

Lithium Battery Update

Full Scale Tests

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

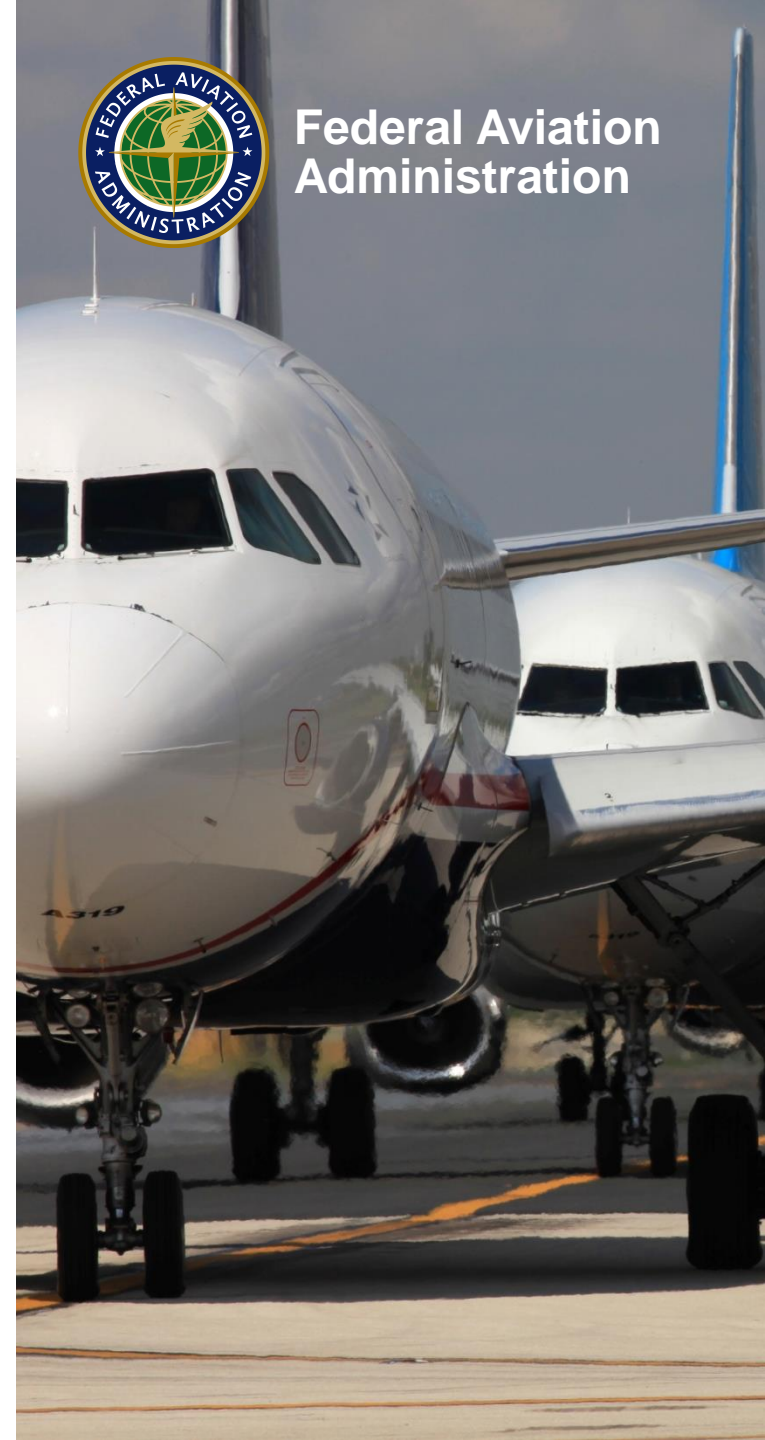
Presented to: Systems Working Group

By: Harry Webster, FAA

Date: May 22-23, 2013



Federal Aviation
Administration



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

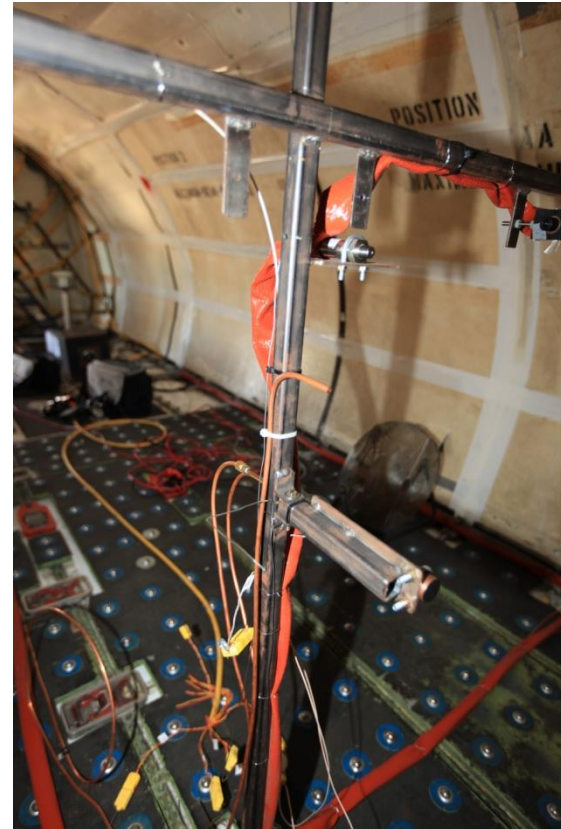


Instrumented 727 Test Article



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**



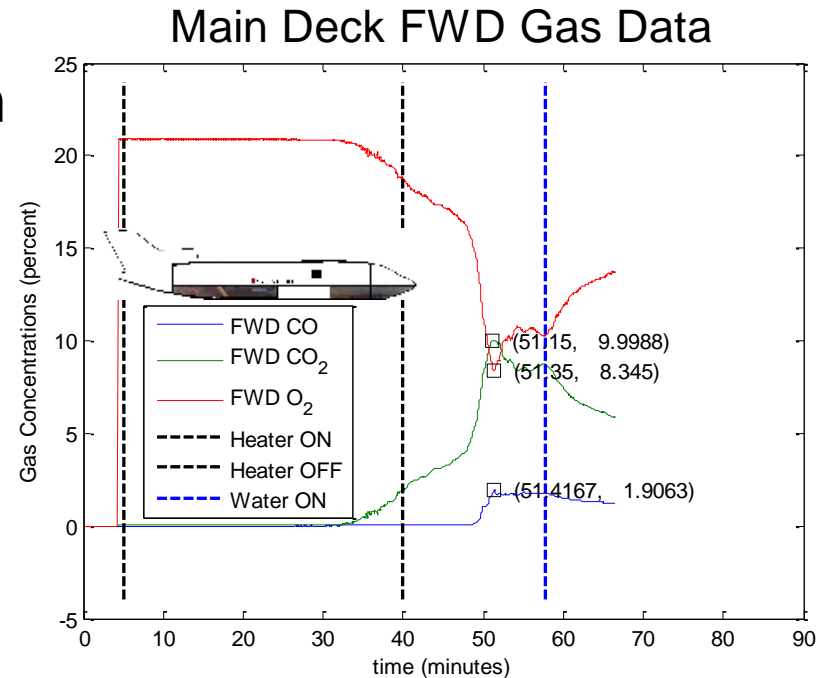
5000 Lithium-ion (CH) Results

- **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.**



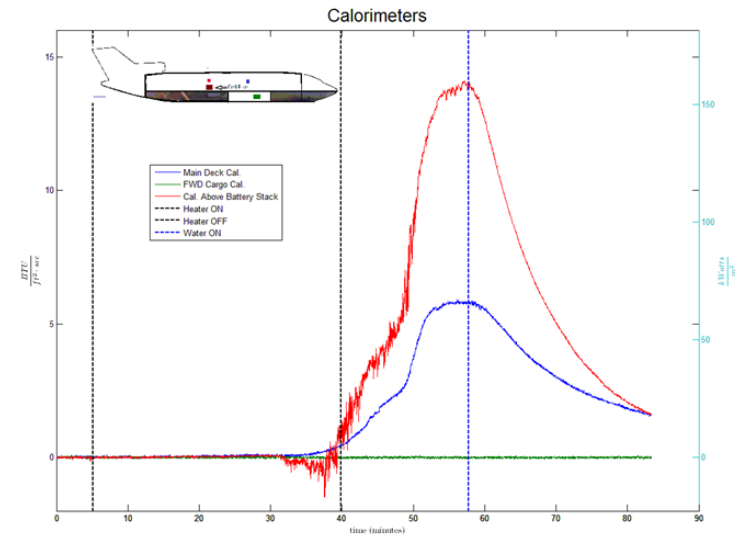
5000 Lithium-ion (CH) Results

- **Cabin gas data:**
