International Civil Aviation Organization

WORKING PAPER

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DANGEROUS GOODS PANEL (DGP)
WORKING GROUP OF THE WHOLE ON LITHIUM BATTERIES

FIRST MEETING

Montréal, 6 to 10 February 2012

Agenda Item 2: ANC work items:
2.3: Lithium battery related tests

TEST DATA ON LITHIUM ION BATTERIES

(Presented by PRBA – The Rechargeable Battery Association)

SUMMARY

This paper provides information on lithium ion battery test data that has been prepared for PRBA. It also includes a recent letter from PRBA to the ICAO DGP Secretariat regarding a recent FAA study on the potential fire threat from the bulk shipment of lithium batteries.

1. INTRODUCTION

1.1 At DGP/23 meeting, the Secretariat requested data on tests that have been conducted on lithium batteries. Since 2005 PRBA has contracted with an independent third-party to conduct several tests on lithium ion cells and batteries in response to rulemakings on lithium batteries from the U.S. Department of Transportation and testing by the U.S. Federal Aviation Administration. A summary of the four tests conducted for PRBA and a weblink to where the test reports can be downloaded are provided in Appendix A to this paper.

1.2 The DGP also may be interested in a recent report prepared in 2011 for the U.S.-based Fire Protection Research Foundation entitled "Lithium-ion Batteries Hazardous and Use Assessment." The report provides a very good literature review of lithium ion battery technology, failure modes and events, usage, codes and standards, and a hazard assessment during the life cycle of storage and distribution. It also sets out a research approach toward evaluating appropriate facility fire protection strategies. The report, referenced as Exponent NFPA Report, can be downloaded from PRBA's website at http://www.prba.org/prba/publications/battery_studies_and_reports/Default.ashx.

1.3 We also wanted to alert the DGP to a letter PRBA sent to Secretariat Rooney regarding the U.S. Federal Aviation Administration report on a risk model for freighter fire accidents caused by cargo compartment fire and possible accidents caused by lithium batteries in the next 10 years. When this report was presented to the DGP/23, PRBA noted that the study was based on flawed assumptions, unsound methodology and faulty data. Our letter to Secretariat Rooney expands on these comments. A copy of the letter is attached in Appendix B.

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APPENDIX A

LIST OF REPORTS PREPARED FOR PRBA FROM TESTING CONDUCTED ON LITHIUM ION CELLS AND BATTERIES

1. FLAMMABILITY ASSESSMENT OF LITHIUM ION BATTERIES PACKED WITH AND CONTAINED IN EQUIPMENT – MARCH 2010

A heat release analysis was conducted from testing of lithium ion batteries “contained in” and “packed with” notebook computer systems as packaged for air shipment.

Air shipment packages were analyzed to estimate the quantity of stored energy that would be released by complete combustion of all components (packing materials, plastics, notebook computer, and battery) and to compare the contribution of the battery to the heat release expected from the entire package. Flame attack tests were conducted to compare the fire behaviour of packages containing batteries to those not containing batteries. Cell initiation testing was conducted to assess the effect of a single cell internal fault occurring in a battery contained in or packed with equipment.

The analysis and test conducted showed that:

1. Analysis of notebook computer packages indicates the chemical and electrical energy contained in batteries is less than 10% of the total energy released if the entire package is burned (for the specific packages examined, it was 6% -7% with fully charged battery packs, and 5% - 6% with packs at 50% state of charge (SOC). Combustion of materials such as cardboard, paper, and plastic within the package produce the bulk of the heat release.

2. During flame attack testing in a closed chamber, flames initially attack and ignite external packaging materials (cardboard) and are likely to be self extinguished due to limited airflow before the cells in the package vent or go into thermal runaway. Cells may not vent for an extended subsequent period, or not vent at all, depending upon a variety of factors such as chamber temperature, airflow conditions, battery location, cell design, and cell SOC.

3. Flame attack testing on systems with and without batteries showed temperature and heat flux values during the initial flaming period were effectively identical (within normally expected variation of fire tests). The presence of the battery had no discernable effect on the overall heat release during this time. Subsequent cell thermal runaway and venting, if it occurs (after the initial period) can produce hot spots that cause re-ignition of combustibles, if sufficient air can enter the enclosure to sustain flaming combustion. However, under these conditions, normal, smoldering combustibles in packages without batteries can also re-ignited.

4. Cell initiation testing showed that spontaneous thermal runaway (due to an external short circuit or internal cell fault) of cells inside equipment packages, will produce smoke and soot. With cells at a reduced state of charge, flaming combustion is unlikely to occur due to limited oxygen in a closed environment. If cells are near 100% SOC, ignition of vent gases becomes more likely.

