Assessment Report – Battery Event at Narita on
a Boeing 787 aircraft operated by Japan Airlines

December 19, 2014
Japan Civil Aviation Bureau

○Operator	:	Japan Airlines Co., Ltd. (JAL)
○Type	:	Boeing 787-8
○Registration Number	:	JA834J
○Time of event	:	Approximately 16:15 (time is Japan Standard Time, the same shall apply hereinafter) January 14, 2014
○Assessment	:	Battery event at Narita International Airport

1. Outline of event

a) While preparing for the next departure of a JAL 787 aircraft at Narita airport from parking spot 72, a maintenance technician in the cockpit noticed white smoke coming up from under the fuselage at approximately 16:15 (Tue) January 14. (The aircraft departed from Beijing at 09:25, arrived in Narita at 12:32 and was scheduled to depart at 18:05.) The technician went outside immediately but did not see any smoke. Upon returning to the cockpit, the technician noticed messages showing that the main battery and the main battery charger had anomalies. The voltage of the main battery was 27V. There was no record that any messages for abnormal battery voltages had been displayed during the previous flight. (Maximum 32V, Minimum 30V)

While parking, electrical power of the aircraft was supplied from the Fixed Ground Power Unit.

Note: This report is a translation of the Japanese original assessment report. The text in Japanese shall prevail in the interpretation of the report.

b)　Upon opening the main battery enclosure after the aircraft was towed into a hangar, traces of spilled electrolyte were observed inside the enclosure. Also, it was confirmed that the rupture disk of cell 5, which is one of eight (8) cells within the battery, was ruptured.

Outside surface of the battery
(Only the rupture disk of cell 5, most right, was ruptured).

c)　Also, brownish liquid residue was around the area adjacent to the external vent port, which is located at the bottom of the aircraft and vents smoke and gas, etc from the battery enclosure.

External view of the vent port area

d) In the forward Electrical/Electronics bay, no damage was found at the area adjacent to the enclosure.

Conditions surrounding the battery enclosure

e) Since this event occurred while parking on the ground and was not considered a serious incident, this assessment was led by JCAB with the participation and cooperation of JTSB, NTSB, FAA, Boeing, Thales, GS Yuasa, JAL and ANA.

2. Information about the aircraft and battery

(1) Aircraft

Manufacture serial number	:	34842
Date of manufacture	:	February 21, 2013
Delivery	:	June 12, 2013
Total flight hours	:	2,686 hour (as of this event)

(2) Main battery

Part number	:	B3856-902
Manufacture serial number	:	00001586
Date of manufacture	:	May 9, 2013

Total flight hours and cycles : 2,686 hour, 349 cycles
(as of this event)

(The main battery was delivered with the subject aircraft and removed for the first time due to this event.)

(3) Main battery charger

Part number : C3808-901

Manufacture serial number : 1135876

Date of manufacture : March 26, 2013

Total flight hours and cycles : 2,686 hour, 349 cycles
(as of this event)

(The main battery charger was delivered with the subject aircraft and removed for the first time due to this event.)