 - Minimum O₂: 8.3% @ 51 min
 - Peak CO₂: 10% @ 51 min
 - Peak CO: 1.9% @ 51 min



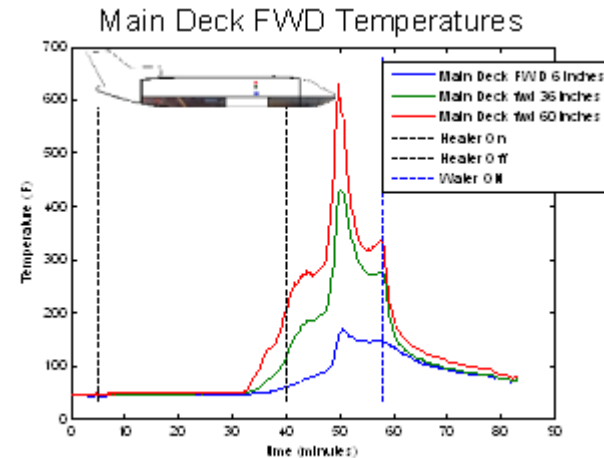
5000 Lithium-ion (CH) Results

- **Peak Heat Flux above the battery stack: 14 Btu/ft²-sec @ 58 minutes**
- **Peak heat flux at the forward instrument tree: 6 Btu/ft²=sec @57 minutes**



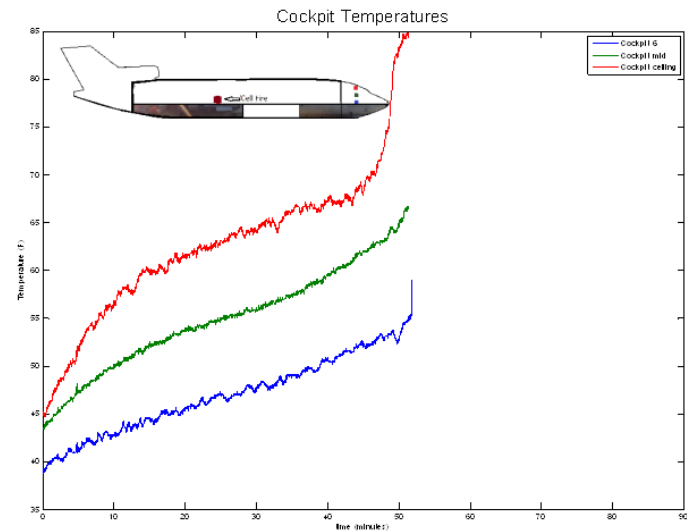
5000 Lithium-ion (CH) Results

- Cabin air peak temperature, forward instrument tree:
- 60" 625 DegF
- 36" 430 DegF
- 6" 190 DegF



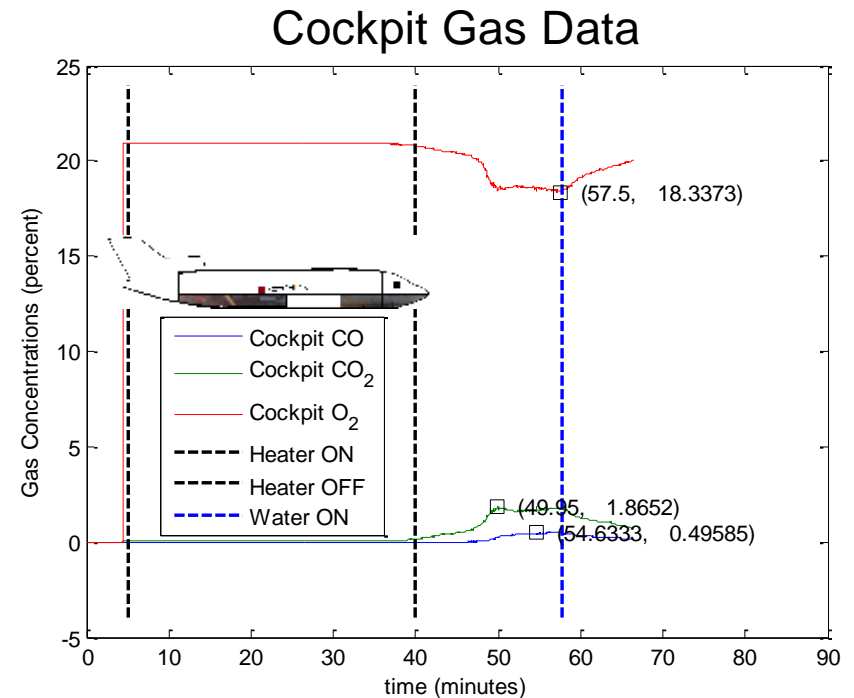
5000 Lithium-ion (CH) Results

- **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 O₂: 18.3% @ 58 min
 - Peak CO₂: 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



