Lithium Battery Update

Full Scale Tests

Class E: lithium-ion, Lithium metal, mixed Alkaline, NiCad, NiMH

Presented to: Systems Working Group
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Date: May 22-23, 2013
Full Scale Fire Tests
Objective

- To document the characteristics of large battery fires in a realistic aircraft environment.
- No Suppression-Class E
- With Suppression-Class C
Full Scale Fire Test Plan

- **Baseline**
- **Class E Cargo**
  - Lithium-ion 5000 18650 cells
  - Lithium metal 4800 SF123A Cells
  - 5000 mixed alkaline, NiCad, NiMH
Full Scale Fire Test Plan

• Class C Cargo w/ Halon 1301 Suppression
  – Lithium-ion 5000 18650 cells
  – Lithium-metal 4800 SF123A cells
  – 5000 mixed alkaline, NiCad, NiMH
Instrumented 727 Test Article
Instrumentation: Class E

- Two trees
  - Thermocouples
  - Calorimeter
  - Smoke meter
  - Gas measurement – CO, CO2, O2
  - Compartment pressure

- Ceiling T/C’s
  - 6” below cargo liner
  - Above cargo liner

- Video
  - cameras, infrared
Instrumentation: Flight Deck

- Instrumentation tree
  - Thermocouples
  - Smoke density meter
  - Gas measurement
  - Pressure

- Video
  - Overall
    - Looking aft
    - Looking forward
  - Smoke detector panel
Instrumentation: Class C

- Instrumentation tree
  - Thermocouples
  - Calorimeter
  - Smoke density
  - Gas measurement
  - Compartment pressure

- Ceiling T/C’s above and below the cargo liner
Instrumentation: Battery Stack

- Distributed thermocouples
  - Track progress of thermal runaway
- Cartridge heater, igniter box thermocouple
- Calorimeter
  - Above center of fire load
Aircraft Ventilation

- Airflow patterns within the aircraft can have significant impact on the behavior of the battery fire and smoke penetration.
- The aircraft air packs are configured differently depending on the location of the fire.
- Two configurations were developed with input from the Boeing Company, one for the main deck class E fire and one for the forward class C compartment.
Conducted Air Exchange Tests
Air Exchange Rate Results

• **Pressurized configuration**
  – Main deck cabin: 5.75 minutes per air change
  – Flight deck: 1.68 minutes per air change

• **Unpressurized configuration**
  – Main deck cabin: 47.72 minutes per air change
  – Flight deck: 1.71 minutes per air change
Conducted Baseline Test
Class E Tests
5000 Lithium-ion, cartridge heater

- 18650 cells, 50% charge
- 2 boxes of 100 cells per carton
- 50 cartons
- Cartridge heater in bottom carton
5000 Lithium-ion (CH) Results

- Test terminated at 57 minutes with water
- Cells consumed: 2792
- Peak ceiling temp: 1490 DegF@ 49 min
- Peak battery stack temp: 1300 DegF@ 55 min.
5000 Lithium-ion (CH) Results

- **Cabin gas data:**
  - Minimum $O_2$: 8.3% @ 51 min
  - Peak $CO_2$: 10% @ 51 min
  - Peak CO: 1.9% @ 51 min
5000 Lithium-ion (CH) Results

- Peak Heat Flux above the battery stack: 14 Btu/ft$^2$-sec @ 58 minutes
- Peak heat flux at the forward instrument tree: 6 Btu/ft$^2$-sec @57 minutes
5000 Lithium-ion (CH) Results

- Cabin air peak temperature, forward instrument tree:
  - 60” 625 DegF
  - 36” 430 DegF
  - 6” 190 DegF
5000 Lithium-ion (CH) Results

- Flight deck peak air temperatures (data loss at 51 min):
  - Ceiling: 85 DegF
  - Mid: 66 DegF
  - 6” above floor: 54 DegF
5000 Lithium-ion (CH) Results

- **Flight deck gas data:**
  - Minimum $\text{O}_2$: 18.3% @ 58 min
  - Peak $\text{CO}_2$: 1.9% @ 50 min
  - Peak CO: .5% @ 55 min
5000 Lithium-ion, external fire

- 18650 cells, 50% charge
- 2 boxes of 100 cells per carton
- 50 cartons
- Igniter box: shredded paper, rag soaked in heptane
5000 Lithium-ion (EF) Results

• Test terminated at 36 minutes with water
• Cells consumed: 3878
• Peak ceiling temp: 1250 DegF@ 29 min
• Peak battery stack temp: 1380 DegF@ 27 min.
5000 Lithium-ion (EF) Results

- **Cabin gas data:**
  - Minimum O₂: 8.8% @ 34 min
  - Peak CO₂: 10% @ 30 min
  - Peak CO: .5% @ 35 min
5000 Lithium-ion (EF) Results

- Peak Heat Flux above the battery stack: 9.09 Btu/ft\(^2\)-sec @ 40 minutes
- Peak heat flux at the forward instrument tree: 5.68 Btu/ft\(^2\)=sec @38 minutes
5000 Lithium-ion (EF) Results

• Cabin air peak temperature, forward instrument tree:
  • 60” 480 DegF
  • 36” 370 DegF
  • 6” 200 DegF
5000 Lithium-ion (EF) Results

