----- AIRWORTHINESS GROUP CHAIRMAN'S FACTUAL REPORT -------
ADDENDUM

A. INCIDENT:

Location: Boston, MA
Date: January 7, 2013
Time: 10:21 AM EST
Aircraft: Boeing 787-8
Registration: JA829J

B. SYSTEM'S GROUP:

Group Chairman: Robert L. Swaim
National Transportation Safety Board
Washington, D.C.

Co-chairman: Michael Bauer
National Transportation Safety Board
Washington, D.C.

Member: Eric West
Federal Aviation Administration
Washington, D.C.

Member: Kazuhiko Hirai
Japan Transport Safety Board
Tokyo, Japan

Member: Johan Condette
Bureau d'Enquêtes et d'Analyses pour la sécurité de l'aviation civile
Paris, France

Member: Lori Anglin
Boeing Company
Seattle, Washington

Member: Sandra Voglino
Thales Avionics, Inc.
Chatou, France

Member: Takahiro Shizuki
GS-Yuasa
Kyoto, Japan

Member: Kenji Miyahara
Japan Air Lines
Tokyo, Japan

C. SUMMARY

On January 7, 2013, about 1021 Eastern Standard Time, smoke was discovered by cleaning personnel in the aft cabin of a Japan Airlines (JAL) Boeing 787, JA829J that was parked at a gate at Logan International Airport, Boston, Massachusetts. At about the same time, a maintenance manager in the cockpit observed that the auxiliary power unit (APU) had automatically shut down. Shortly afterward, a mechanic opened the aft electronic equipment bay and found smoke coming from the B3856-901 APU battery. The mechanic also saw two small flames coming from the battery connector. No passengers or crewmembers were aboard the airplane at the time, and none of the maintenance or cleaning personnel aboard the airplane was injured. Aircraft rescue and firefighting responded to the battery fire, and one firefighter received minor injuries. The airplane had arrived from Narita International Airport, Narita, Japan, as a regularly scheduled passenger flight operated as JAL flight 008 and conducted under the provisions of 14 *Code of Federal Regulations* Part 129.

This addendum covers additional testing work completed to date that was reviewed by the airworthiness group. For further airworthiness information, refer to the Airworthiness Group Factual.

D. DETAILS OF THE TESTING PERFORMED TO DATE:

D.1 Airworthiness Group Testing:

D.1.1 Battery and Battery Charger Integration Testing:

In conjunction with the aircraft manufacturing testing, the airworthiness group conducted testing of the battery charger and battery system. Testing was conducted at the Boeing Company Hazardous Test Facility (HTF) on February 16, 2013. The tests were conducted by Boeing personnel and witnessed by the NTSB, JTSB, Boeing Company, Thales Avionics Electrical Systems (TAES), Securaplane and GS-Yuasa (GSY). The test described in this section is also referred to in Section D.2 and designated by test number 010.

The test procedure was written by Boeing and reviewed by airworthiness group members. During the testing if any changes were necessary to the test procedure, the group was consulted and if agreed, the test procedure was modified.

D.1.1.1 Test Setup:

The testing was conducted using both a production representative battery charger unit (BCU) and the incident battery charger. Testing also used an exemplar battery. Table 1 contains information from the Battery and BCU data plate for the units used during the testing.

Table 1 –Battery and Battery Charger Data Plate Information

	Battery	Production BCU	Incident BCU
Manufacturer	GS-Yuasa	Securaplane	Securaplane
Part Number	B3856-901	C3808-900	C3808-900
Serial Number	428	1018068	1129884
Amendment	A,B	A,B,C	A,B,C

The test bench consisted of the battery, the BCU under test, a battery diode module (BDM), a load bank, and a power supply for the BCU, see Figure 2. Forced cooling air was supplied to the BCU per design specifications. A battery breakout box (BOB) was installed between the battery and the BCU to provide connections for instrumentation and injection of fault signals into the system. Multiple current, voltage and temperature sensors were installed on the wiring and components. A simplified schematic of the test setup is shown in Figure 1.

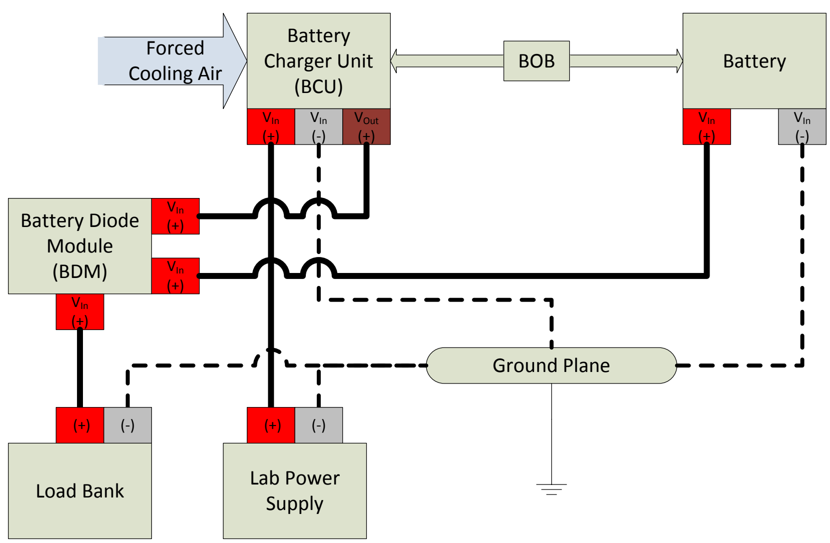

Figure 1- Simplified test bench schematic

The bench used for the testing was designed to allow for testing of the main or APU battery bus setup. Fundamentally the battery busses are similar except the design of the main battery bus system contains a battery diode module (BDM). The purpose of the BDM is to prevent any other power source, other than the BCU, from charging the battery. The design of the APU battery bus does not have an alternate path which could provide a power source to charge the battery, therefore a BDM is not required. The inclusion of the BDM in the test setup when simulating the APU battery bus system adds an additional voltage drop of up to 1 VDC during unassisted APU starts. The test team agreed to keep the BDM in the system setup during APU tests.