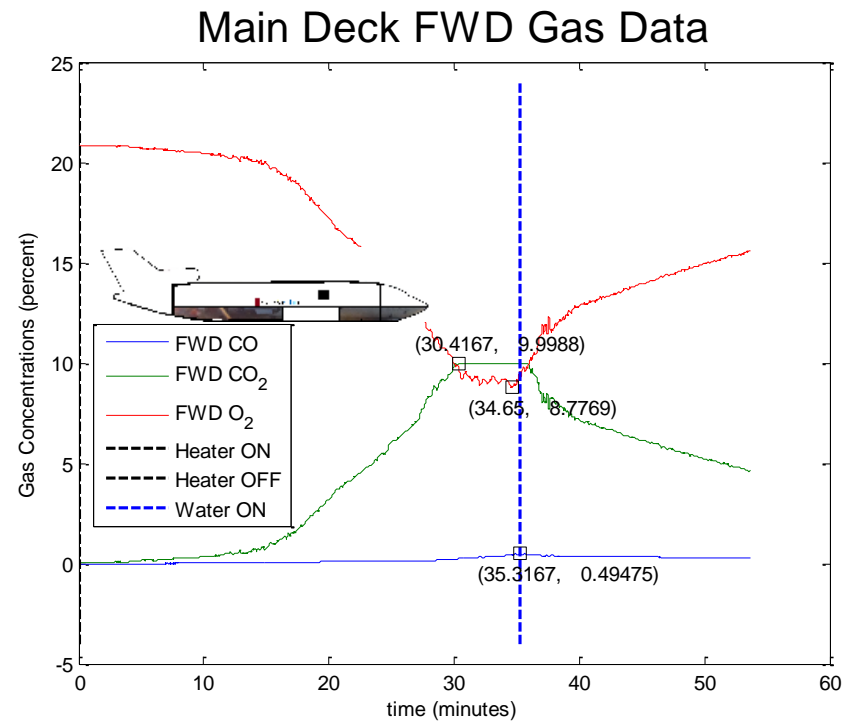
5000 Lithium-ion (EF) Results

- 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.



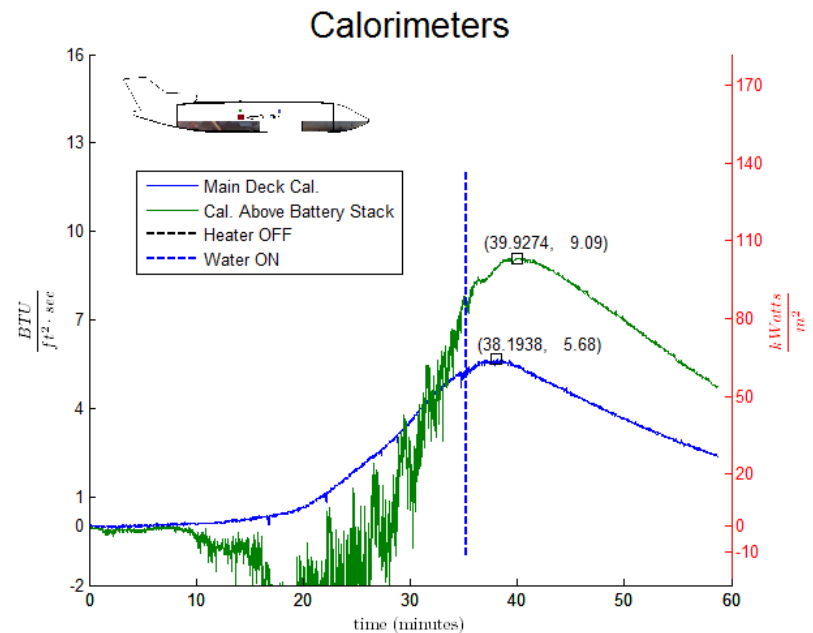
5000 Lithium-ion (EF) Results

- **Cabin gas data:**
 - Minimum O₂: 8.8% @ 34 min
 - Peak CO₂: 10% @ 30 min
 - Peak CO: .5% @ 35 min



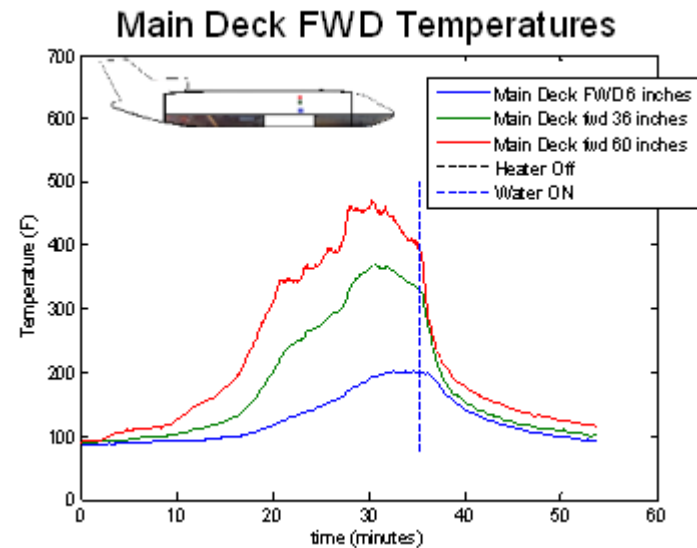
5000 Lithium-ion (EF) Results

- **Peak Heat Flux above the battery stack: 9.09 Btu/ft²-sec @ 40 minutes**
- **Peak heat flux at the forward instrument tree: 5.68 Btu/ft²=sec @38 minutes**



