SPACE STATION FREEDOM ELECTRIC POWER SYSTEM EVOLUTION ANALYSIS STATUS

Presented to
Space Station Evolution Symposium
August 8, 1991

Michael J. Zernic
LeRC/Power System Operations and Planning Branch

SPACE STATION FREEDOM ELECTRIC POWER SYSTEM EVOLUTION ANALYSIS STATUS

This presentation has been compiled as a status of the Electric Power System (EPS) Evolution Analysis for Space Station Freedom (SSF) as directed by Headquarters Code MT, stated in Task Order No. 7, NASA Contract NAS3-25711, and performed by the Rocketdyne Division of Rockwell International.

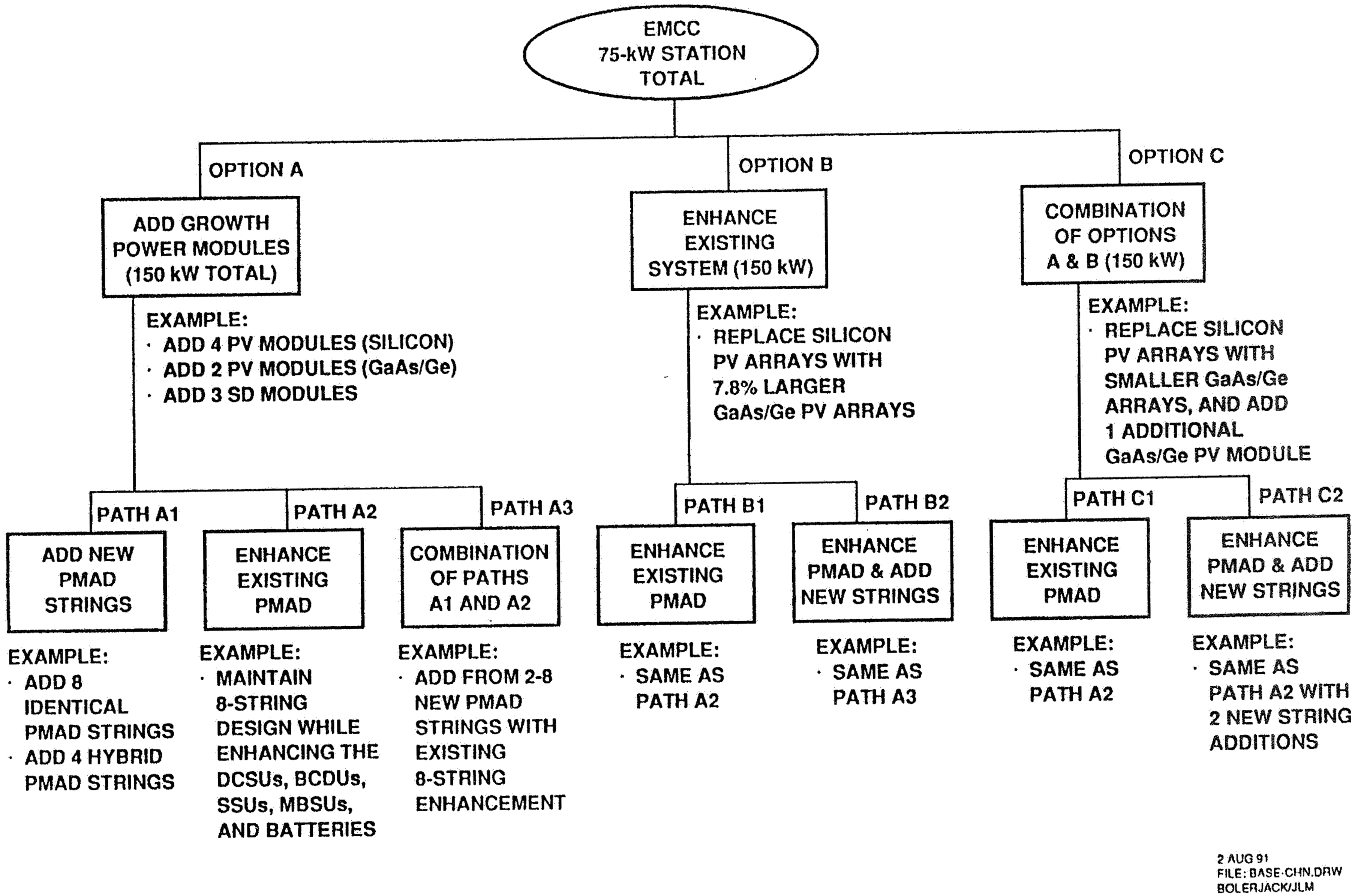
This presentation will examine the ability of the SSF baselined EPS to transition to operate at a greater system capacity beyond the SSF Permanent Manned Capability (PMC) milestone. Specifically, a status of a current analysis will be discussed concerning additions (new or duplications), modification, change-out, or combination thereof of baseline EPS hardware/software needed to accomplish the power generation, distribution, operation, and utilization needed to meet evolving SSF mission objectives. This discussion will result in several EPS architectural options that facilitate the addition or substitution of new technologies.

