Full Scale Battery Fire Test Plan Update

Presented to: Systems Working Group
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Full Scale Battery Tests

• **Purpose:** To document the characteristics of large battery fires in a realistic aircraft environment.

• **Test article:** FAA Fire Safety 727 freighter
  – Class C compartment with Halon 1301 suppression
  – Class E main deck compartment, no suppression
    • Fire hardened with cargo liner material
  – Fully operational air-packs
  – Extinguishment system: CO2 and water spray
FAA Fire Safety 727
Full Scale Battery Tests

• Fire load:
  – 5000 cells in original fiberboard packing
  – Adjacent flammable materials: 18”x18”x18” cardboard boxes with shredded paper

• Cell types:
  – Lithium-ion, type 18650
  – Lithium metal, type 123
  – Mixed (AA size)
    • Nickel Cadmium
    • Nickel metal hydride
    • Alkaline
Full Scale Battery Tests

• Test locations
  – Forward Class C compartment
  – Main deck Class E compartment

• Ignition sources
  – Nichrome wire in adjacent box with shredded paper.
    • Simulate fire from external source
  – Cartridge heater replacing a single cell
    • Simulate a cell in thermal runaway
Full Scale Battery Tests
Full Scale Battery Tests

• **Measure:**
  – Propagation of thermal runaway within the battery shipment
  – Spread of fire to adjacent combustibles
  – Smoke density
  – Smoke penetration into the cabin and cockpit
  – Temperatures
  – Pressure

• **Compare:** Baseline (no cells), cell chemistries, ignition sources
Full Scale Battery Tests

• Considerations
  – Compartment loading
    • Full compartment will increase smoke density
  – Containerized or palletized cargo
  – Aircraft emergency procedures
    • Air-pack setting
  – Test article limitations
    • Temperature limits
    • Pressure limits
Full Scale Battery Test Matrix

• Cargo compartment location
  – Test 1. Baseline (no cells)
  – Test 2. 5000 mixed NiCad, NiMH, Alkaline, cartridge heater
  – Test 3. 5000 mixed, adjacent fire
  – Test 4. 5000 lithium-ion, cartridge heater
  – Test 5. 5000 lithium-ion, adjacent fire
  – Test 6. 5000 lithium metal, cartridge heater
  – Test 7. 5000 lithium metal, adjacent fire
Full Scale Battery Test Matrix

• Main deck location
  – Test 8. Baseline (no cells)
  – Test 9. 5000 mixed, cartridge heater
  – Test 10. 5000 mixed, adjacent fire
  – Test 11. 5000 lithium-ion, cartridge heater
  – Test 12. 5000 lithium-ion, adjacent fire
  – Test 13. 5000 lithium metal, cartridge heater
  – Test 14. 5000 lithium metal, adjacent fire.
5000 Cell Battery Fire Characterization

Purpose

• To determine the severity of a large lithium-ion and lithium metal battery fire

• Outdoor Location

• Determine
  – Peak temperatures
  – Duration
  – Controllability
    • Water
5000 Cell Lithium-ion Fire

- 18650 lithium-ion cells
- 50 100 cell boxes
- 100 watt cartridge heater replaced one cell in box #3
- Thermocouples used to monitor propagation of thermal runaway
- Exterior thermocouples to measure fire severity
5000 Cell Lithium-ion Fire
5000 Cell Lithium-ion Fire
5000 Cell Lithium-ion Fire
5000 Cell Lithium-ion Fire
5000 Cell Lithium-ion Fire

Results:

• Propagation
  – Much like the smaller scale tests the propagation of thermal runaway progressed from cell to adjacent cell
  – Cell explosions, rocketing- flaming cells up to 133’

• Peak temperature
  – 1400 DegF, 4” above the top box
  – 1668 DegF, inside battery stack

• Test duration: 1:05
4800 Lithium Metal Cells

- 123A lithium metal cells
- 12- 400 cell boxes
- 100 watt cartridge heater replaced one cell in box #2
- Thermocouples used to monitor propagation of thermal runaway
- Exterior thermocouples to measure fire severity
4800 Lithium Metal Cells
4800 Lithium Metal Cells
4800 Lithium Metal Cells
4800 Lithium Metal Cells

Results

• Propagation
  – Similar to small scale, rapid escalation, fully involved
  – Minimal rocketing, some explosions, cells fused together

• Peak temperatures
  – 1933 DegF, 4” above battery stack
  – 2009 DegF, in the battery stack

• Test duration: 17 minutes
Test 1&2 Video
Water Extinguisher Test

• A deluge water extinguisher was designed to protect the aircraft
• Four nozzles rated at 15 gpm @ 60 psi
• Concern about the effectiveness against a lithium metal battery fire.
• Test was conducted with 400 123A lithium metal cells
• Test was initiated with a cartridge heater and allowed to buildup to full intensity
Water Extinguisher Test

• Results
  – The water was effective in knocking down the large fire
  – Cells continued to go into thermal runaway and vent flames and molten lithium for approximately 20 seconds
  – Temperature were reduced to 65 DegF after several minutes of water application
  – After water shut off, several thermocouples showed a temperature rise, necessitating a second water application.
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