Boeing Battery Task Group: Mitigating the Risk of Carrying Lithium Batteries as Cargo

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Boeing Lithium Battery Cargo Task Group

Battery Working Group

- Multi-Operator Message (MOM)
- Battery Information Presentation
- Transport Regulations
- Cargo Compartment Design Regulations
- Lithium Battery Concerns

Commercial Aviation Safety Team (CAST)

Fire Resistant Cover (FRC) and Container (FCC) Standards

Battery Research

Summary

Next Steps

Boeing Lithium Battery Cargo Task Group

Boeing Lithium Battery Working Council

- Comprised of individuals from Flight Operations, Payloads, Environmental Control Systems, Fire Marshal Office, Accident Investigation, Structures

Responsibility

- Identify and communicate Boeing position regarding carriage of lithium batteries
  - Multi Operator Message (MOM-MOM-12-0356-01B)

- Prepare background material for internal and external education
  - Lithium Battery Cargo Awareness – Darrin Noe presented to Nov 2012 IASFPWG meeting.
    - https://www.fire.tc.faa.gov/pdf/systems/Nov12Meeting/Boeing-1112-LithiumBatteryCargoAwareness.pdf

Boeing Lithium Battery Cargo Task Group
- Boeing Multi-Operator Message

Boeing released MOM-MOM-12-0356-01B (dated 22 May 2012) to share regulatory and guidance information for lithium battery cargo transport

- Boeing supports recommendations made by the FAA in the Safety Alert for Operators (SAFO) 10017, dated 10/8/10, for transport of lithium batteries:
  1) Request customers identify bulk shipments of currently excepted lithium batteries by information on air waybills and other documents provided by shippers offering shipments of lithium batteries
  2) Where feasible and appropriate, stow bulk shipments of lithium batteries in Class C cargo compartments or in locations where alternative fire suppression is available
  3) Evaluate the training, stowage, and communication protocols in your operation with respect to the transportation of lithium batteries in the event of an unrelated fire
  4) Pay special attention to ensuring careful handling and compliance with existing regulations covering the air transportation of Class 9 hazardous materials, including lithium batteries

- Additional Guidance can be found in:
  - EASA Safety Information Bulletin (SIB) No. 2010-30R1, dated 31 March 2011
  - ICAO Electronic Bulletin (EB) No. 2011/7, dated 15 February 2011
  - IATA Website: www.iata.org/whatwedo/cargo/dangerous_goods/Pages/lithium_batteries.aspx

Boeing Lithium Battery Cargo Task Group
- Boeing Position

An overall solution which reduces the risks associated with transport of lithium batteries will likely require concerted efforts by an industry forum consisting of airlines, airplane manufacturers, regulatory agencies, battery producers, package manufacturers, shippers, freight forwarders, ULD and equipment manufacturers, and other involved parties

- Suggest industry forum be led by DOT (FAA), since FAA Tech Center testing on FCCs, FRCs, and 727 vehicle will be focus of industry attention

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- Transport Regulations

– Air transport of lithium batteries is controlled by international and local regulations governing the transport of dangerous goods (also referred to as hazardous material regulations)

– Most countries follow the ICAO Technical Instructions for the Safe Transport of Dangerous Goods by Air but many also have local variations contained in their own regulations

– An example of local variations are United States 49 CFR Parts 171-180 administered by the Department of Transportation Pipeline and Hazardous Materials Safety Administration

  • A significant US local variation is that lithium metal batteries packed alone are prohibited from being transported on passenger airplanes

– Some airlines also have their own policies for transporting specific types of dangerous goods (known as airline variations)

– Many airlines, freight forwarders, and shippers use the IATA Dangerous Goods Regulations as the working reference for dangerous goods transport requirements because it includes the ICAO Technical Instructions, local variations, airline variations, and additional requirements agreed to by IATA-member airlines to reflect operational considerations

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- Transport Regulations

– The regulations governing shipment of lithium batteries typically provide six distinct packing instructions to accommodate various combinations of battery types and shipping situations

1. Lithium ion batteries packed alone
2. Lithium ion batteries packed with equipment
3. Lithium ion batteries contained in equipment
4. Lithium metal batteries packed alone
5. Lithium metal batteries packed with equipment
6. Lithium metal batteries contained in equipment