Rocketdyne acknowledgements:

Scott Boller
Burl Bolerjack
Dan Saine

Reference: EPS Evolution Analysis Trade Study Final Report, December 21, 1990
(Study based on SSF pre-restructured program and emphasized solar dynamic additions)

Potential Growth/Evolution Configurations



Configuration (PMC+). After the station has reached the eight man crew capability (EMCC), the addition of more power modules (growth) to provide 75 kW of additional power, or the enhancement (evolution) of the existing (baseline) Electric Power System (EPS) design to provide the needed 7 kW of power, will bring the total station power to 150 kW.

This study identified three possible options by which SSF's power generation capability could be increased. The first option, labled Option A, adds growth power modules to be attached outboard of the existing Photovoltaic (PV) Modules. These power modules could consist of four more identical silicon array PV Modules, two gallium arsenide on germanium (GaAs/Ge) array PV Modules, or three Solar Dynamic (SD) Modules. The second option, Option B, would provide the additional 75 kW of power by enhancing the existing EPS. An example of this growth by evolution is replacing the existing silicon array PV Modules with slightly larger (7.8%) GaAs/Ge array PV Modules. The third option, Option C, would accomplish the generation of an additional 75 kW through a combination of both growth and evolution (Options A and B). One example of this option is to replace the silicon array PV Modules with smaller GaAs/Ge array modules along with the addition of another GaAsGe module. The number of PV Modules would then total five, each having two independent distribution strings.

For each power generation option, this study identified at least two Power Management and Distribution (PMAD) paths by which the growth/evolution power could be distributed.

For Option A, three unique PMAD paths have been identified. Path A1 would simply add new PMAD strings. Examples of this path include adding eight more baseline design PMAD strings to be used with the four silicon array PV Modules, adding four hybrid PMAD strings to distribute the power from the two GaAs/Ge array modules, or even three hybrid strings for the three SD Modules. These growth PMAD strings would remain independent from the existing PMAD system. Path A2 would simply enhance the existing PMAD system with new and allow the growth power cabling to "plug into" the hybrid PMAD system at the existing outboard PV Modules. Path A3 would modify the existing PMAD system to accommodate a portion of the growth power, and add anywhere from two to eight new PMAD strings to distribute the remaining power.

For Option B, two PMAD paths have been identified. Path B1 would enhance the existing PMAD system to accommodate the higher output of the GaAs/Ge array modules. ORUs to be replaced at their mean replacement interval (MRI) would include the Dc Switching Units (DCSUs), the Battery Charge/Discharge Units (BCDUs), the Sequential Shunt Units (SSUs), the Main Bus Switching Units (MBSUs), and the Batteries. This path is similar to Path A2. Path B2 is the same as Path A3.

For Option C, two PMAD paths have been identified. Path C1 is similar to Path A2, and Path C2 is also similar to Path A2, with the addition of two new PMAD strings.

Growth/Evolution Path Comparisons

Advantages	A1	A2	A3	B1	B2	C1	C2
Requires minimum "down time" of existing EPS	X						
Maintains "independent string" PMAD philosophy	X		X		X		X
Requires minimum EVA hours for installation and checkout				X			
Requires minimum hooks and scars to baseline design				X			
Requires the development of a minimum number of new ORUs	X						
Requires the minimum launch mass				X			
Utilizes existing PMAD ORU mean replacement intervals for upgrading		X	X	X	X	X	X

2 August, 1991
FILE: BASE-CAP.DOC
BOLERJACK/JLM

Growth/Evolution Path Comparisons (Continued)

Disadvantages	A1	A2	A3	B1	B2	C1	C2
Requires maximum "down-time" of existing EPS							X
Violates "independent string" PMAD philosophy		X		X		X	
Requires maximum EVA hours for installation and checkout	X						
Requires maximum hooks and scars to baseline design	X						
Requires the development of a maximum number of new ORUs						X	
Requires the maximum launch mass	X						
Requires growth ORUs be launched along with existing ORUs	X	X	X	X	X	X	X

2 August, 1991
FILE: BASE-CAP.DOC
BOLERJACK/JLM

are shown on this table. A brief description of the rationale for each selection follows.

