Lithium Ion Thermal Runaway

Less than 2 Wh Lithium Ion Batteries

Presented to: International Aircraft Systems Fire Protection Working Group

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Federal Aviation Administration

Scope of Test

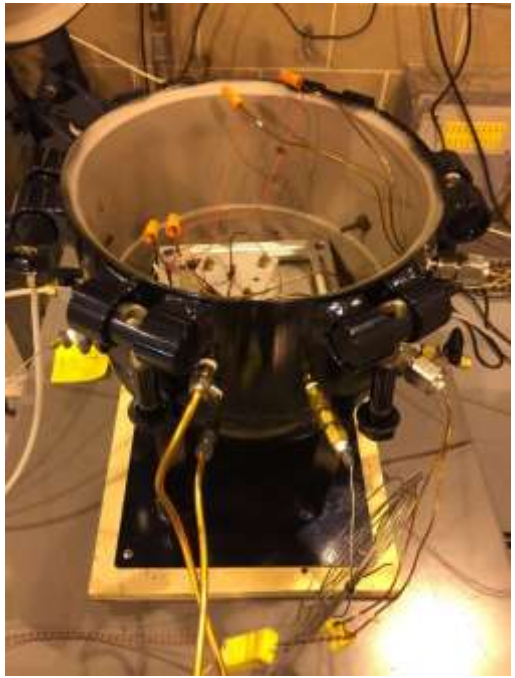
- RTCA SC-225 committee working on developing document DO-311A
  - Document contains Minimum Operational Performance Standards (MOPS) for rechargeable lithium battery systems
- Proposed to exempt battery cells that are < 2Wh from testing standards
  - provided they are certified to existing UL and IEC standards
- Comments were received that the exemption level should be raised to as high as 5 Wh
- Tests were conducted to determine if the exemption level should be raised

Scope of Test

- Tests were conducted with lithium ion rechargeable 3.7V 500mAh (1.85Wh) polymer pouch cells and button cells at 100% SOC
- The cells were forced into thermal runaway using the overheat method at 20°C/min
- Tests were conducted in a 21.7L pressure vessel where a pressure transducer and thermocouple were used to quantify the gas release from each lithium battery cell
- The gases were collected and analyzed for percent hydrogen, carbon monoxide, carbon dioxide, oxygen, and total hydrocarbon content (THC)
- The maximum temperature rise and peak pressure rise were annotated

Test Equipment

- Experiments were conducted in a 21.7 liter stainless steel pressure vessel
- Gas chromatography (GC) with thermal conductivity detector (TCD) to measure H2
- Paramagnetic sensor (pO2) to measure CO/O2
- Non-dispersive infrared radiation to measure CO2
- Flame ionization detector (FID) to measure total hydrocarbon content (THC)



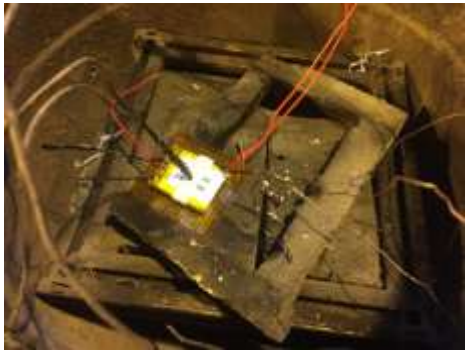
Test Apparatus

Test Procedure

- The pressure vessel is vacuumed to less than 0.1 psia
- The pressure vessel is filled to 14.7 psia with nitrogen gas
    - Nitrogen gas is used because of its inert properties and to prevent interference with the gas analyzers
- The battery is forced into thermal runaway by overheating and the vent gases are released
- More nitrogen is added to the pressure vessel until the pressure reaches 18 psia, this creates a positive pressure to feed into gas analyzers
- The samples are analyzed for gas composition