– The different packing instructions allow different quantities of batteries and/or types of packaging to accommodate the various shipping scenarios that may be encountered

– Dangerous goods considered less hazardous and packaged in small quantities are frequently not subject to regulation and are referred to as excepted quantities or excepted shipments of dangerous goods – under current regulations many lithium batteries are shipped in excepted quantities

– There are no limits to the number of packages containing dangerous goods that can be transported on any single airplane

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- Recent Regulatory Change

- ICAO Dangerous Goods Panel (DGP) met in Montreal on February and developed new rules for lithium battery transport (effective January 2013)
    - Eliminated some of the exceptions to the regulations governing lithium battery transport
    - New rules are a compromise ➔ a new intermediate category is introduced that increases control over battery/cell shipments that have relatively high power or large quantities of cells/batteries in a package; however, relief from more rigorous reporting and packaging requirements of fully regulated shipments is provided

- FAA reauthorization legislation H.R. 658 signed into law February 14th includes limits on U.S. regulations related to the transport of lithium batteries by air
    - DOT may not issue or enforce any regulation regarding the transportation by aircraft of lithium batteries that is more stringent than the requirements of the ICAO Technical Instructions, except-
        - For existing passenger airplane prohibition on lithium metal batteries
        - If a credible report demonstrates that lithium batteries transported in compliance with the ICAO Technical Instructions have substantially contributed to the initiation or propagation of an onboard fire…
    - An industry coalition consisting of The Rechargeable Battery Association (PRBA), key aviation stakeholders and battery sellers lobbied Congress to require DOT to follow ICAO rules
    - PHMSA has initiated NPRM to harmonize US regulations with ICAO regulations

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- Title 14 CFR Part 25 Cargo Compartment Fire-Related Design Regulations

- Regulations:
  - 25.857 provides cargo compartment classifications and contains fire-related requirements
    - smoke detection
    - fire suppression
    - hazardous quantities of smoke, flames, or extinguishing agent must be excluded from compartments having occupants
    - airflow must be controlled in cargo compartment to maintain fire suppression
  - 25.855 requires cargo compartments to have a liner which meets test requirements of Appendix F
    - Appendix F part III test requirements provide flame penetration resistance requirements for cargo liners
  - Protection of critical systems for main deck Class E cargo compartments is commonly addressed by Issue Papers

- The fireworthiness standards for cargo compartments in CFR 25.855 and demonstrated by testing per CFR 25 Appendix F, were developed prior to shipments of lithium batteries becoming widespread

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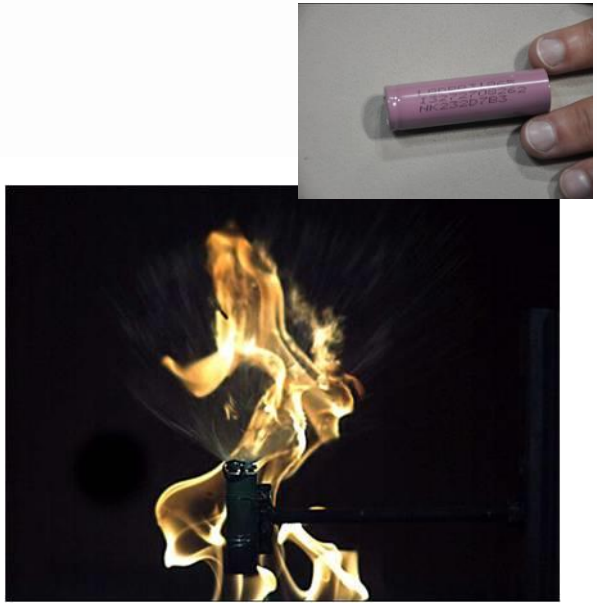
- Heat Release Comparison: Oil Burner vs Lithium-ion Batteries

Oil burner (cargo liner criteria test)
~79 KW peak HRR
~23,700 KJ total HR
Ref: 14 CFR 25 Appendix F, Part III



One 18650 Li-Ion cell
~12 KW peak HRR
~82 KJ total HR
Ref: Presentation by Dave Blake, FAA Technical Center, 3/21/2012

