EASA
European Union Aviation Safety Agency

SABATAIR:
Safe Transporation of battery by air

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EASA Certification Directorate

Tenth Triennial International Aircraft Fire and Cabin Safety Research Conference

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Your safety is our mission.

An Agency of the European Union

SABATAIR Research Project

SaBatAir Project
(Safe Battery Transport by air)

- Research project funded by the European Union and supervised by EASA and DG MOVE with the support of a Scientific Committee.

- The Consortium:

SABATAIR Research Project

- Assessment of the effectiveness of the test methods as described in draft AS6413 dated 12th November 2018 issued by the SAE G-27 Committee

→ Give inputs and recommendations to the SAE G-27 committee

- Study and assess the effectiveness of potential mitigating measures against fire risk related to the transport of lithium metal and lithium ion batteries on Large Aeroplanes.

- Develop guidelines to support the production of a safety risk assessment for operators.

SABATAIR Research Project

Task 1	Definition of Baseline - Review of State-of-the-Art and Hazard Identification
Task 2	The assessment of the definition and of the effectiveness of the test methods defined in the draft AS 6413
Task 3	Identification and assessment of additional mitigating measures related to packaging solutions or based on multi-layered approaches
Task 4	Evaluation of the effectiveness of the proposed mitigating measures through testing in an environment representative of a typical large aeroplane Class C cargo compartment
Task 5	Development of guidance to support a safety risk assessment for the air transport of lithium batteries/cells

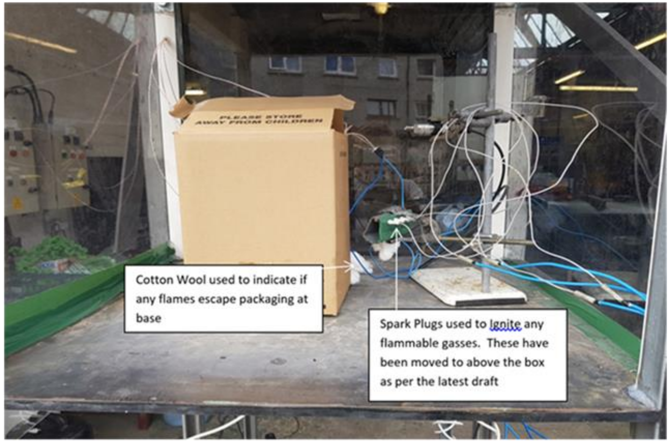
Task 2: assessment of draft AS6413

Initial objectives

- Review of three test methods from the draft SAE AS6413 (Nov 2018 version):
  - Test(VIII) Reduced Cell configuration
  - Test (VII): Generic packaging
  - Test (I) Cells and/or batteries in specific packaging

  → Verify that reduced cell configuration test results match the results of Test(I) and Test (VII)
- Construction of test rig inline with draft SAE AS6413
- Review of available packaging and key failure modes
- Evaluation of repeatability of test results with focus on failures
- Recommendation of improvements

Task 2: assessment of draft AS6413



Setup of spark ignitors and cheesecloth

Item	Description	Calibration method
Chamber	Unistrut/Perspex design. Variable height floor to adjust air space as described in section 7 of the standard.	Chamber filled with CO_2 and verified that CO_2 level had not changed after 1 hour showing less than one air exchange.
Spark Ignitors	Motor vehicle spark ignitors x 4, sparking at 1HZ	N/A
Pressure sensor	642R-601 programmable pressure transmitter ranging from 0 – 6 Bar	Manufacturer calibrated with ISO17025 certificate
Thermocouples	7 K-type thermocouples	In house process against ISO 17025 traceable equipment @ 100°C and 200°C
Data Logger	Squirrel SQ2020 Data logger	N/A
Heater Cartridge	300W 10mm x 650mm heating cartridge	ISO 17025 certified methodology
PIC controller	Programmable controller for heating cartridge	N/A

All the tests were performed at Impact Solutions (Scotland)

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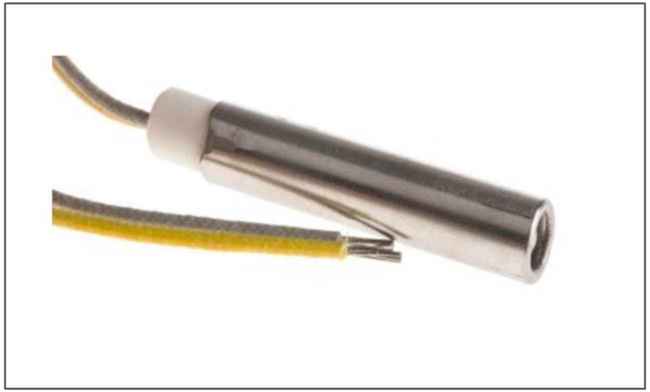
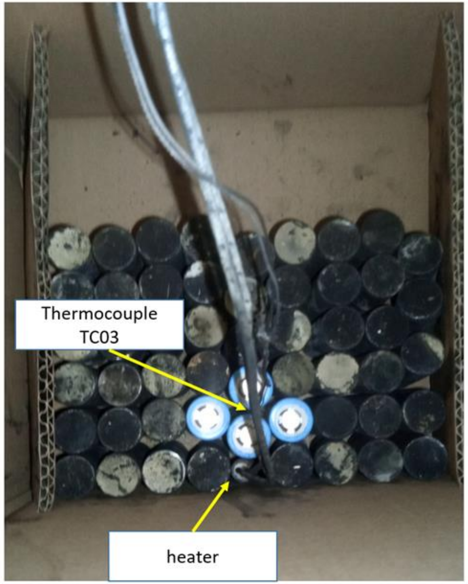
Task 2: assessment of draft AS6413

- The test chamber functionalities were validated with some initial tests on some random cells.
- The tests were conducted on commercial 18650 cells 3,5Ah (NMC)
- Packaging: UN 4G Fibreboard





Task 2: assessment of draft AS6413

- Conclusion of the first set of tests with the reduced cell configuration

→ Limited repeatability of test results both at 30% and 100% SOC.