Data was recorded at two different predetermined rates[1]. During the initial transient condition and up to a minimum of 3 transients in multiple transient tests, a high speed the recording rate was used. After the original transients were recorded at the high rate the rate was reduced to the slower rate.

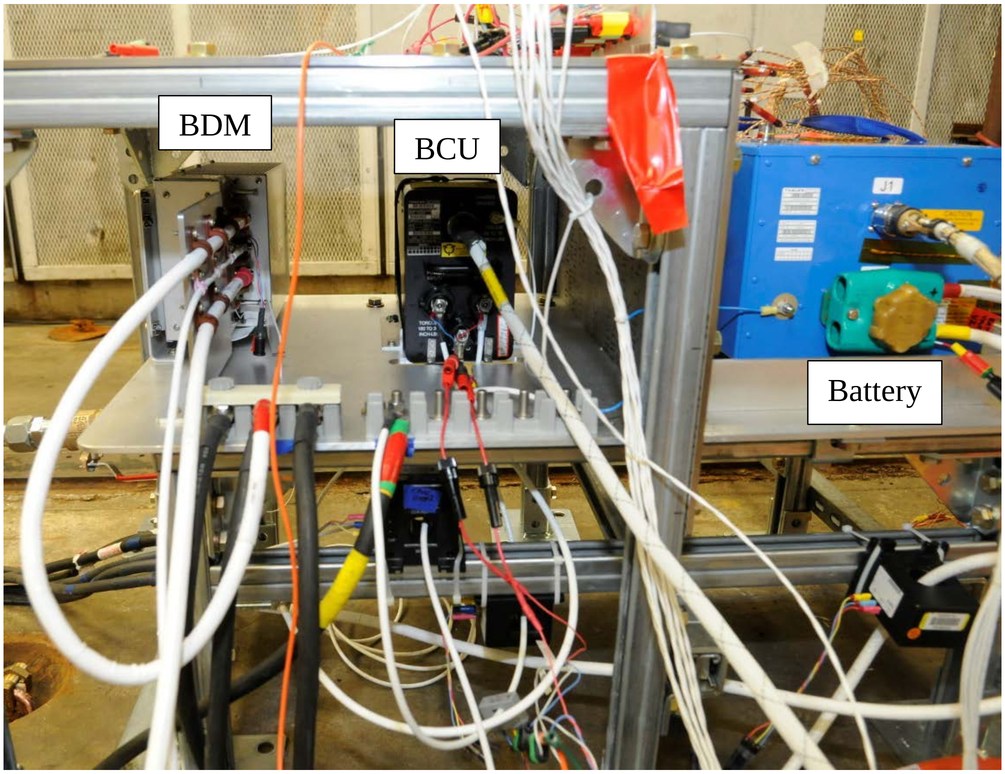

Figure 2 - Test bench setup

D.1.1.2 Test Procedures and Results:

The following test procedures were performed on both the production representative battery and the incident BCU. A test was considered successful if the system or component operated as designed and if no anomalous voltage, current or temperature transients were noted during the test or the post test data review.

[1] For the testing, low and high speed recording rates were used for data acquisition. The low speed rates were lower than 10k Hz and the high speed rates were in excess of 250k Hz.

D.1.1.2.1 BCU Power Up Check under Normal Conditions:

The purpose of this test was to ensure that the BCU and battery were functioning properly. The test started with a fully charged battery. Power was then applied to the BCU. After power was applied to the BCU and the signals stabilized and built in tests (BIT) were completed a constant current load of 75 amps was applied to the system for 15 minutes. After the load was applied for 15 minutes the load was removed and the test was completed.

The production BCU completed the test condition successfully.

The incident BCU completed the test condition successfully.

No anomalies were noted on the battery.

D.1.1.2.2 BCU Power Up Check under Failed Conditions:

The purpose of this test was to ensure that the BCU and battery operated properly in the event the battery's battery monitoring unit (BMU) detected a failure. The test started with the battery in the diminished state of charge after the completion of the BCU power-up check in a normal configuration. Power was then applied to the BCU and a failure was injected using the breakout box. Once the failure was set, the BCU was verified to discontinue the charge current output. The test was repeated for all failure conditions that could be set by the BMU, except for an overheat situation.

The production BCU completed the test condition successfully.

During the test condition when simulating a "battery fail" signal, the BCU remained off after the fail condition was reset. The BCU will remain latched if the fail condition is set for a predetermined length of time. A review of the test data showed that the logic to satisfy the latch condition was met while performing the test. The BCU power was cycled and the system operated as expected. All remaining test conditions with incident BCU were completed successfully.

No anomalies were noted on the battery.

