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HIGH RELIABILITY, MAINTENANCE-FREE INS BATTERY DEVELOPMENT

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This report documents the findings of a study undertaken to develop a high reliability, maintenance-free battery (HRMFB) for application in the Litton LTN-72 and Delco Carousel IV Inertial Navigation Systems (INS). The results indicated that the sealed lead-acid battery technology is the best candidate from a cost and risk standpoint. A specification sheet was developed detailing the performance and test requirements for the proposed INS HRMFB.

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EXECUTIVE SUMMARY

This report documents the results of a study to develop a high reliability, maintenance-free battery (HRMFB) for application in the Litton LTN-72 and the Delco Carousel IV Inertial Navigation Systems (INS). These systems currently use vented nickel-cadmium (VNC) batteries, which suffer from low reliability and high maintenance costs. The following battery technologies were investigated as candidate HRMFBs for the INS application: sealed nickel-cadmium (SNC), ultra low maintenance (ULM) nickel-cadmium, and sealed lead-acid (SLA). Functional and physical analysis of the LTN-72 INS and Carousel IV INS determined that all three of these candidate technologies are capable of meeting specification requirements. Compatibility with the existing charging circuitry is a potential problem area with the SNC battery, but incorporation of an electronic control module within the battery case appears to be a workable approach to achieve compatibility. Thus, any one of the candidate HRMFB's can be used to replace existing INS batteries without system modification.

The low reliability and high maintenance costs of the existing VNC battery can be substantially improved by any of the candidate battery technologies. However, the SLA battery technology represents the best alternative for the INS application based on lowest acquisition cost, lowest operating and support (O&S) costs, lowest life cycle cost and lowest technology risk. Changing from the VNC battery to the SLA battery is conservatively projected to achieve the following results:

- Life cycle cost savings of $147 million over a 10-year period
- Payback period of 8 months
- Manpower reduction of 153 maintenance personnel
- Aircraft availability increase of 12 aircraft.

It is recommended that the specification sheet developed under Task 4 be used in the next phase of the program to procure preproduction units for qualification and flight tests. The qualified and validated design will then serve as the basis for competitive procurement of the production units for fleetwide integration.

1.0 INTRODUCTION

A wide variety of Air Force and Navy Weapon Systems utilize either the LTN-72 or Delco Carousel IV Inertial Navigation System (INS), both of which require a dedicated battery. Vented nickel-cadmium (VNC) batteries are currently used for this application, but these batteries suffer from high maintenance costs. In addition, multiple versions of the INS battery exist encompassing eight different National Stock Numbers (NSNs). Some versions contain 15-minute cells, while other versions contain 30-minute cells. However, all versions have the same basic footprint and mounting provisions. Therefore, further cost reductions are possible by replacing the multiple versions with one standard version.

The objective of this program was to develop a common, 30-minute INS battery specification utilizing High Reliability, Maintenance-Free Battery (HRMFB) technology. Recent experience with HRMFBs has demonstrated significant reliability and maintainability (R&M) improvements and cost reductions compared with conventional vented battery technology. Originally, two types of HRMFBs were considered to be potentially viable for this application: sealed lead-acid (SLA) batteries and sealed nickel-cadmium (SNC) batteries. A third type of HRMFB, the ultra low maintenance (ULM) nickel-cadmium battery, was later included as part of the investigation. The SLA type has found widespread use in aircraft applications, whereas the SNC and ULM types have found few applications to date. However, the SNC and ULM types may offer advantages over the SLA type for certain applications. Therefore, all three battery types were investigated to determine which one would be the best candidate for the INS application.

The Statement of Work (SOW) was divided into the following four tasks:

- Task 1 - System Analysis
- Task 2 - Battery Selection
- Task 3 - Life Cycle Cost Analysis
- Task 4 - Specification Development.

This final report covers the results of Tasks 1 through 4, and is the final deliverable required by the contract.

2.0 SYSTEM ANALYSIS

2.1 General Description of Litton LTN-72 and Delco Carousel IV INS [1]*

The LTN-72 INS and Carousel IV INS are old systems, having been introduced nearly 20 years ago. Each INS consists of a navigation unit (NU), control and display unit (CDU), mode selector unit (MSU), and battery unit (BU). The fundamental method used by each INS to accomplish the navigation function is the sensing and measurement of acceleration. Each INS contains a precision, gyro-stabilized platform on which acceleration sensors (accelerometers) are mounted. The platform is housed in the NU along with a digital computer, which performs the navigation computations. So equipped, each INS calculates and monitors track, groundspeed, heading, drift angle, wind direction, and velocity and position (latitude and longitude). Insertion of the desired flight plan (waypoint coordinates) provides the INS with the information necessary to compute flight plan related information, such as desired track, cross track distance, track angle error, and distance and time to the next waypoint (a point on the earth to be overflown). All of this information can be called up and displayed on the CDU. In addition to performing primary navigation functions, each INS is also a source for en route steering signals for the autopilot and signals for flight instruments.

2.1.1 Navigation Unit

The NU is normally installed in a prealigned avionics rack mounted within the avionics equipment bay. Temperature control is provided for the NU in this location from the aircraft environmental control system.

The NU senses all airplane movement and produces all INS output signals. The INS has three functional sections that operate together to determine all navigation and attitude output signals. Located in the navigation unit, these sections are the stabilized platform, electronics, and

* References are listed in Section 8.0.

digital computer. The platform, a four-gimbal assembly, is controlled to maintain a vertical and horizontal reference with respect to the earth from which all airplane movement is measured. Gyros, accelerometers, torque motors, synchros, and resolvers are mounted on the platform. These devices,with the electronics, form stabilization and accelerometer loops. The gyros sense platform movement around the pitch and roll axes and generate output signals that are routed to the electronics, along with travel-over-the-earth corrections signals from the computer. The electronic outputs drive the torque motors which correct for platform movement. The accelerometers sense acceleration along the pitch and roll axes of the airplane and provide corresponding signals to the computer where they are translated into information required for navigation calculations. In addition to its function in the stabilization and accelerometer loops, the electronics also conditions and distributes input power and controls the temperature of the platform.

The NU digital computer is a binary, serial machine that continuously performs many computations at high speed. The computer performs the following functions:

a. Solves great circle navigation problems.

b. Provides great circle, en route steering signals.

c. Provides navigation data to the control and display unit and airplane equipment.

d. Provides system status information to the control and display unit and airplane equipment.

e. Provides gyro torquing signals used to maintain the platform's earth reference.

f. Monitors operation of the INS and issues malfunction information (malfunction codes) to the control and display unit and airplane equipment.

g. Monitors gyro and accelerometer characteristics during platform alignment and performs calibration calculations that are used in solving navigation problems.

h. Transmits and accepts inertial position data from other INS systems aboard the aircraft and performs a mix to derive the best estimate of present position and associated navigation information.

i. Provides for aided-inertial operation where TACAN navigational radio inputs are used to update navigation calculations in conjunction with INS mix results.

In performing these functions, the digital computer enables the platform to stabilize at a reference attitude and provide signals proportional to changes in airplane attitude and velocity. The digital computer translates these signals into complete navigation data for display and airplane navigation.

2.1.2 Control/Display Unit

The CDU is normally installed in the flight station console. The CDU serves as the communications link between the operator and the navigation unit digital computer. All pertinent navigation data are displayed on the CDU in decimal form. The CDU is also used to insert flight plan data, select waypoints, which determine desired track, and monitor system operation and status. The CDU contains a power supply, logic circuits, controls and indicators. The controls and indicators are used to insert information into the computer and to display information contained within the computer. The logic circuits transform inserted data into digital form (binary-coded decimal), which in turn are transformed into visual, numerical displays. The CDU also displays system operating status.

2.1.3 Mode Selection Unit

The MSU is normally installed in the flight station console, in close proximity to the CDU. The MSU contains a selector and two indicators. The selector provides the pilot/copilot with the means of selecting system modes of operation. The selector has five positions: OFF, STBY, ALIGN, NAV, and ATT. The STBY and ALIGN positions normally are used on the ground only, while the NAV and ATT positions are associated with in-flight functions.

2.1.4 Battery Unit

The BU is normally mounted on the floor of the avionics equipment bay. Temperature control is provided for the BU in this location from the aircraft environmental control system, as with the NU. The BU provides reserve power for the INS, should the 115-volt primary input power be interrupted, or should it drop below the minimum allowable voltage level. The battery is nominally rated at 24 volts, and is charged by a charging circuit contained within the NU. A circuit breaker on the front of the BU protects it from excessive current flow.

2.2 Physical Analysis of the BU

The BU in each INS is a 19-cell VNC battery that comes in multiple versions depending on time of rated performance (15 or 30 minutes) and venting provisions (louvered versus forced-air vented). Table 2-1 lists the different configurations of INS batteries developed by the original equipment manufacturers (Litton and Delco), along with a cross-reference of battery manufacturer part numbers designations. Table 2-2 gives the physical characteristics for the batteries listed in Table 2-1 [2,3]. Additional data are provided in Appendix A for the Delco Carousel IV INS and in Appendix B for the Litton LTN-72 INS. The battery case is equivalent to an Aeronautical Radio, Inc. (ARINC) Specification 404A short 1/2 ATR case [4]. The Litton battery specifications allow for an option of forced ventilation of the BU via a vent hole on the back of the BU, which mates with a vacuum line on the rack upon which it sits. Such venting appears to be very uncommon in military weapon systems. Interestingly, only the Litton 30-minute BU uses the full height allowed by the ARINC specification.

Examination of Table 2-2 reveals that one 30-minute battery using HRMFB technology could replace all the 30-minute batteries listed if its maximum height were limited to 6.3 inches. This same 30-minute HRMFB also could be used as a replacement for the 15-minute batteries, provided that the additional weight does not present a problem. As presented later in Section 2.4, the 15-minute INS battery is widely used in Navy aircraft (P-3, C-130), and only in a small number of Air Forc. aircraft (E-3, KC-10). The Navy has

TABLE 2-1. INS BATTERY PART NUMBERS

			Alternate Part Nos.		
Battery Part No.	INS Type	National Stock No.	Marathon	SAFT	Eagle-Picher
500012-01	LTN-72	6140-00-283-7855	28002-001		
500012-02	LTN-72	Not assigned	28002-002		
500040-03	LTN-72	6140-01-078-1108 6140-01-074-7150	28695-001		
510014-01	LTN-72	6140-01-302-3815	29449-001		
510018-01	LTN-72	6140-01-200-4773			18085
7883480-011	Carousel IV	6140-00-449-9839	27826-002	19535	
7888701-011	Carousel IV	6140-01-106-1306 6140-01-047-0185	28656-002	19536	

TABLE 2-2. INS BATTERY PHYSICAL CHARACTERISTICS

Battery Part No.	INS Type	Capacity, minutes	Max. Weight, lbs	Max. Height, in.	Max. Length[(a)], in.	Max. Width[(b)], in.	Venting
500012-01	LTN-72	15	17	6.281	12.62	5.077	Louvered
500012-02	LTN-72	15	17	6.281	12.62	5.077	Forced
500040-03	LTN-72	30	26.5	7.65	12.62	5.077	Forced
510014-01	LTN-72	30	27	7.65	12.62	5.077	Louvered
510018-01	LTN-72	30	26.5	7.65	12.62	5.077	Forced
7883480-011	Carousel IV	15	17	6.312	12.697	5.046	Louvered
7888701-011	Carousel IV	30	27	6.312	12.697	5.046	Louvered

(a) Length does not include handles.
(b) Width includes lid.

indicated that added weight associated with a 30-minute version would be acceptable. In the Air Force E-3, added weight could be difficult to accommodate, so the 30-minute battery may not be acceptable for this particular weapon system. In the case of the KC-10, weight is not considered an issue, and the 30-minute battery should be an acceptable alternative.

2.3 Functional Analysis of the BU

For the purpose of this investigation, the primary function of the INS is not particularly important. However, the details of the functional interaction of each INS with its BU is crucial to establishing the compatibility of the candidate technologies. The single purpose of the BU is to provide back-up power to the INS in the case of loss of primary aircraft power. In each INS, the charging circuitry for the BU is contained within the NU, and control circuitry for the BU is contained in the NU, CDU and MSU. Figure 2-1 documents the functional interfaces between the BU and NU, CDU and MSU for the Carousel IV INS [5-7]. Likewise, Figure 2-2 documents the functional interfaces for the Litton LTN-72 INS [8-14].

With the Carousel IV INS, a 12.8-second load of approximately 200 watts is placed on the BU during INS start-up. This is a battery worthiness test and if the battery voltage falls below 16.5 volts (measured within the NU), then the INS shuts down and start-up cannot proceed. With the LTN-72, the BU experiences discharge only upon loss of primary power; there are no provisions for a load test. The unloaded battery voltage is sensed, however, to determine if the battery voltage is above 18 volts. If the battery voltage is below this value, then the INS cannot initiate start-up.

Figures 2-3 and 2-4 illustrate the charging profiles for the Carousel IV INS and LTN-72 INS, respectively. The information presented in these figures was derived from Delco documentation [3,5,6] and Litton documentation [2,13,14], respectively. In the main charging mode, the LTN-72 charger provides an unregulated, half-wave rectified output, while the Carousel IV charger provides a constant current output. The main differences between the two systems is the voltage cut-off for the main mode charge. This cut-off is set at 29 volts in the Carousel IV and at 27 volts in the LTN-72.

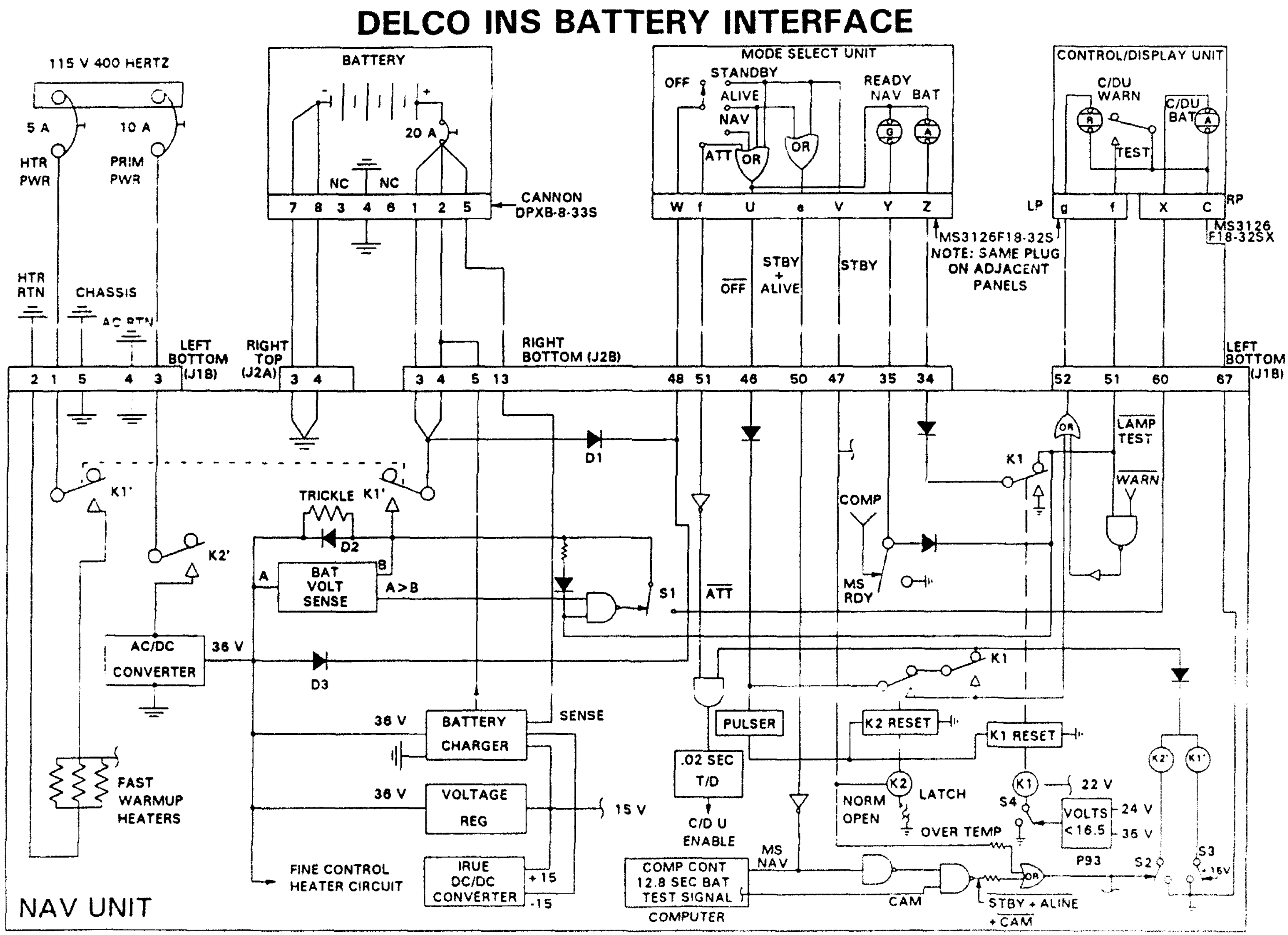


FIGURE 2-1. CAROUSEL IV INS BATTERY INTERFACE SCHEMATIC

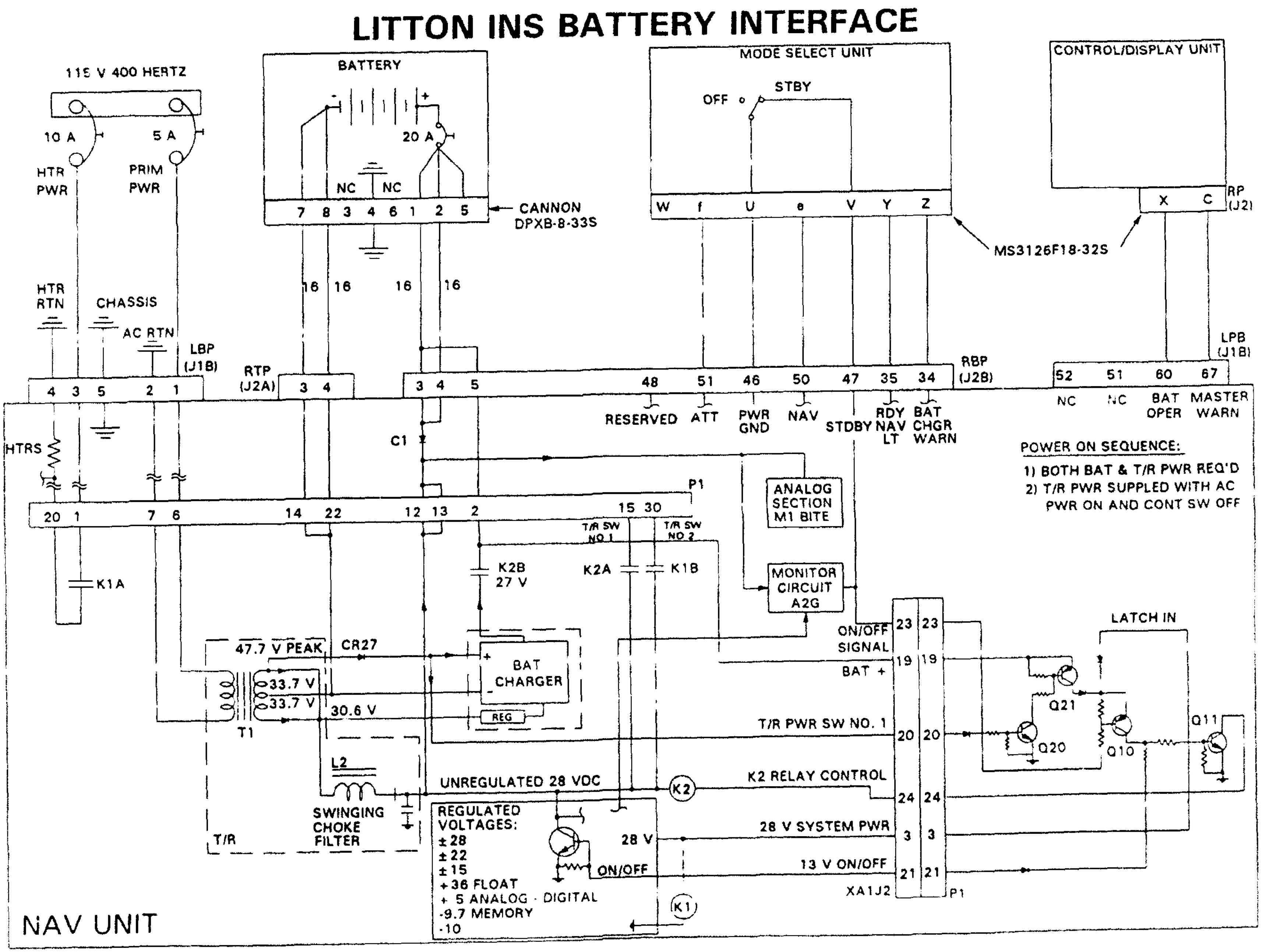


FIGURE 2-2. LTN-72 INS BATTERY INTERFACE SCHEMATIC

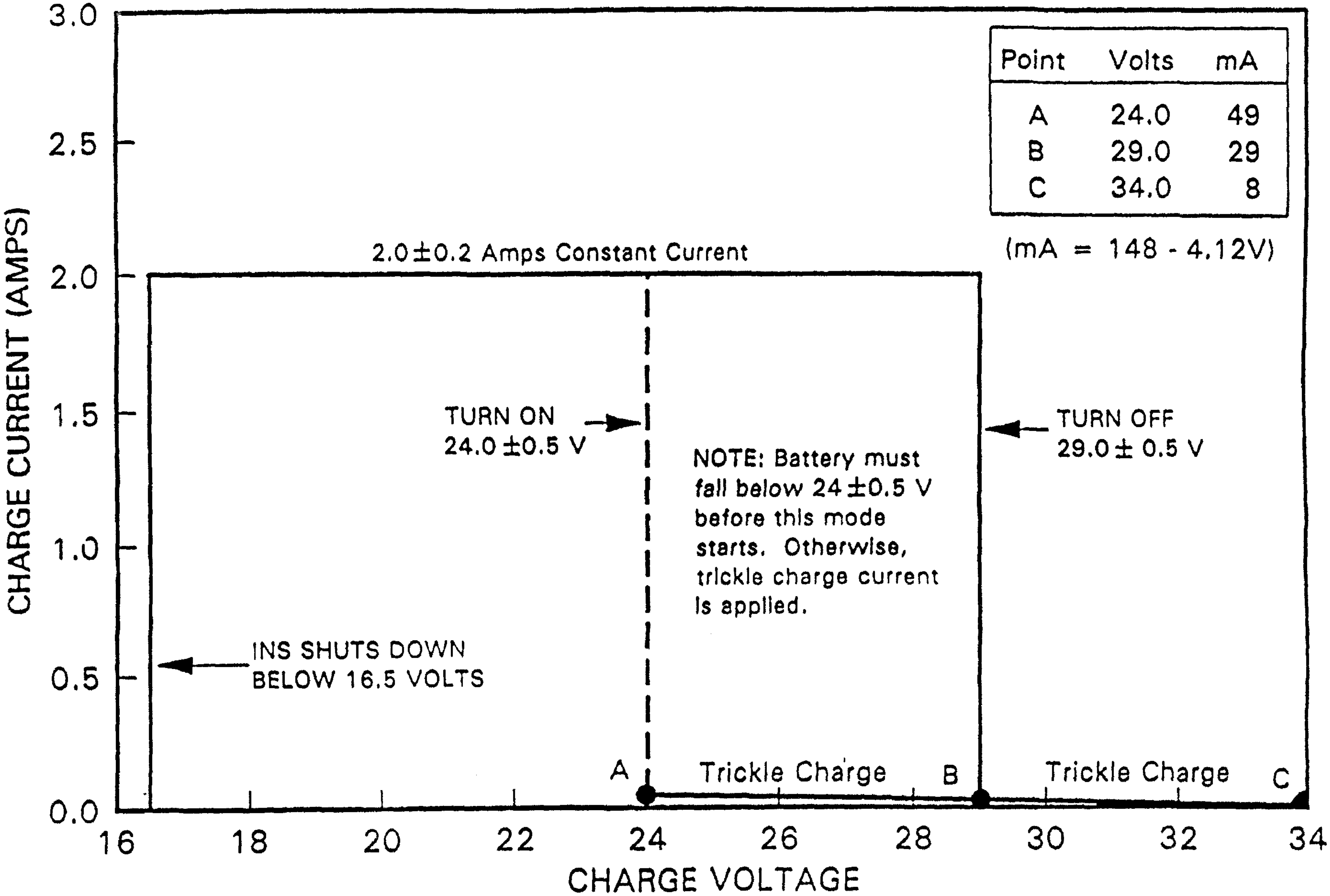


FIGURE 2-3. CAROUSEL IV INS BATTERY CHARGE PROFILE

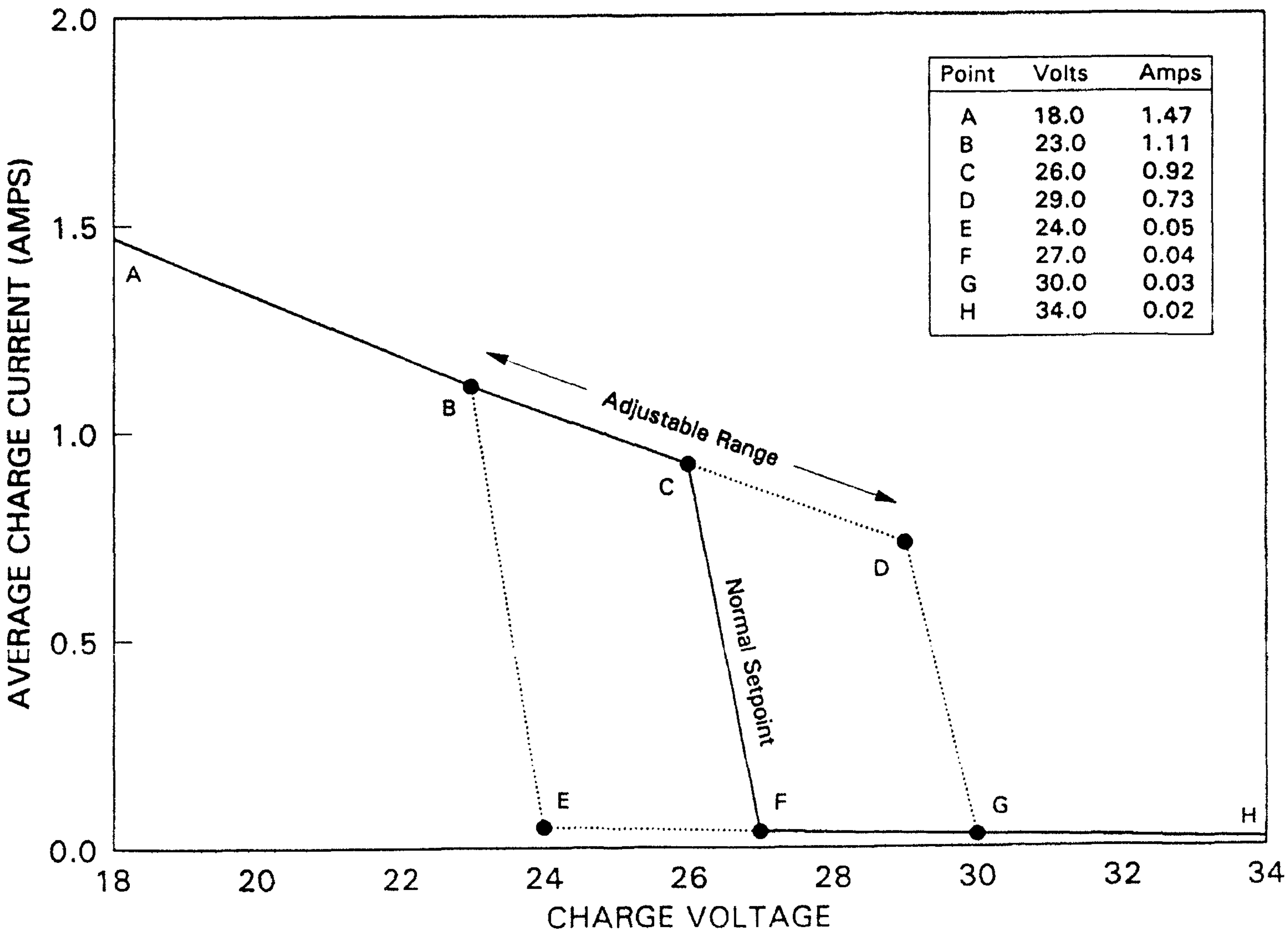
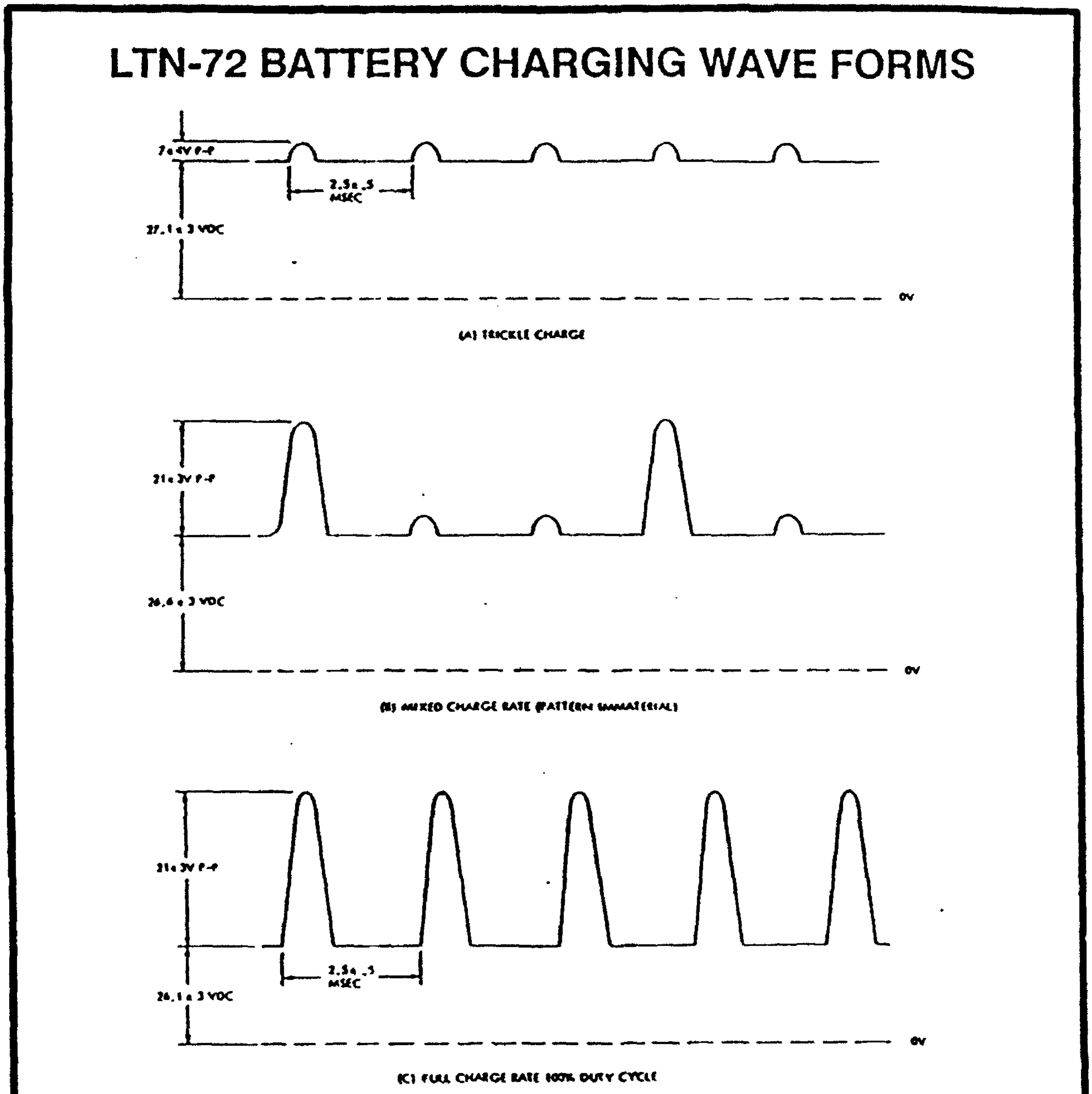


FIGURE 2-4a. LTN-72 INS BATTERY CHARGE PROFILE



Source: Litton TP72155-20

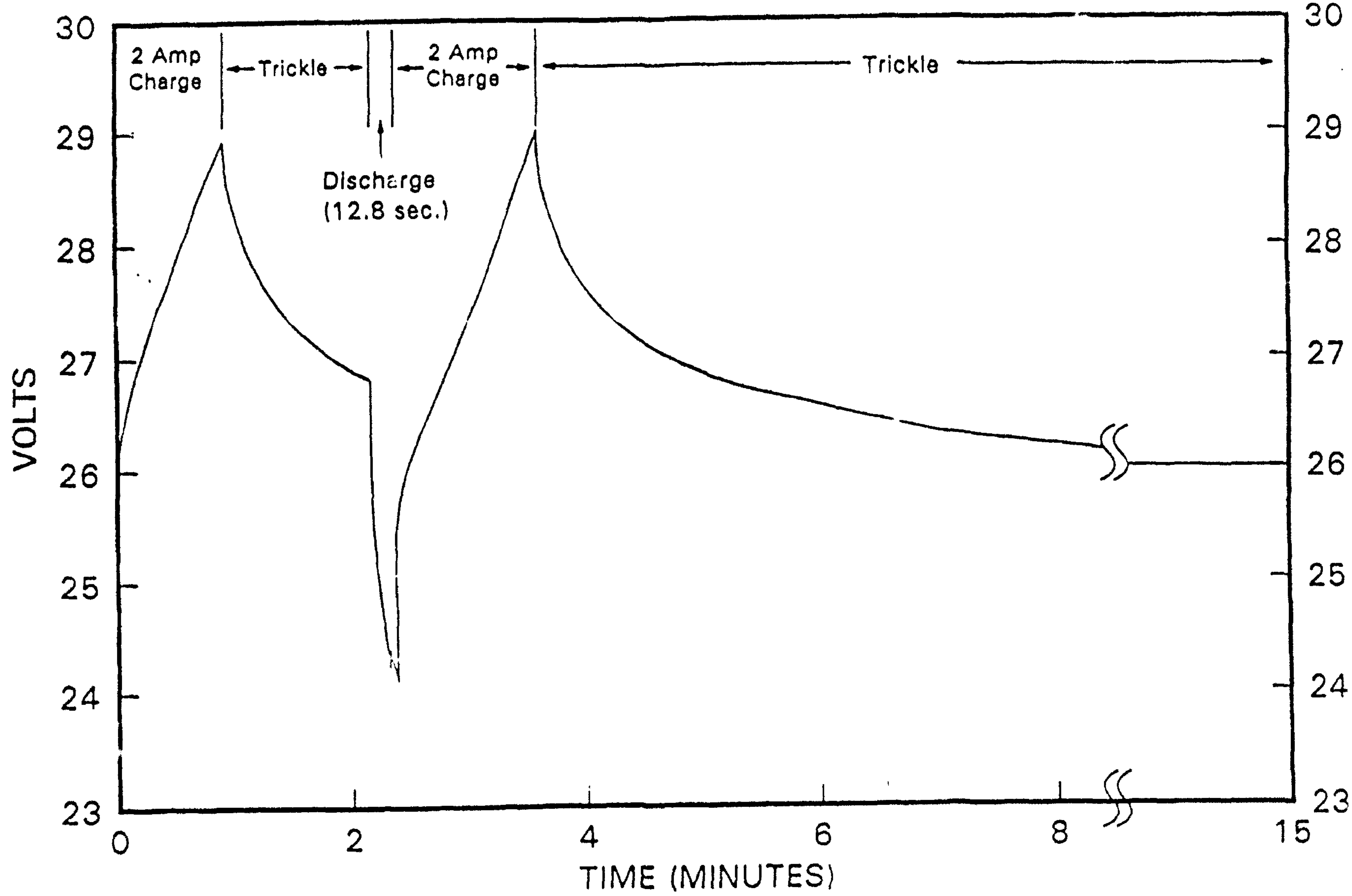
FIGURE 2-4b. LTN-72 INS BATTERY CHARGE PROFILE

Electrical measurements on both types of INS were made to verify the details of Figures 2-3 and 2-4. Measurements by Battelle on a C-5A aircraft (Figures 2-5 and 2-6) confirmed the details of Figure 2-3, except that the battery immediately went into high current charge upon INS start-up, even though the battery voltage was not below 24.0 ± 0.5V. Discussion with Delco has revealed that the charge initiation trigger of the Carousel IV INS is erratic; the electronics of a particular Delco INS may work either way. Fortunately, this behavior is not expected to adversely affect the BU. Measurements by the Navy on a P-3 aircraft (Figure 2-7) confirmed most details of Figure 2-4. The apparent noise was caused by a slow sampling frequency (approximately 4 hertz) when collecting the 400 hertz charger output waveform.

Further testing of the LTN-72 charger output was conducted at Battelle to determine the magnitude of the ripple voltage, as seen at the battery terminals. Testing was done using a Hawker 24 volt/15 Ah SLA battery to measure the ripple waveforms in full and trickle modes. A simplified charging circuit was used for this test, as shown in Figure 2-8. Charging curves, showing the resulting trickle waveform and full charge waveform, are given in Figures 2-9 and 2-10, respectively. The results indicate that the ripple voltage at the battery terminals, 10 mV peak in the trickle mode and 80 mV peak in the full mode, is negligible for the battery technologies under consideration.

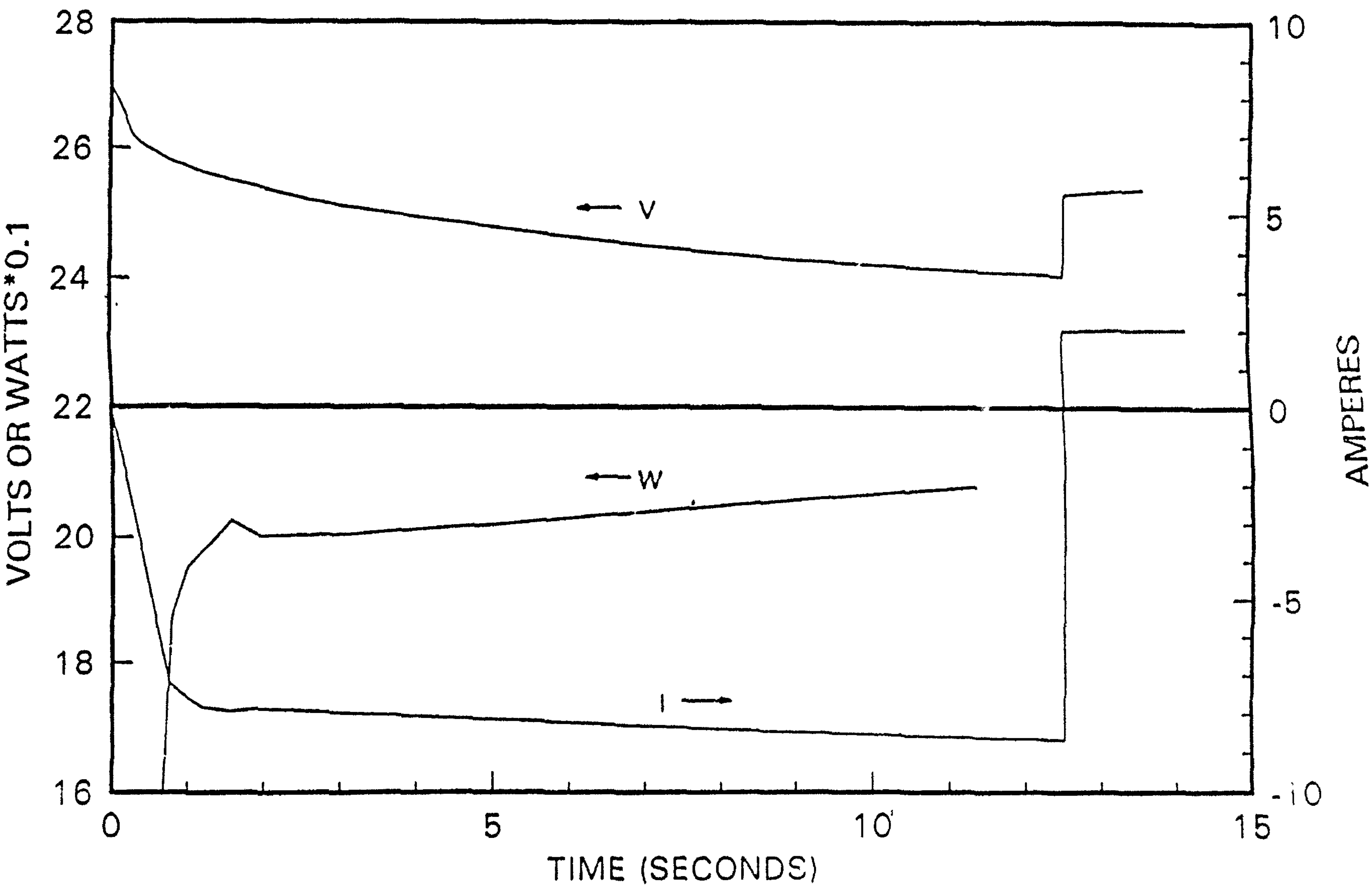
Table 2-3 gives the electrical requirements for the INS battery according to Delco and Litton specifications. The Carousel IV power requirement (400 W continuous, 425 watts peak) is slightly higher than that of the LTN-72 (375 watts continuous), although the actual loads as measured on the P-3 and C-5 are about one half of the specification values (see Figures 2-6 and 2-7). The full 15-minute or 30-minute performance is only required to 40-41 F; below this temperature, the minimum discharge duration is undefined (except for the 1-minute peak load at 0 F with the Carousel IV). The minimum voltage requirement is higher with the Carousel IV INS than with the LTN-72 INS (21 volts versus 19 volts). The 20-ampere circuit breaker is standard, except for one of the 30-minute Litton batteries (Part No. 500040-03), which has a 25-ampere circuit breaker. The reason for the higher rating on this particular battery is unknown.