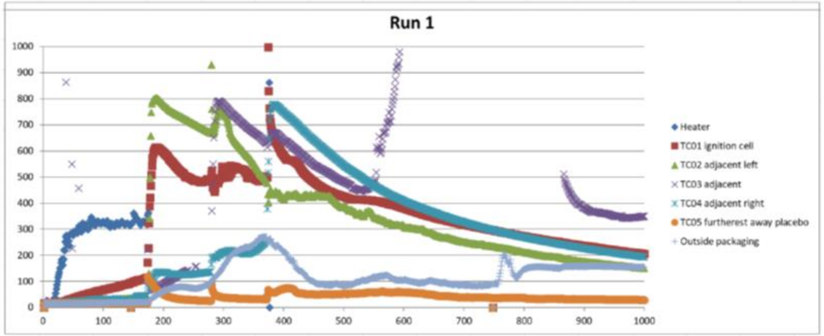
- Main identified cause: control of the heater band from the other side of the cell results in inconsistent results.

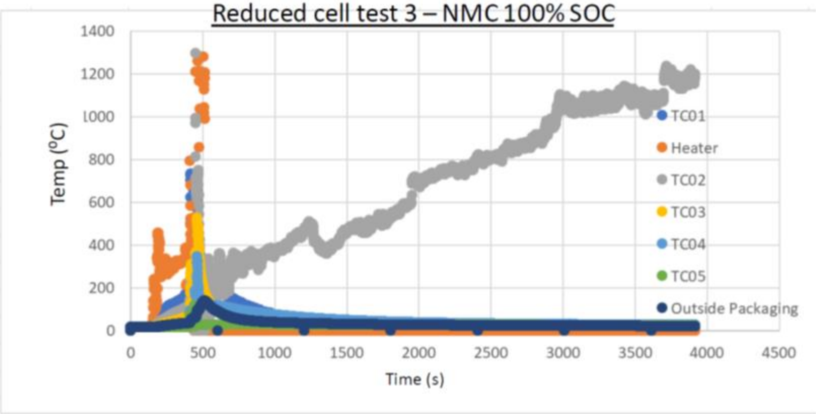
- Identified key variables:
  - Type, position and method of control of the heater
  - Amount of heat not directly transferred to the initiation cell

Task 2: assessment of draft AS6413

Repeatability assessment NMC-100%SOC

- Both 100% SOC have failed.
- Temp difference of ~ 300ºC.
- Adjacent and right hand cell much lower reaction (less propagation between cells)





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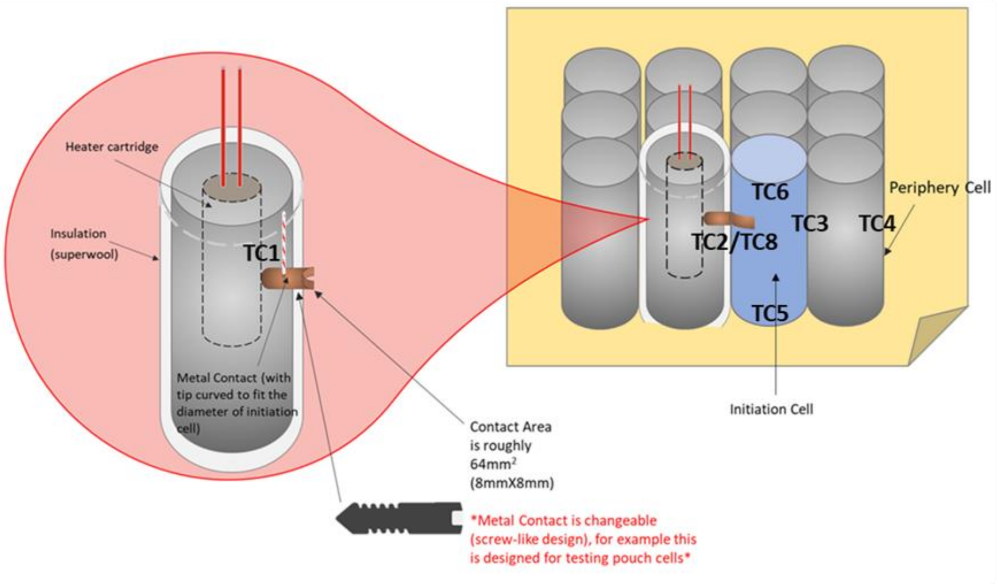
Task 2: assessment of draft AS6413

Proposed set up improvements

- Tighter control of the heat transfer to the initiation cell:
  - contact between the heater and the initiation cell is ensured by means of a metallic adapter of specified material and size;
  - the contact area between the adapter and the initiation cell is specified.
- Insulation should fully encapsulate the heater and the adapter except for the contact area with the initiation cell.
- No heat transfer from the heater to:
  - cells other than the initiation cell
  - the packaging.
- Temperature of the initiation cell monitored in proximity of the contact area with the heater and not at the back of the cell.

Task 2: assessment of draft AS6413

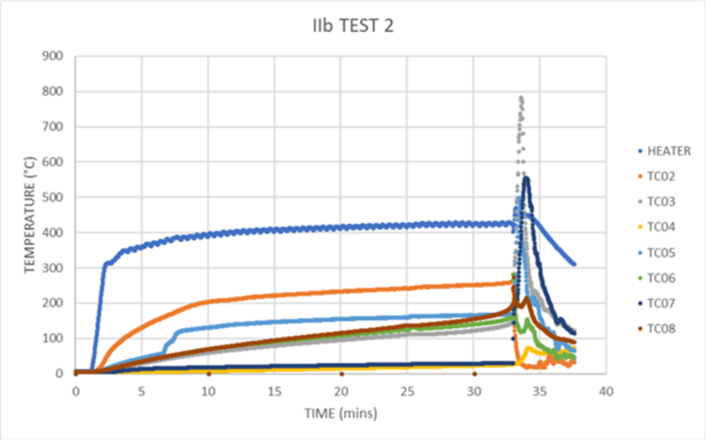


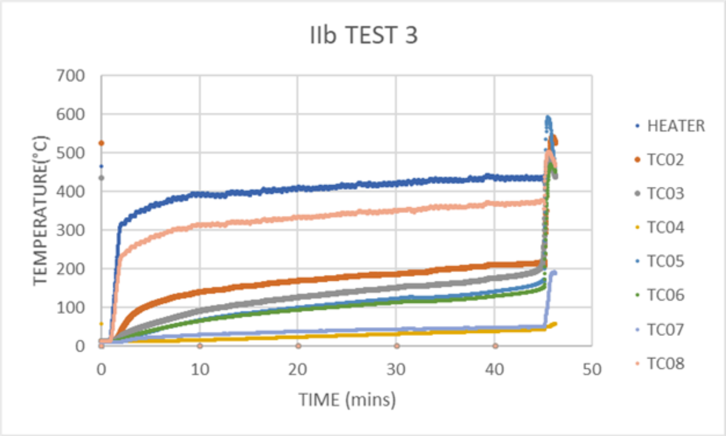
- Purpose: repeatability
- Use of 1 cell (initiation)
- Measure temperatures at points as indicated
- Temperature increase rate at T3: minimum 5°/C min.
- Hold TC3 at 200°C for 1 hour

