Aircraft Nickel-Cadmium Battery Testing Guidelines

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The information presented here is intended as a reference for the end users of equipment manufactured by JFM Engineering and in no way substitutes or supersedes the official information that battery manufacturers provide in their CMMs

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1. Introduction

Battery testing does not have to be complicated or difficult.
It is a complex test, because of the exacting testing parameters that have to be met and because of the multiplicity of tests that must be performed, but it certainly does not have to be complicated.
With the proper equipment and methodology, battery testing can be easily made accurate and efficient. That is, it can be made to meet the requirements of the manufacturer of the batteries while maximizing the utilization of equipment and personnel.

2. Testing for Airworthiness

Batteries must be removed from the aircraft and tested to determine if they meet the requirements of the manufacturer[1].
In this, batteries are no different from any other part of the aircraft.
Where is the importance? Batteries are part of the emergency system of the aircraft. In case of a power failure, the battery is needed to start the APU (Auxiliary Power Unit) or simply to provide power to the 28V bus.
In case of such an emergency, it is expected that the battery will supply power for the time required to restore power generation or to directly power electrical and electronic devices until the aircraft is safely on the ground.
As an example, note that a Qantas 747, on January 8, 2008, lost all power generation while en route to Bangkok, Thailand. The crew was forced to use power from the backup battery to safely land the aircraft. In this case, the pilot counted on that battery would supply the needed power. A properly tested battery will deliver power as needed[2].
On a lesser note, an improperly serviced battery can result in a costly AOG as the aircraft will not be able to take off with battery problems.
One of the difficulties with battery testing is that batteries are heavy [3] and that they may not be located in places where it is easy for their removal and replacement. In addition, replacement batteries must be made available (extra expense). Hence, an opportunity for a resistance to test the batteries resulting in poorly maintained batteries. Also an opportunity to consider migration to Lead-Acid batteries because of their "easier" maintenance[4],[5]

3. How often do batteries have to be tested?

The frequency of testing of batteries is normally established by the aircraft manufacturer or by the battery manufacturer. But, ultimately, the frequency of testing (testing intervals) is determined by test results, with water level consumption and the degree of cell imbalance being the governing figures.
When the testing interval is in excess of what it "should" be, the consequence is that cells may lose significant amounts of water (in excess of the maximum specified in the CMM) resulting in a degradation of cell separators. See more details under "The importance of Electrolyte Level" in section [5]. Also, cells will become so imbalanced that the battery will no longer be capable of delivering the required current, both of which will lead to premature cell/battery failure.
If testing is "costly", premature replacement of cells/batteries is much more costly (by orders of magnitude), not to mention the cost of AOGs and in-flight emergencies.

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[1] Requirements of the battery manufacturer and/or of the aircraft manufacturer and/or accessory manufacturer.
[2] The aircraft manufacturer specifies the amount of current that the battery can supply and the amount of time that it will last until exhausted.
[3] 60 to 80 lbs (27 to 36KG)
[4] Note that Maintenance Free should not be equated with "care free"
[5] Note that Lead-Acid batteries are not as powerful and rugged as Nickel-Cadmium batteries are. Also, Lead-Acid Batteries can be damaged if allowed to deep discharge

4. Testing Details

There are two basic types of electrical tests that must be performed: Capacity and Charge Acceptance

4.1 Capacity Test

Supply of required current for a minimum time duration

4.1.1. Delivery of rated current (constant)

4.1.2. For one hour (typical)

4.1.3. The battery must remain above a minimum voltage

Battery Voltage Minimum = Number of Cells x Minimum Cell Voltage.

4.1.3.1. Cell voltage levels:

4.1.3.1.1. Minimum: 1.00V

4.1.3.1.2. Marginal 1.00V to 1.05V

4.1.3.1.3. Acceptable: 1.05V to 1.10V

4.1.3.1.4. Good: above 1.10V

4.1.3.2. Note that if any of the cells falls below the minimum, the battery has failed the capacity test, even though the battery terminal voltage may be well above the required minimum.

4.2 Charge Acceptance

Transformation of input current into charge stored in the plates

4.2.1. Cell Voltage

4.2.1.1. Under Constant Current conditions[6]

4.2.1.2. Cell voltages are expected to increase continuously and may appear to remain flat once the cell is well charged[7].

4.2.1.3. Cell voltages must not droop[8].

4.2.1.4. Cells must achieve a minimum End Charge Voltage:

4.2.1.4.1. Minimum: 1.50V

4.2.1.4.2. Typical: 1.55V to 1.65V

4.2.1.4.3. Maximum: 1.70V/1.75V

[6] Charging with other than constant current will mask off cell performance issues.
[7] Cell voltages are always climbing, albeit with an imperceptible slope, but they will rise abruptly once the cell is fully charged.
[8] Cell voltage droop is an indication of cell separator failure.

4.2.2. Battery Temperature

The charging of Nickel-Cadmium cells is an endothermic process, meaning that under normal conditions, cells are not expected to have an increase in temperature.

In order to be able to determine if a battery is developing an appreciable warming, it is very important to perform all battery tests in a controlled environment where the temperature can be maintained below 30^{o}C (86^{o}F).

Equally important is to avoid freezing temperatures. Perform tests above 5^{o}C (41^{o}F).