Table 2-4 gives the battery environmental requirements according to Delco and Litton specifications. The operational temperature range of the



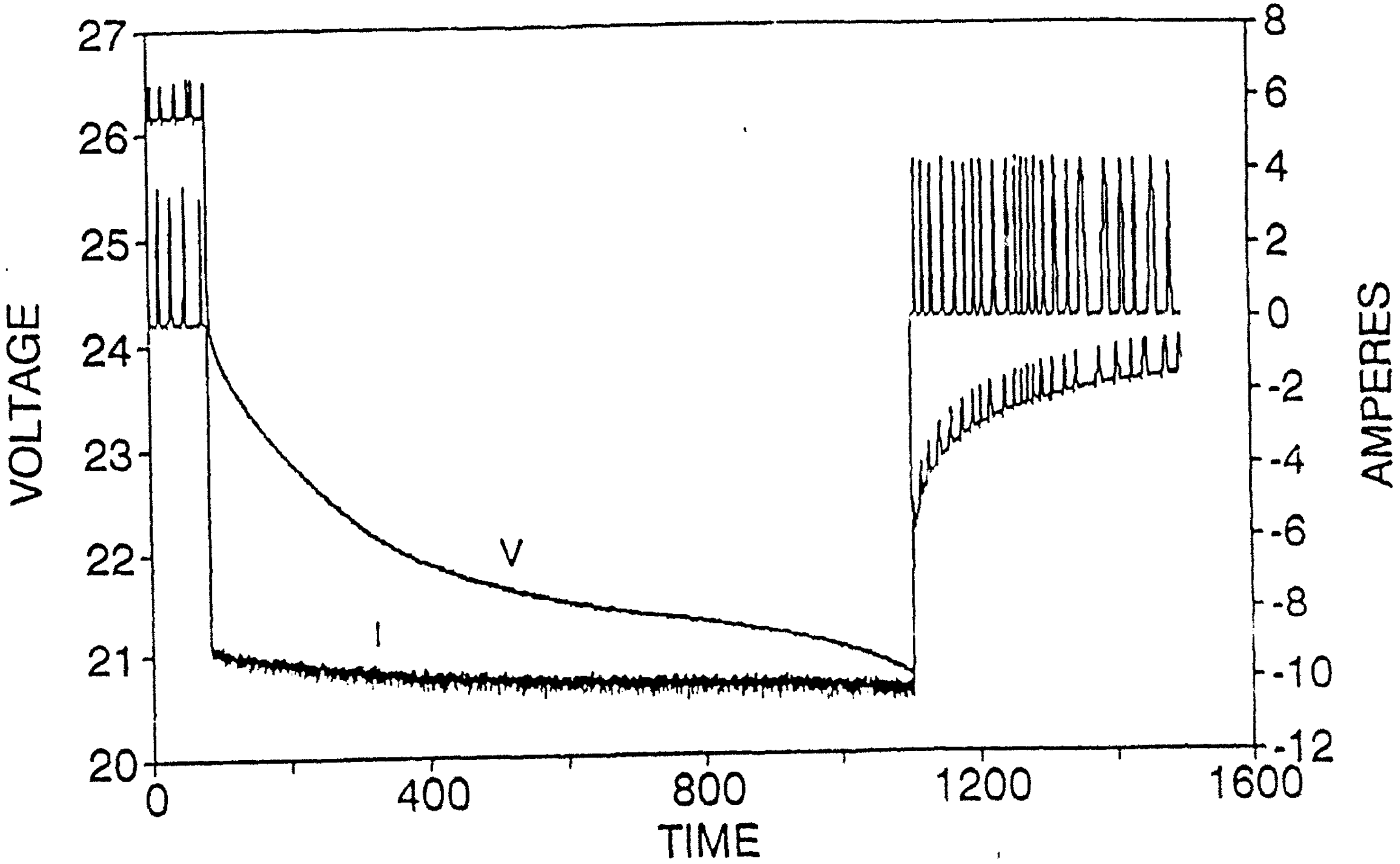
Measured on C-5A on 2-13-92

FIGURE 2-5. CAROUSEL IV INS BATTERY CHARGE TEST



C-5A DATA MEASURED ON 2-13-92

FIGURE 2-6. CAROUSEL IV INS BATTERY LOAD TEST



Data Measured on P-3 by Navy

FIGURE 2-7. LTN-72 INS BATTERY CHARGE TEST

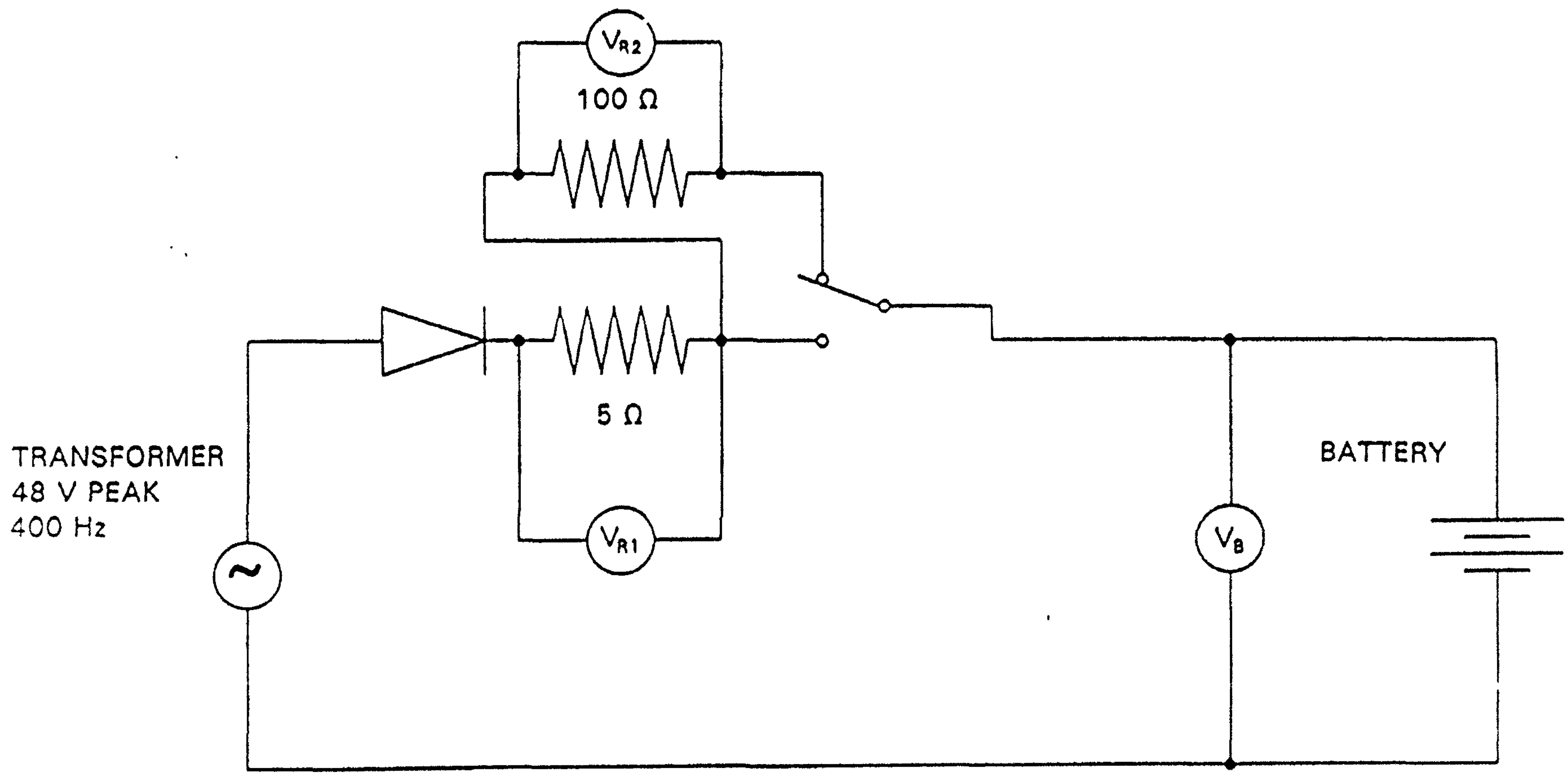


FIGURE 2-8. SIMPLIFIED LTN-72 CHARGE CIRCUIT

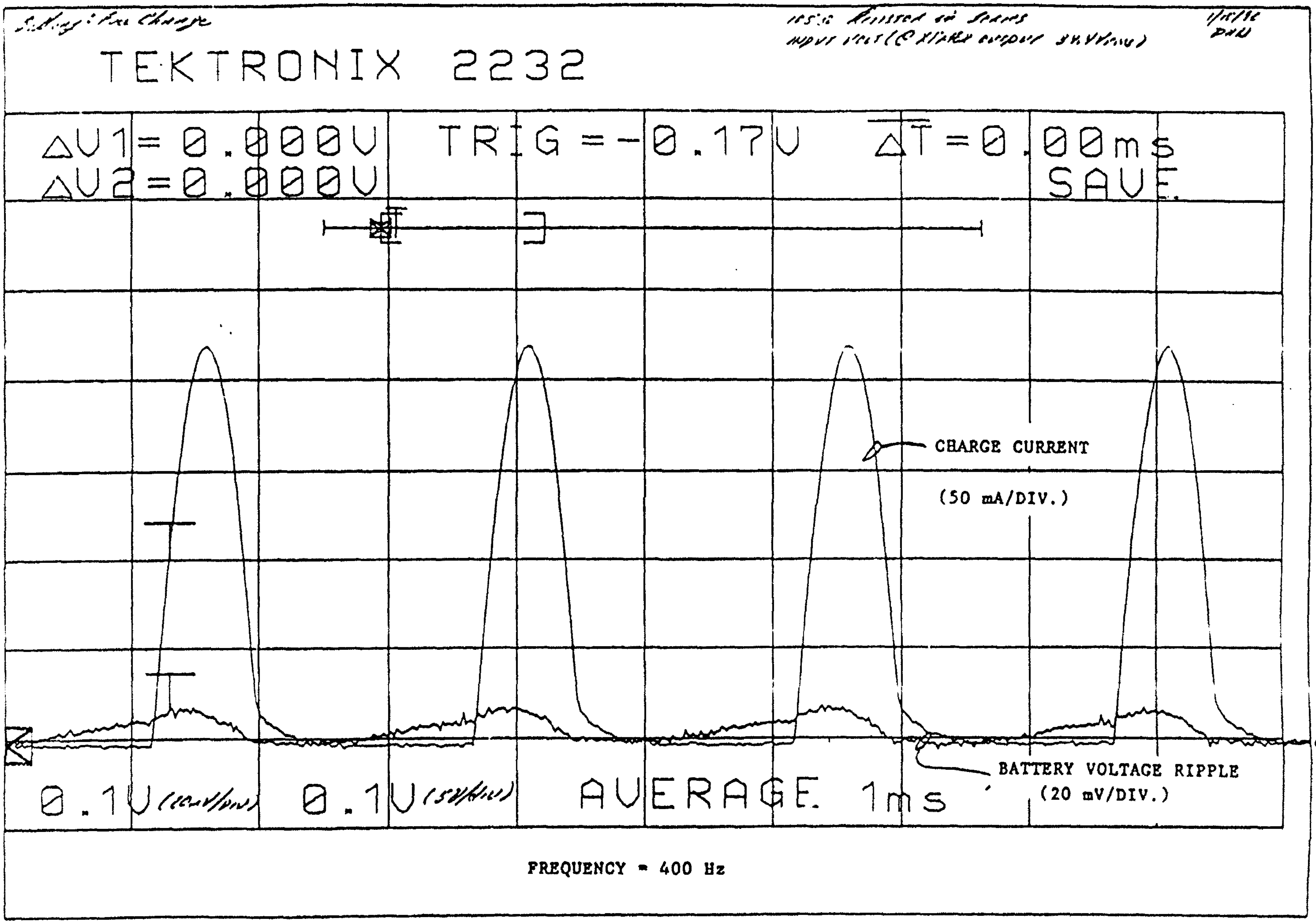


FIGURE 2-9. SLA BATTERY TRICKLE CHARGE WAVEFORM USING SIMPLIFIED LTN-27 CHARGE CIRCUIT

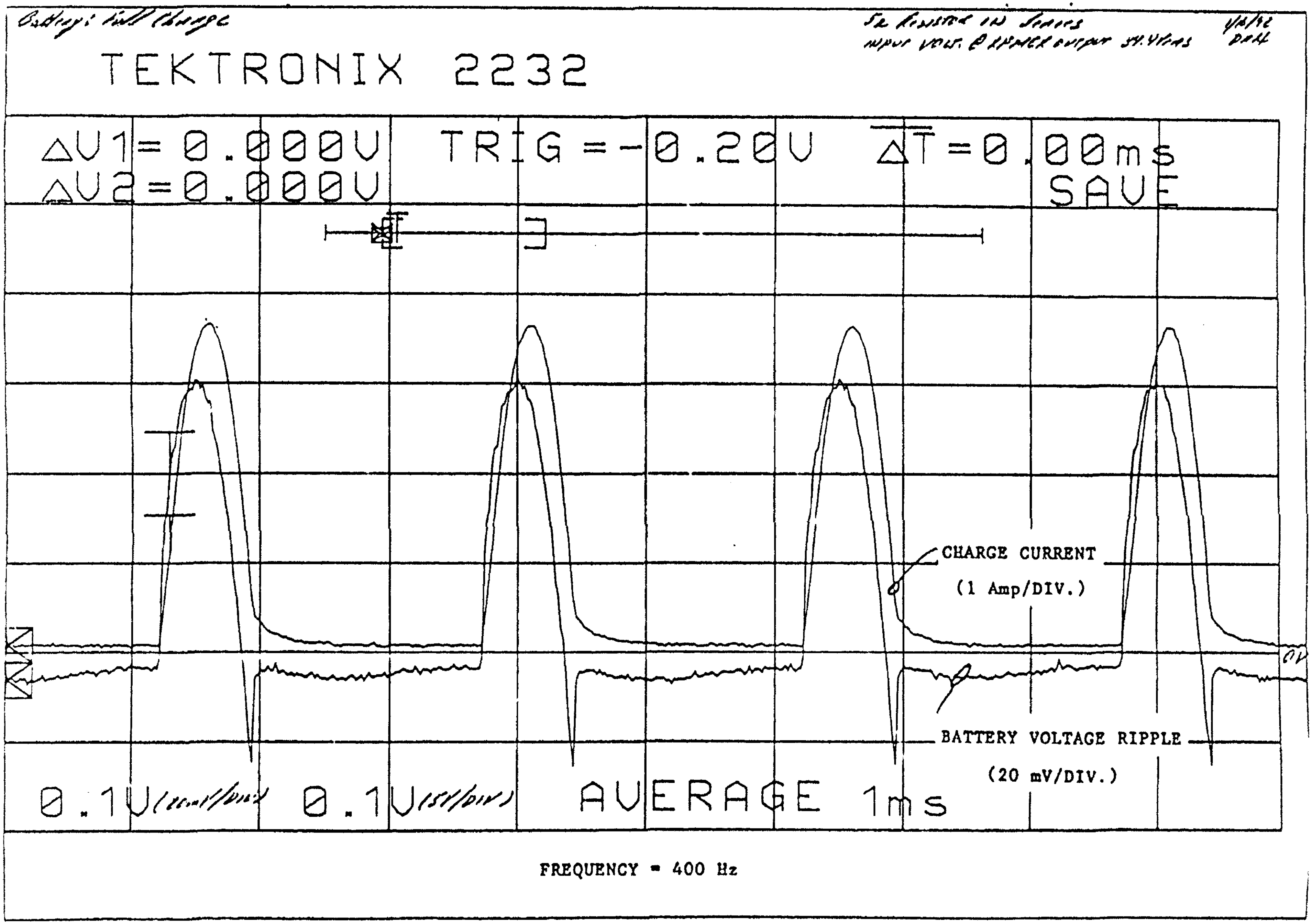


FIGURE 2-10. SLA BATTERY FULL CHARGE WAVEFORM USING SIMPLIFIED LTN-27 CHARGE CIRCUIT

TABLE 2-3. INS BATTERY ELECTRICAL REQUIREMENTS

	Litton Specifications		Delco Specifications	
Parameter	**15-Minute Battery**	**30-Minute Battery**	**15-Minute Battery**	**30-Minute Battery**
Nominal Voltage	24 volts DC	24 volts DC	24 volts DC	24 volts DC
Nominal Capacity	6.5 Ah @ C/5 rate	15 Ah @ C/5 rate	6.5 Ah @ C/5 rate	15 Ah @ C/5 rate
Circuit Breaker	20 Amperes	20 amperes 25A on P/N 500040-03	20 amperes	20 amperes
Power Output	375 W (continuous)	375 W (continuous)	400 W (continuous) 425 W (peak)	400 W (continuous) 425 W (peak)
• Minimum Duration* • Minimum Voltage	15 minutes (40-122 F) 19.0 volts	30 minutes (40-122 F) 19.0 volts	15 min. @ 400W (41-160 F) 1 min. @ 425 W (0-160 F) 21.0 volts	30 min. @ 400 W (41-160 F) 1 min. @ 425 W (0-160 F) 21.0 volts

* Minimum duration is undefined outside of indicated temperature range.

battery extends to -40 F with the LTN-72 and to 0 F with the Carousel IV. The -40 F limit is interpreted as the minimum charging temperature, and the 0 F limit is interpreted as the minimum discharge temperature. The other environmental requirements (humidity, altitude, vibration and shock) are relatively straightforward. However, the environmental test methods cited in the original battery specifications are about 20 years old, and are now obsolete. For example, MIL-F-5272 [15] has been superseded by MIL-STD-810 and RCTA DO-138 [16] has been superseded by RCTA DO-160C [17]. For new INS batteries, test methods will have to be adapted in accordance with current environmental specifications. Based on comparison with environmental requirements given in current aircraft battery specifications (e.g., MIL-B-8565), these requirements pose little concern for the battery technologies under consideration.

2.4 INS Applications

Tables 2-5 and 2-6 provide an inventory of all known aircraft applications that currently utilize the Carousel IV or LTN-72 INS in the Navy and Air Force, respectively. The total number of INS batteries tabulates to 858 for the Navy and to 2,996 for the Air Force. A figure of 926 total installs was quoted by the Navy INS Inventory Manager at North Island, which matches well with the Navy tabulation. In the Air Force inventory, there are modifications in process that will change the total number of installed INS batteries. For example, the INS battery on the MH-60 is planned to be deleted and the INS will be backed up using a SLA main battery (D8565/11-1). Also, the Air Force C-130's are planning to replace the existing VNC INS battery with a different size SLA battery (D8565/5-1).

Tables 2-7 and 2-8 give reliability and maintainability data for INS batteries used by Navy and Air Force aircraft, respectively. The mean time between failures (MTBF) for the Navy aircraft is 834 hours, whereas the MTBF for the Air Force aircraft is 450 hours. On the other hand, the mean time between removals (MTBR, excluding scheduled removals) for the Navy aircraft is 140 hours and the MTBR for the Air Force aircraft is 1480. Part of this disparity may be due to the fact that the Navy has a 112-day scheduled maintenance interval, while the Air Force has a 60-day scheduled maintenance interval.

TABLE 2-4. INS BATTERY ENVIRONMENTAL REQUIREMENTS

Parameter	Litton Specification (500040)	Delco Specification (ST 7890436)
Surrounding Temperature Storage Operational Full Performance	 -65 to 165 F -40 to 140 F +40 to 122 F	 -65 to 160 F 0 to 160 F +41 to 160 F
Humidity	95% RH max. Test per RTCA DO-138, Category B	95% RH max. Test per MIL-E-5272, Procedure 1
Altitude Normal Operation Emergency Operation Decompression	 < 22,300 ft. < 48,300 ft. 8,200 to 40,000 ft. in 10 min.	 1,000 to 25,000 ft. 100 to 45,100 ft. 9 psi drop to 45,100 ft. in 15 sec.
Vibration	RTCA DO-138, Category K&O	MIL-E-5272C, Procedure XII
Shock	10 G max. for 12 milliseconds Test per RTCA DO-138, Section 6.0	15 G max. for 11 milliseconds Test per MIL-E-5272C, Procedure V

TABLE 2-5. US NAVY INS BATTERY APPLICATIONS

Aircraft	TAI	QPA	Installs	INS Type	Battery P/N
P-3A	29	1	29	LTN-72	500012-01
P-3B	110	1	110	LTN-72	500012-01
P-3C	257	2	514	LTN-72	500012-01
EP-3E	12	2	24	LTN-72	500012-01
C-130F	7	1	7	LTN-72	500012-01
KC-130F	40	1	40	LTN-72	500012-01
EC-130Q	14	2	28	LTN-72	500012-01
KC-130R	14	1	14	LTN-72	500012-01
LC-130R	4	1	4	LTN-72	500012-01
KC-130T	19	2	38	LTN-72	500012-01
PINS	50	1	50	LTN-72	500012-01
TOTAL	556		858		

KEY: TAI = Total Active Inventory
QPA = Quantity Per Aircraft
Installs = Total INS Battery Installs (TAI X QPA)
PINS = Palletized INS

TABLE 2-6. US AIR FORCE INS BATTERY APPLICATIONS

AIRCRAFT	TAI	QPA	INSTALLS	INS TYPE	BATTERY P/N
C-5A	77	3	231	C-IV	7888701-011
C-5B	50	3	150	C-IV	7888701-011
C-9A	20	1	1	LTN-92	500040-03
C-9C	3	1	3	LTN-92	500040-03
KC-10A	59	3	177	LTN-72	500012-01
C-18A	1	2	2	C-IV	7888701-011
C-18B	1	2	2	C-IV	7888701-011
EC-18B	4	2	8	C-IV	7888701-011
EC-18D	1	2	2	C-IV	7888701-011
C-22A	1	2	2	C-IV	7888701-011
C-22B	4	2	8	C-IV	7888701-011
VC-25A	2	3	6	LTN-92	?
C-27A	20	1	5	LTN-92	?
C-130E	280	1	50	C-IV	7888701-011
C-130H	194	2	225	C-IV	7888701-011
EC-130E	15	1	15	C-IV	7888701-011
EC-130H	13	1	3	C-IV	7888701-011
HC-130H	3	1	1	C-IV	7888701-011
HC-130N	19	1	3	C-IV	7888701-011
HC-130P	34	1	5	C-IV	7888701-011
LC-130H	4	2	8	C-IV	7888701-011
NC-130H	1	1	1	C-IV	7888701-011
WC-130E	6	1	3	C-IV	7888701-011
WC-130H	6	1	1	C-IV	7888701-011
C-135A	2	2	4	C-IV	7888701-011
C-135B	4	2	8	C-IV	7888701-011
C-135C	3	2	6	C-IV	7888701-011
C-135E	3	2	6	C-IV	7888701-011
EC-135A	5	2	10	C-IV	7888701-011
EC-135C	13	2	26	C-IV	7888701-011
EC-135E	4	2	8	C-IV	7888701-011
EC-135G	4	2	8	C-IV	7888701-011
EC-135H	3	2	6	C-IV	7888701-011
EC-135J	4	2	8	C-IV	7888701-011
EC-135K	2	2	4	C-IV	7888701-011
EC-135L	5	2	10	C-IV	7888701-011
EC-135N	1	2	2	C-IV	7888701-011
EC-135P	4	2	8	C-IV	7888701-011
EC-135Y	1	2	2	C-IV	7888701-011
KC-135A	170	2	340	C-IV	7888701-011
KC-135E	163	2	326	C-IV	7888701-011
KC-135Q	54	2	108	C-IV	7888701-011
KC-135R	246	2	492	C-IV	7888701-011
NC-135A	1	2	2	C-IV	7888701-011
WC-135B	7	2	14	C-IV	7888701-011
NKC-135A	8	2	16	C-IV	7888701-011
NKC-135E	1	2	2	C-IV	7888701-011
C-137B	3	1	3	LTN-72	?
C-137C	4	2	8	LTN-72	?
C-141B	266	2	532	C-IV	7888701-011
NC-141A	4	2	8	C-IV	7888701-011
E-3B	24	2	48	C-IV	7883480-011
E-3C	10	2	20	C-IV	7883480-011
E-4B	4	3	12	C-IV	7888701-011
MH-60G	49	1	16	C-IV	7888701-011
T-43A	19	1	19	LTN-72	?
TOTAL	1909		2996		

KEY: TAI = TOTAL ACTIVE INVENTORY
QPA = QUANTITY PER AIRCRAFT
INSTALLS = TOTAL INS BATTERY INSTALLS (USUALLY TAI X QPA)
C-IV = CAROUSEL IV

TABLE 2-7. NALDA DATA FOR NAVY AIRCRAFT

Aircraft	Equipment Flight Hours	Failures	Removals	Total Man-Hours	MTBF (a)	MTBR (b)	Flight Hrs Per Man-Hour	Man-Hours Per Removal
P-3A	1886	-	3	79	-	629	24	-
P-3B	53048	64	273	5463	829	194	10	20
P-3C	214888	246	1978	26143	874	109	8	13
EP-3E	10161	14	62	1309	726	164	8	21
C-130F	7873	3	15	231	2624	525	34	15
KC-130F	27280	23	40	1427	1186	682	19	36
EC-130Q	8914	59	87	545	151	102	16	6
KC-130R	9986	-	-	-	-	-	-	-
LC-130R	4402	-	1	2	-	4402	2201	2
KC-130T	11007	10	30	582	1101	367	19	19
TOTAL	349445	419	2489	35781	-	-	-	-
AVERAGE	-	-	-	-	834	140	10	14

(a) MTBF = Mean Time Between Failures (Flight Hours ÷ No. Failures).
(b) MTBR = Mean Time Between Removals (Flight Hours ÷ No. Removals).

TABLE 2-8. MODAS DATA FOR USAF AIRCRAFT

Aircraft	Equipment Flight Hours	Failures	Removals	Total Man-Hours	MTBF (a)	MTBR (b)	Flight Hrs Per Man-Hour	Man-Hours Per Failure
C-5A	353649	944	424	9174	375	834	39	10
C-5B	390879	79	275	5760	502	1421	68	7
C-9C	2624	4	4	19	656	656	138	5
KC-10A	355428	80	71	288	4443	5006	1234	4
EC-18B	2050	43	6	786	48	342	3	18
KC-135A	132527	1086	229	9903	122	579	13	9
KC-135E	121182	703	86	6370	172	1409	19	9
KC-135Q	37811	125	30	1397	302	1260	27	11
KC-135R	168233	929	150	7787	181	1122	22	8
EC-135C	13443	87	14	1094	155	960	12	13
C-141B	1402578	1841	742	22794	762	1890	62	12
T-43A	27746	60	1	294	462	27746	94	5
TOTAL	3008150	6681	2032	65666	-	-	-	-
AVERAGE	-	-	-	-	450	1480	46	10

(a) MTBF = Mean Time Between Failures (Flight Hours ÷ No. Failures).
(b) MTBR = Mean Time Between Removals (Flight Hours ÷ No. Removals).

3.0 BATTERY SELECTION

The following ground rules were applied to establish a baseline for comparing each candidate battery technology:

- The new BU must retain the same form and fit as the smallest existing 30-minute BU (i.e., Delco Part No. 7888701-011).
- The new BU must be compatible with the Carousel IV INS and LTN-72 INS without system modification.
- The new BU must be commercially available in the 1993-1994 time frame (this precludes rechargeable technologies presently being developed, such as lithium.)
- The new BU must be able to meet all the performance, environmental, and functional requirements presently met by the original BU. However, a slight weight increase (1-2 lb) is considered acceptable for the new BU.

3.1 Candidate Technologies

Based on the ground rules specified above, three candidate HRFMB technologies were identified that would be potentially viable. These three technologies are sealed nickel-cadmium (SNC), ultra low maintenance nickel-cadmium (ULM) and sealed lead-acid (SLA), as discussed previously. The leading manufacturers of these technologies are as follows:

- ACME Advanced Energy Systems - SNC
- Eagle-Picher Industries (EPI) - SNC
- SAFT - ULM
- Concorde Battery Corporation - SLA
- Hawker Energy Products - SLA.

The ACME SNC battery is a gas-recombinant, starved electrolyte system utilizing fiber structured electrode plaques. The EPI SNC battery is also a gas-recombinant, starved electrolyte system, but sintered electrode plaques are utilized. The SAFT ULM is not a sealed cell, but partial gas recombination minimizes the amount of water loss during overcharge.

Conventional sintered electrode plaques are utilized in the ULM. The Concorde SLA battery is a gas-recombinant, starved electrolyte system utilizing lead-calcium electrode grids. The Hawker SLA battery is a gas-recombinant, starved electrolyte system utilizing pure lead electrode grids.

Table 3-1 gives a listing of cell sizes presently available from these manufacturers. These sizes were investigated first to determine if any would fit within the INS battery size constraints. Out of these existing cell sizes, only one was identified that could be used without form factor modification, viz., the EPI 3112 cell. In all other cases, a new cell configuration was deemed necessary.

Table 3-2 gives the results of preliminary cell sizing for INS application. These data were generated through discussions with the various battery manufacturers, based on the ground rules stated above. The cell ratings shown in Table 3-2 represent a conservative estimate of the capacity that can fit within the required battery envelope. The technical comparisons made in the following sections were based on these cell ratings.

TABLE 3-2. PRELIMINARY CELL SIZING FOR INS BATTERY

Battery Technology	EPI SNC	ACME SNC	SAFT ULM	Concorde SLA	Hawker SLA
Cell Part No.	3112 (existing)	New	New	New	New
Capacity Rating @ C-Rate (Ah)	12	13	12	10-12	10-12
No. Cells Required	19/20	19/20	19/20	12	12
Cell Design Effort	None	Substantial	Minimal	Substantial	Moderate

3.2 Technology Comparison

Several technical areas were investigated in detail to identify any inherent limitations that would preclude any of the candidates from meeting the baseline requirements, or that would represent a significant deficiency when compared with the other technologies. The areas investigated were the discharge performance, charge performance, heater blanket provisioning, service life and shelf life.

TABLE 3-1. EXISTING CELL SIZES

EPI SNC		ACME SNC		SAFT ULM		Concorde SLA		Hawker SLA	
Type	Rating	Type	Rating	Type	Rating	Type	Rating	Type	Rating
3105	5 Ah	KCFX7	7 Ah	V023-ULM-1	20 Ah	RG8-10	10 Ah/8V	SBS 15	10 Ah/12V
3106	6 Ah	KCFX7S	7 Ah	V023-ULM-2	20 Ah	RG24-12	12Ah/24V	SBS 30	18 Ah/12V
3108	8 Ah	KCFX15	15 Ah	V034-ULM-1 (XP53157)	30 Ah	RG12-17	17 Ah/12V	SBS 31	18 Ah/10V
3112	12 Ah	KCFX18	18 Ah	V034-ULM-2	30 Ah	RG12-24	24 Ah/12V	SBS 40	25 Ah/12V
3212	12 Ah	KCFH19	19 Ah @ C/5	V056-ULM-2 (XP53121)	50 Ah	RG12-28	28 Ah/12V	SBS 41	25 Ah/12V
3117	17 Ah	KCFXX45	52 Ah			RG24-28	28 Ah/24V	SBS 60	37 Ah/12V
3223	23 Ah					RG24-36	36 Ah/24V	SBS 110	65 Ah/6V
3140	40 Ah					RG24-40	40 Ah/24V	SBS 114	65 Ah/4V
3160	70 Ah					RG24-44	44 Ah/24V	SBS 300	200 Ah/2V

Note: All ratings are at C-rate unless otherwise specified.

3.2.1 Discharge Performance

Figures 3-1 and 3-2 compare the energy density (watt-hours/liter) and specific energy (watt-hours/kilogram) of the five candidates, respectively. These data are based on the actual dimensions and weight of single cells (or monoblocs for the SLA types) using their rated capacities and nominal voltages. The SLA batteries have less capacity per unit volume and per unit weight compared with the nickel-cadmium types, although the difference is not great. The SLA values from the two different manufacturers were very close to each other, while a wide variation was found among the different varieties of nickel-cadmium types. The highest energy density was found with the EPI SNC, which had a energy density about 27 percent higher than the SLA batteries.

To determine if the candidate technologies could meet the discharge performance requirements, discharge test data at the rated load (400 watts or equivalent scaled for cell size) were obtained from the manufacturers over the full range of temperature (-40 F to 160 F). These data are summarized in Figure 3-3. The 30-minute minimum requirement down to 40 F is that given by the Litton and Delco battery specifications (Table 2-3). The 20-minute minimum requirement down to 0 F was taken from a Boeing 747 INS battery specification. The results indicate that the discharge performance of all candidates complies with the specified discharge requirements, with an acceptable degree of margin.

3.2.2 Charge Performance

Compatibility with the INS charging circuits turned out to be a key consideration. Each manufacturer was asked to provide charging data for their batteries at 80, 120, and 160 F using a 2-ampere constant current charge until the voltage roll-over point was reached. This was done to determine the compatibility of the battery charge voltage with the different cut-off voltage set points built into the LTN-72 INS and Carousel IV INS (27 volts versus 29 volts). Of primary concern was that the roll-over point would occur below the voltage cut-off, causing the charger to remain in the main charge mode and the

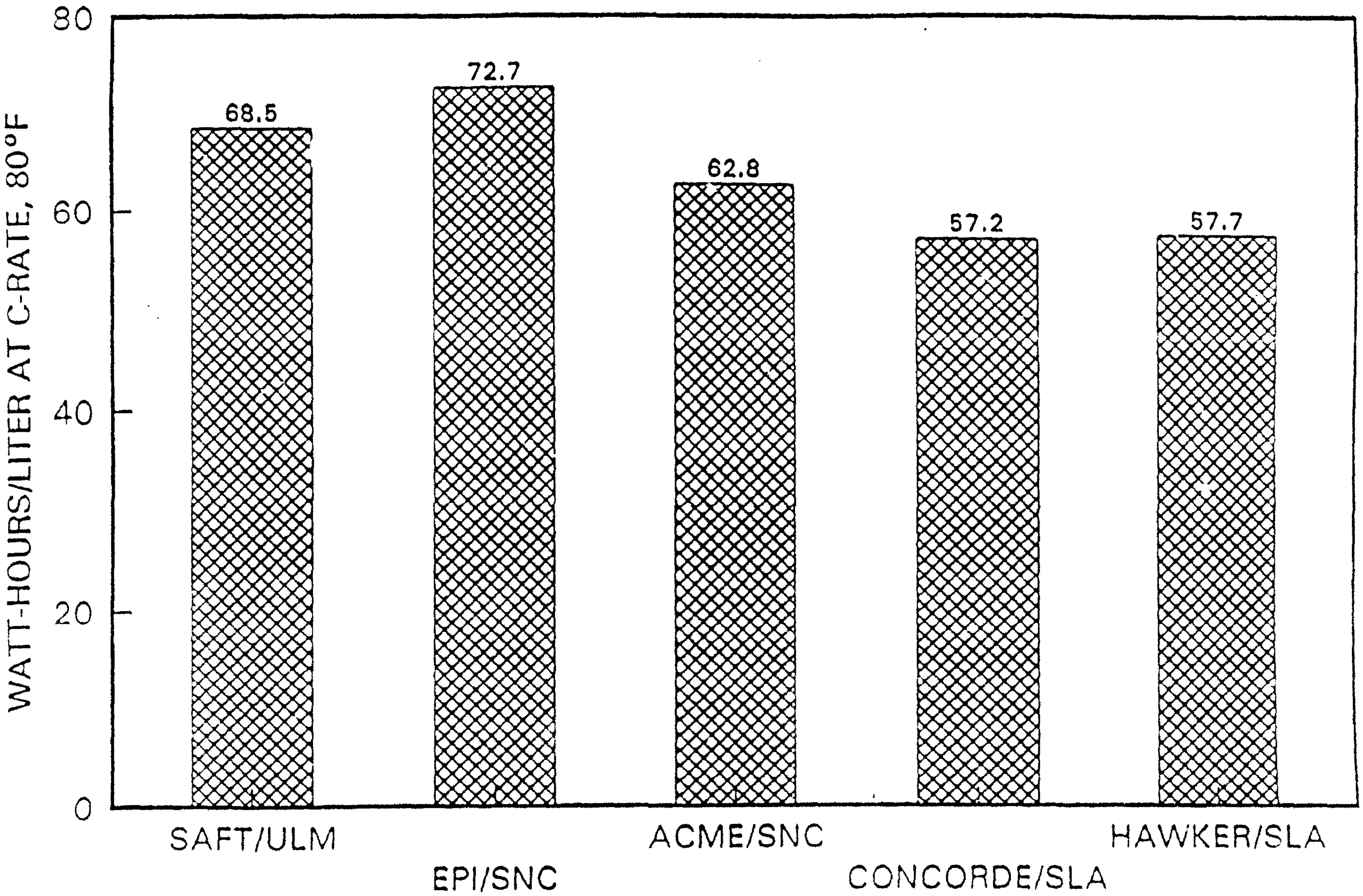


FIGURE 3-1. ENERGY DENSITY COMPARISON

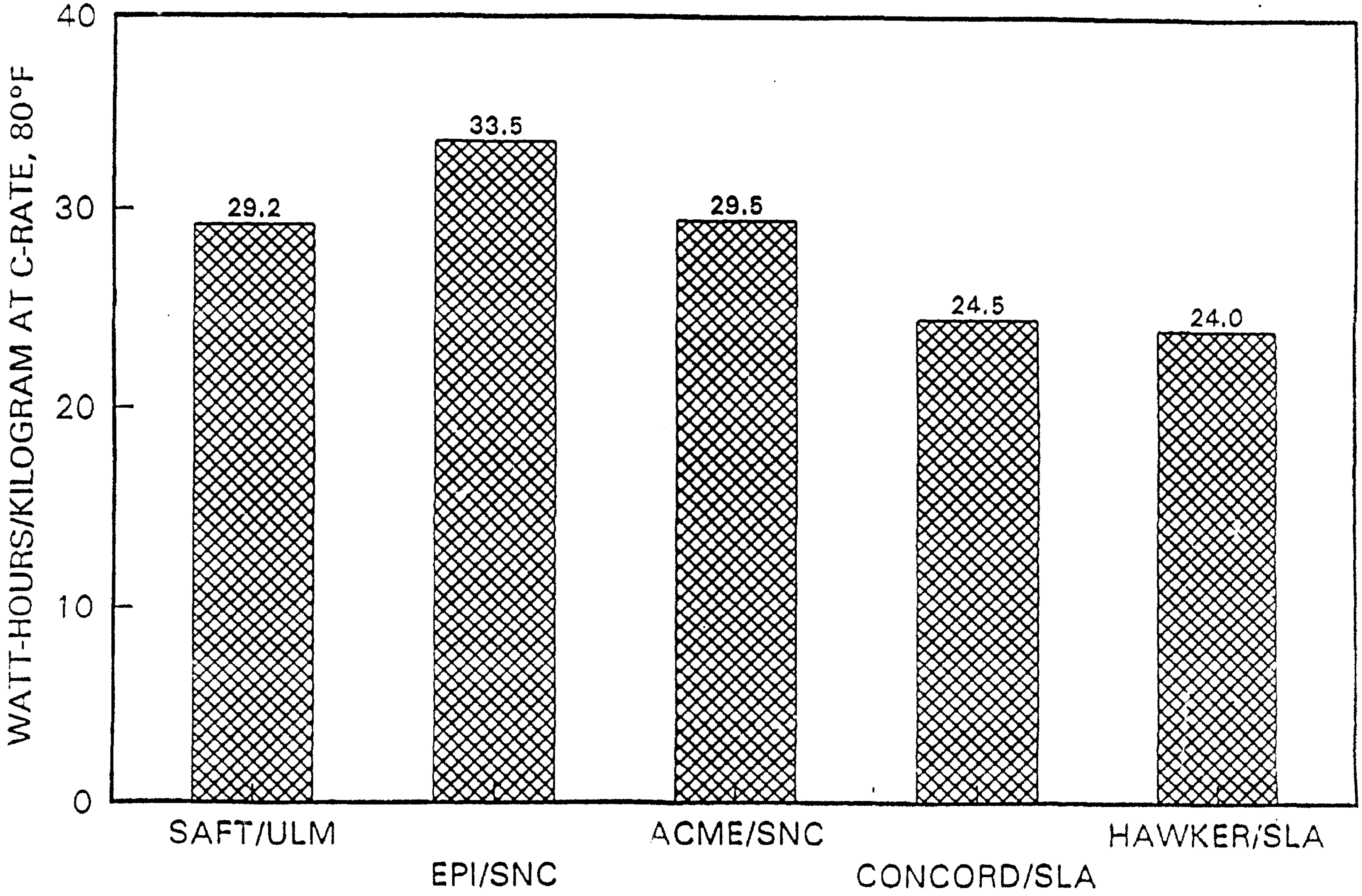


FIGURE 3-2. SPECIFIC ENERGY COMPARISON

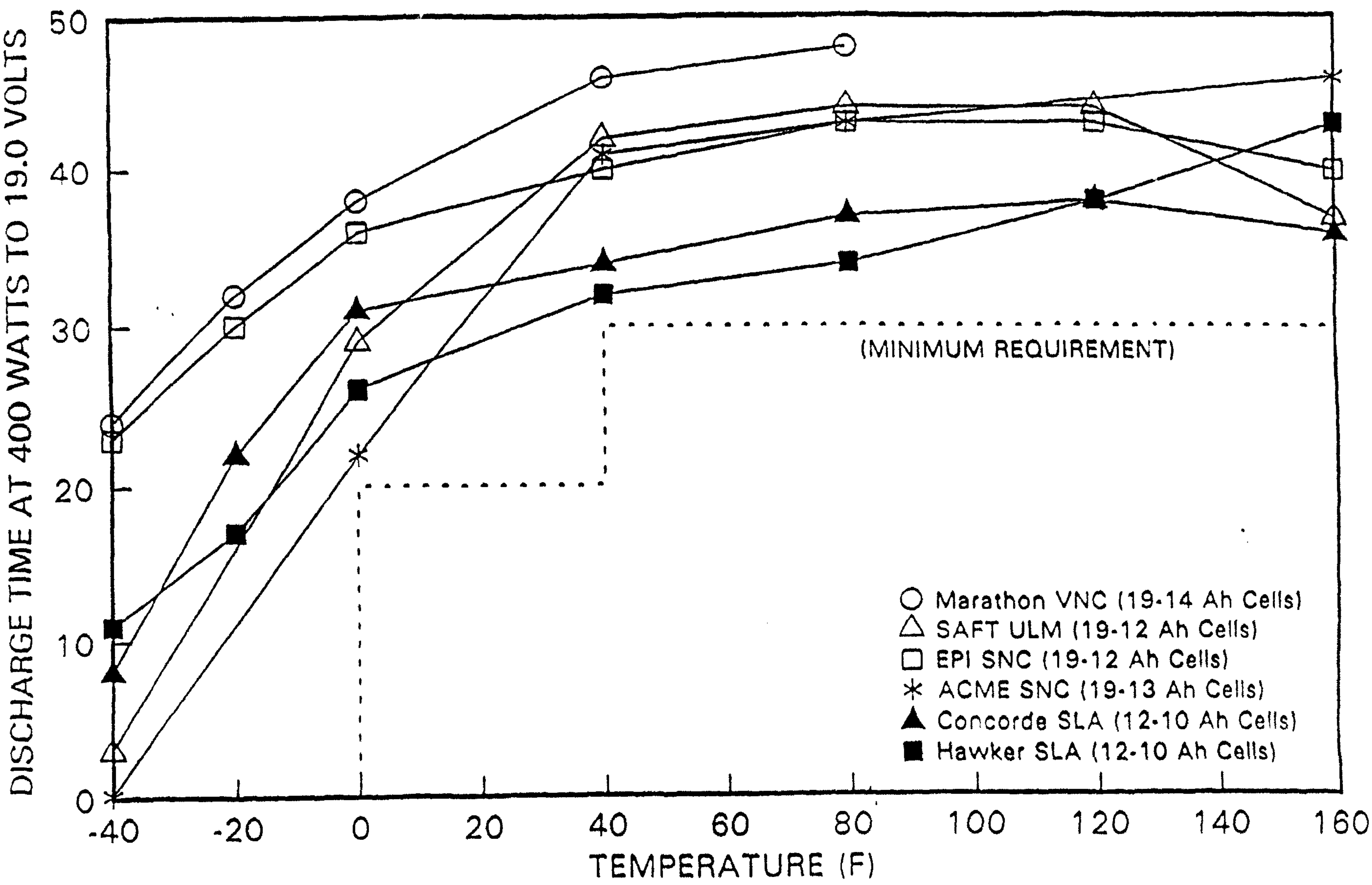


FIGURE 3-3. DISCHARGE PERFORMANCE COMPARISON

battery to overheat. The charging curves presented in Appendix D were plotted using data submitted by the manufacturers.

The SLA batteries were found to be fully compatible with both INS charging circuits. The voltage rise at the top of charge is well above the 29-volt cut-off of the Carousel IV INS, and the voltage stays low enough before the top of charge, that the 27.1-volt cut-off of LTN-72 INS does not present a problem.

The ULM battery also appeared to be fully compatible with both INS charging circuits. However, discussions with SAFT revealed that the voltage roll-over point has a tendency to become depressed with age. To circumvent this problem, SAFT proposed the incorporation of an external switch, on the back of the battery case, to allow changing from 19 cells (for the LTN-72 INS) to 20 cells (for the Carousel IV INS). This switch would have to be set upon installation. Although this switch represents an undesirable addition, it does ensure that the ULM battery would be compatible with both charging circuits.

The SNC charging curves from both manufacturers (ACME and EPI) have little or no upturn at the top of charge. Therefore, these batteries are not directly compatible with the INS charging circuits. In order to be compatible with the INS charging circuits, a battery using these cells would need to have an internal electronics module to control the charging current. ACME proposed a temperature-controlled electronics module that would be compatible with both INS types. EPI also proposed a temperature-controlled electronics module, but with the added provision of an external switch, as proposed for the ULM battery, to change between 19 and 20 cells.

One further note should be made regarding the charging curves at lower temperatures (below 80 F). Some lower temperature data were provided ACME (0 F) and by SAFT (40 F). At these temperatures, the battery voltage reaches the voltage cut-off very early in charge, causing the charger to switch into trickle charge mode. Similar behavior also would be expected of the SLA batteries. Thus, the charging time from a deep discharge would be much longer at low temperatures. Fortunately, the INS battery is seldom discharged to a deep level. Operation at low temperature is further discussed in the following sections.