TC1: Contact point
TC2: 5 mm away from contact area (at the same height)
TC3: Back of ignition cell
TC4: back of periphery cell
TC5: 10mm from base of initiation cell
TC6: 10mm from top of initiation cell
TC8: Mirror of TC2
Voltage

Task 2: assessment of draft AS6413

100%SOC results





- Thermal runaway observed after 35 and 45 minutes (circled in red)
- Consistent temperature peak around 600C

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Task 2: assessment of draft AS6413

Conclusions

1) The proposed test setup ensures that:

- repeatable results (thermal runaway events) are generated using linear temperature increase;
- a thermocouple close to the contact surface with the heater can be used to monitor the temperature of the initiation cell;
- the amount of energy transferred by the heater to the packaging and to the cells adjacent to the initiation cell is minimized;
- a tighter range of the rate of temperature increase could be specified.

2) The area of the contact surface between the initiation cell/battery and the heater adapter may be function of the size/design of the cell/battery to be tested.

3) Monitoring voltage drop does not significantly help determining if thermal runaway of the initiation cell is on-going.

Task 3: additional mitigating measures

The goal was to propose additional measures to be used together with packaging as part of a multi-layered approach for the mitigation of hazards associated to the transportation of lithium batteries by air.

1) Prognostic software @ ALGOLiON

2) Thermal Runaway modeling @ VITO

3) SAE G-27 conditions @ Impact Solutions

4) Class C cargo compartment fire tests @ DLR (Task 4)

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Task 3: additional mitigating measures

Target Level	Mitigation Measure	Project Priority	Test Comment	Overall Priority
Cell / Battery	Pre-evaluation of battery safety with early warning diagnostic software	HIGH	Task 3	**HIGH**
Packaging	New materials, e.g., flame retardant, intumescent, thermal insulation	HIGH	Task 2	**HIGH**
Packaging	Pre-coat existing packaging materials with intumescent materials	MEDIUM	Task 2	**MEDIUM**
Packaging	Use gas and electrolyte absorbing materials inside packaging	MEDIUM	linked High Priority Testing in Task 2	**MEDIUM**
Packaging	Fire resistant overpack (shipper)	MEDIUM	Task 4	**MEDIUM**
Packaging	Increase the minimum safe distance between cells inside the packaging	LOW	Outside of scope of Sabatair	**MEDIUM**
Alert Notification	Validation of early warning diagnostic software on to-be-transported cells	LOW	Outside of scope of Sabatair	**MEDIUM**

Task 3: additional mitigating measures

No.	Target Level	Mitigation Measure	Project Priority	Test Comment	Overall Priority
13	Operator Equipment	Fire Resistant Container (aircraft rigid ULD)	MEDIUM	if considered, part of Task 4	**MEDIUM**
14	Operator Equipment	Over-layer fire containment cover applied by Operator	HIGH	Task 4	**HIGH**
17	Operator Equipment	ULD smoke alarm, independent of aircraft system	LOW	Outside of scope of Sabataiir	**LOW**
18	Operator Equipment	ULD fire suppression system, independent of aircraft system	LOW	Outside of scope of Sabatair	**LOW**
23	Operator Equipment	Thermal insulation/non-flammable spacers between packagings in ULD	LOW	Outside of scope of Sabatair	**LOW**
24	Alarms	Heat sensors on/in ULD independenet of certified aircraft system	LOW	Outside of scope of Sabatair	**MEDIUM**
25	Alarms	Cargo compartment IR camera system aircraft equipment	LOW	Outside of scope of Sabatair	**MEDIUM**
26	Alarms	Cargo compartment HF Sensor (inorganic) aircraft equipment	LOW	Outside of scope of Sabatair	**LOW**
27	Alarms	Cargo compartment volotile organic gas sensor	LOW	Outside of scope of Sabatair	**LOW**

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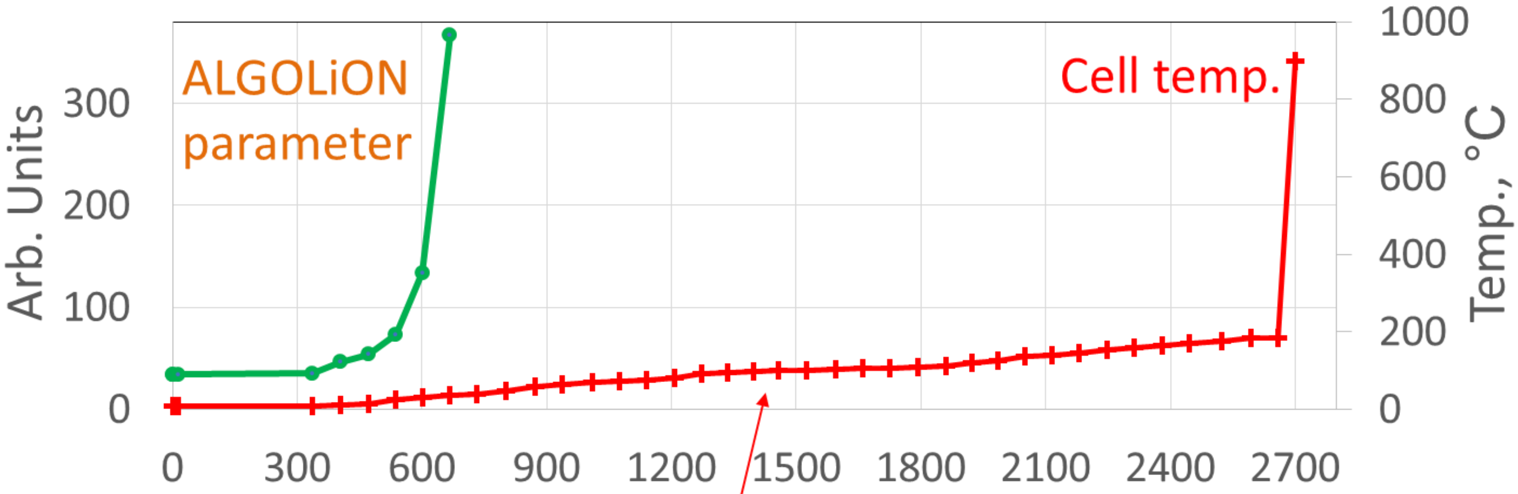
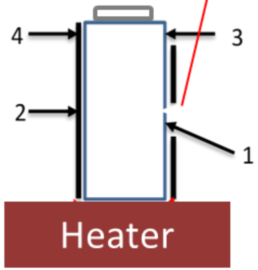
Task 3: prognostic alghorithm