(100 18650 cells)
~90 KW peak HRR
~11,200 KJ total HR
Ref: FAA/NTSB Test 6552 data, 8/11/2011

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- Threat Assessment – Class C Cargo Compartment Concerns

<u>Class C Cargo Compartment</u> – Halon suppression in a closed environment

- Bulk-packed lithium batteries in thermal runaway will act as a persistent ignition source
- Bulk-packed lithium batteries in thermal runaway in a suppressed compartment will generate a sustained high temperature release that may be greater than the aircraft design criteria
- Pressure pulses generated by energetic failure of lithium cells or batteries may cause airplane damage
  - Fire resistant cargo linings could be compromised
  - Decompression relief features could be activated
    - May accelerate leakage of Halon fire suppressant
    - May allow smoke to penetrate into occupied areas
- If Halon concentration is reduced due to leakage from compromised cargo linings, fire could continue to burn unsuppressed and possibly spread to other flammable cargo in compartment
- Burning lithium batteries can generate significant temperatures (>1100 deg. F; approaching the melting point of aluminum) that may damage airplane
- Lithium metal battery fires cannot be suppressed by Halon allowing hot fire to continue burning even in Halon environment
- Heat release from a large bulk shipment of unsuppressed burning lithium batteries would be much greater than cargo lining design criteria

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- Threat Assessment – Class E Cargo Compartment Concerns

Class E Cargo Compartment – Depressurized compartment to starve fire

- Bulk-packed lithium batteries in thermal runaway will act as a persistent ignition source
- Bulk-packed lithium batteries in thermal runaway in a depressurized compartment will generate a sustained high temperature release that may be greater than the aircraft design criteria
- Pressure pulses generated by energetic failure of lithium cells or batteries may cause airplane damage
  - Fire resistant cargo linings could be compromised
  - Decompression relief features could be activated
    - May allow smoke to penetrate into occupied areas
- Burning lithium batteries can generate significant temperatures (>1100 deg. F; approaching the melting point of aluminum) that may damage airplane
- Lithium metal battery fires cannot be suppressed by oxygen deprivation allowing hot fire to continue burning even in depressurized environment
- Heat release from a large bulk shipment of unsuppressed burning lithium batteries would be much greater than cargo lining design criteria

Boeing Lithium Battery Cargo Task Group
- Commercial Aviation Safety Team (CAST) Safety Enhancement (SE) 126

- Commercial Aviation Safety Team (CAST) sponsoring Safety Enhancement (SE) 126 Output 1 Working Group (SE 126 OP1 WG)

- SE126 Action: “To reduce the occurrence of accidents and incidents from fires involving high-consequence hazardous materials, develop systems to contain or suppress such fires as a final line of defense for personnel, equipment and cargo. The system should be usable for both ground (e.g., cargo loading/unloading, and ramp movement) and flight operations”

- Working Group members include FAA, Boeing, Airbus, ALPA, CAPA, cargo operators, NACA, MITRE. Group is co-chaired by representatives from UPS and FAA

Boeing Lithium Battery Cargo Task Group
- Commercial Aviation Safety Team (CAST) Safety Enhancement (SE) 126

- SE 126 kick-off meeting held July 30-August 1 2013. 2nd meeting November 12-14 (hosted by Boeing). Next face-to-face meeting scheduled for January 7-9.

- One year to complete output #1 - gap analysis evaluating the causal and contributing factors of the three recent accidents:
  - UPS DC-8 at Philadelphia, 2006
  - UPS 747-400F at Dubai, 2010
  - Asiana 747-400F over Pacific Ocean, 2011

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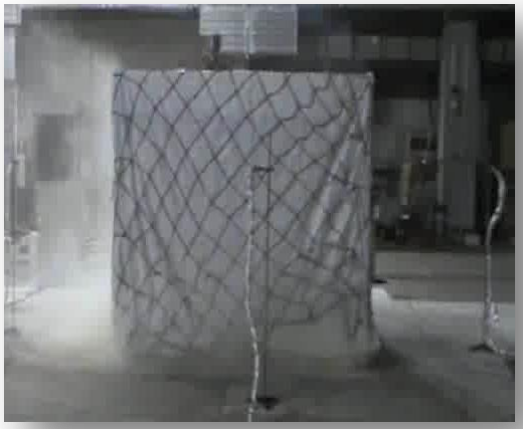
- Cargo Pallet Fire Containment Covers and Fire Resistant Cargo Containers