However, even when flaming combustion is initiated, the resulting fire is a short duration and relatively low intensity event, and the fire self-extinguishes due to limited oxygen in the chamber.

The report, referenced as Exponent Laptop Report, can be downloaded from PRBA's website at http://www.prba.org/prba/publications/battery_studies_and_reports/Default.ashx.

2. US FAA-STYLE FLAMMABILITY ASSESSMENT OF LITHIUM ION CELLS AND BATTERY PACKS IN AIRCRAFT CARGO HOLDS – APRIL 2005

Flammability tests were conducted on lithium ion cells and batteries. Tests were conducted on single, multiple, and bulk packaged lithium ion cells and batteries. Tests also were conducted to assess the impact on cargo hold liner material of lithium ion cells and batteries attacked by fire and the effectiveness of Halon 1301 in suppressing lithium ion cell and batteries.

The results of the tests are listed below:

1. Direct flame impingement on small, unpackaged quantities of bare cells and batteries can lead to internal thermal runaway of individual cells and venting of gases. The vent gases are generally ignited by the pre-existing flame, increasing the total heat flux produced by the fire. In a few cases, cells will rupture and ejected their contents.

2. Halon 1301 is very effective in controlling burning lithium ion cells.

3. The fires used in the testing program had minimal effects on bulk packaged lithium ion cells at 50% or less state of charge. Direct flame impingement over a few minutes on bulk packages of cells did not lead to significant venting or involvement of the cells in the fire.

4. The aircraft cargo liner material used in the testing, which is commercially available and which is believed typical, is capable of withstanding the tested flame impingement from burning gases vented by lithium ion cells subjected to external heating.

The report, referenced as Exponent Burn Box 1, can be downloaded from PRBA's website at http://www.prba.org/prba/publications/battery_studies_and_reports/Default.ashx.

3. US FAA-STYLE FLAMMABILITY ASSESSMENT OF LITHIUM ION CELLS AND BATTERY PACKS IN AIRCRAFT CARGO HOLDS – PRISMATIC BATTERY PACKS AND PRESSURE MEASUREMENTS – JUNE 2005

Additional flammability tests were conducted but in the current study tests were performed on single and multiple cell-phone-style (prismatic) lithium ion batteries and dynamic pressure measurements were obtained during flame attack tests on 18650-style lithium ion cells.

The results of the tests are listed below:

1. Prismatic batteries performed comparably to previously tested 18650 cells with regard to heat release and effectiveness of suppressant. Since prismatic cells are often designed to vent through

a case rupture mechanism, frequent case rupture events were observed in the prismatic battery testing.

2. Direct flame impingement on small, unpackaged quantities of prismatic batteries can lead to internal thermal runaway of individual cells and venting of gases. The vent gases are generally ignited by the pre-existing flame, increasing the total heat flux produced by the fire.

3. Halon 1301 is very effective in controlling burning lithium ion prismatic batteries.

4. The aircraft cargo liner materials used in the testing, which is commercially available and which we believe is typical, is capable of withstanding the tested flame impingement from burning gases vented by lithium ion prismatic batteries subjected to external heating.

5. When lithium ion cells vent they release gases. However, the magnitudes of measured dynamic pressure pulses, associated with venting of 18650 cells and prismatic batteries, were small; less than 0.08 psi. In a scenario representative of a cargo hold that is not airtight and where cells vent sequentially, we observed only a negligible additive pressure rise within the chamber.

The report, referenced as Exponent Burn Box 3, can be downloaded from PRBA's website at http://www.prba.org/prba/publications/battery_studies_and_reports/Default.ashx.

4. EFFECT OF CELL STATE-OF-CHARGE ON OUTCOME OF INTERNAL CELL FAULTS: PRELIMINARY REPORT – AUGUST 2004

The test examined the effect of cell state-of-charge (SOC) on the outcome of a low impedance internal cell fault. The higher the SOC, the more energy available for release by an internal cell fault for comparable capacity cells. Higher energy release increases the probability of severe outcomes.

The testing showed that the severity of the outcome is strongly affected by state of charge. At 100% SOC, a refined crush would typically produce a severe outcome using a refined test method. At 70% SOC, a refined crush resulted in severe outcomes for a majority of tests for each brand. At 50% SOC, all tests but one resulted in a minimum outcome. The one test resulted in a moderate outcome (case rupture). At 40% SOC, all of the tests resulted in a minimum outcome.

The report, referenced as Exponent State of Chare Report, can be downloaded from PRBA's website at http://www.prba.org/prba/publications/battery_studies_and_reports/Default.ashx.