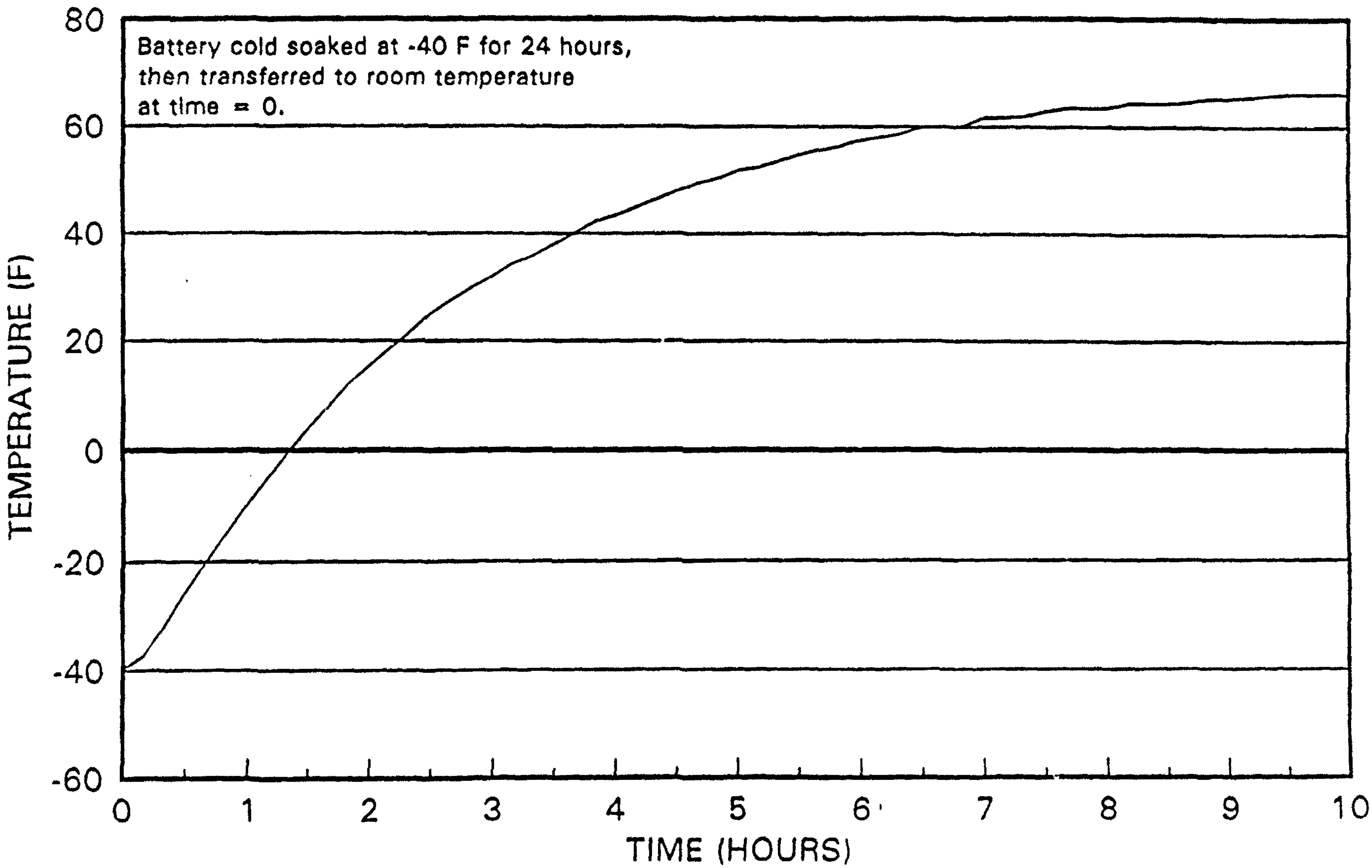
3.2.3 Heater Blankets

An analysis was done to determine if heater blankets would be necessary for the new INS battery. Although the existing battery does not contain a heater, it was not certain if the candidate battery technologies could perform satisfactorily without a heater. The heater blankets offer the advantages of increasing charge acceptance and discharge capacity of batteries that have been cold soaked. However, the disadvantages are noteworthy. They are increased cost, addition of components that can fail, space consumption within the battery case, and the possible need for modification of AC aircraft power.

With respect to charge acceptance at low temperature, it was noted that for the normal situation, the Delco INS discharge is about 10 amperes for 12.8 seconds, which equates to 35.6 mAh. Assuming only the trickle charge of 40 mA is available, it would take 35.6 mAh/40 mA = 0.9 hour to recharge. Since flight times normally average well in excess of 1 hour, the charge rate is adequate to maintain the BU in a charged condition.

With respect to discharge capacity at low temperature, some "worst case" testing was done. A 30-minute INS battery (Marathon P/N 28656-002) was cold soaked for 24 hours at -40 F. The battery then was placed on a steel plate at room temperature. Six thermocouples within the BU measured the temperature rise over time. The results of this test are given in Figure 3-4. Within 1 hour, the battery temperature reached approximately -10 F, which corresponds to a discharge capacity of 20-25 minutes (Figure 3-3). Further data showing SLA discharge performance were obtained from Concorde, as presented in Figures 3-5 and 3-6. These data show a large capacity increase upon exposure to room temperature conditions, without the assistance of heater blankets.

As a result of the above considerations, it was concluded that heater blankets are unnecessary for the new INS battery. This conclusion results from the fact that the battery has a low duty cycle requirement; the battery is located on board in a heated equipment bay; and the battery is exposed to long charging periods during flight.



Marathon INS Battery
Average temperature from 6 locations

FIGURE 3-4. TEMPERATURE PROFILE OF INS BATTERY

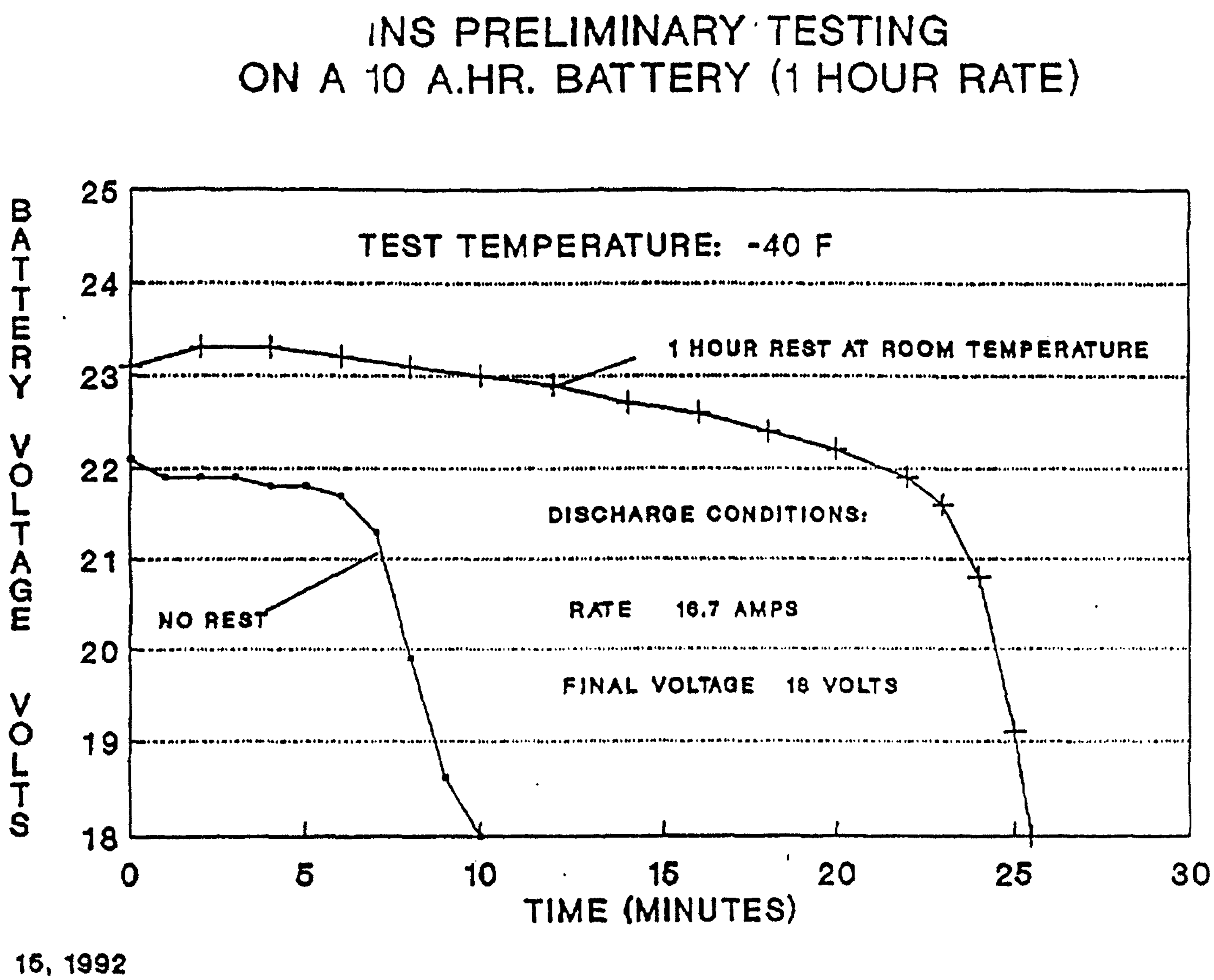


Figure 3-5. SLA BATTERY TEST DATA AT -40 F
(Data obtained from Concorde)

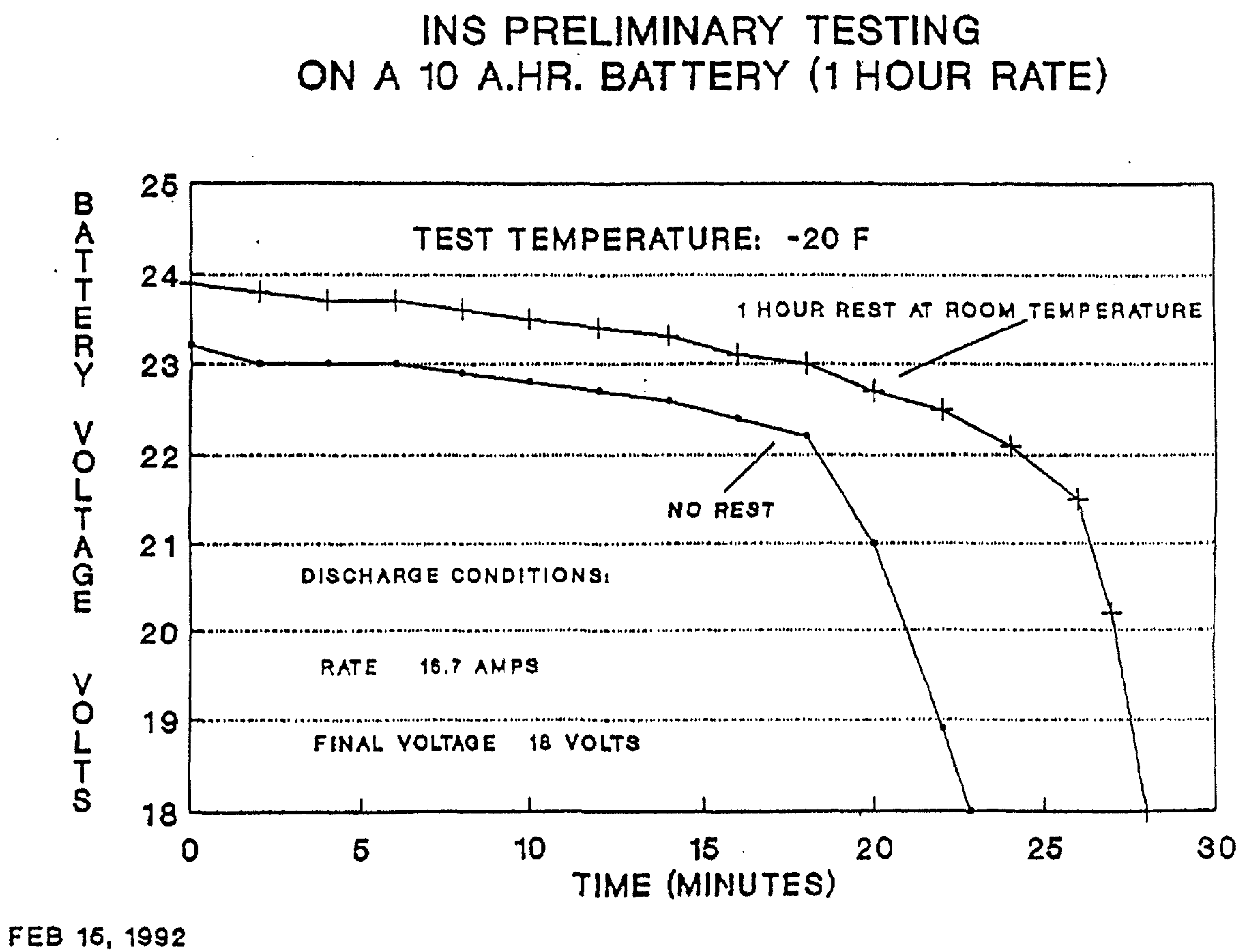


Figure 3-6. SLA BATTERY TEST DATA AT -20 F
(Data obtained from Concorde)

3.2.4 Service Life

In the INS application, the battery is normally kept fully charged under trickle charge conditions and only rarely experiences a deep discharge (similar to a computer back-up application). Therefore, the best approximation for battery service life is float life rather than cycle life. Float life data are readily available for SLA batteries, but not for the ULM and SNC batteries. Figures 3-7 and 3-8 show data obtained from Hawker on their SLA batteries (SBS series). The data in Figure 3-7 indicate a float life of about 10 years at room temperature with a charging voltage of 2.25 volts per cell (27 volts for a 12-cell battery). The float life is shortened considerably if the charging voltage is higher (e.g., 3 to 4 years at 2.4 volts per cell). The LTN-72 INS charge voltage regulates very close to 27 volts, which is the ideal setpoint for maximum float life of the SLA battery. Even though the Carousel IV INS has a 29 volt cut-off, the trickle charge rate of 40 milliamperes will result in about the same operating point as the LTN-72 INS. Thus, the charging conditions provided by both the LTN-72 INS and Carousel IV INS are considered ideal for float charging the SLA battery.

Figure 3-8 shows additional SLA battery float data obtained from Hawker. After 5 years in service on continuous float, over 90 percent of the SBS batteries sampled gave 120 percent of nominal capacity. It was noticed, however, that a low percentage of the batteries sampled had less than 100 percent of nominal capacity; one sample had essentially no capacity. Based on these data, it appears that regularly scheduled capacity checks (e.g., once a year) would be advisable in order to assure emergency capacity was still available. According to Hawker, annual capacity checks are performed on the SLA batteries utilized by British Telecom in float service applications.

The lack of data makes it difficult to predict float life for the ULM and SNC batteries. Because ULM batteries are not completely sealed, some idea of service life can be calculated based on water loss. Data from SAFT are given in Figure 3-9 for the ULM-II technology, which features partial gas recombination. Assuming an operating time of 750 hours/year, an electrolyte reserve of 23 ml, a charge rate of 40 mA (C/300 rate), and a recombination efficiency of 70 percent, then water loss per year would equal (1-0.7) (0.04) (9 ml/Faraday) (750 hours/year/26.8 Ah/Faraday) or 3 ml/year. Thus, the

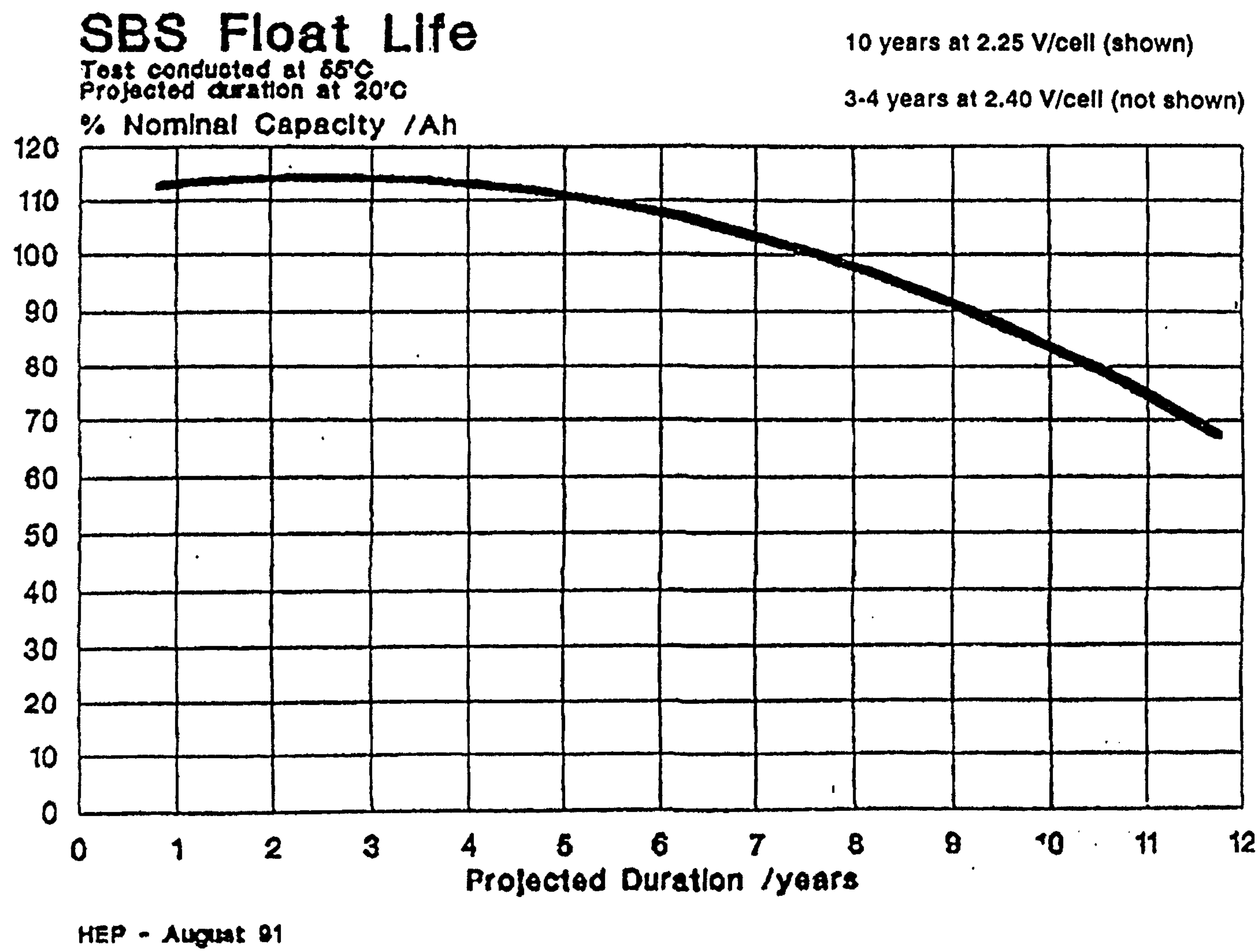


Figure 3-7. SLA BATTERY FLOAT LIFE DATA
(Data obtained from Hawker)

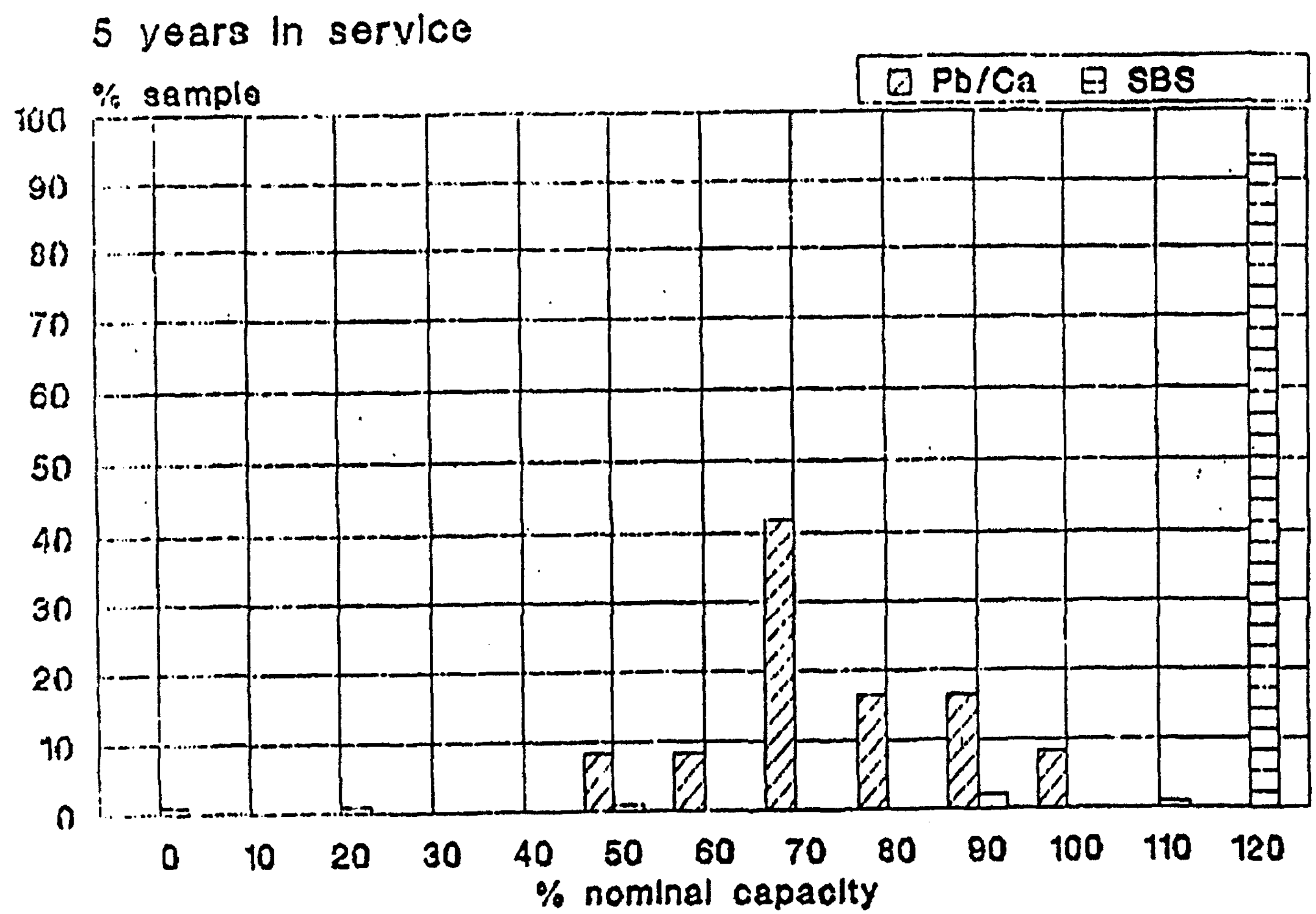


Figure 3-8. FLOAT LIFE COMPARISON OF DIFFERENT TYPES OF SLA BATTERIES (Data obtained from Hawker)

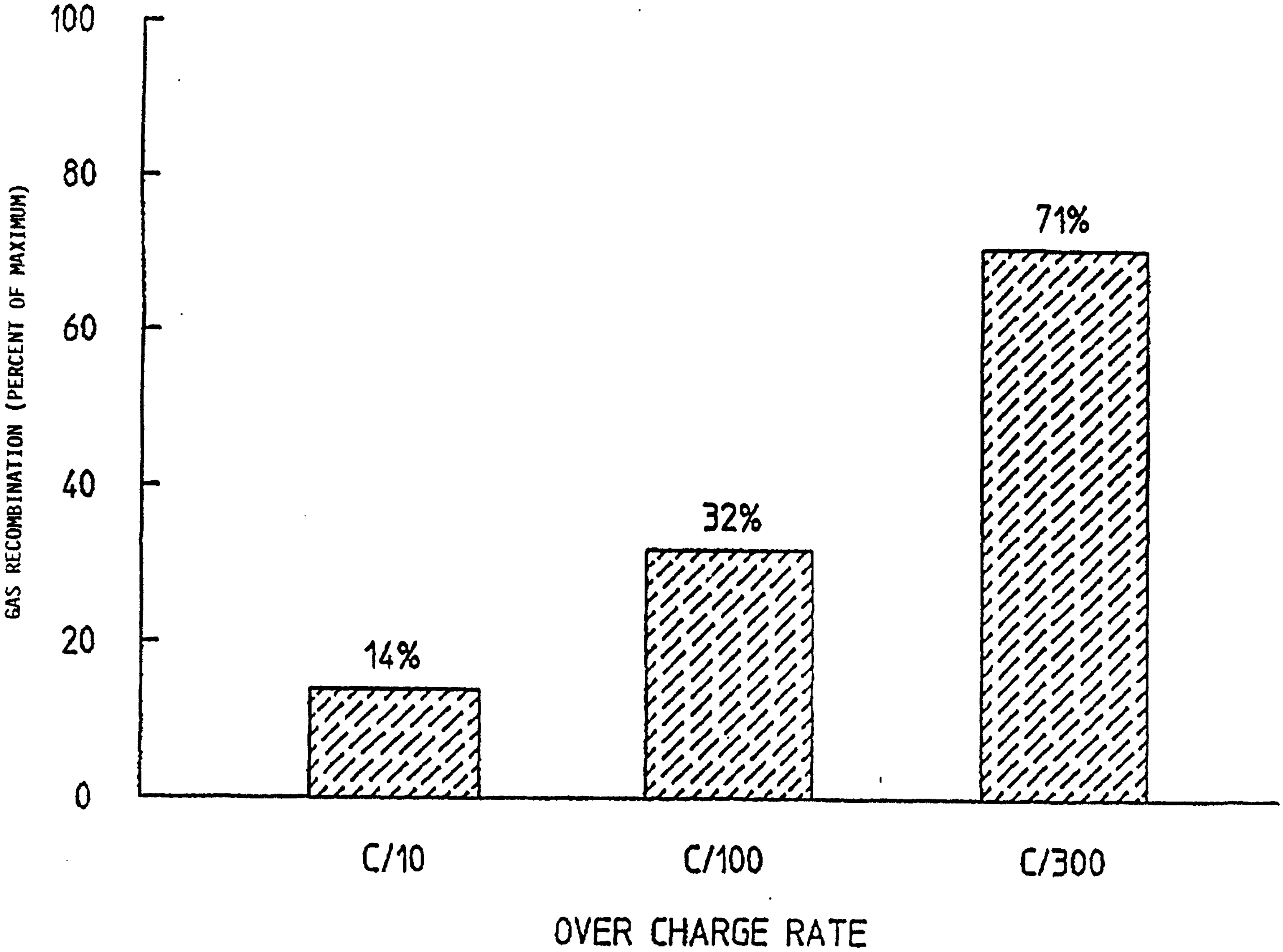


FIGURE 3-9. ULM-II CELL RECOMBINATION RATES
(Data obtained from SAFT)

number of years before the cell would need to be refilled is equal to 23/3 or 7.7 years. It should be noted, however, that if annual capacity checks are instituted, water could be added to this cell, which would further extend its service life.

The service lives of each battery technology, for the INS application, were estimated independently by the prospective manufacturers, and these data are given Table 3-3. The manufacturer's estimates were "normalized" to provide a consistent, conservative estimate of the service life. The normalized estimates were used to generate Figure 3-10. Using a average of 500 flight hours per year, the average MTBF is predicted to be 2,000 hours for the SLA and ULM batteries and 2,500 hours for the SNC battery.

TABLE 3-3. SERVICE LIFE ESTIMATES

Battery Technology	EPI SNC	ACME SNC	SAFT ULM	Concorde SLA	Hawker SLA
Manufacturer's Estimate (Years)	10	10-15	8-10	7.5	8-10
Normalized Estimate (Years)	10	10	8	8	8

3.2.5 Shelf Life

The shelf life for the ULM and SNC batteries is estimated to be at least 5 years. Such a shelf life is not expected to pose a storage problem. However, the shelf life for the SLA battery is estimated to be about 2 years, which may pose a storage problem. Data on shelf life for Hawker and Concorde SLA batteries are given in Figure 3-11 and Table 3-4, respectively. In Figure 3-11, "normal" refers to regular storage of batteries at room temperature (60 to 77 F) after being fully charged. "High temperature" refers to conditions in which the batteries are heated to 95 F for 6 hours a day, for 5 days a week, with the remaining time at ambient temperature. The "variant" batteries from the same lot as "normal" received one extra conditioning cycle, which was thought to improve their charge retention properties during storage. All

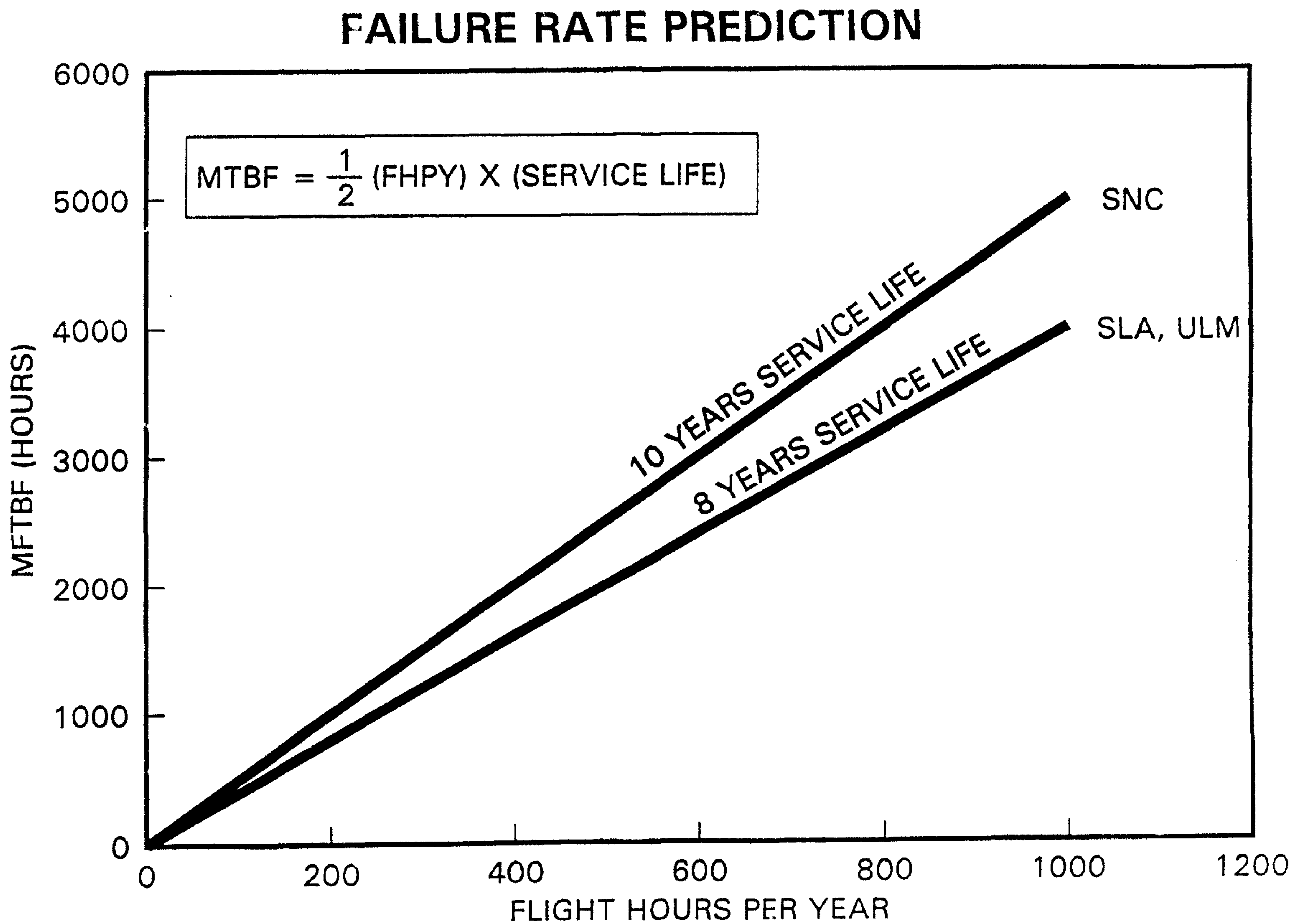


FIGURE 3-10. FAILURE RATE PREDICTION

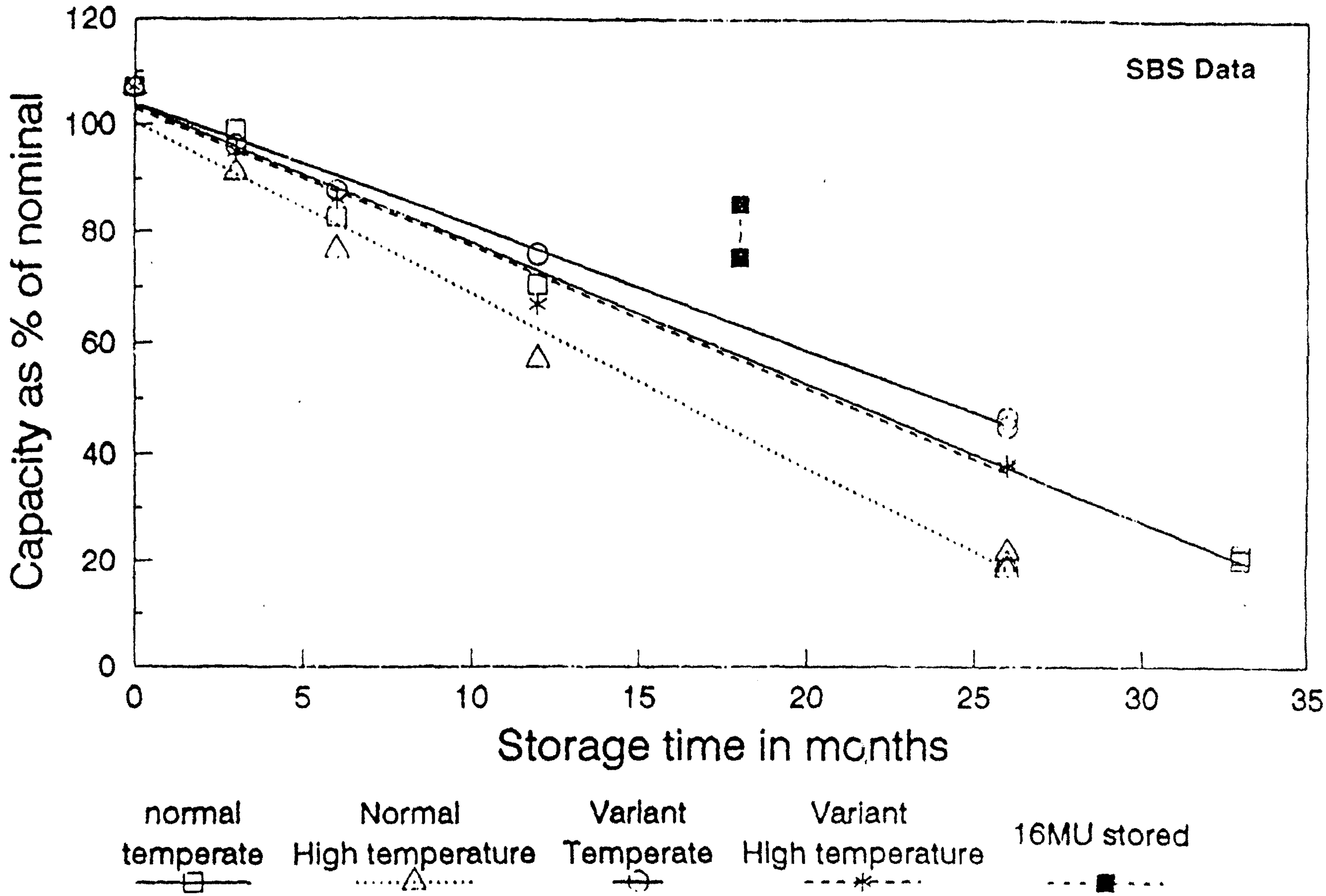


Figure 3-11. RESIDUAL CAPACITY OF SLA BATTERIES VERSUS STORAGE TIME (Data obtained from Hawker)

batteries retained at least 20 percent of their capacity after 24 months. Such retention suggests that full capacity restoration can be accomplished after 2 years of storage.

The data in Table 3-4 were measured by the Naval Weapons Support Center, Crane on Concorde D8565/4-1 (7.5 Ah) SLA batteries. Even after 2 years of storage at 100 F, the batteries could be restored to full capacity. Some degradation of cycle life was experienced after 2 years of storage, but this is not of particular concern for the INS application. The above data indicate that the 2 year shelf life is realistic for the SLA battery. As presented later in the life cycle cost analysis (Section 4.0), this storage burden can be taken into account by assigning an annual attrition rate on the spares inventory.

TABLE 3-4. SLA BATTERY SHELF LIFE DATA*

Parameter	Storage Time at 100 F					
	1.0 Year		1.5 Years		2.0 Years	
	A	B	C	D	E	F
Percent Rated Capacity After 36-Hour Conditioning Charge	122	125	143	135	135	128
Cycle Life to Failure	312**	–	229	–	–	156

* Data measured by NWSCC.

** Cycling discontinued, no failure.

3.3 Compatibility Assessment

Table 3-5 summarizes the results of the compatibility assessment based on the data presented in the previous sections. All candidates are expected to satisfy specification requirements and be compatible without INS modification. The incorporation of an internal electronics module within the SNC batteries represents a potential problem area, but this approach is considered technically sound. Therefore, the best candidate technology should be selected based on lowest life cycle cost and lowest risk factors.

TABLE 3-5. COMPATIBILITY MATRIX FOR CANDIDATE BATTERIES

Item	INS Type	Requirement	Candidate Battery Types EPI SNC	ACME SNC	SAFT ULM	Concorde SLA	Hawker SLA
Energy Density	Carousel IV	31.2 Wh/L at 400 W, 41-160 F	C	C	C	C	C
	LTN-72	29.3 Wh/L at 375 W, 40-120 F	C	C	C	C	C
Charge Method	Carousel IV	2.0A DC to 29.0 V	(1)	(1)	C	C	C
	LTN-72	1.7A RMS to 27.1 V	(1)	(1)	C	C	C
	Both	–	(1,2)	(1)	(2)	C	C
Operational Temp. (Charge & Discharge)	Carousel IV	0 to 160 F	C	C	C	C	C
	LTN-72	-40 to 140 F	C	C	C	C	C
	Both	-40 to 160 F	C	C	C	C	C
Max. Altitude	Carousel IV	45,100 ft	C	C	C	C	C
	LTN-72	48,300 ft	C	C	C	C	C
Vibration	Carousel IV	± 10 g (70-500 Hz)	C	C	C	C	C
	LTN-72	± 2.5 g (70-500 Hz)	C	C	C	C	C
Shock	Carousel IV	± 15 g, 11 ms	C	C	C	C	C
	LTN-72	± 10 g, 12 ms	C	C	C	C	C

Notes:
(1) Requires internal electronics module for charge control.
(2) Requires 19/20 cell switch or else adjustment of LTN-72 power supply voltage setpoint.

3.4 Selection Results

Using the results from the compatibility assessment and the life cycle cost analysis, a selection matrix was prepared (Table 3-6). All candidates are expected to be compatible with the INS requirements, so each received a satisfactory rating. When the acquisition and life cycle costs are compared, it is clear that the SLA battery is the lowest cost alternative. Since the SLA technology has established reliability in various military aircraft applications, the technology risk is low. On the other hand, since the ULM and SNC have little experience in aircraft applications, the technology risk is considered moderate. The number of sources shows that competitive procurement is possible with the SLA and SNC types but not with the ULM battery. Based on these criteria, the SLA battery received an "A" rating, and is clearly the top choice.

TABLE 3-6. SELECTION MATRIX

Criteria	SNC	ULM	SLA
Performance/Environmental Compatibility	Satisfactory	Satisfactory	Satisfactory
Acquisition Cost ($M)	8.9	5.1	4.0
LCC at Year 10 ($M)	55.4	48.6	46.0
Technology Risk	Moderate	Moderate	Low
"Qualified" Sources	2	1	2
Overall Rating (a)	C	B	A

(a) A is the highest rating; C is the lowest rating.

4.0 LIFE CYCLE COST ANALYSIS

4.1 Analysis Method

A life cycle cost (LCC) analysis was performed to compare the candidate technologies with themselves and with the existing VNC battery. Detailed computations and sensitivity analyses were performed using a spreadsheet program developed by Battelle. For a given set of input parameters, the spreadsheet calculates the following measures of merit:

- Cumulative Life Cycle Cost
- Manpower Requirements
- Operational Capability.

The LCC includes both nonrecurring acquisition costs and recurring operating and support (O&S) costs. Nonrecurring costs encompass the expense of developing and qualifying the new battery, preparing manuals and technical orders, buying initial replacement parts, and installing them in the aircraft. Recurring costs consist of the parts and labor required to operate and maintain the installed battery system.

The manpower requirement represents the number of full-time, direct maintenance personnel required to maintain the batteries, including both preventive and corrective actions (scheduled and unscheduled removals).

Operational capability is defined as the percentage of aircraft expected to be mission capable at any given point in time with respect to battery downtime. Operational capability was estimated using achieved availability. The achieved availability is the probability that an aircraft, when used in an ideal support environment, will operate satisfactorily at any given time. It includes both preventive (scheduled) maintenance actions and corrective (unscheduled) maintenance actions. Achieved availability was computed using the following formula:

$$\frac{\text{Operating time}}{\text{(Operating time plus Downtime)}}$$

where the down time for each maintenance action was assumed to be equal to the time for removing and replacing a battery and for performing necessary operational checkouts. The total operating time was computed based on the average flying hours per month.

4.2 Input Parameters

Table 4-1 lists the baseline input parameters used in the computations for each battery technology. A description of each input parameter and applicable assumptions are given below.

Usage rate. The usage rate (flight hours per year) was obtained from Table 2-7 for the Navy aircraft and Table 2-8 for the Air Force aircraft. For the VNC battery, different usage rates were used for the Navy and Air Force aircraft. For the candidate batteries, the Navy and Air Force usage rates were combined into one average value.

Total Installs. For the Navy, the total number of installs obtained from the INS Inventory Manager was used. For the Air Force, the total number of installs was based on Table 2-6 (rounded to 3,000).

Initial Spares. The number of initial spares was determined using the economical order quantity (EOQ), which is calculated using the following formula:

$$EOQ = \sqrt{2C_oD/C_i}$$

where: C_o = Cost to Order (assumed equal to \$1000)

D = Demand per year = (No. aircraft) X (Hours per year)/(MTBF)

C_i = Cost to hold in inventory (assumed equal to 10 percent of spares valuation).

Nonrecurring Costs. The nonrecurring costs include all R&D costs, qualification costs, and costs for changing technical manuals and maintenance technical orders (T.O.'s).

TABLE 4-1. INPUT PARAMETERS FOR LIFE CYCLE COST ANALYSIS

Battery Type	VNC		SNC	ULM	SLA
Service Branch	Navy	Air Force	Combined	Combined	Combined
Usage Rate (flight hours per year)	450	550	500	500	500
Total Installs	926	3000	3926	3926	3926
Initial Spares (EOQ)	-	-	88	128	153
Nonrecurring Costs ($)	-	-	*	*	*
Unit Price, 1000 Lot ($)	950	1050	*	*	*
Initial Installation (man-hours)	-	-	2	2	2
Scheduled Removals					
Time Interval (months)	3.7	2.0	12	12	12
Labor Per Event (man-hours)	10	10	4	4	4
Unscheduled Removals					
MTBR (flight hours)	150	225	1250	1000	1000
Labor Per Event (man-hours)	12	12	6	6	6
Failures					
MTBF (flight hours)	800	450	2500	2000	2000
Labor Per Event (man-hours)	4	4	2	2	2
Material Per Event ($)	125	145	(unit price)	(unit price)	(unit price)
Attrition (% per year of spares)	-	-	-	-	10

* Denotes proprietary data.

Unit Price. The unit prices were obtained from manufacturers quotations, based on a production quantity of 1,000 units. In the case of multiple sources, the lowest unit price was used, but the development and qualification costs for the second source were added to the nonrecurring costs.

Scheduled Removals. The time intervals for the VNC were based on the current maintenance intervals used by the Navy (112 days) and by the Air Force (60 days). The time interval for the candidate batteries was based on an annual capacity check, as mentioned in paragraph 3.2.4.

Unscheduled Removals. The MTBR values for the VNC battery were based on the data from Tables 2-7 and 2-8. The MTBR values for the candidate batteries were assumed to be one-half the MTBF values.

Failures. The MTBF values for the VNC battery were based on the data shown in Tables 2-7 and 2-8. The MTBF values for the candidate batteries were based on the data given in Figure 3-10.

Attrition. The attrition due to shelf life limitations was assumed equal to a fixed percentage of the spares inventory. This parameter was applied only to the SLA battery.

In addition to the input parameters shown in Table 4-1, the following assumptions were employed:

- Battery will be replaced as a preferred spare, with a 2-year phase-in period.
- The labor rate for maintenance personnel is $54 per hour (taken from AFLC Pamphlet 173-10).
- All cost figures are expressed in constant 1992 dollars and the time value of money was ignored.

4.3 Results

The results of the cost analysis are presented in the following sections in terms of life cycle cost, manpower requirements, and operational capability.

4.3.1 Life Cycle Costs

The LCC results, using the baseline input parameters, are summarized in Figures 4-1 through 4-6. Based on these results, the following conclusions can be made:

- The SLA is projected to have the lowest acquisition cost, lowest O&S cost, and lowest cumulative life cycle cost, although the ULM battery is not much more expensive. The SNC battery is by far the most expensive alternative.

