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# ON-ORBIT PERFORMANCE OF TOPEX/POSEIDON ELECTRICAL POWER SYSTEM THROUGH ITS DESIGN LIFE OF THREE YEARS

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**ABSTRACT**

The main objective of the TOPEX Spacecraft is to monitor the World's oceans for both scientific study of weather and climate prediction, coastal storm warning and maritime safety. TOPEX carries a radar altimeter, a microwave radiometer, a laser retro-reflector array, a frequency reference onit and an experimental GPS demonstration receiver provided by NASA, and a DORIS doppler tracking receiver and a solid-state radar altimeter provided by CNES, the French Space Agency. The spacecraft with these payloads imposed challenging requirements for the on-board Electrical Power System (EPS). This paper presents an overview of the EPS and its flight performance obtained through telemetry since launch.

**INTRODUCTION**

The TOPEX/Poseidon Satellite, herein abbreviated TOPEX (ocean Topography Experiment), measures the earth's ocean surface topography (wave heights) from space using radar altimeters. TOPEX was launched on August 10, 1992 from the Kourou Space Center in French Guiana into a nominal circular orbit with an altitude of 1334 Km and an inclination of 66 degrees. The satellite's electronics are designed for a three year primary mission. Because of a potential mission extension, the solar array, batteries, and propellant are sized for a five year mission.

**Organization.** TOPEX/Poseidon is a joint mission between NASA and the French CNES, in support of the World Climate Research Program. JPL manages the project for the NASA office of Space Science and Applications. As the TOPEX prime contractor under JPL, Fairchild Space (now orbital Sciences Corporation) designed, built, integrated, tested the satellite, and supported its launch. The power subsystem engineering and solar amry subsystem design were performed by Fairchild.

**Satellite Overview**

A diagram of the TOPEX satellite is shown in Figure 1. TOPEX uses the NASA Multimission Modular Spacecraft (MMS) bus with a mission unique instrument module. The MMS contains the modular power subsystem (MPS) and the instrument module has the sun tracking solar array mounted on its -Y side.

**Electrical Power Subsystem**

A block diagram of the EPS is shown in Figure 2. Solar array power is transferred through the solar array drive assembly via slip rings. The standard power regulator unit (SPRU) within the MPS serves as the power processing interface between the solar array and the satellite load. Three 50 AH batteries located in the MPS supply power whenever the load requirements exceed the SPRU output and during sun occultations. A detailed description of design, analysis and development of the TOPEX Electrical Power System was presented at IECEC-91 [1 ]. The main goal of this paper is to present EPS flight performance obtained from telemetry and compared with the design.

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## ON-ORBIT PERFORMANCE

### EPS Configuration

The EPS configuration one hour after launch is presented in Table-l.

### Operational Measures

Due to higher than normal differential half battery voltages observed on-board UARS, GRO, and other satellites, implementation of certain operational measures were thought to be very appropriate even though the battery related parameters and circumstances were not identical. in view of this, the following operational changes were made to the batteries: (i) Limit peak charge current to **20** amps maximum, by off-pointing the solar array appropriately (1'able-2); (ii) Limit overcharge by controlling the recharge fraction, namely, charge/discharge (C/D) ratio 10 1.05 +/- 0.03 at $6^0$C, by changing V/T levels between level-2, level-3, and level-4; (iii) Limit taper charge currents during full sunlight periods to less thao 200 mA; and (iv) Use LOW current sensor data rather than HIGH current sensor to improve the C/D ratio computational accuracy when the battery currents arc equal or lower than 3 amps.

### Solar Array Performance-Output Power

The Solar Array (S/A) deployed successfully in about 7 minutes and solar arr ay drive acquired the sun almost instantaneously. The S/A is designed to provide about 1043 watts of power to satellite loads after processing through the Ml%, at the end of five years. A detailed description of design, analysis and development of the TOPEX/Poseidon solar arr ay was presented al IECIW-91 [2].

**Performance at BOL.** Solar array output performance is evaluated first using the BOL telemetry data. From this data, a time period is selected where the SPRU is in peak power tracking mode extracting all the power available from the S/A, namely, 261T12:36 102611'12:38.