- Cargo pallet Fire Containment Cover (FCC) requirements definition and development testing has been completed through cooperative industry effort (airlines, regulators, standardization committees)

- SAE and ISO standards (SAE AS6453 , ISO 14186) are now available to provide performance and test requirements for the manufacture of FCCs

- Airline implementation of FCCs is just beginning (voluntary basis)

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- Cargo Pallet Fire Containment Covers and Fire Resistant Cargo Containers

- Development and testing of Fire Resistant Cargo Containers (FRCs) is underway through cooperative effort similar to what was used to develop FCCs

- Goal is to have defined standards for containers that will protect against hazardous material fires, similar to FCCs -- lithium battery fires are a design consideration

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- FAA Tech Center Full Scale Lithium Battery Testing

- FAA Tech Center in Atlantic City, NJ has conducted basic research to document the characteristics of large battery fires in a realistic aircraft environment (no suppression – Class E main deck; with suppression – Class C lower hold)

- Test runs include 5000 lithium-ion 18650 cells; 4800 lithium metal SF123A cells; 5000 mixed alkaline, NiCad, NiMH cells
- Data gathered includes various temperatures, heat flux, and gas concentrations in cargo compartments and cockpit
- Boeing provided consultation for configuring 727 test vehicle and has witnessed some test runs

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– IATA Best Practices Guide for Industry

- Boeing shared suggestions to help minimize the hazards associated with transporting lithium batteries with IATA (David Tindley - IATA) in March, 2013 (Boeing contact – Darrin Noe)

- IATA encouraged to continue Best Practices development

Boeing Lithium Battery Cargo Task Group
– Battery Research

- Literature Review
  - Limited data is available for Secondary or Primary battery Heat Release Rate (HRR) and pressure pulse
    - Recent HRR data disclosed from FAA presentation by Dave Blake at conference during May 22-23, 2013. Koeln, Germany
  - The relationships between Weight Loss Rate, HRR and Pressure Pulse are not well defined
  - A primary (Lithium-metal) battery fire is much more energetic and represents a greater threat than a secondary (Lithium-ion) battery fire

Boeing Lithium Battery Cargo Task Group
– Battery Research

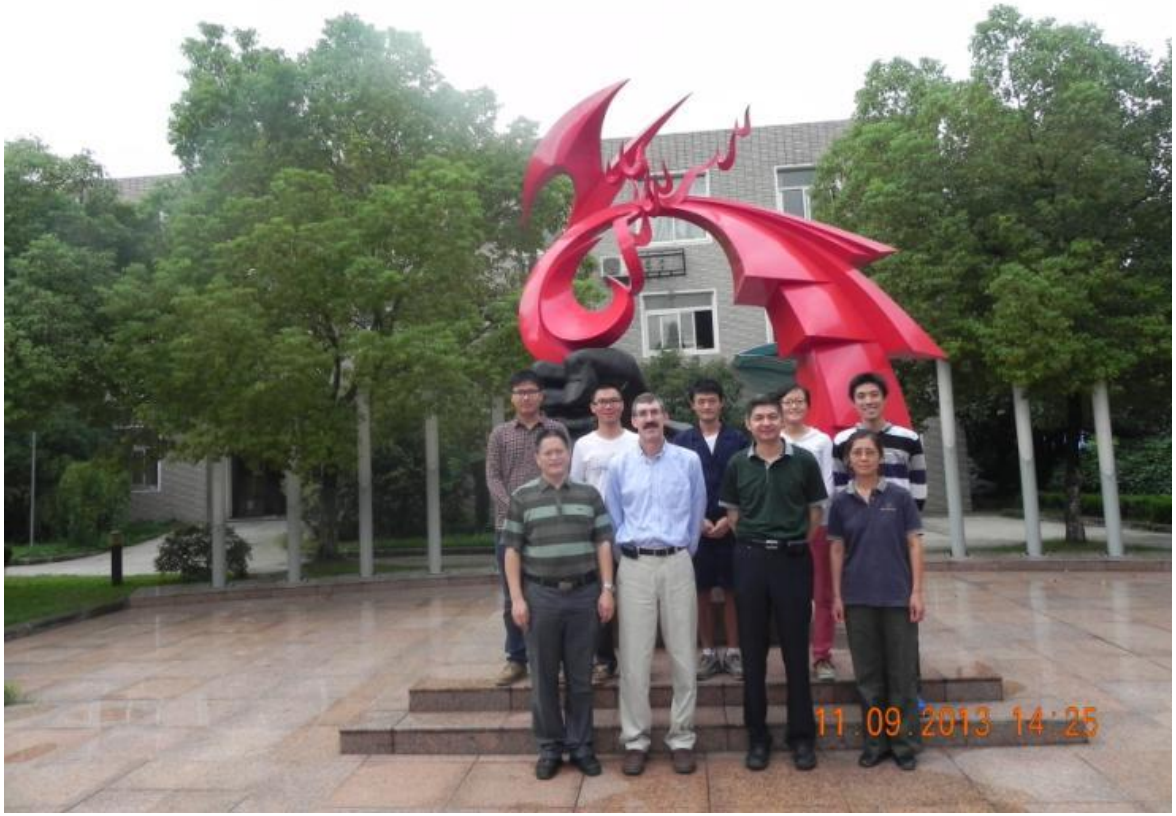
- Literature Review
  - Limited pressure pulse data publicly available
  - Available data in chambers is limited
    - FAA Lithium Ion Battery tests done in 10 m^3 chamber, pressure rise from 1.1 to 2.6 PSI depending on the number of cells burned
    - Exponent tests in 64 ft^3 chamber, 4 cells to 16 cells, pressure range from 0.03psi to 0.07 psi (source: April 2005 Exponent report)