The advantage of Path A1, requiring the *minimum "down time" of existing* EPS, is the result of adding growth PMAD strings, and not having to disrupt the existing system to do so, with the exception of Alpha joint-related operations.

Those paths which provide one PMAD string per array, or SD Module, maintain the "independent string" philosophy, and consist of Paths A1, A3, B2, and C2.

Path B1 requires both the minimum extravehicular activity (EVA) hours for installation, assembly, and checkout of the new hybrid PMAD ORUs, and the minimum number of hooks and scars to accommodate the addition of 75 kW to the station. The rationale behind this selection is that no new power modules will be added in Option B, and no new PMAD strings will be added in Path B1.

The *minimum number* of new ORUs to be developed is associated with Path A1 as a result of the possibility that all growth EPS hardware could be "off-the-shelf."

Path B1 also requires the least amount of hardware to be launched specifically for the growth/evolution of the EPS. This is the result of making use of the natural MRIs for the existing hardware.

Those paths which utilize the existing PMAD's natural MRIs as opportunities for replacement with enhanced ORUs include: A2, A3, B1, B2, C1, and C2.

Path C2 has the *disadvantage of requiring* the maximum "down time" as a result of both upgrading the existing PMAD system and adding new PmAD strings.

Those paths which violate the "independent string" philosophy include A2, B1, and C1 due to the fact that additional power is being introduced into the EPS without providing additional channels for the power to be distributed.

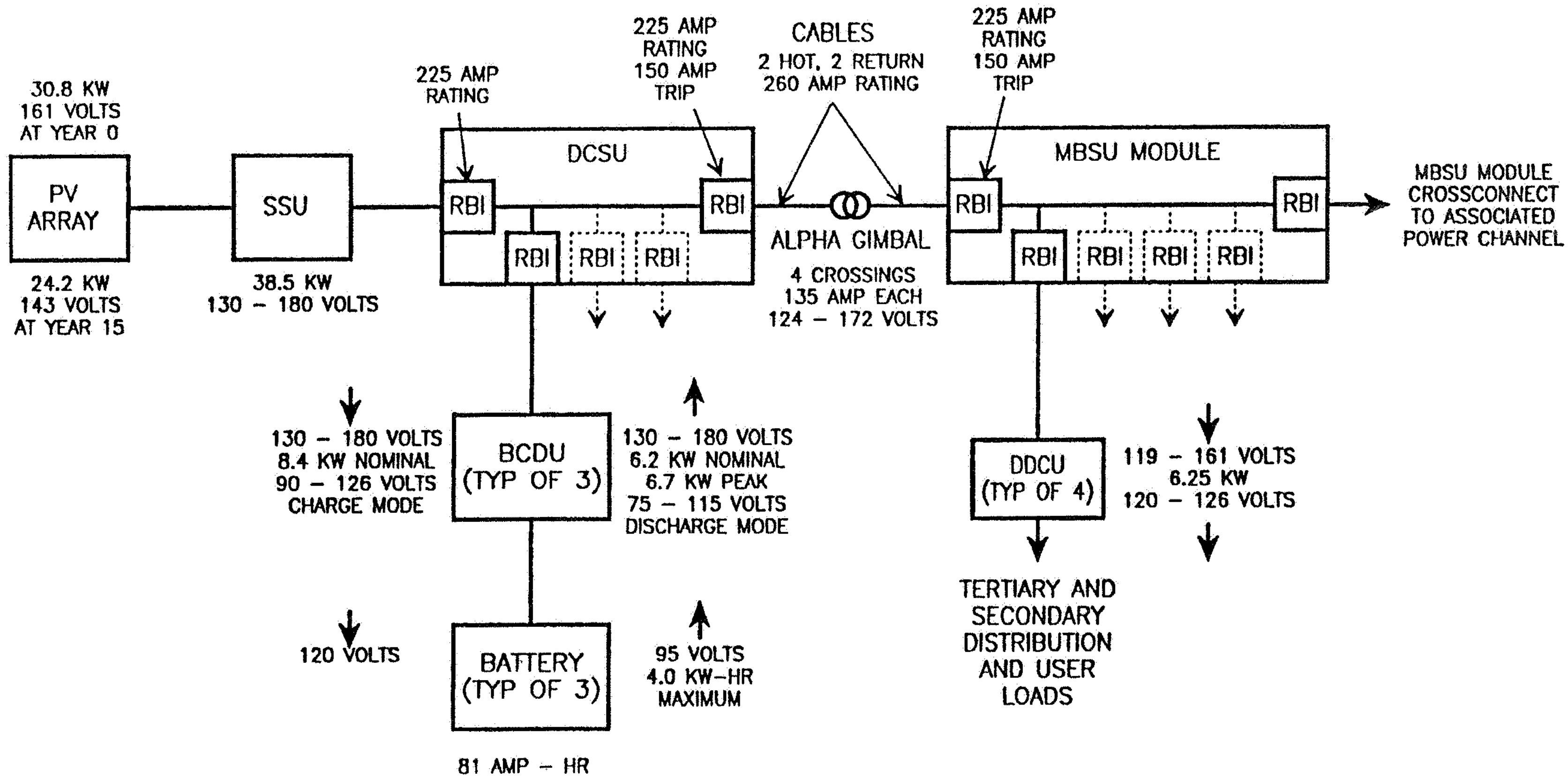
Path A1 would require the most of both EVA hours and hooks and scars, since the entire existing EPS could be duplicated.