- Compared with the VNC battery, the SLA battery will save $147 million in O&S costs over a 10 year period. Most of this saving is brought about by eliminating the labor intensive maintenance burden inherent with the VNC technology.

- Acquisition costs associated with the SLA battery will be recovered within 8 months. Thus, the breakeven point occurs even before one-half of the batteries are retrofitted, assuming a 2 year change-over period.

Sensitivity analyses were performed by varying a single input parameter over a selected range of values, while holding all other parameters constant. The following parameters were subjected to the sensitivity analyses:

- Total installs
- Nonrecurring costs
- Unit price
- Scheduled removals
- Unscheduled removals
- Failure rate
- Attrition rate
- Change-over period.

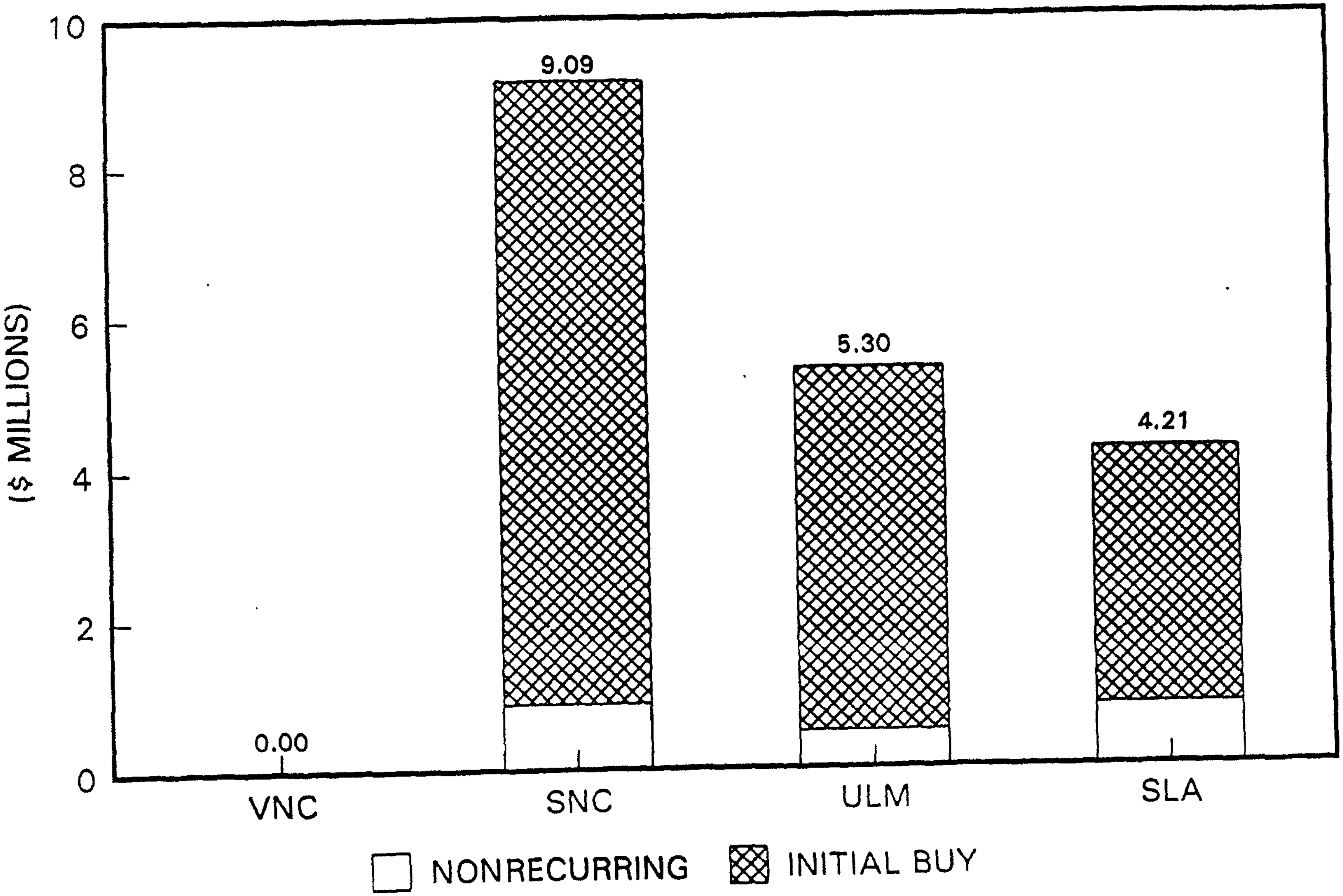


FIGURE 4-1. ACQUISITION COSTS

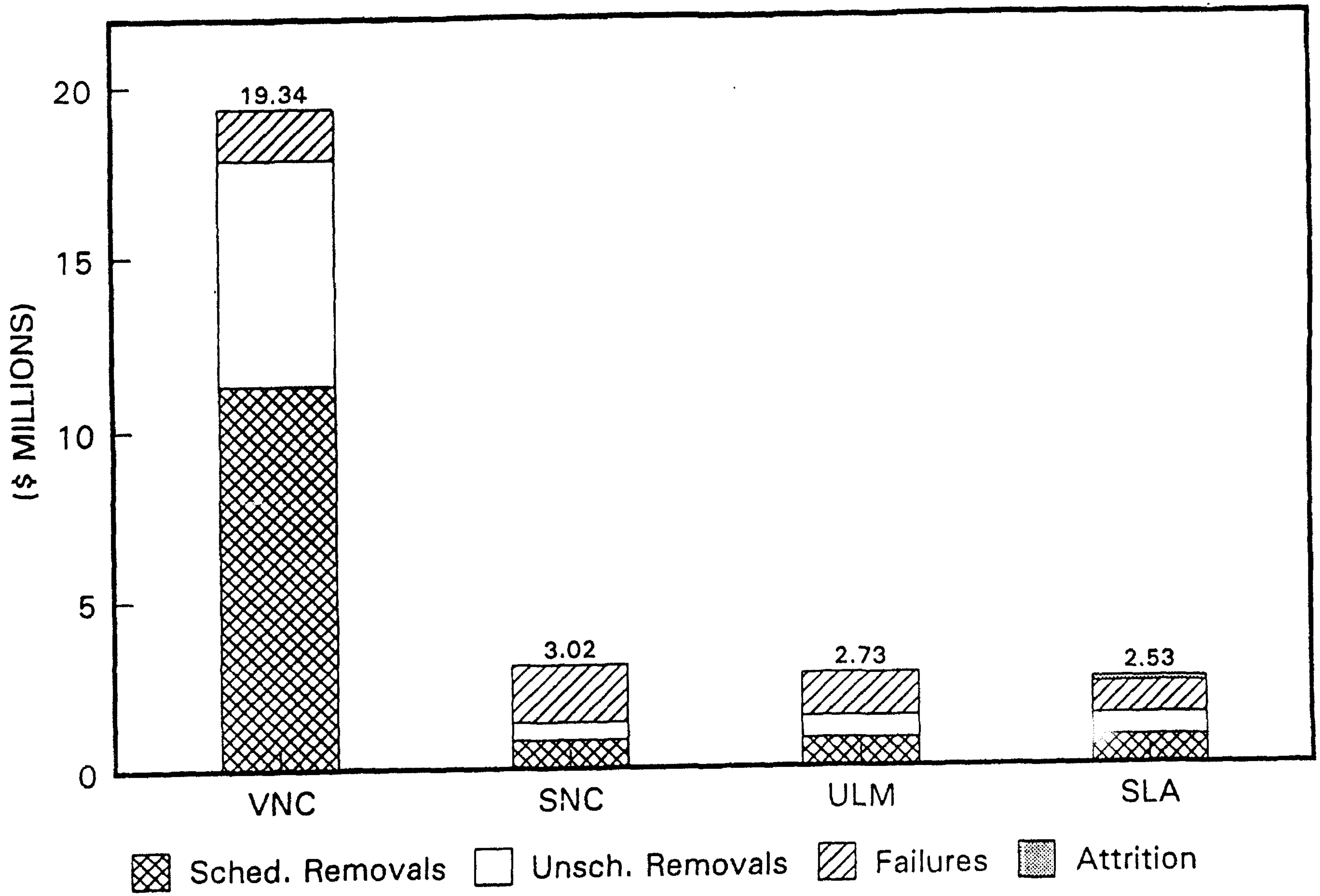


FIGURE 4-2. ANNUAL O & S COSTS

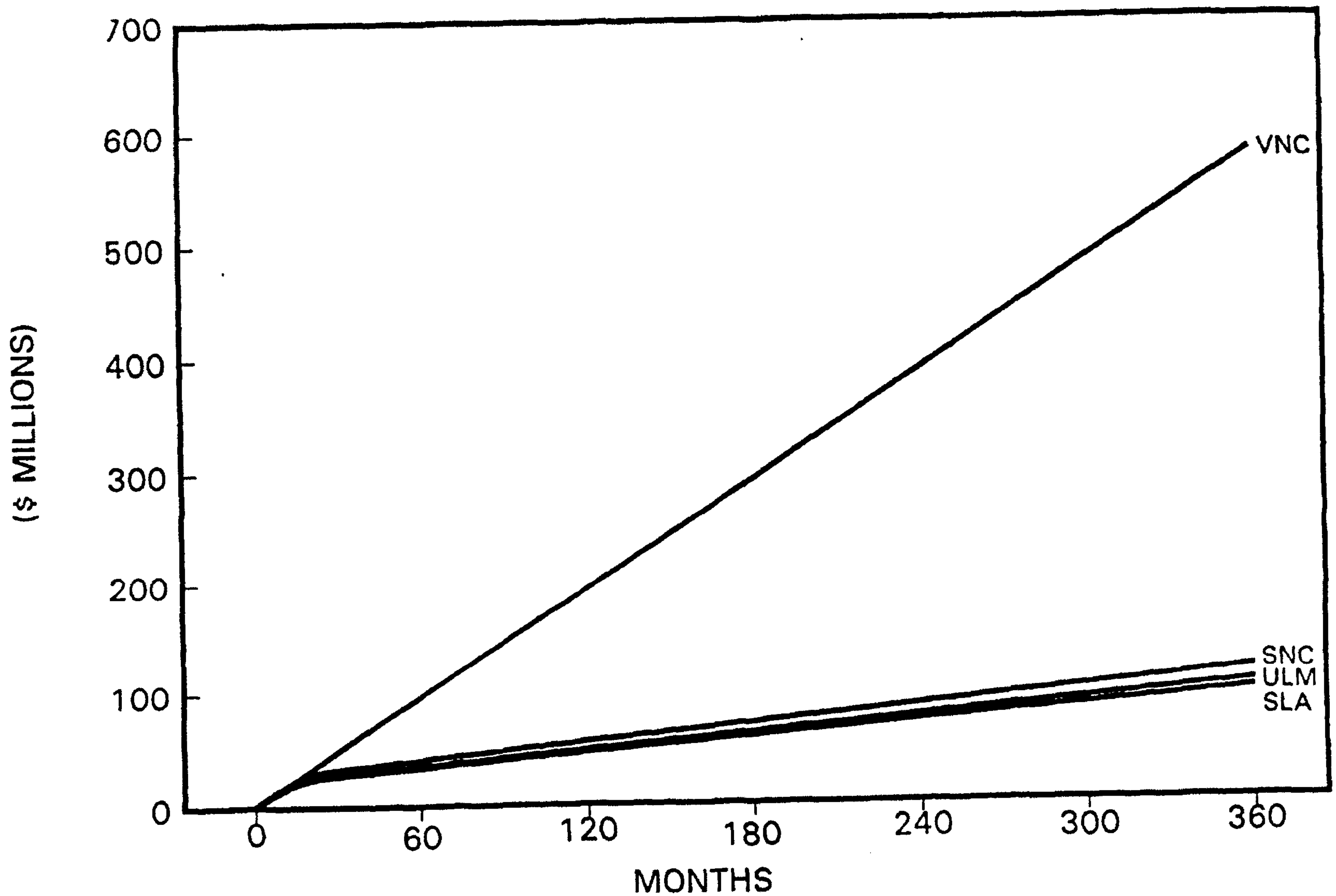


FIGURE 4-3. CUMULATIVE LIFE CYCLE COST (30 YEARS)

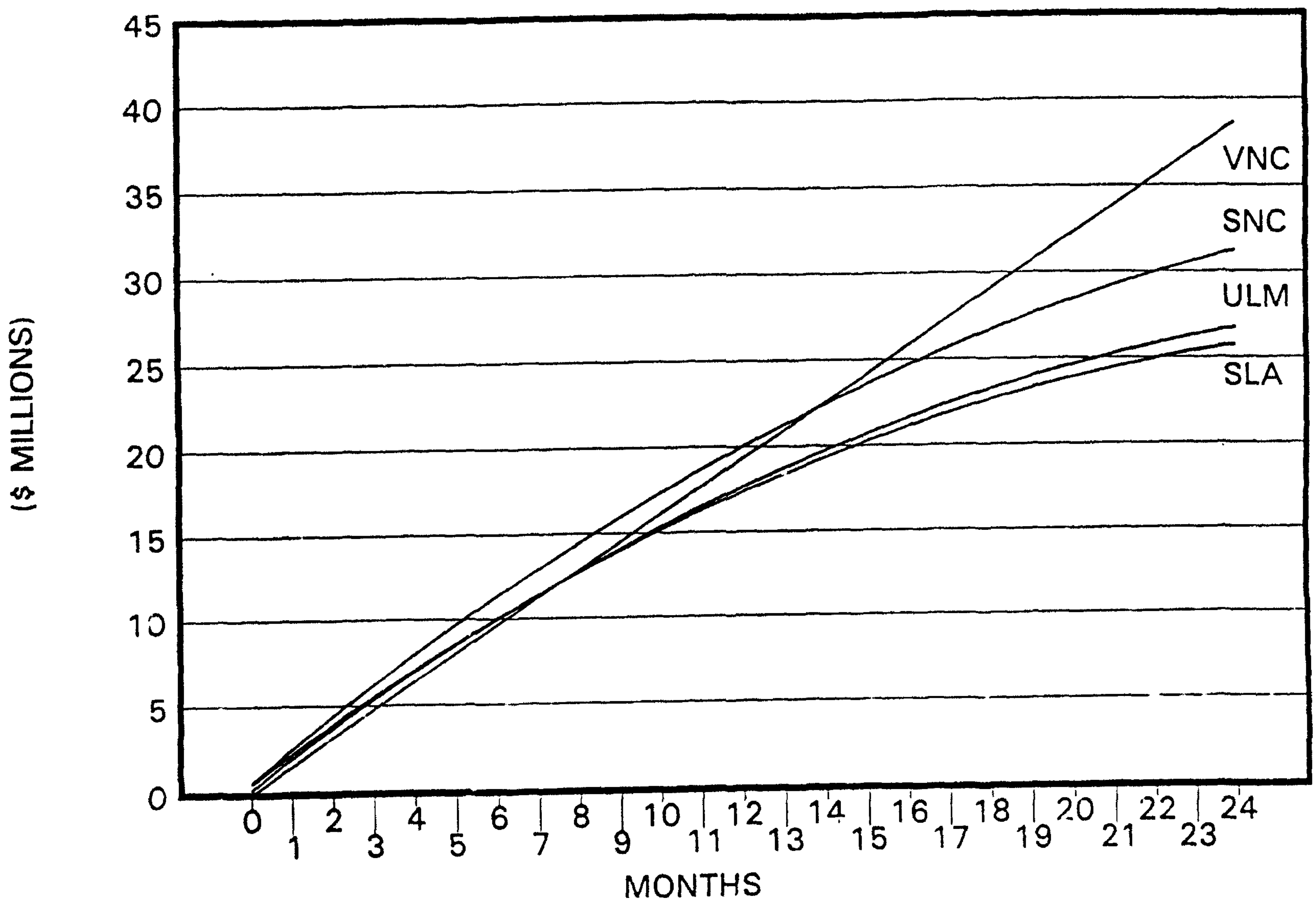


FIGURE 4-4. CUMULATIVE LIFE CYCLE COST (2 YEARS)

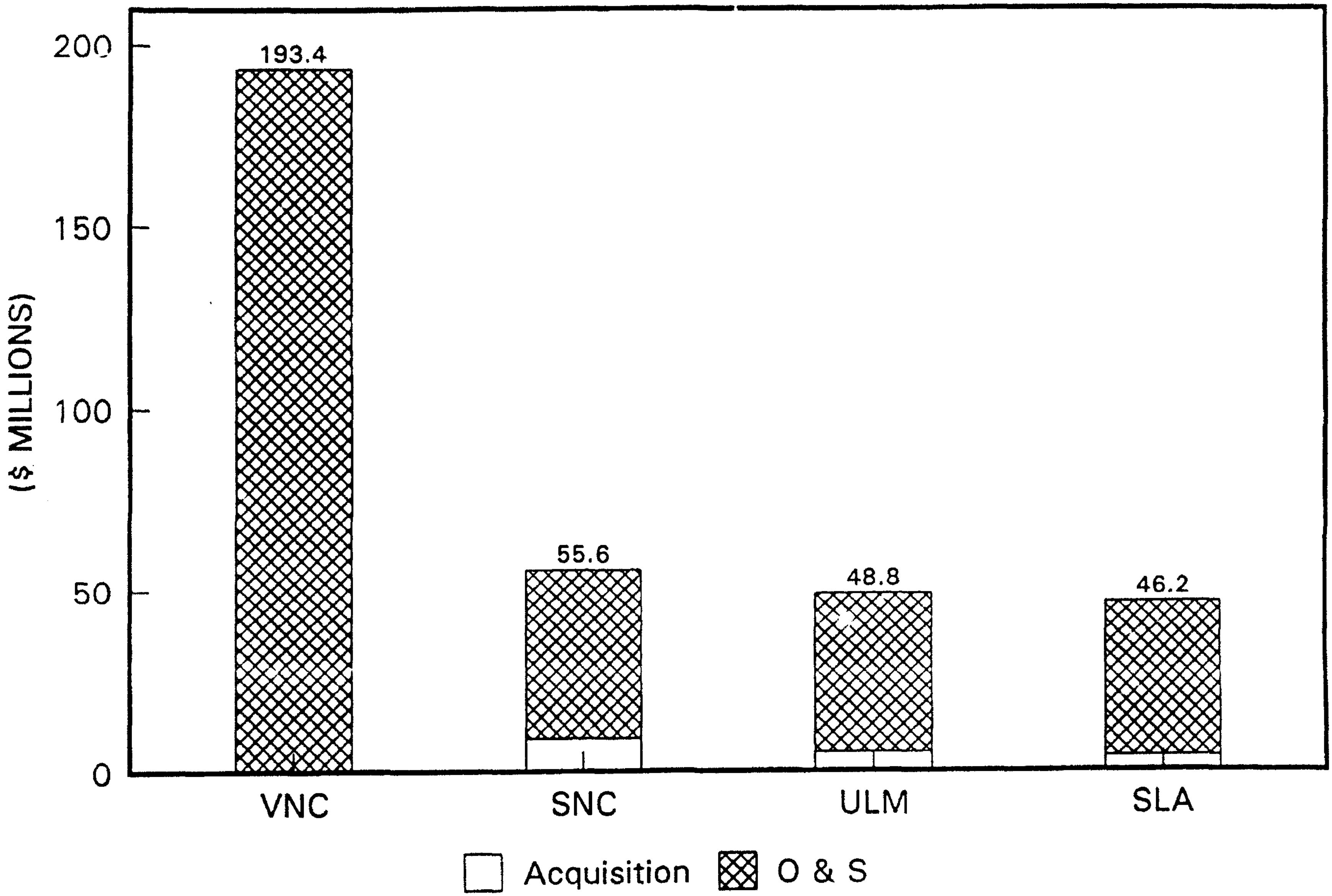


FIGURE 4-5. CUMULATIVE LIFE CYCLE COST AT YEAR 10

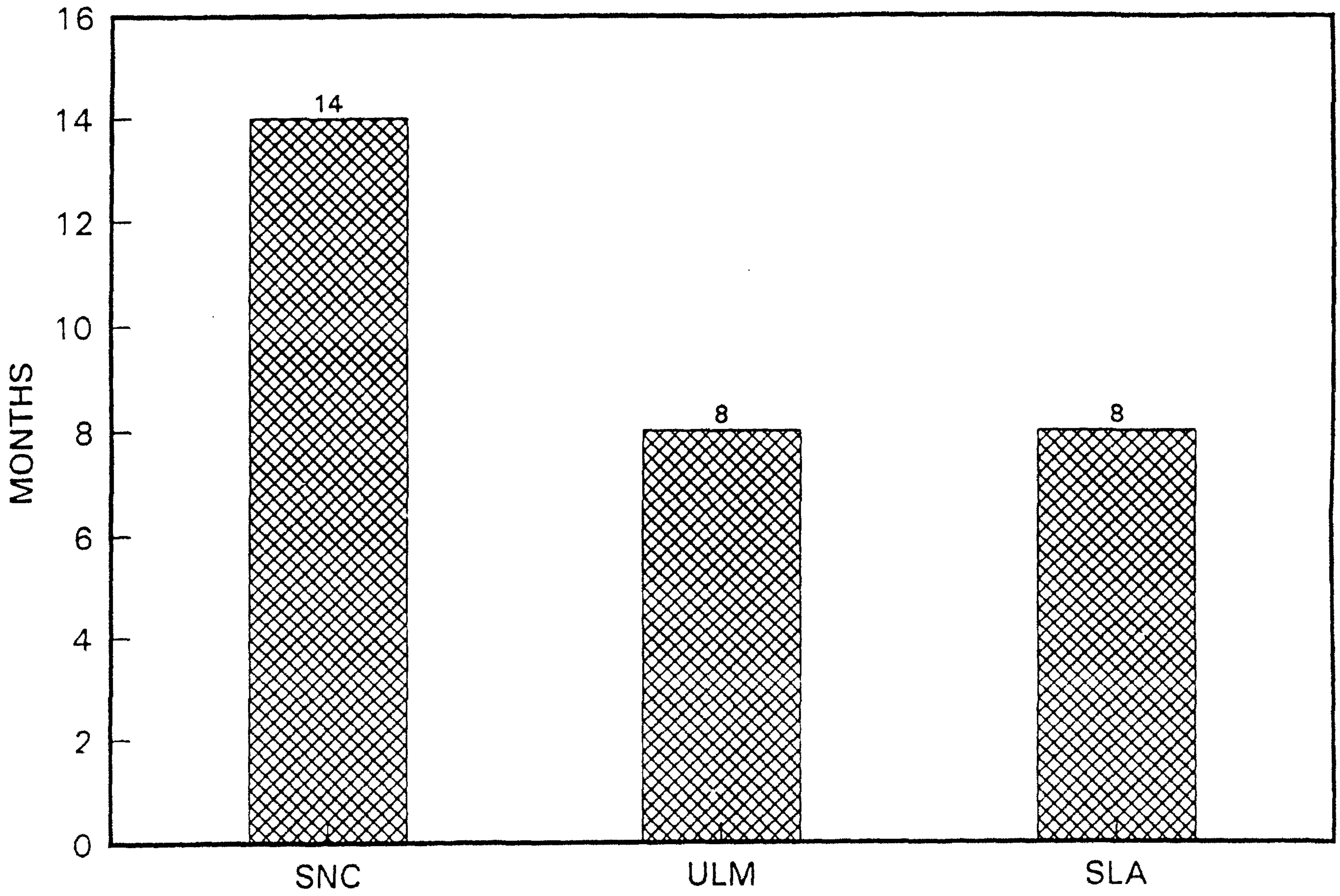


FIGURE 4-6. PAY BACK PERIOD

The results of the sensitivity analysis are presented in Figures 4-7 through 4-14. These figures allow for a "what if" analysis to determine the affect of changing input parameters from their baseline values. In general, the most sensitive parameters are the total number of installs, change-over period, unit costs, and failure rate.

4.3.2 Manpower Requirements

Manpower requirements for the existing and candidate batteries are summarized in Table 4-2 and Figure 4-15. The values reported include preventive (scheduled) and corrective (unscheduled) maintenance man-hour requirements. The frequent scheduled maintenance coupled with the high failure rate of the VNC battery drives the manpower requirement to 166 men per year working full time on INS batteries. For the candidate batteries, the manpower requirement drops to around 13 men per year. This represents a manpower savings of 153 men per year compared with the existing VNC battery.

TABLE 4-2. MANPOWER REQUIREMENTS

Battery Type	VNC		SNC	ULM	SLA
Service Branch	Navy	Air Force	Combined	Combined	Combined
Hours Per Year Flight	416,000	1,650,000	1,963,000	1,963,000	1,963,000
Man-hours Per Year	65,400	281,700	26,200	29,000	29,000
Man-hours Per 1000 Flight Hours	156.9	170.7	13.4	14.8	14.8
Personnel Equivalents (Men Per Year)	31.3	134.9	12.6	13.9	13.9

4.3.3 Operational Capability

Operational capability was expressed in terms of achieved availability, as previously defined in paragraph 4.1. As shown in Table 4-3, the percent availability with the candidate batteries increases by about one-half of a percentage point compared with the VNC battery . Although this

