Presentation Outline

• Features of ESMO
• EPS Overview
• Power Budget
• Solar Array
• Secondary Batteries
• Power Control Unit
• Power Distribution Unit
Features of ESMO

- **Dimensions**: 700 x 700 x 800 mm
- **Mass**: 150 kg
- **Lunar Orbit**: 100 km Polar Orbit
- **Structure**: Aluminium Honeycomb
- **Payload**: Narrow Angle Camera (NAC)
- **Electric Propulsion**: T5 Ion Engine
- **Uplink**: 2275 MHz, 2 kbps
- **Downlink**: 2275, 2.5 kbps
- **Antennas**: S-band Omnidirectional x 2
- **Transmit Power**: 5W
- **Attitude Control**: 3-Axis Stabilized
- **Thermal Control**: Passive
- **Mission Lifetime**: 18 months
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EPS Overview

- Solar Array
  - Ultra-Triple Junction (UTJ) GaAs Cells

- Secondary Batteries
  - Li-Ion

- Power Control Unit
  - MPPT

- Power Distribution Unit
  - Distributive Load Regulation
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## Power Budget

### Subsystem Power Requirement

<table>
<thead>
<tr>
<th>Subsystem/Component</th>
<th>Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AOCS</td>
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<tr>
<td>Star Tracker</td>
<td>4.0</td>
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<tr>
<td>Gyroscope</td>
<td>1.0</td>
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<tr>
<td>Reaction Wheels</td>
<td>12.0</td>
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<tr>
<td>Communications</td>
<td></td>
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<tr>
<td>Receiver (Rx) and RF Distribution Unit</td>
<td>6.0</td>
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<tr>
<td>Transmitter (Tx)</td>
<td>25.0</td>
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<tr>
<td>On-Board Data Handling</td>
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<td>On-Board Computer</td>
<td>22.0</td>
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<tr>
<td>Payload</td>
<td></td>
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<tr>
<td>Narrow Angle Camera</td>
<td>10.0</td>
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<td>Propulsion</td>
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<tr>
<td>T5 Ion Engine PPU – HIGH</td>
<td>600.0</td>
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<tr>
<td>T5 Ion Engine PPU – LOW</td>
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<td>Hollow Cathode Thruster (HCT) PPU</td>
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<td>Power</td>
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<td>Power Control Unit (PCU)</td>
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<td>Power Distribution Unit (PDU)</td>
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<tr>
<td>Battery Heaters</td>
<td>60.0</td>
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<tr>
<td>Mechanism</td>
<td></td>
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<tr>
<td>Solar Array Drive Mechanism (SADM)</td>
<td>9.0</td>
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</tbody>
</table>
Power Budget

- **Power Requirement for Lunar Orbital Injection**
  - Maximum Power Demand = 675 W
  - Sizing Case for Solar Array Design
Power Budget

- **Power Requirement for Initial LEOP**
  - Capacity Requirement = 265 Whr
  - Sizing Case for Secondary Batteries Design

<table>
<thead>
<tr>
<th>Subphase</th>
<th>Power (W)</th>
<th>Duration (hrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Separation and AOS</td>
<td>28.0</td>
<td>5.00</td>
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<tr>
<td>Check-Up</td>
<td>53.0</td>
<td>1.00</td>
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<tr>
<td>De-Spin</td>
<td>54.0</td>
<td>0.50</td>
</tr>
<tr>
<td>Sun Acquisition</td>
<td>47.0</td>
<td>0.50</td>
</tr>
<tr>
<td>Solar Array Deployment</td>
<td>63.0</td>
<td>0.25</td>
</tr>
</tbody>
</table>
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• Features of ESMO
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• **Solar Array**
• Secondary Batteries
• Power Control Unit
• Power Distribution Unit
Solar Array

• UTJ GaAs solar cells
  – Manufactured by Boeing Spectrolab

• Efficiency
  – 28.3% BOL
  – 24.3% EOL

UTJ GaAs Cell
**Solar Array**

- **Maximum array size**
  - 800mm x 600mm
- **Array characteristics**
  - 28 V, 720 W, 25.7 A
- **Array sizing**
  - Cell size: 24 cm$^2$
    - 5.5cm x 4.4cm
  - 12 cells per strings
  - 11 strings per panels

