Compendium of Military Aviation Batteries

A Comprehensive Reference Guide for Certified Indigenous Batteries

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Compiled
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FOREWORD

After many decades of sustained design / development efforts, the Indian Industries have now acquired the state-of-the-art technology and expertise to realise international quality aircraft batteries. It is CEMILAC's strong desire that the experience acquired in the design / development of aircraft batteries during the past few decades should be made available in a single document for the benefit of the future generation interested in development and use of aircraft batteries.

A compendium has been generated with the above vision to facilitate the designers, manufacturers and users with the technical and airworthiness requirements of different types of aircraft batteries along with details of aircraft batteries cleared by CEMILAC through its Regional Centres.

The dedicated efforts made by Shri N.Yadaiah, TO 'C' and the help and support provided by his colleagues of RCMA, Hyderabad in assimilating the information from various sources and compiling the same in to this compendium is highly appreciated.

CEMILAC desires that this compendium serves its purpose of providing essential requirements / data to the users, designers and manufacturers of aircraft batteries.

(K. Tamilmani)

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Preface

Battery has become an inevitable part of any modern aircraft. Batteries are used for various applications onboard aircraft such as engine cranking, starting auxiliary/standby power unit, canopy opening, emergency power, flight control backup or a combination of above. Even though the basic concept of an aircraft battery is similar to any electro-chemical cell, the design of an aircraft battery for military applications should cater for harsh environments, high reliability and endurance as well as compactness. Also aircraft batteries come in many varieties, classified based on technology, application and capacity.

The Indian Military fleet has a variety of aircrafts, helicopters and Unmanned Aerial Vehicles to meet various operational requirements. These aircrafts are predominantly of Russian and western origin. Battery, a ubiquitous requirement for all these aircrafts is a consumable store with high consumption rate. To achieve self reliance and save enormous foreign exchange great emphasis is given to indigenous design/development and production of aircraft batteries. Both public sector and private sector industries are actively involved in the supply of aircraft batteries to Indian military aviation. Centre for Military Airworthiness and Certification (CEMILAC), Bangalore is the airworthiness approval authority for military aircrafts in India. CEMILAC, through its various field centres called Regional Centre for Military Airworthiness (RCMA), has type approved various aircraft batteries. RCMA(Hyd) is one of the centres involved in the certification of aviation batteries for over two decades.

The design/production agencies of the aircraft batteries, Regional Centres for Military Airworthiness and the place of end use of the batteries are geographically spread across the country. The information about airworthiness approved batteries is also spread among these agencies. CEMILAC felt a need of consolidating all the data available on the type approved indigenous aircraft batteries into a single document. The users and aircraft manufacturers (like HAL aircraft divisions) can use this as a battery selection guide. The aircraft maintenance staff can learn the underlying battery technology and maintenance aspects of the batteries they work with. Certifying authorities and inspection agencies can use this document to know the airworthiness clearance status. With this motivation, RCMA, Hyderabad took up the daunting task of congregating, assimilating and compiling all the information about aircraft batteries. The result of this endeavor is the "Compendium of Military Aviation Batteries – A Comprehensive Reference Guide For Certified Indigenous Batteries".

The compendium is designed to accommodate all the relevant information of batteries type approved by CEMILAC for use in Indian military aviation. Keeping in view of the requirements of the intended users, the compendium is organized in three parts. Part-1 provides an overview of various contemporary aircraft battery technologies. Other than typical aircraft battery technologies, thermal batteries for missile applications and lithium batteries for rescue beacons are also discussed. A chapter is devoted for maintenance aspects for aircraft batteries. Part – II of the compendium encompasses certification methodology and compendium of various airworthiness certified batteries. The chapter on certification methodology provides details about certification process, typical qualification tests applicable to batteries. A list of all the CEMILAC approved indigenous aviation batteries along with technical specification is also enumerated. Part-III gives ready reference information covering the various battery standards, typical acronyms and glossary of terms used in battery. The future trends in design and development of aviation battery technology is discussed as part of conclusion.

Pioneering efforts made by DGAQA in identifying and nurturing indigenous sources for design, development and manufacture of aircraft batteries are highly appreciated. Coordinated efforts made by Air HQrs., DGAQA and CEMILAC have resulted in many indigenous sources for supply of high quality aircraft batteries of various types. The information outlined in this compendium is the result of dedicated efforts of many scientists of the CEMILAC / RCMAs involved in evaluation and certification of various types of batteries at different work centers. Technical information has been culled from various technical books and Web sites. I thank my professional associates in the battery industries for their providing me with the necessary details. My special thanks to Sri K.Tamilmani, Chief Executive (Airworthiness), CEMILAC for his encouragement and guidance to complete this compendium. Also, I sincerely acknowledge the untiring assistance and support received from the RCMA (Hyderabad) team in the preparation of manuscripts.

I hope that this compendium meets its envisaged purpose and serves Indian military aviation community. Any suggestions, comments for improvement of this compendium, are welcome. The comments may be communicated to the address below,

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Part I

Introduction to Battery Technology

- Basic Concepts of Aviation Batteries
- Aircraft Power Supply Sources and Its Distribution
- Overview of Ni-Cd, Ag-Zn and Lead Acid Aircraft Battery Technologies
- Overview of Lithium Thionyl Chloride Battery Technology
- Overview of Thermal Battery Technology
- Operational, Maintenance and Overhaul Practices

1 Basic Concepts of Aviation Batteries

1.1 Introduction

This compendium broadly divided into three parts. Part-I will be discussed on general aviation batteries and over view of the technologies, and their maintenance aspects. Part-II will be discussed certification methodology and compendium of batteries along with technical specifications. And Part-III covers battery standards, conclusions and references etc.

The first chapter will discuss the basic concept of Aviation batteries & theirs technologies such as Nickel Cadmium, Silver Zinc, Lead Acid batteries for aircraft use.

1.1.1 Battery History

The first practical battery, the silver zinc voltaic pile was built by Alessandro Volta nearly 200 years ago. For this distinguishing accomplishment the unit of electrical force, the volt was named after Volta. Shortly after Volta's discovery the first rechargeable battery was constructed by Johann Wilihelm Ritter. Unfortunately no practical means existed to recharge it except from a primary battery. The electric generator was not to come along for another twenty years so the development of rechargeable technology was essentially stalled for the lack of a charger. The next significant step in battery development came 60 years latter as George Leclanche introduced his carbon zinc "wet" battery, a technology that paved the way for today's common flashlight battery.

1.1.2 Early Lead Acid History

At the same time Plante began studies which lead to the development of the lead acid cell. It is interesting to note that his early work involved spiral wound cells similar to the Hawker Energy Products sealed lead battery. In the next 20 year period, Fauare and others developed pasted lead oxide for the positive electrode and freeing the way for the commercialization of the lead acid battery in telephone exchanges and railway car lighting. While not a major step in battery development, the selection of the sealed lead acid system by Charles Kettering of General Motors to support his automotive self starting invention was a major step in the mass production of batteries. The Germans are credited with the development of gelled electrolyte cells. This was a major step in broadening the application base for the lead acid system which earlier had been limited to rather stationary applications where the chance of acid spillage was minimized.

1.1.3 Early Ni-Cd History

The nickel electrode and the alkaline system lagged the lead acid development by 30 years. Edison's experiments in 1890 resulted in the Nickel hydroxide positive electrode working in conjunction with an iron negative electrode in an alkaline electrolyte to form the first rechargeable alkaline system. A commercial nickel iron battery targeting the electric car market was demonstrated in 1910. At the same time Waldmar Jungner a

Swedish inventor developed the Nickel Cadmium pocket plate battery. To support the need for a light weight, high energy battery for their military effort of WWII, the Germans perfected a sintered plate, flooded electrolyte nickel-cadmium battery that is essentially identical to those used on today's jet military and commercial jet aircraft. European experimenters designed the first recombinant nickel-cadmium battery in the early 1950's that is the basis for today's nickel-cadmium industry.

1.2 Basic Battery Technology

A battery is a device that converts the chemical energy contained in its active materials directly into electric energy by means of electrochemical oxidation-reduction (redox) reactions. This takes place through an electric circuit. In the case of a rechargeable system, the battery is recharged by a reversal of the process. The type of reaction involves the transfer of electrons from one material to another through an electric circuit. In a non-electrochemical redox reaction, such as rusting or burning the transfer of electrons occurs directly and only heat is involved.

While the term "battery" is often used, the basic electrochemical unit being referred to is the "cell". A battery consists of one or more of these cells, connected in series or parallel or both, depending on the desired output voltage and capacity. Popular usage considers the "battery" and not the "cell" to be the product that is sold or provided to the "user". The term cell will be used when describing the cell component of the battery and its chemistry. The term "battery" will be used when presenting performance characteristics etc of the product. Most often the electrical data is resented on the basis if a single- cell battery. The performance of a multi cell battery will be usually be different than the performance of the individual cells or single cell battery.

1.2.1 Basic cell components

The cell consists of three major components. These are:

i. **The anode or negative electrode**
The reducing or fuel electrode, which gives up electrons to the external circuit and gets oxidized during electrochemical reaction (battery discharge).

ii. **The cathode or positive electrode**
The oxidising electrode, which accepts electrons from the external circuit and gets reduced during electrochemical reaction (battery discharge).

iii. **The- electrolyte**
The ionic conductor -which provides the medium for transfer of electrons as ions inside the cell between the anode and cathode. The electrolyte is typically a liquid, such as water or other solvents with dissolved salts, acids or alkalis to impart ionic conductivity.

The most advantageous combination of anode and cathode materials is those that will be lightest and give a highest voltage and capacity. Such combinations may not always be practical however, due to reactivity with other cell components, polarization and difficulty in handling, high cost and other deficiencies.

Every battery has the three basic components. The anode or positive plate, the cathode or negative plate and an electrolyte system in which the chemical reaction takes place. Some means for inputting and extracting energy from the cell must be provided in the form of current collectors.

1.2.2 The Ideal Battery

If we were to define the attributes for the ideal battery we would come up with the following:

- It should have a high energy density
- It would be rugged to withstand the rigors of portability
- It would have a long life
- It would be safe
- It would provide for application flexibility
- And it would be rechargeable.

Let's examine then, what the battery world has available for us.

1.2.3 Voltage

The voltage of any type cell is determined by wet materials are used in its construction. The total cell voltage equals the sum of the oxidation potential of the anode and the reduction potential of the cathode. The anode is the positive electrode and the cathode is the negative. The use of different materials for the anode and cathode yields different cell voltages.

ELECTRODE REACTION	ELECTRODE POTENTIAL
ANODES (-)	*
$Zn > ZnO$	1.2 volts
$Cd > Cd(OH)_2$	0.8 volts
$Pb > PbSO_4$	0.4 volts
CATHODES (+)	*
$HgO > Hg$	0.1 volts
$AgO > Ag$	0.3 volts
$MnO_2 > Mn(OH)_2$	0.4 volts
$NiOOH > Ni(OH)_2$	0.5 volts
$PbO_2 > PbSO_4$	1.7 volts

Table 1-1 Common Material used for anode and cathode with the Electrode Potential

Table 1-1 shows some of the common materials used for anodes and cathodes with their corresponding electrode potential. Adding together the potentials for the cadmium anode and the nickel cathode yields the predicted cell voltage for a nickel-cadmium cell, 1.3 volts. As it turns out, actual open circuit cell voltages are quite close to the predicted values. The same is evident when we examine the Pb and PbO electrodes of a sealed lead cell.

1.2.4 The Electro Chemical cell

A characteristic feature of an electrochemical cell is that the electronic current, which is the movement of electrons in the external circuit, is generated by the electrochemical processes at the electrodes. In contrast to the electronic current, the charge is transported between the positive and the negative electrodes in the electrolyte by ions. Generally the current in the electrolyte consists of the movement of negative and positive ions.

The simplified electrode processes are shown schematically in Figure 1-1. Starting with an open circuit, when a metal A is dipped into the solution it partly dissolves and electrons remain at the electrode until a characteristic electron density has been built up. For metal B, which is more noble than A the same process takes place, but the amount of dissolution and therefore the resulting electron density are lower.

If these two electrodes are connected by an electronic conductor, the electron flow starts from the negative electrode (with higher electron density) to the positive electrode. The electrode A / electrolyte system tries to keep the electron density constant. As a consequence additional metal A dissolves at the negative electrode, forming A^+ in solution and electrons e^-, which are located on the surface of metal A:

$$A \rightarrow A^+ + e^-$$

At the positive electrode the electronic current results in an increasing electron density. The electrode B / electrolyte system compensates this process by the consumption of electrons for the deposition of B^+ ions:

$$B^+ + e^- \rightarrow B$$

The electronic current stops if one of the flowing conditions is fulfilled:

- The base metal A is completely dissolved or
- All B^+ ions are precipitated

It is therefore necessary to add a soluble salt to the positive electrode compartment to maintain the current for a longer period. This salt consists of B^+ ions and corresponding negative ions. The two electrode compartments are divided by an appropriate separator to prevent the migration and the deposition of B^+ ions at the negative electrode A. Since this separator blocks the exchange of positive ions, only the negative ions are responsible for the charge transport in the cell.

This means that for each electron flowing in the outer circuit from the negative to the positive electrode, a negative ion in the electrolyte diffuses to the negative electrode compartment.

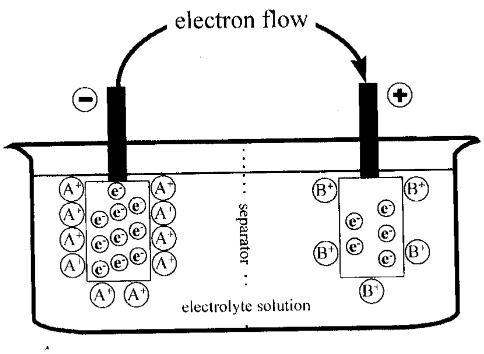


Figure 1-1 Electrochemical cell with negative and positive electrodes

Generally, the limiting factor for the electronic current flow is the transport of these ions. Therefore the electrolyte solution should have a low resistance.

An electrolyte may be characterized by resistance ϱ [Ω cm], which is defined as the resistance of the solution between two electrodes at a distance of 1 cm and an area of 1 cm^2. The reciprocal value is called the specific conductivity K [Ω^{-1} cm^{-1}]. Here is a wide spread for different electrolyte solutions. The selection of a suitable, high conductivity electrolyte solution for an electrochemical cell depends on its compatibility with other components, such as the positive and negative electrodes.

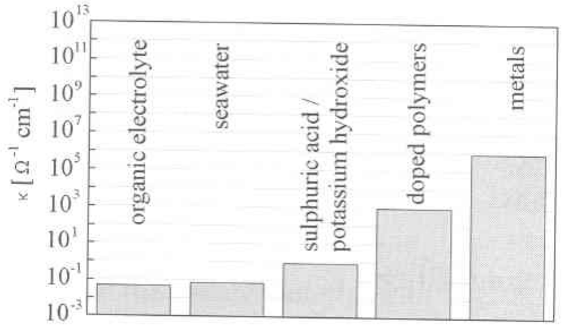


Figure 1-2 Comparison of Specific Conductivity of different material

From the chemical viewpoint, the galvanic cell is a current source in which a local separation of oxidation and reduction process exists. However it is briefly explained with a galvanic cell operation with an example of the Daniell element at Figure 1-3. Here the galvanic cell contains copper as the positive electrode, zinc as the negative electrode and their corresponding ion sulphates as the aqueous electrolyte.

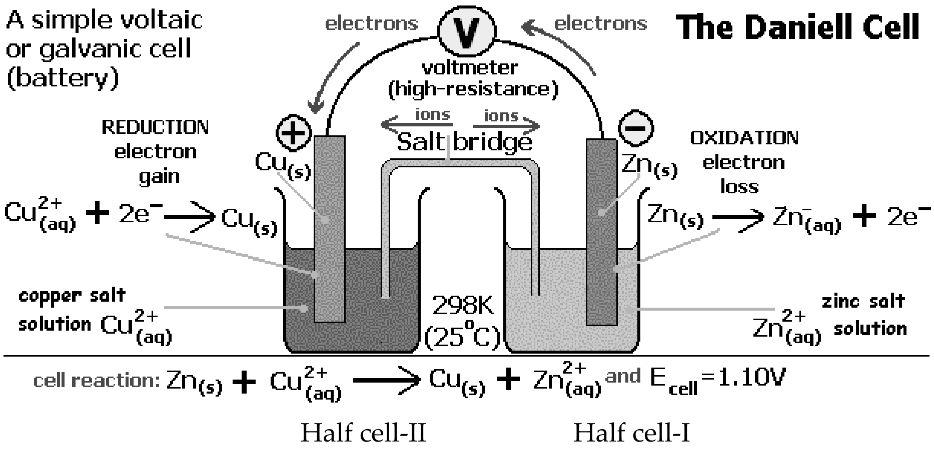


Figure 1-3 Daniell element

A salt bridge serves as an ion conducting connection between the two half-cells. When the external circuit is closed, the oxidation reaction starts with the dissolution of the zinc electrode and the formation of zinc ions in half-cell I. In half-cell II copper ions are reduced and metallic copper is deposited. The sulphate ions remain unchanged in the aqueous solution. The overall cell reaction consists of an electron transfer between zinc and copper ions:

Oxidation/half cell I:

$$Zn \rightarrow Zn^{2+} + 2e^{-}$$

Reduction / half cell II:

$$Cu^{2+} + 2e^{-} \rightarrow Cu$$

Overall cell reaction:

$$Zn + Cu^{2+} \rightarrow Zn^{2+} + Cu$$

A typical feature of a redox reaction is an exchange of electrons between at least two reaction partners. It is characterized by the fact that oxidation and reduction always occur at the same time. For the Daniell element the copper ions are the oxidizing agent and the zinc ions the reducing agent. Both together form the corresponding redox pair:

$$Red_1 + OX_2 \rightarrow Ox_1 + Red_2$$

$$CuSO_4 + Zn \rightarrow ZnSO_4 + Cu$$

The electrode where the oxidation dominates during discharge is called the anode (negative pole), the other electrode where the reduction predominates is the cathode (positive pole).

1.2.5 The Voltaic Cell

A voltaic cell is the basic device for converting chemical energy into electrical energy. It consists of two different metal plates immersed in a solution. The metal plates are called positive and negative electrodes and the solution is called the electrolyte.

Various dissimilar substances have opposite polarities with respect to one another and that when two such substances are rubbed together, one will have a positive charge and the other a negative charge. Dissimilar metals also have this property and when two such metals are placed in contact with each other, there will be a momentary flow of electrons from the one having a negative characteristic to the one having a positive characteristic. If two plates of dissimilar metals are placed in a chemical solution called electrolyte opposite electric charges will be established on the two plates.

An electrolyte is technically defined as a compound that when molten or in solution, conducts electric current and is decomposed by it. In simple terms, an electrolyte is a solution of water and a chemical compound that will conduct an electric current. The electrolyte in a typical aircraft storage battery consists of sulphuric acid and water. Various salts dissolved in water will also form electrolytes.

An electrolyte will conduct an electric current because it contains positive and negative ions. When a chemical compound is dissolved in water, it separates into its component parts. Some of these parts carry a positive charge and others carry a negative charge. The action of an electrolyte will be clear if a specific case is considered. When a rod of carbon and a plate of zinc are placed in a solution of ammonium chloride, the result is an elementary voltaic cell Figure 1-4. The carbon and zinc elements are called electrodes. The carbon, which is the positively charged electrode, is called the anode and the zinc plate is called the cathode. The combination of two electrodes surrounded by an electrolyte will form a cell.

As soon as the zinc (Zn) plate is placed in the electrolyte, zinc atoms begin to go into solution as ions each leaving two electrons at the plate. An ion is an atom or molecule that is either positively or negatively charged. A positively charged ion has a deficiency of electrons and a negatively charged ion has an excess of electrons. The zinc atoms going into solution as positive ions cause the zinc plate to become negatively charged. The zinc ions in the solution are positive because each one lacks the two electrons left at the plate. This positive charge causes the zinc ions to remain near the zinc plate because the plate has become negative. The effect of the zinc ions gathered near the plate is to stop the decomposition of the zinc plate for as long as the negative charge of the plate is balanced by the positive charge of the zinc ions in solution.

The ammonium chloride solution in the electrolyte apparently separates into positive hydrogen ions and a combination of ammonium and chlorine that is negatively charged. When the two electrodes are connected by an external conductor, the free electrons from the zinc plate flow to the carbon rod and the hydrogen Ions move to the carbon rod where each ion picks up one electron and becomes a neutral hydrogen atom. The positive zinc ions combine with the negative ammonium chloride to take the place of the hydrogen ions released into solution. The effect of these chemical actions is to remove electrons from the carbon rod and to liberate free electrons at the zinc plate. This results in a continuous supply of electrons available at the negative (zinc) electrode. When the two electrodes are connected, the electrons will flow to the carbon rod where the hydrogen ions become hydrogen atoms as the result of their neutralization by the electrons. Eventually, hydrogen gas bubbles form on the carbon rod and insulate it from the solution. This is called polarization and will cause the current flow to stop until the hydrogen is removed. For practical voltaic cells it is necessary to employ a method of depolarization.

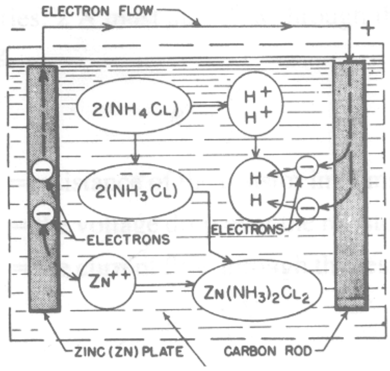


Figure 1-4 Chemical action in a voltaic cell

The standard dry cell used in flashlights and for other purposes for which a low-voltage DC supply is desired employs a compound called manganese dioxide (MnO_2) to prevent the accumulation of hydrogen at the positive electrode in the cell.

Figure 1-5 is a drawing of this type of cell. A dry cell is so called because the electrolyte is in the form of a paste, the cell may therefore be handled without the danger of spillage. The zinc can is the negative electrode and the paste electrolyte is held in close contact with the zinc by means of a porous liner. The space between the carbon rod and the zinc can is filled with manganese dioxide saturated with electrolyte. Graphite is mixed with the manganese dioxide to reduce the internal resistance of the cell. The top of the cell is sealed with a wax compound to prevent leaking and drying of the electrolyte. Many cells are encased in a tin-plated steel can to make them more durable, a layer of insulating material is then placed between the inner zinc can and the outer can to prevent short circuiting.

The voltage developed by a zinc-carbon cell is approximately 1.5 V. The voltage of any cell depends on the materials used as the electrodes. A lead-acid secondary cell, such as those employed in storage batteries develops a voltage of 2.1 V. The electrodes (plates) are composed of lead for the negative and lead peroxide for the positive. As previously stated dissimilar metals always have a definite polarity with respect to one another. For example, if nickel and aluminum are placed in an electrolyte, the nickel will be positive and the aluminum negative. However, if nickel and silver are acted upon by the same electrolyte, the nickel will be negative and the silver positive. The more active a metal is chemically the greater is its negative characteristic.

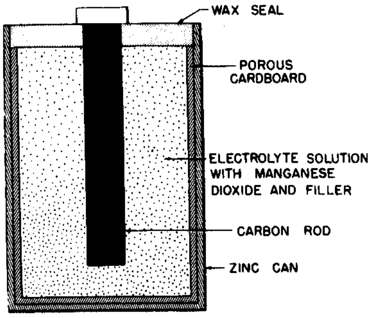


Figure 1-5 Construction of a simple dry cell

In a secondary cell, the chemical action that produces the electric current can be reversed. In other words, secondary cells can be recharged. This is accomplished by applying a voltage higher than that of the cell to the cell terminals, this causes a current to flow through the cell in a direction opposite to that in which the current normally flows. The positive terminal of the charging source is connected to the positive terminal of the cell and the negative terminal of the charging source is connected to the negative terminal of the cell. Since the voltage of the charger is higher than that of the cell, electrons flow into the negative plate and out of the positive plate. This causes a chemical action to take place that is the reverse of the one that occurs during operation of the cell, the elements of the cell return to their original composition. At this time, the cell is said to be charged. Secondary cells can be charged and discharged many times before they deteriorate to the point at which they must be discarded.

A cell that cannot be recharged satisfactorily is called a primary cell. The elementary voltaic cell described previously in this section is a primary cell. Some of the elements deteriorate as the cell produces current, hence the cell cannot be restored to its original condition by charging. The common flashlight cell is a familiar example of a primary cell. The negative plate of a primary cell deteriorates because the material goes into solution with the electrolyte. In the secondary cell, the material of the plates does not go into solution but remains in the plates, where it undergoes a chemical change during operation.

1.2.6 Alkaline Cells / Batteries

Voltaic cells utilizing an alkaline electrolyte are usually termed alkaline cells. The electrolyte consists primarily of a potassium hydroxide solution. A variety of alkaline cells are currently available. Potassium hydroxide (KOH) is a powerful caustic similar to household lye and can cause severe bums if it comes into contact with the skin. The electrodes of such cells can be of several different types of materials. Such as manganese dioxide and zinc, silver oxide and zinc, silver oxide and cadmium, mercuric oxide and zinc, or nickel and cadmium. These various electrode materials will determine if the alkaline cell is a rechargeable secondary cell or a non rechargeable primary cell. The different electrodes will also determine the cell's voltage output. Most common alkaline cells produce approximately 1.5 V without a load applied to the cell.

For aircraft applications Ni-Cd, Lead Acid and Silver Zinc secondary batteries are used. Basic concept of operations for these batteries is given in following paragraphs.

1.2.7 Electrochemical Cell Concept

A cell is a single electrochemical device with a single anode and a single cathode. A battery is a collection of cells, usually connected in series to obtain a higher terminal voltage.

Batteries, whether they are primary (use once) or secondary (rechargeable) are devices which convert chemical energy into electrical energy. In the case of the latter, they can take electrical energy and store it as chemical energy for later use.

The key to electrochemistry are the processes of oxidation and reduction. Remember the phrase “ LEO (the lion) goes GER”

LEO = Lose Electrons Oxidation

GER = Gain Electrons Reduction

When one oxidizes a material, it gives up electrons and becomes more positively charged or enters a higher oxidation state. Likewise, when one reduces a material, one is adding electrons to it and either making it negatively charged or reducing its oxidation state.

Now, one can make a cell using two materials, say A and B and immersing them in a solution which can conduct ions called an electrolyte. (An ion is a charged atom or radical of a molecule capable of transferring electrical charge). Now, let us say that material A is easily oxidized it likes to lose electrons, while B is a material that likes to be reduced. When these two materials are immersed in an electrolyte and a circuit is completed from A to B, A is oxidized and electrons are released to flow to the circuit. After performing electrical work, the electrons flow into B where B is reduced. The circuit from B to A is completed by the flow of ions in the electrolyte. A secondary cell can be reversed by forcing electrons into A and reducing the oxidized A to regain un- oxidized A for use again.

This of course is an oversimplified view, as only certain combinations of materials and electrolytes provide useful and practical batteries.

The cathode is where reduction takes place and the anode is where oxidation takes place. So, in a battery which is producing current, the positive terminal is the cathode and the negative terminal is the anode. Yes, this is counterintuitive from our understanding of diodes, where the cathode is negative with respect to the anode.

1.2.8 Operating principle of a Cell

1.2.8.1 Discharge Operation

The operation of a cell during discharge is also shown schematically in Figure 1-6. When the cell is connected to an external load, electrons flow from the anode, which is oxidized through the external load to the cathode, where the electrons are accepted and the cathode material reduced. The electrical circuit is completed in the electrolyte by the flow of anions (negative ions) and cations (positive ions).

The discharge reaction can be written, assuming a metal as the anode material and a cathode material such as chlorine (Cl_2), as follows:

Negative electrode: anodic reaction (oxidation, loss of electrons)

$$\mathbf{Zn \rightarrow Zn^{2+} + 2e}$$

Positive electrode: cathodic reaction (reduction, gain of electrons)

$$\mathbf{Cl_2 + 2e \rightarrow 2Cl^-}$$

Overall reaction (charge):

$$\mathbf{Zn + Cl_2 \rightarrow Zn^{2+} + 2Cl^- \ (ZnCl_2)}$$

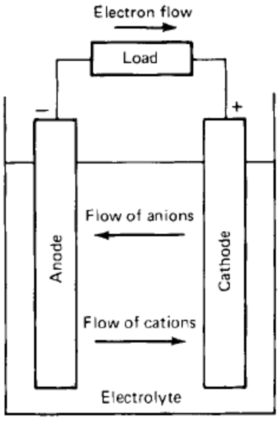


Figure 1-6 Electrochemical operation of a cell (discharge)

1.2.8.2 Charge Operation

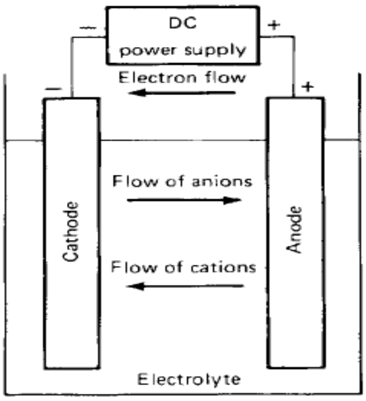


Figure 1-7 Electrochemical operation of a cell (charge)

During the recharge of a rechargeable or storage battery, the current flow is reversed and oxidation takes place at the positive electrode and reduction at the negative electrode, as shown in Figure 1-7. As the anode is, by definition the electrode at which oxidation occurs and the cathode the one where reduction takes place, the positive electrode is now the anode and the negative the cathode. In the example of the Zn/Cl_2 cell the reaction on charge can be written:

Negative electrode: **cathodic reaction (reduction, gain of electrons)**

$$Zn^{2+} + 2e \rightarrow Zn$$

Positive electrode: **anodic reaction (oxidation, loss of electrons)**

$$2Cl^{-} \rightarrow Cl_2 + 2e$$

Overall reaction (charge):

$$Zn^{2+} + 2Cl^{-} \rightarrow Zn + Cl_2$$

So the processes that produce electricity in a battery is that the electronic current, which is the movement of electrons in the external circuit generated by the electrochemical processes(chemical reactions) at the electrodes which either release or consume electrons as the electrode reaction proceeds to completion. In contrast to the electronic current, the charge is transported between the positive and the negative electrodes in the electrolyte by ions. Generally the current in the electrolyte consists of the movement of negative and positive ions.

1.2.9 Theoretical Cell Voltage, Capacity and Energy density

The theoretical voltage and capacity of a cell are a function of the anode and cathode materials.

1.2.9.1 Free Energy

Whenever a reaction occurs there is a decrease in the free energy of the system, which is expressed as :

$$\Delta G^\circ = -nFE^\circ$$

where F = a constant known as the Faraday ($\approxeq$ 96,500 C or 26.8 Ah)

n = number of electrons involved in stoichiometric reaction

E° = standard potential, V

1.2.9.2 Theoretical Voltage

The standard potential of the cell is determined by its active materials and can be calculated from free-energy data or obtained experimentally. A listing of electrode potentials (reduction potentials) under standard conditions is given in Table 1-2.

The standard potential of a cell can be calculated from the standard electrode potentials as follows (the oxidation potential is the negative value of the reduction potential):

Anode (oxidation potential) + cathode (reduction potential) = standard cell potential

For example-1

$$\begin{array}{ll} \mathbf{Zn + Cl_2 \rightarrow ZnCl_2} & \\ \mathbf{Zn \rightarrow Zn^{2+} \ + \ 2e \ - } & \mathbf{(-0.76\,V)} \\ \mathbf{Cl_2 \rightarrow 2Cl^- \ - \ 2e} & \underline{\mathbf{1.36\,V}} \\ & \mathbf{2.12\,V} \end{array}$$

Example -2

1. In the case of Silver Oxide – zinc battery, the overall reaction is :

$$\mathbf{Ag\,O + Zn = Ag + ZnO}$$

2. The Anode reaction is :

$$\mathbf{Zn \rightarrow Zn^{\ 2+} + 2\,e\,(-1.25V)}$$

3. The Cathode reaction is :

$$\mathbf{Ag\,O + H_2O + 2e \rightarrow Ag + 2\,OH^- \quad (+0.57V)}$$

Hence the cell voltage = Cathode Potential + (- Anode Potential)

$$\mathbf{0.57 + 1.25 = 1.82V}$$

The cell voltage is also dependent on other factors like concentration & temperature.

The capacity of a cell is expressed as the total quantity of electricity involved in the electrochemical reaction and is defined in terms of coulombs or ampere-hours. The ampere-hour-capacity of the battery is directly associated with the quantity of electricity obtained from the active materials. The capacity of the battery system, based only on the active materials participating in the electrochemical reaction is calculated theoretically.

Table 1-2 Characteristics of Electrode Materials

Material	Atomic or molecular weight, g	Standard potential, 25°C,V	Valence change	Melting Point, °C	Density g/cm^3	Electrochemical equivalents		
						Ah/g	g/Ah	Ah/cm^3*
Anode Materials								
H_2	2.01	0 -0.83†	2	--	--	26.59	0.037	--
Li	6.94	-3.01	1	180	0.54	3.86	0.259	2.06
Na	23.0	-2.71	1	98	0.97	1.16	0.858	1.14
Mg	24.3	-2.38 -2.69†	2	650	1.74	2.20	0.454	3.8
Al	26.9	-1.66	3	659	2.69	2.98	0.335	8.1
Ca	40.1	-2.84 -2.35†	2	851	1.54	1.34	0.748	2.06
Fe	55.8	-0.44 -0.88†	2	1528	7.85	0.96	1.04	7.5
Zn	65.4	-0.76 -1.25†	2	419	7.14	0.82	1.22	5.8
Cd	112.4	-0.40 -0.81†	2	321	8.65	0.48	2.10	4.1
Pb	207.2	-0.13	2	327	11.34	0.26	3.87	2.9
$(Li)C_6$(1)	72.06	~-2.8	1	--	2.25	0.37	2.68	0.84
MH(2)	116.2	-0.83†	2	--	--	0.45	2.21	--
CH_3OH	32.04	--	6	--	--	5.02	0.20	--
Cathode materials								
O_2	32.0	1.23 0.40†	4	--	--	3.35	0.30	--
Cl_2	71.0	1.36	2	--	--	0.756	1.32	--

SO_2	64.0	--	1	--	--	0.419	2.38	--
MnO_2	86.9	1.28†	1	--	5.0	0.308	3.24	1.54
NiOOH	91.7	0.49†	1	--	7.4	0.292	3.42	2.16
CuCl	99.0	0.14	1	--	3.5	0.270	3.69	0.95
FeS_2	119.9	--	4	--	--	0.89	1.12	
AgO	123.8	0.57†	2	--	7.4	0.432	2.31	3.20
Br_2	159.8	1.07	2	--	--	0.335	2.98	
HgO	216.6	0.10†	2	--	11.1	0.247	4.05	2.74
Ag_2O	231.7	0.35†	2	--	7.1	0.231	4.43	1.64
PbO_2	239.2	1.69	2	--	9.4	0.224	4.45	2.11
Li_xCoO_2(3)	98	~2.7	0.5	--	--	0.137	7.29	--
I_2	253.8	0.54	2	--	4.94	0.211	4.73	1.04

† Basic electrolyte; all others aqueous acid electrolyte

*** Based on density values shown**

1.2.9.3 Theoretical Capacity

The capacity of a cell is expressed as the total quantity of electricity involved in the electrochemical reaction and is defined in terms of coulombs or ampere-hours. The "ampere-hour capacity" of a battery is directly associated with the quantity of electricity obtained from the active materials. Theoretically 1 gram-equivalent weight of material will deliver 96,487 C or 26.8 Ah (a gram-equivalent weight is the atomic or molecular weight of the active material in grams divided by the number of electrons involved in the reaction). The electrochemical equivalence of typical materials is listed in Table 1-2.

The theoretical capacity of a battery system, based only on the active materials participating in the electrochemical reaction is calculated from the equivalent weight of the reactants. Hence, the theoretical capacity of the Zn/Cl_2 system is 0.394Ah/g:

$$\begin{array}{ccccc} \mathbf{Zn} & + & \mathbf{Cl_2} & \rightarrow & \mathbf{ZnCl_2} \\ & & & & \\ \mathbf{0.82\,Ah/g} & & \mathbf{0.76\,Ah/g} & = & \mathbf{2.54\,g/Ah} \quad \mathbf{or} \\ \mathbf{1.22\,g/Ah} & & \mathbf{1.32\,g/Ah} & & \mathbf{0.394\,Ah/g} \end{array}$$

The capacity of batteries is also considered on an energy (watt-hour) basis by taking the voltage as well as the quantity of electricity into consideration:

Watt-hour (Wh) = voltage (V) X ampere-hour (Ah)

In the Zn/CI_2 cell example, if the standard potential is taken as 2.12 V, theoretical watt-hour capacity per gram of active material (theoretical gravimetric energy density) is:

Watt-hour/gram capacity = 2.12 V X 0.395 Ah/g
= 0.838 Whig

Similarly, the ampere-hour or watt-hour capacity on a volume basis can be calculated by using the appropriate data for ampere-hours per cubic centimeter.

The theoretical voltages and capacities of a number of the major electrochemical systems are given in Table 1-3 . The values given are based on the active anode and cathode material only. Water, electrolyte or any other material that may be involved in the cell reaction are not included in the calculation.

1.2.9.4 Specific Energy and Energy Density of Practical batteries

Energy per Unit of Weight and Volume

In practice, only a fraction of the theoretical capacity of a battery is realized. This is due not only to the presence of non-reactive components (containers, separators, electrolyte) that add to the weight and volume of the battery but also to many other factors that prevent the battery from performing at its theoretical level. The need for materials of cell construction reduces the energy density (watt-hour/kg) of a battery by almost 50% and further, that the rated capacity of a battery may only be 50 – 75% of that value. The actual performance depending on the discharge conditions may even be lower in particular if the battery is discharged under more stringent conditions than those under which it was rated.

The energy density of a sintered plate battery may vary with the loading of the electrodes, the degree of utilization of the active materials, the internal cell design, and the size of the cells and the arrangement of cells in the battery.

The loading of the electrodes or filling of the pores of the plates with active materials is obviously an important factor for the capacity. Usually, positive electrodes contain 1.0-1.5 g of nickel hydroxide and negative electrodes 1.3-1.9 g of cadmium hydroxide per cubic centimeter. For special applications these figures may however be higher.

The utilization of the active materials varies to some extent with the method of impregnation applied. For example, whereas the cadmium nitrate polarization process results in a utilization of about 75%, only 50-60% of the theoretical value is obtained when cadmium chloride or sulfate is used. Most manufacturers generally use methods giving about 90% utilization at the positive electrode and 65-75% at the negative electrode.

The internal cell construction has a bearing on the energy per unit of volume and weight. Thick plate cells have higher energy densities, since the ratio between electrode thickness and space between electrodes is favorable. Other internal cell factors of importance are separator thickness and head space above the element.

The cell size also has some effect on the energy density. The smaller cells have, usually lower energy per weight and volume than the bigger types. However, this is not as pronounced as with the pocket type cells.

In summary, the maximum energy that can be delivered by an electrochemical system is based on the types of active materials that are used (this determines the voltage) and on the amount of the active materials that are used (this determines ampere-hour capacity). In practice, only a fraction of the theoretical energy of the battery is realized. This is due to the need for electrolyte and nonreactive components (containers, separators, electrodes) that add to the weight and volume of the battery, as illustrated in Figure 1-8.

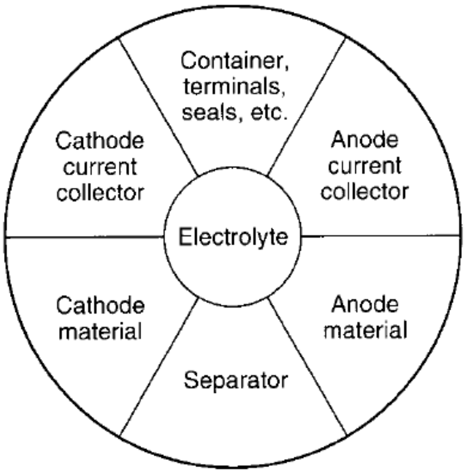


Figure 1-8 Components of a cell

Table 1-3 Theoretical Voltage and Capacity of Major Battery Systems*

Battery system	Anode	Cathode	Reaction mechanism	Theoretical		
				V	Capacity†	
					g/Ah	Ah/kg
Primary						
Leclanche	Zn	MnO_2	$Zn + 2MnO_2 \rightarrow ZnO \cdot Mn2O_3$	1.6	4.46	224
Magnesium	Mg	MnO_2	$Mg + 2MnO_2 + H_2O \rightarrow Mn_2O_3 + Mg(OH)_2$	2.8	3.69	271
Alkaline MnO_2	Zn	MnO_2	$Zn + 2MnO_2 \rightarrow ZnO + Mn_2O_3$	1.5	4.46	224
Mercury	Zn	HgO	$Zn + HgO \rightarrow ZnO + Hg$	1.34	5.27	190
Mercad	Cd	HgO	$Cd + HgO + H_2O \rightarrow Cd(OH)_2 + Hg$	0.91	6.15	163
Silver oxide	Zn	Ag_2O	$Zn + Ag2O + H_2O \rightarrow Zn(OH)_2 + 2Ag$	1.6	5.55	180
Zinc / air	Zn	O_2(air)	$Zn + 1/2\, O_2 \rightarrow ZnO$	1.65	1.55	800
Li / SO_2	Li	SO_2	$2Li + 2SO_2 \rightarrow Li_2S_2O_4$	3.1	2.64	379
Li / MnO_2	Li	MnO_2	$Li + Mn^{IV}O_2 \rightarrow Mn^{III}O_2(Li^+)$	3.5	3.50	286
Reserve						
Cuprous chloride	Mg	CuCl	$Mg + Cu_2Cl_2 \rightarrow MgCl_2 + 2Cu$	1.6	4.14	241
Zinc / silver oxide	Zn	Ag_2O	$Zn + AgO + H_2O \rightarrow Zn(OH)_2 + Ag$	1.81	3.53	283

Secondary						
Lead-acid	Pb	PbO_2	$\mathbf{Pb + PbO_2 + 2H_2SO_4 \rightarrow 2PbSO_4 + 2H_2O}$	2.1	8.32	120
Edison	Fe	Ni Oxide	$\mathbf{Fe + 2NiOOH + 2H_2O \rightarrow 2Ni(OH)_2 + Fe(OH)_2}$	1.4	4.46	224
Nickel cadmium	Cd	Ni Oxide	$\mathbf{Cd + 2NiOOH + 2H_2O \rightarrow 2Ni(OH)_2 + Cd(OH)_2}$	1.35	5.52	181
Silver – zinc	Za	AgO	$\mathbf{Zn + AgO + H_2O \rightarrow Zn(OH)_2 + Ag}$	1.85	3.53	283
Nickel –Zinc	Zn	Ni Oxide	$\mathbf{Zn + 2NiOOH + 2H_2O \rightarrow 2Ni(OH)_2 + Zn(OH)_2}$	1.73	4.64	215
Nickel–hydrogen	H_2	Ni Oxide	$\mathbf{H_2 + 2NiOOH \rightarrow 2Ni(OH)_2}$	1.5	3.46	289
Silver– cadmium	Cd	AgO	$\mathbf{Cd + O + H_2O \rightarrow Cd(OH)_2 + Ag}$	1.4	4.41	227
Zinc / Chlorine	Zn	Cl_2	$\mathbf{Zn + Cl_2 \rightarrow ZnCl_2}$	2.12	2.54	394
High temperature	Li(Al)	FeS	$\mathbf{2Li(Al) + FeS \rightarrow Li_2S + Fe + 2Al}$	1.33	2.99	345
High temperature	Na	S	$\mathbf{2Na + 3S \rightarrow Na_2S_3}$	2.1	2.65	377
Fuel cell						

$\mathbf{H_2/O_2}$	H_2	O_2 (or air)	$\mathbf{H_2 + {}^{1}\!/_{2}O_2 \rightarrow H_2O}$	1.23	0.336	2975

* presents data on the practical operating characteristics of these battery systems.

† Based on the active anode and cathode materials only.

1.2.10 Open- and Closed-Circuit Voltages

There are two different ways to measure the voltage of a battery or cell. Voltage measured when there is no load applied to the battery is called the open-circuit voltage (OCV). The voltage measured while a load is applied to the battery is called the closed-circuit voltage (CCV). The OCV is always higher than the CCV because a battery can maintain a higher pressure (voltage) when there is no current flow leaving the battery. The OCV of a fully charged aircraft battery may reach typically above 26 V, in case of Ni-Cd 20 Cell pack. However, when even a small load is applied, the CCV will measure near 24 V. This battery would typically be referred to as a 24V battery. The CCV of a battery is usually a function of the load applied and the state of charge of that battery. If a battery is connected to a heavy load, the CCV will be lower than if that battery was connected to a light load. If a battery is near total discharge, the CCV will be lower than if that same battery was fully charged. The OCV of a battery is

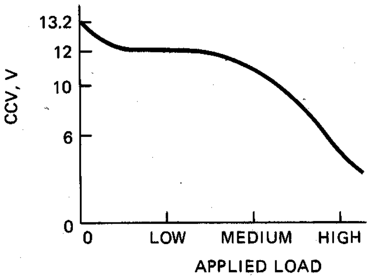


Figure 1-9 Closed Circuit voltage versus applied load

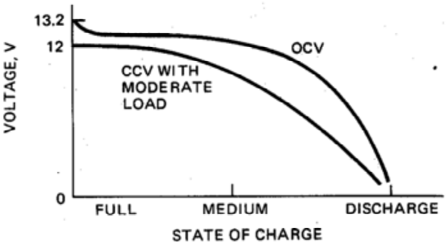


Figure 1-10 Open-and closed-circuit voltage versus a battery's state of charge

Typically affected very little by its state of charge until the battery reaches near complete discharge. Figure 1-9 and Figure 1-10 illustrates the relationships between OCV and CCV for various loads and battery states of charge.

1.2.11 Internal Resistance

Internal resistance R_{in} is defined as the opposition or resistance to the flow of an electric current with in a cell or battery -the sum of the ionic and electronic resistances of the cell components. Electronic resistance includes the resistance of the materials of construction, namely metal coves, carbon rods, conductive cathode components and so on.

Ionic resistance encompasses factors which interfere with the movement and flow of ions to and fro from the individual electrodes. These include electrolyte conductivity, ion mobility (electrode porosity, electrode surface area, secondary reactions and so on. These factors are encompassed by the terms of polarization. Other considerations include cell size and construction as well as temperature, age and depth of discharge.

The alkaline batteries such as Lead acid, NI-CD, Silver Zinc cells, because of their construction and highly conductive electrolyte, have a relatively low internal resistance. This low internal resistance is a benefit in applications involving high current pulses.

The resistance present inside of a battery while connected to a load is called internal resistance (IR). IR restricts the movement of current inside of any power source, including batteries. In the case of a battery, the IR is generally determined by the load applied and the battery's state of charge. A battery's IR is equal to the difference between the OCV and the CCV divided by the applied load. That is, IR = (OCV - CCV)/load amperage. This equation is derived from Ohm's law, R=E/I. A battery's internal resistance can be determined as follows. If a typical battery, the OCV = 14 V and the CCV = 12 V with a 100-A load applied, the IR is 0.02 Ω. The calculation is

$$\begin{aligned} \mathrm{IR} &= \frac{\mathrm{OCV} - \mathrm{CCV}}{\mathrm{I\,load}} \\ &= \frac{14\mathrm{V} - 12\mathrm{V}}{100\mathrm{A}} \\ &= \frac{2\mathrm{V}}{100\mathrm{A}} \\ &= 0.02\Omega \end{aligned}$$

A battery's internal resistance always becomes greater as the battery becomes discharged. This is due to the lowering of a battery's CCV as the battery becomes weaker. The OCV remains nearly constant while the CCV drops therefore, the difference between these two voltages increases. Hence IR increases.

The IR of a battery becomes very significant when a power source is chosen or a delicate circuit is designed. However, for general-purpose applications, a battery's internal resistance will not adversely affect an aircraft electrical system until that battery becomes over 75 percent discharged. When the battery reaches this low state of charge, its internal resistance becomes too high and the CCV lowers. This low CCV obviously affects circuit performance.

1.3 Classification of Cells and Batteries

Electrochemical cells and batteries are identified as primary (non-rechargeable) or secondary (rechargeable) depending on their capability of being electrically recharged. Within this classification, other classifications are to identify particular structures or designs. The classification used in this compendium for the different types of electrochemical cells and batteries is described below.

1.3.1 Primary Cells or Batteries

These are not capable of being easily recharged electrically and hence, are discharged once and discarded. Many primary cells in which the electrolyte is contained by an absorbent or separator material (there is no free or liquid electrolyte) are termed "dry cells." The primary battery is a convenient, usually relatively inexpensive, lightweight source of packaged power for portable electronic and electrical devices, lighting, photographic equipment, toys, memory backup and a host of other applications giving freedom from utility power. The general advantages of primary batteries are good shelf life, high energy density at low to moderate discharge rates, little maintenance, if any and ease of use. Although large, high-capacity primary batteries are used in military applications, signaling, standby power, etc. the vast majority of primary batteries are the familiar cylindrical and flat cells.

1.3.2 Secondary or Rechargeable Cells or Batteries

These can be recharged electrically after discharge to their original condition by passing current through them in the opposite direction to that of the discharge current. They are storage devices for electrical energy and are known also as "storage batteries" or "accumulators". The applications of secondary batteries fall into two main categories: Those applications in which the secondary battery is used as an energy-storage device, generally being electrically connected to and charged by a prime energy source and delivering its energy to the load on demand. Examples are automotive and aircraft systems, emergency no-fail and standby power sources and stationary energy storage (SES) systems for electric utility load leveling.

Those applications in which the secondary battery is used or discharged essentially as a primary battery, but recharged after use rather than being discarded. Secondary batteries are used in this manner in electric vehicles for cost savings (as they can be recharged rather than replaced) and in applications requiring power drains beyond the capability of primary batteries.

Secondary batteries are characterized (in addition to their ability to be recharged) by high power density, high discharge rate, flat discharge curves and good low temperature performance. Their energy densities are generally lower than those of primary batteries. Their charge retention also is poorer than most primary batteries, although the capacity of the secondary battery that is lost on standing can be restored by recharging.

Some batteries, known as "mechanically rechargeable types" are "recharged" by replacement of the discharged or depleted electrode, usually the metal anode with a fresh one. The metal-air batteries, proposed for electric vehicle use are representative of this type of battery.

Once the active materials are used up, a primary battery is not capable of yielding any more electric energy and is then discarded. Other battery systems use materials that can be restored to their original chemical state by reversing the current flow, i.e. by providing electric energy to the cell from some external source. This process is known as charging and a battery that is capable of undergoing a number of discharge-charge cycles is called a secondary battery. By definition, the anode on discharge becomes the cathode on charge. Similarly, the cathode on discharge becomes the anode on charge. However, the terminal designations of positive and negative do not change since the current flow reverses when the roles of the electrodes of secondary batteries are most often referred to as positives and negatives and while this designation can also be used for primaries, the electrodes of the latter are more usually referred to as anodes and cathodes. In their most common forms both primary and secondary batteries are entirely operative when they are made. Because of this, slow deteriorations can occur owing to a small amount of spontaneous reaction or "local action" that goes on all the time in activated batteries.

1.4 Nickel-Cadmium Cells (Vented type and Portable Sealed cylindrical)

1.4.1 Stored Charge

The amount of stored charge in a cell is determined by how much active material is used. This amount of stored charge determines the capacity and is expressed in ampere-hours which is the product of the discharge current and the duration of the discharge. The ampere-hour rating of cells can be used to compare the capability of cells, but this comparison is really only valid for cells which have the same chemical system. Cells that use different chemistry should be compared on a variety of factors such as weight or power delivery as well as capacity. We will frequently use the term "C" or "C" rate when discussing charge and discharge rates of batteries. This term "C" is numerically equivalent to the rated capacity of a cell. A cell discharged at the "C" rate will extend its minimum capacity in one hour. Because nickel cadmium manufacturers establish their capacity ratings as either the five hour or one hour rate, some manufacturers provide both ratings for ease of comparison. Sealed lead product line are rated at the ten hour or twenty hour rate but as with nickel-cadmium, some provide ratings at the five, ten and twenty hour rates for comparison with other sealed lead manufacturers. Some Ni-Cd cells are rated at the one hour rate. At 0.25C discharge rate, a cell's one hour rated capacity will be delivered in four hours and at the 4C discharge rate, the rated capacity will be delivered in 15 minutes. For example, the "C" rate of a 600 milliampere-hour AA cell is 600 milli amperes. The 0.1C discharge or charge rate for this cell would be 60 milli amperes. When discussing battery applications, the use of "C" rate simplifies understanding the fundamentals of the application and helps normalize data for easier comparison between different operating conditions.

1.4.2 Electrochemistry of the Nickel Cadmium Cell

The nickel-cadmium cell is an electrochemical system in which the electrodes containing the active materials undergo changes in oxidation state without any change in physical state. This is because the active materials are highly insoluble in the alkaline electrolyte. They remain as solids and do not dissolve while undergoing changes in oxidation state. This is what makes a nickel-cadmium cell long-lived, since no chemical mechanism exists to cause the loss of the active materials. An important cell characteristic which results from these chemical and other properties is that the cell voltage is essentially constant throughout nearly all of the discharge. In the nickel-cadmium cell, nickel oxyhydroxide (NiOOH) is the charged active material in the positive plate. During discharge the charged nickel hydroxide goes to a lower valence state, $Ni(OH)_2$, by accepting electrons from the external circuit. Cadmium metal (Cd), is the charged active material in the negative plate. During discharge, it is oxidized to cadmium hydroxide $Cd(OH)_2$ and releases electrons to the external circuit. During charging of the battery, the reactions are reversed, thus returning the cell to the original voltage and capacity. The electrolyte in which the reaction occurs is potassium hydroxide (KOH) solution in water at concentrations in the 32% range. When a cell is overcharged, oxygen gas is generated at the positive electrode, but the sealed nickel-cadmium cell is designed to accommodate the excess oxygen during slow overcharge with no noticeable loss of performance. This is accomplished by building the cell with a negative plate which is not fully charged when the positive plate becomes fully charged. Inspection of the plates will reveal that the negative plate is physically larger than the positive as depicted in Figure 1-11. A typical vented 40AH Ni-Cd cells arranged in a battery box is shown in Figure 1-12.

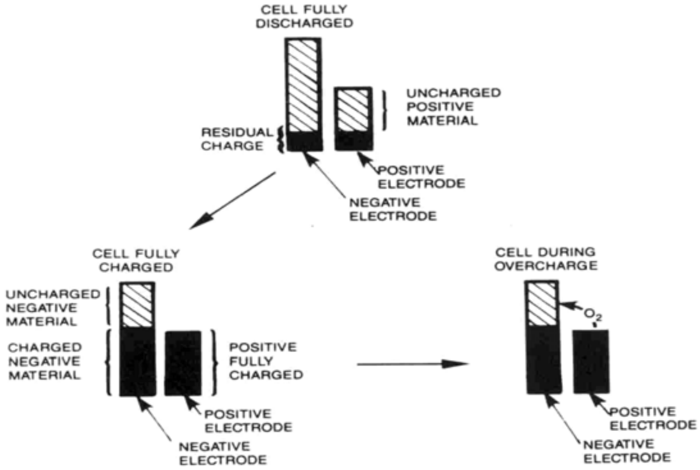


Figure 1-11 Electrode performance schematic

The excess oxygen quickly passes through the porous separator reaching the active sites on the negative plate where it is recombined from the gaseous state forming hydroxyl ions. These hydroxyl ions then move back to the positive plate completing the circuit. In the unusual instance where a cell is overcharged in the unusual instance where a cell is overcharged at a higher rate than can be handled by the cell design, a resealable safety vent will open letting the excess oxygen escape.

1.4.2.1 Typical Battery Designs

A typical arrangement of vented sintered nickel-cadmium cells into a battery configuration is the conventional aircraft battery. An example of this use is shown in Figure 1-12 and Figure 3-10. This arrangement generally consists of a completely enclosing battery case and cover made of either stainless steel or steel with a KOH-resistant finish of epoxy or paint. The cover is typically secured with over-center-type latches. The battery case is provided with gas-purging vents or with freely convective gas-diffusion openings for dilution. The cells are encased in nylon-molded cell cases with terminals extending through a nylon cover sealed to the case. The cells are electrically connected in series with nickel-plated copper links from cell terminal to cell terminal and from the first and last cell to the battery termination and disconnect device. This battery termination extends through the battery case wall and is present on the outside surface of the battery case as a recessed double-male, polarized, high-current receptacle. Functional requirements of aircraft batteries are specified in SAE standard AS 8033A.

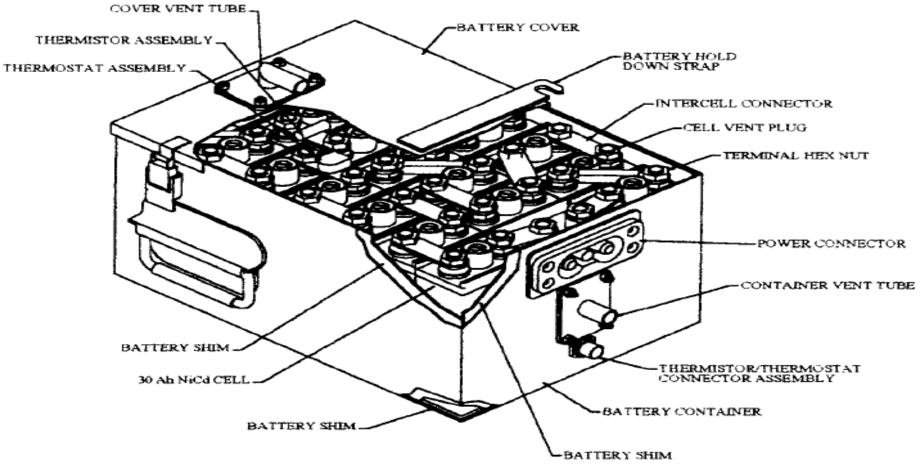


Figure 1-12 A typical Vented Ni-Cd battery (20 cells arranged in a battery box)

1.5 Lead-Acid Storage Batteries

The term storage battery has been used for many years as the name for a battery of secondary cells and particularly for lead-acid and nickel-cadmium batteries.

Two types of lead-acid batteries currently being used in aviation are the vented cell and the sealed (recombinant gas) battery (Figure 1-13). The modem sealed-cell lead-acid batteries are more powerful and require less maintenance than the older vented lead-acid aircraft batteries. For this reason, lead-acid batteries are being used to replace the more expensive nickel-cadmium battery in some turbine powered aircraft. On turbine-powered aircraft however, the installation of lead-acid batteries typically requires that external power be readily available for engine starting and the lead-acid batteries require more frequent replacement. Despite the great strides made to improve lead-acid batteries, they are still unable to deliver the current generated by nickel-cadmium batteries therefore, nickel-cadmium batteries will remain a practical power source for aircraft. Nickel-cadmium batteries are discussed later in this chapter.

Lead-acid secondary cells consist of lead-compound plates immersed in a solution of sulfuric acid and water, which is the electrolyte. Each cell has an OCV of approximately 2.1

V when fully charged. When connected to a substantial load the voltage is approximately 2.0 V.

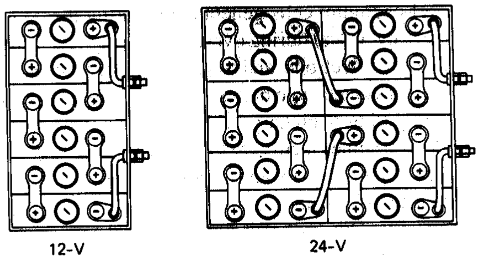


Figure 1-13 Arrangement of cells in a lead-acid storage battery

1.6 **Silver-Zinc Batteries (Ag-Zn)**

Rechargeable silver-zinc batteries can provide higher currents more level voltage and up to six times greater watt hour capacity per unit weight and volume than the lead-acid, nickel-zinc and nickel-cadmium storage batteries. Because it is capable of delivering high watt hour capacities at discharge rates less than 30 min, the silver-zinc battery is used extensively for missile and torpedo applications. Its high energy density makes it attractive in electronics applications, satellites and portable equipment where low weight and high performance are prime considerations. It is highly efficient and mechanically rugged, operates over a wide temperature range and offers good shelf life, quick readiness for use and the ability to operate at -40°C without heating are few of the features of this battery. It is available in both high-rate and low-rate cells. Until now, the fact that it is more expensive, sensitive to overcharge and has a shorter cycle life than ordinary storage batteries has limited the silver-zinc battery to applications where space and weight are prime considerations.

The cell having the active material of the positive plates is silver oxide which is pressed in to the plate and then subjected to a heat treatment. The active materiel of the negative plates is a mixture of zinc powder and zinc oxide. A typical Silver Zinc battery shown in Figure 1-14 is indigenously developed by M/s.HAL, Hyderabad. The same type of batteries also manufactured by M/s.HBL, Hyderabad and M/s.HEB, Tirucurapally also are developing Silver Zinc battery for application of MIG-21 Aircraft.

Figure 1-14 Silver Zinc 45AH A/c battery

1.7 Reserve Batteries

In these primary types a key component is separated from the rest of the battery prior to activation. In this condition, chemical deterioration or self-discharge is essentially eliminated and the battery is capable of long-term storage. Usually, the electrolyte is the component that is isolated in other systems, such as the thermal battery, the battery is inactive until it is heated, melting a solid electrolyte, which then becomes conductive. The reserve battery design is used to meet extremely long or environmentally severe storage requirements that cannot be met with an "active" battery designed for the same performance characteristics. These batteries are used primarily to deliver high power for relatively short periods of time needed as in missiles, torpedoes and other weapon systems.

Where extra long shelf life (i.e. ability to yield its electric energy after long storage) is desired the electrolyte is withheld from the battery and steps are taken to exclude moisture since water in some form is usually required for the local action reactions. Such batteries are extremely stable in storage and are activated by the addition of the appropriate electrolyte. Since the power of such batteries is thereby kept in reserve, they are frequently referred to as "reserve batteries." A special type of reserve battery is sometimes also referred to as a "dry charged" battery. In this case the electrodes of the battery are brought to a state of full charge at the time they are made and then deactivated by the removal of electrolyte. The restoration of electrolyte at the time and place the battery needed results in a virtually factory-fresh battery. A great many automobile batteries are now shipped in the dry charged condition with the station attendant adding the (sulfuric acid) electrolyte at the time of installation.

1.8 Thermal Batteries

There is a special class of reserve batteries that use non aqueous or molten salt electrolytes. Such electrolytes contain no water and utilize organic liquids or salts that become conductive in the molten condition. This later kind of electrolyte must be liquefied before it becomes functional and the battery can therefore be activated by heat. This is usually accomplished by a heat squib, which melts the electrolyte to activate the battery. Such batteries are known as thermal-type reserve batteries, heat-activated reserve batteries, or simply thermal batteries. A typical thermal battery consists of chromate cathode and a mixture of potassium, sodium and lithium chlorides as electrolyte. Such batteries have an indefinite storage capability, but discharge times of only a few minutes at best. However, they have found special application such as power for proximity fuses.

1.8.1 High Temperature Thermally Activated Primary Batteries

It is a new group of source which requires operating temperatures above the ambient. They possess the advantages of high specific energy and power coupled with low cost. These batteries find uses in fast activation applications such as firing squibs and explosive bolts. Other applications include electric matches, dimple motors and emergency starting power for military vehicles and aircraft. We will briefly describe the following cell from which high-temperature batteries are made.

Lithium/Chlorine Cell - It has an emf of 3.5V, a theoretical specific energy of 2200 Wh/Kg at 614°C and operating temperature of 650°C.

Lithium/Sulphur Cells - It has an emf of 2.25V, specific energy of 2625 Wh/Kg and an operating temperature of 365°C.

Lithium Aluminum/Iron- Sulphide Cell - The emf of these cells is 1.3V and a theoretical specific energy of 450 Wh/Kg.

Sodium / Sulphur Cells - It utilizes liquid sodium as negative electrode and sulphur as positive electrode and employs polycrystalline beta alumina

1.9 Battery Applications

1.9.1 Batteries for Aerospace Applications

For control, telemetry and operation of equipment on remote solar bodies, and communication satellites for emergency backup etc. generally Ni-Cd batteries are utilised.

1.9.2 Batteries for Missile Applications

For guidance, Telemetry, Power in some rockets, torpedoes and ballistic missiles etc generally Thermal batteries are used.

1.9.3 Batteries for Aircraft Applications

Generally an airborne battery has the following principal functions –

- To help maintain the DC system voltage under transient conditions, the starting of large DC motor- driven accessories, such as inverters and pumps, requires high input current which would lower the bus bar voltage momentarily unless the battery was available to assume a share of the load. A similar condition exists should a short circuit develop in a circuit protected by a heavy duty circuit breaker or current limiter. This function possibly applies to a lesser degree on aircraft where the electrical system is predominantly AC, but the basic principle still holds true.
- To supply power for short term heavy loads when generator or ground power is not available, e.g. internal starting of an engine.
- Under emergency conditions, a battery could be the sole remaining source of power to operate essential flight instruments, radio communication equipment, etc. for as long as the capacity of the battery allows.
- To supply power to meet the emergency electrical load requirements in case of DC generator failure, Flight control backup, starting of engines when external power supply is not available, relight in the air in case of engine flame out etc.
- Emergency situation occurs due to failure of the generator supply or main bus bar. The batteries then supply the essential services for time period pre-

calculated on the basis of the battery capacity and current consumption of the essential services to ensure the safety of flight and personnel.

Currently, many types and sizes of batteries and cells are in use. An increase in the various forms of electronic devices has created a demand for a variety of batteries. The aircraft technician may find several types of cells used to power monitoring or test equipment. However, there are currently three types of storage batteries used on nearly all aircrafts, those are nickel-cadmium, silver zinc and lead-acid batteries. These batteries generally are rechargeable type with high peak power ratings with capacity ranging from 15AH to 40AH in various physical sizes. Also small capacity batteries are used in emergency communication /equipments for airborne applications

Battery cells are assembled in series to generate a 28V DC system on board aircraft (MIL-STD-704). It may be 20 cells for nickel cadmium (Ni-Cd), battery, 15 cells for Silver-Zinc (Ag-zn) battery and 12 cells for Lead Acid (Lead acid) battery.

1.9.4 Battery Conditions Aboard Aircraft

Batteries are charged by the constant potential method aboard aircraft. They are connected at all times during aircraft operation to the d-c bus through a voltage regulator, thus are either being charged or discharged. Charging is limited only by the upper voltage, whose setting at the regulator, although adjustable, is kept usually at a selected single value such as 28.5V (28.5±0.5)V. This practice does not compensate for the effect of temperature (ambient) ranging from less than 0°C to above 32.2°C on battery charging characteristics. Since individual cells are not monitored, they are vulnerable to excessive overcharging during extended float charging situations and reverse discharging during high rate discharges. Batteries used in engine starting systems are subjected to high rate charging following discharge in order to be fully charged for emergency situations.

a) Battery design should cater for providing voltage of 28V DC to equipment for their normal operation and for at least 20-30 minutes to emergency / standby equipments, high power for auxiliary power unit / engine starts (up to 2000 Amp.) at operating temperatures(–30°C to 65°C) at various altitudes (7 to 25 Kms).

b) Holds worth and Eggelton described a theoretical takeoff' procedure, for a modern. Medium size aircraft using one 35 Ah. 24 V nickel-cadmium battery or two 25 Ah. 24 V lead-acid batteries as follows:

   i. "The aircraft ground services are operated for 2 min whilst the pilot carries out his pre-flight checks and cockpit drill. The engines assuming a twin engine aircraft are then started separately. The battery is required to supply initially a load of 60-70 A and a further 200 A for 10 sec when starting the engines if using an iso-propylnitrate system. The aircraft would then taxi to the end of the runway, its engines would be shut down whilst waiting for a signal to take off, but during this period its navigation and cockpit lights may be required consuming some 5 A-hr. Prior to take-off, the aircraft must be capable of again starting on internal battery and in this case, a simultaneous double engine start would be carried out taking 400 A for 10 sec in addition to the standard aircraft load. If the engines failed to reach self-sustaining speed, the battery would be required after a very brief pause to start the engines separately, consuming 200 A per single start as before. During this procedure the ambient temperature may be as low as 0°C and the battery if not preheated would be at this temperature.

ii. Following take-off the aircraft would normally cruise at an economical speed for possibly 2 hr during which time the battery would be on charge from a constant potential 28/28.5 V but the battery bay might be as cold as -40°C. At the end of the cruise period a generator failure could occur in which event, the battery must be capable of supplying a current of something rather less than the standard aircraft load say 50 A (at battery voltage) for some predetermined time of the order of 25 min. In the most general case, however, the battery must be capable of allowing the aircraft to reach a suitable base from the point of no return. During the early part of the flight, the requirement is that the battery must be capable of supplying the aircraft load for a time equal to "Flight Time Out" plus 10 min. Since the battery is at its lowest state of charge at take-off it follows that a generation failure at any time up to 15 min after take-off may be as critical as a failure after 25 min as far as the battery is concerned. Also to be considered is the fact that as the flight endurance increases in the economical cruise case the battery temperature continues to fall whilst charging continues. These two effects respectively reduce and increase the available energy and tests may have to be carried out which lead to a plot of available battery endurance against flight-time in order to determine the worst case. This cycle shows that the duties which are required of the battery are extremely onerous and, therefore, extensive testing must be carried out to ensure that the conditions are met.

iii. On any particular aircraft, the minimum voltage at which the electrical equipment will operate within its specification is known to the electrical designer responsible and therefore, all battery endurances must be considered down to this predetermined value. The requirement therefore is a plot of load voltage against time down to a stated voltage level at various temperatures whilst the battery is supplying the aircraft load together with an adequate knowledge of the charging characteristics of the battery on constant potential charge."

1.10 Condition Monitoring of Batteries

AC conductance testing was introduced in 1992 as a new way of measuring the cold cranking amps (CCA) of a battery. This non-invasive method was hailed as a major breakthrough and to a large degree eliminates load testing to measure battery performance. The test only takes a few seconds, the readings are displayed in digital numbers and a message spells out the condition of the battery. There are no sparks at the battery terminals and the instrument remains cool.

But single frequency AC conductance has limitations. It does not measure CCA according to SAE standards but offers an approximation relating to the battery's power output capability. This relative power figure often varies with state-of-charge and other battery conditions. At times, a good battery fails and a faulty one passes by error. But the most significant drawback is its inability to read the reserve capacity (RC). Despite these shortcomings, AC conductance has become an accepted standard for predicting battery life and determining when to replace an old battery before it becomes a nuisance.

1.10.1 Difference between CCA and RC

A good battery needs high CCA and high capacity readings but these attributes reflect differently depending on the application. A high CCA reading assures good battery conductivity and provides strong cranking ability. High CCA goes hand-in-hand with a low internal battery resistance. Figure 1-15 compares high CCA with a large open tap that allows unrestricted flow.

Figure 1-15 Battery with high CCA and 100% reserve capacity

A high CCA battery can be compared to a large open tap that allows unrestricted flow.

Reserve capacity governs the amount of energy the battery can store. A new battery is rated at a nominal capacity of 100%. As the battery ages, the reserve capacity drops and the battery eventually needs replacing when the reserve capacity falls below 70%. The RC reading always refers to a fully charged battery; the state-of-charge (SOC) should not affect the readings when measured with a rapid-tester.

A battery may provide a good CCA reading and start a car well but be low on reserve capacity. This battery would be run down in no time when drawing auxiliary power. Figure 1-16 illustrates such a battery. The so-called 'rock content' that builds up as the battery ages is permanent and cannot be reversed.

Figure 1-16 Battery with high CCA but low reserve capacity

The cranking on this battery is good but running on auxiliary power will drain the battery quickly

Figure 1-17 illustrates a battery with good reserve capacity but low CCA. This battery has a difficult task turning the starter and needs replacing even though it could be used for low load applications.

Figure 1-17 Battery with low CCA but high reserve capacity

The low CCA of this battery provides poor cranking although the reserve capacity is high

1.10.2 Capacity measurements, the most comprehensive battery test

With increased demand for auxiliary power on vehicles measuring energy reserve is more relevant than CCA. The slogan goes “Starting is easy... but can I steer and brake?” Modern battery testers must adapt to this new requirement and also include RC measurement. European car manufacturers place heavy emphasis on reserve capacity, while in North America CCA is still the accepted standard to assess battery performance. Most modern battery testers also provide state-of-charge readings (SOC).

Measuring reserve capacity is more complex than CCA. Many methods have been tried including multi-frequency conductance, but most have limitations. One of the main obstacles is processing large volumes of data received when scanning a battery with multiple frequencies. Collecting data is easy making practical use of the information is the problem. A method has been developed that evolves the processing of a large volume of data received through multi model Electrochemical Impedance Spectroscopy (EIS). Cadex electronics has developed a battery rapid tester (CA-12) for automotive batteries. One of the strongest features of this is its ability to reveal CCA, reserve capacity and SOC on a single measurement.

1.11 Comparative Characteristics of aircraft batteries

1.11.1 General Characteristics

A comparison table for relative performance of Ni-Cd, Silver Zinc(Ag-Zn) and Lead Acid (Pb acid) batteries are given in Table 1-4. Comparison of various batteries for energy per unit, weight and per unit volume and typical discharges also given in Figure 1-19 and Figure 1-20 respectively.

1.11.2 Selection criteria for batteries

A number of factors must be considered in selecting the best battery for a particular application. There is still no one battery that combine optimum performance under all operating conditions with light weight, safety, reliability, low cost and the other required features. The characteristics of each available battery must be weighed against the system requirements and one selected that best fulfils these requirements.

A few considerations that are important and influence the aerospace battery includes the following:

1. Application, including details of size, weight, configuration, life and cost limitations.
2. Information on type of duty involved, whether pure battery operation or parallel operation or any floating effect
3. Discharge current (preferably including indication of limits of load varies).
4. Discharge period required per charge (if intermittent duty is involved information should also be given where possible concerned actual current flow time and intervals, a diagram being provided if necessary)
5. Minimum discharge voltage at the discharge current concerned, including details of voltage regulation required (voltage window).
6. Temperature limits of use or storage or temperature de rating are allowed for performance
7. Charging method visualized and state of charge or recharge time justified.
8. Degree of maintenance available or desired or any ageing value requirement
9. Number of cells in a battery is determined by the maximum voltage available in the voltage window

Table 1-4 Alkali storage battery performance characteristics

Property	Nickel Cadmium	Silver-Zinc	Lead Acid
Positive Electrode	Nickel Hydro Oxide $(NiOOH)_4$	Silver Oxide (Ago)	Lead peroxide (Pbo_2)
Negative Electrode	Cadmium Hydroxide (CdOH)	Zinc(Zn)	Sponge Lead (Pb)
Electrolyte	KOH, 31%	KOH, 40%	H_2SO_4
Cell Voltage (V)			
Opens Circuit	1.29	1.86 + 0.04	2.1
Nominal Operating	1.25 – 1.10	1.7 – 1.3	1.8 – 2.0
End	1.0	1.0	1.7
Number of Cells in battery pack	20	15	12
Operating Temperature (°C)	-42 to +60	+5 to +73, -21 with heaters	-54 to +55
Discharge profile (Relative)	Very flat	Double plateau	Flat
Power Density	High	High (for high rate designs)	High
Energy Density (Wh/Kg)	37	90	35
Charging Profile	Constant current and constant voltage	Constant current and constant voltage	Constant current and constant voltage
Cycle Life	500 to 2000	100 to 150	200 to 700
Calendar Life (YEARS)	3 to 10 years	Up to 5 years in dry 6-12 months in wet	3 to 6 years
Self discharge (%)	3 to 10	1 to 3	3 to 5
Advantages	Rugged, excellent storage, good specific energy and high rate and low temperature performance	Highest energy density, high discharge rate, low shelf discharge.	Low cost, good high rate, high and low temperature operation (good Cranking service New MF design), No memory effect or thermal runway.
Limitations	High cost, memory effect, Thermal runaway.	High cost, low cycle life, decreased performance at low temperature.	Relatively low cycle life, Low energy density, poor charge retention and cannot be stored in discharged condition.

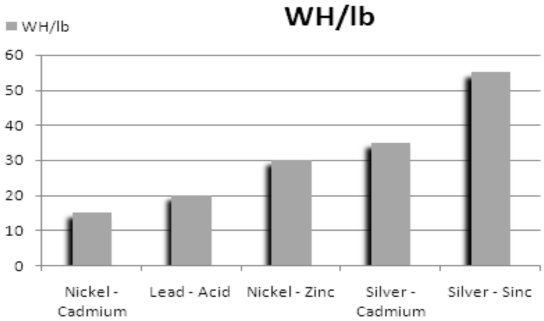


Figure 1-18 Comparison of energy for unit weight output for rechargeable battery systems

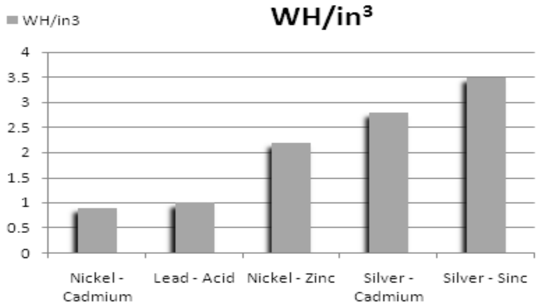


Figure 1-19 Comparison of energy for unit volume output for rechargeable battery systems

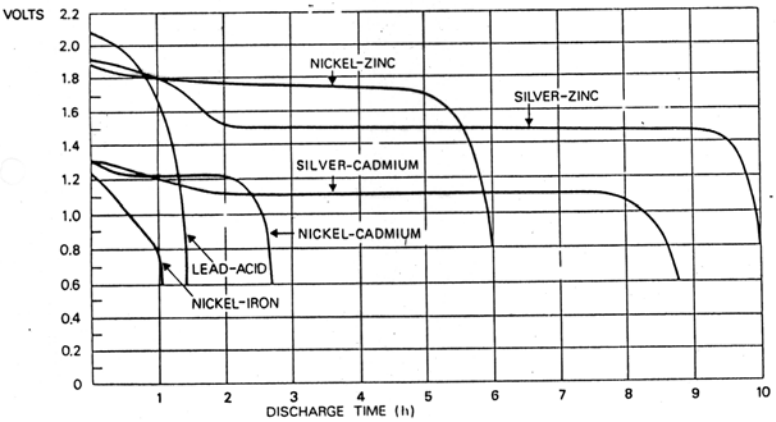


Figure 1-20 Typical discharge characteristics of various secondary battery systems.

1.12 **Aircraft Battery Connectors**

1.12.1 Quick-Disconnect Plugs

Quick-disconnect battery connectors are found on some lead-acid batteries and practically all nickel-cadmium batteries. The quick-disconnect consists of an adaptor secured to the battery case in place of the terminal cover and a plug to which the battery leads are attached. Two smooth contact prongs are screwed onto the battery terminals and the plug is pulled into place on the battery by means of a large screw attached to a hand wheel. This screw also pushes the plug off the terminals to disconnect the battery.

A popular battery connector is shown in Figure 1-21. The connector consists of two main assemblies, the terminal assembly, which is attached to the battery to serve as a receptacle and the connector plug assembly, to which the battery cables are connected. The plug assembly is inserted into the receptacle on the battery and is seated firmly by means of the center screw in the lug.

The design of the contacts provides for many contact surfaces with the mating male pin, thus assuring a low-resistance contact. The contacts are made of silver-plated soft copper wire and are designed to fit snugly onto the pins of the battery terminal. The pins and sockets of the connectors should be inspected at regular intervals. If loose connections, burned spots, corrosion or pitting are noticed, the contacts should be replaced.

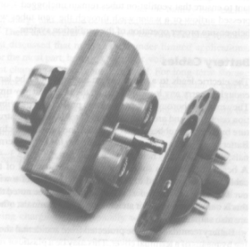


Figure 1-21 Elcon Battery connector

Figure 1-22 shows Rebling 7002, Style 2 Aero-Battery receptacles are two pin receptacles conforming to MS3509 style 2.

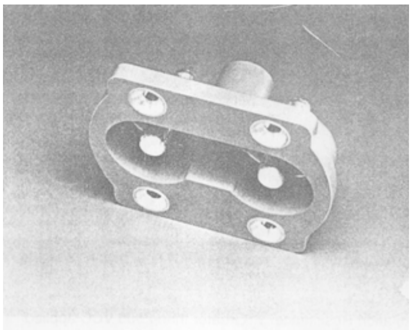


Figure 1-22 Aircraft battery receptacle Rebling 7002, Style 2

Figure 1-23 shows Rebling 7002, Style 1 Aero-Battery receptacles are two pin receptacles conforming to MS3509 style1.

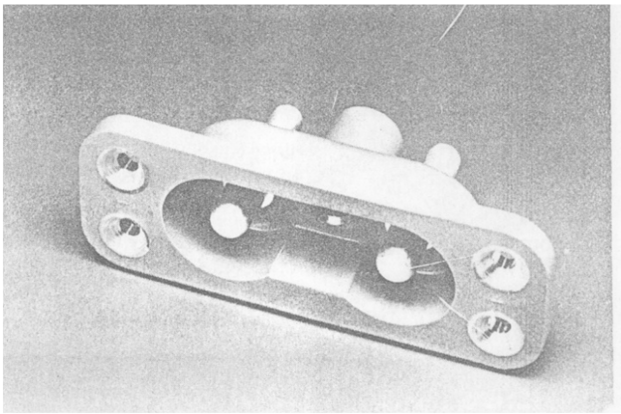


Figure 1-23 Aircraft battery receptacle Rebling 7002, Style 1

Figure 1-24 Shows Rebling series 7002 Aero-Battery receptacle supplied assembled with various styles of terminal adapters.

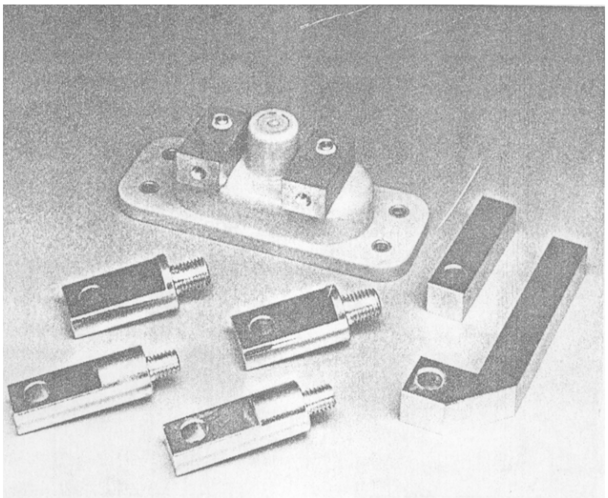


Figure 1-24 Aircraft battery receptacle terminal adapters for Rebling series 7002

1.13 Special Tools, Equipment and Fixtures

1.13.1 Special Tools

Battery Maintenance Kit

The battery maintenance kit contains items, other than electrical testing equipment, that may be required during normal maintenance of aviation battery. A typical battery maintenance kit may contain the following:-

- Cell Puller
- Syringe Assembly
- Proper Socket or Wrench (14mm or 17mm) typical
- Vent-Valve Wrench

- Spring Washers (or Belleville) (terminal)
- O-rings (terminal)
- Vent Valve Assemblies
- Nuts (terminal)
- Screws, Main power connector

1.14 Physical Dimensions & Weight

- The battery shall meet the overall dimensional requirements in defined battery assembly drawing.
- The mass of the battery when correctly filled in accordance with the manufacturer's instructions shall be as per battery assembly drawing or specification.

1.15 Temperature Range

- The battery operational temperature range shall be -26° to +50°C (for Ni-Cd batteries) as demonstrated by the tests contained within the QTP.
- The battery operational temperature range shall be +10° to +50°C (for Silver Zinc batteries) as demonstrated by the tests contained in the QTP.
- The battery shall be stored in generally an ambient temperature of 20 ± 10°C and a relative humidity between 45% and 75%.

1.16 Identification

Type of battery (Ni-Cd, Ag-Zn, Pb/specific Acid etc.,)

- Manufacturers part number or Type number
- Manufacturers name or identification
- Defense Service catalogue number, if any
- Date of manufacture
- Modification issues
- Positive terminal polarity
- Nominal battery voltage and capacity rating

2 Aircraft Power Supply Sources and its Distribution

2.1 Introduction on Aircraft Electric Power Systems Requirements

Two basic types of power available on board aircraft are AC & DC. The aircraft electric power system consists of a main power source, emergency power source, power conversion equipment, control and protection devices and an interconnection network (wires, cables, connectors, circuit breakers, etc.). The main power is derived from aircraft alternators / generators driven by the aircraft engines. Emergency power is derived from batteries, independent auxiliary power units, ram air or hydraulically driven generators.

2.2 Electrical Power Supply for Military aircraft

As mentioned above, every aircraft has an AC & DC power system as per MIL-STD-704. This standard defines the requirements and describes the characteristics of aircraft electric power provided at the input terminals of the electric utilization equipment. It also establishes the area of responsibility for aircraft electric system performance. The requirements of DC power system are shown in Table 2-1**.**

Table 2-1 Aircraft Electrical DC Power System - Standards.

Operational status	**BS3G 100**	**MIL STD – 704E**	**GOST 19705 -8.1**
Normal Voltage operation	24-29V	22-29V	24-29.4V
Abnormal Voltage operation	21-32V	20-31.5V	21-33V
Emergency Voltage operation	18-29V	18-29V	18-31V
Starting	--	12 – 29V	--

The electrical power is nominally 28Vdc. The supply voltage is allowed to have steady state values in the range from 22.0 to 29.0 V. Ripple must be less than 1.5 V. There are two important points to be made during under voltage conditions supply may be completely interrupted for up to 7sec and under transient conditions supply may be interrupted for up to 50 ms followed by return to the normal curve.

MIL-STD- 704 also prescribes how the user equipment must perform for all power conditions. "When supplied electric power having characteristics specified herein, aircraft utilization equipment shall provide the level of performance required by its detailed specification for each operating condition." For abnormal and transient conditions, the user equipment may be permitted a degradation or loss of function (unless otherwise stated in its own specification), but it must not produce a dangerous or unsafe condition and must automatically recover to full specified performance when power is restored to normal operating limits. When the user equipment specification requires operation in emergency or starting conditions, the equipment shall be capable of full operation when the voltage is within the limits shown in Figure 2-1. For voltage transients lasting less than 50 μs, equipment performance is governed by MIL-E-6051.

If the equipment is supplied with more than one type of power, the loss of any one type shall not result in an unsafe condition or damage the equipment.

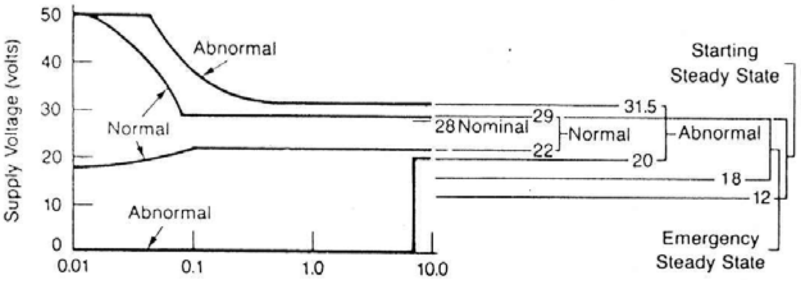


Figure 2-1 MIL-STD-704E 28Vdc power voltages for various conditions

The electrical loads on aircraft must be classified as critical, essential or utility and buses with appropriate levels of power quality and redundancy must be established for each type of load. Critical loads are typified by the flight control system and the cockpit displays. Essential loads for all types of aircraft include anti- and de-icing and the Environmental Control System (ECS). For military aircraft the mission avionics such as electronic warfare or antisubmarine warfare should be treated as essential loads. Typical utility loads on commercial transports are the galley and passenger entertainment system etc.

Critical electrical loads, by definition are the most important loads on the aircraft and require the most attention. Fortunately, critical loads are usually a small fraction of the total load. Quadruple redundant supplies from dissimilar sources are strongly recommended for critical loads. As a general rule, these loads are supplied by two redundant main buses, a backup bus, an emergency bus and/or batteries. The main buses are fed from different generators on different engines if it is a multiengine aircraft, the backup can be from an auxiliary power unit or a hydraulically driven generator. For emergency power, ram air turbines do a good job and wing-tip-mounted vortex-driven turbines are also another source.

Batteries are always a possible last-ditch power source. However, there are significant maintenance ramifications in their use. They offer the capability of providing instant power to support the load while other emergency sources are brought on line. The selection of equipment to be powered by batteries must be strictly limited since the larger the emergency load, the larger the batteries need to support it. Batteries must be constantly recharged and have a provision for conveniently checking their charge state.

Essential loads usually receive at least triple redundant power being supplied by two main buses and at least one backup bus. Since essential loads can generally be selectively operated, instantaneous power on the essential bus can be considerably reduced.

Finally, utility buses are usually dual redundant and supplied by two main generators. Loads on the utility bus can be operated in a completely selective way so that if less than normal power is available most power demanding activities can proceed albeit at a slower pace.

There are many electrical system design tips that have been formulated over the years, which are summarized below:

- The routing of power buses, like data buses should be dispersed throughout the aircraft to minimize possible damage from a single hazardous event.
- Switching from one AC source to another without severe transients can be achieved through microprocessor-controlled synchronization prior to putting the second machine online.
- The N1 stage of a jet engine can be used for emergency electrical power generation by installing small magnets in the tips of the turbine blades and installing small coils in the engine housing. This approach has the advantage that power can be generated even when the engine is only wind milling and there is no delay in connecting the source. Small turbine generators for emergency power can be powered by gases produced from burning hydrazine, a monopropellant.
- Batteries are an obvious choice to provide emergency power. However, they should be centrally located so that they can be easily checked and maintained. There should be provisions for trickle charge at all times both in flight and on the ground.
- Small hydroelectric generators that convert hydraulic power to electrical power can be remotely located at sensors and microprocessors.

2.3 **Aircraft Power Generation**

The generator is the source of electrical energy for the power system. The generator must be provided with a source of mechanical energy from the engine or an APU.

2.3.1 DC Generators

Ever since the first aircraft to use any kind of electric equipment was launched, the electrical loads on airplanes and other flying devices have increased. Today modem aircrafts are equipped with scores of different electrical systems, each requiring a substantial amount of electric energy.

Generators were the first means of supplying electric power for aircraft. Currently, generators or generator derivatives called alternators are found in a wide variety of sizes and output capacities. On multiengine aircraft, one generator is driven by each engine to allow for redundancy in the event of a generator failure.

2.3.2 Alternators

There are two major types of alternators currently used on aircraft, the DC alternator and the AC alternator. DC alternators are most often found on light aircraft where the electric load is relatively small. AC alternators are found on large commercial airliners and many military aircraft. Since these aircraft require large amounts of electric power, the uses of AC systems create a valuable weight savings. Through the use of transformers, the transmission of AC electric power can be accomplished more efficiently and therefore with lighter equipment. With the transmission of electric power at relatively high voltages and low current, the power loss is kept to a minimum.

2.3.3 DC Alternator System for Light Aircraft

A typical electric power circuit is shown in Figure 2-2. Since the rectifier is mounted in the end frame of the alternator, the alternator output terminals are marked for direct current.

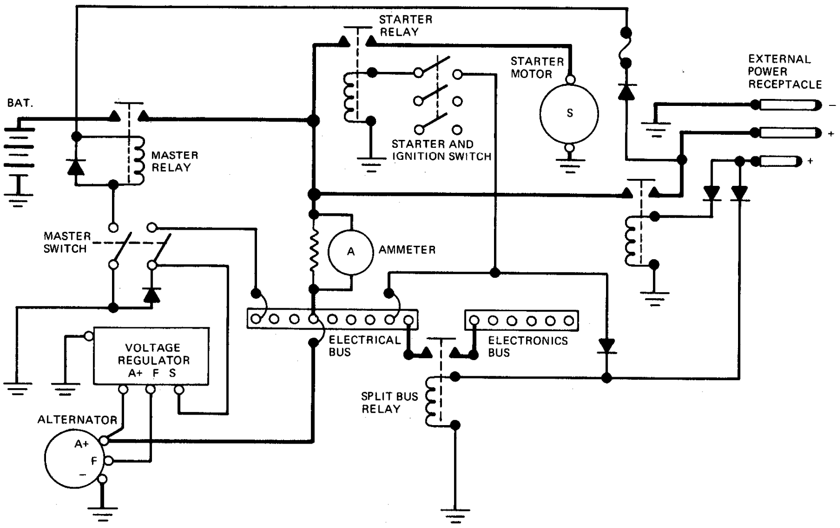


Figure 2-2 A typical power distribution schematic for a light aircraft containing a DC alternator

2.4 External DC Power Supply Sources

Electrical power is required for the starting of engines, operation of certain services during "turn-round" servicing periods at airports, e.g. lighting and for the testing of electrical systems during routine maintenance checks. The batteries of an aircraft are of course a means of supplying the necessary power, and although capable of effecting engine starts their capacity does not permit wide scale use on the ground, they are restricted to the supply of power under emergency conditions. It is necessary therefore to incorporate a separate circuit through which power from an external ground power unit may be connected to the aircraft's distribution bus bar system. In its simplest form an external power supply system consists of a connector located in the aircraft at a conveniently accessible point and a switch for completing the circuit between the ground power unit and the bus bar system.

In addition to the external power supply system, some types of aircraft carry separate batteries which can supply the ground services in the event that a ground power unit is not available in order to conserve the main batteries for engine starting.

In the majority of large public transport aircraft, complete independence of ground power units is obtained by special auxiliary power units installed within the aircraft.

2.4.1 DC Systems

A basic system for the supply of DC is shown in Figure 2-3 and from this it will also be noted how in addition to the external power supply the battery may be connected to the main bus bar by selecting the "flight" position of the switch.

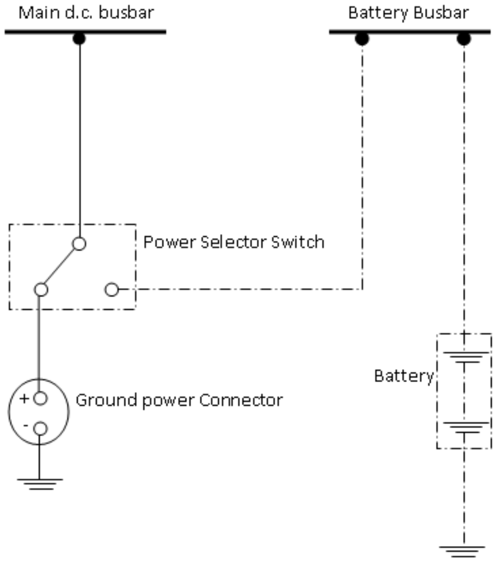


Figure 2-3 Basic External Power System

As the name suggests, this is the position to which the switch is selected when the aircraft is in flight since under this condition the generator system supplies the main bus bar and the battery is constantly supplied with charging current.

2.5 Power Distribution Systems

Modem aircraft require a consistent and reliable supply of electric power. There are four common sources of electric power used during normal aircraft operations. These sources are DC alternators / generators AC alternators and the aircraft's storage battery. The aircraft's battery is typically used for emergency operations and any intermittent system overloads. DC alternators are typically used on piston engine aircraft. DC starter generators are used on medium-sized turbine-powered aircraft. AC alternators are used on transport-category aircraft and some military aircraft. Some form of electrical distribution system must be employed on every aircraft containing an electrical system. A simple power distribution system consists of a basic copper conductor called a bus bar or bus. This type of system is found on most single-engine aircraft. The bus is a conductor designed to carry the entire electrical load and distribute that load to the individual power users. Each electric power user is connected to the bus through a fuse or circuit breaker.

On almost all aircraft the bus bar is connected to the positive output terminal of the generator and/or battery. The negative voltage is distributed through the metal structure of the aircraft. The metal airframe (negative side of the voltage) is often referred to as the ground. Hence this type of distribution is often called a negative-ground system. In all negative-ground aircraft, the positive voltage is distributed to any given piece of electrical equipment through an insulated wire and the negative voltage is connected through the airframe. Since only one wire (and title ground) is needed to operate electrical equipment, this is known as a single-wire system. Single-wire systems are possible only where the airframe is constructed from a conductive material, such as aluminum. On composite aircraft some type of ground (negative) conductor is required. In some cases two wires (one positive, one negative) are used, in other cases a ground plane is added to the structure of the aircraft.

Larger, more complex aircraft typically contain several bus bars. Each bus has the specific task of distributing electric power to a given group of electrical loads. Bus bars are often categorized as AC and DC, left and right and essential and nonessential distribution buses. On multiengine aircraft each engine-driven alternator typically employs its own distribution bus. These generator buses are then connected to their respective loads via distribution buses and associated bus ties.

2.5.1 Electrical Load Analysis- Basic Principles

Prior to installing any electric equipment in an aircraft, the technician must perform an electrical load analysis. This is done to ensure that the aircraft's electric power system will not be overloaded by the addition of the new equipment. The goal is to compare the sum of all continuous electrical loads with the generator's (alternator's) maximum output. If the total continuous load is less than the rated generator output, more equipment may be added. However, the maximum generator output may never be exceeded by a continuous load.

The principle of an electrical load analysis demands the listing of each item or circuit of electrically powered equipment and the associated power requirement. The power requirement for a piece of equipment or circuit may have several values depending on the utilization for each phase of aircraft operation.

In order to arrive at overall evaluations of electrical powered requirements, it is necessary to give adequate consideration to transit demand requirements which are order of magnitude or duration to impair system voltage and/or frequency stability, or to exceed short time ratings of power sources (i.e. intermittent/ momentary and cyclic loads). This is essential, since the ultimate use of an aircraft’s ELA is for the proper selection of characteristics and capacity of power-source components and resulting assurance of satisfactory performance of equipment, under normal, abnormal and emergency operating power conditions (see Table 2-1 for operational status).

2.5.1.1 Content of Electrical Load Analysis :

The load and power source capacity analysis report should include the following :-

a) Assumptions & Criteria
b) AC & DC load analysis (tabulator of values)
c) Emergency and standby power operation
d) Summery and conclusion.

2.5.1.2 System Regulation :

The system voltage regulation as per Para 2.2 should be ensured for reliable and continued safe operating under the normal and emergency conditions taking into account the voltage drops which occur in the cables and connectors to the equipment.

2.5.1.3 Battery Condition Calculations

Battery Duration

Battery endurance can be estimated from either a practical test, which involves applying typical aircraft loads for a period of time or by calculation. It is important that considerations be given to the initial conditions of the aircraft (e.g. condition and state of charge of battery).