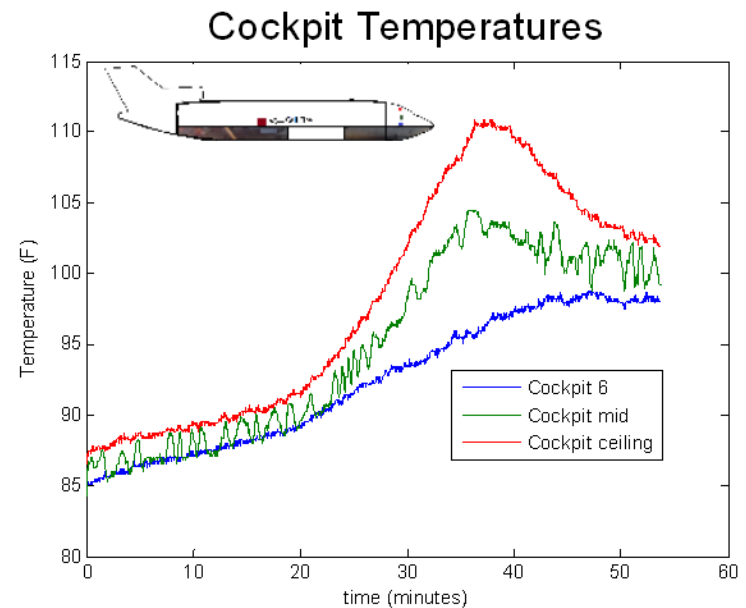
5000 Lithium-ion (EF) Results

- Cabin air peak temperature, forward instrument tree:
- 60" 480 DegF
- 36" 370 DegF
- 6" 200 DegF



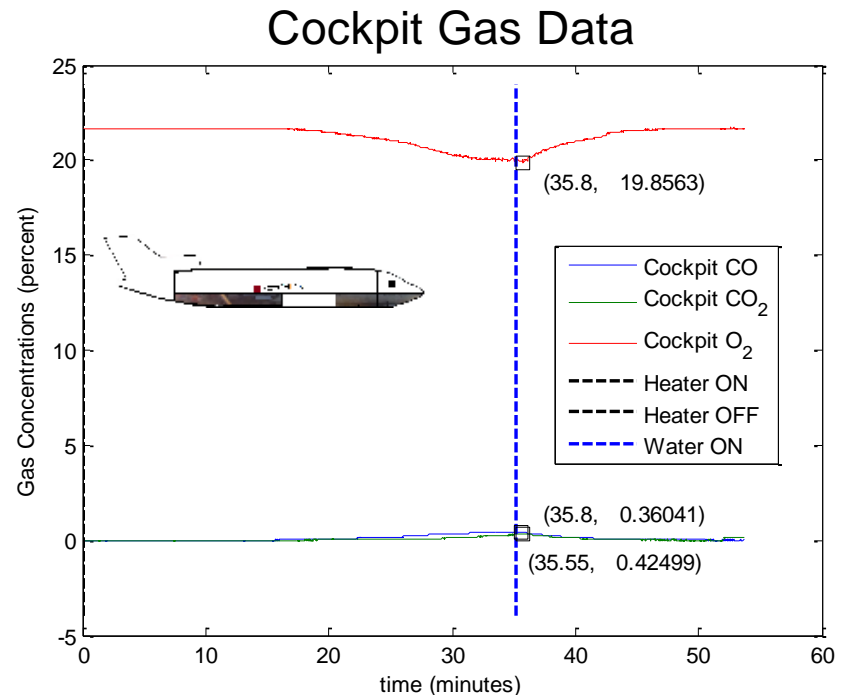
5000 Lithium-ion (EF) Results

- Flight deck peak air temperatures:
- Ceiling: 112 DegF
- Mid: 105 DegF
- 6" above floor: 98 DegF



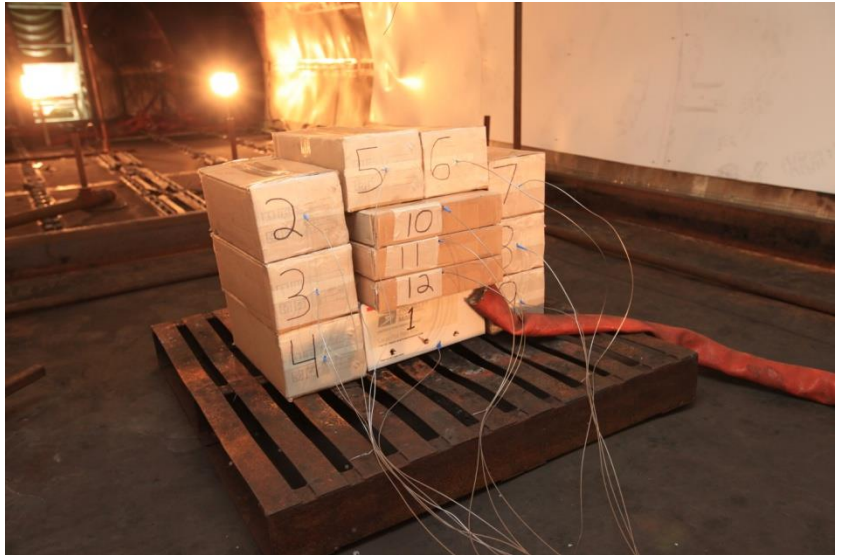
5000 Lithium-ion (EF) Results

- **Flight deck gas data:**
 - Minimum O₂: 19.9% @ 36 min
 - Peak CO₂: .36% @ 36 min
 - Peak CO: .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