D.1.1.2.3 Nominal Takeoff Condition:

The purpose of this test was to record voltage and current transients of the battery system during a simulated normal takeoff. The test started with a fully charged battery. Power was then applied to the BCU. After power was applied to the BCU the system was allowed to stabilize with a small preload applied. Once the system was stabilized, the BCU was powered down and a small load was applied to the system for two minutes in order to simulate the hot battery bus operation during a takeoff. Once two minutes passed the BCU was powered on and the battery was allowed to recharge to a full state of charge. The simulated takeoff was repeated with the preload removed from the bus prior to the simulated takeoff.

The production BCU completed the test condition successfully.

Since the incident BCU was used for the APU battery bus, the group determined that only the steps required to charge the battery would be performed for this condition. The incident BCU completed the test condition successfully.

No anomalies were noted on the battery.

D.1.1.2.4 Nominal APU Start Condition:

The purpose of this test was to record voltage and current transients of the battery system during simulated normal APU start with engines running. The test started with a fully charged battery. Power was then applied to the BCU. After power was applied to the BCU the system was allowed to stabilize. Once the system was stabilized, a load of 66 amps[2] was applied to the system for thirty seconds. Once thirty seconds had passed the battery was allowed to recharge to a full state of charge.

The production BCU completed the test condition successfully.

During the initial start of the test, after the simulated APU start load was applied, the battery contactor was exercised by the BMU as part of a built in test (BIT). The contactor cycled while the BCU was supplying current to the battery/system. High transient voltages and current were seen on the individual cells during the contactor cycling. The voltage and current transients were present for approximately 1 millisecond, see Figure 3. The contactor remained open for approximately 24 milliseconds[3]. After the contactor BIT, the voltages and currents returned to stable values for the remainder of the test condition.

In normal aircraft operations, the contactor BIT operation is supposed to occur after the BMU receives an indication signal from the BCU after the BCU measures a state of low current charge and the battery has indicated it has reached its minimum state of charge. The contactor BIT will only occur once per power cycle of the aircraft, estimated by Boeing to be once per 100 flight hours. During this test the BIT test was in progress, the activation logic was satisfied, reported to the BMU and the contactor BIT was not completed before the simulated APU load was applied. The contactor was exercised per the BIT while the battery was discharging at a nominal load of approximately 20 amps. There are no protections in the contactor BIT test to inhibit the exercising the contactor while the battery is discharging or during a high current charge if the logic to initiate the BIT has been satisfied.

---

[2] Based on historical and design data the 66 amp load is representative of a typical load during an APU start with engines operating.
[3] During the BIT, the contactor will remain open for a maximum time of 100 msec.

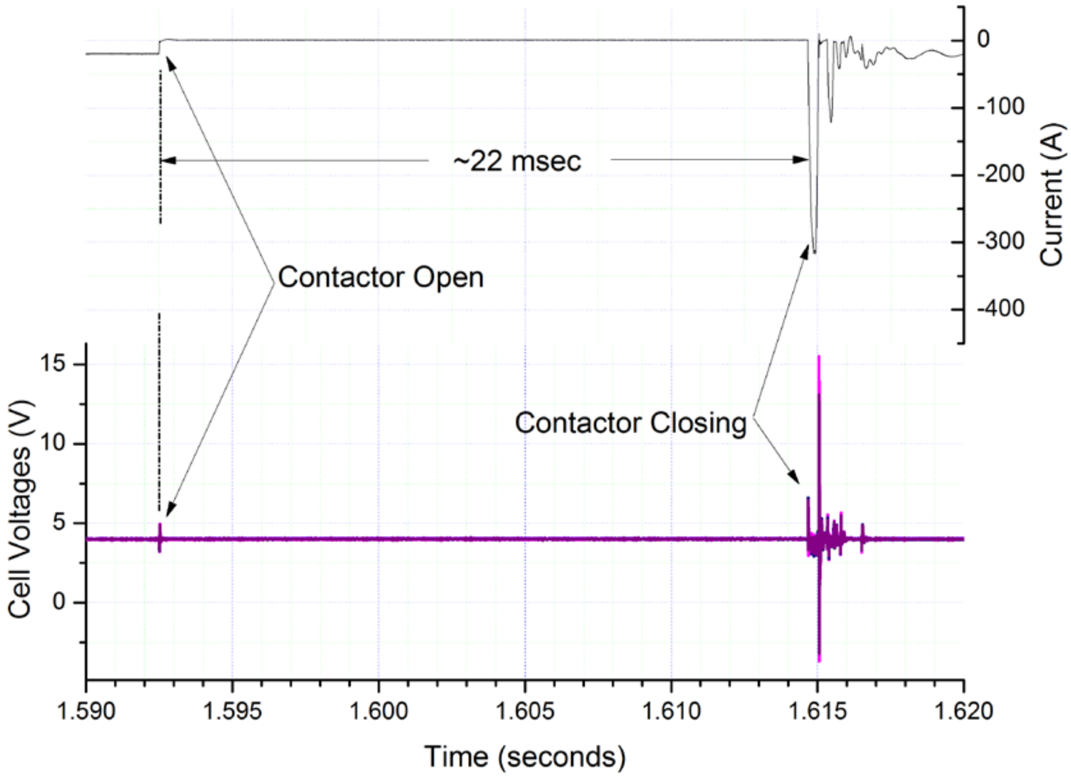

Figure 3 - Voltage and current transient seen during contactor operation (negative current is a discharge from the battery)

D.1.1.2.5 Battery Only APU Start Condition:

The purpose of this test was to record voltage and current transients of the battery system during a simulated APU start on battery only. The test started with a fully charged battery. Once the system was stabilized, a load of 18kW[4] was applied to the system for thirty seconds. Once thirty seconds had passed, the load was removed and the battery was allowed to recharge to a full state of charge.