- Generate additional test data for better understanding of lithium battery fires

Boeing Lithium Battery Cargo Task Group
– Battery Research

中国科学技术大学
University of Science and Technology of China

Boeing is collaborating with the University of Science and Technology of China to conduct lithium battery research



Prof. Jian Wang and his research team

Boeing Lithium Battery Cargo Task Group
– Battery Research

Phase 1 of Lithium Battery Fire Characterization

Battery Configuration	Primary		Secondary	
	Panasonic	Nitecore	Sanyo	Samsung
2 x 2	5 tests	5 tests	5 tests	5 tests
2 x 4	5 tests	5 tests	5 tests	5 tests
6 x 6	3 tests	--	--	3 tests
10 x 10	3 tests	--	--	3 tests

Measurements:

Mass loss, Heat Release Rate (HRR), Total Heat Release, Side Heat Flux, Pressure Pulse, Centerline Temperatures, Side Temperatures

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2X2

2X4

Primary battery

NITECORE

Panasonic

6X6

10X10

Secondary battery

Samsung

SANYO

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– Battery Research

Reduced-scale ISO9705 platform

Type K Thermal Couple for Centerline Temperature

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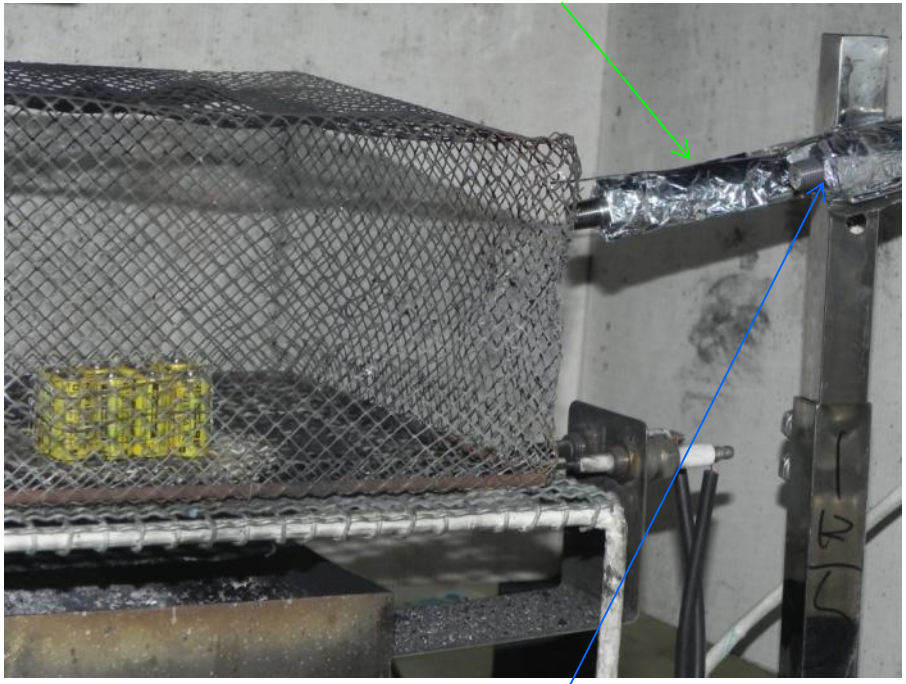
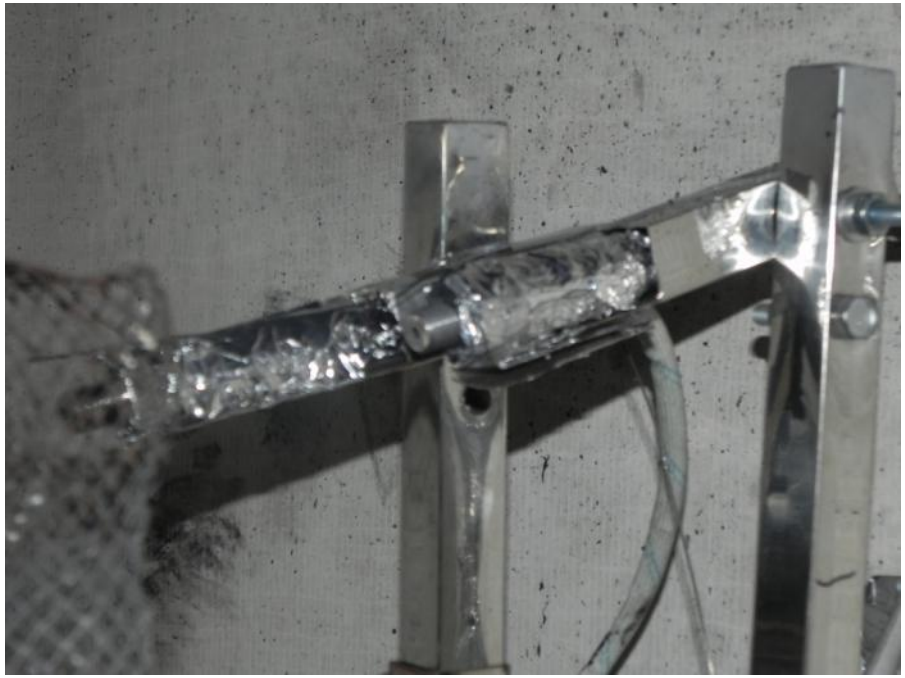
– Battery Research

Goal: Capture pressure pulses in an open volume

Pressure at 20cm from the center at Right





Two OMEGA pressure sensors at the right side

Pressure at 30cm from the center at Right

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– Battery Research

Flame Exposure:
Propane heater

Propagation thermal runway test:
Electric heater

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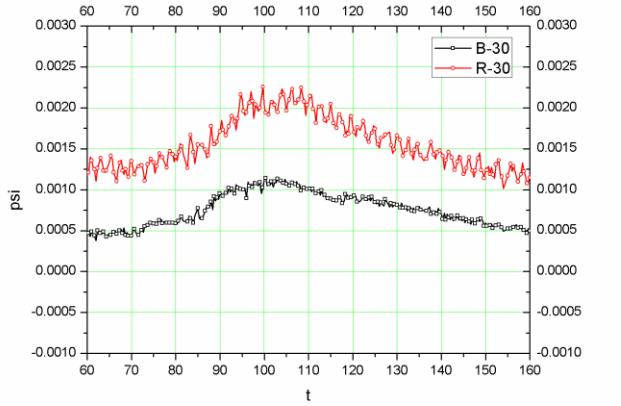
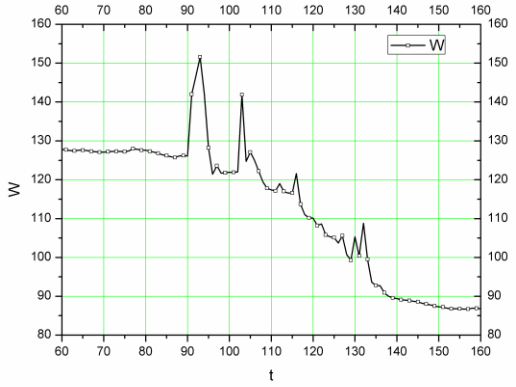
– Battery Research

