Intermixing of Cells in Nickel-Cadmium Batteries for Aircraft Usage

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Background

- RTCA SC-211 committee addresses the design, performance, operational and testing issues for Ni-Cd, Lead Acid and rechargeable Lithium batteries

- Issues have been raised at RTCA SC-211 meetings regarding the intermixing of cells within Ni-Cd batteries used in aircraft

- It is typical practice to replace individual cells within the battery as they reach their end of life, and there are aftermarket PMA cells approved for direct replacement

- Manufacturers claim that this intermixing of cells from different producers results in a safety of flight issue in the form of reduced battery performance, increased maintenance, and an increase in thermal runaway potential

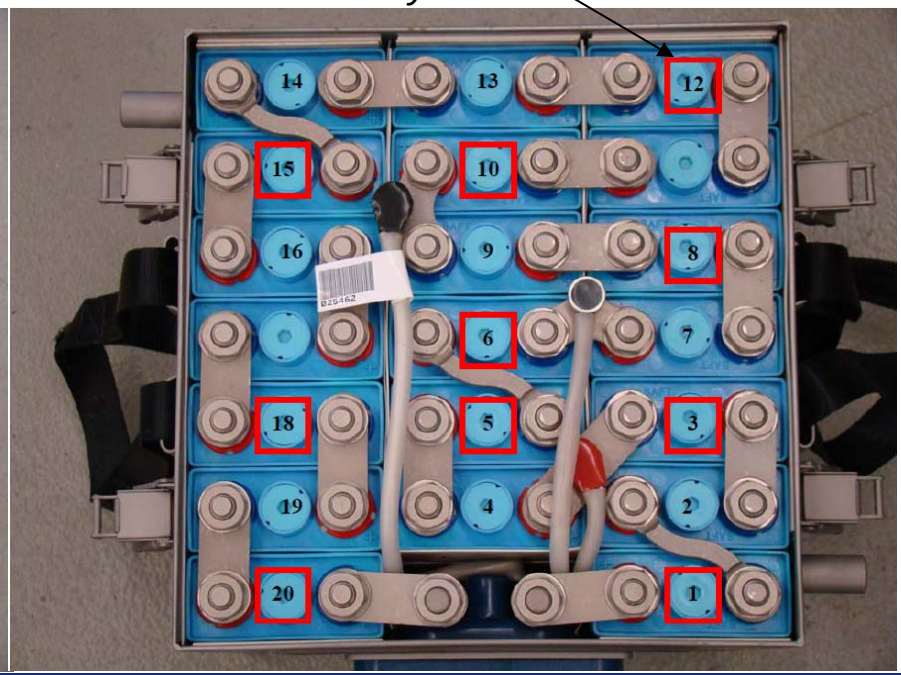
Background

- TSO C173 specifies the minimum performance standards for NiCd and Lead Acid batteries and states that they must adhere to the conditions specified in RTCA DO-293.
- DO-293 states:
  - “mixing of cells or batteries is not an acceptable practice”
  - “Cells or batteries may have differenct capacities because they have different designs, manufacturing processes or storage, use or age histories. Therefore, mixing cells or batteries with different part number, made by different manufacturers from different sources, is a non acceptable practice.”
- These statements are contradictory to the FAA’s PMA process, thus adding confusion to the issue.
- The Tech Center set out to run some testing to determine if the intermixing of cells does in fact create a safety of flight issue.

Test Equipment

- Two Saft 4078-7 batteries utilized (20 cell, 24 V, 43 Ah)
  - One kept in original form – all OEM cells
  - One with half OEM cells and half PMA approved replacement cells.

PMA cells denoted by red box



Test Equipment

- Arbin Instruments BT2000 battery analyzer utilized to conduct tests.
  - Voltage range of 0 – 50 V
  - Current range of 0 – 400 A
  - Ability to monitor and record voltage data from each individual cell (0 – 10 V range)
  - Temperature measurement through externally connected K-type thermocouples
  - Charging cables were fed into the FAA's environmental chamber for the high/low temperature tests.