- Accesses current and voltage from battery control unit during charge and discharge
- Option: use a dedicated analysis unit to ‘QC’ check cells
- Processes and analyzes signals
- Calculates several high sensitivity unique parameters
- Detects early signs of changes in cell leading to safety hazards
- Provides real time notifications
- Triggers preventive action

Task 3: prognostic alghorithm



fresh cell



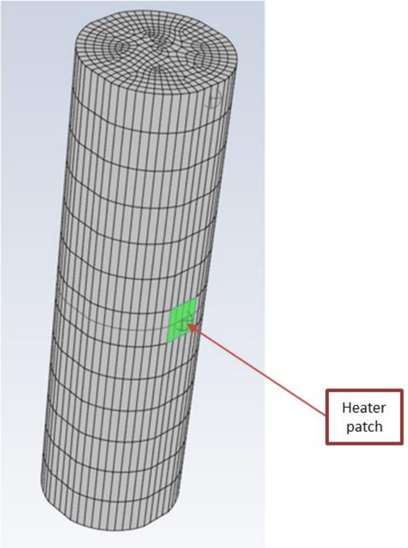
heating @ 4°C/min

exploded cell

Task 3: thermal model

Computational Setup

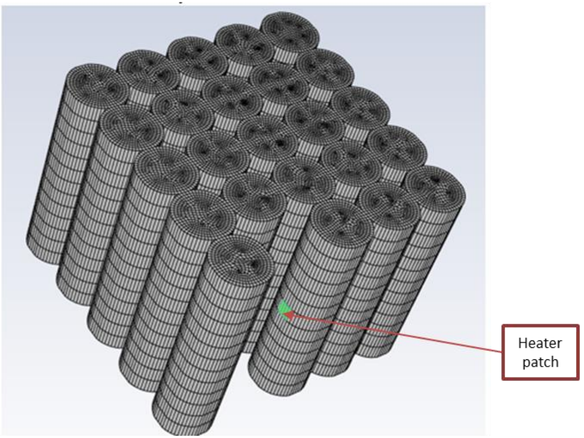
- ALGOLiON Experiments



Computational mesh with heater zone highlighted

Thermal Properties of 18650 LGMJ1 cells	
Cp [J/KgK]	918.8
Kx, Ky [W/mK]	2.3
Kz [W/mK]	24.3
Rho [Kg/m^3]	2761.7

- Impact Solutions Experiments

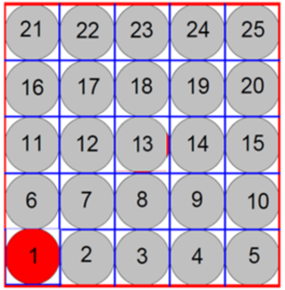


Computational domain for simulating IS experiments

Task 3: thermal model

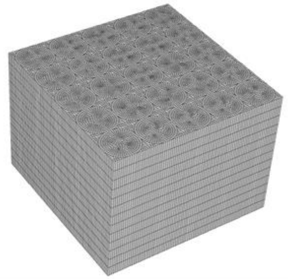
Development of mitigation strategies for a reference setup

- 25 cells of type 18650 at 100% SOC
- Packed in 5x5 configuration
- Corner cell instantaneously goes into TR



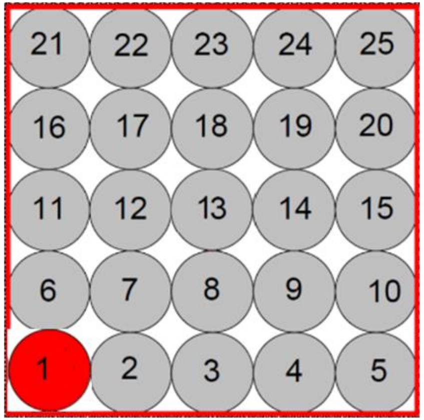
Subsequent Cases development of mitigation strategy for this reference setup for prevention of TR propagation

Task 3: thermal model



Case with No Separators

- Step back from base case
- **No presence of cardboard separators**
- Comparison with Case 1 to understand effect of separators presence