**Measured S/A Output Power.** Various parameters, i.e., S/A temperat urc, S/A operating voltage, S/A operating current, etc obtained through the telemetry for the above selected time period arc presented in l'able-3. The sun incidence angle is obtained by vectorially summing the solar panel offset with the beta-angle. The S/A output power measured at the MI'S input is obtained by multiplying the S/A operating current with S/A operating voltage and is presented in the same table.

**Predicted S/A Output Power.** Relative sun intensity for day 261 is 0.9911. The S/A output power is computed using the "POWERT" program [3] for the same conditions as the telemetry data in Table-3 and is presented in Table-4. The "POWERT" computer program was developed uniquely for the TOPEX/Poseidon spacecraft and was validated using ground measured data on flight solar panels.

**Measured Vs Predicted S/A Output Power.** The measured S/A output power is compared with the predicted S/A output power in Table-5. Thus, onc can infer that the S/A is performing better than expected. The measurement of solar array current is carried out using a magnetic sensor and the voltage using a simple resistive divider. Both of these sensors have some temperature tolerance and a certain amount of inherent error. The output of these sensors is processed through an 8-bit A/D converter in the telemetry system before lhc data is downlinked. The overall error in the measurement and signal processing is computed to be +/-3%.

**S/A Performance at 6, 12, 20,30 Months.** Following the same approach as above, measured S/A output power is obtained from the telemetry data and the "POWERT" computer program is used 10 obtain the predicted S/A output power. The losses duc to various degradations of S/A over time that arc used by the "POWERT" computer program arc listed in Table-6. The measured S/A output power is compared with the predicted S/A output power ia Table-7 for 6-months, 12-months, 20- months, and N-months and it closely matches with the predicted values. Thus, the S/A is performing as expected and designed.

In the above analyses, each measured data set had a different operating environment, i.e., sun incidence angle, sun intensity, temperature, etc. Now, measurements and predictions are recomputed/converted for the same operating environment (temperature of $28^0$C, sun intensity of 1353 w/m$^2$, and $16^0$ sun incidence angle) and presented in Figure 3. From this figure, onc can infer that the solar array is performing as expected.

### Solar Array Performance - Temperature

Figure 4 presents temperature plots of one of four solar panels, onc taken soon after launch and the second one taken recently for the same beta- prime angle. There is no apparent degradation of the thermal materials of the pane]. Figure 5 presents front-k-back temperature plots of onc of four solar panels, onc taken soon after launch and the second one. taken recently for the same beta-prime angle. Again, there seems to be no apparent degradation.

### Storage Batteries

To date the TOPEX test cells, under-going ground tests (Life/Stress Test. Mission Simulation Test, and Temperature effect Test), have exhibited results comparing favorably with results from traditionally "good" cells.

The MPS housed three NASA Standard 50 AH Nickel-Cadmium (22 cell) batteries. Baseplate imbedded heatpipes force all three batteries to operate at the same temperature, thereby eliminating the degradat ion otherwise induced by the temperature differentials between the three batter its. All three batteries arc performing in an excellent manner. The "operational measures" taken might have further assured excellent performance being exhibited by the batter its.

The end of night voltage degradation, presented in Figure 6, seems to be within acceptable rates as compared to decay rates from previously tested cells [4].

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## Power Electronics

**Spacecraft Actual Load Power Consumption,** Using the data from four current sensors in the MPS and the unregulated bus voltage, instantaneous power was computed at one minute intervals over 24 hoor period and is averaged to obtain total spacecraft orbital average power. The orbital average load power from launch to date during low beta-prime is presented in Figure 7 and it was aboot 869 watts al launch with two transmitters operating simultaneously. After about two months, one of two transmitters were switched-off and the load demand reduced to about 854 watts and has decreased to about 847 watts since then. One possible explanation is that healers arc consuming relatively less power as some thermal surfaces might have degraded. Thos, current load consumption is lower than the worst case predicted EOL value of 933 watts with two transmitters operating.

