COMPARATIVE PERFORMANCE ASSESSMENT

OF

INTELSAT V NICKEL HYDROGEN AND NICKEL CADMIUM BATTERIES

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ABSTRACT

The first Nickel Hydrogen battery deployment onboard a commercial geosynchronous communications satellite was realized with the launch of the INTELSAT V, Flight 6 spacecraft on 19 May 1983. The initial five spacecrafts in this series are equipped with Nickel Cadmium batteries. Based on the data available on both types of batteries, design and operational performance comparisons of INTELSAT-V Nickel Hydrogen and Nickel Cadmium batteries are presented. General characteristics of the INTELSAT-V spacecraft as related to electrical-power-subsystem functions and battery operations are summarized.

1.0 INTRODUCTION

INTELSAT (International Telecommunications Satellite Organization), with headquarters in Washington, D.C., is a global satellite communications system formed in 1964 by its member countries in two segments as space and earth segments. The space segment consists of 14 operational and spare satellites distributed among the three ocean regions as Atlantic (AOR), Indian (IOR), and Pacific Ocean Region (POR). The INTELSAT earth segment is formed by 678 ground stations (owned by 109 user countries) which are linked to those satellites operating in each region. Although the planning, procurement, launch, TTC&M functions, and operational management of the space segment are administered by the INTELSAT organization, the construction and operation of the individual earth stations are performed by the user countries under the guidelines and standards established by INTELSAT. INTELSAT's services include provision of capacity in telephone, data, and television communications to the world community in general, as well as lease services in maritime and regional/domestic communications to various organizations.

INTELSAT began operations in 1965 with INTELSAT I (Early Bird) and recently launched Flight 7 of the fifth generation satellites in the INTELSAT-V series. The next generation satellites of the INTELSAT-VI series are currently under procurement with planned commencement of service in mid-1986. The evolution of the INTELSAT space segment is shown in Figure 1.

In regards to INTELSAT's experience with in-orbit operation of spacecraft batteries, we experienced the first major problem with INTELSAT-IV batteries during the 1976-1978 period. The degraded performance of batteries on board INTELSAT-IV's resulted in five to six years of full capacity operations in contrast to seven years design life. During this period various attempts were made to make the optimum use of these batteries, among which powering half of the transponders onboard each malfunctioning spacecraft and thereby reducing the necessary depth-of-discharge helped to prolong the satellites' operational life. In addition, colocation of poorly performing satellites were initiated in early 1980 with two INTELSAT-IV's (F4-F5 at 179°E location) when neither spacecraft could provide full communications capability during eclipse periods due to insufficient power availability.

The Nickel-Cadmium batteries of INTELSAT-IVA satellites, which commenced service in 1974 with a seven-year design life, have performed exceptionally well. Current data indicate that there is no significant performance degradation on INTELSAT-IVA batteries even after nine years of service corresponding to 18 eclipse seasons. The minimum voltage on 14 batteries is approximately 28.8 Volts (1.15 Volts/cell), with measured capacity during reconditioning periods maintaining a minimum value of 30 Amp Hours (reconditioning voltage: 25 V). The measured capacity of INTELSAT-IVA batteries, which consist of 25 Nickel-Cadmium cells, is 26 Amp Hours (22 Amp Hour name-plate rating). The nominal depth-of-discharge of 14 operational batteries ranged between 26-43 percent of the measured capacity during the recent eclipse season of Fall 1983.

After having reasonably successful operational experiences with Nickel Cadmium batteries, especially during the INTELSAT-IVA and early INTELSAT-V era, the current INTELSAT-V and VA's (starting with Flight 6 launched in May 1983), and INTELSAT-VI satellites are equipped with Nickel-Hydrogen batteries. Aside from theoretically proven improvements and limited test/low orbit performance results available on Nickel-Hydrogen batteries, it can be expected that the long-term, practical benefits of using these batteries may be proven towards the end-of-life of INTELSAT-V satellites.

2.0 GENERAL DESIGN AND OPERATIONAL CHARACTERISTICS

The first INTELSAT-V spacecraft (Flight 506) equipped with a Ni-H2 battery was launched on 19 May 1983. Since the launch and during the recent eclipse season of Fall 1983, the batteries have been used during three inclination maneuver periods utilizing the electro-thermal thrusters (ETT). Both batteries of spacecraft 506 were reconditioned prior to the eclipse.

All INTELSAT-V's are three-axis-stabilized spacecraft with total end-of-life solar array power capability of approximately 1500 Watts. The Ni-H2 batteries of the later spacecraft (506 through 516) consist of two 27-cell modules located on the north and south panels. The battery temperature control is accomplished by means of optical solar radiators (OSR) and thermostatically controlled heaters. The modular design and location of batteries on all INTELSAT-V spacecraft are shown in Figure 2.

The Ni-H2 batteries were direct replacements for the Ni-Cad batteries of earlier spacecraft with nearly identical volume and shelf area requirements. The top view of each Ni-H2 battery assembly on the north and south panels of the INTELSAT-V support subsystem module is shown in Figure 3.

The INTELSAT Ni-H2 battery cell design is similar to that of NTS-2 (Navigation Technology Satellite) launched in June 1977 into low earth orbit with 12 hours orbit period. The experimental battery package onboard NTS-2, which was developed and manufactured under INTELSAT sponsorship, consists of fourteen 35-Amp Hour Ni-H2 cells with a design DOD of 60 percent and a total eclipse load of 350 Watts. A pictorial view of the INTELSAT-V battery assembly and the cell design diagram are shown in Figure 4. This figure also shows the typical temperature sensor (thermistor) locations on a single cell. Each battery assembly contains one cell with a thermistor and another with a strain gage bridge to provide pressure readouts in the telemetry data.

Table 1 shows the design characteristics of Ni-Cad and Ni-H2 batteries for comparison. The charge current characteristics on all INTELSAT-V spacecraft are listed in Table 2.