The required duration of a time limited power source (e.g. battery), which is used as an alternative to the normal power sources will depend on the type and role of the aircraft. Unless it can be shown that a lesser time is adequate, such a power source should have an endurance of at least 60 minutes. The endurances of the time limited power source with any associated procedures should be specified in the Flight Manual.

Calculation

An accurate theoretical assessment of the battery performance requires a load analysis to be compiled and the discharge figures checked against the battery manufacturer's discharge curves and data sheets.

The capacity of a battery is Rate of discharge (amps) x Time to discharge.

Normally expressed in ampere-hours, but for a typical load analysis, calculations are usually expressed in amp-min (i.e. amp-hours x 60). However, this is not a linear function as with heavier discharge currents the discharge time decreases more rapidly so that the power available is less (i.e. reduced efficiency).

Therefore, in order to make an accurate assessment of battery duration reference should be made to the manufacturer's discharge curves. However, in case they are not available, then certain assumptions and approximations are provided in the following paragraphs to assess.

Because of the problem of definition of capacity it is first necessary to ensure that all calculations are based on the one-hour rate. Some manufacturers however do not give this on the name plate and quote the five-hour rate. For these calculations as a general rule it may be assumed that the one-hour rate is 85% of the quoted five-hour rate.

Following the generator system failure and before the pilot has completed the load shedding drills the battery may be subjected to high discharge currents with a resultant loss of efficiency and capacity on the principle explained in the previous paragraph.

To make allowance for such losses, the calculated power consumed during the pre-load shed period should be factored by an additional 20% if the average discharge current in amps is numerically more than twice the one-hour rating of the battery.

It should be noted that the discharge rate of a lead-acid battery is different than that of a nickel cadmium battery. The graph has shown in Figure 2-4 a typical discharge curve for lead acid and nickel cadmium battery at a 5 Amp discharge rate.

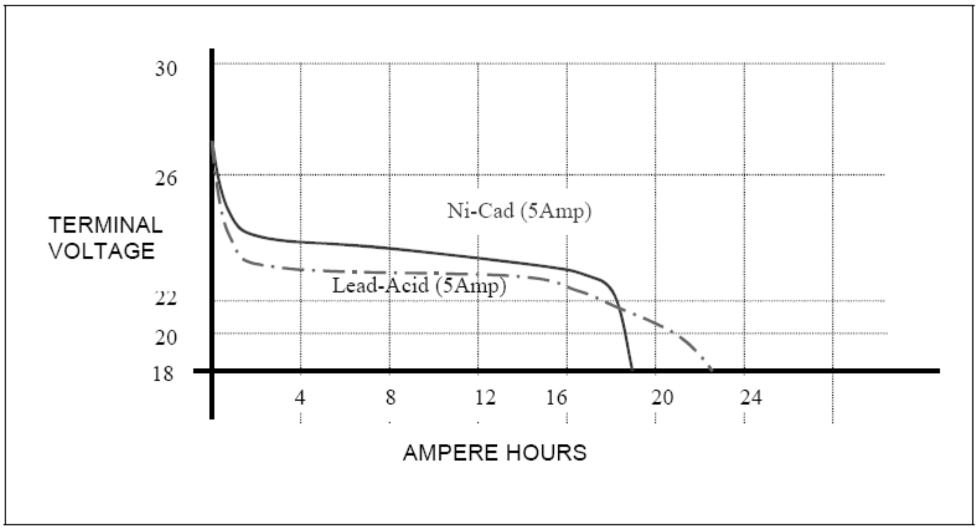


Figure 2-4 Typical discharge rates of Lead acid and Nickel cadmium batteries

“Unless otherwise agreed, for the purpose of this calculation, a battery capacity at normal ambient conditions of 80% of the name plate rated capacity, at the one-hour rate and a 90% state of charge may be assumed (i.e. 72% of nominal demonstrated rated capacity at +20°C). The allowance for battery endurance presumes that adequate requirements for periodic battery maintenance have been agreed.”

2.5.2 Battery-Charging Current Analysis

The charging current for any aircraft battery is based on the total elapsed time from the beginning of the charge and is calculated using the following formula:

$$I = A \times C$$

Where,

I is the average charging current in Amperes.

A is the Ampere-hour capacity of the battery, based on the one-hour discharge rate.

C is the battery-charging factor taken from the battery-charging curve supplied with battery data (graphical data).

An example of how to calculate the battery duration is given below:

i. Check the name plate capacity of the battery and assume 72% is available e.g. 12 amp-hour = 720 amp-min.

   Therefore, 72% is equal to 518.4 amp-min.

ii. Estimate the normal or pre-load shed cruise consumption (assume worst-case cruise at night). For example, 15 amps (15 amps x 5 min = 75 amp-min).

   This assumes 5 minutes for pilot to shed non-essential loads following a low voltage warning. Any automatic load shedding can be assumed to be immediate and need not be considered in the pre-load shed calculations.

iii. Estimate the minimum cruise load necessary to maintain flight after the generator / alternator has failed e.g. 10 amps.

iv. Estimate the consumption required during the landing approach e.g. 20 amps for 5 minutes (100 amp-min).

The cruise duration is therefore:

$$\frac{\text{BatteryCapacity}(\text{i}) - [\text{Pre} - \text{LoadShed}(\text{ii}) + \text{LandingLoad}(\text{iv})]}{\text{CruiseLoad}(\text{iii})} = \frac{(\text{i}) - [(\text{ii}) + (\text{iv})]}{(\text{iii})}$$

$$= \frac{518.4 - \{75 + 100\}}{10} = \frac{343.4}{10} = 34\text{mins}$$

Total Duration = Pre-Load Shed Cruise Time + Cruise Duration + Landing Time

Total Duration = 5 + 34 + 5 = 44 minutes.

Summary &Conclusions

The Electrical Load Analysis summary should provide evidence that for each operating condition, the available power can meet the loading requirements with adequate margin for both peak loads and maximum continuous loads. This should take into account both the normal and abnormal (including emergency) operating conditions.

The conclusions should include statements that confirm that the various power sources can satisfactorily supply electrical power to necessary equipment during normal and abnormal operation under the most severe operating conditions as identified in the analysis. It should be confirmed that the limits of the power supplies are not exceeded.

Practical testing may be used as an expedient method of verifying certain loads and would be used as supporting data in the compilation of the Electrical Load Analysis.

2.6 A Simple aircraft Electrical System

A simple electrical system for a light aircraft consists of a battery circuit, an alternator circuit with associated controls, an engine starter circuit, a bus bar with circuit breakers, control switches, an ammeter, lighting circuits and radio circuits. A schematic diagram of the basic power distribution system is shown in

Figure 2-5. The distribution bus receives power from the alternator and/or battery during different operating modes. The bus then distributes the electric current through the individual circuit breakers to their respective loads. As shown in the

Figure 2-5, the circuit breakers are connected directly to the distribution bus to prevent any accidental short to ground.

Although the schematic diagram in

Figure 2-5 shows an entire aircraft electrical system, this is not typical. Most manufacturers prefer to divide aircraft schematics into individual systems. This becomes a necessity when dealing with large, complex aircraft. If an entire electrical system were represented in one schematic, the diagram would be extremely cluttered and too difficult to read.

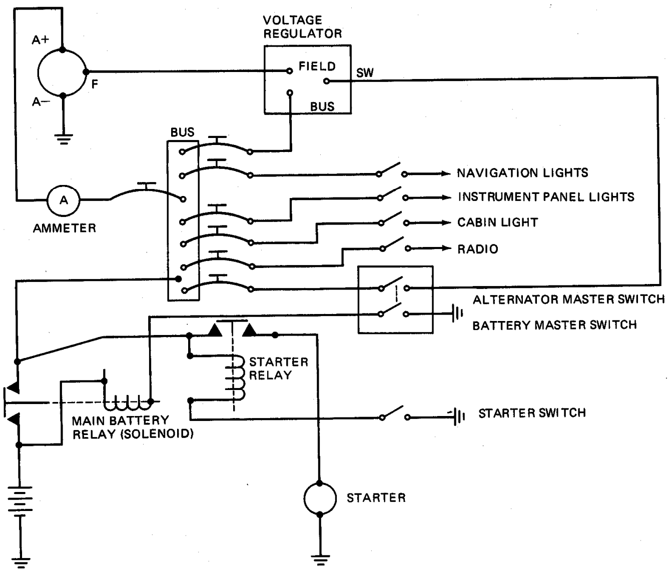


Figure 2-5 Basic power distribution system

3 Overview of Ni-Cd, Ag-Zn and Lead Acid Aircraft Battery Technologies

3.1 Introduction

Presently in our country Military Aircrafts are utilizing alkaline Ni-Cd, Silver Zinc and Lead Acid storage batteries for emergency backup and engine starting applications. Alkaline cells offer higher energy capacity, better high and low temperature performance and long shelf life than do carbon zinc or zinc chloride cells. In alkaline cell has different electrolyte chemistry and is constructed differently than a carbon zinc cells. It is this difference that provides higher electro chemical efficiency. In this chapter the constructional details with various technologies and general characteristics are discussed.

This chapter divided in three parts. First part will discuss an overview of Ni-Cd battery (vented and sealed type) technology. It covers the constructional and design features of nickel-cadmium batteries. Then this part wrap up with some general considerations on myths and misconceptions about Ni-Cd batteries. Second part covers the silver - zinc battery technology and its performance characteristics. Third part will discuss about lead acid batteries including VRLA type, their Performance and application characteristics etc.

3.2 The principal advantages of Nickel - Cadmium batteries

a) Exceptionally long life.

b) No deterioration during prolonged storage irrespective of the state of charge.

c) Minimum maintenance requirements.

d) Robustness in construction with the ability to withstand rough treatment and different service conditions.

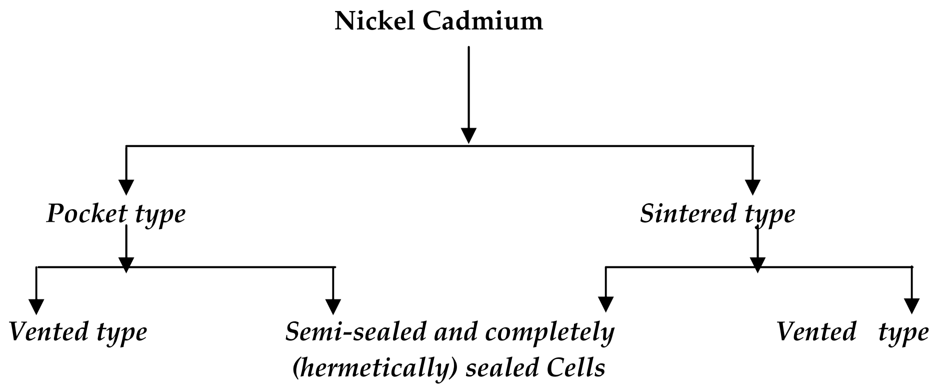
e) Unusual electrical flexibility. Efficiency being high over all parts of the charge and discharge cycle even at rapid rates.

f) Wide range of operating temperature i.e.; from -50°C to +55°C.

g) Capability to produce as hermetically scaled cells.

3.2.1 Classification of Ni-Cd Alkali Batteries

The nickel cadmium batteries can be classified as follows:



3.2.2 General Characteristics of aircraft Ni-Cd battery (Vented type)

The sintered plate type Ni-Cd aircraft storage battery has a higher energy density up to 50% more than the pocket type construction. For this reason vented sintered-plate nickel-cadmium batteries are used in applications requiring high power discharge rate such as aircraft turbine engine, diesel engine starting etc. In many applications the vented sintered plate battery is used because of its reduction in weight, size and maintenance efforts as compared to other batteries. It has a better performance in low temperature operation. Also the rise in battery voltage at the end of charge of the vented cell also provides useful characteristic for controlling the charge.

Nickel-cadmium batteries may be divided based on design into following:

Sealed Batteries: The cells in this type of battery are completely sealed. In general the batteries are of small capacity and may be used for emergency lighting purposes.

Semi-Sealed Batteries: The cells in this type of battery are usually mounted in steel containers and fitted with safety valves. The batteries may be charged fairly rapidly but are very sensitive to overcharge and for aircraft usage they are usually fitted with a thermal protective device. Under normal conditions the battery requires practically no maintenance beyond periodic cleaning and capacity checks.

Semi-Open Batteries: These are generally used as the main aircraft batteries. The cells are similar in appearance to those of the semi-sealed type, but are deliberately allowed to 'gas' to avoid excessive heating should the battery be on overcharge. The cell cases are usually manufactured from nylon. Because of gassing, the electrolyte has to be 'topped-up' at periods which vary according to the duty cycle of the battery and the conditions under which it is operated. 'Topping-up' periods are specified in the approved Maintenance Schedule for the aircraft concerned.

3.2.3 Overview of Ni-Cd Storage Technology

Nickel cadmium (Ni-Cd) batteries have been in industrial production almost as long as lead acid batteries. The vented pocket plate (PP) type Ni-Cd battery was invented by Jungner in 1899 and is still being used with the same design today. Ni-Cd batteries for industrial applications are today a niche product in a market dominated by lead acid batteries. The main applications for industrial Ni-Cd batteries are railroad service, switch gear operations, telecommunications, emergency lighting and in uninterrupted power supply systems. Industrial Ni-Cd batteries of more modern weight and volume efficient designs than the pocket plate are also used in modern trains, aircrafts, electrical vehicles (EV) and hybrid electrical vehicles (HEV). Industrial Ni-Cd cells are designed as vented prismatic cells with positive and negative plates containing the positive and negative active materials. Four types of vented industrial Ni-Cd batteries are available commercially.

- Pocket plate batteries
- Sinter plate batteries
- Fiber plate batteries
- Sinter/plastic bonded plate batteries

Pocket plate batteries are the oldest and least expensive type with a very reliable and long-life cell design that can withstand severe mechanical and electrical abuse. The sinter plate battery was invented 1932 by Shlecht and Ackermann. They have superior high discharge and low temperature performance but are the most expensive battery due to high manufacturing cost and high nickel content. The gap between the superior but high cost and size limited (<100Ah/cell) sinter battery and the low cost but bulky and heavy PP battery was filled in the eighties by the development of fiber plate batteries and later the plastic bonded electrode (PBE) batteries. Fiber plate Ni-Cd (FNC) batteries were developed for electrical vehicles (EV) applications. In sinter/PBE batteries the positive plates are made with sinter plate technology and the negative plates are made with plastic bonded technology.

Ni-Cd batteries have gained large technical importance as portable and completely sealed maintenance free batteries. Sealed portable Ni-Cd batteries were until 1990 the major sealed rechargeable battery for portable applications but, today, competition exists from nickel metal hydride (NiMH) batteries and lithium ion batteries. Sealed Ni-Cd cells are produced in different geometries. The most common is the cylindrical cell geometry that is relatively easy to produce and well suited to withstand internal pressure during overcharge. Cylindrical cells are used in a large variety of applications and are produced in different cell designs for different requirements. Common cell designs are:

Standard cells	Most economical design for applications with no special requirements.
High current cells	Low internal resistance for high discharge rates used for applications like motor drives.
High capacity cells	Designed for maximum capacity.
High temperature cells	Stabilized positive active material and heat resistant separators used for applications like emergency lighting.

Fast charge cells	Charged within one hour or less used for applications like power tools.
Memory back up cells	High temperature resistance separators and special leak safe vents used in applications such as protection of electronic memories.

3.2.3.1 Manufacturing Of Sintered Plate Ni-Cd Battery Technology

The preparation of sintered electrodes is more difficult and more costly than that of pocket plate electrodes, but leads to cells with superior electrical and mechanical characteristics. For high rate applications, accurate, thin section, closely spaced electrodes can be produced and since the active material is in close contact with the current collector, the cell resistance remains fairly constant right up to the end of the discharge. The sintered plate substrates are made by pressing and then sintering at 800-1000°C in hydrogen nickel powder (usually formed by thermal decomposition of $Ni(CO)_4$) on a supporting nickel perforated foil or wire screen. By incorporating gas forming materials such as $(NH_4)_2CO_3$ in the nickel powder before sintering, a highly porous, mechanically stable matrix is produced. Up to 75-85% of the volume is void and by carefully controlling the starting materials and thermal treatment, uniform pore radii ($\approx$5-30μm) can be guaranteed. In the past 10 years or so, there have been significant developments to improve the porosity of the 'plaque' (while retaining mechanical strength) by forming powders of very low but uniform particle size with high surface area.

This is most used technology for aircraft storage batteries. This type of electrode is prepared by sintering high bulk density carbonyl nickel powder into a porous plaque (75 to 80% porous). The plaque usually contains a woven nickel screen or nickel-plated screen. The active nickel hydroxide is loaded into the pores of the plaque. The plaque serves to give the electrode structural integrity and to provide a conductive matrix for contact with the active material but does not participate in the electrochemistry of the cell.

A number of techniques are utilized to prepare the porous plaque and load the pores with active material. The impregnation process can be accomplished by successive dipping or vacuum impregnation of the plaque with concentrated nickel nitrate solution and subsequently converting the nitrate solution in the pores of the plaque to nickel hydrate by precipitation with alkali. An alternate process is the thermal decomposition of the nickel nitrate and subsequent reaction with alkali to form a nickel hydrate.

Both of the above processes require multiple steps to fill the pores with a sufficient amount of active material.

A third impregnation approach consists of the electro-chemical deposition of the nickel hydroxide into the pores of the plaque. This is accomplished by cathodizing the nickel plaque in a molten or high-temperature solution of nitrate against counteractive or inert anodes. Typical sintered-nickel electrodes have an inactive to active nickel ratio of 1:1 to 1.4:1. These electrodes are similar to those used in the nickel-cadmium cell have demonstrated excellent cycle life and stability.

A variety of plate constructions are in common use in vented sintered nickel-cadmium cells produced by different manufacturers. The plates differ according to the manufacturer in the nature of the substrate, method of sintering, impregnation process, formation and termination technique.

Substrate: The substrate services as a mechanical support for the sintered structure and as a current collector for the electrochemical reactions which occur throughout the plate. It also provides mechanical strength and continuity during the manufacturing processes. Two types of substrate are typically used: (1) perforated nickel-plated steel or pure nickel strip in continuous lengths, and (2) woven screens of nickel or nickel clad steel wire. A common perforated type may be 0.1 mm thick with 2 mm holes and a void area of about 40%. A typical screen may use 0.18 mm diameter wire with 1.0 mm openings.

Plaque: The sintered structure before impregnation is generally referred to as "plaque." It usually has a porosity of from 80 to 85% and ranges in thickness from 0.40 to 1.0 mm. Two generic sintering processes are used : (1) the slurry coating process and (2) the dry powder process. Both processes employ special low density battery grades of carbonyl nickel powder.

In the slurry coating process the nickel powder is suspended in a viscous, aqueous solution containing a low percentage of a thixotropic agent. The nickel plated strip with the desired perforated pattern is pulled through the suspension. The thickness is controlled by passing it through doctor blades, while wiping the edges free of slurry. The continuous strip is then dried before sintering in a reducing atmosphere at about 1000° C.

The dry powder processes generally employ wire screen precut to the so-called master plaque dimension. The screens are placed into molds with loose powder on each side. They are then typically sintered in a belt furnace in a reducing atmosphere at 800 to 1000°C.

Impregnation: A review of various impregnation processes are used to load the porous sintered structure of the positive with nickel hydroxide and of the negative with cadmium hydroxide. The plaque is impregnated with a concentrated solution of the nitrate, dried to remove most of the water, the hydroxide is precipitated with caustic and the plaque is washed and dried. This sequence of steps is repeated a number of times so as to fill about 40 to 60% of the pore volume (or until a targeted weight gain is achieved).

Plate Formation: Following impregnation, the plates are mechanically brushed and electrochemically cleaned and formed by charging and discharging the electrode. In the master plaque process they are formed against inert counter electrodes (typically stainless steel or nickel) and can be performed in a loose pack or tight pack configuration. Formation is essential for properly converting hydroxide into the pores of the sintered structure, as well as the reduction of nitrates in the plates. Typical formation cycles for chemical plates consists of a high current cycling. This regime or time may vary for plaque type and capacity. In the case of the continuous strip process the formation is done on a machine similar in appearance to a continuous strip electroplating machine. Plates blanked from the continuous strip have a clean, wiped area at the top which serves as attachment points for nickel or nickel plated steel current collector tabs. In the case of the master plaque process, a coined or dandified area is provided for attachment of these collector tabs.

The sintered product is cut into the required shape and the active material is infused using one of a number of techniques, e.g. for the negative electrode by impregnating the sinter with concentrated aqueous cadmium nitrate, followed by thermal decomposition or by cathodic polarization in molten $Cd(NO_3)_2$ baths etc. The plates are washed and the impregnation cycle is repeated up to 5-10 times until the required loading is attained. Finally the plates are 'formed' by a sequence of carefully controlled charge/discharge cycles. Safety precautions are very important in the manufacture of cadmium-based electrodes because of the health hazards associated with this material. Further , cell assembly and other aspects are discussed in para 3.2.5. also, Sinter plate Ni-Cd cell core components for assembly is shown in Figure 3-7and its schematic view illustrated in the Figure 3-8.

3.2.3.2 Manufacturing Of Fiber Ni-Cd (Fnc) Battery Technology

The sintered-plate battery was found to be too expensive and complex to manufacture. It used a large amount of nickel and was impractical for medium-rate thick electrodes or for cells larger than 100 Ah. The pocket plate battery was too heavy for many applications. Recent developmental work has been directed to more effectively use the costly materials—nickel and cadmium and toward simplified manufacturing processes. The design philosophy was to develop a high-surface-area, conductive-plate structure that would be light, easy to manufacture, inexpensive and to eliminate the troublesome aspects of sintered plate technology, namely the sintering process and the chemical impregnation of the active materials. Taking advantage of new polymer materials and plating techniques, this work has resulted in a new electrode structure, the fiber-structured electrode (the Fiber Nickel Cadmium Battery—FNC)

The fiber plates are manufactured from either a mat of pure nickel fibers or more commonly nickel-plated plastic fibers. To make the plastic fiber conductive, a thin layer of nickel is applied by electro-less plating and thereafter a sufficiently thick layer of nickel for good conductivity is applied by electroplating. The plastic is then burned off, leaving a mat of hollow nickel fibers. The nickel fiber plaque is welded to a nickel-plated steel tab. Figure 3-1 shows the structure of a nickel fiber plaque before impregnation and Figure 3-2 shows an unformed positive electrode.

This fiber electrode technology, while originally developed for EV applications, was first used for industrial low and medium rate vented cells. It is now being used in all types of nickel-cadmium as well as nickel-metal hydride batteries, including high-rate batteries for engine-cranking and sealed cells with oxygen recombination.

A more recent design that has shown significantly improved performance characteristics is the plastic-bonded or pressed-plate electrode. This new development of electrode materials in industrial batteries is a spin-off from the development of electrode materials for use in aircraft and sealed portable consumer batteries. In the plastic-bonded plate, which is mainly used in the cadmium electrode, the active material cadmium oxide is mixed with a plastic powder, normally PTFE, and a solvent to produce a paste. The paste is isotropic and the materials are manufactured at the final density for the active material. As a result, dust problems are eliminated during manufacturing. The paste is extruded, rolled, or pasted onto a center current collector normally made of nickel-plated perforated steel. The plate structure is welded to nickel-plated steel tabs.

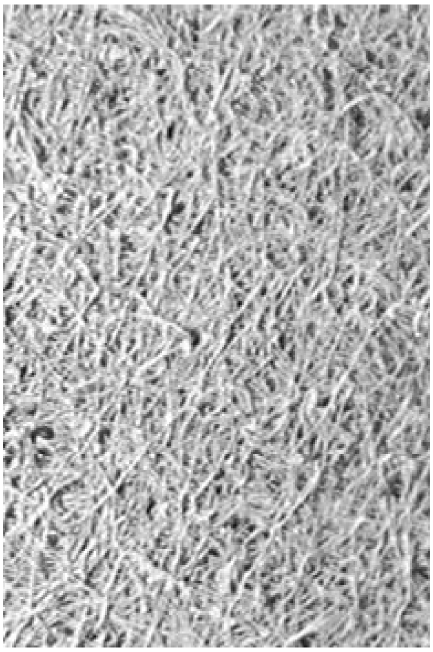


Figure 3-1 Nickel fiber electrode structure before impregnation

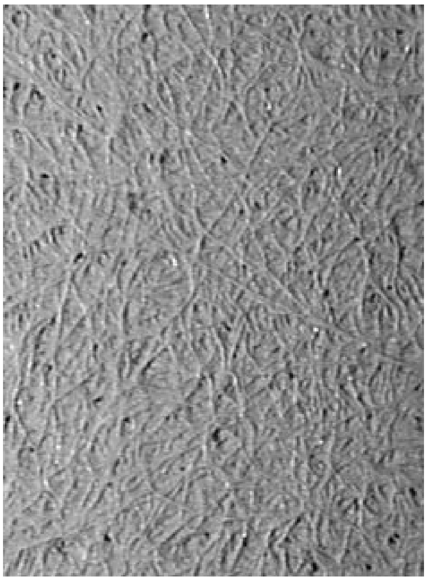


Figure 3-2 Unformed pasted nickel positive electrode

3.2.3.3 Manufacturing Of Plastic Bonded Or Pressed Plate Electrodes

An alternative approach is to deposit nickel from $Ni(CO)_4$ directly onto polyurethane foam or carbon based felts. The thermal gas decomposition has excellent throwing power which permits an even distribution of nickel throughout fibrous matrix. Electrodes of this type are used for a wide range of high rate applications (including electric vehicles) and are sometimes referred to as fiber plate systems. Another technique is to form plastic-bonded plates with PTFE as a binder using a pasting method and a nickel-plated steel mesh.

A more recent design that has shown significantly improved performance characteristics is the plastic-bonded or pressed-plate electrode. This new development of electrode materials in industrial batteries is a spin-off from the development of electrode materials for use in aircraft and sealed portable consumer batteries. In the plastic-bonded plate, which is mainly used in the cadmium electrode, the active material cadmium oxide is mixed with a plastic powder, normally PTFE and a solvent to produce a paste. The paste is isotropic and the materials are manufactured at the final density for the active material. As a result, dust problems are eliminated during manufacturing. The paste is extruded, rolled, or pasted onto a center current collector normally made of nickel-plated perforated steel. The plate structure is welded to nickel-plated steel tabs.

This invention relates to non-sintered nickel electrodes for alkaline batteries and more particularly to an improved substrate for the active material of such an electrode.Nickel electrodes for alkaline batteries fall primarily into one of two categories i.e. sintered or non-sintered. Sintered electrodes typically employ porous, sintered nickel plaques electrochemically impregnated with nickel hydroxide and have demonstrated excellent peak power retention after repeated cycling. Non-sintered nickel electrodes (often called "plastic bonded" electrodes) are made by pressing a mass of active material on to a conductive substrate (e.g., expanded metal, wire mesh or foils made from copper, nickel or iron) and compared to sintered electrodes have generally poor peak power retention after cycling.

3.2.3.4 A Typical Process/Method Of Manufacturing Of “Plastic Bonded Electrodes”

A method of manufacturing plastic bonded electrodes and battery plates having a pre-selected porosity. The electrodes and battery plates are adopted for use in electro chemical power sources. A loose active mass in mixed with a plastic material and a plasticizing and or pore forming agent. The mixture in homogenized and there after rolled on to a metallic current collector so that a plastic selection is formed there on or there in the active mass then reacts with an electrolyte so as to act as a two phase electrode.

The characteristics of nickel-cadmium batteries with plastic bonded electrodes, which are presently manufacturing with active materials, nickel hydroxide powder and a solvent to form a thick paste. The paste is extruded or rolled into a strip, which is then laminated to current collectors of pure nickel or nickel plated steel. The manufacturing process allows more efficient use of the costly raw materials nickel & cadmium. Readily automated, this novel manufacturing process retains the cost competitiveness of the nickel-cadmium pocket plate. The charge characteristics and volumetric density of this type of battery are evaluated.

In non-sintered plastic-bonded electrodes the active material mixture typically comprises: nickel hydroxide as the electrochemically active material conductive diluent (e.g., nickel or graphite particles) distributed throughout the nickel hydroxide for imparting conductivity to the mass cobalt hydroxide to improve the charge efficiency of the electrode and a plastic binder (e.g. styrene or poly tetra fluoro ethylene (PTFE)) for holding the active material and diluent together on to the conductive substrate. More specifically, these active material masses optimally contain about 20% to about 25% percent by weight of graphite as the conductive diluent in particles which range in size up to about ten micrometers. Lower conductive diluent loadings generally tend to reduce the conductivity and power performance of the active material while greater diluent loadings unnecessarily consume space otherwise available for the active nickel hydroxide without any significant offsetting benefit. The binder content of the active mass can vary from about 1 to about 10 percent by weight of the active mass depending on the particular binder chosen. A PTFE binder content, for example, of about three to about five percent by weight is not unusual.

Most manufacturers also include a small amount of cobalt hydroxide (i.e., equal to about five percent of the nickel present) to improve charging of the electrode. The active mass of the non-sintered electrodes is pressed (e.g., by rolling) on to a metallic substrate (e.g., nickel or nickel-plated copper) which serves not only to support the active material relative to a counter-electrode of the battery but also as the primary current collector for the electrode. This conductive substrate can take many forms such as expanded metal, stabbed foil (i.e., a punctured sheet with puncture tears projecting from both sides thereof) or open-cell foam metal.

Non-sintered plastic-bonded nickel electrodes are more economical to produce than their sintered counterparts and offer the distinct advantage of utilizing manufacturing techniques and equipment quite similar to those commonly used for pasting lead-acid battery plates.

However, non-sintered electrodes have not achieved the same power performance levels the sintered electrodes. In this regard, non-sintered nickel electrodes typically have a lower initial peak power than sintered electrodes and unlike sintered electrodes their peak power (e.g. at 50% depth of discharge (DoD)) fades quite rapidly upon repeated cycling. One of the major causes of this power fade in non-sintered nickel electrodes is believed to be the interfacial resistance that exists between the active material mass and the substrate which resistance increases dramatically with repeated cycling.

Untoward interfacial resistance increase upon repeated cycling is believed to be associated with low interfacial contact between the active material and the surface of the substrate loss of adhesion between the active material and the substrate and the formation of a resistive oxide film on the surface of the substrate.

3.2.4 Cell Construction with various Electrode design

A cutaway view of a plastic bonded plate cell in a plastic container is shown in Figure 3-3. The active material for the positive electrodes consists of nickel hydroxide additives such as barium or cobalt compounds for improved life and capacity. The active material for the negative electrodes is prepared from cadmium hydroxide or cadmium oxide mixed with iron or iron compounds and sometimes also with nickel. The iron and nickel materials are added to stabilize the cadmium, prevent crystal growth and agglomeration and improve conductivity.

The active mass is either pressed into briquettes, which are fed into the pre-shaped perforated strip or fed into the pre-shaped strip as a powder. The upper and lower steel strips are folded together by rollers. A number of these folded strips are arranged to interlock with each other to form long electrode sheets, which are then cut to electrode blanks. Electrodes are made from these blanks by providing them with steel frames for mechanical stability and for current takeoff.

The electrodes are made with different thicknesses (1.5 to 5 mm) to provide cells for high, medium and low-rate discharge rates. The negative plate is always thinner (30 to 40%) than the positive.

The electrodes are bolted or welded to electrode groups. Plate groups of opposite polarity are intermeshed and electrically separated from each other by plastic pins and plate edge insulators. Sometimes separators or perforated plastic sheets or plastic ladders are used between the electrodes. The distance between plates of different polarity in an element may vary from less than 1 mm for high-rate cells to 3 mm for low-rate cells.

The elements are inserted into cell containers of plastic or stainless steel. Plastic containers are made from polystyrene, polypropylene or flame-retardant plastics. Important advantages of plastic containers over steel containers are that they allow visual control of the electrolyte level and they require no protection against corrosion. Also, they have lower weight and they can be more closely packed in the battery. The main drawbacks are that they are more sensitive to high temperatures and they require somewhat more space than steel containers. A plastic-bonded plate cell in a plastic container is shown in Figure 3-3. Cells are assembled into batteries in many different ways. Often 20 cells are mounted in each battery unit for typical aircraft applications. A typical battery assembly is shown Figure 3-10.

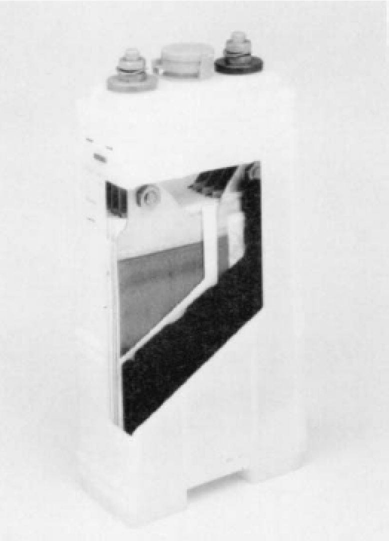


Figure 3-3 Plastic-bonded plate cell.

Figure 3-4 shows a partial cut-away view of a fiber nickel-cadmium (FNC) cell. The case and cover are polypropylene and are welded together. The electrode assembly shows a negative electrode, a corrugated separator and a positive electrode. O-ring seals are employed in the bushings for the terminals to ensure gas retention and a vent valve is seen in the case cover between the terminals. A catalytic gas recombination plug in the vent valve is employed for some applications. The terminals are nickel-plated copper and a 1.19 kg/L KOH electrolyte is typically employed.

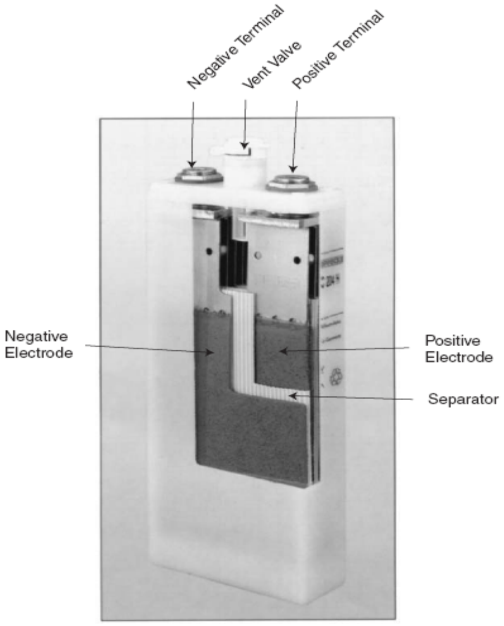


Figure 3-4 Partial cut-away view of fiber nickel-cadmium (FNC) cell.

3.2.5 Cell and Battery Construction / Assembly

The nickel-cadmium cell is a vented cell similar to that of a lead-acid battery. The cells are placed in an insulated metal or plastic case in proper order and then connected in series by the cell connectors. The end cells may be connected to external posts or to a quick-disconnect unit. A complete battery is illustrated in Figure 3-5.

Most nickel-cadmium aircraft batteries contain vented cell caps as illustrated in Figure 3-6. They are designed in such a way that the rubber seal will allow any expanding gases inside the cell to escape. However, if the gas inside the cell is not under pressure, the rubber seal will close against the cap's outlet and seal the electrolyte from accidental spillage during flight. The vent for each cell is required to emit gas only in case the battery becomes overcharged. Little vapor is emitted during normal operation and the battery box is typically sealed.

Each cell of the battery consists of negative and positive plates, separators, electrolyte, cell container, cell cover and vent cap. The plates are made from sintered metal plaques impregnated with the active materials for the negative and positive plates. The plaques are made of nickel carbonyl powder sintered at a high temperature to a perforated nickel-plated steel base or a woven nickel wire base. This results in a porous material that is 80 to 85 percent open volume and 15 to 20 percent solid material. The porous plaque is impregnated with nickel salts to make the positive plates and cadmium salts to make the negative plates. After the plaques have absorbed sufficient active material to provide the desired capacity, they are placed in an electrolyte and subjected to an electric current, which converts the nickel and cadmium salts to the final form. The plaques are then washed and dried and cut into plates. A nickel tab is welded to a comer of each plate and is the means by which the plates are joined into plate groups.

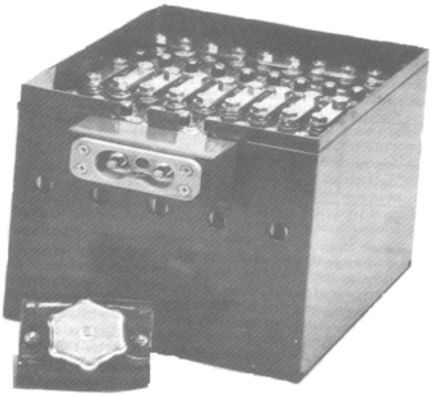


Figure 3-5 Nickel Cadmium aircraft battery

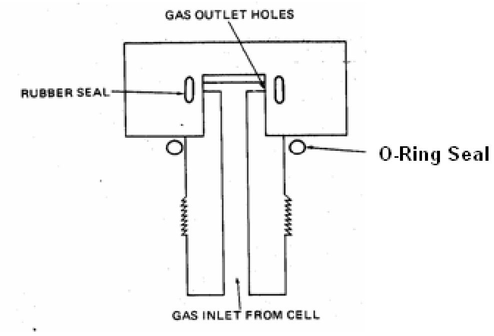


Figure 3-6 Nickel cadmium vented cell cap

The electrolyte for a nickel-cadmium battery is a solution of 70 percent distilled water and 30 percent potassium hydroxide, which gives a specific gravity of 1.3. Specific gravities for nickel-cadmium batteries may range between 1.24 and 1.32 without appreciably affecting battery operation. The electrolyte in a nickel-cadmium battery does not enter into the charge-discharge reaction and this is the reason why the state of charge of a nickel-cadmium battery cannot be determined by testing the electrolyte's specific gravity with a hydrometer. The specific gravity of the electrolyte in a nickel-cadmium battery does not change.

The cell container consists of a plastic cell jar and a matching cover, which are permanently joined at assembly. It is designed to provide a sealed enclosure for the cell, preventing electrolyte leakage or contamination. The vent cap is mounted in the cover of the cell and is constructed of plastic. It is fitted with an elastomeric (flexible rubber or plastic) sleeve valve to permit release of gases as necessary, especially when the battery is on overcharge. The cap can be removed whenever necessary to adjust the electrolyte level. The vent valve automatically seals the cap to prevent leakage of electrolyte.

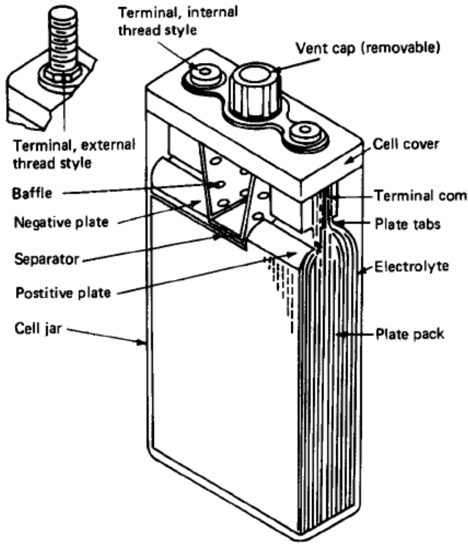


Figure 3-7 Nickel cadmium cell components

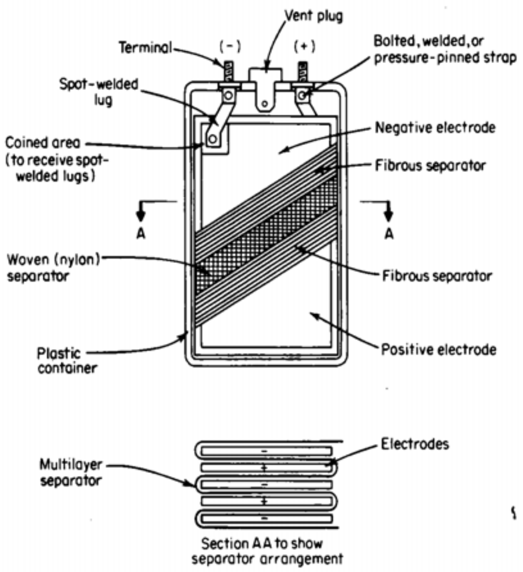


Figure 3-8 Schematic diagram of sintered-plate nickel-cadmium cell.

A cell core and the assembly of a complete cell and its components for a nickel-cadmium cell are shown in the Figure 3-7 and its schematic view of sintered plate Ni-Cd cell is illustrated in the Figure 3-8.

Another type of complete nickel-cadmium cell is illustrated in Figure 3-8 and Figure 3-9. The cell is assembled by welding the tabs of the plates to their respective terminal posts. The terminal and plate-pack assembly is then inserted into the cell container, and the baffle, cover, and terminal seal are installed. The cover is permanently joined to the jar to produce a sealed assembly.

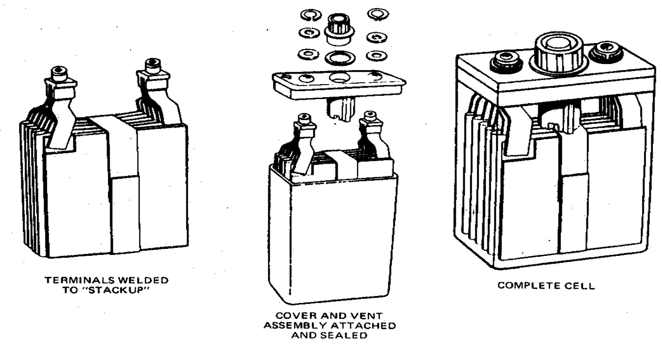


Figure 3-9 Nickel cadmium cell construction.

The cells are assembled into a battery container and connected together with stainless steel conductor links. Usually, 19 or 20 cells (depending on the total voltage required) are assembled into a battery with the correct polarity so that each cell is in series. The battery container is typically made of stainless steel, carbon steel or a fiberglass material. All metal cases require an internal insulator. Stainless steel cases use a plastic liner, while most carbon steel cases are coated with an alkali-resistant epoxy that contains high dielectric properties. A typical battery assembly is illustrated in Figure 3-10 and its items are described in Table 3-1.

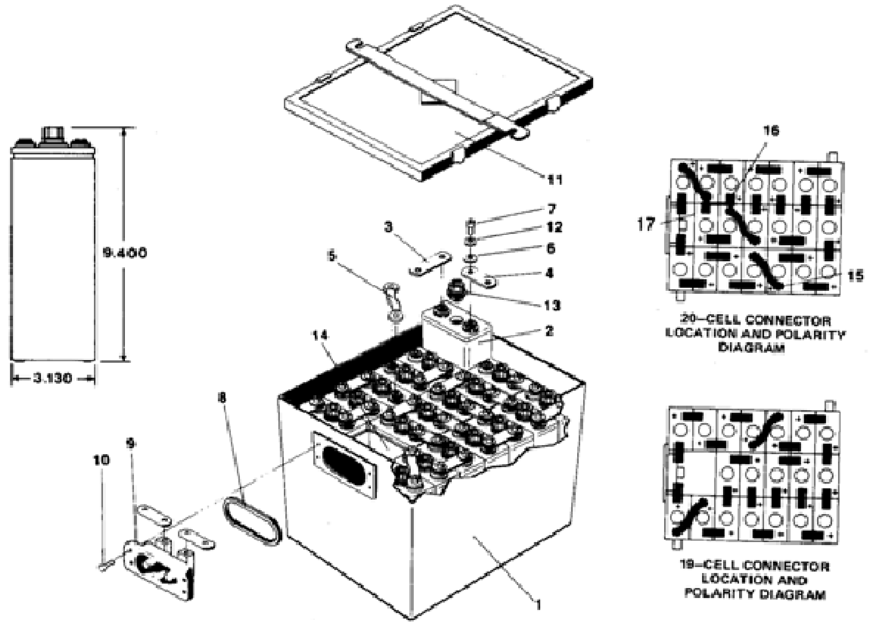


Figure 3-10 Typical Battery Assembly

Table 3-1 Typical Battery Assembly Parts

Item	Description	Item	Description	Item	Description
1	Can Assembly	7	Socket Head Cap Screw	13	Filler Cap & Vent Assembly
2	Cell Assembly	8	Rectangular Ring	14	Spacer
3	Connector	9	Receptacle Assembly	15	Connector
4	Connector	10	Phillips Head Screw	16	Connector
5	Connector	11	Cover Assembly	17	Spacer
6	Belleville Spring	12	Double “D” Washer		

3.2.5.1 Separator

The separator in a nickel-cadmium cell is a thin, porous multivariate of woven nylon with a layer of cellophane. The separator serves to prevent contact between the negative and positive plates. The separator is continuous and is inter posed between the plates as each successive plate is added to the plate pack or stack. The cellophane portion of the separator acts as a barrier membrane to keep the oxygen that is formed at the positive plates during overcharge from reaching the negative plates. Oxygen at the negative plates would recombine with cadmium and create heat that might lead to thermal runaway; thus the cellophane serves to inhibit thermal runaway. Thermal runaway is a condition where the battery chemicals overheat to such a degree that the battery can be destroyed or even explode.

Thermal runaway or vicious cycling does not accurately describe the overheating of a nickel cadmium battery. It is not self-sustaining and can be controlled. An aircraft charging system perpetuates this condition and it can be stopped by isolating the battery from the charging system. A nickel-cadmium battery cannot overheat unless something internal is causing its temperature to rise. Nickel-cadmium batteries typically overheat from improper maintenance or improper use. Improper use of the battery usually occurs by drawing too much current from the battery during multiple engine starts in a short period of time. The heat retained within the battery weakens and destroys the material that separates the positive and negative plates in the cells. When this occurs, the cell's electrical resistance lowers and decreases the cell's voltage. The battery receives excessive amounts of charge current from the aircraft's constant potential charging system, which generates a great deal of heat within the battery. Temperature and/or over current sensors are generally used on nickel cadmium batteries used for engine starting. These sensors are connected to warning indicators, which allow the pilot to take corrective measures in case of extreme battery stress. Typically, if the battery reaches a thermal runaway condition, the pilot must disconnect the battery from the electrical system and land the aircraft as soon as practical.

The separator system is a thin, multilayered combination of a cloth that electrically separates the positive and negative plates and an ion-permeable plastic membrane that serves as the gas barrier.

Electrical and mechanical separation of the plates is typically provided by either woven or felted nylon material. This material is relatively porous in order to provide sufficient cross section of ionic conduction path through the electrolyte.

The ion-permeable plastic membrane, typically cellophane, is utilized as the gas barrier while at the same time it offers minimum ionic resistance. This thin gas barrier, which becomes relatively soft when wetted, is frequently placed between two layers of the nylon separator and receives significant mechanical support from them.

The microporous polypropylene membrane, typically Celgard (Celgard 3400, manufactured by Celgard LLC, Carlotte, NC, 28273) is utilized as the gas barrier while at the same time it offers minimum ionic resistance. This thin gas barrier, which becomes relatively soft when wetted, is frequently placed between two layers of the cloth separator and receives significant mechanical support from them. Substantial improvements have been made in recent years to the toughness of the plastic membrane gas barrier.

3.2.5.2 Plate pack & Cell Assembly

Plate packs are assembled by alternating positive and negative plates with the separator gas barrier system interleaved between them. The cell terminals are bolted or welded to the current collector plate tabs.

3.2.5.3 Electrolyte

The electrolyte for a nickel-cadmium battery is a solution of 70 percent distilled water and 30 percent potassium hydroxide, which gives a specific gravity of 1.3. Specific gravities for nickel-cadmium batteries may range between 1.24 and 1.32 without appreciably affecting battery operation. The electrolyte in a nickel-cadmium battery does not enter into the charge-discharge reaction and this is the reason why the state of charge of a nickel-cadmium battery cannot be determined by testing the electrolyte's specific gravity with a hydrometer. The specific gravity of the electrolyte in a nickel-cadmium battery does not change.

Potassium hydroxide electrolyte is used so as to yield a finished concentration of approximately 31% at full charge (specific gravity of 1.30). Performance of the cell particularly at low temperature is significantly dependent on this concentration.

The electrolyte generally used is an aqueous solution of potassium hydroxide with a concentration of 20-28% by weight and a density of 1.18- 1.27 g/cm^3 at 25°C. The low end of the range is used for cells designed to operate at normal temperatures (say above -10°C). About 1-2% of lithium hydroxide is usually added to such electrolytes to minimize coagulation of the NiO(OH) electrode on cycling. For low temperature applications, the more concentrated KOH solutions are used (without LiOH which increases electrolyte resistance). However, some problems with swelling are encountered with pocket plate electrodes and these concentrated solutions. Cells operating at high temperatures occasionally use aqueous sodium hydroxide as electrolyte. Some water loss occurs, especially if there is prolonged overcharging of cells. Cells may be designed so as to contain a large reserve of electrolyte, so that topping up is only necessary after long intervals, e.g. 5-8 years in some stationary standby applications.

3.2.5.4 Cell Container

The plate pack is placed into the cell container with the cell terminals extending through the cover. The cell container is usually made of a low moisture absorbent nylon and consists of the cell jar and matching cover that are permanently joined together at assembly by solvent scaling, thermal fusion or ultrasonic bonding. The container is designed to provide a sealed enclosure for the cell, thus preventing electrolyte leakage or contamination, as well as providing physical support for the cell components. The terminal seal is generally provided by means of O rings with Belleville washers and retaining clips.

3.2.5.5 Vent Cap and Check Valve

The vent cap serves both as a removable plug to provide the access required for replenishment of water to the electrolyte and also as a check valve to release gases generated when water is consumed during overcharge. The check valve prevents atmospheric contamination of the electrolyte. It consists of a nylon body with a hollow center post around which is placed an electrometric sleeve which functions as a Bunsen valve to allow gas to escape from the cell but not to enter.

3.2.6 Performance Characteristics

3.2.6.1 Chemistry

The basic electrochemistry is the same for the vented pocket plate, sintered plate, fiber and plastic-bonded plate types as well as for other variations of the nickel-cadmium system. The reactions of charge and discharge can be illustrated by the following simplified equation:

$$2NiOOH + 2H_2O + Cd \underset{\textbf{Charge}}{\overset{\textbf{Discharge}}{\leftrightarrow}} 2Ni(OH)_2 + Cd(OH)_2$$

On discharge, trivalent nickel oxy-hydroxide is reduced to divalent nickel hydroxide with consumption of water. Metallic cadmium is oxidized to form cadmium hydroxide. On charge, the opposite reactions take place. The electromotive force (EMF) is 1.29 V. The potassium hydroxide electrolyte is not significantly changed with regard to density or composition during charge and discharge, in contrast to the sulfuric acid in lead-acid batteries. The electrolyte density is generally approximately 1.2 g/mL. Lithium hydroxide is often added to the electrolyte for improved cycle life and high-temperature operation.

3.2.6.2 Voltage rating

The OCV of 1.28 V is consistent for all nickel-cadmium vented cells regardless of cell size. The OCV does vary slightly with temperature and elapsed time since the battery's last charge. Immediately after charge, the OCV may reach 1.40 V however, it soon lowers to between 1.35 and 1.28 V. A 20-cell Ni-cad battery would, therefore, have an OCV between 25.6 and 27 V.

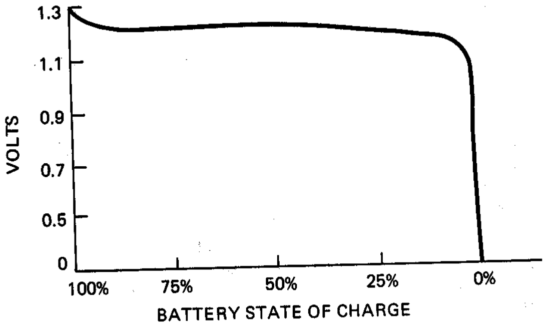


Figure 3-11 Typical discharge voltage curve under moderate load

The voltage obtained by a cell immediately after charging is typically slightly higher than the average OCV. A nickel-cadmium battery may reach 27.5 V immediately after charging or 1.5 V per cell for a 19-cell battery. Near the end of the charge cycle the same battery may reach 28.5 V if the charging current is still applied. This voltage diminishes quickly after the battery is removed from the charger and will soon reach near 25 V.

The CCV of a vented-cell nickel-cadmium battery ranges between 1.2 and 1.25 V. This voltage will vary depending on the battery temperature, the length of time since the battery's last charge, and the discharge current applied. The CCV of a nickel-cadmium cell remains nearly constant under moderate load until the cell is near the completely discharged state. Figure 3-11 illustrates the CCV of a nickel-cadmium cell.

3.2.6.3 Capacity and Internal Resistance

A nickel cadmium battery has tremendous peak power and delivers far more power than a lead-acid battery of the same size and weight. The large amount of instantly available power produced by a nickel-cadmium battery is why it is so well suited for starting turbine engines. The capacity of a nickel-cadmium battery is a function of the total plate area contained inside the cells (more plate area, more capacity). Mostly for aircraft Ni-Cd batteries are designed for 24V systems with a capacity between 15 to 80 Ah. The ampere-hour rating is determined at a 5-h discharge rate unless otherwise denoted.

The capacitance of any battery is partially a function of that battery's internal resistance. The internal resistance of most vented nickel-cadmium cells is very low (less than 1 milli ohm per cell), which allows these cells to maintain a high discharge current and still maintain acceptable voltage levels. The low internal resistance of a nickel-cadmium battery allows it to recharge very rapidly. This resistance in part results from the large surface area of active materials made available through the use of a highly porous plate.

The output of a nickel-cadmium battery is relatively constant, even in harsh operating conditions such as very cold weather. The optimum temperature range is between 60 and 90°F, above or below these values the total capacity will diminish slightly as illustrated in Figure 3-12.

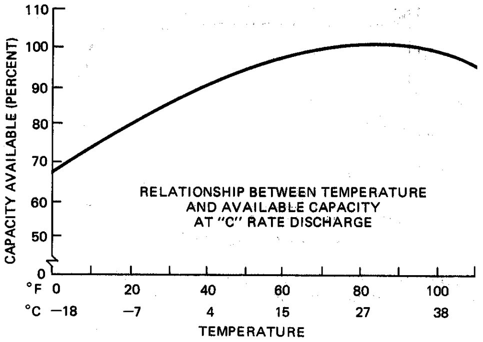


Figure 3-12 Relationship between temperature and available capacity

3.2.6.4 Measurement of Battery internal resistance

i. **Output Impedance:** The output impedance, source impedance or internal impedance of an electronic device is the opposition exhibited by its output terminals to the flow of an alternating current (AC) of a particular frequency as a result of resistance, inductance and capacitance. The impedance at DC (frequency of 0) is the same as the resistance component of the impedance and is termed output resistance. It is important to realize that no real device (battery, generator and amplifier) is a perfect source all have an internal impedance, though this may have negligible effect depending on the load.

Depending on perspective, this impedance appears in series with a perfect voltage source or in parallel with a perfect current source (*See:* Thevenin's theorem, Norton's theorem).

ii. **Measurement :** The source resistance of a purely resistive device can be experimentally determined by increasingly loading the device until the voltage across the load (AC or DC) is 1/2

It can more accurately be described by keeping track of the voltage versus current curves for various loads and calculating the resistance from Ohm's law. (The internal resistance may not be the same for different types of loading, especially in devices like chemical batteries).

iii. **Internal Resistance** is a concept that helps us model the complex chemical reactions that occur inside a battery. It is impossible to directly measure the internal resistance of a battery, but it can be calculated from current and voltage data measured from a circuit. When a load is applied to a battery the internal resistance can be calculated from the following equations :-

$$R_B = (V_s/I) - R_L$$

or

$$R_B = (V_s - V)\ /I$$

Where

R_B is the internal resistance of the battery

V_S is the battery voltage without a load

V is the battery voltage with a load

R_L is the total resistance of the circuit

I is the total current supplied by the battery

3.2.6.5 Energy Density and Specific Energy

Typical specific energy and energy density values for pocket plate single-cell batteries are 20 Wh/kg and 40 Wh/L with the best values for commercially available units reaching 27Wh/kg and 55 Wh/L. The corresponding values for complete pocket plate batteries are 19Wh/kg and 32 Wh/L and 27 Wh/kg and 44 Wh/L, respectively. These data are based on the nominal capacity and the average discharge voltage at the 5-h rate. The specific energy and energy density of larger fiber plate batteries approach 40 Wh/kg and 80 Wh/L. Batteries with plastic-bonded plates approach 56 Wh/kg and 110 Wh/L. This compares to a specific energy of 30 to 37 Wh/kg and an energy density of 58 to 96 Wh/L for sintered-plate designs.

3.2.6.6 Discharge Properties of plastic bonded Ni-Cd batteries.

The nominal voltage of a nickel-cadmium battery is 1.2 V. Although discharge rate and temperature are of importance for the discharge characteristics of all electrochemical systems, these parameters have a much smaller effect on the nickel-cadmium battery than on for instance the lead-acid battery.

Typical charge and various discharge curves at room temperature for plastic-bonded plate batteries at various constant discharge rates are shown in Figure 3-13 (refer charging curve). Even at a discharge current as high as 5C (where *C* is the numerical value of the capacity in Ah), a high-rate battery can deliver 60% of the rated capacity and a plastic-bonded battery as much as 80%. Battery capacities as a function of discharge rate and cutoff voltage are given in Figure 3-14.

Batteries can also be used at elevated temperatures. Although occasional operation at very high temperatures is not detrimental, 45 to 50°C is generally considered as the maximum permissible temperature for extended periods of operation.

Occasional over discharge or reversal of nickel-cadmium batteries is not detrimental nor is complete freezing of the cells. After warming up, they will function normally again.

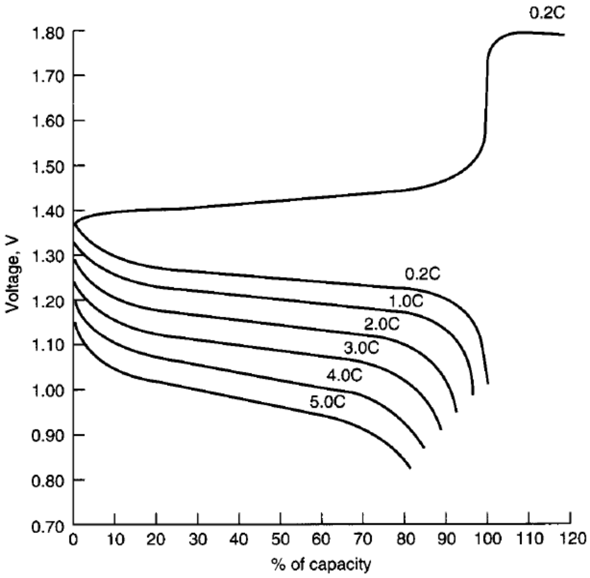


Figure 3-13 Charge and Discharge Characteristics of Ni-Cd (plastic bonded plate) battery at 25°C.

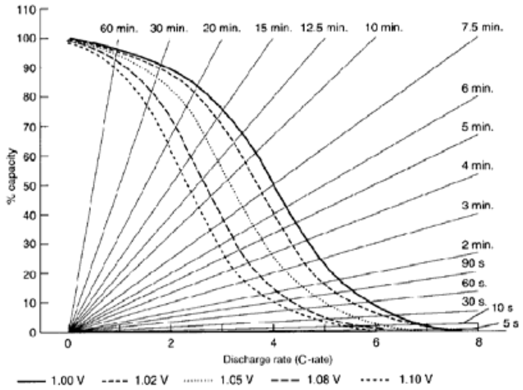


Figure 3-14 Discharge characteristics of Ni-Cd (Plastic bonded plate) Batteries at 25°C.

3.2.6.7 Internal Resistance

Nickel-cadmium batteries generally have a low internal resistance. Typical DC resistance values are 0.4, 1 and 2 mΩ, respectively, for a charged 100-Ah high, medium and low rate pocket plate single-cell battery. The internal resistance is largely inversely proportional to the battery size in a given series. Decreasing temperature and decreasing state of charge of a battery will result in an increase of the internal resistance. The internal resistance of fiber-plate batteries is 0.3 mΩ for a high-rate design and 0.9 mΩ for a low-rate design. Plastic-bonded plate batteries have an internal resistance as low as 0.15 mΩ.

3.2.7 Discharge Properties of sintered plate Ni-Cd batteries

The discharge curves for a typical vented sintered-plate nickel-cadmium battery at various constant-discharge loads are shown in Figure 3-15. The discharge curves for a typical battery at various temperatures are shown in Figure 3-16. The curves for this battery are characterized by a flat voltage profile, even at relatively high discharge rates and low temperatures. Voltages at various constant-current discharge loads and states of discharge are given in Figure 3-17.

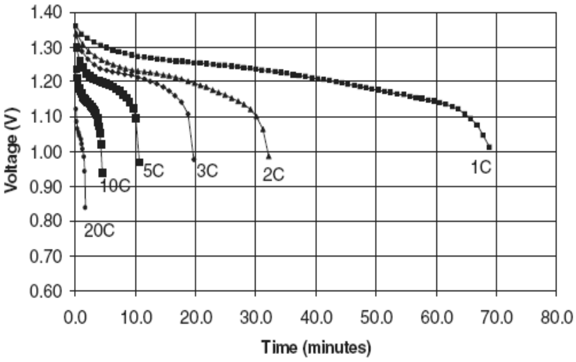


Figure 3-15 Typical discharge curves at various C rates, 25°C.

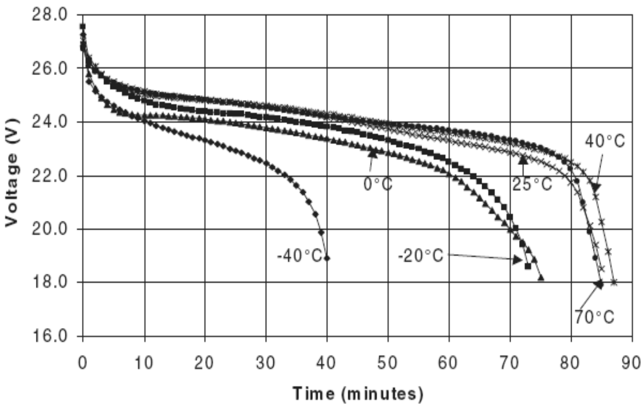


Figure 3-16 Typical discharge curves at various temperatures 1C-Rate, 20 cell battery.

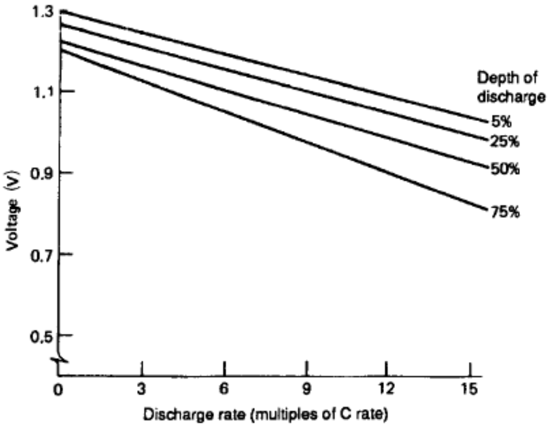


Figure 3-17 Voltage as a function of discharge load and at various states of charge at 25°C.

The battery because of its low internal resistance is capable of delivering pulse currents as high as the 20 to 40C rate. For this reason it can be used successfully for very high power applications, such as engine starting.

3.2.7.1 Factors Affecting Capacity

The total capacity that the fully charged sintered-plate vented battery is capable of delivering is dependent on both discharge rate and temperature, although the sintered-plate battery is less sensitive to these variables than most other battery systems. The relationships of capacity to discharge load and temperature are shown in Figure 3-18 and Figure 3-19 respectively. Low-temperature performance is enhanced by the use of eutectic 31% KOH (1.30 specific gravity) electrolyte which freezes at -66°C. Higher or lower concentrations will freeze at higher temperatures for example, 26% KOH freezes at -42°C. As shown in Figure 3-19, more than 60% of the 25°C capacity is available at -35°C, with the temperature having an increasingly significant effect as it is reduced toward -50°C. At high discharge rates heat that is generated may cause the battery to warm up giving improved performance on immediate subsequent discharges than would be expected under the ambient conditions. Vented sintered-plate batteries can also be discharged at elevated temperatures. Strict control is required however, when charging at high temperature. As with most chemically based devices, exposure to high temperatures for extended periods of time will detract from the life of the battery. The combined effects of both increased discharge rate and low temperature may be approximated by multiplying the two derating factors.

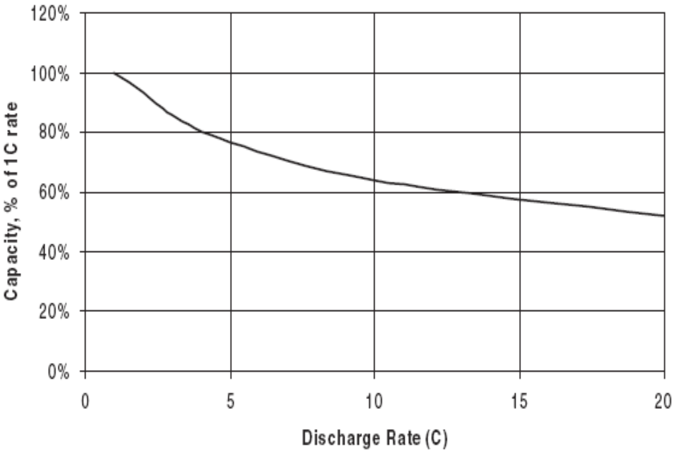


Figure 3-18 Capacity derating as a function of discharge rate at 25°C.

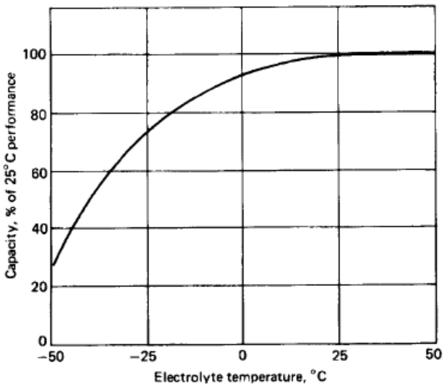


Figure 3-19 Capacity derating as a function of discharge temperature at 1C rate discharge.

3.2.7.2 Variable-load Engine-Start Power

The most common and demanding use of the vented sintered-plate nickel-cadmium battery is as the power source for starting turbine engines on board aircraft. The discharge in this application occurs at relatively high rates for periods of 15 to 45 s. Typically the load resistance when the start is initiated particularly in low-temperature in a marginal-start situations is of the same order of magnitude as the effective internal resistance of the battery, R_e. The apparent load resistance increases as the engine rotor gradually comes up to speed.

This results in a typical discharge current which slowly decreases from some high initial value while the battery voltage recovers from an initial drop of perhaps 50% or more, back toward 1.2V per cell, the effective zero load voltage. A representative graph of the battery starter voltage and current, expressed as a function of time is shown in Figure 3-20. A common and useful measure of battery performance is the maximum power current. This property is generally defined as the load current at which the battery voltage would be 0.6N V or one-half of the effective open-circuit voltage (1.2 V/ cell) and where *N* is the number of cells in the battery. The instantaneous maximum power current decreases with decreasing state of charge due to rising internal resistance. Its value versus state of charge tends to behave exponentially, as shown in Figure 3-21. An approximation of I_{mp} may also be measured by performing a ''constant-potential'' discharge at 0.6N V for 15 to 120 seconds. A typical discharge is shown in Figure 3-22.

The maximum power delivery P_{mp} and the effective internal resistance R_e are related to the value of I_{mp} as follows:

$$\mathbf{P_{mp} = 0.6\,N\,I_{mp}}$$

and

$$\mathbf{R_e = \frac{0.6N}{I_{mp}}}$$

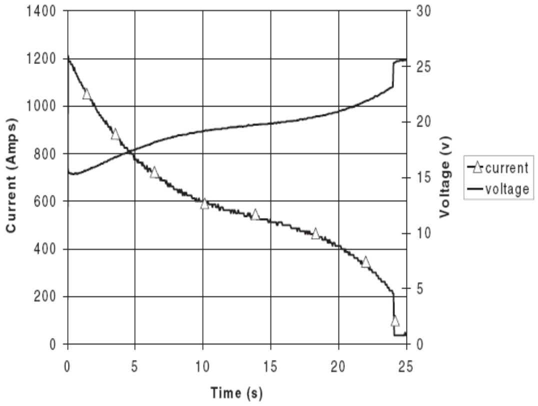


Figure 3-20 Battery voltage and current as a function of time for a typical turbine engine start (20 cell battery).

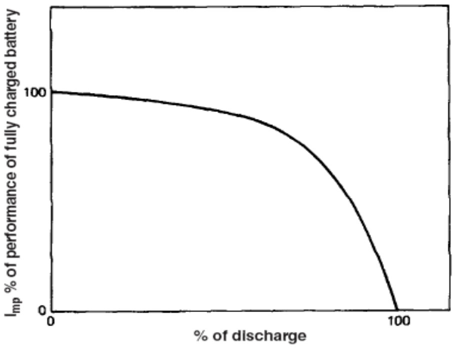


Figure 3-21 Maximum power current derating as a function of state of charge at 25°C.

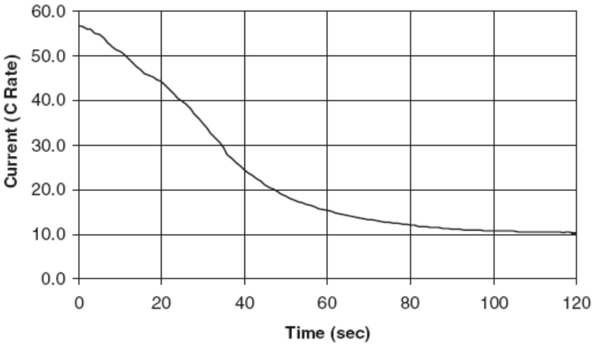


Figure 3-22 Representative 0.6V constant potential discharge at 25°C.

3.2.7.3 Factors Affecting Maximum Power Current

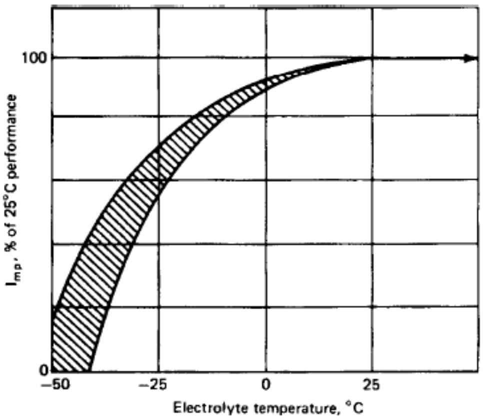


Figure 3-23 Maximum power current derating as a function of battery temperature (fully charged).

The value of I_{mp}, which a battery is capable of delivering is maximum at full charge and at 25°C electrolyte temperature. Derating effects due to state-of-charge and electrolyte temperature factors are shown in Figure 3-21 and Figure 3-23 respectively. It will be noted that both relationships are nonlinear in that the effects on maximum power delivery, per unit of change increase with decreasing state of charge and with decreasing temperature. As with capacity, the approximate effect of combined low electrolyte temperature and decreased state of charge may be determined by multiplying the individual factors. It should be noted however, that high-rate discharge at low temperature may increase the battery temperature. This self heating must be accounted for when determining the combined derating factors for a subsequent discharge. A negligible effect on I_{mp} occurs with increases in electrolyte temperature above 25°C.

3.2.7.4 Energy/Power Density

Typical average values for the energy and power densities of the vented sintered-plate nickel cadmium battery at 25°C are shown in Table 3-2

Table 3-2 Energy and power characteristics of vented sintered-plate Ni-Cd battery (single cell basis)

Capacity specific (single cell, C rate)	25-31 Ah/Kg
Capacity density	48-80 Ah/L
Specific energy (C rate)	30-37 Wh/Kg
Energy density	58-96 Wh/L
Power specific (at maximum power)	330-460 W/Kg
Power density	730-1250 W/L

3.2.8 Charging Characteristics

The functional design of the vented cell differs from that of the sealed cell primarily by the inclusion of a gas barrier between the positive and negative electrodes. This gas barrier has one principal function which is to prevent, the recombination of generated gases within the cell thereby allowing both positive and negative plates to return to full charge. This results in an over voltage during initiation of overcharge which is used as the feedback signal to control the charging device. As a consequence of this characteristic however, the vented cell consumes water in overcharge which must be replenished during maintenance. Charging of the vented sintered nickel-cadmium cell, following its discharge in cyclic use has four significant objectives.

These may be stated as follows:

- Restore the charge used during discharge as quickly as possible.
- Maintain the "fully charged" capacity as high as possible during the use intervals and between maintenance removals.
- Minimize the amount of water usage during overcharge.
- Minimize the damaging effects of overcharge.

Fulfillment of the first objective is the principal reason for the design and use of vented cells since, the gas barrier provides the "voltage signal" which may be utilized in several different ways to terminate the fast recharge. The charge may thus be accomplished at the desired high rate without compromising the battery by continuing that rate in overcharge. Second objective must inherently be balanced against objectives third and forth in the design and control of charging method. Generally, a continued good capacity between reconditioning is enhanced by providing more overcharge while more overcharge inherently utilizes more water and if sufficiently high, may result in damage to the battery. A compromise must therefore be struck usually about 101 to 105% of the ampere-hours removed on discharge are replaced on the subsequent charge.

Charging techniques which are used in "on-board" systems utilize the "signal" provided by the overvoltage of the vented cell in overcharge. This overvoltage signal is shown in Figure 3-13(refer charging curve). This significant voltage rise is present at all charge rates and its sharpness actually improves as the cell is cycled in high-rate discharge and recharge. The corollary to this curve, which shows voltage response at constant current is the current response at constant voltage, which may be expected to be somewhat the reverse of Figure 3-13(refer charging curve) and is illustrated in Figure 3-24.

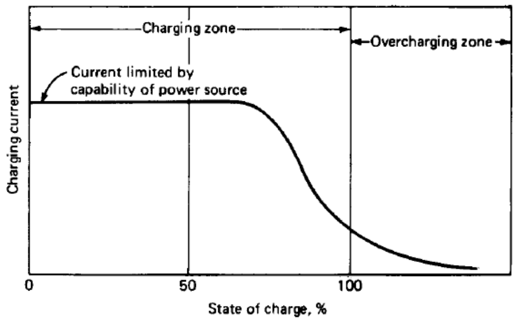


Figure 3-24 Constant-potential charge current

3.2.8.1 Constant-Potential Recharging

Constant-potential (CP) charging is the oldest of the methods still in use and is typically utilized in general aviation aircraft. Similar to an automobile battery charging system, CP charging utilizes a regulated voltage output from the aircraft DC generator, which is mechanically coupled to the engine. The voltage is typically regulated at 1.40 to 1.50 V per cell. Figure 3-24 illustrates the form of the charge current as a function of the state of charge of the vented cell battery during CP recharging. Although the initial current could be quite high if limited only by the voltage response of the battery, it most frequently is limited by the capability of the source as shown. As the battery approaches full charge however, the "back EMF" of the battery, illustrated as the charge voltage for the constant-current case in Figure 3-13(refer charging curve), reduces the current to that required by the battery to provide an overvoltage equal to the regulated voltage of the charging source. CP charging requires very careful consideration of the selection of charge voltage and its proper maintenance in order to achieve the balance between objectives 2 and 3. This is particularly difficult to achieve when the battery temperature experiences significant variation, since overvoltage is dependent on battery temperature. This balance may be made essentially independent of battery temperature effects by means of temperature compensation of the CP voltage.

3.2.8.2 Constant-Current, Voltage-Controlled Recharging

A number of commercially available chargers based in general on constant-current charging with voltage cutoff control are utilized in modern aircraft. One of the simplest and most effective of these chargers applies an approximately C-rate constant-current charge to the battery and then terminates it when the battery voltage reaches a predetermined voltage cutoff (VCO) value such as 1.50 V per cell. The control also reinitiates the constant-charge current whenever the open-circuit battery voltage falls to a predetermined lower level, such as 1.36 V per cell. The net result is that the charger will recharge the capacity used during an engine start, typically 10% of the battery's total in approximately 6 min and then cut the charger "off" due to the sharp rise in voltage as the cells go into overcharge as illustrated in Figure 3-13(refer charging curve). Shortly thereafter, as the voltage falls below the turn-on voltage, the charge is reinitiated for a short period of time until the battery voltage again reaches the cutoff voltage. This simple on-off action continues at decreasing frequency and decreasing lengths of "on time," there by maintaining the battery in a "float" condition at a completely full state of charge.

The battery voltage reduction due to a discharge inherently initiates the recharging of the battery without additional controls, thus automatically providing the recharge signal function regardless of the discharge rate or the reason. Adjustment of the "cutoff" and "turn-on" voltages as a function of battery temperature, which is described in under this head matches this mode of charging to the temperature characteristics of the vented sintered nickel-cadmium battery, thereby maintaining the desired balance of objectives. Both cutoff and turn-on voltages are compensated at the same rate thereby maintaining a constant differential between turn-on and cutoff.

3.3 Portable Sealed Ni-Cd Batteries

3.3.1 General Characteristics

Sealed nickel-cadmium batteries incorporate specific battery design features to prevent a buildup of pressure in the battery caused by gassing during overcharge. As a result batteries can be sealed and require no servicing or maintenance other than recharging. These unique characteristics for a secondary battery have created wide acceptance for use in a variety of applications ranging from lightweight portable power (photography, toys, housewares) to high-rate, high-capacity power (electronic devices such as phones, computers, camcorders, power tools) and standby power (emergency lighting, alarm, memory backup). Some nickel cadmium batteries are now incorporating smart battery control circuitry to give state-of charge indication and to control overcharge and over discharge.

- **Maintenance-free operation:** The batteries are sealed, contain no free electrolyte, and require no servicing or maintenance other than recharging.
- **High-rate charging:** Sealed nickel-cadmium batteries are capable of recharge at high rates within 1 h under controlled conditions. Many batteries can be charged in 3 to 5 h without special controls, and all can be recharged within 14 h.
- **High-rate discharge:** Low internal resistance and constant-discharge voltage make the Nickel-cadmium battery especially suited for high-rate discharge or pulse-current applications.
- **Wide temperature range:** Sealed nickel-cadmium batteries can operate over the range from about -40 to 50°C and are particularly noted for their low-temperature performance. Premium performance batteries extend this range to 70°C.
- **Long service life:** Over 500 cycles of discharge or up to 5 to 7 years of standby power are common to sealed nickel-cadmium batteries.

3.3.2 Chemistry

The active materials of the sealed nickel-cadmium battery are the same as for other types of nickel-cadmium batteries namely, in the charged state, cadmium for the negative electrode, nickel oxy-hydroxide for the positive and a solution of potassium hydroxide for the electrolyte In the discharged state, nickel hydroxide is the active material of the positive electrode and cadmium hydroxide that of the negative.

3.3.3 Cylindrical Batteries: Typical Constructional Features

The cylindrical battery is the most widely used type because the cylindrical design lends itself readily to mass production and because excellent mechanical and electrical characteristics are achieved with this design. Figure 3-25 shows a cross section of the cylindrical cell design.

The positive electrodes in cylindrical cells are available in sintered nickel powder on metal substrate mucilage of foam active material on substrate or fibroid nickel structure into which the active material (nickel hydroxide) is introduced by embedding or impregnating into the carrier electrode system. Electro deposition also has been used to load substrate with active material. The negative electrodes are also available in various designs such as sintered nickel substrate similar to the positive electrode or by pasting an active material (cadmium) onto a substrate. Electro deposition is also used for negative construction.

After electrodes have been processed, the positive and negative electrodes are cut to size and wound together in a jelly roll technique. The electrodes are separated in the jelly roll by a porous separator material. The separator material, usually nylon or polypropylene is highly absorbent and used to store the potassium hydroxide distilled water electrolyte solution as well as to serve as a gas membrane permeable to oxygen.

The finished electrode roll with separator is inserted in a nickel plated steel can and electrical connections are made to the positive and negative electrodes. The positive electrode is then electrically connected to the cell positive cover assembly and the negative electrode is electrically connected to the negative can. The electrolyte is then introduced to the electrode roll in the nickel-plated can. The amount of electrolyte is specified to ensure proper performance and allow overcharge operation without causing excessive gas buildup in the cell that might result in venting and cell failure. In final cell assembly, a positive cover assembly which incorporates a re-sealable vent mechanism (some designs use one time vent) is positioned near the top of the electrode roll and crimp scaled into position. This fail safe vent mechanism prevents premature failure or cell rupture due to extreme overcharge or discharge which could lead to an+ unsafe condition.

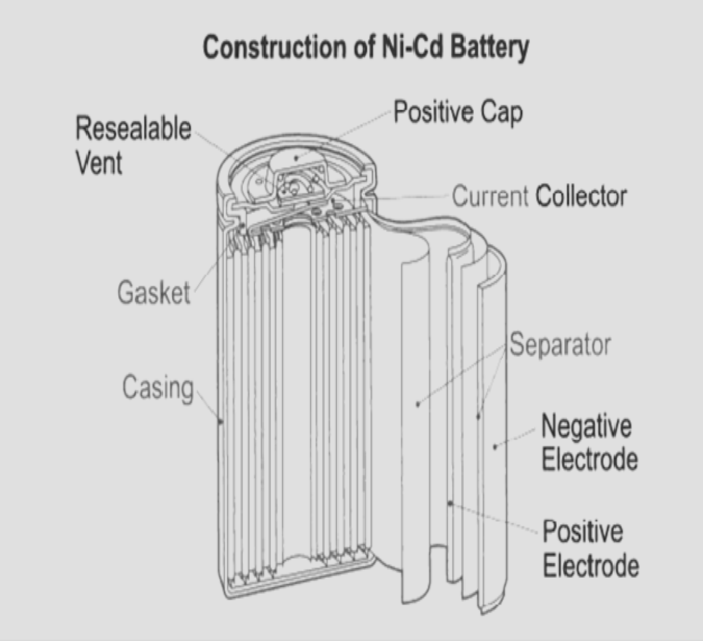


Figure 3-25 Cross-structural design of cylindrical cell

3.3.3.1 Discharge Characteristics

Typical discharge curves for the cylindrical battery at 20°C at various discharge loads are shown in Figure 3-26. The flat voltage profile, after the initial voltage drop is characteristic. The capacity that can be obtained from a battery is dependent on the rate of discharge, the voltage at which discharge is terminated, the discharge temperature and the previous history of the battery. Figure 3-27 shows the percentage of rated capacity delivered during discharges at various rates and temperatures. The midpoint voltage during discharge decreases as the discharge rate increases. If the battery were allowed to discharge to a lower cutoff voltage, a greater percentage of the *C*/5 rate capacity will be obtained. However, batteries should not be discharged to too low, a cutoff voltage as the battery may be damaged.

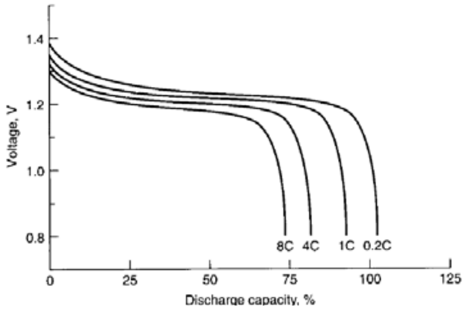


Figure 3-26 Constant-current discharge curves for sealed nickel-cadmium batteries at 20°C, charge 0.1C, 16 h.

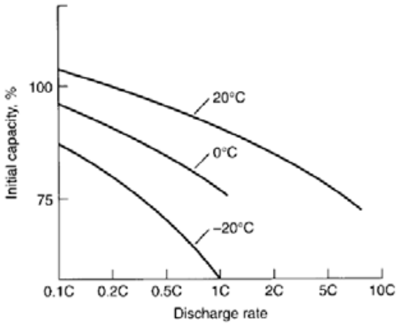


Figure 3-27 Percent of C/ 5-rate capacity vs. discharge rate to 1.0V cutoff for typical sealed nickel-cadmium battery.

3.3.3.2 Effect of Temperature

The sealed nickel-cadmium battery is capable of good performance over a wide temperature range. Best operation is between -20 and +30°C, although usable performance can be obtained beyond this range. The low-temperature performance particularly at high rates is generally better than that of the lead-acid battery but usually inferior to that of the vented sintered-plate battery. The reduction in performance at low temperatures is due to an increase in the internal resistance. At high temperatures, the loss can be due to a depressed operating voltage or to self-discharge. Figure 3-28 shows some typical discharge curves of the sealed battery at various temperatures at the 0.2*C* and 8*C* rates. Figure 3-29 shows typical discharge curves at -20°C. A flat discharge profile is still characteristic, but at a lower operating voltage than at room temperature.

The effect of temperature and discharge rate on the capacity of a sealed nickel-cadmium battery is shown in Figure 3-30. These data are typical of standard batteries. Manufacturers should be contacted to obtain performance characteristics of specific batteries.

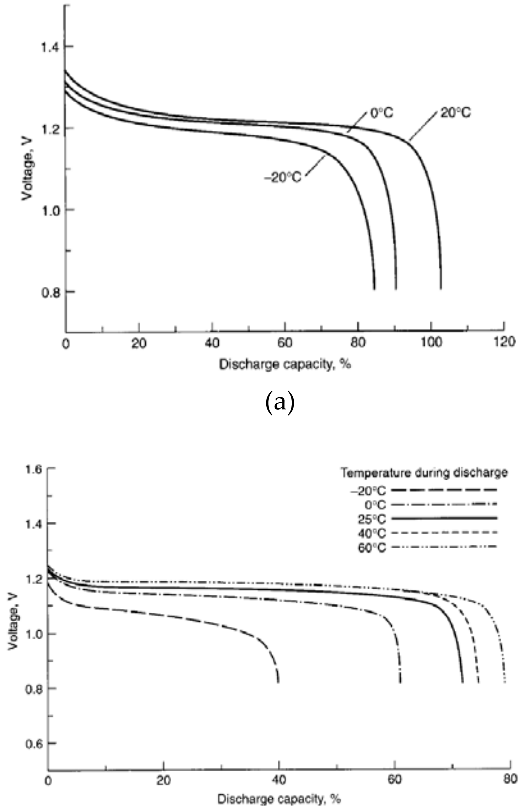


Figure 3-28 Constant-current discharge curves of sealed nickel-cadmium batteries at various temperatures. (a) 0.2C discharge rate. (b) 8C discharge rate.

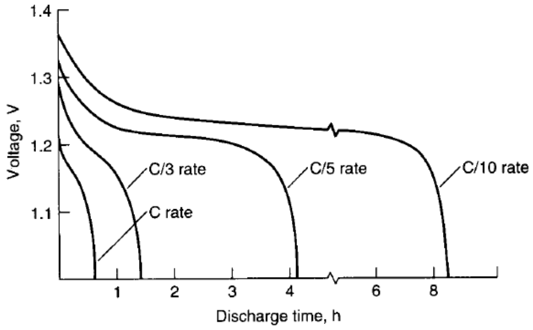


Figure 3-29 Constant-current discharge curves of sealed nickel-cadmium batteries at -20°C.

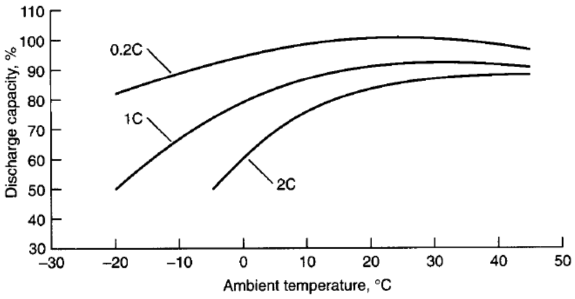


Figure 3-30 Percentage of rated capacity vs. temperature at different discharge rates for typical sealed nickel-cadmium batteries, 1.0V cutoff.

3.3.3.3 Battery (Cell) Polarity Reversal

Refer Figure 3-31, when Ni-Cd cells (cell = one unit: 1.2 volts) are connected in a series, parallel or series-parallel in a multi-cell battery, the potential for a cell or cells in a multiple cell battery pack to be discharged below normal operational cutoff voltage (usually between 1.10 volts/cell to 0.9 volts/cell) exists. The propensity of a cell or cells to over discharge in a reversed polarity is dependent on the following factors:

- Number of cells in series or parallel
- Discharge current
- Designed or expected discharge cutoff criteria
- Charging system
- Battery pack design (temperature profile during charge)

Although some Ni-Cd batteries are designed to accommodate some discharge reversal through special proprietary electrode formulations, Ni-Cd batteries have demonstrated serviceability. However, reversal is not desirable and battery design should accommodate system cutoff voltages if possible to prevent this condition. Reviewing the voltage characteristics of a Ni-Cd battery during over discharge reversal, the discharge voltage of the cell is somewhat proportionate to the level of active charge in each electrode of the Ni-Cd system. Referring to Figure 3-31, during the first phase of discharge, the normal discharge voltage to 0.3 to 0.0 volts is supported by active material in both the positive and negative material operating in a normal electrochemical reduction process. During second phase, the active material at the positive electrode has been fully discharged, therefore making a Ni-Cd cell positive electrode limiting and is no longer available to support a reactive. The oxygen gas resulting from the complete discharge of the positive electrode continues to support the discharging of the negative electrode. The voltage level during the continued discharging of the negative electrode to its completion remains at -0.2 to -0.4 volts. In the third phase, both the positive and negative have been completely discharged. Oxygen and hydrogen gas is generated at the negative electrodes and electrolysis of the electrolyte respectively. In prolonged discharging due to power supply failure to constant power discharge source the gas pressure within the cells will increase causing cells to vent or-rupture. Due to this condition, one-time vent or re-sealable vents are incorporated within cell designs. To maximize battery life, battery discharge criteria should be established to minimize the potential of a cell or multiple cells within the battery pack to being subjected to long term over discharge described in second phase and third phase. Voltage cutoff systems or other types of user interfaces will prevent battery from over charging.

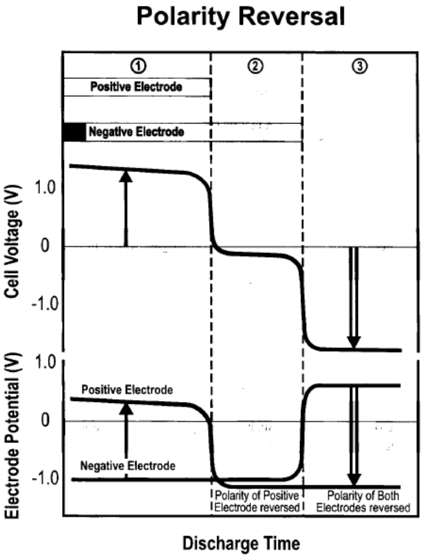


Figure 3-31 Polarity reversal

3.3.3.4 Cycle Life

The cycle life is usually measured to the point when the battery will not deliver more than a given percentage (usually 60 to 80%) of its rated capacity. Sealed nickel-cadmium batteries have long cycle lives. Under controlled conditions over 500 cycles can be expected on a full discharge, as illustrated in Figure 3-32. On shallow discharges considerably higher cycle life can be obtained, as shown in Figure 3-33. Cycle life is also very dependent on the many conditions to which the battery has been exposed, including charge, overcharge, discharge rates, frequency of cycling, the temperatures to which the battery has been exposed, and battery age, as well as battery design and battery components. Specially designed batteries, such as those using alkali-resistant materials, are also manufactured, which have longer life particularly at the higher temperatures.

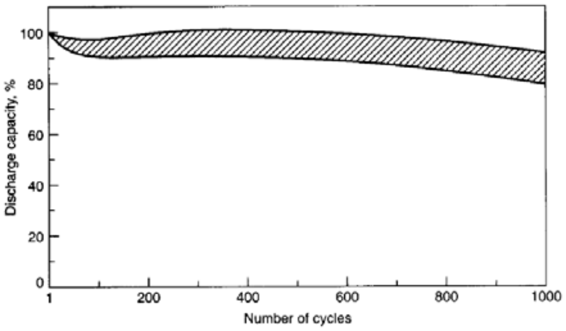


Figure 3-32 Cycle life of sealed nickel-cadmium batteries at 20°C. Cycle conditions: charge—0.1C×11 h: discharge—0.7C×1 h. Capacity-measuring conditions: charge—0.1C×16 h; discharge—0.2C, end voltage—1 V.

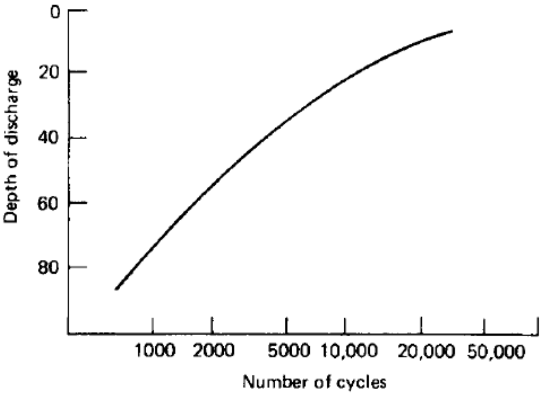


Figure 3-33 Cycle life of sealed nickel-cadmium batteries at shallow discharge.

3.3.3.5 Life Expectancy and Failure Mechanisms

The useful life of a nickel-cadmium battery can be measured either in terms of the number of cycles before failure or in units of time. It is virtually impossible to know all the detailed information necessary to make any kind of accurate prediction of battery life in a given application. The best that can be provided is an estimate based on laboratory test data and field experience or extrapolation of accelerated test data.

Basically, failure of a battery occurs when it ceases to operate the device for whatever reason at the prescribed performance level, despite the possibility that the battery may still be useful in another application with less demanding requirements. Failure of a nickel-cadmium battery can be classified into two general categories: reversible and irreversible failure. When a battery fails to meet the specified performance requirements but can, by appropriate reconditioning, be brought back to an acceptable condition, it is considered to have suffered a reversible failure. Permanent or irreversible failure occurs when the battery cannot be returned to an acceptable performance level by reconditioning or any other means.

a) Reversible Failures

Voltage Depression (Memory Effect): A sealed nickel-cadmium battery may suffer a reversible loss of capacity when it is cycled repetitively on shallow discharges (discharge terminated before its full capacity is delivered) and recharged. For example, as shown in Figure 3-34, if a battery is cycled repetitively, but only partially discharged and then recharged, the voltage and delivered capacity will gradually decrease with cycling (curves 2 representing repetitive cycling). If the battery is then fully discharged (curve 3), the discharge voltage is depressed compared to the original full discharge (curve 1). The discharge profile may show two steps and the battery may not deliver the full capacity to the original cutoff voltage. This phenomenon is known as ''voltage depression''. It also is referred to as ''memory effect'', as the battery appears to ''remember'' the lower capacity of the shallow discharge. Operation at higher temperatures accelerates this type of loss. The battery can be restored to full capacity with a few full discharge-charge reconditioning cycles. The discharge characteristics on the reconditioning cycles are illustrated in Figure 3-34 (curves 4 and 5).

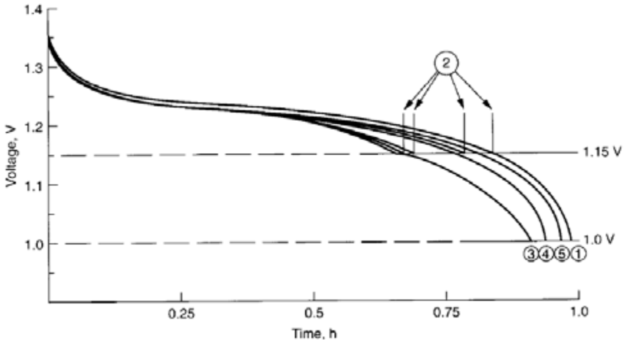


Figure 3-34 Voltage depression and subsequent recovery.

The voltage drop occurs because only a portion of the active materials is discharged and recharged during shallow or partial discharging. The active materials that have not been cycled, particularly the cadmium electrode, may undergo a change in physical characteristics and an increase in resistance. The effect has also been ascribed to structural changes in the nickel electrode. Subsequent cycling restores the active materials to their original state. The extent of voltage depression depends on the depth of discharge and can be avoided or minimized by the selection of an appropriate end voltage. Too high an end voltage, such as 1.16 V per cell, terminates the discharge prematurely. (A high end voltage should be used only if an extended cycle life is desired and the lower capacity can be tolerated, as in some satellite applications.) A small voltage depression may be observed if the discharge is terminated between 1.16 and 1.10 V per cell. The extent of the depression is dependent on the depth of discharge, which is also rate-dependent. Discharging to an end voltage below 1.1 V per cell should not result in a subsequent voltage depression. Discharging to too low an end voltage however, should be avoided.

This phenomenon varies with the design and formulation of the electrode and may not be evident with all sealed nickel-cadmium batteries. Modern nickel-cadmium batteries use electrode structures and formation processes that reduce the susceptibility to voltage depression and most users may never experience low performance due to memory effect. However, the use of the term ''memory effect'' persists, since it is often used to explain low battery capacity that is attributable to other problems, such as ineffective charging, overcharge, battery aging or exposure to high temperatures.

Overcharging: A similar reversible failure can occur with long-term overcharging, particularly at elevated temperatures. Figure 3-35 shows the voltage ''step'' near the end of discharge that can be induced by long-term overcharging. The capacity is still available, but at a lower voltage than when it was freshly cycled. Again, this is a reversible failure a few charge and discharge cycles will restore normal voltage and expected capacity.

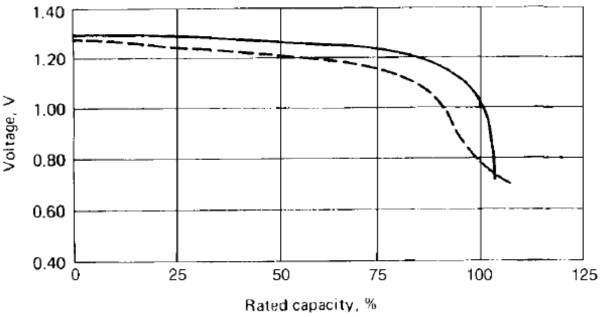


Figure 3-35 Typical discharge voltage profile of sealed nickel-cadmium batteries after long-term overcharge (dotted line) vs. 16-h charge, both at C / 10 rate.

b) Irreversible Failures

Permanent failure in nickel-cadmium batteries results from essentially two causes: short-circuiting and loss of electrolyte. An internal short circuit may be of relatively high resistance and will be evidenced by an abnormally low on-charge voltage and by a drop of voltage as the battery's energy is dissipated through the internal short circuit. A short circuit may also be of such a low resistance that virtually all the charge current travels through it or the battery electrodes are totally shorted internally. Any loss of electrolyte will cause degradation in capacity. Charging at high rates, repeated voltage reversal and direct short-circuiting are ways that can cause loss of electrolyte through the pressure relief device. Electrolyte can also be lost over a long period of time through the battery seals and capacity is lost in proportion to the reduction in electrolyte volume. Capacity degradation caused by electrolyte losses is more pronounced at high discharge rates. High temperature degrades battery performance and life. A nickel-cadmium battery gives optimum performance and life at temperatures between 18 and 30°C. Higher temperatures reduce life by promoting separator deterioration and increasing the probability of short circuiting. Higher temperatures also cause more rapid evaporation of moisture through the seals. These effects are all long-term but the higher the temperature, the more rapid the deterioration. Table 3-3 lists the recommended temperature limits for sealed nickel-cadmium batteries.