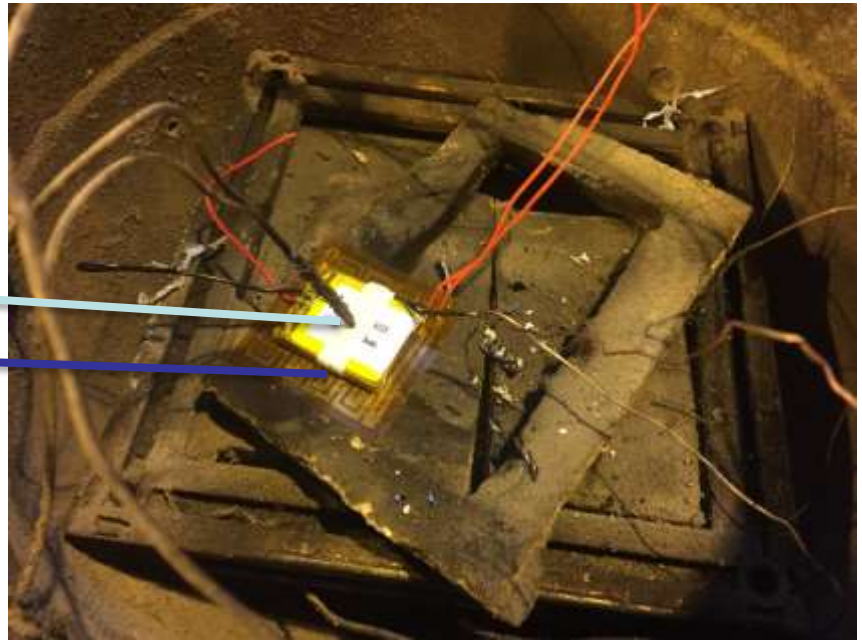
Test Procedure

- The battery cells were placed on top of a flexible heater
- Heated at 20°C/min until thermal runaway is induced
  - The temperature heating rate was controlled by a Proportional-Integral-Derivative (PID) controller
- Temperature was measured at the side of the pouch cell and on top of the button cell



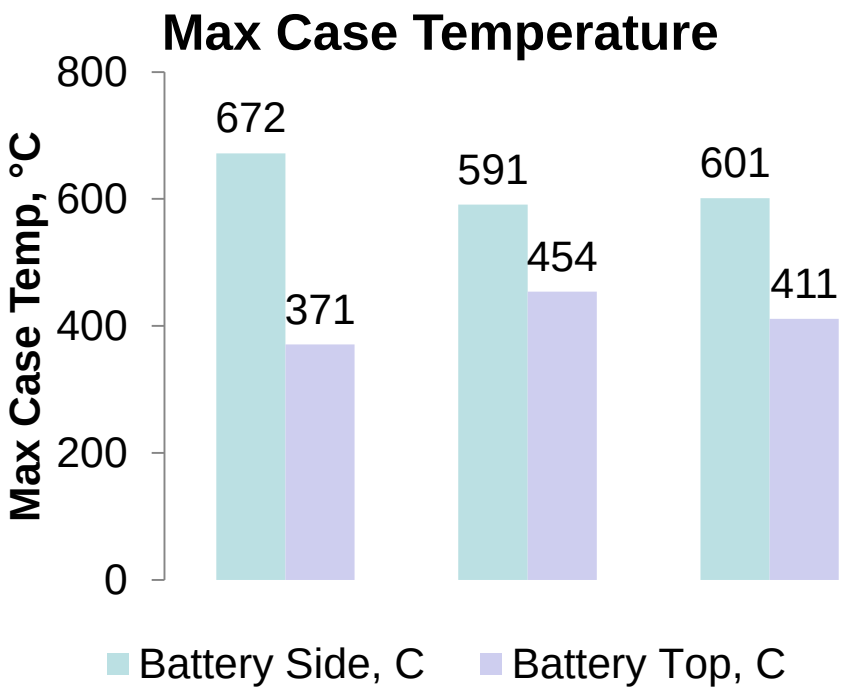
Pouch Thermocouple Location

- Thermocouples were placed at two separate locations
- The locations
  - On top
  - On the side



