Hazards and Risks Incurred When Shipping Lithium Batteries as Cargo by Air

1. Video: Photo of various lithium batteries, lithium battery powered devices.

   Text: Lithium batteries are a common type of portable power source. They are used to power cell phones, laptops, tablets, portable power tools, electric vehicles, and many other devices. These batteries are available as single use lithium metal batteries or rechargeable lithium ion batteries. Lithium-ion cells and batteries come in many different sizes. Generally, the hazard increases with the increased size of the cell or battery. Large automotive batteries, including untested prototypes, are often shipped by air. All forecasts indicate that large sized cells and batteries will see significant growth over the next decade.

2. Video: Flammability Comparison of Lithium Primary, Lithium Ion and Nickel Metal Hydride Batteries.

   Text: Lithium batteries are constructed differently from other common batteries such as alkaline, Nickel Cadmium, nickel metal hydride and lead acid. Unlike those other batteries, which are water based, lithium batteries use a flammable electrolyte and single use batteries have flammable lithium metal as part of their construction. The demonstration video illustrates the flammability differences between lithium metal, lithium-ion and other chemistry rechargeable batteries, in this case nickel metal hydride. For convenience, a low intensity alcohol fire is being used to heat the batteries, forcing them into thermal runaway. Thermal runaway is a state where there is a sudden and very rapid uncontrollable pressure and temperature rise within the battery. The lithium metal 123A sized batteries in the left hand bay can be seen jetting flaming electrolyte and small particles of molten flaming lithium metal. In the center bay, the lithium-ion 18650 sized batteries are slower to go into thermal runaway, but also jet flaming electrolyte. Each lithium battery type present risks, the difference is timing and intensity. The non-lithium batteries (nickel metal hydride) in the right hand bay are essentially inert under these conditions. Seven batteries of each type were used in this demonstration. Lithium batteries such as these two examples are often shipped in packages by themselves and may be shipped in large quantities.

3. Video: 5000 Cell Lithium-Ion 18650 Propagation Test.

   Text: When lithium batteries are packaged together, thermal runaway in a single battery can generate enough heat to cause other nearby batteries to go into thermal runaway. This process, called propagation, will continue from battery to battery and from package to package until all batteries have been consumed. In this video, a single battery was simulated in thermal runaway. The heat generated from the single battery caused adjacent batteries to go into thermal runaway. Thermal runaway propagated within the package and then from package to package.

4. Video: Full Scale Lithium Battery Testing (Class E Compartment).

Text: Full Scale Fire Tests on aircraft at the FAA Technical Center performed under realistic conditions, have shown that the class E and class C cargo compartment fire suppression systems are not capable of controlling a lithium battery fire involving a large number of batteries. The tests simulated a single cell in thermal runaway that propagated to the adjacent cells in the package and from package to package. Fires of this type build up rapidly generating extreme temperatures, thick smoke, increased compartment pressure and toxic flammable gases. The thick smoke may penetrate into the flight deck and interfere with flight crew's ability in operation of the aircraft as experienced in the fatal UPS, Dubai and Asiana, China Sea accidents. The fire intensity can cause structural damage to the aircraft. Halon 1301, the fire suppressant agent in class C cargo compartments, is not effective in controlling a lithium metal battery fire and will not prevent the propagation of thermal runaway in lithium-ion fires. Due to the unusual hazards of Lithium metal battery fires, and the ineffectiveness of halon, the United States prohibited bulk shipments of Lithium metal batteries, as cargo, in passenger aircraft in December of 2004. The International Civil Aviation Organization (ICAO) enacted a similar prohibition on January 1, 2015.

5. Video: 5000 Lithium Ion Battery Test (Fire Resistant Container with Suppression).

   Text: Tests of prototype fire resistant containers or unit load devices (ULDs) were conducted. In this video, the cargo load included five thousand lithium ion 18650 sized batteries. A single battery in thermal runaway was simulated, resulting in thermal runaway propagating throughout the shipment. The video illustrates the danger of concentrating the flammable gases given off by lithium batteries in a confined space. Ignition of these gases can result in an explosion. Only a small number of lithium batteries were involved and contributed to the fire prior to the explosion.

6. Video: Combustion Sphere.

   Text: Analysis of the flammable gases emitted during thermal runaway have shown that in addition to flammable hydrocarbons and carbon monoxide, the gas may contain up to thirty percent pure hydrogen. Large quantities of gas can be produced during thermal runaway. For lithium ion batteries, the volume of gas produced increases as the state of charge increases.

7. Video: Thermal Runaway Flammable Gases.

   Text: Full scale tests have confirmed that the design concentration of Halon 1301 in class C cargo compartments, which is 5%, is insufficient to suppress an explosion of the flammable gases released during lithium battery thermal runaway. The ineffectiveness of halon is due mostly to the large quantity of the vented flammable hydrogen gas generated by the batteries.

8. Video: Class C Cargo Compartment Flammable Gas Test.

   Text: Tests have shown that the gases produced by as little as six lithium-ion batteries can produce enough flammable gas, that when confined and ignited, can raise the pressure in a

class C cargo compartment more than one pound per square inch (psi) or 6.89 kilo Pascals (kPa). This can cause damage to the cargo liners, activate the pressure relief features, allow the fire suppressant agent to leak out of the compartment, and cause passengers and crew to be exposed to the smoke and gases. An explosion from the gases produced by a large number of batteries in thermal runaway could potentially cause structural damage to the aircraft.

9. Video: State of Charge Propagation Tests.

   Text: Many lithium-ion batteries are shipped at a 50 percent state of charge. Tests have shown that there is an improvement in safety when the state of charge for lithium-ion batteries is reduced to thirty percent or less. Lithium-ion batteries at thirty percent state of charge are less likely to go into thermal runaway, are less likely to propagate during thermal runaway, and produce less flammable gases when in thermal runaway. In contrast, lithium ion batteries shipped at higher states of charge are more likely to go into thermal runaway, more likely to propagate and produce greater quantities of flammable gases. It is very difficult, however, to verify the state of charge of a battery presented for shipment.

10. Video: High speed video of 18650 Lithium-Ion Cell in Thermal Runaway.

    Text: Both lithium metal and lithium ion battery types can go into thermal runaway. Again, thermal runaway is a state where there is a sudden and very rapid uncontrollable pressure and temperature rise within the battery. The consequences of thermal runaway depend on the specific battery chemistry, the state of charge, the size of the battery (energy storage capacity), and may include one or more of the following effects: The contents of the battery will be expelled or vented as flame, smoke, toxic/flammable gases, the battery may burn, explode, or become a projectile. Thermal runaway can be caused by an external short, an internal manufacturing defect in the battery, physical damage to the battery, over heating the battery, and over charging or rapid discharging of the battery.

11. Video: FAA Fire Safety Web page address

    Text: For more information on the hazards of shipping lithium batteries, including a transcript of this video, please visit the FAA Fire Safety web page.

    A report is available, “Summary of FAA Studies Related to the Hazards Produced by Lithium Cells in Thermal Runaway in Aircraft Cargo Compartments”, H. Webster et al, June 2016. DOT/FAA/TC-16/37.