr>
<td><em>Abort engine simpler, no throttling requirements.</em></td>
<td><em>Engine-control signal transmitted across staging disconnect.</em></td>
<td><em>Compact, short vehicle, less landing legs, short C-5 adapter.</em></td>
</tr>
<tr>
<td><strong>PARTIAL STAGED</strong></td>
<td><strong>MAIN PROPELLANT LINE DISCONNECT REQUIRED.</strong></td>
<td><strong>SOME MANEUVERABILITY ADVANTAGE.</strong></td>
</tr>
<tr>
<td><strong>UNSTAGED</strong></td>
<td><strong>NO SEPARATE ABORT ENGINE.</strong></td>
<td><strong>NO SEPARATE ABORT ENGINE.</strong></td>
</tr>
<tr>
<td><em>Compact, short vehicle, less landing legs, short C-5 adapter.</em></td>
<td></td>
<td><em>Some maneuverability advantage.</em></td>
</tr>
<tr>
<td><em>Some maneuverability advantage.</em></td>
<td></td>
<td><em>Some maneuverability advantage.</em></td>
</tr>
<tr>
<td><em>Complete integrated package, no staging disconnects.</em></td>
<td><em>Can not perform mission with SAT C-5 unless high energy propellants are used.</em></td>
<td><em>Complete integrated package, no staging disconnects.</em></td>
</tr>
<tr>
<td></td>
<td><em>May have propellant dynamics problems during landing maneuver.</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>All systems activated during full LEM mission.</em></td>
<td></td>
</tr>
</tbody>
</table>
SPACECRAFT INTEGRATION
SYSTEM DESIGN CRITERIA

LUNAR EXCURSION MODULE

SYSTEMS NOT ACTIVATED UNTIL LUNAR APPROACH

COMMAND MODULE

SUPPLIES ALL LIFE SUPPORT, POWER, ENVIRONMENTAL, GUIDANCE, CONTROL & COMMUNICATIONS UNTIL LUNAR ORBIT ESTABLISHED

REDUCTION IN C/M & S/M WEIGHT CRITERIA

<table>
<thead>
<tr>
<th>Equipment Type</th>
<th>Weight Change</th>
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</thead>
<tbody>
<tr>
<td>8-1/2-DAYS EQUIPMENT OPERATION</td>
<td></td>
</tr>
<tr>
<td>20-1/2 MAN-DAYS OF CREW LIFE</td>
<td></td>
</tr>
<tr>
<td>SUPPORT</td>
<td></td>
</tr>
<tr>
<td>(PLUS 9 MAN-DAYS EARTH RECOVERY)</td>
<td></td>
</tr>
<tr>
<td>COMMAND MODULE EQUIPMENT</td>
<td></td>
</tr>
<tr>
<td>FOOD &amp; CONTAINERS</td>
<td>46 LB</td>
</tr>
<tr>
<td>CO₂ ABSORBERS</td>
<td>50 LB</td>
</tr>
<tr>
<td>SERVICE MODULE EQUIPMENT</td>
<td></td>
</tr>
<tr>
<td>NITROGEN &amp; CONTAINERS</td>
<td>23 LB</td>
</tr>
<tr>
<td>OXYGEN &amp; CONTAINERS</td>
<td>67 LB</td>
</tr>
<tr>
<td>FUEL-CELL REACTANTS</td>
<td>250 LB</td>
</tr>
<tr>
<td>REACTION CONTROL</td>
<td>21 LB</td>
</tr>
<tr>
<td>HEAT-PUMP SYSTEM</td>
<td>43 LB</td>
</tr>
<tr>
<td></td>
<td>500 LB</td>
</tr>
</tbody>
</table>

*WEIGHT CHANGE FROM MARCH 9 STATUS
SHUTTLE TRANSFER SYSTEM

COMMAND MODULE

SERVICE MODULE

ADAPTER

S-IVB BOOSTER

BOOST CONDITION

MIDCOURSE DOCKING OPERATION

AIRLOCK ATTACHMENT

LUNAR EXCURSION VEHICLE

COMMAND MODULE

SERVICE MODULE

INFLATABLE SEALS

LUNAR EXCURSION VEHICLE

MANUAL OVERRIDE

RING GEAR

PINION

LATCH

MANUAL OVERRIDE

COMMAND MODULE

STRUCTURE

PARACHUTE STOWAGE

PINION

BALL BEARINGS

LATCH LOCATIONS

PINION

DETAIL B

DETAIL A
ADAPTER ATTACHMENT & SEPARATION

SERVICE MODULE
COMMAND MODULE

STA 630

STA 786

ADAPTER
(4 SEGMENTS)