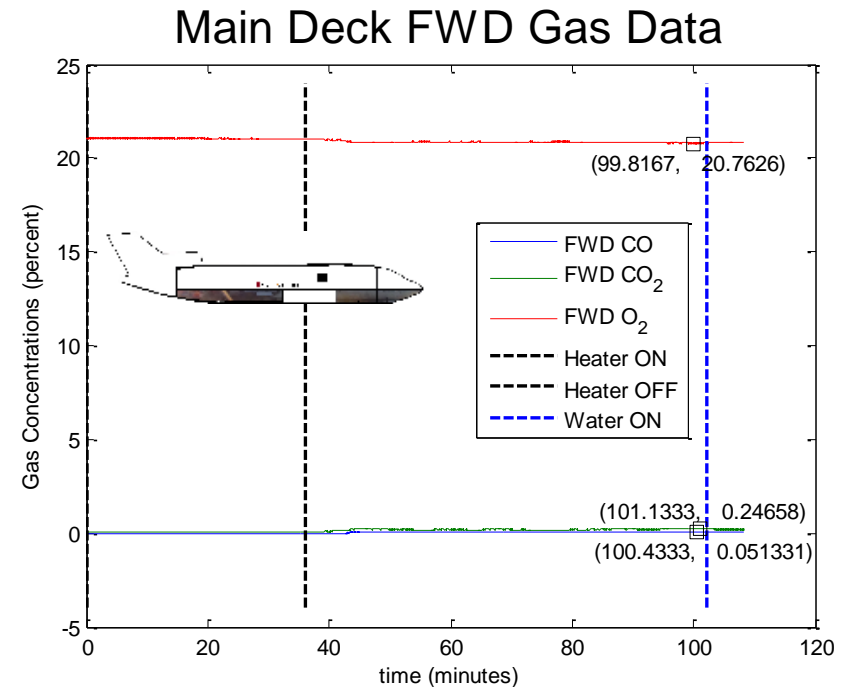
- **Test terminated at 102 minutes with water**
- **Cells damaged (no voltage):**
 - Alkaline: 318
 - NiCad: 153
 - NiMH: 139
- **Peak ceiling temp: 119 DegF @ 40 min**
- **Peak battery stack temp: 975 DegF @ 44 min.**



5000 Mixed Cells (EF) Results

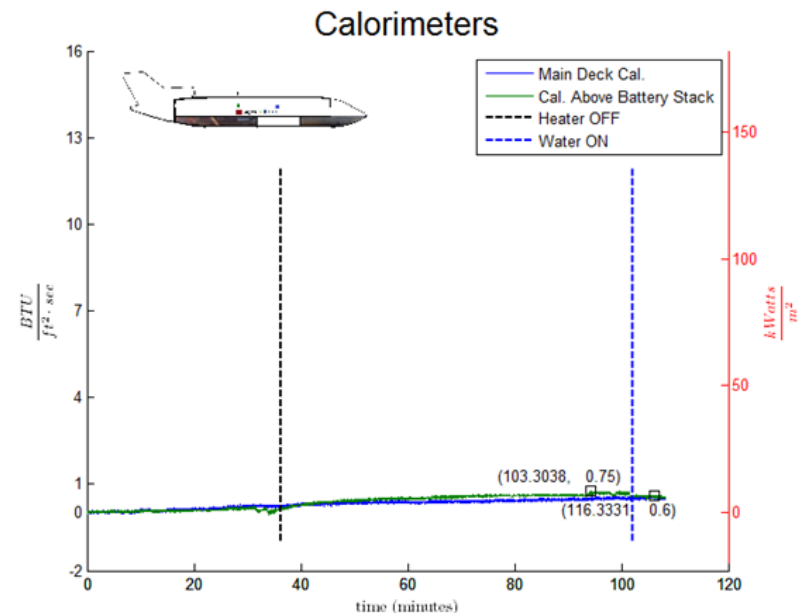
- **Cabin gas data:**

- Minimum O₂: 20.8% @ 100 min
- Peak CO₂: .25% @ 101 min
- Peak CO: .05% @ 100 min



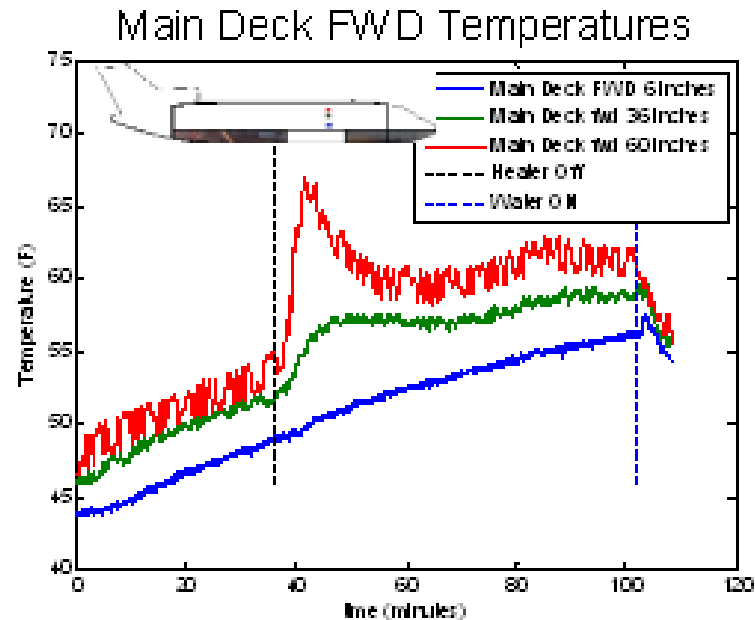
5000 Mixed Cells (EF) Results

- **Peak Heat Flux above the battery stack: 0.75 Btu/ft²-sec @ 103 minutes**
- **Peak heat flux at the forward instrument tree: 0.6 Btu/ft²=sec @116 minutes**



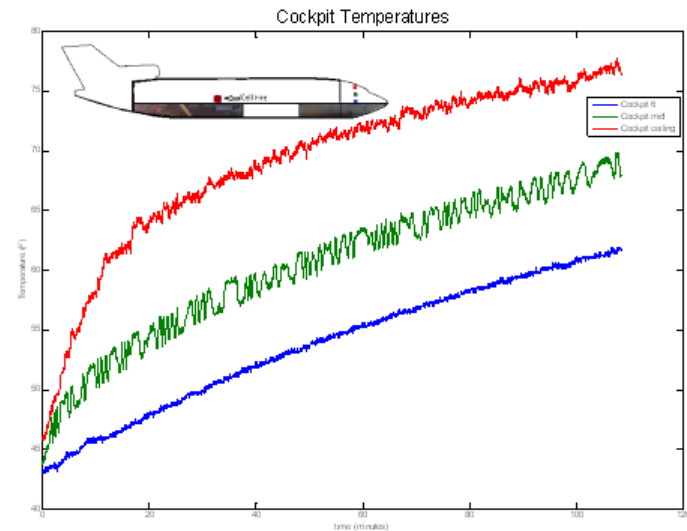
5000 Mixed Cells (EF) Results

- Cabin air peak temperature, forward instrument tree:
- 60" 67 DegF
- 36" 58 DegF
- 6" 56 DegF