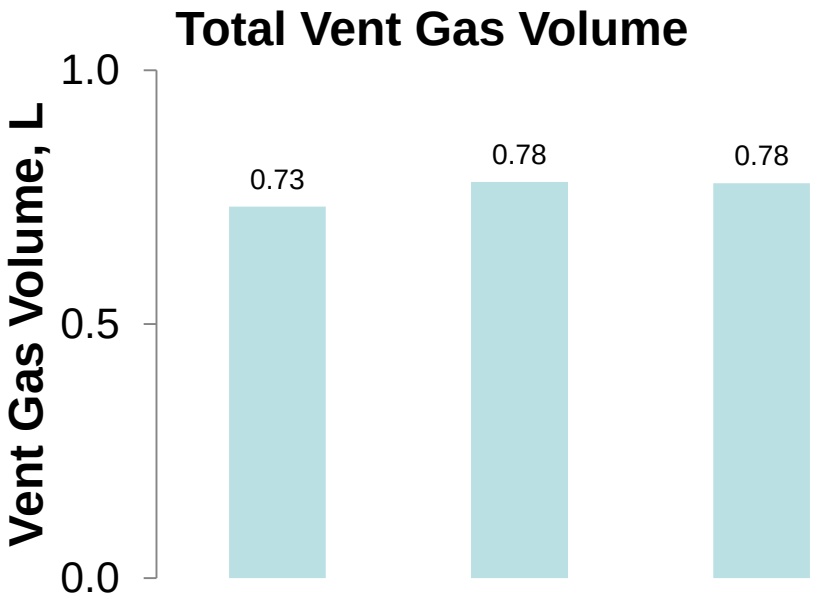
Pouch Maximum Temperature

- The maximum temperature at the side of the pouch cell is hotter than on top of the pouch cell
  - Vent gas vents out of the sides
- The average maximum temperature are:
  - Side 621±25°C
  - Top 412±24°C
- The average thermal runaway onset temperature is 135±13°C