Test Procedures

- Both batteries initially serviced as though they were being commissioned for service on board an aircraft including:
  - Visual inspection of the battery case and cells for signs of damage
  - Removal of the battery cover for internal inspection of cells and verification of correct cell polarity
  - Inspection of cell vents
  - Check of cell to case insulation
  - Check of torque on all hardware
  - Inspection of temperature sensor blanket for signs of wear
  - Check of cannon plug pins
  - Inspection of condition of connector
  - Charging per instructions in CMM
  - Electrolyte levels adjusted
  - Clean up of any spilled/bubbled electrolyte

Test Procedures

- A series of tests from RTCA/DO-293 were conducted on each of the batteries to evaluate battery performance:

1. Rated Capacity (DO-293, test #2.2.2)
2. Rated Capacity at -22ºF (DO-293, test #2.2.4)
3. Rated Capacity at 122ºF (DO-293, test #2.2.5)
4. Charge Stability (DO-293, test #2.6)
5. Duty Cycle Performance (DO-293, test #2.10)
6. Repeat Rated Capacity (DO-293, test #2.2.2)
7. Induced Destructive Overcharge(DO-293, test #2.14)

Test Procedures – Rated Capacity Tests

- **Objective:**

  Designed to determine the minimum capacity obtained from a charged battery when discharged at a 1C rate to its End Point Voltage (EPV).

- **Method:**

  1. Full charge cycle.
  2. Open circuit for 20 - 24 hours
  3. Discharge at the 1C rate to EPV

- **Criteria:**

  - Battery must deliver a capacity of not less than 100% its rated capacity for a period of 1 hour prior to reaching it EPV.

Test Procedures – Charge Stability Test

- **Objective:**

  Designed to establish acceptability of the separator system during high temperature constant potential charging.
- **Method:**
  1. Full charge cycle
  2. Placed in environmental chamber at 122ºF
  3. Open circuit for 20 – 24 hours
  4. Discharge at 6C rate for 5 minutes while in chamber
  5. Charge at 28.5 V for 10 hours
  6. Open circuit for 1 hour
  7. Discharge at 1C rate to EPV
  8. Open Circuit at ambient conditions for 24 hours
  9. Rated capacity test at ambient conditions
- **Criteria:**
  - Temperature of center section shall not exceed 158ºF (70ºC)
  - Battery should deliver at least 75% full capacity during the 1C rate discharge (step 7)
  - Battery should meet the rated capacity test requirements at the end of the test.

Test Procedures – Duty Cycle Performance Test

- **Objective:**

  Designed to simulate engine starts and charge cycling to determine the ability of the battery to perform as intended without maintenance over a period of 100 duty cycles.

- **Method:**

  1. Full charge cycle
  2. Discharge through a fixed resistor of 0.0195Ω for 20 s.
  3. Open Circuit for 2 minutes, followed by another discharge through the fixed resistor for 20s.
  4. Charge at 28.5V for 1 hour, followed by an open circuit period of 1 hour
  5. Repeat steps 2-4 50 times
  6. Discharge at the 1C rate to its EPV
  7. Full charge cycle, discharge at 1C rate to its EPV, and another full charge cycle.
  8. Repeat steps 2-7, to give a total of 100 duty cycles.

Test Procedures – Duty Cycle Performance Test (cont.)

- **Criteria:**
  - Minimum voltage during discharge through the resistor should be no less than 13 V
  - Temperature should not exceed 140ºF (60ºC)
  - The current during the CV charge should reduce to and remain below 8.6 A
  - The duration of the discharge during step 6 should be no less than 48 min (80% of capacity)
  - The final charge cycle should yield a discharge duration of no less than 54 min (90% of capacity)
  - Dimension distortion remains within specified limits of the battery.
  - No cracking of case or covers of either cells or the battery

Test Procedures – Induced Destructive Overcharge Test

- **Objective:**

  Designed to examine the safety of the battery by simulating conditions that could occur if one or more of the cells were to short and the charger failed to shut off.