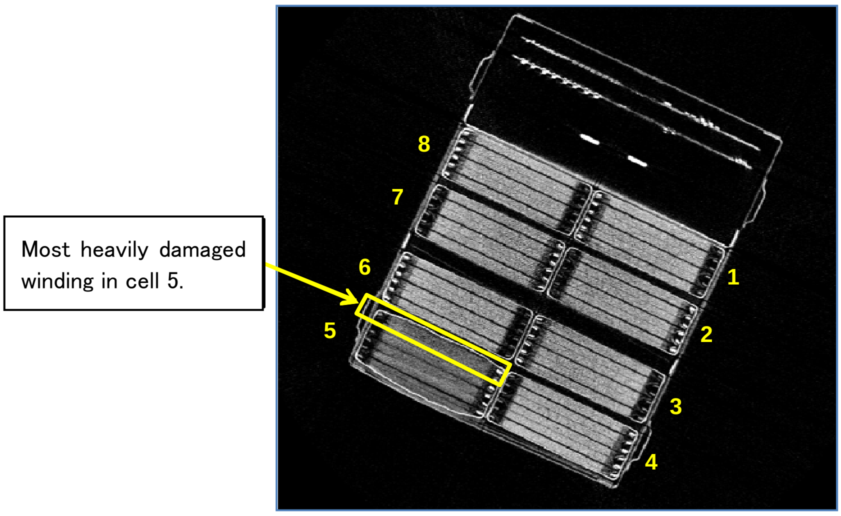
3. Assessment

(1) Battery

a) Inspections of the battery enclosure, surrounding components/structure, the battery outside surface, and measurements of battery/cell voltages and battery resistance were performed at Narita airport.
(January 14 through 18)

Conditions inside the battery

b) A whole-battery CT scanning inspection was performed at JAXA (Mitaka). (January 19 through 20)



CT scan of the Battery

c) The following inspections and measurements were performed at GS Yuasa (Kyoto). (January 21 through February 14)

① Disassembly of the battery

② Visual inspection of battery components

③ Visual inspection, electrical characterization and CT scanning inspection of each cell

④ Destructive Physical Analysis (DPA) of cell 5

⑤ DPA of cell 6

Cell 5 (Rupture disk was ruptured)

d) DPA of cell 2 at Boeing (Seattle, USA).
(March 4 through 6)

e) DPA of cell 3 at GS Yuasa (Kyoto).
(March 31 through April 3)

f) DPA of cell 4 at Boeing (Seattle, USA).
(May 13 through 15)

g) Chemical analysis of samples collected from disassembled cells at GS Yuasa (Kyoto) and Boeing (Seattle, USA).
(February 15 through September 19)

h) Detailed inspection of main/APU batteries removed from ANA and JAL aircraft other than the incident aircraft at GS Yuasa (Kyoto). These batteries were used for approximately one year.
(August 5 through September 9)

<u>(2) Battery Monitoring Unit (BMU)</u>

a) Acceptance Test Procedure (ATP) at BMU manufacturer

(Fujisawa). (January 23)

(3) Battery charger unit (BCU)

a) Acceptance Test Procedure (ATP) at BCU manufacturer (Arizona, USA). (January 29 through 30)

4. Findings revealed by assessment

(1) Summary

a) Cell 5 of the main battery was overheated/damaged and the rupture disk was ruptured.

b) The area of the EE bay outside the enclosure was clean and no damage was confirmed to the surrounding components.

c) The Battery Monitoring Unit (BMU) and the Battery Charger Unit (BCU) had no anomaly.