The production BCU completed the test condition successfully.

The incident BCU was not tested for this condition, as this test was primarily related to the performance of the battery during a simulated APU start.

No anomalies were noted on the battery.

[4] The load applied is shorter in time by 15 seconds based on the Boeing SCD for the battery design.

D.1.1.2.6 BCU Input Voltage Interrupts:

The purpose of this test was to record voltage and current transients of the battery system during battery charging if the BCU input voltage was interrupted during various bus loadings. Loading conditions of 0A, 10A, 20A and 30A were used. The test started by discharging the battery with a constant current load for fifteen minutes. Power was then applied to the BCU and the BCU would begin charging the battery and a predetermined load was applied to the system. During the charge cycle, the input power to the BCU was interrupted for 50 ms and the system was allowed 20 seconds to recover prior to interrupting the power again. The cycle was repeated a total of 50 times. After 50 cycles, the power interrupt time was increased to 200 ms and repeated until 50 cycles were completed. After completing the 100 cycles at the predetermined load, three other loading conditions were tested with ten cycles for each power interrupt.

The production BCU completed the test condition successfully.

The incident BCU completed the test condition successfully for the 10A, 20A and 30A conditions. During the 0A loading condition, the charger output began cycling between -1.5A and 2.25A over 250 ms, see Figure 4 and Figure 5. The cycle is preceded by a short burst of current oscillation approximately 275 ms in duration. The cycle would occur approximately every 2 seconds. The cycling was observed to occur over a range of frequencies. For comparison purposes, Figure 6 contains the output of the BCU from the production BCU used in the testing that did not produce the cycling condition during testing.

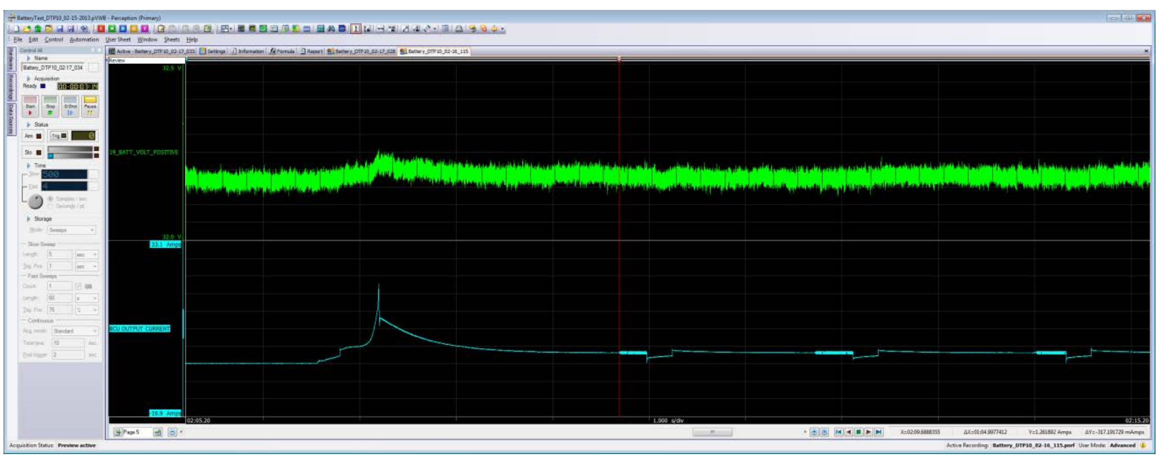

Figure 4 - Typical cycling seen during 0A loading condition on incident BCU

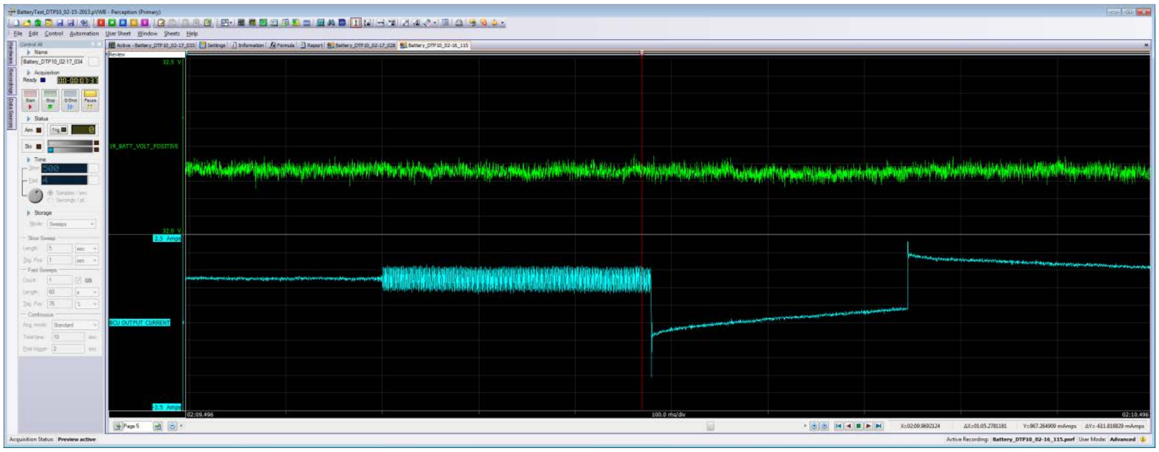

Figure 5 - Expanded view of one cycle seen during the 0A loading condition on incident BCU