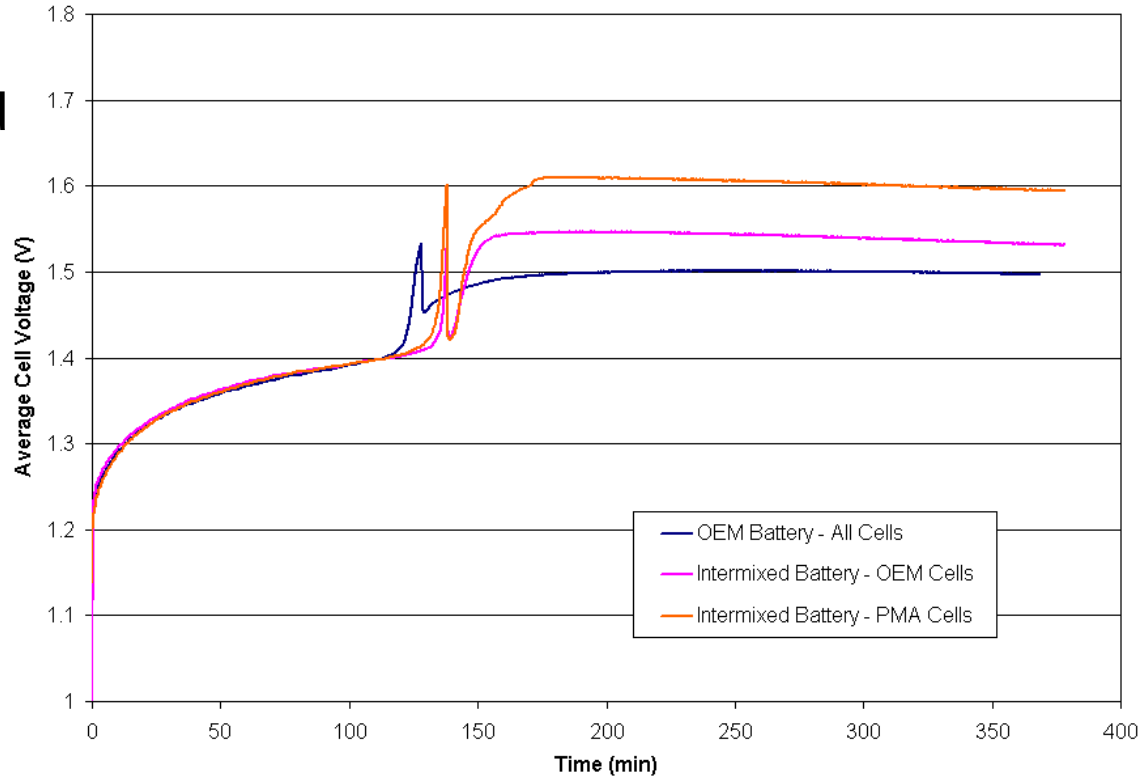
- **Method:**
  1. Full charge cycle
  2. Constant voltage charge at 1.8 V/cell (36 V)
  3. Continue CV charge until the battery current stabilizes for a minimum of 1 hour.
  4. Open circuit for 3 hours.

- **Criteria:**
  - No evidence of flame from battery throughout test
  - Battery case must contain any debris resulting from any explosion during test.

Results – Initial Rated Capacity Test

- Both batteries successfully passed test (minimum capacity of 43.0 Ah):
  - OEM battery had a capacity of 44.7 Ah
  - Intermixed battery had a capacity of 45.7 Ah

- Cells from the Intermixed battery exhibited a higher charging voltage, however never exceeded the maximum cell voltage of 1.7 V.



Results - Rated Capacity at -22ºF

- Both batteries exhibited diminished capabilities from those observed at ambient:
  - OEM battery had a capacity of 29.3 Ah
  - Intermixed battery had a capacity of 22.0 Ah

  - OEM battery was able to discharge at the 1C rate for a period of 41 minutes
  - Intermixed battery was able to discharge at the 1C rate for a period of 31 minutes.

- This data is in contrast to the minimum 43 Ah, and 60 minute discharge period specified by the test requirements.

Results - Rated Capacity at 122ºF

- Both batteries exhibited slightly increased capacities from those observed at ambient:
  - OEM battery had a capacity of 45.0 Ah
  - Intermixed battery had a capacity of 46.3 Ah

  - OEM battery was able to discharge at the 1C rate for a period of 67 minutes
  - Intermixed battery was able to discharge at the 1C rate for a period of 65 minutes.

Results – Charge Stability

- During the 6C discharge, both batteries behaved similarly, with both exceeding the temperature limitations of the test:

	Capacity	Battery Temperature
OEM Battery	44.8 Ah	170ºF
Intermixed Battery	44.1 Ah	169ºF

- The subsequent rated capacity resulted in similar results between the batteries as well:
  - OEM battery capacity – 45.3 Ah
  - Intermixed battery capacity – 46.9 Ah