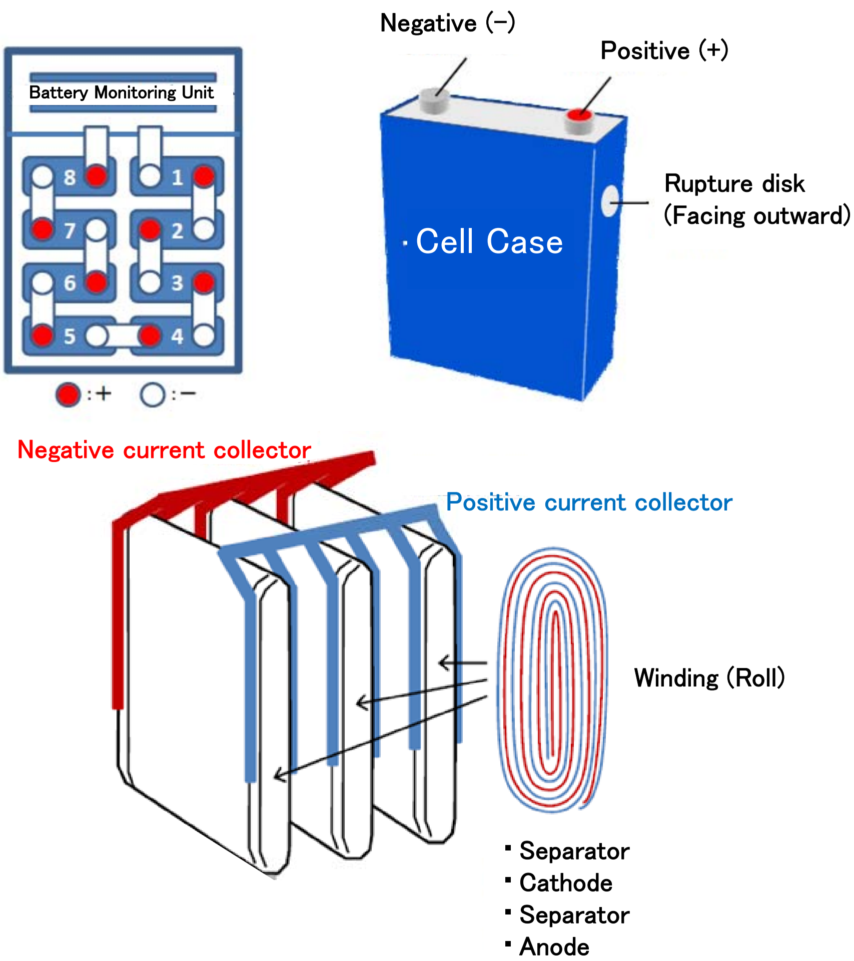
d) Just after this event, all cells maintained the voltage except for cell 5.

e) Cell 6 adjacent to cell 5 was functionally operational although some thermal effects, etc. were observed.

f) Levels of electrolyte were confirmed to vary between cells. Also, a very small amount of material, which seems to be possibly metallic lithium, was observed on one electrode (roll) from a disassembled cell. Additionally, it was confirmed that wrinkles were found on the anode foils of cell windings.

g) Water droplets were observed at the time of the battery opening at Narita on the top cover insulator (on the face close to the battery cells) and also on bus bars. Other water traces were also observed inside the battery box at various locations such as: battery box sides, and on the bottom face close to the drain holes during the DPA of the battery at GS Yuasa.

(2) Detail



1) Components surrounding the battery

a) The area adjacent to the main battery enclosure was clean and no damage was confirmed in the surrounding components.

b) For the battery charging unit (BCU), no anomaly was confirmed by the successful completion of the usual acceptance test procedure (ATP) tests and checks at the manufacturer of BCU (Arizona, USA).

2) DPA of the battery (Refer to paragraph “3) DPA of cells”)

a) Among the eight (8) cells in the main battery, cell 5 was overheated/damaged and the rupture disk of cell 5 was ruptured.

b) Cell 5 was swollen and the positive current collector (aluminum) was partially melted.

c) CT scanning inspection of each cell revealed no internal damage in any cell except for cell 5.

d) Damage was found in the vicinity of cell 5 inside the battery. (For example, discoloration of the upper cover and deformation of the fixation frames due to heat.)

e) Cells, except for cell 5, were tested for detailed electrical characteristics and cell 6 had a slight decay in voltage (Approximately 0.05V drop after 180 hours). No significant electrical anomalies were observed in any operational cell except for cell 6.

f) For the battery monitoring unit (BMU), no anomaly was found as confirmed by the successful completion of the acceptance test procedure (ATP) tests and checks at the manufacturer of the BMU (Fujisawa).

g) Uneven levels of electrolyte between cells:

A CT scanning inspection revealed that levels of electrolyte varied slightly between cells, except for the vented cell 5. This result was deemed to possibly indicate leakage from cells. However, a leakage test by helium gas revealed that all cells, except for cell 5, met the leakage criteria required at manufacturing. Thus, no leakage was detected by the He leak test.

Following the inspection above, detailed inspection of batteries removed from ANA/JAL aircraft revealed that levels of electrolyte vary from cell to cell even on normal batteries.