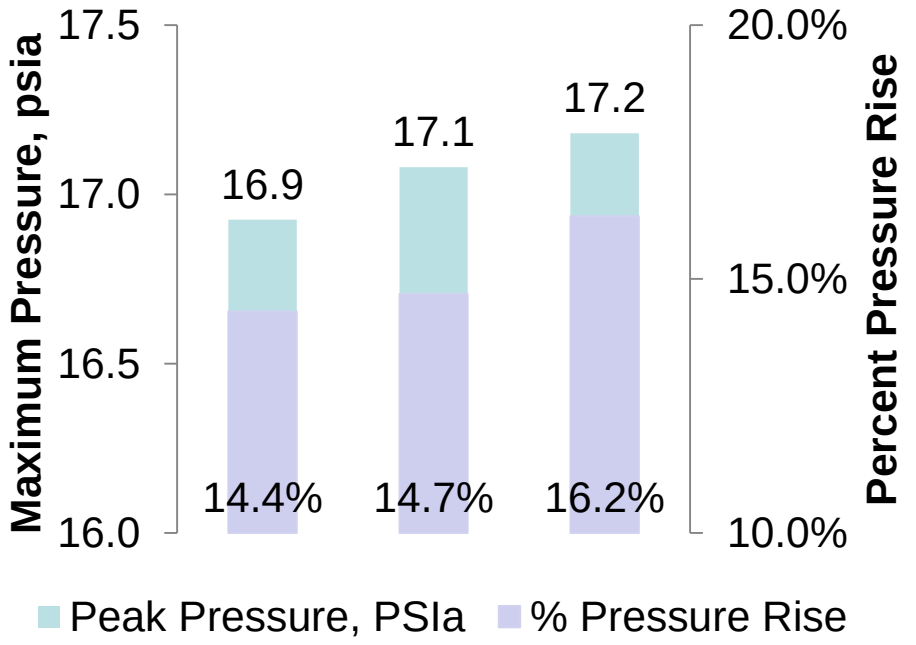
Pouch Vent Gas Volume

•The average vent gas volume is 0.76±0.03L



Pouch Pressure Rise

- The pressure is measured inside of a 21.7L pressure vessel.
  - Note: The measured pressure is inversely proportional to the pressure vessels volume.
- The average maximum pressure is
  - 17.1±0.1psia
- The average percent pressure rise is
  - 15.1±0.6%



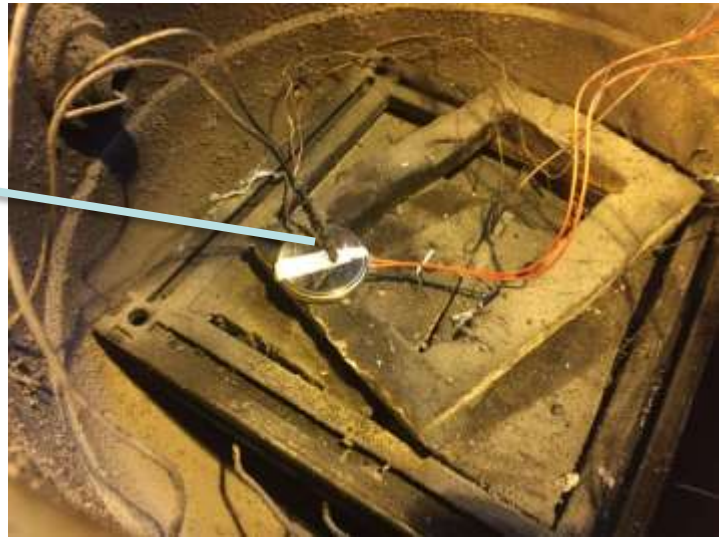
Pouch Cell Gas Constituents

- The gas concentrations used for the calculation of the lower flammability limit (LFL) were measured and averaged. The results are tabulated
- The LFL can be calculated using Le Chatelier's Mixing Rule
- **The calculated LFL is 8.5%vol battery gas in air**

Gas Specie	Averaged Gas Concentration, %vol	LFL, %vol
carbon dioxide	25.3±0.7	0
carbon monoxide	20.0±6.2	12.5
ethane	0.6±0.1	3.00
ethylene	7.3±0.8	3.10
hydrogen	24.0±2.5	4.95
methane	3.1±0.3	5.30
propane	0.2±0.02	2.10
propylene	1.6±0.4	2.40
oxygen	6.0±2.7	NA
THC	18.7±1.0	NA