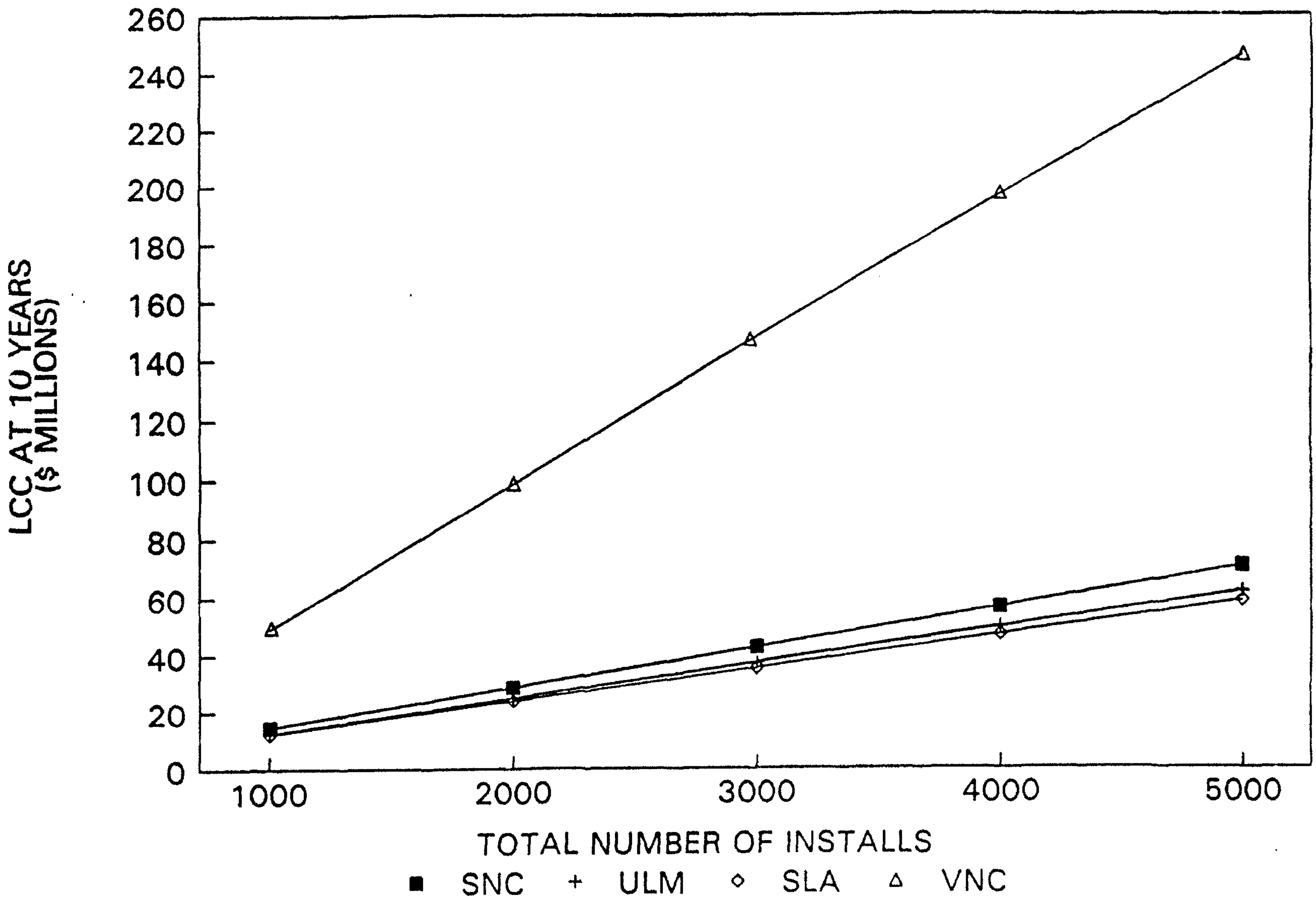


FIGURE 4-7. SENSITIVITY TO TOTAL INSTALLS

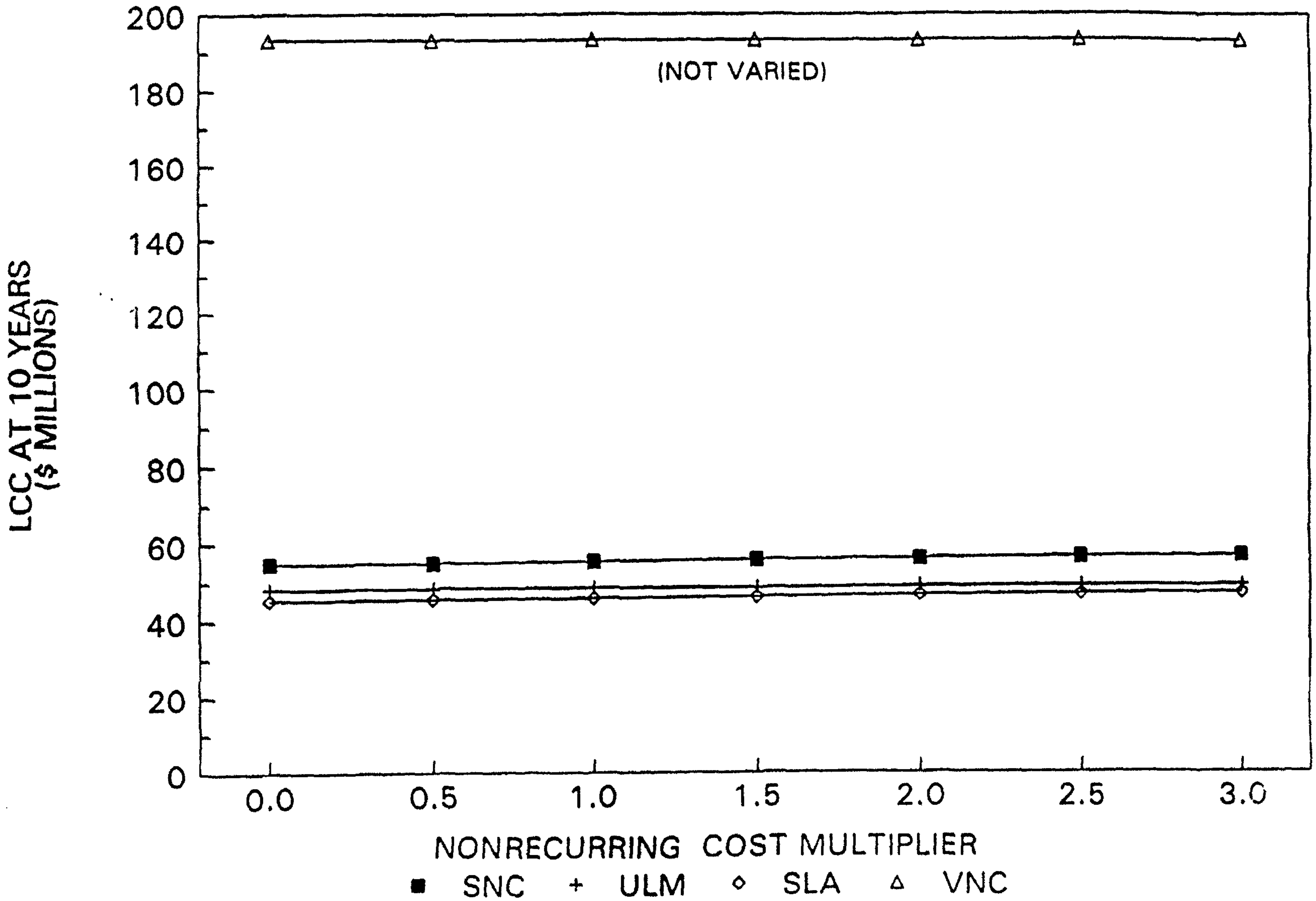


FIGURE 4.8 SENSITIVITY TO NONRECURRING COSTS

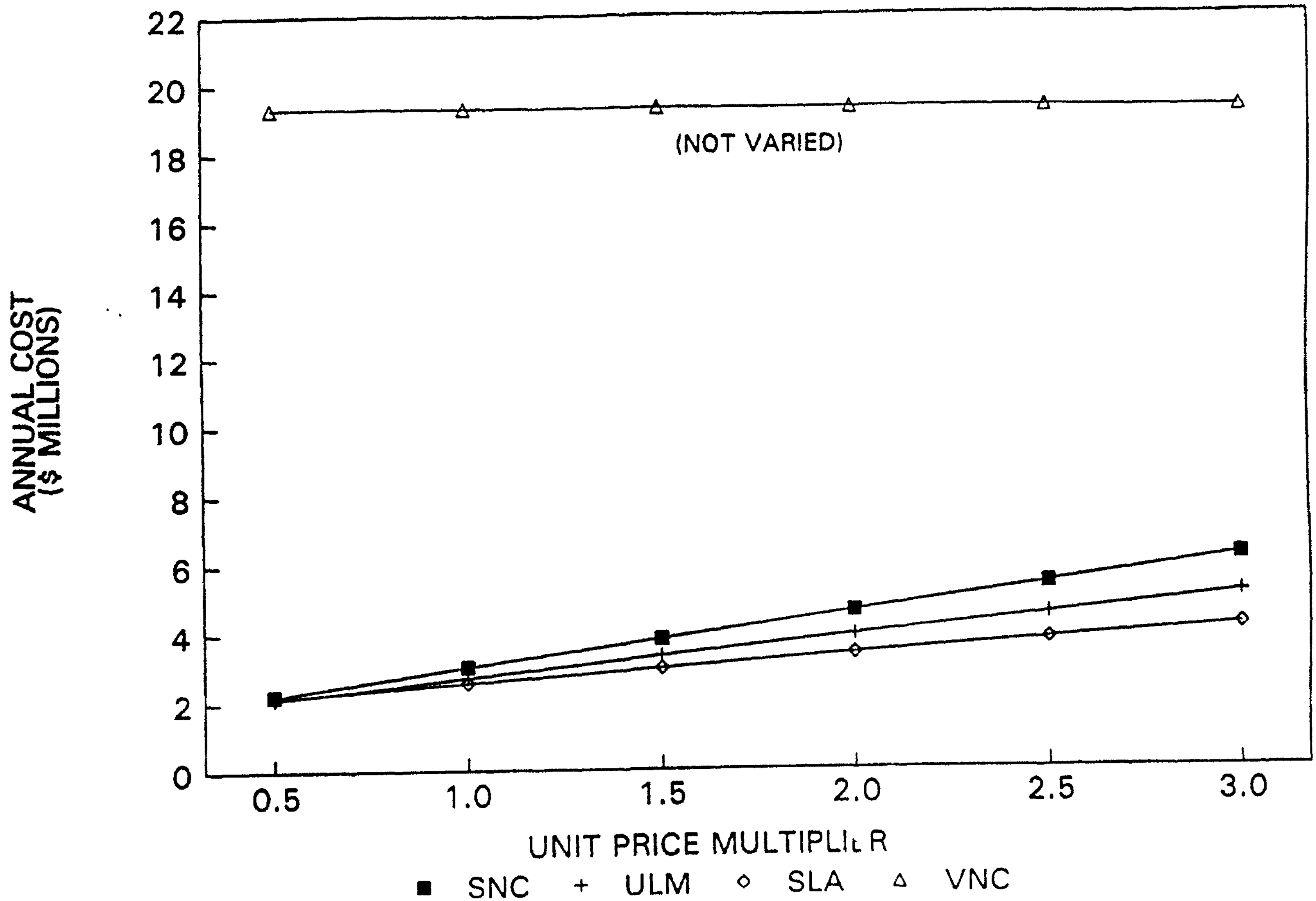


FIGURE 4-9. SENSITIVITY TO UNIT PRICE

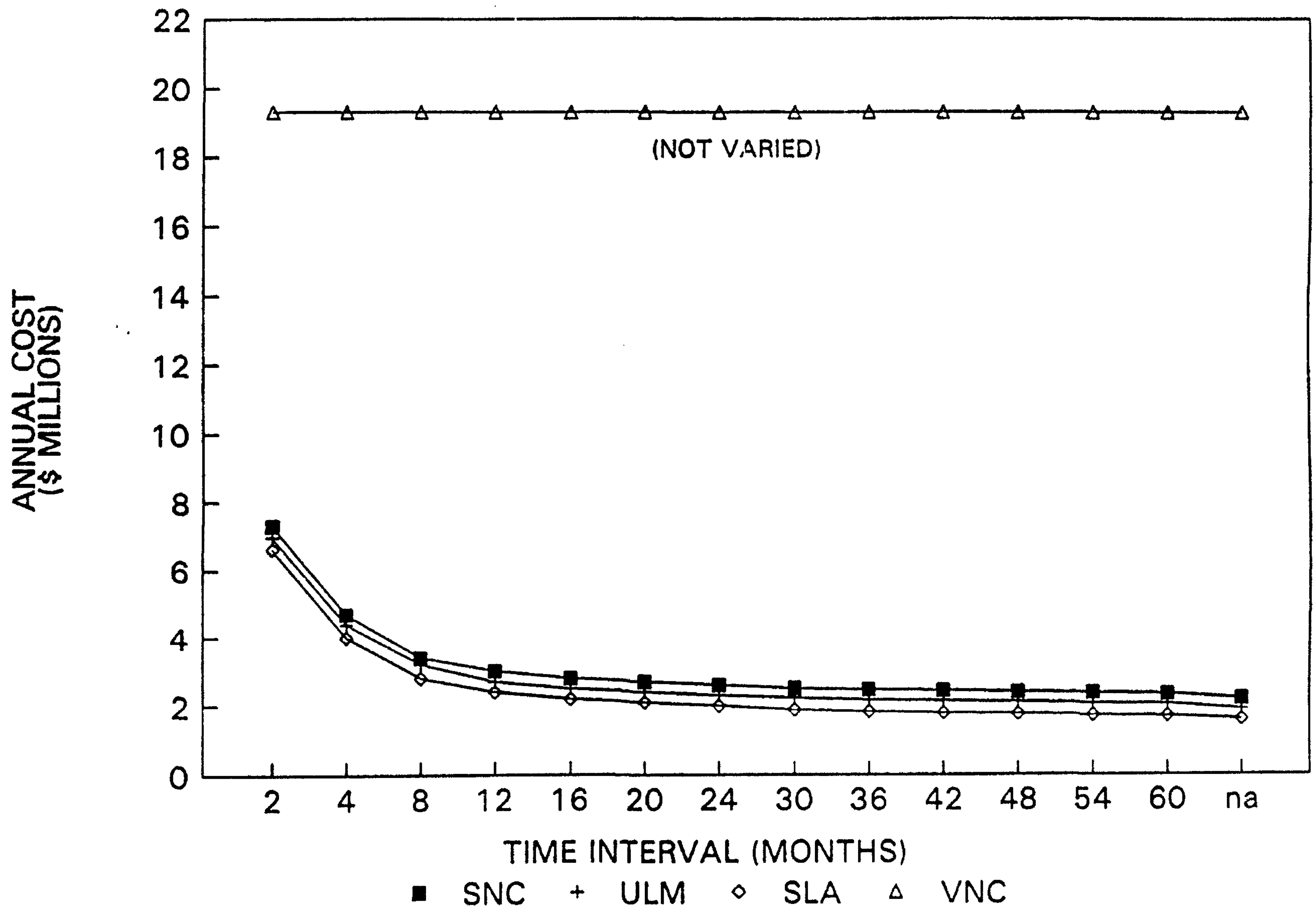


FIGURE 4-10. SENSITIVITY TO SCHEDULED REMOVAL PERIOD

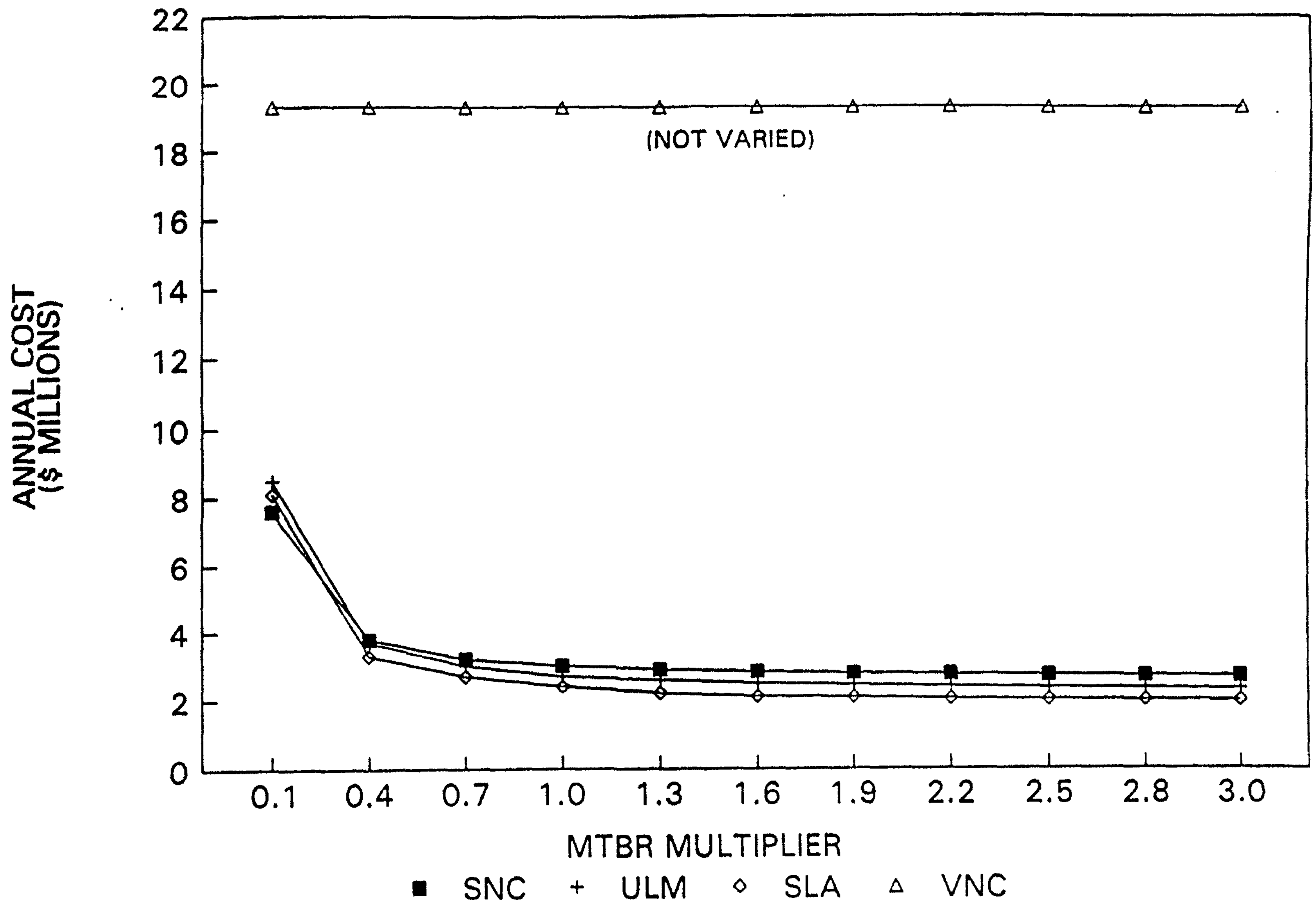


FIGURE 4-11. SENSITIVITY TO UNSCHEDULED REMOVAL RATE

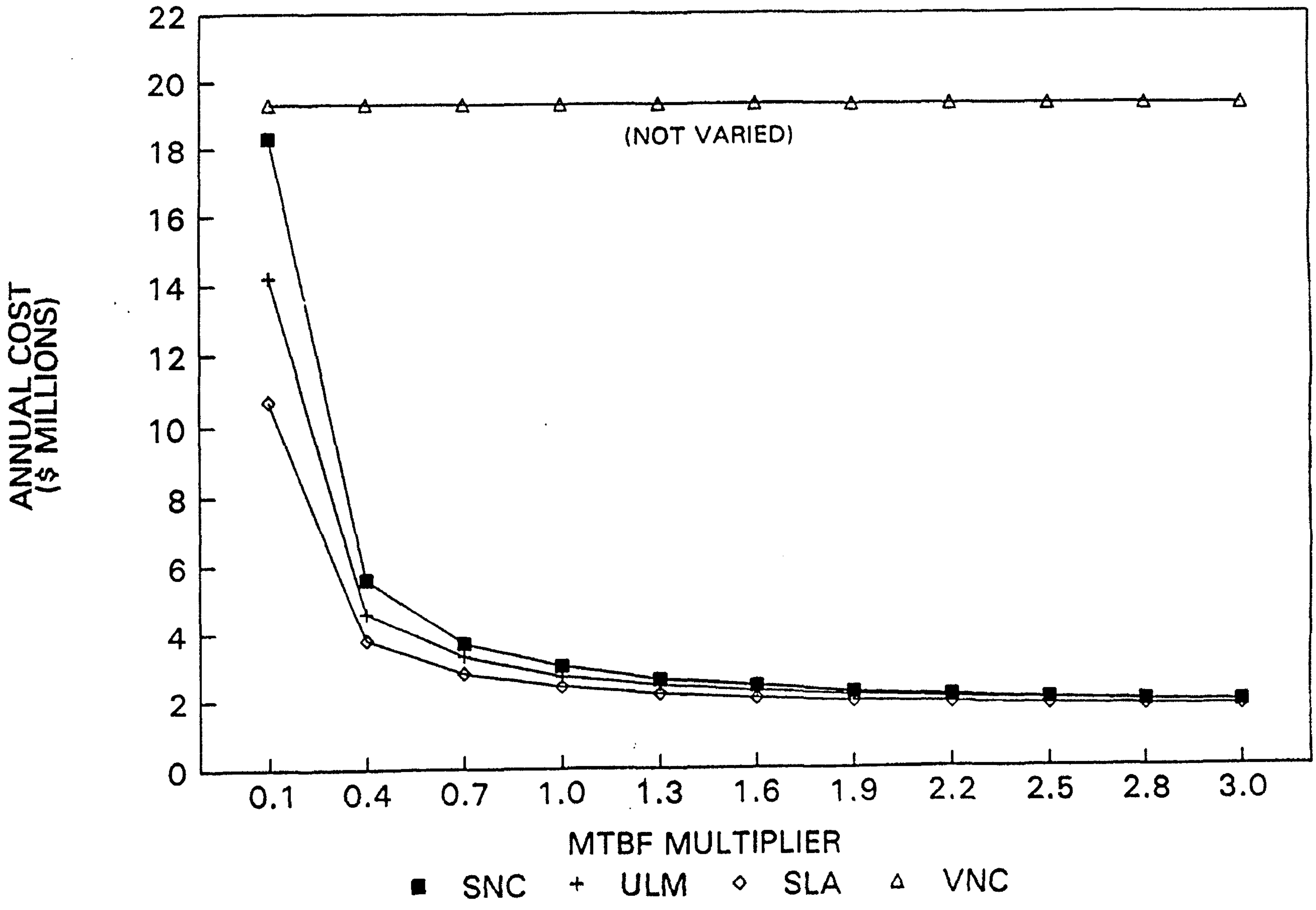


FIGURE 4-12. SENSITIVITY TO FAILURE RATE

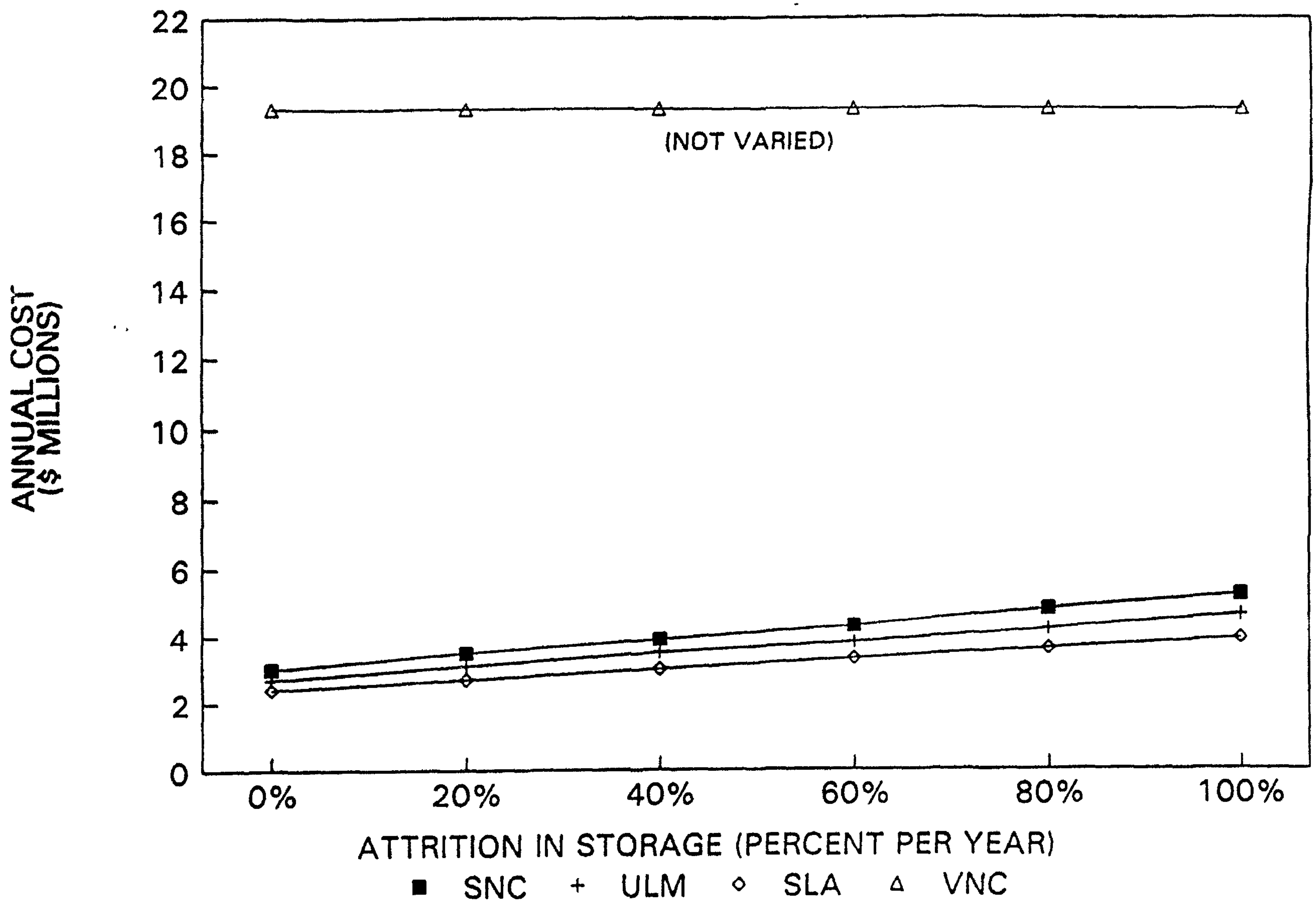


FIGURE 4-13. SENSITIVITY TO ATTRITION RATE

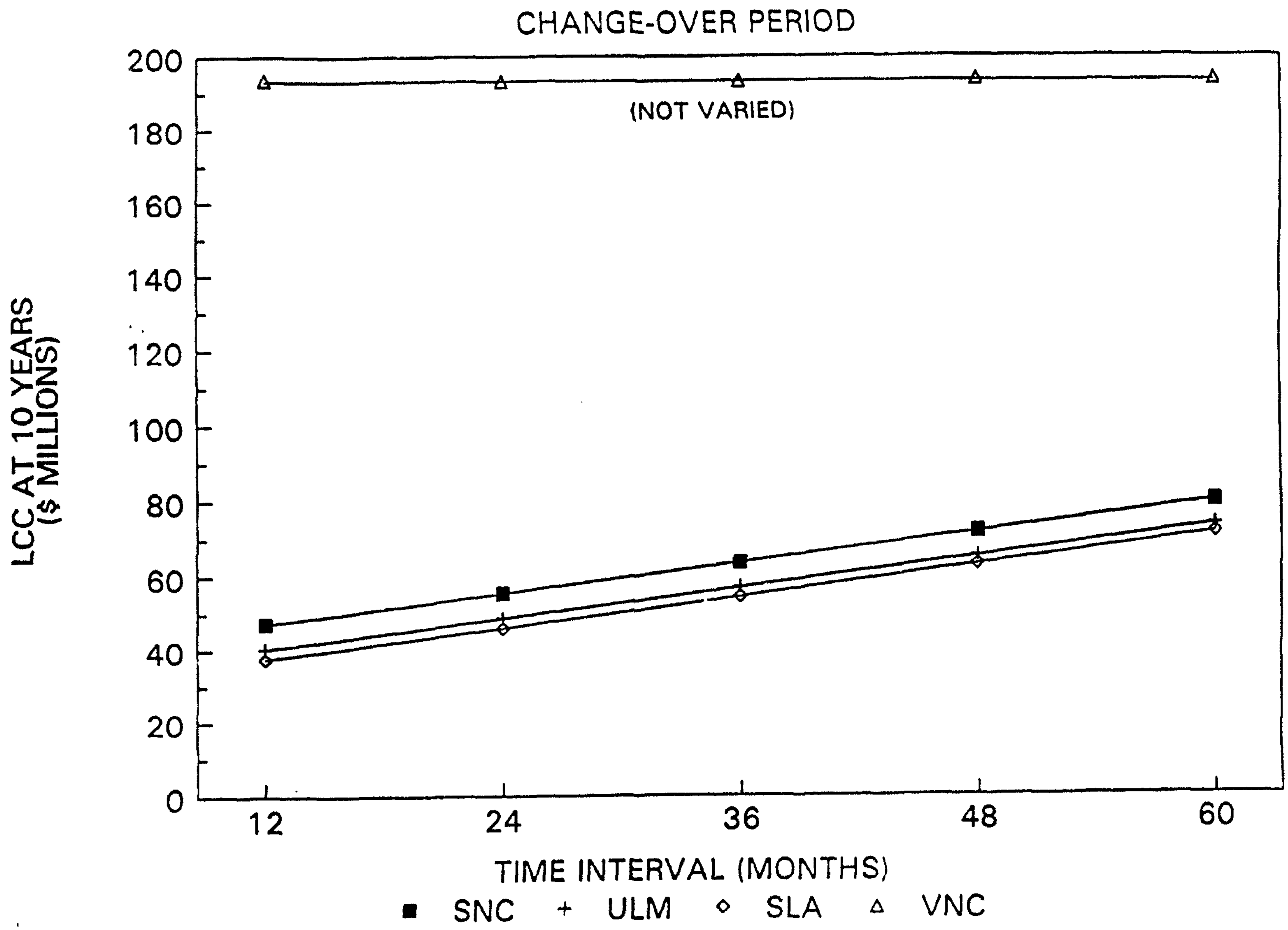


FIGURE 4-14. SENSITIVITY TO CHANGE-OVER PERIOD

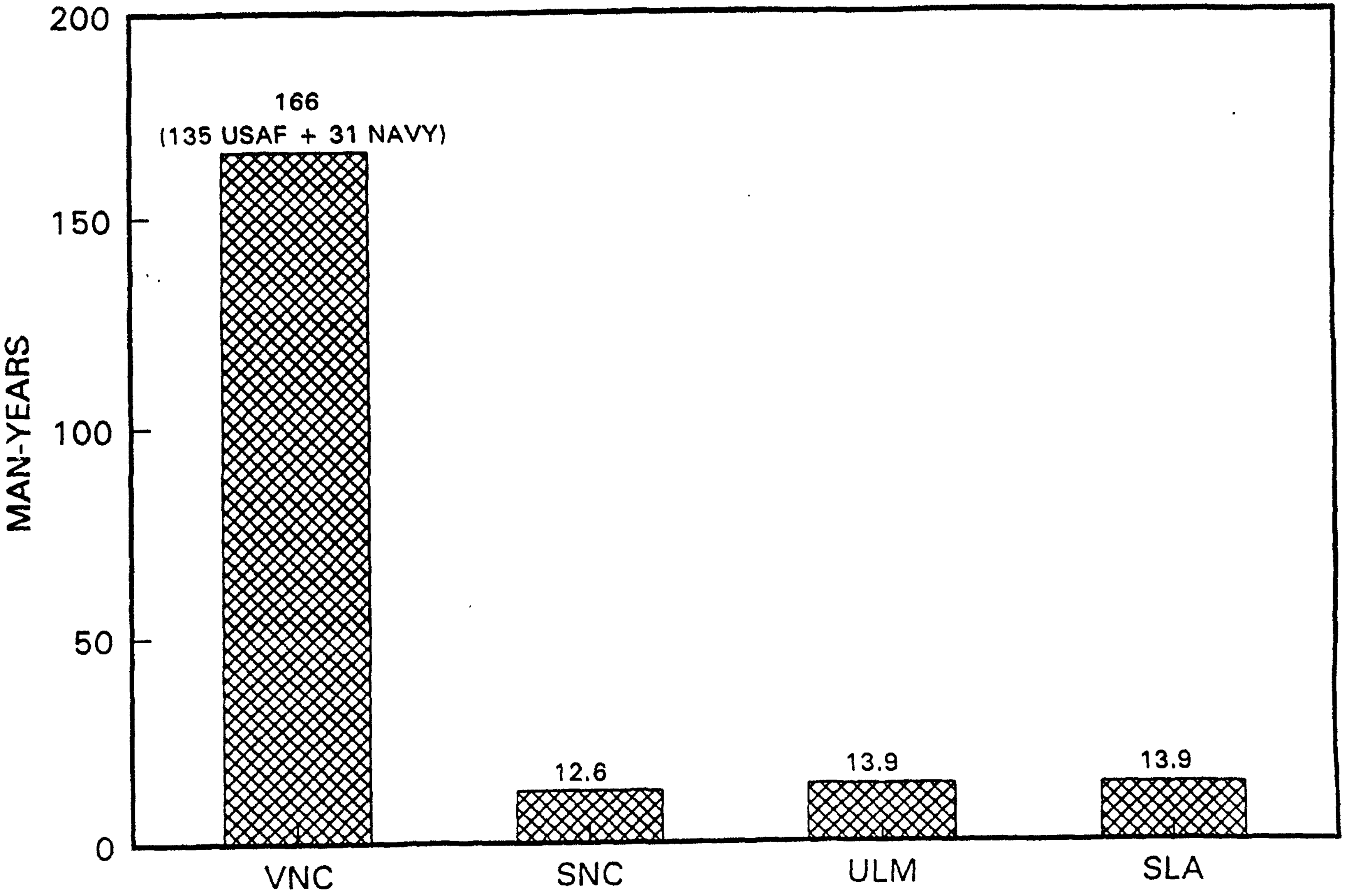


FIGURE 4-15. ANNUAL MANPOWER REQUIREMENTS

TABLE 4-3. OPERATIONAL CAPABILITY COMPARISON

Battery Type	VNC		SNC	ULM	SLA
Service Branch	Navy	Air Force	Combined	Combined	Combined
Flight Hours Per Year	416,000	1,650,000	1,963,000	1,963,000	1,963,000
Unscheduled Removals Per Year	278	733	157	196	196
Scheduled Removals Per Year	3003	18,000	3926	3926	3926
Downtime Hours Per Year[(a)]	2058	10,466	2277	2355	2355
Aircraft Availability, %	99.508	99.370	99.884	99.880	99.880
No. Aircraft With INS Battery	550	1900	2450	2450	2450
No. Aircraft Available	547	1888	2447	2447	2447

(a) Assumes 0.5 hour downtime per scheduled removal and 2.0 hours downtime per unscheduled removal.

increase does not seem great on a percentage basis, it translates into about 12 additional aircraft being operational at any given time. Figure 4-16 compares the number of aircraft that would be available of the total Navy/Air Force aircraft equipped with INS batteries (2,450 aircraft). Note that these availability factors account only for the INS battery contributions to downtime; other aircraft subsystems would also contribute to a greater or lesser extent.

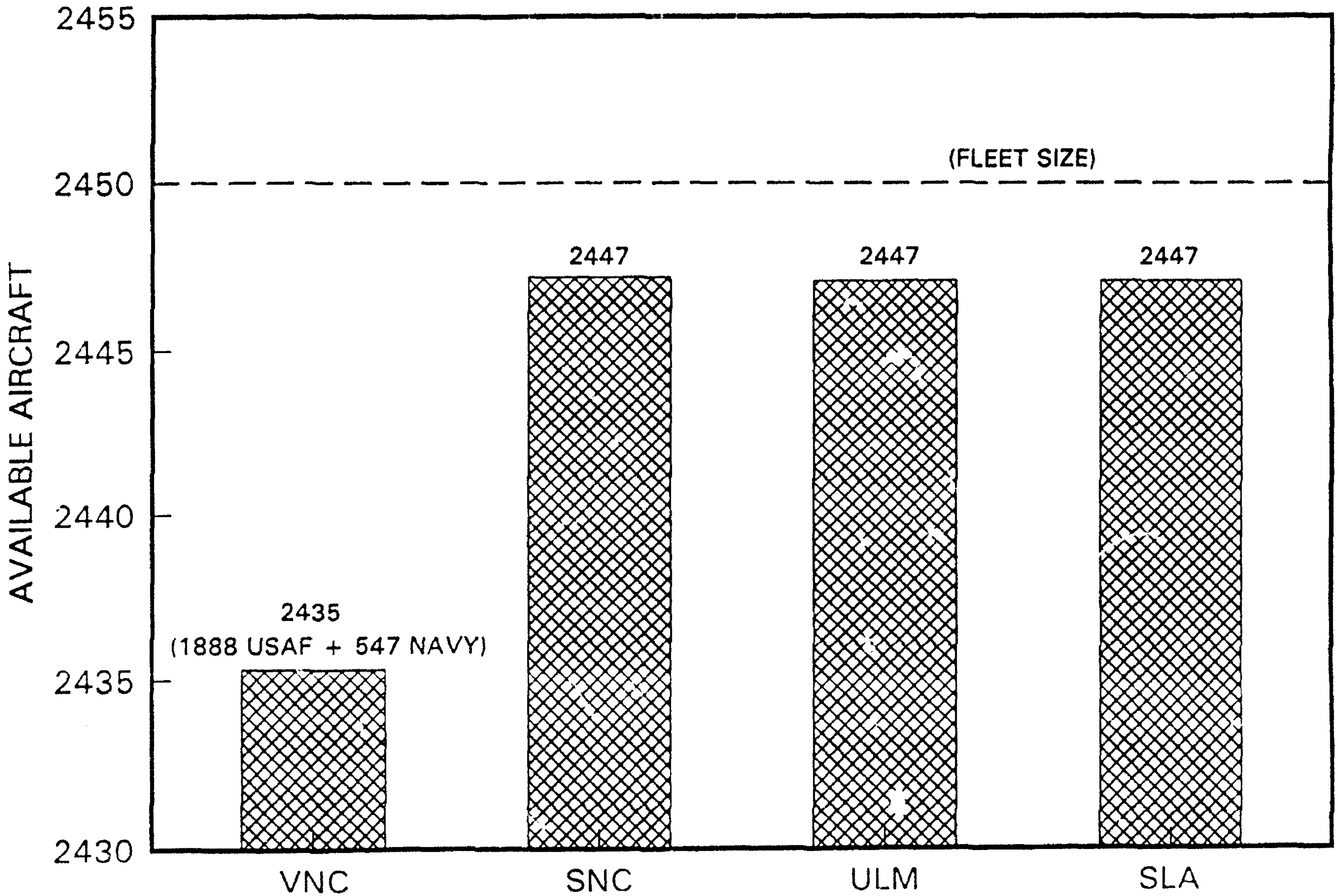


FIGURE 4-16. OPERATIONAL CAPABILITY

5.0 SPECIFICATION DEVELOPMENT

In accordance with paragraph 3.4 of the SOW, a specification was developed detailing the performance and test requirements for a maintenance-free INS battery. This specification was prepared as a "slash sheet" under the General Military Specification MIL-B-8565, and has been given the preliminary designation DOD-B-8565/INS. A copy of this specification is exhibited in Appendix E.

In line with the general requirements of MIL-B-8565, this specification sheet does not dictate which type of battery technology must be used. However, it is anticipated that a competitive procurement will favor SLA technology, as supported by the life cycle cost data presented in Section 4.0.

6.0 CONCLUSIONS

Based on the results presented in Sections 1 through 5, overall conclusions can be summarized as follows:

- All the candidate technologies (SNC, ULM and SLA) are capable of meeting the INS battery requirements.
- At present, the SLA technology represents the best choice among the candidates due to lowest acquisition cost, lowest O&S costs, lowest life cycle cost and lowest technology risk.
- A Specification Sheet (DOD-B-8565/INS) has been developed to provide detailed performance and test requirements for a maintenance-free INS battery. Prototype batteries need to be manufactured and tested to validate that all specification requirements can be achieved.
- Change-over from VNC to SLA technology will result in the following benefits to the Navy and Air Force:
    - Savings of $147 million over a 10-year period
    - Payback period of 8 months
    - Manpower reduction of 153 men per year
    - Aircraft availability increase of 12 aircraft.
- The new battery design does not require heater blankets.
- Regular (e.g., annual) capacity checks should be scheduled to confirm the emergency back-up capability of installed batteries.
- The transition period from the presently used VNC technology should be accelerated as much as possible to maximize cost savings.

7.0 RECOMMENDATIONS

Recommendations for follow-on activities are as follows:

- Use the Specification Sheet in Appendix E to procure preproduction prototypes for qualification and flight tests.
- Develop two qualified sources to provide the opportunity for competitive procurement in the production phase.
- Coordinate INS battery replacement efforts with Air Force and Navy weapon system managers to achieve maximum commonality.

8.0 REFERENCES

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4. ARINC Specification 404A, 15 March 1974, "Air Transport Equipment Cases and Racking," Aeronautical Radio, Inc.

5. Maintenance Manual, 34-41-00, 30 October 1973/Revision 5 - 1 March 1981, "Carousel IV-A Inertial Navigation System," Delco Electronics, General Motors Corporation.

6. Installation Manual, November 1988, "Carousel Inertial Navigation Systems," Delco Electronics, General Motors Corporation.

7. Overhaul Manual, 7884280, 34-40-16, 2 September 1982, "PR Electronics and Battery Charger Card Assembly (P/N 7891888-011) Schematic Design," Figure 802A, Delco Electronics, General Motors Corporation.

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9. Overhaul Manual TP72155, 34-44-57, 29 October 1976/Revision 11 - 15 March 1989, "Power Supply Assembly 456000," Litton Aero Products.

10. Overhaul Manual TP72101, 34-44-63, Vol. 1, 30 November 1977/Revision 13 - 20 December 1989, "LTN Inertial Navigation Unit 452080-05," Litton Aero Products.

11. Overhaul Manual TP 72158, 34-44-60, 7 December 1976/Revision - 24 August 1988, "Voltage Monitor/ON-OFF Logic Board Assembly 452309," Litton Aero Products.

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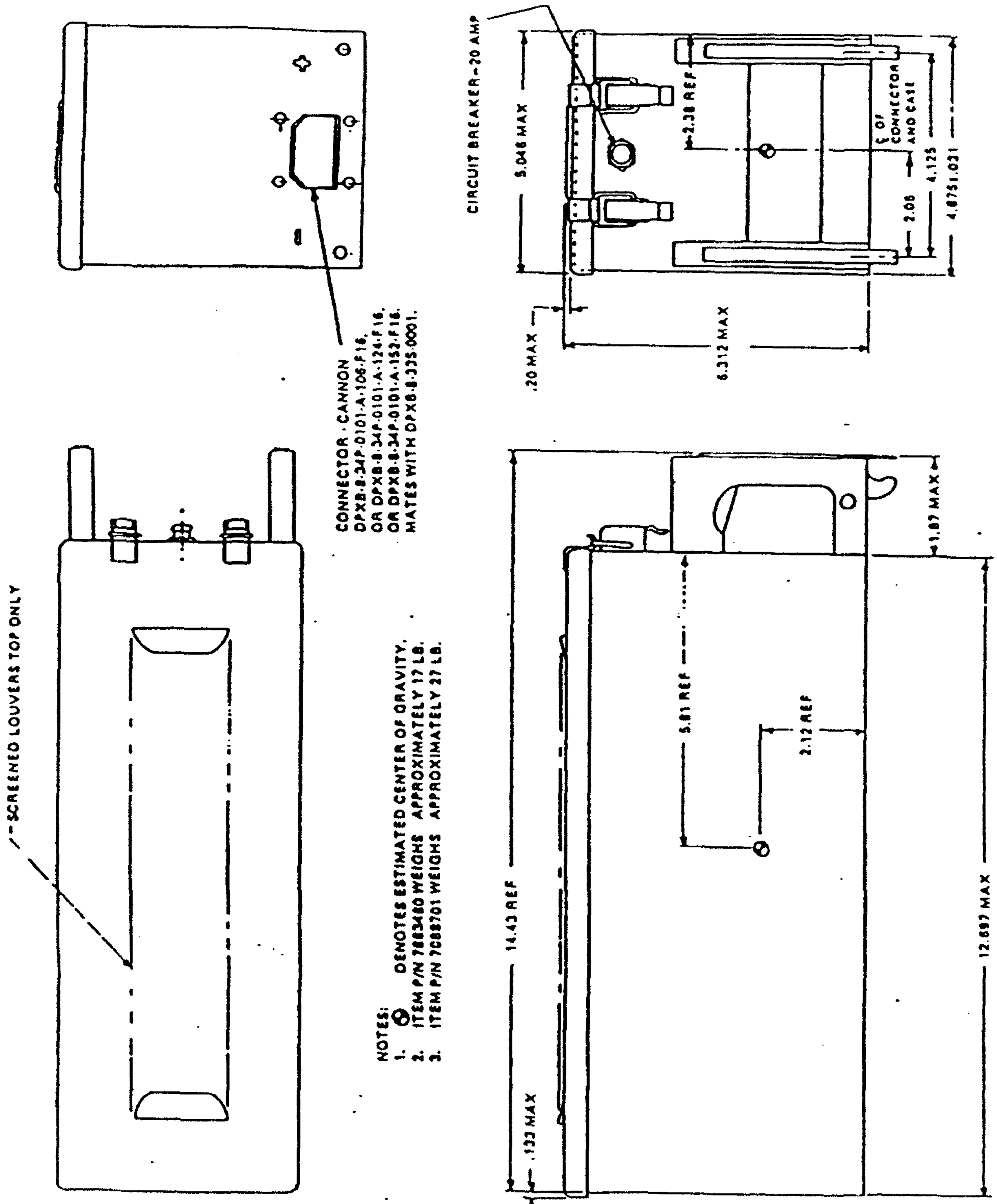
15. Military Specification MIL-E-5272C, 13 April 1959/Amendment 2 - 18 September 1970/Notice 2 - 21 January 1981, "General Specification for Environmental Testing, Aeronautical and Associated Equipment."

16. Document DO-138, 27 June 1968/Change 1 - 1 July 1969/Change 2 - 1 July 1975, "Environmental Conditions and Test Procedures for Airborne Electronic/Electrical Equipment and Investments," Radio Technical Commission for Aeronautics.

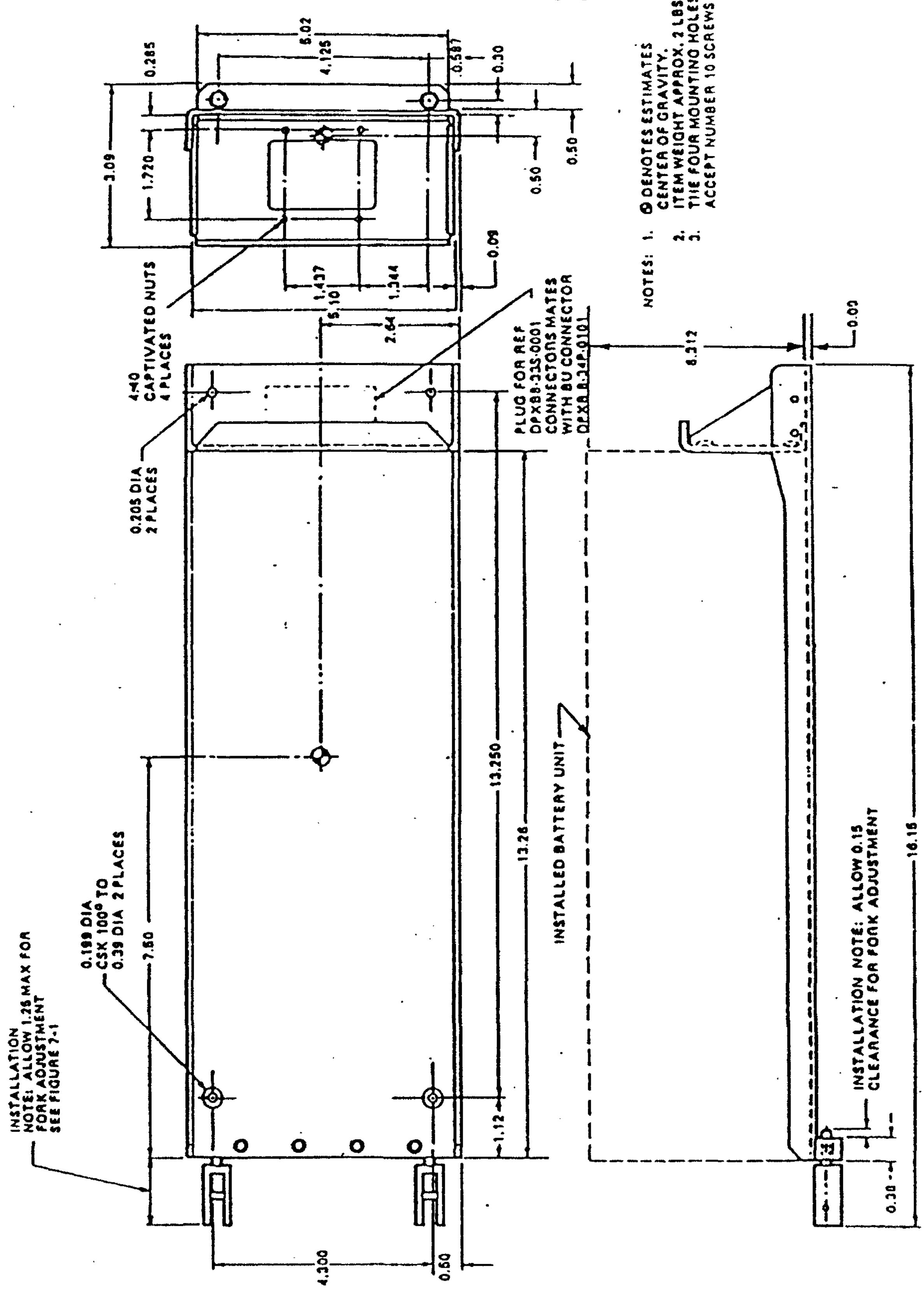
17. Document DO-160C, 4 December 1989, "Environmental Conditions and Test Procedures for Airborne Equipment," Radio Technical Commission for Aeronautics.

APPENDIX A

<u>CAROUSEL IV INS DATA</u>



Battery Unit (P/N 7883480 or 7888701)



Battery Tray (P/N 7891441)

1-4. PURPOSE OF EQUIPMENT

1-5. The 24-volt, 15.0 ampere-hours (nominal) battery unit (battery) provides up to 30 minutes of auxiliary power (fully charged) for an aircraft inertial navigation system (INS) if the 400-Hz primary input power is interrupted or falls below the required voltage. Power from the battery also is used momentarily to initiate INS operation at turn-on and for a 12.8-second period during automatic alignment of the INS.

1-6. During in-flight operation, the charging section of the INS automatically provides the battery with a 40 ma trickle charge. If the battery terminal voltage drops to 24.0 volts dc, or constant-current charging circuit is activated to charge the battery at a constant 2 ampere-hour rate. The 2 ampere-hour charging is automatically turned off when the battery voltage reaches 29.0 volts dc.

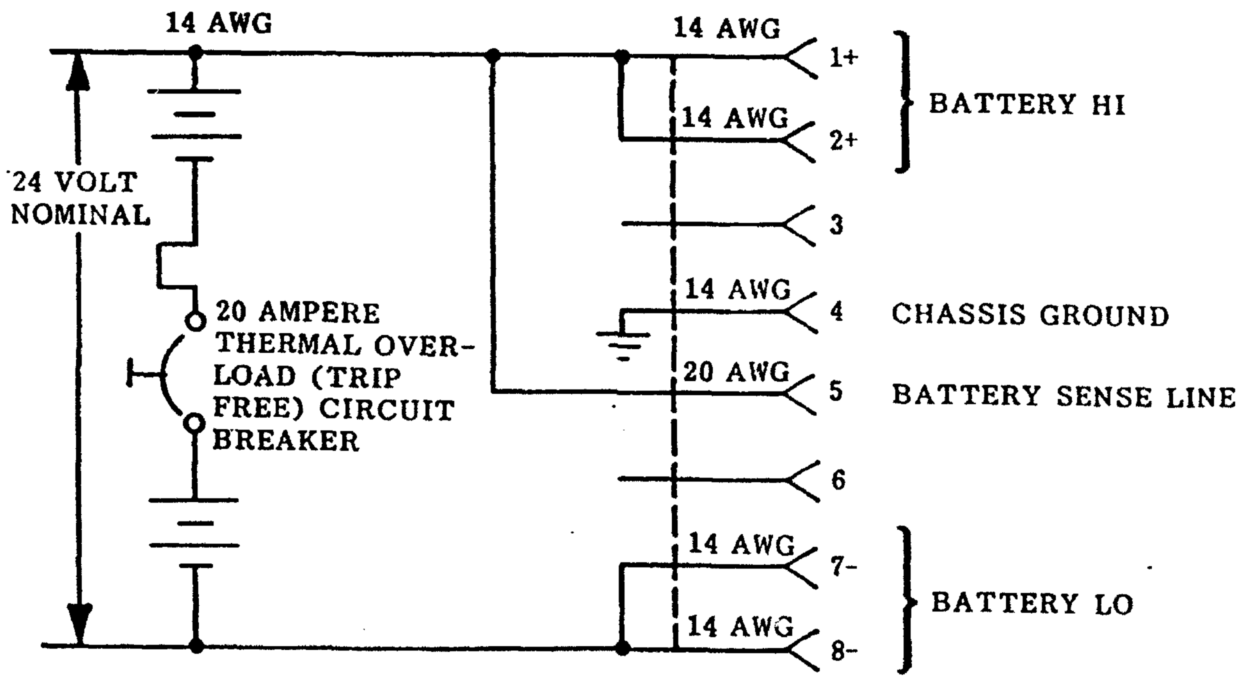
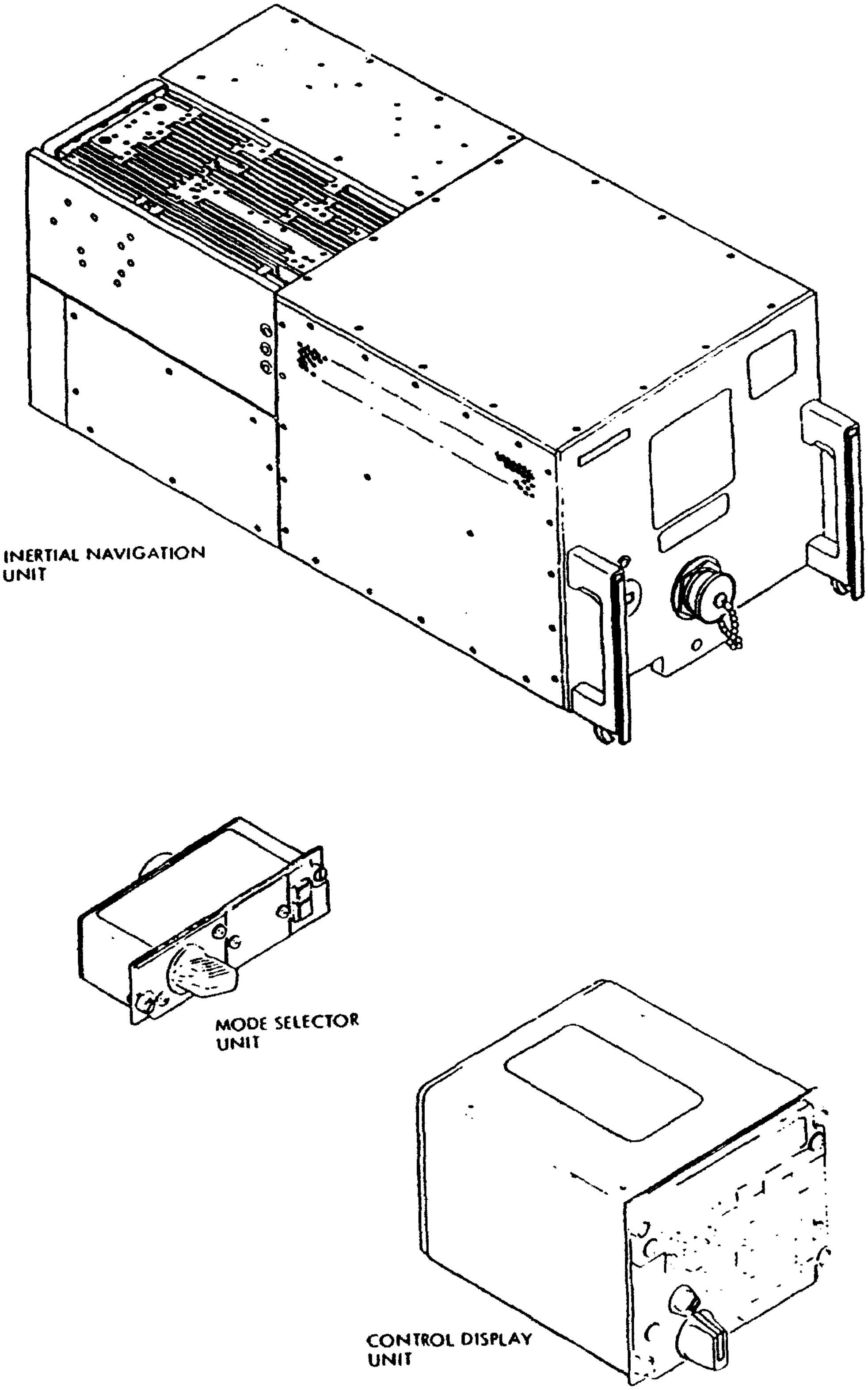


Figure 1-2. Battery Schematic Diagram

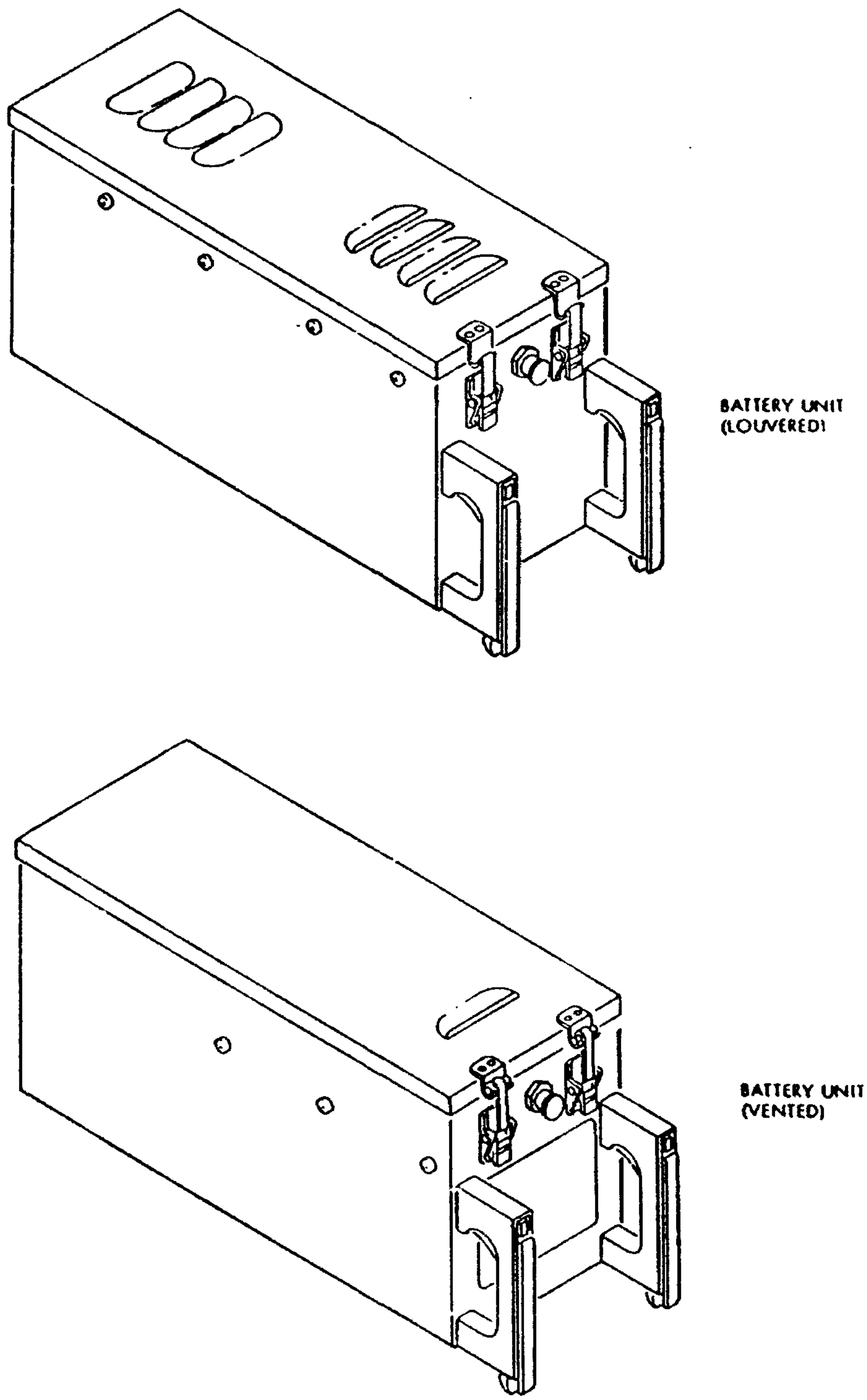
APPENDIX B

LTN-72 INS DATA



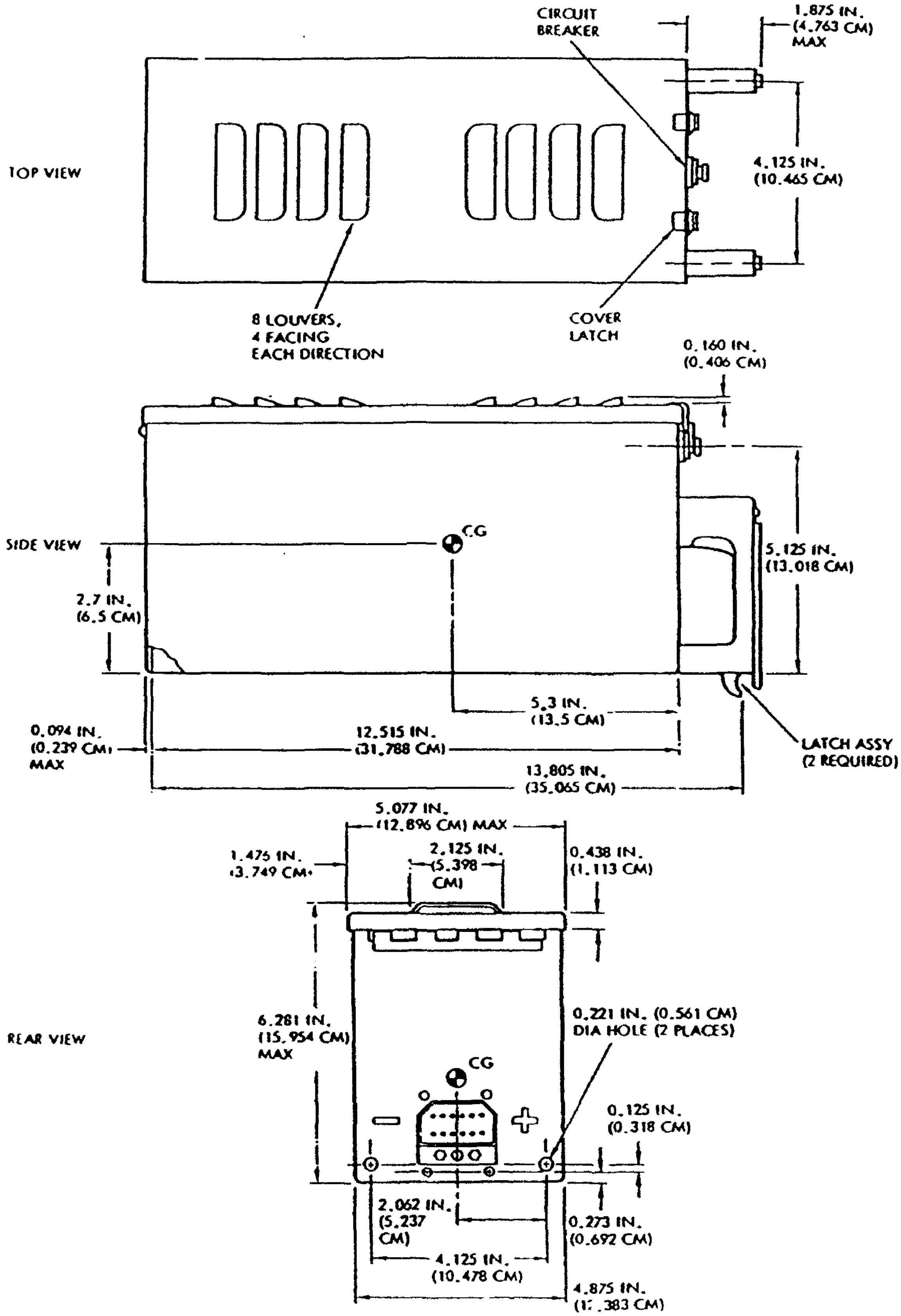
INS/ANS

Figure 1-1



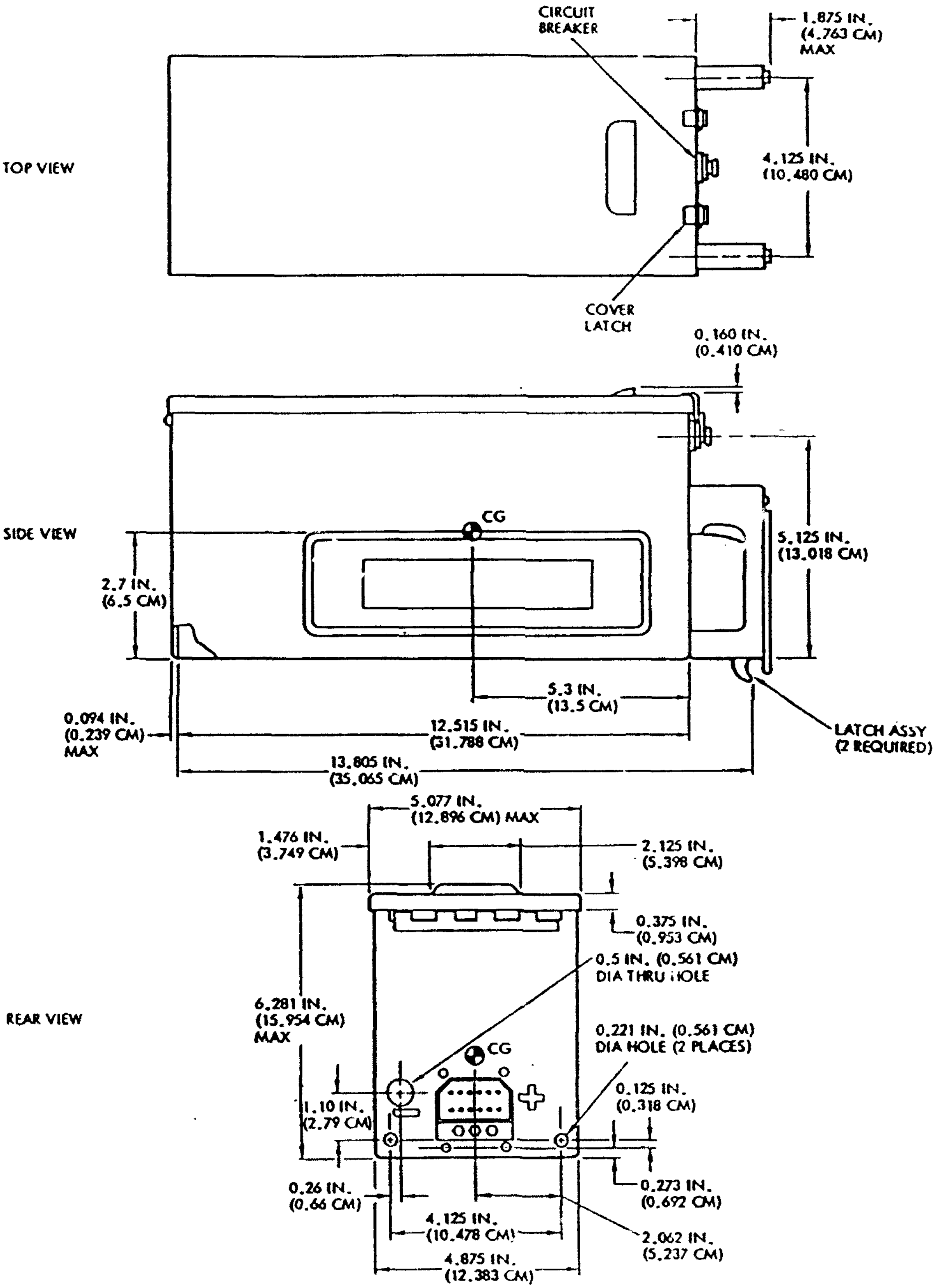
Optional Auxiliary Units

Figure 1-2 (Sheet 1 of 2)