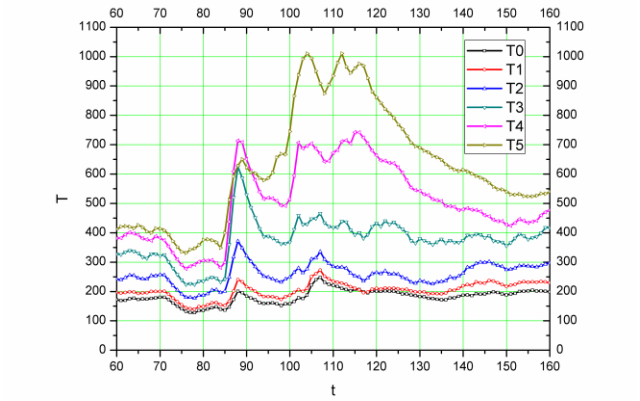
Data example for 2 x 4 Primary Battery test



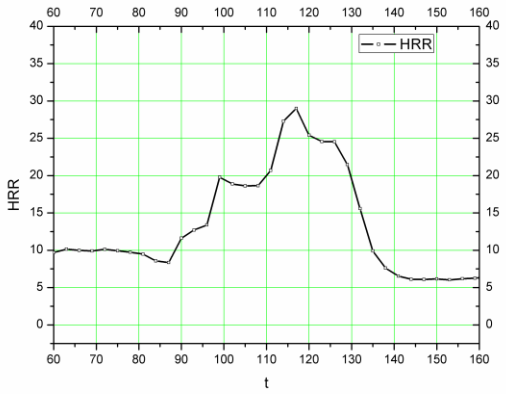
Pressure at back and right



Weight loss



Temperature at the centerline



HRR

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– Battery Research

Batteries after the tests












TEST OBSERVATIONS

- Test setup successfully captured the HRR for bulk tests of Lithium Batteries along with some of the pressure pulses simultaneously within an open space environment .
- Locating the pressure sensors closer to the centerline of the batteries resulted in higher pressures captured, but also resulted in greater risk of sensors being damaged due to extreme temperatures.
- At the beginning of the explosions, the burning of propane was temporarily reduced, aligning with the majority of CO2 vented.
- A correlation among HRR, Pressure, Mass loss rate and centerline temperature was observed.

REMAINING CHALLENGES

- Random explosion of the batteries or the vented gases causes difficulties in measuring explosions from multiple directions – different methodology and setup is advised for more precision.
- Increasing the quantity of batteries under test will also increase the solid matter ejection (splatter) and explosions, requiring facility changes for measurement and for safety
- Modeling the impact of multi-factors associated with the batteries will be challenging

Boeing Lithium Battery Cargo Task Group
- Summary

- Increasing Awareness within industry of potential hazards of lithium batteries involved in fires.
- Some dangerous goods handling regulatory changes have been made.
- Strong industry interest is driving activity.
- Improved mitigation features are available (FCC's) and are being developed (FRC's).
- Re-assessment of aircraft level threats based on ongoing FAA testing.
- Modeling lithium battery fire threats.

Boeing Lithium Battery Cargo Task Group
- Next Steps

- Encourage IATA to release Lithium Battery Transport Best Practices
- Encourage continued industry cooperation in the development of Fire Resistant Containers for cargo, through participation in ISO and SAE standards committees.
- Continue efforts to increase airline, shipper, freight forwarder awareness (e.g. IATA lithium battery transport workshops)
- Continue CAST SE-126 activities
- Encourage development of an industry team, led by the FAA, to assess strategies to mitigate potential hazards associated with the carriage of lithium batteries.
- Share results from Boeing / USTC battery testing at future IASFPWG meeting.

Boeing Lithium Battery Cargo Task Group

THANK YOU