V/l **Levels.** Appropriate charging of batteries is carried by proper selection of V/T levels and the voltage levels determined by the V/T levels dots not degrade with time. This is indirectly measured by the state of charge (SOC) at the start of the V/T limit. Table-8 presents the SOC taken soon after launch and recently for different V/T levels. There seems to be no apparent degradation.

**SPRU Efficiency.** Power telemetry data was analyzed from four different 24-hour time periods and instantaneous SPRU efficiency was calculated at one minute intervals over a 24 hour period and is averaged to obtain average efficiency. As presented in Figure 8, the computed efficiency using the telemetry measurements is greater than the design specification value of 91 .5%, al SPRU output power levels of 1500102.500 watts.

**SPRU Operation.** The SPRU is operating as expected and the peak power tracking accuracy is indirectly predicted to be 100%. There is no direct indicator to measure peak power tracking accuracy and it has to be interpreted indirectly.

## CONCLUSION

Previous sections presented detailed performance of entire Electrical Power System. The EPS performance including S/A, storage batteries and power electronics exceeded our expectations and is performing in an excellent manner and to elaborate:

(i) Solar array deployed successfully in about 7 minutes (predicted was 3 to 12 minutes) and soJar array drive acquired the sun almost instantaneously.

(ii) Off-pointing of the solar array has been used successfully, to limit peak charge current.

(iii) Solar Array output power is higher than predicted; and is degrad ing per dcs ign pred ictions.

iv) The storage batteries arc performing per design and the cod of night/d ischarge voltage degradation seems to be within acceptable rates.

(v) Thermal control of the solar array, storage batteries and power electronics is keeping the operating temperatures within the design specification.

(vi) TOPEX/Poseidon spacecraft power consumption is lower than predicted.

(vii) SPRU peak power tracking accuracy and conversion efficiency are higher than predicted.


## ACKNOWLEDGEMENTS

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4. 1. Deligiannis, K. Sherwood, D. Perrone, and S. Di Stefano, " TOPEX/Poseidon NiCd Battery performance: Comparison of flight and ground test results" 29th Annual Intersociety Energy Conversion Engineering Conference (IECEC-93); Monterey, CA, August 8-13, 1994.