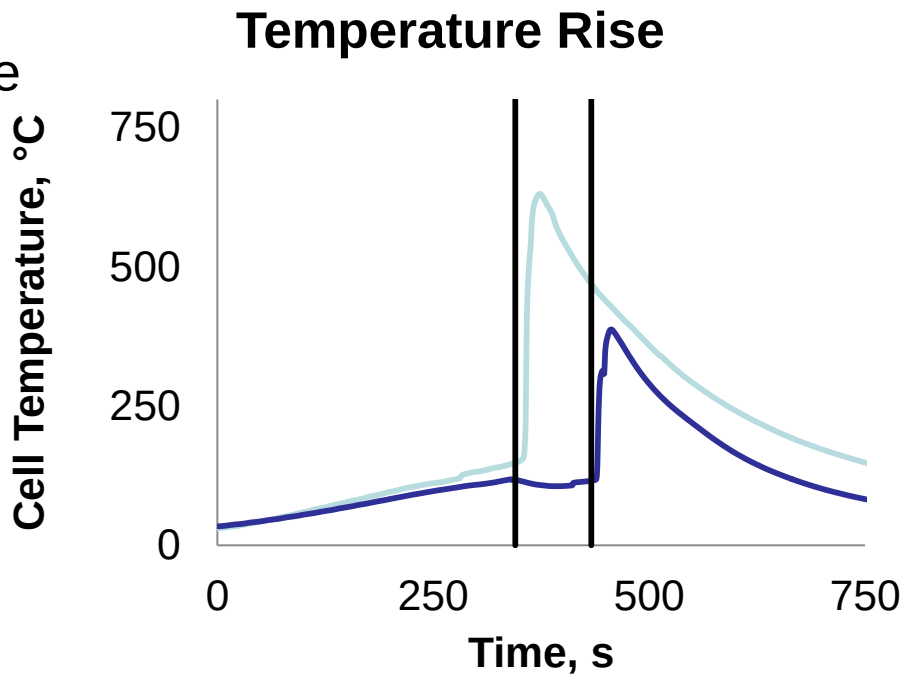
Button Thermocouple Location

•The thermocouple was places on top of the button cell and wrapped with fiberglass tape to insure good contact