Table 3-3 Operating and Storage Limits for Sealed Nickel-Cadmium Batteries

Type	Temperature, °C	
	Storage	Operating
Button	-40 to 50	-20 to 50
Standard cylindrical	-40 to 50	-40 to 70
Premium cylindrical	-40 to 70	-40 to 70

3.3.3.6 Charging Characteristics

Sealed nickel-cadmium batteries are usually charged by means of the constant-current method. The 0.1*C* rate can be used and the battery is charged for 12 to 16 h (140%). At this rate the battery can withstand overcharging without harm, although most sealed nickel cadmium.

Batteries can be safely charged at the *C*/100 to *C*/3 rate. At higher charge rates care must be taken not to overcharge the battery excessively or develop high battery temperatures. The voltage profile of a sealed nickel-cadmium battery during charge at the *C*/10 and *C*/3 rates is shown in Figure 3-36. A sharp rise in voltage to a peak near the end of the charge is evident. The voltage profile of a sealed nickel-cadmium batteries is different from the one for a vented one, as illustrated in Figure 3-37 The end-of-charge voltage for the sealed battery is lower. The negative plate does not reach as high a state of charge as it does in the vented construction because of the oxygen recombination reaction. Constant-potential charging is not recommended for sealed nickel-cadmium batteries as it can lead to thermal runaway. It can however, be used if precautions are taken to limit the current toward the end of charge.

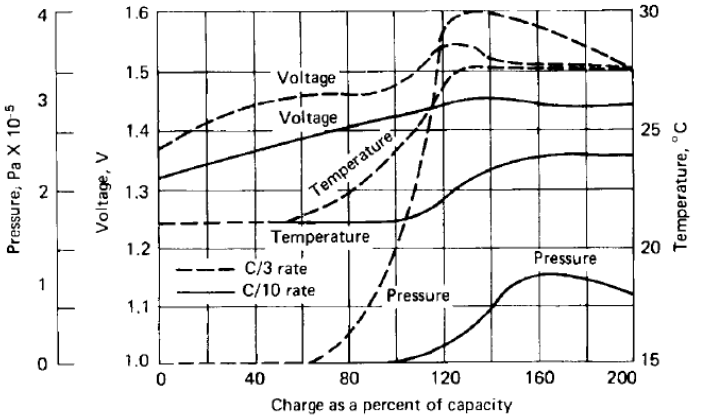


Figure 3-36 Typical pressure, temperature, and voltage relationships of sealed nickel-cadmium battery during charge.

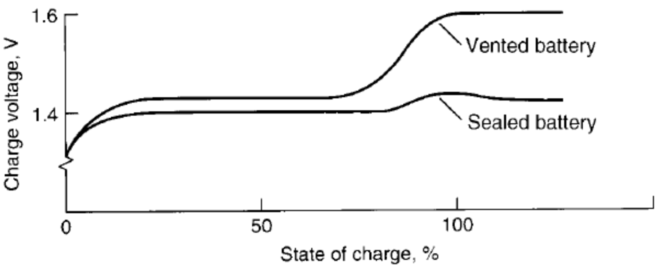


Figure 3-37 Charge vs. voltage for sealed and vented nickel-cadmium batteries at 25°C; 0.1C charge rate.

3.3.4 General considerations of Ni-Cd batteries

3.3.4.1 Performance

Assembled cells or batteries will be tested i.e., charged and discharged to evaluate their performance. Normal rating of sintered type batteries is at 5 hour rate only. Higher rates of charging also possible and the batteries can be charged even at one hour rate. They can be rapidly charged in a wide range of temperature varying from -55°C to +75°C adopting either constant current or constant potential method. A high rate discharge property is excellent. At the 10% C rate more than 75% of the nominal capacity and the 15%C rate more than 60% to a final voltage of 0.6V can be obtained. Pulse discharges as higher as 20-40 % C are possible with vented sintered plate cells. The nickel cadmium cells are less sensitive to temperature changes than most other systems and the sintered plate design is the best one in this respect. Thin plate cells are capable of giving about 70% of rated capacity at 5 hour rate at -40°C. At higher rates, the effect of temperature is somewhat more marked still at 10% C rate and at 20 °C about 40% of the rated capacity can be drawn out. Values even better than these may be obtained from cells with extra thin plate. Sintered plate cells have a very good cycle life and are reliable in most applications.

These cells have a higher energy density than pocket type cells. The charges retention is good and can be stored in any state of charge for many years. Sintered type cells have a great resistance to shock, vibration and physical damages. They can also stand overcharging, short circuited and reversal maintenance is usually limited to occasional topping up with water.

3.3.4.2 Battery Life

The life of the sintered plate battery is ordinarily characterized in terms of the number of charge-discharge cycles that can be delivered or in terms of total life time in years. Sintered plate batteries last 10 years or gives more than 2000 cycles depending upon the operating conditions. The life is mostly limited by the failure or separator materials which are influenced marked by high temperature, high electrolyte density and high carbonate concentration. For maximum battery life the following operating conditions should be followed.

a. High temperature (>45°C) musts be avoided especially during charging.

b. Deep discharge and reversals on cycling must be avoided.
c. On hard cycling electrolyte addition agents can be tried.
d. The carbonates content of the electrolyte is to be kept minimum value.

Ordinarily, the battery life is considered to be ended when the capacity drops to 60 - 80%. Now let's discuss two common concerns, myths, and misconceptions about Ni-Cd cells: reversal and memory.

3.3.4.3 Reversal

What is cell reversal? Batteries made up of more than one cell have the potential for cell reversal problems when the discharge is deep enough to bring one or more of the cells in a battery to zero voltage. If discharge continues beyond this point, the voltage on the depleted cell will reverse polarity. Refer the general voltage curve as has been shown in Figure 3-26 before, except now it is continued into the area of over discharge. The positive electrode is usually the first to run out of capacity. Continuation of the discharge will cause the reversal of the negative electrode and the voltage will be further reduced to about -1.4 volts. The problem that occurs is the generation of hydrogen gas. As the electrodes change polarity they will generate hydrogen. Since the hydrogen will not recombine the internal cell pressure will build up to a level that causes the cell to vent if the reverse charge current is maintained for a significant period of time. The solution to cell reversal is to avoid design applications where the cells will be reversed repetitively or deeply. This is done by selecting a sufficiently high cutoff voltage to assure that cells will not be reversed. Cell reversal is more damaging at lower rates since the electrochemical reversal occurs at nearly the same time as the electrical reversal caused by the increase in internal resistance as the cell capacity is depleted. At higher discharge rates, such as we find in power tools, the electrical reversal occurs before the electrochemical reversal with a significant fall off in performance of the product. The use of tapped cell packs for speed control in power tools depends upon this principle and has been tested to verify that there is no damage to the cell pack. Cells received several hundred cycles of 40% reversal at a 10 C rate, that is the cells were charged in reverse at 12 amps for 40% of their capacity with no detrimental effects noted.

3.3.4.4 Memory Or Voltage Depression

Contrary to popular belief, the memory effect is not a loss of cell capacity. Memory is a step in the discharge curve of a cell.

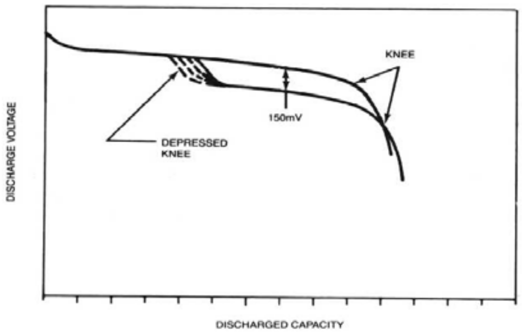


Figure 3-38 Effect of Long-term overcharge at elevated temperature

See the Figure 3-38 how the voltage of the lower curve is depressed compared with the normal discharge curve that we have seen before. The end result of the step is significant only if a device is designed with too high a cutoff voltage. Most designers take this effect into account and allow for their devices to be run at low enough voltage to avoid this problem. What causes memory? Actually there are two ways to create a step in the voltage profile. One is a precisely repetitive partial discharge followed by a slow full charge. The discharge must be to exactly the same point every discharge in order for this effect to appear. The second and more frequently encountered effect is voltage depression, which is also called memory. This is caused by continuous overcharge at the overnight rate. If a battery is left on slow charge for long periods, the crystals of active material in the plates grow larger. As the crystals grow, the surface area of active material in contact with the electrolyte decreases and this phenomenon manifests itself as a very slight increase in internal resistance plus a decrease in the open circuit voltage. The voltage step will occur at different times, depending upon how long the overcharge occurs and the temperature of the battery in overcharge. As the overcharge continues the area of voltage depression will occur earlier in the discharge curve. The area of depression can be removed by one or more discharge/charge cycles, thereby returning the cell's voltage profile to normal. Today’s cell designs have improved to the point where this condition is seldom exhibited.

3.3.4.5 Uses

Nickel cadmium battery can be used as a replacement for practically any other type of battery limited solely by cost and a slight difference in weight and volume. The nickel cadmium sintered type batteries can find use in any field whenever secondary batteries are useful. They are widely used in industries for diesel engine, cranking, electric truck operations. Sintered type batteries are extensively used in military operations since the low temperature and high rate performance are excellent when compared to all other power sources. Sintered plate sealed or vented cells find use in electrical and electronic applications used in civilian applications and for communication equipments in military telephones etc. and aircraft storage batteries.

3.4 Silver-Zinc Storage Technology

These batteries provide the highest energy per unit weight and volume of any commercially available secondary batteries. They can operate efficiently at extremely high discharge rates, and they exhibit good charge acceptance at moderate rates and low self discharge. The disadvantages are low cycle life (ranging from 10 to 200 deep cycles, depending on design and use), decreased performance at low temperatures, sensitivity to overcharge, and high cost. Rates as high as 20 times the nominal capacity (20C rate) can be obtained from specially designed silver-zinc batteries because of their low internal impedance. These high rates however must often be limited in time duration because of a potentially damaging temperature rise within the cells.

3.4.1 General Characteristics

The rechargeable silver oxide batteries are noted for their high energy and power density. The high cost of the silver electrode, however has limited their use to applications where high energy density is a prime requisite, such as lightweight radio and electronics equipment, submarines and torpedoes and space applications.

3.4.1.1 Cell Reactions

The overall electrochemical cell reactions for the silver-zinc, which use aqueous solutions of potassium hydroxide (KOH) for electrolyte, can be summarized as follows:

$$\mathbf{AgO + Zn + H_2O \quad \underset{\text{charge}}{\overset{\text{Discharge}}{\Leftrightarrow}} \quad Zn(OH)_2 + Ag}$$

3.4.1.2 Positive-Electrode Reactions

The charge and discharge processes of the silver electrode in alkaline systems are of special interest because they are characterized by two discrete steps which manifest themselves as two plateaus in the charge and discharge curves. The reaction occurring at the silver electrode at the higher (peroxide) voltage plateau is shown as

$$\mathbf{2AgO + H_2O + 2e \quad \underset{\text{charge}}{\overset{\text{Discharge}}{\Leftrightarrow}} \quad Ag_2O + 2OH^-}$$

and at the lower, monoxide, voltage plateau as

$$\mathbf{Ag_2O + H_2O + 2e \quad \underset{\text{charge}}{\overset{\text{Discharge}}{\Leftrightarrow}} \quad 2Ag + 2OH^-}$$

As shown, these reactions are reversible.

3.4.2 Cell construction and components

While there are a number of methods used for manufacturing the positive electrodes, the two most important processes are the sintering of silver powders and slurry pasting. The former procedure produces electrodes with superior mechanical properties. The silver mass which is formed by sintering silver powder at temperatures between 400°C and 700°C is supported on silver or silver-plated copper grids. This method allows a continuous manufacturing process and a final assembly with the positive electrode in a fully discharged condition, which greatly improves the storage characteristics of the system. Organic resins and pore-forming materials may be added to the silver and continuous sheets formed by a rolling process. This method is used when thin sintered plates are required. Non-sintering methods are based on electroforming plates which have been prepared by spreading a silver oxide / water slurry onto suitable support grids. In some processes, thermal decomposition at 400°C precedes electroforming. Again, this method of manufacture may be performed on a continuous basis. Many different fabrication procedures are used for the zinc electrode. One group of methods starts with zinc oxide and various additives and follows with electrochemical reduction in dilute aqueous KOH. In another, zinc is electrodeposited from a cyanide bath. Others use mixtures of zinc, zinc oxide and organic binding agents. Generally the electrodes are formed on open-mesh grids. In all cases the aim is to produce electrodes of high porosity and controlled thickness. Additives include surface active agents to minimize dendritic growth and mercuric ions to increase the hydrogen over voltage of the zinc and so reduce corrosion. The separator assembly is the most critical component of zinc-silver oxide secondary cells. In addition to its normal function of preventing contact and short circuit between electrodes of different polarity, a separator will also:

- Prevent silver migration to the negative electrode.
- Control zincate migration.
- Have the swelling properties required to establish favorable zinc morphology and distribution on charge.
- Preserve the integrity of the zinc electrode.

In addition, the separator must have a low electrical resistance, good thermal and chemical stability and must be light in order to retain the high energy density characteristics of the cell. Practical separators have a composite multilayer configuration. A 'silver-stopping' layer of cellophane or non-woven synthetic polyamide is located next to the positive electrode which reduces soluble silver species back to the metal. A potassium titanate paper layer may be placed next to the zinc electrode and a number of cellophane layers which swell in aqueous KOH make up the middle section. In most cells the separators are fabricated as envelopes or 'sacks' which completely enclose the zinc electrodes. Commercial cells are generally rectangular (prismatic) in shape and the case is usually plastic, with a rugged construction to withstand the mechanical stress to which this system is often subjected. The cells are sealed, but normally have a safety filler valve assembly. (Small quantities of oxygen evolved at the silver electrode during recharge may recombine with excess zinc on the negative electrode however, the membrane separator assembly slows down oxygen diffusion.) The quantity of free electrolyte is very small, the majority is contained within the electrode pores or separator. Freshly assembled cells are subjected to a series of formation cycles in order to activate the system. Cells are often sold in a charged but dry state, in which case the formation process is performed before the final cell assembly. Dry charged batteries can be stored indefinitely. Cells containing electrolyte should be stored in the completely discharged state since dissolution of silver oxide is then avoided.

Secondary silver cells have been produced in prismatic, spirally wound cylindrical, and button shape configurations. The most common shape is the prismatic. The construction of a typical prismatic cell is shown in Figure 3-39. This cell contains flat plates which are wrapped with multiple layers of separator to provide mechanical separation and inhibit migration of the silver to the zinc plate and the growth of zinc dendrites toward the positive plate. The plate groups are intermeshed and the pack is placed in a tightly fitting case (Figure 3-40). Because of the relatively short shelf life of the activated silver cells, they are usually supplied by the manufacturers in the dry-charged or dry unformed condition, with filling kits and instructions.

System Components

Anode - Zinc powder electrode

Cathode - Silver Oxide (sintered or pasted)

Electrode Grids - Silver wire mesh

Electrolyte - 40% KOH

Separator - Cellophane or Nylon cloth

Container material - Polystyrene (Transparent and softening temp. is 80°C.)

Binding Materials - Epoxy Araldite and Hyzol solvent

Terminal Bolts and Nuts - Silver plated Steel/Brass terminals for maximum conductivity and corrosion resistance.

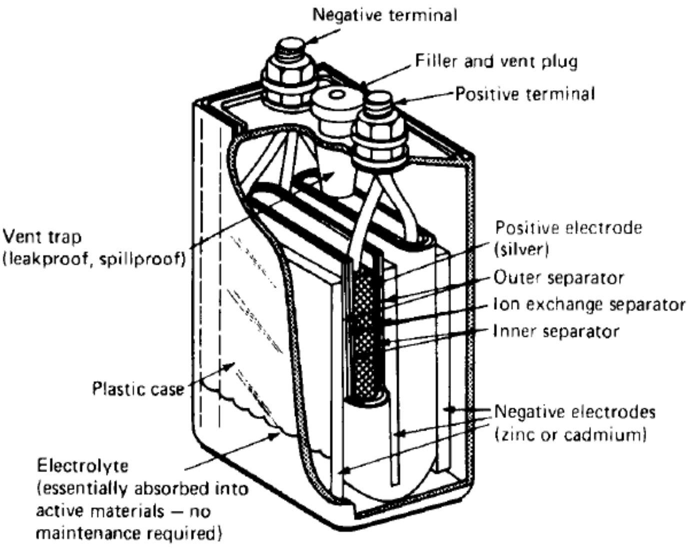


Figure 3-39 Zinc / Silver Oxide secondary battery-cutaway view

The cells are filled with electrolyte and activated just prior to use. They may also be supplied in the filled and ready-to-use condition if required by the user.

The mechanical strength of these cells is generally excellent. The electrodes are generally strong and are fitted tightly into the containers. The cell containers are made of high-impact plastics. Various designs of these cells, when properly packaged have met the high-shock and acceleration requirements of missiles and torpedoes with no degradation.

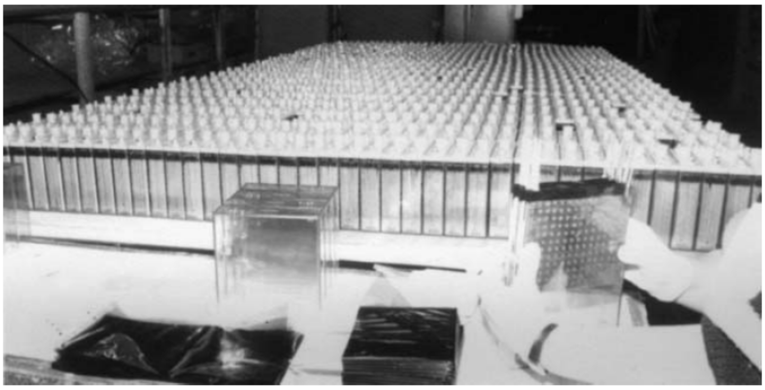


Figure 3-40 Cells stack being assembled into cell case, model 45AH Silver Zinc battery

3.4.2.1 Silver Electrodes

The most common fabrication technique for silver electrodes is by sintering silver powder onto a supporting silver grid. The electrodes are manufactured either in molds (as individual or as master plates which are later cut to size) or by continuous rolling techniques; they are then sintered in a furnace at approximately 700°C.

Alternate techniques include the dry processing and pressing or slurry pasting with a binder of AgO or Ag_2O onto a grid. If pasted, the plates are often sintered during which the silver oxide is converted into metallic silver and the organic additives are burned off. The grid may be a woven or expanded metal form of silver, silver-plated copper or in some cases nickel.

After being cut to size and having wires or tabs welded onto an appropriately coined (compressed)area to carry current to the cell terminals, the electrodes are either electroformed (charged in tanks against inert counter electrodes) before assembly in to cells or assembled in to the cells in the metallic state and later charged in the cell.

Grid material, density and thickness, electrical lead type and size, final electrode size, are all design variables which depend on the intended application for the cells.

3.4.2.2 Zinc Electrodes

Zinc electrodes are most widely made by dry-pressing by a slurry or paste method or by electro deposition. In the dry-pressing metho, a mixture of zinc oxide, binder and additives is compressed around a metal grid, this is normally done in a mold. The grid usually has the current-carrying leads pre-welded in place. As the unformed powder electrodes have little strength, one component of the separator system, the negative inter separator, is usually assembled around the electrode as part of the fabricating operation. Rolling techniques have also been developed to permit continuous fabrication of dry-powder electrodes.

In the paste or slurry method the mixture of zinc oxide, binder and additives is combined with water and applied continuously to a carrier paper or directly to an appropriate metal grid. Again the negative inter separator is usually integral to provide needed physical strength. After drying, multiple layers of these pasted slabs may be pressed together about a pre-tabbed grid to form the final electrode. These plates may be assembled unformed into the cell or may be electroformed in a tank against inert counter electrodes.

Electrodeposited negative electrodes are manufactured by plating zinc in tanks onto metallic grids. The plates must then be dried and pressed or rolled to the desired thickness and density.

The zinc electrode is acknowledged as the life-limiting component in both the silver-zinc and nickel-zinc systems. Accordingly, much work has been done in the area of additives for these electrodes both to reduce the hydrogen evolution and to improve cycle life. The common additive to reduce hydrogen evolution has traditionally been mercury (1 to 4% of the total mix), but this is being replaced for personnel safety reasons by small amounts or mixes of the oxide of lead, cadmium, indium, thallium or gallium. Many other (proprietary) additives have been introduced into the zinc electrode by various manufacturers in attempts to increase life.

Zinc electrodes also suffer capacity loss, which results from "shape change" or material migration from the surface of the zinc electrode. Several approaches have been taken to improve the stability of the zinc electrode: (a) an excess of zinc is used to compensate for losses during cycling (b) oversized electrodes are used on the basis that shape change starts on the electrode edges where current densities are higher and (c) binders such as Teflon or potassium titanate are used to hold the active materials together.

As is the case for the silver electrodes, the grid material, additives, and final electrode size, thickness and density are all design variables which depend on the final application.

3.4.2.3 Separators

The separators in the silver cells must meet the following major requirements:

- Provide a physical barrier between the positive and negative electrodes.
- Have minimum resistance to the flow of electrolyte and ions.
- Prevent migration of particles and dissolved silver compounds between the positive and negative electrodes.
- Be stable in the electrolyte and cell operating environment.

In general, secondary silver-zinc and silver-cadmium cells require a minimum of three different separators as shown in Figure 3-39. The "inner separator" or positive inter separator serves both as an electrolyte reservoir and as a barrier to minimize oxidation of the main separator by the highly oxidative silver electrode. This separator is usually made of an inert fiber such as nylon or polypropylene.

The "outer separator" or negative inter separator also serves as an electrolyte reservoir and can also ideally serve to stabilize the zinc electrode and retard zinc penetration of the main separator, thus minimizing dendrite growth. Much work has been done recently to develop improved inorganic negative electrode inter separators utilizing such materials as asbestos and potassium titanate. Improvements in cell life have been reported as a result of this work.

The main "ion exchange" separator remains the key to the life of the secondary silver cell. It was Andre's use of cellophane as a main separator that first made the secondary silver cells feasible. The cellulosics (cellophane, treated cellophane and fibrous sausage casing) are usually employed in multiple layers as the main separators for these cells. Again, much work has been done in recent years to develop improved separators utilizing such materials as radiation-grafted polyethylene, inorganic separators and other synthetic polymer membranes. Improved cell life has been reported through use of these new membranes either alone or in combination with the cellulosics. They have yet to be applied extensively to commercial silver cells however, because of drawbacks usually involving high impedance or availability and cost.

3.4.2.4 Cell Cases

The cell cases must be chemically resistant to attack by the corrosive concentrated potassium hydroxide electrolyte and to oxidizing effects of the silver electrodes. They must also be strong enough to contain any internal pressure generated in the cells and to maintain structural integrity throughout the anticipated range of environmental conditions that will be experienced by the cells.

The majority of secondary silver cells are assembled in plastic cases. The plastic most commonly used is an acrilonitrile styrene copolymer (SAN). This material is relatively transparent and can be easily sealed by solvent cement or epoxy. However, its relatively low softening temperature (80°C) precludes it for use in some applications. A wide variety of plastics have been used for cell cases.

Electrolyte and Other Components

The electrolyte used in secondary silver cells is generally an aqueous solution (30 to 45% concentration) of potassium hydroxide (KOH). Terminals are typically made of steel or brass and are almost always silver-plated for maximum conductivity and corrosion resistance.

3.4.3 Performance Characteristics

3.4.3.1 Performance and Design Tradeoffs

The performance of the cells for any specific application will depend on the internal design and history of the cells. It is rare that one can select an "off-the-shelf" cell that will meet all the requirements of a specific specialized application. Starting with the basic parameters, the cell design will consist of a series of compromises to obtain the most favorable combination of voltage, electrical capacity and cycle life characteristics within the allowable battery weight and volume.

Assuming for example, a nominal 1.5 V per silver-zinc cell at low current densities (0.01 to 0.03 A/cm^2) and lower voltages at higher currents, the designer selects the number of cells for the application. The problem is increased if high current pulse loads are required and the battery must provide voltage above the minimum allowable at the high rate, while not exceeding the maximum allowable voltage at initial low rates. The size of the cell is then chosen by dividing the allowable volume by the calculated required number of cells.

The voltage, current, electrical capacity and cycle-life requirements must then be reviewed in conjunction with the allowable weight and the environmental conditions that the battery must be able to withstand. Each of these will be a factor in determining the choice of separator material for the cell. The stability and number of layers of separator must be sufficient to provide the desired wet life under these conditions while having a resistance low enough to prevent undue voltage drops at the high current loads. Each of these requirements is also a factor in choosing the number of electrodes within the cell. As the number of electrodes (and thus the active electrode area) is increased, the current density during any discharge is decreased-raising the output voltage. It should be noted that a cell design optimized for high discharge rates will, by nature of the design, have a reduced capacity under low discharge rates. This is a result of having many electrodes each of which must be wrapped with the required number of layers of separators. Given a fixed internal volume, it follows that less space is available for active electrode material in such a high-rate cell.

The cell must also be designed to contain enough active electrode material (e.g., silver and zinc) to supply the required electrical capacity for the desired number of cycles. Theoretically, 2 g of silver and 1.2 g of zinc are required in the cell for each ampere-hour of electrical capacity desired. Since these values are the theoretical capability of the pure material and since some of the active materials will go into solution with each charge-discharge cycle, the designer must work with higher values-in the order of magnitude of 4 g of silver and 3.5 g of zinc per nominal ampere-hour for multiple-cycle cells. Other design variables, such as silver powder particle size, will also ultimately affect cell performance.

Because of the above considerations, the performance curves shown in Figure 3-41, Figure 3-42, Figure 3-43 & Figure 3-44 below must be viewed in general terms as characteristic of the systems and not necessarily of specific cells for a specific application.

3.4.3.2 Discharge Performance for Zinc/Silver Oxide Cells

The open-circuit voltage of the zinc/silver oxide cell is 1.82 to 1.86 V. The discharge as shown in Figure 3-41 is characterized by two discrete steps, the first corresponding to the divalent oxide and the second corresponding to the monovalent oxide. The flat portion of the curves is referred to as “plateau voltage”. This voltage is rate-dependent at high rates the voltage steps may be obscured.

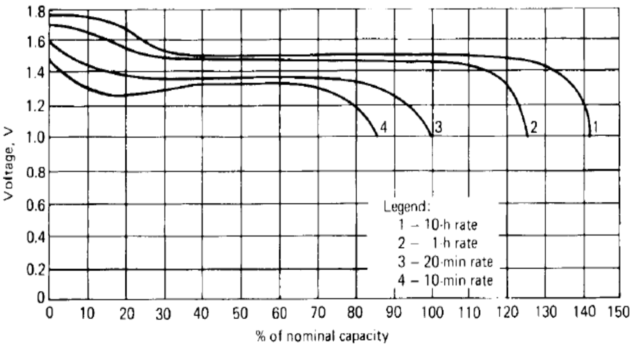


Figure 3-41 Typical discharge curves of Silver Zinc cells at various rates, 20°C

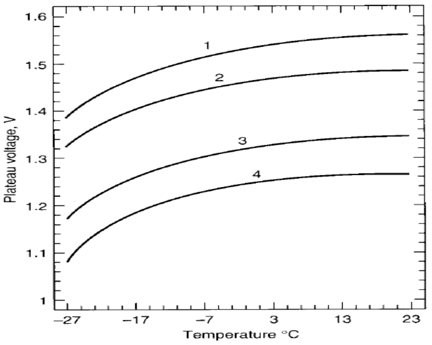


Figure 3-42 Typical effect of temperature on plateau voltage for high-rate silver-zinc battery (operated without heaters). Curve 1–10-h rate; curve 2–1-h rate; curve 3–20-min. rate; curve 4–10-min. rate.

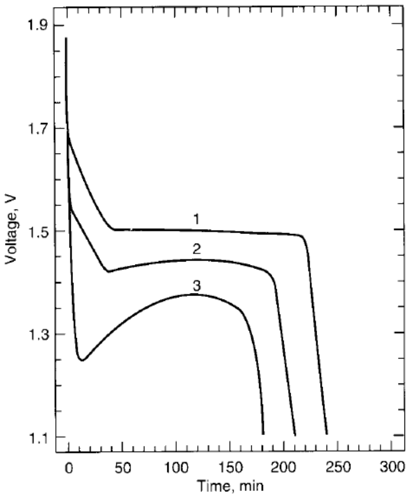


Figure 3-43 Typical discharge curves of high rate silver zinc battery at C/ 5 (9-A) rate. Curve 1—25°C; curve 2— 0°C; curve 3– -18°C.

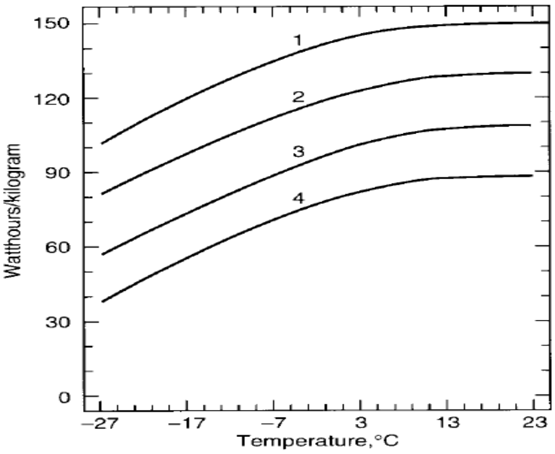


Figure 3-44 Typical effect of temperature on energy per unit weight for silver-zinc battery (operated without heaters). Curve 1—10-h rate: curve 2—1-h rate: curve 3—20-min rate: curve 4—10-min rate.

The performance of the cell at various discharge rates and temperatures can be seen at Figure 3-42, Figure 3-43 and Figure 3-44 showing the effect on plateau voltage and capacity. The high rate capability of the zinc/silver oxide cell is due to the electrical conductivity of the silver grid and the conductivity of the positive electrode as it is discharged, as well as the thin multi-plate design of the cell. The performance of the cell falls off with decreasing temperature particularly below -20°C. Heating the cell with external heaters or by internal heat generated by high-rate discharge can improve the performance at low ambient temperatures.

3.4.3.3 Cycle Life and Wet Life

The cycle life and the wet life of these silver oxide cells will vary greatly with design and with operating and storage conditions. The life of the zinc/silver oxide cell is poor, which is one of its main disadvantages. This poor life is due to the solubility of the active materials, the properties of the separator, the growth of zinc dendrites and the change of shape of the zinc electrode. The nominal wet life and cycle life ratings for the silver-zinc cells are given in Table 3-4.

Table 3-4 Nominal life characteristics of secondary Silver Zinc Cells*

	High – rate Ag-Zn	**Low-rate Ag-Zn**
Wet shelf	6-12 months	1-3years
†Cycle life	10-50 cycles	100-150 cycles

*These characteristics are nominal and vary with operating conditions and design of individual models.

†Cycle life characteristics are for deep (80-100% of full capacity) discharge cycles. Cycle’s life improves considerably with partial discharges.

3.4.4 Charging Characteristics

3.4.4.1 Efficiency

The ampere-hour efficiency (ampere-hour output/ampere-hour input) of the silver-zinc system under normal operating conditions is high-greater than 98% because practically no side reactions occur when charging at normal rates. The watt-hour efficiency (watt-hour output/watt-hour input) is about 70% under normal conditions because of the difference between the charge and discharge polarization potentials.

3.4.4.2 Constant current charging

The manufacturers of these cells recommend constant-current charging at the 10 to 20 h rate for most applications. However, constant potential and pulsed charging techniques have also been applied.

A typical charge curve at constant current is shown in Figure 3-45. The two level areas (plateaus) reflect the two levels of oxidation of the silver electrode, the first from silver to monovalent silver oxide ($Ag_2 O$) which occurs at a potential of approximately 1.6 V, the second from the monovalent to the divalent silver oxide (AgO), which occurs at approximately 1.9 V.

Charging is normally terminated when the voltage during charge rises to 2.0 V. Above 2.1 V the cell begins to generate oxygen at the silver electrode and hydrogen at the zinc electrode decomposing water from the electrolyte. Overcharge is also detrimental to cell life in that it promotes the growth of zinc dendrites and subsequent short circuit.

The importance of proper charging to the life of these cells cannot be overemphasized. Special provisions must be made for those applications which do not permit the use of a constant current with preset voltage cutoff or a similar controlled charging method.

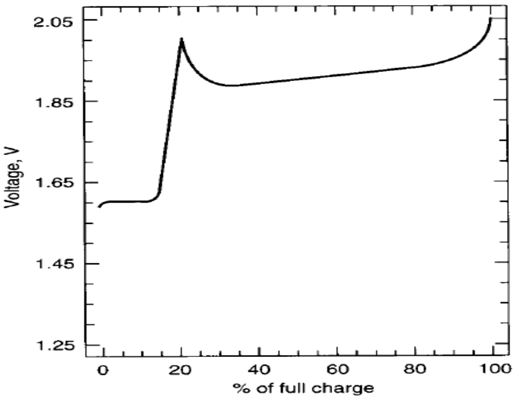


Figure 3-45 Typical charge curve of the silver-zinc cell, 20°C, 10-h charge rate

3.4.5 Special features and Handling

The silver cells are capable of providing extremely high currents if short-circuited. Accordingly, provisions must be made to insulate all tools used with the batteries and to protect the cells against grounding in their application.

The electrolyte is a caustic solution of potassium hydroxide. Precautions such as the use of gloves and safety glasses are required when handling the electrolyte. In most applications addition of electrolyte or water is not required. However, the manufacturer's recommendations for periodic maintenance and electrolyte checks should be followed closely.

Proper ventilation of these as well as other vented cells, although not as much a problem here as with other battery systems is required to avoid the accumulation of hazardous hydrogen, especially during charge. For larger installations, forced air or fans may also be required to prevent undesirable temperature buildups. When close voltage regulation is required at cold temperatures, thermostatically controlled heaters are often used with the batteries.

3.4.6 Applications

Because of the high cost of silver, the major applications of these batteries have historically been and continue to be governmental. However, these batteries have found many varied uses because of their high power and energy density where space and weight limitations are critical.

One of the original applications for the silver-zinc battery was in the underwater area for use in torpedoes. Much of the original development work was sponsored by the U.S. Navy. Later, development expanded to other underwater applications including mines, buoys, special test vehicles, swimmer aids and presently to the deep submergence and rescue vehicles (DSRV), such exploratory underwater vehicles as UUB and NR-l and various antisubmarine warfare (ASW) applications.

Space applications include use in various satellites and space probes powering the life-support equipment used by the Apollo astronauts, power for the Lunar Rover and Lunar Drill, space shuttle payload launching and controls and many missile functions including guidance and control, tele-metering and destruction. Aircraft applications span the range from tethered balloons to helicopters to target drones to aircraft and missiles.

Ground applications include communications equipment, portable TV cameras, portable lights, camera drives, medical equipment, automotive power and similar ones requiring a high energy density rechargeable battery.

The user should keep in mind that no one type of battery is suitable for all applications. Optimum performance of a battery in an application can usually be achieved only by meeting the critical needs of the application and subordinating the others. The best approach for battery selection is to work with the battery manufacturers to "design a battery that meets all requirements and fits into this remaining cavity in equipment".

3.5 Lead-Acid Storage Technology

The term storage battery has been used for many years as the name for a battery of secondary cells and particularly for lead-acid and nickel-cadmium batteries.

Two types of lead-acid batteries currently being used in aviation are (a) the vented cell and (b) the sealed (recombinant gas) battery (Figure 3-46). The modern sealed-cell lead-acid batteries are more powerful and require less maintenance than the older vented lead-acid aircraft batteries. For this reason, lead-acid batteries are being used to replace the more expensive nickel-cadmium battery in some turbine powered aircraft. On turbine-powered aircraft however, the installation of lead-acid batteries typically requires that external power be readily available for engine starting and the lead-acid batteries require more frequent replacement. Despite the great strides made to improve lead-acid batteries, they are still unable to deliver the current generated by nickel-cadmium batteries therefore, nickel-cadmium batteries will remain a practical power source for aircraft.

Lead-acid secondary cells consist of lead-compound plates immersed in a solution of sulfuric acid and water, which is the electrolyte. Each cell has an OCV of approximately 2.1 V when fully charged. When connected to a substantial load, the voltage is approximately 2 V. Aircraft storage batteries of the lead-acid type are generally rated at 12 V or 24 V that is, they have either 6 or 12 cells connected in series (Figure 3-46).

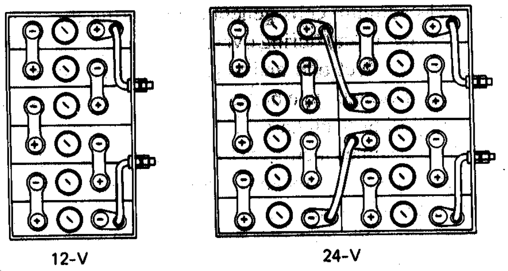


Figure 3-46 Arrangement of cell in a lead acid storage battery

Actually, the voltage of a l2-V battery is near 12.6 V (6 cells X 2.1 V/cell) when the battery is fully charged. A 24-V battery actually provides 25.2 V (12 cellsx2.l V/cell).

Table 3-5 Advantages and Limitations of Lead Acid Batteries(SLA)

Advantages	Inexpensive and simple to manufacture - in terms of cost per watt hours, the SLA is the least expensive. Mature, reliable and well-understood technology — when used correctly, the SLA is durable and provides dependable service. Low self-discharge —the self-discharge rate is among the lowest in rechargeable battery systems. Low maintenance requirements — no memory, no electrolyte to fill. Capable of high discharge rates.
Limitations	Cannot be stored in a discharged condition. Low energy density — poor weight-to-energy density limits use to stationary and wheeled applications. Allows only a limited number of full discharge cycles — well suited for standby applications that require only occasional deep discharges. Environmentally unfriendly — the electrolyte and the lead content can cause environmental damage. Transportation restrictions on flooded lead acid — there are environmental concerns regarding spillage in case of an accident. Thermal runaway can occur with improper charging.

3.5.1 Theory of the Lead-Acid Cell

The lead-acid secondary cell used in a storage battery consists of positive plates filled with lead peroxide (PbO_2), negative plates filled with pure spongy lead (Pb), and an electrolyte consisting of a mixture of 30 percent sulfuric acid (H_2SO_4) and 70 percent water by volume. A chemical action takes place when a battery is delivering current as shown in Figure 3-47.

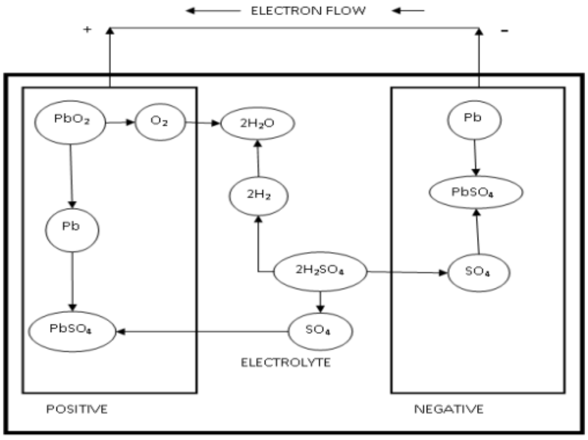


Figure 3-47 Chemical action in a lead acid secondary cell

The sulfuric acid in the electrolyte breaks up into hydrogen ions (H_2) carrying a positive charge and sulfate ions (SO_4) carrying a negative charge. The SO_4 ions combine with the lead plate and form lead sulfate ($PbSO_4$). At the same time, they give up their negative charge, thus creating an excess of electrons on the negative plate.

The H_2 ions go to the positive plate and combine with the oxygen of the lead peroxide (PbO_2), forming water (H_2O) and during the process they take electrons from the positive plate. The lead of the lead peroxide combines with some of the SO_4 ions to form lead sulfate on the positive plate. The result of this action is that the positive plate has a deficiency of electrons and the negative plate has an excess of electrons.

When the plates are connected together externally by a conductor, the electrons from the negative plate flow to the positive plate. This process will continue until both plates are coated with lead sulfate and no further chemical action is possible, the battery is then said to be discharged. The lead sulfate is highly resistant to the flow of current and it is chiefly this formation of lead sulfate that gradually lowers the capacity of the battery until it is discharged.

During the charging process, current is passed through the storage battery in a reverse direction. A DC supply is applied to the battery with the positive pole connected to the positive plate of the battery and the negative pole connected to the negative plate. The voltage of the source is greater than the voltage of the battery. This causes the current to flow in a direction to charge the battery. The SO_4 ions are driven back into solution in the electrolyte, where they combine with the H_2 ions of the water, thus forming sulfuric acid. The plates then return to their original composition of lead peroxide and spongy lead. When this process is complete the battery is charged.

Figure 3-48 shows the chemical changes that occur to a lead-acid battery during charge and discharge.

	CHARGED STATE	**CHEMICAL CHANGE**	**DISCHARGE**
POSITIVE PLATE	$Pb0_2$ ●	LOOSES O_2 GAINS SO_4	$PbSO_4$ ▶
NEGATIVE PLATE	Pb ●	GAINS SO_4	$PbSO_4$ ▶
ELECTROLYTE	H_2SO_4 ●	LOOSES SO_4 GAINS O_2	H_2O ▶

Figure 3-48 Chemical changes of a lead acid battery during charge & discharge

3.5.2 Lead-Acid Battery Construction (Vented type)

A storage battery consists of a group of lead-acid cells connected in series and arranged somewhat as shown in Figure 3-46. Under moderate load the closed circuit voltage (CCV) of the 6-cell battery is approximately 12 V and that of a 12cell battery is about 24 V. As stated earlier, CCV is the voltage of the battery when connected to a load.

Each cell of a storage battery has positive and negative plates arranged alternately and insulated from each other by separators. Each plate consists of a framework called the grid and the active material held in the grid. A standard formula for the grid material is 90 percent lead and 10 percent antimony. The purpose of the antimony is to harden the lead and make it less susceptible to chemical action. Other metals such as silver are also used in some grids to increase their durability.

A typical grid is illustrated in Figure 3-49. The heavy border adds strength to the plate and the small horizontal and vertical bars form cavities to hold the active material. The structural bars also act as conductors for the current, which is distributed evenly throughout the plate. Each plate is provided with extensions or feet, which rest upon ribs on the bottom of the cell container. These feet are arranged so the positive plates rest upon two of the ribs and the negative plates upon the two alternative ribs. The purpose of this arrangement is to avoid the short-circuiting that could occur as active material is shed from the plates and collects at the bottom of the cell.

The plates are made by applying a lead compound to the grid. The paste is mixed to the proper consistency with diluted sulfuric acid, magnesium sulfate or ammonium sulfate and is applied to the grid in much the same manner as plaster is applied to a lath wall. The paste for the positive plates is usually made of red lead (Pb_3O_4) and a small amount of litharge (PbO). In the case of the negative plates, the mixture is essentially litharge with a small percentage of red lead. The consistencies of the various materials and the manner of combining them have considerable bearing on the capacity and life of the finished battery.

In compounding the negative-plate paste a material called an expander is added. This material is relatively inert chemically and makes up less than 1 percent of the mixture. Its purpose is to prevent the loss of porosity of the negative material during the life of the battery. Without the use of an expander the negative material contracts until it becomes quite dense, thus limiting the chemical action to the immediate surface. To obtain the maximum use of the plate material the chemical action must take place throughout the plate from the surface to the center. Typical expanding materials are lampblack, barium sulfate, graphite, fine sawdust and ground carbon. Other materials known as hardness and porosity agents are

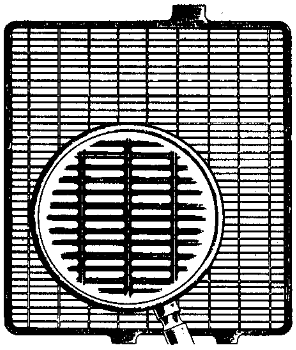


Figure 3-49 Grid for a lead acid cell plate

Sometimes used to give the positive plates desired characteristics for certain applications. One or more manufacturers reinforce the active material of the battery plates with plastic fibers 0.118 to 0.236 inches [3 to 6 mm] long. This adds substantially to the active life of the battery.

After the active-material paste is applied to the grids, the plates are dried by a carefully controlled process until the paste is hardened. They are then given a forming treatment in which a large number of positive plates are connected to the positive terminal of a charging apparatus and a like number of negative plates plus one are connected to the negative terminal. They are placed in a solution of sulfuric acid and water (electrolyte) and charged slowly over a long period of time. A few cycles of charging and discharging convert the lead compounds in the plates into active material. The positive plates thus formed are chocolate brown in color and of a hard texture. The negative-plate material has been converted into spongy lead of a pearl-gray color. After forming the plates are washed and dried. They are then ready to be assembled into plate groups.

Plate groups are made by joining a number of similar plates to a common terminal post (Figure 3-50). The number of plates in a group is determined by the capacity desired in as much as capacity is determined by the amount (area) of active material exposed to the electrolyte.

Since increasing plate area will increase a battery's capacity, many manufacturers strive for the maximum in internal battery dimensions. That is, if the inside of the battery can be kept as large as possible, the plate area can be increased. To do this, ultra thin plastic cases have been employed to "squeeze" the maximum plate area inside the battery of a given size. It also stands to reason that increasing the battery's outer (and inner) dimensions could be a means to increase capacity. However, for aircraft use we typically strive for the smallest, lightest battery with a relatively high capacity.

a. Each plate is made with a lug at the top to which the plate strap is fused. A positive-plate group consists of a number of positive plates connected to a plate strap and a negative group is a number of negative plates connected in the same manner. The two groups meshed together with separators between the positive and negative plates constitute a cell element (Figure 3-511). It will be noted in the illustrations that there is one less positive plate than negative plates.

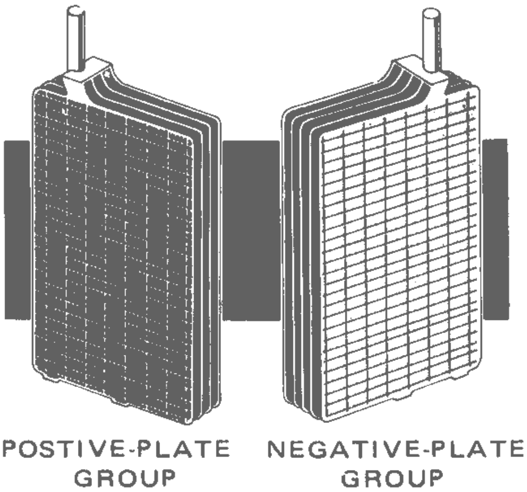


Figure 3-50 Plate groups

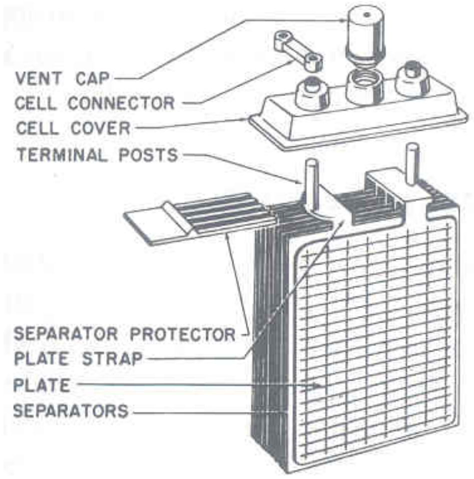


Figure 3-51 Cell element for a lead acid cell

This acid cell arrangement provides protection for the positive plates, in as much as they are more subject to warping and deterioration than the negative plates. By placing negative plates on each side of every positive plate, the chemical action is distributed evenly on both sides of the positive plate, and there is less tendency for the plate to warp.

The separators used in lead-acid storage batteries are made of fiberglass, rubber or other insulating materials. Their purpose is to keep the plates separated and thus prevent an internal short circuit. Without separators, even if the containers were slotted to keep the plates from touching, material might flake off the positive plates and fall against the negative plates. Negative material might expand sufficiently to come in contact with the positive plates or the positive plates might buckle enough to touch the negative plates.

The material of the separators must be very porous so that it will offer a minimum of resistance to the current passing through. The separators are saturated with electrolyte during operation and it is this electrolyte that conducts the electric current. It is obvious also that the separators must resist the chemical action of the electrolyte.

Glass-wool separators are used by some manufacturers. Fine glass fibers are laid together at different angles and cemented on the surface with soluble cement. The glass wool is placed in the cell adjacent to the positive plate. Because of the compressibility of glass wool it comes into very close contact with the positive plate and prevents the loosened active material from shedding. It is claimed that batteries with this type of separator have a longer life than those without it.

Another very effective method for providing plate separation is to enclose the positive plates in micro porous polyethylene pouches. This increases the efficiency of the battery because the plates are much closer together, approximately 0.05 in. [1.25 mm], than they are with other types of separators. The pouches also prevent the shedding of active material from the positive plates.

The term storage battery has been used for many years as the name for a battery of secondary cells and particularly for lead-acid and nickel-cadmium batteries.

Two types of lead-acid batteries currently being used in aviation are the vented cell and the sealed (recombinant gas) battery. The modem sealed-cell lead-acid batteries are more powerful and require less maintenance than the older vented lead-acid aircraft batteries. For this reason, lead-acid batteries are being used to replace the more expensive nickel-cadmium battery in some turbine powered aircraft. On turbine-powered aircraft, however, the installation of lead-acid batteries typically requires that external power be readily available for engine starting and the lead-acid batteries require more frequent replacement. Despite the great strides made to improve lead-acid batteries, they are still unable to deliver the current generated by nickel-cadmium batteries therefore, nickel-cadmium batteries will remain a practical power source for aircraft.

3.5.3 Parts of Lead Acid battery (Russian 12-CAM-28)

A battery consists of a number of cells and each cell of the battery consists of (a) positive and negative plates (b) separators and (c) electrolyte, all contained in one of many compartments of the battery container. Different parts of a lead acid battery are as under:

a) **Plates**: A plate consists of a lattice type of grid of cast antimonial lead alloy which is covered with active material. The grid not only serves as a support for the fragile active material but also conducts electric current. Grid for the positive and negative plates is often of the same design although negative plate grids are made somewhat lighter.

b) **Separators**: These are thin sheets of a porous material placed between the positive and negative plates for preventing contact between them and thus avoiding internal short-circuiting of the battery. A separator must however, be sufficiently porous to allow diffusion or circulation of electrolyte between the plates. These are made of especially-treated cedar wood, glass wool mat, microporous rubber (mipor), microporous plastics (plastipore, miplast) and perforated PVC as shown in Figure 3-52. In addition to good porosity, a separator must possess high electrical resistance and mechanical strength.

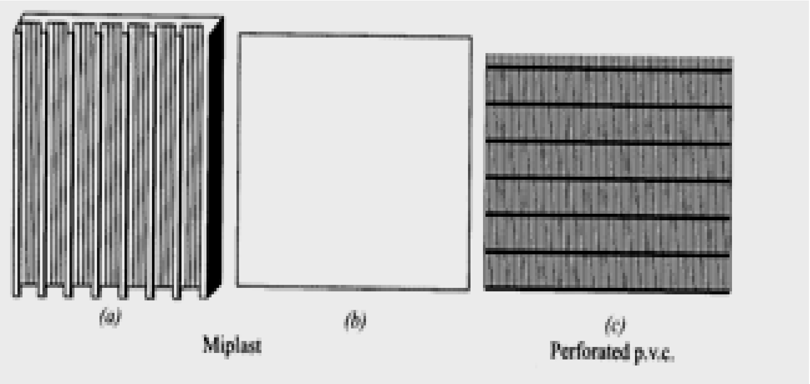


Figure 3-52 Microporous plastics (Plastipore, miplast) and perforated P.V.C.

c) **Electrolyte**: It is diluted sulphuric acid which fills the cell compartment to immerse the plates completely.

d) **Container**: It may be made of vulcanized rubber or moulded hard rubber (ebonite), moulded plastic, ceramics, glass or celluloid. The vulcanized rubber containers are used for car service, while glass containers are superior for lighting plants and wireless sets. Celluloid containers are mostly used for portable wireless set batteries. A single monobloc type container with 6 compartments generally used for starting batteries is shown in Figure 3-53. Full details of a Russian 12-CAM-28 lead-acid battery parts are shown in Figure 3-54. Details of some of these parts are as follows:

   i. **Bottom Grooved Support Blocks:** These are raised ribs, either fitted in the bottom of the container or made with the container itself. Their function is to support the plates and hold them in position and at the same time protect them from short-circuits that would otherwise occur as a result of fall of the active material from the plates onto the bottom of the container.

   ii. **Connecting Bar:** It is the lead alloy link which joins the cells together in series connecting positive pillar of one cell to the negative pillar of the next one.

   iii. **Terminal Post or Pillar:** It is the upward extension from each connecting bar which passes through the cell cover for cable connections to the outside circuits.

For easy identification, the negative terminal post is smaller in diameter than the positive terminal post.

iv. **Vent Plugs or Filler Caps:** These are made of polystyrene or rubber and are usually screw to the cover. Their function is to prevent escape of electrolyte but allow the free exit of the gas. These can be easily removed for topping up or taking hydrometer readings.

v. **External Connecting Straps:** These are the antimonial lead alloy flat bars which connect the positive terminal post of one cell to the negative of the next across the top of the cover. These are of very solid construction especially in starting batteries because they have to carry very heavy currents.

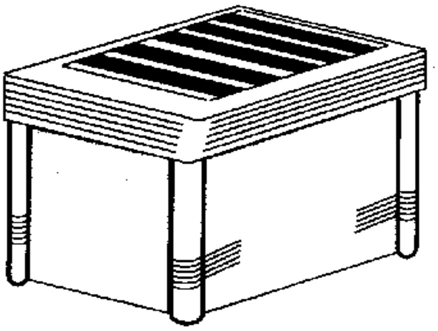


Figure 3-53 Mono block type container with six compartments

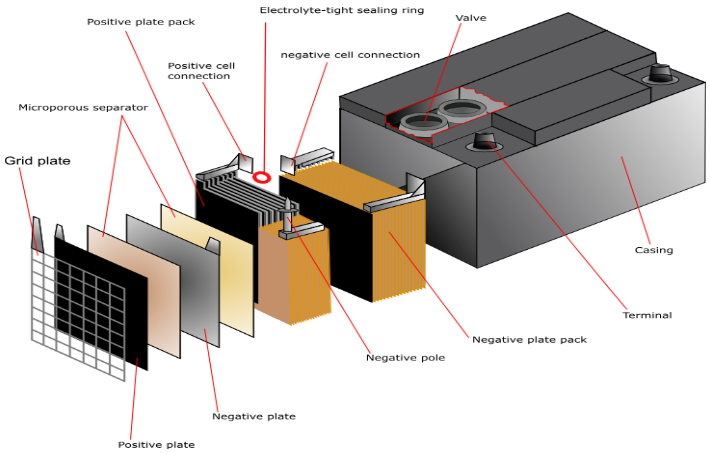


Figure 3-54 Details of some of the parts as described for Russian 12CAM 28 lead acid battery

3.5.4 Active materials of a Lead-acid Cell

Those substances of the cell which take active part in chemical combination and hence absorb or produce electricity during charging or discharging are known as active materials of the cell.

The active materials of a lead-acid cell are:

- Lead peroxide (PbO_2) for positive plate.
- Sponge Lead (Pb) for negative plate.
- Dilute Sulphuric Acid (H_2SO_4) as electrolyte.

a) Lead Peroxide: It is a combination of lead and oxygen is dark chocolate brown in colour and is quite hard but brittle substance. It is made up of one atom of lead (Pb) and two atoms of oxygen (O_2) and its chemical formula is PbO_2. As said earlier, it forms the positive active material.

b) Sponge Lead: It is pure lead in soft sponge or porous condition. Its chemical formula is Pb and forms the negative active material.

c) Diluted Sulphuric Acid: It is approximately 3 parts water and one part sulphuric acid. The chemical formula of the acid is H_2SO_4. The positive and negative plates are immersed in this solution which is known as electrolyte. It is this medium through which the current produces chemical changes.

Hence, the lead-acid cell depends for its action on the presence of two plates covered with PbO_2 and Pb in a solution of dilute H_2SO_4 of specific gravity 1.21 or near about.

Lead in the form of PbO_2 or sponge Pb has very little mechanical strength hence it is supported by plates of pure lead. Those plates covered with or otherwise supporting PbO_2 are known as positive plates and those supporting sponge lead are called negative plates. The positive and negative plates are arranged alternately and are connected to two common positive and negative terminals. These plates are assembled in a suitable jar or container to make a complete cell.

The specific gravity of the electrolyte in a lead-acid cell decreases as the charge in the cell decreases. This is because the acid in the electrolyte becomes chemically combined with the active material in the plates as the battery produces current; hence less acid remains in the electrolyte. Since the specific gravity of the acid is considerably greater than that of water, the loss of acid causes the specific gravity of the electrolyte to drop.

In Flooded batteries the oxygen generated at the positive electrode escapes from the cell. Concurrently, at the negative electrode, hydrogen is generated from water and also escapes from the cell. The overall result is water loss and cell gassing therefore, flooded cells require periodic water replenishment.

3.5.5 VRLA Battery Construction

In valve-regulated (VRLA) batteries, oxygen combines chemically with the freshly formed lead at the negative electrode in the presence of H_2SO_4 to provide lead sulphate and water. This oxygen recombination suppresses the generation of hydrogen at the negative electrode. Overall, there is no water loss during changing. A very small quantity reactions however, such loss is so small that no provision need be made for water replenishment.

Valve Regulated Lead-Acid (VRLA) batteries are designed to promote the chemical recombination of the oxygen at the negative electrode to minimize water loss. VRLA designs have the acid immobilized in a silica gel or absorbed in a porous glass separator with voids for oxygen transport. The oxygen diffuses from the positive to the negative plate where it oxidizes the lead, preventing it from reaching a potential where hydrogen will evolve. Since the plate is simultaneously on charge, the discharge product is immediately reduced to lead, restoring the chemical balance of the cell. The net sum of these chemical reactions is thus zero. Electrical energy input into the cell during charge is therefore converted to heat energy rather than chemical energy.

3.5.5.1 Electrode forming

Forming is defined as the procedure undertaken usually before final assembly in the battery case to convert the active material in the positive and negative plates into their fully charged condition. In effect, the forming process is equivalent to the first charge, but the electrolysis operation is carried out using carefully controlled conditions of temperature and electrolyte composition and low current density (typically < 100 A/m^2), in order to achieve complete conversion throughout the electrode masses while retaining adherence and porosity.

3.5.5.2 Separators

Separators are porous insulating sheets which are placed between the electrodes of opposite polarity to prevent contact and short circuit between them. They also act as a barrier to the transport of active material between the plates, mechanically support the positive active mass (so reducing shedding) and prevent dendrite formation. Effective separators must possess high porosity so that they will have low electrical resistance, low pore diameter in order to achieve good separation and, finally resistance to oxidation and stability in highly acid conditions. In early batteries, separators were made from fir or cedar wood by removing the resinous substances in order to make them acid-resistant. Better results were obtained with microporous rubber separators natural latex becomes highly porous after vulcanization due to water evaporation. However, present-day batteries almost all use separators made from synthetic polymers or glass filters. The porosity characteristics of these substances can be controlled to within close tolerances during the manufacturing process. The most popular polymer materials include sintered polyvinylchloride and extruded polyethylene. Special papers impregnated with phenolic resins are also in current use. Research is continuing to develop separators which are able to retain very large quantities of electrolyte for use in sealed batteries which can be operated in any orientation. Very efficient thin separators are required for high energy density batteries.

Hard rubber or glass fiber is used to fabricate retainers, which are perforated sheets in contact with the positive plate which protect the separators from its strong oxidizing environment.

3.5.5.3 Final assembly

Plates which have been tank-formed are first separated and cut to size. Lugs are milled free of oxide in preparation for welding to lead connector straps. The plates are assembled into parallel groups or stacks (usually with one extra negative plate), which are then interleaved, with separators, retainers and spacers inserted (Figure 3-55). In a battery containing more than one cell group (Figure 3-56), series connections must also be made. In large stationary batteries and older SLI models these are made using external straps. In modern SLI batteries such connections are made within the battery case using through-partition ties, thus saving lead and reducing the internal resistance and weight of the battery.

Cases are now almost exclusively fabricated by injection moulding using synthetic polymers which have replaced the bitumen and hard rubber widely used in the past. Polypropylene has excellent mechanical and chemical properties and allows light, thin-walled monobloc containers to be constructed. Glass containers are still sometimes used for emergency batteries because they permit a rapid check of battery condition, but they are tending to be replaced by either glass-polyester materials with antiacid internal coating or transparent polyvinyl chloride.

Almost all lead-acid battery cases are rectangular (prismatic) in shape. The interior may be manufactured with projections to locate the plates and support them above the case floor in order to leave mud or sludge space where shed materials can accumulate (Figure 3-57). In other batteries the plates are suspended from the case lid or from a ledge in the case wall. The lid is welded or sealed to the case and is provided with apertures for terminal pillars, venting valves and simple screw caps or complex automatic systems for adding distilled water to the electrolyte.

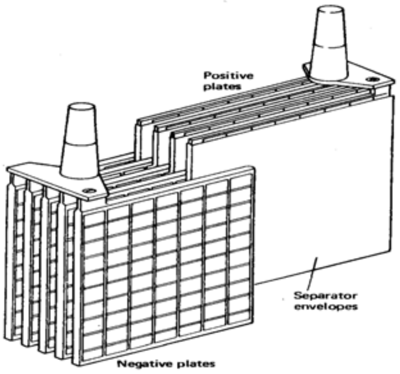


Figure 3-55 Interleaving of positive and negative electrode

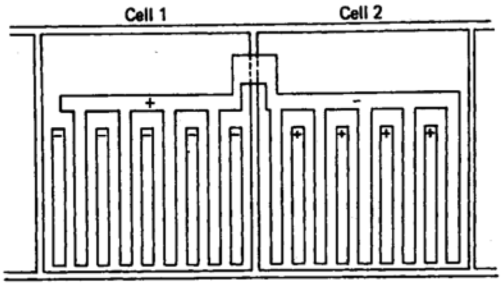


Figure 3-56 Schematic diagram of a lead-acid battery showing through partition connection

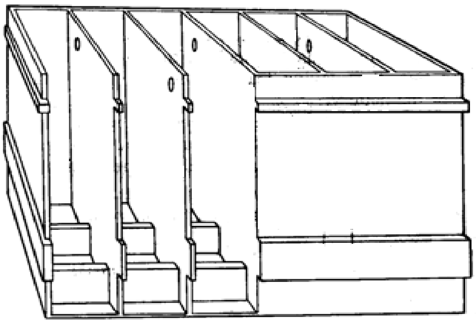


Figure 3-57 Mono block injection moulded case

3.5.6 Electrolyte immobilization Sealed Lead-Acid Batteries(SLA)

General Characteristics: Small lead acid batteries in portable and in some stationary applications, they are sealed and maintenance free because there is no need to replace electrolyte. They differ from the conventional lead Acid cell by containing only a minimum amount of electrolyte ('starved' electrolyte) absorbed in the separator or in a gel. The cells are also positive limited. The starved electrolyte and the excess of negative active material facilitate the recombination of oxygen produced in the cell during over charge or during 'float' charge to prevent gassing. The cells are designed with a re-sealable pressure valve to keep the internal pressure within the specified range and operate to release excess gas if there is a buildup of pressure. The valve closes to prevent the entrance of oxygen from the outside air.

The sealed lead acid cells are made in two designs: one with spirally wound plates (jelly-roll construction) in a cylindrical metal container and the second with flat plate in a prismatic (usually plastic) container. The venting characteristics of the cylindrical and prismatic designs are usually different. The prismatic cell is designed to vent at low pressure (0.04 - 1 x 10^5 Pa) and these designs are commonly referred to as valve regulated lead acid (VRLA) cells. The cylindrical cells have vents that operate at 2 - 4 X 10^5 Pa and commonly referred to as SLA cells.

The electrolyte is immobilized in two ways:

- **Absorbed electrolyte:** A highly porous and absorbent micro fibre glass mat partially filled with electrolyte of the desired specific gravity, is used in the separator.
- **Gelled electrolyte:** Fumed silica is added to the electrolyte causing it to harden into a gel. On subsequent charges some water is lost, drained the gel until a network of cracks and fissure develops between the positive and negative electrodes providing a path for oxygen recombination reaction.

The immobilization of electrolyte allows the batteries to operate in different orientation without spillage. The batteries can be used in portable devices without necessarily being kept up right. In larger industrial application the batteries can be installed on their sides permitting compact installation that will use up to 40% less floor space and volume. The major advantages and disadvantages of SLA batteries are listed in Table 3-5

When the cell is recharged, finely divided particles of $PbSO_4$ are electro chemically converted to sponge lead at the negative electrode and PbO_2 at positive electrode by the charging source, driving current to the battery. As the cell approaches complete recharge when the majority of the $PbSO_4$ has been converted to Pb and PbO_2, the over charge reaction begins. For the typical lead acid cells, the result of these reactions is the production of hydrogen and oxygen gas and subsequent loss of water.

3.5.7 General design practices for VRLA Battery

The newer designation for these designs is as a ''Valve Regulated Lead-Acid Battery'' or VRLA. They differ from the conventional flooded lead-acid battery designs by containing only a limited amount of electrolyte (''starved'' electrolyte) absorbed in a separator or immobilized in a gel. In most designs, the cell capacity is limited by the amount of positive active material. The starved electrolyte and excess of negative active material facilitate the recombination of oxygen produced during overcharge or ''float'' charge with the negative active material. The resealable valves are normally closed to prevent the entrance of oxygen from the outside air. The vent pressure design depends on the manufacturer and predominantly by the case shape and material. VRLA designs have two usual shapes, one with spirally-wound electrodes (jelly-roll construction) in a cylindrical container and the second with flat plates in a prismatic container. The cylindrical containers can maintain higher internal pressures without deformation and can be designed to have a higher release pressure than the prismatic cells. In some designs, an outer metal container is used to prevent deformation of the plastic cases at higher temperatures and internal cell pressures. The range of venting pressures includes a high of 25 to 40 psi for a metal-sheathed, spirally wound cell to 1 to 2 psi for a large prismatic battery.

The electrolyte is commonly immobilized in two ways:

- **Absorbed electrolyte:** A highly porous and absorbent mat fabricated from microglass fibers is partially filled with electrolyte and acts as the separator / electrolyte reservoir.

- **Gelled electrolyte:** Fumed silica is added to the electrolyte causing it to harden into a gel. On subsequent charges, some water is lost drying the gel until a network of cracks and fissure develops between the positive and negative electrodes. The openings created provide the path for the oxygen recombination reaction.

3.5.7.1 Recombination

Recombination means that the oxygen released by the positive plate during charge, is able to pass through the special separators used and combine with the highly reactive negative plate. This slight discharge of the negative plate prevents evolution of hydrogen. This recombination process is highly efficient during normal operation. As a result there is only a small loss of water during service life and no topping up is necessary.

3.5.7.2 Cell Construction

The following discussed in brief for only SLI batteries in particular valve regulated sealed lead acid battery (VRLA) types.

Reliable lead acid cell designs depend upon the attention given to the design, the choice of material used in the cell and the care with which the materials are processed like the following factors for the parts shown in Figure 3-58.

a) Technology: Valve regulated absorbed electrolyte
b) Type of electrode (or plate):Pasted
c) Grid Alloys: Pure lead
d) Cell Geometry: Prismatic, flat plate
e) Operation mode: Engine Starting
f) State of charge as shipped: Wet and fully charged

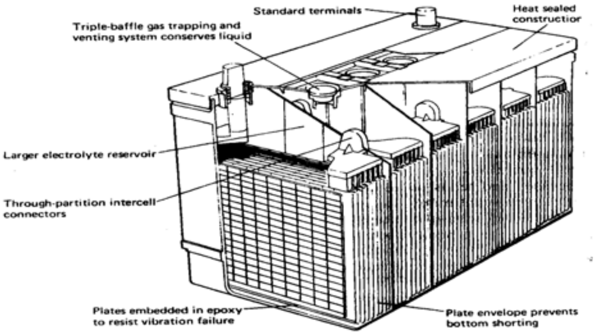


Figure 3-58 12V maintenance free VRLA Aircraft battery

Monobloc batteries, using the cylindrical cell, are produced with two to six cells interconnected in a single plastic container. These 4, 6, and 12V batteries have performance characteristics similar to those of the single cell. A typical monobloc design is illustrated in Figure 3-59.

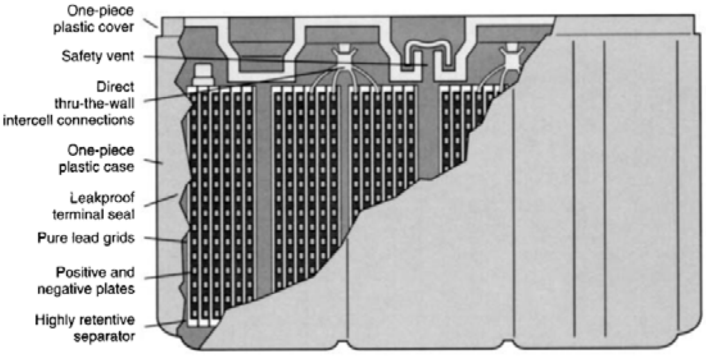


Figure 3-59 A Typical Monobloc battery.

3.5.7.3 Electrodes or Plates

The electrodes are composed of a structural member (the grid) and a lead oxide which is converted to active material electrochemically.

The size of the positive electrode is determined by the capacity required. The negative electrode has the same area but its thickness is determined by the amount of active material needed to balance electrochemically the amount in the positive.

3.5.7.4 Grids

The grid is the support structure used in electrodes. There are definite design requirements to be considered:

1. To withstand all handling operations during production
2. To with stand transportation and operating shock and vibration
3. Contribute to the electrical performance
4. With stand corrosion to the extent that service life will be obtained.

SLI Batteries, especially maintenance free batteries require special grid materials. Lead Calcium Alloys and lead alloys with low antimony content are favored for this application.

3.5.7.5 Active material

There are two types of electrode construction- flat pasted and tubular. All negative plates are the flat pasted type. Positive plates can be either flat pasted or tubular. “Plante” is another type, but it is rarely used due to its high cost and low energy density.

3.5.7.6 Flat Pasted Plates

The active material comes from the lead oxide which is originally applied to the grid as a paste. This paste is later electroformed into the active materials, lead dioxide (PbO_2) in the positive and sponge lead (Pb) in the negative. Most materials used in the paste of both plates are the same-lead oxide (PbO), sulfuric acid and water. Differences result from the amount of acid and water used in the formulations and any additives used primarily in the negative mix. Some additional variation occurs when the manufacturer uses oxides which have a more highly oxidized (Pb_3O_4) component.

To enhance mechanical strength, fiber additives are commonly included in positive paste formulation for flat pasted plates. Additives in the negative paste mix are included to keep the material from densifying during the life of the cell. Material densification during the life of the cell. Material densification would degrade electrical performance both on charge and discharge. These additives are called expanders.

3.5.7.7 Separators

Separators serve the purpose of preventing the plates from touching and electrically shorting. They are usually made from a micro porous rubber material or a micro porous polyethylene material. Other materials, such as sintered polyvinyl chloride (PVC) or resin impregnated substrates are also used. The absorbed electrolyte type of valve-regulated stationery cell uses a highly porous and absorbent glass mat and perforated plastic sheet as a separator.

The electrical resistance of the separators is critical to applications which require high discharge rates (such as UPS and SLI) and is one of the properties for which a specified maximum is given. Other important separator properties controlled by specifications are:

- Burst strength
- Dimensional stability
- Oxidation resistance-critical for deep cycle, long life cells
- Volume porosity
- Metallic impurities

Other separator physical conditions which should be controlled in order to avoid failures are:

- Broken or chipped corners
- Chipped, feathered or wavy edges
- Deformed, notched or voided ribs
- Bulged web
- Pin-holes, cracks or splits

3.5.7.8 Acids

Sulfuric acid (H_2SO_4) solution is the electrolyte of the lead-acid cell. This solution takes an active part of on the chemical reactions that produce energy from the cell. By changing the density or specific gravity of the acid solution, performance factors such as capacity, maintenance, and life can be affected.

In valve regulated cells, the acid is immobilized and absorbed completely in the separator structure or converted to a thixotropic gel by use of an additive.

3.5.8 Containers and Covers

The container design must bear the internal pressure exerted by the elements, the electrolytes and cell gases during service use.

For SLI and aircraft batteries typical materials are polypropylene (PP) High Impact Rubber Styrene-acrylonitrile (SAN). Most designs use SAN. Where flame retardancy is a requirement, PC, PVC, ABS, or modified polypropylene is employed.

3.5.9 Performance Characteristics

The performance characteristics of VRLA batteries are similar to those of the other sealed units. Their advantage becomes more apparent in the fabrication of battery packs as the minimum of void space required in the pack enhances the energy density. The characteristic discharge curves for the thin sealed lead-acid batteries are shown in Figure 3-60

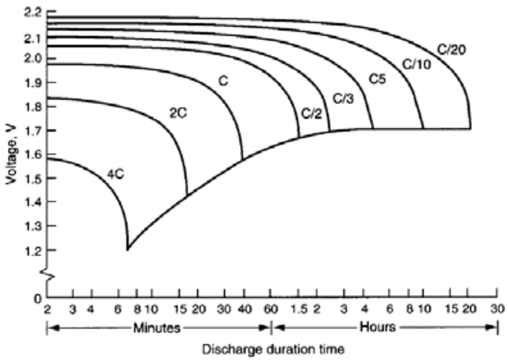


Figure 3-60 Characteristic discharge curves for thin prismatic single-cell sealed lead-acid batteries at 20°C.

3.5.10 Charging Characteristics

3.5.10.1 Battery Charging

Secondary cells are charged by passing a direct current through the battery in a direction opposite to that of the discharge current. This means that the supply current's positive connection must be connected to the battery's positive connection and the negative connected to negative. Various methods of supplying the charge current are available. Onboard the aircraft, the generator or alternator will supply the charging current. Other ground-based charging equipment will convert common 230-V_{AC} current into the DC voltage needed for battery charging. The two general types of charging equipment are constant-current chargers and constant-voltage chargers.

3.5.10.2 Constant-Current Chargers

As the name implies, a constant-current battery charger supplies a consistent current to a battery for the entire charge cycle. The charging equipment monitors current flow and varies the applied voltage in order to charge the battery. As the battery begins to charge, its voltage is lower than when the battery becomes fully charged. The constant-current charger will increase its voltage supplied to the battery during charge in order to maintain the current flow set by the operator.

Figure 3-61 illustrates the proper connection of more than one battery to a constant current charger. The batteries are connected in series with respect to each other and the charger thus allowing for a constant current flow through each battery. Constant-current chargers require careful supervision while in use. Because of the risk of overcharging most constant-current chargers will automatically turn off after a predetermined time. The exact current flow and time of charge must be known and programmed into the charging equipment to prevent over or undercharging of batteries. The specifications are normally available from the battery manufacturer however, unless the original state of charge remaining in the battery is known, an improper charge is still likely. For this reason, constant-current chargers are often used on new batteries where the initial charge state is known, but they are seldom used on lead-acid batteries that have already been placed in service. Nickel-cadmium batteries often use constant current charging equipment.

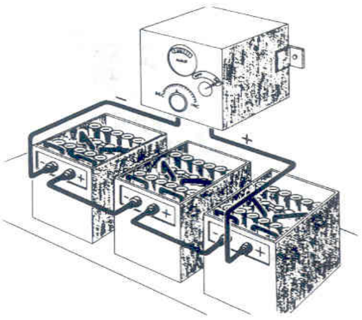


Figure 3-61 Constant current charging

Constant current is another efficient method of charging the VRLA battery. Constant-current charging is accomplished by the application of a non-varying constant-current source. This charge method is especially effective when several cells are charged in series, since it tends to eliminate any charge imbalance in a battery. Constant-current charging charges all cells equally because it is independent of the charging voltage of each cell in the battery. Figure 3-62 shows a family of curves of battery voltage versus percent capacity of previous discharges returned at different constant-current charging rates. As shown by these curves at different charge rates the voltage increases sharply as the full charge state is approached.

This increase in voltage is caused by the plates going into overcharge when most of the active material on the plates has been converted from lead sulfate to lead on the negative plate and to lead dioxide on the positive plate. The voltage increase will occur at lower states of charge when the cell is being charged at higher rates. This is because at the higher constant-current charge rates the charging efficiency is reduced. The voltage curves in Figure 3-62 are somewhat different from those for a conventional lead-acid battery due to the effect of the recombination of gases on overcharge within the system. The VRLA battery is capable of recombining the oxygen produced on overcharge up to the *C*/3 rate of constant current charge. At higher rates the recombination reaction is exceeded by the rate of gas generation.

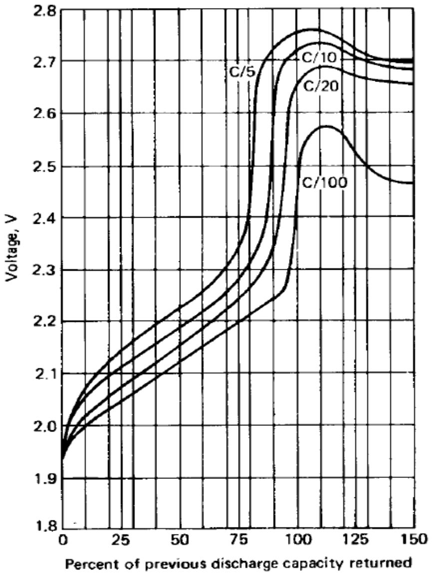


Figure 3-62 Voltage curves for batteries charged at various constant-current rates at 25°C.

3.5.10.3 Constant-Voltage Chargers

As the name implies, this charging equipment supplies a constant voltage to the battery and allows current to change as the battery becomes charged. The constant-voltage charger supplies approximately 14V for charging 12V batteries and 28V for charging 24 V batteries. A higher potential at the charger is necessary to ensure current flows from the charger to the battery. If the battery is nearly discharged, it will offer very little opposition to the electrons flowing into the battery. As the battery becomes charged, it will offer more resistance to the current supplied by the charger. Since that charger supplies a constant voltage a relatively high current will flow into a discharged battery and that current will slowly diminish as the battery becomes charged.

When the battery is fully charged, its voltage will be almost equal to the charger voltage hence the charging current will drop to less than 1A. When the charging current is low, the battery may remain on charge without any appreciable effect however, the electrolyte level should be watched closely to see that it does not fall below desired levels.

Because the current supplied to the battery drops to a very low value as the battery becomes charged, constant-voltage charging is usually considered the safest method of battery charging. A constant-voltage charger is by far the most common type of ground-based battery charger. The aircraft generator system also supplies the constant-voltage charge. If more than one battery is connected to a constant-voltage charger all the batteries and the charger must be connected in parallel. This will ensure a constant voltage to each battery. Charging multiple batteries is illustrated in Figure 3-63.

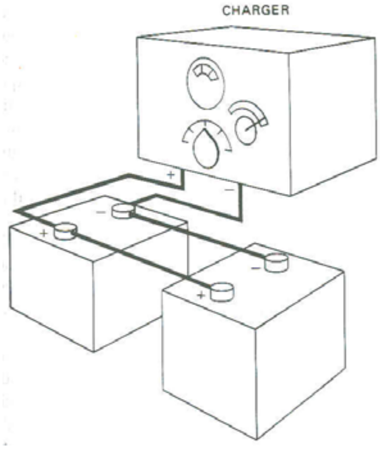


Figure 3-63 Constant voltage charging of multiple batteries

Various types of constant-voltage chargers are available. Typically, they range from 5 to 50 A capacity indicating the maximum current flow into a discharged battery. Each charger will lower current to about 1A when the battery becomes charged. Some chargers come with timers or voltage monitors to shut the system off when the battery reaches the fully charged state. Typically, a low current (about 1 A) can be supplied to a fully charged battery for 24 h or less without damage to the battery. After 24 h the liquid electrolyte level is at risk of becoming too low.

Constant-voltage charging is the most efficient and fastest method of charging a VRLA battery. Figure 3-64 shows the recharge times at various charge voltages for a cell discharged to 100% of capacity. The charger required to achieve these times at given voltages must be capable of at least the 2*C* rate. If the constant-voltage charger used has less than the 2*C* rate of charge capability, the charge times should be lengthened by the hourly rate at which the charger is limited that is, if the charger is limited to the C/10 rate, then 10 h should be added to each of the charge voltage-time relationships if the charger is limited to the C/5 rate then 5 h should be added and so on. There are no limitations on the maximum current imposed by the charging characteristics of the battery.

Figure 3-65 is a set of curves of charge current versus time for 2.5-Ah batteries charged by a constant voltage of 2.45 V with chargers limited to 2, 1, and 0.3A currents. As shown, the only difference in these three charges is the length of time necessary to recharge the battery.

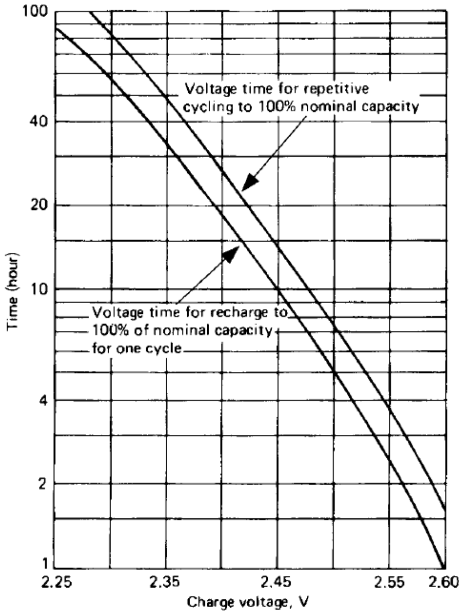


Figure 3-64 Charge voltage vs. time on charge at 25°C.

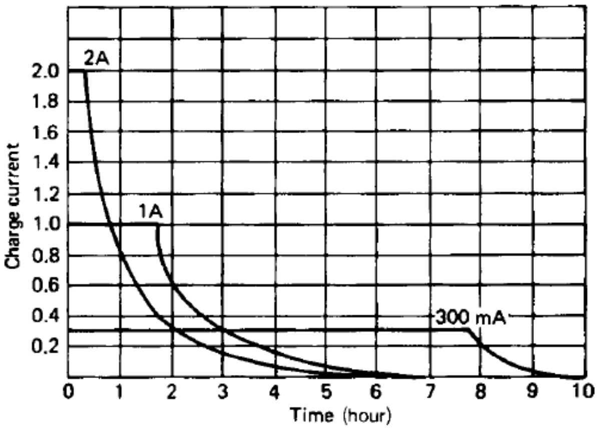


Figure 3-65 Charge current vs. time at 2.45-V constant voltage with various current limits (2.5-Ah battery, C/ 10 rate).

3.5.11 Battery Ratings and Applications

3.5.11.1 Voltage Ratings

Storage batteries of all types are rated according to voltage and ampere-hour capacity. It has been pointed out that the voltage of a fully charged lead-acid cell is approximately 2.1 V when the cell is not connected to a load. A nickel-cadmium cell is rated at about 1.22 CCV. Under a moderate load, the lead-acid cell will provide about 2 V. With an extremely heavy load, such as the operation of an engine start, the voltage may drop to 1.6 V. A lead acid cell that is partially discharged has a higher internal resistance than a fully charged cell; hence it will have a higher voltage drop under the same load. This internal resistance is partially due to the accumulation of lead sulphate in the plates. The lead sulphate reduces the amount of active material exposed to the electrolyte; hence it deters the chemical action and interferes with the current flow.

Figure 3-66 shows the discharge characteristics of a typical lead-acid aircraft battery. The OCV remains almost at 2.1 V until the battery is discharged. It then drops rapidly towards zero. The CCV gradually decreases from 2 to approximately 1.8 V as the cells discharge. Again, the voltage drops rapidly when the cell nears discharge state.

Even though battery cells vary considerably in voltage under various conditions, batteries are nominally rated as 6 V (3 cells), 12 V (6 cells), and 24 V (12 cells). In replacing a battery, the technician must ensure that the replacement of battery is carried out with the correct voltage rating.

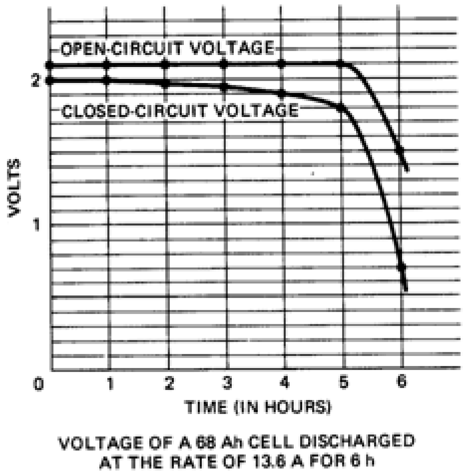


Figure 3-66 Discharge characteristics of a lead-acid cell

3.5.11.2 Power Ratings

As stated above under "Battery Ratings", most storage batteries are rated in ampere-hours at a 5h discharge rate. This means that the battery was discharged to 0 V in 5 h to determine its capacity. Most 12 V batteries used for single-engine aircraft have a capacity rating between 25 and 35 Ah however, larger capacities are also available. A direct comparison of ampere-hours alone does not indicate a battery's total power output. To determine total power, the battery's voltage must be considered because power (wattage) is the product of voltage and amperage. Two 12V batteries can be compared on the basis of ampere-hours alone, as can two 24 V batteries. But one should remember that a 30Ah, l2V battery (360 Wh) contains half the power of a 30Ah, 24V battery (720 Wh).

If the power desired for a specific job is not available in a single battery, often two or more batteries are connected in parallel. Connecting batteries in parallel will increase the available amperage capacity and maintain a constant voltage.

Another rating applied to storage batteries is known as the 5-min discharge rate. This rating is based on the maximum current a battery will deliver for a period of 5 minutes at a starting temperature of 80°F [26.7°C] and a final average voltage of 1.2 V per cell. This applies only to lead-acid batteries. The 5-min rating gives a good indication of the battery's performance for the normal starting of engines.

When a fully charged battery is connected to a very heavy load, it apparently becomes discharged in a short time. A good example of this is the starting of an engine on a very cold morning. After turning the engine for a short time, the starter may refuse to operate. This failure occurs largely because the heavy flow of current has caused a rapid sulphation of the active material on the surface of the plates, while the material inside the plates is still in a charged condition. The lead sulphate on the surface of the plates offers a high resistance to the flow of current; hence the voltage drop within the battery becomes so large that there is not sufficient voltage to continue driving the heavy load. If the battery is allowed to re-main idle for a time, it will again be able to deliver a substantial load current.

3.5.11.3 Ampere-hour Capacity

It is a function of the total plate area i.e. size of the individual plate multiplied by the number of plates. For measuring this capacity, the battery is discharged continuously for 20 hours and its current output supplied to a standard load is measured. Suppose that a battery delivers 4 A current for 20 hours, then its rating is 80 Ah which is stamped on the battery case.

3.5.11.4 Reserve Capacity

It is one of the newly-developed rating standards and is more realistic because it provides a table check on the Ah values. The capacity is given by the number of minutes a battery will operate of 25A drain without dropping below 10.5 V. Higher this rating better the battery.

3.5.11.5 Zero Cranking Power

It was the first cold weather rating and is applicable in relation to aircrafts which fly in freezing weather. This zero-degree performance test gives a valuable insight into battery quality. Large batteries are tested at a 300 A drain with battery chilled to -18°C (0°F) whereas smaller sizes are tested at half this value.

This test consists of two part (a) the battery is first chilled to -18°C (0°F) and the load applied for 5seconds. Meanwhile, the voltage output is recorded. It is the first part of the zero-cranking power rating. (b) The test is continued further till voltage drops to 5 V. The number of minutes it takes to reduce the voltage to 5 V forms the second half of the rating. Higher both the digits, better the battery quality.

3.5.11.6 Cold Cranking Power

This simple rating is applied to all 12 V storage batteries regardless of their size. The battery is loaded at -18°C (0°F) till the total voltage drops to 7.2 V. The output current in amperes is measured for 30 seconds. Higher the output, better the battery.

4 Overview of Lithium Thionyl Chloride Battery Technology

4.1 General Characteristics

Lithium metal is attractive as a battery anode material because of its light weight, high-voltage, high electrochemical equivalence and good conductivity. Because of these outstanding features, the use of lithium has predominated in the development of high-performance primary and secondary batteries during the last decade.

The Lithium-thionyl chloride inorganic electrolyte battery is a new power source that is suited to the requirements of the new generation in microelectronics. CMOS memories for example, require a light-weight power source providing sale and reliable performance over a wide range of environmental conditions for long periods of time.

The Lithium inorganic battery is a component that can be permanently connected to a circuit in many cases for the lifetime of the equipment.

Presently these batteries are utilized in Personal Rescue Beacon (PRB) & PRIBOY Radio sets.

4.2 Advantages

Lithium cells, with their outstanding performance (Bobbin type cylindrical batteries) and characteristics will see wide range of applications in the next decade with reduction in cost and increase in production.

- **High Cell Voltage:** They have an open-circuit voltage of 3.70V and an operating voltage of 3.40V (at a current density of 1 mA/cm^2 at 25°C), which are considerably higher than any other commercially available primary battery The higher cell voltage reduces the number of cells in a battery pack by a factor of about 2.
- **Wide operating temperature range:** The battery is capable of operating at temperatures from -40°C to +70°C. Applications outside this range are also possible under certain limitations.
- **Good Power density:** Some of the lithium cells are designed with the capability to deliver energy at high current and power levels.
- **High energy density:** The battery exhibits the highest energy density of any available primary battery up to 200Wh/Kg and 400 Wh/L.
- **Long shelf life:** Because the battery has extremely low self-discharge characteristics and hermetically sealed construction, a 10 year shelf life at room temperature is projected storage of more than 5 years at 20°C and 1 year at 70°C has been demonstrated.
- **Safety:** Since the battery is a non-pressurized system, no pressure relief valve is employed and hence no gases are released from the battery. The battery contains a very limited amount of lithium, all of it rolled against the outer wall of the cell

container. No danger of accidental high short-circuit current exist and hence no thermal runaway conditions leading to an explosion can develop.

4.3 Bobbin Type Cylindrical Batteries

Construction:

View shows the constructional features of the cylindrical Li/$SOCl_2$ cell, which is built as a bobbin-type cell. The anode is made of lithium foil which is swaged against the inner wall of a stainless or nickel-plated steel can, the separator is made of non woven glass, the cylindrical, highly porous cathode, which takes up most of the cell volume is made of Teflon-bonded carbon black. The cell is hermetically welded and a glass-to-metal seal is used for the positive terminal lead. These low-rate cells may or may not be provided with a vent depending on the manufacturer and cell design.

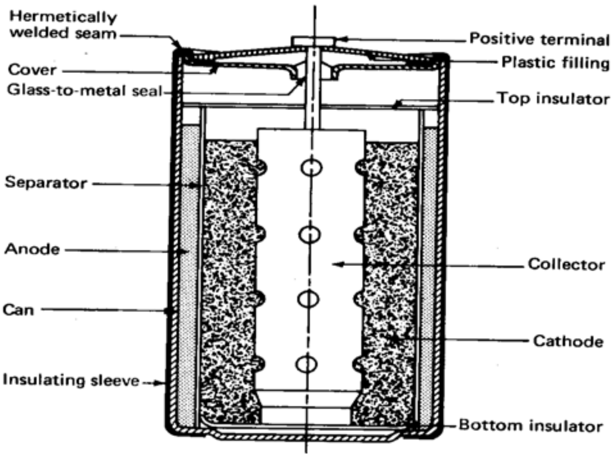


Figure 4-1 Bobbin-type Li/$SOCL_2$ – cross section view

Anode:

The anode is made of battery grade lithium foil, swaged against the inner wall of the cylindrical can. This ensures good thermal, electrical and mechanical contact.

Separator:

The separator between the anode and the cathode prevents internal short circuits, but enables ions to pass freely between the electrodes. It is made of non woven glass carefully selected to be compatible with the chemical system during long term storage and operation.

Cathode:

A cylindrical, highly porous, Teflon bonded carbon cathode is used as the catalytic surface. On this surface, the thionyl chloride cathode reduction takes place when a load is connected. Although the carbon does not participate in the chemical reaction (except as a catalyst), it may determine cell capacity when insoluble LiCl, one of the reduction products (equation 1) is precipitated into its pores and blocks them. Its flexible structure ensures a minimum distance between anode and cathode during the entire discharge and enhances mechanical stability (e.g. resistance to shock, acceleration and vibration).

Electrolyte:

The electrolyte is primarily composed of a solution of 1.8M lithium aluminum tetrachloride in thionyl chloride. The electrical conductivity of the electrolyte decreases only slightly with temperature. The small temperature gradient coupled with the single voltage discharge level of the cell and no mass transport control problems contribute to the extraordinary voltage stability of the $Li/SOCl_2$ system.

The low freezing point of the electrolyte (below -110°C) and its relatively high boiling point (above +80°C) have made it possible to produce a battery which operates efficiently over a wide range of temperatures (typically -55°C to 75°C).

Current Collector:

The current collector provides the electrical connection between the carbon cathode and the positive terminal. It is made of stainless steel (type 304).

Hermetic Package:

A hermetic package is essential to ensure the battery shelf life and protection of the equipment in which the battery is installed. The minimum hermetically level obtained is approximately 10^{-8} cm^3 He-atm/s. This is achieved as follows:

- **Can and Cover:** Both are made of nickel plated cold rolled steel, cathodically protected by the lithium metal. The can is designed to withstand the mechanical stresses encountered over the wide anticipated range of environmental conditions in service.
- **Welded Seam:** The cover is welded to the can by the TIG welding process. The mechanical strength of the welded seam is equivalent to the strength of the total package.
- **Glass to metal seal:** A glass bead is used to insulate the positive terminal from the negative cover. Compression sealing technology ensures good hermeticity and mechanical integrity.

4.4 Spirally Wound Cylindrical Batteries

Medium to moderately high-power $Li/SOCl_2$ batteries which are designed within spirally wound electrode structure are also available. These batteries were developed primarily to meet military specifications where high drains and low-temperature operation were required. They are now also used in selected industrial applications where these features are also needed.

A typical construction is shown in Figure 4-2. The cell container is made of stainless steel, a corrosion-resistant glass-to-metal feed-through is used for the positive terminal and the cell cover is laser sealed or welded to provide a hermetic closure. Safety devices, such as a vent and a fuse or a PTC device are incorporated in the cell to protect against buildup of internal pressure or external short circuits.

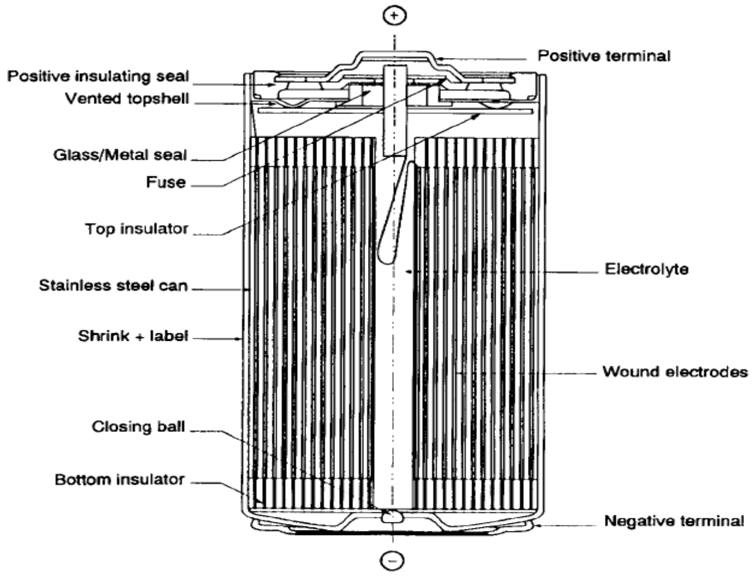
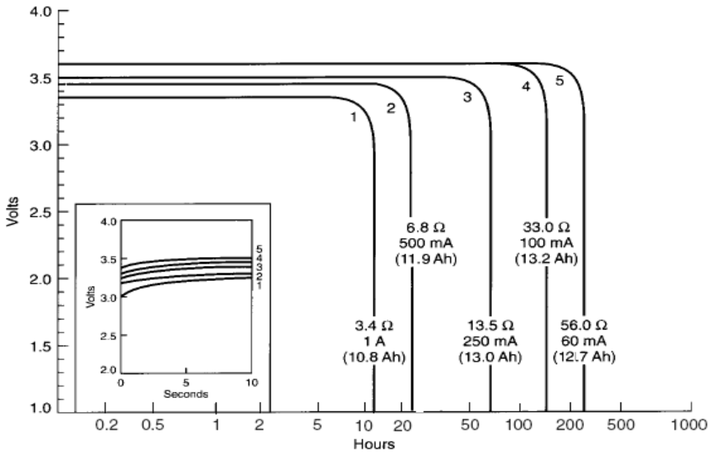
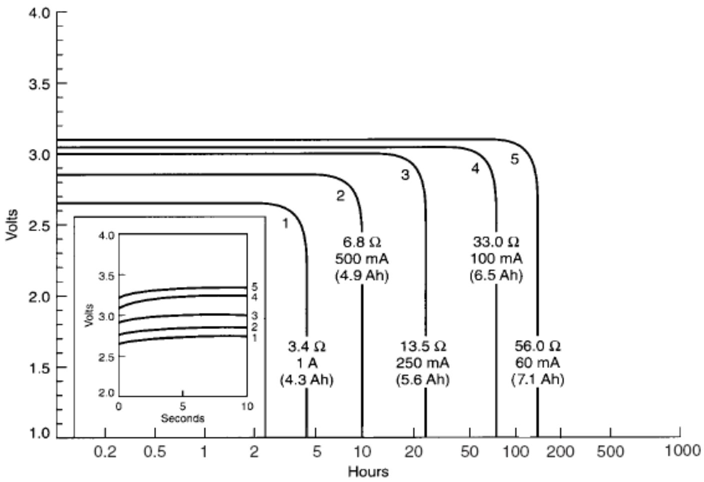


Figure 4-2 Cutaway view of lithium/thionyl chloride spirally wound electrode battery.