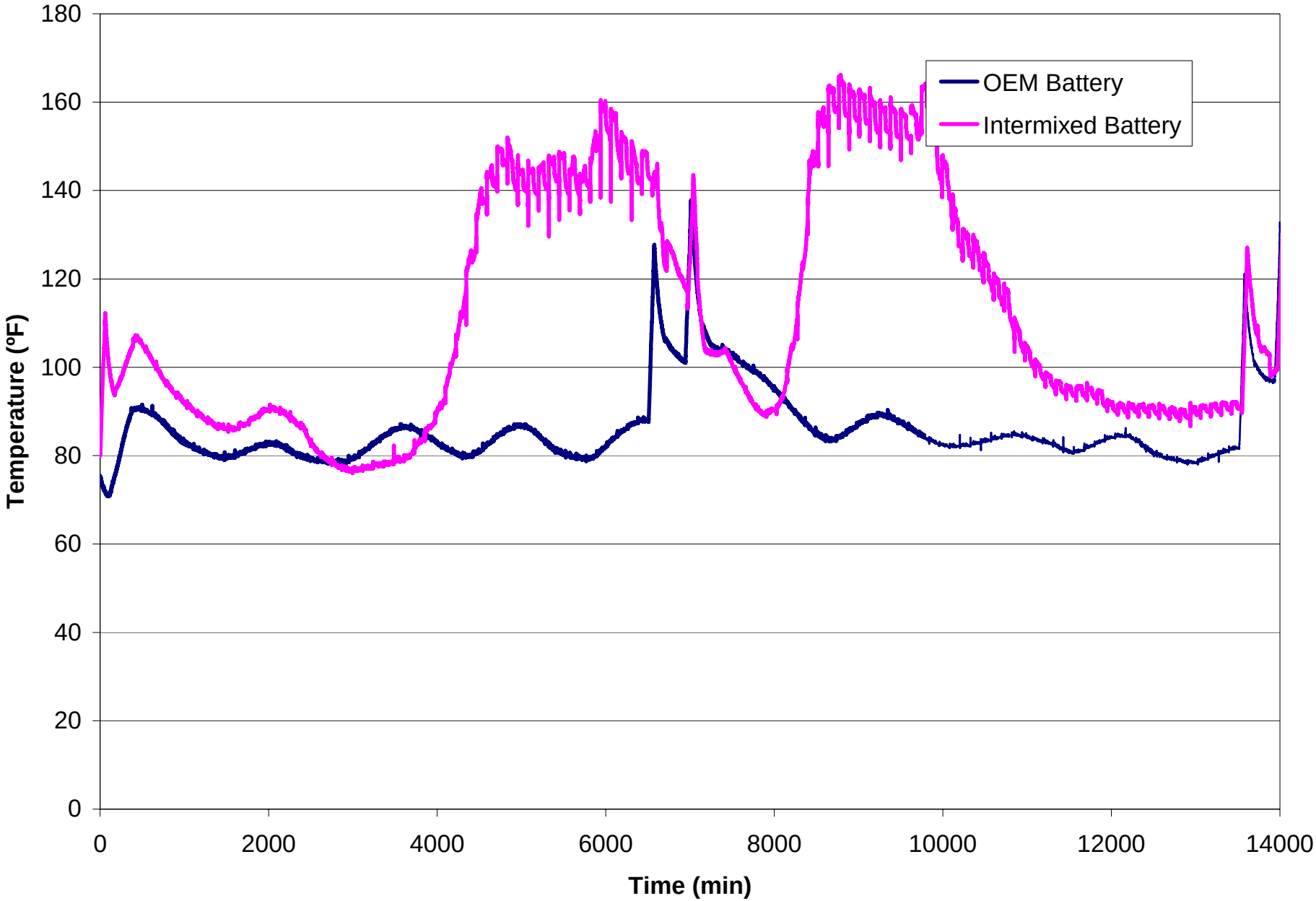
Results – Duty Cycle Performance

- The duty cycle test results in four discharge capacities being reported during test, none of which were below the required 80% of full capacity:

	Capacity 1	Capacity 2	Capacity 3	Capacity 4
OEM Battery	47.1 Ah	47.4 Ah	43.4 Ah	46.1 Ah
Intermixed Battery	42.1 Ah	49.0 Ah	43.1 Ah	48.9 Ah