4.2.2.1. If cells do heat-up during charge, it could mean the following:

4.2.2.1.1. The cell is being overcharged

4.2.2.1.2. The cell is being charged at too high a rate for the A-Hr rating of the cell.

4.2.2.1.3. The cell could have a low electrolyte level[9]

4.2.2.1.4. There is a cell separator failure[10]

4.2.2.2. Note that older cells are expected to exhibit some warming due to their higher internal resistance.

4.2.2.3. Temperature rise levels:

4.2.2.3.1. Typical: no appreciable warming (up to 5^{o}C)

4.2.2.3.2. Appreciable warming: 5^{o}C to 10^{o}C

4.2.2.3.3. Overtemp: above 10^{o}C

[9] Too much water has evaporated

[10] A cell with separator failure must be replaced (it is not repairable)

5. The importance of the Electrolyte Level

Checking the electrolyte level is an integral part of the testing of the battery. Failure to do so will eventually result in premature cell failures.
Note that the electrolyte level can only be checked at the end of the charge process.

5.1 Water consumption

5.1.1. Nickel-Cadmium cells consume water as a normal part of their activity.

5.1.2. Water is consumed as a result of the in-flight charge process and when current is demanded from the battery as it occurs with the starting of engines or the APU.

5.1.3. The amount of water consumed is a measure of the activity of the battery.

5.1.4. When water is consumed beyond the levels given by the manufacturer of the battery, it is an indication that the battery must be serviced more frequently or that there is a possible electrical problem in the aircraft (overcharging).

5.1.5. If the battery is allowed to function with water levels below the minimum specified electrolyte level, then, in-flight battery overheating will be experienced. This in turn will contribute to an accelerated deterioration of the cell separator material and eventual cell failure.

5.1.6. When cells are operating with less than the minimum required electrolyte level, the active area of the plates is reduced hence forcing current over a smaller area (higher current density) resulting in an overheating of individual cells or the entire battery.

5.1.7. In extreme cases, this may result in a catastrophic in-flight failure (thermal runaway), a condition that requires that the battery be disconnected from the bus. Note that when a battery experiences an in-flight thermal runaway it will need to be replaced (new cells/new battery).

5.2 Ground Service

5.2.1. When batteries are serviced, distilled water is added at the end of the charge and the amount of water delivered is recorded for each of the cells.

5.2.2. In the electrochemical process in the cells, water is absorbed by the plates during discharge and water is released during charge. It is for this reason that the only time when the electrolyte level can be tested and adjusted is at the end of the charge process (topping charge). Typically, when cells reach 1.6V or higher.

5.2.3. If water is added at a time other than at full charge, there is the danger that spilling of electrolyte will take place when the battery reaches full charge. When the water evaporates, there will be a conductive white residue[11] deposited over the cell top, links and posts giving a clear indication of overfilling.

[11] Potassium Carbonate

5.2.4. An exception to the when-to-add-water-rule is if a high cell voltage develops during charge (usually over 2V). This is an indication that the cell is “dry”. At this time, an injection of 5cc to 20cc will bring the cell voltages to normal levels.

5.2.5. It is also advised to initially dispense 5cc to 10cc on each cell for a battery that has a known history of high water consumption or if the battery has remained on the shelf for a prolonged period of time.

5.2.6. Uneven water consumption can be an indication of cell imbalance, cell age and cell damage.

5.2.7. Battery overheating during bench charging can be the result of low initial electrolyte levels.

5.2.8. The CMM for each battery/cell provides the basic information of consumable water level as a guide to determine when the electrolyte loss becomes excessive.

5.2.9. Note that there is no need to replace the electrolyte[12] every time that the battery is serviced. Unless the electrolyte is known to be contaminated or someone erroneously tampered with it, the only requirement is to replenish water consumed.

5.2.10. Note also that the concentration of the electrolyte is not an indicator of state of charge[13]. The concentration of 30% is simply needed to provide proper electrolytic conduction.

5.2.11. When vent caps are removed it is important to make sure that cells are protected from ambient contamination such as dust and other foreign materials.

5.3 Summary

5.3.1. It is for all of these reasons that measurement and recording of water levels must be performed to obtain a more complete picture of the condition of the battery.

5.3.2. JFM Engineering offers a product called *Master*Filler that greatly simplifies the task of adjustment of electrolyte levels.

[12] Potassium Hydroxide
[13] Unlike flooded Lead-Acid batteries

6. Test Records

Record keeping is an important part of battery testing. As batteries return to be serviced it is important to review prior test data to determine what might be expected from a new round of tests, and to better analyze data that may help identify an impending battery failure.

The types of records are:

6.1 Test comparison

If the battery received for testing has been tested before, it is very important to review prior results. A review of prior results will determine the degree of testing required. If the battery passed but did not perform well in the prior test, it is likely that the results of new tests will be worse. This comparison can result in significant time savings by not having to perform tests that will result in failure.