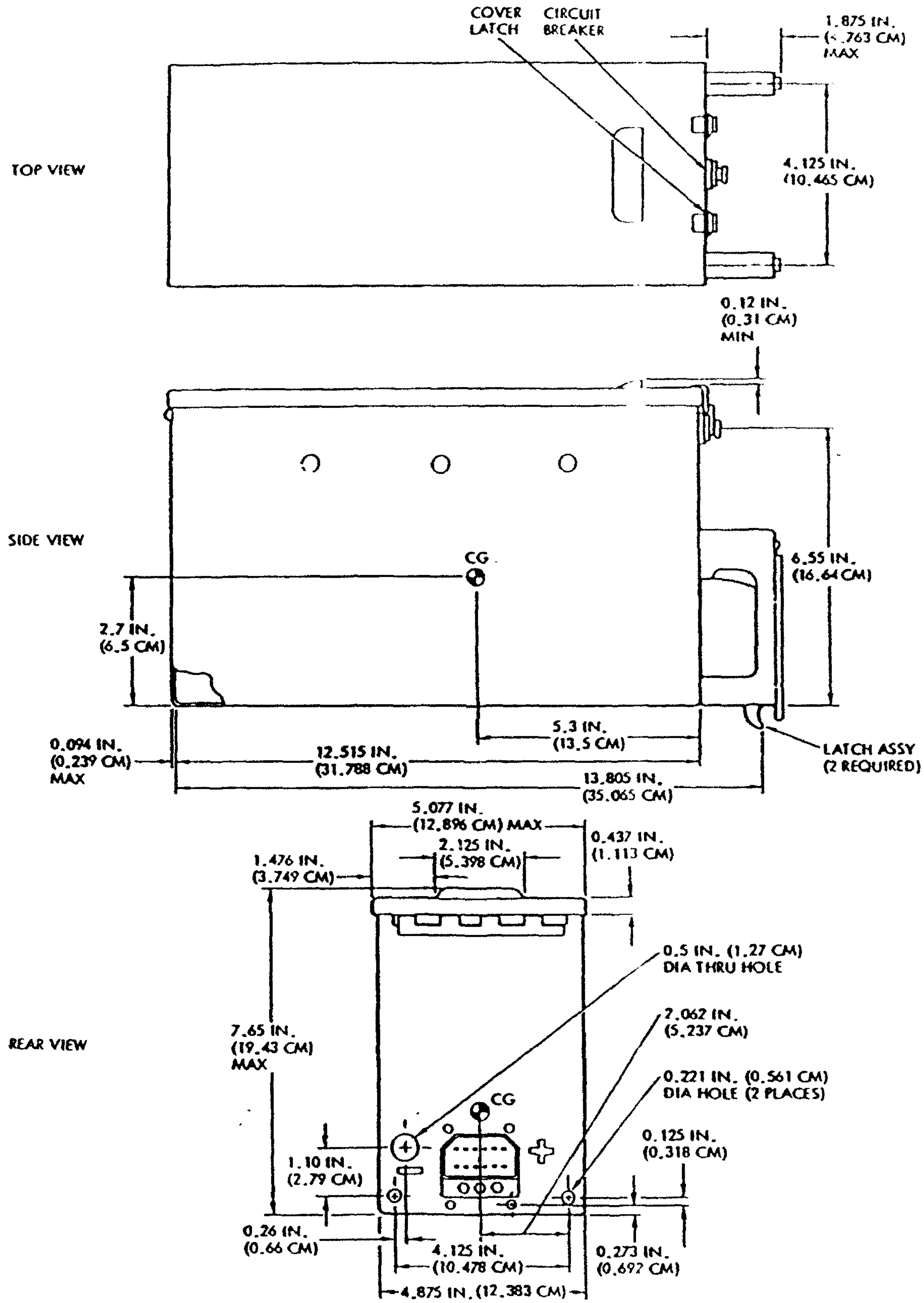
BU 500012-1 (Louvered) Outline and Mounting

Figure 1-11



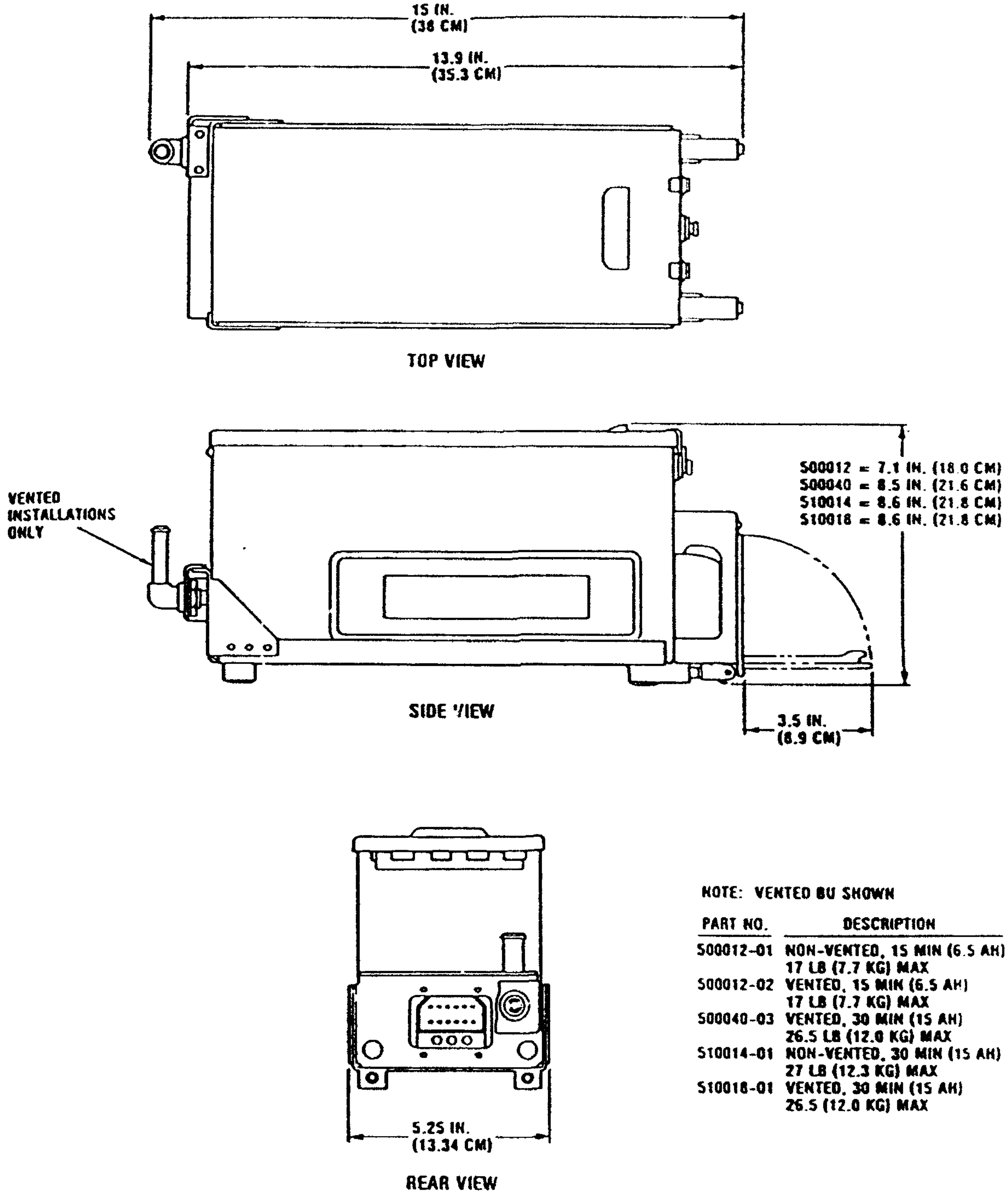
BU 500012-2 (Vented) Outline and Mounting

Figure 1-12



BUs 500040-03 and 510018-1 Outline and Mounting

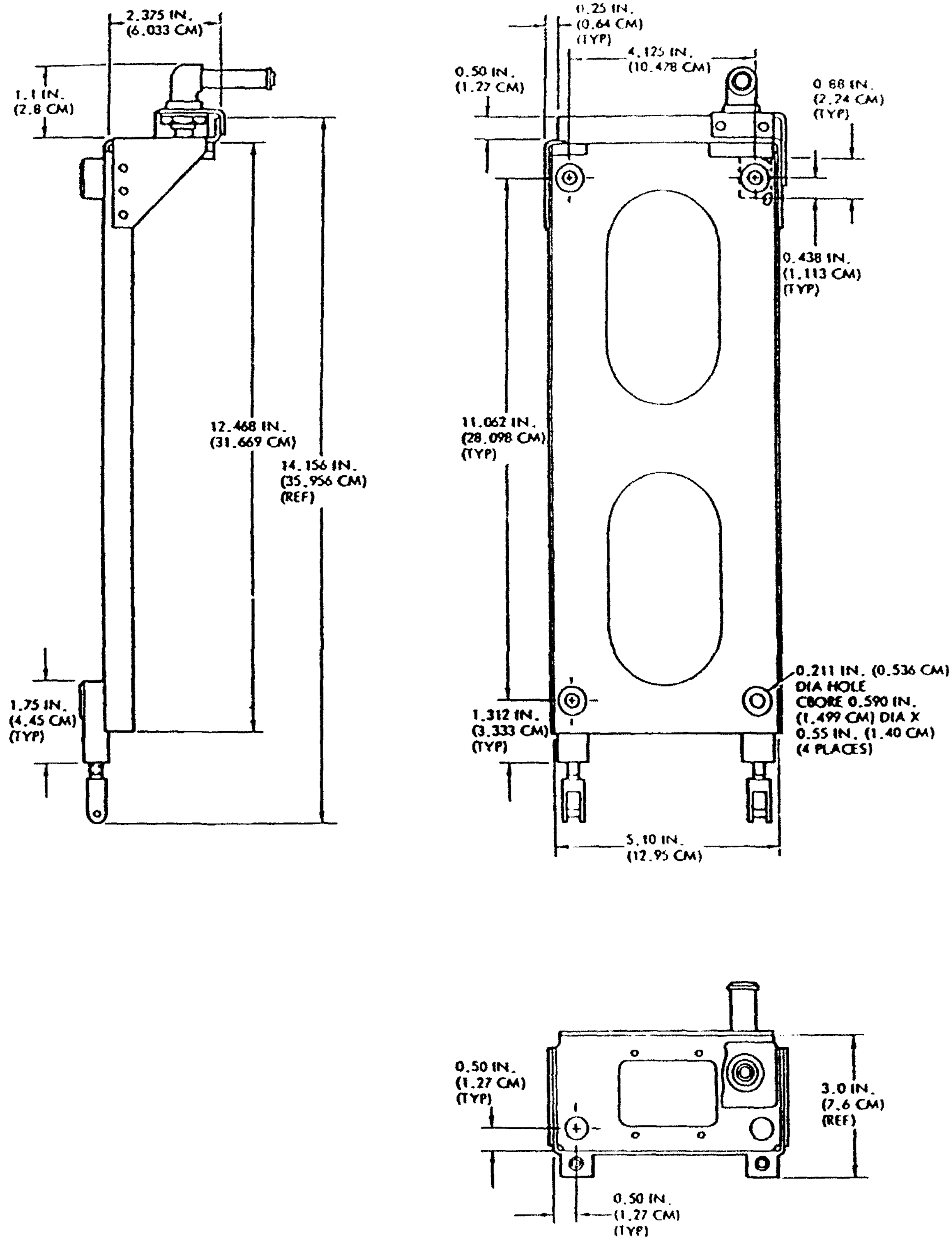
Figure 1-13



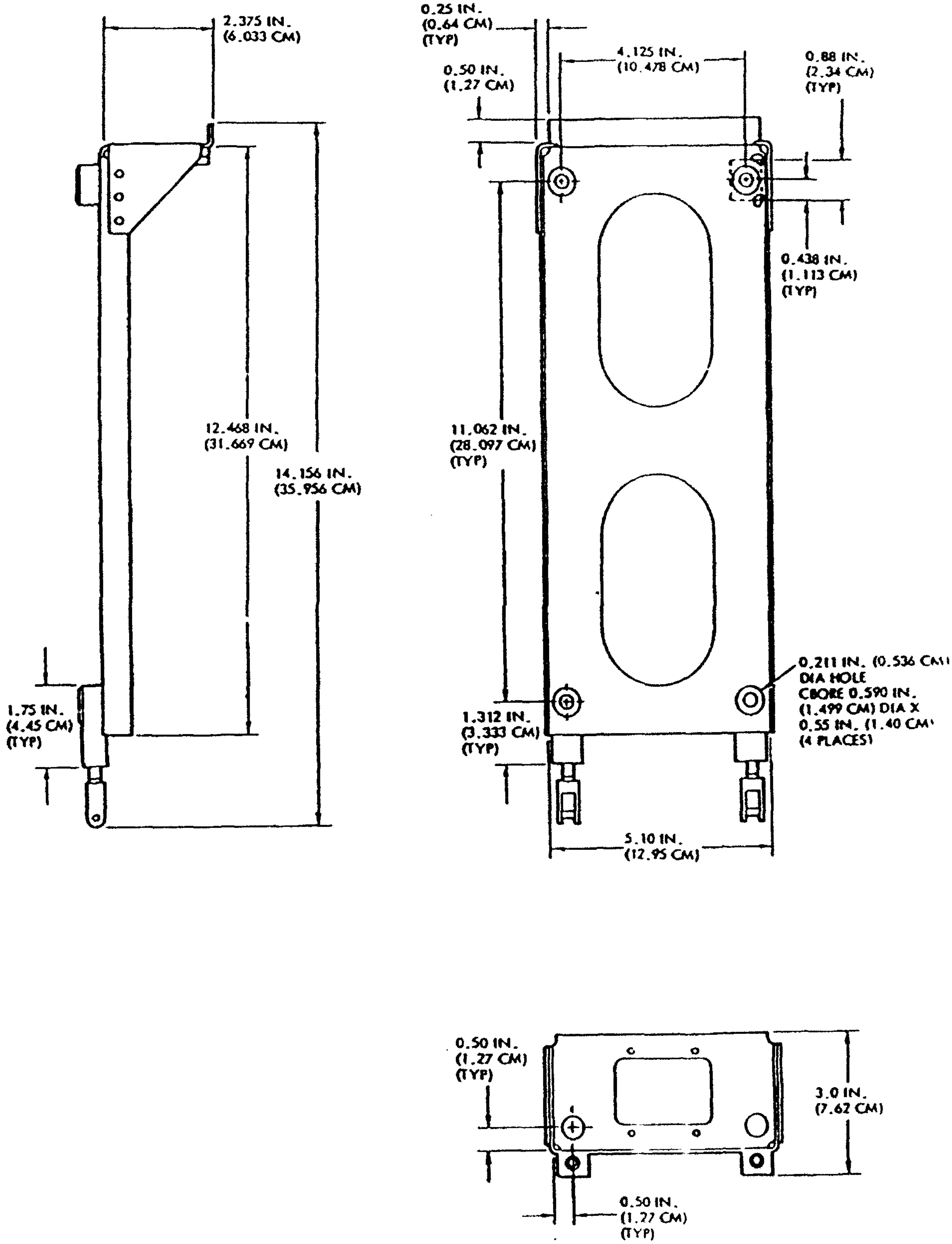
NOTE: VENTED BU SHOWN

PART NO.	DESCRIPTION
500012-01	NON-VENTED, 15 MIN (6.5 AH) 17 LB (7.7 KG) MAX
500012-02	VENTED, 15 MIN (6.5 AH) 17 LB (7.7 KG) MAX
500040-03	VENTED, 30 MIN (15 AH) 26.5 LB (12.0 KG) MAX
510014-01	NON-VENTED, 30 MIN (15 AH) 27 LB (12.3 KG) MAX
510018-01	VENTED, 30 MIN (15 AH) 26.5 (12.0 KG) MAX

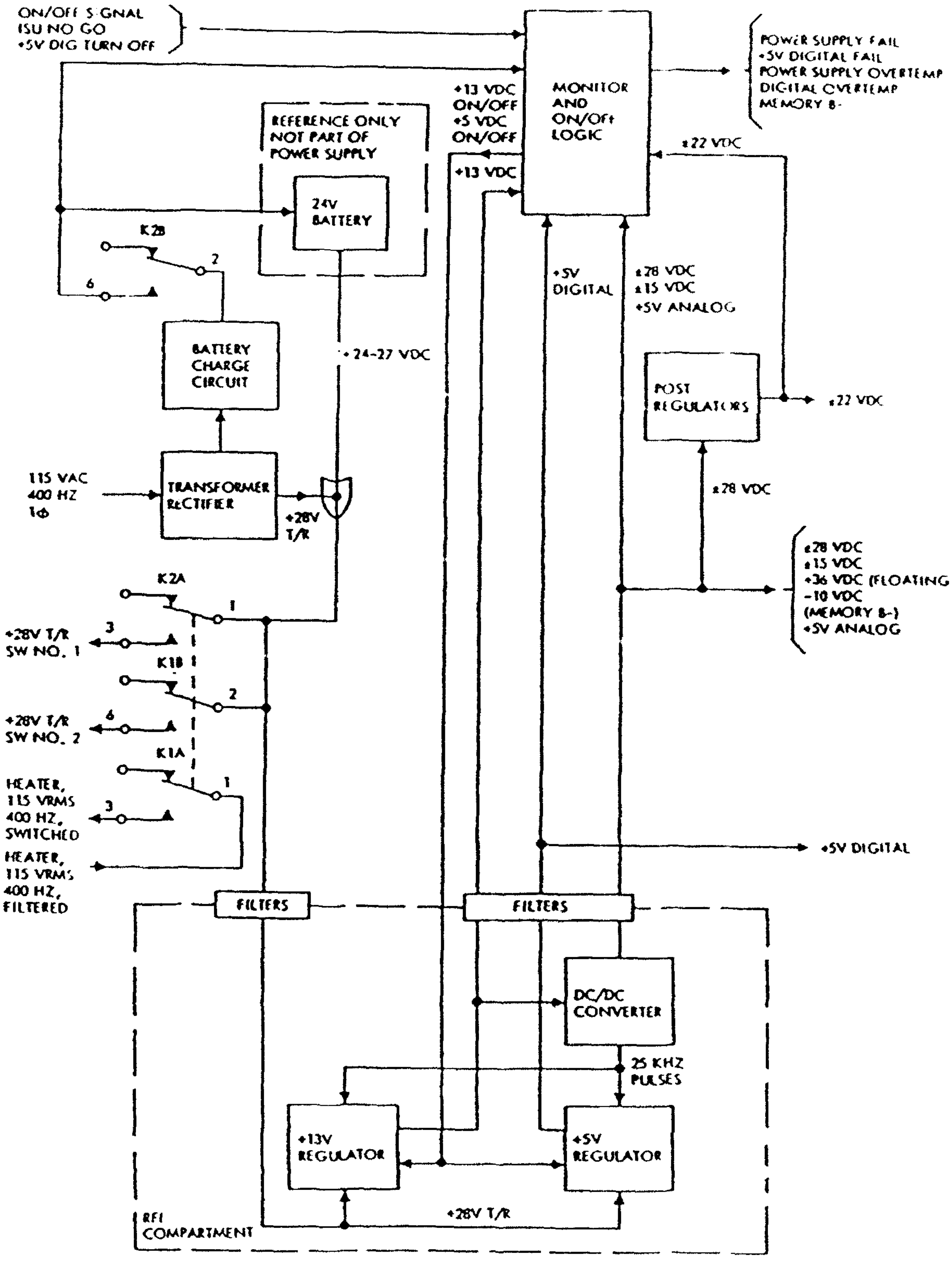
BU Installation, Overall Dimensions
Figure 2-7



Vented BU Tray 673738-01
Figure 2-27



Standard BU Tray 663803-02
Figure 2-28

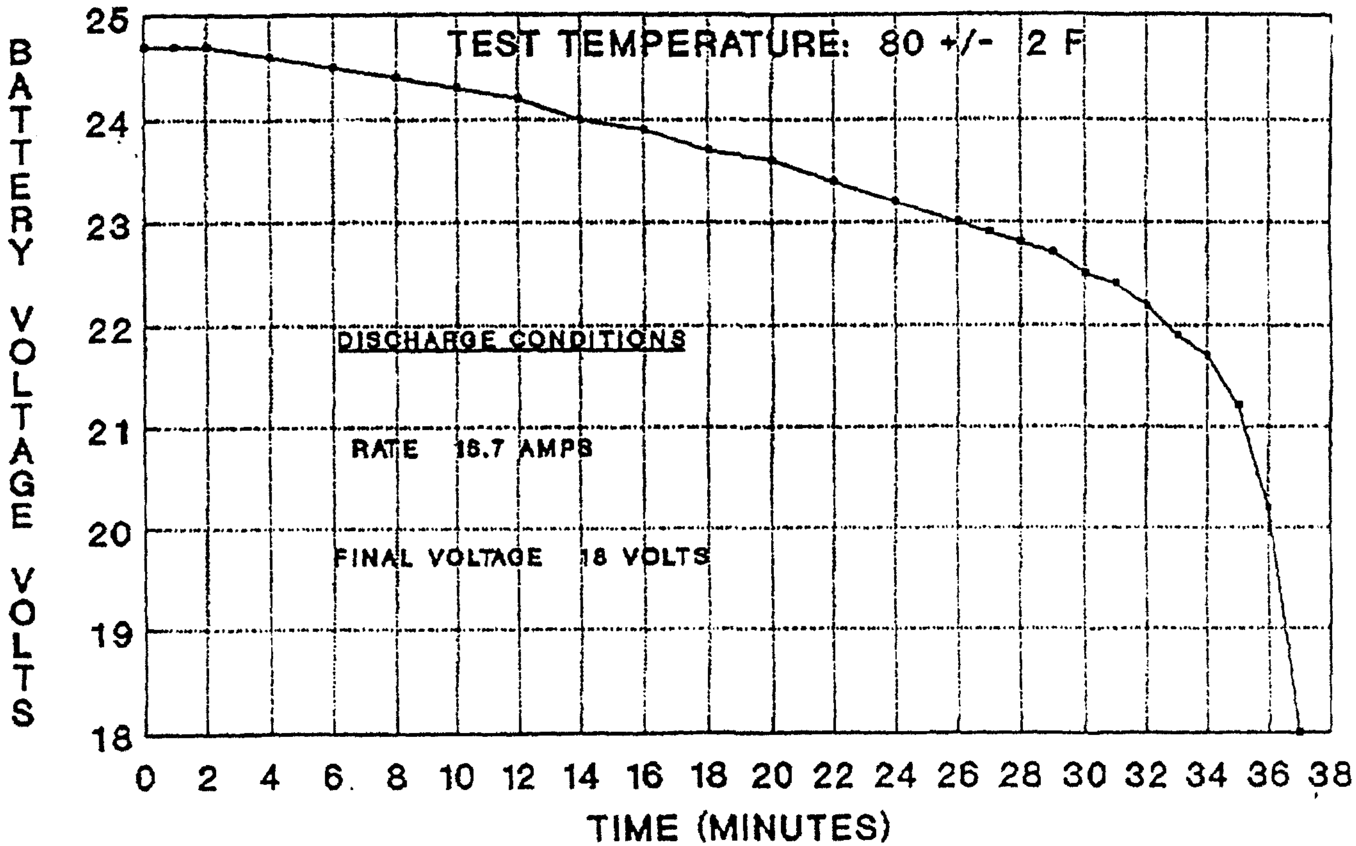


Power Supply Block Diagram

APPENDIX C

DISCHARGE DATA

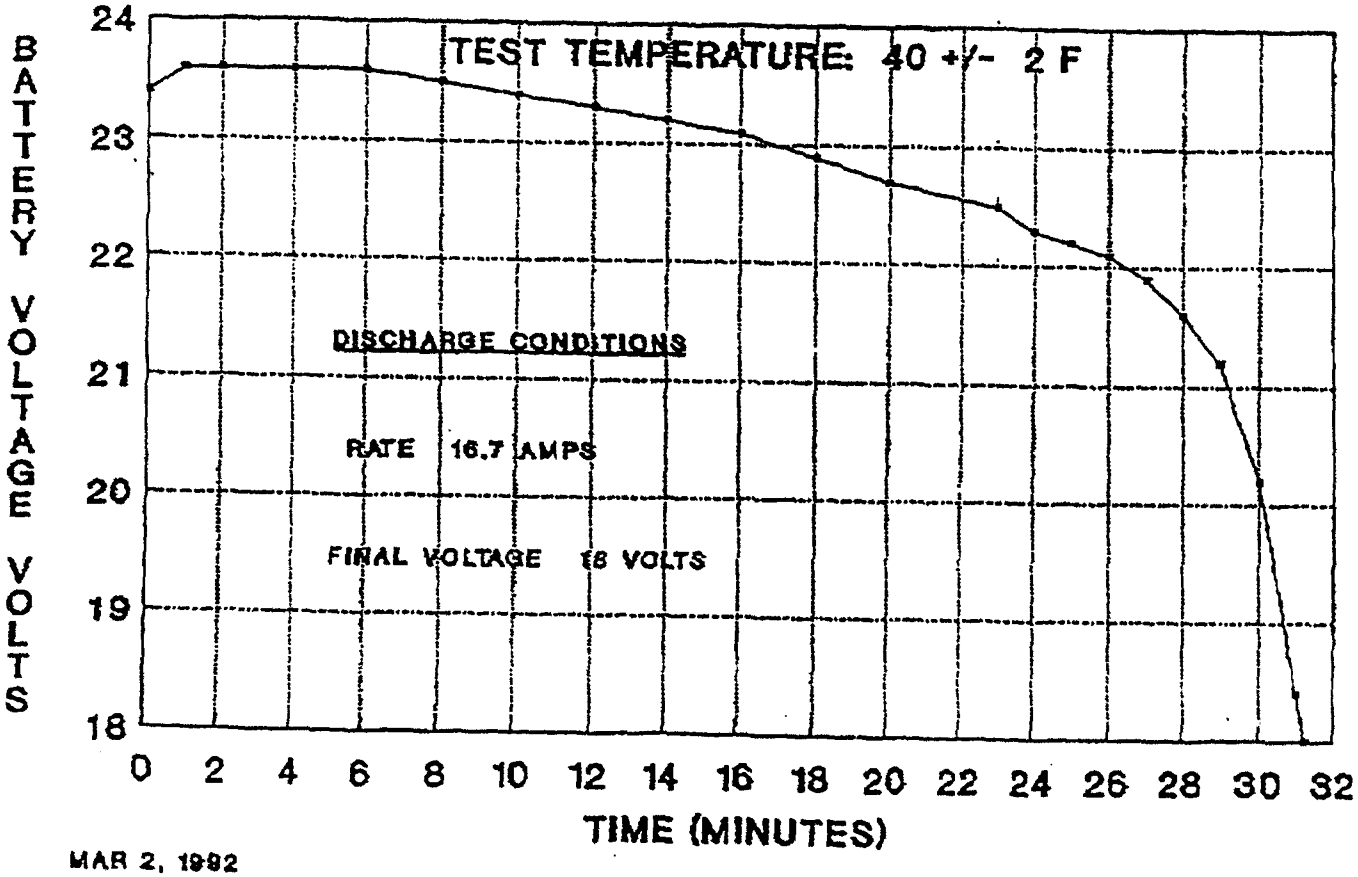
INS PRELIMINARY TESTING
ON A 10 A.HR. BATTERY (1 HOUR RATE)



MAR 3, 1992

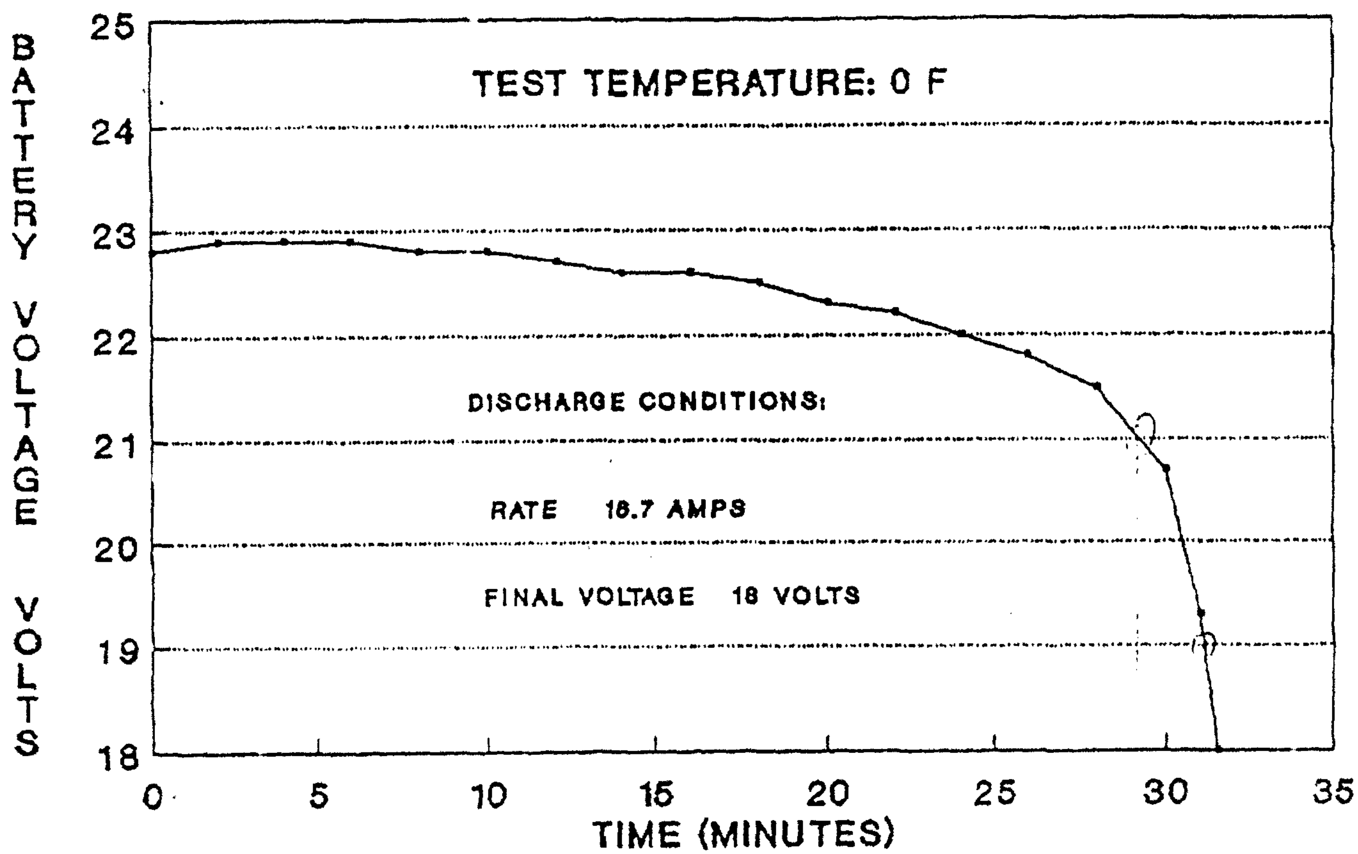
Concorde SLA Battery Data

INS PRELIMINARY TESTING
ON A 10 A.HR. BATTERY (1 HOUR RATE)



Concorde SLA Battery Data

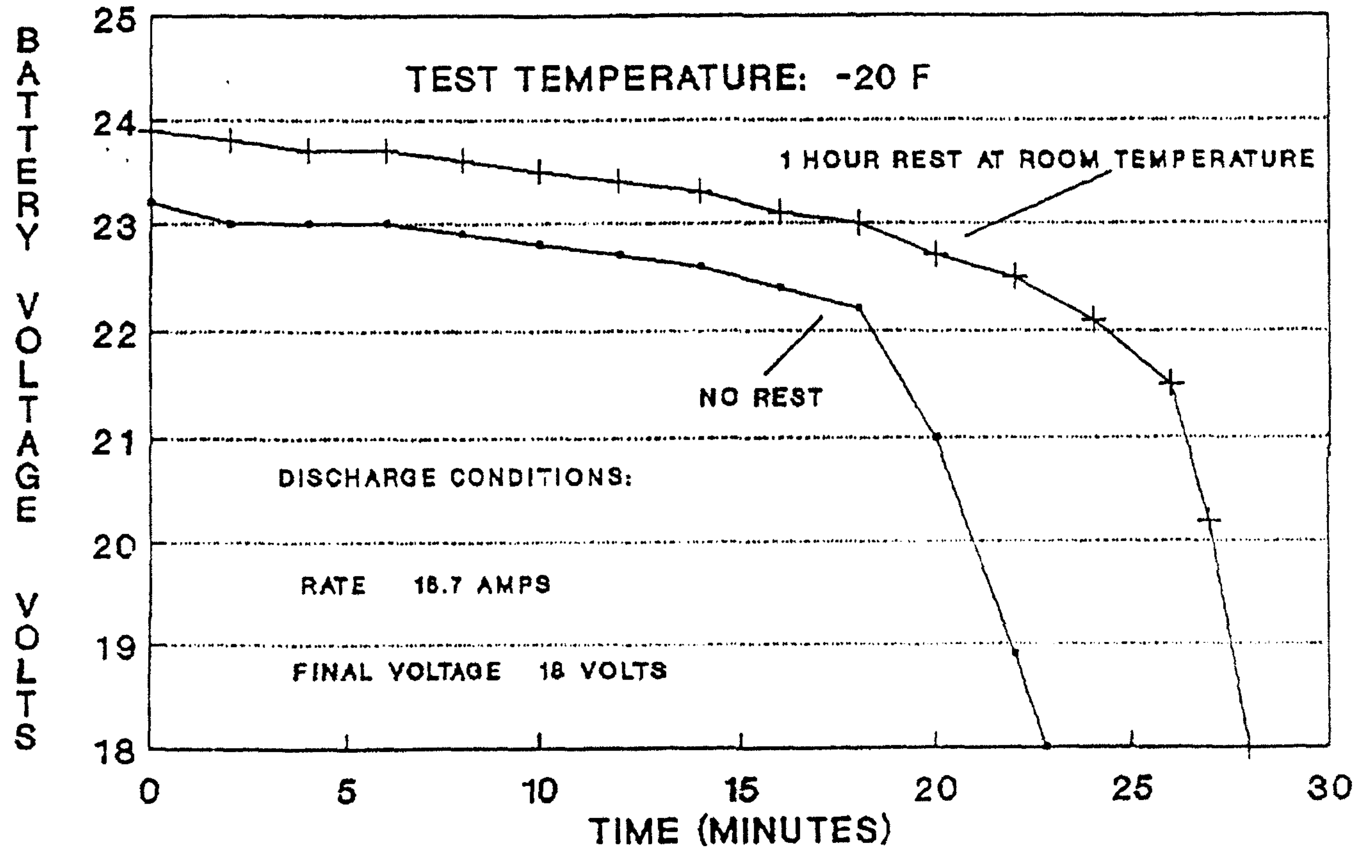
INS PRELIMINARY TESTING
ON A 10 A.HR. BATTERY (1 HOUR RATE)



FEB 8, 1992

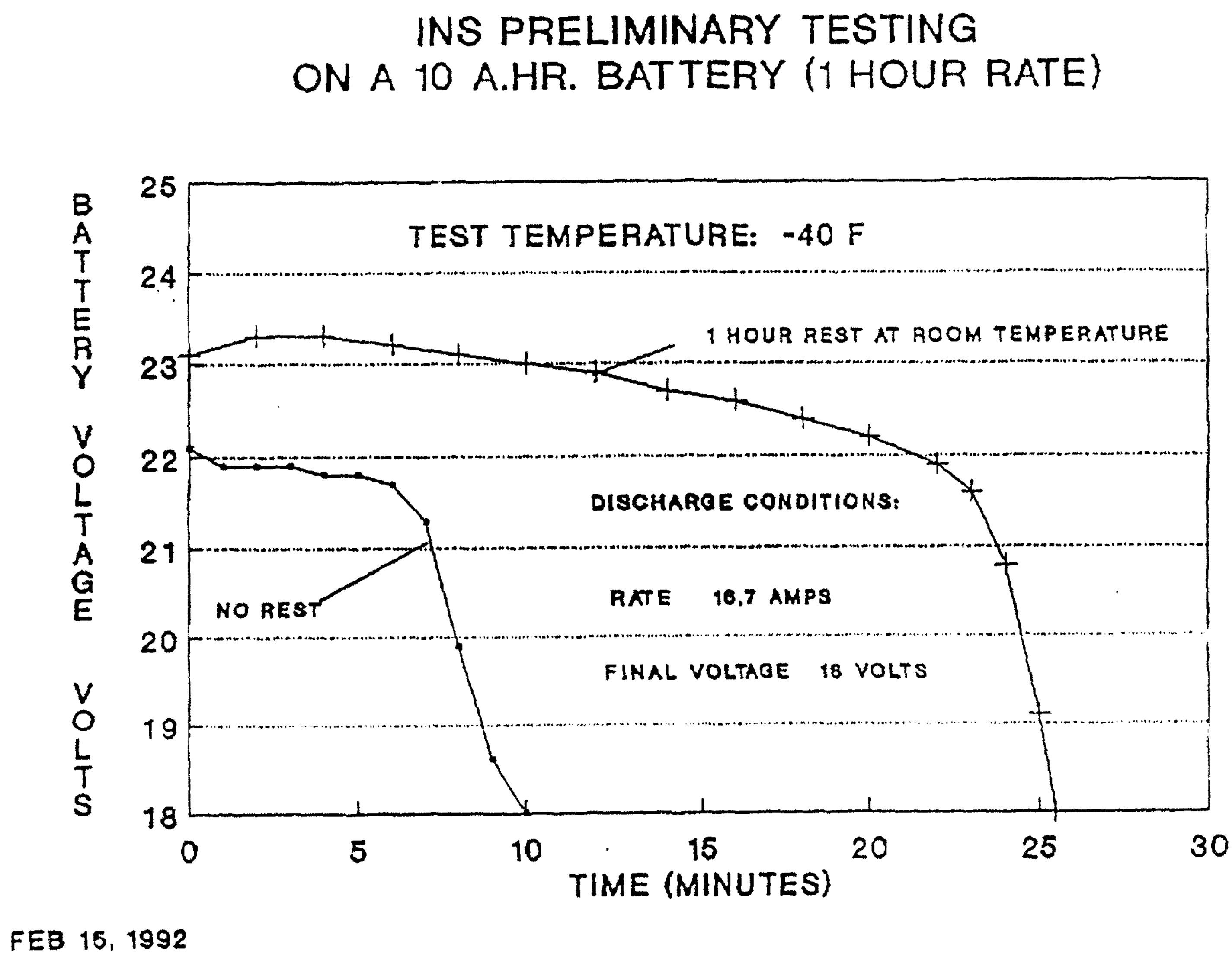
Concorde SLA Battery Data

INS PRELIMINARY TESTING
ON A 10 A.HR. BATTERY (1 HOUR RATE)