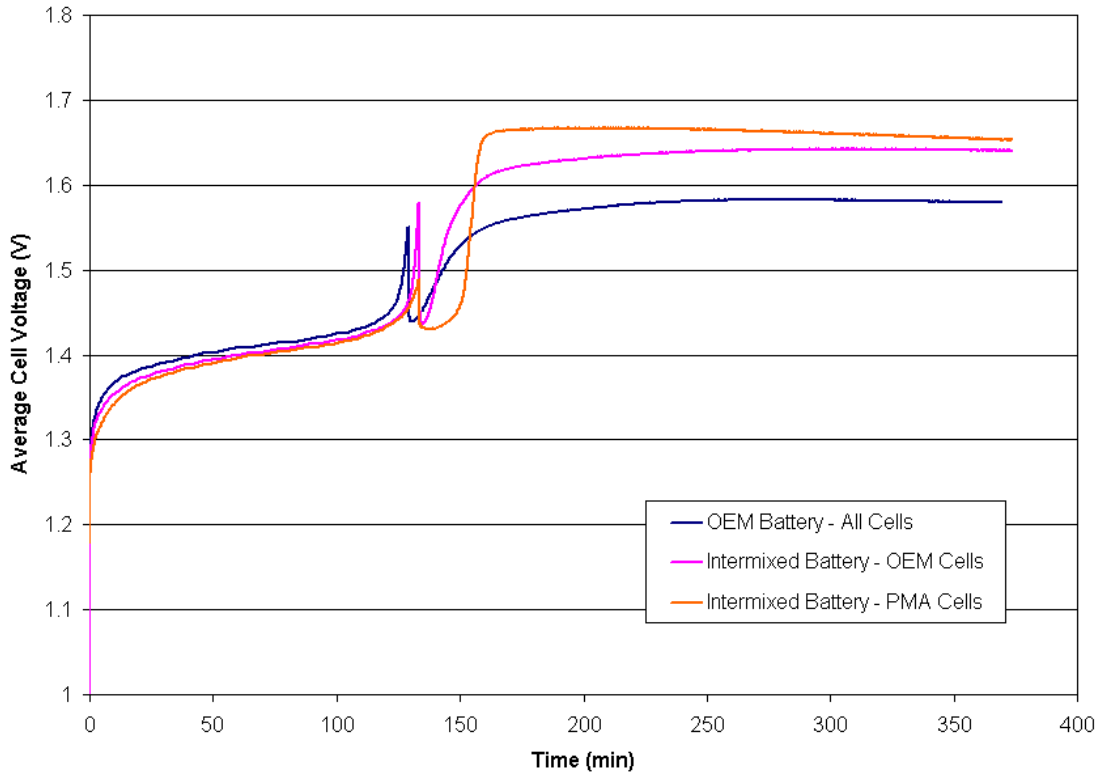
- Battery temperature varied significantly with the Intermixed battery exceeding the requirement of 140ºF