Figure 5 shows the simplified diagram of one bus of the INTELSAT-V electrical power subsystem. The other bus is identical to the one shown in this figure. The available telemetry data on the electrical power subsystem parameters are as follows:

Function	On Each Bus/Battery	On Both Busses/Batteries
Battery Volts	1	2
Cell Volts	27	54
Battery Temp	2	4
Battery Pressure	1	2
Discharge Current	1	2
Charge Current	1	2
Bus Current	1	2
Array Current	1	2
Shunt Current	1	2
Bus Voltage	1	2

The control relays shown in Figure 5 are used to configure the battery charge rates, cross strapping, and reconditioning. The battery sequencer is a five-minute OFF/ON switch which sequentially charges the north and south batteries for a period of five minutes each. Although there exists an override capability on sequential charging to switch to continuous charge, the latter charging mode is rarely used since the thermal and charge rate design of the spacecraft are based on sequential charging.

3.0 IN-ORBIT PERFORMANCE CHARACTERISTICS AND COMPARISON OF NICKEL-HYDROGEN AND NICKEL-CADMIUM BATTERIES

INTELSAT has had extensive experience in the operational aspects of Ni-Cad batteries. With the deployment of spacecraft 506, which represents the first Ni-H2 battery system on board a commercial geosynchronous communication satellite, we are in a position to make a comparative assessment of the performance of each type of battery. An attempt is made in this report to present such a comparison. It should be noted here that although our experience on the in-orbit performance of Ni-H2 batteries is limited to one eclipse season (Fall 1983) following the deployment of spacecraft 506 in June 1983, the comperative assessment as shown in the following diagrams is still of interest.

Comparative performance characteristics of a typical Ni-Cad (Spacecraft 503, Battery No. 1) and Ni-H2 battery during the eclipse season of Fall 1983 is shown in Figure 6. This figure indicates a nominal battery load of 11-11.5 Amps for both batteries, with corresponding minimum end-of-discharge voltages of 33.6 Volts and 32.7 Volts for Ni-Cad and Ni-H2, respectively. Among the five INTELSAT-V's equipped with Ni-Cad batteries, spacecraft 503, Battery No. 1 was selected for comparison with Battery No. 2 of spacecraft 506 because of similar loading characteristics during the eclipse season.

Shown in Figure 7 is the comparison of the voltage and temperature profiles of spacecraft 503, Battery No. 2 with those of Ni-H2 Battery No. 2 of spacecraft 506 during the 24 September 1983 eclipse. Notice here that DOD on both batteries are similar (35 percent), and that the steep voltage rise at the end of charging cycle of the Ni-Cad battery is not apparent in the case of the Ni-H2 battery.

The performance data on Ni-H2 batteries during the longest eclipse of the Fall 1983 season (23 September) is shown in Figure 8. This figure includes battery voltage, discharge current, pressure, and temperature profiles during a 24-hour cycle, as well as the pressure and temperature profiles with time scale of two hours to show the variation on these parameters during the discharge period in more detail. It should be pointed out here that spacecraft 506 is equipped with a Maritime Communications System (MCS), and this system was undergoing in-orbit testing during the time when this data was recorded. Hence, the battery current shown here increased from the nominal value of 11.5 - 12 Amps to approximately 17 Amps, resulting in a 66 percent DOD reference to 30 Amp Hour capacity. The corresponding battery and cell voltages are 31.4 Volts and 1.16 Volts, respectively.

The MCS payload operation as shown in Figure 8 represents a test case, and heavy loading of batteries as observed here usually does not occur during normal operations.

The comparative profiles in voltage, cell voltage, and temperature of a Ni-Cad (spacecraft 502, No. 2), and a Ni-H2 (spacecraft 506, No. 2) battery during reconditioning is shown in Figure 9. The reconditioning of both types of batteries was performed prior to the corresponding eclipse season by discharging through a 50 Ohm resistor until the first cell reached 0.9 Volt. At the reconditioning rates of C/44 (0.7 Amps) of Ni-Cad batteries, an average capacity increase of 3-4 Amp Hours is usually observed in comparison with the reconditioning rate of C/2 (15 Amps). The corresponding capacity differential in the case of Ni-H2 batteries, however, was measured to be $\pm$ 1 Amp Hour (reference to 37 Amp Hour overall capacity). This observation is attributed to the higher self discharging of Ni-H2 batteries and/or errors introduced in the processing of telemetry data.

Table 1

Battery Assembly Performance Characteristics

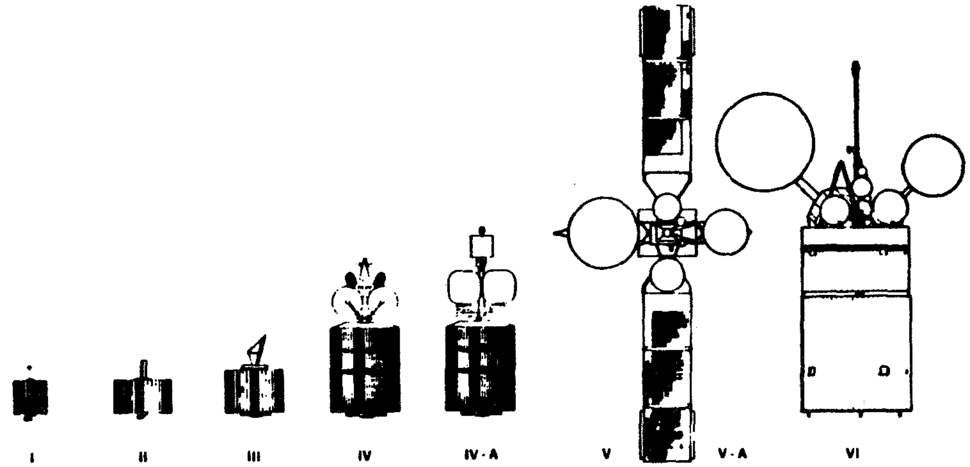
CHARACTERISTIC	VALUE (NI-HYD.)	VALUE (NI-CAD.)
TOTAL ELECTRICAL BUS LOAD	911 W	911 W
MAXIMUM DEPTH OF DISCHARGE	70%	55%
NOMINAL CELL CAPACITY	30 AH	34 AH
MEASURED CELL CAPACITY	37 AH	38 AH
NOMINAL DISCHARGE CURRENT	15 AH	15 AH
MAXIMUM DISCHARGE TIME	1.2 HOURS	1.2 HOURS
HIGH CHARGE CURRENT (BOL - EOL)	[1.42-1.25 C/21-C/24]	[1.42-1.25 C/24-C/27]
TRICKLE CHARGE CURRENT (BOL - EOL)	[0.48-0.43 C/63-C/70]	[0.48-0.43 C/71-C/79]
TOTAL CYCLES AND ECLIPSE (7 YEARS) (616 ECLIPSE CYCLES + 176 ETT FIRINGS)	791 CYCLES	791 CYCLES
ORBITAL LIFE	7 YEARS	7 YEARS
BATTERY CONFIGURATION (2 BATTERIES PER SPACECRAFT)	27 CELL ASSEMBLIES	28 CELL ASSEMBLIES
NOMINAL BATTERY HEAT OUTPUT DURING OVERCHARGE, AVERAGE	50 W (EQUIVALENT)	52 W (EQUIVALENT)
ALLOWABLE BATTERY TEMEPERATURE RANGE DURING ORBITAL OPERATION (THERMISTOR MEASUREMENT)	0° TO +25°C	0° TO +25°C