765 mm x 567 mm Rigid Solar Panel
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Secondary Batteries

- **Li-Ion**
  - High Energy Density (twice as much as NiH₂)
  - Light Weight
  - No Memory Effect

<table>
<thead>
<tr>
<th>Cell Characteristic</th>
<th>Value</th>
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<tr>
<td>Capacity, Ahr</td>
<td>5.80</td>
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<tr>
<td>Capacity, Whr</td>
<td>20.00</td>
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<tr>
<td>Voltage, V</td>
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<tr>
<td>Specific Energy, W/kg</td>
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<tr>
<td>Weight, kg</td>
<td>0.15</td>
</tr>
<tr>
<td>Height, mm</td>
<td>65.00</td>
</tr>
<tr>
<td>Depth, mm</td>
<td>15.00</td>
</tr>
<tr>
<td>Width, mm</td>
<td>65.00</td>
</tr>
</tbody>
</table>
Secondary Batteries

• **Capacity Requirement**
  - 265 Whr
  - Considering DOD of 50% and an efficiency of 90% the required capacity is **589 Whr**
  - 21 Ahr (at 28V)

• **Configuration**
  - 8 cells in series = 28V
  - 4 strings in parallel = 23.2 Ahr
  - 1 string of 8 cells for redundancy
  - Final configuration of **8s5p**
Power Control Unit

- PCU Overview
  - Maximum Power Point Tracker Unit (MPPTU)
  - Battery Monitor (BM)
  - Power Management Unit (PMU)
Power Control Unit - Basics

- The MPPTU functionality is to force the solar array output to operate at the Maximum Power Point (MPP). To do so, two major parts are needed:
  - A DC-DC converter
  - A MPPT algorithm
Power Control Unit - DC-DC Converters

• Series Connected Boost Converter
  – Fault Tolerant:
    • Risks from serial configuration avoided by this type of converter and by choosing $V_{SA} \sim B_{batt}$
    – No redundancy required using this configuration considering its inherent fault tolerance:
      • Mass and costs saving
      – Great efficiency of around 95-98%
Power Control Unit - MPPT Algorithm

• Amongst every MPPT algorithms checked, two were considered:
  – Perturb and Observe
    • Easiest to implement
    • 2 sensed parameters (Current and voltage)
    • Need a two-stage algorithm to get a good convergence speed and a good efficiency
  – Incremental Conductance
    • Also easy to implement
    • 2 sensed parameters (Current and voltage)
    • Also need a two-stage algorithm to get a good convergence speed but give better efficiency than P&O
Thus, the Incremental Conductance algorithm has been chosen for its better accuracy over the Perturb and Observe method.
The functionality of the BM is to monitor the state of health of the secondary battery. To do so, two major parts are required:

- **Current Sensor**
  - Commercial of the Shelf Closed-Loop Hall Effect Current Sensor to keep costs low.
  - The Tamura S22P025S05 represent an attractive and affordable baseline solution.

- **Voltage Sensor**
  - Any voltage sensing method can be used.
Considering that the PMU accomplish the same functions as a Telecommand and Telemetry module (TC/TM), and considering the inherent complexity of this unit, a COTS solution have been adopted.

After considering several available solution, the Alcatel Space TMTC-S3 module has been chosen.
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Power Distribution Unit

- Current Limiter
Power Distribution Unit

- Current Limiter:
  - Higher flexibility
  - Ease of testing
  - Rearming capabilities

- 2 Types:
  - Fold-Back Current Limiter (FCL):
    - For non-switchable essential loads
  - Latching Current Limiter (LCL):
    - For other switchable loads
Power Distribution Unit

• Considering that these device can be quite complex to design, a COTS solution have also been adopted.

• After considering several available solution, the Alcatel Space LCL&Heaters-P2 module has been chosen.