The discharge curves for a D-size battery are plotted in Figure 4-3, showing the higher performance at the moderate drains compared to the bobbin cell. The inserts in Figure 4-3 show the voltage response when the load is initially applied. The voltage of these cells recovers within 10sec as they incorporate an anode-coating technology as discussed earlier.



(a)



(b)

Figure 4-3 Discharge characteristics of spirally wound Li /$SOCl_2$ D-size battery, medium discharge rate at (a) 72°C, (b) -40°C.

4.5 Assembly of Multi-cell Batteries

In assembling batteries from series and parallel connections of cells, the following procedures must be followed in order to assure that the cells have equal internal impedance:

- All cells must be of the same size and stored under the same conditions for not less than one month at room temperature. It is desirable that the cells all be from the same date of manufacture.
- Each cell should be momentarily short circuited. The short circuit current of each cell should be measured after 1 second and the short circuit then removed immediately. (The cells will not be damaged). Only these cells whose short circuit current is within 5% of average measured value may be used in making up the battery.
- The cells should be interconnected in series by soldering or welding of the flat strips of terminals, this avoids overheating that could occur from direct attachment to the case. A diode should be connected in each series string with a maximum reverse leakage current of 10 microamperes.
- It is recommended to connect a slow blow fuse in series with the load whenever several series strings of batteries are connected in parallel.

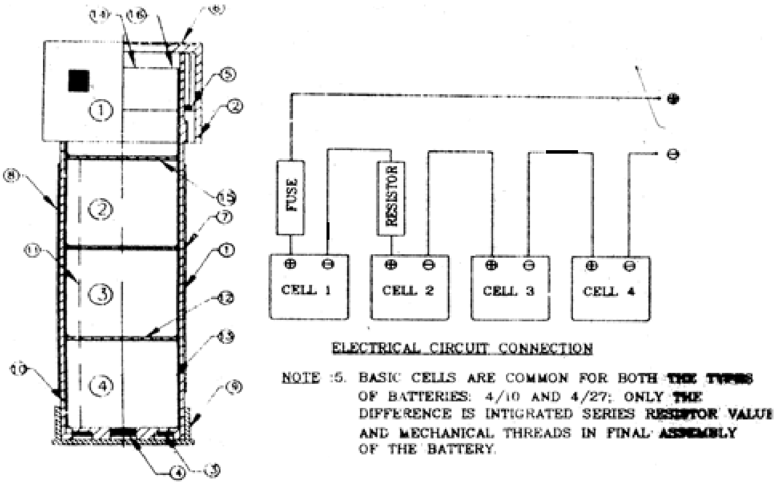


Figure 4-4: A Typical Lithium Thiynol Chloride battery assembly along with safety fuse, dropper resistor and mechanical threads fitment to suite PRB sets.

4.6 Electrical Characteristics

4.6.1 Cell chemistry and general consideration

The Li-SOCl_2 battery consists of a lithium-metal foil anode, a porous carbon cathode, a porous non-woven glass or polymeric separator between them and an electrolyte containing thionyl chloride and a soluble salt, usually lithium tetrachloro aluminate. Thionyl chloride serves as both the cathode active material and the electrolytic solvent. The carbon cathode serves as a catalytic surface for the reduction of thionyl chloride and as a repository for the insoluble products of the discharge reaction.

Although the detailed mechanism for the reduction of thionyl chloride at the carbon surface is rather complicated and has been the subject of much controversy, the battery reactions are described below:

The cell consists of a lithium (Li) anode, a carbon (C) cathode and a solution of lithium aluminum chloride in thionyl chloride. The thionyl chloride serves a dual role - as an electrolyte carrier for ions and as an active cathode depolarizer on catalytic surfaces. In this case, the teflon-bonded carbon cathode serves as the catalytic medium. There is no cathodic reduction of thionyl chloride on the lithium surface because of the high activation energy required for the reduction process and the formation of a thin surface of LiCl which inhibits its reduction.

The most quoted half cell reactions, during current passage are:

Anode reaction:

$$4(\text{Li} \rightarrow \text{Li}^{+} + e^{-})$$

Cathode reaction (on carbon surface):

$$2\,SOCl_2 + 4\,Li^+ + 4e^- \rightarrow 4\,LiCl + S + SO_2$$

Overall reaction:

$$4\,Li + 2\,SOCl_2 \rightarrow 4\,LiCl + S + SO_2$$

The above equation is by no means complete especially as to the sulphur dioxide formed during discharge is dissolved in the electrolyte (possibly by partial chemical bonds). This gives rise to the special properties of thionyl chloride inorganic cells, such as very low internal pressure within the cell – before during and after discharge.

At nominal operating currents, the cell discharge mechanism does not give rise to any gas pressure.

The battery, which features a high 3.6V operating voltage and wide operating temperature range (-55°C to 85°C) can serve as a memory backup power source.

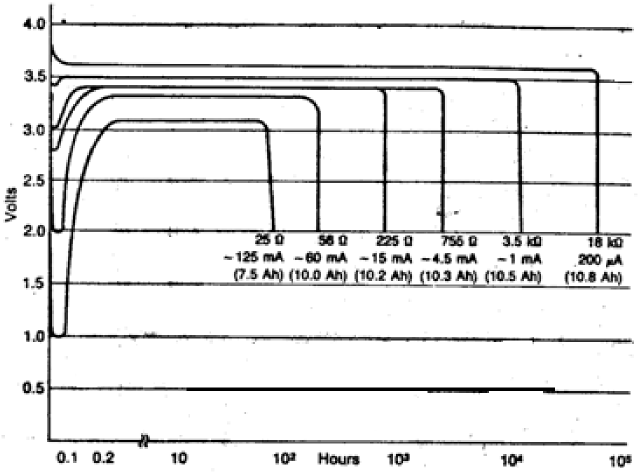
Lithium $SOCl_2$ inorganic cells are designed to be safe from explosion hazards. This has been achieved by optimizing the following parameters:

- High heat dissipation medium (swaging of the lithium foil to the inner wall of the can).
- Limited reactive area.
- Limited short circuit current (with consequent limited temperature rise).

All these factors limit the possibility of explosion hazards. As a result, no vent is required in the cell construction. This is a unique feature as compared to the Li/SO_2 organic cell.

4.6.2 Discharge characteristics of Lithium Thionyl Chloride

Figure 4-5 shows the general typical discharge characteristic for a lithium-thionyl chloride cell. Note the unusual voltage response during the first few tenths of an hour of operation. With a 125mA load, the output drops to 1V and then recovers to 3.1V. This is called the transition period and may be an unacceptable characteristic for some applications. Some of the other types of lithium cells also exhibit a transition effect. The transition voltage drop is usually moderate or nonexistent for moderate to light load currents. The typical lithium cell is used in applications where the load current is not heavy and the transition effect is not a problem. Figure 4-5also shows that greater cell capacity is realized when the drain is small. For example, when the load current is 200µA, a capacity of 10.8 Ah is realized with a life over 50,000 h (about 6 years).



Typical discharge at 20°C after 1 year storage

Figure 4-5: Typical Lithium Thionyl Chloride battery assembly along with safety fuse, dropper resistor and mechanical threads fitment to suite PRB sets.

4.6.3 Long shelf life and general considerations

To appreciate fully the advantages of the lithium inorganic battery, certain aspects of the battery kinetics should be considered. The long shelf life of the lithium cell is a result of the formation of a thin layer of LiCl on the anode during the initial reaction of Li and $SOCl_2$. This layer prevents further reaction or loss of capacity on stand. The problem of anode corrosion, as occurs in aqueous system, is thus eliminated.

On the other hand the protective layer on the anode may cause a delay in the voltage build-up if relatively high loads are applied or after extended storage at elevated temperatures. This voltage delay is not evidenced at all in microampere applications, such as in typical CMOS circuits. At current densities up to 1 mA/cm^2 (5 mA for ½ AA size; 45mA for D size cells), a transient minimum voltage of 2.0 to 2.5V may appear before the cell reaches its working voltage. The voltage delay becomes more pronounced the higher the load or the lower the operating temperature. It also depends on the storage conditions and will be larger with higher storage temperature and longer exposure to the high temperature.

For short-term loads, the lithium cell may also be used at higher current densities up to 10 mA/cm^2 (50mA for ½ AA sizes 450mA for D size cells). In this case, proper initiation procedures which will be recommended by the manufacturer according to the specific application conditions must be performed in order to overcome the initial voltage drop.

4.7 Available Products

There are too many lithium cells to cover them in detail and new types are still being developed. Some use an organic electrolyte and others use an inorganic electrolyte.

Various cathode materials are used, and the list below shows some of the types along with their open circuit voltages:

Lithium-chromium dioxide (Li/CrO_2) - 3.8V
Lithium-thionyl chloride ($Li/SOCl_2$) - 3.7V
Lithium-iodine (Li/I) - 3.6V
Lithium-manganese dioxide (Li/MnO_2) - 3.3V
Lithium-sulfur dioxide (Li/SO_2) - 2.9V
Lithium-bismuth trioxide (Li/Bi_2O_3) - 2.1V

Lithium is the lightest metal and has a specific weight only half that of water. It is also a very active metal and lithium cells can produce as much as 3.5V under load. Lithium cells and batteries are quite expensive but can produce up to 10 times the energy per weight and volume compared to alkaline devices. Also some types can last over 10 years. A few military electronics applications of lithium cells and batteries are given below.

- Coding Equipment.
- Radio Frequency.
- Underwater Detectors.
- Night-vision Equipment.
- A.T. mine electronics.
- Radio Beacon Survival Sets.

4.8 Various Cell Sizes

Lithium inorganic batteries are available in various cell sizes in two series depending on the application-

- Standard series for general use. Cell designations - ½ AA, AA, C, D, 1/3C, 1/3D are available upon special order.
- Series for Low-Current Memory Backup. Cell designations - TEL, AEL, CEL, DEL, 1/6 DEL.

4.9 Shelf Life and Temperature Considerations

The lithium inorganic battery possesses an excellent shelf life. Four year storage has produced a capacity loss below 1.2% per year at room temperature. This enables a projection of 10 year shelf life with a total capacity loss less than 20%. Normal operation is permissible at temperatures up to 75°C. Prolonged storage at 72°C results in a capacity loss of less than 30% per year.

Under certain conditions with the manufacturer's advice, high temperature operation up to 125°C is possible with light loading. High currents can cause a temperature rise. A temperature of 150°C should not be exceeded, because at 200°C the cells may explode. Discarded batteries must therefore not be incinerated.

A further limiting factor is the cell orientation. The cells should not be mounted in a completely upside down position, where a capacity loss of up to 60% may be expected in C or D size cells. A cell may lose up to 20% of its capacity in a static horizontal position.

The effect of the cell orientation on the capacity in the ½ AA and AA size cells are much smaller and would amount to a 10 – 20% loss of capacity at normal loads and room temperature. Capacity losses in the EL series cells are negligible.

Multi-cell batteries composing series or parallel cell arrangements are designed and manufactured according to customers specific requirements. These batteries may be packaged as required in standard polystyrene cubes or in custom made ABS on other thermosetting injection molded enclosures.

4.10 Cell Disposal

Unlike other batteries, such as mercury or nickel cadmium, the lithium inorganic cell contains no material which will have a lasting poisonous environmental effect. The cell does contain corrosive materials that will ultimately decompose and form harmless substances. To avoid damage from contact, the following procedure is applicable for lithium cells which either are mechanically damaged or have been discharged to 1.0V.

Cells should be collected and heat sealed in polyethylene bags with $CaCO_3$ added in the following amounts, which are sufficient to neutralize any electrolyte that leaks after the cells disintegrate:

- 25 grams per D size cell.
- 10 grams per C size cell.
- 3 grams per AA size cell.
- 1.5 grams per ½ AA size cell.

The bags should be buried in landfills to a depth of at least 1 meter. The disposal area should be fenced off and designated a CHEMICAL DISPOSAL AREA.

4.11 Safety Consideration

The electrical and physical abuses that may arise during the use of lithium cells are listed in Table 4-1 with some generalized comments on corrective action. The behavior of specific cells is covered in the other sections of this chapter. The manufacturer's data should be consulted for more details on the performance of individual cells.

High-Rate discharges or shorting

Low capacity cells or those designed as low rate cells may be self limiting and not be capable of high rate discharge. The temperature rise will thus be minimal with no safety problems. Larger and / or high rate cells can develop high internal temperatures if shorted or operated at excessively high rates. These cells are generally equipped with safety venting mechanisms to avoid a more serious hazard. Such cells or batteries should be fuse-protected (to limit discharge current), thermal fuses or thermal switches should also be used to limit the maximum temperature rise.

Table 4-1 Considerations for Use and Handling of Lithium Primary Batteries

Abusive Condition	Corrective procedure
High rate discharge or shorting	Low capacity or low rate cells may be self limiting. Electrical fusing, thermal protection. Limit current drain; apply battery properly
Forced discharge (cell reversal)	Voltage cutoff. Use low voltage batteries. Limit current drain. Special designs ("balanced" cell).
Charging	Prohibit charging. Diode protection.
Overheating	Limit current drain. Fusing, thermal cutoff. Design battery properly. Do not incinerate.
Physical abuse	Avoid opening, puncturing, or mutilating cells. Maintain cell integrity.

Forced Discharge or Voltage Reversal

Voltage reversal can occur in a multicell series connected battery, when the better performing cells can drive the poorer cell below 0V into reversal as the battery is discharged toward 0V. In some types of lithium cells, this forced discharge can result in cell venting or in more extreme cases, cell rupture. Precautionary measures include the use of voltage cutoff circuits to prevent a battery from reaching a low voltage, the use of low voltage batteries (since this phenomenon is unlikely to occur with a battery containing only a few cells in series) and limiting the current drain since the effect of forced discharge is more pronounced on high rate discharges.

Charging

Lithium cells, as well as the other primary cells are not designed to be recharged. If they are they may vent or explode. Cells which are connected in parallel of which may be exposed to a charging source (as in battery backup CMOS memory retention circuits) should be diode-protected to prevent charging. See Figure 4-6 and Figure 4-7 .

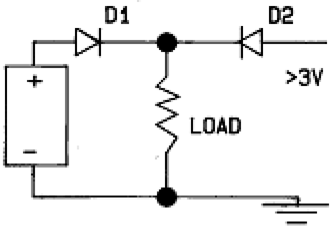


Figure 4-6 Recharge protection for cells in parallel with other cells

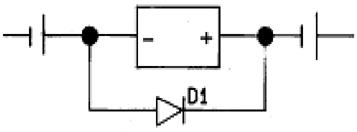


Figure 4-7 Reversal protection for cells in series with other cells

Overheating

As discussed above, overheating should be avoided. This can be accomplished by limiting the current drain, using safety devices such as fusing and thermal cutoffs and designing the battery to provide necessary heat dissipation.

Incineration

Lithium cells are either hermetically or mechanically crimped sealed. They should not be incinerated without proper protection because they may rupture or explode at high temperatures.

Currently, special procedures govern the transportation and shipment of lithium batteries containing more than 0.5g of lithium (equivalent to about 1Ah in capacity). Procedures for the use storage and handling of lithium batteries also have been recommended. Disposal of some types of lithium cells also is regulated. The latest issue of these regulations should be consulted for the most recent procedures.

5 Overview of Thermal Battery Technology

5.1 General Characteristics

Thermal (heat-activated) batteries employ inorganic salt electrolytes that are nonconductive solids at ambient temperatures and an integral pyrotechnic mixture scaled to supply sufficient heat to melt the electrolyte. The battery is activated by an electrical or mechanical signal to a built-in squib or primer, which ignites the pyrotechnic melting the electrolyte which becomes conductive and permitting the battery to deliver high power for relatively short durations. The shelf (pre-activation) life of thermal batteries is greater than 10 years and batteries of more recent manufacture are expected to last at least 20 years. The operational (post activation) life ranges from seconds for high-power "pulse" batteries to more than 1h for suitably insulated designs. Thermal batteries are primary, reserve batteries and once expended are not rechargeable.

Thermal cells originated in the 1940's and were developed mainly for weapons applications. More than 10 million have been produced since Catalyst Research Corporation manufactured the first models in 1947. Their characteristics are ideally suited for military ordnance and they are widely used as power sources in projectiles, rockets, bombs, mines, missiles, decoys, jammers and torpedoes. Figure 5-1 is a photograph of some of the thermal batteries that have been manufactured. The advantages of thermal batteries are:

- Very long shelf life (longer than 10yrs) in a "ready ammunition" state without degradation in performance.
- "Instant" activation-fast-start designs can be activated and provide useful power in tens of milliseconds.
- High peak power exceeding 10 W/cm^2.
- Very high demonstrated reliability and ruggedness following long-term storage at extremes of ambient temperatures, and severe stockpile-to-target environmental forces such as shock, vibration, acceleration and / or spin, concurrent with operation at temperature extremes.
- No maintenance or servicing can be permanently installed in equipment.

However, the design considerations required to achieve these characteristics can result in reduction in energy.

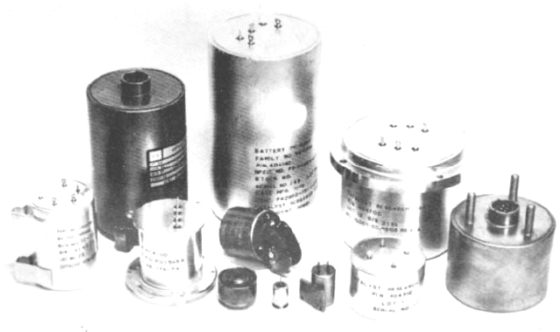


Figure 5-1 Typical Thermal Batteries.

5.2 Description of Electrochemical Systems

Thermal battery electrochemical cells consist of an alkali or alkaline earth metal anode, a fusible salt electrolyte and a metallic salt depolarizer. The pyrotechnic heat source is usually inserted between cells in a series cell stack for rapid activation. The term "thermal battery" does not refer to a single electrochemical system but to a family of batteries using different electrochemical systems. The active materials, the electrolyte and other battery components as well as the design can be varied according to the performance that is desired. Table 5-1 lists some of the popular types in use.

Table 5-1 Types of Thermal Batteries

Electrochemical system: Anode / electrolyte / cathode	Operating cell voltage, V	Characteristics and /or applications
Ca / LiCl-KCl / WO_3	2.4-2.6	Used principally for fuse applications where a low level of electrical noise is essential and where dynamic environments are not severe
Ca / LiCl - KCl / $CaCrO_4$	2.2-2.6	Used in application requiring short- term operation in severe dynamic environments
Mg / LiCl - KCl / V_2O_5	2.2-2.7	Used in application requiring short- term operation in severe dynamic environments
Li (M) / LiCl - KCl /FeS_2	1.6-2.1	Overall advantages: low electrical noise, can operate in severe dynamic environments, long service life(upto 1h)

5.2.1 Anode Materials

Until the 1980’s most thermal battery designs employed a calcium metal anode with calcium foil generally attached to an iron, stainless steel or nickel foil current collector or backing. A ‘’bimetal’’ anode is manufactured by vapor depositing the calcium on the backing material. Here, the calcium anode thickness usually ranges between 0.03 and 0.25 mm. In other designs, calcium foil is either pressed onto a perforated ‘’cheese grater’’ type backing sheet or is spot-welded to the backing. Magnesium metal is another anode material that has been widely used both in ‘’bimetal’’ form and in pressed or spot-welded anode configurations.

Introduced in the mid-1970, lithium has become the most widely used anode material in thermal batteries. There are two major configurations of lithium anodes, lithium alloy and lithium metal. The most commonly used alloys are lithium-aluminum with about 20 weight percent lithium and lithium (silicon) with about 44 weight percent lithium. Lithium-boron alloy has also been evaluated, but has not been used widely because of its higher cost.

LiAl and Li(Si) alloys are processed into powders, which are cold-pressed into anode wafers or pellets that range in thickness from 0.75 to 2.0 mm. In the cell, the alloy pellet is backed with an iron, stainless steel or nickel current collector. Lithium alloy anodes function in activated cells as solid anodes and must be maintained below melt or partial melt temperatures. Forty-four weight percent Li(Si) alloy will partially melt at 709°C, while LiA1 α, β will exhibit partial melting at 600°C. If these melting temperatures are exceeded, the melted anode may come in contact with cathode material allowing a direct, highly exothermic chemical reaction and cell short-circuiting.

Lithium metal anodes function in activated cells at temperatures above the melting temperature of lithium 181°C. To prevent the molten lithium from flowing out of the cells and short-circuiting the battery, it is combined with a high-surface-area binder of metal powder or metal foam. The binder holds the lithium in place by surface tension.

Lithium metal anodes are prepared by combining the binder material with molten lithium, followed by pressing the solidified mixture into thin foil, typically 0.07 to 0.65 mm thick. The foil is then cut into cell-sized parts. The anode foil parts are enclosed in iron-foil cups, which provide added protection against the migration of any free lithium (which can result in cell shorting) and also serve as electron collectors (electrical connections). Such anodes can function at cell temperatures greater than 700°C without significant loss of performance. Each thermal battery designer or manufacturer has developed a number of anode configurations from which the most suitable may be selected depending upon specific battery performance requirements.

5.2.2 Electrolyte

Historically, most thermal battery designs have used a molten eutectic mixture of lithium chloride and potassium chloride as the electrolyte (45:55 LiC1:KC1 by weight, mp = 352°C). Halide mixtures containing lithium have been preferred because of their high conductivities and general overall compatibility with the anodes and cathodes. Compared to most lower melting oxygen-containing salts, the halide mixtures are less susceptible to gas generation via thermal decomposition or other side reactions. More recent electrolyte variations, containing bromides, have been developed for thermal batteries to achieve a lower melting point (and thus extend the operating life) or to reduce the internal resistance (and raise the current capability) of the batteries. These include LiBr-KBr-LiF (mp=320°C), LiCl-LiBr-KBr (mp=321°C), and the all Li^+ electrolyte LiCl-LiBr-LiF (mp = 430°C). Electrolytes with mixed-cations (*e.g.*, Li^+ and K^+, instead of all-Li^+) are subject to the establishment of Li^+ concentration gradients during discharge. These concentration gradients can give rise to localized freezing out of salts, especially during high current draw.

At battery operating temperatures, the viscosity of molten salt electrolytes is very low (ca. 1centiPoise). In order to immobilize the molten electrolytes, binders are added to the salts during compounding. Earlier blends, originally developed for Ca/$CaCrO_4$ systems and the original LiAl/FeS_2 batteries, employed clays, such as kaolin and fumed silica as effective binders for the salts. These siliceous materials will react with Li(Si) and lithium metal anodes, however. High surface area MgO is sufficiently inert for the more reactive anodes and is presently the binder of choice in most systems.

5.2.3 Cathode Materials

A wide variety of cathode materials has been used for thermal batteries. These include calcium chromate ($CaCrO_4$), potassium dichromate ($K_2Cr_2O_7$), potassium chromate (K_2CrO_4), lead chromate ($PbCrO_4$), metal oxides (V_2O_5, WO_3) and sulfides (CuS, FeS_2, CoS_2). The criteria for suitable cathodes include high voltage against a suitable anode, compatibility with halide melts, and thermal stability to approximately 600°C. Calcium chromate has been most often used with calcium anodes because of its high potential (at 500°C, V= 2.7V) and its thermal stability at 600°C. FeS_2 and (more recently) CoS_2 are used with modern lithium-containing anodes (FeS_2 to 550°C and CoS_2 to 650°C).

5.2.4 Pyrotechnic Heat Sources

The two principal heat sources that have been used in thermal batteries are heat paper and heat pellets. Heat paper is a paper-like composition of zirconium and barium chromate powders supported in an inorganic fiber mat. Heat pellets are pressed tablets or pellets consisting of a mixture of iron powder and potassium per chlorate.

The Zr-$BaCrO_4$ heat paper is manufactured from pyrotechnic-grade zirconium powder and $BaCrO_4$, both with particle sizes below 10 microns. Inorganic fibers, such as ceramic and glass fibers are used as a structure for the mat. The mix together with water is formed into a paper either as individual sheets by use of a mold or continuously through a papermaking process. The resultant sheets are cut into parts and dried. Once dried, the material must be handled very carefully since it is very susceptible to ignition by static charge and friction. Heat paper has a burning rate of 10 to 300 cm/ s and a usual heat content of about 1675 J /g (400 cal / g). Heat paper combusts to an inorganic ash with electrical resistivity. If inserted between cells, it must be used in combination with highly conductive inter-cell connectors. In some battery designs, combusted heat paper serves as an electrical insulator between cells. In those applications it may have an additional layer of ceramic fibers only known as base sheet to enhance its dielectric properties. In most modern pellet-type batteries, heat paper is used only as an ignition or fuse train if at all. In this application, the heat paper fuse which is ignited by the initiator in turn ignites the heat pellets, which are the primary heat source in these batteries.

Heat pellets are manufactured by cold-pressing a dry blend of fine iron powder (1 to 10 micron) and potassium per chlorate. The iron content ranges from 80 to 88% by weight and is considerably in excess of stoichiometry. Excess iron provides the combusted pellet with sufficient electronic conductivity eliminating the need for separate inter-cell connectors. The heat content of Fe-$KClO_4$ pellets ranges from 920 J /g for 88% iron to 1420 J /g for 80% iron. Burning rates are generally slower than those of heat paper and the energy required to ignite them is greater. For that reason, the heat pellet is less susceptible to inadvertent ignition during battery manufacture. Heat pellets (and especially unpelletized heat powder) must nevertheless be handled with extreme care and protected from potential ignition sources.

After combustion the heat pellet is an electronic conductor, simplifying inter-cell connection and battery design. It also retains its physical shape and is very stable under dynamic environments (such as shock vibration and spin). This contributes greatly to the general ruggedness of battery designs that incorporate heat pellets. Another major advantage of heat pellets is that their enthalpy of reaction is much higher than that of heat paper ash. Thus, they serve as heat reservoirs retaining considerable heat after combustion and tend to extend the battery active life by virtue of their greater thermal mass.

5.2.5 Methods of Activation

Thermal batteries are activated by applying an external signal to an initiation device that is incorporated in the battery. There are four generally used methods of activation, electric signal to an electric igniter, mechanical impulse to a percussion primer, mechanical shock to an inertial activator and optical energy (laser) signal to a pyrotechnic material.

Electric igniters typically contain one or more bridge wires and a heat-sensitive pyrotechnic material. Upon application of an electric current, the bridge wire ignites the pyrotechnic, which in turn ignites the heat source in the thermal battery. Igniters generally fall into two categories: squibs and electric matches. A typical squib is enclosed in a sealed metal or ceramic enclosure and contains one or two bridge wires. The most commonly used types require a minimum activation current of 3.5A and have a maximum no-fire limit of 1A or 1W (whichever is greater). Electric matches do not have a sealed enclosure and typically contain only one bridge wire. They require an activation current of 500mA to 5A and should not be subjected to a no-fire test current of more than 20mA. Squibs are 4 to 10 times more expensive than electric matches, but are required for applications that may encounter environments with electromagnetic radiation.

Percussion primers are pyrotechnic devices that are activated by impact from a mechanical striking device. Typically, a primer is activated by an impact of 2016 to 2880 g cm applied with a 0.6 to 1.1mm spherical radius firing pin. Primers are installed in primer holders that are integral parts of the battery enclosure.

Inertial or setback activators are devices that are activated by a large-magnitude shock or rapid acceleration, as is generated upon firing of a mortar or artillery round. They are designed to react to a predetermined combination of *g* force and its duration. Inertial activators are typically firmly mounted inside the battery structure in order to withstand severe dynamic environments.

Optical energy (laser) activation of thermal batteries is accomplished by ''firing'' a laser beam through an optical ''window'' installed in the outer enclosure of the battery and igniting a suitable pyrotechnic material inside the unit. This method has found utility in applications where severe electromagnetic interference would be disruptive to an electrical firing method. Thermal batteries can be equipped with more than one activation device. The multiple activators can be of the same type or of any combination required by the application.

5.2.6 Insulation Materials

Thermal batteries are designed to maintain hermeticity throughout their service lives, even though their internal temperatures reach or even exceed 600^{o}C. The thermal insulation used to retard heat loss from the cell stack and minimize peak surface temperatures must be anhydrous and must have high thermal stability. Ceramic fibers, glass fibers, certain high temperature polymers and their combinations have been used as thermal insulators. Older battery designs may still have asbestos insulation, which was widely used before the 1980's. Electrical insulation materials for conductors, terminals, initiators and other electrically conductive components are typically made of mica, glass or ceramic fiber cloths and high temperature-resistant polymers.

Thermal insulation is located around the periphery and at both ends of the cell stack. Some designs also incorporate high-temperature epoxy potting materials as insulation and structural support for the initiators and electric conductors on the terminal end (header) of the batteries. Long-life batteries (20+ min.) usually incorporate high-efficiency thermal insulation materials such as Min-K (Johns Manville Co.) or Micro-Therm (Constantine Wingate, Ltd.). Extended life batteries (1 hr and longer) may incorporate vacuum blankets and /or double cases with vacuum space between them to retard heat loss. Special high-thermal capacity pellets and extra ''dummy'' cells are also used at the ends of cell stacks to retard heat loss and thus prolong the activated life of some batteries. Figure 5-2 shows a typical arrangement of thermal insulation and an encapsulated header assembly with initiator (squib).

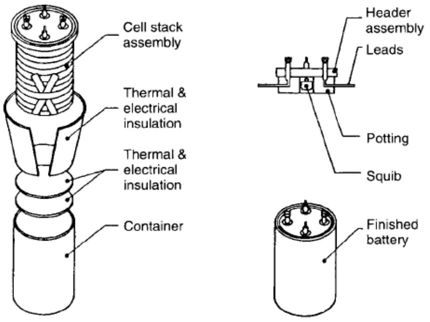


Figure 5-2 Typical thermal battery assembly.

A very effective method for extending the activated battery life and reducing the effects of heat on thermally sensitive components located near the battery is to use an external thermal blanket. Provided that it is protected from external contamination, a thermal blanket is more effective than internal insulation, primarily because the hot gasses that are generated inside the battery during activation cannot penetrate it. External insulation, mounting methods and the surrounding environment have a significant effect on the heat loss from the battery and all of these must be taken into consideration in the design of thermal batteries.

5.3 Cell Chemistry

A wide variety of different cell chemistries have been developed and used in thermal batteries. At this time, the most widely used chemistry is lithium / iron disulfide (Li /FeS_2), with calcium/calcium chromate ($Ca/CaCrO_4$) as a distant second. There are special applications, though, where one of the other less used chemistries could offer special advantages. As an example, the requirement for a very fast activation time with a relatively short activated life would be provided by the calcium/potassium dichromate ($Ca/LiCl\text{-}KCl/K_2Cr_2O_7$) system or the calcium/lead chromate ($Ca/LiCl\text{-}KCl/PbCrO_4$) system for a general overview.

5.3.1 Lithium/Iron Disulfide

There are three common lithium anode configurations: Li(Si) alloy, LiA1 alloy and Li metal in metal matrix, Li(M), where the matrix is usually iron powder. With the difference that the alloy anodes remain solids and the lithium in the Li(Fe) mix is molten in an activated cell all three anodes participate in the cell reaction similarly. All may be used with the same FeS_2 cathode and the same electrolytes. These electrolytes may be the basic LiC1-KC1 eutectic electrolyte, LiCl-LiBr-LiF electrolyte for best ionic conductivity or a lower-melting point electrolyte such as LiBr-KBr-LiF for extended activated life. Since the FeS2 is a good electronic conductor, the electrolyte layer is necessary in order to prevent direct anode-to cathode contact and cell short-circuiting. When molten, the electrolyte between the anode and the cathode is held in place by capillary action through the use of a chemically compatible (inert) binder material. MgO is the preferred material for this application. The Li/FeS_2 electrochemical system has become the preferred system because it does not contain any parasitic chemical reactions. The extent of self-discharge depends on the type of electrolyte used and the cell temperature. The predominant discharge path for cathodes is:

$$3Li + 2FeS_2 \rightarrow Li_3Fe_2S_4 \ (2.1\ V)$$

$$Li_3Fe_2S_4 + Li \rightarrow 2Li_2FeS_2 \ (1.9\ V)$$

$$Li_2FeS_2 + 2Li \rightarrow Fe + 2Li_2S \ (1.6\ V)$$

Most batteries are designed to use only the first and sometimes the second cathode transitions to avoid changes in cell voltage.

The transitions that occur at the anode depend on the alloy used. For LiAl:

β-LiAl (ca. 20 wt % Li) → α –Al (solid solution)

Below approximately 18.4 weight percent lithium (lower limit for all β-LiAl) and above 10 weight percent lithium (upper limit for α-Al), the alloy is two-phase α, β-LiAl. This fixes the alloy voltage on a plateau. This plateau is about 300 mV less than the voltage afforded by pure lithium metal.

The composition transitions for Li (Si) are:

$$\mathbf{Li_{22}S_5 \rightarrow Li_{13}Si_4 \rightarrow Li_7Si_3 \rightarrow Li_{12}S_7}$$

An anode voltage plateau is defined for compositions falling between each adjacent pair of alloys. That is, the first plateau occurs between $Li_{22}Si_5$ and $Li_{13}Si_4$. The 44 weight percent Li (Si) composition falls here and begins its discharge approximately 150 mV less than that of pure lithium.

The use of FeS_2 as a cathode material can cause a large voltage transient or ''spike'' of 0.2V or more per cell, which is evident immediately after activation and lasts from milliseconds to a few seconds. This phenomenon is related to the impact of temperature, the amounts of electro active impurities in the raw material (iron oxides and sulfates), elemental sulfur from FeS_2 decompositi and the activity of lithium not being fixed in the cathode. In applications where the voltage has to be well regulated, this ''spike'' is not acceptable. The voltage transient can be virtually eliminated by the addition of small amounts of Li_2O or Li_2S (typically 0.16 mol Li per mol FeS_2) to the catholyte (FeS_2 and electrolyte blend), a method known as *multiphase lithiation*. The spike can also be reduced (but not eliminated) by thoroughly washing or vacuum treating the FeS_2 to remove acid-soluble impurities and elemental sulfur. The Li/FeS_2 electrochemical system has a number of important advantages over other systems, including Ca/$CaCrO_4$. These advantages include:

- Tolerance of a wide range of discharge conditions from open circuit to high current densities.
- High current capabilities, 3 to 5 times that of Ca/$CaCrO_4$.
- Highly predictable performance.
- Simplicity of construction.

- Tolerance to processing variations.
- Stability in extreme dynamic environments.

As a result of these advantages, this system has become the predominant choice for a wide range of high-reliability military and space applications.

5.3.2 Lithium/Cobalt Disulfide

As a cathode *vs*. lithium in molten salt electrolyte cells, cobalt disulfide exhibits a slightly lower voltage than does iron disulfide. Cobalt disulfide has a greater thermal stability with respect to loss of sulfur. However,the decomposition reactions for cobalt disulfide at elevated temperatures are:

$$\mathbf{3CoS_2 \rightarrow Co_3S_4 + S_2(g)}$$

$$\mathbf{3Co_3S_4 \rightarrow Co_9S_8 + 2S_2(g)}$$

For iron disulfide at elevated temperatures:

$$\mathbf{2FeS_2 \rightarrow 2FeS + S_2(g)}$$

As a rough indicator of the relative stabilities, FeS2 will have a sulfur vapor pressure (p_{S2}) of 1 atm in equilibrium with it at 700°C, whereas p_{S2}=1 atm for CoS_2 at 800°C. It is therefore no surprise that the substitution of CoS_2 for FeS_2 can yield a more high temperature- stable cell and is therefore useful in batteries with activated lives of over 1 hour.13 in an active battery, the decomposition of FeS_2 to FeS and elemental sulfur becomes significant above approximately 550°C. The free sulfur can combine directly with the Li anode in a highly exothermic reaction. Not only would this reduce available anode capacity, but the extra heat can cause even more thermal decomposition of the cathode. CoS_2 which is stable up to 6500°C allows higher initial stack temperatures to be sustained without excessive degradation of the cathode. It has also been demonstrated that cells with CoS_2 cathodes have a lower internal resistance later in activated life than do FeS_2 cathodes.

5.3.3 Calcium/Calcium Chromate

The reactions that take place in a Ca/$CaCrO_4$ thermal cell during activation must be in critical balance for the cell to function properly. Upon activation (application of heat), the calcium anode reacts with lithium ions in the LiCl-KCl eutectic electrolyte to form liquid beads of Ca-Li alloy. This alloy becomes the operational anode in the subsequent electrochemical reaction. The anodic half-cell reaction is:

$$\mathbf{CaLi_x \rightarrow CaLi_{x-y} + yLi^+ + ye^-}$$

The Ca-Li alloy beads also react with dissolved $CaCrO_4$ forming a coating of

$Ca_5(CrO_4)_3Cl$. This Cr(V) compound is the same species that is formed in the cathodic half-cell reaction:

$$\mathbf{3CrO_4^{-2} + 5Ca^{+2} + Cl^- + 3e^- \rightarrow Ca_5(CrO_4)_3Cl}$$

This ''product'' acts as a separator or mass transport barrier between the cathode and the anode to limit electrochemical self-discharge. If the integrity of this separator is breached, the battery can experience a ''thermal runaway'' condition, whereby the active electrochemical components are chemically consumed with accompanying generation of large amounts of excess heat. At the same time, if battery conditions are such that alloy formation exceeds usage, the excess alloy can cause periodic shorting, the ''alloy noise'' sometimes seen in cold-stored batteries. The balance between chemical and electrochemical reactions in this system is dependent on the source of materials (particularly $CaCrO_4$), processing variations and density of compression-formed pellets, operating temperature of the cell, rate of current drain and other variables. Consequently, this system has been gradually phased-out in favor of the more stable and predictable lithium / iron disulfide cell chemistry which also has a higher energy density.

5.4 Cell Construction

A number of factors, including the cell chemistry used the operating environments of the battery and the preferences of the designer, determine the choice of cell design. Basically, all cell designs fall into three categories: cup cells, open cells and pelletized cells. To meet specific performance requirements, some designs may incorporate aspects of more than one cell category. Figure 5-3 illustrates the relative thickness ranges of the different cell designs.

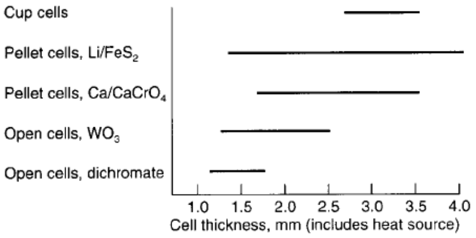


Figure 5-3 Thicknesses of thermal battery cells.

5.4.1 Cup Cells

The typical cup cell features a two layer anode (calcium or magnesium) having active anode material on both sides of a central current collector. On either side of the anode is an electrolyte pad made of glass tape impregnated with eutectic electrolyte. Next to each electrolyte are depolarizer pads consisting of cathode material ($CaCrO_4$ or WO_3) in an inorganic fiber matrix (paper). The cell is enclosed in a nickel foil cup and cover that are tightly crimped (Figure 5-4). Some designs also incorporate inorganic fiber mat gaskets and nickel ''eyelets'' to help prevent the molten electrolyte from leaking out of the activated cell. Zr/ $BaCrO_4$ heat paper pads located on either side provide heat to the cup cell. Cup cells have the advantage of large reactive surfaces (they are two-sided or bipolar)and can contain relatively large amounts of reactive materials. Their disadvantages are that they are difficult to seal against electrolyte leakage and they have low heat capacity. The Ca/$CaCrO_4$ cell chemistry is also prone to ''alloying'' (producing excess molten Ca-Li alloy), which can short-circuit the cells. In order to obtain required short activation times, cup cells typically have to be pre-melted or ''pre-fused'' prior to assembly into cell stacks. Inter-cell electrical connections are accomplished by spot-welding the cell output leads between each cell, which presents a potential reliability problem. Currently, cup cells have limited application and are found primarily in older battery designs.

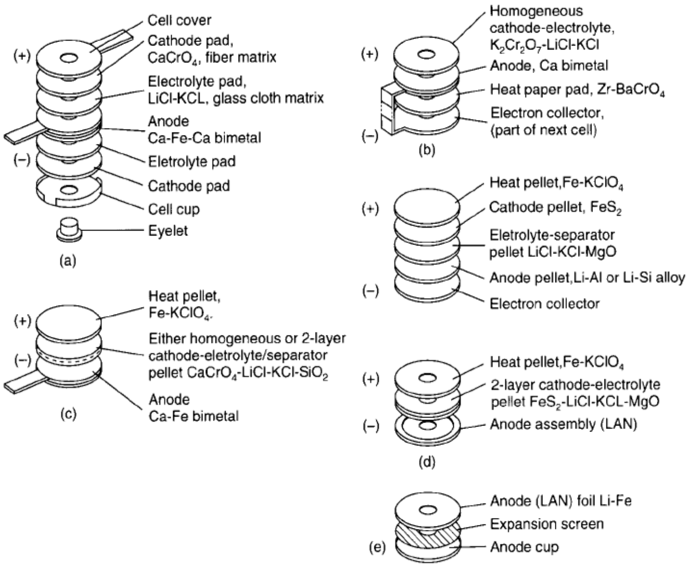


Figure 5-4 Variations in cell configurations: (a) Cup cell. (b) Open cell. (c) Ca /$CaCrO_4$ pellet cell. (d) Li alloy /FeS_2 and Li /FeS_2 pellet cell. (e) Li metal /FeS_2, (LAN) anode assembly.

5.4.2 Open Cells

The open-cell design is similar in construction to the cup cell except that it is not enclosed in a cup (Figure 5-4). Elimination of the cup is possible because the amount of electrolyte is reduced to the extent that practically all of it is bound to the glass fiber cloth matrix by surface tension. Some designs use homogeneous electrolyte-depolarizer pads, others have discrete parts. Open-cell designs typically incorporate a combination anode-electron collector usually in the shape of a ''dumbbell.'' This combination part has anode material vacuum deposited on one end (which serves as anode in one cell), while the other end is an electron collector in the next, series-connected cell. A narrow bridge connects the two ends of the dumbbell. The bridge serves as an inter-cell connector, eliminating the need for spot welds. Zr/$BaCrO_4$ heat paper pads heat the open cells, which are assembled between the folded dumbbells. The open-cell design is used in relatively short-life applications and in pulse batteries. Their parts can be made very thin to promote very rapid heat transfer and obtain short activation times.

5.4.3 Pellet Cells

In pellet cells, the electrolyte, cathode and heat source are in pellet (wafer) form. Anodes can be of different configurations depending on which electrochemical system is used. For pellet production, the cell component chemicals are processed into powders and the powders are uniaxially pressed into the parts. Electrolytes, which melt at cell operating temperatures are combined with inert binders, which hold the molten salts in place by capillary action or surface tension, or both.

A typical pelletized Ca/$CaCrO_4$ cell, as shown in Figure 5-4, is made up of the following:

- **A calcium anode:** Either calcium foil (on nickel or iron foil collector) or calcium bimetal (deposited on either iron or nickel collector).
- **A pelletized electrolyte powder blend:** Consisting of LiCl-KCl eutectic salts and either SiO_2 or kaolin as binders.
- **A pelletized cathode powder blend:** Consisting of $CaCrO_4$, LiCl-KCl eutectic salts and SiO_2 or kaolin binder.
- **A pelletized heat source:** A blend of iron powder and $KClO_4$. (Alternatively, this may be a non-pelletized heat source assembly made up of Zr-$BaCrO_4$ heat paper in a nickel or iron foil dumbbell with the anode of the next cell on the outside—similar to the anode and heat source in open-cell designs).

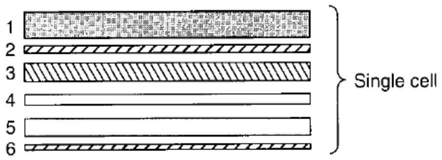
Variations of this cell design include 1) the use of a two-layer pellet with discrete electrolyte and cathode layers formed into one part and 2) the use of a homogeneous pellet that has the electrolyte and cathode powders blended together (depolarizer-electrolyte-binder or DEB pellet). A typical Li/FeS_2 cell, as illustrated in Figure 5-4, is made up of the following:

- **A lithium anode:** Of either pelletized lithium alloy powder or a lithium metal anode assembly.
- **A pelletized electrolyte powder blend:** Consisting of a salt mixture and MgO binder. The salts may include mixtures such as LiCl-KCl eutectic, LiBr-KBr-LiF or LiCl-LiBr-KBr.
- **A pelletized cathode powder blend:** Of FeS_2 and electrolyte with either MgO or SiO_2 Binder.
- **A pelletized heat powder blend:** Of pyrotechnic-grade iron powder and $KClO_4$.
- **An electrical collector:** Of iron or stainless steel foil, located between the heat pellet and the lithium alloy anode pellet. This part is not used with a lithium metal anode assembly, which has an integral metal foil cup. In some cases, especially in longer-life batteries, a second metal foil ''collector'' is placed between the FeS_2 cathode and the heat pellet to buffer or prevent the cathode from exposure to excessive heat.

The pressure used for pelletizing the cell components is critical. In the case of Ca/$CaCrO_4$ designs, the forming pressures and hence the resultant densities of the electrolyte and cathode pellets, have a profound effect on the reactivities of the cells. The components of the Li/FeS_2 systems, except for the heat pellets are less sensitive to variations in density. Heat pellet ignition sensitivity and burning rate are significantly affected by changes in density. However, with high density decreasing ignition sensitivity and rate. The design parameters of a representative Li(Si) /FeS_2 cell are shown in Table 5-2.

The use of pellet-type cell construction has significantly increased the performance capability of thermal batteries. Pellet designs have particular advantages in longer-activated life, high-current-drain applications. They are structurally very rugged, can operate reliably over wider ambient temperature ranges and are generally less expensive to manufacture than older designs. There are applications, however, such as those requiring fast activation times and high-voltage pulses, where open-cell designs with Ca/LiCl-KCl/$K_2Cr_2O_7$ or Ca/LiCl-KCl/$PbCrO_4$ cell chemistries and heat paper are more suitable.

Table 5-2 Cell Components of 3400-A/ s, Li-Si /FeS_2, Thermal Battery Cell



	Component	Chemical composition	Chemical ratio w/% ± 1	Density (g/cm^2) ± 0.05	Forming force, tons	Thickness, cm	Weight, g ± 0.1
				Pellet			
1	Heat pellet	$Fe/KClO_4$	88/12	3.40	60	0.14	22
2	Cathode current collector	SST-304	—	7.75	—	0.013	4.6
3	Cathode pellet	$FeS_2/LiCl\text{-}KCl/SiO_2$	64/16/20	2.9	200	0.06	8.5
4	Separator pellet	$LiCl\text{-}KCl\text{-}Li_2O/MgO$	65/35	1.75	90	0.06	4.5
5	Anode pellet	Li/Si	44/56	1.0	115	0.1	4.5
6	Anode current collector	SST-304	—	7.75	—	0.013	4.6

5.5 Cell-Stack Designs

All thermal batteries are designed to satisfy a specific set of performance requirements, each of which includes output voltage, current drain and activated life. In designing a battery, the output voltage determines the number of cells that must be connected in series. Since each cell produces a fixed maximum voltage (from 1.6 to 3.3 V on open circuit, depending on the cell chemistry used), the battery output will be in multiples of discrete cell voltages. Batteries containing over 180 series-connected cells with an overall output voltage near 400 V have been successfully manufactured. Typical batteries contain 14 to 80 cells and have an output voltage of 28 to 140 V. Figure 5-5 illustrates two different cell-stack configurations, one with cup cells and the other with pellet-type cells. The current-carrying capacity of each cell is determined by the reactive surface area of the cell, which is directly related to the cell size (diameter). As with cell voltages, the maximum useful current densities (Amperes per unit area) differ greatly among cell chemistries (see Table 5-3 and

Table 5-4). The effective cell area and hence the current-carrying capacity of a battery, can be adjusted by electrically connecting any number of cells in parallel. Thermal batteries can be designed to provide multiple output voltages by electrically connecting the required number of cells in series. The multiple-voltage outputs can be drawn either from cells that are common to more than one output or from isolated cells whose output is not shared. An electrically isolated group of cells must be used for circuits that cannot tolerate ''crosstalk'' from other circuits in a system. It is also possible to combine cell-stack sections with different cell chemistries in the same battery.

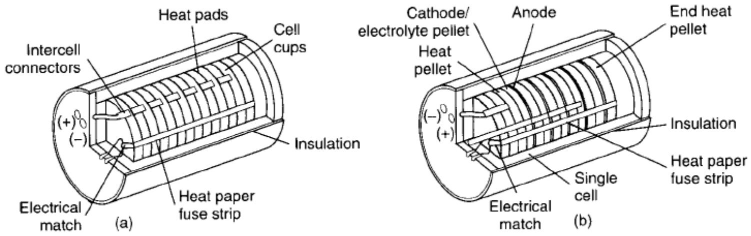


Figure 5-5 Typical thermal battery assemblies. (a) Cup cells. (b) Pellet cells.

Table 5-3 Attainable current density of different cell designs.

Cell design	**Current density, mA/cm^2**		
	10-s rate	**100-s rate**	**1000-s rate**
Cup cell	620	35	-
Open cell/ dichromate	54	-	-
Pellet cell/ two-layer Ca/CaCrO$_4$	790	46	-
Pellet cell/ DEB Ca/CaCrO$_4$	930	122	-
Pellet cell / Li/FeS$_2$	>2500	610	150

Table 5-4 Typical Power and Energy Densities of Li/Fes$_2$Thermal Batteries.

Battery volume, cm^3	**Power density, W/cm^2**	**Energy density, Wh/L**	**Activated life, 's'**
20	11.25	46.87	15
29	1.44	34.20	85
70	2.59	35.97	50
108	0.65	32.41	180

170	1.98	109.80	200
171	10.64	118.26	40
183	2.29	63.75	100
306	0.51	39.65	280
311	2.25	75.03	700
552	0.15	67.63	1600
1176	0.40	101.19	900
1312	0.17	85.37	1800
3120	1.11	83.30	270

Such combinations yield the specific performance characteristics of both chemistries from a common unit. An example of this is a battery that combines a cell stack with a chemistry that has a very short start time with a different cell stack that can provide a high current over a long activated life. Where such combinations are used the outputs from the different cell-stack sections are often diode-isolated to prevent one section from charging the other. Some thermal battery designs combine two or more discrete batteries into an assembly that may have a number of different, mutually isolated voltage outputs with widely varying current capabilities.

Cells comprising a cell stack are typically held in place by the closing compression applied when the battery cover is secured by welding it to the battery case. Some battery designs incorporate an inner case to maintain compressions on the cell stack while the outer case and cover combination provides hermetic enclosure for the unit. Figure 5-6 pictures a battery design that employs an inner cell stack case.

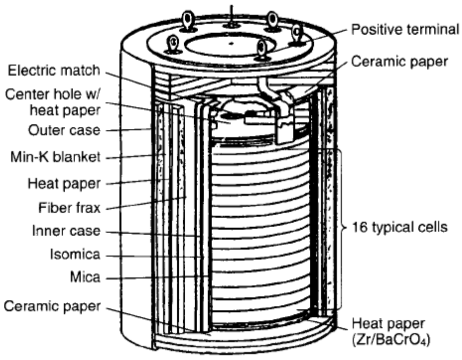


Figure 5-6 Typical thermal battery assembly with inner case.

5.6 **Performance Characteristics**

Thermal batteries are custom-designed to satisfy a specific set of performance requirements. These include not only output voltage, current, activated life and voltage rise time (start), but also storage and activated-life environments, mounting, surface temperature, activation method and energy and others. For this reason it is very important that the user or systems designer have a close technical interface with the battery designer during the design and development phases of the battery.

5.6.1 Voltage Regulation

Thermal battery output voltages are not linear. After reaching a peak level, typically within 1 second after activation, the voltage starts to decay until it eventually drops below the minimum useful level. Voltage regulation is the range between the specified minimum and maximum limits. Typically, the minimum voltage limit is 75% of the peak voltage. The battery output profile (consisting of the rise time, peak voltage, and rate of decay) depends on the cell chemistry and is strongly affected by the operating temperature and applied load. Figure 5-7 illustrates the effects of discharge load on a typical battery output profile.

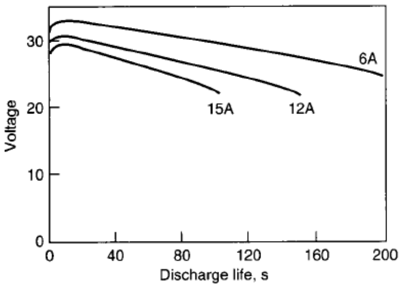


Figure 5-7 Discharge voltage curves of typical Li //FeS_2 battery.

5.6.2 Activation Time

The activation time (rise time) is the time interval from the application of energy to the initiation device until the battery output voltage reaches the minimum specified limit. The activation time is affected by the operating temperature, applied load and cell chemistry used. Lowering the operating temperature or increasing the load typically increases the activation time. Typical Li/FeS_2 batteries have activation times from 0.35 to 1.00 s. Large, high-capacity batteries can have activation times as long as 3s. (Large diameter heat pellets take longer times to burn.) On the other hand, fast-activating chemistries such as Ca/$K_2Cr_2O_7$ can yield activation times as short as 12ms. Figure 5-8 shows activation time ranges for various cell chemistries and Figure 5-9 illustrates the effects of ambient temperature.

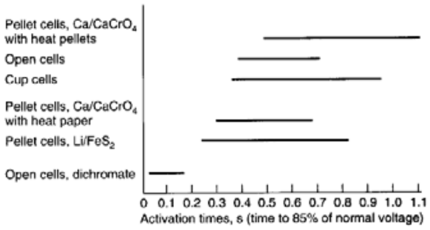


Figure 5-8 Activation times of different thermal battery cell designs.

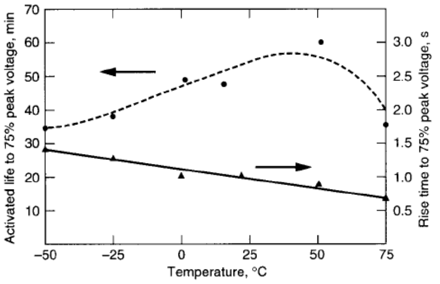


Figure 5-9 Activated life and rise time of Li /FeS_2 battery. (From Quinn and Baldwin.)

5.6.3 Activated Life

The activated (operating) life is typically specified as the time from the initial application of the activation energy until the battery voltage drops below the minimum specified limit. Activated life is affected by the cell chemistry used the operating temperature environment and the current drain. Typically, thermal batteries are thermally balanced (total cell mass *vs.* caloric input) to have the longest activated lives between the high and low operating temperature limits or near room ambient. Lives will get shorter near each temperature limit. At the low limit, the electrolyte will start freezing sooner, whereas at the high limit the thermal degradation of FeS_2 occurs at a faster rate, depleting active materials.

5.6.4 Interface Considerations

The following performance and design characteristics must be noted when designing a system that interfaces with a thermal battery:

- An unactivated battery has a very high internal resistance (mega Ohms). Once activated, an individual cell's resistance is between 0.003 and 0.02 Ohm, depending on the cell design. The internal resistance of the battery is equal to the sum of the resistances of all series-connected cells.
- Some cell chemistries, such as Li/FeS_2, are tolerant of back charging from an external power source. Others however, such as Ca/$CaCrO_4$ must not be subjected to back charging at all.
- Electric actuators contain bridge wires that may not burn through during activation and if not disconnected, may act as a parasitic load on the external ignition circuit.

- Leakage paths that can adversely load the battery may develop in an activated battery between electrically ''live'' components and the battery case or activator circuits. System requirements, such as case grounding, cell-stack common output and activator circuit grounding must be specified so that special insulation provisions can be incorporated into the battery design.
- The surface temperature of an activated battery may reach 400°C. The type of battery mounting, the heat transfer properties of the mounting, the effects of high temperature on the surrounding components and the proximity of combustible materials must be considered. The battery surface temperature can usually be reduced significantly by incorporating added (or more efficient) thermal insulation. This is achieved, however, at considerable cost and increase in battery volume. Figure 5-10 and Figure 5-11 illustrate typical surface temperatures of thermal batteries.

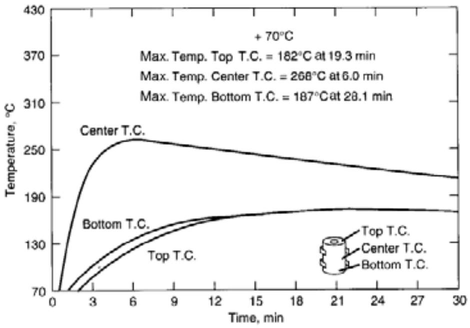


Figure 5-10 Surface temperature profiles for long-life thermal battery.

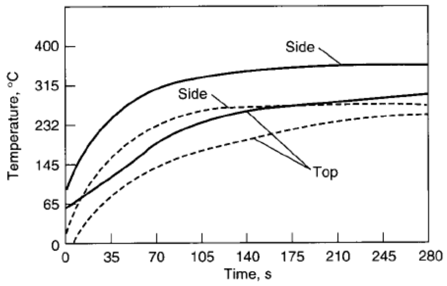


Figure 5-11 Surface temperature profiles for a medium-life thermal battery. Solid line-tested at 71°C; broken line-tested at -53°C.

5.7 Testing And Surveillance

The safety and reliability of thermal batteries has been a matter of continuing study since they were first developed. To identify defective units most designs are 100% tested for hermeticity, polarity, electrical insulation resistance and activation circuit resistance (if applicable) on manufacture. Most units are also radiographed. Prior to commencement of production, a sample group of 10 to as many as 500 batteries is subjected to qualification tests. This series of tests includes the most severe environmental and discharge conditions to which the particular battery design will be exposed in actual field use. Almost all thermal batteries are fabricated in homogeneous groups or lots and samples from each lot are discharged to demonstrate compliance with the performance requirements. Usually the samples are discharged at maximum specified loads, often with concurrently imposed environmental forces. By using such test programs, reliability values greater than 99% and safety values greater than 99.9% have been demonstrated innumerable times in the last five decades. Lithium thermal batteries designed for use in U.S. Navy systems are subject to safety tests per Navy technical manual S9310-AQ-SAF, ''Battery, Navy Lithium Safety Program Responsibilities and Procedures.'' These tests are designed to assure that the battery design is safe not only in proper storage and use, but also when subjected to inadvertent misuse and conditions caused by accidents, such as back charging, short circuits and fires.

5.8 Typical Thermal Battery Features of M/s H.B.L Hyderabad

Operating temperature range : -54°C to +71 °C
Service during storage : No maintenance required
Active life : Seconds to one hour
Voltage range : 2 to 200 Volts
Current density : up to 1 amp/cm^2
Pulse capabilities : 10 amps/cm^2
Self Discharge : Nil
Out Gassing : Nil
Battery sealing : Hermetically sealed in stainless steel container
Rugged construction : Operates reliably and meets stringent environmental conditions encountered by weapon systems
Reliability : 99.95% at confidence level of 90%
Shelf life : > 20 years

Platform used : ASTRA, missile.

Typical view of Thermal Battery supplied by M/s H.B.L Hyderabad in shown in Figure 5-12.

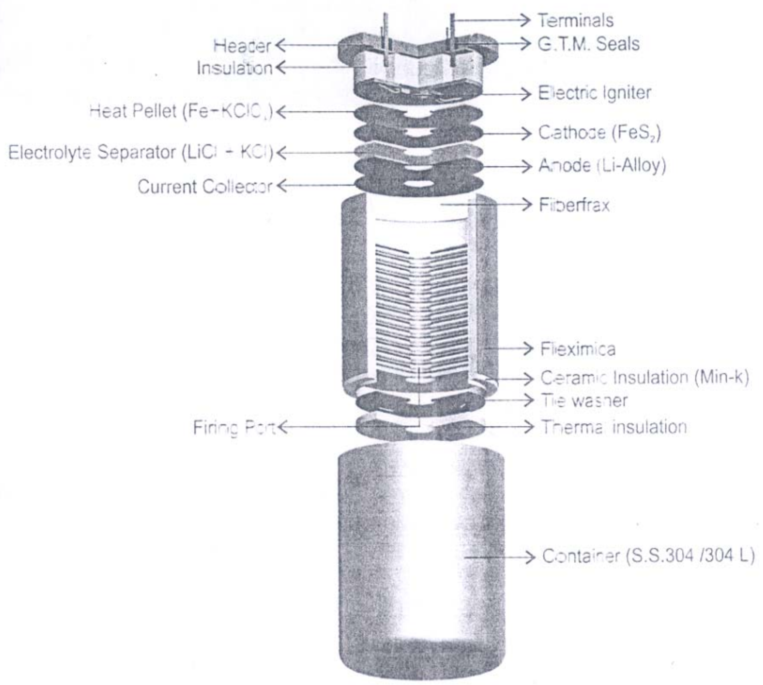


Figure 5-12 Typical Thermal Battery Features supplied by M/s H.B.L Hyderabad

Table 5-5 A Typical specifications of missile “Thermal Battery “manufactured by M/s.HBL, Hyderabad

Battery CODE	Power	No. of Sections	Operating Voltage	Life	Activation Time (max)	Operating Max	Temp Min	Weight (max)	Primer type
	Watts		Volts	Sec	m.sec	°C	°C	gm	
047070B-01	175	Two	15±2	40	600	55	-30	300	Electric Igniter
047070A-01	175	One	28±4	40	600	55	-30	300	Electric Igniter
047070A-02	175	One	28±4	60	600	55	-20	300	Electric Igniter
047145A-01	500	One	28±4	60	1400	55	-30	570	Electric Igniter
055055A-01	150	Two	19.5±3	40	500	55	-30	330	Mechanical percussion
013035A-01	5	One	5V min	0.5	200	55	-30	30	Electric Igniter
034064A-01	56	One	28±4	40	500	55	-30	180	Electric Igniter
044135A-01	336	One	56±8	50	1400	55	-40	530	Electric Igniter
044135B-01	145	Two	19.5 to 25	120	1400	55	-40	530	Electric Igniter
055135A-01	364	One	28±4	120	1400	55	-40	670	Electric Igniter
047135A-01	280	One	28±4	120	1400	55	-40	530	Electric Igniter
043068B-01	180	Two	15±2	40	600	55	-30	300	Electric Igniter
063120B-01	160	Two	40±5	480	1000	Ambient		1000	Electric Igniter
*220220A-01	9750	One	150±50	60	2000	55	-20	12000	Electric Igniter
055155A-01	500	One	37.5±26	140	1400	55	-20	900	Electric Igniter
080140A-01	700	One	28±4	200	1400	55	-20	1800	Electric Igniter

6 Operational, Maintenance and Overhaul Practices

6.1 Introduction

This section provides guidelines for Ni-Cd, Ag-Zn and Lead Acid (Alkali storage) aircraft storage batteries for reliable operational, maintenance and overhaul practices. These procedures are generally given in battery operating instruction manuals. The information also includes reconditioning procedures.

6.2 Background

An increasing number of potentially hazardous incidents involving Ni-Cd / Ag-Zn / Pb acid batteries, during flight and ground operations have been reported. The failures are more prevalent where the batteries are charged directly from the DC bus rather than by a separate battery charger. Although the nickel-cadmium battery is capable of delivering large amounts of current, the battery is inherently temperature sensitive and a majority of the reported incidents can be attributed to overheating. The overheat conditions can be minimized or averted by following proper operational, maintenance and overhaul practices.

6.2.1.1.1.1.1.1 Failure Modes

6.2.2 Lead acid (flooded) failure modes

- Positive grid corrosion
- Sediment (shedding) build-up
- Top lead corrosion
- Plate sulphation
- Hard shorts (paste lumps)

6.2.3 Lead acid (VRLA) failure modes

- Dry-out (Loss of compression)
- Plate Sulphation
- Soft and Hard Shorts
- Post leakage
- Thermal run-away
- Positive grid corrosion

6.2.4 Nickel-cadmium failure modes

Ni-Cd batteries seem to be more robust than lead acid. They are more expensive to purchase but the cost of ownership is similar to lead acid, especially if maintenance costs are used in the cost equation.

The failure modes of Ni-Cd are much more limited than lead acid. Some of the more important modes are:

- Gradual loss of capacity
- Carbonation
- Floating effects
- Cycling
- Iron poisoning of positive plates

Carbonation is gradual and is reversible. Carbonation is caused by the absorption of carbon dioxide from the air into the potassium hydroxide electrolyte which is why it is a gradual process. Without proper maintenance, carbonation can cause the load to not be supported, which can be catastrophic to supported equipment. It can be reversed by exchanging the electrolyte.

Floating effects are the gradual loss of capacity due to long periods on float without being cycled. This can also cause a catastrophic failure of the supported load however, through routine maintenance, this can be avoided and is easily found by impedance testing. Floating effects are reversible by deep cycling the battery once or twice.

Ni-Cd batteries, with their thicker plates, are not well-suited for cycling applications. Shorter duration batteries generally have thinner plates to discharge faster due to a higher surface area. Thinner plates means more plates for a given jar size and capacity, and more surface area. Thicker plates (in the same jar size) have less surface area. Iron poisoning is caused by corroding plates and is irreversible.

6.3 Thermal effects on Ni-Cd / Ag-Zn / Pb acid

The nickel cadmium battery is capable of performing to its rated capacity when the ambient temperature of the battery is in the range of approximately 20° C to 60° C. An increase or decrease in temperature, from this range results in reduced capacity. A combination of high battery temperature (in excess of 60°C) and overcharging can lead to a condition called “thermal runaway”. Basically, “thermal runaway” is an uncontrollable rise in battery temperature that will ultimately destroy the battery. This condition can occur when a nickel cadmium battery is operated at above normal temperatures and subjected to high charging currents associated with constant voltage charging. As the temperature of the battery increases, the effective internal resistance decreases and higher current is drawn from the constant voltage charging source. The higher current increases the battery temperature which in turn results in even higher charging currents and temperatures.

6.4 Battery Overheat Factors

Battery overheating can be caused or accelerated by the following factors:

- Frequent engine starts and excessive engine cranking.
- Aircraft generator bus voltage too high.
- Improper charging and infrequent battery reconditioning.

- Unnecessary use of the aircraft batteries to run auxiliary equipment such as lights, avionics equipment, ventilation systems, etc. during ground operations.
- Poor or no ventilation of the battery compartment during high ambient temperatures particularly during ground operations.
- Loose cell-to-cell connections (commonly called links).
- Current leakage between cell and battery container and airframe ground.
- Cells low on electrolyte.
- Ground operations using power units with voltage settings higher than the recommended aircraft bus voltage or power units with poor regulation.
- Cell imbalance.

6.5 Operational Practices to Prevent battery Overheating

a) Reduce the number of consecutive engine starts by programming the use of a well regulated external power supply when a series of short duration flights or consecutive engine starts are planned. This procedure will allow the battery to dissipate some of its accumulated heat. Avoid prolonged engine cranking and follow the manufacturer's recommended rest periods between starts to minimize battery over-heating.

b) Frequent in flight monitoring of the aircraft bus voltage and load current will provide an indication of any increase, decrease or fluctuations of the aircraft bus voltage or load current indicating an abnormal condition.

c) An increase in load or charge current as indicated on the aircraft load meter, especially during normal cruise with no additional circuits being energized may be an indication of battery overheat or failure. Initiate corrective action as soon as possible.

6.6 Maintenance practices to prevent battery overheating

a) Service batteries at the interval recommended by the aircraft and battery manufacturer however, more frequent servicing may be necessary depending upon the type of operation conducted.

b) The aircraft voltage regulator setting should be checked periodically to correct for out-of-calibration units and replacement of defective units thereby reducing the possibility of an inadvertent increase in charging voltage/current and a resultant rise in battery temperature.

c) During extended ground operation, under high outside ambient temperatures keep the battery loads to a minimum and ensure there is adequate battery compartment ventilation. Additional ventilation may be provided by opening the battery compartment access door or using forced air ventilation.

d) Check and maintain the manufacturer's recommended torque values on inter cell connections during routine maintenance inspections. This will reduce the possibility of localized heating that can be caused by high currents passing through poor connections and feeding back into a cell or cells.

e) Periodic measurement of battery leakage current and removal of any electrolyte that may have accumulated around and between the cells will prevent high leakage currents and short circuits from developing and heating the battery.

f) Cell electrolyte level should be monitored frequently and if below the minimum requirement the battery should be removed from service for reconditioning. This will reduce the possibility of localized cell overheating.

g) When charging a battery in the aircraft assure that :

  - The battery compartment is well ventilated.
  - The ground power unit voltage setting does not exceed the aircraft bus voltage specified by the aircraft manufacturer is well regulated and its volt / ammeters are accurate.
  - The battery cover is off during charging to allow visual monitoring and to increase ventilation.
  - The battery is not charged when the battery temperature or battery compartment temperature is above approximately 60°C.

6.7 Battery Inspection

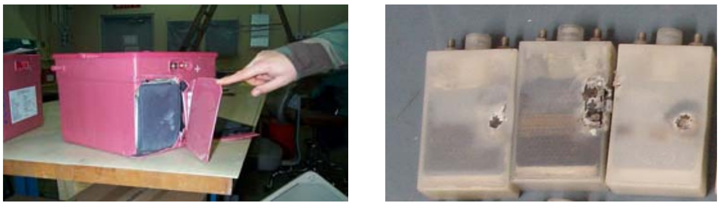


Figure 6-1 Battery overheat samples

Visually inspect (Figure 6-1) the battery and associated hardware on a regular basis. Depending on the type of aircraft operation, it is considered good practice to establish an electrolyte level inspection interval based on the battery and aircraft manufacturer's recommendations. Conduct a detailed investigation when any of the following conditions are noted:

- Cell case distortion indicates the battery may have been overheating. The battery should be removed and sent to a maintenance facility or factory for cell replacement.
- Cell link corrosion.
- Burn marks or signs of overheating on battery terminals or cell links. This indicates that the connectors involved have not been properly tightened.
- Electrolyte has spewed or leaked from cells.
- Battery and cell vents are obstructed.

The use of a service log provides an accurate service record of battery inspection and malfunctions. It can also be a useful tool in determining the optimum period between reconditioning.

6.8 Ni-Cd Battery Reconditioning for Service use

It is characteristics of a Nickel-Cadmium battery to undergo a temporary loss of capacity during its normal duty cycle. This temporary loss of capacity is normally an indication of imbalance between cells. If not regularly maintained, this imbalance can lead to cell reversal and premature battery failure. The purpose of periodic reconditioning is to restore a battery to its full capability and to prevent premature damage and failure. The following factors should be considered when establishing reconditioning cycles for various types of aircraft.

a) Recommendations of the Battery manufacturer

b) Frequency of engine or auxiliary power unit starting service.

c) Battery duty cycle.

d) Ambient operating temperatures.

e) Operator service experience will dictate the need for an increase or decrease of time between reconditioning periods. One method of determining this is by the amount of water consumption between reconditioning. (Each manufacturer specifies the amount of water that can be expected to be needed after a specific period of service). If during servicing, all of the cells require more water than is normally specified by the manufacturer it may indicate problems with the aircraft voltage regulator (charging voltage too high) or you may have a need for more frequent reconditioning.

Aircraft equipped with battery temperature sensors should have the sensor accuracy tested at the time of battery reconditioning. It is important that this test be performed on a regular basis.

6.8.1 Reconditioning procedure for Ni-Cd battery

Reconditioning of Ni-Cd Battery every 3 months during capacity test failure or 50 flying hours, the following procedure may be adopted for reconditioning the battery for improving its rated capacity. A Typical flowchart is shown Figure 6-2.

Ni-Cd Maintenance:

1. Ni-Cd problems can be evaluated without completely disassembling the battery.
2. Current Leakage caused by electrolyte can be fixed by flushing case with water. Wet batteries will not affect electrical leakage test.
   - Cracks in the receptacle housing cause the majority of current leakage problems.

- Cells with electrical / electrolyte leakage problems can easily be found after removing the cell interconnect links.

3. Only disassemble batteries to replace defective component, test component or resolve current leakage problems.
4. Number each cell before disassembly and reinstall cells in the same position to avoid gaps between cells.
5. Subsequent use causes cells to grow together again and gaps between the cell bodies should be avoided to prevent cell jar leakage.
6. New Joint-Use Ni-Cd ReFLEX Charge / Discharge procedures.
7. Initial Charge (15 minutes).
8. ReFLEX (Main Charge up to 2 hours).
9. Topping Charge (40 minutes, measure cell voltages and adjust cell electrolyte).

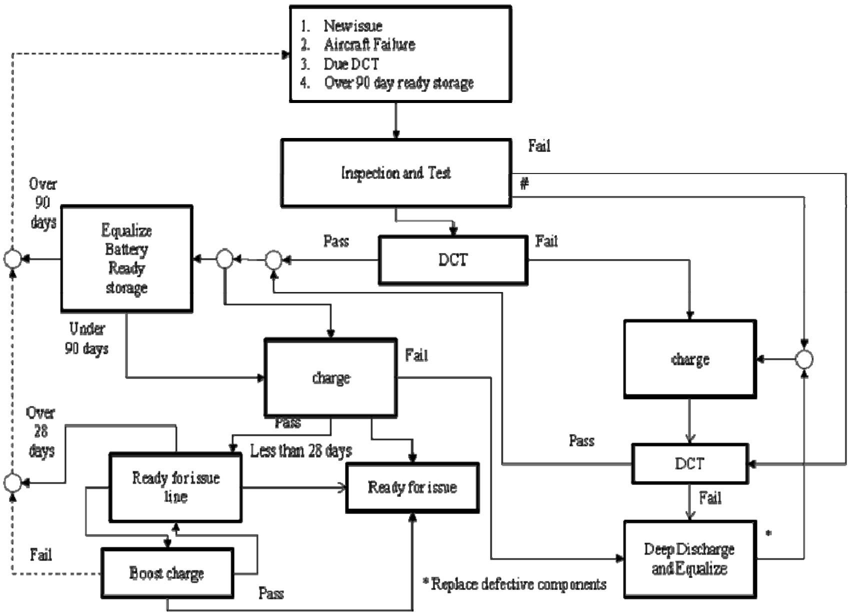


Figure 6-2 Typical Flowchart for reconditioning procedure of NI-CD battery

The method of reconditioning shall be as follows:

1. Discharge the battery at the C rate to 20V. Apply 1Ω resistor across each cell terminals for not less than 24 hours. Remove the resistors and charge with constant current charger as per procedure given below :
2. Discharge the battery at the C rate to a terminal voltage equal to 20V in atleast 60 minutes. If it is not discharged for 60 minutes, perform above charge - discharge procedure three times and verify the capacity requirement of the battery. It should be not less than 85% of its rated capacity.

The reconditioning of nickel-cadmium batteries is usually performed between 50 and 100 flight hours. The exact reconditioning time period depends mainly on the aircraft starting procedures, operating temperatures and generator voltage regulator setting. These factors will also determine the frequency of water additions to the battery cells.

6.8.2 Overhaul Practices & General Maintenance Procedures for Ni-Cd batteries

The construction and design of nickel-cadmium batteries allows easy overhauling of the individual cells. The following guidelines are recommended**:**

- Cells are overhauled at least once in a year. It is the repair agency's responsibility to ensure that the specifications laid by the OEM are met before clearing the reconditioned battery is returned to the service.
- Manufacturers do not recommend mixing cells. Some manufacturer's warranties are void if cells are mixed.
- New and overhauled cells may be identified as follows :
- New cells by the manufacturer's part number stamped on the case.
- Overhauled cells with the manufacturers or repair station's identification stamped on the cell case or color coded on the cell cases.
- The original manufacturer's part number should be retained on the overhauled cell to preclude mixing of cells. Repair agencies should mark the overhauled battery with their identity mark so as to not obliterate the original manufacturer's identification.
- In addition to the standard quality control procedures, inspect plates carefully for evidence of burned, crimped or frayed edges, hot spots or other damages.
- Damaged cell plates or stacks should be discarded. Nickel-cadmium cells are not consistently identical with respect of their capacity.

6.9 General guidelines on the maintenance & installation of Ni-Cd batteries

Also, in addition, paragraph 6.10 of this chapter gives general guidelines and maintenance and installation of Ni-Cd batteries (in particular of the semi-open type), which provide a standby source of DC power in aircraft. It should be read in conjunction with the Maintenance Manuals and Overhaul Manuals issued by the battery manufacturers, relevant aircraft Maintenance Manuals and approved Maintenance Schedules.

6.9.1 Battery Failure Modes

The prime method of assessing any battery is essentially the measurement of discharge capacity and this is sufficiently well appreciated as to require no further comment here. However, for Nickel Cadmium cells of the non sealed type, it is essential that the plate separator is in good condition. Unfortunately, the detection of failure requires close monitoring of cell voltage and it is quite possible for a battery containing cells with failed separators to give acceptable capacity.

The separator in a Nickel Cadmium cell has the obvious task of providing a physical isolation between the plates and less obviously, a significant function in terms of the electrochemistry of the cell. It is composed of a buildup of woven nylon or similar material and a non-porous membrane of cellophane. The cellophane acts both as a physical screen against metallic particle penetration and as a gas barrier to prevent oxygen generated by the positive plates during charge from reaching the negative plates. Unfortunately, these separator materials are the first to be damaged as battery temperature is increased and we no longer have the obvious warning signs of distorted cell boxes to show that overheating has occurred as was the position with earlier cells.

Should a damaged separator remain in service, local overheating will occur because of catalytic action at the negative plates and this in turn will cause poor charge acceptance. This generally results in a loss of balance with the other cells, poor capacity or more seriously an active failure in terms of cell burning. The majority of such burns is relatively minor and can only be seen when a cell is removed from the battery but it is the same mechanism which can develop to give cell to cell or cell to case shorts which may then create significant hazards.

The causes of separator failure can be placed into two broad categories, namely:

a) Adverse aircraft operating conditions – including system management problems or
b) Poor maintenance – either in terms of battery workshop practice or length of time between servicing.

Clearly, these sub-divisions represent an over simplification but it is convenient to proceed in this document under these headings and to discuss these factors in relation to battery failure in general and cell separator failure in particular.

6.9.2 Aircraft Operating Conditions

Basically, there are two groups of aircraft batteries in terms of size and duty, namely high discharge rate units for use with main power systems and small ‘dedicated power supply’ batteries, of which the Inertial Navigation System unit is typical. This second group is clearly less prone to operational failure because the environment is under closer control and the battery is accommodated within a system design. It follows that the prime concern is to see that batteries remain in a good state of charge and do not become ‘sleepy’ and this will be considered as a maintenance function.

The main power system batteries can be sub-divided into those which are connected directly to the bus and therefore receive a ‘constant potential charge’ and those which are connected via a special charging unit which usually provides a combination of limited constant potential charging and constant current charging.

Batteries which ‘float’ on a main DC bus operate in a very narrow band of acceptable conditions of voltage and temperature and for this reason the larger aircraft do not now use this system. A twenty cell battery which is subject to regular discharge loads is unlikely to regain adequate charge unless it receives 28.5 volts at its terminals but should its temperature be raised by say, engine starting, it is possible that 'thermal runaway' could be initiated at 29.0 volts. These are approximate figures but they do serve to show the importance of ensuring that the voltage of each cell is adequate because the loss of perhaps 0.1 volt from the 'top of charge potential' of each of several cells can lead to charge instability of the battery. Such voltage reductions will be evident if separators have been damaged and we do have a classic 'cause and effect' problem to consider when such batteries are returned as unserviceable. Because of the disruptive nature of some of the extreme failures experienced in recent years, it is now generally required that batteries operating on a constant potential bus-bar should be monitored for high temperature levels. Typically, there may be an indication available to flight crew that a battery has reached 50°C and a further warning should a battery reach 70°C, at which point electrical disconnection is required.

Batteries which are charged from their own special system are not generally monitored by temperature in the flight deck but the battery may be temperature sensed as part of the method of charge control. The charging current is usually displayed to flight crew and this enables the charging mode to be observed so that disconnection may be made if abnormal operation occurs. Whilst the dramatic 'thermal runaway' is far less likely to occur on such systems, nevertheless, cell burning can and does occur. Examples are known of maintenance staff 'topping up' batteries on an aircraft, in itself an undesirable practice, only to realize that a failure existed because water issued from ruptured cell boxes.

To summarize, the main causes of cell failure, acting singly or in combination to create a battery failure, are:

- Excessive discharge duty.
- High operating temperature which may be caused either by high discharge current or by ambient conditions.
- High DC voltage, or
- Inadequate maintenance, which will now be considered.

6.9.3 Battery Capacity Levels

In some instances, it may be necessary to establish the battery duration (e.g. for the purpose of producing an Electrical Load Analysis for an aircraft).

The capacity of a battery is defined by the following:

Rate of charge (amps) x time to discharge

Normally expressed in ampere, but typically expressed in amp-mins (i.e. amp-hours x 60). However, this is not a linear function and with heavier discharge currents the discharge time decreases more rapidly so that the power available is less (i.e. reduced efficiency).

Therefore, in order to make an accurate assessment of battery duration, reference should be made to the manufacturer's discharge curves. However, it is recognized that these may not be available and certain assumptions and approximations are provided in the following paragraphs to allow for this case.

Because of the problem of definition of capacity, it is first usual to ensure that all calculations are based on the one-hour rate. Some manufactures however do not give this on the nameplate and quote the five-hour rate (i.e. 5C). For these calculations, as a general rule, it may be assumed that the one-hour rate is 85% of the quoted five hour rate.

For the purpose of calculation, a battery capacity at normal ambient conditions of 80% of the nameplate rated capacity, at the one-hour rate and a 90% state of charge, may be assumed (i.e. 72% of the nominal demonstrated rated one hour capacity at +20°C). The allowance for battery endurance presumes that adequate requirements for periodic battery maintenance have been established.

In some cases, a higher capacity can be recognized (i.e. minimum of 80% of the nominal demonstrated rated capacity at +20°C in lieu of 72%) provided it can be shown that the component maintenance manual (CMM) has a manufacturer's limitation on the state of charge following a battery shop maintenance cycle (e.g. minimum state of charge of 110% following battery shop maintenance cycle). This would then allow a higher duration of the battery to be established.

6.9.4 Maintenance

Probably the most contentious aspect of battery maintenance is that of frequency of removal from aircraft for workshop servicing. The major battery manufacturers usually indicate periods which can be as low as 50 hours and seldom exceed 500 flying hours or 3 months installed life for batteries connected to a constant potential system. If the quantity of 'consumable electrolyte water' is known, then by monitoring each cell for consumption it may be seen if this amount is being exceeded. Ideally, the measured water addition to each cell should not exceed this volume (25 cm^3 is a typical value) when the battery is returned from service. If a charge controller is fitted to the aircraft and this limits the overcharge current accurately for a given battery, then these maintenance periods may extend, in a typical case, to 1,000 flying hours.

A major factor in determining the frequency of battery maintenance may be the need to 'balance' cells. If it is remembered that a battery is an assembly of 20 or more cells in series and that the capacity of these may range by 30%, it will be apparent that the lowest capacity units may become excessively discharged or even 'reverse' charged. All manufacturers now recommend that, on a regular basis, cells are fully discharged and then individually shorted out. Frequent APU or engine starting is the major cause of unbalance, whilst inactive batteries such as those fitted within an INS will show apparent loss of capacity ('sleepiness') which can only be restored by workshop cycling. Thus installed life has to be determined for each type of operation as well as for each type of cell and due regard should be taken of the rate of consumption of 'electrolyte water'.

Battery manufacturers have now produced maintenance instructions which are of an acceptable standard and it is not proposed to repeat such data here. Further more details are discussed in paragraph 6.10.1 information but it is appropriate to emphasize the following points:

a) Record cards showing a history for each battery and including details of the history of each cell are essential.

b) Cell replacement by units of identical type obtained from the battery manufacturers is permitted. However, the addition of more than 5 cells in a 20 cell battery contributes to unbalance and it is strongly recommended that users assemble new cells into battery sets and use older surviving cells from rejected batteries to make up complete batteries of older cells. In this way it becomes possible to retire an old battery when cell failures accelerate and not thereby scrap some reasonably new cells. It is recognized that some USA battery manufactures market rebuilt cells, which are appropriately identified. Because these originate from the original manufacturer, with all that this implies for assurance of performance, they may be considered as 'new' cells. Cells rebuilt by other agencies must not be used as spare units (see Rebuilt Batteries below).

c) No battery should ever be allowed to rotate through a battery shop without having the 'top of charge' voltage measured for each cell and the manufacturers' pass criteria applied.

d) Battery room staff should have a method for reporting serious defects so that air safety procedures can be considered. (Significant failures would include burnt cell boxes or signs of arcing at interconnecting links.)

e) The recording of water addition to batteries should be encouraged and it should be appreciated that a cell with a poor separator tends to use less water than one with a good separator.

f) Facilities and procedures should exist for regular calibration of temperature sensing devices and wiring should be checked thoroughly as this is particularly vulnerable within batteries.

6.9.5 Battery Shops

There has been an upsurge in the range of equipment for charging and testing batteries and some of the equipment does not permit a conventional constant current charging schedule to be applied. For example, one type of equipment now widely used has a charging regime which includes rapid discharge pulses and it is therefore essential that battery workshops' staff have full instructions on the application of such equipment for all the battery types being serviced. These instructions should be officially authorized by a competent engineer and battery history cards should cross reference to the instructions used. Any procedure which does not involve the voltage measurement of every cell is not acceptable. Because of the length of time required to service nickel cadmium batteries, the quantity of work in progress usually demands a considerable working area. This area must be clean and well ventilated and free from an accumulation of scrap batteries.

In no circumstances should the same facilities be used for both nickel-cadmium and lead acid batteries and the ventilation shall be such that no cross contamination can occur.

6.10 Maintenance of Ni Cd Batteries

Nickel-cadmium batteries must be prepared for service, charged, tested and otherwise generally maintained, in a well ventilated workshop area which is entirely separate from that used for the servicing of lead-acid batteries. This also applies to servicing and test equipment, tools and protective clothing all of which should carry some form of identification. Anything associated with lead-acid batteries (acid fumes included) that come into contact with a nickel-cadmium battery or its electrolyte can cause severe damage to this type of battery.

6.10.1 Introduction

Precise details of inspection and maintenance procedures and the sequence in which they should be carried out are given in the relevant battery maintenance and overhaul manuals and other approved supplementary servicing instructions reference should therefore, always be made to such documents. The information given in the following paragraphs are intended to serve as a general guide to the procedures to be carried out appropriate to battery service life and condition and also to the precautions to be observed.

6.10.2 Inspection

The following checks are typical of those comprising a battery inspection schedule:

1. The battery should be identified to establish any known history. If the battery is a new one a servicing record card should be raised.
2. The outside of the battery case should be examined for evidence of damage and of locally overheated areas.
3. The battery cover should be removed and its rubber lining inspected for condition. Cover latches should operate smoothly and provide proper security of the cover. Extreme care must be exercised when working around the top of a battery with its cover removed. Tools should not be dropped onto the cell connecting links, as severe arcing will result with possible injury to personnel and damage to the battery. Such personal items as rings, metal watch straps and identification bracelets should be removed to avoid contact with connecting links and terminals.
4. There should be no evidence of arcing having occurred between the battery and the aircraft structure. The section near the bottom of the case and the slotted lugs of the cover tie-down strap are areas which are most likely to be affected. If signs of arcing are present the aircraft battery compartment should be inspected and the battery should be completely dismantled and overhauled.
5. The battery should be inspected for signs of electrolyte leakage and should be cleaned where necessary.

6. The battery receptacle should be checked for evidence of bums, cracks and bent or pitted terminals. Defective receptacles, which can overheat or cause arcing and depress output voltage should be replaced.
7. All cell links should be checked for security and evidence of overheating, and their terminal nuts should be tightened to the specified torque values. Any cell link showing damage to its plating should be replaced.
8. Vent caps should be checked for security and also to ensure that gas exit holes are free from dirt or potassium carbonate crystals. Clogging of vents causes excessive pressures to build up resulting in cell rupture or distortion of parts. Cell valves, when fitted should also be checked for security and freedom from dirt or crystal formation. Dirty vent caps or valves should be removed and cleaned.

NOTE:

- Potassium carbonate is a white crystal formed by the reaction of potassium hydroxide with carbon dioxide in the air, it is non-corrosive, non-toxic and nonirritating.
- Temperature sensing devices when installed should be checked for secure attachment with leads and connectors showing no signs of chafing or other damage. Electrical checks and/or calibration of these devices should be carried out at the periods specified in the approved Maintenance Schedule.

6.10.3 Electrolyte Level and Adjustments

The level of the electrolyte should depending on manufacturer's recommendations only be adjusted when a battery is at the end of charge, while still charging or after a specified standing time. If electrolyte level adjustments were to be made in the discharged or partially discharged condition then during a charge electrolyte would be expelled from the cells, resulting in corrosive effects on cell links, current leakage paths between cells and battery case and a reduction of electrolyte density. The manufacturer's instructions regarding checks on electrolyte level and adjustments should be carefully followed and the maintenance kit equipment designed for a particular type of battery should be used.

NOTE: Adjustments should not be made when batteries are installed in aircraft.

1. Only the purest water available preferably pure de-mineralized or distilled water should be used for adjusting electrolyte levels and a record of quantity added to all cells should be maintained because it is largely on this evidence that periods between servicing are determined (see battery records). The 'consumable' volume of electrolyte is normally specified in manufacturer's manuals but in the absence of such information a useful guideline is that batteries should not be left for periods which would require the addition of water to any cell by an amount in excess of 1 cc per ampere-hour capacity.
2. In the event that the electrolyte becomes contaminated particularly with oil, foaming of the electrolyte will occur. In such cases, a neutralizing fluid which is available from

the relevant battery manufacturer should be added to the electrolyte strictly in accordance with the manufacturer's instructions.

3. Additional potassium hydroxide should not normally be required, but if electrolyte in solution is necessary for topping-up it must be ensured that it is in the proportions specified in the relevant manual.

NOTE: Contamination of the electrolyte with tap water, acids or other non-compatible substances will result in poor performance or complete failure of a battery.

Potassium hydroxide should be kept in special containers and because of its caustic nature should be handled with extreme care to avoid contamination of the person or clothing. Rubber gloves, a rubber apron and protective goggles should always be worn. If contamination does occur, the affected parts should be immediately rinsed with running water. If available, vinegar, lemon juice or a mild boric acid solution may also be used for treatment of the skin. Immediate medical attention is required if the eyes have been contaminated. As a first-aid precaution, they should be bathed with water or a weak boric acid solution applied with an eye bath.

6.10.4 Battery Cleaning

Dirt, potassium carbonate crystals or other contaminating products can all contribute towards electrical leakage paths and be a prime cause of unbalanced cells. Cleanliness of batteries is therefore essential.

a) Deposits should be removed from the tops of cells by using a cloth soaked in de-mineralized or distilled water and a stiff fiber bristle brush. Wire brushes or solvents should not be used. If any contaminating product is caked under and around cell connecting links, the links should be removed if necessary to facilitate cleaning. Care should always be taken to ensure that debris is not forced down between cells and in some cases it may be better to scrape deposits loose and then blow them with low pressure compressed air. The air itself should be clean and dry and goggles should be worn to protect the eyes.

b) Some manufacturers specify periodic flushing of cell tops and battery case with de-mineralized or distilled water while brushing away deposits. This method is not recommended and batteries in a dirty condition or showing low resistance should be dismantled and completely serviced.

c) When it is necessary to clean vent caps and valves, they should be removed from the cells, using the correct extractor tool, and should be washed in warm water to dissolve any potassium carbonate crystals which may have accumulated within the outlet orifices. They should then be rinsed in de-mineralized or distilled water, dried and re-fitted. Valves should also be tested for correct functioning in accordance with manufacturer's instructions before re-fitting.

NOTE: Cells should not remain open for longer than is necessary.

6.10.5 Charging of Batteries

New nickel-cadmium batteries are normally delivered complete with the correct amount of electrolyte, and in the fully discharged condition. Following a visual check for condition, they must, therefore, be charged in accordance with the manufacturer's instructions before being put into service. Once in service, batteries must then be charged at the periods stated in the approved aircraft Maintenance Schedule. The following information on charging methods and associated aspects is of a general nature only. Precise details are given in relevant manufacturer's manuals and reference must therefore, always be made to such documents.

6.10.5.1 Constant-Current Charging

This method is the one which should normally be adopted for the workshop charging of batteries, the charging equipment being adjusted and monitored throughout the charging period to supply current at either a single rate or at several different rates in a stepped sequence. Although more time consuming than the constant potential method which is often adopted in aircraft battery systems, constant current charging is more effective in maintaining cell balance and capacity. The hour rate of charge current required must be in accordance with that specified by the relevant battery manufacturer.

NOTE: The hour rate of a battery refers to the rate of charge and discharge expressed in multiples of “C” amperes, where “C” is the 1-hour rate. For example, if a battery has a capacity of 23 ampere-hours, then “C” would be 23 amperes and for a 10-hour rate the charge or discharge current rate would be C/10 amperes, i.e. 2.3 amperes.

6.10.5.2 Vent Caps

Before charging, the battery cover should be removed, and with the aid of the special wrench provided in the battery maintenance kit, the vent cap of each cell should also be removed.

6.10.5.3 Connection to Charging Equipment

Charging equipment should not be switched on until after a battery has been connected and the charging circuit has been checked for correct polarity connections.

6.10.5.4 Electrolyte Level

The electrolyte level should be checked and adjusted as necessary in accordance with the manufacturer's recommendations.

6.10.5.5 Gassing

Gassing of cells occurs within the region of final charge, as a result of the electrolysis of water into hydrogen and oxygen gases. When gases escape from a cell, the quantity of fluid electrolyte is reduced vigorous prolonged gassing should therefore be avoided. A ‘dry’ cell is more likely to suffer separator damage and any cell running hotter than its neighbours should be investigated.

The gassing/temperature phenomena provide a useful indication of impending failure of cells e.g. a cell that gasses sooner and more actively than its neighbours is going to lose more electrolyte and as a result will run hotter and tend to dry out. Minor differences in gassing are hard to detect, but large differences should be noted and investigated.

6.10.5.6 State of Charge

The state of charge cannot be determined by measurement of the electrolyte relative density or battery voltage. Unlike the lead-acid battery, the relative density of the nickel-cadmium battery electrolyte does not change. Except for 'dead' batteries, voltage measurements at either open circuit or on-load conditions do not vary appreciably with state of charge. The only way to determine the state of charge is to carry out a measured discharge test.

6.10.5.7 Charging of Individual Cells

Individual cells must be in an upright position and adequately supported at the sides parallel to the plates during charging. A special frame may be built to fit a cell or boards or plates may be placed on each side and held together with a clamp. After charging and removal from its support, the sides of a cell should be inspected to ensure there are no bumps or bulges which would indicate an internal failure.

NOTE: Cells should always be fully discharged before removal from a battery and before reassembly.

6.10.5.8 Thermal Runaway

In some small aircraft the battery may be charged by constant potential supplied directly from the DC bus-bar. Under correct conditions of temperature and voltage, the internal voltage of the cells rises gradually as the electro-chemical action takes place and it opposes the charging voltage until this is decreased to a trickle sufficient to balance continuous losses from the cells. The energy supplied to a fully charged battery results in water loss by electrolysis and in heat generation. For a battery in good condition, a point of stability will be reached where heat as a result of trickle current will just balance radiated and conducted heat losses. At low temperatures, a battery will appear to have a limited capacity and will require more voltage to accept a given amount of charge. As the battery becomes warm however, its responses return to normal. Operation at high temperatures also limits the capacity, but in such conditions a battery is subjected to the danger of a 'thermal runaway' condition.

- At higher than normal temperatures, the heat loss of the battery through radiation and conduction is lower than the heat generating rate and this results in a higher battery temperature. This in turn reduces the internal resistance of the battery, so that higher than normal charge current is admitted resulting in an increase in chemical activity, additional heat and a further increase in charging current. This recurring cycle of temperature rise, resistance and voltage drop and charge current rise, progressively increases the charging rate until sufficient heat is generated to completely destroy a battery.

- Other factors which can cause overheating of a battery are as follows:
  a) Voltage regulator of aircraft generating system incorrectly adjusted.
  b) Frequent or lengthy engine starts at very high discharge rates.
  c) Loose link connections between cells.
  d) Leakage currents between a cell and battery container and the airframe structure. Periodic measurement of leakage current and removal of any electrolyte that may have accumulated around and between cells should be carried out to prevent high leakage and short circuits from developing.
  e) Use of unregulated or poorly regulated, ground support equipment to charge a battery, particularly a battery which has become hot as a result of excessive engine cranking or an aborted engine start.
  f) High initial charging currents imposed on a hot battery.
  g) Cell unbalance refers to an apparent loss of capacity and to variations in cell voltage at the end of charging cycles. These variations can develop over a period of time, particularly when subjected to operating conditions like those occurring in aircraft utilizing charging circuits of the constant potential type. Other factors which may also contribute to cell unbalance are cell position in the battery, e.g. centre cells run warmer than outer cells and the self-discharge of individual cells.
- In some types of aircraft, the batteries specified for use incorporate a thermostat type detector which illuminates a warning light at a pre-set temperature condition. In addition, a thermostat type sensing network may also be incorporated. The network operates in conjunction with a special solid-state, pulse-charging unit, and its function is to monitor the charging current and to de-energize the charging circuit when the battery temperature exceeds a safe operating limit. Detection devices should be checked at the periods stated in the approved aircraft Maintenance Schedule and in accordance with the relevant manufacturer's instructions.

6.10.6 Electrical Leakage Check

Electrical leakage refers to current flowing in a path other than that desired and in connection with batteries, this means current between the terminals or connectors of cells and any exposed metal on the battery case. The only pertinent measure of leakage of importance to a cell is the rate of discharge caused by the leakage and this is only significant when its value approaches that specified for the particular type of battery. In one type for example, a leakage of up to 0.020 amps is quoted as the permissible value. Typical methods of determining electrical leakage are described below.

a) The positive lead from the terminal of a multi-range testmeter should be connected to the positive terminal of the battery and after selecting the appropriate scale range (usually the one amp. range) the negative terminal lead from the testmeter should be touched on any exposed metal of the battery case. If a pointer deflection is obtained it will denote a leakage and the test meter scale setting should be adjusted, if necessary to obtain an accurate reading which should be within the limits specified.