The maximum number of new ORUs to be developed would be required by Path C1 where, not only would all of the new ORUs for Path A2 be needed, but also additional ORUs to accommodate growth power modules such as SD.

The maximum launch mass would most likely be realized by Path A1 where an entire EPS could be added to the existing system.

All paths would require growth ORUs to be launched along with existing ORUs if growth ORUs include those associated with SD Modules.

SSF Baseline Power Channel
Typical of Eight at PMC+



1 August, 1991
FILE: BASE-CAP.DOC
BOLERJACK/JLM

Space Station Freedom (SSF) Electric Power System (EPS) function is overall power generation, control, storage, and distribution to the loads. SSF will go through a number of distinct configurations during its growth to full baseline capability. This presentation is oriented Permanently Manned Capability Plus (PMC+), in which there are eight power channels with a full complement of batteries. The EPS Orbital ment Units (ORUs) descriptions are as follows:

Photovoltaic Array - Each power channel contains one wing, made up of two solar array blankets, each blanket containing 82 panels with 200 silicon (Si) solar cells per panel. The panels are wired to provide 82 strings of 400 cells each per wing. These strings provide the power input to the SSU.

Sequential Shunt Unit (SSU) - Each power channel contains one SSU, which functions to control the PV array output. It accepts the 82 strings of power from the wing and, based on a voltage setpoint from the control system, either connects strings in parallel to the output bus or shunts them in order to provide the required power to the DCSU bus.

DC Switching Unit (DCSU) - This ORU contains the DC switchgear to control power flow to and from the energy storage system and to the main bus switching unit, through the Alpha Gimbal. It provides the fault clearing and ORU isolation capability for the primary power distribution system.

Battery Charge/Discharge Unit (BCDU) - The energy storage system is made up of three independent BCDUs, each with an associated battery. The BCDU controls the flow of power into the battery during insolation, and controls the power flow from the battery during eclipse, to maintain the DCSU bus voltage at a setpoint received from the control system.

Battery - The battery is made up of two battery ORUs, each containing 38 Nickel Hydrogen cells. These cells are connected in series to form an 81 ampere-hour battery with an average voltage of 95 volts.

Alpha Gimbal - This ORU provides for primary power flow across the rotating joint. It is made up of roll rings each of which provide one power crossing. Each power channel requires four crossings, two hot and two return, for a total of 16 power crossings per Alpha Gimbal.

Main Bus Switching Unit (MBSU) - This ORU is made up of two MBSU modules, with each power channel feeding one module. It contains the DC switchgear to control power flow to the secondary DC to DC power converters and provides fault clearing and ORU isolation capability. It also provides cross-connect capability between two associated MBSU modules and to other MBSUs.

to DC Conversion Unit (DDCU) - This ORU converts the primary distribution power to secondary distribution regulated power for the users. these units are fed from each MBSU module.