6.2 As Received physical condition

Visual inspection of the physical condition of the battery[14]:

6.2.1. Integrity of the case and lid (including vent tubes, handles, latches, etc.)

6.2.2. Integrity of connector(s). Look for burnt or corroded contacts.

6.2.3. Integrity of links and hardware (including threads on the posts). Look for exposed copper (holes and scratches).

6.2.4. Evidence of hardware corrosion

6.2.5. Evidence of electrolyte leakage or overflow (potassium salt deposits; stains)

6.2.6. Evidence of overheating (overheated electrolyte odor)[15]

6.3 As Received Battery Voltage and Cell Voltages

Battery voltage and individual cell voltages must be recorded prior to performing any tests on the battery[16].

6.4 As Received Leakage Test

Perform leakage tests from the positive and negative terminals to the case to determine if there are any cells that may have bodies[17]. Perform also leakage tests using an insulation tester (check the CMM for specific tests required).

6.5 Overhaul

Overhaul the battery (total disassembly) if there is evidence of cell leakage or electrolyte spills.

[14] If there is any evidence of damaged hardware, corrosion, etc. replacement is often the only solution.
[15] Check the history of the battery and performance in the aircraft. A battery that has overheated could have been operated low on electrolyte affecting the cell separators.
[16] No current
[17] Cells with cracks in their bodies must be replaced

6.6 As Received Capacity Test

Performing an immediate Capacity Test provides an indication of how the battery is treated by the aircraft (provided that the battery is removed immediately after landing and that no appreciable current has been drained). This also provides a uniform starting point for the first charge.

More than likely, this Capacity Test will fail because the battery seldom arrives at the shop fully charged, but if it does, it may be an indication that this is a battery in very good condition.

The requirement here is to determine the degree of cell imbalance (if any). If there is more than a 50mV imbalance[18] between cells, it is necessary to discharge each cell to zero, using resistors and/or clips, to allow the cells to achieve a fresh, balanced start.

Note also that although the cells may be well balanced, their end-of-test voltage may be too close to the bottom limit (less than 50mV reserve voltage). In this case, it is advised to deep cycle the cells and to observe if the reserve voltage has improved. If not, it may be an indication that the cells are reaching their end of life.

6.7 First Charge

The first charge will provide several clues as to the state of the cells in the battery. If cells heat-up at the beginning of the charge, it could be a sign of lack of water. More significantly if any of the cells rises prematurely and in some cases as high as 2V or even more, this is a sign of a “dry” cell. Consequently, it is necessary to add some water (5cc to 10cc to all cells if needed) until the situation is remedied.

As the cells charge, the voltage will remain at 1.4V to 1.45V for most of the Main Charge (and even into the Topping Charger) and will eventually rise to and pass 1.50V towards an end charge voltage of 1.60V to 1.65V per cell.

If any of the cells reach this voltage but later the voltage drops back, then this is an indication that there is separator damage requiring that the cell be replaced. Note that no amount of exercising will remedy this condition. On the contrary, continued testing will result in further voltage drop[19].

6.8 Water Level

At the completion of the first charge (actually, during the last few minutes of the charge cycle) the level of the electrolyte must be checked and corrected as necessary by the addition of distilled water (or de-ionized) to the level specified in the CMM.

6.9 First Capacity Test

The first Capacity Test will provide the first indication of the condition of the battery. If it passes the test, determine the reserve voltage and degree of imbalance as per [6.4] and either discharge fully or recharge.

If the battery does not pass this first Capacity Test, it can be repeated up to three times to allow the cells to recover their specified capacity.

6.10 Second Charge

See [6.7] for details

[18] ±25mV

[19] A cell with separator failure must be replaced (it is not repairable)

6.11 Additional Discharge and Charge cycles, as required to restore the performance of the battery

When the battery does not pass its first capacity test (normal) or does not appear to charge properly (i.e., takes too long for the cell voltages to increase, or cells are highly imbalanced at the end of the charge cycle), additional charge/discharge cycles should result in an improvement. If there is no appreciable improvement, then cells can be considered to be at the end of their useful life.

6.12 Torque Check

Check the torque of the hardware holding the links.

6.13 Vent Cap Check

Wash the Vent Caps to remove any Potassium Salt residues and check for the integrity of the o-ring.

6.14 Final Leakage Test

Perform leakage tests from the positive and negative terminals to the case.
Caution! Not between the battery terminals as this will destroy the measuring device.

6.15 Archival of Test Records

Once a test has been completed it is important to archive the test results as needed for comparison of new/old tests and/or for possible audit trail requirements.

6.16 Samples of Battery Test Graphs

See samples of various battery tests in section [8]

7. Storage of tested batteries

Batteries will self discharge with time[20] therefore it is imperative that they be kept properly charged until it is time to be installed in the aircraft.
For short term storage[21] trickle charging is adequate but for long term storage, a formal Top Charge is required to restore the charge condition.
Check with the battery manufacturers for exact storage recommendations.

[20] Aggravated by high temperatures
[21] A few weeks

8. Test Equipment Requirements

The choice of test equipment is extremely important because equipment must be capable of testing the battery exactly as specified by the manufacturer of the battery.
It must also be easy to use, reliable, easy to maintain and safe.

8.1 Constant current

Battery manufacturers specify that all charge and discharge tests be performed with constant current.

There are many methods to simply charge a battery but it is important to determine that the purpose of the Charger-Analyzer is to be able to test the ability of the cells to transform the charge current into charge stored in the plates and this can only be determined properly when constant current is applied.