A

B

SEPARATION
PLANE

STA 630

SHAPE CHARGE

STEEL SHIELD

DETAIL A

VIEW C-C

TYPICAL 4 PLACES

DETAIL B

SHUTTLE TRANSFER SYSTEM

MIDCOURSE CORRECTION

CREW TRANSFER

DOCKING POSITION

INTERMEDIATE POSITION

ORBITAL LAUNCH & RETURN POSITION

LUNAR ORBITAL OPERATION
LAUNCH & RETURN REQUIREMENTS

| LUNAR ORBITAL RENDEZVOUS | MAXIMUM | POSSIBLE DESIGN | MINIMUM | DIRECT LUNAR LANDING MISSION -RETURN-
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>FREE RETURN TO POINT LANDING 100% MONTH</td>
<td>TRANSLUNAR EQUATORIAL 100% MONTH</td>
<td>ONCE A MONTH</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TRANSLUNAR</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MIDCOURSE</td>
<td>500</td>
<td>500</td>
<td>500</td>
<td></td>
</tr>
<tr>
<td>ORBIT INJECTION</td>
<td>3,281</td>
<td>3,281</td>
<td>3,167</td>
<td></td>
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<tr>
<td>ORBIT TRANSFER -EQUATORIAL</td>
<td>1,770</td>
<td>—</td>
<td>—</td>
<td></td>
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<tr>
<td>CONTROL TOLERANCE 3%</td>
<td>167</td>
<td>113</td>
<td>110</td>
<td></td>
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<tr>
<td>TOTAL</td>
<td>5,718</td>
<td>3,894</td>
<td>3,777</td>
<td></td>
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<tr>
<td>TRANSEARTH</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>LUNAR BOOST</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td></td>
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<tr>
<td>ORBIT EJECTION</td>
<td>3,916</td>
<td>3,916</td>
<td>3,780</td>
<td></td>
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<tr>
<td>MIDCOURSE</td>
<td>500</td>
<td>500</td>
<td>500</td>
<td></td>
</tr>
<tr>
<td>CONTROL TOLERANCE 3%</td>
<td>133</td>
<td>133</td>
<td>128</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>4,549</td>
<td>4,549</td>
<td>4,408</td>
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</table>

TOTAL | 10,267 | 8,443 | 8,185 |

SERVICE MODULE (S/M) WEIGHT VARIATION

COMMAND MODULE (C/M) = 8125
SERVICE MODULE EQUIPMENT = 3375

\[ \Delta V = 8447 \]

\[ V = 8188 \]

\[ V = 10,267 \]
SYSTEM FLEXIBILITY VS INJECTION WT
LEM + ADAPTER = 22,000 LB

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<tr>
<th>LAUNCH FLEXIBILITY</th>
<th>INJECTION WEIGHT</th>
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<tr>
<td>FREE RETURN POINT LANDING 100% MO</td>
<td>94,000 LB</td>
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<tr>
<td>TRANSLUNAR EQUATORIAL 100% MO</td>
<td>70,000 LB</td>
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<tr>
<td>ONCE A MONTH</td>
<td>68,000 LB</td>
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EFFECTS OF VARIATIONS IN C/M & LEM WTS ON S/M WTS

\[
\frac{\delta \text{ SIM}}{\delta \text{ C/M}} = 3.3 \text{ LB/LB}
\]

\[
\frac{\delta \text{ SIM}}{\delta \text{ LEM}} = 0.7 \text{ LB/LB}
\]

LEM = 20,000 LBS
SPACECRAFT WEIGHTS — EFFECT OF EXTENDING MISSION OVER 8 DAYS

\[
\text{\textfrac{\delta \text{POWER SYSTEM}}{\delta \text{TIME}}} = 47 \text{ LB/DAY}
\]

\[
\text{\textfrac{\delta \text{LIFE SUPPORT SYSTEM}}{\delta \text{TIME}}} = 15 \text{ LB/MAN-DAY}
\]

