Analysis of Advanced Modular Power Systems (AMPS) for Deep Space Exploration Presented to Space Power Workshop Los Angeles, CA

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What are Advanced Modular Power Systems? AMPS

Needs, Goals & Objectives:

Need:
- To reduce prohibitive Design, Development, Test & Engineering (DDT&E) costs and logistical costs of electrical power systems across NASA vehicles

Goal:
- Develop a set of standard interfaces (electrical, mechanical, data, thermal) to guide power system development across multiple exploration vehicles
- Reduce DDT&E costs, recurring costs, spare parts, documentation and training
- Enhance reliability and minimize logistics footprint for long-duration missions

.

AMPS for Multi-Vehicle Missions

Future missions beyond Low Earth Orbit have long distances and long duration that drive vehicle scale and complexity

- **Missions will be composed of multiple vehicles.**
- **Some vehicles composed of multiple segments.**

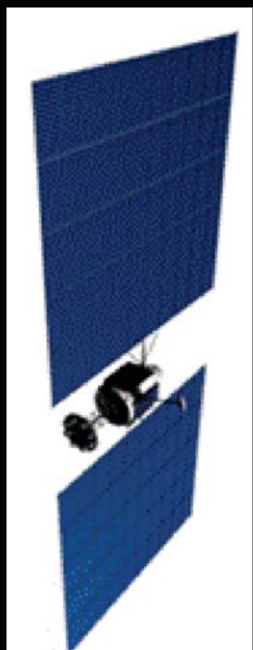
Modular Approach:
Build power architectures composed of common modular blocks:

- **Shared Development Costs (non-recurring)**
- **Shared Integration processes (recurring)**

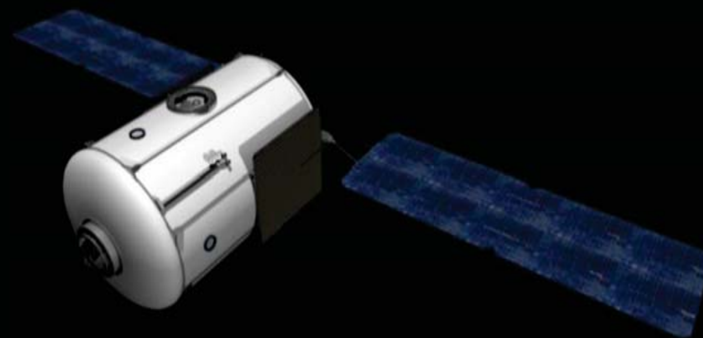
Improved Supportability:

- **Reduced Logistics with Common Spares**
- **Common Maintenance Processes**
- **Common Diagnostics**
- ***Opportunity:* Salvage power hardware from spent stages to exploit as Spares or other mission applications.**

Mission Vehicles



Solar Electric Propulsion Stage



Deep Space Habitats

Advanced Cryo Propulsion Stage

Multi-Mission Space Exploration Vehicle (MMSEV)

Advanced Landers

Levels of Modularity

Modularity is already used on International Space Station (ISS)

- ISS Modularity stops at the Assembly Level.
- ISS depends on frequent Space Shuttle or other logistic vehicle flights.
- Scheduled logistics for Exploration beyond Earth Orbit is not an option.

ISS power system is maintained with "Assembly Level" Orbital Replacement Units (ORU)

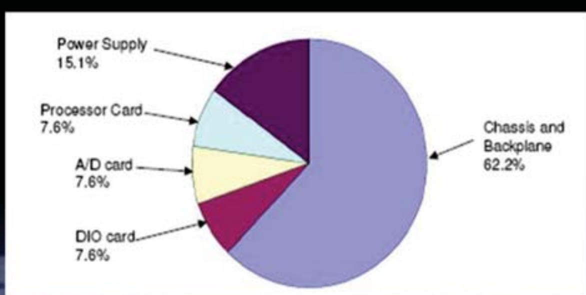
AMPS seeks to drive modularity down to lower levels of assembly

Levels of Assembly	Example
System	ISS Power Channel
Subsystem	ISS PV Module
Assembly (ORU)	Battery Charge Discharge Unit Main Bus Switching Unit Remote Power Controller Module
Sub Assembly Circuit Cards	Remote Power Controller Card
Component	DC/DC Converter
EEE Parts	

Levels of Modularity

ORUs are Operationally efficient,
ORUs are inefficient in terms of logistics mass