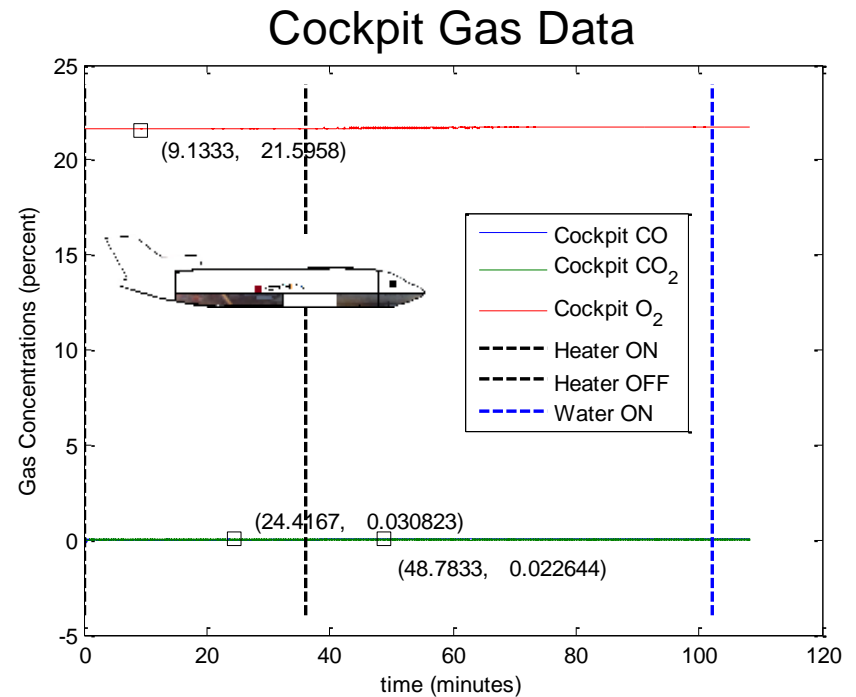
5000 Mixed Cells (EF) Results

- 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 O₂: 21.6% @ 9 min
 - Peak CO₂: .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



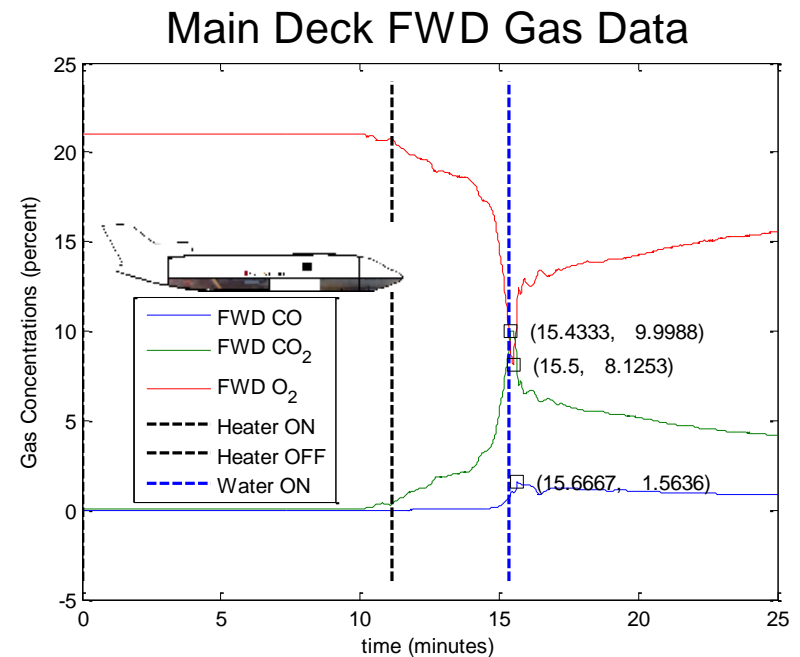
4800 Lithium Metal (CH) Results

- 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.



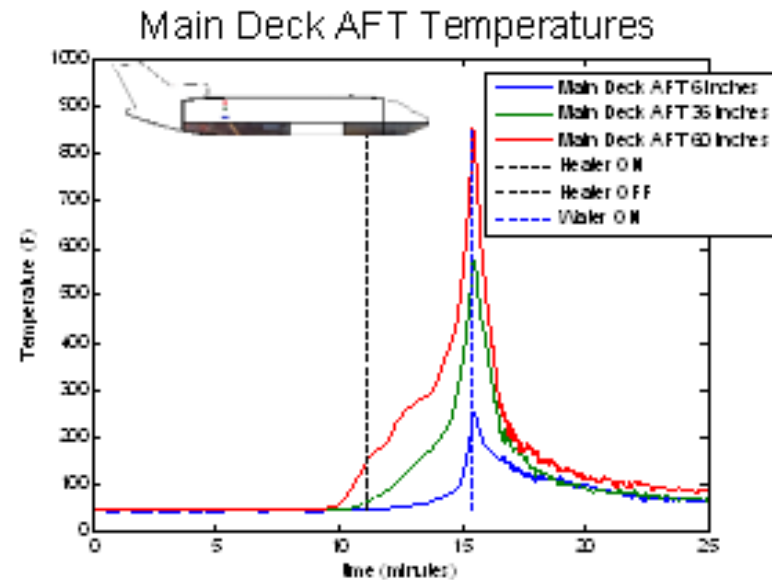
4800 Lithium Metal (CH) Results

- **Cabin gas data:**
 - Minimum O₂: 8.1% @ 15.5 min
 - Peak CO₂: 10% @ 15.4 min
 - Peak CO: 1.56% @ 15.7 min



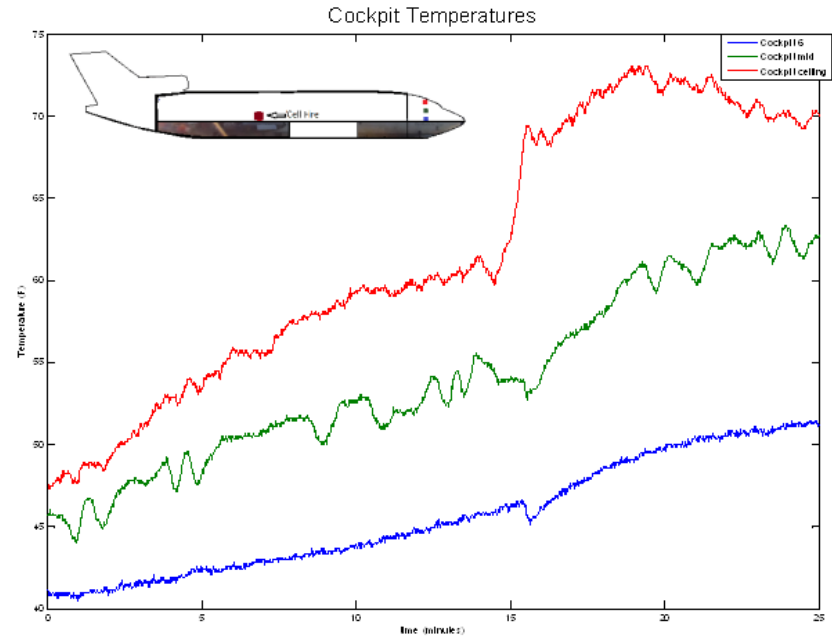
4800 Lithium Metal (CH) Results

- **Cabin air peak temperature, aft instrument tree:**
- **60” 850 DegF**
- **36” 560 DegF**
- **6” 250 DegF**