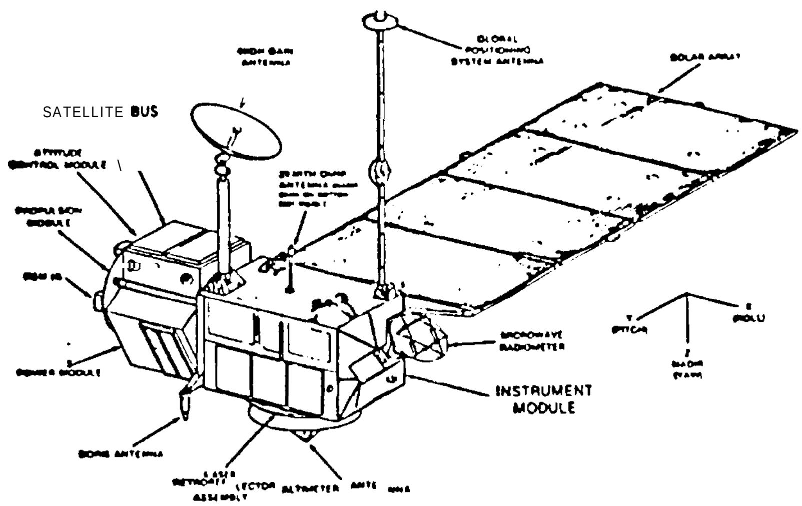


Fig. I On-orbit fully deployed configuration of the TOPEX/Poseidon Satellite

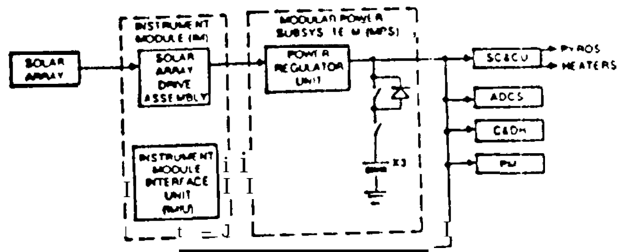


Fig.2 Block Schematic of the TOPEX/Poseidon Electrical Power Subsystem

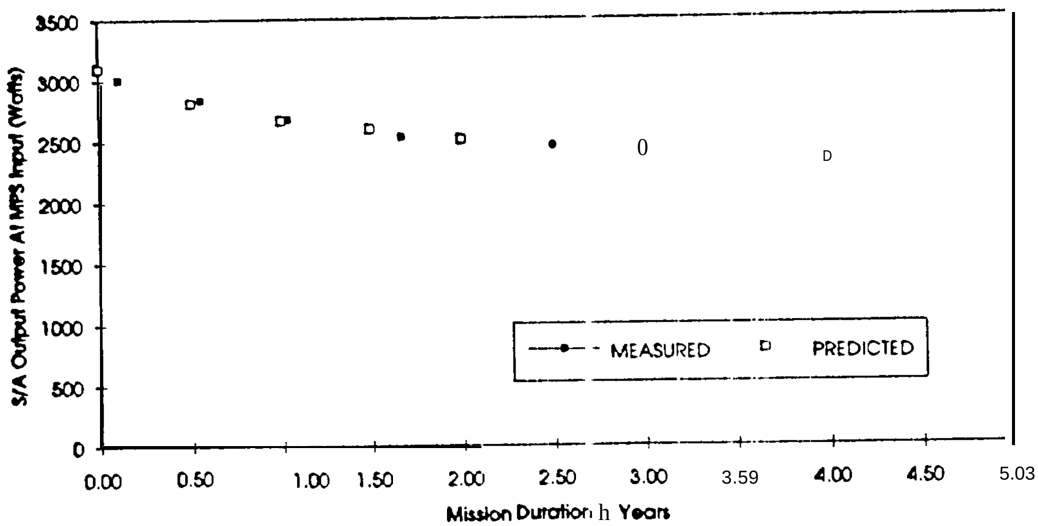


Fig.3 Comparison of Measured Vs Predicted Solar Array Output Power at MPS input

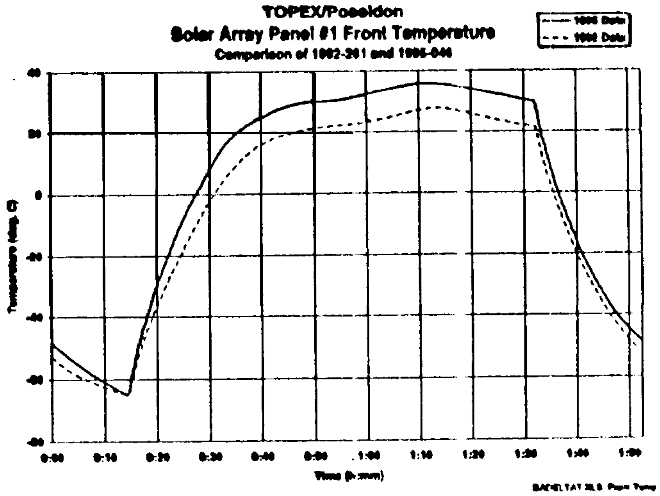


Figure 4 Temperature Plots of Solar Panel-1

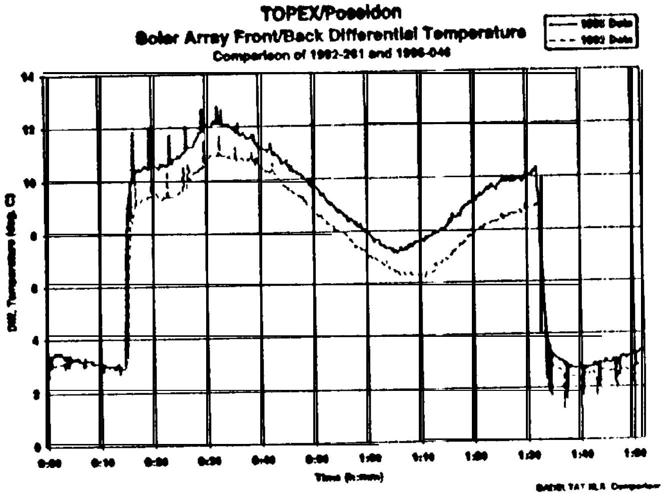


Figure 5 Front-To-Back Temperature Plots Solar Panel-1

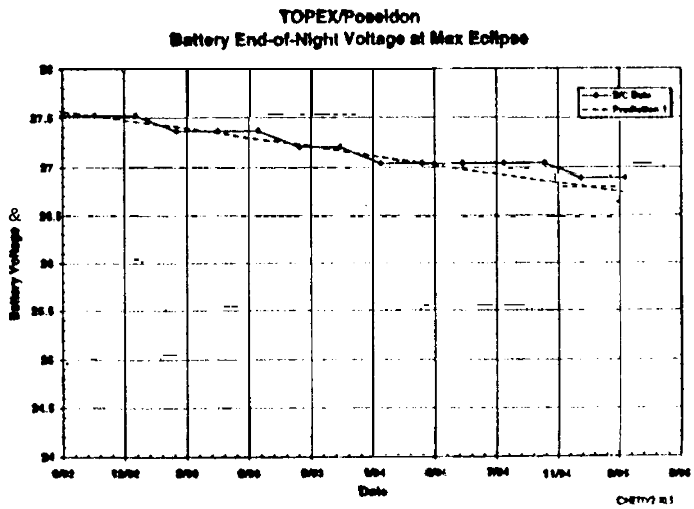