Results – Duty Cycle Performance



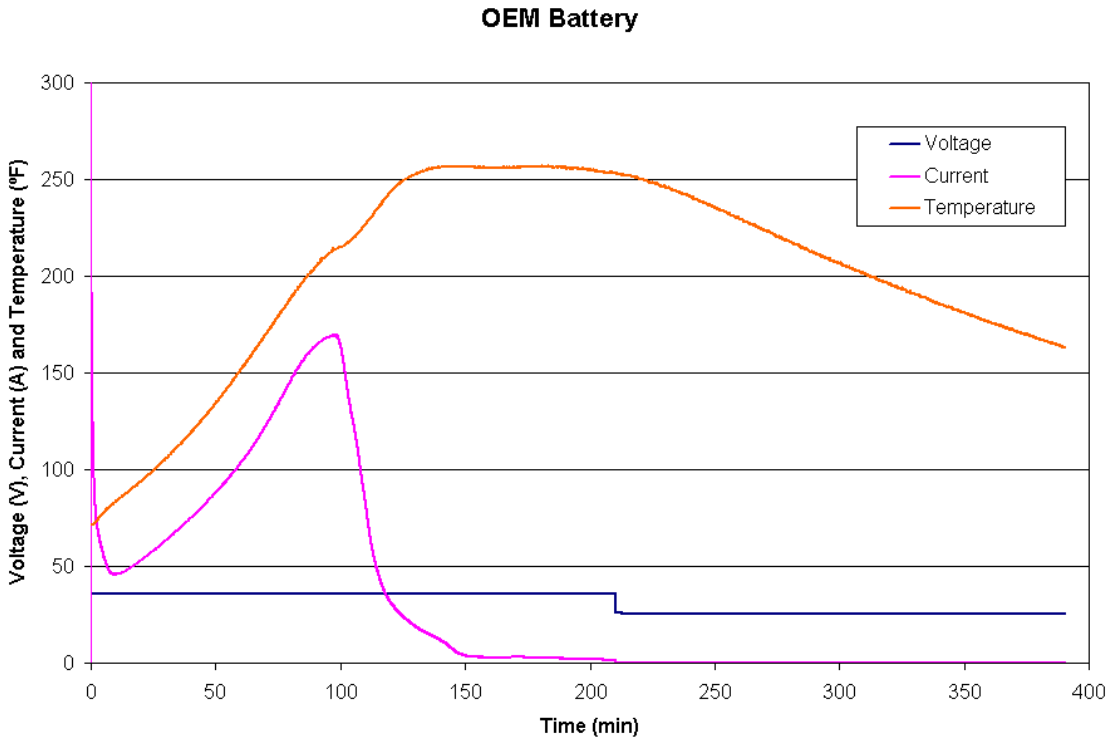
Results – Repeated Rated Capacity Test

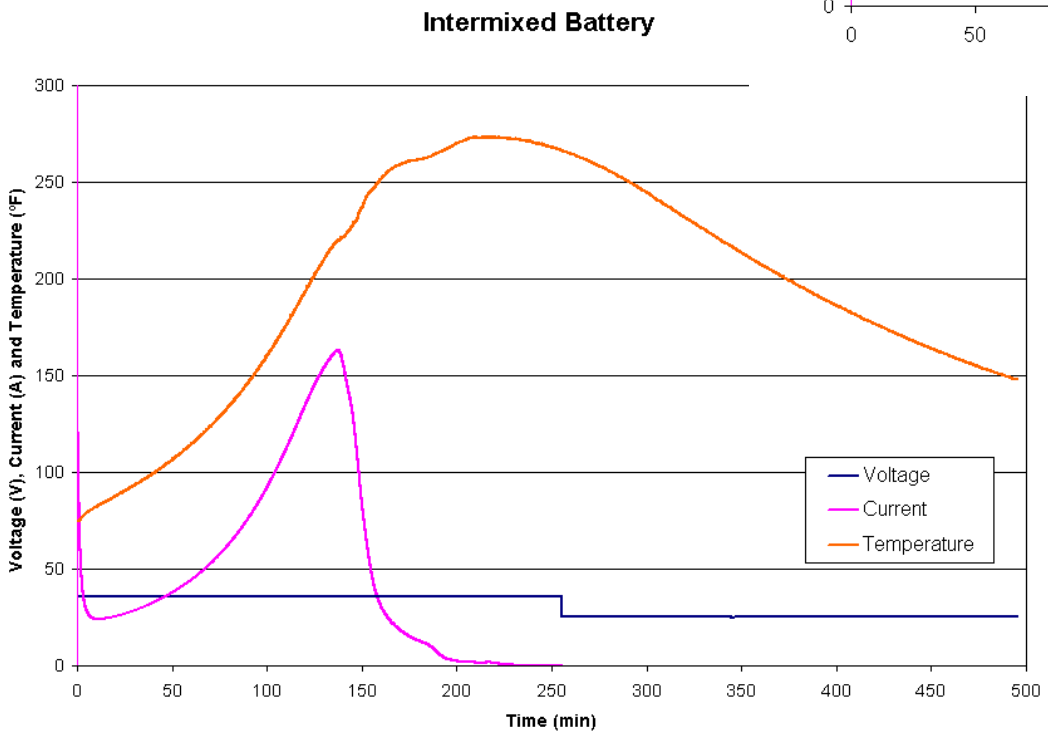
- Both batteries successfully passed test (minimum capacity of 43.0 Ah):
  - OEM battery had a capacity of 45.3 Ah
  - Intermixed battery had a capacity of 48.2 Ah
- As with the initial rated capacity test, cells from the Intermixed battery exhibited a higher charging voltage, however never exceeded the maximum cell voltage of 1.7 V.
- Charging voltage of all cells was higher than during the initial rated capacity test



Results – Induced Destructive Overcharge

- Overall, both batteries behaved very similarly
- No flames or explosion from either battery