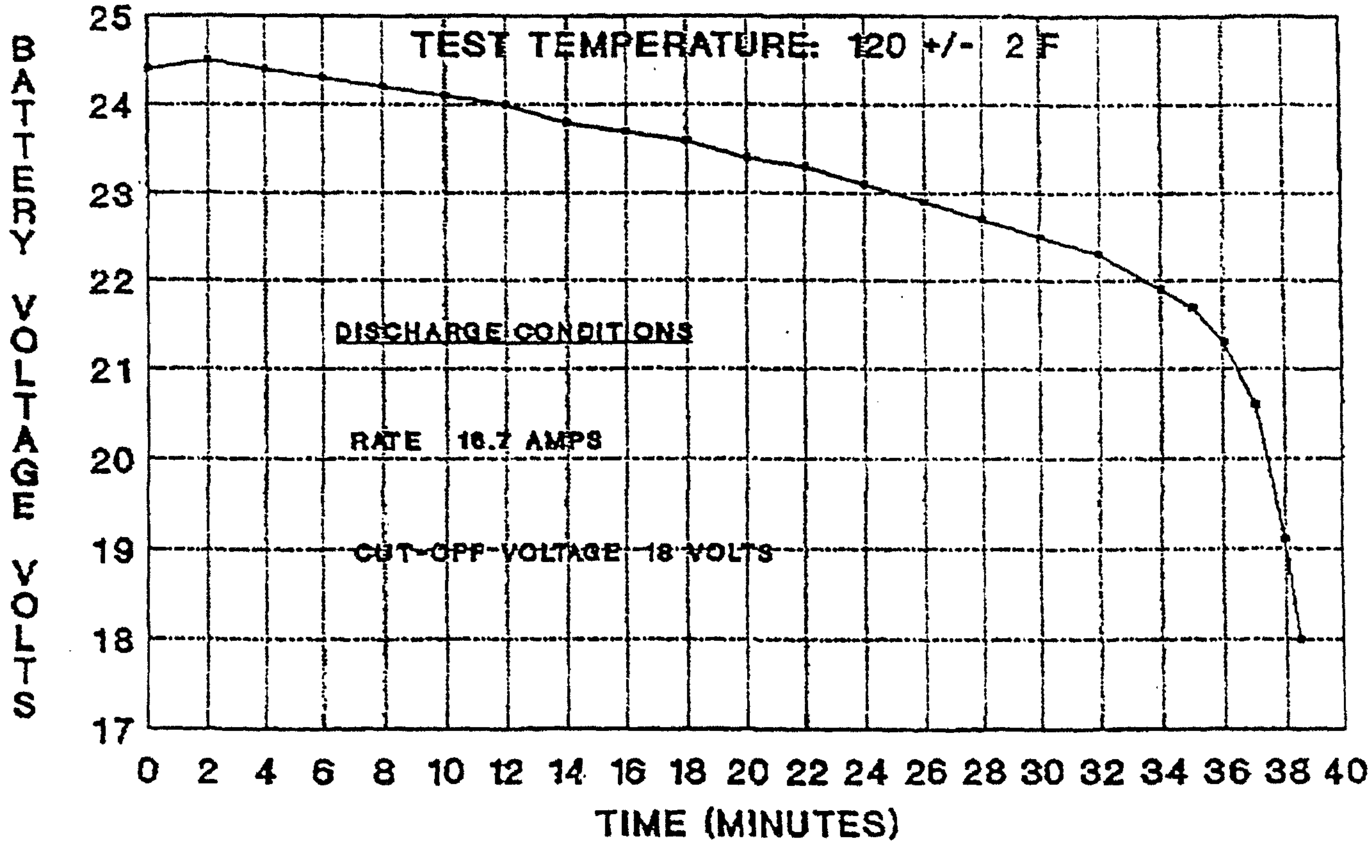
FEB 15, 1992

Concorde SLA Battery Data



Concorde SLA Battery Data

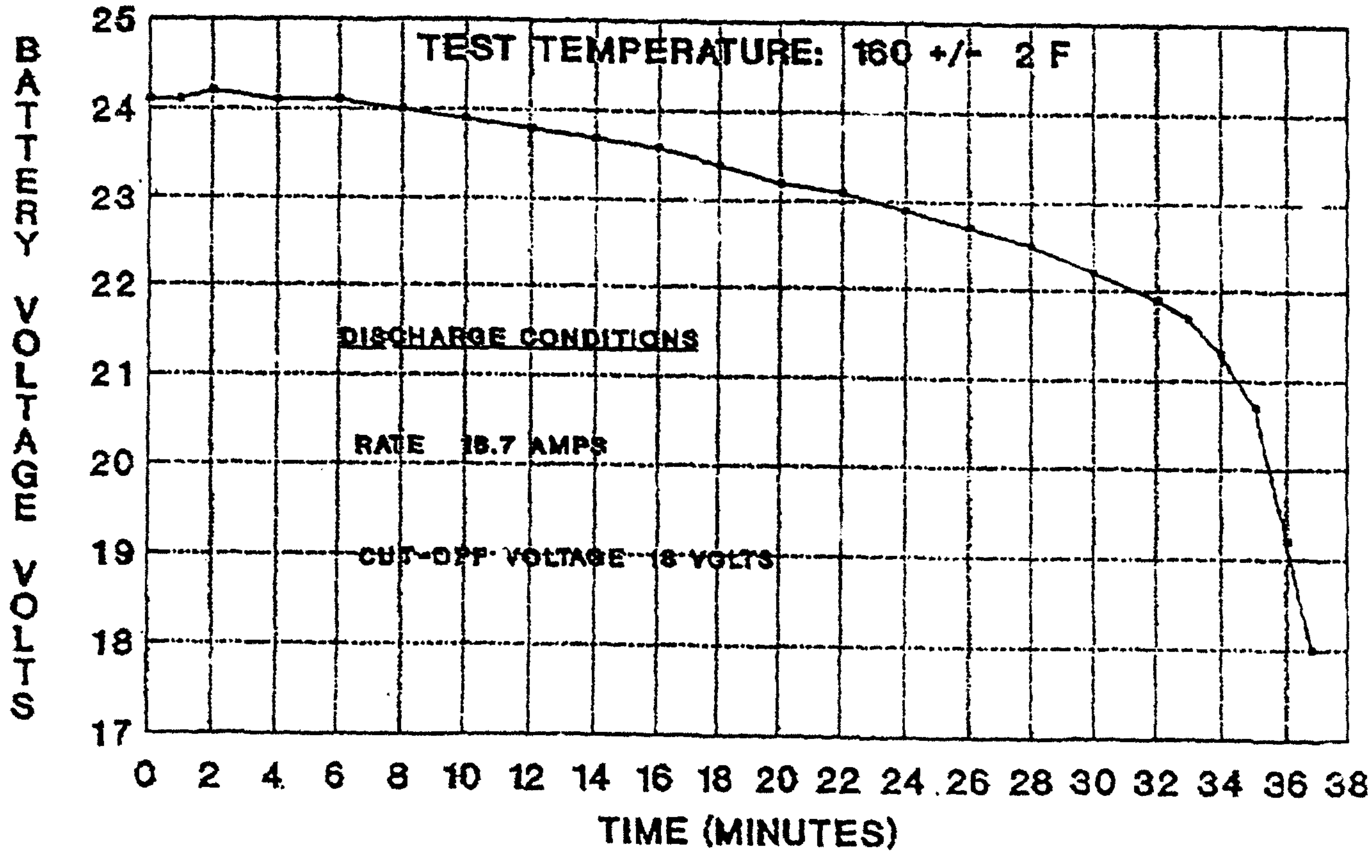
INS PRELIMINARY TESTING ON A 10 A.HR. BATTERY (1 HOUR RATE)



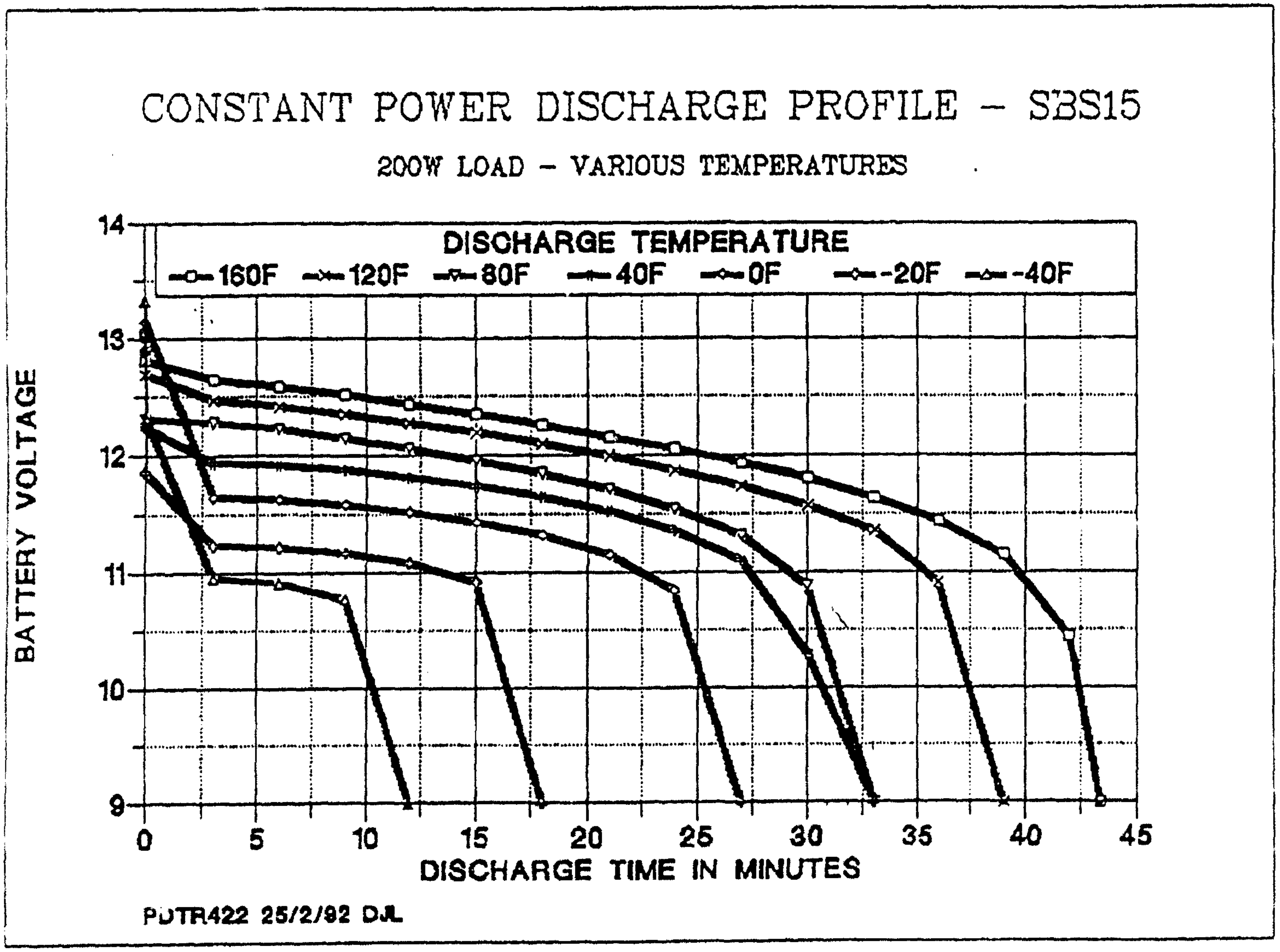
FEB 27, 1992

Concorde SLA Battery Data

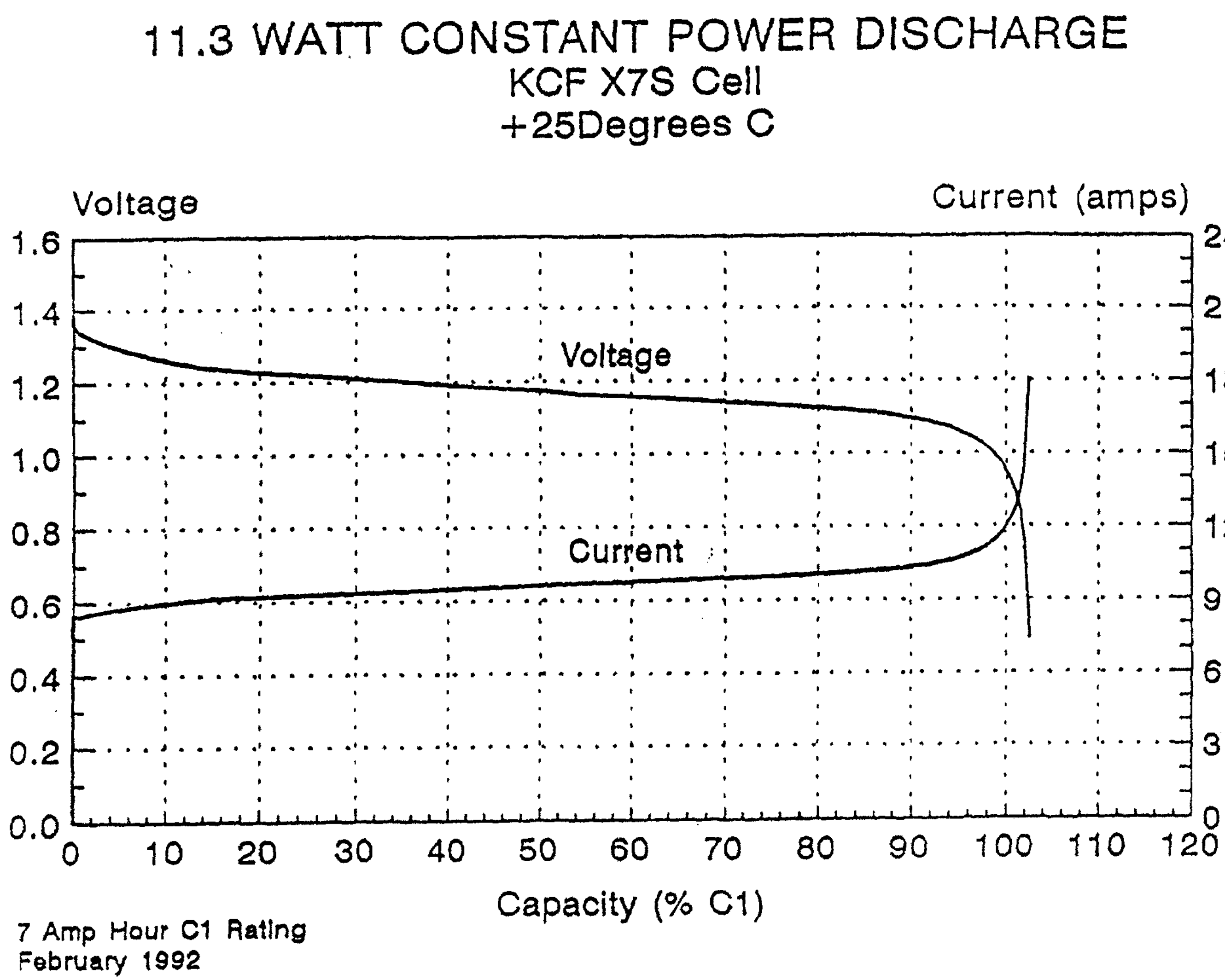
INS PRELIMINARY TESTING
ON A 10 A.HR. BATTERY (1 HOUR RATE)