Equally important is the use of constant current for the Capacity Test, as opposed to using a passive load[22].

8.2 Programmable test parameters

The Charger-Analyzer must also have the flexibility needed to test a wide variety of batteries. Aircraft batteries are available with a wide range of A-Hr capability and number of cells and the Charger-Analyzer must be capable of handling all types equally well.

8.3 Voltage control and voltage limits

Although the charge/discharge methods require constant current, there are occasions when voltage control is needed for the charging of Sealed Lead-Acid batteries.

In addition, it is necessary to be able to detect overvoltage conditions that could be the result of overcharging, dry cells or too high a current for the size of the battery.

A peak detecting capability is also useful when performing accelerated charging at 1C[23]

8.4 Internal Temperature Monitoring

When batteries are discharged there is a high dissipation in the load bank. If cooling were to become insufficient this could damage the load bank. Hence, the need for internal temperature monitoring and automatic shutdown.

This is also applicable to the charge process (although to a lesser degree), due to transformer and semiconductor heating.

8.5 Battery Temperature Monitoring

As stated before, batteries are not supposed to heat-up during charge. If so, charging needs to be halted to avert a destructive thermal runaway. Therefore, it is extremely important for the Charger-Analyzer to be able to monitor the temperature of the battery and to shut-off the charge to prevent any further damage.

8.6 Ease of use

A Charger-Analyzer, while complex because of all of its functions must remain easy to use. The controls must be user friendly and intuitive to permit efficient operation with a minimum of difficulty and training.

[22] Lamps or resistors
[23] Transfer from Main to Topping

8.7 Computer Interfacing

The job of battery testing does not end when the Charger-Analyzer has finished a particular test. As stated in the section on record keeping, information from the battery must be looked at and analyzed prior, during, and after a test. This is the job of the Automated Battery Test System.

The task of automation would be incomplete if the Charger-Analyzer was not included in the process, hence the need for interfacing the Charger-Analyzer so that the Battery Test System can monitor and control the operation of the Charger-Analyzer as well.

8.8 Summary

JFM Engineering offers the Super*Master*Charger. A state of the art Charger-Analyzer, designed for all present and future needs of battery testing.

JFM Engineering also offers the BTAS16, a computer based system designed to automate the process of data acquisition and analysis of battery test results.

9. Sample Graphs

Example of test results as recorded by the BTAS16 Battery Test and Analysis System