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APPENDIX B

FREIGHTER AIRPLANE CARGO FIRE RISK MODEL: COMMENTS ON THE WILLIAM J. HUGHES TECHNICAL CENTER STUDY

December 23, 2011

Dr. Katherine Rooney
Secretary, Dangerous Goods Panel
International Civil Aviation Organization
999 University Street
Montreal, Quebec H3C 5H7
Canada

Dear Dr. Rooney:

I commented during the ICAO Dangerous Goods Panel October 2011 meeting that the premise of the FAA's study entitled *Freighter Airplane Cargo Fire Risk Model* (September 2011) is flawed for several reasons. Although we have not been provided access to the sources, databases and model used to prepare this study, even a quick review reveals it is based on faulty data and assumptions. These include, but are not limited to, the following:

1. FAA looked at five aircraft incidents occurring since 1958. We know that batteries were onboard aircraft in two of these incidents. The FAA assumes that batteries caused those two incidents, and then develops the risk model from this basis. But no facts are presented that indicate any involvement of batteries in the incidents. The mere presence of batteries onboard certainly is not enough to justify this assumption and should not be used as the basis for subsequent studies on the cost benefit ratios for various mitigation strategies.

2. FAA assumes that "bulk shipment of lithium batteries (primary and secondary) …. were likely contributors to two of the freighter fire accidents that occurred on U.S.-registered airplanes." This assumption is unfounded. In fact, the NTSB's report on the 2006 UPS plane incident does not identify any "bulk shipments" (*e.g.*, pallets) of lithium ion or lithium metal batteries onboard the aircraft. While it is true there were several large consignments of lithium batteries on the UPS plane involved in the Dubai incident, there is nothing in the UAE GCAA reports that indicates bulk shipments of lithium batteries were "likely contributors" to the accident.

3. There is no distinction or attempt to account for what are very different shipping practices for lithium ion and lithium metal batteries. Instead, the study assumes, without substantiation, that 50% of the lithium ion and lithium metal batteries are shipped on U.S. all-cargo airlines for an average of 2,116 miles. This is not true. The bulk of lithium metal batteries are shipped by sea via cargo vessel, not by cargo aircraft. Furthermore, most of the lithium ion batteries shipped via U.S. airlines are either included in or shipped with products, not shipped as batteries, either individually or in bulk, thereby greatly overstating the risk.

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4. Many other FAA's assumptions are inconsistent with fact. For example, it appears that FAA assumed that 100% of lithium battery cell production is shipped by air in bulk form. That is a wrong assumption. As noted in paragraph 3 above, most bulk shipments of lithium metal batteries are shipped by sea via cargo vessel, not cargo aircraft. In addition, an economic analysis prepared for PRBA in 2010 in response to a U.S. Department of Transportation rulemaking on lithium batteries showed that only 67% of imported cellular phones, 81% of imported notebooks and 69% of imported lithium ion cells and battery packs moved via air to the United States in 2009.

5. The Total 2010 Battery RTM shown in Table 3 (164.5 million) is 40% smaller than the Battery RTM that is calculated using the method and values described in the text. The corrected calculation, making no other changes in methodology, is provided below. This is not to endorse that methodology, however. The methodology also is wrong at least because it makes use of erroneous estimates of U.S. carrier shipments and product weight. Other inputs also may be wrong, but are not facts with which PRBA is familiar.

   - Lithium ion cells in 2010 x Multiplier for lithium primary (metal) cells x percent carried by U.S. carriers x weight of a typical cell x average stage flight x tons per pound =
   - 3.5 billion* x 1.25 x 50% x 0.1 lbs x 2116 miles x 1 ton/2000 lbs = 231 million

   (* Estimated from Figure 3. Error is +/- 0.2 billion)

6. FAA claims there is a big difference in risk between "battery related" and "non battery related" shipments. However, in fact there is <u>no</u> statistically significant difference between the "battery related" and "non-battery related" incident rates. (The appropriate statistical analysis is based on 2-sample Poisson rates and comparing 3 incidents per 21,286,040,868 RTM ("non battery related") and 2 incidents per 164,521,543 RTM ("battery related")). In fact, the 95% confidence interval indicates that the incident rate for "non-battery related" may be <u>higher</u> than the "battery related" incident rate.

7. The FAA assumes risk is proportional to RTM. However, in the Conclusion on page 25, the FAA notes that "RTMs may not be the best basis for the prediction of cargo fire accidents...." At the least, the study is inconsistent; in fact, since it is correct that RTMs are not a good basis for estimating accidents, the Agency's proportionality analysis is wrong.

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Please contact me if you would like to discuss this matter in more detail. I can be reached at 202.719.4109 or gkerchner@wileyrein.com.

Sincerely,

George A. Kerchner

George A. Kerchner
Executive Director

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