Potential for Growth

- The baseline power channel (DCSU to MBSU) is physically capable of distributing 18.75 kW (200% baseline) to the users (150 kW total)
  - Limiting component is DCSU output and MBSU RBIs fault current interrupt capability (480A)
  - Present RBIs cannot interrupt 200% baseline fault current
- Alternatives
  - Replace baseline RBIs with enhanced RBIs capable of limiting/interrupting growth fault current
  - Duplicate each power channel
    - Provide additional RBIs of existing type in DCSU (1) and MBSU (2); add four Alpha Gimbal crossings (16 total); and add additional cables (2 hot, 2 return) per channel
- The SSUs, BCDUs, and DCSU input RBI require redesign to handle the increased source power
- Growth in user power may require replacing MBSUs with units containing additional RBIs for growth DDCUs in high-power usage locations.

2 August, 1991
FILE: BASE-CAP.DOC
BOLERJACK/JLM

sent RBI design is capable of interrupting 480 Amp, baseline fault current. Increasing the source to 200% baseline will result in a onal increase in potential fault current.

eral alternatives exist for increasing the power channel distribution capability.

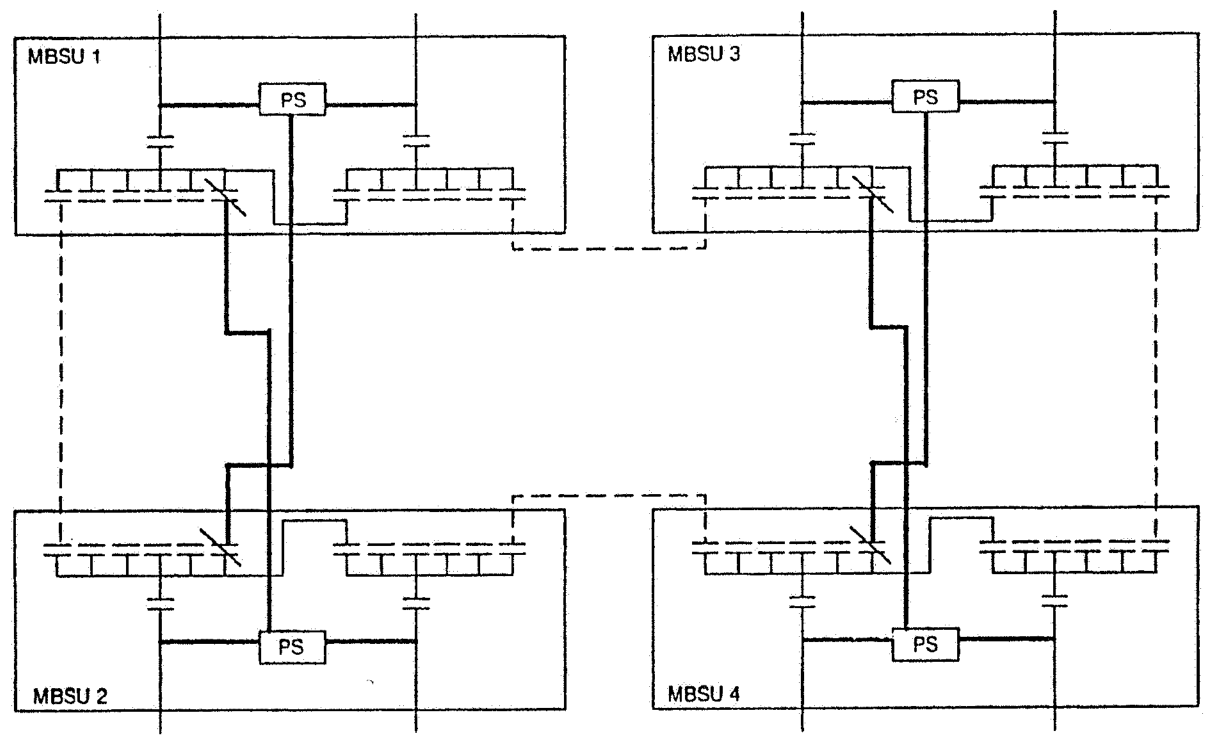
New RBIs can be developed to handle (limit/interrupt) the increased fault current. This would require replacing the SSF DCSUs and MBSUs with units containing the enhanced RBIs.