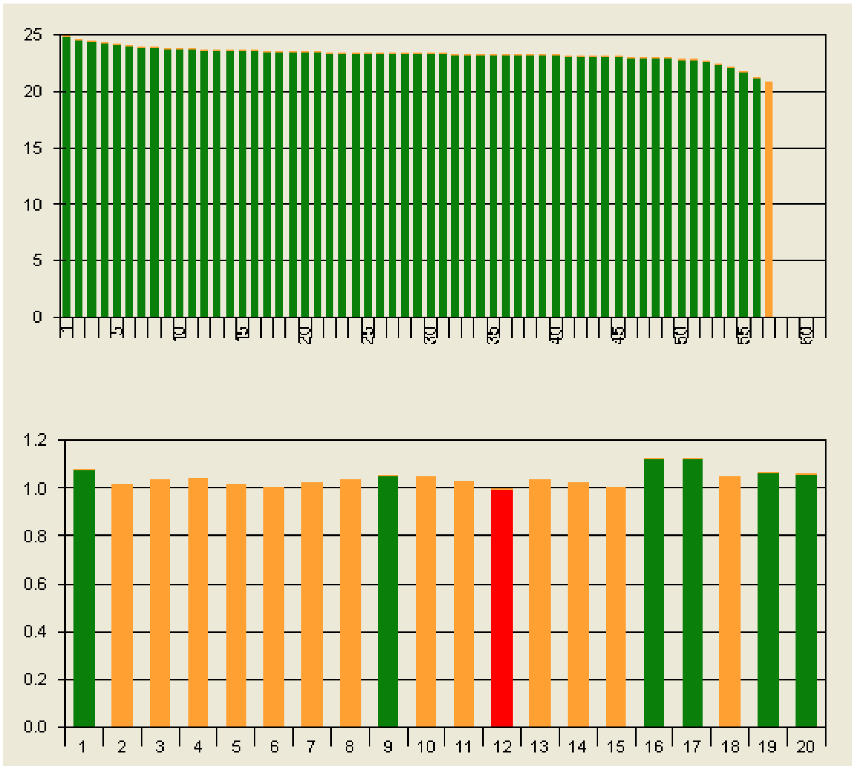

Figure 1 – First Capacity Test with one failed cell and several marginal cells

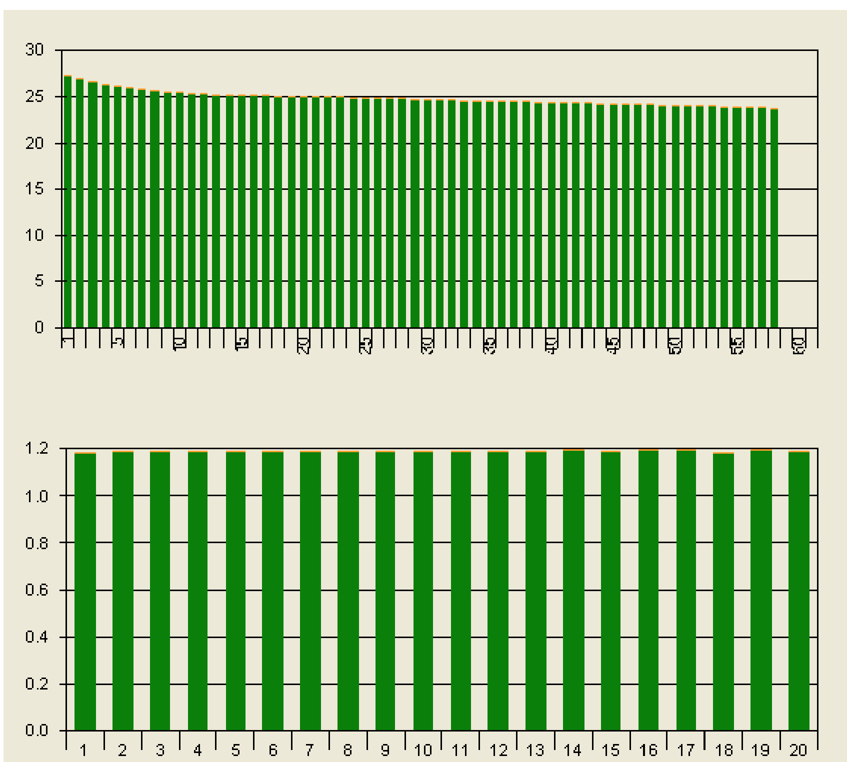

Figure 2 – Second Capacity Test showing a good recovery

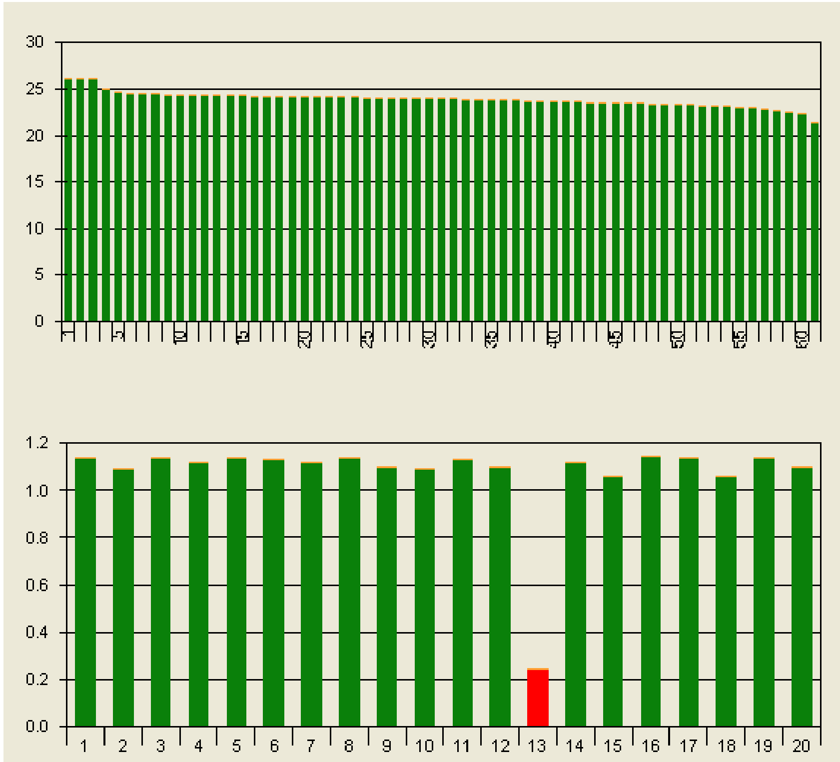

Figure 3 – Apparent good Capacity Test with one bad cell