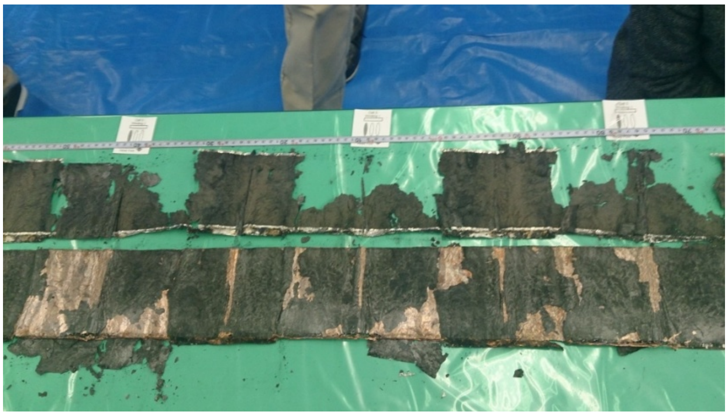
3) DPA of cells

a) Damage of cells

The three windings of cell 5 were damaged and the winding in the vicinity of cell 6 was the most heavily damaged. DPA of windings was not able to identify the initial cause of the heat.

Also, among the six (6) positive electrode current collectors (aluminum, with melting point of about 660 degree C) in cell 5, the two (2) current collectors closest to cell 6 were melted and had opened (fused open).

Among the three (3) windings of cell 6, the separator (porous plastic film, with melting point of about 130 degree C) of the winding near cell 5 exhibited heat damage and a part of the outer roll had discoloration, change in quality and shrink. However, no evidence of edge-short on both positive and negative electodes was confirmed.



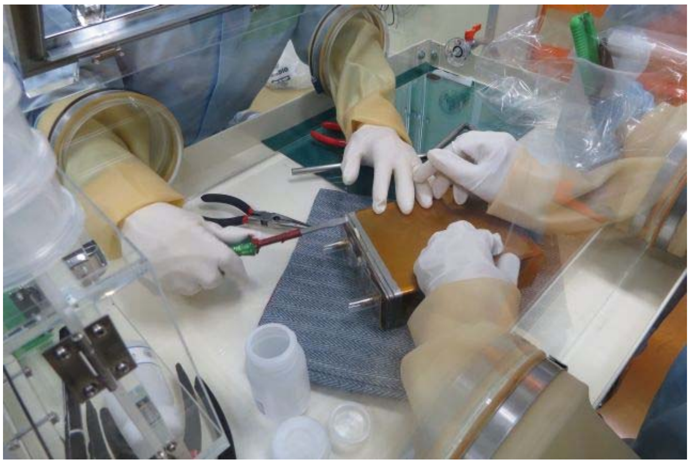
DPA of cell 5

b) Metallic lithium and metallic contaminants within cells:

Cell 5 was heavily damaged and all separators were deemed to be melted due to heat. Also, a large part of the base material of cathode (aluminum foil, with melting point of about 660 degree C) was lost, especially in the area close to the center of the winding near cell 6. Multiple samples selected from the remaining electrodes of cell 5 were analyzed and no contaminant was found that may have originated from outside of the cell.

Since the remainder of the cells, except for cell 5, had no venting, DPA of four (4) cells (Cells 2, 3, 4 and 6) were performed in a glove box with a dry inert atmosphere. During these inspections, many samples were selected for chemical and microscopic analysis.

This inspection found some metallic particles (multiple, the size of 10 to 200 micrometer in diameter) in the windings of cell 2, 3 and 4. Component elemental analysis revealed that the material of the particles was steel, copper, or aluminum.