Concorde SLA Battery Data

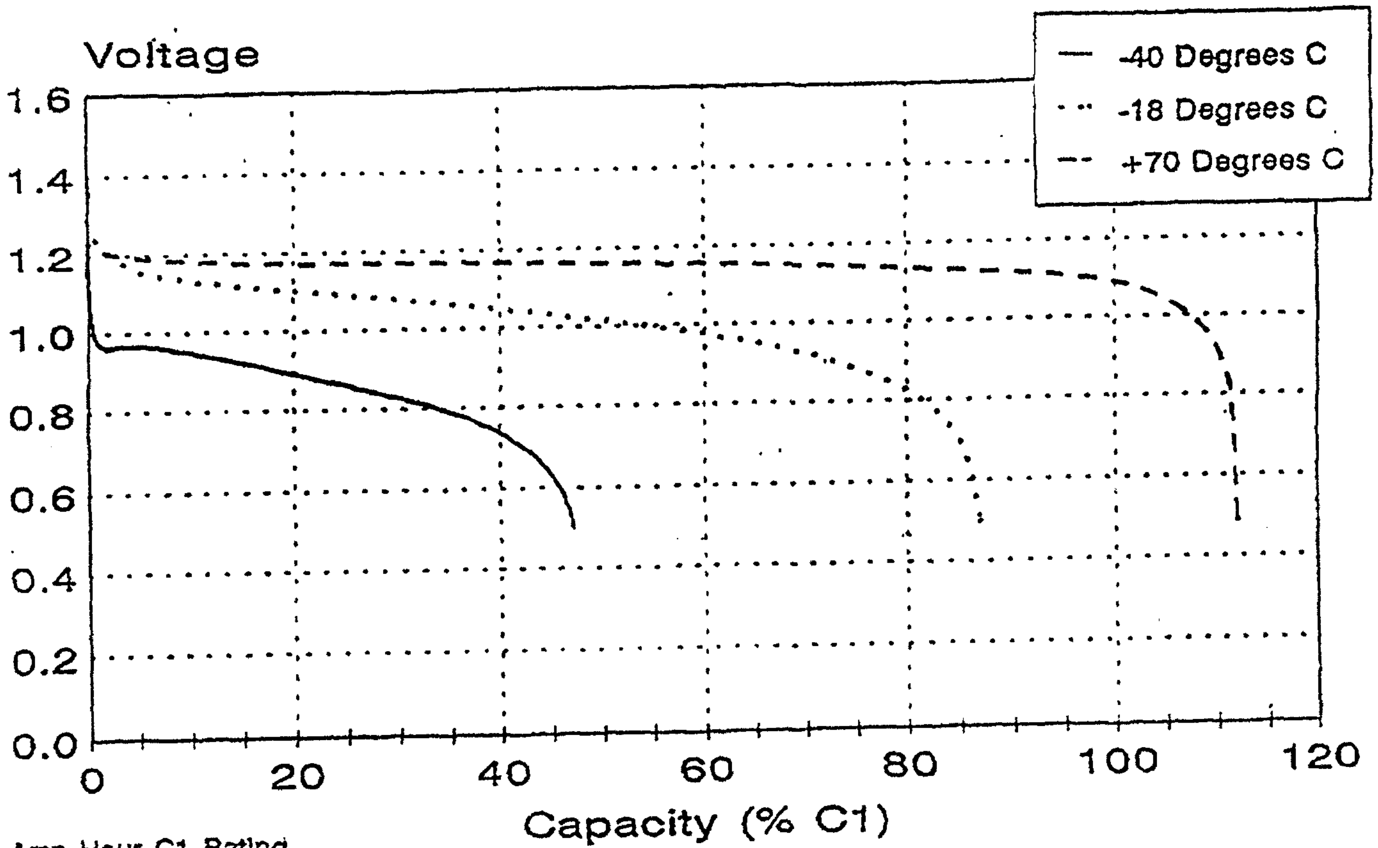


Hawker SLA Battery Data



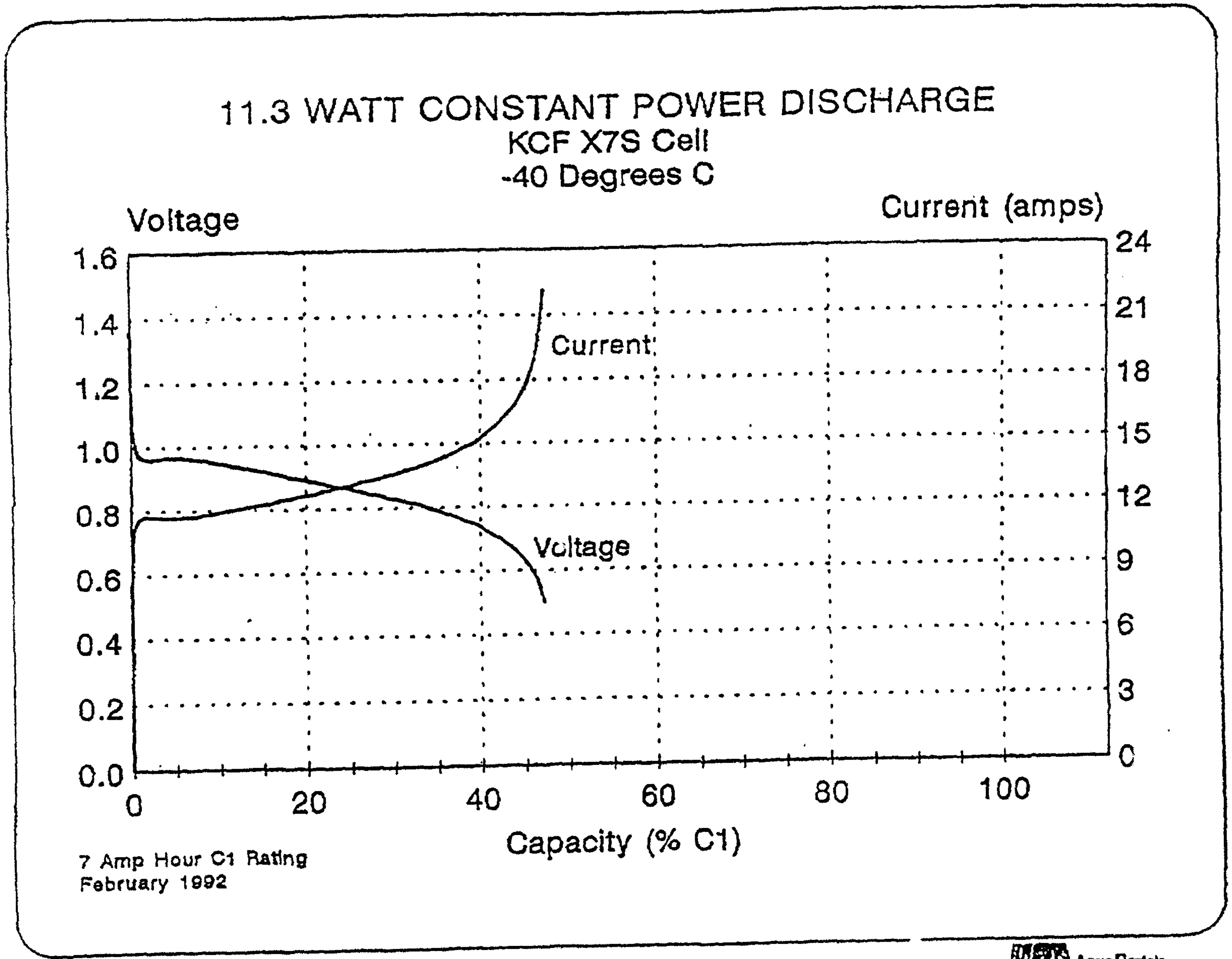
ACME SNC BATTERY DATA

11.3 WATT CONSTANT POWER DISCHARGE
KCF X7S Cell



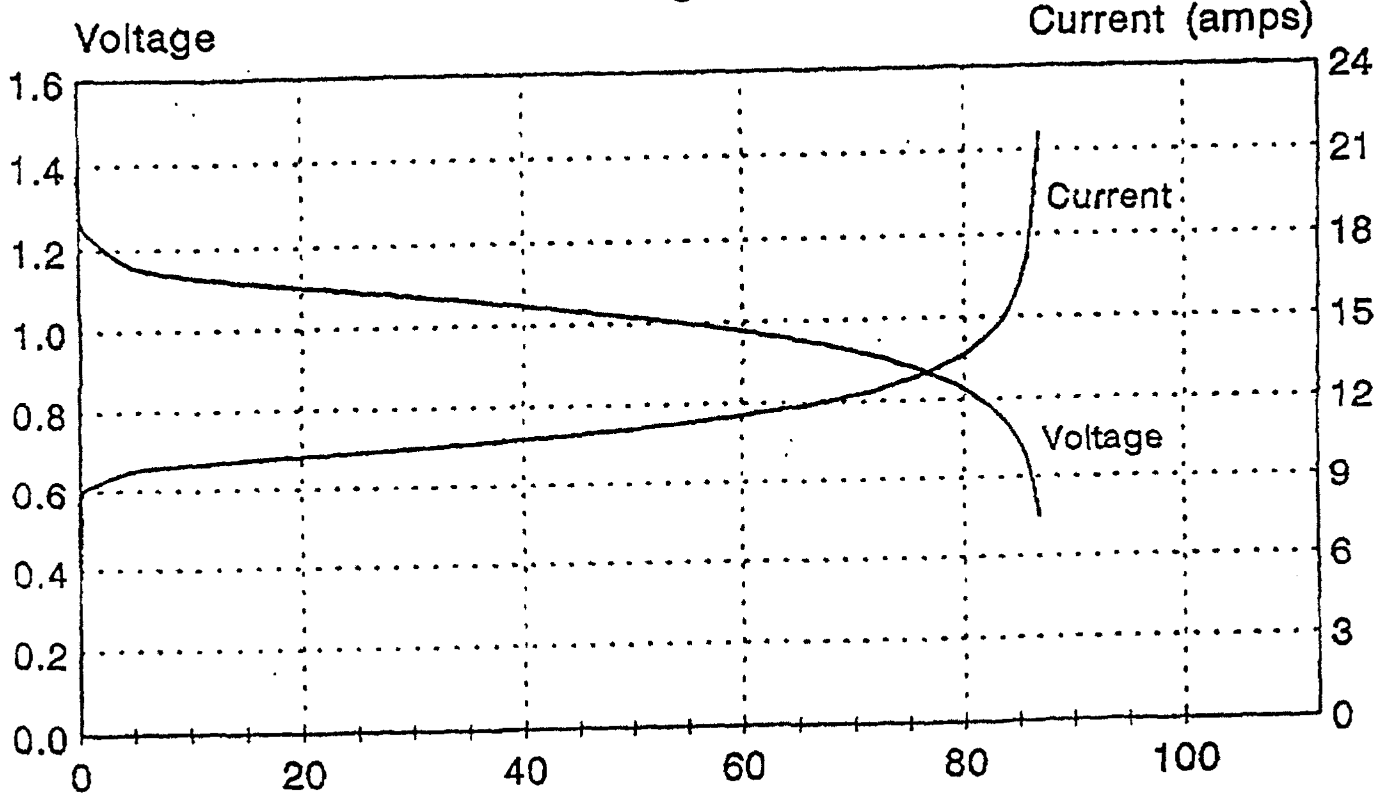
7 Amp Hour C1 Rating
February 1992

ACME SNC BATTERY DATA



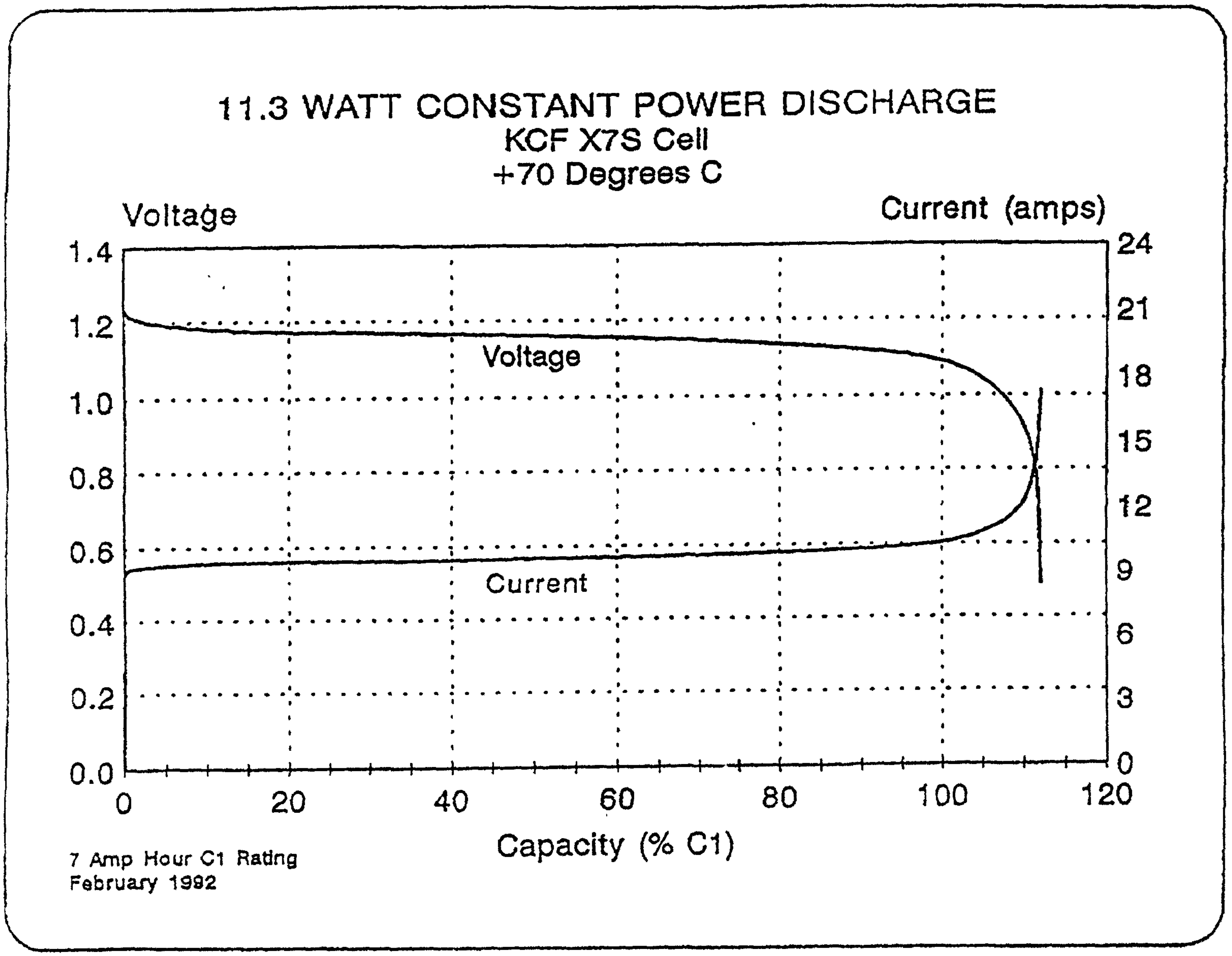
ACME SNC BATTERY DATA

11.3 WATT CONSTANT POWER DISCHARGE
KCF X7S Cell
-18 Degrees C

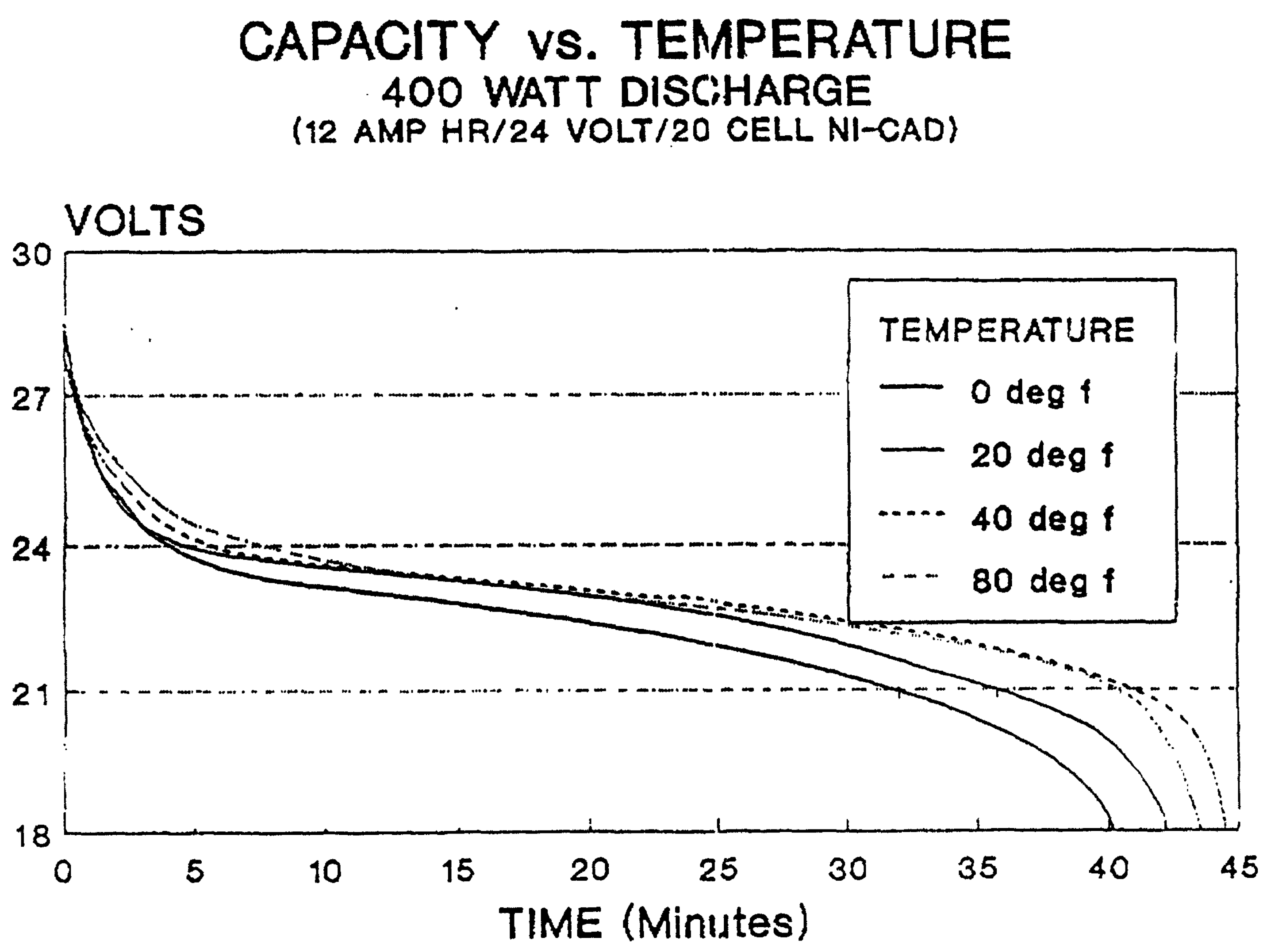


7 Amp Hour C1 Rating
February 1992

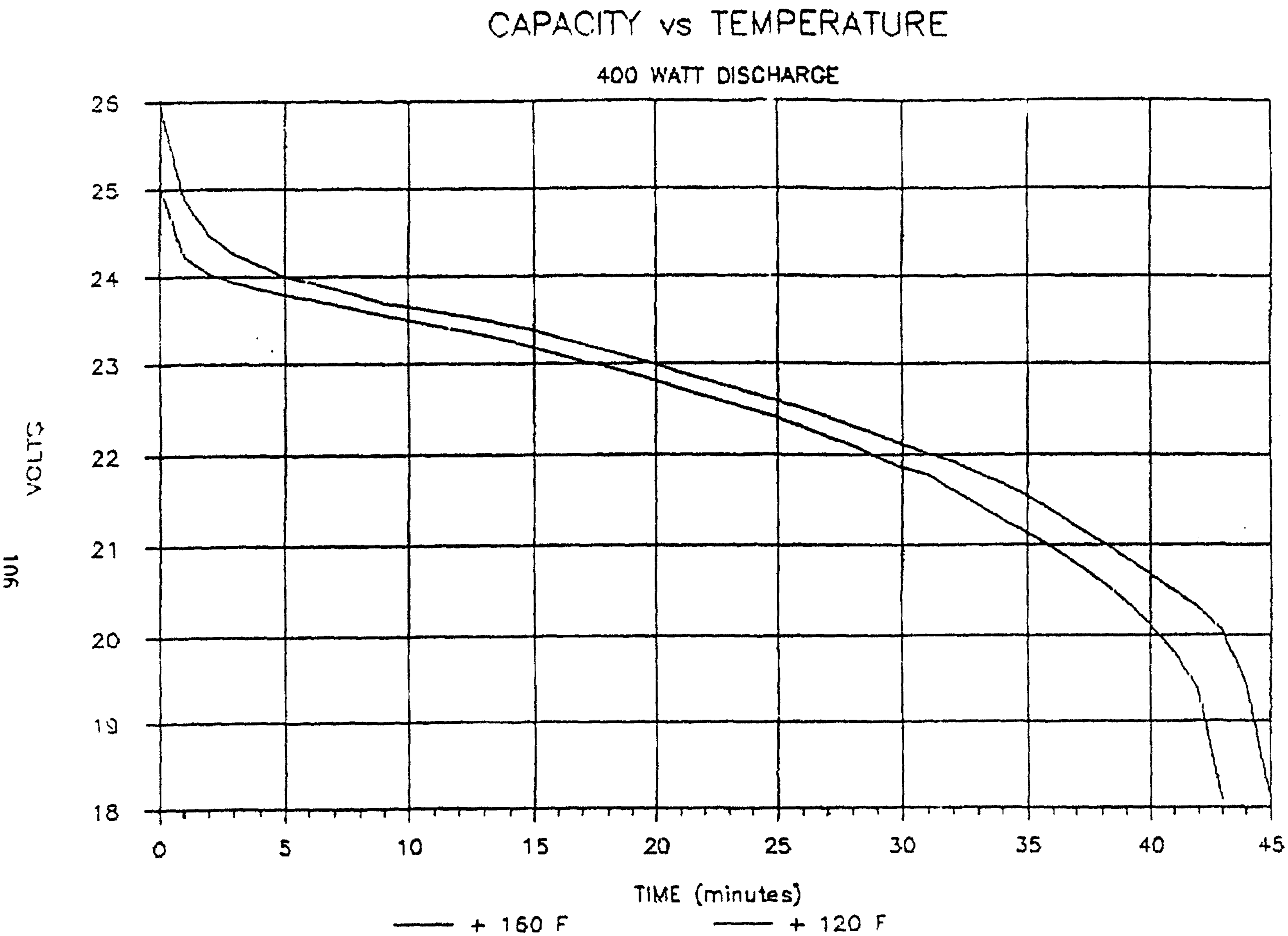
ACME SNC BATTERY DATA



ACME SNC BATTERY DATA



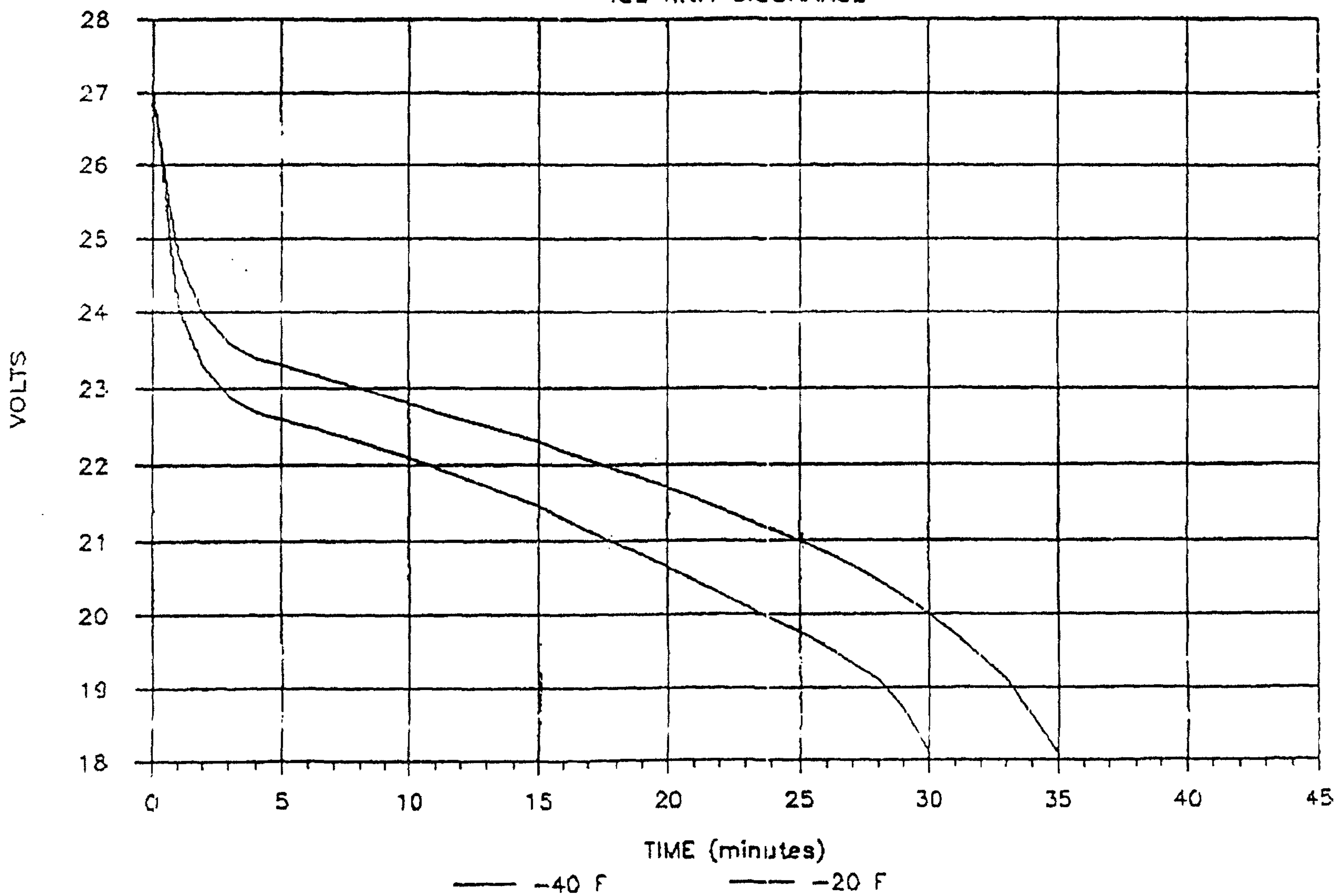
EPI SNC BATTERY DATA



EPI SNC BATTERY DATA

CAPACITY vs TEMPERATURE

400 WATT DISCHARGE

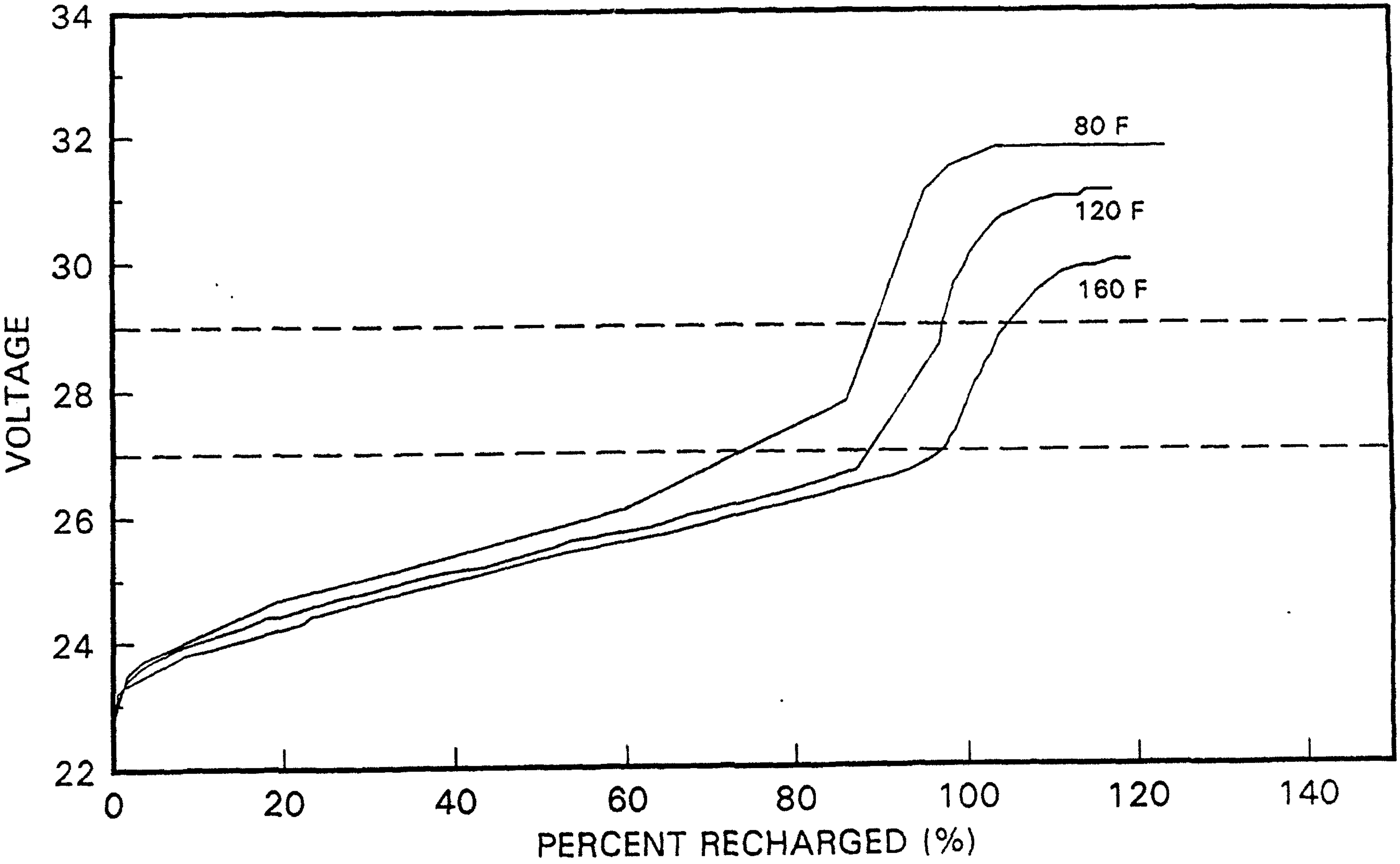


EPI SNC BATTERY DATA

APPENDIX D

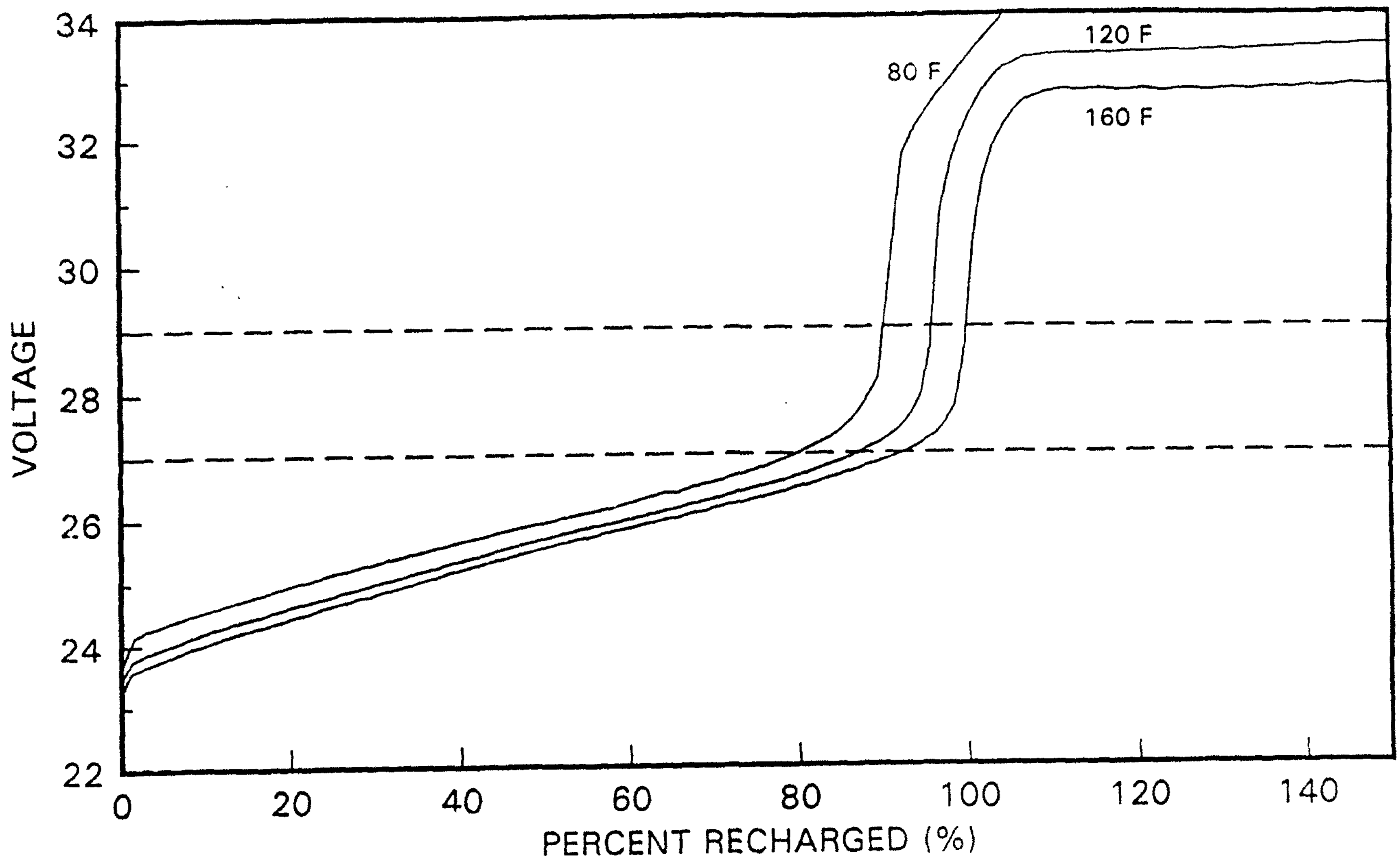
CHARGE DATA

CHARGE CURVES - CONCORDE SLA BATTERY



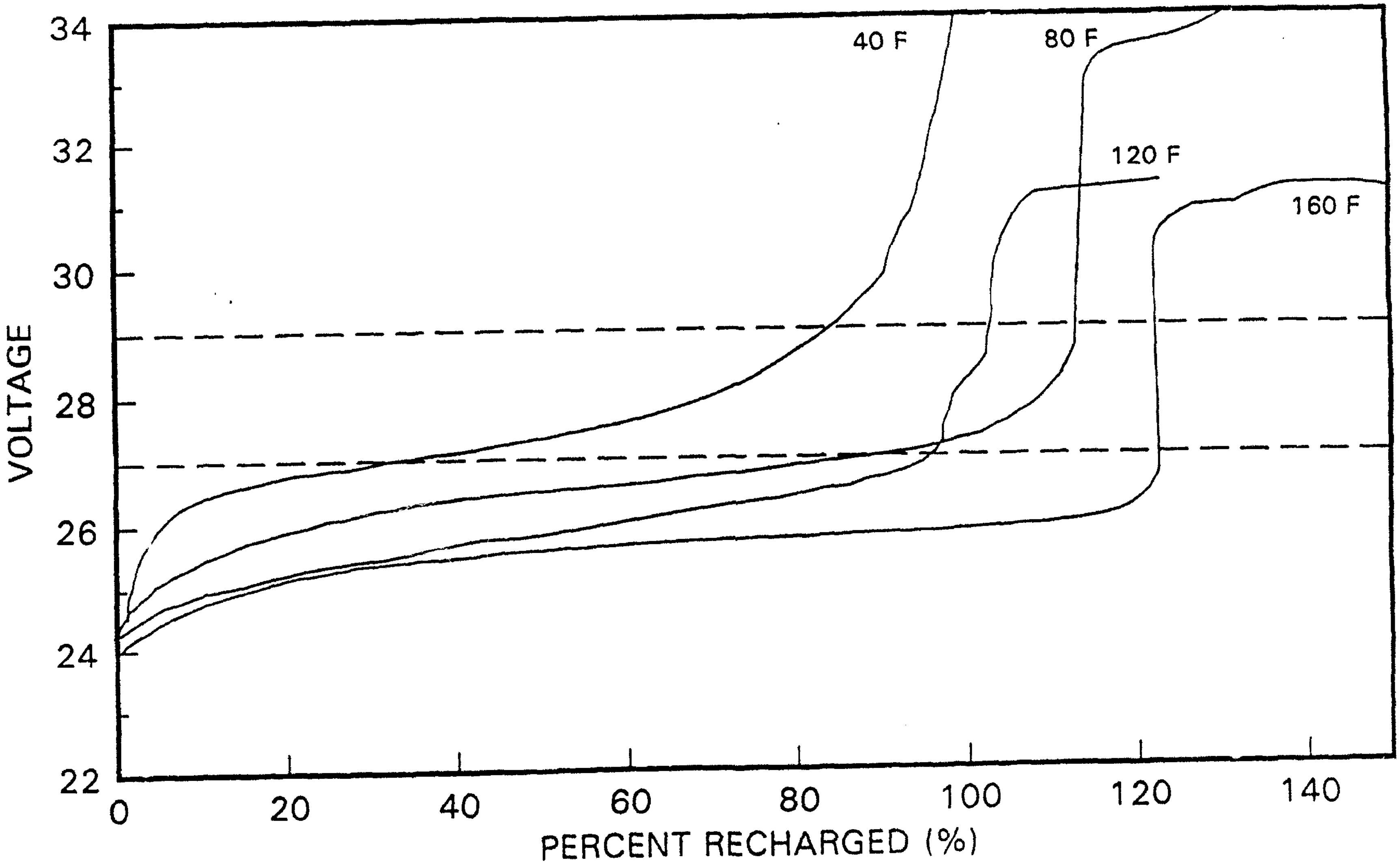
Concorde 10 AH Battery
Charge at 2 Amperes

CHARGE CURVES - HAWKER SLA BATTERY



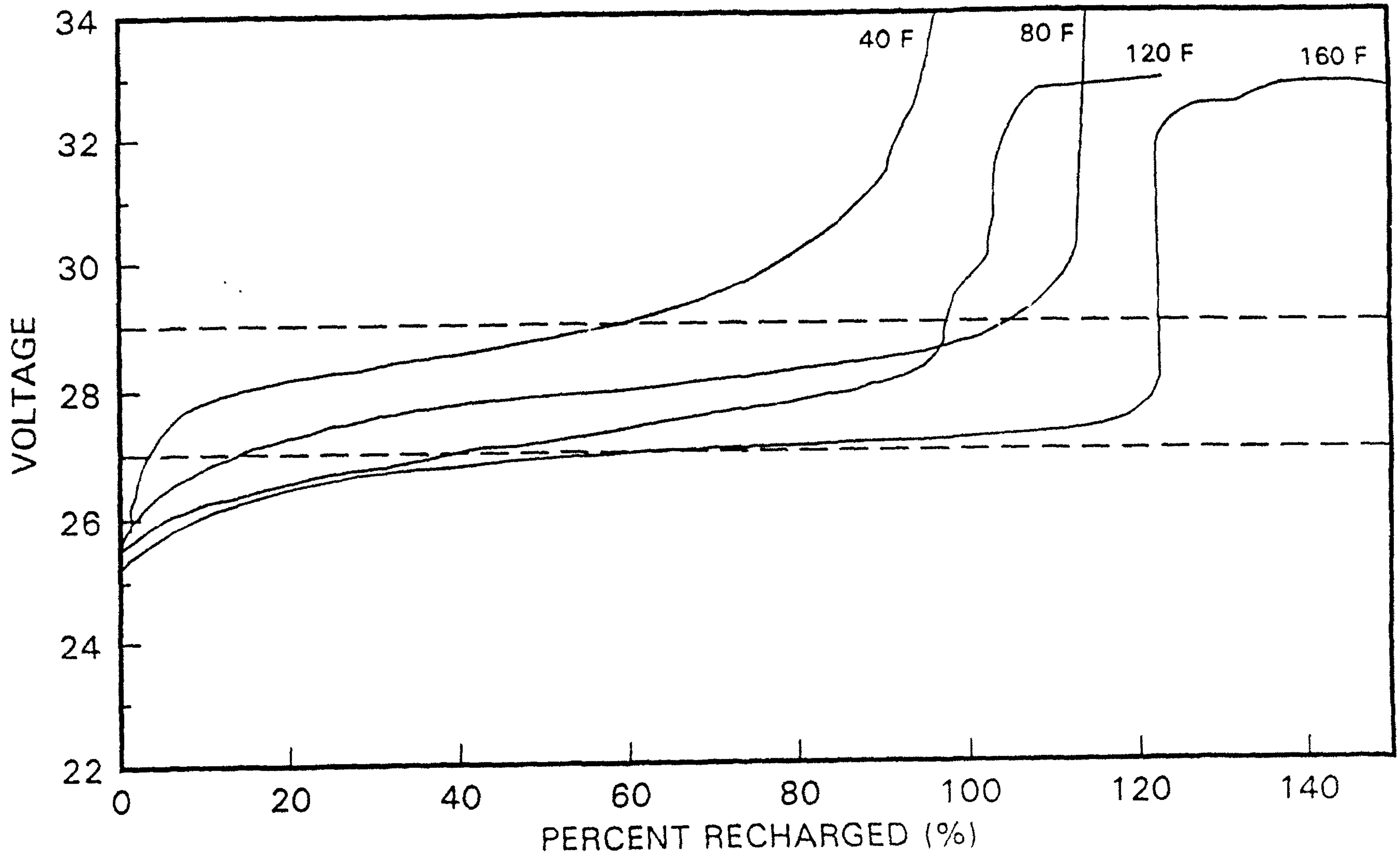
Hawker 12 AH Battery (Type SBS15)
Charge at 2 Amperes

CHARGE CURVES - SAFT ULM BATTERY (19-CELL)



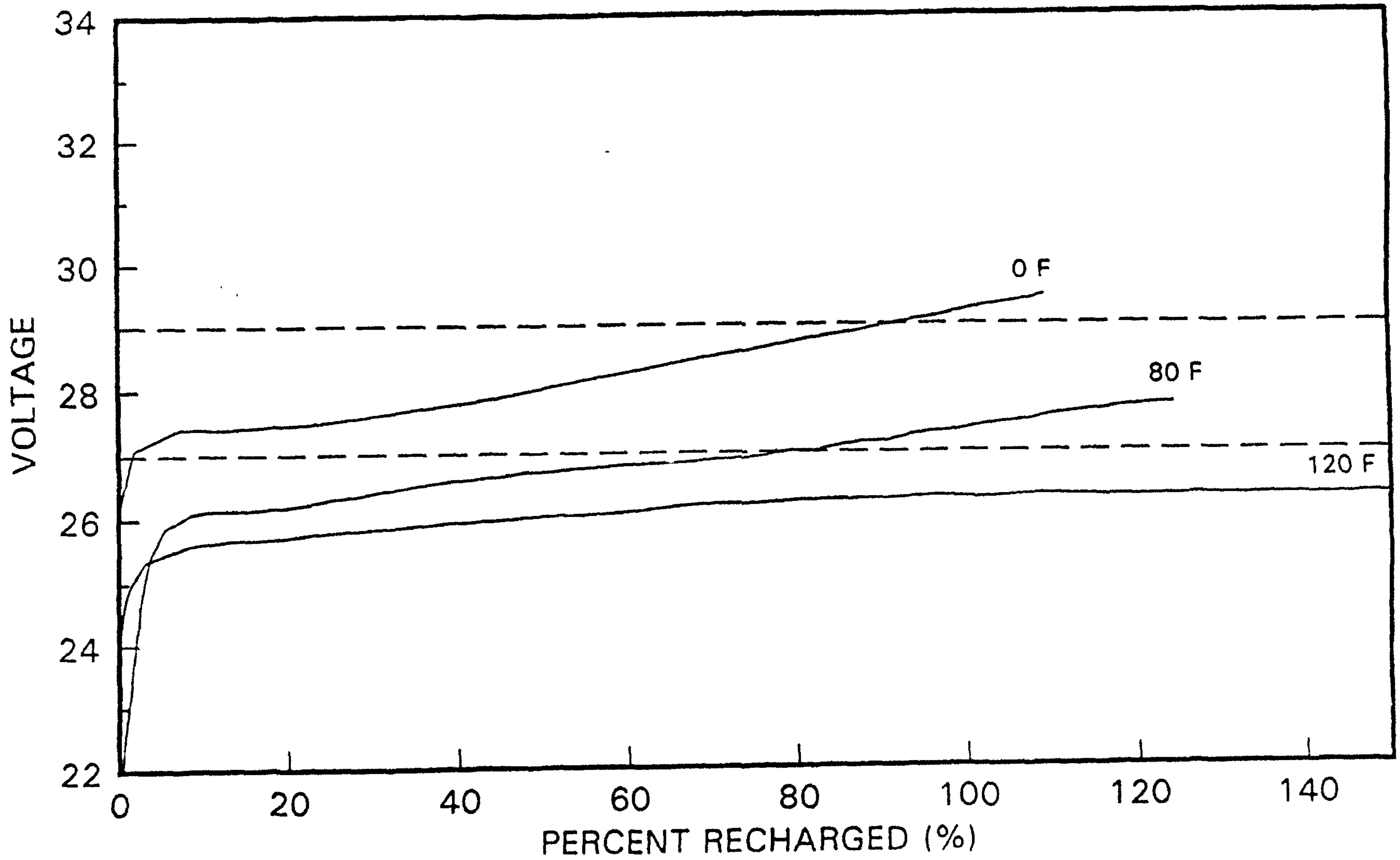
SAFT 50 AH Battery
Charge at 7 Amperes (Equivalent to 2 Amp Charge
on 14 AH Battery)

CHARGE CURVES - SAFT ULM BATTERY (20-CELL)



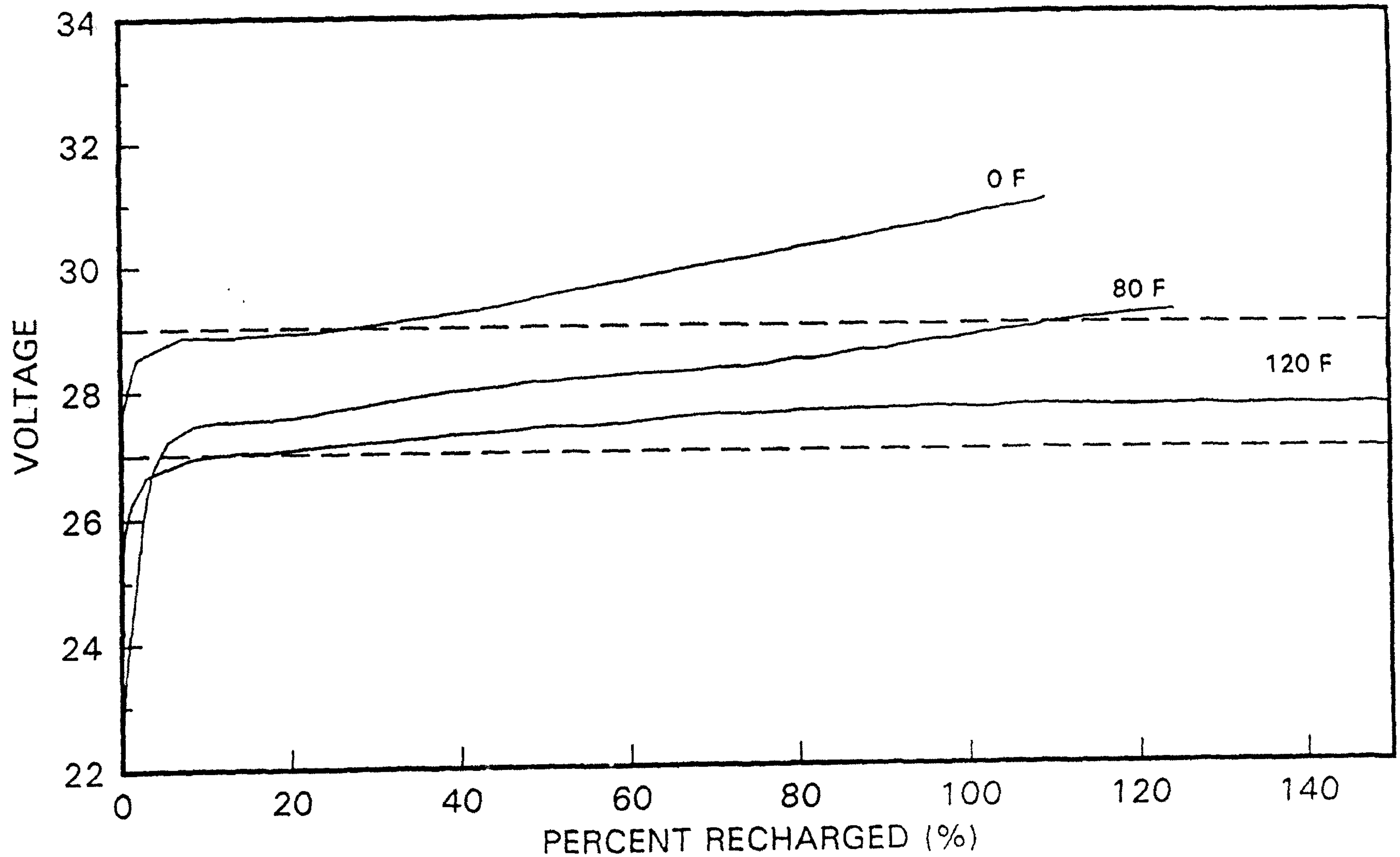
SAFT 50 AH Battery
Charge at 7 Amperes (Equivalent to 2 Amp Charge
on 14 AH Battery)

CHARGE CURVES - ACME SNC BATTERY (19-CELL)



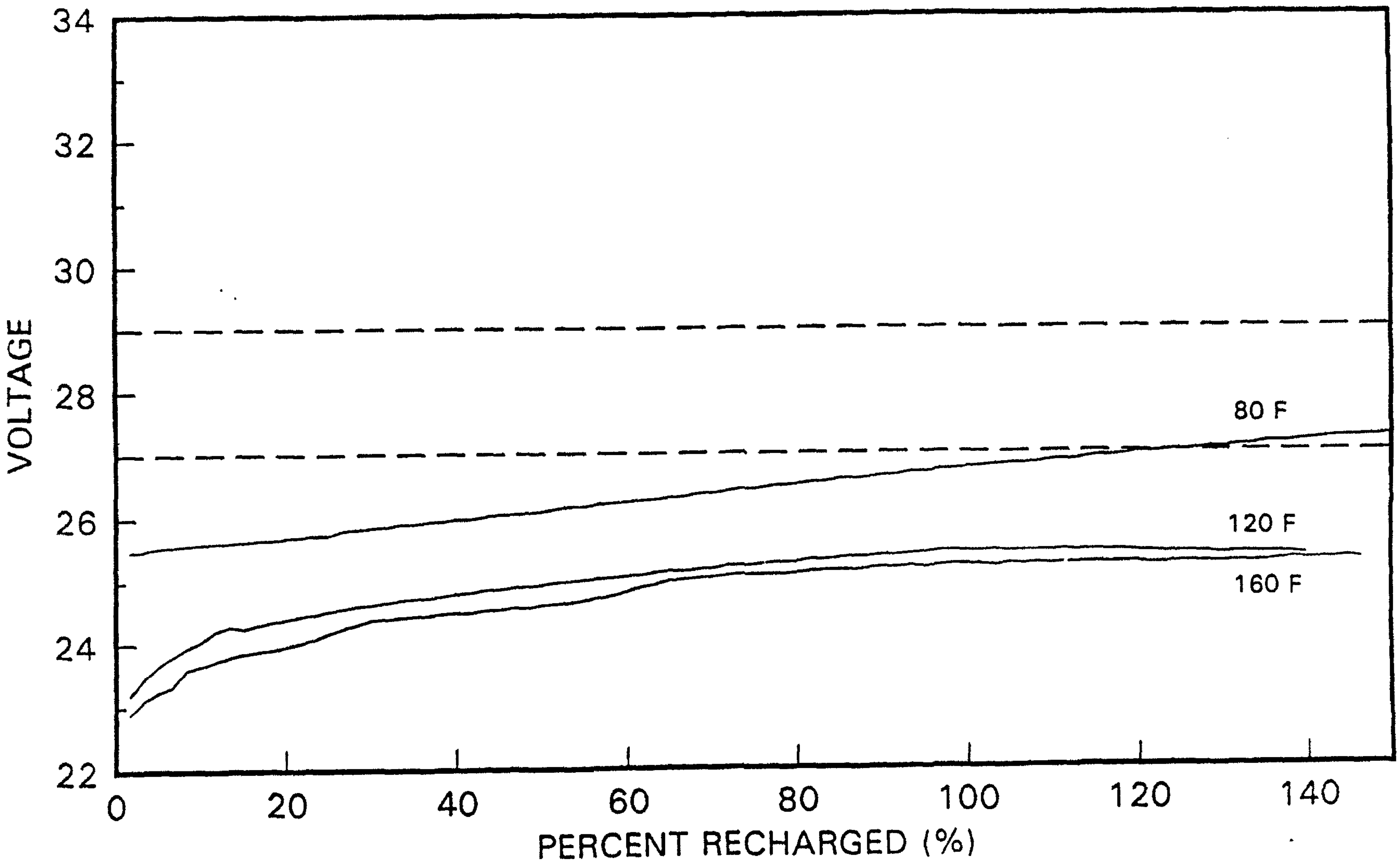
ACME 15AH Battery (Type KCF X15)
Charge at 2 Amp

CHARGE CURVES - ACME SNC BATTERY (20-CELL)



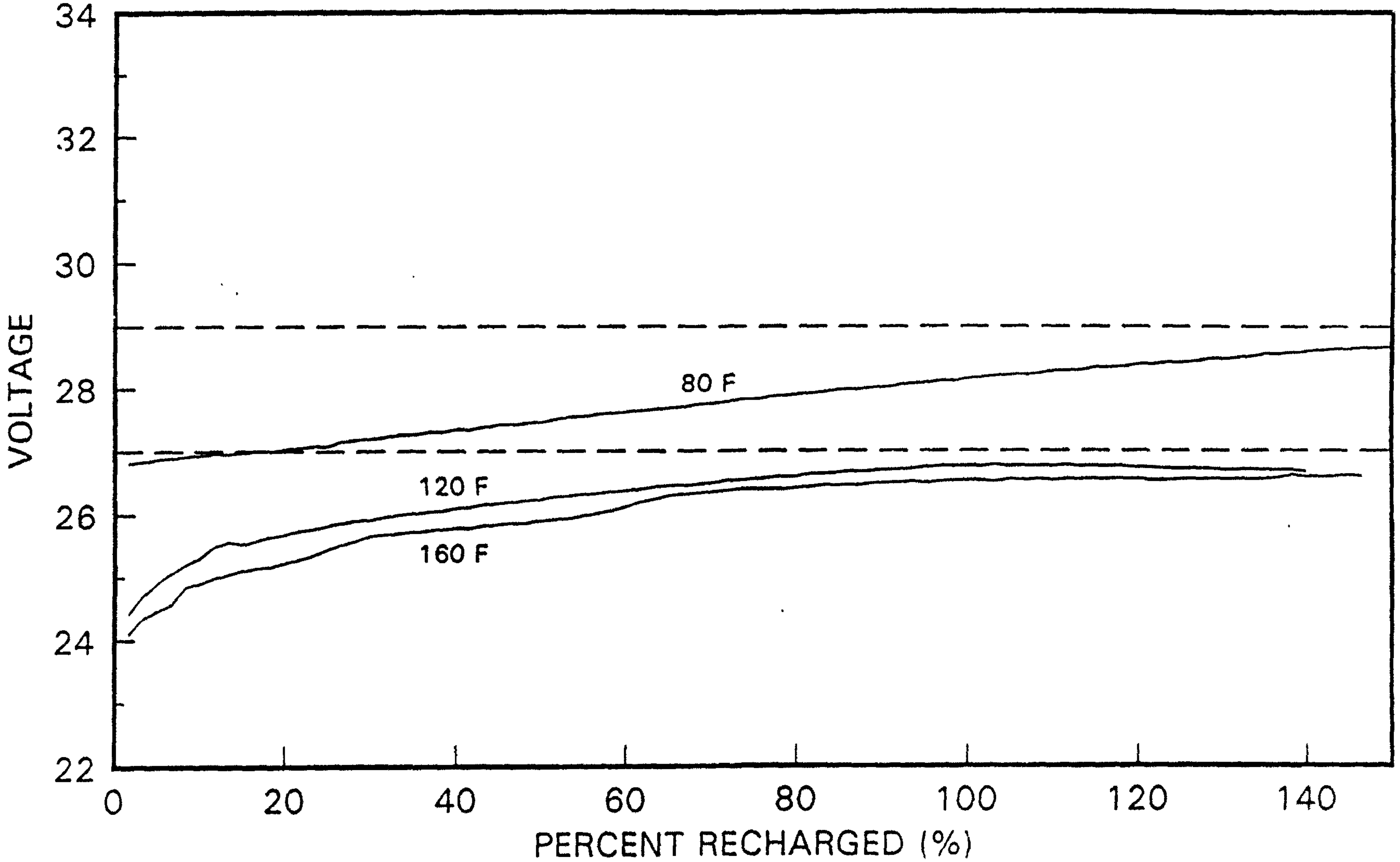
ACME 15AH Battery (Type KCF X15)
Charge at 2 Amperes.

CHARGE CURVES - EPI SNC BATTERY (19-CELL)



EPI 12 AH Battery (Type 3112)
Charged at 2 Amps

CHARGE CURVES - EPI SNC BATTERY (20-CELL)



EPI 12 AH Battery (Type 3112)
Charged at 2 Amps

APPENDIX E

PROPOSED SPECIFICATION SHEET (DOD-B-8565/INS)

DOD-B-8565/INS
31 August 1992

PROCUREMENT SPECIFICATION SHEET

BATTERY, STORAGE, AIRCRAFT, MEDIUM-RATE, TYPE 1, MAINTENANCE-FREE, 24-VOLT, 10 AMPERE-HOUR

The complete requirements for acquiring the storage battery described herein shall consist of this document and the latest issue of Specification MIL-B-8565.

Prepared by:

Battelle
505 King Avenue
Columbus, Ohio 43201

REQUIREMENTS:

1. The dimensions of the battery shall be as shown on Figure 1.

2. The part number of the battery shall be D8565/INS. (Note: This part number is a temporary designation and is subject to change once the specification sheet number has been assigned.)

3. The rated capacity of the battery shall be 10 ampere-hours (10.0 AH/1 HR/21°C/18.0 V at end of life). 1C = 10.0 ampères.

4. The weight of the battery shall not exceed 12.3 kilograms.

5. The battery shall conform to military specification MIL-B-8565 for Type 1 batteries, except as modified by the following:

   3.5.2.1 Type 1 battery. Add the following sentence: "The battery container shall meet the requirements of ARINC Specification 404 for a 1/2 ATR short case size, except as modified herein."

   3.5.4 Venting. Replace entire paragraph with the following: "The battery cover shall contain louvers for venting of gases, as shown on Figure 1. The louvers shall be protected by a plastic or wire screen to prevent debris from entering the battery. The cells shall be equipped with a resealable venting mechanism to prevent excessive internal pressure build-up. When the battery is operating within the requirements of this specification, cell venting shall not cause entrained electrolyte to be discharged from the battery."

   3.5.5 Receptacles. Add the following: "The receptacle for the battery's positive and negative connections shall be a Cannon part number DPXB-8-34P-0101-A152, or equivalent. The receptacle shall be located as shown in Figure 1 and wiring connections shall conform to Figure 2."

   Add the following paragraphs:

   3.5.13 Latching Handles. The battery shall be equipped with two lever latch handles, Camloc part number 61L2-1-2AA, or equivalent. The handles shall be located as shown in Figure 1.

   3.5.14 Circuit breaker. The battery shall be equipped with a 20 ampere thermal overload (trip-free) circuit breaker, Type MS3320-20. The circuit breaker shall be located as shown in Figure 1 and wiring connections shall conform to Figure 2. The circuit breaker may be mounted to a suitable housing extending from the face of the battery case, provided that the total extension (housing plus circuit breaker) does not exceed 63.5 millimeters when the circuit breaker is tripped, and provided that the housing does not interfere with the operation of the latches.

3.6.3.2.1 Polarity marking. Replace with the following: "The container shall be conspicuously and durably marked with "+" and "-" in white as shown in Figure 1. The connector reference designation "P1" shall be located as shown on Figure 1, with white marking no less than 3 mm high. In addition, the schematic diagram of Figure 2 shall be placed on Label No. 3 and located as shown on Figure 1."

3.6.3.2.3 Battery caution marking (Type 1 battery only). Replace the marking for Label 2 with that shown below (0.25 inch lettering height minimum):

MAINTENANCE-FREE BATTERY

DO NOT REMOVE COVER

PROCESS THIS BATTERY IN ACCORDANCE WITH
APPROVED PROCEDURES ONLY

SEE NAVAIR 17-15BAD-1
OR T.O. _____**_____

** Leave blank, to be filled-in once this number is assigned.

3.6.7 Vent tubes. Delete.

3.6.8 Capacity and electrical performance. Replace the requirements listed in Table II with those specified below:

Requirement No.	Discharge Cutoff Voltage and Temp.	Rate of Discharge	Minimum Time to Cutoff Voltage
(1)	18.0 V at 24 ± 3°C	1.0C	60 minutes
(2)	18.0 V at 49 ± 2°C	1.0C	66 minutes
(3)	21.0 V at -18 ± 2°C	400 watts 1/	20 minutes
(4)	21.0 V at 5 ± 2°C	400 watts 1/	30 minutes
(5)	21.0 V at -40 ± 2°C	400 watts	5 minutes

1/ During the first minute of discharge, the discharge rate shall be 425 watts. The minimum voltage of 21.0 volts shall apply during the entire discharge period.

3.6.9 Strength of receptacle. Delete.

3.6.10 Life. Replace with the following paragraph: "Batteries delivered under this specification shall be capable of at least 8 years of service life, demonstrated by successfully completing the cycle life test of 4.6.13.1 and the float life test of 4.6.13.4."

Add the following paragraph:

> 3.6.10.4 Float life. Batteries, when tested in accordance with 4.6.13.4, shall provide no less than rated capacity after 100 days of float charging at a temperature of 65°C and a charging rate of 40 milliamperes.

3.6.11 "Evaluation of Equipment" test. Replace with the following paragraph: "After all environmental tests, the battery shall be subjected to a 400-watt discharge for five (5) minutes as the test for "Evaluation of Equipment". The battery voltage shall be 21.0 volts or greater at the end of the five minutes."

3.6.13 Temperature rise and float. Replace with the following paragraph: "When tested in accordance with 4.6.21, the battery voltage shall be recorded at intervals not to exceed 5 minutes. The battery voltage, during the 8 hours of constant current charge at 2.0 amperes, shall remain above 30.0 volts once 110 percent of the capacity removed during discharge has been returned. The battery shall meet Requirement (1) of Table II following the charge period."

4.5.1.3 Constant potential charge. Delete and add the following paragraph:

> 4.5.1.3 Charge method. Unless otherwise specified, the battery shall be charged at a constant current rate of 2.0 ± 0.05 amperes until the battery voltage reaches 29.0 ± 0.1 volts, then the charging shall be terminated.

4.6.7 Strength of vent tubes. Delete.

4.6.11 Constant voltage discharge (14.0 volts). Delete.

4.6.12 Strength of receptacle. Delete.

4.6.13.1 Cycling test (Type 1 battery). Replace with the following paragraph: "The battery shall be subjected to 85 cycles of discharge and charge. Each cycle shall consist of a 1-hour, 1.0 C-rate discharge, followed immediately by a charge per 4.5.1.3, followed by a 1-hour rest period. The battery shall meet the specified requirements of 3.6.10.1."

Add the following paragraph:

4.6.13.4 Float life. The battery shall be charged at 40 milliamperes at 65 ± 2°C for a period of 100 days. At the end of this time period, the battery shall be stabilized at room temperature and discharged per 4.6.10. The battery shall comply with the requirements of 3.6.10.4.

4.6.15 Charge and discharge test at low temperature. Replace steps (a) through (d) with the following steps:

a. Charge the battery in accordance with 4.5.1.3 at 24 ± 5°C.

b. Stabilize the battery -18°C, then discharge at 400 watts for 15 minutes.

c. Remove the battery from the chamber and charge for 2.0 hours at 27.0 ± 0.1 volts with the current source limited to 2.0 ± 0.1 amperes.

d. Immediately following charge, discharge the battery at 400 watts to 21.0 volts. The discharge time must equal or exceed 20 minutes.

4.6.16 Discharge while inverted. Replace with the following paragraph: " The battery shall be charged as specified in 4.5.1.3 and 4.5.1.1. The battery then shall be discharged at 400 watts for five (5) minutes. During the first 2.5 minutes of discharge, the battery shall be placed in the inverted position. The battery shall meet the requirements of 3.5.8 and the battery voltage shall remain above 21.0 volts during the entire discharge period."

4.6.20 Special tests. Add the following paragraph:

4.6.20.1 Battery output performance. The battery shall be discharged in accordance with Requirements (3), (4) and (5) of Table II. Prior to each discharge, the battery shall be charged in accordance with 4.5.1.3 and 4.5.1.1, then stabilized at the applicable test temperature.

4.6.21 Temperature rise and float test. Replace with the following paragraph: "The battery shall be charged in accordance with 4.5.1.3 and then placed in a temperature chamber at 49 ± 2°C for 12 hours. At this temperature, the battery shall be discharged at 400 watts for 30 minutes. Immediately following this discharge, with the battery still in the chamber at 49°C, a constant current charge of 2.0 ± 0.1 amperes shall be applied for 8 ± 0.1 hours. The battery shall than be stabilized at 24 ± 5°C and discharged per 4.6.10. The battery shall meet the requirements of 3.6.12 and 3.6.13."

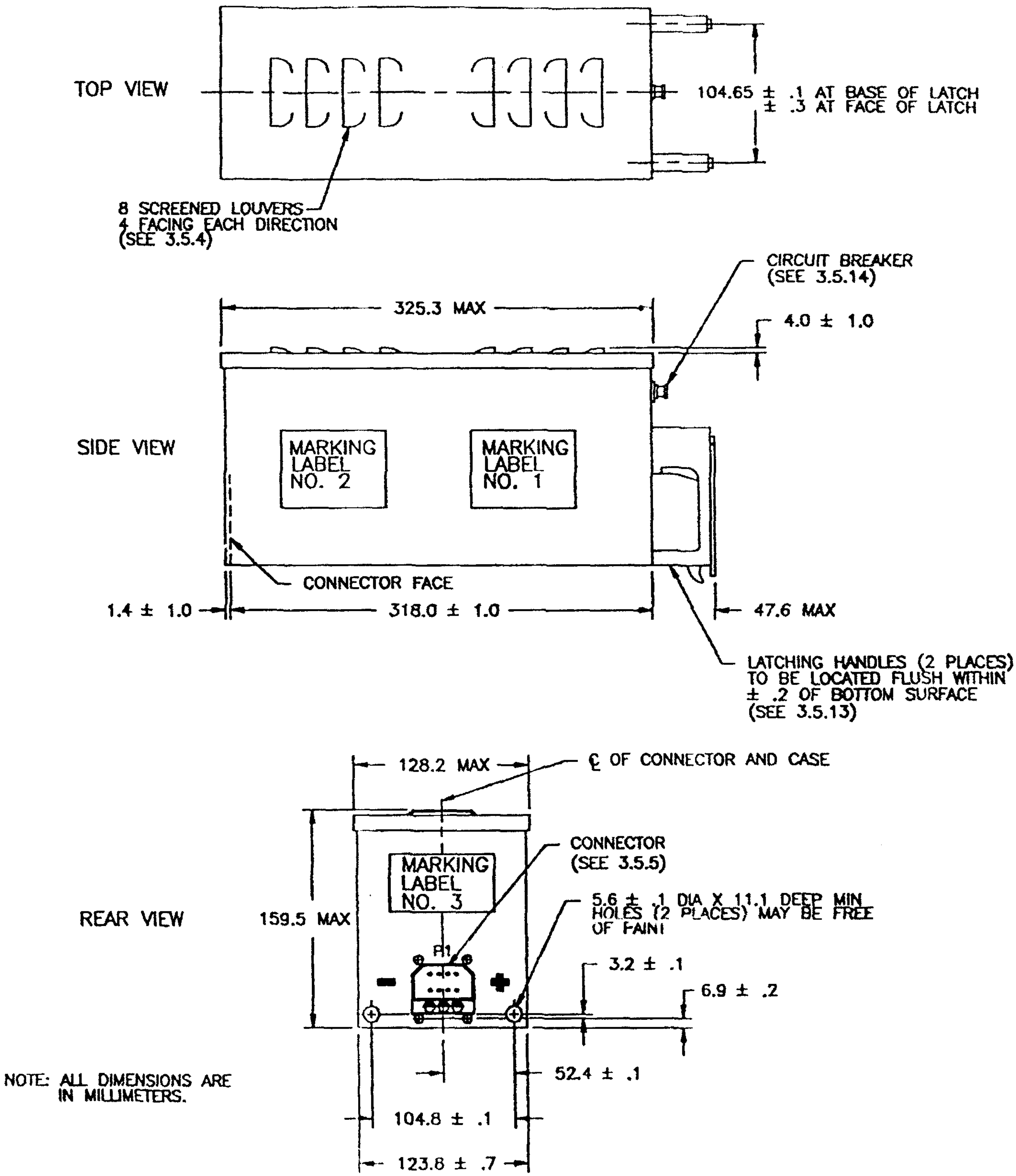


FIGURE 1. Dimensions.

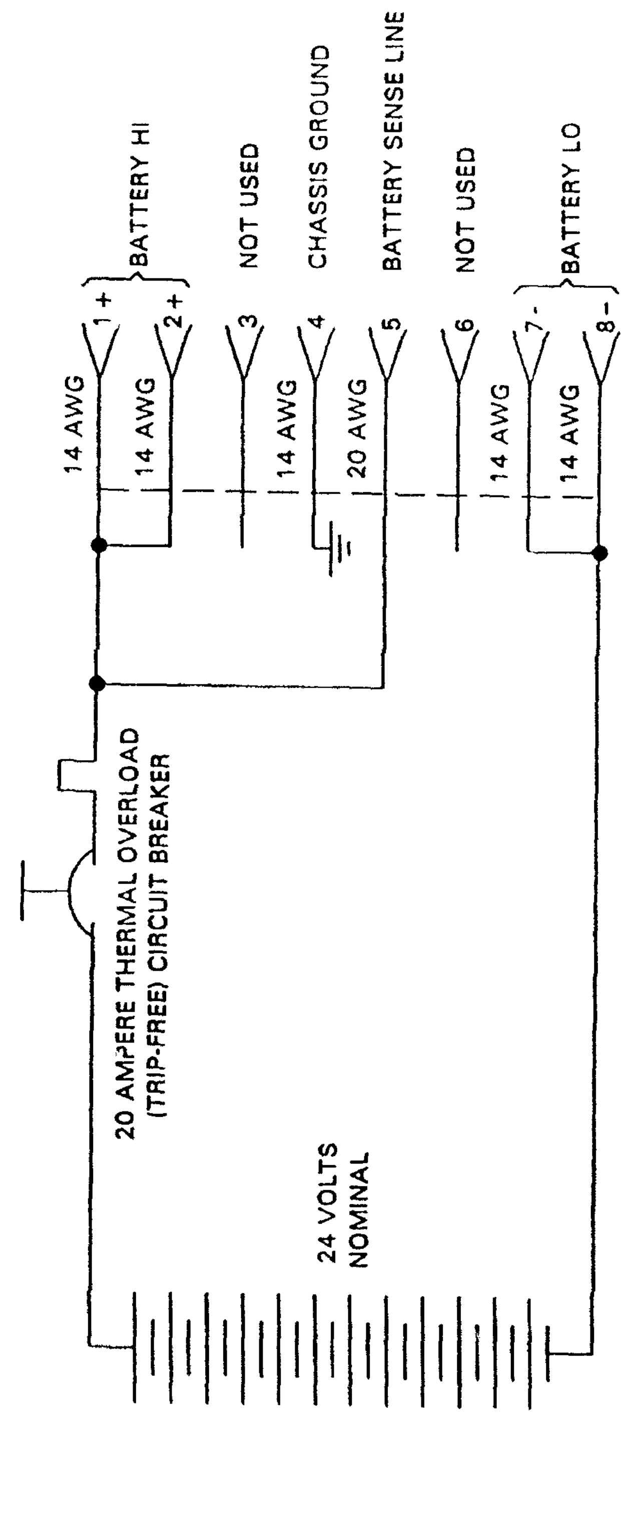


FIGURE 2. Schematic wiring diagram.
(NOTE: Wire sizes are minimum)

TABLE 1. Inspection of batteries and order of test.

Inspection Number	Inspections	Qualification Inspection: Qualification Sample Number 1	2	3	Requirements Paragraph	Method of Inspection Paragraph	Quality Conformance Inspection: Group A Tests	Group B Tests 1	2
1	Visual & Mechnaical Examination	X	X	X	3.5, 3.6.2.2 & 3.6.3	4.6.3	X	X	X
2	Dimensions & Weight	X	X	X	3.6.5	4.6.4	X	X	X
3	Dielectric Strength	X	X	X	3.6.4	4.6.5	X	X	X
4	Color and Marking	X	X	X	3.6.7	4.6.8	X	X	X
5	Conditioning Charge	X	X	X	4.5.1.4	4.6.9		X	X
6	Capacity Discharge	X	X	X	3.6.8	4.6.10	X	X	X
7	Battery Output Performance	X	X	X	3.6.8	4.6.20.1		X	X
8	Capacity Discharge at 49 C	X			3.6.8	4.6.14			
9	Low Temp. Discharge & Charge	X			3.6.8	4.6.15		X	
10	Life Cycling	X			3.6.10.1	4.6.13.1		X	
11	Float Life		X		3.6.10.4	4.6.13.4			X
12	Ground Storage			X	3.6.15	4.6.26			
13	Discharge While Inverted			X	3.5.8 & 3.6.11	4.6.16		X	
14	Altitiude			X	3.6.11 & 3.6.12	4.6.17		X	
15	Mechanical Shock	X			3.6.11 & 3.6.12	4.6.18			
16	Temperature Shock	X			3.6.11 & 3.6.12	4.6.19		X	
17	Temperature Rise & Float			X	3.6.13	4.6.21			X
18	Battery Gas Emission Test			X	3.6.14	4.6.22			
19	Vibration			X	3.6.16	4.6.23			
20	Humidity	X			3.6.17	4.6.24		X	
21	Salt Fog	X			3.6.18	4.6.25		X	
22	Physical Integrity at High Temp.	X			3.6.12	4.6.27			
23	Final Examination	X	X	X	3.6.4	4.6.30		X	X