Another option, if growth is in total channel power and not in number of channels, is to duplicate the baseline distribution channel. Again the DCSUs and MBSUs would be replaced, this time with units containing additional baseline RBIs. This would require additional cables from DCSU to Alpha Gimbal to MBSU, and an additional four Alpha Gimbal power crossings per channel. If growth is number of power channels (two additional wings , for ten total) this would be a total duplication of two baseline power channels. The Alpha Gimbal still be required to provide eight additional crossings and a location would need to be established for the additional MBSU.

either alternative, the SSUs, BCDUs, and DCSU input RBI would have to be redesigned and replaced with units capable of handling 200% : power.

hough the baseline DDCU complement is capable of handling a total of 162.5 KW, this power may not be available in locations where its One option is to replace the MBSUs with units containing additional RBIs for growth DDCUs in locations where the additional power is l.

Potential for Growth



DDCU GROWTH CAPABILITY

31 July, 1991
FILE: BASE-CAP.DOC
BOLERJACK/JLM

. This RBI is closed only when power has been lost to one module and it is desired to power its loads from the associated power channel. ıed lines show cross-tie capability between MBSUs and serve a similar purpose, in that an entire MBSU can be repowered if desired. These o will never be closed between energized buses (paralleling power channels). The dark power lines, connecting an MBSU power supply normally closed RBI in the opposite MBSU represent the control power feed for each MBSU (Port feeds control power to Starboard and Starboard to Port). This leaves four feeder RBIs per MBSU module (32 total) for DDCU power feeds. The baseline EPS provides 26 (inboard the Alpha Gimbals) representing total user power capability of 162.5 KW. Two NSTS (shuttle) power converter units are also from the MBSU RBIs, leaving 4 spare RBIs for growth DDCUs (25 KW).

SSF Source Growth

- Growth in array source power capability to 200% baseline is not feasible using baseline silicon solar cells (14% eff.) due to weight, volume, and resupply constraints
  - An alternative is gallium arsenide on germanium (Ga As/Ge) cells (25% eff.), presently in limited development
    - Preliminary study indicates 206% baseline power with a 7.8% increase in wing area
  - Add Solar Dynamic Power Modules
- Growth in source energy storage capability to 200% baseline is not feasible using the baseline nickel hydrogen batteries (NHB) due to weight, volume, and cooling requirements
  - An alternative is the sodium sulfur battery (SSB) technology
    - SSB has a specific energy of 50 watt-hours/pound compared to 18 watt-hours/pound for NHB
    - The SSB operates at 300 to 400 deg C significantly reducing load on the thermal control system
    - Replacing NHB with SSB can double storage capability while reducing ORU volume by 75%

2 August, 1991
FILE: BASE-CAP.DOC
BOLERJACK/JLM

ıese cells have an enhanced efficiency (25% vs 14% for Si). The GaAs/Ge cell also exhibits increased radiation tolerance, its output voltage ted to degrade 3% over a 15 year lifetime as compared to 6% for the Si cell.

ncrease to 200% baseline power, using GaAs/Ge cells, can be accomplished in several ways with variable impact on the baseline design.

Maintain eight power channels and replace the Si cells with GaAs/Ge. This option has a large impact on wing and SSU designs. A preliminary study indicates that the wing would be made up of 208 strings of 170 cells in series. These strings could be paralleled to provide 104 input strings to the SSU (compared with the 82 string baseline input). A wing providing 206% baseline power is estimated to increase in area by 7.8% and weight by 4.9%.

An alternative is to increase the number of channels to ten (two additional wings) and redesign the wings for the GaAs/Ge cells. These wings would be smaller than baseline, each containing 162 strings of 170 cells wired up with two strings each paralleled to provide 82 input strings to the SSU. The total wing area would still increase approximately 7.8% and two additional power channels are required; however the SSU and DC switchgear redesigns are minimized.

Another alternative for additional power channels is the Solar Dynamic power module. However this option was analyzed, in great detail under NASA Contract NAS3-25082 and written up in a final report " EPS Evolution Analysis Trade Study" Technical Directive B-0001-127, and will not be further addressed by this study.

wth in source energy storage capability to 200% of baseline is not feasible using the baseline nickel hydrogen batteries (NHB) due to weight, and cooling requirements. One alternative is the sodium sulfur battery (SSB).

The SSB has a specific energy of 50 watt-hours per pound (compared to 18 watt-hours per pound for the NHB). Also, while the NHB is limited to about a 35% depth of discharge (DOD) due to life cycle considerations, the SSB can be taken to 50% DOD without impacting the cell life.