corrugated cardboard 5 mm

$T_{external} = 20^{o}C$

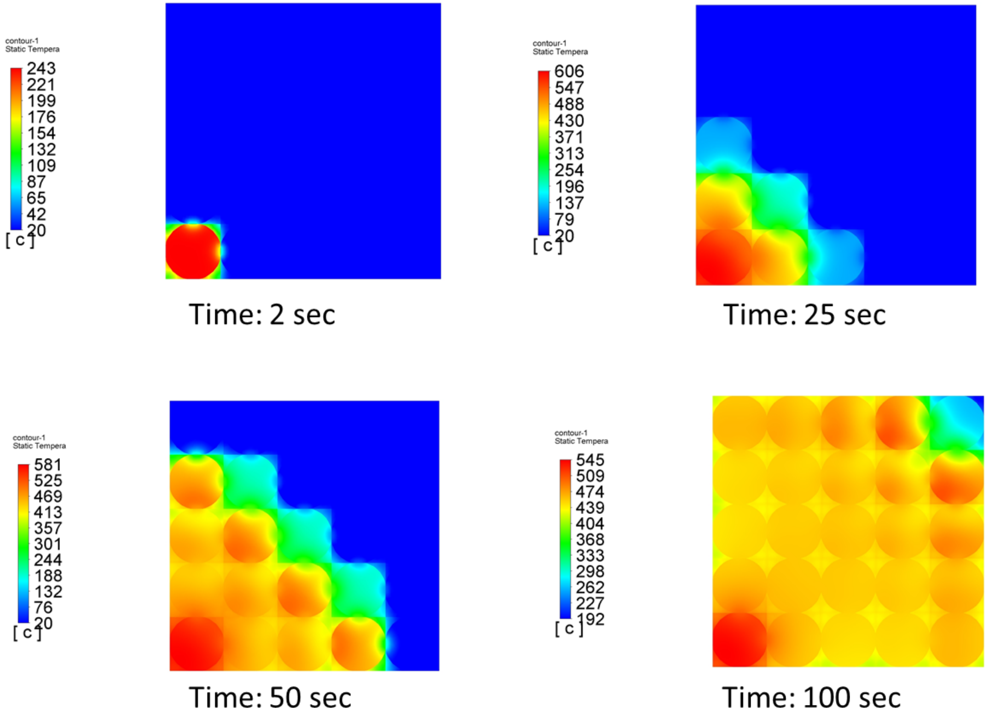
$h_{external} = 5$ [W/m2K]

Self heating onset temperature 118ºC
TR onset temperature 176ºC

Task 3: thermal model

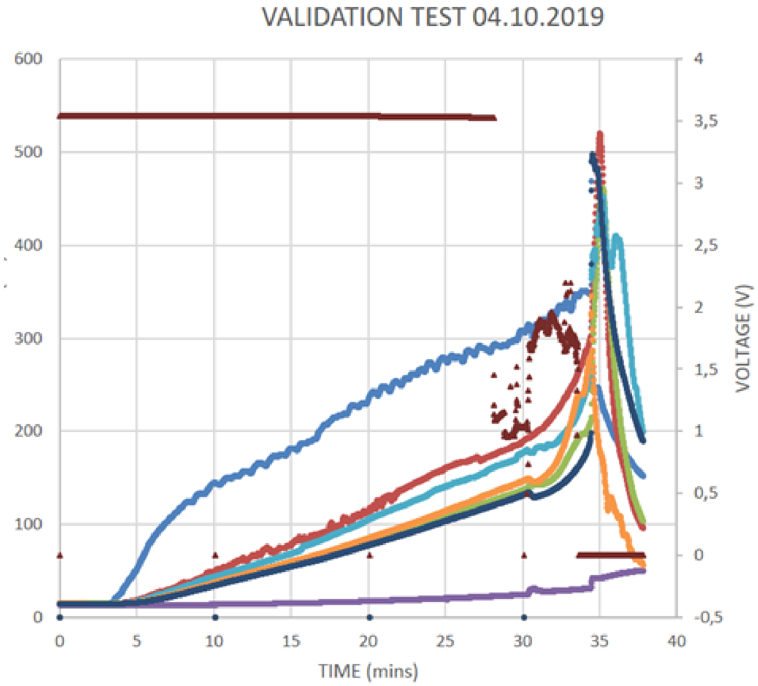
Case with No Separators

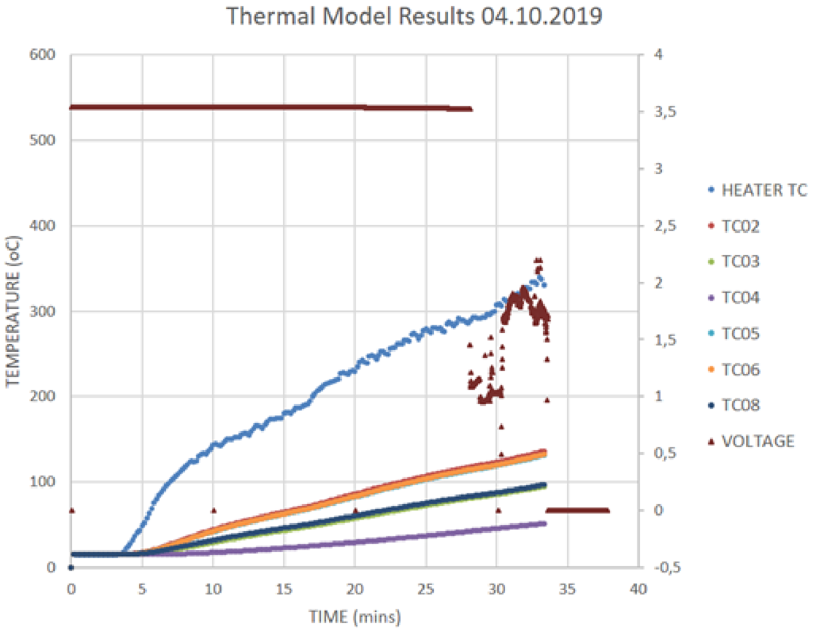
- All cells undergo TR
- TR propagation 20x faster than Case 1



Temperature contour at mid-height level plane at different times

Task 3: thermal model





Temperature evolution in experiment (left) and in numerical results (right)

Task 3: thermal model

Case Name	Mitigation Strategy	Description	Result
Case 00	None	No separators	TR for all cells
Case 01	Thin cardboard separators **BASE CASE**	Base Case of 5x5 with TR cell at a corner	TR for all cells
Case 02	Thicker cardboard separators	Base Case with 4mm separator thickness	no TR propagation
Case 03	Colder environment with higher h	Base Case with more convection heat transfer: h=50, T=0	no TR propagation
Case 04	Thin fiberboard separators	Base Case with 2mm fiberboard separators	TR for all cells
Case 05	Thin fiberboard + vermiculite	Base Case with 2mm fiberboard separators & vermiculite	TR for all cells
Case 06	Thicker fiberboard	Base Case with 2mm fiberboard separators	TR for all cells
Case 07	Thicker cardboard + vermiculite	Base Case with 4mm separator thickness & vermiculite	no TR propagation
Case 08	Sand filled cardboard box	Base Case sand filled with cells at 2mm seperation	adjacent cells vented but no TR propagation
Case 09	Alumina full container	Base Case layout in Alumina container with 4mm cell separation	no TR propagation
Case 10	Graphite full container	Base Case layout in Graphite container with 4mm cell separation	no TR propagation

