Aircraft Accident Report No: 2/2015

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Report on the serious incident to Boeing B787-8, ET-AOP London Heathrow Airport on 12 July 2013

Registered Owner and Operator:	Ethiopian Airlines
Aircraft Type:	Boeing B787-8
Nationality:	Ethiopia
Registration:	ET-AOP
Place of Accident:	London Heathrow Airport
Date and Time:	12 July 2013 at 1534 hrs

Introduction

On the afternoon of Friday 12 July 2013 the Air Accidents Investigation Branch (AAIB) was notified of a ground fire in a parked and unoccupied Boeing 787-8 on Stand 592 at London Heathrow Airport. The circumstances surrounding the occurrence did not fall within the definitions of an accident or serious incident as defined in ICAO Annex 13, however, the Chief Inspector, in exercise of his powers under the Civil Aviation (Investigation of Air Accidents and Incidents) Regulations 1996, initiated an investigation, treating the occurrence as a serious incident and invoking the protocols of ICAO Annex 13 with regard to the participation of other interested States. An investigation was commenced immediately and a team of AAIB Inspectors was deployed.

The AAIB were assisted in the investigation by Accredited Representatives from the National Transportation Safety Board (NTSB) (representing the State of Design and Manufacture), the Civil Aviation Authority of Ethiopia (representing the State of Registry and the Operator) and the Transportation Safety Board of Canada (representing a State of component manufacture), with technical advisors from the Federal Aviation Administration (FAA), the operator and the aircraft and component manufacturers.

Summary

The aircraft suffered extensive heat damage in the upper portion of the aircraft's rear fuselage, in an area coincident with the location of the Emergency Locator Transmitter (ELT). The absence of any other aircraft systems in this area containing stored energy capable of initiating a fire, together with evidence from forensic examination of the ELT, led the investigation to conclude that the fire originated within the ELT.

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The ground fire on ET-AOP was initiated by the uncontrolled release of stored energy from the lithium-metal battery in the ELT. It was identified early in the investigation that ELT battery wires, crossed and trapped under the battery compartment cover-plate, probably created a short-circuit current path which could allow a rapid, uncontrolled discharge of the battery. Root Cause testing performed by the aircraft and ELT manufacturers confirmed this latent fault as the most likely cause of the ELT battery fire, most probably in combination with the early depletion of a single cell.

Neither the cell-level nor battery-level safety features prevented this single-cell failure, which propagated to adjacent cells, resulting in a cascading thermal runaway, rupture of the cells and consequent release of smoke, fire and flammable electrolyte.

The trapped battery wires compromised the environmental seal between the battery coverplate and the ELT, providing a path for flames and battery decomposition products to escape from the ELT. The flames directly impinged on the surrounding thermo-acoustic insulation blankets and on the composite aircraft structure in the immediate vicinity of the ELT. This elevated the temperature in the fuselage crown to the point where the resin in the composite material began to decompose, providing further fuel for the fire. As a result, a slow-burning fire became established in the fuselage crown and this fire continued to propagate from the ELT location, even after the energy from the battery thermal event was exhausted.

Fourteen Safety Recommendations have been made during the course of the investigation. In addition the ELT manufacturer carried out several safety actions and is redesigning the ELT unit taking into account the findings of this investigation. Boeing and the FAA have also undertaken safety actions.

The following causal factors were identified in the ground fire:

a) A thermal runaway failure of the lithium manganese dioxide battery in the ELT resulted in the uncontrolled release of stored energy within the battery cells.

b) The location and orientation of the ELT, and the compromised seal on the battery cover-plate, allowed the resulting hot gas, flames and battery decomposition products to impinge directly on the aircraft's composite fuselage structure, providing sufficient thermal energy to initiate a fire in the rear fuselage crown.

c) The resin in the composite material provided fuel for the fire, allowing a slow-burning fire to become established in the fuselage crown, which continued to propagate from the ELT location even after the energy from the battery thermal runaway was exhausted.

d) The Navigation Radio System safety assessment conducted in support of the ELT certification, did not identify any ELT battery failure modes which could represent a hazard to the aircraft, and therefore these failure modes were not mitigated in the ELT design or the B787 ELT installation.