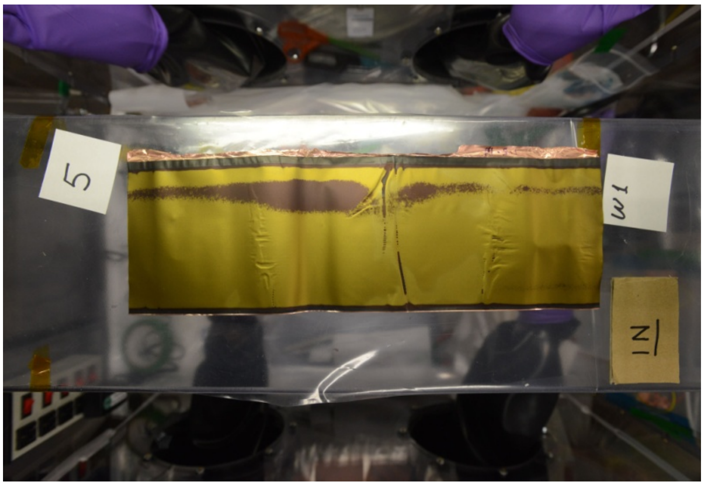


DPA of a cell in a glove box

Also, a small white/gray deposit was observed on the anode of cell 3 winding (at one (1) location) and monochromatic X-ray photoelectron spectroscopy (XPS) analysis revealed that small deposit was possibly metallic lithium.

Very small amounts of various materials were also observed on other samples. However, no material which may be expected to directly affect the performance of a cell was detected. Thus, no significant anomaly was found on the other samples.

c) Wrinkle in cell winding



Wrinkle in anode foil

Except for cell 5, the four (4) cells (Cells 2, 3, 4 and 6) were disassembled, at 100% SOC (State of Charge) for cell 2, 3, and 4, and at 30% SOC for cell 6 respectively, to easily determine the electrode charge condition and it was confirmed that wrinkles were present on the anode foils in each cell. Due to the thermal damage and results of the electrical tests, cell 6 was disassembled at 30% SOC to avoid further damage.

4) Other assessments

a) Detailed inspections were performed on 2 (two) main/APU batteries following approximately 1 year of service on ANA/JAL aircraft.

Battery performance checks (Resistance measurement, charge/discharge voltage test and discharge capacity of the batteries and their cells) and detailed inspection of cells (CT scanning inspection, etc.) were performed and all inspection and electrical performance criteria were passed.

5. Consideration

a) After the events at Boston and Takamatsu in January 2013, the design of the battery and the battery charger unit was modified and a new enclosure for the battery was additionally installed by Boeing. This event at Narita was the first case where smoke was observed from any in-service battery after these improvements were incorporated.

b) During the events at Boston and Takamatsu, the windings of all eight cells in each battery were heat damaged. During the event at Narita, only cell 5 was overheated/damaged. Also, no damage was found at the area adjacent to the enclosure in the forward Electrical/Electronics bay.

c) Just after this event, the voltage of the main battery was 27V, which is lower than the nominal voltage of 31V by the voltage value equivalent to one cell. Just after this event, all cells maintained voltage except for cell 5 and it is considered that the main battery would be able to provide the required voltage for continued flight, should the event occur during flight operations.

d) Discoloration, change in quality and shrink observed on a part of the separator of the cell 6's winding near cell 5 are considered to be due to heat from cell 5. However, no sign of any short circuit or significant anomaly was confirmed within the cell, thus, it is considered that the cell was able to provide required voltage when this event happened.

e) The finding above indicates that the three layers of improvements, incorporated after the Boston/Takamatsu events and listed below (in this case, the second layer and third layer in the three layers) functioned as intended and were effective in terms of maintaining continued safe flight operations.

【 Three layers of improvements 】

First layer	:	Prevent cell overheat
Second layer	:	Prevent cell to cell propagation in case of cell overheat
Third layer	:	Prevent fire, etc. in case of cell to cell propagation

f) Examination of both the inside and outside of the battery enclosure and both the inside and outside of the battery box showed no evidence of external short circuits, such as electrical cable damage, indication of arcing or mechanical damage. Therefore, it is believed that cell 5 was overheated due to an internal short circuit. Among the six (6) positive current collectors of cell 5, two collectors near cell 6 were melted. It is assumed that the winding in cell 5 near cell 6 had an internal short circuit and discharged completely, then the current flow from the other two (2) windings connected in parallel caused two current collectors to fuse (melt) to an open circuit state.

g) Scientific literature currently states that metallic particle contaminants and dendrites of metallic lithium could be possible causes of internal short circuits. Therefore, cells were disassembled for inspections, and metallic particles and a small white/gray deposit which was possibly metallic lithium were observed in several cells, except for cell 5.