Task 4: objectives

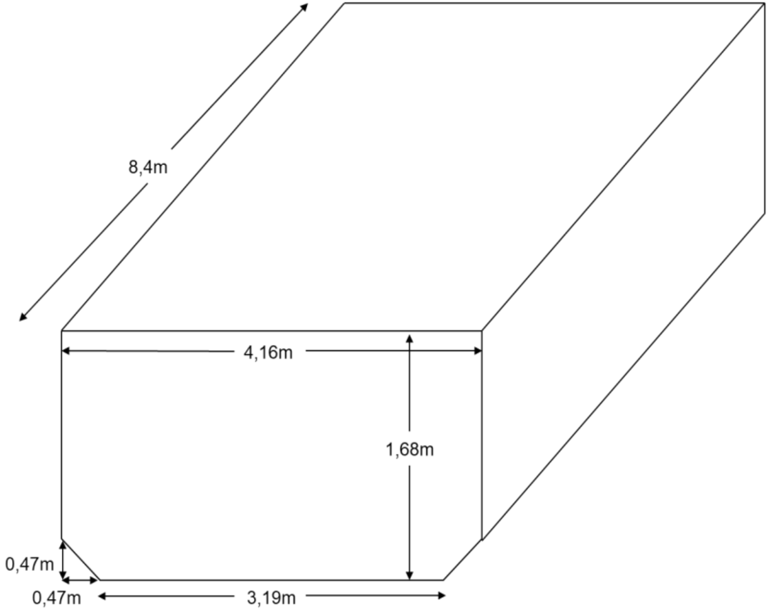
- Scope of Task 4: evaluation of the effectiveness of mitigating for lithium battery fires measures through testing in an environment representative of a typical large aeroplane Class C cargo compartment

- The fire scenario selected for Task 4 is the External Fire: to which extent 18650 cells (in UN 3840 packaging) transported in a Class C cargo compartment are affected by a cargo fire (not a battery fire) developing in their proximity.

Cold Test: Proof that the Halon concentration is 3% at the location of the battery box	Fire initiation test: Place half amount of cells (400) next to the ignition box – do not use the Fire Suppression System	Halon baseline test 800 cells	FCC test 800 cells	FCC + thermal insulation test 800 cells

Task 4: test setup

Tests were conducted in the cargo compartment Halon replacement MPS test chamber at DLR (Trauen, Germany)



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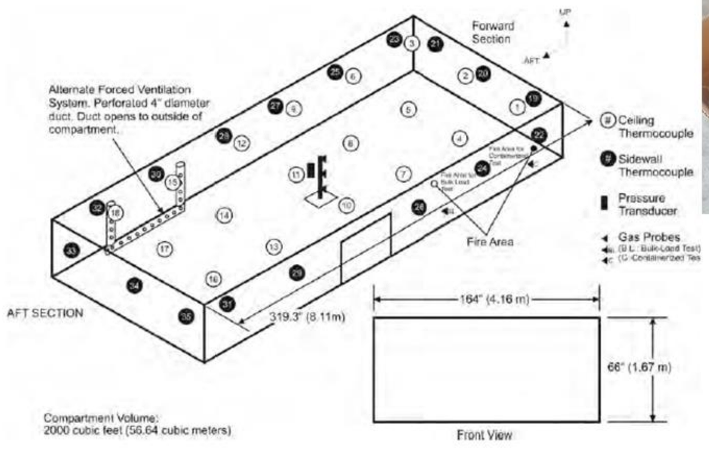
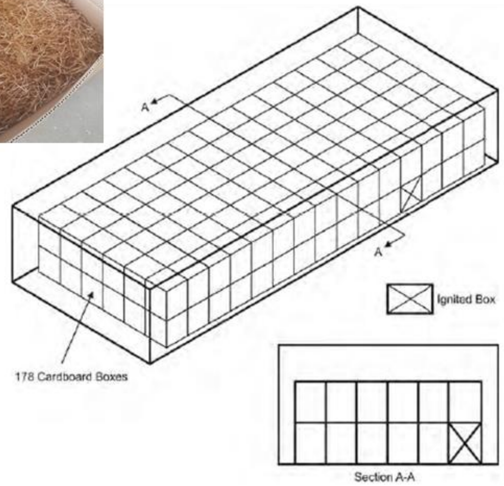
Task 4: test setup

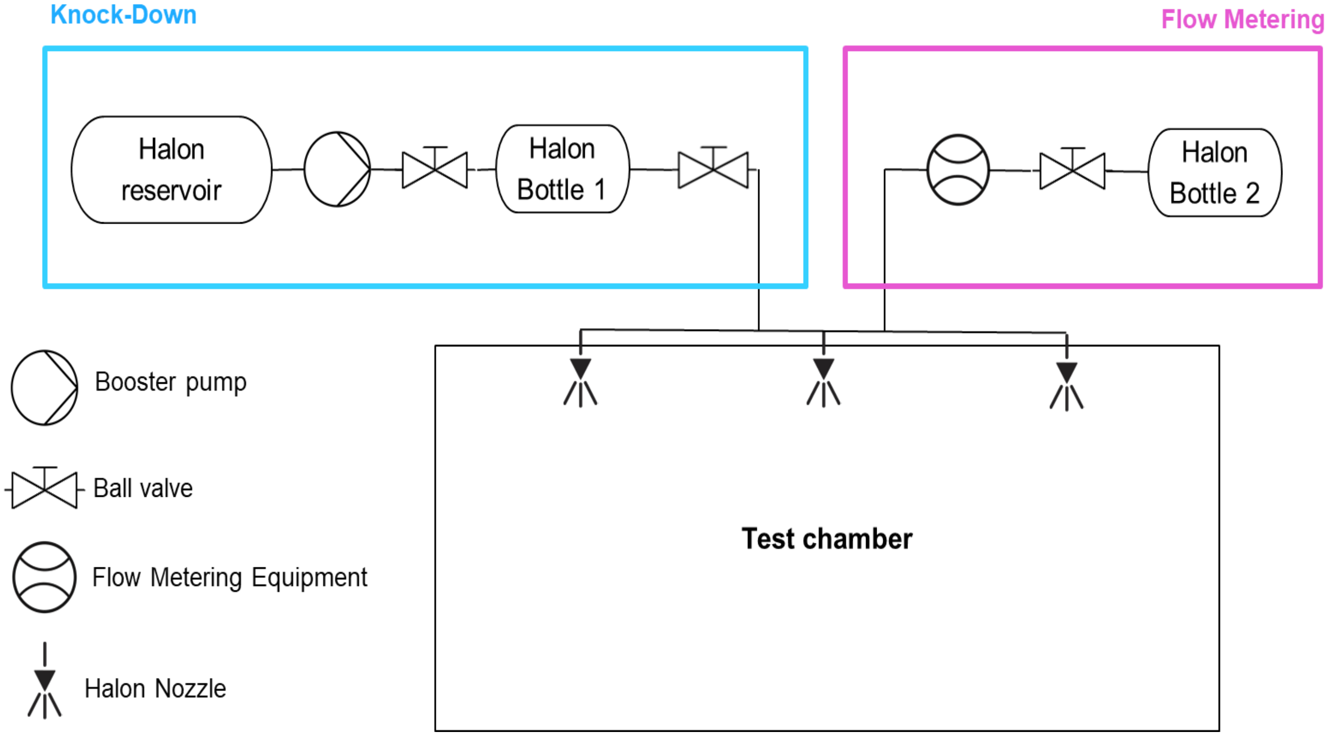
The reference for the development of the test setup was the bulk-load fire test as defined in DOT/FAA/TC-TN12/11 (Minimum Performance Standard for Aircraft Cargo Compartment Halon Replacement Fire Suppression System (2012 Update))