Table 2

Battery Charge Array Current (In Amperes)

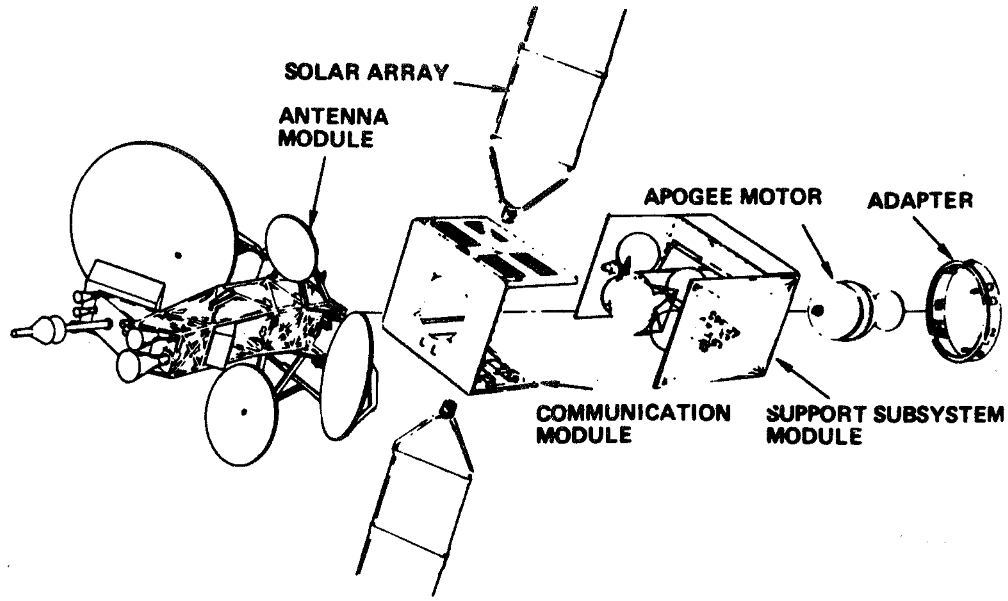
SEASON/LIFE	CHARGE CONTROL ARRAY MODULE		
	A,D (6P x 9S)	B,E (2P x 9S)	C,F (3P x 8S)
VERNAL EQUINOX			
BOL	1.89	0.64	0.95
EOL	1.68	0.57	0.86
AUTUMNAL EQUINOX			
BOL	1.86	0.63	0.94
EOL	1.65	0.56	0.85
SUMMER SOLSTICE			
BOL	1.66	0.56	0.84
EOL	1.46	0.50	0.75
WINTER SOLSTICE			
BOL	1.77	0.60	0.90
EOL	1.56	0.53	0.80

The charge arrays can be used in various combinations to provide rates in the range C/100 to C/5.