The foregoing check should be repeated between the battery negative terminal and battery case, when again any readings obtained should be within limits. If either of the readings obtained exceed the specified limits the battery should be thoroughly cleaned (see Paragraph 3.4) and the checks again repeated.

b) If after thorough cleaning the leakage current is in excess of the limits it is probable that one of the cells is leaking electrolyte and is therefore defective. This cell may be found by measuring the voltage between each cell connecting link and the battery case. The lowest voltage will be indicated at the connecting links on each side of the defective cell which should be replaced.

6.10.7 Capacity Test:

The capacity or state-of-charge of a fully-charged battery is checked by discharging it at a specified rate (preferably automatically controlled) after it has been standing for a certain time period and noting the time taken for it to reach a specified on-load voltage. For example, a 23 ampere-hour battery is left to stand for 15 to 24 hours and is then discharged at 23 amperes, i.e. the 1-hour rate to 20 volts. A battery should give at least 80% of the capacity specified on its nameplate or the minimum authorized design capacity, whichever is the greater.

NOTE**:** Some batteries of U.S. origin have initial capacity ratings which are significantly higher than those specified on their nameplates. When the nameplate ratings are no longer obtainable such batteries are rejected.

a) True capacity must always be recorded, meaning that a full discharge is required and not one which is terminated when the minimum acceptable level has been reached. Because it is essential to monitor a number of cell voltages very closely, the service of two persons is desirable towards the end of discharge for measurement and recording. At this stage, voltages fall very quickly and it is highly desirable that measurements be made with a digital voltmeter.

NOTE: No cell should be allowed to go into reverse polarity before the measured discharge is complete and the terminal voltage should not go below 1 volt per cell, since excessive gassing may result.

6.10.8 Capacity Recycling Procedures:

The purpose of recycling is to restore a battery to its full capability and to prevent premature damage and failure. The discharge rates and voltage values appropriate to the recycling procedures vary between types of battery and reference should always be made to the relevant manual. The figures quoted below are typical and serve only as a guide to the limits normally specified.

a. The battery should be discharged at a current equal to or less than the one-hour rate and as each cell drops below 0.5 volts (measured by a digital voltmeter) it should be shorted out by means of a shorting strip. The cells should remain in this condition for a minimum period of 16 hours, preferably 24 hours.

NOTE: A battery should not be discharged at an excessively high rate and cells then short-circuited since this produces severe arcing and excessive heat generation.

b. The shorting strips should then be removed and the battery charged for 24 hours at the specified recycling charging rate. After approximately five minutes of charge, individual cell voltages should be measured and if any cell voltage is greater than 1.50 volts distilled water should be added. The amount of water required depends on the rated ampere-hour capacity a typical maximum value is approximately 1 cc per rated ampere-hour.

c. After approximately 10 minutes of charge individual cell voltages should again be measured. Any cell measuring below 1.20 volts or above 1.55 volts should be rejected and replaced.

d. After 20 hours of charging, individual cell voltages should be measured and recorded and if necessary, distilled water should be added to the normal level appropriate to the type of battery.

e. At the end of the 24 hours charge period, cell voltages should again be measured and compared with those obtained after 20 hours. If the 24 hour voltage reading is below the 20 hour reading by more than 0.04 volts, the cell concerned should be rejected and replaced.

6.10.9 Cell Balancing

If a battery fails to give 80% capacity on test and if premature ageing of some cells is suspected, a cell balancing test should be carried out. The procedure for carrying out the test appropriate to a particular type of battery is prescribed in the relevant manual and reference should always be made to such document. The following details, based on the test specified for a typical 23 ampere-hour battery are given only as a general guide.

a. Note the time, and discharge the battery at 23 amperes until the terminal on-load voltage falls to 20 volts, then stop the discharge. During the discharge, the voltage of each cell should be frequently checked with a digital voltmeter. A zero reading early in the discharge indicates a short circuit cell, a reverse reading indicates a weak cell. In either case the discharge should be stopped even if the overall battery voltage has not yet fallen to 20 volts. The weak or faulty cell should be shorted out, preferably through a 1 ohm resistor.

b. Note the time and recommence the discharge at the lower rate of 2.3 amperes. Frequently check the voltage of the cells and short out each cell (with individual shorting strips) as it falls below 1 volt. Record the time elapsed of discharge for the cell to fall below 1 volt, thus obtaining an indication of the relative efficiency of the cells. Some manufacturers specify 0.5 volts as the point at which shorting of the cells should be carried out. This is satisfactory providing that sufficient time is available to permit shorting of all cells before any are subjected to reverse voltage resulting from the charging effect of stronger cells.

c. The discharge should be stopped when all the cells are shorted out. The battery should be left in this condition, and also with the main terminals shorted together, for as long as possible, but never less than 16 hours.

d. The battery should then be charged and the cell-balancing procedure repeated. The discharge times recorded for each cell to fall below 1 volt should show an improvement over those previously recorded.

e. Weak and internally short-circuited cells should be replaced in accordance with the instructions detailed in the relevant battery Maintenance Manual.

6.10.10 Voltage Recovery Check

This check, which should be made at a given time after shorting strips have been removed from the cells or main battery terminals, provides a ready means of detecting high resistance short-circuits and damaged connections within a battery. A typical procedure for this check is given below.

a. Shorting strips of one ohm resistance should be connected between cells and the battery should be allowed to stand for 16 to 17 hours. At the end of this period, the voltage of individual cells should be measured to ensure that they do not exceed the minimum value specified for the battery (a typical minimum value is 0.20 volts).

b. The shorting strips should then be removed and after a further standing period of

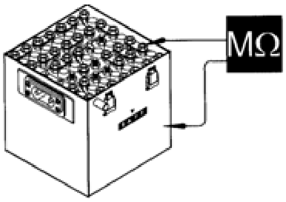
c. 24 hours, individual cell voltages should again be measured to check their recovery to within normal operating values. A typical minimum value specified as a basis for rejection of a cell is 1.08 volts.

6.10.11 Insulation Resistance Test

A test for insulation resistance may be specified by some manufacturers as the means of checking for electrical leakage. Reference should therefore, be made to the appropriate maintenance manual for the procedure to be adopted for permissible values and for any remedial action to be taken.

Cell-to-Case Insulation Test (Insulation Test)

A breakdown in electrical insulation between the cells and the battery box (case) (1) will result in a "leakage" current, which over time will discharge the battery. The most common cause for the loss of insulation is the leakage of electrolyte from the cells that acts as a conductor between the cells and the battery box (case) . Because leakage current can affect battery performance, it is necessary that it be kept to a minimum. The cell-to-case insulation test can be carried out using one of the following methods. A typical Ni-Cd battery insulation measurement test details are given at Figure 6-3.



<table>
<thead>
<tr><th></th><th>250KΩ</th><th>2MΩ</th><th>10MΩ</th></tr>
</thead>
<tbody>
<tr><td>Unacceptable</td><td>To be cleaned</td><td>Can wait until next maintenance</td><td>OK</td></tr>
<tr><td colspan="3">In battery maintenance shop</td><td rowspan="2">Minimum value after cleaning and drying</td></tr>
<tr><td rowspan="3">Cleaning Required
Fault Isolation</td><td rowspan="3">Cleaning Recommended</td><td></td></tr>
<tr><td colspan="2">Acceptable</td></tr>
<tr><td></td><td></td></tr>
</tbody>
</table>

Figure 6-3 Insulation test for nickel cadmium aircraft battery during operation and maintenance.

a. On a completely assembled battery, use a megohmeter to measure the insulation resistance between the positive terminal of each cell and the outer metal box (case). Set the megohmeter for 250 V continuous. Touch one of the leads to the battery box (case) and the other to each cell terminal in the battery. On a battery from service, the value of each reading should be at least 250 KΩ under 250 V_{DC}.

b. On a completely assembled battery, use an analog multifunction meter capable of measurement in the 250mA range. Adjust the meter and input leads for measurement of 250mA. Connect the negative lead to the battery box. Touch the positive lead to the positive terminal of each cell, then to the positive terminal of the battery. If there is any deflection in the needle from zero, the insulation is inadequate and a General Overhaul should be performed. Following a General Overhaul, if there is still a leakage current in excess of 250mA, the leakage should be traced to the failed cells and those cells replaced.

NOTE: Failure to meet the 250KΩ minimum value, indicates a need for a General Overhaul. On a new battery (or an in-service battery following disassembly, cleaning and drying) this value must be at least 10 MΩ under 250 V_{DC}. Any cell with less than the minimum resistance (as specified above) is considered defective and should be replaced.

6.10.12 Cell Removal and Replacement

Cells should be removed from a battery whenever they are suspected of leakage of electrolyte, internal short-circuits, when they fail to balance or if the insulation resistance is found to be below the value specified for the particular battery. The method of removing and replacing cells may vary between types of battery and the instructions issued by the relevant manufacturers must, therefore, always be carefully followed. The information given below, although based on a specific type of battery is intended to serve only as a guide to the practical aspects generally involved.

a. The battery should be discharged and the cell links disconnected and removed both from the faulty cell and from the adjoining cells. The cell position should be noted for subsequent entry in the battery record card.

b. The vent cap should be loosened using the special key provided with the battery maintenance kit.

c. A cell extractor tool should then be fitted to the cell on the terminals normally used for connecting the cell links. The battery is then held firmly and the cell withdrawn vertically upwards without using undue force. When one cell is removed and all other cell links are disconnected, it is relatively simple to withdraw the remaining cells without the aid of the extractor.

NOTE: After removing a cell its vent cap should be retightened.

d. Cells and the inside of the battery case should be thoroughly cleaned and dried.

e. After carrying out all necessary checks, serviceable cells should be replaced in the battery case in their correct positions and a cell-to-cell voltage check should be carried out to ensure that polarities are not reversed. It must be ensured that any new cells are of the same manufacture, part number and are of matched capacity rating.

NOTE: A steady force should be used on terminals to press cells into place. Tight cells should not be hammered into place. For easiest assembly, the cell at the middle of a row should be inserted last.

f. The surfaces of cell terminals and connecting links should be clean and after ensuring the correct positioning of links, terminal nuts should be tightened to the specified torque value and in a sequence commencing from the battery positive terminal. Care should always be taken to ensure that nuts actually tighten the connector assemblies and are not binding as a result of thread damage or bottoming.

NOTE: Once a tightening sequence has been started it should be completed, thereby ensuring that a nut has not been overlooked. One loose connection can permanently damage a battery and may cause an explosion.

g. On completion of cell replacement procedures, the battery should be re-charged, tested for insulation resistance and if any new cells have been fitted, a capacity test should also be carried out.

6.10.13 Rejected Batteries or Cells:

Any batteries or cells which are rejected should be conspicuously and permanently marked on their cases to indicate that they are to be used only for general ground use.

6.10.14 Installation

It should be ensured that the battery is of the correct ampere-hour rating, fully charged and that the electrolyte is at the correct level. Depending on the service history of the battery appropriate tests e.g. capacity test, capacity recycling and cell balancing must also have been carried out in the manner prescribed for the particular battery manual. Reference should be made to the relevant aircraft Maintenance Manual for details of the battery system and associated installation instructions. Before coupling the system connecting plug, a check should be made to ensure that the battery system switch is OFF, and that all electrical services are isolated.

NOTE: Batteries are heavy units and they require the use of approved handling methods to prevent possible injury to personnel and damage to the cases or components adjacent to the battery location. Vent pipes should not be used for lifting purposes.

a. The battery compartment should be thoroughly clean and dry and the battery should be securely attached in its mounting. Clamp nuts should not be over-tightened since distortion of the battery cover may result, which could affect the venting arrangements.

NOTE: If a battery compartment has been previously used for lead-acid batteries, it should be washed out with an acid neutralising agent, dried thoroughly and painted with an alkaline-resistant paint.

b. The supply cables from the battery and where appropriate, thermostat and battery charging system cables should be checked for signs of chafing or other damage. Cable connecting plugs should be securely made without any strain on the plugs or cables.

c. Battery installations are normally designed so that in flight, sufficient air is passed through the compartment to dilute the hydrogen gas given off by a battery to a safe level. Ventilation systems should therefore be checked to ensure there is no obstruction or if integral venting is used the connections should be checked for security and leaks.

NOTE: In some ventilation systems, non-return valves are incorporated in the battery compartment vent lines. These valves should also be checked for security and correct location.

d. After installation, a check should be made that the electrical connections of the battery supply cables have been correctly secured by switching on some electrical services for a specific time period and noting that readings of the aircraft voltmeter remain steady. A typical load and time is 30 amperes for 30 seconds. For battery systems having a separate 'in situ' charging unit, the unit should be switched on and its electrical settings checked to ensure proper charging of the battery.

6.10.15 Maintenance of Installed Batteries

Batteries should be inspected at the periods specified in the approved aircraft Maintenance Schedule. The details given below serve as a general guide to the checks normally required.

a. The battery mounting should be checked for security and the outside of the battery case should be examined for signs of damage and for evidence of locally overheated areas. The latches of the cover should operate smoothly and should firmly secure the cover in position. Connecting plugs of the battery receptacle, thermostat and battery charger units, where fitted should be checked for signs of contamination, burns, cracks and bent or pitted terminal fittings.

b. The tops of all cells and vent caps should be inspected for signs of electrolyte leakages and should be cleaned where necessary.

c. The electrolyte level should be checked and if any adjustments are necessary, these should be made after removing the battery from the aircraft and checking that it is in the fully charged condition. The amount of water added to the cells should be noted on the battery record card. A cell requiring more than the specified amount should be regarded as suspect and the battery should be replaced by a serviceable unit. In aircraft having an independent charging unit, the unit should be switched on and the battery charged in accordance with the procedure specified in the relevant aircraft Maintenance Manual.

   NOTE: When removed the battery cover and cell vent caps should not be placed on any part of the aircraft structure or equipment.

d. The battery ventilation system should be checked to ensure security of connection and freedom from obstruction.

6.10.16 Battery Records

A technical or service record should be maintained on each battery in service. Discretion may be exercised as to the layout of such a record and the extent of the details it should contain. It should however, provide a fairly comprehensive history of the specific battery, so that in the event of a malfunction it will assist in establishing the fault.

6.10.17 Storage and Transportation

Nickel-cadmium batteries should be stored in a clean, dry, well-ventilated area and should be completely segregated from lead-acid batteries. The area should also be free from corrosive liquids or gases. It is recommended that they should be stored in the condition in which they are normally received from the manufacturer, i.e. filled with electrolyte, discharged and with shorting strips fitted across receptacle pins. Cell connecting strips and terminals should be given a coating of acid-free petroleum jelly (e.g. white Vaseline).

a) The temperatures at which batteries may be stored are quoted in the relevant manuals, and reference should therefore be made to these. In general, a temperature of 20°C is recommended for long-term storage.

b) If batteries are to be stored in a charged condition, they must be trickle charged periodically in order to balance the inherent self-discharge characteristic. Since this discharge is temperature sensitive, the trickle charge rate is therefore dependent on the storage temperature conditions.

c) If it is necessary to return a battery to the manufacturer or to an approved overhaul organisation, it should be discharged but not drained of electrolyte. It should be packed in its original container, together with its service record and 'This Way Up' international signs affixed to the outside.

NOTE: If transportation is to be by air, the container must comply with Military Air force regulations concerning the carriage of batteries containing alkaline electrolyte.

NICKEL-CADMIUM BATTERY SERVICE RECORD BATTERY AND AIRCRAFT DATA

Manufacturer		Aircraft Type	
Part No		Registration	
Serial No		Battery Function (e.g. Standby, APU starting)	
Rating: Volts		Ah	
Modification state		Date Installed	
		Hours Flown	
SERVICING DATA			
Date Removed		Reason for Removal	
Date Serviced		Servicing Instructions Used	
Workshop Ambient Temp		Date Released	

Operation	Result/Comments	Initials	
Details of operations performed and measurements required		Mech	Insp

CELL DATA

Position in Battery	**Serial No**	**Water Added (c.c.)**	**Voltage**	**Temperature**	**Final Voltage**	**Capacity (Ah)**
1						
2						
**						
19						
20						

MAIN TERMINAL VOLTAGE …………………………

I hereby certify that the inspection/overhaul/repair/replacement/modification specified above has been carried out in accordance with the requirements of operating manual instructions supplied by manufacturer.

Signed: ………………….

Station: ....

Date: ....

6.11 Placing New Silver Zinc Batteries in Service

The principal rule to observe when placing new silver zinc batteries in service is to follow the manufacturer's instructions. Because these instructions may vary considerably, care must be taken to follow them accurately. Often, new silver zinc batteries that are stored in warehouses for long periods of time or placed in storage pending sale are not filled with electrolyte. The plates are not formed before assembly, and no electrolyte is placed in the cells until the battery is put in service. When new batteries are received in the dry state, they should be filled with electrolyte having the specific gravity recommended by the manufacturer. After 48 to 72 hours, the electrolyte level should be checked and if it has fallen more electrolytes should be added to bring it up to the recommended level. The battery can be placed in service after verifying its rated capacity (1C rate for 60 minutes) during formation cycles of battery, this information is usually included in the instructions supplied with the battery. When a silver zinc storage battery containing electrolyte is placed in storage, it should first be fully discharged. All electrolyte spilled on the top of the battery should be removed and the battery should then be washed with clean water and thoroughly dried.

Follow the battery manufacturer’s instructions regarding periodic servicing, capacity checks and reconditioning procedures to ensure a reliable and properly conditioned battery. The following areas should be given special attention:

a. Battery facilities, separate shops, equipment and tools are recommended for servicing silver zinc, nickel-cadmium and lead-acid batteries.
b. Anything associated with lead- acid batteries (acid fumes included), which comes in contact with a nickel-cadmium battery or its electrolyte can cause severe damage.

Reconditioning of Silver Zinc Battery every 30 days during capacity test failure or 10 flying hours with autonomous starts, the following procedure may be adopted as a reconditioning the battery for improving the its rated capacity.

Normal Charge: Battery should be given normal charge and test discharge procedure mentioned below. Apply 1 ohm resistor across each cell’s terminals for not less than 24 hours. Remove the resistors and constant current charge the battery in accordance with (i) & (ii) given below. Adjust electrolyte levels as per marking given at cells. Discharge the battery at the test discharge procedure given below

i) Charge at 4.5 amps till any two cells reach 2.0 volts or 15 hours of total charge, whichever is earlier.
ii) Rest for 2 to 24 hours.

Test Discharge:

i) Discharge at 45 amps till any one cell reaches 1.2 volts or total battery voltage is 20.0 volts, whichever is earlier.
ii) Duration should not be less than 60 minutes.

NOTE:

a. In case discharge time is less than 60 minutes, perform the above procedure three times and battery should give minimum capacity 90% of its rated value. Replace all cells, without any further testing if it is below 90% of rated capacity.

b. The battery after normal charge can be fitted on the aircraft.

c. Over charging/discharging of cell beyond above specification will result in permanent damage to the cell.

6.12 Reconditioning procedure for Sealed Lead Acid battery

Reconditioning of Lead Acid Battery (VRLA Type) every 3 months during capacity test failure or 50 flying hours, the following procedure may be adopted for reconditioning the battery for improving the its rated capacity.

Once in a month, the storage battery in service should receive heavy charge and once in a three month there should be subjected to a charge / discharge test cycles to protect them against sulfation. To cycle the storage battery proceed as follows:-

a. Give the battery a heavy charge

b. Discharge the battery to 20V as per operation instruction battery manual and verify the C rate capacity of the battery. If it is observed in all cases the electrical characteristics of the batteries shows sharp deterioration, it is advisable to cycle the battery three times before the schedule due.

Charging Procedure:

To take care of losses during storage, a freshening charge is required to be given to ensure that the batteries are fully charged before use.

Freshening charge should be given at a constant voltage of 28.5 + 0.3 volts until the current and voltage across the battery have stabilized for three consecutive hourly readings or for a total period of 24 hours. There is no need for limiting the charge current when charging the battery at the specified constant voltage.

In case constant voltage chargers are not available, the freshening charge can be given using a constant current charger set at a current of 2.8A until the voltage has stabilized for 3 consecutive hourly readings or for a total period of 12 hours.

6.12.1 Shop Maintenance

Note: In section 3 under maintenance section procedure given for Battery maintenance procedure with Battery Load Testers, battery charging, (constant current charging and constant voltage charging and charging procedures etc). Reader may refer for further details.

6.12.1.1 Maintenance of Lead-acid Cells

The following important points should be kept in mind for keeping the battery in good condition:

a. Discharging should not be prolonged after the minimum value of the voltage for the particular rate of discharge is reached.
b. It should not be left in discharged condition for long.
c. The level of the electrolyte should always be 10 to 15 mm above the top of the plates which must not be left exposed to air. Evaporation of electrolyte should be made up by adding distilled water occasionally.
d. Since acid does not vaporize, none should be added.
e. Vent openings in the filling plug should be kept open to prevent gases formed within from building a high pressure.
f. The acid and corrosion on the battery top should be washed off with a cloth moistened with baking soda or ammonia and water.
g. The battery terminals and metal supports should be cleaned down to bare metal and covered with Vaseline or petroleum jelly.

A typical flow chart on the maintenance of Lead Acid Battery is shown in Figure 6-4.

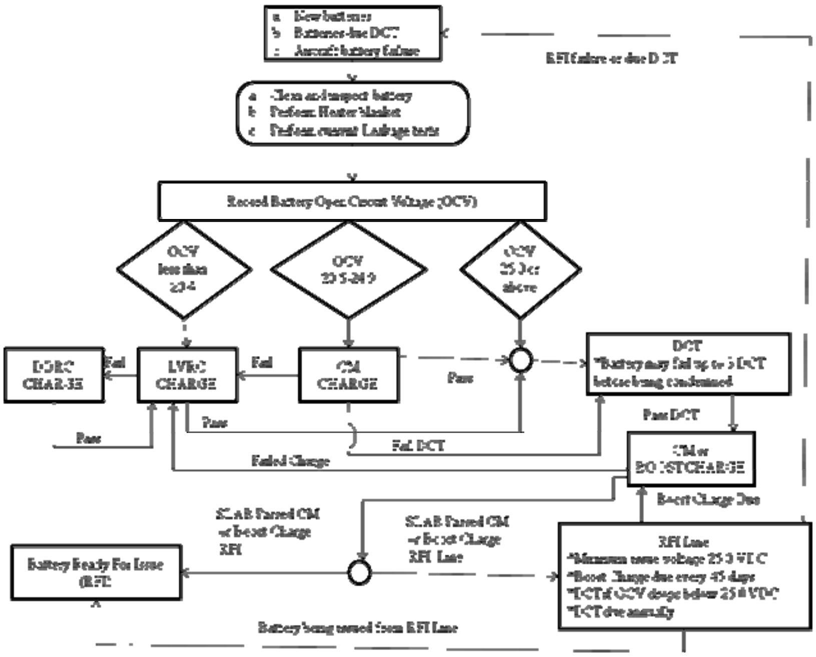


Figure 6-4 Maintenance of Lead-Acid Battery

6.13 **Storage of Aircraft Batteries**

6.13.1 Introduction

The optimum storage conditions for batteries depend on the active chemicals used in the cells. During storage the cells are subject to both self discharge and possible decomposition of the chemical contents. Over time solvents in the electrolyte may permeate through the seals causing the electrolyte to dry out and lose its effectiveness. In all cases these processes are accelerated by heat and it is wise to store the cells in a cool, benign environment to maximize their shelf life. The glove compartment of a car does not qualify as a suitable storage location since temperatures may exceed 60°C shortening dramatically the life of the battery. (See Battery Life)

For cells with the same nominal cell chemistry, individual manufacturers may add different additives to optimize their cell performance for a particular parameter and this may affect the behavior of the cells during storage. It is possible to make some general recommendation about storage but the best guidance for storage is to consult the manufacturers' specifications and recommendations for their products.

6.13.2 Rechargeable Cells

Lead Acid

When a lead acid battery is fully or partially discharged, lead sulphate forms at the electrodes. If the battery is allowed to remain for a prolonged period in a discharged state or with a very low state of charge the lead sulphate may form into large crystals which are very difficult to convert back into lead and sulphuric acid by the charging process. The formation of these crystals is called sulphation and causes a permanent loss of capacity of the battery. To avoid this problem lead acid batteries should therefore only be stored in a fully charged condition and the charge should be topped up from time to time during storage to compensate for the self discharge of the cells.

To prolong shelf life without charging, the batteries should be stored at 10°C or less but the electrolyte should not be allowed to freeze. When the battery is fully charged the electrolyte is sulphuric acid solution and the freezing point is -36°C but it rises to in the fully discharged state when the electrolyte is simply water.

6.13.3 Lead-Acid Batteries

A charged battery which is to be stored for any length of time should be in the “fully charged” condition. Before storing, the electrolyte levels should be checked and the battery bench-charged in accordance with manufacturer’s instructions. When fully charged, the battery should be stored in a cool, dry, well ventilated store on an acid resistant tray. Batteries may also be stored in the dry, uncharged state. Additional points to note are as follows:

a. Every 4 to 6 weeks (depending on manufacturer's instructions) the battery should be removed from storage and fully recharged, i.e. until voltage and specific gravity readings cease to rise.

NOTE: Damage to the battery will occur if it is allowed to stand idle beyond the period for charging specified by the manufacturer.

b. Regardless of periodic check charges, the battery should be given a complete charge and capacity check immediately before being put into service.

c. For new batteries, a complete capacity test to the manufacturer's instructions should be made every 6 months, but if the battery has been in service this test should be made every 3 months.

d. Every 12 months or earlier if a leak is suspected, an insulation resistance test should be carried out to the manufacturer's instructions.

e. If the conditions mentioned in the previous paragraphs are observed, a battery may remain in storage up to 18 months. A battery should not be allowed to stand in a discharged condition and electrolyte temperatures should not exceed 48.8ºC.

NOTE: Trickle charging at low rates is not recommended as damage will occur if idle batteries are subjected to this form of charging.

6.13.4 Silver-Zinc Batteries

These batteries should be stored in clean, dry, cool and well ventilated surrounds not exposed to direct sunlight or stored near radiators.

NOTES:

a. There are certain proprietary light white spirits which are suitable for use with very small bearings and which eliminate some of the dangers associated with the use of benzene.

b. Miniature steel balls and special high precision balls are immersed in instrument oil contained in plastics phials with screw-on caps.

New batteries will normally be supplied in the dry condition with the electrolyte contained in polythene ampoules. If possible, new batteries should be stored in their original packaging together with the related ampoules of electrolyte. For storage periods of more than 2 years, special instructions should be requested from the manufacturers.

Filled and formed batteries required for use at very short notice may be stored in the charged condition. Manufacturers normally recommend that such batteries should be discharged and recharged every 4 to 6 weeks. The manufacturer's schedule of maintenance should be applied to batteries stored in the charged condition.

Batteries to be stored out of use for protracted periods, should be discharged at the 40-hour rate until the voltage level measured while discharging, falls below the equivalent of 0·8 volt per cell. Before storing batteries, the electrolyte level should be adjusted to near the maximum specified by topping up using a potassium hydroxide solution of manufacturer supplied.

The need for care in handling potassium hydroxide because of its caustic content is stressed. After topping up or filling, the top of the batteries should be cleaned and the connections and terminals lightly smeared with white petroleum jelly. In no circumstances should sulphuric acid or acid contaminated utensils be used in close proximity to silver-zinc or silver-cadmium batteries.

6.13.5 Nickel-Cadmium Batteries

This type of battery can be stored for long periods without damage, in any state of charge provided the storage place is clean and dry and the battery is correctly filled.

a. For the battery to be ready for use in the shortest possible time, it should be fully charged, correctly topped up and then discharged at normal rate for a period of 1 hour before storage.

b. The battery should be cleaned and dried and the terminals and connectors lightly smeared with pure mineral jelly.

c. The battery should be inspected at intervals of 6 to 9 months and topped up if necessary.

d. Before going into service, the battery should be given a double charge and capacity check as recommended by the manufacturer of the particular type of battery.

e. The battery should be stored on a shelf or rack, protected from dirt or dust and where metallic objects such as bolts, hand-tools, etc. cannot drop onto the battery or touch the cell sides.

NOTE: The above refers to pocket plate nickel-cadmium cells and not to sintered plate nickel-cadmium cells, for which reference should be made to the manufacturer’s instructions.

6.13.6 Precautions

It should be noted that sulphuric acid will destroy alkaline batteries therefore, utensils which have been used for this acid should not be used with such batteries. It is also important to avoid any contamination from the fumes of lead-acid types of batteries.

6.14 Life

6.14.1 Ni-Cd Battery

The life of a sintered plate battery is ordinarily characterized in terms of the number of charge-discharge cycles that can be delivered or in terms of total lifetime in years. It is very difficult to produce general life data in a quantitative form, as the life of a sintered plate battery depends on a large number of factors, such as discharge depth, operating temperature and mechanical stresses. Therefore data in the literature stating, for instance, that a sintered plate battery lasts for 10 years or gives 2000 cycles are not very meaningful unless at the same time the operating conditions are specified. Constructional details, such as type of separator and amount and composition of electrolyte may also be important.

For maximum battery life the following operating rules should be followed where possible.

a. High Temperatures (>45°C) must be avoided especially during charging.

b. Deep discharges and reversals on cycling must be avoided.

c. On hard cycling service at elevated temperature, lithium hydroxide to an amount of 15-30 g/1 should be used in the electrolyte.

d. The carbonate content of the electrolyte is to be kept will below 100 g $K_2 CO_3$/I.

It should also be noted that there are no fixed rules about the capacity end point to which the battery life should be calculated. It depends very much on the application. Ordinarily, the battery life is considered to be ended when the capacity drops to 60-80% of the rated value.

6.14.2 Silver Zinc Battery

Although the discharge rate and other operating conditions do affect the cycle life, it can be stated that in general, high rate silver zinc batteries deliver 10-25 deep discharge cycles before the output drops to 80% of rated capacity. For low rate batteries the corresponding figures are 80-150 cycles. Batteries subject to shallow discharges at moderate rates and slow recharges can yield 200-300 cycles. Experimental cells have been reported to give as many as 350 deep and 650 shallow discharge cycles. The average operating life for high rate silver zinc batteries is 6-9 months and for low rate batteries 12-18 months.

The poor life of the silver zinc system is related to the solubility of the active materials and the properties of the separator. During cycling and overcharging, dendrite zinc lends to grow into the cellulosic separator material and may ultimately cause internal short circuits. Losses of capacity during cycling are often experienced as the result of erosion or inactivation of the zinc electrode. Furthermore, dissolved silver oxide attacks many separator materials and causes them to deteriorate.

6.15 Battery life and How to improve it

An understanding of the factors affecting battery life is vitally important for managing both product performance and warranty liabilities particularly with high cost high power batteries.

That batteries have a finite life is due to occurrence of the unwanted chemical or physical changes to, or the loss of, the active materials of which they are made. Otherwise they would last indefinitely. These changes are usually irreversible and they affect the electrical performance of the cell. Battery life can usually only be extended by preventing or reducing the cause of the unwanted parasitic chemical effects which occur in the cells. Some ways of improving battery life and hence reliability are considered below

6.15.1 Battery cycle life

It is defined as the number of cycles a battery can perform before its nominal capacity falls below 80% of its initial rated capacity. Lifetimes of 500 to 1200 cycles are typical. The actual ageing process results in a gradual reduction in capacity over time. When a cell reaches its specified lifetime it does not stop working suddenly. The ageing process continues at the same rate as before so that a cell whose capacity had fallen to 80% after 1000 cycles will probably continue working to perhaps 2000 cycles when its effective capacity will have fallen to 60% of its original capacity. There is fore no need to fear a sudden death when a cell reaches the end of its specified life.

6.15.2 Shelf life

It is the time an inactive battery can be stored before it becomes unusable, usually considered as having only 80% of its initial capacity as above. See also Battery Storage.

6.15.3 Calendar life

It is the elapsed time before a battery becomes unusable whether it is in active use or inactive as above.

6.15.4 Chemical Changes

Batteries are electrochemical devices which convert chemical energy into electrical energy or vice versa by means of controlled chemical reactions between a set of active chemicals. Unfortunately the desired chemical reactions on which the battery depends are usually accompanied by unwanted chemical reactions which consume some of the active chemicals or impede their reactions. Even if the cell's active chemicals remain unaffected over time, cells can fail because unwanted chemical or physical changes to the seals keeping the electrolyte in place.

As noted above some cells suffering capacity loss can be restored by repeating the formation process thus extending their life.

6.15.5 Demand Management

The "effective" life of a battery in a particular application can also be extended by controlling the load which the application places on the battery. This does not actually improve the battery performance, instead it reduces the load that the battery has to supply.

6.15.6 Premature Death (Murder)

The most likely cause of premature failure of a battery is abuse, subjecting a battery to conditions for which it was never designed.

Apart from obvious physical abuse, the following examples should also be considered abuse, whether deliberate, inadvertent or through poor maintenance disciplines.

1. Drawing more current than the battery was designed for or short circuiting the battery.
2. Using undersized batteries for the application.

3. Circuit or system designs which subject the battery to repeated "coup de fouet" (whiplash) effects.

This effect is a temporary, severe voltage drop which occurs when a heavy load is suddenly placed on the battery and is caused by the inability of the rate of the chemical action in the battery to accommodate the instantaneous demand for current.

- Operating or storing the battery in too high or too low ambient temperatures.
- Using chargers designed for charging batteries with different cell chemistry.
- Overcharging - either to too high a voltage or for too long a period.
- Over discharging - allowing the battery to become completely discharged.
- In aqueous batteries- allowing electrolyte level to fall below the recommended minimum.
- In aqueous batteries - topping up with tap water instead of distilled water (or inappropriate electrolyte).
- Subjecting the battery to excessive vibration or shock.

Battery designers try to design out the possibility of abuse wherever possible but ultimately the life of the battery is in the user's hands.

The initial tolerance spread which caused these interactions may be very low but it can build up overtime as the damage increases with every charge-discharge cycle until the weak cells eventually fail.

6.15.7 Improving Battery Life

The simplest and most obvious way of getting the maximum life out of a battery is to ensure that it always works well within its designed operating limits. There are however some further actions which can be taken to increase the battery life. These are summarized below and in depth explanations and examples are available by following the links.

6.15.8 Charging

As noted in the section on charging most battery failures are due to inappropriate charging. The use of intelligent chargers and safety systems which prevent the connection of unapproved chargers to the battery may not extend battery life but at least they can prevent it from being cut short.

6.15.9 Battery Management

Battery management is essentially the method of keeping the cells within their desired operating limits during both charging and discharging either by controlling the load on the battery or by isolating the battery from the load if the load cannot be controlled.

6.15.10 Cell Balancing

As noted above, in multi-cell batteries problems could arise from interactions between the cells caused by small differences in the characteristics of the individual cells making up the battery. Cell balancing is designed to equalize the charge on every cell in the pack and prevent individual cells from becoming over stressed thus prolonging the life of the battery.

6.15.11 Leakage

Leakage used to be a major problem with Alkaline storage cells. This was because the in proper vent plugs or more than the required level of KOH top up. Causing IR value reduced and internal shorts may develop. The escaping chemicals also create corrosion on the battery terminals compounding the problem. New cell constructions and modern materials have significantly diminished this problem. Nevertheless some cells may still leak due to poor sealing or corrosion problems.

6.16 Summary & Conclusion

Optimum and reliable performance can be expected from nickel-cadmium, Silver zinc and lead acid (VRLA) type batteries only when they are operated, maintained and overhauled in accordance with the battery and aircraft manufacturer's instructions. Overheating and thermal runaway are the prime causes of battery degradation and cell/battery destruction. The degree of reliability is directly proportional to the quality or the practices followed in their operation, maintenance and overhaul.

Part II

Certification Methodology and Compendium of Aviation Batteries

- Airworthiness Evaluation of Aircraft Batteries
- Airworthiness Certified Batteries for Military Aircraft
- Aviation Batteries From M/s.HBL Power Systems Ltd., Hyderabad
- Aviation Batteries From M/s.HEB Tiruchirapalli
- Aviation Batteries From M/s.HAL, Hyderabad and Others

7 Airworthiness Evaluation of Aircraft Batteries

7.1 Introduction

All aircraft designs, military or civil, are required to be certified for meeting the airworthiness requirements. The certification is carried out by the regulatory bodies or Airworthiness Approval Authority (AAA). In India, Centre for Military Airworthiness and Certification (CEMILAC), Bangalore, is the AAA for Military aircraft.

"Certification in a way is the manifestation of the good engineering work to meet the user requirement rather than the accredition of the designer." In this context, the certification authority evaluates and analyses the attributes like safety, reliability, fault tolerance, failure modes and their criticality etc, in a particular design.

7.2 Airworthiness

Airworthiness can be defined as fitness to fly. This implies the demonstrated capability of the aircraft/equipment to perform satisfactorily and fulfil the mission requirements, throughout the specified life in the preyailing environment, with acceptable level of safety and reliability. Airworthiness requirements are to ensure safety and reliability during design, manufacture, and maintenance. These requirements are specified as design requirements and various other requirements. As no machine can be built which would never fail and human error is inescapable, a certain amount of risk is to be tolerated in any mode of transportation. Airworthiness evaluation inter alia becomes a question of assessing the level of risk, which is considered acceptable.

All airworthiness standards, military or civil, whether those of USA, Europe, or Russia, have a common point of reference, which is that an inverse relation should exist between probability of occurrence and degree of hazard inherent in its effect.

A fundamental difference between civil and military airworthiness lies in the fact that military aircraft design quite often precedes the development of well-matured technology. To get slight edge over the contemporaries, military aircraft development uses technologies, which are yet to be proven to the maturity level to be acceptable for civil application. Thus, the civil aircraft design aims at passenger comfort and safety.

For military aircraft design, on the other hand, maximum priority is given to completion of mission/task, while safety levels are set as agreed between the manufacturer and the user. For comparison, safety levels are defined as fatalities per ton kilometer of transportation for civil aircraft while for military fighter aircraft, it is the number of accidents per 10,000 h of flight..

7.2.1 Airworthiness Certification Philosophy

Airworthiness Certification means guaranteeing:

- Fitness for flight.
- Demonstrated capability of any aircraft to perform safely within prescribed limits.

- Continued capability of the aircraft to perform satisfactorily and fulfill the mission requirements, throughout its specified life in the prevailing environments with acceptable levels of safety and reliability.
- The process of auditing and assessing the design is to ensure that it complies with a set of standards/rules/regulations as applicable, demonstrating an acceptable level of safety while performing its intended function and conforming to a certified type design .

7.2.2 Airworthiness Certification process

Certification is a process of evaluation and documentation of compliance of a product that it meets the stipulated requirements of the specifications and is declared safe to fly by the competent authority. It is an assurance to the user that the product has been designed, developed, evaluated and produced in such a manner that its quality, reliability and integrity is as the standards that meet the requirements.

The basic concept of airworthiness certification is that an independent body, not under the command and control of the contracting firm, examines the design for safety and performance. It can be seen that while certification is a declaration that a product conforms to the stipulations as defined in specifications, airworthiness is an explicit declaration that the product is certified to be airworthy, with limitations as applicable. A product that is certified need not to be airworthy, unless certified as also airworthy. A flow chart generally used for airworthiness activities for airborne batteries is given Figure 7-1.

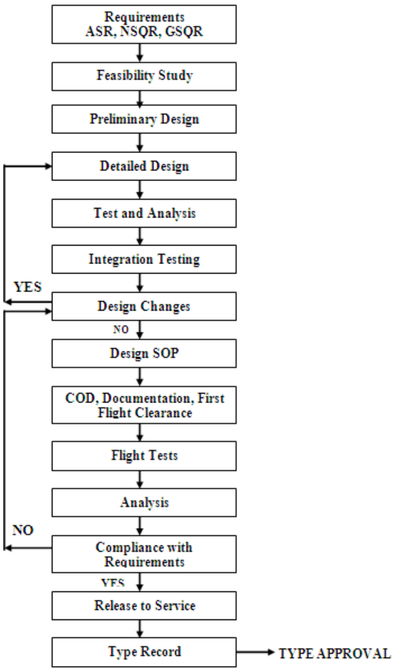


Figure 7-1 Airworthiness flow chart

7.3 Concurrent development process

It is also necessary to differentiate between the terminologies of clearance and certification. In a system of concurrence certification, viz., the action to eventually certify the aircraft along with progress of the design/development activity, an element of work/stage is then accepted by the certification authority and the work then progresses to the next element. Such a procedure is necessary if the program is a major one, like an aircraft development. This permission to go to the next stage is given through clearance issued by the airworthiness authorities.

7.4 Functional Authority

a) **Design/ Development authority**: Design/Development authority is the firm responsible for the detailed design/ modification/ indigenous substitution, etc of a system, to approved standards and authorized to sign certificates of design (CODs) in accordance with the procedures laid down in DDPMAS-75.

b) **Coordinating Design Authority**: Coordinating design authority is responsible for the overall design of the system, including integration of sub-systems/airborne stores designed by the other design approvals into the main system. The CDA may also be a design approval for some of such subsystems/ airborne stores.

c) **Airworthiness Approval Authority**: Airworthiness Approval Authority is the Government authorized regulatory body responsible for accepting the design. While Director General Civil Aviation (DGCA) is the AAA for the civil aircraft, Chief Executive, CEMILAC is the AAA for the military aircraft in India.

d) **Approval Authority for Quality Assurance**: Director General Aeronautical Quality Assurance (DGAQA) is the authority for quality assurance for the military aircraft in India.

7.5 User Expectation

Generally the Users expect the following features in the new item being developed:

- Safe, Reliable and Maintainable Product.
- No Performance Shortfalls.
- Meet Indian Environmental Conditions.
- State-of-the-Art Technologies.
- Scope for Extension of Life.

Quick Resolution of Problems.

7.6 Delegation of Responsibility among the various agencies

The design and development of airborne stores in totality would be the responsibility of the Indian Agencies. Such development may consist of Vender/ Contractor / Designer / Manufacturer / quality control production inspection etc. The airborne store would be certified by the Indian certification authorities' nominated regulated body CEMILAC. The task undertaken by associated agencies and their responsibilities / actions and general requirements and guidelines are discussed in brief for grant of type approval and production, inspection, etc. (for more detailed information on this topics refer various military specifications, defence standards, and DDPMAS-2002 documents)

7.6.1 Airworthiness Groups (AWG)

CEMILAC (Centre for Military Airworthiness and Certification) may approve setting up of Airworthiness groups in CEMILAC approved design and development agencies for progression of airworthiness certification on behalf of CEMILAC. The procedure for approval and responsibilities of Airworthiness groups shall be as per CEMILAC document CEMILAC/TC/03 Dt: Sep 2000 and its amendments from time to time.

7.6.2 Quality Assurance Approval

The Directorate General of Aeronautical Quality Assurance (DGAQA) may grant approval to the Quality Assurance Organization of development / manufacturing agencies subject to their meeting with DGAQA requirements. These agencies should be competent to ensure satisfactory Quality Assurance during development and manufacture in accordance with documents AFIO and QCSR issued by DGAQA.

7.6.3 Chief Resident Engineer (CRE) / Regional Director (RD)

Where a contractor has received Design Approval for certain classes of aircraft stores, CEMILAC will open a RCMA or authorize any other RCMA to attend to technical and development clearance of the store on behalf of CEMILAC, during its development, production and in-service phase of the life of aircraft. The RCMA so created may be headed by a Chief Resident Engineer or a Regional Director. The details of responsibilities of the Chief Resident Engineer/Regional Director heading RCMA are given below.

7.6.3.1 Responsibilities of Chief Resident Engineers / Regional Directors

i. Introduction

The Chief Resident Engineer/Regional Director is the Resident representative of Type Certification Authority for airworthiness certification i.e. the CEMILAC at the contractor's works. This annexure sets out his main duties but additional information will be found in the main chapters of the publication.

The main duty of CRE/RD is to ensure Airworthiness through evaluation of design by a process of FMEA, FMECA, Analysis of reports, Simulation Studies, Analogy Studies, Test schedules, Acceptance test procedures, Test results etc., CRE/RD is to ensure promulgation of such actions as are necessary for maintenance of Airworthiness of aircraft in service. The administration of technical supervision of CRE/RDs is vested with the CEMILAC.

The Chief Resident Engineers/RDs may be required to act as Visiting Officers to certain firms/organizations to attend to specific assignments in regard to type or development clearance of airborne stores. Their functions as Visiting Technical Officers will be similar to those outlined below.

ii. Technical Development

The CRE/RD is responsible for ensuring that the firm is cognizant with, correctly interprets and applies the technical requirements.

In cases where there are differences of opinion between the contractor and CRE/RD regarding compliance of a particular requirement, the subject matter should be brought up to the attention of CEMILAC, Air/Naval/Army Headquarters/ Ministry of Defence.

The CRE/RD shall evaluate design features of all military aircraft projects at the contractor's works and verify conformity to design requirements. The CRE/RD is also responsible to ensure compliance of design and test requirements required for technical clearance of the stores by the CEMILAC.

The CRE/RD shall approve the Development and Qualification Test Schedule and specify the Test and Analysis requirements for clearance of airborne systems and stores.

The CRE/RD shall witness where necessary, ground tests and verify adequacy of loading and testing conditions. Where loading and testing are inadequate, he shall advise the contractor for revision of testing to the appropriate loading and test conditions.

The CRE/RD shall analyse flight results and examine adequacy. Additional tests should be called for where necessary. CRE/RD shall attend the debriefing meeting where necessary.

The CRE/RD shall submit technical appreciation reports to Headquarters, CEMILAC periodically on evaluation of design features, ground and flight tests carried out.

The CRE/RD shall arrange to collect and maintain Type Records, including test reports on wind tunnel, structural, mechanical and system tests, bench test, proving trials and flight tests. One set of these shall be forwarded periodically to CEMILAC.

iii. Production Phase

The CRE/RD shall be Chairman for Local Type Certification Committee, Local Concession Committee and Lifing Committee.

The CRE/RD shall examine the acceptability or otherwise concessions referred to by CRI, when strength, safety, interchangeability etc are affected. The CRE/RD shall examine modification proposals put up by the contractor in respect of projects under his control, call for the tests required, technically accept mods and act as Chairman of the Local Modification Committee constituted for the various projects. In the discharge of this responsibility, he shall take all necessary action to ensure acceptance of the mod by User services prior to his formal technical clearance and prescription in the standard of preparation.

The CRE/RD shall examine and approve all draft Sls, STls, Urgent Operating Notices, Urgent Servicing Notices, Service Bulletins, Lifing Policy that are required to be issued for the maintenance of airworthiness standard of aircraft manufactured at the contractor's works.

The CRE/RD shall define periodically the design standard for production/overhaul aircraft, examine and approve changes to ground and flight test schedules, examine cases of concession put up by the contractor for non-compliance of modifications, Sls, STls, Urgent Operating Notices, Urgent Servicing Notices, Repair Schemes etc., during manufacture and overhaul of aircraft manufactured by the contractor.

In respect of aircraft in Service use, the CRE/RD shall maintain day to day contact with Service Headquarters on matters arising from technical and operational experience of such aircraft and take action as considered necessary to ensure maintenance of airworthiness.

The CRE/RD shall participate and ensure adequacy of investigations on defects and incidents carried out by the contractor on design aspects. The CRE/RD shall also examine tests carried out on components indigenously developed at the contractor's works and forward to CEMILAC, his recommendations for Type Approval.

The CRE/RD shall satisfy himself of the adequacy of production ground and flight test schedules. He will approve the ground and flight test schedules and their amendments.

During certain phase of production of aircraft/airborne stores the main contractor may propose to indigenise or substitute from other countries material and components. On receipt of such proposal from contractor, it is the responsibility of CRE/RD to approve the specification/drawing of the material/component and lay down test requirement for approving the same.

All Defect Investigations carried out during development phase shall have member from RCMA.

7.6.4 Chief Resident Inspector (CRI)

Where a contractor is engaged in the development/manufacture/overhaul/ repair of aircraft/ aero-engine/ associated equipment, DGAQA may position Chief Resident Inspectors for ensuring Quality Assurance of the stores. The broad details of responsibilities of Chief Resident Inspectors are given below.

7.6.4.1 Responsibilities of Chief Resident Inspectors

i. Introduction

The Directorate General of Aeronautical Quality Assurance is the authorized under the Dept. of Defence Production and Supplies in the Ministry of Defence responsible for Quality Assurance and Acceptance of Aircraft/Aero-engines/Aeronautical Stores manufactured/ overhauled/repaired at various Divisions of Hindustan Aeronautics Limited and for such stores manufactured at Ordnance Factories and in private sector, besides other responsibilities. The inspection of aeronautical stores for the Services is generally based on the principles laid down in AvP/DEFST AN-83 and AvP/DEF ST AN-84.

Chief Resident Inspectors are therefore located by Headquarters, DGAQA to carry out Executive Quality Assurance functions at firms established for the purposes of manufacture/overhaul/repair of aero-engines/aircraft! Associated equipments. The primary function of the CRI's is to verify by adequate inspection, testing, quality audits and effective supervisory inspection control over the firm's Quality Assurance authorized, that all supplies and equipment delivered under the Ministry of Defence contracts / orders, which designate DGAQA as the Inspection Authority, confirm to the stipulated requirements. The responsibilities are broadly defined as follows:

1. Exercise control over the Quality Assurance Organization of the firm and report to Headquarters of any fall in standard of the firm's Quality Assurance Organization/Staff.
2. To satisfy him through physical supervision that the firm's Quality Assurance staffs have carried out comprehensive Quality Assurance at all stages from the raw material stage to the final delivery of the product and introduce such checks and procedures as considered necessary from time to time.
3. Introduce stages of physical Quality Assurance which should be comprehensive and cover Quality Assurance right from the incoming raw material and stores to the finished product and final assembly stage. They are to be reviewed periodically for ensuring better supervision over the firm's Quality Assurance authorized. Wherever the CRI's stages of Quality Assurance have been communicated to the firm, the firm's Quality Assurance responsibility should be permitted. If there is need to deviate, it should be done in consultation with Chief Resident Inspector only.
4. To ensure that all deviations to stipulated requirements are properly authorized and recorded. Wherever there are deviations of major nature affecting safety or strength or interchangeability or other operational aspects, he shall refer the case to CRE/RD for his decision. Deviation affecting operational aspects shall be referred to Air/Naval/Army Hors/RCMA for decision.
5. Report to Headquarters, details of new design projects or manufacturing methods or processes which may affect the established inspection procedure and raise critical observations thereon.
6. Assist Headquarters, DGAOA in the indigenous substitution activity.

ii. Prototype Development of Stores and Trials Installation Inspection

Whenever a new aeronautical store is developed under a contract, for which DGAOA is the Inspection Authority, the CRI is associated with all phases of development and testing of stores from the initial stages, for progressive appraisal and for making critical observations of engineering features especially from maintenance, servicing and inspection point of view. Such report from CRI's would be given consideration by CRE/RD before according the Type Approval.

iii. Release of Aircraft for Test Flights (Form-1090)

CRI is responsible for the issue of a Certificate of Safety for Flight for undertaking any test flights at Contractor's works, for purposes of trials/acceptance and ferry to the user units in respect of aircraft under development! Manufacture/ overhaul/repair.

The Certificate is issued after inspection to ensure that the aircraft has been constructed/overhauled/repaired and ground tested in accordance with the applicable drawings or approved schedules and that the requirements of the contractor have been complied with.

iv. Certification of Contractors Advice and Inspection Note

All stores manufactured/overhauled/repaired under the Ministry of Defence contracts are accepted and so certified by CRI's on the Contractors Advice and Inspection Note. This certificate forms the basis of all contractual transactions.

v. Defect Investigation

CRI will be associated with investigations of defects reported during development and in service and at the manufacturers works/overhaul agencies and make suitable recommendations as per laid down procedures.

7.6.5 Association of IAF, IN, IA and Coast Guard during development

In addition to RCMA and CRI, the ASTE of IAF would be associated during development to ensure user acceptance during development. Indian Navy, Indian Army and Cost Guard would be similarly associated during development in respect of Naval Air Projects, Indian Army projects and Coast Guard projects respectively.

7.6.6 Responsibility for Design

The main Contractor is solely responsible for the design, development, construction and ground-and-flight tests of the aircraft/engine or airborne store to the requirements/specifications. In case of Trial Installation of airborne stores, an aircraft would be made available for flight tests by the IAF/ Indian Navy/Indian Army/Coast Guard/HAL as applicable. As for overall development flight test schedule is concerned, this will be specified by RCMA in consultation with the sponsoring agency/main contractor. RCMA is fully responsible for the adequacy of tests prescribed before clearing equipment for development trials/use. This would also apply to clearances given by RCMA for part systems of major weapon systems, aircraft or aero engines. It would be the responsibility of RCMA and CEMILAC that the stores/equipment/aircraft involved, meet the design standard/requirements laid down for military aircraft. While giving concessions RCMA must ensure level of safety equivalent to that provided in the design requirements. These concessions should be properly documented giving proper justification. Wherever necessary, concurrence of service HQ would be obtained before granting concessions.

7.6.7 Responsibility for Quality Control

The contractor firm would primarily be responsible for instituting adequate quality assurance provisions for fulfilling the quality requirements of the development projects/manufacture/ repair/overhaul in conformance to the drawings/test schedules. Such a QA arrangement should adequately conform to Quality Management System invoked from time to time and as specified in the applicable documents of DGAQA like Quality Control System Requirement for Industry (QCSR) and Approval of Firm's Inspection Organization (AFIO). The Contractor firm will be responsible for veracity of the information supplied by it to the representatives of Type Certifying Authority. The responsibility of the contractor/firm also includes the sub-contracted portion of work, if any. Such sub-contracting arrangements are to be duly communicated to the CRI concerned.

7.6.8 Division of Responsibility between the Contractor and CEMILAC

In view of the overall responsibility for certification of the product being that of the CEMILAC, CE, and CEMILAC reserves the right for its officers to exercise such supervision as are detailed herein in the discharge of this responsibility.

The contractor shall prepare and forward to RCMA a list of all new items of equipment which he proposes to develop for the aircraft. When the contractor places or accepts a sub-contract for any major design and development, he shall notify the RCMA and OCRI, of the nature of the work and the technical requirements supplied at all times during the design, development, construction and test, the contractor shall make available to RCMA all ground and flight test reports. The contractor shall also provide the drawings, design calculations, etc. whenever necessary.

The main Contractor or development agency is also responsible for the store as a whole including any items sub-contracted by them and which have been designed indigenously or adapted to suit the store. The main contractor shall use only items of stores, materials and processes called in the approved drawing. In case uses of unapproved components are unavoidable, the main equipment/store so built will be subjected to type test. In the event of satisfactory results RCMA may accept these components in the build standard of that particular series of equipment. This acceptance will be valid as long as these components are obtained as per specifications and source of supply is not changed. Any change in these will invalidate the approval. The use of Commercial off the Shelf (COTS) items in an electronic equipment are governed by JSG: 755:2001.

7.7 Aircraft Battery Design Specifications / Requirements- Check List

Proper definitions of application requirements can be achieved through a compressive assist both the user and manufacturer in selecting the right battery for each specific cover electrical, mechanical and environmental consideration.

Therefore a check list for the cell and the battery based on the QRs received from the User service is to be prepared by the Designer / developer and forward it to certification agency for their acceptance. The specification should contain in Table 7-1and Table 7-2.

Table 7-1: Cell Technical Specifications / Requirements check list.

1.	Cell design / technology type.
2.	Charged cell voltage and capacity rating.
3.	Cell geometry details, physical dimensions and weight.
4.	Cell drawing No.

5.	Type of electrodes (or plates) and its active material for its density & its pre-selected porosity.
6.	Give details of electrolyte used and its preparation.
7.	Indicate No. of positive and negative electrodes for plate-pack/stack assembly/group configuration details. Give cell power density/energy density.
8.	Type of grid substrate / alloys.
9.	Type of Separator materials / systems used.
10.	Cell Sealing method / procedure for its lid joints etc.,
11.	Efficiency of sealing.
12.	Cell container material.
13.	Cell terminal torque requirements.
14.	Identification of polarity.
15.	Cell vent type and its venting pressure limits.
16.	Details of cell nomenclature (Type, Sl.No., Manufacturing Date and Company Name).
17.	Manufacturing process control and Quality Assurance plan document issue No. and date.
18.	Cell nomenclature details.

Table 7-2: Battery Technical specifications/ Requirements check list.

1.	No. of cells used in a battery pack and its configuration.
2.	Battery terminal voltage/open circuit voltage (OCV) and capacity rating. Also indicate Power density/Energy density.
3.	Type of inter-cell connectors, terminal nuts & its torque and any temperature sensor provided? If so give its operating limits.
4.	Type of battery connector and its model type / standard type model.
5.	Battery physical dimensions and weight and drawing No.
6.	Battery tray and its container details including any heating pads provided
7.	Battery nomenclature / identification of marking / finishing etc.,

8.	Recommended charging methods and its cutoff voltage or current. State Of Charge(SOC) determination ? Give methods of estimating the SOC
9.	Recommended discharge and its cutoff voltage /or current
10.	Define battery maximum power and peak power capability & Battery service life capacity ratings for 5C, 10C, 15C & 30C at Room temperature & -30°C. Give for these typical curves in the graphs.
11.	At RT & low temperature (-30°C) charging (at constant voltage) and discharging capabilities. Define charging efficiency. Give for these typical curves in the graphs.
12.	What is the high current pulse capability?
13.	Define internal resistance values at room temperature and at -30°C
14.	Temperature limits of battery usage and what are the conditions for storage.(normal storage & long term storage) Any temperature derating for performance?
15.	Platform requirements / end use of operation like No. of batteries installed, size, weight, configuration, type of duty involved whether pure battery operation or parallel operation or floating effect.
16.	Any engine cranking with battery? And No. of engine cranking (give peak current and voltages required during engine cranking).
17.	Emergency load requirements / back - up period.
18.	Battery life with intended duty cycles of operation and what is the shelf life and calendar life of battery? What is the self discharge rate?
19.	Give details of environmental specifications at which battery was designed for airworthiness evaluation
20.	Battery Build Standard (Approved Standard Of Preparation (SOP) of battery including MDI list engineering/design drawings, manufacturer specifications, process flow chart, bill of material, break down chart etc.,).
21.	Maintainability requirements including degree of maintenance available (operating & maintenance) or desired or any ageing value requirement for battery reliability, safety of operation etc.(,such as KOH topping /adjustment, & its periodicity. If it is repairable battery how many cells are allowed for replacement over the life of the battery. What is the State of Health(SOH) used for this battery? & how it is determined?
22.	Does it generate any interference or electrical noise?
23.	Is it affected by interference of electrical noise?

24.	Technical support and warranty clause.
25.	Cost of the item.
26.	Battery buildup standard / SOP document details.

Note: Any other parameter required specific to platform may also be included in the specification.

7.8 Battery Testing

A qualification test plan has to be prepared by the Designer / developer based on the platform and other environmental requirements to check the performance of the battery in those conditions. In case for any reason Safety of Flight Tests route to be followed, a test plan (SOFT plan) to be prepared by the Designer / developer. These documents to be forwarded to CEMILAC for the approval.

7.8.1 Safety Of Flight Test (SOFT) Requirements

To shorten time of evaluation and feed back of performance during flight, generally SOFT and minimum integrity test are conducted for its suitability conformance.

For development trails on a particular platform requirements SOFT may be evaluated (for feasibility study purpose also a limited qualification (LQT) with less endurance and minimum severity can be evauled for evaluation. Generally SOFT samples may be cleared for small period of field use only)

SOFT test requirements shall consist of the following:

1. Ensuring dimensional accuracy of cells, battery, boxes, connectors, cell insertion force, weight check, insulation, dielectric checks, etc.
2. Carry out all the electrical parameters check such as :
    - Amp. hour capacity.
    - Charge acceptance.
    - Unassailability, Peak power discharge test.
    - Engine cranking profile test.
    - Emergency load test (Reserve capacity).
3. Vibrations test for 15 min. each axis.
4. Altitude test.
5. 20 sec pulse discharge test at -18°C.
6. Constant voltage discharge for 1 minute
7. Temperature rise and float test.
8. Physical integrity at high temperature .
9. Deep discharge recoverability test.

Note: Any other tests required specific to platform may also be included in the SOFT.

7.9 Qualification Testing (QT)

Qualification testing is designed to determine whether a cell or battery is fit for the purpose for which it was intended before it is approved for use in the product. This is particularly important if the cell is to be used in a “mission critical” application. These are comprehensive tests carried out initially on a small number of cells including testing some of them to destruction if necessary. As a second stage, qualification also includes testing finished battery packs before the product is approved for release to the customer. The tests are usually carried out to verify that the cell meet the manufacturer’s specification but they could also be used to test the cells to arbitrary limits set by the applications engineer to determine how long the cells survive under adverse conditions or unusual loads, to determine failure modes or safety factors.

The battery packs should also to be tested with the charger recommended for the application to ensure compatibility.

The qualification test plan (QTP) for Airborne batteries shall consist of the following:

i. **Physical Inspection / Test**

Visual and Mechanical inspection

1. Size (Dimensions) and weight.
2. Cell vent test.
3. Electrolyte leakage / pressure test.
4. Cell Insertion force test.
5. Dielectric and insulation resistance.
6. Arrangement of receptacle / strength of receptacle test given below or MIL-3509 may be tested (Separate test scheduled may be prepared for receptacle approval).
7. Thermal sensor arrangement and its functional test may be evaluated (Separate test scheduled may be followed for aero design application and its functional checks like opening-closing temperature of thermal sensor and chemical resistance with stand in electrolyte and dielectric strength and insulation resistance tests etc.).

ii. **Electrical Performance Test**

Typical capacity discharges 1C, 5C, 10C, 15C, 30C at RT & -30°C, 20 sec pulse discharge test (for 3 cycles) (At –18°C cold cranking capability test).

1. Emergency load conformance test.
2. Engine start cycle test (heavy duty discharge).
3. Instantaneous Peak power & Maximum power delivery test & Internal resistance evaluation at RT & -30°C.
4. Duty cycling test / Cycling test .
5. Gas Barrier material test.

iii. Mechanical Testing

Typical test are included as per safety standards below. They include simple test for dimensional accuracy to dynamic testing to verify that the product can survive any mechanical stresses to which it may be subject.

(Procedural details may refer from MIL-STD- 810F / JSS 55555)

1. Vibration resistance (Sine / Random).
2. Gun Fire vibration.
3. Linear Acceleration.
4. Mechanical Shock (Basic design).
5. Temperature Shock.
6. Drop Test.

iv. Environmental Testing

Typical tests are included in the safety standards below. They are designed to exercise the product through all the environmental condition likely to be encountered by the product during its lifetime.

(Procedural details may refer from MIL-STD-810F / JSS 55555)

1. Humidity and charge retention test.
2. Temperature rise and float test.
3. High altitude test.
4. Low temperature performance test.
5. Salt fog test.
6. Storage test.
7. Shelf life test (Accelerated shelf life).
8. Sand and Dust test.
9. Physical integrity at high temperature (+85°C) test.
10. Safety issues (Explosive Atmosphere, Short Circuit test etc.).
11. Fluid contamination and Resistance to KOH test.
12. Fungus (Mould Growth) Test.
13. User Trials etc.

Each battery Qualification Test Procedure (QTP) document will be defined in detailed pertaining to above test and requirements etc., this document to be approved from RCMA/CEMILAC before proceeding for evaluation test.

v. Number of samples and samples distributions.

Generally batteries are manufactured in various types and sizes (with variety of materials and various process oriented techniques) Battery importance such as energy content for unit of volume and weight, discharge characteristics at different rates and temperature, internal resistance, charge retention, life and mechanical stability etc.

Due to this wild diversity of cell designs and materials, used by various manufactures, specific values have not been assigned to control parameters. However in aviation battery certification the role of quality assurance is at most important. A few general methodology on process control and samples testing for reliability functioning etc. are evolved.

A typical sample distribution and sequence of test for airborne Ni-Cd battery (Vented) are given below Table 7-3, depending upon platform requirements, any tests may be added or deleted.

Table 7-3 Typical sample distribution & sequence of tests for QT / SOFT for Ni-Cd (vented) battery

Sl No	Test Name	QT sample No's					SOF Tests
		1	2	3	4	5	
1	Physical examination of components as per SOP document	X	X	X	X	X	X
2	Overall Physical Dimensions and weight & Initial capacity test	X	x	x	x	x	X
3	Markings	X	X	X	X	X	X
4	Polarity of plates	X	X	X	X	X	X
5	Cell container test	X	-	X	-	-	-
6	Cell insertion force test	X	X	X	X	X	X
7	Handle strength test	-	-	X	X	-	-
8	Cell vent test	X	X	X	X	X	X
9	Base line parameters: (a) Typical discharge performance for 1C, 5C, 10C, 15C, 30C at RT & -30°C (b) Instantaneous power and maximum power delivery test and internal resistance at RT & -30°C (d) Engine starting profile and emergency load test as per Aircraft platform profile.	X - -	X - -	- X X	- X X	- - -	X
10	Low temperature at -18°C, CP charge & 1C rate performance at RT	X	X	-	-	-	X
11	Humidity and charge retention test	-	-	X	X	-	-
12	Shock test (basic design)	-	-	x	X	X	-

13	Vibration test &Acceleration test *	-	-	X	X	-	X
14	Temperature shock test	-	-	X	X	-	-
15	Altitude test *	-	-	x	x	-	X
16	Salt fog test	X	X	-	-	-	-
17	20 second pulse discharge test	-	-	X	X	-	X
18	Medium rate operating position test	-	-	X	X	-	-
19	Constant voltage discharge test *	X	X	X	X	X	X
20	Duty Cycling test	X	X	-	-	-	-
21	Temperature rise and float test	X	X	-	-	-	X
22	Physical integrity test at 85°C	X	-	-	-	-	-
23	Constant voltage discharge test *	-	X	-	-	-	-
24	Internal pressure test	X	-	-	-	-	-
25	Di-electric and insulation test	X	X	X	X	X	X
26	Gas barrier material test	-	X	X	-	-	-
27	Storage test	-	-	-	-	X	-
28	Shelf life & Calendar life test	X	-	-	X	-	-
29	Short circuit test	-	-	X	-	-	-
30	Cell baffle test	Only on 2 sample cells					-
31	Explosion containment	-	-	-	-	X	-
32	Fungus (Mould Growth)Test	-	-	-	-	X	-
33	Fluid contamination	-	-	X	-	-	-
34	Resistance to electrolyte test	Only on 2 sample cells					-

35	Battery connector/receptacle plug test	As per Appendix '1'					-
36	User trials *						#

- Note: QTP of test procedures etc may be defined from JSS 6140-10:2007,MIL-STD-81757D/MIL-STD 810F/BSEN 2570./JSS 55555
- * Additional requirements, if any, may be evaluated as per Aircraft requirements.
- # For SOF evaluation, required samples may be evaluated with reduced endurance levels

7.9.1 Subsystem qualification requirements

Procedures for specific subsystem airworthiness qualification are identified. Generally identified for aircraft battery requirements covered are (1) Main battery connector or receptacle and (2) Temperature sensors and its associated cables and connector, etc.

Identified subsystems that normally undergo subsystem qualification. In general test setups environment conditions, etc., not necessarily representative of actual positioning of hardware. Hot mockups constitute the next higher level of integration and representation of the actual subsystem configuration and actual environment.

7.9.2 Aircraft Battery connector / receptacle evaluation

The following tests may be carried out separately only, on two samples of connector block / electric plug assembly of aircraft battery:

1. Examination of the product, dimensional checks & weight. Each plug shall be examined to determine compliance with all requirements as per related drawings. (Material specification, Contacts, Lock-in socket, Mounting reinforcement, Expander pins, etc., shall be defined proper annealing material etc.).
2. **Mechanical engagement, disengagement and operating torque:** Each plug shall be engaged and disengaged from a receptacle for a number of times. The operating torque shall be measured to determine conformance with requirements (11.5 inch pounds maximum).
3. **Dielectric strength:** A potential having an effective value of 2.5 KV ±0.5KV, 50Hz or DC, shall be applied between live terminals for one minute. There shall not be any break down of insulation.
4. **Insulation Resistance (IR):** A potential having an effective value of 500±100 volts DC shall be applied between the line terminals for one minute. The IR shall be at least 5Giga Ω.
5. **Contact Resistance:** The plug and receptacle shall be wired and engaged. A current of 1200±25 amps shall be flown for one minute. The potential shall be measured between each wire connected to the plug, by means of a needle contact piercing the insulation of the wire and contacting the conductors of the wire at a point just before

the wire enters the plug, and the back end of the corresponding pin of the receptacle, by means of a connection directly to the pin and not to the shorting bar. It shall not exceed 88 mV. The flow of current shall be switched off and left idle for 1±0.1 hour. A current of 750±15 amps shall be passed for 5 minutes and neither potential measured as described above. It shall not exceed 55mV.

6. For extreme temperatures tests at -55°C and 71±1°C
    - Dielectric test.
    - Insulation Resistance tests.
    - Operating torque.
    - Contact Resistance.
7. **Life:** The plug shall be engaged with and disengaged from a receptacle 5000 times at a rate of 10±1 cycles per minute. The plug shall be subjected thereafter in respect of operating torque and contact resistance as per 2 and 5 respectively.
8. **Mechanical shock:** Wired plugs and receptacles engaged shall be rigidly installed and subjected to 30g shock (sine wave for 11ms). Subsequently, the contact resistance shall be measured. Two shocks in each of six directions.
9. **Thermal shock:** The plug shall be subjected to this test as per MIL-STD-810. Subsequently, the plug shall be subjected to dielectric test as per 3 above. Stabilize at –40°Cand soak for one hour. Transfer and stabilize at +85°C and soak it for an hour. Transfer it –40°C and soak for 1 hour. This constitutes one cycle. Repeat for a total of 5 Cycles.
10. **Vibration:** The plug and receptacle shall be engaged and vibrated as per MIL-STD-810. There shall be no derangement or damage to the plug and receptacle. PSD=0.04g^2/Hz from 15 Hz to 1KHz and falling off at the rate 6db/octave from 1 KHz to 2 KHz. Duration 1 hr per axis.
11. **Humidity:** The plug shall meet test requirements as per MIL-STD-810. Temp +30°C to +60°C, RH85% to 95% total of 15 cycles.
12. **Immersion test :** The plug shall be Immersed in the following fluids in turn for the length of time listed below :
    - Aircraft hydraulic fluid – 20 hours.
    - Aircraft Lubricating oil – 20 hours.
    - Sulphuric acid (sp.gr 1.1) – 8 hours.
    - Potassium hydroxide (sp.gr 1.3) – 8 hours.
    - The plug shall be washed and dried and shall then be subjected to the tests namely, Dielectric strength, installation resistance, operating torque and contact resistance.
13. **Fungus:** As per JSS-55555 for 28 days. After this test shall be checked for any fungus and should not support for any fungus growth.

14. **Salt Spray:** As per JSS-55555 for 96 hours. At the conclusion of test, the plug shall be washed with water (temp not exceeding 37±1°C),dried for 24±1 hours at +50°C ±1°C and then subjected to IR test to meet requirements.

Note: For details of evaluation on aircraft battery power connectors, aircraft battery high power receptacles and connectors may be referred MIL-3509, MIL-P-18148 & MIL-PRF-18148 respectively.

7.9.3 Battery Temperature Sensor - A typical evaluation

7.9.3.1 Charge Control Aspects By various “Thermal Sensors”

The controls for voltage and current during charge for most batteries are contained in the charger. Nickel–cadmium and nickel–metal hydride batteries may be charged over a fairly broad range of input current, ranging from less than a 0.05C rate to greater than 1.0C. As the charge rate increases, the degree of charger control increases. While a simple, constant current control circuit may be adequate for a battery being charged at a 0.05C rate, it would not suffice at a rate of 0.5C or greater. Protective devices are installed within the battery to stop the charge in the event of an unacceptable temperature rise. The thermal devices that can be used include the following:

1. Thermistor*:* This device is a calibrated resistor whose value varies inversely with temperature. The nominal resistance is its value at 25°C. The nominal value is in the KΩ range with 10K being the most common. By proper placement within the battery pack, a measurement of the temperature of the battery is available and Tmax, Tmin and $\Delta T/\Delta t$ or other such parameters can be established for charge control. In addition, the battery temperature can be sensed during discharge to control the discharge, e.g., turn off loads to lower the battery temperature, in the event that excessively high temperatures are reached during the discharge.

2. Thermostat (Temperature Cutoff, TCO): This device operates at a fixed temperature and is used to cut off the charge (or discharge) when a pre-established internal battery temperature is reached. TCOs are usually resettable. They are connected in series within the cell stack.

3. Thermal Fuse*:* This device is wired in series with the cell stack and will open the circuit when a predetermined temperature is reached. Thermal fuses are included as a protection against thermal runaway and are normally set to open at approximately 30–50°C above the maximum battery operating temperature. They do not reset.

4. Positive Temperature Coefficient (PTC) Device*:* This is a resettable device, connected in series with the cells, whose resistance increases rapidly when a pre-established temperature is reached, thereby reducing the current in the battery to a low and acceptable current level. The characteristics of the PTC device are shown in Figure 7-2. It will respond to high circuit current beyond design limits (such as a short circuit) and acts like a resettable fuse. It will also respond to high temperatures surrounding the PTC device, in which case it operates like a temperature cutoff (TCO) device.

Figure 7-3 shows a schematic of a battery circuit, indicating the electrical location of these protective devices. The location of the thermal devices in the battery assembly is critical to ensure that they will respond properly as the temperature may not be uniform throughout the battery pack. Examples of recommended locations in a battery pack are shown in Figure 7-4. Other arrangements are possible, depending on the particular battery design and application.

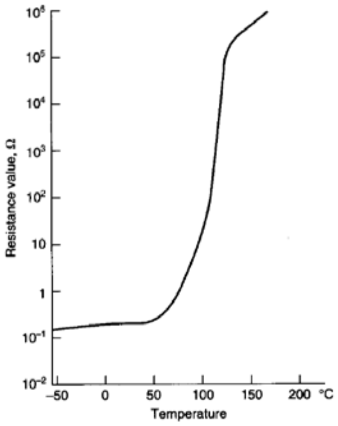


Figure 7-2 Characteristics of a typical positive temperature coefficient (PTC) device.

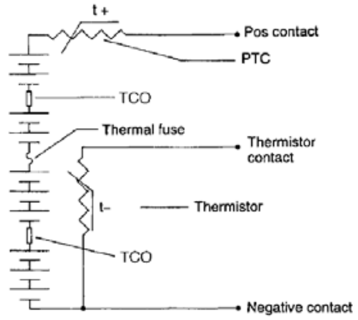


Figure 7-3 Protective devices for charge control.

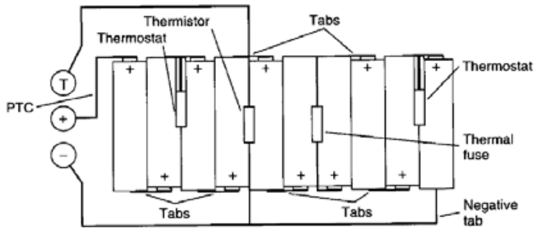


Figure 7-4 Location of protective devices in battery.

Sensors may be provided inside the battery case which sense either typical or average cell temperature. They are equipped with a provision for external electrical connections.

These devices may be of the on-off type, such as thermostats, or they may be the continuous type, such as thermistor assemblies. Continuous types have the capability of providing continuous modulation of the regulated charging voltage of a CP charging source or of the cut-off turn-on voltages of a constant-current VCO charging system.

The thermal sensor / thermo-stat and its harness assembly shall be approved for aero design approval. If it is aero design approved, then the following functional checks may be carried out for confirmation.

- Physical Inspection of any cracks, bends etc.
- Dielectric strength and Insulation resistance test as per 4.5.27 of MIL-STD-81757D and Insulation resistance value should be above 20 MΩ when measured with 500VDC megger.
- **Initial Measurement:** Two temperature sensor/thermostats devices shall be checked for opening and closing temperature. Thermostats shall open when temperature is <57°C (across A&B pins of connector) & <71°C (across C&D pins of connector) and close when the temperature is $\geq$57°C (across A&B pins) and temperature is $\geq$71°C (across C&D pins). Observe and record when closing condition resistance value at above temperatures.

7.9.3.2 Temperature Sensor Test

- Enclose the thermocouple and a temperature measuring device in a plastic bag (remove as much air as possible), and insert the device into a beaker of water.
- Raise the temperature to the specified level and allow the unit to stabilize for 5 minutes at that temperature.
- Take the measurement specified (resistance or conductivity).

Active Pins	Temperature Parameters	Temperature Range
A-B	CLOSE ON RISE	57°C / 135°F
C-D	CLOSE ON RISE	71°C / 160°F

- **Chemical resistance with stand in Electrolyte:** Thermal sensor/thermostat and its harness assembly shall be immersed in an aqueous solution of potassium hydroxide of 1.30±0.004 SP gravity in a temperature chamber at 65°C for 168±2hrs. After completing this soaking, thermal sensor harness assembly shall be rinsed with water and wipe dry.

  Note: Any other tests required specific to platform may also be included in the QTP.

7.10 SOFT Clearances

On successful completion of Safety of Flight Tests (SOFT) a clearance will be issued by the Certification Agency for developmental flight trials on specific platform.

7.11 User Trials

The User / HAL in consultation with the Certification and QA Agencies shall prepare a detailed trial schedule for the conduct of Ground and flight trials for assessing the mechanical and electrical integration and performance of the battery. A report on the performance of the battery shall be forwarded to all concerned agencies.

7.12 Provisional Clearance

On successful completion of the QT and flight trials the Certification Agency shall issue a Provisional Clearance for bulk production of Batteries.

7.13 Performance Feedback / Modification

The field performance of the battery shall be monitored for at least one year on issue of PC. Defects if any reported shall be analyzed and modification if required to overcome the defects reported or improve the performance carried out as per the procedure enumerated in DDPMAS 2002.

7.14 Issue of Type Approval

Type Approval is a certificate issued by the Approving Authority, i.e. CE, CEMILAC to the effect that the store under reference meets all design specifications and test requirements laid down by CEMILAC. The type approval is issued after the Design Authority or Main Contractor submits a full type record with all relevant documents to the satisfaction of CEMILAC viz., specifications, SOP including drawings, QTP, QTR and compliance statement with field performance feedback reports if any, along with Provisional /Service clearance certificates etc., design certificate, with recommendation of RCMA, and type approval Performa duly filled, etc. The address of CEMILAC is as follows:

The Chief Executive (Airworthiness),
CEMILAC,
Ministry of Defense, DRDO,
Marathahally Colony PO,
BANGALORE – 560037 .
Phone: 080 - 2512 1401/ 2512 1201.
Fax : 080 - 2523 0856/ 2523 0335.

7.15 Acceptance Philosophy During Production

After the successful completion of above program the battery is said to have been qualify for meeting the power requirements of platform system. To ensure the same quality standards later during bulk production has been made to ensure that the quality of the product rolling out also enjoys high reliability. The following acceptance philosophy suggested, so that the reliability of the battery is assured.

- Manufacturer should define SOP (standard of preparation)document and quality assurance process procedures / plan for audit and inspection testing.
- For all batteries, the inspection agency will complete the stage inspection. After successful completion of this inspection only, the production agency will start assembling batteries.
- All assembled batteries will undergo battery assembly checks one out of 21 numbers (or choice of the inspection authorities production samples for acceptance test criteria may be decided) [Ni-Cd or Silver-zinc or lead acid as the case may be] batteries shall be subjected to acceptance criteria test which will have the combined climatic and dynamic test at the minimum level. After subjecting the battery to the acceptance criteria test it shall be discharged for its specifications.

8 Airworthiness Certified Batteries for Military Aircraft

The indigenous design, development, manufacturing of military aviation batteries have matured due to the active participation of both public sector and private sector. The batteries from these sources are subjected for their airworthiness tests and approved for aircraft use by CEMILAC (Centre for Military Airworthiness and Certification). This chapter enumerates all the batteries certified by CEMILAC and its Regional Centres for use in Indian Military Aviation. The batteries that have successfully undergone all the qualification tests are either Type Approved or Provisionally Cleared. During Design and Development a battery is cleared for "Development Flight Trials" after subjecting it to Safety of Flight Tests (SOFT). Table 8-1 gives a list of batteries that are accorded type approval certificate, Provisionally Cleared or SOFT Cleared. The user can place an order on the OEMs for the procurement of batteries that have a valid Type Approved or Provisional Clearance Certificate.

8.1 Military Aircraft Batteries Approved by CEMILAC

The following information is given for each of the battery.

Battery Title : Gives the Nominal Capacity, Voltage and the type of the battery

Manufacturer : The Original Manufacturer who holds the TA or PC of the Battery. The major Manufacturers listed are

- M/s Hyderabad Batteries Limited, Hyderabad (HBL)
- M/s High Energy Batteries, Trichirapally (HEB)
- M/s Hindustan Aeronautics Limited, Hyderabad (HAL)
- Mysore Thermo Electric (P) Ltd, Bangalore

Aircraft/End Use : The aircraft and/or the application of the battery.

Certification Agency : The field establishment of CEMILAC that has coordinated during the qualification and certification process

Certification Status : The nature of the certificate the Manufacturer holds for the battery. It can be Type Approval or Provisional Clearance or Safety of Test Certificate.

Approval Validity : The date of expiry of the Type Approval Certificate

Details : Cross reference detail about the battery and its technical descriptions in later chapters is provided. For some batteries a brief note is also added.

The Table 8-1 is sorted primarily based on the Battery Capacity and then by the Manufacturer name.

Table 8-1 List of Military Aircraft Batteries Cleared by CEMILAC and Other Development Status

Sl. No.	Battery Title	Aircraft / End use	Manufacturer	Certification Agency	Certification Status	Approval Validity	Chapter Ref for technical aspects/ remarks
1.	3.5AH,24V Emergency battery Ni-Cd sealed type	Kiran-1 / 1A, aircraft	HBL	RCMA(Hyd)	TA No. 1096	31/12/09	9.2.10
2.	2.5 AH, 14.4V Lithium Thionyl Chloride battery	PRB Radio Beacon of ECIL / Unitron and SARBE	HBL	RCMA(Hyd)	TA No. 968	30/06/12	9.2.12
3.	16AH, 24V Ni-Cd battery (Vented)	HPT-32 aircraft	HBL	RCMA(Hyd)	TA No. 1070	30/06/09	9.2.9
4.	18AH, 24V Ni-Cd battery (Vented)	Kiran-1 / 1A, aircraft	HBL	RCMA(Hyd)	TA No. 1132	30/06/10	9.2.8
5.	23AH, 24V Ni-Cd battery (Vented)	HS-748(Chitra)	HBL	RCMA(Hyd)	TA No. 726 (PC 151 accorded for design modification)	30/06/08	9.2.7 (new SOP for Si/Pbe, included vide PC-151).
6.	25AH, 24V Ni-Cd battery (Vented)	AN-32 aircraft	HBL	RCMA(Hyd)	TA No. 1049 (PC 150 accorded for design modification)	31/12/08	9.2.4 (new SOP for Si/Pbe, included vide PC-150).
7.	25AH, 24V Ni-Cd battery (Vented)	IL-76 & SU-30 aircraft	HBL	RCMA(Hyd)	TA No. 1048 (PC 150 accorded for design modification)	31/12/08	9.2.3 (new SOP for Si/Pbe , SOP included vide PC-150).
8.	25AH, 24V Ni-Cd battery (Vented)	MI-8/MI-17 aircraft	HBL	RCMA(Hyd)	TA No. 1041 (PC 150 accorded for design modification)	31/12/08	9.2.5 (new SOP for Si/Pbe, SOP included vide

Sl. No.	**Battery Title**	**Aircraft / End use**	**Manufacturer**	**Certification Agency**	**Certification Status**	**Approval Validity**	**Chapter Ref for technical aspects/ remarks**
							PC-150).
9.	40AH, 24V, Ni-Cd battery (Vented)	Jaguar, Cheetah, Chetak, Mirage, Kiran-II aircraft	HBL	RCMA(Hyd)	TA No. 1033	30/06/09	9.2.1 (new SOP for Si/Pbe, SOP included vide PC-149).
10.	45AH, 22.5V, Silver Oxide Zinc battery (Vented)	MIG-21 aircraft	HBL	RCMA(Hyd)	TA No. 605	30/06/09	9.2.11
11.	25AH, 24V Ni-Cd battery (Vented)	KA-28	HBL	RCMA(H/C)	PC: RCMA(H/C)/1341/2 dt.18/3/04	-	9.2.3
12.	25AH , 24V Ni-Cd battery (Vented)	KA-31	HBL	RCMA(H/C)	PC: RCMA(H/C)/1341/2 dt.15/9/01	-	9.2.3
13.	45AH , 22.5V Silver Zinc battery(Vented)	KA-25	HBL	RCMA(H/C)	PC: CRE(H)/1341/2 dt.18/6/93	-	9.2.11
14.	40AH, 1.2V Ni-Cd Cells(Vented)	SEA KING, MK-42BC	HBL	RCMA(H/C)	PC: RCMA(H/C)/1342/2 dt.16/7/04	-	9.2.2.2
15.	25AH, 24V Ni-Cd battery(Vented)	IL-38	HBL	RCMA(A/C)	PC: CRE(A/C)/HAL BC/527/11 Dt.01/04/1993	-	9.2.3
16.	25AH , 24V Ni-Cd battery(Vented)	TU-142	HBL	RCMA(A/C)	PC: CRE(A/C)/HAL BC/527/11 Dt.01/04/1993	-	9.2.3
17.	18AH, 24V	ISLANDER	HBL	RCMA(A/C)	PC:	-	9.2.8

Sl. No.	Battery Title	Aircraft / End use	Manufacturer	Certification Agency	Certification Status	Approval Validity	Chapter Ref for technical aspects/ remarks
	Ni-Cd battery(Vented)				CRE(A/C)/HAL BC/527/11(i) Dt.22/11/1993		
18.	18AH , 24V Ni-Cd battery (Vented)	SEA HARRIER	HBL	RCMA(A/C)	PC: CRE(A/C)/HAL BC/527/11 Dt.23/02/1994	-	9.2.8
19.	27AH, 24V Ni-Cd (Si/Si) battery (Vented)	DO-228 aircraft	HBL	RCMA(Hyd)	PC - issued	28-02-2009	9.2.14 (field performance feedback under observation)
20.	27AH, 24V Ni-Cd (Si/Pbe) battery (Vented)	MIG-21 / Bison aircraft	HBL	RCMA(Hyd)	PC - issued	-	9.2.15 (MIG-27 flight trials under progress)
21.	28AH, 24V Sealed Lead Acid batteries, (Maintenance free) - VRLA Type	MI-8/MI-17 H/C	HBL	RCMA(Hyd)	SOF cleared	-	9.2.6 (QT completed flight trial under progress)
22.	30AH, 24V, Ni-Cd battery (Si / PBE) (Vented) (Reduced maintenance type)	ALH aircraft	HBL	RCMA(Hyd)	SOF cleared	-	9.2.13. (QT completed flight trial under progress)
23.	3AH, 10.5V Lithium thionyl chloride Battery (PRIBOY-PZ)	Rescue beacon Komar-2M for MIG-21	HBL	RCMA(Na)	TA1025	31-12-2008	9.2.15

Sl. No.	Battery Title	Aircraft / End use	Manufacturer	Certification Agency	Certification Status	Approval Validity	Chapter Ref for technical aspects/ remarks
24.	20AH, 24V Ni-Cd battery	UH-3H for Navy H/C	HBL	RCMA(Hyd)	--	-	Under development Proposal for UH-3H H/C.
25.	i) 15AH, 24V, Ni-Cd battery ii) 4.4AH, 28V, Ni-Cd battery (Vented)	Hearon & Searcher UAV for Navy	HBL	RCMA,(Hyd)	--	--	Under development
26.	56V, 28V, 28V, 25V Thermal Batteries	ASTRA Missile	HBL	RCMA(Hyd)	--	-	Type-I to IV models of Thermal batteries are being evaluated
27.	45 AH, 22.5 V Silver Oxide Zinc Battery (Vented)	MIG & its variants	HEB	RCMA(A/C)	TA No. 342	30/06/12	10.3.1
28.	40 Ah, 24 V Nickel Cadmium Battery Part No. NC 001 Cell Part No. NC-40 (Vented)	JAGUAR STRIKE & TRAINER Aircraft	HEB	RCMA(A/C)	TA No. 789	31/12/12	10.3.2
29.	40 Ah, 24 V Nickel Cadmium Battery Battery Part No. NC 115 Cell Part No. NC-40 (Vented)	KIRAN MK-II	HEB	RCMA(A/C)	TA No. 790	31/12/12	10.3.11
30.	40 Ah, 24 V Nickel Cadmium Battery Battery Part No. NC 001 Cell Part No. NC-40 (Vented)	MIRAGE 2000	HEB	RCMA(A/C)	TA No. 791	31/12/12	10.3.2

Sl. No.	Battery Title	Aircraft / End use	Manufacturer	Certification Agency	Certification Status	Approval Validity	Chapter Ref for technical aspects/ remarks
31.	40 Ah, 24 V, Nickel Cadmium Battery Part No. NC 001(Vented)	CHETAK / CHEETAH	HEB	RCMA(H/C)	TA No. 789	31/12/12	10.3.2
32.	40 Ah, 24 V Nickel Cadmium Battery Battery Part No. NC 230 (Vented)	SEAKING	HEB	RCMA(H/C)	TA No. 789	31/12/12	10.3.2
33.	25 Ah, 24 V Nickel Cadmium Battery FTNC 0155 (Vented)	TU 142 M	HEB	RCMA(A/C)	TA No. 792	31/12/12	10.3.7
34.	18 Ah, 24 V, Nickel Cadmium Battery Battery Part No. FTNC 076 (5J/3388) Cell Part No.5J/NIV/K1(Vented)	KIRAN MK1/1A	HEB	RCMA(A/C)	TA No. 793	31/12/12	10.3.3
35.	18 Ah , 24 V Nickel Cadmium Battery Type FTNC 076/1 (5J/NIV/ISL) & Cell Part No. 5J/NIV/K1 (Vented)	ISLANDER	HEB	RCMA(A/C)	TA No. 794	31/12/12	10.3.4
36.	25 Ah , 24 V, Nickel Cadmium Battery FTNC 0202 (Vented)	IL 76	HEB	RCMA(A/C)	TA No. 795	31/12/12	10.3.7

Sl. No.	Battery Title	Aircraft / End use	Manufacturer	Certification Agency	Certification Status	Approval Validity	Chapter Ref for technical aspects/ remarks
37.	25 Ah, 24 V Nickel Cadmium Battery FTNC 0156 Battery Part No. MI-8/NIV (Vented)	MI 8 / MI 17	HEB	RCMA(CHD)	TA No. 1039	31/12/08	10.3.10
38.	18 Ah, 24 V Nickel Cadmium Battery Type No. FTNC 0160& Cell type FTNC 18 (Vented)	SEA HARRIER	HEB	RCMA(A/C)	TA No. 1123	30/06/10	10.3.5
39.	25 Ah , 24 V Nickel Cadmium Battery Type FTNC 0155 (Vented)	SU 30	HEB	RCMA(NK)	TA No. 1241	31/12/11	10.3.7
40.	25 Ah, 24 V Nickel Cadmium Battery Type FTNC 0184 (AN-32 / NIV) (Vented)	AN 32	HEB	RCMA(CHD)	TA No. 1281	30/06/12	10.3.8
41.	23 Ah, 24 V Nickel Cadmium Battery 1.2V, 23 Ah Nickel Cadmium Cells FTNC 23 (Vented)	HS-748 (AVRO)	HEB	RCMA(A/C)	Provisional Clearance	NIL	10.3.6
42.	16Ah, 24V, Nickel Cadmium Battery NC 250 (Vented)	HPT-32	HEB	RCMA(KN)	Provisional Clearance	08/04/08 (applied for regular TA)	10.3.9
43.	27 Ah , 24 V Nickel Cadmium Battery Type No. NC252 & Cell type NC 27 (Vented)	DORNIER (DO-228)	HEB	RCMA(Hyd)	QT Completed. Ground & Flight trials completed.	To be applied for PC	10.3.13

Sl. No.	Battery Title	Aircraft / End use	Manufacturer	Certification Agency	Certification Status	Approval Validity	Chapter Ref for technical aspects/ remarks
44.	30 Ah , 24 V, Nickel Cadmium Battery Type No. NC253 & Cell type NC 30 (Vented)	ALH	HEB	RCMA(H/C)	QT under progress. Ground trials completed.		10.3.14
45.	27Ah, 24 V, (MOD-1X) Nickel Cadmium Battery Type No. NC & Cell type NC27M (Vented)	MIG-21	HEB	RCMA,(Hyd)	QT under progress.		Under development
46.	iii) 15AH, 24V, Ni-Cd battery iv) 4.4AH, 28V, Ni-Cd battery (Vented)	Hearon & Searcher UAV for Navy	HEB	RCMA,(Hyd)	Two prototypes of 15 AH,&4.4AH Ni-Cd battery		i) Under development ii) Deferred
47.	45AH, 22.5V Silver Oxide Zinc (Vented)	MIG-21 aircraft	HAL	RCMA(Hyd)	TA No. 900	31/12/08	11.1.3
48.	45AH, 22.5V Silver Oxide Zinc battery (Vented)	LCA aircraft	HAL	RCMA(A/C)	TD-2 & PV series of aircrafts Cleared		11.1.4
49.	28AH, 24V Lead Acid Battery Type 12 CAM 28 MTE	MI-8 & MI-17 helicopter	Mysore Thermo Electric (P) Ltd	RCMA(A/C)	TA No. 1112	31/12/09	11.2.1

9 Aviation Batteries From M/s.HBL Power Systems Ltd, Hyderabad

Introduction

M/s.HBL Power Systems Ltd , is one of the market leader in the indigenous design, development and production of aviation batteries. This chapter gives details of the batteries supplied by HBL. Company profile and their product list given in section 9.1. in section9.2 & 9.3 discussed about battery brief technical specification of various aircraft batteries supplied to MOD including Thermal batteries for missile applications. Section 0 described typical Ni-Cd cells with physical dimensional aspects. The data presented in this section considered up to December-2008 by the OEM.

9.1 Company Profile of M/s.HBL Power Systems Ltd., Hyderabad

Name	M/s.HBL Power Systems Ltd.,
Address & Tel	**M/s.HBL Power Systems Ltd., Lalgadi, Malakpet, Shaameerpet Mandal, R.R.District, Hyderabad – 500 078 Tel.No.91-8418-244640, Fax No.91-8418-244574, 244627 e-mail : contact@hbl.in**
ISO 9000 Status Accreditation Body : Certificate Ref :	**ISO 9001 : 2000 for NCSP 205408 dt.02/3/2007 Validity 11/12/2009 Issued by : Bureau Veritas Certification (India) Pvt. Ltd.,**
Test laboratory address	**Central test facility at M/S HBL power system .ltd Hyderabad.**

HBL was incorporated in 1977 and registered as a Research and Development company. One of the first products commercialized in 1980, based on indigenous technology was nickel cadmium aircraft battery.

Today, HBL is a leading company engaged in the manufacture of specialized batteries and DC power systems with an experience of almost three decades. The main focus of the business is on the Aviation, Defence, Communication, Industry and the Railway sectors.

HBL is based at Hyderabad, India. Its resources include a dedicated team of qualified personnel including Doctorates, Engineers and Graduates and a wide sales and service network covering all major cities and towns in the country. The company also has marketing offices and sales agents in other countries as well.

HBL has the unique distinction of being the only company in the world to have expertise in all the major battery technologies including:

Nickel Cadmium (pocket plate, fiber plate, sintered plate and sintered plate plastic bonded) Silver Zinc (primary and secondary) Lead Acid (VRLA, pure lead, tubular gel, low maintenance tubular) Lithium Thionyl chloride, Thermal batteries.

HBL has a Quality Management System complying with ISO 9001:2000.

9.1.1 Product Range – Aircraft Batteries and Cells from M/s.HBL, Hyderabad

Given below is the range of nickel cadmium aviation cells and batteries offered to the Indian Defence Services and for other Defence customers abroad.

Sl. No.	Cell Type	Cell Capacity (Ah)	Battery Type
1	NCSP-C-3.5-60	3.5	24-NCS-B-3.5-60
2	NCSP-C-16060	16	NCSP-B-16060
3	NCSP-C-18060	18	NCSP-B-18060A NCSP-B-18060B
4	NCSP-C-23060RM	23	NCSP-B-23060
5	NCSP-C-25150RM	25	NCSP-B-25150 NCSP-B-25150AN NCSP-B-25150MI
6	NCSP-C-27060	27	NCSP-B-27060
7	NCSP-C-27060 MRM	27	NCSP-B-27060 MRM
8	NCSP-C-30060 RM	30	NCSP-B-30060 RM
9	NCSP-C-40060RM	40	NCSP-B-40060A NCSP-B-40060B

Given below is the list of other batteries/cells supplied by M/s HBL

Sl. No.	Cell Type	Cell Capacity (Ah)	Battery Type
1	Silver Zinc battery	45	HBL-SZ-45AH
2	SLA battery(VRLA)	28	SS28300MI
Lithium based batteries			
1	Lithium thionyl chloride Sub-C	2.5	PRB 4/10 & 4/27
2	AA	3	PRIBOY-PZ
3	Thermal batteries (Lithium type)	336W, 145W, 364W, 280W	LTB-1, LTB-2, LTB-3, LTB-4

Other products supplied to MOD from M/s.HBL HYDERABAD

9.1.2 Product name

- Silver Oxide Zinc batteries for Aircraft, and Missiles
- Nickel Cadmium batteries for military and civil aircraft
- Pure Lead batteries for Battle Tanks, APCs and Aircraft
- Lithium Thionyl Chloride batteries for radio sets, naval mines sonobuoys etc
- Thermal batteries for missiles, decoys, torpedoes and mines
- Large lead acid batteries for Submarines (under approval)
- Battery monitoring systems for Onboard Submarine batteries
- Valve regulated led acid batteries for UPS, Telecom services, Railways
- Large Industrial nickel cadmium batteries for Refineries, offshore platforms, nuclear power stations and large industrial applications.
- UAV batteries for Searcher and Heron Aircrafts.