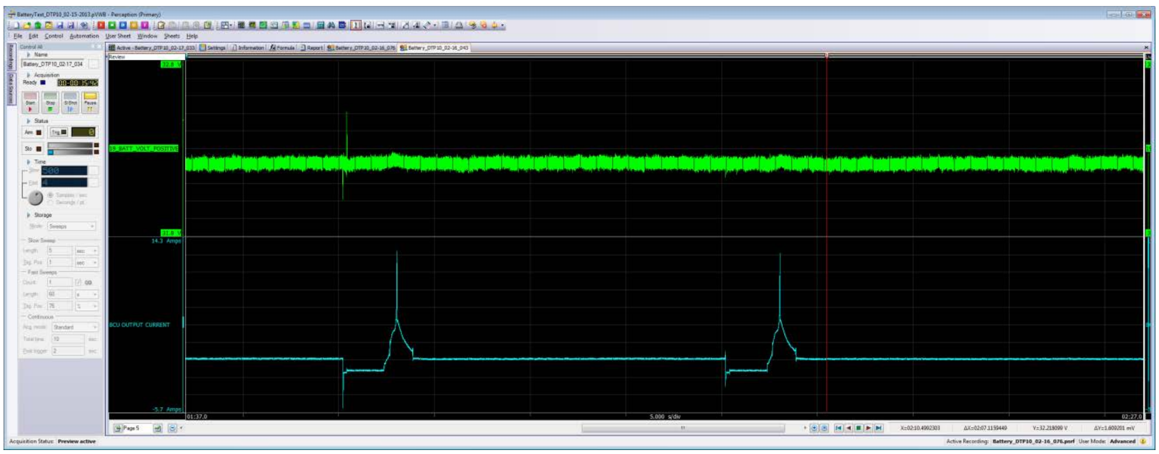

Figure 6 - Production BCU output during 0A loading condition

D.2 Aircraft Manufacturer Testing:

After the incident, the aircraft manufacturer conducted over 40 different tests to understand various battery failure modes. Table 2 contains the titles of tests the Airworthiness Group determined were relevant to the investigation; tests were developed and completed by Boeing, with assistance for certain tests from component suppliers TAES and GSY and various contractors. The tests were performed to support the Root Cause Corrective Action (RCCA) efforts and also for the aircraft manufacturer to gain information to support the redesign efforts of the battery system.

Table 2 – Relevant RCCA testing for the battery investigation

Test Number[5]	Test Title	Month/Year Test Performed
001	Cell Vent Proof of Concept	January 2013
002	Wet Cell Test	January 2013
004	Full Battery Vent (No Enclosure)	January 2013
005	Full Battery Vent with Enclosure and Duct	January 2013
006	Ground APU Start with Battery Enclosure	February 2013
009	Airplane Grounding Test	February 2013
010	Enhanced Battery Charger Test	February 2013
026	Cell Case Short to Ground	February 2013
031	Battery Vibration Testing	March 2013
033	ZA005 Battery Checkout/Vibration – Ground/Flight Test	February 2013
048	2.4V Hold Test	February 2013
054	Battery Terminal Seal Integrity	February 2013
059	Development Battery Internal Condensation Test	February 2013
061	Cell and Battery Current Pulse Cycling Tests	March 2013
068	Hot Day APU Start Electrical Contact Resistance	No Date Provided
086	Pulse Charge Damage Test	No Date Provided

The NTSB was present for only two of the tests, 001 Cell Vent Proof of Concept and 010 Enhanced Battery Charger Test[6]. These tests were conducted by Boeing in Seattle, Washington.

During the testing series, Boeing conducted a total of five full scale battery tests, four of which resulted in propagation. Four of the tests were conducted with the battery contained in an enclosure, similar to the current production design; one test was performed outside the enclosure (test 004). Three of the tests were performed using the -901 configuration batteries and the remaining test using the -902 batteries. Tests 004 and 005 are summarized in this report. The three other tests were conducted in support of the new battery installation and are not contained in this report due to proprietary concerns, but the test results were reviewed as part of the investigation.

The following summarizes the tests the airworthiness group determined were relevant to the investigation.

---

[5] The test number was assigned by the manufacturer during initial test planning and is not necessarily reflective of the actual number of tests performed

[6] Details of test number 010 are in section D.1.1

D.2.1 Test 001 – Cell Vent Proof of Concept:

The purpose of the test was to ensure the Boeing laboratory could fail single cell, obtain temperature data of a cell during an event and capture escaped contents of the cell for further chemical analysis.

A fully charge cell was heated with a heater blanket to induce a failure. The cell was instrumented to capture voltage and temperatures on the cell and in the vicinity of the cell.

The cell vented through the vent rupture disc and shortly after the venting of the cell began, the vented material ignited[7].

The test was repeated with a modification to the heating profile using another fully charged cell. During the repeated test, the cell vented and was destroyed. No further information on this test was provided to the airworthiness group.

D.2.2 Test 002 – Wet Cell Test:

The purpose of the test was to test a theory that if water accumulates inside the battery it could potentially cause a short circuit.

The test was performed on a single cell placed inside a grounded aluminum container in a saline solution. A voltage bias was applied to cell's negative terminal, simulating the cell in position 8 of the battery. The test demonstrated that shorting a cell case to ground using a saline solution can lead to a cell venting.