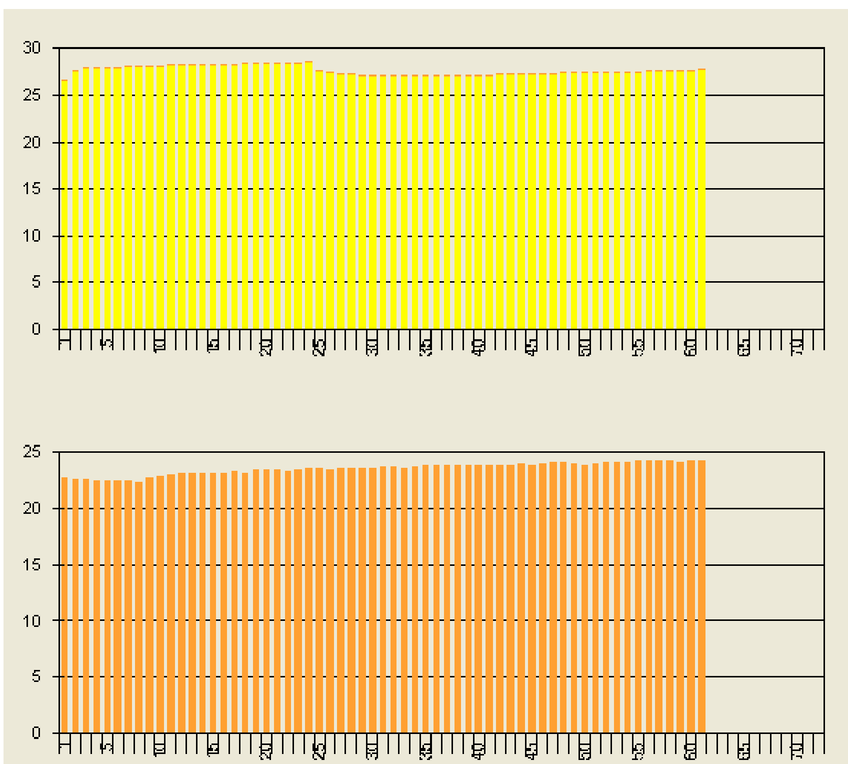

Figure 4 – Charge Voltage failure and slight elevation of temperature

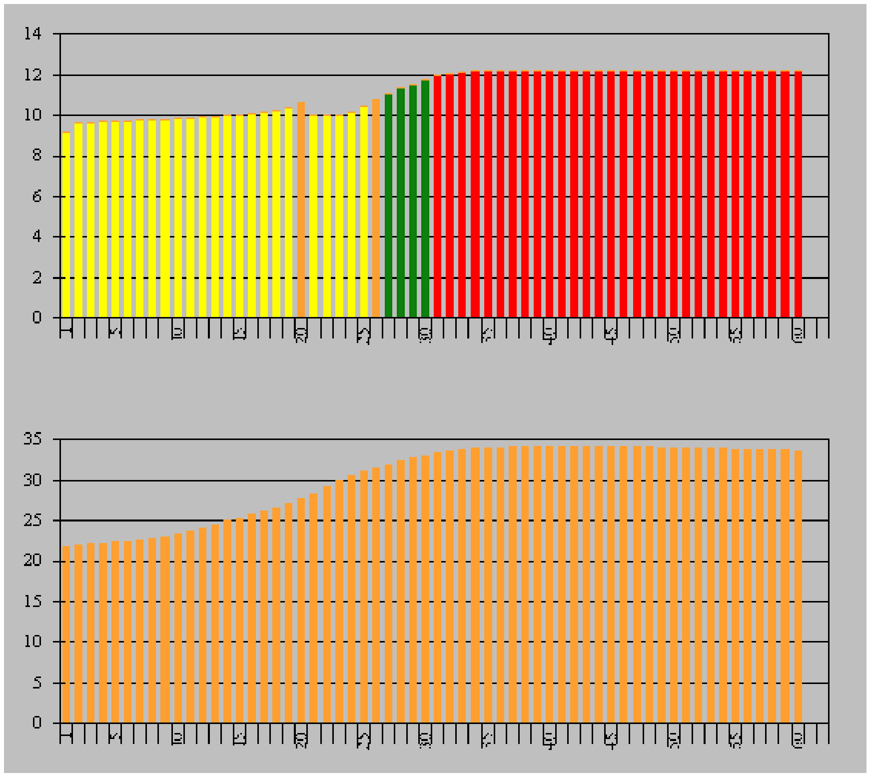

Figure 5 – Charge profile showing a significant elevation in battery temperature

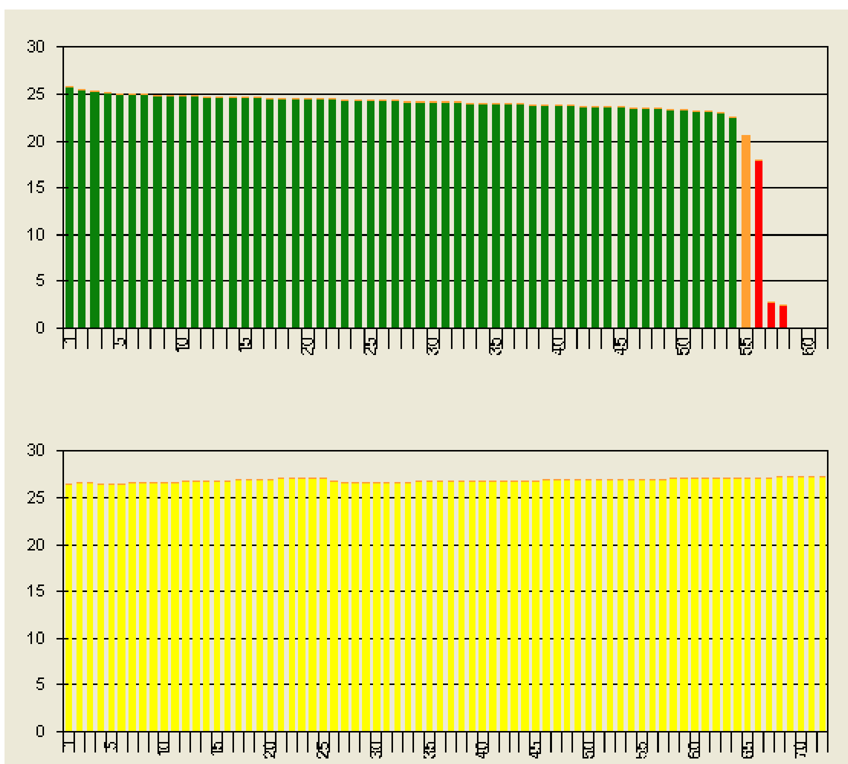