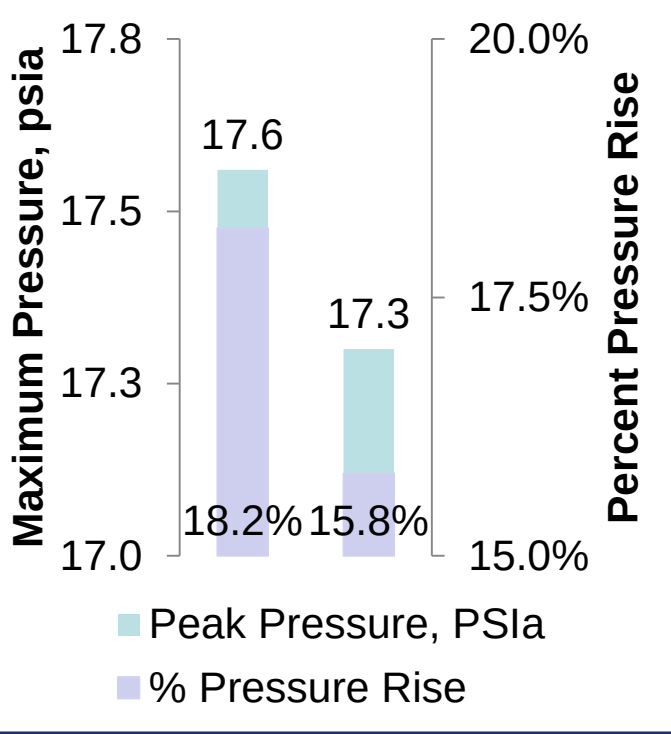


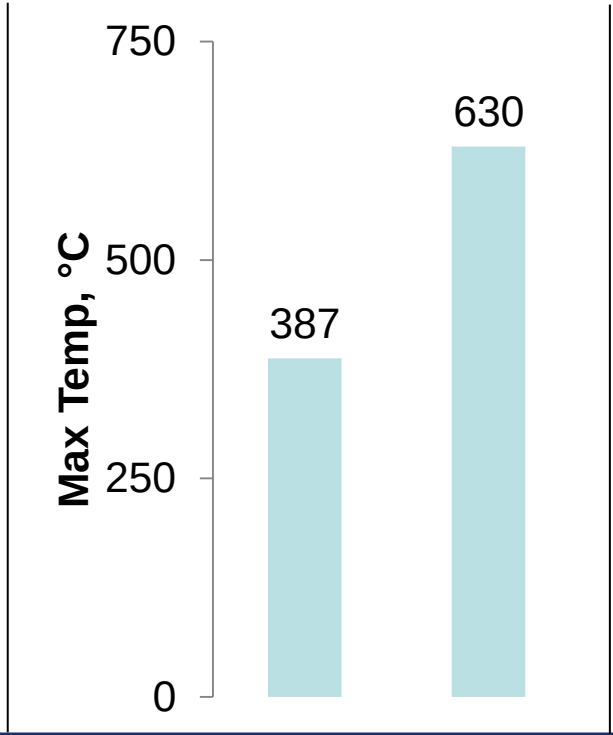
Button Maximum Temperature

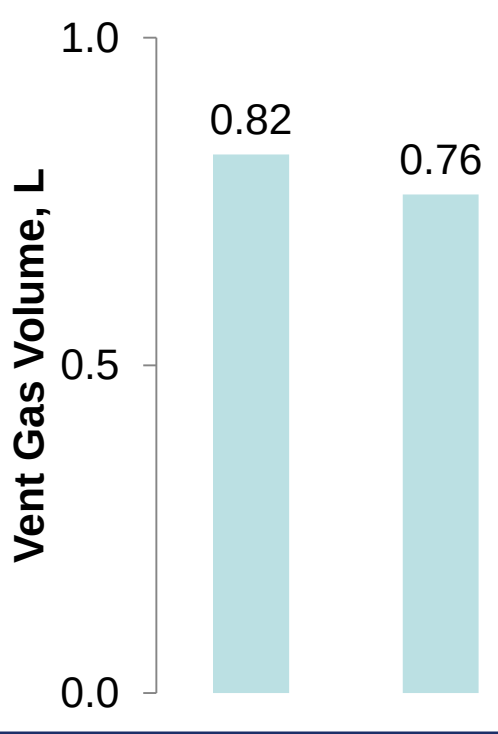
- The two tested button cells had drastically different maximum temperature
- Variations in thermal runaway reactions has also been observed in 18650 cells
- This is often observed with a delay in thermal runaway reaction as represented by the black vertical lines
- The delayed reaction allows time for the electrolyte to evaporate away from the cell



Button Cell Significant Values







Button Cell Gas Constituents

- The gas concentrations used for the calculation of the lower flammability limit (LFL) were measured and averaged. The results are tabulated
- The LFL can be calculated using Le Chatelier's Mixing Rule
- **The calculated LFL is 8.2%vol battery gas in air**

Gas Specie	Averaged Gas Concentration, %vol	LFL, %vol
carbon dioxide	23.4±0.8	0
carbon monoxide	25.0±3.7	12.5
ethane	0.5±0.04	3.00
ethylene	8.4±0.4	3.10
hydrogen	23.8±1.9	4.95
methane	2.7±0.2	5.30
propane	0.1±0.01	2.10
propylene	2.0±0.2	2.40
oxygen	5.1±3.0	NA
THC	17.9±1.7	NA

Summary <2Wh Lithium Ion

	Pouch Cell	Button Cell	Total Average	9.25 Wh Pouch Cell 30% SOC
Carbon Dioxide	25.3±0.7%	23.4±0.8%	24.5±1.0%	41.2%
Carbon Monoxide	20.0±6.2%	25.0±3.7%	22.0±4.3%	3.82%
Hydrogen	24±2.5%	23.8±1.9%	23.9±1.5%	16.98%
Percent Pressure Rise	15.1±1.13%	17.0±2.3%	15.9±1.3%	20.4%
Maximum Pressure	17.1±0.1%	17.4±0.3psia	17.2±0.2psia	NA
Off Gas Volume	0.76±0.03L	0.79±0.06L	0.77±0.04L	0.92L
Maximum Temperature	621±50°C	508±238°C	576±97°C	404°C
Calculated LFL	8.5%	8.2%	NA	9.1%

Conclusion

•While there may be examples of safer cells of higher capacity, there are also cells at or near the 2 Wh level that could pose a threat to aircraft safety

•Based on the testing, the committee decided to maintain the 2Whr limit and not to extend the exemption level.

References

[1] Coward, Hubert Frank, and George William Jones. *Limits of flammability of gases and vapors*. No. BM-BULL-503. Bureau of Mines Washington DC, 1952.

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