Post-test inspection of the cell revealed damage to internal to the cell header. The damage to the cell included signs of arcing, shorting and heat damage.

D.2.3 Test 004 – Full Battery (-901) Vent – No Enclosure:

The purpose of the test was to demonstrate cell propagation throughout a battery if one cell was subject to failure.

A -901 battery assembly was modified to induce a failure in cell 7. The assembly was connected to a battery charger unit (BCU) and battery diode module (similar to a main battery installation). The test conductor halted the operation of the BCU and approximately one hour later smoke was seen emanating from the battery. The test conductor restarted the test, which resulted in the failure of a test configuration grounding wire prior to the cell failing.

[7] The electrolyte in the individual cells is flammable. During a cell venting, the vented electrolyte acts like a fuel; if an ignition source exists and sufficient oxygen is present, the vented material can ignite and start a fire.

Post-test inspection of the battery assembly revealed damage to cell 7 and to the insulation in the vicinity of cell 7, but the vent disc remained intact. Propagation to the other cells was not observed.

D.2.4 Test 005 – Full Battery (-901) Vent with Enclosure and Duct

The purpose of the test was to demonstrate cell propagation throughout a battery if one cell was subject to failure. The test was also performed with an early design of the battery enclosure box to demonstrate the ability to contain the battery and its contents during a full battery venting. This test was performed using a -901 configuration battery.

A -901 battery assembly was modified to induce a failure in cell 7. The assembly was connected to a battery charger unit (BCU) and battery diode module (similar to a main battery installation). Temperature, voltages and pressures in the battery box were recorded. The targeted cell failed and propagation was observed. All cells in the battery failed or depleted their electrical energy during the failure sequence.

Post-test inspection of the battery assembly revealed evidence of internal arcing was seen between the battery case components and individual cells, which included welding of the battery case center brace bar to the cell 7 case. The battery case grounding wire was also fused open during the failure sequence.

D.2.5 Test 009 – Airplane Grounding Test:

The purpose of the test was measure the resistance between multiple ground locations at the main and APU battery locations with the battery installed and removed..

The resistances were measured and the information was reviewed by the group. Actual recorded values are not provided in this report due to proprietary concerns.

D.2.6 Test 026 – Cell Case Short to Ground:

The purpose of this test was to determine if shorting a cell case to ground could cause a short circuit of the cell and lead to venting. Four cells were subjected to the same test conditions with the process stopped at various points in order to allow for cell destructive physical analysis (DPA) to characterize various levels of internal damage.

During the initial cell test the cell vented and failed after an extended period of the cell case connected to ground. The cell DPA revealed one set of current collectors fused open and the voltage trace showed an initial drop followed by a recovery and then a final drop in voltage as the cell failed.

The DPAs of the four cells halted at various points in the test showed black deposits on the anode and white deposits on the cathode as well as discolorations and markings on the electrode foils and separators.

D.2.7 Test 031 – Battery Vibration Testing:

The purpose of the test was to investigate possible root cause items that can be affected by vibration. These items included terminal nut loosening, abrasion of wire and lining insulations, current collector fracturing, internal battery shorting and current collector clearance inside the cell. During the testing, battery performance parameters were monitored. The battery was subject to vibration levels specified in Boeing's requirements, which are in excess of the DO-160 requirements and are higher than the actual service environment.

Post-test inspections of the battery revealed areas of slight abrasions around the top insulation cover and the cell wrapping insulation. One voltage sense wire, located on the contactor, failed during the posttest disassembly.[8] Small changes in cell case voltage were noted, but no changes in battery performance were seen.

D.2.8 Test 033 – ZA005 Battery Checkout/Vibration – Ground/Flight Test:

The purpose of this test was to record electrical system data in additional to thermal and vibration data while operating the aircraft during normal ground and flight modes. Data was recorded at various rates (low and high speed) throughout the test conditions. The testing included conditions with maximum and extended loading of the batteries.

The testing consisted of two ground test sessions and two flight test sessions. The battery and charger performed as expected and no unexpected thermal or vibration data was seen during the test conditions. Bay temperatures for the battery and equipment bays during the two flights were comparable to temperatures recorded by FCE QAR data (ref section D.4). Post flight examinations of the flight test data showed cycling during the constant voltage charging cycle at low current loading similar to the cycling seen during DTP 010. No other abnormal electrical transients were noted during the testing.

D.2.9 Test 048 – 2.4v Hold Test:

The purpose of the tests was to determine the extents of copper plating internal to the cell when the cell voltage is held to a low discharge level, which is above the internal protection device setting. The battery has an internal protection device that will fail the battery if any cell is discharged below a predetermined voltage level.

The cell was discharged to the predetermined level and held at that voltage for an extended time. After the extended time, the cell was cycled and then subject to a post-test inspection, which included CT scanning prior to disassembly. The test cell post-test inspection results were compared to a control cell which was not subject to the test conditions.

The test results showed that after the cell was held at the test condition voltage, no detectable levels of dissolved copper were found.

[8] The -902 battery design has incorporated improvements to the BMU sense wire installation.

D.2.10 Test 054 – Battery Terminal Seal Integrity Test:

The purpose of the battery terminal seal integrity test was to verify the integrity of the terminal assembly of the cell after the application of torque to the terminal posts.

An empty cell case was constructed and leak checked prior to any torque application. Multiple torque values greater than the normal installation torque where applied and a leak check of the cell case was performed.