Figure 6 – Capacity Test and Charge failures

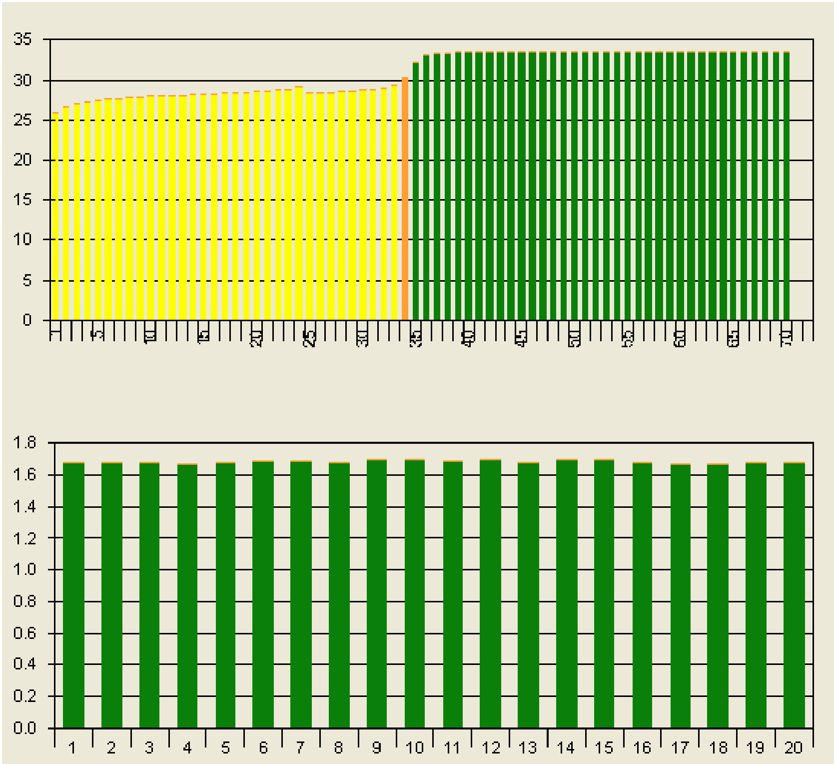

Figure 7 – Good Charge Voltage and Cell Voltages profile

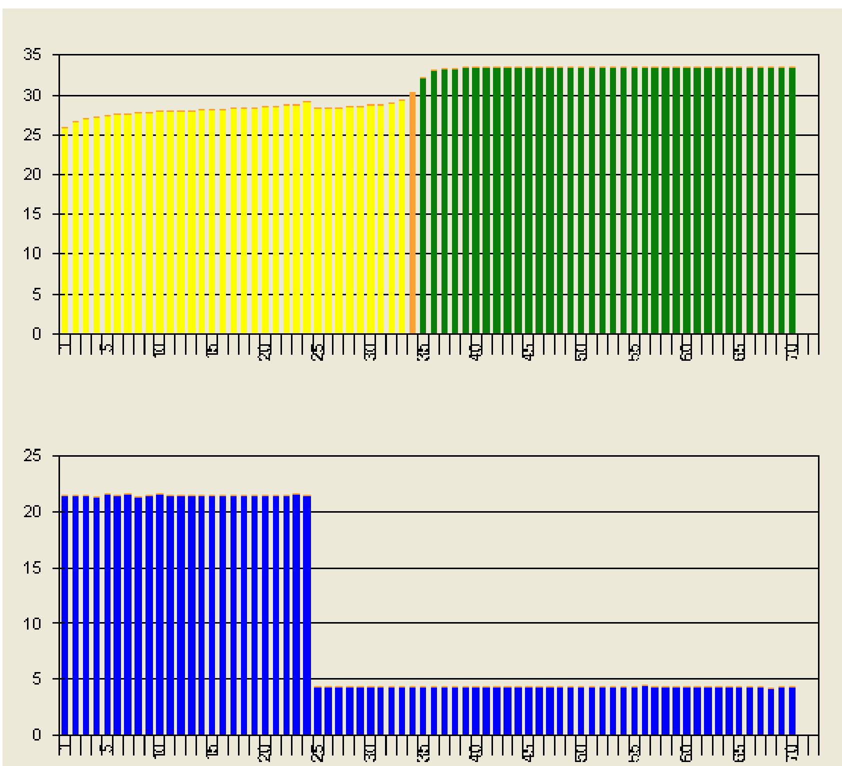

Figure 8 – Charge Voltage profile showing the current delivered by the Charger-Analyzer