PRIMARY INTERFACE REQUIREMENTS
COMMAND MODULE - SERVICE MODULE - LUNAR EXCURSION MODULE

- Interstage Attachment (Attachment & Separation)
- Transfer Mechanism (Operation & Control)
- Equipment & Accommodations
- Airlock Attachment (Seal & Release)
- Command & Control Communication
- Functional Systems Interconnects
REVISIONS TO APOLLO SPACECRAFT

CONFIGURATIONS

- COMPATIBLE DOCKING PROVISIONS
- PROVIDE SYSTEM INTERCONNECTORS
- LOADS ON AIRLOCK
- PROVIDE EARTH LAUNCH STOWAGE

REVISIONS TO APOLLO SPACECRAFT (CONT)

COMMUNICATIONS SYSTEMS

- ADD: 310-MC & 270-MC POWER AMPS & TRANSMITTERS
  
  VHF OMNI-ANTENNA
  
  RADAR TRANSPONDER
  
  CHECKOUT EQUIPMENT

  (WT—37 LB—PEAK POWER: 99 W)
REVISIONS TO APOLLO SPACECRAFT (CONT)

POWER SYSTEMS

- REMOVE LUNAR LANDING OPERATIONAL LOADS
- CHANGE EQUIPMENT OPERATION FROM 14 DAYS TO 8-1/2 DAYS
- SUPPLY POWER FOR LEM IN-FLIGHT CHECKOUT

TOTAL ENERGY APPROXIMATELY - 500 W HR

PEAK POWER APPROXIMATELY - 750 W

ENVIRONMENTAL CONTROL

- REMOVE LUNAR LANDING HEAT LOADS

CREW PROVISIONS

- REDUCE MISSION PROVISIONS TO 20-1/2 MAN-DAYS (FROM 42 MAN-DAYS)

GUIDANCE & NAVIGATION

- SUPPLY - INERTIAL SYSTEM ALINEMENT DATA
- ORBITAL EPHEMERIS DATA & TIME REFERENCE
- ADD - LIGHT BEACON (200 W), RADAR BEACON TRANSPOUNDER
MISSION DEVELOPMENT PLAN
<table>
<thead>
<tr>
<th>SPACECRAFT COMPONENT</th>
<th>FLIGHT RESUME</th>
<th>LAUNCH VEHICLE</th>
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<tbody>
<tr>
<td>LAUNCH ESCAPE SYSTEM</td>
<td>SUB-ORBITAL</td>
<td>OFF- PAD LITTLE JOE II</td>
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<tr>
<td>COMMAND MODULE</td>
<td>SUB-ORBITAL</td>
<td>LITTLE JOE II C-5</td>
</tr>
<tr>
<td>COMMAND &amp; SERVICE MODULE</td>
<td>SUB-ORBITAL ORBITAL</td>
<td>LITTLE JOE II C-1 C-IB</td>
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<tr>
<td>LUNAR EXCURSION MODULE</td>
<td>SUB-ORBITAL</td>
<td>LITTLE JOE II C-1B</td>
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<tr>
<td>COMPLETE SPACECRAFT</td>
<td>ORBITAL LUNAR</td>
<td>C-1B C-5</td>
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</tbody>
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**SPACECRAFT CONFIGURATIONS TO BE TESTED**

- PAD ABORT
- LJ-II SUB ORBITAL
- C-I ORBITAL
- C-I-B ORBITAL
- C-5 ORBITAL AND ESCAPE VEL.
# Apollo Flight Schedule

## Lunar Rendezvous Technique

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<tr>
<td><strong>Off-Pad</strong></td>
<td><img src="image1.png" alt="Diagram" /></td>
<td><img src="image2.png" alt="Diagram" /></td>
<td><img src="image3.png" alt="Diagram" /></td>
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<tr>
<td><strong>Little Joe</strong></td>
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<tr>
<td><strong>C-1</strong></td>
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<tr>
<td><strong>C-5</strong></td>
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<td><img src="image27.png" alt="Diagram" /></td>
<td><img src="image28.png" alt="Diagram" /></td>
<td><img src="image29.png" alt="Diagram" /></td>
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