The SSB is a high temperature battery operating in a range of 300 to 400 deg. C. It also has coulombic efficiency of 100%, such that no excess charge current is required , and the SSB cell will not self discharge (no trickle charge required). This greatly enhances the cell efficiency and simplifies the on-orbit cooling requirements, and associated load on the thermal control system (TCS). The baseline NHB battery operates at 0 to 10 deg. C and, due to the heat generated during charge by its inherent coulombic inefficiency (5 to 10 % additional charge must be returned to the battery), it is a much larger load on the TCS.

The energy storage system capability can be doubled, using the SSB technology, with a 75% reduction in ORU volume and an 80% decrease in weight.

A five year SSB development program, for flight prototype modules was started in 1986 and is nearing completion. A flight test is planned as part of a Air Force program.

Power Growth Through Control Enhancement

- DDCU Unequal Power Share Capability
  - Provides additional power to the users by balancing power provided by each source
  - Allows full utilization of available source power
  - Eliminates the DDCU power limitation based on least source capability
- Peak Power Tracking
  - Adjusts the SSU output voltage setpoint to operate the array near its peak power point
  - Recent testing at NASA-LeRC PSF Test Bed established capability to detect and operate near the peak power point
  - Provides estimated 8% increase in user power

1 August, 1991
FILE: BASE-CAP.DOC
BOLERJACK/JLM

ıseline design.

Twelve of the total 26 DDCUs (46%) are operated in parallel, each fed from a different power channel. The baseline DDCU control hardware forces the DDCUs to share power equally. Therefor the power output is limited by the power channel with the least capability. This results in some channels being fully loaded, while others are underutilized. By modifying the DDCU controls, the DDCUs can be allowed to share power unequally, resulting in increased power to the users and less wasted power.

Peak power tracking refers to controls algorithms/hardware, associated with the SSU, that allows the array to operate at a voltage which results in maximum power being delivered to the DCSU. A solar array has operating characteristics which can be described on a current verses voltage (I/V) curve. At the peak power point on that curve, a small change in voltage results in a equal change in current. If the DCSU bus voltage can be controlled, such that the SSU operates the array at this point, then maximum power is being produced by the array. Some recent preliminary testing, at the NASA LeRC PSF test lab, has confirmed the ability to detect and operate close to this peak power point. Estimates are that power to the users can be increased by about 8% if this type control is implemented.

Non-Work Package 4 Hooks and Scars

- Guidance Navigation and Control (GN&C)
- Data Management System (DMS)
- Central Thermal Control System (TCS)
- Truss
- Integrated Truss Assembly (ITA) Cabling
- Propulsion Element Modules
- Pressurized Modules Penetration/Bus Amp Rating
- Solar Alpha Rotary Joint (SARJ)

electrical power to the users, several non-Work Package 4 (WP-04) hooks and scars are necessary depending on the particular option and path selected. Hooks and scars are design accommodations to facilitate the addition or update of computer software and hardware, respectively.

The GN&C provides attitude and orbital corrections of the SSF. The GN&C must be able to control the SSF throughout growth/evolution.

The DMS provides the standard processing support for all SSF systems and must have the capacity to control the SSF throughout growth/evolution.

The central TCS must accommodate the added heat dissipation requirements due to the growth/evolution power levels.

The Truss structure must have the required stiffness to support the addition of growth or evolved power modules, as well as provide the necessary vacant space needed for growth/evolution hardware.

The ITA cabling from the Alpha Gimbal to existing or growth/evolution MBSUs, as well as from growth/evolution MBSUs to the new users, needs to be, or have the capacity to be installed.

The propulsion element, including the Resistojet and H/Ox (or Hydrazine) Thruster, must provide the capability to reboost the growth SSF.

The existing and new pressurized modules should have the capacity to accommodate growth/evolution power through both their power penetrations and buses. Sufficient amp ratings of these conductors will allow flexibility in allocating growth power.

The SARJ must be capable of allowing the addition of more or higher amp-rated roll rings, to accommodate the power crossing requirements needed by the selected option.

Future Work/Considerations

Requirements to complete task

- Finilize Growth/Evolution Task Order
- Conduct Detailed Option Evaluations
- Identify any Problems or limitiaions
- Identify Option Associated Hooks and Scars
- Submit Final Report Documenting Study Results

Future Work

- Recommend Studies to Evaluate New Technology Feasibility
- Continue EPS Growth/Evolution Option Evaluation