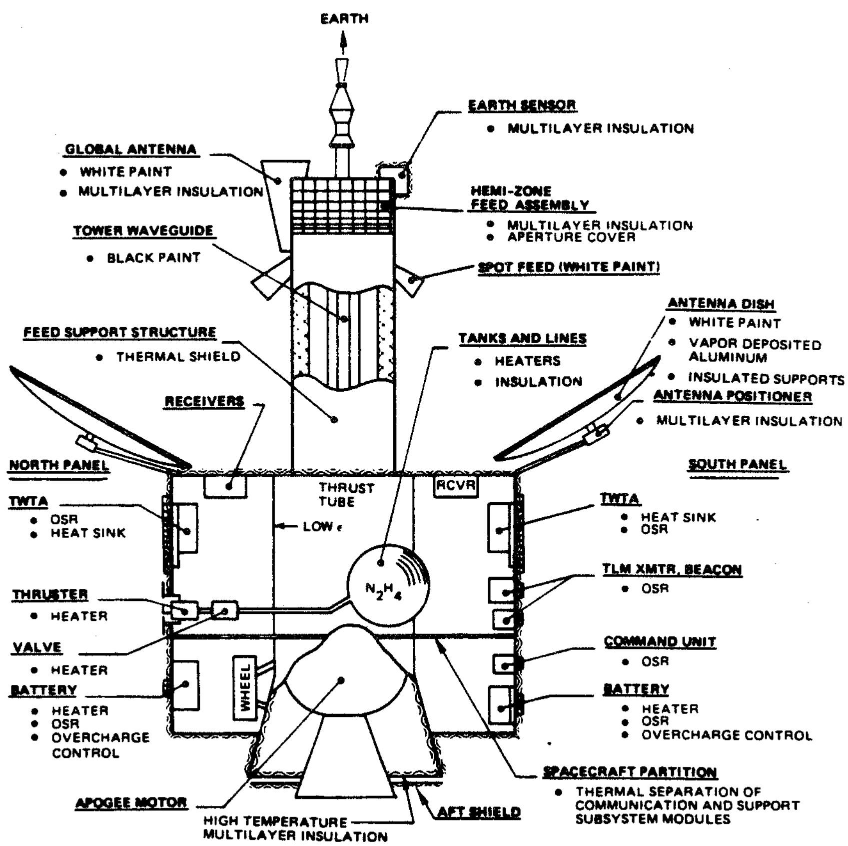


INTELSAT DESIGNATION	I	II	III	IV	IV - A	V	V - A	VI
YEAR OF FIRST LAUNCH	1965	1966	1968	1971	1975	1980	1983	1986
PRIME CONTRACTOR	HUGHES	HUGHES	TRW	HUGHES	HUGHES	FORD AEROSPACE	FORD AEROSPACE	HUGHES
DIMENSIONS (Undeployed)								
WIDTH, m.	0.7	1.4	1.4	2.4	2.4	2.0	2.0	3.6
HEIGHT, m.	0.6	0.7	1.0	5.3	6.8	6.4	6.4	5.3
LAUNCH VEHICLES	——— THOR DELTA ———			ATLAS CENTAUR		ATLAS CENTAUR, OR ARIANE 1, 2		STS OR ARIANE 4
SPACECRAFT TRANSFER ORBIT MASS, Kg.	68	162	293	1,385	1,469	1,946	2,140	12,100/3,720
COMMUNICATIONS PAYLOAD MASS, Kg.	13	36	56	185	190	235	280	800
POWER EOL EQUINOX, Watts	40	75	134	460	800	1,270	1,270	2,200
DESIGN LIFETIME, YEARS	1.5	3	5	7	7	7	7	10
RATED VOICE CHANNEL CAPACITY IN AOR	480	480	2,400	8,000	12,000	25,000	30,000	80,000
BANDWIDTH, MHz.	50	130	300	500	800	2,300	2,180	3,680
ANTENNA BEAM COVERAGES								
C – BAND	TOROIDAL NORTHERN ONLY	TOROIDAL ALMOST FULL EARTH	DESPUN EARTH COVER	DESPUN EARTH COV AND 2 SPOTS STEERABLE	DESPUN EARTH COV. AND 2 HEMI	3 – AXIS EARTH COV., 2 HEMI, 2 ZONE	3 – AXIS DUAL POL. EARTH COV., 2 HEMI, 2 ZONE 2 SPOTS	DESPUN DUAL POL. EARTH COV., 2 HEMI, 4 ZONE
Ku – BAND	N.A.	N.A.	N.A.	N.A.	N.A.	2 SPOTS STEERABLE	2 SPOTS STEERABLE	2 SPOTS STEERABLE
L – BAND	N.A.	N.A.	N.A.	N.A.	N.A.	EARTH COV.	N.A.	N.A.

Figure 1. Evolution of Intelsat satellites.



INTELSAT - V Spacecraft Modular Design



Thermal Subsystem Operation Configuration

Figure 2

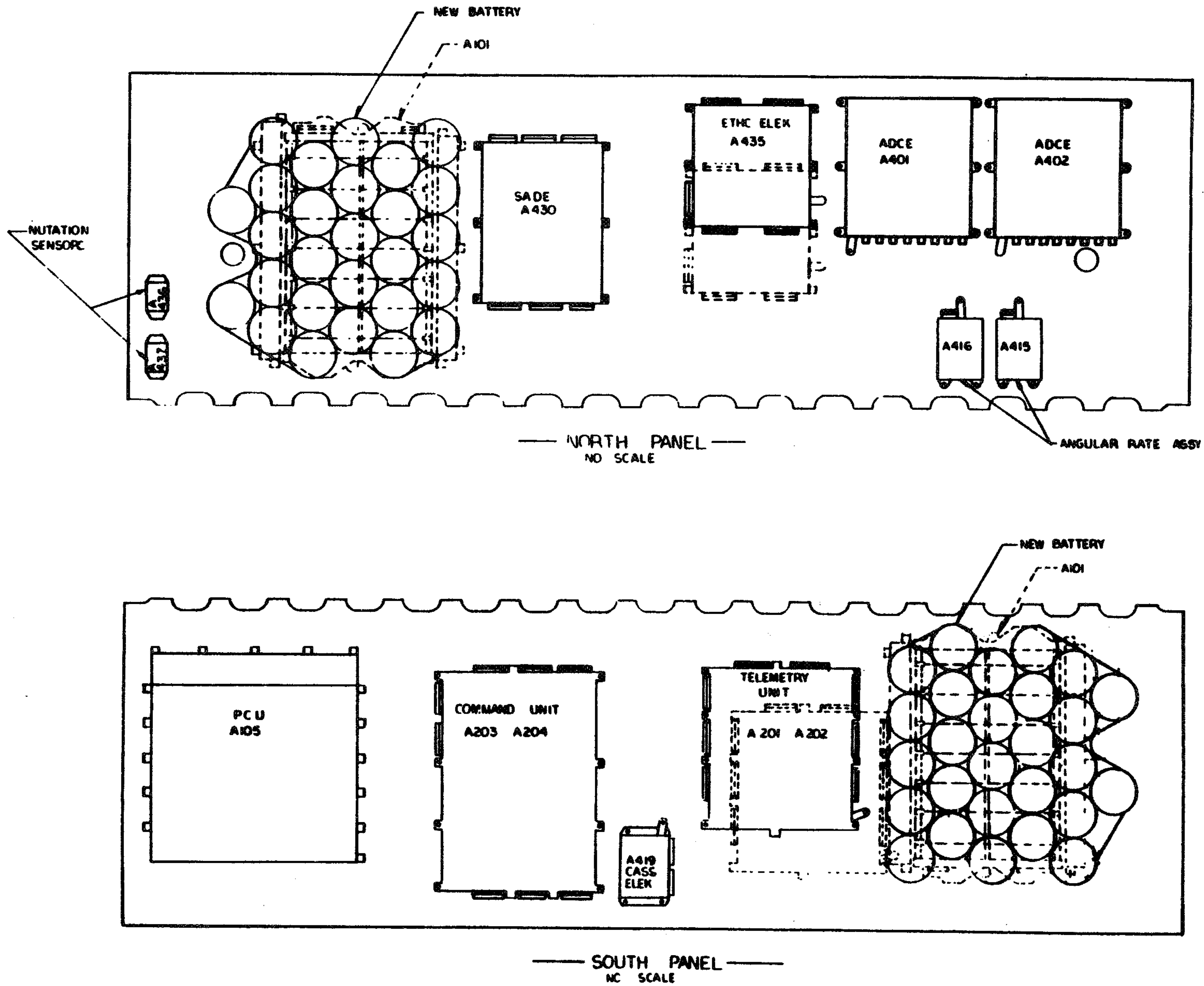
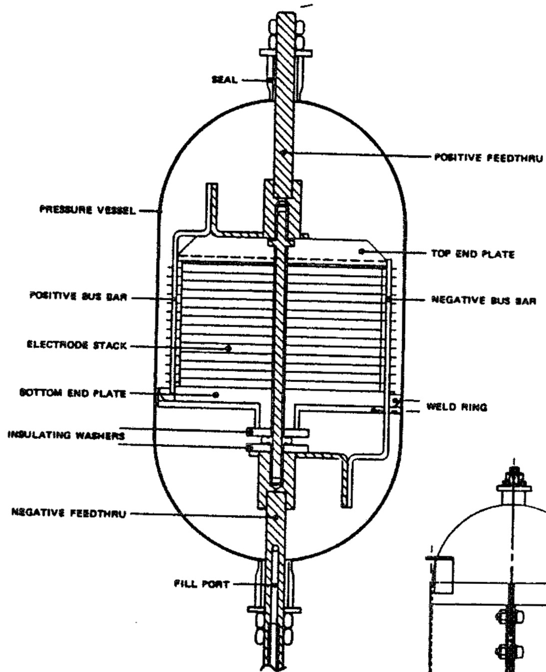
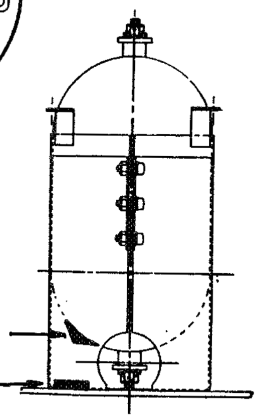