The material of the metallic particles was either steel, copper or aluminum. Since those particles were same material of parts which comprise cell, the metallic particles could possibly be caused by disassembly process. However, it was not decided when those particles were contained.

Also, various materials other than aforementioned materials were observed. However, all those materials were very small.

Taking into account that those cells were operating normally, no evidence was found that observed metallic particles could directly cause an internal short circuit.

It is extremely difficult to perform analysis for detecting metallic lithium. During the analysis of this event, small white/gray deposit which was possibly metallic lithium was observed. However, it was not confirmed in certain as metallic lithium. Also, possibly metallic lithium that was observed was only in a small amount and the probability that it could have caused an internal short circuit is considered to be extremely low.

h) Regarding the wrinkles observed on anodes, it is said that wrinkles result in uneven distances between the anode and cathode and may facilitate the formation of lithium dendrites. However, only a small amount of possibly lithium metal was detected during the assessment of the cells from this event. Thus, no evidence was found that wrinkles could directly cause an internal short circuit.

i) Regarding uneven levels of electrolyte between cells, it was confirmed that levels of electrolyte vary even for cells in normal batteries since cells were slightly swollen during operations. Also, a leakage test by helium gas demonstrated that all cells met the original criteria for leakage required at manufacturing. Thus, no sign of leakage was confirmed.

j) Regarding the presence of water droplets that were observed at the time of the battery opening at Narita, the chemical analysis indicates that it is water (pH7). The timing when the water droplets were contained was undetermined. However, after the cell venting, high temperature moisture could possibly become condensation with the lapse of time.

k) Since all events including Boston, Takamatsu and this event occurred in the midst of cold January, the mechanism that low temperature environment causes the internal short circuit was considered. However, it was not be able to be identified.

6. Conclusion

a) Detailed tests of electrical characteristics and DPA were performed on several cells, except for the overheated/damaged cell 5. These tests revealed that all other cells were functionally operative and could provide the required voltage for continued flight although some thermal effects were observed on cell 6, which is in the vicinity of the overheated cell. Therefore, it was confirmed that improvements incorporated following the events last year were able to effectively prevent cell to cell propagation of overheat and damage to the overall battery.

b) Metallic contaminants, lithium deposits, leakage of electrolyte from cells and wrinkles in cell windings were examined as possible factors for cell overheat as mentioned in paragraphs 4 and 5. However, there was no objective finding proving that those factors caused overheat under the environment of this event. Thus, no conclusive evidence was identified that could isolate the cause of the overheat of cell 5.

7. Follow-on action

a) The assessment regarding the Narita battery event revealed that the second and third layers among the 3 layer protection functioned properly, and capability for safe flight of the 787 aircraft was maintained. It was confirmed that improvements incorporated following the events last year were able to effectively prevent cell to cell propagation of overheat and damage to the overall battery, and to secure the safety of whole aircraft.

b) However, considering the fact that one cell was overheated/damaged during this event following the Boston and Takamatsu events, it is considered that, for keeping peace of mind for the passengers and the public people on the safety of B787 fleet, further improvements of the reliability for cells and battery system are necessary.

Therefore, it is considered to be necessary that

① Boeing examines the potential causes pointed out in Boston and Takamatsu incident investigations and Narita event assessment further, accelerates the consideration for the design improvements, gets the certification early for the design changes which should be implemented, and provides the design changes early for airlines.

② Airlines adopt the design changes which will be prepared by Boeing and implement them as soon as possible.

c) To achieve aforementioned matters, JCAB will keep close cooperation with the FAA, Boeing, airlines and so forth.