Figure 6 Battery End of Night Voltage at Maximum Eclipse Since Launch

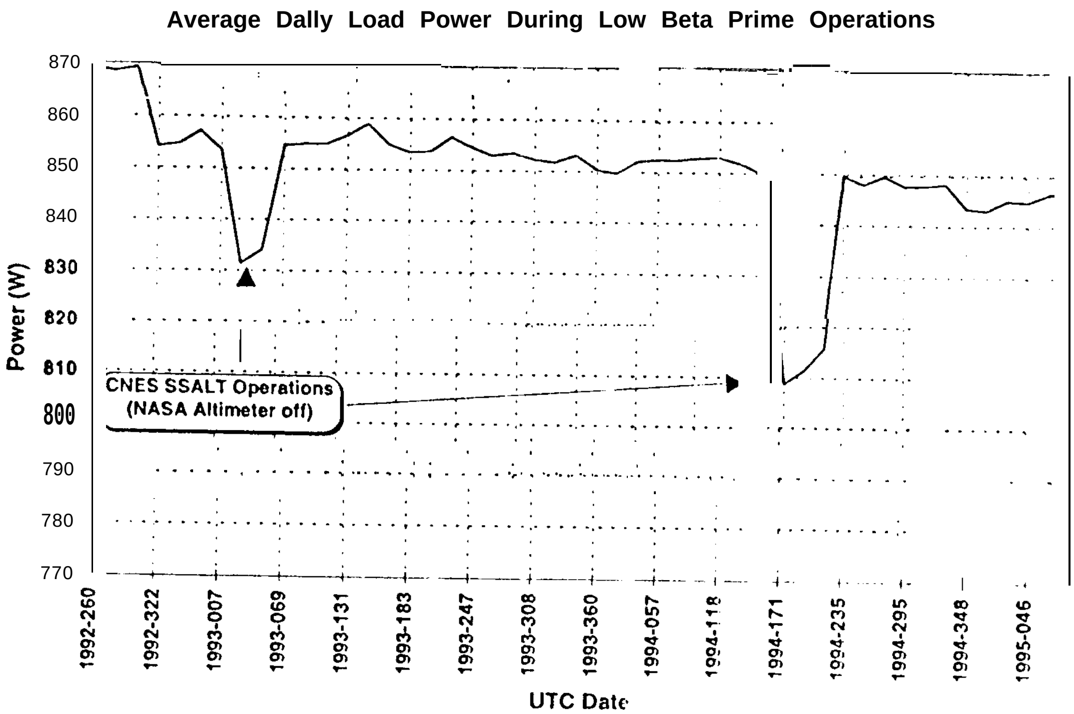


FIGURE 7

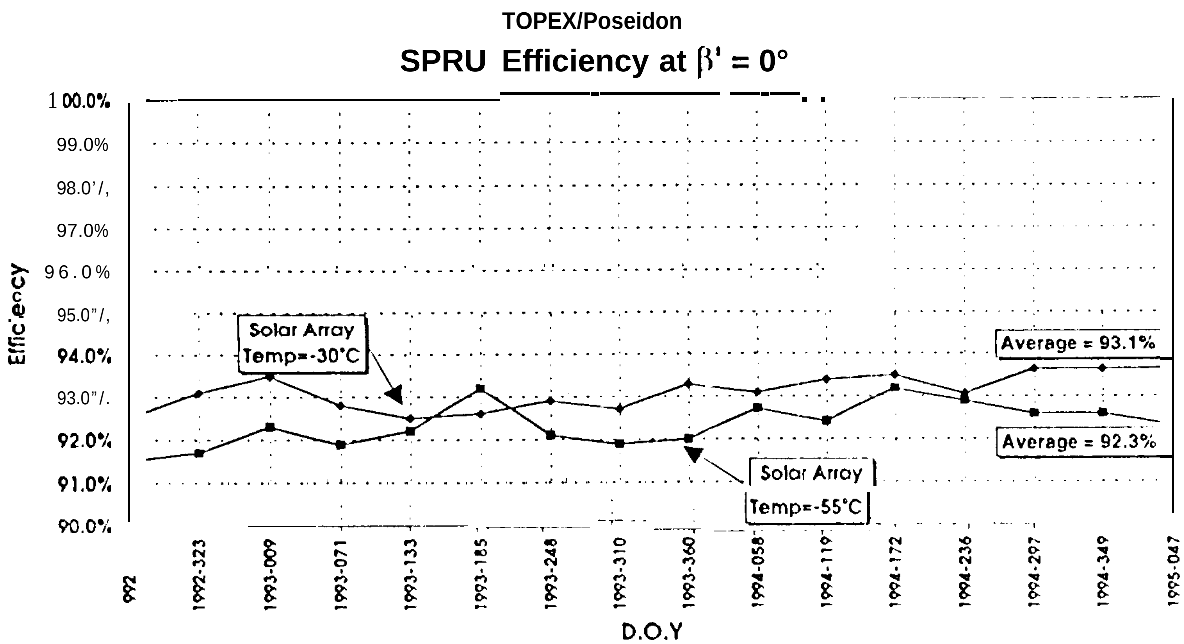


FIGURE-8

**Table-1** EPS **Configuration**

| | |
|---|---|
| **Solar** Array: | **Fully deployed and sun tracking** |
| **Storage Batteries SOC:** | **100%** |
| ***V/T* Level:** | 3 |
| Power Disconnect Relays: | Closed |
| All Heaters: | Enabled |
| All thermostats: | Enabled |
| **Battery** Thermal Switches: | Enabled (reset state) |
| **Safehold** Enable Relay: | A-side Enabled/13 -side Disabled |
| SPRU Command Control Relays: | A-side ARMED/ B-side DISARMED |
| Heater Control Relays: | DISARMED |
| PDR Control Relays: | DISARMED |
| Battery charge control Relays: | A-side ARMED/ B-side DISARMED |
| RIU-3A: | Standby II Mode |
| RIU-3B: | OFF |

**Table-2 Solar Array *Off* set Changes Since Launch**

| Day of the Year | Offset |
|---|---|
| 1992-241 | +55.0 |
| 1992-247 | +57.5 |
| 1992-256 | -57.5 |
| 1992-261 | +57.5 |
| 1992-324 | -57.5 |
| 1992-329 | +57.5 |
| 1993-208 | +53.0 |
| 1993-277 | +54.0 |

Table- 3 Solar Array Measured Data from Telemetry .