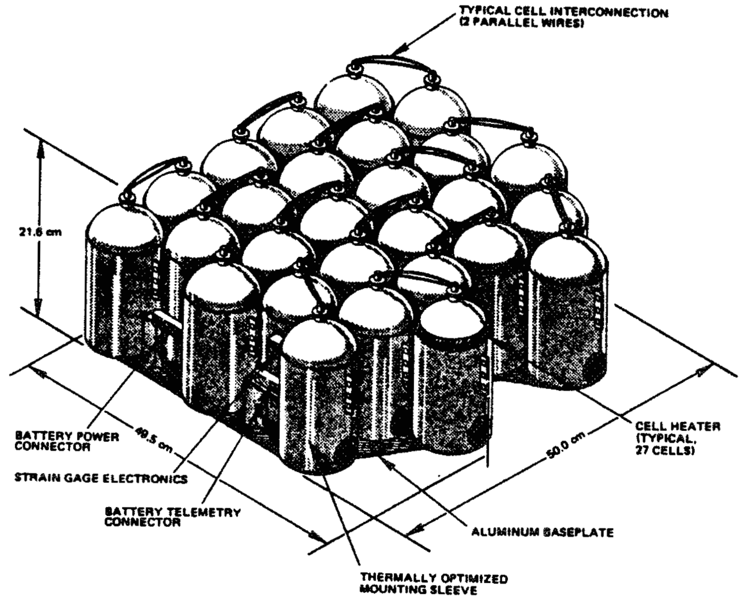
Figure 3. Intelsat-V nickel-hydrogen battery location.

INTELSAT-V Nickel-Hydrogen Battery Cell Design Diagram





TYPICAL TEMPERATURE SENSOR (THERMISTOR) LOCATIONS



INTELSAT-V Nickel-Hydrogen Battery

Figure 4

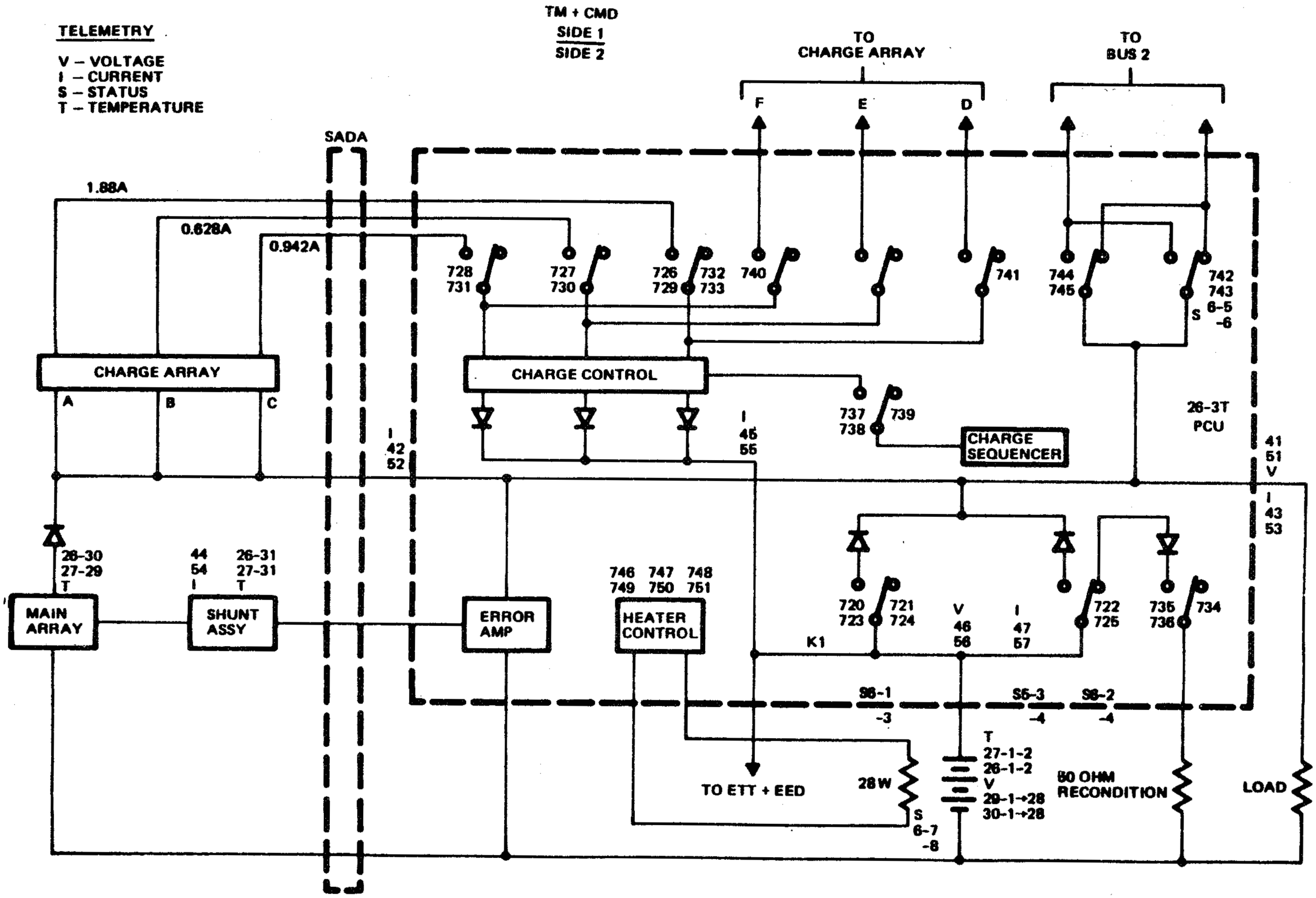


Figure 5. Intelsat-V electrical power subsystem simplified block diagram.