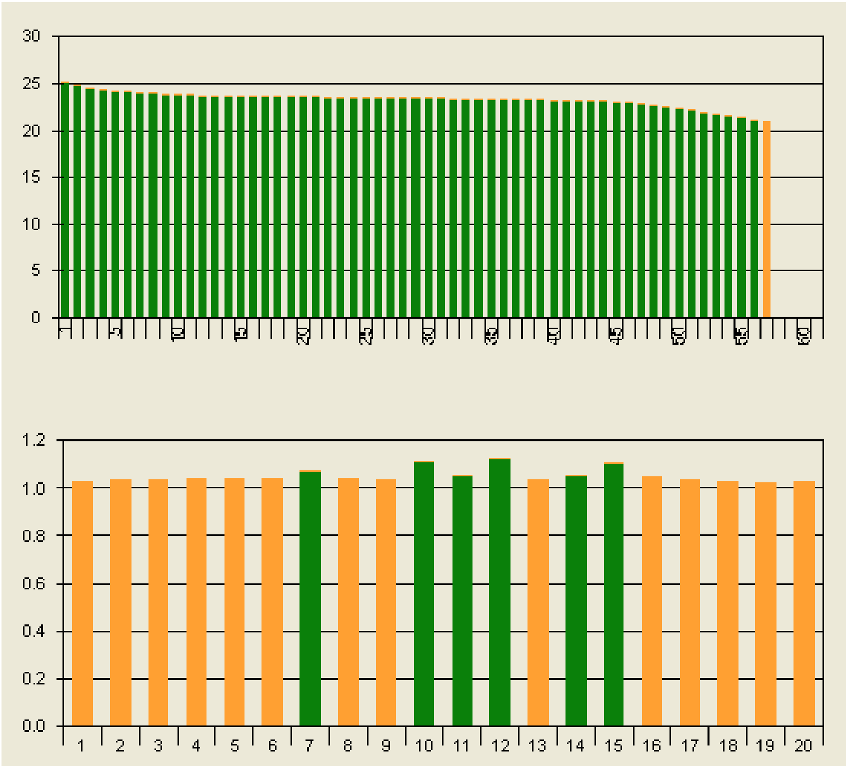

Figure 9 – Marginal first Capacity Test

Figure 10 – Second Capacity Test showing a good recovery

10. GLOSSARY

- Battery Manual: General Technical information provided by a manufacturer applicable to a series of batteries.
- Battery Test Profile: A specific group of parameters for a specific type of test (i.e., Time, Current and Voltage).
- BTAS16: A computerized Battery Test System
- Capacity Test: Test performed to determine if a battery can deliver the advertised, specified or required amount of current.
- Cell Imbalance: The difference of voltage from cell to cell at the end of a Capacity Test or Charge.
- Charge Acceptance: The capability of the cells to transform the incoming current into charge stored in the plates.
- CMM: Component Maintenance Manual - Technical information provided by a manufacturer for a specific battery.
- Constant Current: As applicable to a charge or discharge test, a current that remains within a few percent of a center value, independent of battery voltage, temperature or line voltage (mains). This is the preferred charge/discharge method for Nickel-Cadmium batteries.
- Constant Voltage: As applicable to a charge test, a voltage that remains within a few percent of a center value. In this case, as the battery is charged the current is automatically decreased by the charger to maintain the voltage at the required level. This is the typical charge method for Lead-Acid batteries. Note that in the aircraft, the charge method is constant voltage, regardless of the type of batteries used.
- C-SCAN: A Data Acquisition Terminal (part of the BTAS16)
- Deep Cycle: As applicable to Nickel-Cadmium batteries, the process of discharge to zero for each of the cells, done to equalize the cells.
- Electrolyte Level Test: As applied to Nickel-Cadmium cells that have a vent cap, the process of verifying the level of the electrolyte and the addition of distilled water as required (Note that this test is performed only at the end of a charge cycle).
- Full Discharge: Constant Current Discharge with no voltage limit (discharge to 0V first by the Charger-Analyzer and finished by resistors and/or shorting clips).
- Lead-Acid: Chemistry system of batteries used for most stand-by applications and for applications demanding less severe discharge currents (as compared with Nickel-Cadmium).
- Main Charge: As applicable to Nickel-Cadmium batteries, the C/2 charge current that provides 100% of the A-hr rating.
- Nickel-Cadmium: Chemistry system of batteries as used in aviation and other heavy duty applications.
- Overhaul: The process of disassembly of all interconnections, cleaning/replacement of interconnecting hardware, removal of cells and cleaning of cells and the interior of the battery. This is applicable to batteries that are made up from an interconnection of multiple cells.
- Reserve Voltage: The difference between the Capacity Test Voltage and the minimum voltage for each of the cells.

- SLA: Sealed Lead-Acid Battery
- Temp-Plate: A plate used to measure the temperature of batteries under test.
- Thermal Runaway: Destructive condition under constant voltage charging where one cell fails and heats up and causes all other cells to fail by the transmission of heat from one cell to the next. The drop in internal voltage causes an increase in charge current that intensifies the heating, thus accelerating the process.
- Topping Charge: As applicable to Nickel-Cadmium batteries, the C/10 charge current that provides 40% of the A-hr rating (after the Main Charge)
- VRLA: Valve Regulated Lead-Acid Battery
- Water Leveling: The process of bringing the electrolyte level to the prescribed level by the addition of distilled water (or de-ionized).

11. REVISION INDEX

Table 1 - Index of Revisions

REVISION	DATE	NOTES
V0.5	10 May 2010	Preliminary writing
V1.0	20 May 2011	Minor text corrections and enhancements
V1.1	2 June 2011	Title Change
V1.2	4 June 2012	Address change
V1.3	8 December 2012	Text enhancements

12. Notes