9.2 Technical Specifications for A/c Batteries from M/s.HBL Power Systems Ltd

9.2.1 40AH, 24V, Ni-Cd Battery for Jaguar Aircraft & Cheeta, Chetak Helicopters

9.2.1.1 Salient Features

Type of Battery	NICKEL CADMIUM BATTERY TYPE i) NCSPB 40060A with Cell part No. NCSPC 40060-4 ii) NCSPB 40060 A RM Cell part No. NCSPC 40060RM
Technology developers and Coordinated RCMA	M/s HBL, Hyderabad RCMA(HD)
Nominal voltage & Capacity	24V & 40AH
End use	Jaguar, Mirage Aircraft Cheetah, Chetak Helicopters
Battery Dimensions & Weight	361 X168 X265 mm & 36.4 Kgs.
Type Approval No. & Validity	i) CEMILAC TA No.1033 validity up to 30-06-2009 ii) Si/PBE design modified and PC issued vide RCMA(HD)/767/1/40AH/NI-CD dated 29/01/2008.PC No.149 for NCSPB -40060ARM
Technical Specification	i) QTP Reference No.: HNPS/TA/QTP/40AH/A&B/2003 Issue No.I Dt. Oct. 2003 for Type NCSPB 40060A and ii) limited QTP document No.HBL/TA/QTP/Si/PBE/40 AH/2007, Issue-II Oct.07 for Type NCSPB 40060A RM iii) JSS:6140-10:2007 for NI-CD batteries
Manufacturing & Qulity Assurance Plan	i) HBL/NCSS/PP/006 Feb.2000 ii) HBL/NC/PS/PBE/07 Jan.2007

Note: Same type of cells of 1.2V, 40AH Ni-Cd, was cleared for Sea King MK42BC H/C vide Ltr.No.RCMA(H/C)/1342/2 dated 16/7/2004

9.2.2 40AH, 24V, Ni-Cd Battery for KIRAN MK-II Aircraft

9.2.2.1 Salient Features

Type of Battery	NICKEL CADMIUM BATTERYTYPE: i) NCSPB 40060B with Cell part No. NCSPC 40060-4 ii) NCSPB 40060B RM with Cell part No. NCSPC 40060RM
Technology developers and Coordinated RCMA	M/s HBL, Hyderabad RCMA (HD)
Nominal voltage & Capacity	24V & 40AH
End use	Kiran MK-II Aircraft
Battery Dimensions & Weight	361 X168 X265 mm & 36.1 Kg.
Type Approval No. & Validity	i) CEMILAC TA No.1033 validity up to 30-06-2009 ii) Si/PBE design modified and PC issued vide RCMA(HD)/767/1/40AH/NI-CD dated 29/01/2008.PC No.149 for NCSPB -40060 B RM
Technical Specification	i) QTP Reference No.: HNPS/TA/QTP/ 40AH/A&B/2003 Issue No.I Dt. Oct. 2003 for Type NCSPB 40060B and ii) limited QTP document No.HBL/TA/QTP/Si/PBE/ 40AH/2007, Issue-II Oct.2007 for Type NCSPB 40060B RM iii) JSS:6140-10:2007 for NI-CD batteries
Manufacturing & Quality Assurance Plan	i) HBL/NCSS/PP/006 Feb.2000 ii) HBL/NC/PS/PBE/07 Jan.2007

9.2.2.2 Cell Details

	Cell Parameter	**Requirements**
1.	a). Type of cell b). Nominal Voltage & Capacity	NCSPC40060-4 (Vented Ni-Cd) **or** NCSPC40060 RM 1.2V, 40Ah
2.	OCV of Charged cell	1.25V Min.
3.	Physical dimensions & Weight	Height up to terminal top: 236.0 +0.5mm -1.5 mm Height up to cell lid top : 219.0 -1.0mm Width : 79.0 ±0.5mm Thickness : 34.5 ±0.5mm Torque requirement : Bottom Nut : 5 Nm Top Nut : 11 Nm Cell Drawing No. : HBL 40K 6001 3A Weight : 1.50 Kg Max.
4.	Type of sealing for Container & Lid	Thermal Welding
5.	Electrolyte	Solution of KOH 30 to 35%Concentration.
6.	Cell container material	Nylon-11
7.	Identification of Polarity	'+' Embossing provided on the cell lid. Red and black indication washers provided on the cell '+' & '- 'terminals. '+' & ' - ' Marked on the cell against the respective terminal by Screen-printing.
8.	Efficiency of sealing	Each cell checked for leak at a pressure of 14Kpa for 15 seconds and there shall not be any leak.
9.	Cell vent valve	Made of stainless steel with hollow center post covered with rubber sleeve to operate as a Bunsen valve at pressure of 0.2 to 0.6Kg/Cm^2
10.	Separator Systems	Polyamide (Non-Woven) – One layer Polyamide (Woven) – One layer Gas Barrier : Celgard – 3400
11.	No of electrodes (or Plates)Design	+ve plates (17 Nos.) are sintered & -ve (18 Nos.) are plastic bonded type for RM Design

9.2.2.3 Battery Overall Physical Dimensional details

Battery type & aircraft use	Dimensions & weight	Main power, receptacle arrangement with	Type of container used	Battery pack with cell type details	Battery assembly drawing No
NCSPB 40060 A for Cheetah, Chetak, Jaguar & Mirage-2000 aircraft	Overall Length: 409 +3 -1 mm(Top) Width: 206.0 mm Height: 265 ±1mm Weight: 36.4 Kgs.	Connector type BAC – 102 + & - ve markings are embossed on battery container	Stainless steel with sand blasted finish.	20 cells in series arrangement (Cell type NCSPC-40060-4)	401 1000 2 B
NCSPB 40060 B for Kiran MK-II aircraft.	Over all Length: 409 +3 -1 mm(Top) Width: 208.0 mm Height: 265±1mm Weight: 36.1 Kgs.	Connector type MIL-E-81099 A Part No.7002 'PENNA' + & -ve markings are embossed on battery container	Stainless steel with sand blasted finish.	20 cells in series arrangement (Cell type NCSPC-40060-4)	402 1000 2 B

9.2.2.4 Battery Electrical & environmental test general requirements:

Sl No	Battery Parameter	Requirement
1	a) Open circuit voltage of fully charged battery	25.0 Volts Minimum
	b). Nominal voltage	24.0 Volts (for 20 cells connected in series, replaceable)
	c)Nominal Capacity	40AH, with a load discharge of 40 Amp. Continuously for a period of 60 minutes to a cutoff voltage of 20V
2	Aerobatic or Non aerobatic cut off voltage of 20.0 Volts)	Aerobatic
3	Un spill ability test	Fully charged battery shall be CP charged for a period of 2 hours prior to the test and CP charge shall continue during the test. Battery shall be securely mounted on to a platform capable of being rotated about its horizontal axis. The platform and the battery shall be rotated ten times with a pause of 30 seconds after each half revolution. The speed of rotation shall be equivalent to one revolution per 5 seconds. The test shall be repeated with the minor length of the battery also, centralized over the axis of rotation. There shall be no spillage of electrolyte from the battery and the battery shall satisfy the insulation resistance value.
4	Insulation Resistance	Shall be greater than 15K Ω before cleaning and 10M Ω after cleaning.
5	Internal Resistance	Shall be At 25°C – 11 m Ω At -10°C – 15 m Ω At -26°C – 21 m Ω
6	Dielectric Strength	A potential of 1500 V_{rms} commercial frequency shall be applied between current carrying parts and the container for a duration of 1 minute. There shall be no chattering or breakdown of insulation during the test.
7	Charge retention	Fully charged battery after standing on open circuit for 28days, capacity shall not be less than 75% of rated capacity at $1C_1$ rate.

8	General Environmental Test a. Humidity & Charge Retention Test b. Mechanical shock test (Basic Design) c. Vibration Test d. Temperature shock Test e. Altitude Test f. Salt Fog Test g. 20 Sec. pulse discharge Test h. Medium rate discharge operation position Test i. Cycling Test j. Temperature rise and float Test k. Physical integrity Temperature ($85^{\circ C}$) l. Gas barrier Material Test m. Storage Test n. Shelf life Test o. Main battery receptacle or electric plug Test p. Temperature sensor Thermo switches (if) applicable for battery q. User Trials Above tests shall be followed from JSS 6140-10:2007 of Nickel Cadmium for aviation use

9.2.2.5 Baseline Parameters

Typical Discharges:

Battery service life with different rate of discharge on fully charged batteries. Following minimum capacities shall be available at the two temperatures as given in the table below.

Discharge Rate	**Discharge Time (minimum)**	
	At RT(+25°C)	At – 30° C
$1C_1$ (40amps)	60 min (cut off voltage 20V)	46 min (cut off voltage 20V)
$5C_1$ (200amps)	10.5 min (cut off voltage 16V)	7.4 min (cut off voltage 14V)
$10C_1$(400amps)	4.8 min (cut off voltage 16V)	1.2 min (cut off voltage 14V)
$15C_1$(600amps)	2.2 min (cut off voltage of 16V)	0.5 min (cut off voltage of 14V)
$30C_1$(1200amps)	1.0 min (cut off voltage of 10V)	------

Instantaneous Power & Maximum Power Delivery Test :

Power behaviour under 25°C and – 30°C test conditions, the currents ensuring while discharge from fully charged state at half the OCV (ocv/2 = 13.5V constant) for 15 seconds in above temperature conditions are to be evaluated. From the discharged current and battery voltage, power calculation and internal resistance values are derived. The battery shall meet the requirements as given in the table below. The internal resistance values given in the table below are the maximum values for the battery. Lower the value, it is better for the battery.

Temperature	Peak Power at 1 Sec (approx. 300 milli seconds) Instantaneous Peak values			Power rating at 15 seconds Steady state values		
	I_i(min)	P_i(min)	r_i(max)	I_{mp}(min)	P_m(min)	r_{em}(max)
At 25°C	1125A	15KW	12mΩ	800A	11KW	17mΩ
At-30°C	525A	07KW	25mΩ	375A	5.0KW	36mΩ

Constant voltage at 14V discharge test :

The test shall be carried out after CP charge (28.5V) battery shall be subjected to a constant voltage discharge at 14V for 60 seconds at 24 ±2°C and – 26 ±2°C. The discharge current at 1.0, 5.0, 15.0 and 60.0 seconds after the start of discharge shall be as per the specified values given below :

Temperature	Currents at			
	1 second	5 second	15 second	Average current over the total 60 seconds
24 ±2°C	1250 amps	1125 amps	1000 amps	950 amps
– 26 ±2°C	600 amps	525 amps	500 amps	500 amps

Individual aircraft load profile : Engine Starting Cycles & Emergency Loads

In field use, these batteries are considered for its service life up to 85% of it's rated capacity. To confirm the battery performance, the individual a/c requirements like engine starting cycles and emergency load checks of the a/c are considered for evaluation. The battery 24V, 40AH is used on Jaguar, Mirage and Kiran MK-II aircraft and their engine starting is by pneumatic/gas starter and no electrical starter generator is used. Hence no starting cycle is defined. However emergency loads for the following aircraft are given below:

Jaguar Aircraft : 82 amps for 25 minutes to cut off voltage of 20 volts
Mirage 2000Aircraft : 77 amps for 25 minutes to cut off voltage of 20 volts
Kiran MkII Aircraft : 45 amps for 25 minutes to cut off voltage of 20 volts

Cheetah/Chetak H/C : 35 amps for 53 minutes to cut off voltage of 20 volts

Requirements for Chetak, Cheetah Helicopters: The engine starting profile data is not available. However, following profile for engine starting may be verified with 3 min interval between two starts.

0-1 sec : 650 amps
5 sec : 510 amps
10 sec : 400 amps
15 sec : 315 amps
20 sec : 250 amps
25 sec : 200 amps
30 sec : 150 amps
35 sec : 125 amps
40 sec : 100 amps
45 sec : 75 amps

9.2.3 25AH, 24V, Ni-Cd battery for IL-76 & SU-30 Aircrafts

9.2.3.1 Salient Features

Type of Battery	NICKEL CADMIUM BATTERY TYPE: i) NCSPB 25150 with Cell part No. NCSPC 25150-4 ii) NCSPB 25150 RM with Cell part No. NCSPC 25150RM
Technology developers and	M/s HBL, Hyderabad
Coordinated RCMA	RCMA (HD)
Nominal voltage & Capacity	24V & 25AH
End use	IL-76 & SU-30 Aircraft
Battery Dimensions & Weight	363 X196 X226 mm & 25 Kgs.
Type Approval No. & Validity	i) CEMILAC TA No1048. Validity up to 31-12-08 ii) for Si / Pbe design modified and issued PC No.150 vide RCMA(HD) /767/1/25AH/NI-CD Dated 06-02-2008 for NCSPB 25150 RM
Technical Specification	i) QTP Reference No. :HNPS/TA/QTP/25AH/IL-76/2003 Issue No.I Dt. Jul. 2003 and ii) Limited QTP Doc.No.HBL/TA/QTP/ Si/PBE/25AH / 2007, Issue-I, Oct.2007 iii) JSS:6140-10:2007 for NI-CD batteries
Manufacturing & Quality Assurance Plan	i) HBL/NCSS/PP/006 Feb.2000 ii) HBL/NC/PS/PBE/07 Jan.2007

Note:

The same battery is cleared for KA-31 H/C vide Ltr.No.RCMA(H/C)/1341/2 dated 15/9/06

The same battery is cleared for KA-28 H/C vide Ltr.No.RCMA(H/C)/1341/2 dated 18/3/04

The same battery is cleared for IL-38 Aircraft vide Ltr.No.CRE(A/C)/HAL-BC/527/11 dt 01/4/93

The same battery is cleared for TU-142 Aircraft vide Ltr.No.CRE(A/C)/HAL-BC/527/11 dt 01/4/93

9.2.3.2 Cell Details for IL-76 & Su-30

	Cell Parameter	Requirements
1.	a). Type of cell b). Nominal Voltage & Capacity	NCSPC 25150-4 (Vented type Ni-Cd) **or** NCSPC 25150 RM 1.2V, 25Ah
2.	OCV of Charged cell	1.25V Min.
3.	Physical dimensions & Weight	Height up to terminal top: 211.0 ±1.0mm Height up to cell lid top : 197.5 ±1.0mm Width : 81.0 ±0.5mm Thickness : 27.5 ±0.5mm Torque requirements : Bottom nut : 5 Nm Top nut : 11 Nm Weight : 950 ±30gr
4.	Type of sealing for Container & Lid	Thermal Welding
5.	Electrolyte	Solution of KOH 30 to 35%Concentration.
6.	Cell container material	Nylon-11
7.	Identification of Polarity	‘+’ Embossing provided on the lid. ‘+’ & ‘-’ Marked on the cell against the respective terminal by Screen-printing.
8.	Efficiency of sealing	Each cell checked for leak at a pressure of 14Kpa for 15 seconds and there shall not be any leak.
9.	Cell vent valve	Made of stainless steel with hollow center post covered with rubber sleeve to operate as a Bunsen valve at pressure of 0.2 to 0.6Kg/Cm^2
10.	Separator systems	Polyamide (Non-Woven) – One layer Gas Barrier – One layer of Celgard-3400 Polyamide (Woven) – One layer
11.	No of electrodes (or Plates) Design	+ve plates (13 Nos.) are with sintered & -ve plates (14 Nos.) are plastic bonded electrodes for RM Design

9.2.3.3 Battery Electrical & Environmental test requirements for IL-76

	Battery Parameter	Requirement
1.	a) Type of battery b) Drg. No c) Nominal voltage	NCSPB 25150 **or** NCSPB 25150 RM 251 1000 2D **or** 251 1000 2A 24Volts (for 20cells connected in series, replaceable)
2.	OCV of charged battery	25V Minimum
3.	Nominal capacity at 1 hour rate a) Number of cell b) Type of connector	25Ah (at cut off voltage of 20V, 60minutes discharge time with 25Amps.load) 20 cells connected in series replaceable Two pin connector (Imported) Part No.PWA-1(RSCh A-1)
4.	Polarity Identification	'+' Marking is embossed on the connector block. Red and black indication washers provided on the cell positive and negative terminals. Battery and lid are identified with labels as per Drg. No.251 1006 4A & 251 1007 4A respectively
5.	Weight	25.0Kg
6.	Dimensions	As per drg.No.251 1000 2A Length 363 ±1.0 mm Width 174.0 -1.0 mm Height 226.0 ±1.0 mm
7.	Battery container	Made of stainless steel with sand blasted finish.
8.	General Environmental Test	
	a. Humidity & Charge Retention Test b. Mechanical shock test (Basic Design) c. Vibration Test d. Temperature shock Test e. Altitude Test f. Salt Fog Test g. 20 Sec. pulse discharge Test h. Medium rate discharge operation position Test i. Cycling Test j. Temperature rise and float Test k. Physical integrity Temperature ($85^{\circ C}$) l. Gas barrier Material Test m. Storage Test n. Shelf life Test o. Main battery receptacle or electric plug Test	

p. Temperature sensor Thermo switches (if) applicable for battery

q. User Trials

Above tests shall be followed from JSS 6140-10:2007 of Nickel Cadmium for aviation use

9.2.3.4 Base Line Parameters for IL-76 & Su-30

Battery service life with different rate of discharge on fully charged batteries. Following minimum capacities shall be available at the two temperatures as given in the table below.

Discharge Rate	**Discharge Time (minimum)**	
	At RT(+25°C)	At – 30° C
$1C_1$ (25amps)	60 min (cut off voltage 20V)	46 min (cut off voltage 20V)
$5C_1$ (125amps)	10.5 min (cut off voltage 16V)	7.4 min (cut off voltage 14V)
$10C_1$(250amps)	4.8 min (cut off voltage 16V)	1.2 min (cut off voltage 14V)
$15C_1$(375amps)	2.2 min (cut off voltage of 16V)	0.5 min (cut off voltage of 14V)
$30C_1$(750amps)	1.0 min (cut off voltage of 10V)	------

Instantaneous Power & Maximum Power Delivery Test :

Power behaviour under 25°C and – 30°C test conditions, the currents ensuring while discharge from fully charged state at half the OCV (OCV/2 = 12V constant) for 15 seconds in above temperature conditions are to be evaluated. From the discharged current and battery voltage, power calculation and internal resistance values are derived. The battery shall meet the requirements as given in the table below. The internal resistance values given in the table below are the maximum values for the battery. Lower the value, it is better for the battery.

Temperature	Peak Power at 1 Sec (approx. 300 milli seconds) Instantaneous Peak values			Power rating at 15 seconds Steady state values		
	I_i(min)	P_i(min)	r_i(max)	I_{mp}(min)	P_m(min)	r_{em}(max)
At 25°C	900A	12KW	15mΩ	650A	8.5KW	21mΩ
At-30°C	400A	5.5KW	33mΩ	250A	3.5KW	53mΩ

Constant voltage at 14V discharge test :

The test shall be carried out after CP charge (28.5V) battery shall be subjected to a constant voltage discharge at 14V for 60 seconds at 24 ± 2°C and – 26 ± 2°C. The discharge current at 1.0, 5.0, 15.0 and 60.0 seconds after the start of discharge shall be as per the specified values given below :

Temperature	Currents at

	1 second	5 second	15 second	Average current over the total 60 seconds
24 ±2°C	925 amps	825 amps	700 amps	650 amps
– 26 ±2°C	450 amps	350 amps	350 amps	350 amps

Engine Cranking Test for IL-76 Aircraft

On each battery, the variation of the current magnitude with respect to time under the starting discharge condition is presented in fig. 1of SK No.14/9 starting with max. discharge currents are given below :

650 amps – 1 second

520 amps – 4 seconds

420 amps – 5 seconds

380 amps – 5 seconds

300 amps – 5 seconds

220 amps – 5 seconds

180 amps – 5 seconds

110 amps – 5 seconds

90 amps - 5 seconds

75 amps - 5 seconds

The battery shall give minimum of five starts with 3 minutes interval between starts and the voltage at the end of 5th start shall not be less than 18 volts.

(a) During the first year

i) Five starting under normal climatic conditions with time pause in between the starts of 3 minutes, the battery voltage at the end of fifth start should at least be 16.0 Volts.

ii) Three starting at electrolyte temp. of -5°C.

(b) During the subsequent period of service, the number of starting is one less than the number indicated under (i) above.

For emergency load in IL-76 Aircraft

For emergency load on single battery with 85% SOC, an average load of 52A to a cut off voltage of 20 volts shall be applied and the duration obtained shall not be less than 24 minutes.

9.2.3.5 Battery Electrical & Environmental test requirements for SU-30

Sl. No.	Battery Parameter	Requirement
1.	a) Type of battery b) Drg. No c) Nominal voltage	NCSPB 25150 or NCSPB 25150RM 251 1000 2D or 251 10002A 24Volts (for 20 cells connected in series, replaceable)
2.	OCV of charged battery	25V Minimum
3.	Nominal capacity at 1 hour rate a) Number of cells b) Type of connector	25Ah (at cut off voltage of 20V, 60minutes discharge time with 25Amps.load) 20 Nos in series Two pin connector (Imported) Part No. PWA-1(RSCh A-1)
4.	Physical examination including std of preparation & production acceptance tests.	The physical condition, construction and workmanship of the batteries shall be satisfactory and they shall conform to the standards laid down in MDI and acceptance tests as per normal procedure.
5.	Weight	25.0Kg.
6.	Dimensions	As per drg.No.251 1000 2A Length 363 ± 1.0 mm Width 174.0 ± 1.0 mm Height 226.0 ± 1.0 mm
7.	Battery container	Made of stainless steel with sand blasted finish.
8.	Nominal capacity at 2½ hour rate.	The duration of discharge at 10 Amps. to an end voltage of 20V of the battery, prepared and charged as per manufacturer's instructions, shall not less than 150 minutes.
9.	Polarity & Identification	'+' Marking is embossed on the connector block. Red and black indication washers provided on the cell positive and negative terminals. Battery and lid are identified with labels as per Drawing No. 251 1006 4A & 251 1007 4A respectively.
10.	General Environmental Test	
	a. Humidity & Charge Retention Test b. Mechanical shock test (Basic Design) c. Vibration Test d. Temperature shock Test	

	e. Altitude Test f. Salt Fog Test g. 20 Sec. pulse discharge Test h. Medium rate discharge operation position Test i. Cycling Test j. Temperature rise and float Test k. Physical integrity Temperature (85$^{\circ C}$) l. Gas barrier Material Test m. Storage Test n. Shelf life Test o. Main battery receptacle or electric plug Test p. Temperature sensor Thermo switches (if) applicable for battery q. User Trials Above tests shall be followed from JSS 6140-10:2007 of Nickel Cadmium for aviation use

Important Test Details

Vibration Test shall be carried out on the battery for

(i) Resonance Search and
(ii) Standard Endurance

(i) Resonance Search

If resonance is observed at any particular frequency in any direction the battery shall be vibrated for a period of 1 hour at each fundamental resonant frequency in the appropriate axis and observe the general requirements etc., like interruption of output voltage & current during above vibration tests from the battery with 0.1C rate discharge.

Sl. No.	Frequency	Acceleration / Amplitude	Duration/ Axis	Axis
a)	5 to 10 Hz	2.5 mm constant amplitude	----	Vertical, Lateral and Longitudinal
b)	10 to 300 Hz	5.0 ‘g’ (constant g)	----	---------do-----------
c)	300 to 1000 Hz	2.0 ‘g’ (constant g)	----	---------do-----------

Sweep Rate: 0.1 octaves per minute, 1 sweep for each frequency range

(ii) Standard Endurance Test

With fully charge battery the following vibration endurance may be carried out while observing the general requirements like output voltage/current from the battery with 0.1C rate discharge.

Sl. No.	Frequency	Acceleration / Amplitude	Duration/ Axis	Axis
a)	5 to 10 Hz	2.5 mm constant amplitude	60 minutes	Vertical, Lateral and Longitudinal
b)	10 to 300 Hz	5.0 ‘g’ (constant g)	60 minutes	---------do-----------
c)	300 to 1000 Hz	2.0 ‘g’ (constant g)	60 minutes	---------do-----------

Sweep Rate: Less than 1 octave per minute.

Acceleration test

A charged battery shall be secured by its normal method of mounting to a suitable fixture, which in turn is securely fixed to the centrifuge.

The batteries shall be tested in all three directions at an acceleration of 98 m/s^2 (10g) Maximum, in the direction “Lid-bottom” acceleration conditions shall be as follows and shall be applied in each case for not less than 1 minute.

During test, the battery shall be discharged at 0.1C$_1$ rate and the battery voltage and current shall be continuously recorded. There shall be no interruption of output and no abnormal variation of voltage or current. On completion of testing there shall be no apparent damage to the battery or leakage of electrolyte from the battery.

On completion of testing the battery may exhibit damage but shall not have broken loose from its mountings nor have ignited.

Altitude test

The battery shall be designed for operation, at a low atmospheric pressure of 666.5 Pa (5mm of Hg) and the variation of the altitude of 26 Km/min. A fully charged battery shall be placed in altitude chamber and the chamber pressure shall be reduced to a pressure equivalent to 666.5 Pa (5mm of Hg) (maximum possible).

The battery shall then be discharged at 1C$_1$ rate to an end voltage of 1.0V per cell. The duration of discharge obtained shall not be less than 54 minutes. After completion of the test, the battery from the chamber shall be examined for any spillage of electrolyte. The battery is again placed in the chamber in discharged condition; the pressure adjusted corresponding to 5mm of Hg at the rate of 20 Km/min (maximum possible).

The battery is charged with Constant Potential of 1.425 ± 0.01V per cell. The constant potential supply shall have a current rating of more than 8C$_1$A. The charging of the battery is continued till the charging current becomes less than 3A. Release the altitude to bring to normal pressure. The battery is removed from the chamber and examined for any spillage of electrolyte.

9.2.4 25AH, 24V, Ni-Cd battery for AN-32 Aircraft

9.2.4.1 Salient Features

Type of Battery	NICKEL CADMIUM BATTERY TYPE: i) NCSPB 25150 AN with Cell part No. NCSPC25150-4 ii) NCSPB 25150 AN RM with Cell part No. NCSPC 25150RM
Technology developers and	M/s HBL, Hyderabad
Coordinated RCMA	RCMA (HD)
Nominal voltage & Capacity	24V & 25AH
End use	AN-32 Aircraft
Battery Dimensions Weight	411 X175 X222 mm & 28 Kgs.
Type Approval No. & Validity	i) CEMILAC TA No1049. Validity up to 31-12-2008 ii) for Si / Pbe design modified and issued PC No.150 vide RCMA(HD) /767/1/25AH/NI-CD Dated 06-02-2008 for NCSPB 25150 AN RM
Technical Specification	i) QTP Reference No.: HNPS/TA/QTP /25AH/AN/2003 Issue No.I, Dt. Aug. 2003 ii) Limited QTP Doc.No.HBL/TA/QTP/Si/PBE/25AH/ 2007, Issue-I, Oct.2007 iii) JSS:6140-10:2007 for NI-CD batteries
Manufacturing & Quality Assurance Plan	i) HBL/NCSS/PP/006 Feb.2000 ii) HBL/NC/PS/PBE/07 Jan.2007

9.2.4.2 Cell Details

Sl.No	Cell Parameter	Requirements
1.	a). Type of cell b). Nominal Voltage & Capacity	NCSPC 25150-4 (Vented type, Ni-Cd) or NCSPC 25150 RM 1.2V, 25Ah
2.	OCV of Charged cell	1.25V Min.
3.	Physical dimensions & Weight	Height up to terminal top: 211.0 ±1.0mm Height up to cell lid top : 197.5 ±1.0mm Width : 81.0 ±0.5mm Thickness : 27.5 ±0.5mm Torque requirement : Bottom nut : 5Nm Top nut : 11Nm Weight : 1050 ±30 grams
4.	Type of sealing for Container & Lid	Thermal Welding
5.	Electrolyte	Solution of KOH 30 to 35%Concentration.
6.	Cell container material	Zytel 151L
7.	Identification of Polarity	'+' Embossing provided on the cell lid. Red and black indication washers provided on the cell '+' & '-' terminals. '+' & ' - ' Marked on the cell against the respective terminal by Screen-printing.
8.	Efficiency of sealing	Each cell checked for leak at a pressure of 14Kpa for 15 seconds and there shall not be any leak.
9.	Cell vent valve	Made of stainless steel with hollow center post covered with rubber sleeve to operate as a Bunsen valve at pressure of 0.2 to 0.6Kg/Cm^2
10.	Separator systems	Polyamide (Non-Woven) – One layer Gas Barrier – One layer of Celgard-3400 Polyamide (Woven) – One layer
11.	No of electrodes (or Plates)Design	+ve plates (13 Nos.) are with sintered & -ve plates (14 Nos.) are plastic bonded electrodes for RM design

9.2.4.3 Battery Electrical & Environmental Test Requirements

Test	Battery Parameter	Requirement
1.	a) Type of battery b) Drawing. No c) Nominal voltage	NCSPB 25150 AN or NCSPB 25150 AN RM 253 1000 2B or 251 1000 2A 24Volts
2.	OCV of charged battery	25V Minimum
3.	Nominal capacity at 1 hour rate a) Number of cell b) Type of connector	25Ah (at cut off voltage of 20V, 60minutes discharge time with 25Amps.load) 20 connected in series , replaceable) Two pin connector (indigenous approved) Drg.No.253 3001 3A
4.	Polarity Identification	'+' & '-' Markings are embossed on the connector block.
5.	Weight	28.0Kg
6.	Dimensions	As per drg.No.253 1000 2A Length 444.0 ±1.0 mm Width 175.0 ±0.5 mm (top) Width 170.0 ±1.0 mm Height 232.0 ±1.0 mm
7.	Battery container	Made of stainless steel with sand blasted finish.

8. General Environmental Test
    - a. Humidity & Charge Retention Test
    - b. Mechanical shock test (Basic Design)
    - c. Vibration Test
    - d. Temperature shock Test
    - e. Altitude Test
    - f. Salt Fog Test
    - g. 20 Sec. pulse discharge Test
    - h. Medium rate discharge operation position Test
    - i. Cycling Test
    - j. Temperature rise and float Test
    - k. Physical integrity Temperature (85°C)

l. Gas barrier Material Test
m. Storage Test
n. Shelf life Test
o. Main battery receptacle or electric plug Test
p. Temperature sensor Thermo switches (if) applicable for battery
q. User Trials

Above tests shall be followed from JSS 6140-10:2007 of Nickel Cadmium for aviation use

9.2.4.4 Base Line Parameters for 25 AH Ni-Cd Battery: Si/pbe (with plastic bonded electrodes)

Typical Discharges:

Battery service life with different rate of discharge on fully charged batteries. Following minimum capacities shall be available at the two temperatures as given in the table below.

Discharge Rate	**Discharge Time (minimum)**	
	At RT(+25°C)	**At – 30° C**
1C1 (25amps)	60 min (cut off voltage 20V)	46 min (cut off voltage 20V)
5C1 (125amps)	10.5 min (cut off voltage 16V)	7.4 min (cut off voltage 14V)
10C1(250amps)	4.8 min (cut off voltage 16V)	1.2 min (cut off voltage 14V)
15C1(375amps)	2.2 min (cut off voltage of 16V)	0.5 min (cut off voltage of 14V)
30C1(750amps)	1.0 min (cut off voltage of 10V)	------

Instantaneous Power & Maximum Power Delivery Test:

Power behavior under 25°C and – 30°C test conditions, the currents ensuring while discharge from fully charged state at half the OCV (OCV/2 = 12V constant) for 15 seconds in above temperature conditions are to be evaluated. From the discharged current and battery voltage, power calculation and internal resistance values are derived. The battery shall meet the requirements as given in the table below. The internal resistance values given in the table below are the maximum values for the battery. Lower the value, it is better for the battery.

Temperature	Peak Power at 1 Sec (approx. 300 milli seconds) Instantaneous Peak values			Power rating at 15 seconds Steady state values		
	I_i(min)	P_i(min)	r_i(max)	I_{mp}(min)	P_m(min)	r_{em}(max)
At 25°C	900A	12KW	15mΩ	650A	8.5KW	21mΩ
At-30°C	400A	5.5KW	33mΩ	250A	3.5KW	53mΩ

Constant voltage at 14V discharge test :

The test shall be carried out after CP charge (28.5V) battery shall be subjected to a constant voltage discharge at 14V for 60 seconds at 24 ±2°C and – 26 ±2°C. The discharge current at 1.0, 5.0, 15.0 and 60.0 seconds after the start of discharge shall be as per the specified values given below :

Temperature	Currents at			
	1 second	5 second	15 second	Average current over the total 60 seconds
24 ±2°C	925 amps	825 amps	700 amps	650 amps
– 26 ±2°C	450 amps	350 amps	350 amps	350 amps

Elect& Environmental Profiles of AN-32 A/c

a) Engine Cranking Test for AN-32 Aircraft

Profile for AN-32 a/c

Total number of batteries 3, as per clause No.4 of individual specification No: DGAQA/ E&I-502/8 Issue 1 May 98. All three batteries in parallel shall be subjected to the engine cranking profile

650 amps – 1 second
520 amps – 4 seconds
420 amps – 5 seconds
380 amps – 5 seconds
300 amps – 5 seconds
220 amps – 5 seconds
180 amps – 5 seconds
110 amps – 5 seconds
90 amps – 5 seconds
75amps – 5 seconds

The battery shall give minimum of five starts with 3 minutes interval between starts and the voltage at the end of 5th start shall not be less than 18 volts.

Note: For evaluations, more stringent IL-76 a/c engine starting profile, was followed on a single battery, because basic cells (20 numbers) are common for IL-76, AN-32 a/c and MI-8/MI-17 Helicopters.

b) Emergency load Requirements

i) 3 batteries connected in parallel when discharged at 60 amps, shall give a minimum duration of 45 minutes

ii) 3 batteries connected in parallel when discharged at 100 amps, shall give a minimum duration of 30 minutes

9.2.5 25AH, 24V, Ni-Cd battery for MI-8 / MI-17 Aircraft

9.2.5.1 Salient Features

Type of Battery	NICKEL CADMIUM BATTERY TYPE: i) NCSPB 25150 MI with Cell part No. NCSPC 25150-4 ii) NCSPB 25150 MI RMwith Cell part No. NCSPC 25150RM
Technology developers and	M/s HBL, Hyderabad
Coordinated RCMA	RCMA (HD)
Nominal voltage & Capacity	24V & 25AH
End use	MI-8 /MI-17 Helicopters
Battery Dimensions & Weight	411 X170 X240 mm & 28 Kgs.
Type Approval No. & Validity	i) CEMILAC TA No.1041. Validity up to 31-12-2008 ii) for Si / Pbe design modified and issued PC No.150 vide RCMA(HD) /767/1/25AH/NI-CD Dated 06-02-2008 for NCSPB 25150 AN RM
Technical Specification	i) QTP Reference No.:HNPS/TA/QTP/25AH/MI-8/MI-17/2002 Issue No.I Dt. May, 2003 ii) Limited QTP Doc. No.HBL/TA/QTP/Si/PBE/ 2 5 AH / 2007, Issue-I, Oct.2007 iii) JSS:6140-10:2007 for NI-CD batteries
Manufacturing & Quality Assurance Plan	i) HBL/NCSS/PP/006 Feb.2000 ii) HBL/NC/PS/PBE/07 Jan.2007

9.2.5.2 Cell Details

Test	Cell Parameter	REQUIREMENTS
1.	a). Type of cell b). Nominal Voltage & Capacity	NCSPC 25150-4 (Vented type , Ni-Cd) or NCSPC 25150 RM 1.2V, 25Ah
2.	OCV of Charged cell	1.25V Min.
3.	Physical dimensions & Weight	Height up to terminal top: 211.0 ±1.0mm Height up to cell lid top : 197.5 ±1.0mm Width : 81.0 ±0.5mm Thickness : 27.5 ±0.5mm Torque requirement : Bottom nut : 5Nm Top nut : 11Nm Weight : 950 ±30gr
4.	Type of sealing for Container & Lid	Thermal Welding
5.	Electrolyte	Solution of KOH 30 to 35%Concentration.
6.	Cell container material	Nylon-11
7.	Identification of Polarity	'+' Embossing provided on the lid. '+' & '-' marked on the cell against the respective terminal by Screen-printing.
8.	Efficiency of sealing	Each cell checked for leak at a pressure of 14Kpa for 15 seconds and there shall not be any leak.
9.	Cell vent valve	Made of stainless steel with hollow center post covered with rubber sleeve to operate as a Bunsen valve at pressure of 0.2 to 0.6Kg/Cm^2
10.	Separator systems	Polyamide (Non-Woven) – One layer Gas Barrier – One layer of Celgard-3400 Polyamide (Woven) – One layer
11.	No. of electrodes (or Plates)Design	+ve plates (13 Nos.) are with sintered & -ve plates (14 Nos.) are plastic bonded electrodes for RM Design

9.2.5.3 Battery Electrical & Environmental Test Requirements

Test	Battery Parameter	Requirement
1.	a) Type of battery b) Drawing/Part No c) Nominal voltage	NCSPB 25150 MI or NCSPB 25150 MI RM 252 1000 2B or 252 1000 2A 24Volts
2.	OCV of charged battery	25V Minimum
3.	Nominal capacity at 1 hour rate	25Ah (at cut off voltage of 20V, 60minutes discharge time with 25Amps.load)
	a). Number of cell	20 connected in series, replaceable
	b). Type of connector	Two pin connector as per Drawing No. 252 2009 3A
4.	Identification polarity	'+' & '-' Markings are embossed on the connector block. Red and black indication washers provided on the cell positive and negative terminals.
5.	Weight	28.0 Kg.
6.	Dimensions	As per drg.No.252 1000 2A Length 462.5 ±1.0 mm Width 170.0 ±1.0 mm Height 240.0 ±1.0 mm
7.	Battery container	Made of stainless steel with sand blast finish.
8.	General Environmental Test a. Humidity & Charge Retention Test b. Mechanical shock test (Basic Design) c. Vibration Test d. Temperature shock Test e. Altitude Test f. Salt Fog Test g. 20 Sec. pulse discharge Test h. Medium rate discharge operation position Test i. Cycling Test j. Temperature rise and float Test k. Physical integrity Temperature (85°C)	

l. Gas barrier Material Test
m. Storage Test
n. Shelf life Test
o. Main battery receptacle or electric plug Test
p. Temperature sensor Thermo switches (if) applicable for battery
q. User Trials

Above tests shall be followed from JSS 6140-10:2007 of Nickel Cadmium for aviation use

9.2.5.4 Base Line Parameters for IL-76 &Su-30

Battery service life with different rate of discharge on fully charged batteries. Following minimum capacities shall be available at the two temperatures as given in the table below.

Discharge Rate	**Discharge Time (minimum)**	
	At RT(+25°C)	**At – 30° C**
$1C_1$ (25amps)	60 min (cut off voltage 20V)	46 min (cut off voltage 20V)
$5C_1$ (125amps)	10.5 min (cut off voltage 16V)	7.4 min (cut off voltage 14V)
$10C_1$(250amps)	4.8 min (cut off voltage 16V)	1.2 min (cut off voltage 14V)
$15C_1$(375amps)	2.2 min (cut off voltage of 16V)	0.5 min (cut off voltage of 14V)
$30C_1$(750amps)	1.0 min (cut off voltage of 10V)	------

Instantaneous Power & Maximum Power Delivery Test:

Power behavior under 25°C and – 30°C test conditions, the currents ensuring while discharge from fully charged state at half the OCV (OCV/2 = 12V constant) for 15 seconds in above temperature conditions are to be evaluated. From the discharged current and battery voltage, power calculation and internal resistance values are derived. The battery shall meet the requirements as given in the table below. The internal resistance values given in the table below are the maximum values for the battery. Lower the value, it is better for the battery.

Temperature	Peak Power at 1 Sec (approx. 300 milli seconds) Instantaneous Peak values			Power rating at 15 seconds Steady state values		
	I_i(min)	P_i(min)	r_i(max)	I_{mp}(min)	P_m(min)	r_{em}(max)
At 25°C	900A	12KW	15mΩ	650A	8.5KW	21mΩ
At-30°C	400A	5.5KW	33mΩ	250A	3.5KW	53mΩ

Constant voltage at 14V discharge test :

The test shall be carried out after CP charge (28.5V) battery shall be subjected to a constant voltage discharge at 14V for 60 seconds at 24 +2°C and – 26 +2°C. The discharge current at 1.0, 5.0, 15.0 and 60.0 seconds after the start of discharge shall be as per the specified values given below:

Temperature	Currents at			
	1 second	5 second	15 second	Average current over the total 60 seconds
24 ±2°C	925 amps	825 amps	700 amps	650 amps
– 26 ±2°C	450 amps	350 amps	350 amps	350 amps

Elect& Environmental Profiles

a) Engine Cranking

No batteries: 6

Time in Seconds	Current in Amps	Mode of connection of batteries
0 – 2	1000	Parallel
2 – 9	600	Parallel
9 – 32	600	Group of three battery's (connected in parallel) in series with other group of three bytes (connected in parallel)
32 – 33	600	Parallel
33 – 50	150	Parallel

Note: No. of starts – 5 with interval between starts 3 minutes. Battery Voltage at the end of each cycle should not be less than 18 Volts

b) Emergency load Requirements

310 Amps for 24 minutes

(All six batteries in parallel)

180 Amps for 43 minutes (All six batteries in parallel for MI-8 H/C)

9.2.6 28AH, 24V, Sealed Lead Acid (VRLA) battery for MI-8 / MI-17 H/C

9.2.6.1 Salient Features

Type of Battery	Sealed Lead Acid Battery (VRLA Type) Mono block type SS28300
Technology developers and Coordinated RCMA	M/s.HBL, Hyderabad & RCMA(Hyderabad)
Nominal voltage & Capacity	24V & 28AH with 5 hour rate
End use	MI-8 / MI-17 H/C
Battery Dimensions & Weight	L 482 X W 200 X H 240mm & Weight = 32.5 Kgs.
Type Approval No. & Validity	QT completed. &Under SOF trials
Technical Specification	QTP Doc.No.HNPS/TA/QTP/MBD/18AH/MI/2002 Issue : 001 dated 24th July, 2002
Manufacturing &Quality Assurance Plan	HNPS/MBD/TA/28/MI/2008 & MBD/PS/SS28300/ASSLY 02&03

9.2.6.2 Cell and Monoblock Parameters

	Cell Parameter	Requirements
1.	Cell drawing No.	12V, Monoblock Assembly Drg 10020100 & six cells stacks are arranged in each Monoblock
2.	No. of plates	9 positive & 10 negative plates
3.	Grid Type	Pure lead tin alloy
4.	Separator System	Absorptive Glass Mat (AGM) separator
5.	Sealing methods	Thermal sealing
6.	Electrolyte	Sulfuric acid with specific gravity 1.28 gm/cm^3
7.	Cell vent type	Vent seals are made with EPDM rubber and the opening pressure is 3-5psi
8.	Charging system	CP charge with voltage of 28.5 ±0.25V with a current limit of 8 times the capacity of battery at 1 hour rate. The battery can be fully charged with in 2 hours.
9.	No. of cells per 1 mono block	06 cells connected in series (non replaceable)
10.	No. of mono blocks in a battery	02 mono blocks connected in series (non repairable / replaceable) & final battery (24V) Drg No 10020000
11.	Strength of Pressure Relief Valve (VRLA) Batteries	The battery shall be capable of to have sufficient pressure relief valve maintains and internal pressure of designed value (a typical value 40-60 psi 1 psi = 6804 X 10^{-2} atm=or 6894.7 Pascal's)

9.2.6.3 Table 2: Battery Parameters

Sl. No.	Battery Title	Requirements
1	Polarity Marking	The container body shall be conspicuously and durably marked "+" white in the location shown on applicable specification sheet
2	Identification Marking	The battery identification marking shall be in **white or black print**. The, marking shall contain the required titles and information in accordance with the applicable specification sheet
3	Battery Caution marking	The battery caution marking shall contain the required titles and information in accordance with the applicable, specification sheet. The lettering height shall not less than 025 inches. The marking shall be in **white or black print**
4	Receptacle	Each battery shall include a main power receptacle In accordance With the applicable specification sheet as the batteries electrical interface to the aircraft
5	Connector	Shall conform to the applicable specification sheet. All electrical connections with in the battery shall be by surface to surface conduction and not through screw threads
6	Electrolyte leakage	Any evidence of electrolyte leakage during the performance of any of the tests specified shall not occur except when tested in accordance with battery gas emission test
7	Operating Position	The battery shall be capable of operating in any inverted position or altitude without loss of any electrolyte after being tested as per QTP
8	Visual & mechanical	Batteries shall be in accordance with table -II and applicable specification sheet
9	Dimensions & Weights	The dimensions & weights shall be shown on applicable on the specification sheet / or drawings etc. defined. (See the individual aircraft wise for details of physical dimensions and weight of the battery (for MI-8/MI-17 a/c shall be matched with existing 12CAM -28-Lead Acid batteries.) Length: Top Part 369 ±3 / Bottom Part 323 ±4 Width: 163 ±3 Height with Cover: 214±2 (all are in mm) Max Weight: 28.5kg
10	Handle Strength	Each handle shall checked out for swing out from the container against its stop Apply a force of 135 pounds at handles grasp
11	Dielectric Strength	All current carrying parts shall be insulated from the battery container. The insulation resistance between any current carrying part and the battery container shall be not less than **one Mega Ohms** after being tested
12	Vent tubes	If vent tubes are provided with the battery, then the vent tubes shall support the load without sharing, breaking, bending. or

<table>
<tr><td></td><td></td><td>deterioration at the point of connection with the battery</td></tr>
<tr><td>13</td><td>Capacity performance</td><td>The rated capacity of the battery shall not be less than 18AH (1 hr. rate), to meet the capacity requirement with 1 hr rate. Each battery shall produce a potential of not less than 20.0V and not less than 60 minutes when connected to 18A.load after being tested in accordance QTP. And also shall meet 28AH with 5 hr. rate discharge (5.6 A. load)</td></tr>
<tr><td>14</td><td>Service life</td><td>The batteries service life (useful life} in aircraft shall not be more than 3 years. Battery shall require no schedule maintenance during the 3 years</td></tr>
<tr><td>15</td><td>Initial Installation date</td><td>The initial installer will write the date the battery is first installed In the air craft (date first placed in service) in this space provided on the battery's identification label</td></tr>
<tr><td>16</td><td>Removal date from aircraft</td><td>The battery will be removed mandatorily form the aircraft after three years of use.</td></tr>
<tr><td>17</td><td>Maintenance Free</td><td>The battery will require no periodically scheduled maintenance during the service life, except recharging</td></tr>
<tr><td>18</td><td>Repeat upon failure of test</td><td>If the battery fails to meet the specified minimum requirements of any electrical test the battery shall be recharged, after which test will be repeated. Inability to meet the specified minimum requirements during repeated test shall constitute failure. If the battery meets the requirements of the repeated test. Further specified schedule resumed</td></tr>
<tr><td>19</td><td>Constant Voltage Discharge (14V)</td><td>The battery shall be discharged for 1 minute with constant voltage of 14 volts and shall be performed at two temperatures specified (room temperature and -26^{0} C) temperature. The current requirements shall be specified in the applicable specification sheet for specific aircraft requirement. (For MI-8 / MI-17 Helicopter 14KW peak power defined, this can be calculated from the above table)
<table>
<tr><th>Temperature</th><th>Current at peak value, time=0 sec.</th><th>Current at 15 seconds</th><th>Current at 30 seconds</th><th>Capacity at 60 seconds</th></tr>
<tr><td>Room Temp</td><td>1150A</td><td>875A</td><td>725A</td><td>12.0 AH</td></tr>
<tr><td>-26° C±2° C</td><td>725A</td><td>575A</td><td>400A</td><td>6.6 AH</td></tr>
</table></td></tr>
<tr><td>20</td><td>Strength of Receptacle</td><td>The receptacle and receptacle mounting shall withstand an axial pullout force of 250 ± 25 pounds and a torsional force of 6 ± 0.5 foot-pounds after being tested in accordance with QTP. The battery shall also meet the requirements.</td></tr>
</table>

21	Cycling	Batteries shall successfully complete not less than 85 cycles minimum. (as per MIL-PRF-8565/7 A(AS) defined 120 cycles of discharge and charge)
22	Evaluation of equipment	The battery potential shall be not less than 14.0 volts at not less than 3 minutes in to the discharge after being tested accordance with Altitude test, shock test (basic design) temperature shock test, battery gas emission test, vibration test, humidity test, salt fog test, physical integrity at high temperature test, shock test (Crash safety)
23	Temperature rise and float	The battery shall perform as follows after being tested in accordance with QTP. If the charging current rises, its increase in amperes compared to the current's minimum value shall be not greater than 10°/" of the batteries rated capacity (for ex : 1.5 Amps for 15 Amper -hour battery) at any time during charge. The battery shall meet requirement of1 C rate discharge for 1 hr and QTP.
24	Battery Gas emission	The percent of hydrogen concentration shall be not greeter than 3.5% at any time during the test
25	Storage	**a) Ground Storage** The battery shall be capable of storage in un controlled temperature condition. Conditions from -26°C to 50°C for not less than 30 days (in charged condition). After storage in each temperature battery shall meet the requirement of engine sorting cycles for 3 OR, 85% of rated capacity of the batter may be achieved with 1C1 rate of discharge. **b) (i) Shelf life:** In order to maintain qualification, successful completion of the shelf life test QTP shall be required. The batteries shall be capable of storage in un controlled temp conditions, for not less than 12 month without damage. The capacity shall be recoverable after being tested by two cycles of constant current charge and discharge and verify 1 C rate performance for one hour. Examine the battery for the requirement of cycling test (85 cycles minimum). **(ii) Service life:** The batteries life (useful life) in aircraft is limited to maximum 3 years A battery will not be used in aircraft service after 3 years from the date of the manufacturing of the battery. • Initial installation date: The initial installer will write the date on the battery itself (date of first placed in service) • Removal date from the aircraft: Battery will be removed

		from aircraft service three years after the date it was first installed in an aircraft. • Deep Discharge Recovery: The battery shall be capable of storage in the fully discharged state (D. Volts) and (then shorted out) in un controlled temperature conditions from minus 40°C to plus 50°C for not less than 7 days without damage. After such storage, the battery shall be capable of recovering the capacity specified by applicable specification sheet or one hour 1 C rate discharge requirements
26	Impact Resistance (Non metallic battery container only)	The non metallic battery container shall not crack on the side apposite the point of Impact after being tested in accordance with QTP.
27	Shock Test (Basic Design)	The battery shall be subjected to 15 impacts as per QTP after the shock verify the discharge 6.5 C rate for 3 minutes
28	Shock (Crash Safety)	The battery shall be tested as per QTP (i) the batteries normal attachment points such as brackets, flunges, or hold down bars shall retain the entire battery intact in the test fixture during and after the test. (ii) Mechanical bending and distortion or acceptable provided hazardous condition is not created. The battery shall meet 6.5C rate discharge for 14 V cut off for 3 min
29	Output Performance (Stand by power output)	(a) Engine Starting cycle: Curvilinearly from maximum to minimum up to required durations with ensured voltage of not less than minimum and final voltage at the end of cycle may be performed. The battery shall produce not less than the specified amount of current and voltage within the specified time period shown in specification sheet of individual aircraft (for MI-8 and MI-17 aircraft the following typical pattern of cycle defined as):- Based on MI-8 operating and maintenance Manual book-III part-I, a typical engine starting approximately defined below **Time (seconds)** — **Current (8mp)** — **Voltage (Volts)** 0 – 2 — 750 — 12 2 - 5 — 700 — 13 5 - 10 — 650 — 14 10 – 15 — 550 — 15 15 – 20 — 450 — 16 20 – 25 — 400 — 17 25 – 30 — 300 — 18 30 – 35 — 250 — 19 35 – 40 — 150 — 20 40 – 45 — 75 — 21

		During 1st year of operation 4 engine starts shall be met and 2nd year onwards 3 starts minimum required. Based on 12-CAM-28 battery operating instruction manual, used in MI-8/MI-17 the following may be verified for engine starting cycle defined with above time sequence Current Values: 650A, 600A, 500A, 400A, 300A, 250A, 175A, 100A, 75A Voltage Values: 12V, 12,5V, 13V, 14V, 15V, 16V, 16V, 16V, 16V, respectively for appropriate time duration defined above. (b) The battery shall produce not less than 21 Volts during the discharges with 6 Ohms load as per QTP at -26° C for 1 hr., -18° C for 2 hrs. and 0° C for 4 hrs. and 25°C for 7 hrs. and 49°C for 7 hrs. after removing the load open circuit voltage of the battery shall not be less than 24V, subsequently after completing the 16 Ohms load discharge remove the battery from test temperature environment immediately discharge the battery for engine starting cycles as per profile of the a/c defined above, or any general standard engine starting profile. (c) Any emergency load requirements as per individual aircraft specification requirements (for MI-8/MI-17 emergency loads defined at QTP)
30	High & low temperature performance	High & low temperature charge and discharge test shall be conducted at the temperature indicated in the applicable test paragraph with storage time of 20-24 hours prior to discharge
31	Safety Hazardous Requirements	a) Over charge Test b) Over Discharge Test c) Short Circuit of the battery Test

<table>
<tr>
<td>32</td>
<td>Designated Discharge Rate</td>
<td>To meet the capacity requirement each battery shall produce a potential of not less than 20V and not less than 60 minutes when connected to its rated Ah load at different temperature mentioned in table-III below. The current tolerance shall be ± one percent of the specified value
Table: III
<table>
<tr><th>Requirement No</th><th>Discharge Cut off Volts & Temperature</th><th>Rate of Discharge Factor</th><th>Minimum time to cut off voltage</th></tr>
<tr><td>1.</td><td>20Volts at room temperature</td><td>1.0C (18 A. load) & 5C (5.6 A. load)</td><td>1 hr & 5hrs.</td></tr>
<tr><td>2.</td><td>20 volts at 49°C & 60°C</td><td>1.0C</td><td>1.1hr</td></tr>
<tr><td>3.</td><td>20 volts -18°C</td><td>1.0C</td><td>30 minutes</td></tr>
<tr><td>4.</td><td>14Volts at room temp. & -26°C</td><td>Constant voltage discharge for 1 minute each of the two temp.</td><td>Constant voltage discharge for 1minute each of the two temp.</td></tr>
<tr><td>5.</td><td>14 volts at room temp.</td><td>6.5C</td><td>5 minutes</td></tr>
<tr><td>6.</td><td>Autonomous starting of the engine</td><td>As per aircraft load profile.</td><td>At ambient temperature at least four cycles and at -18° C two staring cycles should meet.</td></tr>
</table>
</td>
</tr>
<tr>
<td>33</td>
<td>Ground Trails & Flight trails</td>
<td>Practically battery shall be fitted in the aircraft to meet the aircraft physical installation and fitment checks. On aircraft with battery load test and analysis shall be verified as per platform requirements</td>
</tr>
</table>

9.2.7 23AH, 24V, Ni-Cd battery for AVRO (CHITRA) Aircraft

9.2.7.1 Salient Features

Type of Battery	NICKEL CADMIUM BATTERY TYPE: i) NCSPB 23060 with Cell part No. NCSPC 23060-4 ii) NCSPB 23060 RM with Cell part No. NCSPC 23060RM
Technology developers and	M/s HBL, Hyderabad
Coordinated RCMA	RCMA (HD)
Nominal voltage & Capacity	24V & 23AH
End use	HS-748 (AVRO) Aircraft
Battery Dimensions & Weight	253 X197 X221 mm & 25 Kgs
Type Approval No. & Validity	i) CEMILAC TA No726. Validity up to 30-06-2008 ii) for Si / Pbe design modified and issued PC No.151 vide RCMA(HD) /767/1/23AH/NI-CD Dated 06-02-2008 for NCSPB 23060 RM
Technical Specification	i) General Specification of DTD&P(AIR)/E&I/502/1 Issue-I, Mar.1987 for Ni-Cd battery ii) Limited QTP Doc.No.HBL/TA/QTP/Si/PBE/ 23AH/2007, Issue-I, Oct.2007 iii) JSS:6140-10:2007 for NI-CD batteries
Manufacturing &Quality Assurance Plan	i) HBL/NCSS/PP/006 Feb.2000 ii) HBL/NC/PS/PBE/07 Jan.2007

9.2.7.2 Cell Details

	Cell Parameter	Requirements
1.	a) Type of cell & Drawing No. b) Nominal Voltage & Capacity	i) Vented type , Ni-Cd, NCSPC 23060-4 (Vented Ni-Cd) & 231 4001 3A ii) Vented type, Ni-Cd, NCSPC 23060 RM & 23A 6001 3A 1.2V, 23Ah
2.	OCV of Charged cell	1.25V Min.
3.	Physical dimensions & Weight	Height up to terminal top : 211.5 ±1.5mm Height up to cell lid top : 196.0 ±1.0mm Width : 80.5 ±0.5mm Thickness : 27.0 ±0.2mm Weight : 850 gms (max) Torque requirement : Bottom Nut 5Nm Top Nut 11 Nm
4.	Type of sealing for Container & Lid	Thermal Welding
5.	Electrolyte	Solution of KOH 30 to 35%Concentration.
6.	Cell container material	Nylon-11
7.	Identification of Polarity	'+' Embossing provided on the lid. '+' & '-' Marked on the cell against the respective terminal by Screen-printing.
8.	Efficiency of sealing	Each cell checked for leak at a pressure of 14Kpa for 15 seconds and there shall not be any leak.
9.	Cell vent valve	Made of stainless steel with hollow center post covered with rubber sleeve to operate as a Bunsen valve at pressure of 0.2 to 0.6Kg/Cm^2
10.	Separator Systems	Polyamide (Non-Woven) – One layer Celgard-3400 – One layer Polyamide (Woven) – One layer
11.	No. electrodes (or Plates)Design	'+' plates (12 Nos.) are sintered & '-' plates (13 Nos. are plastic bonded for RM Design

9.2.7.3 Battery Electrical & Environmental Test Requirements

Sl. No	Description	Requirement
1.	a) Type of battery & Drg. No b) Nominal voltage	i) NCSPB 23060 & NCSPB 231 1000 3A ii) NCSPB 23060 RM & NCSPB 231 1000 2A 24Volts
2.	OCV of charged battery	25V Minimum
3.	Nominal capacity at 1 hour rate a). Number of cell b). Type of connector	23Ah (at cut off voltage of 20V, 60minutes discharge time with 23Amps.load) 20 Nos connected in series replaceable Imported connector (MIL-E-81099 A) Rebling Plastic Part No.7002
4.	Polarity Identification	'+' Marking is embossed on the connector block. Red and black indication washers provided on the cell positive and negative terminals. Battery and lid are identified with labels as per drawings.
5.	Weight	25.0Kg (max)
6.	Dimensions	Length 257 ±1.0 mm Width 247.5 ±1.0 mm Height 224.5 ±1.5 mm
7.	Battery container	Made of stainless steel with sand blasted finish
8.	Electrical & Environmental Profiles of Avro aircraft	No specific profile for engine cranking and emergency loads are available for this aircraft. Hence loads applicable for IL-76 aircraft battery (24V, 25AH) may be carried out on this battery.
9. General Environmental Test		
	a. Humidity & Charge Retention Test b. Mechanical shock test (Basic Design) c. Vibration Test d. Temperature shock Test e. Altitude Test f. Salt Fog Test g. 20 Sec. pulse discharge Test h. Medium rate discharge operation position Test i. Cycling Test j. Temperature rise and float Test k. Physical integrity Temperature (85℃)	

l. Gas barrier Material Test
m. Storage Test
n. Shelf life Test
o. Main battery receptacle or electric plug Test
p. Temperature sensor Thermo switches (if) applicable for battery
q. User Trials

Above tests shall be followed from JSS 6140-10:2007 of Nickel Cadmium for aviation use

9.2.7.4 Baseline Parameters

Typical Discharges:

Battery service life with different rate of discharge on fully charged batteries. Following minimum capacities shall be available at the two temperatures as given in the table below.

Discharge Rate	**Discharge Time (minimum)**	
	At RT(+25°C)	**At – 30° C**
$1C_1$ (23amps)	60 min (cut off voltage 20V)	46 min (cut off voltage 20V)
$5C_1$ (115amps)	10.5 min (cut off voltage 16V)	7.4 min (cut off voltage 14V)
$10C_1$(230amps)	4.8 min (cut off voltage 16V)	1.2 min (cut off voltage 14V)
$15C_1$(345amps)	2.2 min (cut off voltage of 16V)	0.5 min (cut off voltage of 14V)
$30C_1$(690amps)	1.0 min (cut off voltage of 10V)	------

Instantaneous Power & Maximum Power Delivery Test:

Power behavior under 25°C and – 30°C test conditions, the currents ensuring while discharge from fully charged state at half the OCV (OCV/2 = 12V constant) for 15 seconds in above temperature conditions are to be evaluated. From the discharged current and battery voltage, power calculation and internal resistance values are derived. The battery shall meet the requirements as given in the table below. The internal resistance values given in the table below are the maximum values for the battery. Lower the value, it is better for the battery.

Temperature	Peak Power at 1 Sec (approx. 300 milli seconds) Instantaneous Peak values			Power rating at 15 seconds Steady state values		
	I_i(min)	P_i(min)	r_i(max)	I_{mp}(min)	P_m(min)	r_{em}(max)
At 25°C	800A	11KW	17mΩ	600A	8KW	23mΩ
At-30°C	375A	5KW	36mΩ	225A	3KW	60mΩ

Constant voltage at 14V discharge test:

The test shall be carried out after CP charge (28.5V) battery shall be subjected to a constant voltage discharge at 14V for 60 seconds at 24 ±2°C and – 26 ±2°C. The discharge current at 1.0, 5.0, 15.0 and 60.0 seconds after the start of discharge shall be as per the specified values given below:

Temperature	Currents at			
	1 second	5 second	15 second	Average current over the total 60 seconds
24 ±2°C	850 amps	750 amps	625 amps	575 amps
– 26 ±2°C	375 amps	300 amps	275 amps	300 amps

a) Engine Cranking Test for AVRO (Chitra)

Aircraft not available, however IL-76 engine cranking profile followed for laboratory evaluation

On each battery, the variation of the current magnitude with respect to time under the starting discharge condition is presented in fig. 1of SK No.14/9 starting with max. discharge currents are given below:-

650 amps – 1 second
520 amps – 4 seconds
420 amps – 5 seconds
380 amps – 5 seconds
300 amps – 5 seconds
220 amps – 5 seconds
180 amps – 5 seconds
110 amps – 5 seconds
90 amps – 5 seconds
75 amps – 5 seconds

The battery shall give minimum of five starts with 3 minutes interval between starts and the voltage at the end of 5th start shall not be less than 18 volts.

(a) During the first year

i) Five starting under normal climatic conditions with time pause in between the starts of 3 minutes, the battery voltage at the end of fifth start should at least be 16.0 Volts.

ii) Three starting at electrolyte temp of -5°C.

(b) During the subsequent period of service, the number of starting is one less than the number indicated under (i) above.

b) Emergency load test for AVRO (Chitra)

Aircraft not available, however IL-76 emergency load followed for laboratory evaluation. For emergency load on single battery with 85% SOC, an average load of 52A to a cut off voltage of 20 volts shall be applied and the duration obtained shall not be less than 24 minutes.

9.2.8 18AH, 24V, Ni-Cd battery for KIRAN-I / IA Aircraft

9.2.8.1 Salient Features

Type of Battery	NICKEL CADMIUM BATTERY TYPE: NCSPB 18060 B with Cell part No. NCSPC 18060-4
Technology developers and	M/s HBL, Hyderabad
Coordinated RCMA	RCMA (HD)
Nominal voltage & Capacity	24V & 18 AH
End use	Kiran MK-I / IA Aircraft
Battery Dimensions & Weight	247 X193.5 X164 mm & 19 Kgs.
Type Approval No. & Validity	CEMILAC TA No1132. Validity up to 30-06-2010
Technical Specification	QTP Reference No.:HNPS/TA/QTP/18AH/ KIRAN/ 2004, Issue No.I , Dt. Dec. 2004 & JSS:6140-10:2007 for NI-CD batteries
Manufacturing & Quality Assurance plan	HBL/NCSS/PP/006 Feb.2000

Note : The same battery connector is changed and with battery part No.NCSP B 180 60 C & 180 060 D is provisionally cleared for ISLANDER and SEA HARRIER Aircraft vide Ltr.No.CRE(A/C)/HAL BC/527/11/(i) dated 22/11/1993 & 19/02/1994

9.2.8.2 Cell Specifications

	Cell Parameter	**Requirements**
1.	a) Type of cell b) Nominal Voltage & Capacity	Ni-Cd Vented type, NCSPC 18060-4 1.2V, 18Ah
2.	OCV of Charged cell	1.25V Min.
3.	Physical dimensions & Weight.	**Kiran Mk-I/IA** Height up to terminal top: 156.0 ±0.5 mm Height up to cell lid top : 143.0 ±0.5mm Length : 80.5 ±0.2mm Width : 27.0 ±0.2mm Weight : 0.780 Kg Max.
4.	Drawing No.	181 4001 3A
5.	Type of sealing for Container & Lid	Thermal Welding
6.	Electrolyte	Solution of KOH 30 to 35%Concentration.
7.	Cell container material	Nylon 11
8.	Identification of Polarity	'+' Embossing provided on the cell lid. Red and black indication washers provided on the cell '+' & ' - ' terminals. '+' & ' - ' Marked on the cell against the respective terminal by Screen-printing.
9.	Efficiency of sealing	Each cell checked for leak at a pressure of 14Kpa for 15 seconds and there shall not be any leak.
10.	Cell vent valve	Made of stainless steel with hollow center post covered with rubber sleeve to operate as a Bunsen valve at pressure of 0.2 to 0.6Kg/Cm^2
11.	No. of Electrodes	12 Nos. positives & 13 Nos. negatives

9.2.8.3 Battery Electrical & Environmental Test Requirement

Sl No	Battery Parameter	Requirement
1.	a) Type of battery b) Nominal voltage	NCSP B 18060 B For Kiran MK- I / IA aircraft, Drg No. 181 1000 2B 24Volts
2.	OCV of charged battery	25V Minimum
3.	Nominal capacity at 1 hour rate a) Number of cells b) Type of connector	18Ah (at cut off voltage of 20V, 60minutes discharge time with 18Amps.load) 20 Nos connected in series, replaceable KIRAN MK-I / IA : Spade lug connector, Drg.No.181 3000 3B, Type 'B' Assembly
4.	Polarity Identification	+ & - Embossed markings are made on the battery container on both sides of the connector.
5.	Weight	19.0 Kgs. Max.
6.	Dimensions as per Drg.No.181 1000 2B	Over all length 295.0 mm (Approx) Length (Bottom) 247.0 ±1.0 mm Length (Top) 264.0 ±1.0 mm Width (Bottom) 193.5 ±1.0 mm Height over all 164.0 ±1.0 mm
7.	Battery container	Made of stainless steel with sand blasted finish.
8.	Operating temperature.	-18°C to 55°C
9.	Battery capacity at 1 hour rate	18AH
10.	Power rating Or constant Voltage discharge test at 14V	a) Fully charged battery shall be stabilized at 24±2°C and subject the battery to constant potential discharge for 60 seconds. During the 60 seconds, the discharge potential shall be 14.0±0.5Volts for the initial 5 seconds and 14.0±0.1 Volts for the remaining 55 second. Measure discharge current at 1.0, 5.0, 15.0 and 60.0 seconds after the sart6 of discharge. Peak power shall be calculated at 300m seconds value of current and voltage and maximum delivery shall be calculated from output current during 0 to 30 seconds period. b) Repeat the above test after stabilizing the battery at -26 ±2°C. **Note:** These tests are considered essential for aircraft battery. It gives valuable information of battery quality. However specific values are not defined. Higher the output, better the battery. Data generated as reference.

		Obtained Values : 1) At room temperature 17.25Kw Peak power at 300 milli seconds and 11.34Kw max. power (at 15 Sec.) 2) At -26°C, 7.15Kw Peak power at 300 milli seconds and 5.28Kw max power (at 15 Sec)
11.	Engine Starting and Emergency load Test with 85% rated capacity of the battery	For engine start and emergency load profile of individual aircraft : Fully charged battery shall be discharged such that it should have only 85% of rated capacity shall be verified as per individual aircraft load profiles such as engine starting cycle and emergency load requirements. **Note :** In field use these batteries are allowed up to 85% of the rated capacity. To confirm the battery performance by imposing their individual a/c requirements like engine-starting cycles and emergency load checks are considered for evaluation. These tests have been not carried out since the specific profile of KIRAN Aircraft are not available. Alternatively Starting capability at -18°C ±2°C (Low temperature performance for 20 seconds pulse discharge for three times, Sl.No.36 test of constant voltage discharge test at 14V & Typical discharge characteristics shall be carried out which is considered acceptable.
12.	General Environmental Test	

a. Humidity & Charge Retention Test
b. Mechanical shock test (Basic Design)
c. Vibration Test
d. Temperature shock Test
e. Altitude Test
f. Salt Fog Test
g. 20 Sec. pulse discharge Test
h. Medium rate discharge operation position Test
i. Cycling Test
j. Temperature rise and float Test
k. Physical integrity Temperature (85°C)

l. Gas barrier Material Test
m. Storage Test
n. Shelf life Test
o. Main battery receptacle or electric plug Test
p. Temperature sensor Thermo switches (if) applicable for battery
q. User Trials

Above tests shall be followed from JSS 6140-10:2007 of Nickel Cadmium for aviation use

9.2.9 16AH, 24V, Ni-Cd battery for HPT 32 Aircraft

9.2.9.1 Salient Features

Type of Battery	NICKEL CADMIUM BATTERY TYPE NCSPB 16060 with Cell part No. NCSPC 16060-4
Technology developers and Coordinated RCMA	M/s HBL, Hyderabad RCMA (HD)
Nominal voltage & Capacity	24V & 16AH
End use	HPT-32 Aircraft
Battery Dimensions & Weight	369 X129 X179 mm & 18.2 Kgs.
Type Approval No. & Validity	CEMILAC TA No1070. Validity up to 30-06-2009
Technical Specification	QTP Reference No.: HNPS/TA/QTP/16AH/HPT/2004 Issue No.I, Dt. Mar. 2004& JSS:6140-10:2007 for NI-CD batteries
Manufacturing & Quality Assurance Plan	HBL/NCSS/PP/006 Feb.2000

9.2.9.2 Cell Specification

Sl No	Cell Parameter	Requirements
1.	a). Type of cell b). Nominal Voltage & Capacity	Nickel Cadmium, Vented type NCSPC16060-4 (Vented Ni-Cd) 1.2V, 16Ah
2.	OCV of Charged cell	1.25V Min.
3.	Physical dimensions & Weight	Height up to terminal top: 169.0 ±1.0 mm Height up to cell lid top : 156.0 ±0.5mm Width : 57.0 ±0.2mm Thickness : 31.5 ±0.2mm Weight : 740 g Max.
4.	Drawing No.	161 4001 3A
5.	Type of sealing for Container & Lid	Thermal Welding
6.	Electrolyte	Solution of KOH 30 to 35%Concentration.
7.	Cell container material	Nylon 11
8.	Identification of Polarity	'+' Embossing provided on the cell lid. Red and black indication washers provided on the cell'+' & '-' terminals. '+' & '-' Marked on the cell against the respective terminal by screen-printing.
9.	Efficiency of sealing	Each cell checked for leak at a pressure of 14Kpa for 15 seconds and there shall not be any leak.
10.	Cell vent valve	Made of stainless steel with hollow center post covered with rubber sleeve to operate as a Bunsen valve at pressure of 0.2 to 0.6Kg/Cm^2
11.	No. of Electrodes	17 positives & 16 negatives

9.2.9.3 Battery Electrical & Environmental specification :

Sl No	Battery Parameter	Requirement
1.	Type of battery	NCSP B 16060
2.	Dimensions & Weight as per drg. No.161 1000 2B	Length 374.0 ±1.0 mm Top Bottom Over all Length 338.0 ±1.0 mm 407.5 mm (max) Width 129.0 ±1.0 mm 133 mm (max) Height 179.0 ±1.0 mm 182 mm (max) (up to Lid) 18.2 Kgs. Max.
3.	Main power receptacle arrangement with battery	'CANNON' make Part No.MS 3102 R - 24 - 9 SF 80 or equivalent. MS 3470 W 10-6 or equivalent/one thermostat operating at 71°C
4.	Type of container	Made of stainless steel with sand blasted finish.
5.	Battery pack with cell type	20 Cells in series arrangement, replaceable Cell type: NCSPC 16060 – 4
6.	Polarity of identification	'+' Embossing provided on the cell lid. Red and black indication washers provided on the cell '+' & ' - ' terminals. '+' & ' - ' Marked on the cell against the respective terminal by Screen-printing.
7.	Cell insertion force test	The force limit of 20 ±10lbs.
8.	OCV of charged battery	25V Min.
9.	Nominal voltage	24V Min.
10.	Rated Capacity	16AH (at cut off voltage of 20.0V and discharge duration minimum 60 minutes)

<table>
<tr>
<td>11.</td>
<td colspan="2">Individual aircraft load profile:
For HPT – 32 aircraft load profile not available. Alternatively, the following were considered for evaluation.
a) **Capacity discharge profile derived from M/s SAFT battery**
i) For $1C_1$ = 16Amps. load = Should be discharged up to 22.0V as cut off value. Final battery capacity shall be verified as 110% of its rated value (66 minutes)
ii) For $5C_1$ = 80 Amps. Load = Should be discharged up to 20.0V cut off value and battery capacity shall be verified at 100% of the rated value ie 12 minutes)
iii) For $10C_1$ = 160 Amps. Load = Should be discharged up to 17.5 V as cut off value and battery capacity shall be verified 90% of its rated value (ie. 5 min.15 secs).
iv) For $15C_1$ = 240 Amps Load = Should be discharged up to 15 volts as cut off voltage and battery capacity shall be verified 85% of its rated value (ie. 3.3 min +0.0/-30.0secs).

b) **Constant voltage at 12.0V discharge test:**
(Power rating of the battery at 12.0V constant)
i) At 25°C Peak power = 9Kw, shall be discharged for peak value current 700+0.0/-35 Amps. and voltage at 12.0 ±0.5V constant discharge for 15 sec.

ii) For 0°C Peak power = 7.5Kw; Shall be discharged for peak current value of 600Amps.=0.0/-30Amps., and voltage at 12.0 V(±0.5V) constant discharge for 15 seconds.

iii) For -15°C Peak power = 5.95Kw; shall be discharged for peak value of current 500 Amps. +0.0/-25 Amps. and voltage at 12.0V ±0.5V constant discharge for 15 seconds.

iv) For -30°C Peak power = 3.5 Kw; Shall be discharged for peak value of current 275 Amps.+0.0 / -15 Amps. and voltage at 12.0V (±0.5V) Constant discharge for 15 seconds.</td>
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<tr>
<td>12</td>
<td>Constant voltage(14.00) discharge /power rating test at 24°C and -26°C</td>
<td>Fully charged battery shall be discharged at 14 Volts constant for 60 seconds at 24°C temperature and at -26° C temperatures also. During discharge out put current in amperes shall be measured at 300m sec. And 30 secs. Period, for calculation of peak power and power rating (max power delivery) of the battery. These tests are considered essential for aircraft battery. It gives valuable information of battery quality.</td>
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</table>

		Obtained values as a reference from M/s.HBL Battery is at 25°C 17.2Kw peak power at 300 milli seconds and 11.34Kw maximum power at 15 seconds. At -26°C peak power was 7.15Kw (at 300 milli seconds and 5.28Kw maximum power at 15 seconds)

13. General Environmental Test

    a. Humidity & Charge Retention Test
    b. Mechanical shock test (Basic Design)
    c. Vibration Test
    d. Temperature shock Test
    e. Altitude Test
    f. Salt Fog Test
    g. 20 Sec. pulse discharge Test
    h. Medium rate discharge operation position Test
    i. Cycling Test
    j. Temperature rise and float Test
    k. Physical integrity Temperature (85$^{\circ\mathrm{C}}$)
    l. Gas barrier Material Test
    m. Storage Test
    n. Shelf life Test
    o. Main battery receptacle or electric plug Test
    p. Temperature sensor Thermo switches (if) applicable for battery
    q. User Trials

Above tests shall be followed from JSS 6140-10:2007 of Nickel Cadmium for aviation use

9.2.10 3.5AH, 24V, Ni-Cd for emergency battery for KIRAN-1/1A Aircraft

9.2.10.1 Salient Feature

Type of Battery	NICKEL CADMIUM BATTERY TYPE 24NCS-B-3.5-60 with Cell part No. 1.2-NCS-C-3.5-60 Sealed Cylindrical Type
Technology developers and	M/s HBL, Hyderabad
Coordinated RCMA	RCMA (HD)
Nominal voltage & Capacity	24V & 3.5AH
End use	Emergency battery for Kiran MK-I / IA Aircraft
Battery Dimensions & Weight	231 X105 X 75 mm & 3.4 Kgs.
Type Approval No. & Validity	CEMILAC TA No1096. Validity up to 31-12-2009
Technical Specification	QTP Reference No.: HNPS/TA/QTP/3.5AH/ KIRAN/2000 Issue No.II Dt. June, 2004 & JSS:6140-05:2005 for Sealed cylindrical NI-CD batteries
Manufacturing &Quality Assurance Plan	HBL/QAP/NCSC/3.5AH

9.2.10.2 Cell Specifications

Sl.No	Cell Parameter	Requirements
1.	Type of cell	Nickel Cadmium Sealed cylindrical rechargeable cell with automatic releasing safety valve. Type: 1.2 NCS – C – 3.5 – 60
2.	Dimensions & Weight	Over all height : 61.6 ±0.3 MM Diameter : 33.0 ±0.5 mm Weight : 160g (max) As per Drawing No.D 01 1000 4D of M/s HNPS, Hyd
3.	Open Circuit Voltage	1.25V to 1.35V
4.	Nominal Voltage	1.2V
5.	Capacity	3.5AH at 1 hour rate
6.	Safety Device (Self releasing)	An automatic self releasing safety valve shall safety valve for high pressure) be incorporated in each cell, this valve shall be designed to release well below the bursting gas pressure of the cell container and appreciable above the nominal operating pressure.
7.	Cell Leakage	Free of electrolyte leakage will be indicated by the presence of white carbonate deposits at the vent closure area of the cell.
8.	Charging Method	Constant current method as per user handbook of the battery.
9.	Discharge Method	Continuous 3.5 Amps discharge

9.2.10.3 Battery Electrical & Environmental Specifications :

Sl.No	Battery Parameter	Requirements
1.	Type of Battery	24V, 3.5AH Ni-Cd rechargeable Type : 24 - NCS - B - 3.5 - 60
2.	Type of Cells	Sealed Cylindrical Rechargeable Ni-Cd cells with automatic releasing safety Valve Type :1.2 - NCS - C - 3.5 - 60
3.	Type of Connector	Connector assembly with banana type pins as per HNPS Drawing No. D20 1201 3D
4.	Battery Dimensions & Weight	With battery container material Aluminum (IS 7852) as per HNPS Drawing No. D20 1000 2 Overall length : 260 ±1.0 mm Over all width : 105 ±0.5 mm Height : 75 ±1.0 mm Weight : 3.4Kg Max
5.	No. of Cells in battery	20 Nos. for 24V battery connected in Series FIXED(cannot be replaceable) (No Voltage limiting device to avoid cell reversal)
6.	Identification of polarity	+ve terminal marked with depression filled with red color, and –ve terminal marked with depression filled with black color. Battery terminals polarity marking is made both on the container and on connector block.
7.	Electrical leakage	No potential in excess of 0.5 V shall be obtained from the case or non connected terminals to any terminal when measured with a voltmeter.
8.	Workmanship	Shall be processed in such a manner as to confirm in quality and shall be free from defects, no cracking, pitting, corrosion or other deterious effects on battery.
9.	Open circuit Voltage	≤ 26.0 Volts
10.	Initial closed circuit voltage	≤ 24.0 Volts
11.	Battery Nominal Voltage	24.0 Volts

12.	Battery Capacity	For 24V battery with 3.5 Amps load discharge shall give minimum 60 minutes duration at cut of voltage of 20.0 Volts and in case of 12 Volts battery at cut off voltage of 10V.
13.	Charging Method	Constant current with 800ma for 7 hours or any other method as per operating instructions of battery manual.
14.	Voltage at the end of charge	30.0 Volts(Approx) for 24V battery
15.	End voltage on discharge	20.0 Volts for 24V battery
16.	Insulation Resistance	For fully charged battery shall not be less than 100 MΩ tested with 250 Volts megger instrument
17.	High Temperature survival at 70°C	Charged battery shall be stored at 70°C for 72 hours. Bring the battery back to ambient temperature and given 24 hours rest. Then discharge with 12 Amps. Battery shall give 12 minutes duration to a cut off voltage of 20 Volts without getting damaged. (for 12V battery cut off voltage is 10V)
18.	Low Temperature survival at – 40	The battery shall be able to survive at 40°C. After soaking at -40°C for 72 hours bring the battery to ambient and rest for 24 hours. Discharge the battery with 12 amps. The battery shall give minimum of 12 minutes to a cut off voltage of 20 V. (in case of 12V battery cut off voltage is 10V)
19.	Low Temperature performance at -18°C	The battery shall be able to deliver 70% of its initial capacity at 3.5 Amps load after soaking for 16 hours,
20.	High Temperature performance	The battery shall be discharged at high at 55 ±2°C temperature of 55 ±2°C after soaking for 16 to 24 hours. Discharge the battery with a current of 3.5 Amps. The battery shall give at least 70% of nominal capacity.
21.	High Rate Performance	The battery can be discharged for 12 minutes with a load of 12 Amps. at ambient temperature of 25 ±5°C up to an end voltage of 20 Volts and a voltage reading at 5th second shall be not less than 23.0 Volts.
22.	Charge Retention	Charged battery shall be stored for 28 days

		in ambient temperature of 25 ±5°C. After 28 days storage, the battery shall give 70% of its nominal capacity when discharged at 3.5 Amps to an end voltage of 20V (10 V in case of 12V battery for 42 minutes)
23.	Over Charge Test	Fully charged battery shall be able to accept an over charge with 800 milli amps for 24Hrs. or 400 milli amps for 72 hours and temperature of the cells may increase up to max 70°C. After this the battery shall meet 1C_1 rate discharge requirement
24.	Cycle Life	Charge & discharge consists one cycle. The total number of cycles shall not be less than 200 with the following method, battery shall be charge with 800 ma for 6/7 hours and within one-hour discharge with 800 ma up to 20 V (up to 10 V in case of 12V battery) Such cycles shall be performed until the discharge duration is less than 3.75 hours.
25.	Safety Device Operation	To release the gas pressure during any (Automatic Self releasing valve malfunction for each cell while over test by over discharge) discharged with 400 ma to zero voltage and the battery forced discharged with 2.2 Amps until opening of the safety device. During the discharge the cell shall not explode or disintegrate.
26.	Shelf Life (Storage Test)	The battery shall be stored for two years at room temperature in discharged condition. It shall meet the acceptance tests mentioned in table - II given in this document
27.	Temperature of Operation	Battery may be charged, discharged and stored over wide temperature range. Charge : 0 to 45°C Discharge : -20 to 55°C Storage : 25°C
		Mechanical Tests
28.	Topple Test	The battery shall withstand the requirements of the test procedure described Para 15 of details of test procedures given in the QTP
29.	Vibration Test	Fully charged battery shall meet the requirements of

		vibration test as per Procedure described under Para 16 of details of test procedures given in the QTP.
30.	Acceleration Test	The battery shall meet the requirements of the test as described under Para 17 of details of test procedures given in the QTP.
31.	Tropical Exposure Test	Charged battery be subjected for Tropical exposure test of 14 cycles as per Para 18 of details of test procedures given in the QTP.
32.	Altitude Test	The charged battery shall be subjected to altitude test as per Para 19 of details of test procedures given in the QTP.
33.	Cell Reversal Test (Created mal treatment by short circuit method)	The battery (series connected cells can be driven into reversal by others) shall be short circuited for 60 seconds and it shall not get damaged permanently. Safety vent shall operate on all 20 cells without causing damage to cell body except the self releasing vent opens for release of internal gas pressure
34.	User Trials	The battery shall meet ground integration checks like physical fitment in the aircraft, and flight trials as per Flight Test Schedule issued by competent authority
35.	Production Acceptance Test Procedures (ATP)	Quality conformance inspection & acceptance test procedures may be as per Table – II of this QTP.

9.2.11 45AH, 22.5V, Silver Oxide Zinc battery for MIG-21 Aircraft

9.2.11.1 Salient Features

Type of Battery	SILVER OXIDE ZINC BATTREY TYPE: HBL-SZ-45AH
Technology developers and Coordinated RCMA	M/s HBL, Hyderabad RCMA (HD)
Nominal voltage & Capacity	22.5 V & 45AH
End use	MIG Aircraft
Battery Dimensions & Weight	432 ±1, 130 + 2.5 -1.5, 225 ±2 mm & 17.9 Kgs.
Type Approval No. & Validity	**CEMILAC TA No 605.** Validity up to 30-06-09
Technical Specification	i) Test Schedule No.TS/IND/72/17 on aircraft storage Specification Battery 15 STS S-45B and ii) RCMA(Hyd) issued additional evaluation letters

Note : Same battery is cleared for KA-25 H/C vide CRE(H/C)/1341/2 dt.18/6/1993

9.2.11.2 Cell Specification

Cell Parameter	Requirement
Type of Cell and its chemistry	Vented type Silver Oxide Zinc Rechargeable, $Ag + Zn\ (OH)_2 \overset{(Charged)}{\underset{(Discharged)}{\leftrightarrow}} Ago + Zn + H_2O$
Open Circuit Voltage of cell (OCV)	1.86+0.02V
Nominal voltage under load (OLV)	1.5V with rated 45Amp. load for 45AH capacity battery
Recommended charging cutoff voltage	2.05V
Recommended discharge cutoff voltage	1.0V
Physical dimensions in m.m. and Weight in Kgs.	159±1 (H); 55±0.5 (W); 51.5±0.5 (Thickness) 775 gms. (Weight) M/s.HAL, Hyd drg. No.E120003A1 type 15SZ - 45A, M/s.HBL, Hyd drg. No.45041003C type HBLSZ45AH-1
Electrolyte	KOH with 1.42 specific gravity
Cell container material	Nylon-11
Identification of Polarity	'+' embossing provided in the cell lid and '+' & '-' marked on the cell against respective terminals by screen printing
Efficiency of ceiling	Each cell checked for leak at pressure of 14KPA for 15 Sec. and there shall not be any leakage
Cell vent valve	Made of stainless steel with hollow center port covered with rubber sleeve to operate as a Bunsen valve at pressure of 0.2 to 0.0.6Kg./ Cm2
No of electrodes (Plates)	Alternatively placed 21 pieces of positive electrodes having with silver powder and sintered type & 20 pieces of negative electrodes having with Zinc oxide on metallic zinc plates
Separator systems	Polyimide separator along with regenerated cellulose membrane / cellophane (C-19 from Yardney Techn.Prod..,Inc with silver treated)
Internal resistance of cell	Very low, varying with temperature and rate of discharge
Di-electric test	1500V RMS or DC for 60 seconds

9.2.11.3 Battery Electrical & Environmental specification

Battery Parameter	Requirement
Type of battery	Rechargeable vented 45AH Silver Zinc cells having 15 cells in a battery pack
Overall physical dimensions of battery and weight	432±1 ; 130+ 2.5 – 1.5 ; 225±2 mm In field condition 17.9Kg. and un-field condition 15.2Kg. M/s.HBL, Hyderabad make : Drawing No.45010002D type HBL-SZ-45AH
Type of connector	Two pin terminals and socket plug type arranged in a dummy cell to interface (HBL TYPE) in MIG Aircraft. This shall be evaluated separately as per standard MS 3509 for its requirements
Battery Container	Stainless steel
OCV of charged battery	27.8V
Nominal voltage under load and its capacity rating	22.5V with 45Amp load with a cutoff voltage of 20V for 45AH capacity
Cell insertion force test	9.08±4.54Kg.
Charging time (Nominal input for battery)	a) DC source of 28.5V to 30V constant potential charging method for 3 hours or till the charging current become 3A b) DC source of 35V, with 4.5 constant current method for 14 hours maximum
Battery rating / output performance at room temperature	Given in Table 11.1.3.3(a) for typical discharges
Electrical power budget requirement for MIG-21 Bison Aircraft & its variants	Given in Table 11.1.3.3(b) for engine start profile a) **Starting mode parameters:** Staring current from 150Amp to 1000Amp and voltage dip is 9 to 19V for each start (HDD). Three such autonomous series starts are capable within 3 minutes interval in between two engine starts shown in section 11.1.3.4. b) **Cycle life :** 60 cycles of operation with 3HDD discharges c) **Service period:** 9 months with KOH filled condition of battery 36 months for dry unfilled condition of storage period 180 flying hrs. or 60 flights with three HDD autonomous series starts d) **Emergency load test :** capable of 50Amp load discharge up to 21V cutoff and duration of discharge not less than 20 minutes
Insulation resistance	Battery terminal to container body shall not be less

	than 20Mohms / 2Mohms per cell when tested with 500V DC Megger
Charge retention	After storing for 30 days in charged condition at 25°C temperature battery should give minimum discharged capacity of 40AH without any additional charging
Electrolyte retention	Electrolyte should not spill out when battery is inverted per 30 minutes after filling KOH and when altitude is 25 Kilo meter operation for 1 minute
Vibration test (For MIG Aircraft profile)	a) **Vibration stability**: Requirements from 10Hz to 200Hz, 200Hz to multiples of 10Hz per 1.5 minute at each frequency and with overload of 2.5 to 4.5g. b) **Vibration resistance** : Battery should with stand i) 30Hz for 9 Hrs 15 minutes with overload of 2.7g. ii) 70Hz for 4 Hrs with overload of 3g. iii) 200Hz for 11 Hrs. with overload 4.5g
Acceleration test	The following each loading for 1 minute duration shall be imposed Forward acceleration : 11g. Backward acceleration : 11g. Side acceleration : 6.5g. Upward acceleration : 6.5g. Downward acceleration : 17.5g. Crash case : forward deceleration of 25g. Lateral acceleration of +4.8
Operating temperature range and Altitude level	With external temperature of +50°C to -50°C, for operation less than -50°C battery should work with heating jackets and altitude up to 25 Kms.
Impact test	Total of 10,000 impacts at the rate of 50 impacts per minute and an overload of 4g.
Humidity test	48Hrs. at RH 95% and temperature 40°C
Salt Corrosion test	48Hrs. as per procedure 2 test No.9 section 4 of JSS 55555
User trials	Battery shall meet ground integration checks in the aircraft and flight trials as per flight test schedule issued vide TS/IND/72/42 issued by RCMA(Nasik)

9.2.11.4 Electrical characteristics of Silver Oxide Zinc 45AH batteries

Discharge Rates :

Battery Parameter	10 Hr Rate	5 Hr Rate	1 Hr Rate
Capacity Ah	45 40	45 40	45
Discharge Current	4.5	9	45
Final Voltage per Cell V	1.0	1.0	1.0
Final Voltage per Battery	15	15	20

Engine Starting Rates for MiG-21 Bison and its variants Aircraft:

Three discharges with an interval of 3 minutes	100% capacity		85% capacity	
	Current in Amps		Current in Amps	
	Peak at 0 seconds	At 20 sec	Peak at 0 seconds	At 20 sec
1st Discharge	1035 A	815 A	875 A	700 A
2nd Discharge	960 A	740 A	820 A	645 A
3rd Discharge	885 A	675 A	770 A	600 A

NOTE:

a) During Engine starts maximum permissible discharge current is 1200 Amp. and duration for 20 Sec.

b) Interval between the starting for each engine starts is permitted 3 minutes.

c) It is allowed to store charged batteries more than 15 days (after 6 month operation), if their capacity is at least 40 Ah before setting on the storage

9.2.12 2.5AH,14.4V, Lithium Thionyl Chloride battery for PRB (ECIL) Sets

9.2.12.1 Salient Features

Type of Battery	Lithium Thionyl Chloride 4 cell pack TYPE: 4/10 & 4/27
Technology developers and Coordinated RCMA	M/s HBL, Hyderabad RCMA (HD)
Nominal voltage & Capacity	14.6 V & 2.5AH
End use	SARBE and PRB Radio sets
Battery Dimensions & Weight	Dia 36 x102 mm & 185 Grams
Type Approval No. & Validity	CEMILAC TA No 968. Validity up to 30-06-2012
Technical Specification	QTP Reference No.:HNPS/TA/QTP/PRB/001 Issue No.1 Dt. Sep. 2001

9.2.12.2 Technical Specification Of Lithium Thionyl Chloride ($LiSOCl_2$) Battery

(PRIMARY, 4 CELLS PACK 14.4V) FOR USE PRB RADIO SETS (PRB= MEANS, S.A.R.B.E RADIO SET OR ECIL RADIO SET OR UNITRON RADIO SET)

9.2.12.3 CELL SPECIFICATION

1)	Physical Dimensions	:Dia = 25.5mm, Height=24mm
2)	Cell container	:SS
3)	Cell	:Hermetically sealed type
4)	Open circuit voltage (OCV)	:3.6 Volts (Min.)
5)	On load voltage (OLV)	:3.4 Volts at rated discharge
6)	Max. Continuous current	:250mA (Cell is capable of withstanding occasional pulse drain of 500mA
7)	Weight	:30grams (Approx.)

9.2.12.4 Battery Specification For Following P.R.B Radio Sets

	Battery Parameter	**PRB sets of SARBE sets (of U.K)**	**PRB sets of (ECIL & Unitron)**
A.	Battery pack, general physical dimensions and workmanship	4 cell pack [Type 4/10] Weight :185 g(Max) Dia base : 28±0.5mm Nominal Knob :36±0.5mm Nominal Length :100.5±0.5mm Battery container: Nylon Threads details : 24TPI, 3 leads, 3 starts	4 cell pack [Type 4/27] Weight : 185g (Max.) Dia base : 28±0.5mm Nominal Knob : 36±0.5mm Nominal Length : 100.5±0.5mm Battery container: Nylon Threads details: M30xl, 3 leads, 3 starts
B.	ELECTRICAL		
1.	Battery type	Lithium Thionly chloride	Lithium Thionly chloride
2.	No. of Cells	4(four) per pack in series arranged	4(four) per pack in series arranged

3.	Battery Open circuit voltage (OCV)	14.4 Volts(Min.)	14.4 Volts(Min.)
4.	On load voltage (OLV)	13 V at ambient temp. across a load of 225 Ω at 120 sec. after (initial voltage delay period) applying a load.	12.4 V at ambient temp. across a load of 208 Ω at 120 sec. after (initial voltage delay period) applying a load.
5.	Storage life (shelf life)	3 Years (min) at storage temp. of 20°C±5°C	3 Years (min) at storage temp. of 20°C±5°C
6.	Battery continuous operating service life discharge test at various temp.	Across 225Ω loads & cut-off voltage of 10.5V Ambient : 24 Hrs -10°C : 18 Hrs +55°C : 18 Hrs	Across 208Ω loads & cut-off voltage of 10.5V Ambient : 24 Hrs -10°C : 18 Hrs +55°C : 18 Hrs
7.	Cut-off voltage of battery for discharge	10.5 V	9.4V
8.	Operating temp. range	-10°C to +55°C	-10°C to +55°C
9.	Safety feature (short circuit protection)	Electrical fuse (500mA) is provided in series (not replaceable) while battery pack assembly itself	Electrical fuse (500mA) is provided in series (not replaceable) while battery pack assembly itself
10.	Dropper resistor	10Ω, 0.25 Watts±5% provided to bring down the OLV	27Ω, 0.25 watts ±5% provided to bring down the OLV
11.	Insulation resistance	Not less than 2 MΩ	Not less than 2 MΩ

C.	ENVIRONMENTAL SPECIFICATIONS	
1.	Vibration (initial resonance)	As per MIL-E-5400T, curve III, Fig.2 sheet 1 of 3 and duration indicated below: Vibration Severity Freq (Hz) — Vibration Severity 5-14 — 0.10″ double amplitude 14-23 — ±1 g 23-52 — 0.036″ double amplitude 52-500 — ±5 g Sweep rate: Logarithmic and not exceeding one octave per minute, Sweep time 5-500-5 Hz is 15 minutes.
2.	Vibration cycling endurance duration	Axis — Duration — Frequency (Hz) Fore and after — 3 Hrs — 5-500 Lateral — 3 Hrs — 5-500 Vertical — 3 Hrs — 50-500
3.	Final resonance search test	Vibration Severity Freq (Hz) — Vibration Severity 5-14 — 0.10″ double amplitude 14-23 — ±1 g 23-52 — 0.036″ double amplitude 52-500 — ±5 g Sweep rate: Logarithmic and not exceeding one octave per minute, sweep time 5-500-5 Hz is 15 minutes. The difference resonance frequency observed shall be within 20%.In above tests in all vibrations, after conclusion of this test visual examination and electrical tests
4.	Acceleration test	Along each of both directions of all three mutually perpendicular axis (total six) subjected to 13g,for a period of 10 sec.,as per test No. 1 of JSS 55555 Procedure-I after conclusion of this test visual examination and electrical parameters .
5.	Bump test	As per test No. 5 of JSS 55555 shall be 4000 ± 10 bumps at 60-90 bumps/minutes with peak acceleration of 400 ± 40 m/sec after conclusion of this test, visual examination and electrical parameters

6.	Mechanical Shock test	As per test No.24, Procedure 2, of JSS 55555.Two shocks in each of both directions, along the three mutually perpendicular axes(Total 12 shocks).Shock pulse shall be half sine wave (as per fig.3) with peak amplitude A=300m/sec , duration=11m sec, conclusion this test, visual examination and electrical parameters
7.	Dry heat storage test (High temp. survival)	After conditioning at 70±2 C for 72 Hrs and back to room temperature allowed recovery time and shall comply with examination and electrical parameters
8.	Low temperature Storage altitude test	-30 C with pressure of 4.4 Kpa. After conditioning at minus 30 C±3 C for 20 Hrs and then with air pressure in chamber reduced to 4.4 Kpa for further 4 hours and then back to room temperature (as per clause 5.4.2), the battery shall comply with electrical parameters in QTP
9.	High temperature operation test	After 2 hours storage at +55 degC ±2degC and then shall comply with electrical parameters in QTP
10.	High temperature Safety Hazardous Storage test (at +85degC	The battery shall be kept at 85±2degC for 2 hours after thermal stabilization. The battery shall not explode or leak or internal heat during test and visual examination
11.	Low temperature Operation test (at -10degC):	After conditioning of battery for 2 hours at minus 10±2degC the battery shall with electrical parameters in QTP and discharge as per test 5.2.4 shall be carried out for 18 hours.
12.	Water immersion test	As per test No. 19 of JSS 55555 severity G and subsequently visual examination and electrical test as per QTP shall comply with the requirements.
13.	Tropical exposure (Damp heat cycling test)	As per test JSS 55555. As per test No. 27 test conclusion-B-14 cycles, after conclusion visual examination and electrical test as per QTP.
14.	Salt corrosion test	): As per test JSS 55555 (3 cycles, 3 days) test No: 9 procedure 2, after conclusion visual examination and electrical tests of QTP.
15.	Safety features tests Or (hazard evaluation tests)	i) Short circuit test for 2 sec. ii) Over discharge test-below the cut-off voltage, (beyond the rated capacity). iii) High temperature (+85°C) Storage (exposure) test (Thermal stability test) for 2 hours.

