Apollo Lunar Module
Electrical Power System Overview
Objectives

• Describe LM Electrical System original specifications
• Describe the decision to change from fuel cells to batteries and other changes
• Describe the Electrical system
• Describe the Apollo 13 failure from the LM perspective
Lunar Module (LM) electrical system designed for:

- Low power during coast to Moon
- High loads during lunar descent
- Lower loads during lunar ascent
- Redundant power supply such that entire mission (although shortened) could be done if one system on ascent or descent stage was lost
Original Requirements

- 65 kW-hr at 4 kW max for a 35-hr lunar stay

- Designed fail-safe
  - Redundant buses, isolation equipment
  - Converters for equipment needing other than 28 V DC
  - Circuit protection by circuit breakers, fuses, electronic circuitry

- Originally designed for fuel cells
  - Three fuel cells
  - Peaking battery and battery charger
Power Source Changes

Due to complexity, development costs, time constraints, and mission profile changes, off-the-shelf battery technology was used

- LM battery charger not needed (only for CSM)
- Decreased time between lunar liftoff and docking meant lower power requirements
- Took a 45.35kg (100 lb) weight hit to LM by switching to batteries
- Later mission increased lunar stay time from 35 to 72 hrs required extra batteries
<table>
<thead>
<tr>
<th></th>
<th>LM Descent</th>
<th>LM Ascent</th>
<th>CSM Entry/Post-Landing</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Voltage (volts)</strong></td>
<td>29</td>
<td>29</td>
<td>29</td>
</tr>
<tr>
<td><strong>Capacity (amp-hrs)</strong></td>
<td>400</td>
<td>296</td>
<td>40</td>
</tr>
<tr>
<td><strong>Dimensions</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Length</strong></td>
<td>0.025m³ (1525.3 in³)</td>
<td>0.022m³ (1376.8 in³)</td>
<td>0.006m³ (373.5 in³)</td>
</tr>
<tr>
<td><strong>Width</strong></td>
<td>0.43m (16.94”)</td>
<td>0.90m (35.75”)</td>
<td>0.25m (10.15”)</td>
</tr>
<tr>
<td><strong>Height</strong></td>
<td>0.23m (9.04”)</td>
<td>0.12m (4.95”)</td>
<td>0.16m (6.4”)</td>
</tr>
<tr>
<td><strong>Weight</strong></td>
<td>60kg (132.7lbs)</td>
<td>56kg (123.7lbs)</td>
<td>10kg (22lbs)</td>
</tr>
<tr>
<td><strong>Quantity</strong></td>
<td>4 or 5</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>
Final Configuration

- Seven batteries
  - Five descent-stage @ 400 amp-hrs each
  - Two ascent-stage @ 296 amp-hrs each
- Electrical Control Assembly (ECA)
  - For control and protection of batteries
  - 2 for descent and 2 for ascent
- Redundant feeder systems
  - Get the power from the batteries to the buses
- Deadface assembly
  - Separate the descent stage from the ascent stage via Explosive Device Subsystem (which has its own separate power system)
- DC buses feed AC converters
Other Changes

AC System

- Most of the ECLSS pumps and fans changed to brushless DC motors instead of AC motors, so they ended up with oversized AC inverters

Design changes as a result of Apollo 13

- Capability of the LM to initiate power transfer to CSM
- Added circuit protection to LM buses during power transfer
- Capability to transfer power after LM staging
- Added fifth descent stage battery (Lunar Battery), 12 kW
- Any battery could be tied to any electrical bus
Battery Subsystem

• Timeline
  – Prior to docking: DC power from low-voltage taps on descent stage batteries.
  – Descent: all 7 Ascent and Descent batteries were paralleled
  – Ascent: Ascent batteries activated, Descent batteries deactivated, lines deadfaced and severed

• Loss of a single battery
  – If Descent stage, led to curtailed mission, but other battery could handle loads on the main bus
  – If Ascent stage, enough to accomplish liftoff, rendezvous, and docking.

• Lunar Battery was a spare added after Apollo 13
  – Could be connected to either bus (but not both simo).
LUNAR MODULE POWER SYSTEM

Electrical Control Assembly subsystem

Note: Functional Flow diagram, many details not included.
Electrical Control Assembly

Batteries controlled and protected by four electrical control assemblies (ECAs)

- Two Descent stage ECAs allowed high and/or low voltage onto the buses
- Two Ascent stage ECAs provided a primary and backup path from the batteries to the buses.

ECAs provided auto-trip protection

- In case of overcurrent, reverse current, or overtemp
LUNAR MODULE POWER SYSTEM

Interface Control subsystem

Descent Stage

Ascent Stage

LUT power

From LCC

RJB

ECA 1

ECA 2

DFRB

ECA 3

ECA 4

Bat. 1

Bat. 2

Bat. 3

Bat. 4

Bat. 5

Bat. 6

Inverter 1

Inverter 2

Translunar bus

CDR bus

AC bus A

AC bus B

DFRB

Transistor

Note: Functional Flow diagram, many details not included.
Junction boxes on feeder wires between batteries and electrical buses

- Disconnected, deadheaded, and isolated Descent stage from the Ascent stage prior to liftoff from the lunar surface

Deadface Relay Box (DFRB) on CDR’s side

Relay Junction Box (RJB) on the LMP side

- RJB had additional relays and electronics for the various battery controls from the automatic checkout equipment, the LM cabin, and the command module (CM).
- Also contained the relays that connected the Launch Umbilical Tower (LUT) to the LM prior to launch.
LUNAR MODULE POWER SYSTEM

DC Feeder subsystem

Note: Functional Flow diagram, many details not included
Two feeder systems consisting of redundant power wires to transfer power from the batteries through the ECA to the DC buses.