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The following factors most likely contributed to the thermal runaway of the ELT battery:

a) The trapped ELT battery wires created a short-circuit condition, providing a current path for an unplanned discharge of the ELT battery.

b) The ELT battery may have exhibited an unbalanced discharge response, resulting in the early depletion of a single cell which experienced a voltage reversal, leading to a thermal runaway failure.

c) The Positive Temperature Coefficient (PTC) protective device in the battery did not provide the level of external short-circuit protection intended in the design.

d) There was no evidence that the reset behaviour, and the implications of the variable switching point of the PTC, had been fully taken into account during the design of the ELT battery.

e) The absence of cell segregation features in the battery or ELT design meant the single-cell thermal runaway failure was able to propagate rapidly to the remaining cells.

Findings

General

1) The fire in ET-AOP initiated while the aircraft was parked, unpowered and unoccupied.

2) The extent of the damage to the ELT and the absence of other systems in the vicinity of the ELT capable of providing an ignition source, identified the ELT as the source of the fire.

ELT battery failure

3) The ELT fire resulted from the uncontrolled release of the stored energy within the battery cells.

4) The battery failure most likely resulted from an external short-circuit, in combination with the early depletion of a single cell, leading to thermal runaway which propagated to adjacent cells.

5) The ELT battery failure did not result from external heating, mechanical damage or environmental conditions within the aircraft.

6) The external short-circuit was created by the battery wires being crossed and trapped under the ELT battery compartment coverplate, when the ELT battery was last accessed.

7) The trapped wires remained undetected until the incident.

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8) The PTC protective device did not provide the level of external short-circuit protection intended in the battery design.

9) The trapped wires compromised the environmental seal of the battery cover-plate, allowing the escape of hot gas, flames and battery decomposition products.

10) The location and orientation of the ELT within the aircraft, and the compromised seal on the battery cover-plate, allowed the hot gas, flames and battery decomposition products to impinge directly on the composite fuselage structure, providing sufficient thermal energy to initiate a slow-burning fire in the rear fuselage crown.

Battery design

11) The range of temperatures across which the PTC is required to operate means that in certain conditions, the switching point of the PTC exceeds the rated maximum continuous discharge current for the battery.

12) The PTC reset behaviour was not well understood during the battery design.

13) The absence of cell segregation features in the battery or ELT design contributed to the severity of the incident, as the initial cell thermal runaway was able to propagate rapidly to the remaining cells.

Battery and ELT certification

14) The ELT battery held a valid TSO-C142 approval.

15) The guidance and requirements of RTCA DO-227, invoked by TSO-C142, were outdated and did not adequately take account of advances in lithium battery technology since the inception of DO227 in 1995.

16) The NRS system safety assessment, conducted in support of the B787 certification campaign, did not identify any battery failure modes which could represent a hazard to the aircraft, and as a result, the ELT battery was not identified as a potential ignition source.

Structural fire

17) The location of the fuselage insulation blankets in the region of the ELT allowed sufficient heat to be retained close to the skin to allow the fire to become self-sustaining.

18) The fire progressed outward from the location of the ELT, in the space between the insulation blankets and the fuselage skin, moving between frame bays, through the stringer cut-outs in the shear ties.

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19) There was no evidence that a flash-over fire occurred, or was about to occur, nor that the rate of progression of the structural fire was increasing.

20) Structural loads modelling, based on the damage sustained during the ground fire, determined that the aircraft's ability to carry flight loads had been compromised.

21) Thermal modelling conducted to assess the likely effects of a similar fire occurring in-flight, predicted that the increased rate of convective cooling, from the external airflow and lower air temperatures, would substantially reduce the progression of such a fire.

22) Boeing's structural loads modelling, based on the predicted damage from the thermal modelling of an in-flight ELT fire, predicted that the fuselage would remain capable of carrying flight loads but might experience a depressurisation if the damage were extensive.

Fire detection and firefighting

23) The location of the ELT in the fuselage crown made it difficult for the Heathrow Airport RFFS to locate the source of the fire.

24) At the time of the incident, the published ARFF information for the B787 did not indicate the location of ELT battery and the Heathrow Airport RFFS were not aware that there was a lithium-metal battery above the ceiling panels that could be the source of the fire.