- Flight deck peak air temperatures:
  - Ceiling: 112 DegF
  - Mid: 105 DegF
  - 6” above floor: 98 DegF
5000 Lithium-ion (EF) Results

- **Flight deck gas data:**
  - Minimum $\text{O}_2$: 19.9% @ 36 min
  - Peak $\text{CO}_2$: 0.36% @ 36 min
  - Peak CO: 0.42% @ 36 min
5000 Mixed Cells, External Fire

- 1666 AA size Alkaline cells
- 1666 AA size Nickel Cadmium cells*
- 1667 AA size Nickel Metal Hydride*
- Igniter box
- * unknown charge, as received
5000 Mixed Cells (EF) Results

- Test terminated at 102 minutes with water
- Cells damaged (no voltage:  
  - Alkaline: 318  
  - NiCad: 153  
  - NiMH: 139
- Peak ceiling temp: 119 DegF@ 40 min
- Peak battery stack temp: 975 DegF@ 44 min.
5000 Mixed Cells (EF) Results

- **Cabin gas data:**
  - Minimum $O_2$: 20.8% @ 100 min
  - Peak $CO_2$: .25% @ 101 min
  - Peak CO: .05% @ 100 min
5000 Mixed Cells (EF) Results

- Peak Heat Flux above the battery stack: 0.75 Btu/ft\(^2\)-sec @ 103 minutes
- Peak heat flux at the forward instrument tree: 0.6 Btu/ft\(^2\)-sec @ 116 minutes
5000 Mixed Cells (EF) Results

- Cabin air peak temperature, forward instrument tree:
  - 60” 67 DegF
  - 36” 58 DegF
  - 6” 56 DegF
5000 Mixed Cells (EF) Results

- Flight deck peak air temperatures:
  - Ceiling: 77 DegF
  - Mid: 68 DegF
  - 6” above floor: 60 DegF
5000 Mixed Cells (EF) Results

- **Flight deck gas data:**
  - Minimum O\(_2\): 21.6% @ 9 min
  - Peak CO\(_2\): .03% @ 24 min
  - Peak CO: .02% @ 49 min
4800 Lithium Metal, cartridge htr

- 123A cells, 100% charge
- 4 boxes of 200 cells per carton
- 6 cartons
- Cartridge heater in bottom box
4800 Lithium Metal (CH) Results

- Test terminated at 16 minutes with water
- Cells consumed: 2445
- Peak ceiling temp: 1700 DegF @ 16 min
- Peak battery stack temp: 2250 DegF @ 12 min.
4800 Lithium Metal (CH) Results

• Cabin gas data:
  – Minimum $O_2$: 8.1% @ 15.5 min
  – Peak $CO_2$: 10% @ 15.4 min
  – Peak CO: 1.56% @ 15.7 min
4800 Lithium Metal (CH) Results

- Cabin air peak temperature, aft instrument tree:
  - 60” 850 DegF
  - 36” 560 DegF
  - 6” 250 DegF
4800 Lithium Metal (CH) Results

- Flight deck peak air temperatures:
  - Ceiling: 73 DegF
  - Mid: 63 DegF
  - 6” above floor: 51 DegF
4800 Lithium Metal (CH) Results

- **Flight deck gas data:**
  - Minimum $O_2$: 16% @ 20 min
  - Peak $CO_2$: .65% @ 18 min
  - Peak CO: .4% @ 16 min
4800 Lithium Metal, external fire

• 123A cells, 100% charge
• 4 boxes of 200 cells per carton
• 6 cartons
• Igniter box: shredded paper, rag soaked in heptane
4800 Lithium Metal (EF) Results

- Test terminated at 18 minutes with water
- Cells consumed: TBD
- Peak ceiling temp: 1510 DegF@ 29 min
- Peak battery stack temp: 2300 DegF@ 27 min.
4800 Lithium Metal (EF) Results

- **Cabin gas data:**
  - Minimum $O_2$: 3.5% @ 18 min
  - Peak $CO_2$: 10% @ 16.9 min
  - Peak CO: 2% @ 17.3 min
4800 Lithium Metal (EF) Results

- Peak Heat Flux above the battery stack: 8.56 Btu/ft²-sec @ 15.5 minutes
- Peak heat flux at the forward instrument tree: 0.14 Btu/ft²-sec @15.5 minutes
4800 Lithium Metal (EF) Results

- Cabin air peak temperature, forward instrument tree:
  - 60” 885 DegF
  - 36” 620 DegF
  - 6” 250 DegF
4800 Lithium Metal (EF) Results

- Flight deck peak air temperatures:
- Ceiling: 86 DegF
- Mid: 79 DegF
- 6” above floor: 72 DegF
4800 Lithium Metal (EF) Results

- **Flight deck gas data:**
  - Minimum $O_2$: 17.5% @ 18.7 min
  - Peak $CO_2$: 2.4% @ 18.6 min
  - Peak CO: 0.6% @ 18 min
Class C Upcoming Tests

- Halon discharge concentration test
- Mixed cell external ignition test
- Lithium-ion external ignition and cartridge heater tests
- Lithium Metal external ignition and cartridge heater tests
Notes

• Smoke density and cabin pressure data are under review

• Time lapse video of 4800 lithium metal with cartridge heater test is in separate file
Contact Information

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