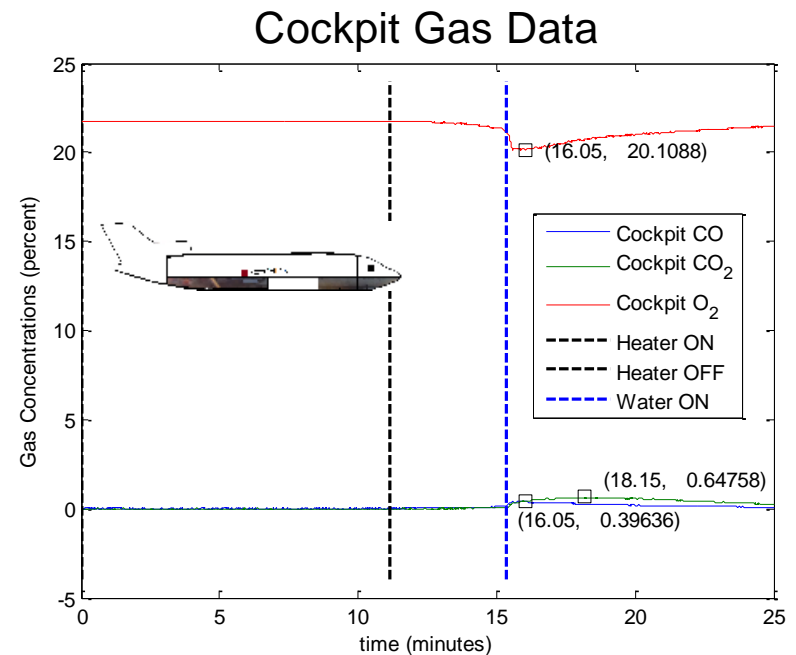
4800 Lithium Metal (CH) Results

- **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 O₂: 16% @ 20 min
 - Peak CO₂: .65% @ 18 min
 - Peak CO: .4% @ 16 min



4800 Lithium Metal, external fire

- 123A cells, 100% charge
- charge
- 4 boxes of 200 cells per carton
- 6 cartons
- Igniter box: shredded paper, rag soaked in heptane



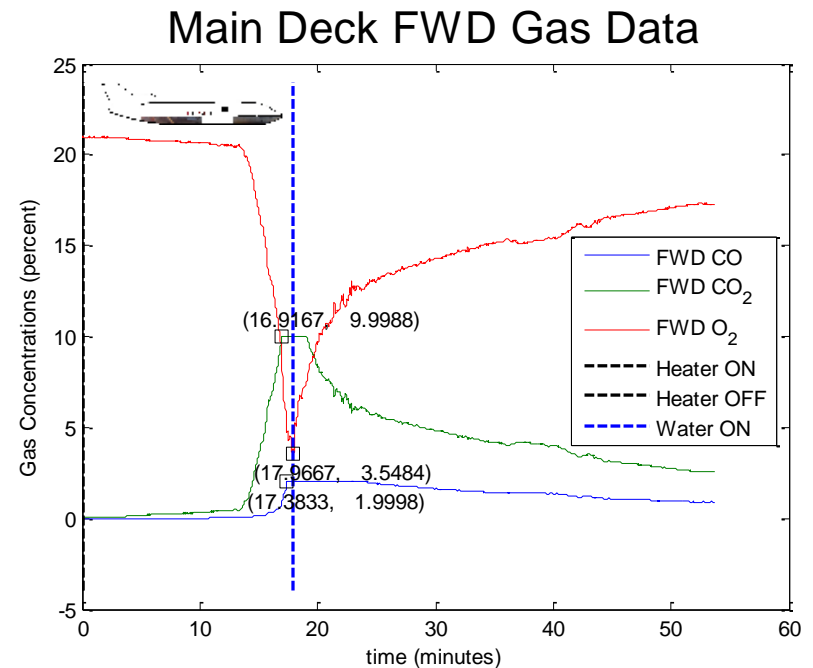
4800 Lithium Metal (EF) Results

- 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.



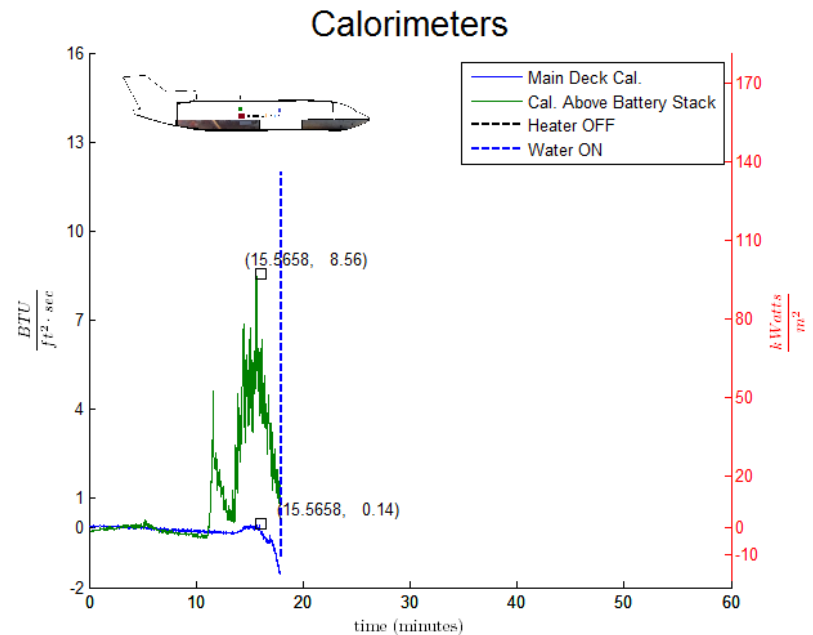
4800 Lithium Metal (EF) Results

- **Cabin gas data:**
 - Minimum O₂: 3.5% @ 18 min
 - Peak CO₂: 10% @ 16.9 min
 - Peak CO: 2% @ 17.3 min