Remote Power Controller Module [RPCM] is a typical ISS ORU



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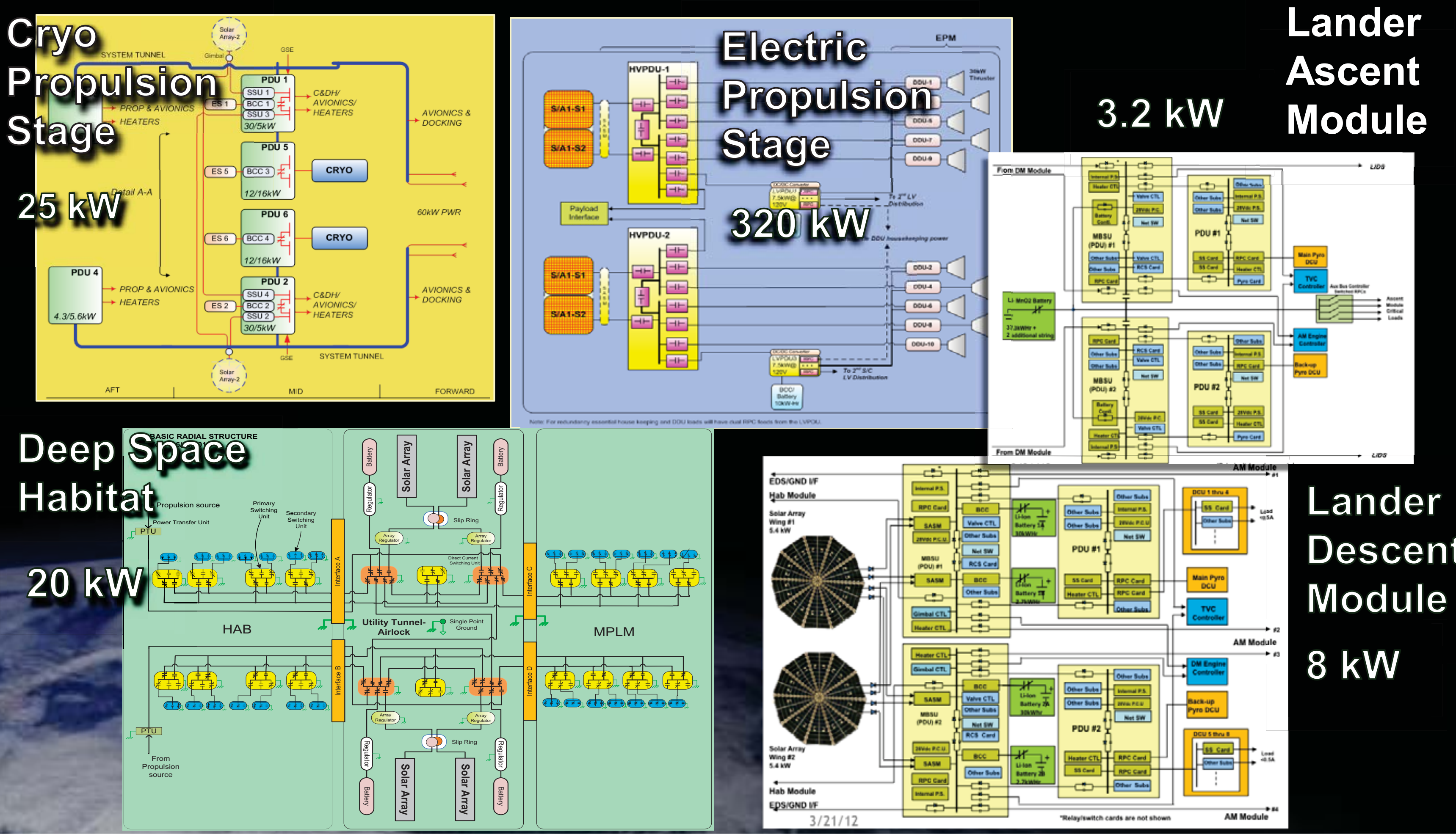
Sparing modules at the subassembly level provides a dramatic reduction in logistics mass.
Electronic Subassemblies are rarely over 15% of ORU mass.

Power Architecture Commonality

Challenge: Define common modular power elements applicable to multiple vehicles and perform a cost analysis.



Cost Analysis Approach

The 2012 study focused on the costs benefits of using a common power modules across multiple vehicles.

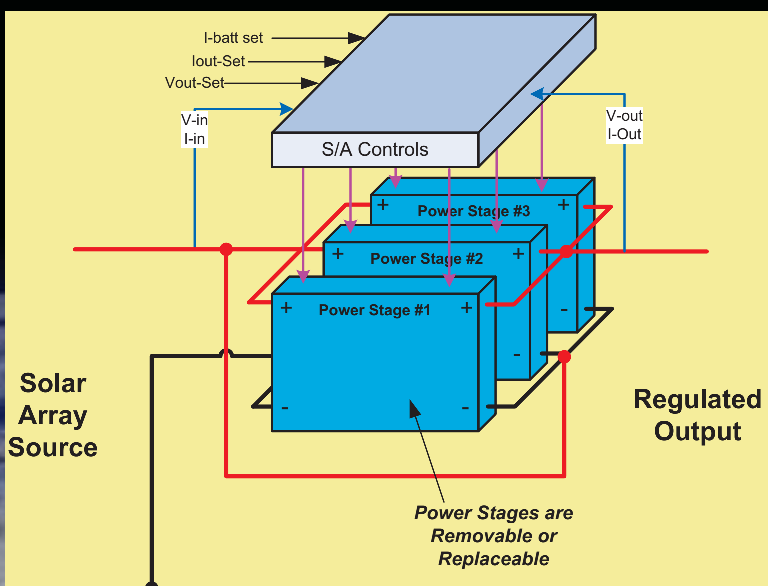
- **DDT&E costs, recurring costs, production spares, documentation and training**
- **Develop cost model inputs for PRICE H COTS estimating tool.**
  - Define vehicle and mission assumptions
  - Establish a modular approach and assembly hierarchy for energy storage, power generation and power distribution
  - Define appropriately sized modules applicable to all study vehicles
  - Estimate chassis, cable mass at each level of assembly
  - Identify developmental and production spares
  - Estimate complexity factors
- **This cost study did not address the Space Logistics benefit of exploiting common modular blocks.**