25) In the event of an in-flight ELT battery fire, detecting the fire and locating its source, would be challenging for cabin crew, due to the inaccessible location of the ELT in the cabin.

26) In the event of an in-flight ELT battery fire, fighting the ELT fire and any subsequent structural fire would be challenging for cabin crew, due to the inaccessible location of the ELT in the cabin.

Toxicity

27) It has not been possible to determine accurately the composition and quantity of the combustion products produced by the structural fire.

Aircraft certification aspects

28) At the time of the B787 certification the ELT battery was not identified as a possible ignition source close to the aircraft skin, so the composite flammability tests did not take this into account as a specific source of ignition.

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Safety Recommendations

Safety Recommendation 2013-016 issued on 18 July 2013

> **Safety Recommendation 2013-016**
>
> It is recommended that the Federal Aviation Administration initiate action for making inert the Honeywell International RESCU 406AFN fixed Emergency Locator Transmitter system in Boeing 787 aircraft until appropriate airworthiness actions can be completed.

In response to Safety Recommendation 2013-016, the FAA issued Airworthiness Directive (AD) 2013-15-07 on 26 July 2013 requiring, within 10 days, either the removal, or inspection and corrective action as necessary, of Honeywell RESCU 406AFN ELTs installed on B787-8 aircraft[1].

Honeywell subsequently issued an Alert Service Bulletin (SB) instructing operators of all aircraft types equipped with specified RESCU 406AF / AFN ELTs, to perform an inspection of the ELT and its battery and to correct any anomalies. Embodiment of this SB was mandated by Transport Canada AD CF-2013-25 issued 15 Aug 2013 and FAA AD 2013-18-09 issued 18 September 2013.

This Safety Recommendation has been assessed by the AAIB as '*Adequate – Closed*'.

Safety Recommendation 2013-017 issued on 18 July 2013

> **Safety Recommendation 2013-017**
>
> It is recommended that the Federal Aviation Administration, in association with other regulatory authorities, conduct a safety review of installations of Lithium-powered Emergency Locator Transmitter systems in other aircraft types and, where appropriate, initiate airworthiness action.

In April 2014 the FAA provided the following response to the recommendation:

> *'The FAA is currently conducting a safety review of Lithiumpowered ELT systems with other regulatory authorities to identify any unsafe conditions in other aircraft types. The FAA expects to provide an update on the status of the safety review by March 31 2015.'*

This Safety Recommendation has been assessed by the AAIB as '*Adequate – Closed*'.

Footnote

[1] On 26 July 2013 the European Aviation Safety Agency (EASA) issued AD 2013-0168, with the same intent.

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Safety Recommendations 2014-020 to 2014-024

The following Safety Recommendations were issued on 18 June 2014.

Safety Recommendations 2014-020

It is recommended that the Federal Aviation Administration develop enhanced certification requirements for the use of lithium-metal batteries in aviation equipment, to take account of current industry knowledge on the design, operational characteristics and failure modes of lithium-metal batteries.

Safety Recommendation 2014-021

It is recommended that the Federal Aviation Administration require that electrical performance and design-abuse certification tests for lithium-metal batteries are conducted with the battery installed in the parent equipment, to take account of battery thermal performance.

Safety Recommendation 2014-022

It is recommended that the Federal Aviation Administration work with industry to determine the best methods to force a lithium-metal cell into thermal runaway and develop design-abuse testing that subjects a single cell within a lithium-metal battery to thermal runaway in order to demonstrate the worst possible effects during certification testing.

Safety Recommendation 2014-023

It is recommended that the Federal Aviation Administration require equipment manufacturers wishing to use lithium-metal batteries to demonstrate (using the design-abuse testing described in Safety Recommendation 2014-022) that the battery and equipment design mitigates all hazardous effects of propagation of a single-cell thermal runaway to other cells and the release of electrolyte, fire or explosive debris.

Safety Recommendation 2014-024

It is recommended that the Federal Aviation Administration review whether the Technical Standard Order (TSO) process is the most effective means for the certification of lithium-metal batteries installed in aircraft equipment, the actual performance of which can only be verified when demonstrated in the parent equipment and the aircraft installation.