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Day/ Year/ Time | Angle between Sun & Panel Normal | S/A Temp-erature Cell side (c) | Sun Intensity | Measured Data (at MPS input) | | |
| | | | | S/A Operating Current (A) | S/A Operating Voltage (V) | S/A Output Power (W) |
| 261/92/12:36 | 57.5 | -s3.2 | 0.9916 | 25.6 | 102.5 | 2624.0 |
| 261/92/12:37 | 57,5 | -46.2 | 0.9916 | 25.6 | 100.5 | 2572.8 |
| 261/92/1238 | 57.5 | -41.4 | O.W16 | 25.6 | 99.0 | 2534.4 |

Table-4 Solar Array Output Power Prediction

| 1 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|
| Day/ Year/ Time | Angle between Sun & panel Normal | S/A Temperature Cell side (c) | Sun Intensity | Predicted Data |
| | | | | S/A Power at MPS input (W) |
| 261/92/12.36 | 57.5 | -50.2 | 0.9916 | 2493.3 |
| 261/92/12:37 | 57.5 | -46.2 | 0.9916 | 2470.6 |
| 261/92/12:38 | 57.5 | -41.4 | 0.9916 | 2443.1 |

Table- 5 Measured V/ Predicted Solar Array Output Power

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| Day/ Year/ Time | Measured Date | Predicted Data | Difference | |
| | S/A Output Power at MPS (W) | S/A Output Power at MPS (W) | Measured minus Predicted (W) | Measured - Predicted / Predicted % |
| 261/92/12:36 | 2624.0 | 2493.3 | 130.7 | 5 |
| 261/92/12:37 | 2572.8 | 2470.6 | 102.2 | 4 |
| 261/92/12:38 | 2534.4 | 2443.1 | 91.3 | 4 |

Table- 6 'blew Array Degradation Factors

| Mission Duration (Yrs) | w | MM | Thermal Cycling | Radiation |
|---|---|---|---|---|
| 0.5 | 0.9900 | 0.9990 | 0.9980 | 0.9100 |
| 1.0 | 0.9850 | 0.9980 | 0.9960 | 0.8700 |
| 1.5 | 0.9842 | 0.9970 | 0.9940 | 0.8450 |
| 2.0 | 0.9838 | 0.9960 | 0.9920 | 0.8260 |
| 3.0 | 0.9825 | 0.9940 | 0.9880 | 0.8000 |
| 4.0 | 0.9813 | 0.9920 | 0.9840 | 0.7820 |
| .s.0 | 0.9800 | 0.9900 | 0.980% | 0.7650 |

Table- Measured V, Predicted Solar Array Output Power

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| Day/ Year/ Time | Measured Dote | Predicted Data | Difference | |
| | WA Output Power at MPS (W) | /A Output Power at MPS (W) | Measured minus Predicted (W) | Measured - Predicted / Predicted % |
| **6-Months** | | | | |
| X62/93/13:36 | 24704 | 2370.4 | 100.0 | 4 |
| X62/93/13:37 | 2406.4 | 2340.7 | 65.7 | 3 |
| X62/93/13:38 | 2379.0 | 2312.9 | 65.1 | 3 |
| **12-Months** | | | | |
| 237/93/6:14 | 25%5.2 | 2499.2 | 87.0 | 3 |
| 237/93/6:15 | 2516.0 | 2459.6 | 56.4 | 2 |
| 237/93/6:16 | 2516.0 | 2424.8 | 91.2 | 4 |
| **20-Months** | | | | |
| 102 I94I4,32 | 2240.0 | 2300.1 | #.1 | -3 |
| 102/94/4:33 | 2283.6 | 226s.s | 17.1 | 1 |
| 102/94/4:34 | 2249.0 | 2235.9 | 13.1 | 1 |
| **30-MONTHS** | | | | |
| 39/1/95/13:09 | 2327.5 | 2286.2 | 41.3 | Z |
| 39/95/13:10 | 2318.2 | 2253.0 | 65.2 | 3 |
| 39/1/95/13:1 | 2291.4 | 2243.5 | 47.9 | 2 |

**Table-8 Comparison of State of Charge at Different V/T Levels**

| V/T Level | State of Charge At launch | State of Charge Recently |
|---|---|---|
| 3 | 93.5% | 93.5% |
| 4 | 94.5% | 94.5% |