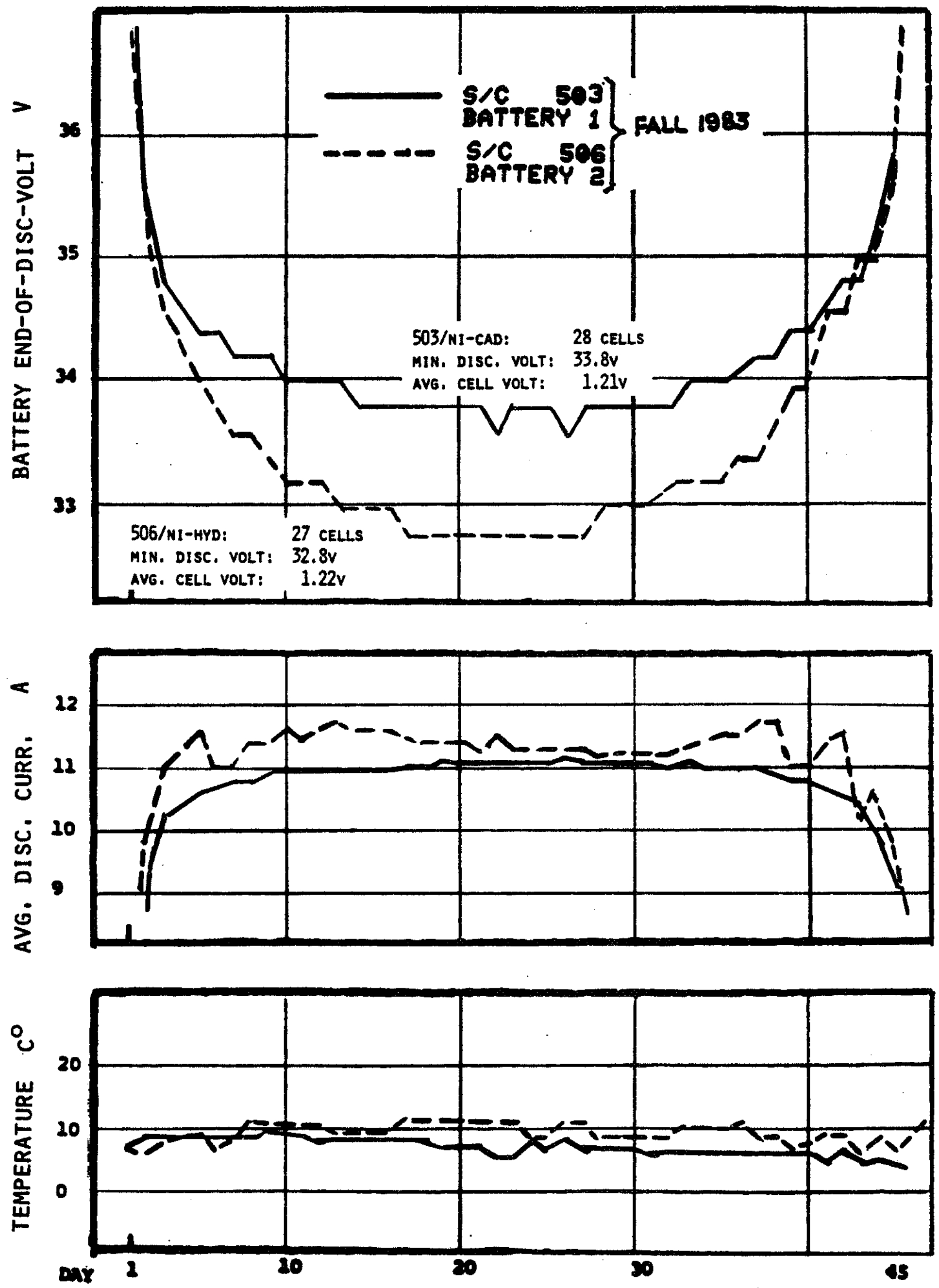


Figure 6. Performance comparison of nickel-cadmium and nickel-hydrogen batteries during eclipse season of fall 1983.