		At conclusion of above tests there shall be no explode or leak of electrolyte, or Internal heat or any damage
16.	Mould growth test	As per JSS 55555, test No. 21 at the conclusion, visual examination for mould growth and electrical parameters as QTP.
17.	Operational life test with PRB sets	With PRB radio set PRB shall be operated with this battery and record the functional parameters of respective PRB's and Beacon RF output etc. shall operate at least 24 hours duration continuously.
18.	Shelf life Storage test	Battery shall be stored for min 3 years in normal packed condition, after conclusion electrical tests shall be comply as per Para visual examination and electrical tests of QTP for low temperature at minus 10degC operation shall meet the respective battery specification.
19.	Acceptance test procedures for product delivery	The following are the 100% inspection for all batteries i. Visual examination, labeling, marking, physical dimensions etc, fitment with dummy PRB box. ii. Insulation check. iii. Insulation resistance iv. Open Circuit Voltage (OLV) v. Voltage test under load (OLV) (after 120 sec elapse initial voltage delay) vi. One sample of battery per lot hall be for safety feature test (+85 °C) storage test. vii. One sample of battery per lot shall be minus 10°C operations for capacity discharge test. viii. Certification from manufacture of age of cells ix. Certification from manufacture of columbic ratio. x. Certification from manufacture for water content. xi. Certification of manufacture process traceability.

SEQUENCE OF QUALIFICATION TYPE APPROVAL TESTS AND SAMPLE DISTRIBUTION SHOWN FOR LITHIUM BATTERY FOR PRB APPLICATIONS DEVELOPED AND MANUFACTURED BY M/S. HBL NIFE POWER SYSTEMS LIMITED, HYDERABAD

NUMBER OF SAMPLES AND SEQUENCE OF TEST

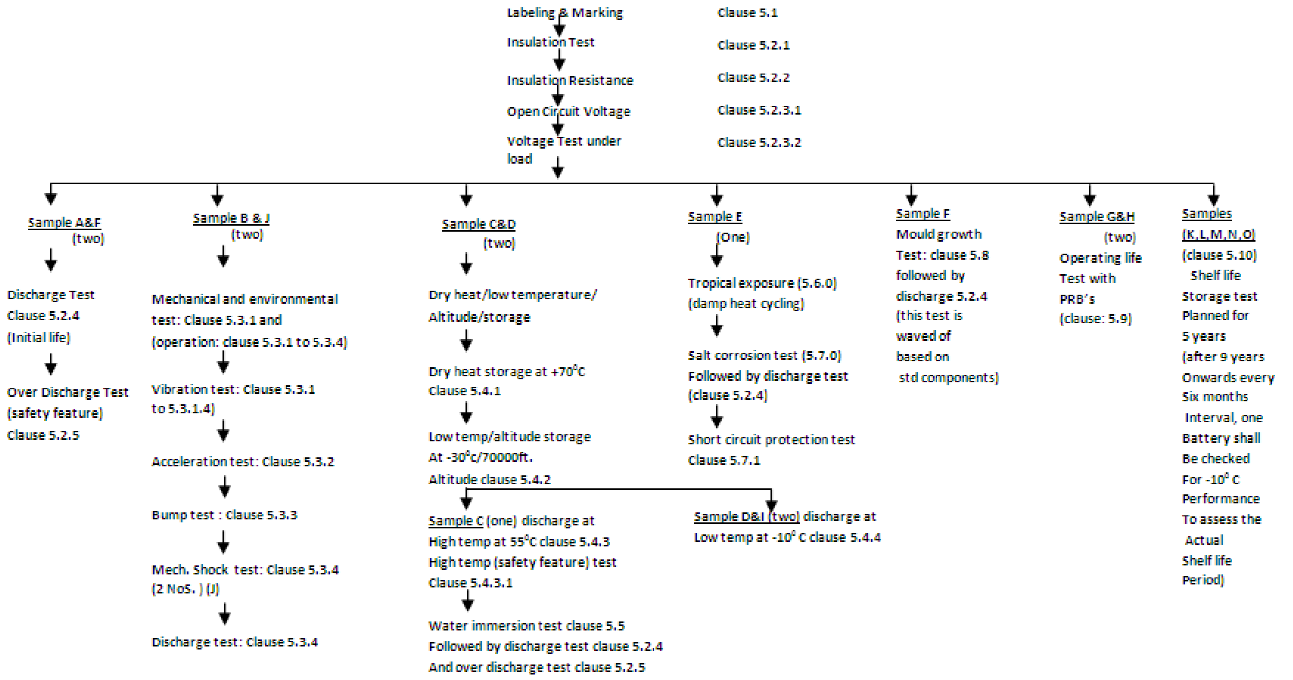
A. No. of samples: a) 10 Samples marked A,B,C,D,E,F,G,H,I,J for Test No. 5.1 to 5.9

b) 5 Samples for Test No. 5.10 marked as K, L, M, N, O to assess shelf life

B. Test Sequence

All fifteen samples marked A,B,C,D,E,F,G,H,I,J,K,L,M,N,O

Visual Examination, Dimension, Check and weight.



Note : Samples batteries of A,B,C,D,G,are the 4/27 type configuration and sample batteries of F,J,I,H,K,L,M,N,O are the 4/10 type configuration. Both the type of Batteries having common cells and only difference in the integrated series resistor value and mechanical threads in the final assembly of the battery.

9.2.13 30AH, 24V Ni-Cd (Si/Pbe) Battery for ALH

9.2.13.1 Salient Features

Type of Battery	NICKEL CADMIUM BATTERY TYPE: NCSP B 30060 RM with Cell part No. NCSPC 30060RM
Technology developers and	M/s HBL, Hyderabad
Coordinated RCMA	RCMA (HD)
Nominal voltage & Capacity	24V & 30 AH
End use	ALH
Battery Dimensions & Weight	406X120X215 mm & 24 Kgs.
Type Approval No. & Validity	Under Evaluation, SOF CLEARED
Technical Specification	QTP Reference No.:HNPS/TA/QTP/30AH/ALH / 2006. Issue No.I Dt. Sept, 2006 JSS:6140-10:2007 for NI-CD batteries
Manufacturing & Quality Assurance Plan	HBL/NC/PS/PBE/07 Jan.2007

9.2.13.2 Cell Specification

1	a) Type of cell b) Rated voltage & Capacity	Vented Nickel Cadmium cell (Si / PBE) Type : NCSPC 30060 RM 1.2V, 30Ah (at one hour rate)
2	OCV of Charged cell	1.25V Min
3	Physical dimensions Weight	Height up to terminal top: 200.0 -0.5 mm Height up to cell lid top : 183.5 –0.5 mm Length : 58.0 ±0.2 mm Width : 36.5 ±0.2 mm Weight : 980 ±20 gm Torque requirement Bottom nut : 5 Nm Top nut : 8 Nm
4	Drawing No.	302 5001 3A
5	Type of sealing for Container & Lid	Thermal Welding
6	Electrolyte	Solution of KOH 30 to 35% concentrations.
7	Cell container material	Nylon-11 (302 5112 3A)
8	Identification of Polarity cell Identification	'+' Embossing provided on the cell lid. Red and blue indication bushes provided on the cell '+' & ' -' terminals. '+' & ' - ' Marked on the cell against the respective terminal by Screen-printing. Each cell shall be marked with manufacturer name, part No, date& lot code imposed the cell container
9	Efficiency of sealing	Each cell checked for leak at a pressure of 14Kpa for 15 seconds and there shall not be any leak.
10	Cell vent valve	Made of stainless steel with hollow center post covered with rubber sleeve to operate as Bunsen valve at pressure of 0.2 to 0.6Kg/Cm^2
11	Separator	Polyamide (non-oven) – two layers
12	Gas barrier	Celgard - 3400
13	Cell baffle	Nylon 6
14	Electrode design (Si/PBE)	20 plates of Sintered positive with nickel hydroxide & 20 plates of plastic bonded negative cadmium oxide electrodes.
15	Polarity of plates	In relation to the terminals, polarity of the plates shall be verified physically during stack assembly and final inspection on cell terminals with polarity identification markings.

9.2.13.3 Battery Specifications for ALH

Sl.No.	Battery Parameter	Requirements
1	Battery Type & Battery Drawing No a) Number of cells b) Battery inter face/ Connector Assembly c) Temperature switch d) Battery container	NCSPB 30060 RM 302 1000 2A 20 Nos connected in series, replaceable As per MS 3509 standard (Rebling plastics No.7002, PENNA) As per Drawing No. 302 3000 3A Thermal sensor normally in open conditions and close at 65±2.8°C Made of stainless steel
2	OCV of charged battery	25V Minimum
3	Rated Capacity	30AH (When discharged with 30Ato a cutoff voltage of 20V, the battery shall give a minimum duration of 60 min)
4	Rated voltage	24Volts
5	Physical Examination	The battery, cells and the components shall be physically examined for general condition construction and work man ship as per the relevant SOP drawings.
6	Physical Dimensions & Weight	As per drawing No. 302 1000 2B Length (Bottom) 414.0 mm Max Width (Bottom) 120.0 mm Max. Width over all 140.0 mm Height over all 215.0 mm Max Weight: 24Kg.Max.
7	Markings	Polarity of battery terminals shall be as per markings on the connector (Drg.No.302 30003A) Identification labels are provided on the battery and lid. Markings as per Drg.Nos.302 1001 4A & 302 1002 4A (as per clause No.10.4.3 of JSS 6140-10:2007)
8	Handle Strength Test:	Swing each handle out from the container against its stop. Apply a force of 600 Newton's (135 pounds) at the handle's grasp. Apply the force in a direction of maximum torque acting on the handle stop. Continuously apply the force for not less than 5 minutes. Handle of the battery shall not show any evidence of breaking away from the container or other damages.

<table>
<tr><td>9</td><td>Initial Capacity discharge
(C rate discharge):</td><td>30AH (with 30 Amps load, discharge duration shall be 60 minutes to a cut off voltage of 20Volts).</td></tr>
<tr><td>10</td><td>Electrical Power Requirements:
a) Engine Starting requirements</td><td>Total number of 10 engine starts is required.
Two batteries with 80% SOC (state of charge) in parallel shall be subjected to a/c engine cranking profile given in Figure 1 with an interval of 30 seconds between two starts. After 5 consecutive starts there shall be a rest period of 15 minutes followed by remaining 5 starts with 30 seconds interval as above. Battery terminal voltage during all the starts should be greater than 16 volts during engine starts.</td></tr>
<tr><td></td><td></td><td><table>
<tr><th>Time (Seconds)</th><th>Current (Amps)</th><th>Time (Seconds)</th><th>Current (Amps)</th></tr>
<tr><td>0-1</td><td>200</td><td>7-8</td><td>400</td></tr>
<tr><td>1-2</td><td>300</td><td>8-9</td><td>350</td></tr>
<tr><td>2-3</td><td>500</td><td>9-10</td><td>300</td></tr>
<tr><td>3-4</td><td>700</td><td>10-20</td><td>250</td></tr>
<tr><td>4-5</td><td>850</td><td>20-30</td><td>225</td></tr>
<tr><td>5-6</td><td>700</td><td>30-40</td><td>200</td></tr>
<tr><td>6-7</td><td>600</td><td>40-50</td><td>200</td></tr>
</table></td></tr>
<tr><td></td><td></td><td>The test shall be repeated at –30°C for 5 starts as given above. The battery terminal voltage should be greater than 16 volts during the first three starts and during 4th &5th starts battery terminal voltage should be more than 15 V</td></tr>
<tr><td></td><td>b) Emergency Load requirement:</td><td>Two batteries with 80% SOC (state of charge) in parallel shall be discharged with a fixed resistor of 160±5 milli Ohms till the battery terminal voltage drops to 20 volts. The batteries shall give a minimum duration of 20 minutes.</td></tr>
<tr><td></td><td>c) Instantaneous Peak Power, Power Delivery and Internal Resistance</td><td>Fully charged batteries shall be verified for internal resistance at 25±C, - 10°C & - 30°C. The internal resistance values shall be 9 milli ohms, 11 milli ohms and17 milli ohms at respective temperatures. Power behavior under 25°C and –30°C test conditions, the currents ensuring while discharge from fully charged state at half the OCV (OCV/2=say 12V constant) for 15 seconds in above temperature conditions are to be evaluated. From this discharge current and battery voltage, power calculation and internal resistance values are derived. The battery shall meet the requirements as given in the table below. The internal resistance values given in the table below are the maximum values for the battery.</td></tr>
</table>

<table>
<tr><td></td><td></td><td>
<table>
<tr><th></th><th colspan="3">Peak power
(at 300 milli seconds)
Instantaneous Peak values</th></tr>
<tr><th></th><th>I_i(min)</th><th>P_i(min)</th><th>r_i (max)</th></tr>
<tr><td>At 25°C</td><td>950 A</td><td>12.5KW</td><td>14 mΩ</td></tr>
<tr><td>At –30°C</td><td>445 A</td><td>6 KW</td><td>29 mΩ</td></tr>
<tr><th></th><th colspan="3">Power rating (at 15 seconds)
Steady state values</th></tr>
<tr><td></td><td>I_{mp}(min</td><td>P_m(min)</td><td>r_{em}(max)</td></tr>
<tr><td>At 25°C</td><td>675 A</td><td>9 KW</td><td>19 mΩ</td></tr>
<tr><td>At–30°C</td><td>315 A</td><td>4 KW</td><td>41 mΩ</td></tr>
</table>

P = Power expressed in Watts = $V * I_i$;
or $I^2r = V * I_i$ Therefore $r = \frac{V}{I}$
$r_i = \frac{OCV/2}{I_i}$; $r_{em} = \frac{OCV/2}{I_{mp}}$
P_i = Instantaneous Peak Power =Instantaneous current (I_i) at 300 milli secs x $\frac{OCV}{2}$
P_{max} = Maximum power = Steady state current (I_{mp}) at 15 seconds X $\frac{OCV}{2}$
I_i = instantaneous peak current at 300 milli seconds
I_{mp} = Steady state current at 15 seconds
OCV = Battery open circuit voltage
r_i = Instantaneous (breakaway) resistance in Ohms
r_{em} = effective internal resistance in Ohms
</td></tr>
<tr><td></td><td>d) Battery Rating</td><td>Battery service life with different ratings of discharges at 25°C and – 30°C: On fully charged batteries, discharges at the flowing rates and duration up to cut off voltages as specified in the table below shall be carried out.</td></tr>
</table>

<table>
<tr><td></td><td></td><td>
<table>
<tr><td>Discharge Rate</td><td colspan="2">Discharge Time (minimum)</td></tr>
<tr><td></td><td>At RT (+25°C)</td><td>At (-30°C)</td></tr>
<tr><td>$1C_1$ (30 amps)</td><td>60 min (cut off voltage 20 V)</td><td>46 min (cut off voltage 20 V)</td></tr>
<tr><td>$5C_1$(150 amps)</td><td>10.5 min (cut off voltage 16 V)</td><td>7.4 min (cut off voltage 14 V)</td></tr>
<tr><td>$10C_1$(300 amps)</td><td>4.8 min (cut off voltage 16 V)</td><td>1.2 min (cut off voltage 14 V)</td></tr>
<tr><td>$15C_1$(450 amps)</td><td>2.2 min(cut off voltage of 16 V)</td><td>0.5 min (cut off voltage of 14V)</td></tr>
<tr><td>$30C_1$(900 amps)</td><td>1 min(cut off voltage of 10 V)</td><td>-----------------</td></tr>
</table>
</td></tr>
<tr><td></td><td>e) CP charge capability at – 18°C</td><td>Charged battery shall be verified for capacity at the C rate. The battery shall be stabilized at least for 16 hours at –18°C ± 2°C and then charged at 28.5 volts for 3 hours at this temperature. The current shall be noted during charging. The battery shall be brought to room temperature and carry out capacity test at C rate (30 amps). The minimum duration of discharge to a cut off voltage of 20 volts shall not be less than 10 minutes.</td></tr>
<tr><td>11</td><td>Constant Voltage (14V) Discharge Test</td><td>This test shall be carried out as per clause No.10.4.20 of JSS 6140-10:2007.CP Charged battery shall be subjected to a constant voltage discharge for 60 seconds. The battery discharge voltage for the initial 5 seconds shall be 14 ± 0.5V and for the remaining period of 55 seconds, it shall be 14 ±0.1V. The discharge current at 1.0, 5.0, 15.0 and 60.0 seconds after the start of discharge shall not be less than that specified in the table given below. The battery shall also meet the environmental requirements after charge and discharge.
<table>
<tr><th>CP discharge time</th><th>Current at 24±2°C</th><th>Current at – 26°C</th></tr>
<tr><td>01 second</td><td>1120 amps</td><td>500 amps</td></tr>
<tr><td>05 seconds</td><td>1030 amps</td><td>470 amps</td></tr>
<tr><td>15 seconds</td><td>940 amps</td><td>490 amps</td></tr>
<tr><td>60 seconds</td><td>690 amps</td><td>390 amps</td></tr>
</table>
</td></tr>
<tr><td>12</td><td>Vibration and Acceleration Test:
a) Resonance search test</td><td>Shall be carried out as per clause 10.4.14 of JSS 6140-10:2007
Test shall be carried out at one octave per minute between 5 Hz to 500 Hz and 0.5 peak acceleration to identify the resonance frequency before and after exposure to main</td></tr>
</table>

	b) Vibration Test:	vibration test. CP Charged battery shall be subjected to sine on random vibration as per MIL-STD-810F, test method 514.5-table 514.5C-IV(general condition), Fig 514.5C-10. For vibration test curve main rotor frequency = 21 Hz is the fundamental frequency
	c) Acceleration Test	and other harmonic frequencies with corresponding amplitudes are given below. Frequency HZ Amplitude g f_1 5.23 A_1 0.128 f_2 (4 f_1) 21 A_2 2.1 f_3(2 f2) 42 A_3 2.3 f_4(3 f_2) 63 A_4 1.5 f_t = 500Hz ; f_x = f_1 w_0 = 0.0010 g^2/Hz ; w_1 = 0.010 g^2/Hz Total test duration: 4 hours per axis. Upon completion of vibration test on each axis, constant potential charge the battery. Discharge the battery at 30 C_1 rate for 60±1 seconds. The battery shall meet the given requirements given therein. Acceleration test shall be carried out as per MIL-810F, test method 513.5 Direction **Structural** **Operational** UP 10.5g 7g DOWN 4.5g 3g FORE &AFT 4g 2g LATERAL R&L 6g 4g
13	High rate discharge at –30°C	This test shall be carried out as per clause No. 5.4.1.2 of BSEN 2570 Soak the battery at –30°C for 16 hours. a) The battery shall be discharged at 1C_1 rate to an end voltage of 20.0V per battery shall give the discharge duration of 46 minutes. b) Also verify 10C(300Amps) discharge upto14 Volts. The battery shall give a duration of not less than 1.2 minutes.

14	Low temperature performance at -45°C	This test shall be carried out as per MIL-STD-810F, Method 502.4, and Procedure II.Fully charged battery shall be soaked at –45° C and discharge the battery at $1C_1$ (30A) at –45° C till the battery terminal voltage reaches to 20V. Record the terminal voltage at every one minute during discharge and each cell voltage at the end of discharge. Note down the total time duration and observe any abnormalities during discharge. There shall be no mechanical distortion, no damage of either cells or batteries, no radical fluctuations in current or voltage, no electrolyte leakage, and no breakdown of insulation and thermal runaway. The battery shall give a minimum of 10 minutes duration during $1C_1$ rate discharge. (derating is allowed 20% of 1C rate at room temperature)
15	Sand and Dust Test	Shall be carried out as per MIL-STD 810F, Method 510.4, and Procedure III. (a) With the test battery in the test chamber, adjust the temperature to 23°C or as otherwise specified, and the relative humidity to less than 30%. Maintain RH at less than 30% through out the test. (b) Following stabilization at this temperature, introduce the required quantity of dust in to the test section for 60±5 S. (c) Allow the dust to settle for 59 minutes. (d) Verify the dust fall out rate and if required, repeat steps (b) and (c) above for required number of cycles as determined (dust settlement rate of 6 g/m^2/day). (e) Inspect the test item for dust penetration, giving special attention to bearings, grease seals, lubricants, filters, ventilation points etc and document the results. (f) Determine if dust has penetrated in sufficient quantity to cause binding, clogging, seizure or blocking of moving parts, non operation contacts or relays or formation of electrically conductive bridges with resulting shorts and determine if protective coatings were compromised.
16	Thermal Sensor Test	This test shall be carried out as per RCMA (HD) letter No. RCMA(HD)/767/1/ALH/NI-CD/ 30AH dated 12 Oct 06 for a. Physical inspection b. Dielectric strength and insulation resistance c. Opening and closing of thermostat at 65°C d. Chemical resistance withstand in KOH for 168 hours at 65°C

17. General Environmental Test

a. Humidity & Charge Retention Test
b. Mechanical shock test (Basic Design)
c. Vibration Test
d. Temperature shock Test
e. Altitude Test
f. Salt Fog Test
g. 20 Sec. pulse discharge Test
h. Medium rate discharge operation position Test
i. Cycling Test
j. Temperature rise and float Test
k. Physical integrity Temperature (85℃)
l. Gas barrier Material Test
m. Storage Test
n. Shelf life Test
o. Main battery receptacle or electric plug Test
p. Temperature sensor Thermo switches (if) applicable for battery
q. User Trials

Above tests shall be followed from JSS 6140-10:2007 of Nickel Cadmium for aviation use

9.2.14 27AH, 24V Ni-Cd (Sintered) Battery for DORNIER-228 Aircraft

9.2.14.1 Salient Features

Type of Battery	NICKEL CADMIUM BATTERY TYPE: NCSPB 27060 with Cell part No. NCSPC 27060-5
Technology developers and Coordinated RCMA	M/s HBL, Hyderabad RCMA (HD)
Nominal voltage & Capacity	24V & 27AH
End use	Dornier Aircraft -228
Battery Dimensions & Weight	247 X252.5 X192 mm & 28 Kgs.
Type Approval No. & Validity	PC extension Issued vide RCMA (HD)/767/1/DO-228 dated 25/02/2008 Validity up to 24/02/2009
Technical Specification	i) QTP Reference No.:HNPS/TA/QTP/27AH/ DORNIER/Specification 2007 Issue No.II Dt. Nov, 2007 ii) JSS:6140-10:2007 for NI-CD batteries
Manufacturing & Quality Assurance Plan	HBL/NC/PS/PS/2006 , Dt- Sept.2006

9.2.14.2 Cell Specifications

	Cell Parameter		Requirements
1	a) Type of cell	:	HBL Type: NCSPC 27060 -5,vented, Ni-Cd
	b) Nominal voltage & capacity	:	1.2V, 27AH
2	OCV of Charged cell	:	1.25V Min.
3	Physical dimensions	:	Height up to terminal top : 178.0 ±1.0mm Height up to cell lid top : 162.0-1.0 mm Length : 79.0 ±0.5 mm Width : 34.5 ±0.5 mm Weight : 1.12 ±5% Kg
4	Drawing No.	:	HBL Drawing No.271 5001 3A
5	Type of sealing for Container & Lid	:	Thermal welding
6	Electrolyte	:	Solution of KOH 30 to 35% Concentrations
7	Cell container material	:	Nylon 11
8	Identification of Polarity	:	'+' Embossing provided on the cell lid. Red and Black indication washers provided on the cell '+' & '-' terminals marked on the cell against the respective terminal by screen-printing.
9	Efficiency of sealing	:	Each cell is checked for leak at a pressure of 14Kpa for 15 seconds and there shall not be any leak.
10	Cell vent valve	:	Made of stainless steel with hollow center post covered with rubber sleeve to operate as a Bunsen valve at pressure of 0.2 to 0.6Kg/Cm^2.

9.2.14.3 Battery Electrical & Environmental Specifications

	Battery Parameter		Requirements
1	a. Type of Battery	:	HBL Part No. NCSPB 27060 for Dornier aircraft(DO-228)Drawing No271 1000 2C
	b. Nominal voltage	:	24 Volts
2	OCV of charged battery	:	25 V minimum
3	Nominal capacity	:	27AH (60 minutes discharge time with 27 amps at 1 hour rate load to a cut off voltage of 20V).
	a. Number of cells	:	20 Numbers in series connected, replaceable
	b. Type of connector	:	As per spec. MS-3509/MIL-E-81099A Rebling plastic. Part No.7002, PENNA
	c. Thermostat	:	CANNON KPSE – 07E – 10 – 6 – P or equivalent.
4	Polarity identification	:	'+' & '-' embossed markings are made on the battery container on both sides of the connector,
5	Physical dimensions & Weight	:	28Kgs Max. Length (Bottom) : 252.5 ±0.5 m Width (Bottom) : 247.0 ±0.5 m Width (Top) : 299.0 ±0.5 m Width over all : 301.0 ±1.0 m Height over all : 192.0 ±1.0 m
6	Drawing Number	:	HBL Drawing No.271 1000 2C
7	Battery container	:	Made of stainless steel with sand blast finish.
8	Internal Resistance	:	8.4 mΩ at 25°C. The values at – 10°C and –26°C were not defined. However, the IR values obtained are 21.8mΩ and 41.2mΩ respectively.

9	Electrical power Requirement for DO-228 A/c	
	a. Typical Discharge Performance at 25°C at various current ratings:	
	1.	27Amps load for 66 minutes up to 20V cut off.
	2.	135 Amps load for 12 minutes up to 19V cut off.
	3.	270 Amps load for 5 minutes 35 seconds up to 17V cut off.
	4.	405 Amps load for 3 minutes 24 seconds up to 13V cut off.
	b. Power delivery while maintaining 12V constant voltage discharge for 30 seconds:	

Temp.			Current at		
	0 secs	2 secs	10 secs	20 secs	30 secs
At 25°C	1733A (20.8Kw)	1583A (19Kw)	1333A (16Kw)	1250A (15Kw)	1083A (13Kw)
At -18°C	958A (11.5Kw)	812A (9.75Kw)	750A (9Kw)	729A (8.75Kw)	729A (8.75Kw)
At -30°C	583A (7.0Kw)	483A (5.8Kw)	458A (5.5Kw)	483A (5.8Kw)	500A (6Kw)

Temperature of the battery shall not be more than 70°C during above discharges.

c. Engine cranking profile: Two batteries connected in series shall perform 4 engine start cycles with a rest period of 60 seconds between two cycles. Total battery voltage shall not be less than 48 volts before sating the engine.(this is a approximate data generated during ground trails at (HAL ,KANAPUR))

Time in Seconds	**Current in Amps**
2	1000Amps
5	675 Amps
10	576 Amps
15	520 Amps
20	455 Amps
25	260 Amps
30	37 Amps

10	Vibration Profile:		
	5 to 10 Hz	:	Constant displacement ±1 mm
	10 to 55 Hz	:	Constant displacement ±0.75 mm
	55 to 2000 Hz	:	Constant Acceleration = $100 m/s^2$ $(10g_n)$
	• Sweep rate from 5 Hz to 2000 Hz and return to 5 Hz in 20 minutes.		

- Total vibration time for each direction (three axes) 3 hours including search for resonance frequency and fatigue limits. Fatigue limits comprise one hour spread over the main resonance and the remaining time, sweep.

11 Acceleration Test: (for cell Type NCSPC 27060-5)

Conditions	**Normal**	**Crash**
Horizontal acceleration (X & Y axis)	±47 m/s^2	±90 m/s^2
Vertical acceleration Z axis upwards	36 m/s^2	40 m/s^2
Z axis downwards	100 m/s^2	100 m/s^2
Duration (Stabilize)	1 min	10 sec.

12 Altitude test for Cell Type : NCSPC 27060-5

Battery shall be subjected to two cycles of altitude test in the chamber with reduced absolute pressure over 15 minutes to 5.5 Kpa and at ambient temperature. The following constitute one cycle of test.

- Discharge at $5C_1$ rate for 5 minutes and charge with CP method (29V) for 3 hours. After completion of this test battery shall brought to 23°C and stabilized for minimum 12 to 16 hours. Then verify the $1C_1$ (27 amps) rate discharge capacity for 60 minutes. Details of test are indicated at Sl.No.24 Appendix 'A4'.

13 Thermostat Assembly :

Thermostats / temperature sensors shall be approved for aviation purpose. Two thermostats / thermal sensors and its harness assembly shall be checked for opening and closing temperatures. One thermostat shall be open when temperature is at 57±3°C and second thermostat shall open at 71±3°C. Also the thermostat assembly is subjected to dielectric strength, insulation resistance (>20 MΩ), chemical resistance (KOH) withstand for seven days at 65°C.

14 General Environmental Test

a.	Humidity & Charge Retention Test
b.	Mechanical shock test (Basic Design)
c.	Vibration Test
d.	Temperature shock Test
e.	Altitude Test
f.	Salt Fog Test
g.	20 Sec. pulse discharge Test
h.	Medium rate discharge operation position Test

i.	Cycling Test
j.	Temperature rise and float Test
k.	Physical integrity Temperature (85℃)
l.	Gas barrier Material Test
m.	Storage Test
n.	Shelf life Test
o.	Main battery receptacle or electric plug Test
p.	Temperature sensor Thermo switches (if) applicable for battery
q.	User Trials

Above tests shall be followed from JSS 6140-10:2007 of Nickel Cadmium for aviation use

9.2.15 27AH, 24V Ni-Cd (Si/Pbe) battery for MIG-21 Aircraft

9.2.15.1 Salient Features

Type of Battery	NICKEL CADMIUM BATTERY TYPE: NCSP B 27060 M RM with Cell part No. NCSP C 27060 M RM
Technology developers and	M/s HBL, Hyderabad
Coordinated RCMA	RCMA (HD)
Nominal voltage	24V & 27AH
End use	MIG Aircraft & its variants
Battery Dimensions	424X118X215 mm & 22.5 Kgs.
Type Approval No. & Validity	QT Evaluation completed, PC issued
Technical Specification	i) QTP Reference No.: HNPS/TA/QTP/ 27AH/MIG/ 2006 / Specification Rev-B. Issue No.II Dt. Dec, 2006 ii) JSS:6140-10:2007 for NI-CD batteries
Manufacturing & Quality Assurance Plan	HBL/NC/PS/PBE/07 Jan.2007

9.2.15.2 Cell Specifications

Sl. No.	Cell Parameter	Requirements
1	a) Type of cell b) Rated voltage & Capacity & Power Density	Vented Nickel Cadmium type with Sintered positive and plastic bounded negative M/s.HBL Type : NCSPC 27060 M RM 1.20V,& 27Ah (at one hour rate)& 740 W/KG
2	OCV of Charged cell	1.26V Min
3	Physical dimensions Weight	Height up to terminal top : 165±1.0 mm Height up to cell lid top : 151.5±0.5mm Length : 57.1±0.2 mm Width : 38.1±0.2 mm Weight : 01 Kg. Max Torque requirement Bottom nut : 5 Nm Top nut : 8 Nm
4	Drawing No.	277 4001 3A
5	Type of sealing for Container & Lid	Thermal Welding
6	Electrolyte	Solution of KOH 30 to 35% concentrations.
7	Cell container material	Nylon 11
8	Identification of Polarity cell Identification of name plate	'+' Embossing provided on the cell lid. Red and blue indication washers provided on the cell '+' & '-' terminals. '+' & '-' marked on the cell against the respective terminal by Screen printing cell name plate provided with manufacturer name, part No, date& lot code imposed on cell container.
9	Efficiency of sealing	1 Kg. per Cm^2 for 15 seconds and there shall not be any leak.
10	Cell vent valve	Made of stainless steel with hollow center post covered with rubber sleeve to operate as Bunsen valve at pressure of 3 psi.
11	Separator systems	First layer Non Woven type Second layer Celgard 3400 Third layer Woven type
12	Cell baffle	Nylon 6
13	Type of Electrode design (Si/PBE)	19 plates of Sintered positive with nickel hydroxide & 19 plates of plastic bonded negative cadmium

		oxide electrodes.
14	Polarity of plates	In relation to the terminals, polarity of the plates shall be verified physically during stack assembly and final inspection on cell terminals with polarity identification markings also checked.
15	Manufacturing process control and quality assurance plan document, Issue No. & Date	Process document No.HBL/NC/PS/PB/007 Rev.0 Jan.2007

9.2.15.3 Battery Electrical And Environmental Requirements

Sl.No.	Battery Parameter	Requirements
1	Battery Type & Battery Drawing No a) Number of cells b) Battery inter face/ Connector Assembly c) Battery container	HBL Type : NCSPB 27060 M RM HBL Drawing No. : 2771000-2A 20 Nos connected in series, replaceable As per HBL Std. 2 pin socket assembled in dummy cell drawing No.2773001-2A Made of stainless steel
2	OCV of charged battery	26V Nominal
3	Rated Capacity & Power Density / Energy Density/Self discharge rate	27AH (When discharged with 27 amps to a cut off voltage of 20 volts, the battery shall give a minimum duration of 60 minutes) Power Density 740W/Kg. Energy Density 30 WH / Kg. Self discharge rate 0.5% of rated capacity per day at 25 degree centigrade over 90 days period
4	Rated voltage	24Volts
5	Aerobatic / Non aerobatic	Aerobatic
6	Physical Examination	The battery, cells and the components shall be physically examined for general condition construction and work man ship as per the relevant SOP document No.HBL/TA/27AH/M RM/MIG/2007 Issue-1 dated Jan.2007
7	Physical Dimensions & Weight	As per drawing No. : 277 1000 2A Length (Bottom) : 424.0 Width (Bottom) : 118.0 Width over all : 130.0 Height over all : 225.0 Weight : 22.5 Kg. Max.

8	Markings	Polarity of battery terminals shall be as per markings on the box (Drg.No. 2771001). Identification labels are provided on the battery side markings as per Drg.Nos. 40K 2004
9	Polarity of plates	The polarity of plates in relation to that of the terminals are inter cell connectors to which they are connected shall be verified electrically (as per clause No.10.4.4 of JSS 6140-10:2007)
10	Recommended Charging Methods	With constant current of C / 5 (5.4 Amps) for 8 Hrs. duration. Constant potential of 28.5V for 1 Hr 55 Mints.
11	State Of Charge (SOC)	Performing 1C rate discharge test for 60 minutes
12	Recommended Discharge	Normal 1C rate discharge up to 1V per cell
13	High current pulse capabilities	A series of 1055A, 960A, 885A without recharge of battery
14	Temperature limits of battery usage	Operation range -30°C to +55°C and storage temperature -40°C to +70°C
15	Temperature derating for performance	At -30°C for 1C rate discharge de-rated by __________%
16	Base line Parameters	Defined below in Table (a) (b) (c) & (d) of 9.2.15.4

17. General Environmental Test

- a. Humidity & Charge Retention Test
- b. Mechanical shock test (Basic Design)
- c. Vibration Test
- d. Temperature shock Test
- e. Altitude Test
- f. Salt Fog Test
- g. 20 Sec. pulse discharge Test
- h. Medium rate discharge operation position Test
- i. Cycling Test
- j. Temperature rise and float Test
- k. Physical integrity Temperature (85°C)
- l. Gas barrier Material Test
- m. Storage Test
- n. Shelf life Test
- o. Main battery receptacle or electric plug Test
- p. Temperature sensor Thermo switches (if) applicable for battery
- q. User Trials

Above tests shall be followed from JSS 6140-10:2007 of Nickel Cadmium for aviation use

9.2.15.4 Base Line Parameters for 27AH Ni-Cd Battery: Si/pbe for MIG -21 Aircraft

a) Typical Discharges

Battery service life with different rate of discharge on fully charged batteries. Following minimum capacities shall be available at the two temperatures as given in the table below.

Discharge Rate	Discharge Time (minimum)	
	At RT(+25°C)	At – 30° C
$1C_1$ (27amps)	60 min (cut off voltage 20V)	46 min (cut off voltage 20V)
$5C_1$ (135amps)	10.5 min (cut off voltage 16V)	7.4 min (cut off voltage 14V)
$10C_1$(270amps)	4.8 min (cut off voltage 16V)	1.2 min (cut off voltage 14V)
$15C_1$(405amps)	2.2 min (cut off voltage of 16V)	30 Sec (cut off voltage of 14V)
$30C_1$(810amps)	1 min (cut off voltage of 10V)	

b) Instantaneous Power & Maximum Power Delivery Test :

Power behavior under 25°C and – 30°C test conditions, the currents ensuring while discharge from fully charged state at half the OCV (ocv/2 = 12V constant) for 15 seconds in above temperature conditions are to be evaluated. From the discharged current and battery voltage, power calculation and internal resistance values are derived. The battery shall meet the requirements as given in the table below. The internal resistance values given in the table below are the maximum values for the battery. Lower the value, it is better for the battery.

	Peak Power at 1 Sec (approx. 300 milli seconds) Instantaneous Peak values			Power rating at 15 seconds Steady state values		
	I_i(min)	P_i(min)	r_i(max)	I_{mp}(min)	P_m(min)	r_{em}(max)
At 25°C	1059A	14.16KW	12.6mΩ	825A	11KW	16mΩ
At-30°C	545A	7.31KW	24mΩ	285A	3.81KW	46.9mΩ

c) Constant voltage at 14V discharge test :

The test shall be carried out after CP charge (28.5V) battery shall be subjected to a constant voltage discharge at 14V for 60 seconds at 24±2°C and – 26±2°C. The discharge current at 1.0, 5.0, 15.0 and 60.0 seconds after the start of discharge shall be as per the specified values given below:

Temperature	Currents at			
	1 second	5 second	15 second	Average current over the total 60 seconds
At 24 ± 2°C	1025amps	950amps	850amps	650amps
– 26 ± 2°C	450amps	400amps	400amps	350 amps

MIG-21 Aircraft engine starting profile and emergency load details:

Table 9-1MIG-21 (BISON) engine start profile

Three discharges with an interval of 3 minutes	**100% capacity**		**85% capacity**	
	Current in Amps		**Current in Amps**	
	Peak at 0 seconds	**At 20 sec**	**Peak at 0 seconds**	**At 20 sec**
1st Discharge	1035 A	815 A	875 A	700 A
2nd Discharge	960 A	740 A	820 A	645 A
3rd Discharge	885 A	675 A	770 A	600 A

(a) Each battery with 100% and 85% capacity shall be subjected to aircraft engine start simulation given figure above for three times continuously with an interval of 3 minutes between 2 discharges. For this discharge battery kept at 12V constant discharge for 20 seconds. The battery shall deliver the currents not less than specified values in Table 9-1 (Refer 9.2.15.5 for engine start simulation at 12V discharge).

(b) Immediately after three discharges as above, the battery shall be CP Charged for 15 minutes. Battery voltage and charging current are noted every 5 minutes. The individual voltages of the cells are to be measured at the end of the charging.

(c) Immediately after the CP charge as above, emergency load of 50 amps shall be applied till the voltage reaches 21 volts. The duration of discharge obtained shall not be less than 20 minutes. During the entire operation, battery temperature shall not exceed maximum 100°C.

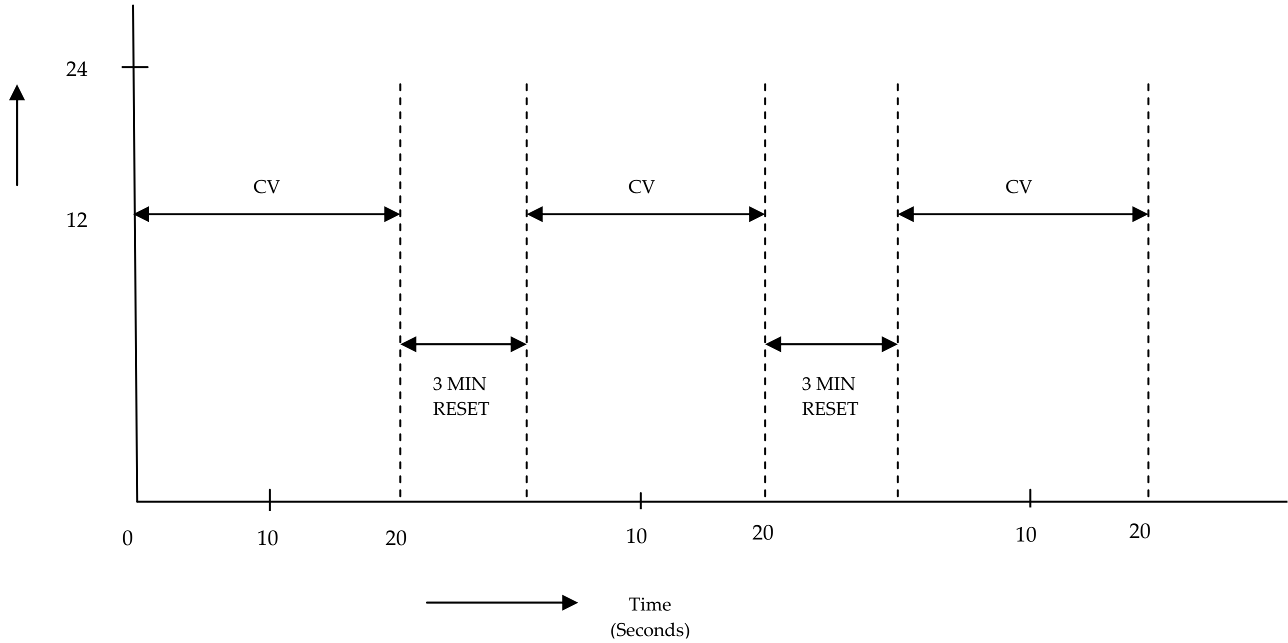
(d) For MiG-27 aircraft also engine starting simulation shall be followed similar to Para-a above except the following :

(i) Simulation of engine start for 3 starts shall be 20V at constant discharge for 20 sec. with an interval of between 2 starts. The battery currents shall be not less than 180 Amps.

(ii) For immediately after engine start CP charge at 28.5±0.5Vshall be followed for 15 minutes.

Immediately after CP charge emergency load of 100 amps. (MiG-27 Aircraft equivalent load) for 15 minutes shall be applied for a cut off voltage of 21 Volts.

9.2.15.5 ENGINE START SIMULATION AT 12V CONSTANT VOLTAGE DISCHARGE



Note: During the discharge, battery shall deliver currents as specified in Table 9-1.

Note: During the discharge battery should deliver a current not less than 1000 Amp. for initial peak within 5 Seconds, and total CV(constant voltage) discharge period is 20 Seconds. Discharge current shall not be less than 675 Amps. at the end of 20 seconds period.

9.2.16 3AH, 10.5V Lithium Thionyl Chloride Battery for *Priboy* Sets

9.2.16.1 Salient Features

Type of Battery	Primary Lithium Thionyl Chloride PRIBOY-PZ
Technology developers and Coordinated RCMA	M/s HBL, Hyderabad RCMA (N)
Nominal voltage	10.5 V (3cell)
Nominal Capacity	3 AH
End use	Rescue beacon Kamor 2M on MIG Aircraft
Battery Dimensions	136 X80 X25 mm
Battery Weight	500 Grams
Type Approval No. & Validity	CEMILAC TA No 1025. Validity up to 31-12-2008
Technical Specification	TS/IND/72/47

9.2.16.2 3AH, 10.5V Lithium Thionyl Chloride Battery Technical specification for Priboy Radio Beacon Set

Sl.No.	Battery Parameter	Requirements
1	Battery Weight	500G(max)
2	Battery Dimensions	Length : 136 ±1.5 mm Width : 80±1 mm Height : 25mm (max) Cable length : 200±15 mm
3	Paint	Color Yellow
4	Battery Type	Primary Lithium Thionyl Chloride
5	No. of Cells	3 Cells connected in series & 3 such series connected are finally in parallel mode.(for cell specification refer 9.2.12.3)
6	Open Circuit Voltage	10.5V
7	On Load Voltage (OLV)	Greater than 9.4V at ambient temperature across a load of 200Ωand 80Ω
8	Storage Life	2 years at atmospheric storage condition
9	Battery continuous operating service life discharge test at various temperature	See table 9.2.16.3
10	Cut –off voltage battery for discharge	7.2V
11	Operating temperature range	-10°C to +55°C
12	Safety feature	500mA fuse of non-replaceable is provided in series
13	Insulation resistance	Under normal climatic conditions : 20MΩ At temperature(+60°C) : 5MΩ At RH of 95±3% : 1MΩ

9.2.16.3 Electrical Discharge Characteristics of Lithium Thionyl Chloride ($LiSOCL_2$) Battery (10.5V,3AH) for Priboy Radio Set (Type: rescue BEACON KUMAR2M for MIG-21)

Inspection mode of Temp. 20+50°C	Intial voltage V, not less than		9.4
Mode of continuous discharge	Resistance ohms		200
	Resistance ohms		80
	Intial voltage V, during temp. not less than	From 20 to 50°C	9
	Intial voltage V, during temp. not less than	From 0 to 20°C	8

	Intial voltage V, during temp. not less than	minus 10 ± 2V	7.8
	During of discharge in hours not less than	From 20 to 50°C	14
	During of discharge in hours not less than	From 0 to 20°C	5
	During of discharge in hours not less than	minus 10 ± 2V	1
Details of intermittent mode of discharge during temperatures+20 to +50°C	For 15 minutes	Initial voltage ,V, not less than	10
	For 15 minutes		550
	For 5 minutes		9
	For 5 minutes		80
	Continuation of operation, hours not less than		55
	Final voltage not less than, Volts		7.2

9.2.16.4 Qualification Tests on Lithium Thionyl Chloride ($LiSOCL_2$) Battery (10.5V,3AH) for Priboy Radio Set

Sl.No	Test	Requirements
1	Visual Examination	In this test batteries are examined for absence of dusts, cracks, dents and for correctness of polarity etc
2	Dimensions and Weight	The dimensions and weight of the battery should correspond to Table-9.2.16.2 (for individual cell specification refer table 9.2.13.3)
3	Measurement of Initial Voltage	Measurement of initial voltage of the battery should be done by voltmeter , with in 30 seconds. Refer Table –9.2.16.2.
4	Checking of Insulation Resistance	Checking of electrical insulation resistance is carried out between each current lead and body of plug connector and similarly between each current lead and body of the article with a 500 volts megger. The values of insulation resistance should be a) Under normal climatic conditions 20 MΩ b) At temperature (+60°C) 05MΩ c) At RH of 95±3% 01MΩ
5	Drop Test	Testing of battery on strength during falling is carried out by the method of free dropping from a height of 750mm. Dropping is done on felt packing having a thickness of 1.5mm. It is kept

<table>
<tr><td></td><td></td><td>on thick metallic plate having thickness of not less than 60mm. The number of impacts are divided as follows :
<table><tr><td>On edges</td><td>-</td><td>5droppings</td></tr><tr><td>On ribs</td><td>-</td><td>3droppings</td></tr><tr><td>On corner</td><td>-</td><td>2droppings</td></tr></table>After this measure of initial voltage, insulation resistance is carried out as per Sl.No.3 & 4 of this table.</td></tr>
<tr><td>6</td><td>Testing of Vibration Strength</td><td>Testing of the battery is carried out on vibration stand in accordance with the table given below :
<table><tr><th>Frequency CPS</th><th>Amplitude (mm)</th><th>Acceleration Three positions (Hrs)</th></tr><tr><td>18</td><td>0.5</td><td>--</td></tr><tr><td></td><td>1.0</td><td>--</td></tr><tr><td>24</td><td>0.7</td><td>--</td></tr><tr><td></td><td>0.9</td><td>--</td></tr><tr><td>36</td><td>0.3</td><td>--</td></tr><tr><td></td><td>0.4</td><td>--</td></tr><tr><td>48</td><td>--</td><td>1.5</td></tr><tr><td></td><td>--</td><td>2.0</td></tr><tr><td>300</td><td>--</td><td>5</td></tr><tr><td>400</td><td>--</td><td>5</td></tr><tr><td>500</td><td>--</td><td>5</td></tr></table>The battery is fastened to vibration stand with the help of special fixture, ensuring the reliable and rigid fastening they are tested in all the three mutually perpendicular axes
After testing, the battery is externally inspected and measurement of initial voltage and insulation resistance is carried as per Sl.No.3 and 4 of this table.</td></tr>
<tr><td>7</td><td>Impact Test</td><td>Testing of the battery for impact strength is carried out on impact stand with a over load of 12 kg and 40 to 80 impacts per minute, the total number of impacts being 10000. The batteries are fastened to the impact stand with the help of special fixture ensuring reliable and rigid fastened and tested on all three mutually perpendicular axes (total number of impacts are divided equally).After testing measurement of initial voltage and insulation resistance are carried out as per Sl.No.3 and 4</td></tr>
<tr><td>8</td><td>Testing on keeping the sea water</td><td>Testing of battery for staying in sea water is carried out by the following method. The battery is kept in bath, which is filled with a composition of water with sea salt(20gms/liter).The water level should be 1 meters and the battery is held there for 1 hour >Temperature of the water should be within 10 to 15°C. After testing the battery is externally inspected. There should not any peeling of paint and presence of moisture on the</td></tr>
</table>

		current leads of plug connector. Measurements of initial voltage, insulation resistance are carried out as per Sl.No.3 and 4 of this table.
9	Action of cyclic charge of temperature	Testing of battery for action of cyclic charge of temperature is carried out by the method of subsequent holding of battery in cold chamber at –50±2°C for 4 hours and heats it in the thermostat upto –50±2°C for a period of 2 hours. Shifting of batteries from one chamber to the other should be carried out within 5 minutes and the cycle is repeated. At the end of 3 cycles the batteries are kept in normal climatic conditions for a period of 2 hours. After this measurement of initial voltage and insulation resistance are carried out as per Sl.No.3 and 4 of this table.
10	Humidity Test	The battery is kept in humidity chamber for 10 days at a temperature of 40±2°C and at 95 to 98 % relative humidity. The battery is externally inspected, there should not be any peeling of the paint and presence of moisture on the leads of plug connector. After testing the batteries are removed from the chamber and measurement of initial voltage and insulation resistance are carried out as per Sl.No. 3 and 4 of this table.
11	Testing for action of Ice and Dew	The batteries are kept for 2 hours in the clod chamber at –20°±5°C.Then they are removed and kept in normal climatic conditions for 3 hours. After this measurement of initial voltage and insulation resistance are carried out as per Sl.No. 3 and 4. within 30 minutes
12	Testing for discharge at low Temperature	The batteries are kept in cold chamber at –10±2°C for a period of 4 hours, then without removing them from the chamber , discharge is carried. Measurement of voltages is carried out in the following time intervals. First measurement --- at the start of discharge Second and subsequent--- at intervals of 30 minutes till the voltage falls below the specific value. The same test is carried out for a temperature of 0±2°C in similar way. Discharge duration should meet the specification. Refer Table –9.2.16.2.
13	Testing for discharge at high Temperature	The batteries are kept in the thermostat at 50±2°C for period of 2 hours and without removing from the chamber they are discharged. Measurement of voltages is carried out in the following intervals First measurement---Within 1 minute from starting of discharge. Second and subsequent—After every 30 minutes till the voltages falls below the specific value. The same test is carried out for a temperature of 0±2°C in similar way. Discharge duration should meet the specification.

		Refer Table –9.2.16.2.
14	Intermittent mode of discharge	The batteries are kept in the thermostat at50±2°C for period of 2 hours and without removing them from the chamber. They are subjected to intermittent discharge (550 ohms for 15 minutes and 80 ohms for 5 minutes). Measurement of voltages for intermittent mode of discharge is carried out in the following time intervals. First measurement---Within 1 minute from starting of discharge. Second and subsequent—After intervals of one hour before voltage falls below the specific value. The same test is carried out for a temperature of 0±2°C in similar way. Discharge duration should meet the specification. Refer Table –9.2.16.2.
15	Storage Life Test	The batteries are stored for 18 months and 24 months as specified and tested for discharge capacity at each temperature as specified in the table. The results should be within limits. The battery should be stored under atmospheric conditions of humidity less than 85%and temperature within –10 to+25°C
16	Acceptance Test Procedure for product delivery	All batteries are subjected to the following tests : a) Visual examination b) Dimensions & Weight c) Insulation resistance check d) Measurement of initial voltage e) Capacity test 1% of the batch

9.3 Thermal Batteries for ASTRA Missile

9.3.1.1 Salient Features

Type of Battery	Lithium Thermal Batteries
Technology developers and Coordinated RCMA	M/s HBL, Hyderabad RCMA (Missiles)
Nominal voltage	56V, 21V, 28V, 28V
Nominal Capacity	336W, 145W, 364W, 280W
End use	ASTRA Missile
Battery Dimensions & Weight	Refer Technical Specification below
Type Approval No. & Validity	Under QT evaluation
Technical Specification	QTP Reference No.DRDL/DR&QA/ASTRA/008 Issue No.01 Dt.29th Dec.2003 for LTB-1 & LTB-2. & DRDL/ASTRA/6015/12/01 Dt.17th Dec 2007 for LTB-3 & LTB-4

9.3.1.2 Baseline Specifications

2.1	Type	LTB-1	LTB-2	LTB-3	LTB-4
2.1.1	No. of sections	1	1	1	1
2.1.2	Material for Battery container and lid	SS304 (ASTM A240)	SS304 (ASTM A240)	SS304 (ASTM A240)	SS304 (ASTM A240)
2.2	Voltage on Load Range Peak Voltage at +71°C Noise Levels	56V 50V-62V <800mV in 5Hz-300KHz	Sec.I: +21 19.5V-25V Sec.II: -21V (19.5V-25V) <300mV in 5Hz-300KHz Sec.III: 10V min. Noise Level <150mV in 5Hz-300KHz	28V 24V- 32V 33.0 Volts <400mV in 5Hz-300KHz	28V 24V- 32V 33.0 Volts <400mV in 5Hz-300KHz
2.3	Insulation resistance	≥ 50 MΩ	≥ 50 MΩ	≥ 50 MΩ	≥ 50 MΩ
2.4 2.4.1 2.4.2 2.4.3	Electric Igniter Igniter resistance No fire current All fire current Recommended fire current	0.4 to 0.6Ω 500mA for 5.0 minutes 2A for 25ms(Max) 3A for 10ms(Max)	0.4 to 0.6Ω 500mA for 5.0 minutes 2A for 25ms(Max) 3A for 10ms(Max)	0.5 to 0.7Ω 500mA for 5.0 minutes 2A for 25ms(Max) 3A for 10ms(Max)	0.5 to 0.7Ω 500mA for 5.0 minutes 2A for 25ms(Max) 3A for 10ms(Max)
2.5	Activation time (in milliseconds)	1400 (Max)	1400 (Max)	1400 (Max)	1400 (Max)
2.6	Discharge Duration (s)	50 Seconds	120 Seconds	100 Seconds Fig 9(i)	100 Seconds Fig 9(ii)
2.7	Leak (Max.) Std cc/s	1.20×10^{-8}	1.20×10^{-8}	1.20×10^{-8}	1.20×10^{-8}
2.8	Size Diameter (mm) Height (mm)	44+/-0.3 mm 135 ±0.5 mm (5mm for Pin)	44+/-0.3 mm 135 +/-0.5 mm (5mm for Pin)	55+/-0.3 mm 135 +/-0.5 mm (5mm for Pin)	47+/-0.3 mm 135 +/-0.5 mm (5mm for Pin)
2.9	Weight (gm)	530+/- 10	530+/- 10	800 +/- 10	530 ±10
2.10	Shelf Life	≥ 25 yrs	≥ 25 yrs	≥ 25 yrs	≥ 25 yrs

High temperature

35°C for 6 hrs, 35°C to 80°C in 5.5 hrs, At 80°C for 2 hrs
80 to 85°C in % hrs, At 85°C for 1 hr, 85 to 71°C in % hr.
At 71°C for 3&1/2 hrs, 71 to 35°C in 5 hrs
1 such 24hr Cycle with performance check at 71°C
Total cycles: 7
NOTE: During last cycle battery to be soaked to 8hrs (min) at 71°C before discharge.

Shock

20g, 11 m sec, half sine wave, 3 shocks in each direction for 5 directions

Ageing

Ageing at elevated temperature

110°C, 35 days **Qty -1 battery**
discharge at -40°C ± 2°C

Ageing (thermal cycling test)

No of days 28 as per appendix 'B' **Qty -1 battery**
discharge at +71°C ± 2°C

Note:

a) As the LTB's are hermetically sealed and Leak test is carried out as per plan, it is opined that Icing, Blowing Rain, Sand & Dust, Fungus and Saline tests are not applicable. Hence those tests are not included.

b) As the Container for L TB's is made of SS-304, Icing, Blowing Rain, Sand& Dust, Fungus are not applicable. Hence those tests are not included. However on sample saline test is to be done

Various Cell Sizes for Aircraft Batteries

CELL TYPE	NOMINAL CAPACITY	TYPICAL DIMENSIONS (LxWxH) mm	APPROXIMATE WEIGHT (Kg)
NCSP C 25150 RM	1.2V 25Ah	81×27.5×211	1.05
NCSP C 23060 RM	1.2V 23Ah	80.5×27×211.5	1.0
NCSP C 27060 M RM	1.2V 27Ah	57.1×38.1×165	1.0
NCSP C 27060-5	1.2V 27Ah	79×34.5×178	1.12
NCSP C 27060 M RM	1.2V 30Ah	58×36.5×200	0.98
NCSP C 27060 M RM	1.2V 40Ah	79×34.5×236	1.5

CELL TYPE	NOMINAL CAPACITY	TYPICAL DIMENSIONS (LxWxH) mm	APPROXIMATE WEIGHT (Kg)
NCSP C 16060-4	1.2V 16Ah	57×31.5×169	0.740
NCSP C 18060-4	1.2V 18Ah	80.5×27×156	0.780
NCSP C 23060 RM	1.2V 23Ah	80.5×27×211.5	1.0
NCSP C 25150 RM	1.2V 25Ah	81×27.5×211	1.05
NCSP C 40060 RM	1.2V 40Ah	79×34.5×236	1.5
1.2 NCS C 3.5-60	1.2V 3.5Ah	33Ø×62H	0.160

10 Aviation Batteries From M/s HEB, Tiruchurapalli

Introduction

M/s.HEB, Tiruchurapalli is one of the market leader in the indigenous design, development and production of aviation batteries. This chapter gives details of the batteries supplied by HEB. Company profile is given in section 10.1. And their product list of aircraft batteries & its brief technical specification of various aircraft batteries supplied to MOD is given in 10.2.

10.1 Company Profile of HEB, Tiruchurapalli

Name	M/s.HEB, Tiruchurapalli
Address & Tel	**M/s.HEB** **Pakkudi Road** **Mathur 622 515 (Near Tiruchurapalli)** **Pudukkottai Dist.** **Tamil Nadu, India** **Phone No. 91-431-2660314** **Fax No. 91-4339-250516** **e-mail : info@highenergyltd.com**
ISO 9000 Status **Accreditation Body :** **Certificate Ref / QAP reference**	**ISO 9001 & ISO14001 Certified** **QAP documents defined by M/S HEB on each product wise.**
Test Laboratory facilities	**M/S HEB having own test laboratory and approved sub contractor calibration testing.**

10.2 **About M/s HEB, Tiruchirapalli**

High energy batteries (India) Limited, (HEB) was established in the year 1979 for the manufacture of silver Oxide Zinc batteries for MIG Aircraft starting and emergency application, at the instance of Ministry of Defence, Government of India, as Plant-II of erstwhile SIMCO Meters Ltd, Tiruchirapalli.

HEB obtained technical collaboration for manufacture of 45Ah silver oxide zinc batteries from Yardney Electric Corporation, USA, a pioneer in the field, during 1979.HEB Aircraft battery was type tested and approved for bulk manufacture in the year 1981.HEB has so far supplied more than 22000 batteries including exports. The design has been constantly upgraded to suit Indian tropical conditions and enhancement in life achieved through in-house R&D.

In 1983 HEB ventured to develop Nickel Cadmium batteries using sintered plate technology.HEB has developed and has been supplying Nickel Cadmium Batteries of 24V 40Ah, 24V 25Ah, 24V 23Ah and 24V 18Ah ratings to the Indian Air Force and Indian Navy for use in Jaguar, Mirage, Kiran MKI, Kiran MKII,AN32, Sea Harrier ,Hunter Aircrafts and Cheetah, Chetak, Mi8,Mi17,Mi25,Mi35 and Seaking helicopters for starting & emergency load applications since 1988. Over 2,00,000 cells have been produced and supplied to Indian Defence and exports as well.

In 1996, HEB completed the development and pilot plant phase for the manufacture of Fibre Technology Nickel Cadmium cells(FTNC Cells) for aircraft applications.

ESTABLISHED CAPABILITIES

HEB received **R&D Award** for the development of batteries for Aircraft and Missile applications in the year 1990 from Ministry **of Science and Technology**. HEB also received indigenisation award for the year 1998-99 form Ministry of Defence for the development of sophisticated Torpedo batteries to Indian Navy. Again during 2004, HEB was conferred the DSIR Award for design modification of high rate-high power Silver Zinc battery. In addition, HEB has also developed primary and secondary batteries intended for Missile application for Integrated Missile Development Programmes like P!5,P20,PRITHVI and other strategic programmes undertaken by DRDL, Hyderabad. In addition , HEB has also developed and been supplying 1Ah,3Ah,5Ah,10Ah and 15Ah silver oxide zinc cells to ISRO, Trivandrum for various satellite programmes such as IRS,ASLV,PSLV and GSLV.

The experience and knowledge gained over the years on Battery Technology and the application-specific requirements, gives strength in developing and supplying sophisticated, high reliability product required for satellite application.

HEB’s strength lies in undertaking engineering development as well as fundamental materials research. Through in-house R&D and limited tie-up Defence Labs such as NSTL, Vizag; NMRL, Mumbai and DRDE Gwalior, HEB has developed a number of batteries and systems. Work on Fuel Cells pertaining to Phosphoric Acid (PAFC) and (PEMFC) is being pursued, for remote area power applications.

10.2.1 QUALITY SYSTEM

HEB Quality Management System (QMS) has been accredited with ISO 9001 certification in the year 1999 by Underwriters Laboratories Inc., USA and further upgraded to 2000 Standards during 2003 for development, manufacture and supply of High Tech Silver Chloride Magnesium and Zinc Manganese dioxide cells/batteries. The Quality System employed has a four tier truncated Quality management System. The Quality System employed is periodically audited by our Internal Quality Auditors and also by the accreditation agency of Underwrites Laboratories Inc., USA.

Quality Policy

1. To be a preferred power source supplier.
2. To meet the customer requirements with continual improvements in products and services by constantly upgrading our processes, human resources.

10.2.2 PRODUCT CERTIFICATION

The product certification has been obtained for all products from the following Agencies:

1	CEMILAC, Bangalore& DGAQA, New Delhi	-	Aircrafts and Helicopter Batteries
2	DGNAI, New Delhi	-	Torpedo and Naval Batteries

3	MSQAA, Hyderabad	-	Missile Batteries
4	ISRO, Trivandrum	-	Satellite Launch Vehicle and Aerospace batteries
5	DGCA, Chennai	-	For Civil Aviation
6	CQA(L)	-	Army communication and Battle Tank Batteries

The Certification is revalidated through periodic field reports received by the respective agencies and need-based repeat type test on product.

10.2.3 ENVIORNMENTAL SYSTEM

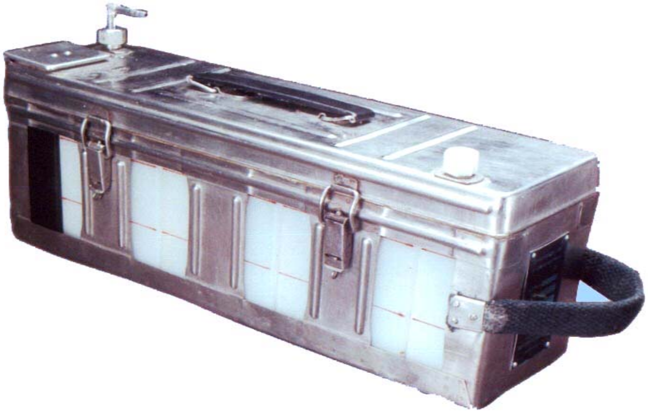
HEB Environmental Management System (EMS) has been accredited with ISO 14001:1996 certification in the year 2003 by M/s Underwriters Laboratories, USA. The environmental system employed is periodically audited by internal Auditors and also by the accreditation agency.

Environmental Policy

a. To excel in the field of Battery manufacture.
b. To improve our environmental performance continually by reducing emissions, effluents and solid waste.
c. To optimize use of resources by minimizing waste generation by recovery, recycle and reuse.
d. To comply with all statutory regulations.
e. To train and motivate our human resources to be environmentally responsible.
f. To make the policy known to all interested parties.

10.3 Technical Specifications for A/c Batteries from M/s.HEB, Tiruchurapally

10.3.1 45AH, 22.5V Silver Zinc Secondary battery for MIG Aircraft



10.3.1.1 Salient Features

Type of battery	Silver Zinc secondary battery HEB battery type SIMEC-56-15-1 Battery P/N-15-STSS-45B with cell P/N HR-45-2 Mod-2
Technology developers and coordinated RCMA	M/s.HEB, Tiruchurapally & RCMA(Aircraft)
Nominal Voltage & Nominal Capacity	22.5 V 45Ah @ 1 h Rate
End use	MIG Aircraft and its Variants
Battery Dimension	427 (L) x 130 (W) x 225 (H) mm
Battery Weight	17.90 Kg.
Type Approval No. & Validity	CEMILAC TA No.342 & 30/06/2012
Technical Specification	E & I 300, issue no. 3 / JSS 6140-06:1999/platform requirements
Connector type	2 Pin Socket type connector as per HEB company standard

Note: The same battery is cleared for KA-25 H/C vide Ltr. No.CRE (H)/1341/2 dated 11-12-2002

10.3.1.2 45AH, 22.5V, Silver Zinc battery Base Line Specifications for MIG-21Aircraft & KA-25 H/C

Test	Cell Parameter	Requirements
01	a) Type of cell b) Nominal Voltage & Capacity	VENTED, SILVER ZINC cell type : HR45-2 Mod 2 22.5V & 45AH
02	OCV of Charged cell	1.85V
03	Physical dimensions & Weight cell drg No	55(L), 52(W), 158 (H) mm and WT: O.95Kg HEB DRNo.SZ3-3
04	Type of sealing for Container & Lid	High Frequency Sealing Technique
05	Electrolyte details	KOH(Specific Gravity 1.4)
06	Cell container material	NYLON-grade
07	Identification of Polarity	Red & Blue color marked on the cell ± terminals
08	Efficiency of sealing	Pressure of 14psi for 2 minutes, their shall not be any leak
09	Cell vent valve	Nickel plated steel
10	Separator systems	Polymeric separator and Cellophane
11	No of Plates & type of substrate	21 positives and 20 negatives & with Grid as substrate
12	Torque requirements for terminals	For top terminal nut 6.5 - 7 Nm

10.3.1.3 Battery Electrical & Environmental Specifications of Silver Zinc Battery

The following tests are complied

1. General physical dimensions and mass, Options of short circuit and cell leak test
2. Capacity Test at 5 Hr rate and 1 Hr rate
3. Electrolyte retention test and spillage test
4. Heavy rate discharge at 27^0 C and 0^0 C
5. Service cycle life for 35 charge discharge cycles with including general environmental and mechanical tests
    1. Low temperature test
    2. Self discharge test
    3. High altitude test
    4. Vibration test
    5. High temperature test
6. Acceleration test
7. Impact test
8. Humidity test
9. Salt corrosion test
10. Storage life test (Un-field)
11. Storage life test (Field)
12. User Trials as per the platform wise individual spec.
13. Engine Start Profile and emergency loads of MiG-Aircraft as per HAL, Nasik letter D/4505/12/DE/06/1083 dated 08th Nov.2006.

Note: For detailed information refer 11.1.3.3 and 11.1.3.4.

10.3.2 40AH, 24V Ni-Cd battery for Jaguar, Mirage-2000 Aircraft

10.3.2.1 Salient Features

Type of battery	Nickel Cadmium secondary battery HEB Battery type : NC-001 with Cell Pt.No.NC-40
Technology developers and coordinated RCMA	M/s.HEB, Tiruchurapally RCMA(A/C) for Jaguar & Mirage Aircraft RCMA(H/C) for Cheeta, Chetak H/C
Nominal Voltage & Nominal Capacity	24 V 40Ah @ 1 h Rate
End use	Jaguar Aircraft, Cheeta, Chetak H/C, Mirage Aircraft
Battery Dimension	412 (L) x 209 (W) x 267 (H) mm
Battery Weight	36 Kg.
Type Approval No. & Validity	CEMILAC TA No : 789 for JAGUAR Aircraft CEMILAC TA No : 791 for MIRAGE Aircraft- 31-12-2012
Technical Specification	a. General Ni-Cd spec.DTD & P (Air) / E&I 502 issue 1, E&I 502/1 issue1 Mar 87, Amendment No.1 Sept. 88 b. JSS :6140-10:2007 for NI-CD batteries
Manufacturing & Quality Assurance Plan	HEB / QAP / FTF / NC 40

Note : As per RCMA(H/C) instructions the same batteries can be used in Cheeta, Chetak H/C if type approved for use in H/C

10.3.2.2 Cell Specifications

Test	Cell Parameter	Requirements
1.	a). Type of cell & Drg. No. b). Nominal Voltage & Capacity	Ni-Cd HEB Part No.NC-40, vented type & Drg.No.NC2-0071E 1.2V and 40AH at 1 Hr. rate
2.	OCV of Charged cell	More than 1.25 Volts
3.	Physical dimensions & Weight	(H) = 235 ± 3, (W) = 80 ± 2, (Thickness) = 35 ± 2mm & 1500 grams (Nominal)
4.	Type of sealing for Container & Lid	High frequency sealing techniques
5.	Electrolyte	Solution of KOH 1.3 ± 0.04 specific gravity
6.	Cell container material	Zytel (Nylon Grade) or equivalent
7.	Identification of Polarity	Red & Blue colour marked on the cell cell + & - electrodes
8.	Efficiency of sealing	With 10psi immersed in DM water there shall not be any leak
9.	Cell vent valve	Stainless steel
10.	Separator systems	Polymeric and Celgard as gas barrier material
11.	No. of Plates & Type of substrate	17 positive plates 16 negative plates & with Grid as substrate
12.	Torque requirement	6 – 7 Nm on top nut of cell terminal

10.3.2.3 Battery Electrical & Environmental Specifications

Sl.No.	Battery Parameter	Requirement
1.	Type of Battery & Drg. No.	Ni-Cd battery NC-001 with Cell Pt.No.NC-40 Drg. No.NC0-0201E
2.	Type of Container	Stainless steel with sand blast finish / any suitable material viz. plastic, nylon, etc.
3.	Battery Connector / Receptacle	BAC 102 & BR 8-1
4.	Battery physical dimensions & weight	412(L) x 209 (W) x 267 (H) mm 36 Kgs.
5.	No. of cells in battery pack	20 connected in series (replaceable)
6.	Nominal voltage & Capacity	24V, 40AH
7.	Internal resistance of battery	At 25°C =11 mΩ At -10°C =15 mΩ At -26°C =21 mΩ
8.	Engine Cranking ability test	**Details not available**
9.	Emergency load test	**Details not available**
10.	General environmental details	a. General Ni-Cd spec. DTD & P (Air) / E&I 502 issue 1, E&I 502/1 issue1 Mar 87, Amendment No.1 Sept. 88 b. JSS :6140-10:2007 for NI-CD batteries
11.	Temperature sensors	Not used
12.	Peak power	Data Not available

10.3.3 18AH, 24V Ni-Cd battery for KIRAN MK-I Aircraft

10.3.3.1 Salient Features

Type of battery	Nickel Cadmium secondary battery HEB Battery type : FTNC-076 with cell Pt.No.5j/NIV/K1
Technology developers and coordinated RCMA	M/s.HEB, Tiruchurapally RCMA(A/C)
Nominal Voltage &	24 V
Nominal Capacity	18Ah @ 1 h Rate
End use	Kiran MK-I Aircraft
Battery Dimension	258 (L) x 193.4 (W) x 165 (H) mm
Battery Weight	19 Kg.
Type Approval Details	CEMILAC TA No.793 dt; 31-12-2012
Technical Specification	General Ni-Cd spec.DTD & P (Air) / E&I 502 issue 1 E&I 502/3 issue1 Apr 94 E&I 502/3/1 issue1 Apr 94 JSS :6140-10:2007 for NI-CD batteries
QA Plan	HEB / QAP / FTF / FTNC 18

10.3.3.2 Cell Specifications

Test	Cell Parameter	Requirements
1.	a). Type of cell b). Nominal Voltage & Capacity	Part No.5J/NIV/K1,vented type FTNC-18 1.2V and 18AH at 1 Hr. rate Drg.No.FN3-2131
2.	OCV of Charged cell	More than 1.25 Volts
3.	Physical dimensions & Weight	(H) = 155 ± 0.5, (W) = 80 ± 1.5, (Thickness) = 27.5 ± 0.5mm 775 grams (Maximum)
4.	Type of sealing for Container & Lid	High frequency sealing techniques
5.	Electrolyte	Solution of KOH 1.3 ± 0.04 specific gravity
6.	Cell container material	Zytel (Nylon Grade) or equivalent
7.	Identification of Polarity	Red & Blue indication washers provided in the cell + & - terminals
8.	Efficiency of sealing	With pressure of 10psi when immersed in DM water. There shall not be any leak.
9.	Cell vent valve	Stainless steel
10.	Separator systems	Polymeric & celgard as gas barrier material
11.	No of Plates & type of substrate	11 positive plates and 10 negative plates & with Fibre as substrate
12.	Torque requirement	6 – 7 Nm on top terminal nut

10.3.3.3 Battery Electrical & Environmental Specifications

Sl.No.	Battery Parameter	Requirement
1.	Type of Battery & Drg. No.	Ni-Cd battery HEB Battery type : FTNC-076 (5J/3388) Drg.No.FN2-0135
2.	Type of Container	Stainless steel with sand blast finish / any suitable material viz. plastic, nylon, etc.
3.	Battery Connector / Receptacle	SPADELUG (Company Standard HEB type connector)
4.	Battery physical dimensions & weight	258(L) x 193.4 (W) x 165 (H) mm 19 Kgs.
5.	No. of cells in a battery pack	20 connected in series (replaceable)
6.	Nominal voltage & Capacity	24V, 18AH at 1 Hr. rate
7.	Internal resistance of battery	At 25°C =13 mΩ At -10°C =19 mΩ At -26°C =25 mΩ
8.	Engine Cranking ability test	**Details not available**
9.	Emergency load test	**Details not available**
10.	General environmental details	i) General Ni-Cd spec. DTD & P (Air) /E&I 502 issue 1 E&I 502/3 issue1 Apr 94 E&I 502/3/1 issue1 Apr 94 ii) JSS :6140-10:2007 for NI-CD batteries
11.	Temperature sensors	Not used
12.	Peak power	Data Not available

10.3.4 18AH, 24V Ni-Cd battery for Islander Aircraft

10.3.4.1 Salient Features

Type of battery	Nickel Cadmium secondary battery HEB Battery type : FTNC 076/1 with Cell Pt.No.5j/NIV/K1
Technology developers and coordinated RCMA	M/s.HEB, Tiruchurapally RCMA(A/C)
Nominal Voltage &	24 V
Nominal Capacity	18Ah @ 1 h Rate
End use	Islander a/c
Battery Dimension	258 (L) x 193.5 (W) x 178 (H) mm
Battery Weight	19 Kg.
Type Approval Details and its validity	CEMILAC TA No.794 - 31-12-2012
Technical Specification	i) General Ni-Cd spec.DTD & P (Air) / E&I 502 issue 1 E&I 502/3 issue1 Apr 94 E&I 502/3/1 issue1 Apr 94 ii) JSS :6140-10:2007 for NI-CD batteries
QA Plan	HEB / QAP / FTF / FTNC 18

10.3.4.2 Cell Specifications

Test	Cell Parameter	Requirements
1.	a) Type of cell & Drg. No. b) Nominal Voltage & Capacity	Part No.5J/NIV/K1(Ni-Cd, vented type) FTNC-18 Drg. No.FN3-0701 1.2V and 18AH at 1 Hr. rate
2.	OCV of Charged cell	More than 1.25 Volts
3.	Physical dimensions & Weight	(H) = 150 ± 0.5, (W) = 80 ± 1.5, (Thickness) = 27.5 ± 0.5mm 775 grams (Maximum)
4.	Type of sealing for Container & Lid	High frequency sealing technique
5.	Electrolyte	Solution of KOH 1.3 ± 0.04 specific gravity
6.	Cell container material	Zytel (Nylon Grade) or equivalent
7.	Identification of Polarity	Red & Blue indication washers provided on the cell + & - terminals
8.	Efficiency of sealing	With pressure of 10psi when immersed in DM water, there shall not be any leak
9.	Cell vent valve	Stainless steel
10.	Separator systems	Polymeric & celgard as gas barrier material
11.	No of Plates & type of substrate	11 positive plates and 10 negative plates & with Fibre as substrate
12.	Torque requirement	6 – 7 Nm on top terminal nut

10.3.4.3 Battery Electrical & Environmental Specifications

Sl. No.	Battery Parameter	Requirement
1.	Type of Battery & Drg. No.	Ni-Cd battery HEB Battery type : FTNC-076/1 (5J/NIV/ISL) Drg. No.FN2-0135/1
2.	Type of Container	Stainless steel with sand blast finish / any suitable material viz. plastic, nylon, etc.
3.	Battery Connector / Receptacle	--
4.	Battery physical dimensions & weight	258(L) x 193.5 (W) x 178 (H) mm 19 Kgs.
5.	No. of cells in a battery pack	20 connected in series (replaceable)
6.	Nominal voltage & Capacity	24V, 18AH at 1 Hr. rate
7.	Internal resistance of battery	At 25°C =13 mΩ At -10°C =19 mΩ At -26°C =25 mΩ
8.	Engine Cranking ability test	**Details not available**
9.	Emergency load test	**Details not available**
10.	General environmental details	i) General Ni-Cd spec. DTD & P (Air) /E&I 502 issue 1 E&I 502/3 issue1 Apr 94 E&I 502/3/1 issue1 Apr 94 ii) JSS :6140-10:2007 for NI-CD batteries
11.	Temperature sensors	Not used
12.	Peak power	Data Not available

10.3.5 18AH, 24V Ni-Cd battery for Sea Harrier Aircraft

10.3.5.1 Salient Features

Type of battery	Nickel Cadmium secondary battery HEB Battery type : FTNC-0160 with cell Type No.FTNC-18
Technology developers and coordinated RCMA	M/s.HEB, Tiruchurapally RCMA(A/C)
Nominal Voltage & Nominal Capacity	24 V 18Ah @ 1 h Rate
End use	Sea Harrier Aircraft
Battery Dimension	258 (L) x 193.4 (W) x 157 (H) mm
Battery Weight	19 Kg.
Type Approval Details	CEMILAC TA No.1123 - 30-06-2010
Technical Specification	i) GENRAL Ni-Cd spec. DTD & P (Air) / E&I 502 issue 1 E&I 502/4 issue1 Mar 89 ii) JSS :6140-10:2007 for NI-CD batteries
Manufacturing & Quality Assurance Plan	HEB / QAP / FTF / FTNC 18

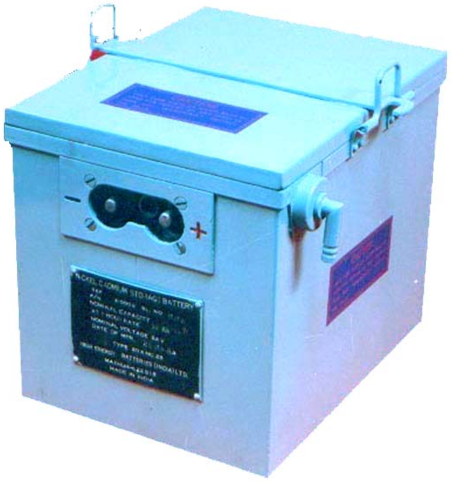
10.3.5.2 Cell Specifications

Test	Cell Parameter	Requirements
1.	a) Type of cell & Drg. No. b) Nominal Voltage & Capacity	Part No.5J/NIV/K1 (Ni-Cd, vented type) Drg.No. FTNC-18 Drg. No.FN3-0701 1.2V and 18AH at 1 Hr. rate
2.	OCV of Charged cell	More than 1.25 Volts
3.	Physical dimensions & Weight	(H) = 150 ± 0.5, (W) = 80 ± 1.5, (Thickness) = 27.5 ± 0.5mm 750 grams (Maximum)
4.	Type of sealing for Container & Lid	High frequency sealing technique
5.	Electrolyte	Solution of KOH 1.3 ± 0.04 specific gravity
6.	Cell container material	Zytel (Nylon Grade) or equivalent
7.	Identification of Polarity	Red & Blue indication washers provided on the cell + & - terminals
8.	Efficiency of sealing	With pressure of 10psi when immersed in DM water, there shall not be any leak
9.	Cell vent valve	Stainless steel
10.	Separator systems	Polymeric & celgard as gas barrier material
11.	No of Plates & type of substrate	11 positive plates and 10 negative plates & with Fibre as substrate
12.	Torque requirement	6 – 7 Nm on top terminal nut

10.3.5.3 Battery Electrical & Environmental Specifications

Sl.No.	Battery Parameter	Requirement
1.	Type of Battery & Drg.No.	Ni-Cd battery HEB Battery type : FTNC-0160 Drg.No.FN2-0187
2.	Type of Container	Stainless steel with sand blast finish / any suitable material viz. plastic, nylon, etc.
3.	Battery Connector / Receptacle	---
4.	Battery physical dimensions & weight	258(L) x 193.4 (W) x 157 (H) mm 19 Kgs.
5.	No. of cells in a battery pack	20 connected in series (replaceable)
6.	Nominal voltage & Capacity	24V, 18AH at 1 Hr. rate
7.	Internal resistance of battery	At 25°C =13 mΩ At -10°C = 19 mΩ At -26°C = 25 mΩ
8.	Engine Cranking ability test	**Details not available**
9.	Emergency load test	**Details not available**
10.	General environmental details	i) General Ni-Cd spec.DTD & P (Air) /E&I 502 issue 1 E&I 502/4 issue1 Mar 89 ii) JSS :6140-10:2007 for NI-CD batteries
11.	Temperature sensors	Not used
12.	Peak power	Data Not available

10.3.6 23AH, 24V Ni-Cd battery for AVRO (HS - 748)



10.3.6.1 Salient Features

Type of battery	Nickel Cadmium secondary battery HEB Battery type : FTNC-0101 with Cell type.No.FTNC-23
Technology developers and coordinated RCMA	M/s.HEB, Tiruchurapally RCMA(Aircraft)
Nominal Voltage & Nominal Capacity	24 V 23Ah @ 1 h Rate
End use	AVRO (HS - 748) aircraft
Battery Dimension	262(L) X 194(W) X 223 (H) mm
Battery Weight	28 Kg.
Type Approval Details / Provisional Clearance	PC given by RCMA(A/C)/456/1/PC-23 Dt. 19.07.06 VALIDITY – NOT MENTIONED
Technical Specification	i) General Ni-Cd spec.DTD & P (Air) / E&I 502 issue 1 E&I 502/2 issue1 ii) JSS :6140-10:2007 for NI-CD batteries
Manufacturing & Quality Assurance Plan	HEB / QAP / FTF / FTNC 23

10.3.6.2 Cell Specifications

	Cell Parameter	Requirements
1.	a) Type of cell & Drg.No. b) Nominal Voltage & Capacity	Ni-Cd HEB Part No.NC-230, vented type and Drg.No. NC2-0071E 1.2V and 23AH at 1 Hr. rate
2.	OCV of Charged cell	More than 1.25 Volts
3.	Physical dimensions & Weight	(H) = 214 ± 0, (W) = 80 ± 0, (Thickness) = 28 ± 0mm 1050 grams (Maximum)
4.	Type of sealing for Container & Lid	High frequency sealing technique
5.	Electrolyte	Solution of KOH 1.3 ± 0.04 specific gravity
6.	Cell container material	Zytel (Nylon Grade) or equivalent
7.	Identification of Polarity	Red & Blue indication washers provided on the cell + & - terminals
8.	Efficiency of sealing	With pressure of 10psi when immersed in DM water. There shall not be any leak.
9.	Cell vent valve	Stainless steel
10.	Separator systems	Polymeric and celgard as gas barrier material
11.	No. of Plates & Substrate type	17 positives & 16 negatives & with Fibre as substrate
12.	Torque requirement	6 – 7 Nm on cell top terminal nut

10.3.6.3 Battery Electrical & Environmental Specifications

Sl.No.	Battery Parameter	Requirement
1.	Type of Battery & Drg. No.	Ni-Cd battery HEB Battery type : FTNC-0101 Drg.No.NC2-2251
2.	Type of Container	Stainless steel with sand blast finish / any suitable material viz. plastic, nylon, etc.
3.	Battery Connector / Receptacle	ELCON
4.	Battery physical dimensions & weight	262(L) x 250 (W) x 223 (H) mm 28 Kgs.
5.	No. of cells in a battery pack	20 connected in series (replaceable)
6.	Nominal voltage & Capacity	24V, 23AH
7.	Internal resistance of battery	At 25°C =15 mΩ At -10°C =21.5 mΩ At -26°C = 31 mΩ
8.	Engine Cranking ability test	**Details not available**
9.	Emergency load test	**Details not available**
10.	General environmental details	i) General Ni-Cd spec. DTD & P (Air) /E&I 502 issue 1 E&I 502/2 issue1 ii) JSS :6140-10:2007 for NI-CD batteries
11.	Temperature sensor	Not used
12.	Peak power	Data Not available

10.3.7 25AH, 24V Ni-Cd battery for SU-30, IL-76&TU-142 Aircrafts

10.3.7.1 Salient Features

Type of battery	Nickel Cadmium secondary battery HEB Battery type : FTNC-0155 with cell Pt.No.FTNC-25 for SU-30 FTNC-0202 with cell Pt.No.NC-SP-C-25150 for IL-76 FTNC-0155 with cell Pt.No.NC-SP-C-25150 for TU-142
Technology developers and coordinated RCMA	M/s.HEB, Tiruchurapally RCMA(Nasik) for SU-30; RCMA(Aircraft) for IL-76 & TU-142
Nominal Voltage & Capacity	24 V & 25Ah @ 1 h Rate
End use	SU-30, IL-76 & TU-142 Aircrafts
Battery Dimension	366(L) X 174(W) X 226(H) mm
Battery Weight	24 Kg.
Type Approval Details / and its validity	CEMILAC TA NO : 1241 / 31.12.2011 for SU-30 CEMILAC TA NO : 795 / 31.12.2012 for IL-76 CEMILAC TA NO : 792 / 31.12.2012 for TU-142
Technical Specification	i) General Ni-Cd spec.DTD & P (Air) / E&I 502 issue 1 E&I 502/9 issue1 Jun 98 ii) JSS :6140-10:2007 for NI-CD batteries
Manufacturing & Quality Assurance Plan	HEB / QAP / FTF / FTNC25

10.3.7.2 Cell Specifications

	Cell Parameter	Requirements
1.	a). Type of cell & Drg. No.	FTNC-0155 with cell Pt.No.FTNC-25 for SU-30 Drg.No.FN2-0301 FTNC-0202 with cell Pt.No.NC-SP-C-25150 for IL-76 Drg.No.FN2-0301 FTNC-0155 with cell Pt.No.NC-SP-C-25150 for TU-142 Drg.No.FN2-0301 Ni-cd vented type
	b). Nominal Voltage & Capacity	1.2V and 25AH at 1 Hr. rate
2.	OCV of Charged cell	More than 1.25 Volts
3.	Physical dimensions & Weight	(H) = 212 ± 0 (W) = 80 ± 0, (Thickness) = 28 ± 0mm 1050 grams (Maximum)
4.	Type of sealing for Container & Lid	High frequency sealing techniques
5.	Electrolyte	Solution of KOH 1.3 ± 0.04 specific gravity
6.	Cell container material	Zytel (Nylon Grade) or equivalent
7.	Identification of Polarity	Red & Blue indication washers provided on the cell + & - terminals
8.	Efficiency of sealing	With pressure of 10psi when immersed in DM water. There shall not be any leak.
9.	Cell vent valve	Stainless steel
10.	Separator systems	Polymeric and celgard as gas barrier material
11.	No. of Plates with substrate type	11 positives & 10 negatives & with Fibre as substrate
12.	Torque requirement	6 -7 Nm on cell terminal top nut

10.3.7.3 Battery Electrical & Environmental Specifications

Sl.No.	Battery Parameter	Requirement
1.	Type of Battery & Drg. No.	Ni-Cd battery FTNC-0155 with cell Pt.No.FTNC-25 for SU-30 Drg.No.FN2-1451 FTNC-0202 with cell Pt.No.NC-SP-C-25150 for IL-76 FTNC-0155 with cell Pt.No.NC-SP-C-25150 for TU-142 Drg.No.FN2-1451
2.	Type of Container	Stainless steel with sand blast finish / any suitable material viz. plastic, nylon, etc.
3.	Battery Connector / Receptacle	HEB Standard
4.	Battery physical dimensions & weight	366 (L) x 174 (W) x 226 (H) mm & 24 Kgs.
5.	No. of cells in a battery pack	20 connected in series (replaceable)
6.	Nominal voltage & Capacity	24V, 25AH
7.	Internal resistance of battery	At 25°C =14 mΩ, At -10°C =21.5 mΩ, At -26°C =31 mΩ
8.	Engine Cranking ability test	**Details given below***
9.	Emergency load test	**Details given below***
10.	General environmental details	i) General Ni-Cd spec. DTD & P (Air) /E&I 502 issue1 E&I 502/9 issue1 Jun 98 ii) JSS :6140-10:2007 for NI-CD batteries
11.	Temperature sensor	Not used
12.	Peak power	Data Not available

***SU-30 Engine cranking and emergency loads as follows:**

Engine Cranking Ability Test

The batteries are discharged by a current of up to 650A, but the maximum transient current of 650 Amps is allowed only during switching. The maximum permissible capacity yielded per switching should not exceed 5 Ah.

Emergency Load Test

The fully charged battery shall be subjected to following emergency load with duration.

Emergency loads	--	85 to 100 Amps
Duration	--	Three rectifier failure – 20 minutes
		Two generator failure – 10 minutes

***IL-76 & TU-142 Engine cranking and emergency loads as follows:**

Engine Cranking Ability Test

The variation of the current magnitude with respect to time the starting discharge condition is presented as below starting with max. discharge current of 650A.

a) Five starting under normal climatic conditions with time pause in between the starts of 3 minutes: the battery voltage at the end of fifth start should at least be 16.0Volts.

b) Three starting at electrolyte temp. of minus 5°C , with time pause of 3 minutes between each start: the voltage of battery at the end of third start should be least 16.0 Volts.

TIME IN SECONDS	CURRENT IN AMPS
0-5	650
5-15	550
15-25	350
25-35	220
35-45	120

Emergency Load Test:

The fully charged battery shall be subjected to constant discharge current of 52A to an end point voltage of 20V.

The battery shall give duration not less than 24 minutes.

10.3.8 25AH, 24V Ni-Cd battery for AN-32 Aircraft

10.3.8.1 Salient Features

Type of battery	Nickel Cadmium secondary battery HEB Battery type : FTNC-0184 with cell Pt.No.AN-32/NIV
Technology developers and coordinated RCMA	M/s.HEB, Tiruchurapally RCMA(Chd)
Nominal Voltage & Nominal Capacity	24 V 25Ah @ 1 h Rate
End use	AN-32 Aircraft
Battery Dimension	493(L) X 190(W) X 232(H) mm
Battery Weight	28 Kg.
Type Approval Details	CEMILAC TA No.1281 / 30.06.2012
Technical Specification	i) General Ni-Cd spec.DTD & P (Air) / E&I 502 issue 1 E&I 502/8 issue1 Jun 98 ii) JSS :6140-10:2007 for NI-CD batteries
Manufacturing &Quality Assurance Plan	HEB / QAP / FTF / FTNC25

10.3.8.2 Cell Specifications

	Cell Parameter	Requirements
1.	a) Type of cell& Drg.No. b) Nominal Voltage & Capacity	Ni-Cd HEB Part No. FTNC-0184 with cell Pt.No.AN-32/NIV Vented type Drg,No.FN2-0301 1.2V and 25AH at 1 Hr. rate
2.	OCV of Charged cell	More than 1.25 Volts
3.	Physical dimensions & Weight	(H) = 212 ± 0 (W) = 80 ± 0, (Thickness) = 28 ± 0mm 1050 grams (Maximum)
4.	Type of sealing for Container & Lid	High frequency cell sealing techniques
5.	Electrolyte	Solution of KOH 1.3 ± 0.04 specific gravity
6.	Cell container material	Zytel (Nylon Grade) or equivalent
7.	Identification of Polarity	Red & Blue indication washers provided on the cell + & - terminals
8.	Efficiency of sealing	With pressure of 10psi when immersed in DM water, there shall not be any leak.
9.	Cell vent valve	Stainless steel
10.	Separator systems	Polymeric and celgard as gas barrier material
11.	No. of Plates with substrate type	11 positives & 10 negatives & with fibre as substrate
12.	Torque requirement	6 – 7 Nm cell terminal top nut

10.3.8.3 Battery Electrical & Environmental Specifications

Sl.No.	Battery Parameter	Requirement
1.	Type of Battery and drg no.	Ni-Cd battery HEB Battery type : FTNC-0184 and drg no FN2-1526
2.	Type of Container	Stainless steel with sand blast finish / any suitable material viz. plastic, nylon, etc.
3.	Battery Connector / Receptacle	HEB Make
4.	Battery physical dimensions & weight	493(L) X 190(W) X 232(H) mm & 28 Kgs.
5.	No. of cells in a battery pack	20 connected in series (replicable)
6.	Nominal voltage & Capacity	24V, 25AH
7.	Internal resistance of battery	At 25°C =15 mΩ, At -10°C =21.5 mΩ, At -26°C =31 mΩ
8.	Engine Cranking ability test	**Details given below**
9.	Emergency load test	**Details given below**
10.	General environmental details	i) General Ni-Cd spec.DTD & P (Air) /E&I 502 issue 1 E&I 502/8 issue1 Jun 98 ii) JSS :6140-10:2007 for NI-CD batteries
11.	Peak power	Data Not available

24 V x 25 Ah @ 2.5 HOUR RATE BATTERY FOR AN - 32 AIRCRAFT

Engine Cranking Ability Test

Three fully charged batteries connected in parallel shall be subjected to 45 seconds starting cycles with the discharge current being varied as in the table below. The numbers of cycles is 5 with a rest period of 3 minutes in between consecutive cycles.

Time (Sec)	Current (Amps)	Mode of connection of batteries
0-2	650	Parallel
5	510	-do-
10	400	-do-
15	315	-do-
20	250	-do-
25	200	-do-
30	150	-do-
35	125	-do-
40	100	-do-
45	75	-do-

Battery voltage at the end of each cycle should not be less than 18 V.

Emergency Load Test: The fully charged battery shall be subjected to constant discharge current of 33A to an end point voltage of 20V. The battery shall give duration not less than 30 min.