Task 4: test setup

Architecture of the fire suppression system



Task 4: test setup

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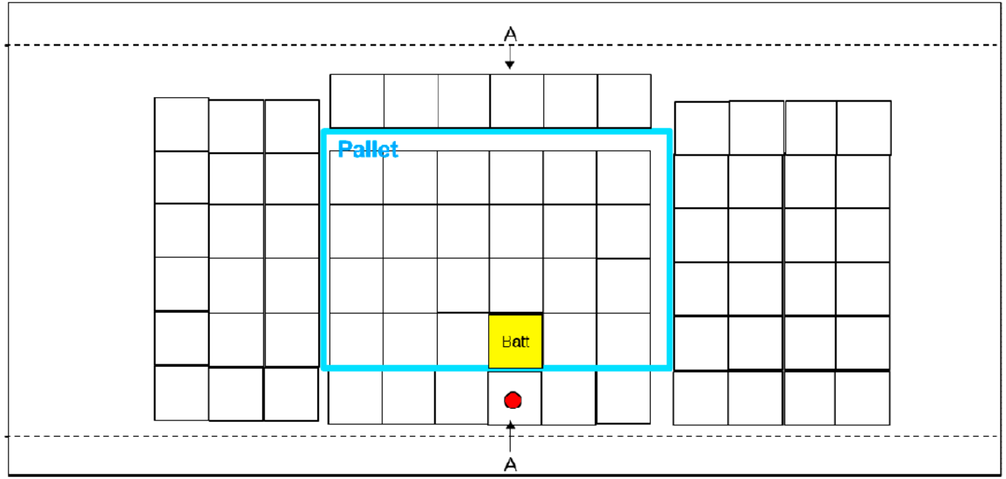
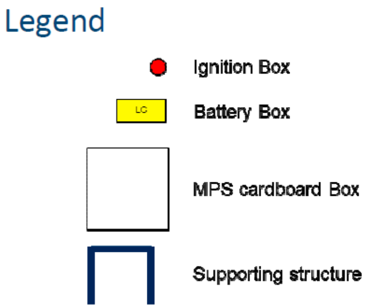
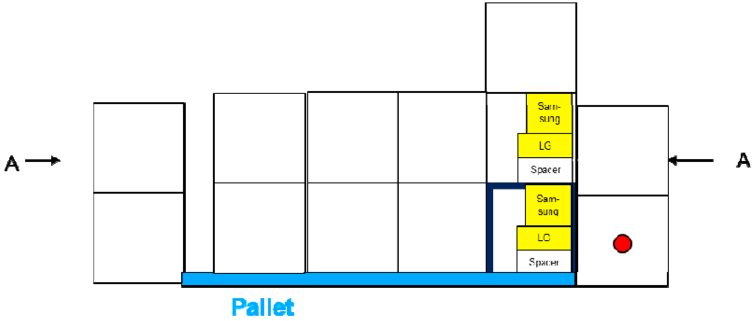




MPS requirements followed as close as possible for cardboard box arrangement



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Task 4: test setup

Task 4: test procedure

- Start the ventilation system (20 l/s)
- Ignite the ignition box
- Record the time when the temperature readings inside 2 different battery boxes exceed 80°C
- Stop the ventilation system
- Wait for 60sec
- Start the Halon Fire Suppression System
- Continue the test and record the data for another 180 minutes