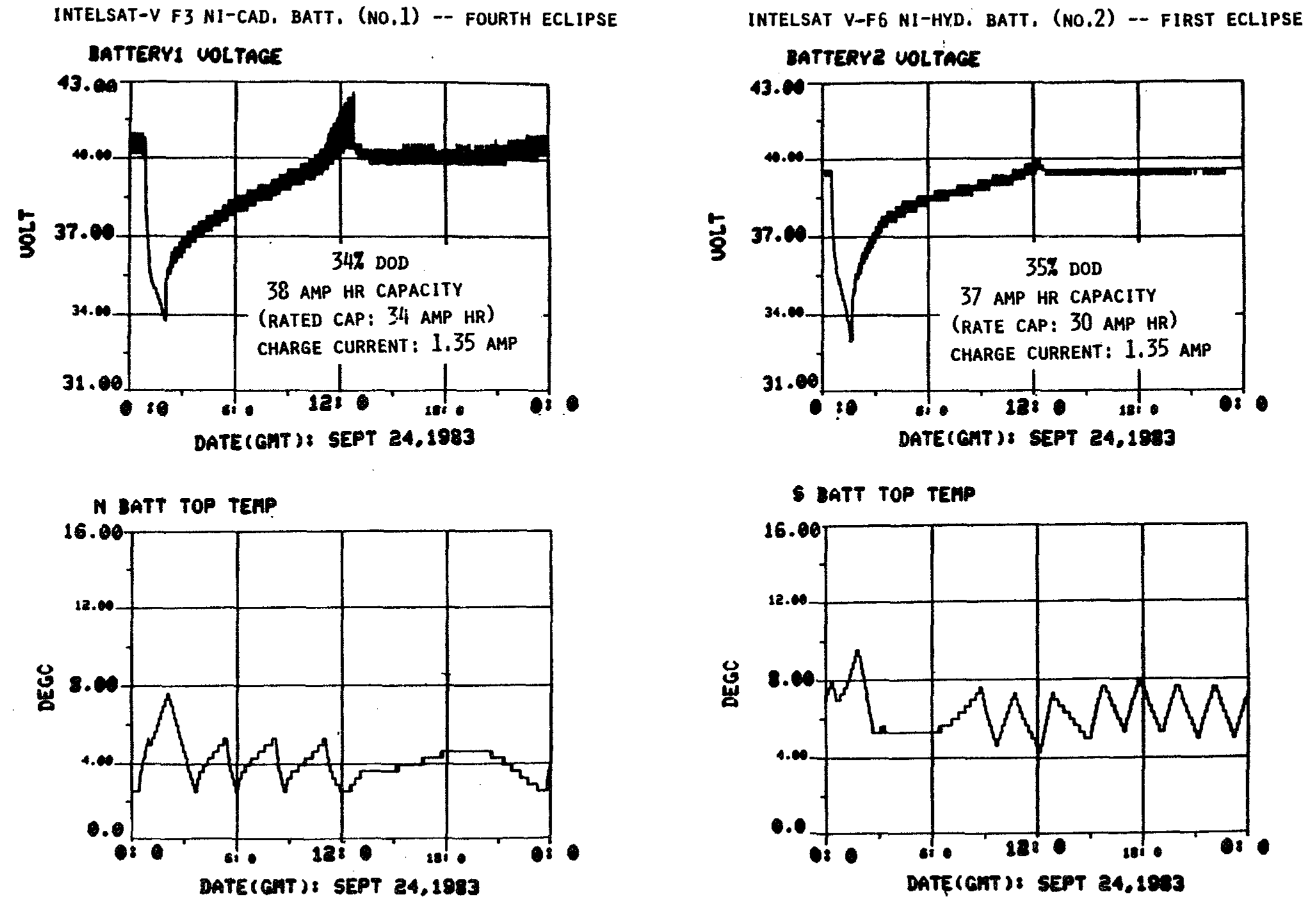


Figure 7. Performance comparison of nickel-cadmium and nickel-hydrogen batteries during longest eclipse of fall 1983.

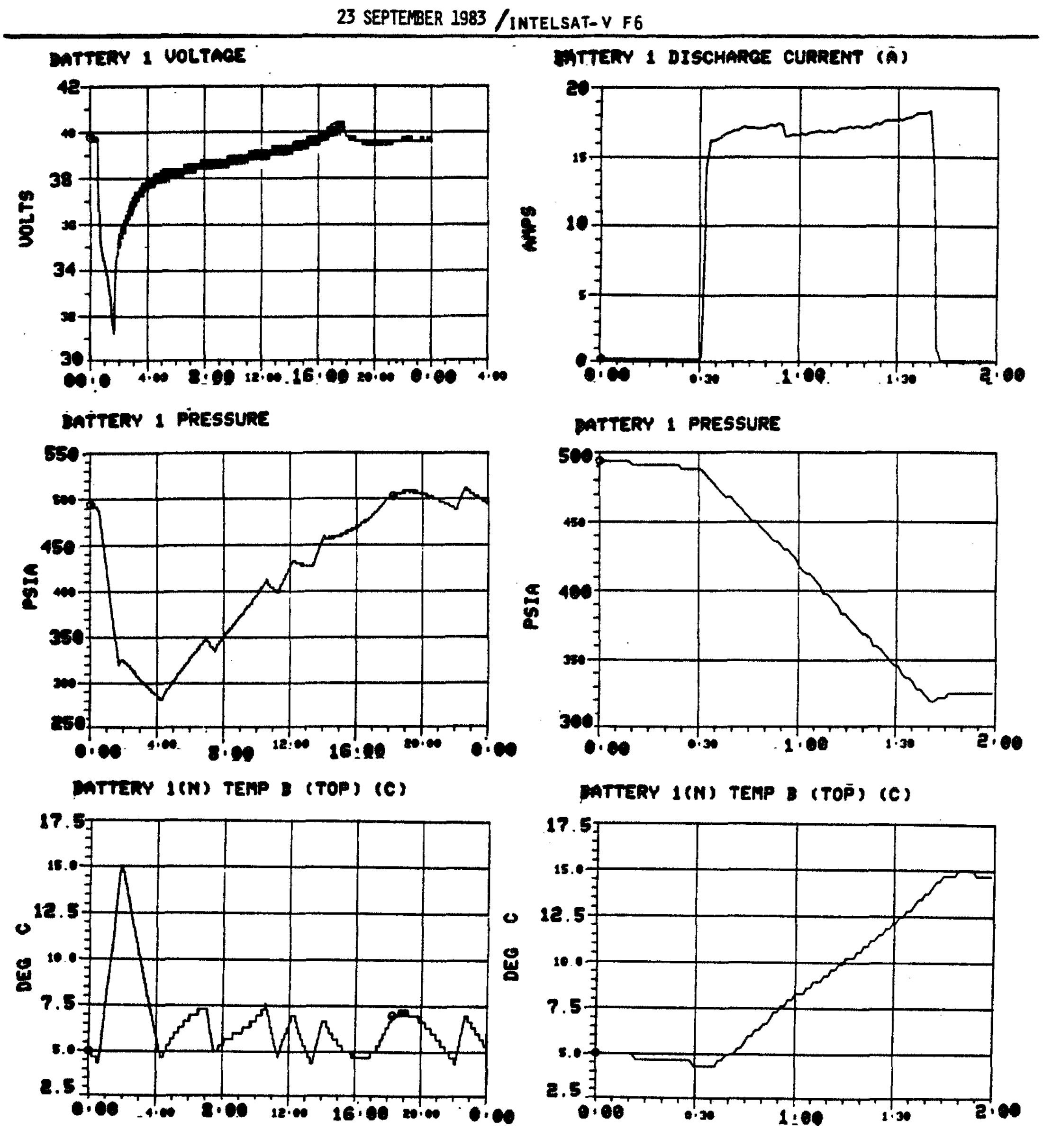


Figure 8. Performance of nickel-hydrogen batteries during eclipse season of fall 1983.