10.3.9 16AH, 24V Ni-Cd battery for HPT-32 Aircraft

10.3.9.1 Salient Features

Type of battery	Nickel Cadmium secondary battery HEB Battery type : NC-250 with cell Type NC-16
Technology developers and coordinated RCMA	M/s.HEB, Tiruchurapally RCMA(Kanpur)
Nominal Voltage &	24 V
Nominal Capacity	16Ah @ 1 h Rate
End use	HPT-32 Aircraft
Battery Dimension	410(L) X 129(W) X 187(H) mm
Battery Weight	18 Kg.
Type Approval Details / Provisional Clearance	Provisional Clearance given RCMA(K)/072/15/Tech/Battery HPT-32 Dt. 09/10/2007 Valid Upto 08.04.2008 (Provisional) Applied for Permanent Type Approval
Technical Specification	i) General Ni-Cd spec.DTD & P (Air) / E&I 502 issue 1 E&I 502/6 issue1 Oct 94 ii) JSS :6140-10:2007 for NI-CD batteries
Manufacturing & Quality Assurance Plan	HEB / QAP / FTF / NC 16

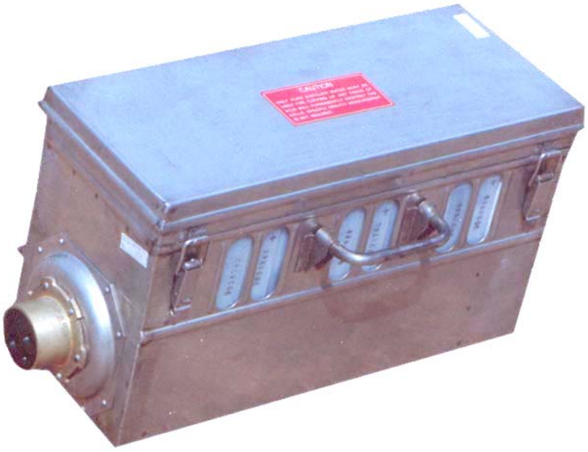
10.3.9.2 Cell Specifications

	Cell Parameter	Requirements
1.	a) Type of cell & Drg. No. b) Nominal Voltage & Capacity	Ni-Cd, HEB Part No. NC-250 with cell Type NC-16 Vented type & Drg. No.FN3-0701 1.2V & 16 AH
2.	OCV of Charged cell	More than 1.25 Volts
3.	Physical dimensions & Weight	(H) = 172 ± 2, (W) = 58 ± 2, (Thickness) = 33 ± 2mm 800 grams (Maximum)
4.	Type of sealing for Container & Lid	High frequency cell sealing techniques
5.	Electrolyte	Solution of KOH 1.3 ± 0.04 specific gravity
6.	Cell container material	Zytel (Nylon Grade) or equivalent
7.	Identification of Polarity	Red & Blue indication washers provided on the cell + & - terminals
8.	Efficiency of sealing	With pressure of 10psi when immersed in DM water, there shall not be any leak.
9.	Cell vent valve	Nickel plated steel
10.	Separator systems	Polymeric & celgard as gas barrier material
11.	No. of Plates with substrate type	17 positives & 16 negatives & with grid as substrate
12.	Torque requirement	6 -7 Nm cell terminal top nut

10.3.9.3 Battery Electrical & Environmental Specifications

Sl.No.	Battery Parameter	Requirement
1.	Type of Battery & Drg. No.	Ni-Cd battery HEB Battery type : NC-250 with Cell Pt.No.NC-16 Drg. No.FN2-0187
2.	Type of Container	Stainless steel with sand blast finish / any suitable material viz. plastic, nylon, etc.
3.	Battery Connector / Receptacle	BAC 102 & BR 8-1
4.	Battery physical dimensions & weight	410(L) X 129(W) X 187(H) mm 18.3 Kgs.
5.	No. of cells in a battery pack	20 connected in series (replaceable)
6.	Nominal voltage & Capacity	24V, 16AH
7.	Internal resistance of battery	At 25°C =13 mΩ At -10°C =19 mΩ At -26°C =25 mΩ
8.	Engine Cranking ability test	**Details not available**
9.	Emergency load test	**Details not available**
10.	General environmental details	i) General Ni-Cd spec. DTD & P (Air) /E&I 502 issue 1 E&I 502/6 issue1 Oct 94 ii) JSS :6140-10:2007 for NI-CD batteries
11.	Temperature sensor	Thermal sensor used
12.	Peak power	Data Not available

10.3.10 25AH, 24V Ni-Cd battery for MI-8/MI-17 Aircraft



10.3.10.1 Salient Features

Type of battery	Nickel Cadmium secondary battery HEB Battery type : FTNC-0156 with cell Pt.No.NC-SP-C-25150
Technology developers and coordinated RCMA	M/s.HEB, Tiruchurapally RCMA(Chd)
Nominal Voltage &	24 V
Nominal Capacity	25Ah @ 1 h Rate
End use	MI-8 / MI-17 aircraft
Battery Dimension	462 (L) x 170 (W) x 257 (H) mm
Battery Weight	28 Kg.
Type Approval Details	CEMILAC TA No.1039 / 31.12.2008
Technical Specification	i) General Ni-Cd spec.DTD & P (Air) / E&I 502 issue 1 E&I 502/7 issue1 May 98 ii) JSS :6140-10:2007 for NI-CD batteries
Manufacturing &Quality Assurance Plan	HEB / QAP / FTF / FTNC25

10.3.10.2 Cell Specifications

	Cell Parameter	Requirements
1.	a) Type of cell & Drg.No. b) Nominal Voltage & Capacity	Ni-Cd HEB Part No.NC-SP-C-25150 Vented type & Drg.No.FN2-0301 1.2V and 40AH at 1 Hr. rate
2.	OCV of Charged cell	More than 1.25 Volts
3.	Physical dimensions & Weight	(H) = 212 ± 0, (W) = 80 ± 0, (Thickness) = 28 ± 0mm 1050 grams (Nominal)
4.	Type of sealing for Container & Lid	High frequency cell sealing technique
5.	Electrolyte	Solution of KOH 1.3 ± 0.04 specific gravity
6.	Cell container material	Zytel (Nylon Grade) or equivalent
7.	Identification of Polarity	Red & Blue indication washers provided on the cell + & - terminals
8.	Efficiency of sealing	With pressure of 10psi when immersed in DM water, there shall not be any leak.
9.	Cell vent valve	Stainless steel
10.	Separator systems	Polymeric & celgard as gas barrier material
11.	No. of Plates with substrate type	11 positives & 10 negatives & with grid as substrate
12.	Torque requirement	6 -7 Nm cell terminal top nut

10.3.10.3 Battery Electrical & Environmental Specifications

Sl.No.	Battery Parameter	Requirement
1.	Type of Battery & Drg.No.	Ni-Cd battery HEB Battery type : FTNC-0156 Drg.No.FN2-1341
2.	Type of Container	Stainless steel with sand blast finish / any suitable material viz. plastic, nylon, etc.
3.	Battery Connector / Receptacle	HEB Make
4.	Battery physical dimensions & weight	462 (L) x 170 (W) x 257 (H) mm 28 Kgs.
5.	No. of cells in a battery pack	20 connected in series (replaceable)
6.	Nominal voltage & Capacity	24V, 25AH
7.	Internal resistance of battery	At 25°C =15 mΩ At -10°C =21.5 mΩ At -26°C =31 mΩ
8.	Engine Cranking ability test	**Details given below***
9.	Emergency load test	**Details given below***
10.	General environmental details	i) General Ni-Cd spec. DTD & P (Air) /E&I 502 issue 1 E&I 502/7 issue1 May 98 ii) JSS :6140-10:2007 for NI-CD batteries
11.	Temperature sensor	Not used
12.	Peak power	Data Not available

*** 24 V x 25 Ah @ 2.5 HOUR RATE or 24 Ah @ 1 HOUR RATE BATTERY FOR MI8 / MI-17 HELICOPTER - Engine Cranking Ability Test**

Six fully charged batteries connected as below shall be subjected to 50 seconds starting cycles with the discharge current being varied as in the table below. The numbers of cycles is 5 with a rest period of 3 minutes in between consecutive cycles.

Time in Seconds	Current in Amps	Mode of connection of batteries
0-2	1000	Parallel
2-9	600	-do-
9-32	600	Group of 3 batteries (connected in parallel) in series with other group of three batteries (connected in parallel)
32-33	600	Parallel
33-50	150	Parallel

Emergency Load Test

The fully charged battery shall be subjected to constant discharge current of 52A to an end point voltage of 20V. The battery shall give duration not less than 24 minutes.

10.3.11 40AH, 24V Ni-Cd battery for KIRAN MK-II Aircraft

10.3.11.1 Salient Features

Type of battery	Nickel Cadmium secondary battery HEB Battery type : NC-115 with cell Pt no. NC-40
Technology developers and coordinated RCMA	M/s.HEB, Tiruchurapally RCMA(A/C)
Nominal Voltage & Nominal Capacity	24 V 40Ah @ 1 h Rate
End use	KIRAN MK-II Aircraft
Battery Dimension	362 (L) x 168 (W) x 267 (H) mm
Battery Weight	37 Kg.
Type Approval Details & Validity details	CEMILAC TA No.790 & 31.12.2012
Technical Specification	i) General Ni-Cd spec.DTD & P (Air) / E&I 502 issue 1 E&I 502/1 issue1 Mar 87 Amendment No.1 Sept. 88 ii) JSS :6140-10:2007 for NI-CD batteries
Manufacturing & Quality Assurance Plan	HEB / QAP / FTF / NC 40

10.3.11.2 Cell Specifications

	Cell Parameter	Requirements
1.	a) Type of cell & Drg.No. b) Nominal Voltage & Capacity	Ni-Cd, HEB Part No.NC-40 vented & Drg.No.NC2-0071E 1.2V and 40AH at 1 Hr. rate
2.	OCV of Charged cell	More than 1.25 Volts
3.	Physical dimensions & Weight	(H) = 225 ± 2, (W) = 80 ± 2, (Thickness) = 35 ± 2mm 1500 grams (Nominal)
4.	Type of sealing for Container & Lid	High frequency cell sealing technique
5.	Electrolyte	Solution of KOH 1.3 ± 0.04 specific gravity
6.	Cell container material	Zytel (Nylon Grade) or equivalent
7.	Identification of Polarity	Red & Blue indication washers provided on the cell + & - terminals
8.	Efficiency of sealing	With pressure of 10psi when immersed in DM water, there shall not be any leak.
9.	Cell vent valve	Stainless steel
10.	Separator systems	Polymeric & celgard as gas barrier material
11.	No. of Plates with substrate type	17 positives & 16 negatives & with grid as substrate
12.	Torque requirement	6 -7 Nm cell terminal top nut

10.3.11.3 Battery Electrical & Environmental Specifications

Sl.No.	Battery Parameter	Requirement
1.	Type of Battery & Drg.No.	Ni-Cd battery HEB Battery type : NC-115 with Cell Pt.No.NC-40 Drg.No.NC0-0256E
2.	Type of Container	Stainless steel with sand blast finish / any suitable material viz. plastic, nylon, etc.
3.	Battery Connector / Receptacle	BR 8-1
4.	Battery physical dimensions & weight	362 (L) x 168 (W) x 267 (H) mm 37 Kgs. (Max.)
5.	No. of cells in a battery pack	20 connected in series (replacable)
6.	Nominal voltage & Capacity	24V, 40AH
7.	Internal resistance of battery	At 25°C = 11 mΩ At -10°C = 15 mΩ At -26°C =21 mΩ
8.	Engine Cranking ability test	**Details not available**
9.	Emergency load test	**Details not available**
10.	General environmental details	i) General Ni-Cd spec. DTD & P (Air) /E&I 502 issue 1 E&I 502/1 issue1 Mar 87 Amendment No.1 Sept. 88 ii) JSS :6140-10:2007 for NI-CD batteries
11.	Temperature sensor	71 ± 2.8°C
12.	Peak power	Data Not available

10.3.12 40AH, 24V Ni-Cd "Cells " for SEA KING

Note : Only 40AH, Ni-Cd cells with cell part No.NC-40 has been cleared by RCMA(H/C) vide letter No.RCMA(H/C)/1341/2 dated 16 Aug. 2004, assembled in Vartha container type F20/4041 for SEA KING Helicopter Mk-42 B/C

10.3.12.1 Salient Features

HEB Battery Type	Nickel Cadmium Battery – NC-230
Nominal Voltage	24 V
Nominal Capacity	40 Ah @ 1 h rate
Application	Sea king
Type Approval No & Validity	Please see note above
Technical Specification	i) General Ni-Cd spec.DTD & P (Air) / E&I 502 issue 1 E&I 502/1 issue1 Mar 87 Amendment No.1 Sept. 88 ii) JSS :6140-10:2007 for NI-CD batteries
Manufacturing &Quality Assurance Plan	HEB / QAP / FTF / NC 40

10.3.12.2 Cell Specifications

	Cell Parameter	Requirements
1.	a) Type of cell & Drg.No. b) Nominal Voltage & Capacity	Ni-Cd, HEB Part No.NC-40 vented & Drg.No.NC2-0071E 1.2V and 40AH at 1 Hr. rate
2.	OCV of Charged cell	More than 1.25 Volts
3.	Physical dimensions & Weight	(H) = 225 ± 2, (W) = 80 ± 2, (Thickness) = 35 ± 2mm 1500 grams (Nominal)
4.	Type of sealing for Container & Lid	High frequency cell sealing technique
5.	Electrolyte	Solution of KOH 1.3 ± 0.04 specific gravity
6.	Cell container material	Zytel (Nylon Grade) or equivalent
7.	Identification of Polarity	Red & Blue indication washers provided on the cell + & - terminals
8.	Efficiency of sealing	With pressure of 10psi when immersed in DM water, there shall not be any leak.
9.	Cell vent valve	Stainless steel
10.	Separator systems	Polymeric & celgard as gas barrier material
11.	No. of Plates with substrate type	17 positives & 16 negatives & with grid as substrate
12.	Torque requirement	6 -7 Nm cell terminal top nut

10.3.13 27AH, 24V Ni-Cd Battery for DORNIER-228 Aircraft

10.3.13.1 Salient Features

Type of battery	Nickel Cadmium secondary battery HEB Battery type : NC-252 with cell Pt no. NC-27
Technology developers and coordinated RCMA	M/s.HEB, Tiruchurapally RCMA(Hyd)
Nominal Voltage & Capacity	24 V & 27AH @ 1 Hr. rate
Battery Dimension & Weight	254(L) X 248(W) X 201(H) mm & 28 Kgs.
Application	DO – 228 Aircraft
Type Approval No. & Validity	QT Completed. SOF also completed and to be applied for Provisional Clearance
Technical Specification	i) QTP Doc. No.HEB/QTP/27AH/NI-CD Issue-2 dated Nov, 2006 ii) Brief Technical specifications given below for DO-228 Platform JSS :6140-10:2007 for NI-CD batteries
QA Plan	HEB / QAP / FTF / NC 27

10.3.13.2 Cell Specifications

	Cell Parameter	Requirements
1.	a). Type of cell & Drg. No. b). Nominal Voltage & Capacity	Ni-Cd, HEB Part No.NC-27 Vented Drg.No.NC3-2651 1.2V and 40AH at 1 Hr. rate
2.	OCV of Charged cell	More than 1.25 Volts
3.	Physical dimensions & Weight	(H) = 179 ± 2mm, (W) = 79 ± 1mm, (Thickness) = 34.7 ± 1.5 / -0.5mm 1200 grams (Max)
4.	Type of sealing for Container & Lid	High frequency cell sealing technique
5.	Electrolyte	Solution of KOH 1.3 ± 0.04 specific gravity
6.	Cell container material	Zytel (Nylon Grade) or equivalent
7.	Identification of Polarity	Red & Blue indication washers provided on the cell + & - terminals
8.	Efficiency of sealing	With pressure of 10psi when immersed in DM water, there shall not be any leak.
9.	Cell vent valve	Stainless steel
10.	Separator systems	Polymeric & celgard as gas barrier material
11.	No. of Plates with substrate	18 positives & 17 negatives & with grid as substrate
12.	Torque requirement	6 -7 Nm cell terminal top nut

10.3.13.3 Battery Electrical & Environmental Specifications

Sl.No.	Battery Parameter	Requirement
1.	Type of Battery & Drg.No.	Ni-Cd battery HEB Battery type : NC-252 with Cell Pt.No.NC-27 Drg.No.NC3-2926
2.	Type of Container	Stainless steel with sand blast finish / any suitable material viz. plastic, nylon, etc.
3.	Battery Connector / Receptacle	BR8-1
4.	Battery physical dimensions & weight	254(L) X 248(W) X 201(H) mm 28 Kgs.
5.	No. of cells in a battery pack	20 connected in series (replaceable)
6.	Nominal voltage & Capacity	24V, 40AH
7.	Internal resistance of battery	
8.	Engine Cranking ability test	**Details are given below**
9.	Emergency load test	**Details are given below**
10.	General environmental details	JSS : 6140 – 10 : 2007& platform requirements
11.	Temperature sensor	2 Sensors used, for opening 71°C ± 2.8°C and closing 57°C ± 2.8°C
12.	Peak power	20.6 Kw.

Engine Cranking Ability Test

Two fully charged batteries connected in series shall be subjected to 30 seconds starting cycles with the discharge current being varied as in the table below. The numbers of cycles is 4 with a rest period of 1 minute in between consecutive cycles.

TIME IN SECONDS	CURRENT IN AMPS
0-2	1000
05	675
10	576
15	520
20	455
25	260
28	37
30	37

Emergency Load Test

The battery after the engine cranking test shall be charged with a constant potential of 28.5 volts for duration of 15 minutes. Immediately after the charging shall be subjected to constant discharge current of 25A to an end point voltage of 20V. The battery shall give duration not less than 30 minutes.

Electrical power Requirement for DO-228 A/c

(a) Discharge Performance at 25°C at various current ratings:

- 27Amps load for 66 minutes up to 20V cut off.
- 135 Amps load for 12 minutes up to 19V cut off.
- 270 Amps load for 5 minutes 35 seconds up to 17V cut off.
- 405 Amps load for 3 minutes 24 seconds up to 13V cut off.

(b) Power delivery while maintaining 12V constant voltage discharge for 30 seconds

Temp.	Current at				
	0 secs	2 secs	10 secs	20 secs	30 secs
At 25°C	1733A (20.8Kw)	1583A (19Kw)	1333A (16Kw)	1250A (15Kw)	1083A (13Kw)
At -18°C	958A (11.5Kw)	812A (9.75Kw)	750A (9Kw)	729A (8.75Kw)	729A (8.75Kw)
At -30°C	583A (7.0Kw)	483A (5.8Kw)	458A (5.5Kw)	483A (5.8Kw)	500A (6Kw)

Temperature of the battery shall not be more than 70°C during above discharges.

10.3.14 30AH, 24V Ni-Cd Battery for ALH

10.3.14.1 Salient Features

Type of battery	Nickel Cadmium secondary battery HEB Battery type : NC-253 with cell Pt no.NC-30
Technology developers and coordinated RCMA	M/s.HEB, Tiruchurapally RCMA(H/C)
Nominal Voltage & Capacity	24 V & 30AH @ 1 Hr. rate
Battery Dimension	407.5 (L) x 121.6 (W) x 215 (H) mm
Battery Weight	24 Kg.
Application	ALH
Type Approval No. & Validity	QT under progress. Ground trials completed. SOF cleared by RCMA(H/C).
Technical Specification	i) JSS 6140 – 10 : 2007 & ALH plat form requirements ii) JSS :6140-10:2007 for NI-CD batteries
QA Plan	HEB / QAP / FTF / NC 30

10.3.14.2 Cell Specifications

	Cell Parameter	Requirements
1.	a) Type of cell & Drg.No. b) Nominal Voltage & Capacity	Ni-Cd, HEB Part No.NC-30vented Drg.No.NC3-2457 1.2V and 30AH at 1 Hr. rate
2.	OCV of Charged cell	More than 1.25 Volts
3.	Physical dimensions & Weight	(H) = 194.9 ± 1mm, (W) = 57.8 ± 1mm, (Thickness) = 35.9 ± 1mm 1050 grams (Max)
4.	Type of sealing for Container & Lid	High frequency cell sealing technique
5.	Electrolyte	Solution of KOH 1.3 ± 0.04 specific gravity
6.	Cell container material	Zytel (Nylon Grade) or equivalent
7.	Identification of Polarity	Red & Blue indication washers provided on the cell + & - terminals
8.	Efficiency of sealing	With pressure of 10psi when immersed in DM water, there shall not be any leak.
9.	Cell vent valve	Stainless steel
10.	Separator systems	Polymeric & celgard as gas barrier material
11.	No. of Plates with substrate	20 positives & 19 negatives & with grid as substrate
12.	Torque requirement	6 -7 Nm cell terminal top nut

10.3.14.3 Battery Electrical & Environmental Specifications

Sl.No.	Battery Parameter	Requirement
1.	Type of Battery & Drg.No.	Ni-Cd battery HEB Battery type : NC-253 with Cell Pt.No.NC-30 Drg.No.NC3-2451
2.	Type of Container	Stainless steel with sand blast finish / any suitable material viz. plastic, nylon, etc.
3.	Battery Connector / Receptacle	BR8-1
4.	Battery physical dimensions & weight	407.5 (L) x 121.6 (W) x 215 (H) mm 24 Kgs.
5.	No. of cells in a battery pack	20 connected in series (replaceable)
6.	Nominal voltage & Capacity	24V, 30AH
7.	Internal resistance of battery	At 25°C = 9 milli Ohm, -10°C =11 milli Ohm & -30°C =17 milli Ohm
8.	Engine Cranking ability test	**Details are given below**
9.	Emergency load test	**Details are given below**
10.	General environmental details	JSS : 6140 -10 : 2007
11.	Temperature sensor	1 Sensor used, for opening at 65 ± 2.8°C
12.	Peak power	18.6 Kw.

Engine Cranking Ability Test

A peak current of 850 A rapidly decreasing to 300A in about 5 to 10 secs and further gradually decreasing to 200A in about a maximum duration of 30-50 secs. Battery voltage should be greater than 16V during engine starting.

Total no of 10 starts should be possible with 2 numbers of 80% charged batteries connected in parallel at 25^0 C and terminal voltage of battery before start-up should be >20V with a gap of 30 secs between each start on each engine.

At -30^0 C, with 2 numbers of 80% charged batteries, connected in parallel shall support 5 engine starts as below;

1. 3 consecutive starts with battery terminal voltage shall be greater than 16 volts
2. 4th and 5th engine starts with battery terminal voltage shall be more than 15 volts.

Emergency Load Test

Two numbers of 80% charged batteries in parallel, shall be discharged with a fixed resistor of 160±5 mΩ till battery terminal voltage drops to 20V. The battery shall meet the requirement of minimum 20 minutes for discharge.

10.4 **Various Cell Sizes for Aircraft Batteries**

HR45 **NC40** **FTNC 25/23** **NC 27** **FTNC 18** **NC 16**

Cell Type	Nominal Capacity	Typical Dimensions (mm)			Approx. Weight (Kg.)
		Length	Width	Height	
HR 45	45	55	52	158	0.95
NC 40	40	80	35	235	1.50
NC 30	30	58	36	150	1.05
NC 27	27	80	35	179	1.20
FTNC 25	25	80	28	212	1.05
FTNC 23	23	80	28	214	1.05
FTNC 18	18	80	28	150	0.75
NC 16	16	58	33	172	0.80

11 Aviation Batteries From M/s HAL and Others

Hindustan Aeronautics Limited, Hyderabad is a public sector organization that supplies aircraft grade batteries.

11.1 Company Profile of HAL, Hyderabad

Name	M/s.HAL, Hyderabad
Address & Tel	**M/s.HAL** **Avionics Division** **(Govt. of India Undertaking), Balanagar,** **Hyderabad -500042** **Tel : 040-23878281** **Fax : 040-23878187**
ISO 9000 Status **Accreditation Body :** **Certificate Ref :** **QA Plan:**	**ISO- 9001 AND** **ISO- 14001 COMPANY** **HAL QA plan documents for silver-zinc battery: 3068PI, 3066PI, 3069PI, 3071PI.**
Test Lab Facilities	**M/S HAL, Hyderabad. All test environmental chambers and other test equipments well established.**

11.1.1 About HAL, Hyderabad

In early sixties, it was strongly felt that our defence services should be more self reliant in defence related equipment, electronics in particular. This resulted in HAL setting up a full - fledged unit to cater to the aviation electronics (AVIONICS). Thus Avionics Division, Hyderabad was born in the year 1965.

11.1.2 Products of HAL, Hyderabad

To begin with, the Division's dedicated design team took up the task of indigenising, the following critical avionics.

- Identification of Friend or Foe
- UHF Communication set
- V/UHF Communication System
- Automatic Direction Finder (ADF)
- Radio Alimeter
- Aircraft storage battery

These systems were developed, qualified, flight tested and inducted into the various MiG aircraft manufactured under licence in India. Later on, the same equipments were fine tuned to meet the requirement of other aircraft like Kiran, Jaguar, Dornier, AN-32 and Helicopters.

So far the division manufactured more than **10,500 Aircraft Storage batteries** for our defence customers and for international customers.

Today the Division has spread its wings further to meet the Communication and Navigation requirements of our defence customers and also the international market.

11.1.3 45AH, 22.5V, Silver Oxide Zinc battery for MIG-21 Aircraft & its Variants

Type of Battery	Vented type Silver Oxide Zinc battery, rechargeable HAL Part No.15 STS-45B
Technology developers and Coordinated RCMA	M/s.HAL, Hyderabad & RCMA(Hyderabad)
Nominal voltage & Capacity	22.5V & 45AH
End use	MIG-21 Aircraft & its variants
Battery Dimensions & Weight	427+1-1.5 x 225+2 x 130+2.5mm & Weight = 17.9Kgs in wet, 15.2Kgs. max. in dry condition
Type Approval No. & Validity	CEMILAC TA No.900 & Validity date : Dec.2008
Technical Specification	i) HAL (NK) Test Schedule No.TS/IND/72/17 on aircraft storage Specification Battery 15 STS S-45B and MIG platform requirements ii) RCMA(Hyd) issued additional evaluation letters
QA Plan	HAL QA plan Nos. 3068PI, 3066PI, 3069PI &3071PI

11.1.3.1 Technical Specification of 45AH 22.5V Silver-oxide Zinc Battery For MIG-21

Test No	Cell Parameter	Requirement
1.	Type of Cell and its chemistry	Vented type Silver Oxide Zinc, Rechargeable, $2Ag0 + H_{2}0 + 2Zn \underset{\text{charge}}{\overset{\text{Discharge}}{\longleftrightarrow}} 2Ag + Zn0 + Zn(OH)_{2}$
2.	Open Circuit Voltage of cell (OCV)	1.86 V
3.	Nominal voltage under load (OLV)	1.5V with rated 9Amp. load
4.	Recommended charging cutoff voltage	2.0 V
5.	Recommended discharge cutoff voltage	1.0 V
6.	Physical dimensions in m.m. and Weight in Kgs.	Dimensions : 55.5 X 52.0 X 161±1 (H) Weight: 775 gms. Max. (dry)
7.	Electrolyte	KOH (specific gravity : 1.40)
8.	Cell container material	Nylon - Zytel 151L OR its equivalent
9.	Identification of Polarity	'+' & '-' embossing provided on the cell lid and '+' & '-' marked on the cell against respective terminals
10.	Efficiency of ceiling	Each cell checked for leak at pressure of 0.8Kg/cm2
11.	Cell vent valve	Made of Nickel Plated Mild steel with hollow center port covered with rubber sleeve to operate as a Bunsen valve at pressure of 0.3 to 0.0.8 Kg./ Cm2
12.	Plates	Alternatively placed 20 positive electrodes made with silver powder and sintered, and 19 negative electrodes made with Zinc oxide on metallic silver mesh
13.	Separator systems	Cellulosic Separator - cellophane (C-19 from Yardney techn.prod., Inc.)

11.1.3.2 Battery Electrical & Environmental specification for MIG -21 aircraft

	Battery Parameter	Requirement
1.	Type of battery	Rechargeable vented 45AH Silver Zinc cells having 15 cells in a battery pack
2.	Overall physical dimensions of battery and weight & Drg.No.	427+1-1.5 x 130 + 2.5 x 225+2mm In field condition 18.9Kg. and un-field condition 16.2Kg. a) M/s.HAL, Hyderabad make: Drawing No. N120010
3.	Type of connector	Two pin socket type for MIG Aircraft
4.	Battery Container	Stainless steel
5.	OCV of charged battery	28.0 V
6.	Nominal voltage under load and its capacity rating	22.5V with 45Amp load with a cutoff voltage of 20V for 45AH capacity
7.	Cell insertion force test	9.08+4.54Kg.
8.	Charging time (Nominal input for battery)	a. DC source of 28.5V to 30V constant potential charging method for 3 hours or till the charging current become 3A b. DC source of 35V, with 4.5 constant current method for 14 hours maximum
9.	Battery rating / output performance at room temperature	Given in table 11.1.3.3(a) for typical battery ratings.
10.	Electrical power budget requirement for MIG-21 (BISON) Aircraft platform requirements	Given in table 11.1.3.3(b) for engine start profile a. **Starting mode parameters**: Staring current from 1000Amp to 150Amp and voltage dip is 9 to 19V for each start(HDD). Three such autonomous series starts are capable within 3 minutes interval in between 2 engine starts shown in fig.1 & 1A below. b. **Cycle life** : 60 cycles of operation with 3HDD discharges c. **Service period** : i. 09 months with KOH filled condition of battery ii. 36 months for dry unfilled condition of storage period iii. 180 flying hrs. or 60 flights with three HDD autonomous series starts iv. Emergency load test : capable of 50Amp load

		discharge up to 21V cutoff and duration of discharge not less than 20 minutes
11.	Insulation resistance	Battery terminal to container body shall not be less than 20Mohms / 2Mohms per cell when tested with 500V DC megger
12.	Service Life Test	This test consists of 60 cycles of charge / discharge cycles of various types in various conditions. This sequence of service life cycle tests include the environmental and mechanical tests suitably interposed.
13.	Charge retention	After storing for 30 days in charged condition at 25°C temperature battery should give minimum discharged capacity of 40AH without any additional charging
14.	Electrolyte retention	Electrolyte should not spill out when battery is inverted per 30 minutes after filling KOH and when altitude is 25 Kilo meter operation for 1 minute
15.	Vibration test (For MIG -21 Aircraft profile)	a) Vibration stability : Requirements from 10Hz to 200Hz, 200Hz to multiples of 10Hz per 1.5 minute at each frequency and with overload of 2.5 to 4.5g. b) Vibration resistance : Battery should with stand i) 30Hz for 9 Hrs 15 minutes with overload of 2.7g. ii) 70Hz for 4 Hrs with overload of 3g. iii) 200Hz for 11 Hrs. with overload 4.5g.
16.	Acceleration test	The following each loading for 1 minute duration shall be imposed a. Forward acceleration: 11g. b. Backward acceleration: 11g. c. Side acceleration: 6.5g. d. Upward acceleration: 6.5g. e. Downward acceleration: 17.5g. f. Crash case: forward deceleration of 25g. g. Lateral acceleration of +4.8
17.	Operating temperature range and Altitude level	With external temperature of +50°C to -50°C, for operation less than -5°C battery should work with heating jackets and altitude up to 25 Kms.
18.	Impact test	Total of 10,000 impacts at the rate of 50 impacts per minute and an overload of 4g.
19.	Humidity test	48Hrs. at RH 95% and temperature 40°C
20.	Salt Corrosion test	48Hrs. as per procedure 2 test No.9 section 4 of JSS 55555
21.	User trials	Battery meets ground integration checks & Flight trailsin the MIG-21aircraft and its variants successfully completed as per HAL Nashik TS flight trials.

11.1.3.3 Electrical characteristics of Silver Oxide Zinc 45AH batteries at a temperature of 20±5^0 for MIG-21 Bison Aircraft – M/s.HAL, Hyderabad

a) Typical Discharge Rates:

Battery Parameter	10 Hr Rate	5 Hr Rate	1 Hr Rate
Capacity Ah	45 40	45 40	45
Discharge Current	4.5	9	45
Final Voltage per Cell V	1.0	1.0	1.0
Final Voltage per Battery	15	15	20

b) MIG-21 (BISON) Aircraft Engine Starting Rates:

Three discharges with an interval of 3 minutes	100% capacity		85% capacity	
	Current in Amps		Current in Amps	
	Peak at 0 seconds	At 20 sec	Peak at 0 seconds	At 20 sec
1st Discharge	1035 A	815 A	875 A	700 A
2nd Discharge	960 A	740 A	820 A	645 A
3rd Discharge	885 A	675 A	770 A	600 A

NOTE-1:

i. Each battery with 100% & 85% capacity subjected engine start profile for 3 times. The battery shall deliver the current not less than the specified values in the above table. Refer 11.1.3.4 for engine start discharge simulation at 12V.

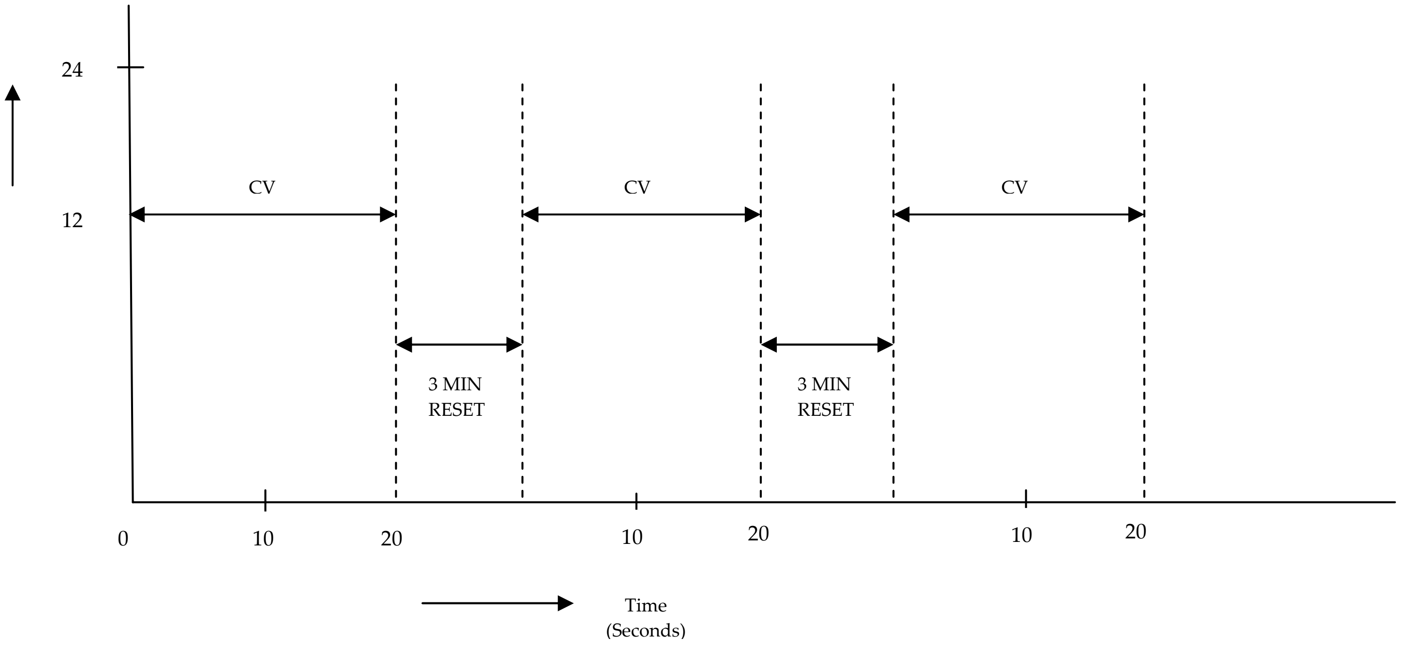
ii. During Engine starts maximum permissible discharge current is 1200 Amp. and duration for 20 Sec.

iii. Interval between the starting for each engine starts is permitted 3 minutes.

iv. Immediately after three starts as above the battery shall be CP charged for 15 minutes.

v. Immediately after CP charged above energy load of 50A shall be applied till the better voltage reaches to 21 volts. The duration of discharge obtained shall not be less than 20 minutes. During the entire operation battery temperature shall not exceed maximum 100°C.

11.1.3.4 ENGINE START SIMULATION AT 12V CONSTANT VOLTAGE DISCHARGE



Note: DURING THE DISCHARGE, BATTERY SHALL DELIVER CURRENTS AS SPECIFIED

Note: During the discharge battery should deliver a current not less than 1000 Amp. for initial peak within 5 Seconds, and total CV (constant voltage) discharge period is 20 Seconds. Discharge current shall not be less than 675 Amps. at the end of 20 seconds period.

11.1.4 45AH, 22.5V, Silver Oxide Zinc battery for LCA Aircraft

Type of Battery	Vented type Silver Oxide Zinc rechargeable Part No.15 STS-45AH for LCA
Technology developers and Coordinated RCMA	M/s.HAL, Hyderabad & RCMA(Aircraft)
Nominal voltage & Capacity	22.5V & 45AH
End use	LCA Aircraft
Battery Dimensions & Weight	475 x 171 x 130mm & Weight = 18.9Kgs. in wet
Type Approval No. & Validity	Provisionally approved for LCA-TD2 and PV series aircraft by RCMA(Aircraft)
Technical Specification	QTP reference No.HAL/ADB/LCA/041200/067, Issue 'A' and TS/IND/72/17 dated 17th Aug. 1979 (Brief Technical specifications outlined below)
QA Plan	HAL QA plan Nos. 3068PI, 3066PI, 3069PI &3071PI

Note : For both aircrafts of MIG and LCA Silver Zinc Battery 45AH is common, except battery main connector (ELCON-BR-8-1) changed for LCA.

Note: For cell specification of Silver-Zinc 45AH, ref table-11.1.3.1 above.

11.1.4.1 Battery Electrical & Environmental specification for LCA (only vibration test carried, other tests are waved off on similarity basis of MIG -21 Aircraft)

Sl No	Battery Parameter	Requirement
1.	Type of battery	Rechargeable vented 45AH Silver Zinc Battery Type – 15 SZ 45AH consists of 15 cells connected in series. Drawing No. N120010
2.	Overall physical dimensions of battery and weight	Dimensions : 475 X 171 X 130 Weight: 18.9Kg. Max. in filled condition (Wet) 16.2 Kg. Max. in un-filled condition(Dry)
3.	Type of connector	**ELCON BR-8-1 for LCA**
4.	Battery Container	Stainless steel
5.	OCV of charged battery	28 V
6.	Nominal voltage under load and its capacity rating	22.5 V nominal, 45 AH
7	Storage Life	3 Years in Electrolyte un-filled condition(Dry)
8	Service Life	09 months in Electrolyte filled condition (Wet) (45 AH in the initial 6 months and 40 AH in the remaining period) 180 flying hrs. or 60 flights with three autonomous series engine starts
9.	Charging time (Nominal input for battery)	a) Charge at the rate of 4.5 A till any two cells reach 2V with DC source of 35V (Approx. time 15 Hrs. maximum) b) DC source of 28.5V to 30V constant potential charging method till the charging current become 3A
10.	Battery rating / out put performance at room temperature	Same as in 11.1.3.2
11.	Electrical power	a) Starting mode parameters: Staring current from 750 Amp to 150 Amp and voltage dip is 9 to 19V for each start (HDD). Maximum 3 times with 3 minutes interval.
12	Service Life Test	This test consist of 60 cycles of charge / discharge cycles of various types in various conditions. This sequence of service life cycle tests include the environmental and mechanical tests suitably interposed.
13.	Vibration test for LCA	a) Random Vibration : Random Vibration PSD 0.04g2 /Hz over 15Hz to 1000 Hz and falling off at the rate of 6db/octave from 1000 Hz to 2000 Hz Duration 1 Hr/ axis on all three axis while battery is 'ON'. b) Sine Vibration : 5Hz to 10Hz 9.9mm (constant) limited

		to 5g. Duration three hours per axis. c) Gun fire vibration: PSD of 0.5g2 /Hz over 250 to 1250Hz and falling off and at the rate of 6db/octave over 1250Hz to 2000Hz to 20Hz. Frequency band with 20 to 2000Hz with narrow band peaks of PSD of 0.28 g2 /Hz superimposed at 50Hz and 100 Hz respectively. The duration for the test is 7 Min/axis.
14.	Acceleration test	The following each loading for 1 minute duration during which the battery is capable of taking a load of 40Amps. a. Forward acceleration: 11g. b. Backward acceleration: 11g. c. Side acceleration: 6.5g. d. Upward acceleration: 6.5g. e. Downward acceleration: 17.5g. f. Crash case: forward deceleration of 25g. g. Lateral acceleration of ± 4g h. Functional : 10 'g' in all directions i. Structural : 15 'g' in all directions
15.	Operating temperature range and Altitude level	With external temperature of +50°C to -50°C, for operation less than -5°C battery should work with heating jackets and altitude up to 25 Kms.
16.	Humidity test	48Hrs. at RH 95% and temperature 40°C
17.	Salt Corrogen test	48Hrs. as per procedure 2 test No.9 section 4 of JSS 55555
18.	User trials	Battery meets ground integration checks in the aircraft and LCA flight trials report not available

11.2 Company Profile of M/s.Mysore Thermo Electric (P) Ltd., Bangalore

Name	M/s. Mysore Thermo Electric (P) Ltd.,
Address & Tel	M/s. Mysore Thermo Electric (P) Ltd., No.36 & 62, 3rd Phase, 4th Main, Peenya Industrial Area, Bangalore – 560 058 Phone No.080-28395525 Fax No.080-28394417 E-mail : info@microtex.in
ISO 9000 Status Accreditation Body : Certificate Ref :	ISO 9001: 2000 Company accredited by National Accreditation Board for Certification Bodies through NVT Quality Certification and the certificate No. is 100119081

11.2.1 28AH, 24V, Lead Acid battery (Flooded type : 12-CAM 28 MTE) for Mi-8/Mi-17 H/C

Table 11-1 Technical Details of 28AH, 24V Lead Acid Battery for Mi-8/Mi-17 Helicopters

1.	Battery technology type	Lead Acid Aircraft Battery – Flooded type assembled in monoblock polypropylene container together with lifting handles.
2.	Cell/Battery Voltage and Capacity	Voltage : 24V Capacity : 28AH
3.	Physical dimension and weight of the Battery	L: 369+ 3 mm W : 163 +3/-1 mm H : 214 +2/-4 Weight(With Electrolyte): 28.50 Kgs
4.	Type of Electrode (or Plates) No. of Positive and Negative electrodes in each cell.	a. Positive and Negative plates b. 72 Nos. of Positive and Negative plates.
5.	Type of Grid alloy	Selenium Lead for Positive grid and Antimonies Lead for Negative grid
6.	Separator system used in cell	Micro porous Polyethylene Separator in between Positive and Negative plates
7.	Type of sealing method for cell lid joints etc Efficiency of sealing	Bituminous sealing compound The sealing of individual cells in the Battery shall be tested by applying to each cell at a air pressure corresponding 14 K(140 cm water gauge)
8.	Electrolyte used Concentration	Dilute Sulphuric Acid. Sp.Gr. of 1.280
9.	Material used in cell container, covers and tray	Polypropylene grade : M13530 of Koylene – cp
10.	a. Type of vents	a. Non-spillable vent plugs of high impact polysterene.

	b. Venting pressure limits of cell/Battery	b. Self sealing type.
11.	Details of Markings/Finishing (Company name plate and Manufacturing date etc.,)	Description of Battery including normal voltage and rated ampere – hour capacity is stenciled in the shorter and longer side of the Battery. the month and year of manufacture and Battery serial number is punched in the connector
12.	Type of Battery connector used	Made up of special Lead alloy with adequate mechanical strength and current carrying capacity and terminal connection.
13.	No. of cells in a Battery pack OCV of Battery Capacity	12 Nos. (24 Volts) 25.5 Volts in charged condition 28Ah @ 5 Hr rate
14.	a. Battery charging profile b. State of charge as shipped	a. Initial charging @2.5Amps for 50 Hrs. Normal charging @ 4 Amps b. Dry uncharged
15.	Battery life	36 Months
16.	Maximum Power capability of Battery Peak Power capability of Battery	Load 180 Amps for 43 minutes. Load 280 Amps for 27 minutes. Load 210 Amps for 36 minutes. Load 310 Amps for 24 minutes. b. 310A for 24 Minutes.
17.	Maximum internal resistance value at room temperature At 30°C (or indicate at which temperature battery was designed)	At 25°C – 17 mΩ At 10°C – 25 mΩ
18.	Engine Cranking profile Emergency load requirements	Current @ 650 Amps to 75 Amps. End voltage of 16.00Volts 180 Amps
19.	Environmental specifications at which Battery was evaluated for Airworthiness	Battery evaluated as per technical specifications No .DTD&P(AIR)E&I(507) 1987 and complied the requirement there.

Part III

Standards, Conclusion and References

- Battery Standardization & List of Standards
- General Conclusion
- Abbreviations
- Glossary
- Bibliography

12 Battery Standardization & List of Standards

12.1 Battery Standardization

The standardization of batteries started in 1912, when a committee of the American Electrochemical Society recommended standard methods of testing dry cells. This eventually leads to the first national publication in 1919 from National Bureau of Standards. It further evolved into the present American National Standards Institute (ANSI). Since then additional professional societies have developed battery standards. Many battery standards were also issued by international, national military and federal organizations.

The International Electrotechnical Commission (IEC) is the designated organization responsible for standardization in the fields of electricity and electronics. The International Standards Organization (ISO) is responsible for international standards in fields other than electrical.

12.1.1 New IEC Nomenclature System

The IEC nomenclature system for primary batteries, which became effective in 1992, is based on the electrochemical system and the shape and size of the cell. The letter designates the electrochemical system. The numerical designations are based on a diameter / height of the cell. The first digits specify the diameter of the cell in mm and the second the height of the cell in cm.

The IEC nomenclature for secondary batteries is similar to primary batteries. In this the first letter designates the electrochemical system, a second letter the shape, the first number the diameter and a second number the height. In addition, the letters L, M and H may be used to classify arbitrarily the rate capability as low, medium or high. The last part of the designation is reserved for two letters which indicate various tab terminal arrangements.

12.2 International Standards (IEC—International Electrotechnical Commission)

Publication	Title	Electrochemical systems
IEC 60086-1,IEC 60086-2	Primary Batteries; Part 1 General and Part 2, Specification Sheets	Zinc-carbon Zinc / air Alkaline-manganese dioxide Mercuric oxide Silver oxide Lithium / carbon monofluoride Lithium /manganese dioxide Lithium / copper oxide Lithium /chromium oxide Lithium / thionyl

		chloride
IEC 60086-3	Watch Batteries	Lead-acid
IEC 60095	Lead-Acid Starter Batteries	Lead-acid
IEC 60254	Lead-Acid Traction Batteries	Nickel cadmium
IEC 60285	Sealed Nickel-Cadmium Cylindrical Rechargeable Single Cells	Nickel-cadmium
IEC 60509	Sealed Nickel-Cadmium Button Rechargeable Single Cells	Nickel-cadmium
IEC 60622	Sealed Nickel-Cadmium Prismatic Rechargeable Single Cells	Nickel-cadmium
IEC 60623	Vented Nickel-Cadmium Prismatic Rechargeable Cells	Nickel-cadmium
IEC 60952	Aircraft Batteries	Lead-acid
IEC 60986	Stationary Lead-Acid Batteries	Lead-acid
IEC 61056	Portable Lead-Acid Cells and Batteries	Lead-acid
IEC 61150	Sealed Nickel-Cadmium Rechargeable Monobloc Batteries in Button Cell Design	Nickel-cadmium
IEC 61436	Sealed Nickel-Metal Hydride Rechargeable Cells	Nickel-metal hydride
IEC 61440	Sealed Nickel-Cadmium Small Prismatic Rechargeable Single Cells	Nickel-cadmium

12.3 National Standards (ANSI - American National Standard Institute)

Publication	Title	Electrochemical systems
ANSI C18.1M, Part 1	Standard for Portable Primary Cells and Batteries with Aqueous Electrolyte	Zinc-carbon Alkaline-manganese dioxide Silver oxide Zinc / air
ANSI C18.2M, Part 1	Standard for Portable Rechargeable Cells and Batteries	Nickel-cadmium Nickel-metal hydride Lithium-ion
ANSI C18.3M, Part 1	Standard for Portable Lithium Primary Cells and Batteries	Lithium / carbon monofluoride Lithium /manganese dioxide

12.4 U.S. Military Standards (MIL)

Publication	Title	Electrochemical systems
MIL-B-18	Batteries Non-Rechargeable	Zinc-carbon, mercury
MIL-B-8565	Aircraft Batteries	Various
MIL-B-11188	Vehicle Batteries	Lead-acid
MIL-B-49030	Batteries, Dry, Alkaline (Non-Rechargeable)	Alkaline-manganese dioxide
MIL-B-55252	Batteries, Magnesium	Magnesium
MIL-B-49430	Batteries, Non-Rechargeable	Lithium / sulfur dioxide
MIL-B-49436	Batteries, Rechargeable, Sealed Nickel-Cadmium	Nickel-cadmium
MIL-B-49450	Vented Aircraft Batteries	Nickel-cadmium
MIL-B-49458	Batteries, Non-Rechargeable	Lithium /manganese dioxide
MIL-B-49461	Batteries, Non-Rechargeable	Lithium / thionyl chloride
MIL-B-55130	Batteries, Rechargeable, Sealed Nickel-Cadmium	Nickel-cadmium
MIL-B-81757	Aircraft Batteries	Nickel-cadmium
MIL-PRF-49471	Batteries, Non-Rechargeable, High Performance	Various

12.5 British Standards Of Lead Acid Batteries

88/74677 DC	Aerospace series. Lead acid batteries for aircraft. General standard (prEN 3199)
00/201034 DC	BS EN 60896-1 Ed.2. Stationary lead-acid batteries. General requirements and methods of test. Part 1. Vented types (IEC Document 21/487/CD)
00/202302 DC	BS EN 60952-2, Ed.2. Aircraft batteries. Part 2. Design and construction requirements (IEC Document 21/509/CD)
00/202303 DC	BS EN 60952-3, Ed. 2. Aircraft batteries. Part 3. External electrical connectors (IEC Document 21/510/CD)
MIL-PRF-8565	Recombinant / Sealed Lead Acid Batteries (SLAB)
BS 4G 205:Part 1:1987	Secondary batteries for aircraft. Specification for lead-acid batteries
BS 5G 205:Part 1:1990	Secondary batteries for aircraft. Specification for lead-acid batteries
99/200338 DC	Aircraft batteries. Part 1. General test requirements and performance levels (IEC document 21/466/CD)
00/202302 DC	BS EN 60952-2, Ed.2. Aircraft batteries. Part 2. Design and construction requirements (IEC Document 21/509/CD)
00/202303 DC	BS EN 60952-3, Ed. 2. Aircraft batteries. Part 3. External electrical connectors (IEC Document 21/510/CD)

12.6 British Standards Of Ni-Cd Batteries

BS EN 2570:1996	Nickel-cadmium batteries. Technical specification
BS EN 60623:1996, IEC 60623:1990	Vented nickel-cadmium prismatic rechargeable single cells
BS EN 60623:2001, IEC 60623:2001	Secondary cells and batteries containing alkaline or other non-acid electrolytes. Vented nickel-cadmium prismatic rechargeable single cells
MIL-P-18148	Aircraft Battery Power Connectors
MIL-PRF-18148	Aircraft Battery High power receptacles and connectors
JSS 6140-10 : 2007	Batteries and cells, storage, NI-CD for Aviation use (General specification)

12.7 **Concepts Of Standardization**

The objective of battery interchangeability is achieved by specifying the preferred values for the physical aspects of the battery, such as dimensions, polarity, terminals, nomenclature and marketing. In addition, performance characteristics such as service life or capacity may be described and specified with test conditions for verification.

It is the inherent nature of batteries in particular primary batteries (also secondary batteries) that replacements will at some time be required. A third-party end-user of the equipment typically replaces the battery. It is therefore essential that certain characteristics of the battery be specified by standard values—size, shape, voltage and terminals. Without a reasonable match of at least these parameters there can be no interchangeability. These characteristics are absolute requirements in order to fit the appliance receptacle to make proper contact and to provide the proper voltage. In addition to the end-user's need for replacement information the original equipment manufacturer (OEM) appliance designer must have a reliable source of in-formation about these parameters in order to design a battery compartment and circuits that will accommodate the tolerances on battery products available for purchase by the end-user.

13 General Conclusion

What does the aviation user expect from batteries?

A battery expert says “You will never understand the battery unless you make it. You will never understand it even though you make it”. This is a ‘golden saying’ when the situation is analyzed from those who manufacture batteries. From the standpoint of those who use batteries, this saying will become “You will never understand the battery unless you use it.” A golden saying becomes a shattered golden saying. Many of users (Military & Civilian customers) experienced the batteries suddenly becoming low in power, battery was supposed to be fully charged but failed during engine starting etc. Recent trends to overcome such problems are by redesigning / modifying the existing batteries to match the user requirements easily. Never the less, many of users admit “You never know the battery even if you use it.”

Herein lies the interest in and difficulty with the battery.

13.1 Recent Advances / Developments

1. Maintenance free (MF) operation is the futures of sealed Pb rechargeable, MF Nickel cadmium batteries.
2. Starved electrolyte system in conjunction with cell closure incorporating crimp or hermetic designs allows operation in any orientation.
3. Interconnect cells straps or lead terminals are assertively welded to cells
4. No cleaning or adjustments of KOH required
5. Consumers demand low-price and easy to handle batteries.

Ni-Cd batteries are mostly used in many Military Aircrafts. Commonly used aviation batteries with sintered plate offer both high power and comparatively high energy density. This construction is used for both positive and negative plates in many designs and also for positive plates in some hybrid designs. Nickel powder is sintered (the particles are welded together but not melted) onto a metallic sheet resulting in a matrix with porosity greater than 80% into which the active materials are chemically or electrochemically impregnated. This results in very uniform filling and good contact with the conducting substrate.

a. Ni-Cd batteries with Fiber plates: Fiber plates are constructed from a fibrous plastic matrix in which the fibers have been coated with nickel to make them conductive. Active material slurries are vibrated into the void spaces in the matrix form either positive or negative plates. Additives may be used and in fact it is normal to have a small percentage of expanders in the negative material.

b. Ni-Cd batteries with Plastic bonded plates: Recently M/s.HBL, Hyderabad and M/s H.E.B Tiruchurapally, proposed aircraft Ni-Cd batteries with sintered positives and plastic bonded electrodes for negatives plates. This recent advanced technology is under evaluation, some of the types already undergone limited QT.

In this technology the plate construction is somewhat similar to the sintered design, but with the nickel matrix replaced by a synthetic rubber compound. Plates are produced by coating slurry of active material, plastic and expanders onto a metallic sheet. Plastic bonded plates are not suitable for positive electrodes, so their use is restricted to the negatives of hybrid designs, typically with sintered or foam positives. Industrial Ni-Cd batteries of type pocket plate, fibre and plastic bonded are used in different types of renewable energy systems. The market share is however small as compared to lead acid batteries.

c. Silver-Zinc Battery

The vast majority of recent efforts in secondary silver cells have been concentrated in the areas of negative electrode and separator improvements for the zinc/ silver oxide system because of its proportionally larger market volume. The major developments are summarized below. Some of the most recent work has been quite successful, including:

- Use of bismuth oxide as an inexpensive additive to the zinc electrodes to improve the capacity retention and the cycle life of the cells.
- The development of new separators, including:
    1. Microporous polypropylene with a proprietary coating, which is very thin and has improved resistance to attack by the electrolyte.
    2. A polyolefin film with inorganic fillers, which has demonstrated to more than double the cycle life of the cells built with it, by inhibiting the ''shape change'' of the zinc electrodes.

Both separators are currently costly, and require further development work prior to production

13.2 Future Trends

13.2.1 Ni-Cd Batteries

a. User expects much minimization and ease of use with light weight and maintenance free operation.

b. Sealed PB acid and Ni-Cd batteries were the power sources at the time sealed PB acid batteries were replaced with Ni-Cd batteries in the field after a while due to poor capacity recovery on charging, triggered by sulphation effect after some period of storage in stock in logistics.

c. Statistics suggested about 80% of small rechargeable batteries are being produced and the leading edge batteries, such as NI-MH and Lithium ion batteries are almost leading in the market. Lithium based primary batteries have high energy compare to other types of batteries; such types may be more useful for military avionics applications.

d. Thus Lithium Ion, NI-MH, Ni-Cd and Polymer batteries will be the predominant batteries for ten more years. Lithium Ion battery will proceed for high capacity and cost effectiveness with the improvement of negative and positive materials.

Ni-Cd battery will die hard because of low price and applicable to a big current drain.

e. Overall assessment and future prospects of silver zinc oxide aircraft batteries, more cost and has a shorter average life than the lead acid and nickel cadmium aircraft battery system. It will, however remain competitive with these battery system for specialized aircraft applications because of its qualities of higher specific energy, high specific volume and ability to deliver high currents. The service performance of existing zinc-silver oxide aircraft batteries must be improved considerably before the rechargeable system becomes a contender battery system for across the board aircraft applications. The prospect of such batteries for future military aircraft applications is somewhat dim. This is because of the inherent mismatch between the rather delicate rechargeable battery system and the abusive nature of the aircraft application.

f. The Ni-Cd battery is a mature technology and a niche product with a market share of about three percent of the total industrial battery market dominated by lead acid batteries. The advantages are mainly the high reliability, long life and the low temperature characteristics. The disadvantages are the high cost, being 4 to 12 times more expensive than lead acid batteries, the Cd content and especially for renewable energy systems, the high self discharge rate and low charge acceptance at high SOC.

g. For Ni-Cd batteries as energy storage for future renewable energy systems R&D should be focused on reduced cost by increased efficiency of the active materials and on the charge acceptance. To address the environmental concerns regarding the Cd R&D should be focused on recycling processes and raw material consumption and life performance to reduce the amount of cadmium used.

h. Recyclers of Ni-Cd: Improvements and cost reductions of recycling processes to promote recycling of especially cylindrical Ni-Cd batteries.

13.2.2 Silver- Zinc Batteries

a) Silver- Zinc battery usage within the Military will grow in the near future with improved Silver Zinc batteries. Research is going on to improve the properties and life cycle of Silver - Zinc batteries.

13.2.3 Lead Acid Batteries

a) Military uses Lead Acid Battery primarily for vehicle starting, lighting and ignition, aircraft engine starting, motive power on submarines and standby power system in Missile silos.

b) The popularity of lead acid batteries is attributed to the maturity of the technology, the low maintenance free (MF) type. One of the most probable batteries for use in electric power supply source in military aircraft. Newer lead acid batteries VRLA types are replacing many of the older lead acid batteries in many aviation systems.

13.2.4 Lithium Batteries

a. Lithium batteries are used primarily in Military applications, though there is some spin off into commercial market. Lithium primary batteries offered performance advantages well above the capabilities of conventional aqueous electrolyte battery systems. They have higher gravimetric energy, highest volumetric energy and one of the best storage lives of any electro chemical battery system.

13.2.5 The Lithium Ion Batteries

a. Attempts to develop rechargeable lithium batteries followed in 1980s, but failed due to safety problems. Because of the inherent instability of lithium metal especially during charging, research shifted to a non-metallic lithium battery using lithium ions. Although slightly lower in energy density than lithium metal, the Li-ion is safe provided certain precautions are met while charging and discharging. Today the Li-ion is the fastest growing and most promising battery chemistry.

13.3 Safety Precautions On Aircraft Batteries

a. Ni-Cd batteries, Silver zinc batteries, Lead acid batteries are commonly used on aircraft as main storage battery. These batteries are required to be equipped with a battery temperature monitoring facility in order to comply the safety measures. However already some aircrafts having thermal sensors / thermal switches are installed in the battery. Those batteries not equipped with thermal sensors/thermal switches may be planned for installation provision. Main benefit of these thermal switches in the battery to give advance warning indication and prevent overheating of the battery, thereby achieving a greater safety of flight operation.

b. The thermal switches are connected to a connector on the battery container from which a cable leads to a warning lamp situated on the instrument panel of the aircraft.

c. This warning lamp lights up when the predetermined temperature limit for the thermal switch is reached, e.g. 71°C. When the warning lamp lights up, charging of the battery must be stopped. When the battery is cooled down the warning lamp goes out and the battery is ready for service.

13.3.1 Overall Conclusion Summary

a. During the last few decades, rechargeable batteries have made only moderate improvements in terms of higher capacity and smaller size. Compared with the vast advancements in areas such as microelectronics, the lack of progress in battery technology is apparent. Consider a computer memory core of the sixties and compare it with a modern microchip of the same byte count. What once measured a cubic foot now sits in a tiny chip. A comparable size reduction would literally shrink a heavy-duty aircraft battery to the size of a coin. Since batteries are still based on an electrochemical process, an aircraft battery in the size of a coin may not be possible using our current techniques.

b. Research has brought about a variety of battery chemistries, each offering distinct advantages but none providing a fully satisfactory solution. With today's increased selection, however better choices can be made to suit a specific user application.

c. Military specifications and standards that govern the design and manufacturing process of different batteries are often out of date and not followed strictly. Presently only Mil-Specs are being followed for developing indigenous Military aircraft batteries. However, JSS 6140 has been updated in 2007 for developing indigenous military aviation batteries.

d. Aircraft batteries are critical item and shall meet highest quality and reliability requirements.

e. Inspection and production testing is carried out with approved SOP and ATP.

f. Airworthiness Qualification test procedure ensures proper evaluation of battery to meet platform requirement and results in defining the standard of preparation (S.O.P) and this documents are required for bulk production and inspection audits.

g. Selection of optimum battery for aircraft use results in a safe, effective, efficient and economical power storage capability. For aircraft application it is generally higher peak power/maximum power delivery for 30 seconds is mandatory requirement apart from emergency load demand for a period of at least 20-25 minutes.

h. The batteries have finite life due to occurrence of unwanted chemical physical changes of issue variable nature which affect electrical performance.

i. Battery life can be prevented from being cut short by observing proper charging methods as most of the failures are due to impropriate charging.

j. In multi cell batteries, problem arise due to inter action between cells causes by small differences in characteristics of individual cells, cell balancing can prevent individual cells for becoming overstates thus prolonging the life of battery.

k. Nickel Cadmium (Ni-Cd) designs, originally developed in the late 1800's consist of a nickel hydroxide positive electrode and a cadmium negative electrode in an electrolyte solution of potassium hydroxide, resulting in a nominal voltage of 1.2V. The traditional design is pocket plate, but over the years the development of sintered plates, fiber plates, plastic bonded electrode (PBE) and foam plates have brought refined attributes for specific applications. Generally, Ni-Cd batteries designs have found areas within the traditional stationary applications where the advantages of its design outweigh the cost disadvantage when compared to lead acid solutions.

l. The need for R&D on aircraft batteries such as Ni-Cd and Ag-Zn batteries for improved charge efficiency at high state of charge, reduced charge retention and to able to compete with lead acid batteries reduced cost.

m. The term thermal battery does not refer to any one type of battery chemistry but to a group of electrochemical systems using different chemistries. The most common configurations are lithium based systems. These types of batteries are for one time use and provide power for mines, missiles, guided artillery, fuses, countermeasure devices and guidance systems. Activated pyrotechnically, the electrochemical reaction cannot be stopped and has duration of a few seconds to a few hours. Thermal batteries are used exclusively by the military, though R&D is underway to address commercial applications.

n. Many aircraft batteries qualified for airworthiness by RCMA/CEMILAC are successfully being manufactured and flying on various platforms of IAF, IN and Army.

13.3.2 Epilogue

Thomas Edison never knew what he got started over 100 years ago when he invented the first rechargeable alkaline storage battery. Today in many areas of our lives battery powered devices are at work making things more convenient, safer, more productive and even more entertaining. Just about any place you can imagine there is a battery system getting things started or keeping things going. They're used for very down to earth reasons and for purposes that are literally out of this world. It might have started with Edison, but even he couldn't possibly have imagined how far battery technology would go. This concludes this section on nickel-cadmium cells (sealed and vented type), silver zinc cells and lead acid batteries (VRLA type). Lithium, thermal batteries and certification process etc. We hope this has helped you to become more familiar with some of the technical aspects of alkali battery technology and that you now have a better understanding of items that should be considered when you are developing applications.

Variety of aviation batteries undertaken for airworthiness evaluation to ensure safety and reliability during design, manufacture & maintenance. These requirements are obtained by practicing well design requirement and various other requirements. Airworthiness Certification aspects depends on various tools used (to eliminate regulator over site of the design process) and in addition to ensure QA role in certification.

As you can see, there is a lot to a battery. It is a complex electrochemical device. Essentially, batteries need maintenance and care to get the most from them. This is the main reason people spend so much on batteries to support far more expensive equipment and to ensure continuous successful operation.

14 Abbreviations

A : Ampere
Å : Angstrom
AAA : Airworthiness Approval Authority
AC : Alternating Current
AH/Ah : Ampere-Hour
AP : Auxiliary Power Unit
AQTP : Airworthiness Qualification Test Procedure
ASR : Air Staff Requirement
ASTE : Airborne Systems and Testing Establishment
ASW : Anti Submarine Warfare
atm : Atmosphere, Standard
AWG : airworthiness group
C : cell size as Ah for a specified, operating temperature, discharge rate and final voltage and also used as SI unit of electric charge Coulomb
CCA : Cold Cranking Amperes
CEMILAC : Centre for Military Airworthiness and Certification
COD : Certification Of Design
CRE : Chief Resident Engineer
CRI : Chief Resident Inspector
DC : Direct Current
DCT : Data for Capacity Test
DDRC : Deep Discharge Reconditioning
DDPMAS : procedure for Design, Development & Production of Military Aircraft &airborne Stores
DEF STD : Defense Standard (British)
DGAQA : Directorate General of Aeronautical Quality Assurance
DGAQA : Director General Aircraft Quality Assurance
DGCA : director general civil aviation
DOD : Depth Of Discharge
DODISS : Department Of Defense Index of Specifications & Standards
Deep Submergence and Rescue Vehicles
DSRV :
ELA : Electrical Load Analysis
EMF : electro motive force
EOL : End of Life, generally to a specific voltage
EV : Electrical Vehicles
FAA : Federal Aviation Administration
GTM : Glass-To-Metal seal
GPU : Ground Power Unit
GSQR : Ground Staff Qualitative Requirement
HEV : Hybrid Electrical Vehicles
IAF : Indian Air force
IN : Indian Navy
JSS : Joint Service Specification

LMV : Low Maintenance Vented
LVRC : Low Voltage Reconditioning
MDI : Master Drawing Index
MPS : Minimum Performance Standard
MIL-STD : Military Standard (department of defense U.S)
MMEL : Master Minimum Equipment List
Ni-Cd : Nickel - Cadmium
Ni –MH : Nickel -Metal Hydride
NSQR : Naval Staff Qualitative Requirement
OEM : Original Equipment Manufacture
PBE : Plastic Bonded Electrode
PC : Provisional Clearance
PP : Pocket Plate
PR : Periodical Renewals
PRB : Personal Rescue Beacon
PTFE : Poly Tetra Fluoro Ethylene (Teflon)
PTC : Positive Temperature Coefficient
RFI : Ready For Issue
QT : Qualification Test
QAP : Quality Assurance Plan
QCSR : Quality Control System Requirements
QTR : Qualification Test Results
RC : Reserve Capacity
RCMA : Regional Center for Military Airworthiness
RD : Regional Director
RM : Reduced Maintenance
SIs : Standing Instructions
SOC : State Of Charge
SOF : Safety Of Flight
SOFT : Safety Of Flight Test.
SOH : State Of Health
SOP : Standard Of Preparation
STC : Supplementary Type Certificate
STIs : Standing Technical Instructions
SLAB : recombinant/sealed Lead Acid Battery
SLI : Starting, Lighting & Ignition
TA : Type Approval
TCO : Temperature Cut Off
TRU : Transformer Rectifier Unit
V : Volt
VPC : Volt Per Cell
VRLA : Valve Regulated Lead Acid
W : Watt
Wh : Watt-hour

15 Glossary

15.1 Electro chemical cells & battery

Activation	The process of wetting the cell with electrolyte followed by the charging or formation process to prepare the cell or battery for use.
Activation Time	The time interval from the moment activation is initiated to the moment the desired operating voltage is obtained in a cell or battery.
Active Material	Electrode material which produces electricity during its chemical conversion.
Ampere Hour (Ah)	The capacity of a storage battery is measured in ampere-hours. One ampere hour is defined as a current flow of one ampere for a period of one hour. Five ampere-hours means a current flow of one ampere for five hours, a current flow of 2 1/2 ampere for 2 hours or any multiple of current and time that will result in five.This relationship can be expressed as follows: Capacity (In ampere hours)= I*T. Where I is the current (in amperes) and T is the time (in hours). The capacity of a storage battery is usually based on a given discharge rate, since the capacity will vary with the rate of discharge. The capacity of an aircraft battery is usually based on a one hour discharge rate. A 17 ampere hour battery will supply a current of approximately 17 amperes for a period of one hour. A 34 ampere battery will deliver twice that amount of current over the same period of time. If a very heavy load is applied to the battery, it may become discharged in a few minutes.
Boost Charge	A charge applied to a battery which is already near a state of full charge usually of short duration.
C1 Rate	Discharge or current rate in amperes numerically equal to rated capacity of a cell in ampere-hours.
Capacity	The quantity of electricity delivered by a battery under specified conditions usually expressed in ampere-hours.
Capacity Reconditioning	See Reconditioning.
Capacity, Functional Loss Of	Reduction in cell capacity due to nonstandard charging or discharging parameters such as cell temperature, current and discharge voltage cutoff. See also Failure, Functional.
Capacity, Permanent Loss Of	Reduction in cell capacity from as new value, under standard rating conditions not recoverable by reconditioning. See also Failure, Permanent.

Capacity, Rated	:	See Nominal Capacity.
Capacity, Residual	:	Capacity remaining at particular point in time after any set of operating conditions usually including a partial discharge or long rest.
Capacity, Restorable	:	See Capacity, Temporary Loss Of.
Capacity, Temporary Loss Of	:	Reduction in cell capacity that is recovered when the cell is subjected to several reconditioning cycles.
Capacity, Useful	:	See Ampere Hour Capacity.
Case	:	The battery box or enclosure which contains the cells and associated connectors and hardware.
Cell	:	An electrochemical device composed of positive and negative plates, separator and electrolyte which are capable of storing electrical energy. When encased in a container and fitted with terminals, it is the basic building block of the battery.
Cell Reversal	:	Reversing of polarity within a cell in a multi-cell battery due to over discharge.
Charge	:	The conversion of electrical energy from an external source into chemical energy within a cell or battery.
Charge Rate	:	The rate at which current is applied to a secondary cell or battery to restore its capacity.
Charge Retention	:	The tendency of a charged cell or battery to resist self-discharge.
Charge, State of	:	The condition of a storage cell or battery in terms of the remaining capacity.
Charger	:	Device capable of supplying electrical energy to a battery.
Charging	:	The process of converting electrical energy to stored chemical energy.
Charging Efficiency	:	Ratio of the capacity delivered on discharge, after being fully charged, to the capacity needed to restore full charge to the cell or battery.
Concavo-Concave	:	RG batteries have one-way cell vent valves designed to relieve excess positive internal pressure. Occasionally, when the atmospheric pressure is greater than the internal pressure of the battery, caused by rapid decrease in altitude, the battery case may become temporarily concave.

Connector	:	An electrically conducive bar or wire which joins individual cells together in a battery.
Constant Current (CI) Charge	:	Charging technique where the output current of the charge source is held constant. Warning! This procedure may damage the battery if performed on a repetitive basis.
Constant Potential (CP) Charge	:	Charging technique where the output voltage of the charge source is held constant and the current is limited only by the resistance of the battery.
Container	:	The cell enclosure in which the plates, separator and electrolyte are held. It is made up of the cell jar and cover that are permanently joined.
Contaminant	:	Undesirable element usually in the electrolyte, which reduced the capability of the cell. In vented cells, contaminants can be introduced by use of tap water or operation without vent cap.
Coulometer	:	Electrochemical or electronic device capable of integrating current time used for charge control.
Counter EMF	:	Voltage or a cell or battery opposing the voltage of the charging source.
Current	:	The rate of flow of electricity. The movement of electrons along a conductor. It is comparable to the flow of a stream of water. The unit of measurement is an ampere.
Current Density	:	The amount of electric current passing through a given cross-sectional area of a conductor in amperes per square inch, i.e., the ratio of the current in amperes to the cross-sectional area of the conductor.
Cut Off Voltage	:	Battery voltage reached at the termination of a discharge. Also known as end point voltage or EPV.
Cycle	:	On sequence of charge and discharge.
Cycle Life	:	For secondary (rechargeable) cells or batteries, the total number of charge/discharge cycles before the cell or battery becomes inoperative.
Deep Discharge	:	Withdrawal of 50% or more of the rated capacity of a cell or battery.
Deionized Water	:	Water which has been freed of ions by treatment with ion exchange resins.
Depth Of Discharge	:	The portion of the nominal capacity from a cell or battery taken out during each discharge cycle, expressed in percent. Shallow depth of discharge is considered as 10% or less, deep depth of discharge is considered 50% or more.

Discharge	:	The conversion of the chemical energy of a cell or battery into electrical energy and withdrawal of the electrical energy into a load.
Discharge rate	:	The rate of current flow from a cell or battery.
Distilled Water	:	Water which has been freed of ions by a process of vaporization and subsequent condensation.
Drain Discharge	:	Withdrawal of all charge capacity from a cell or battery at a reduced current rate after the cell of battery has been partially discharged at a higher current rate.
Dry Charge	:	Process by which the electrodes are formed and assembled in a charged state. The cell or battery is activated when the electrolyte is added.
Dry Shelf Life	:	The period of time that a cell or battery can stand without electrolyte before deteriorating beyond a point where a specified capacity or voltage level can no longer be obtained, when packed and stored accord to specifications.
Duty Cycle	:	The conditions and usage to which a battery is subjected during operation consisting of charge, overcharge and discharge.
Electrode	:	Conducting body in which active materials are placed and through which current enters or leaves cell.
Electrolyte	:	In a lead-acid battery, the electrolyte is sulfuric acid diluted with water. It is a conductor and is also a supplier of hydrogen and sulfate ions for the reaction.
Electromotive Force (EMF)	:	Potential causing electricity to flow in a closed circuit.
Electron	:	The part of an atom having a negative charge.
End Of Discharge Voltage	:	The voltage of the battery at the termination of a discharge but before the discharge is stopped. See End Point Voltage (EPV).
End Of Life	:	The stage at which the battery or cell meet specific failure criteria.
End Point Voltage	:	Cell or battery voltage at which point the rated discharge capacity had been delivered at a specified rate-of-discharge. Also used to specify the cell or battery voltage below which the connected equipment will not operate or below which operation is not recommended. Sometimes called cutoff voltage or voltage end point.
Energy	:	The battery energy capacity is rated in Amp. Hrs. (AH). Cell or battery

Capacity		output capability, expressed as capacity times voltage or watt-hours (W-hr). This capacity is determined by multiplying the amperes of current that the battery will deliver by the No. of hours the battery will deliver it.
Energy Conversion	:	The change from chemical to electrical energy with the cell or the reverse.
Energy Density	:	The ratio of cell or battery energy to either the weight (Wh/lb or Wh/kg) or the volume (Wh/L or Wh/cu.in.). Thus, the energy density of a battery is the ratio of its stored energy to its weight or volume. High energy density batteries provide more capacity in the same size or even in smaller packages
Entrainment	:	The process whereby gases generated in the cell carry electrolyte through the vent cap.
Environmental Conditions	:	External circumstances to which a cell or battery may be subjected, such as ambient temperature, humidity, shock, vibration and altitude.
Equalization	:	See Reconditioning.
Equalization Charge	:	A maintenance procedure consisting of a sustained constant current charge used to correct cell imbalance.
External Power	:	A device that is used to supply electrical power via a cable and plug to the airframe external power receptacle. External power is used to prevent the aircraft batteries from being discharged during maintenance or often used for electrical power during engine starting. Some airframe external power electrical systems are designed to bypass the battery buss to prevent the batteries from being overcharged. To prevent the batteries from being overcharged, we recommend that the batteries be disconnected if the airframe external power electrical system design does not bypass the battery buss when external power is on in excess of four hours. External power should not be set higher than 2.38 volts per cell, 14.2 for 12 volt batteries and 28.5 DC V for 24 volt batteries.
Failure, Functional	:	Condition in which the battery has caused the end-use device to fail to function at the performance level expected.
Failure, Permanent	:	A condition which does not permit a cell or battery to be reconditioned or restored to an acceptable performance level.
Failure, Reversible	:	Failure condition which may be corrected through the application of certain electrical procedures.
Fast charging	:	Rapid return of energy to a battery at the C rate or more.
Float charge	:	A method of maintaining a cell or battery in a charged condition by

		continuous, long-term, constant voltage charging at level sufficient to balance self-discharge.
Flooded cell	:	A cell design which incorporates an excess amount of electrolyte also see Vented Cell.
Gassing	:	The evolution of gas from one or more of the electrodes in a cell. Gassing commonly results from local action (self discharge) or from the electrolysis of water in the electrolyte during charging.
Ground	:	In aircraft use, the result of attaching one battery cable to the body or airframe which is used as a path for completing a circuit in lieu of a direct wire from a component.
High Rate Discharge	:	Withdrawal of large amounts of current for short intervals of time from a cell or battery usually at a rate that will completely discharge a cell or battery in less than 1 hour.
Hydrometer	:	A float type instrument used to determine the state-of-charge of a battery by measuring the specific gravity of the electrolyte (i.e. the amount of sulfuric acid in the electrolyte).
Internal Impedance	:	The opposition to the flow of an alternating current at a particular frequency in a cell or battery at a specified state-of-charge and temperature.
Internal Resistance	:	The opposition or resistance to the flow of a direct electric current within a cell or battery, the sum of the ionic and electronic resistance of the cell components. Its value may vary with the current, state-of-charge, temperature and age. With an extremely heavy load, such as an engine starter the cell voltage may drop to approximately 1.6. This voltage drop is due to the internal resistance of the cell. A cell that is partly discharged has a higher internal resistance than a fully charged cell, hence it will have a greater voltage drop under the same load. This internal resistance is due to the accumulation of lead sulfate on the plates. The lead sulfate reduces the amount of active material exposed to the electrolyte, hence it deters the chemical action and interferes with the current flow.
Ion	:	Part of a molecule or group of atoms, positively or negatively charged, which transports electricity through the electrolyte.
Joules	:	Unit of energy, equal to a watt/second (newton/meter).
Lead Acid	:	Terms used in conjunction with a cell or battery that utilizes lead and lead peroxide as the active plate materials in a diluted electrolyte solution of sulfuric acid and water. Nominal cell voltage about 2.1 volts.

Lead Dioxide	:	A higher oxide of lead present in charged positive plates and frequently referred to as lead peroxide.
Lead Sulfate	:	A lead salt formed by the action of sulfuric acid on lead oxide during paste mixing and formation. It is also formed electrochemically when a battery is discharged.
Life	:	The duration of satisfactory performance measured as usage in years or as the number of charge/discharge cycles.
Lithium Ion Aircraft Battery	:	Main aircraft battery built with safest chemistry in Lithium ion batteries, a cathode material of lithium iron phosphate which inhibits oxygen generation. Lithium ion aircraft batteries must be integrated into the control software and electronics of the aircraft system with redundant built in safety features.
Load Tester	:	An instrument which measures the battery voltage with an electrical load on the battery to determine its overall condition and its ability to perform under engine starting conditions or essential power requirements.
Low Rate Discharge	:	Withdrawal of small amounts of current for long periods of time from a cell or battery usually longer than 1 hour.
Maintenance	:	The care and procedures necessary to keep a battery in usable condition, such as reconditioning and water addition to electrolyte of a vented cell.
Manifold	:	A portion of the battery case enclosing the vent caps or vents valves. Sometimes with ports that can be connected overboard for ventilation.
Manufacturing Variations	:	Differences in performance characteristics between products of the same design, attributable to process deviations within expected tolerances.
Migration	:	Directed movement of an ion of the electrolyte under the influence of an electric field.
Negative Electrode	:	See Negative Plate.
Negative Plate	:	The plate which has an electrical potential below that of the other plate during normal call operation.
Nominal Capacity	:	A designation by the battery manufacturer which helps to identify a particular cell model and also provides an approximation of capacity, usually expressed in ampere-hours at a given discharge current.
Nominal	:	Voltage of a fully charged cell or battery when delivering rated capacity

Voltage		at a specified discharge rate.
Open Circuit Voltage	:	The voltage of a battery when it is not delivering or receiving power.
Overcharge	:	The forcing of current through a cell after all the active material has been converted to the charged state. In other words, charging continued after 100% state-of-charge is achieved. The result will be the decomposition of water in the electrolyte into hydrogen and oxygen gas.
Oxygen recombination	:	The process by which oxygen generated at the positive plate during charge reacts with the pure lead material of the negative plate and in the presence of sulfuric acid and reforms water.
Parallel connection	:	A circuit in which battery poles of like polarity is connected to a common conductor.
Plate	:	A grid or framework that gives mechanical support to the active materials of a cell. The combination is termed an electrode.
Platinum Series	:	As pertaining to Concorde Battery Corporation's extra cranking power aircraft battery line. More capacity designed for essential or emergency power built into a Standard Equipment container.
Polarity	:	The electrical term used to denote the voltage relationship to a reference potential (+).
Positive Electrode	:	See Positive Plate.
Positive Plate	:	The plate which has an electrical potential higher than that of the other plate during normal cell operation.
Power	:	Rate at which energy is released or consumed (expressed in watts).
Power Efficiency	:	The proportion, expressed in percent, of energy recovered from a storage system, i.e., output power divided by input power.
Rate	:	Amount of current, sometimes expressed as a fraction or decimal of the current necessary to discharge the cell in 1 hour, i.e., a fraction of the C rate.
Rated Capacity	:	The number of Ahs a battery can deliver under specific conditions (rate of discharge, end voltage, temperature).
Rating	:	See Capacity, Rated Capacity.
Rechargeable Secondary Cell or	:	A cell or battery which can be recharged many times after being discharged without appreciable depreciation of capacity.

Battery

Recombination	:	State in which the hydrogen and oxygen gases normally formed within the battery cell during charging are recombined to form water.
Reconditioning	:	The deep discharge, constant current charge process used to correct any cell imbalance acquired during battery usage.
Recyclability	:	The capability of a battery system to be charged and discharged.
Re sealable	:	In a cell, pertains to a safety vent valve which is capable of closing after each pressure release in contrast to the non resealable vent cap.
Reversible Reaction	:	A chemical change which takes place in either direction as in the reversible reaction for charging or discharging a secondary battery.
Sealed Cells	:	Cells that are free from routine maintenance and can be operated without regard to position.
Secondary Battery	:	A system which is capable of repeated use by employing chemical reactions that are reversible, i.e., the discharged energy may be restored by supplying electrical current to recharge the cell.
Self Discharge	:	The decrease in the state-of-charge of a cell or a battery over a period of time due to the internal electro-chemical losses.
Separator	:	An insulating sheet or other device employed in a storage battery to prevent metallic contact between plates of opposite polarity within a cell.
Shelf Life	:	For a dry cell or battery, the period of time (measured from date of manufacture) at a specified storage temperature after which the cell or battery retains a specified percentage of its original energy content (Also refer to Wet Shelf Life).
Soak Time	:	The time required for the electrolyte to be absorbed sufficiently into the active materials of the cells after activation to allow the battery or cell to be placed in service.
Specific Energy	:	The energy storage ability of a battery on a weight basis, usually expressed in watt hours per pound (or kilogram), sometimes given on a volume basis in watt hours per cubic foot (or liter).
Specific Gravity (S.G.)	:	The weight of the electrolyte is compared to the weight of an equal volume of pure water used to measure the strength or percentage of sulfuric acid in the electrolyte.
Starved Cell	:	A cell containing little or no free fluid electrolyte solution, this enables gases to reach electrode surfaces readily and permits relative high rates of recombination.

State Of Charge (SOC)	The available ampere-hours in a battery at any given time. State-of-charge is determined by the amount of sulfuric acid remaining in the electrolyte (S.G.) at the time of testing or by the stabilized open-circuit voltage. A measurement that reflects the state of charge of a battery. The SOC alone is not a valid indicator of the batteries run time. The SOC readings will indicate 100%, even if a battery whose acceptance has dropped to 50% is fully charged.
State Of Health (SOH)	A measurement that reflects the state-of-health of a battery taking into account charge acceptance, internal resistance, voltage and self discharge.
Sulfation	In its common usage, the term refers to the formation of lead sulfate of such physical properties that it is extremely difficult if not impossible to reconvert it to active material.
Swelling	RG Battery cases swell or bulge when the cell vent valves maintain an internal pressure that is greater than the outer (atmospheric) pressure.
Temperature, Ambient	The average temperature of the battery's surroundings.
Temperature, Cell	The average temperature of the battery's components.
Terminal	An electrical conductor used in a cell to make external electrical connection to the cell plates.
Thermal Runaway	A chain reaction in which the heat generated within the battery by the overcharge current lowers the battery's internal resistance. This in turn, progressively increases the charging rate and the heat being generated. In the final stages, enough excess heat may be generated to destroy the battery.
Trickle Charging	Method of charging in which a secondary cell or battery is either continuously or intermittently connected to a constant current charging source that maintains the cell in a fully charged condition.
Vent Cap	The plug on top of a cell. It can be removed to allow for electrolyte level adjustments.
Vent Valve	A normally sealed mechanism which allows the controlled escape of gases from within a cell.
Vented Cell	A heavy duty cell design in which the vent operates at low pressures

during the normal duty cycle to expel gases generated in overcharge. A vented cell plate pack contains flat plates separated by a gas barrier and woven nylon separator completely immersed in electrolyte. Often called a 'flooded cell.'

Venting : A release of gas either controlled (through a vent) or accidental.

Volt : Unit of electromotive force, voltage or potential. The volt is the voltage between two points of a conductor carrying a constant current of one ampere, when the power dissipated between these points is one watt.

Voltage Limit : In a charge controlled battery limit beyond which battery potential is not permitted to rise during or after the charging process.

Wet : Term used to denote that the electrolyte in the cell or battery is liquid and free flowing.

Wet Charged Stand : Period of time that a wet secondary cell or battery can stand in charged condition without losing a specified small percentage of its capacity, when stored under specified conditions.

EMF of a cell : Defined as the potential difference between the poles when no current is flowing through the cell. when a current is flowing through a cell and through an external circuit, there is a fall of potential inside the cell owing to its internal resistance and the fall of potential in the outside circuit is less than the potential difference between the poles at open circuit.

In fact if R is the resistance of the outside circuit, r is the internal resistance of the cell and E its electromotive force, the current through the circuit is:

$I = E/R + r$

The potential difference between the poles is now only $E l = IR$, So that

$E l /E = R/R + r$

Cell : The basic electrochemical unit used to generate electrical energy from stored chemical energy or to store electrical energy in the form of chemical energy. A cell consists of two electrodes in a container filled with an electrolyte.

Battery : Two or more cells connected in an appropriate series/parallel arrangement to obtain the required operating voltage and capacity for a certain load. The term battery is also frequently used for single cells. This terminology will also be adopted in this book, except where a distinction between cells and batteries is needed. A good example is a battery pack, which consists of several cells connected in series and/or parallel.

Energy Density : The volumetric energy storage density of a battery, expressed in Watt-hours per liter (Wh/I).

The energy density of a battery is the ratio of its stored energy to its weight or volume.

The energy density is a measurement of how much energy can be delivered from a battery per unit of battery weight or volume. This is generally expressed in units of watt-hours per kilogram (Wh/Kg) or watt-hours per liter (Wh/I) respectively.

Power Density : The volumetric power density of a battery, expressed in Watts per liter (W/I).

The power density is a measurement of how much power can be delivered from a battery per unit of battery weight or volume. This is generally expressed in units of watts per kilogram (W/Kg) or watts per liter (W/I) respectively.

The terminology is not strictly defined. Weight based power density is often called “specific power or gravimetric power density”. Volume based power density is often called power density or volumetric power density.

Rated Capacity : The capacity of a battery, expressed in Ampere-hours (Ah), which is the total charge expressed in [Ah] that can be obtained from a fully charged battery under specified discharge conditions. These conditions are specified by the manufacturer.

Specific Energy: The gravimetric energy storage density of a battery, expressed in Watt-hours per kilogram (Wh/kg).

Specific Power : The gravimetric power density of a battery, expressed in Watts per kilogram (W/kg).

15.2 Design-related definitions

Electrode : Basic building block of an electrochemical cell. Each cell consists of a positive and a negative electrode. The cell voltage is determined by the voltage difference between the positive and the negative electrode.

Anode : The electrode at which an oxidation reaction occurs. This means that the electrode supplies electrons to an external circuit. The electron flow reverses between charging and discharging. Hence, the positive electrode is the anode during charging and the negative electrode is the anode during discharging. Usually a cell's anode is specified during discharging and hence the name anode is commonly used for the negative electrode.

Cathode : The electrode at which a reduction reaction occurs. This means that the electrode takes up electrons from an external circuit. Hence, the negative electrode is the cathode during charging and the positive electrode is the cathode during discharging. Usually a cell's cathode is specified during discharging and hence the name cathode is commonly used for the positive electrode. To avoid confusion, the electrodes will be named positive and negative in this book.

Electrolyte : The medium that provides the essential ionic conductivity between the positive and negative electrodes of a cell.

A substance , which is the molten liquid state or in the dissolved state (in water or any other solvent) gives an electrically conducting liquid or solution is called an electrolyte.

For Example: Liquids of molten salts and aqueous solutions of salts, acids and bases are examples of electrolytic conductors.

Non-Electrolyte : A substance, which in the molten liquid state or in the dissolved state (in water or any other solvent) gives non electrical conducting liquid or solution is called non electrolyte.

Separator : An ion-permeable, electronically non-conductive material or spacer that prevents short-circuiting of the positive and negative electrodes of a cell.

15.3 Application-related definitions

C-rate : A charge or discharge current equal in Amperes to the rated capacity in Ah. Multiples larger or smaller than the C-rate are used to express larger or smaller currents. For example, the C-rate is 600 mA in the case of a 600 mAh battery, whereas the C/2 and 2C-rates are 300 mA and 1.2 A respectively.

Cycle Life : The number of cycles that a cell or battery can be charged and discharged under specific conditions, before the available capacity in [Ah] fails to meet specific performance criteria. This will usually be 80% of the rated capacity.

The cycle life represents the expected number of charge discharge cycles the battery technology would expect to deliver before reaching end of

		life.
Cut-off voltage	:	The cell or battery voltage at which the discharge is terminated. Also often referred to as End-of-Discharge voltage. The symbol V_{EoD} will be used for this voltage throughout this book.
Self-Discharge	:	Recoverable loss of capacity of a cell or battery. This is usually expressed in a percentage of the rated capacity lost per month at a certain temperature because self-discharge rates of batteries are strongly temperature-dependent. Conditions have to be specified for certain definitions in order to be able to quantify them For example, the rated capacity is strongly dependent on the discharge current, battery temperature and cut-off voltage. In general, the capacity obtainable from a battery will be lower at higher discharge currents, lower battery temperatures and higher cut-off voltages. Usually, the rated capacity is specified at a current of C/10 and at room temperature for secondary batteries. The specified cut-off voltage is strongly dependent on the battery chemistry.
Acceptance Tests	:	Tests carried out on samples selected at random from a lot for the purpose of verifying the acceptability of lot.

15.4 **Routine Tests**

Tests carried out on each battery to check the requirements which are likely to vary during production.	
Lot	All batteries of the same type, design and rating manufactured by the same factory during the same period using the same process and materials and offered for inspection at a time shall constitute a lot.
Re-chargeable Cell	A discharged voltaic cell that can be brought back to its initial (charged) chemical state by passing a current through it in a reverse direction to that of discharge.
Re-chargeable Battery	An assembly consisting of more than one re-chargeable cell.
Nominal Cell Voltage	Nominal cell voltage of re-chargeable Nickel Cadmium battery systems is 1.2V.
Nominal Battery Voltage	Nominal cell voltage multiplied by the number of cells in series in the battery.
Capacity	A measure of the energy content of a battery, usually stated in terms of ampere-hours. Capacity is computed by multiplying the number of amperes flowing from a cell or a battery on discharge (at a given

	temperature and down to a specified end voltage) by the time in hours.
Initial Capacity	Newly manufactured batteries and cells must produce not less than a specified amount of capacity (at least 110% of rated capacity or individual battery specification may be defined for this value)
Minimum Capacity	When batteries and cells produce less than specified minimum amount of capacity (after testing and treatment in accordance with the appropriate operating instructions of the battery manual) are considered to be at the end of their useful life (The considered value shall be 80% of its initial rated capacity or as per value stated in the individual battery specification.
Nominal Capacity	Capacity expressed in ampere hours (Ah) equivalent to the 1 hour rate or as stated in the individual specification.
Rated Capacity	The current specified in the individual specification of the battery, that the battery is to deliver throughout its normal service life for 1 hour when it is discharged down to battery voltage corresponding to a mean Voltage per cell of 1.0V multiplied by the number of cells in series at an ambient temperature of 27 °C + 5°C.
Charged Battery	A battery that has been fully charged in accordance with the battery manufacturer's instructions or as laid down in the individual specification sheets.
Normal Servicing	Battery servicing including cleaning, electrolyte topping-up and charging as specified in the manufacturer's instructions book / sheet but does not include the replacement of cells.
Serviceable Battery	A battery that in all respects meets the requirements stated in the manufacturer's instructions for continued use on aircraft.
Thermal runaway	Thermal runaway is manifested during constant current charge by a rise in a battery temperature and a drop in battery voltage, during a constant potential charge by a rise in both battery temperature and charging current. Electrical condition that can quickly lead to the demise. This is known as "runaway" condition, occurs when the battery is charged in such a manner as to create a great deal of internal heat. This can result from excessive charge rates. As the temperature of the battery rises its internal resistance drops very sharply. When the charge is being carried out from a system controlled power source (C.P.) a lowering of internal resistance will result in an increase in the charging current.

	This increased current in turn results in a lowering of the efficiency of the charge acceptance, still further increasing heat generation, still further raising the temperature of the cell. The cell can thus very quickly be brought to a condition where the heat becomes physically disruptive. This runaway condition is prevented by providing for better controls and adequate ventilation of the cells and the compartment in which it is housed.
Memory Effect	NI-CD batteries is the so called "memory effect" in which battery seems to remember the manner in which it has been cycled. The memory effect shows up only in a highly repetitive cycling routine and manifests itself as an apparently permanent loss of reserve capacity. To avoid this, batteries in such service or periodically given conditioning cycles in which the depth of charge and discharge and / or the rates at which these are performed are varied from the routine. This treatment completely avoids the memory effect and in fact can restore the capacity of a battery so affected, although the latter is more difficult and requires a greater number and variety of conditioning cycles.
Vented Cell	Vented cells are cells in which products of electrolysis are not consumed during the course of charging. Provision for venting the gases evolved during over charging is provided.
End Voltage	A specified voltage during the discharge of a cell or battery at which point the capacity will be calculated.
Low-Maintenance Vented Battery	An Aircraft battery that has a one-year maintenance interval and whose gases are vented away from the battery container. That is, the battery will satisfactorily meet the aircraft's power and capacity requirements for not less than one year before removal for scheduled inspection, cleaning, capacity determination, cell equalization, electrolyte adjustment and final charge. This compares to a typical 56-day maintenance interval for older design batteries. In addition, vented batteries contain at least two tubes for venting any electrochemically generated gases that may accumulate inside the battery container. Normally, one tube is used to permit forced air to enter the container while the other tube permits the inlet air and gases to exit the container. Vented batteries normally employ only vented cells, the vented caps of such cells permit the exit of the above gases from the cell and prevent the entry of ambient air and contaminants. "Each cell of a low maintenance vented battery shall have a potential of not less than 1.0 V and each battery shall produce a potential of not less than 20 V at not less than 60 minutes in the C rate discharge after

	being tested at room temperature".
Reconditioning	A laboratory procedure performed to equalize the capacity and voltage of the battery's cells, thereby correcting any acquired capacity and voltage imbalances.
Manufacturer's Instructions	The service instructions contained in the operating and maintenance manual provided by the battery manufacturer and approved by the Quality Assurance Authority.
Individual Specifications	Specifications for individual batteries aircraft wise, provided by the Quality Assurance Authority or purchasing authority.
C-Rate	C is a value which expresses the rated current capacity of a cell or battery. A cel1 discharging at the 'C' rate will deliver its normal rated capacity for 1 hr, Charging and discharging currents are generally expressed as multiples of 'C'. The time to discharge a battery is inversely proportional to the discharge rate. NC is a charge or discharge rate which is N times the rated current capacity of the battery where N is a number (fraction or multiple). CN is the battery capacity in Ampere hours which corresponds to complete discharge of the battery in N hours (N is usually a subscript). Also written as the N Hour rate.
Duty Cycle	The load current or power of battery is expected to supply for specified time periods.
Cycle Life	The number of cycles a battery can perform before its nominal capacity falls below 80% of its initial rated capacity. These tests are needed to verify that the battery performance is in line with the end product reliability and life time expectations.
Constant Current Charge (CC)	A charging scheme which maintains the current flowing through the battery at a constant value specified by the individual battery specification.
Constant Voltage Charge (CV)	A charging scheme which maintains the voltage across the battery terminal at a constant value specified by the individual battery specification.
Negative	Electrode undergoing reduction on charge and / or oxidation on discharge
Overcharge	Electrical charge or process in which more charge is supplied to a battery than is required to convert the electrodes to the fully charged state
Over voltage	Difference between the operating voltage of a cell on charge or

	discharge and the open-circuit voltage of the cell both at the same state of charge.
Oxidation	Chemical process in which a substance donates electrons
Polarization	Departure of the voltage of an electrode or of a battery from its equilibrium value
Positive	Electrode undergoing oxidation on charge and / or reduction on discharge.
Primary	Non-rechargeable battery
Reduction	Chemical process in which a substance accepts electrons
Reversal	Process in which discharge current is forced through a cell after its capacity has been exhausted
Secondary	Rechargeable battery
Separator	Porous, nonconductive material interposed between the electrodes of a cell to prevent internal short circuits

15.5 Aircraft Electrical System Definitions

An **Electrical System** consists of an electrical power source, its power distribution system and the electrical load connected to that system.

An **Electrical Source** is electrical equipment which produces, converts or transforms electrical power. Some common AC sources are AC Generators, inverters, transformers and frequency changers. Some common DC sources are DC Generators, converters and batteries. In practice an electrical source could be a combination of these units connected in parallel e.g. a typical AC bus may have both AC Generators and inverters connected in parallel.

A **Primary** source is equipment that generates electrical power from energy other than electrical and is independent of any other electrical source. For example, the Primary source of an AC electric system may be the main engine-driven generator(s) or Auxiliary Power Unit-driven generator(s). The Primary source of a DC electrical system may be a battery, main engine-driven generator(s) or Auxiliary Power Unit driven generator(s). There may be both AC and DC Primary power sources in the same aircraft.

A **Secondary** source is equipment that transforms and/or converts Primary source power to supply electrical power to either AC or DC powered equipment. A Secondary source is entirely dependent upon the Primary source and is considered as a part of the load of the Primary source. There may be both an AC and DC Secondary source in the same aircraft.

The **Normal** source is that source which provides electrical power throughout the routine aircraft operation.

An **Alternate** source is a second power source, which may be used in lieu of the normal source usually upon failure of the normal source. The use of alternate sources creates a new load and power configuration, and therefore a new electrical system, which may require separate source capacity analysis.

The **Nominal Rating** of a unit power source is its nameplate rating. This rating is usually a continuous duty rating for specified operating conditions.

The **Growth Capacity** is a measure of the power source capacity available to the aircraft electrical system to supply future load equipment. This value is expressed in terms of percent of source capacity.

Ground Operation and Loading is a **p**reparation of aircraft prior to aircraft engine start. During this period power is supplied by APU, internal batteries or an external power source.

Taxi is the condition from the aircraft's first movement under its own power to the start of the take-off run and from completion of landing rollout to engine shutdown.

Take-off and Climb is the condition commencing with the take-off run and ending with the aircraft leveled-off and set for cruising.

Cruise is the condition during which the aircraft is in level flight.

Landing is the condition commencing with the operation of navigational and indication equipment specific to the landing approach and following to the completion of the rollout.

Normal Electrical Power Operation (or Normal Operation) assumes that all of the available electrical power system is functioning correctly within MMEL limitations (e.g. AC and/or DC Generators, Transformer Rectifier Units, Inverters, Main Batteries, Auxiliary Power Unit etc.).

Abnormal Electrical Power Operation (or Abnormal Operation) occurs when a malfunction or failure in the electric system has taken place and the protective devices of the system are operating to remove the malfunction or the failure from the remainder of the system before the limits of abnormal operation are exceeded. The power source may operate in a degraded mode on a continuous basis where the power characteristics supplied to the utilizing equipment exceed normal operation limits but remain within the limits for abnormal operation.

Emergency Electrical Power Operation (or Emergency Operation) is the condition that occurs following a loss of all normal electrical generating power sources or other malfunction that results in operation on standby power(batteries and/or other emergency generating sources such as an APU or Ram Air Turbine) only.

Power Factor is the ratio of real power (measured in watts) to apparent power (measured in volt- amperes)

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7.	*www.mpoweruk.com/soh.htm*	Custom Power Solutions
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