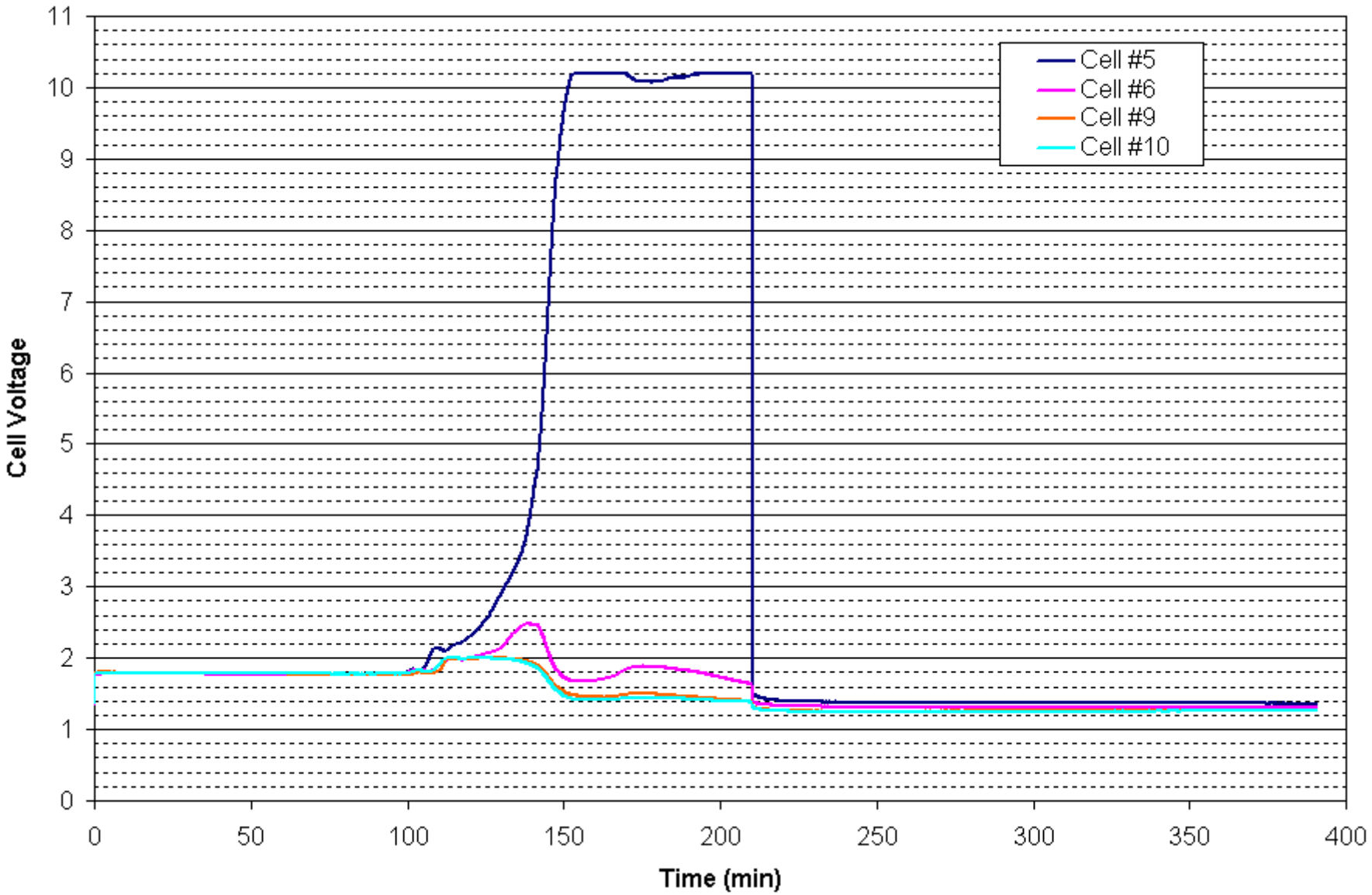


- Smoke was observed emanating from both batteries as the electrolyte evaporated due to the extreme temperatures