Architecture Trade Study Summary

Power Management & Distribution

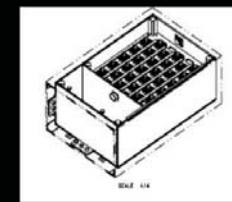
Established 120V distribution voltage

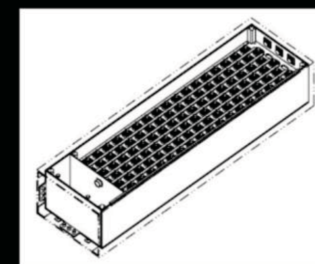
- Power distribution ORUs include chassis + converter + switch modules
- 4 Chassis types defined
  - 2 Converter Modules (500W & 2500W)
  - 5 Switching Module Types (2 Solid State, 3 Hybrids)



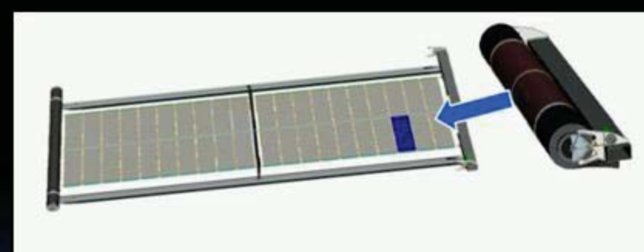
Batteries

- Batteries contain 33 Cells
- Two battery cell sizes
  - 27 amp*hr
  - 150 amp*hr
- Two Charge/Discharge Modules
  - 750 Watts
  - 1000 Watts





Roll Out Solar Arrays



ROSA array used as modular baseline
Length tailored to power needs

- SEP Solar Arrays @ 300 volts
- All other Solar Arrays @ 120 Volts

Study Cost Analysis Findings

- Cost Analysis evaluated non-modular and modular EPS Cost
- Non-Recurring Development Cost and Recurring Hardware Cost

Study Vehicle EPS	Development Delta Cost	Flight Hardware Delta Cost	Combined (weighted) Delta Cost
Deep Space Habitat	-31%	-11%	-27%
Solar Electric Propulsion	-31%	-1%	-17%
MMSEV Near Earth Object	-61%	-17%	-55%
MMSEV Lunar Rover	-57%	-43%	-53%
Cryo Propulsion Stage	-66%	3%	-52%
Lunar Lander	-63%	-21%	-54%

- **Design Legacy** assumed in both non-modular and modular cases.
- **Deep Space Habitat** assumed to be the "first vehicle" (No Legacy)
  - Other study vehicles inherited legacy designs
  - For first system (No Legacy) the modular approach still reduces costs.
- **Overall: Modular Power approach provides a 36% Cost Reduction when applied to the fleet of vehicles.**

Cost and Mass Analysis

Cost and Mass Delta (%) by Power Subsystems

Subsystem	PMAD	Battery	Solar Array	Power I&T
Cost Delta	-50%	-57%	-3%	-12%
Mass Delta	+1.5%	+1.0%	-1.1%	---

Cost Delta: Varied by System

- Clear cost benefit for Energy Storage and Power Distribution
- Solar Arrays are innately modular

Overall Mass: only 1.3% penalty .

- Increase due primarily to encapsulation mass at lower levels of assembly for Battery and PMAD hardware.
- Solar Array mass improved slightly.

Space Logistics and Operational Impact

Potential Impact: Under Constellation Lunar Supportability the Component level Electronics Assembly Repair Life Cycle Cost Impact Study examined the impact of sparing avionics and power hardware at assembly levels below the typical ORU over a 10 year period.

- Logistics spares mass reduced by 82.4%
- Logistics spares cost reduction by 67%
- Operational Penalty: Crew time and training was a significant penalty.

Related Supportability studies indicated that ~80% of the maintenance effort involved diagnostics, de-integration, re-integration, and checkout.

Recommended Solution: Smart Modularization

- Sub-assembly encapsulation simplifies physical integration process
- Deeper level built-in diagnostics and self tests
- Embedded Health monitoring and prognostics
- Smart "plug and play" interfaces to simplify electrical integration

Summary Chart

- **AMPS study has shown that there is a 36% cost advantage of developing modular hardware that can be used across platforms**
- **Mass impact of using modular systems is small for initial deployment**
- **Favorable mass and cost numbers expected when logistics of long missions in taken into account**

Further work:

- Develop and standardize modular mechanical, thermal, electrical and data interfaces
- Embed refined Diagnostic and Prognostic capability
- Embed intelligent “plug and play” capabilities to simplify integration of modular hardware.