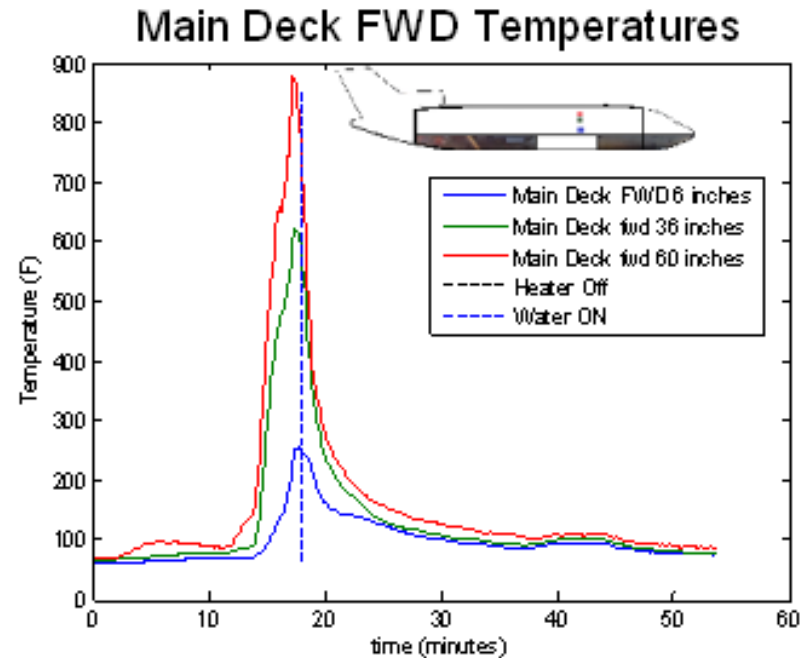
4800 Lithium Metal (EF) Results

- **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**



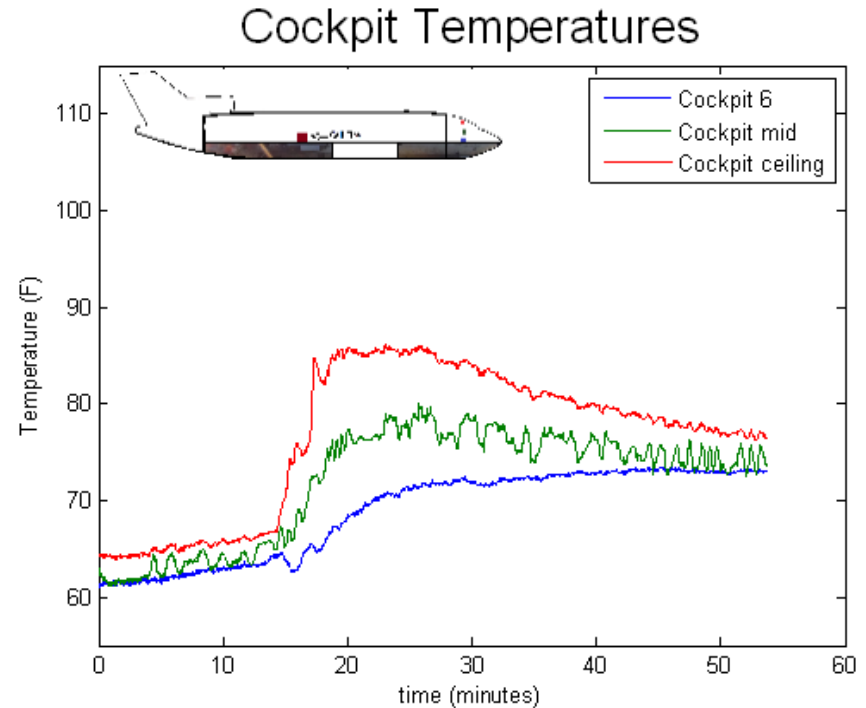
4800 Lithium Metal (EF) Results

- **Cabin air peak temperature, forward instrument tree:**
- **60" 885 DegF**
- **36" 620 DegF**
- **6" 250 DegF**



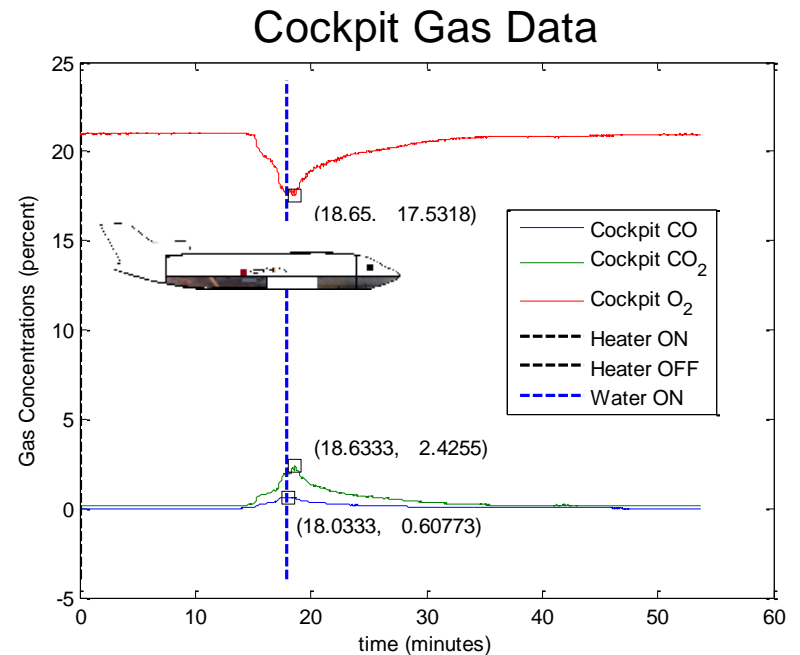
4800 Lithium Metal (EF) Results

- **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 O₂: 17.5% @ 18.7 min
 - Peak CO₂: 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

Harry Webster

609-485-4183

Harry.Webster@faa.gov

www.fire.tc.faa.gov