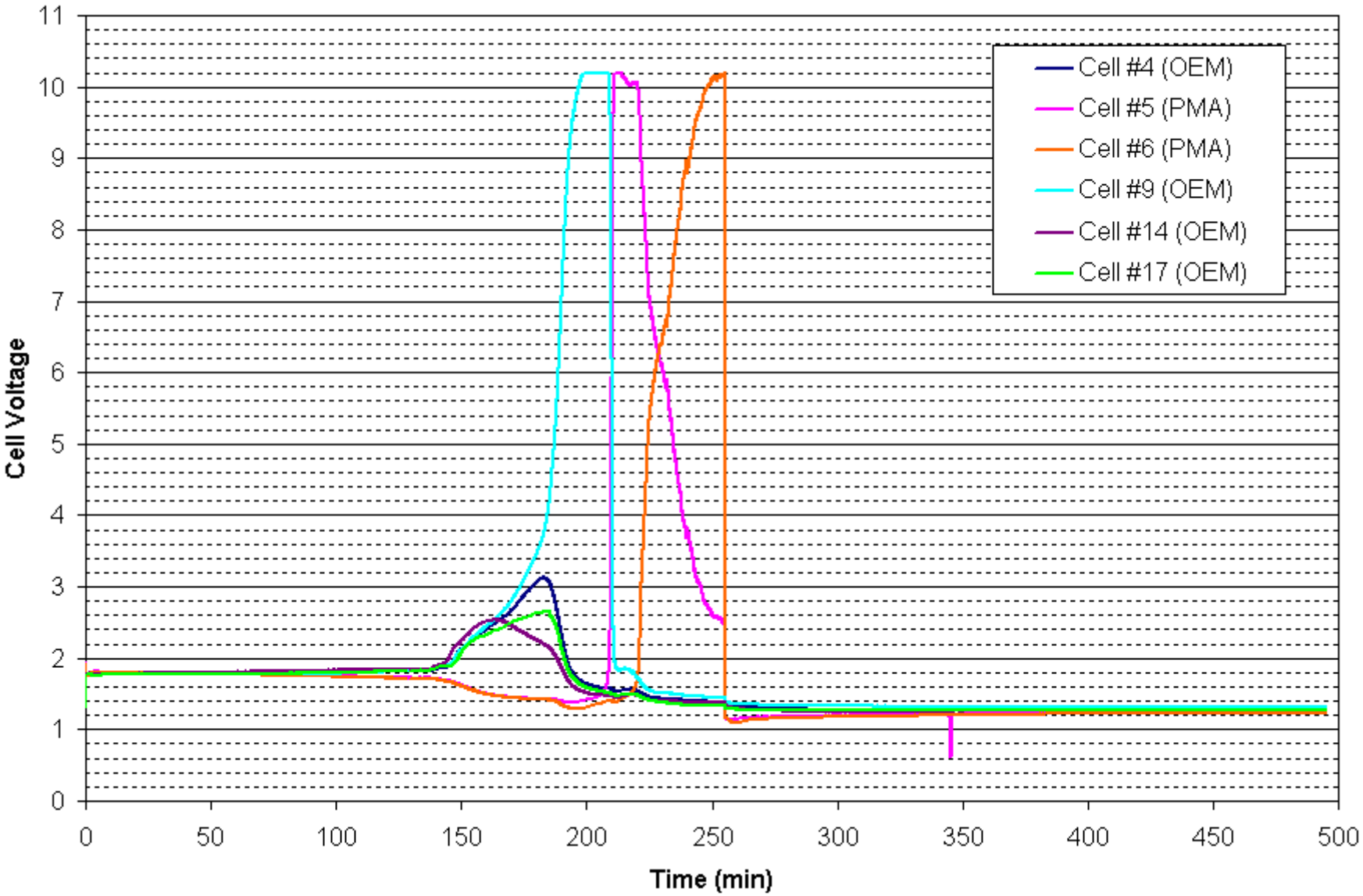
Results – Induced Destructive Overcharge (cont.)

- While overall performance of batteries was similar, individual cells behaved quite differently.
  - OEM battery contained 4 cells that exceeded 2.0 V during the test
    - Of these, 1 of them exceeded 10 V, indicating thermal runaway conditions.
  - Intermixed battery contained 6 cells that exceeded 2.0 V during the test
    - 4 OEM cells and 2 PMA cells
    - The 2 PMA cells both exceeded 10 V
    - Of the 4 OEM cells, 1 exceeded 10 V

Results – Induced Destructive Overcharge (OEM Battery)



Results – Induced Destructive Overcharge (Intermixed Battery)



Summary

	Initial Rated Capacity	Rated Capacity @-22°F	Rated Capacity @122°F	Charge Stability	Duty Cycle	Repeated Rated Capacity	Induced Destructive Overcharge
OEM	44.7 Ah	29.3 Ah	45.0 Ah	44.8 Ah 45.3 Ah 170°F	max temp 138°F 1st discharge=66 min, 47.1 Ah 2nd discharge=66.15 min, 47.4 Ah 3rd discharge =60.5 min, 43.4 Ah 4th discharge =64.3 min, 46.1 Ah	45.3 Ah	No flame or explosion 4 Cells exceeded 2 V 1 Cell exceeded 10 V
PMA	45.7 Ah	22.0 Ah	46.3 Ah	44.1 Ah 46.9 Ah 169°F	max temp 169°F 1st discharge=58.8 min, 42.1 Ah 2nd discharge=68.4 min, 49.0 Ah 3rd discharge=60.1min, 43.1 Ah 4th discharge=68.3min, 48.9 Ah	48.2 Ah	No flame or explosion 4 OEM Cells exceeded 2 V 1 OEM Cell exceeded 10 V 2 PMA Cells exceeded 10 V

Summary

- PMA Cells consistently charged at a higher voltage than OEM cells, but never exceeded the maximum cell voltage of 1.7 V.
- Minor differences were observed between the OEM battery and Intermixed battery.
- Nothing from the testing conducted indicates a safety of flight issue caused by intermixing battery cells of different manufacturers.
- Draft report is currently undergoing internal review process and will be published shortly. Once published it will be available at:

http://www.fire.tc.faa.gov