The leak rate observed after the torque applications was less than the original values for a newly manufactured cell. Torque values up to two times the installation value did not affect the terminal seal integrity.

D.2.11 Test 059 – Development Battery Internal Condensation Test:

The purpose of the internal condensation test was to determine the susceptibility of the battery box design to internal condensation and if the battery could short circuit due to the accumulation of condensation.

The battery used for the test did not use actual cells, but thermally equivalent “dummy” cells for the test. The battery was subject to a temperature and pressure reduction, to simulate a flight cycle in an environmental chamber. Once the battery and cells stabilized at the cold temperature, the chamber’s humidity, temperature and pressure were increased. The cycle was repeated and then the battery was inspected for signs of visible moisture.

Small amounts of water condensation could be seen on the tops of the cells after the test was completed. Changes in the cell to battery case resistance were seen. The internal battery conditions (pressure and humidity) closely followed the external conditions. A significant thermal lag between the cells and the battery case walls was seen. The case lid seal did not completely seal the battery case and small gaps could be seen along the lid seal[9]. The water condensation was also shown to create an electrical short path between the cell and battery case.

D.2.12 Test 061 – Cell and Battery Current Pulse Cycling Tests:

The purpose of the test was to determine if excessive cell and battery voltages could be created by high current rate pulses, if the cell impedance changed due to the pulses and if any cell damage could result from the pulses

Prior to the test the cells used in the testing were characterized based on cell capacity, AC impedance and DC resistance. A cell was then subjected to current pulses of varying

[9] The design of the battery did not require waterproofness, therefore a complete seal of the lid is not expected.

duration and amplitude. The cell was then re-characterized to compare the results after the test with those taken before the test.

Post-test inspection of the test results showed no changes in the cell impedances and no cell damage was noted.

D.2.13 Test 068 – Hot Day APU Start Electrical Contact Resistance:

The purpose of this test was to gather cell temperature information when subjected to hot day conditions and multiple APU starts, which is considered a worst case thermal environment condition.

The battery was heat soaked to its maximum operating temperature and then subjected to three simulated APU starts. Temperature information was recorded at multiple locations within the battery, including terminal posts, bus bars, cell rivets and cell cases.

During the simulated starts the maximum recorded temperature rise after three start attempts was 65°C at the bus bar from cell 8 to the battery positive terminal. The maximum cell rivet temperature rise was approximately 50°C, also on cell 8.

D.2.14 Test 086 – Pulse Charge Damage Test:

The purpose of this testing was to characterize to the effect on cells subjected to current pulses similar those observed in test 010.

Prior to the test, the subject cells were subject to a variety of general characterization measurements including impedance, resistance, voltage and capacity checks. Pulse charging was then applied to the test cell, representative of the limit cycling seen in BCU testing. The cycling was repeated five times which resulted in ten total exposures to the limit cycle pulses. Once the cycles were completed the baseline tests were performed in order to determine if any changes to the cell occurred due to the testing.

Changes to the cell were noted in some of the baseline test readings. At the time of the test completion, it could not be determined if the changes seen in the readings were sufficient to adversely affect the cell.

Further cycling testing was conducted as part of the NTSB contracted testing with UL.

D.3 System Manufacturer Testing:

In November of 2006 GS-Yuasa developed and performed a developmental (non-certification) test to simulate a “hard” internal short circuit within a single cell. The battery used by the testing was a pre-production version of the -901 battery design[10]. The test was performed by inserting a conductive nail through a hole in the top of the battery case and into the top of a fully charged single cell within a fully charged, non-grounded battery at a temperature of 15° C.[11] The following measurements were recorded: ambient temperature, battery and cell voltage, cell and battery temperature and surrounding temperatures.

Thales provided the results of this test, via a presentation, to Boeing during a Technical Coordination Meeting (TCM) in Seattle, WA in November 2006. In May 2013, the test results in the form of a presentation were also provided to the System Safety and Certification Group and the Airworthiness Group for this investigation. Additional test data was provided to both groups in June 2013.

In planning for the test, GS-Yuasa had wanted to insert the nail into one of the cells (2, 3, 6, or 7) centrally located within the battery since the heat generated from the penetrated cell would radiate to a greater number of adjacent cells. The preferred penetration method would have been to penetrate the cell from one of its sides to ensure that the nail penetrated all three of the windings. However, this method could not be used when a cell was in the battery box. Therefore, they had to apply the nail straight down into the top of the cell through the battery box. Due to interference with the test equipment, it was difficult to access cells 6 and 7 and therefore they chose cell number 2. GS-Yuasa made sure that the penetration position was carefully selected to ensure that the nail would penetrate a winding within the cell. At the time of test, the current configuration of the battery was such that, the vent from cell 2 was directed at cell 7.

The presentation showed that the surface temperature of the nail-penetrated cell increased, the cell and battery vented with smoke, and the surface temperature of an adjacent cell increased with no venting. No other cells in the battery except for the penetrated cell vented. After the test was concluded no DPAs of any of the cells were conducted.

---

[10] The pre-production version used in the 2006 testing contained a different vent disc arraignment from the arraignment in place at the time of the incident. Half of the vent discs in 2006 vented toward the center of the battery and other cells. The other half of the vent discs in 2006 vented toward the sides of the battery case. The arraignment in place at the time of the incident had all vent discs directed away from the center of the battery towards the sides of the case.