– For the Descent stage, both high and low voltage distribution feeder connections had automatic overcurrent protection in the ECA
– For the Ascent stage, autotrip for backup feeder was removed for weight savings
DC electrical power was distributed via the LMP and CDR buses
  – So named because of the switches and circuit breakers on that crewmember’s side of the LM
  – DC power went to other subsystems directly from these buses
  – DC power was also distributed to the AC inverters
During noncritical phases of normal operation
- 30-amp cbs were closed to distribute unbalanced loads between buses so that the batteries discharged evenly.
- Between docking and descent, CSM supplied power to the LM at the CDR bus using the CSM Translunar Negative Bus

During critical phases of normal operation
- Descent and Ascent stage batteries paralleled during descent operations
- CDR and LMP buses were isolated
Redundant loads were put on separate buses
  – Examples: two AC inverters, the system A and B reaction-control quad heaters with control circuitry, the two sets of UHF and VHF transceivers, primary guidance (PGNS), abort guidance (AGS)

Nonredundant critical loads powered by both buses with diode protection
  – Example: battery controls

Nonredundant noncritical loads powered by a single bus
  – Examples: sensors, some lights
LUNAR MODULE POWER SYSTEM

AC subsystem

From LCC To LM subsystems

Descent Stage

Ascent Stage

LMP bus

LUT

power

30 A

LMP bus

30 A

Bat. 1

HV

LV

ECA 1 RJB

100 A

To LM subsystems

30 A

AC bus A

From GSE
crosstie

balance

loads

30 A

100 A

Bat. 2

HV

tie

Inverter 2

2

5 A

2

5 A

AC bus B

Inverter 1

5 A

5 A

1

Off

To LM subsystems

Translunar bus

On

Off/reset

normal

On

Off/reset

backup

5 A

5 A

Note: Functional flow diagram, many details not included.
AC Subsystem

AC power provided by either of two identical, redundant inverters, one from each main bus

- Inverter 2 energized when the LM subsystems first activated and connected to the AC buses.
- Inverter 1 functioned as a backup during the mission, except that it was the operating inverter during LM descent and ascent engine burns.

The AC bus A also received power from the GSE prior to launch
LUNAR MODULE POWER SYSTEM

Outside power sources

Note: Functional Flow diagram, many details not included.
Outside Power Sources

Prelaunch
  – From LUT (DC) and GSE (AC)

Translunar coast
  – Used between docking and descent operations
  – Translunar Negative Bus, which transferred DC power from the CSM to the LM via umbilicals for various heaters and lights during the translunar coast
## Timeline

<table>
<thead>
<tr>
<th>Time</th>
<th>LM power supply</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prior to T-30 min</td>
<td>GSE</td>
</tr>
<tr>
<td>T-30 to transposition and docking</td>
<td>LM Descent batteries</td>
</tr>
<tr>
<td>Translunar coast</td>
<td>CSM via the Translunar Bus</td>
</tr>
<tr>
<td>Lunar orbit</td>
<td>LM Descent batteries</td>
</tr>
<tr>
<td>Lunar descent</td>
<td>LM Ascent and Descent batteries</td>
</tr>
<tr>
<td>Lunar surface stay</td>
<td>LM Descent batteries</td>
</tr>
<tr>
<td>Lunar ascent</td>
<td>LM Ascent batteries</td>
</tr>
</tbody>
</table>
Apollo 13 (as seen from the LM)

Cryo tank explosion on Service Module led to impending loss of all power in the CSM
  – Only remaining power source in CSM were Entry/Post-Landing Batteries, and they were partly discharged

Used Translunar Negative Bus to power CSM from LM
  – Normally the CSM powered the LM during the translunar coast via drag-through umbilicals
  – LM used as a “lifeboat” to power critical equipment on CSM and to recharge the CSM Entry batteries
  – LM not designed to be brought back to Earth
  – Severe powerdowns on both LM and CSM were required (at some points, less than 20% of normal power levels)
Apollo 13 LM Batteries

LM batteries provided power to itself and the CSM for 83 hrs
- Far outside of qual/testing limits
- Provided 350W, normally 1000W
- Continuous zero-G
- Continuous cold temperatures (37° F)
- At jettison, the LM had less than 5 hrs of power left

Extra “Lunar Battery” added afterwards due to longer lunar stays
- Could also be used as extra power in emergency scenario
- Coincidentally already planned for Apollo 15-up
LUNAR MODULE POWER SYSTEM

Apollo 13

Descent Stage

Ascent Stage

LMP bus

LUT

power

From LCC

To LM

sub-systems

LUNAR MODULE POWER SYSTEM

Apollo 13

LMP bus

Bat. 1

HV

LV

ECA 1

RJB

power

From GSE

To LM

sub-systems

30 A

Bat. 2

HV

tie

100 A

ECA 3

ECA 4

Inverter

2

5 A

5 A

crosstie

balance loads

30 A

100A

On

Off/reset

normal

On

Off/reset

backup

Off/reset

backup

2

1

AC bus A

Lunar bat.

Bat. 3

HV

ECA 2

RJB

power

From CSM

Translunar bus

Note: Functional Flow diagram, many details not included
Apollo Experience Reports
  Battery Subsystem, NASA Technical Note TN D-6976, 09/72
  Lunar Module Electrical Power Subsystem, NASA Technical Note TN D-6977, 09/72

Apollo Operations Handbook
  Lunar Module, LM 10 and Subsequent, Volume 1: Subsystem Data,
    Grumman document LMA790-3-LM10, 04/71

Lunar Excursion Module Familiarization Manual
  Grumman document LMA790-1, 10/65

Apollo Mission Familiarization for Constellation Personnel
  Apollo Wiki