As of June 2015, final response from the FAA is awaited for Safety Recommendations 2014-020 to 024, however in a letter dated 31 October 2014, the FAA provided the following interim comment in respect of Safety Recommendation 2014-022:

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'We plan to request that the Radio Technical Commission for Aeronautics (RTCA) task Special Committee 225, 'Rechargeable Lithium Batteries and Battery Systems', to revise and update RTCA Document DO-227, 'Minimum Operational Performance Standards for Lithium Batteries', for non-rechargeable lithium metal batteries. The revision would include methods to force lithium metal cells into thermal runaway and develop design abuse testing that would subject a single cell within a lithium metal battery to thermal runaway conditions.

The tasking would include exploring the mitigation of the worst possible effects of this condition during certification testing. We plan to include evaluation criteria to ascertain pass/fail criteria under these conditions.'

In the same correspondence, the FAA provided the following interim comment in respect of Safety Recommendation 2014-024:

'We believe a Technical Standard order (TSO) is effective in approving the design and production of an article to meet the Minimum Performance Standards. A TSO alone is not sufficient for certification approval. In order to complete a certification of a lithium metal battery installed in aircraft equipment, an airworthiness regulation approval is required. The airworthiness regulation must be complied with during Type certification, and Supplemental Type certification (including their respective amendments).

I believe the FAA has effectively addressed Safety Recommendation [2014-024] and we do not plan any further action.'

Safety Recommendations 2015-014 to 2015-021

The following additional Safety Recommendations are made in this report:

Safety Recommendation 2015-014

It is recommended that the Federal Aviation Administration, in conjunction with the European Aviation Safety Agency and Transport Canada, conduct an assessment of the circuit protection offered by the existing Honeywell RESCU 406AF and 406AFN ELT battery, to determine whether the ELT/battery design incorporates an acceptable level of circuit protection to mitigate against external short-circuits and unbalanced discharge.

Safety Recommendation 2015-015

It is recommended that the Federal Aviation Administration, in conjunction with the European Aviation Safety Agency and Transport Canada, conduct a review of installed aircraft equipment on transport category aircraft powered by lithium-metal batteries, which have been approved under TSO-C142 /C142A or by equivalent means, to ensure that the design of such batteries incorporates an acceptable level of circuit protection to mitigate against known failure modes including, but not limited to, external short-circuits and unbalanced discharge.

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Safety Recommendation 2015-016

It is recommended that the Federal Aviation Administration, in conjunction with the European Aviation Safety Agency and Transport Canada, require equipment manufacturers intending to use lithium-metal batteries in aircraft equipment to demonstrate that the battery design incorporates an acceptable level of circuit protection to mitigate against known failure modes including, but not limited to, external short-circuits and unbalanced discharge.

Safety Recommendation 2015-017

It is recommended that the Federal Aviation Administration, in conjunction with the European Aviation Safety Agency and Transport Canada, require equipment manufacturers, intending to use lithium-metal batteries in aircraft equipment, to quantify the heat produced by the battery over a range of discharge conditions and demonstrate that the battery and equipment design can adequately dissipate the heat produced.

Safety Recommendation 2015-018

It is recommended that the Federal Aviation Administration, in conjunction with the European Aviation Safety Agency and Transport Canada, require the manufacturers of lithium-metal batteries and manufacturers of aircraft equipment powered by lithium-metal batteries, to conduct battery-level and equipment-level 'failure mode and effects analyses' to identify failure modes and their effects.

Safety Recommendation 2015-019

It is recommended that the Federal Aviation Administration, in conjunction with the European Aviation Safety Agency and Transport Canada, review all previously-approved aircraft equipment powered by lithium-metal batteries to determine whether they comply with the intent of the *'Toxic Gas Venting Precautions'* described in TSO-C142/ TSOC142a Appendix 1.

Safety Recommendation 2015-020

It is recommended that the Federal Aviation Administration, in conjunction with the European Aviation Safety Agency and Transport Canada, review whether the *'Toxic Gas Venting Precautions'* described in TSO-C142/ TSO-C142a Appendix 1 should be applied to portable aircraft equipment powered by lithium-metal batteries.

Safety Recommendation 2015-021

It is recommended that the Boeing expedite the modelling of the B787 Environmental Control System, to examine the distribution of the ELT battery combustion products through the aircraft cabin, and demonstrate the results of this modelling to the Federal Aviation Administration.

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