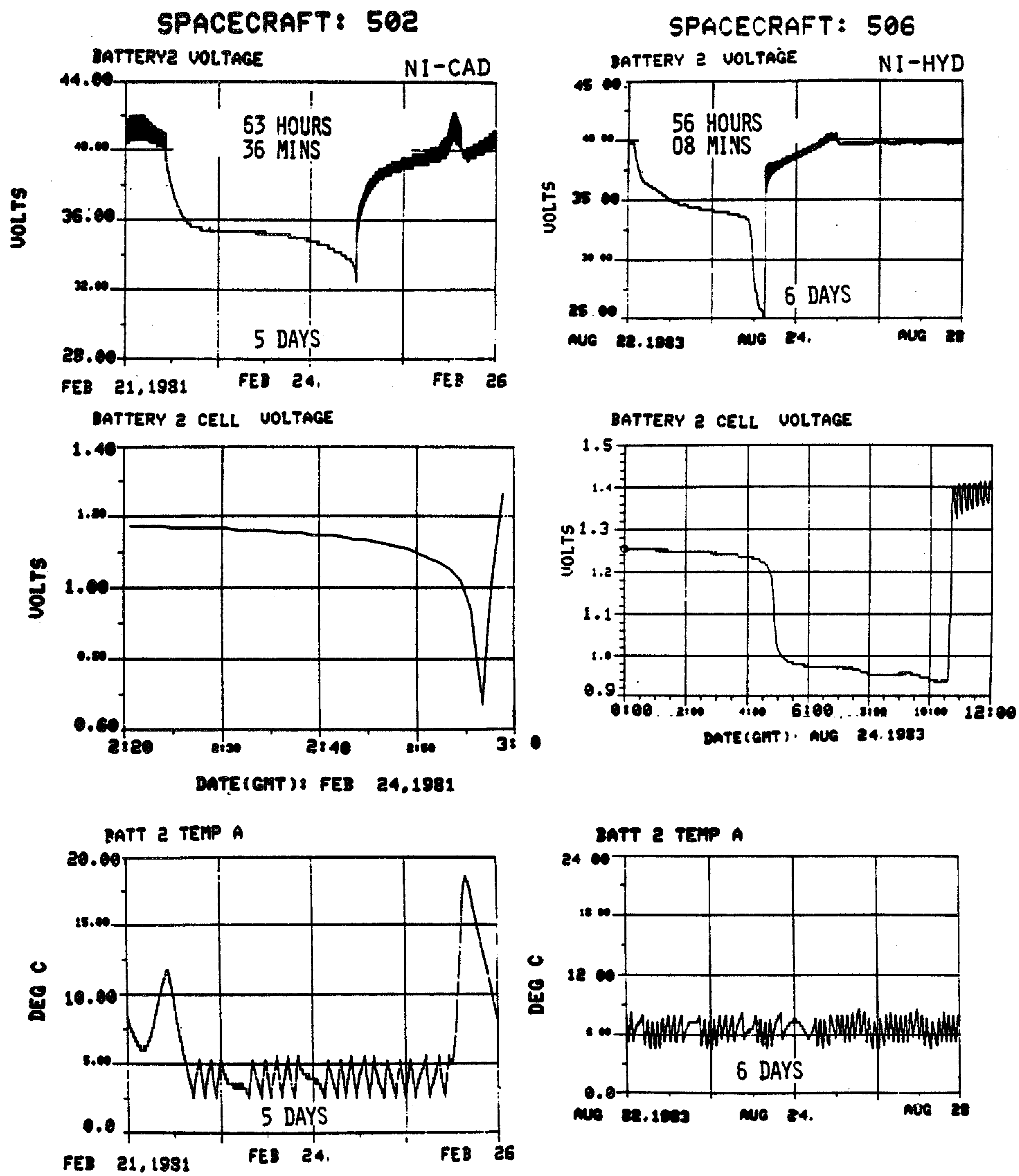


Figure 9. Comparison of nickel-cadmium and nickel-hydrogen batteries during reconditioning.

Q. Rogers, Hughes Aircraft: On the last curve you showed roughly of the .95 volts, is that per cell from a battery average?

A. Cooper, Intelsat: We have individual cell voltages on the spacecraft and we just picked one to show, just an arbitrary choice.

Q. Rogers, Hughes Aircraft: Oh I see. Is that, what is the discharge rate there?

A. Cooper, Intelsat: The discharge rate is about at that time .5 amps or whatever that works out to be. It's a 50 OHM resistor so we are discharging starting out at about .7 and we are down to maybe .5 at this time. Very low rate. That's C over 70.

A. Rogers, Hughes Aircraft: Okay. Low rate. Thank you.

COMMENT

Unidentified: Dennis, just a comment. Isn't there one less cell in nickel hydrogen?

Cooper, Intelsat: Yeah we showed that on one of the first slides maybe I didn't point that out. It's 27 cells on the nickel hydrogen, 28 on the nickel cadmium which obviously makes that first slide like I said if you take the cell out, those numbers the nickel hydrogen would be slightly above the nickel cadmium. I think you can see it is essentially a one volt difference there.

Cooper, Intelsat: Did that answer your question Joe? By the way the measure capacity on the nickel hydrogen I don't know if I mentioned this 37 amp-hours and 38 on the nickel cadmium so they are very close compared to the name plate on the nickel cadmium is 34 and the name plate on the nickel hydrogen is 30 so we have been trying to sort out what C rates to use on all these things. We are having a difficulty presenting this as a matter of fact.

Dunlop, Comsat: A subject has come up a couple of times today so I'm just going to make a comment about the specific energy of these cells and the specific energy of this battery. Specific energy of these cells based on that measured capacity which he just mentioned of 36 is pretty close to 53, 54 watt hours per kilogram. And if you've made, that's a 36 amp-hour cell. If you made that cell bigger the energy per unit weight would go up somewhat because as the capacity increases the rest of the hardware doesn't go up correspondently. If you take those and put that in that battery that he showed there you would find the specific energy per unit weight is something like about 40 to 44 watt hours per killogram and again it depends on the average voltage and where you are talking about beginning life or end of life. But it's something like for the batteries, something like 40 to 44 watt hours per kilogram.