[11] The battery was considered to be in a “floating” ground state because its case was not electrically grounded. When the -901 battery is installed in the airplane, the case is grounded via the Boeing 787 common return network.

D.4 Additional Data:

In late January 2013, after discussions with Boeing and JAL, additional flight data was provided related to equipment bay ambient temperatures. The Enhanced Airborne Flight Recorder (EAFR) records equipment bay cooling air temperature, but not an ambient bay temperature. After the events in January 2013, the quick access recorder (QAR) [also known as continuous parameter logging (CPL)], was modified to record the Flight Control Electronics (FCE) battery temperature.

The FCE battery is a lithium-ion battery that provides electrical power to the FCE if other power sources are not available. The battery has two internal temperature sensors to monitor the internal battery temperature, similar to the main and APU battery installations. In the aft EE bay the FCE battery is located adjacent to the FCE cabinet and just above the APU battery installation. In the forward EE bay the FCE battery is located adjacent to the nose gear on the left hand side of the aircraft below the FCE cabinet and is not in the immediate vicinity of the main battery installation.

At the request of the NTSB, Japan Airlines provided three sets of flight data containing the FCE battery temperatures. The flights took place between Narita International Airport, Narita, Japan (NRT) and Logan International Airport, Boston, Massachusetts (BOS). One flight was from August 2013, one flight was from December 2013 and remaining flight was from January 2014. During all the flights, the temperatures of the FCE battery ranged from 6°C to 32°C. All three flights were over 11 hours in duration. The flight data is shown in Figure 7.

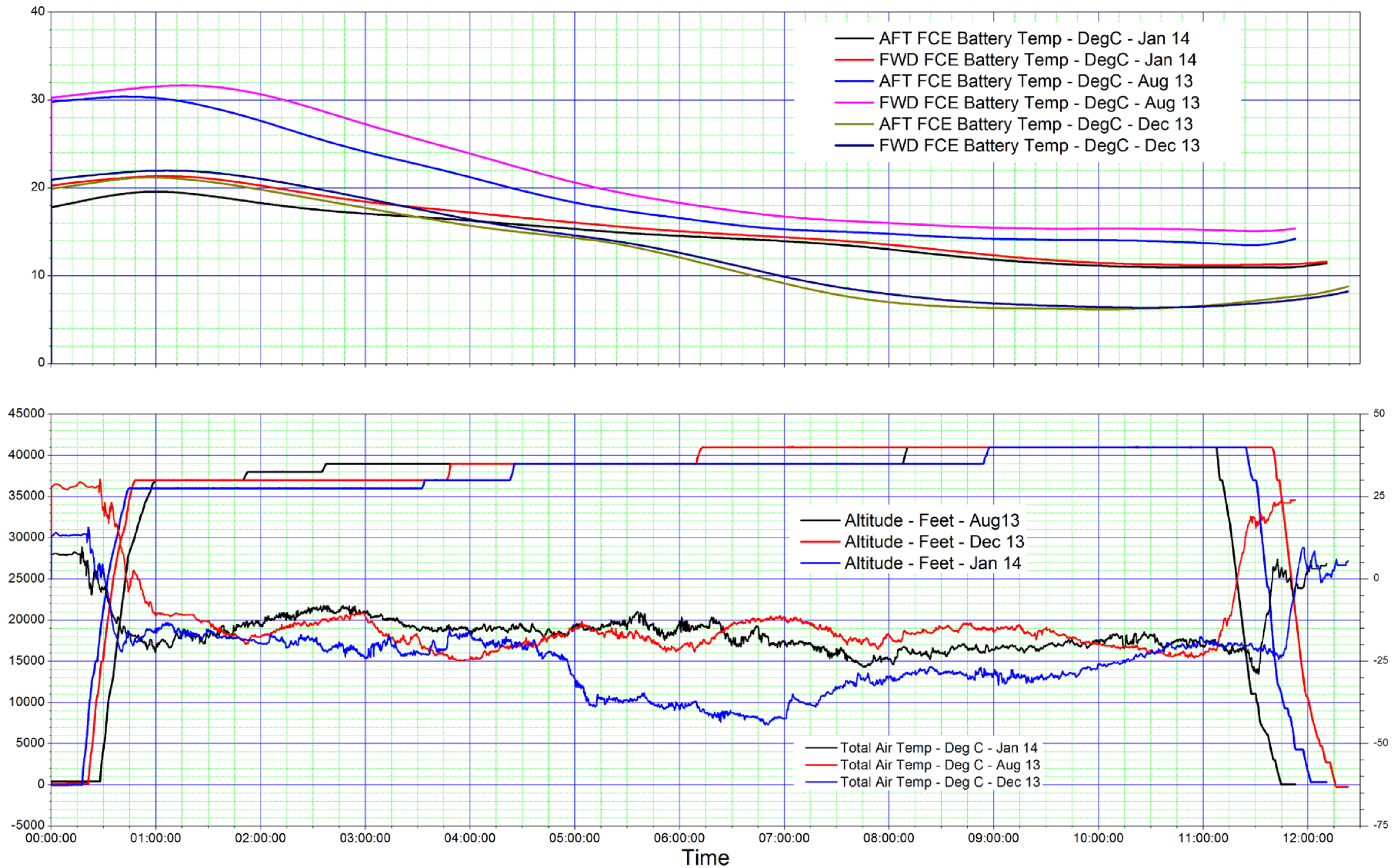

Figure 7 - CPL data of FCE battery temperatures during three NRT-BOS flights