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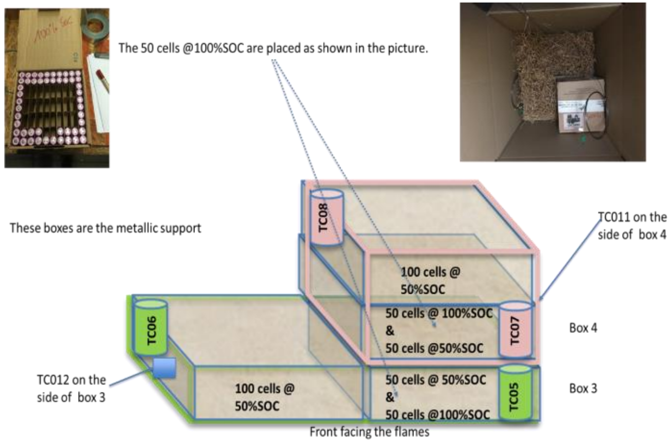
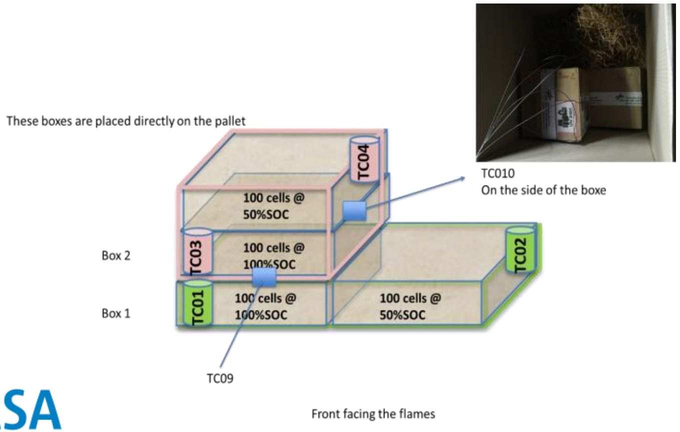
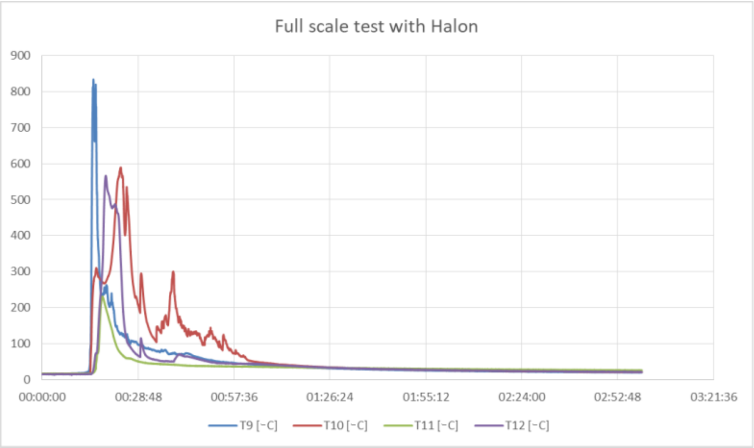
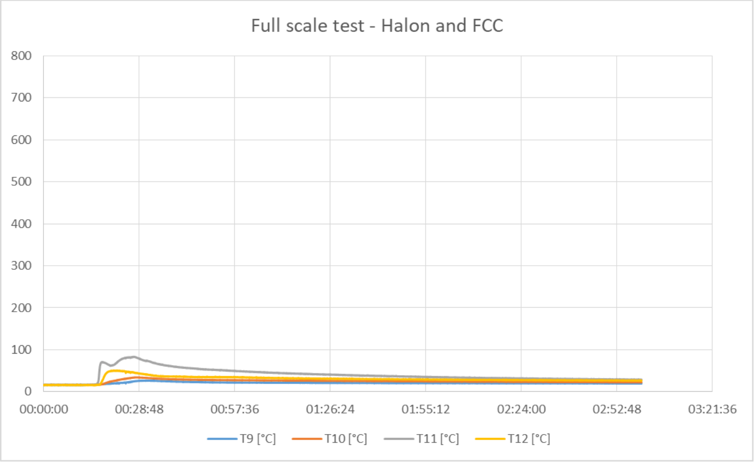
Sabatair: test results









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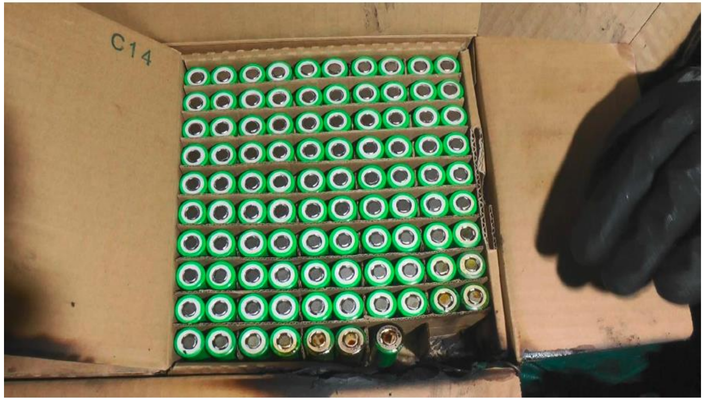
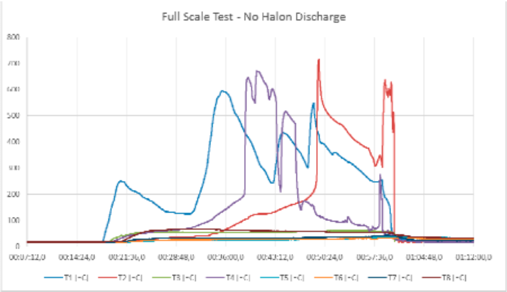
Task 4: Halon baseline test

Task 4: Halon + FCC test

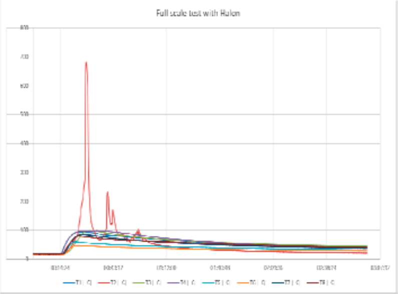


Task 4: conclusions

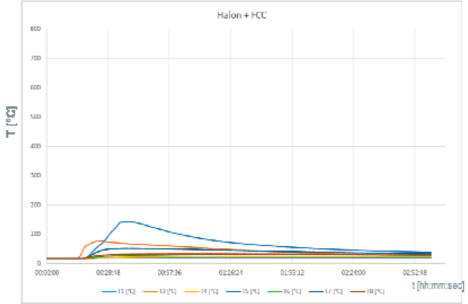
- Only 18650 cells from two manufacturers were tested: additional tests should be performed with different cell designs from different manufacturers.
- FCC provide significant mitigation to the severity of the event: no testing was conducted with additional mitigating measures (thermal acoustic insulation).



No Suppression



Halon Fire Suppression



Halon Fire Suppression + FCC

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Task 5: Objectives

- Initial: Develop a generic risk assessment method based on the results obtained from the previous tasks. The RA was aimed at supporting air transport operators in defining the appropriate requirements for a safe transport of battery consignments.

- Change: Develop guidance for air transport operators:
  - Operators can use different tools and methods.
  - Support operators in the identification of the risks related to the transport of lithium batteries and of the measures needed to mitigate these risks.

Task 5: Step 1

- The outcome of the previous Tasks provides an extensive list of examples that illustrate the hazards and associated potential risks to be considered in the safety risk assessment.
- A process of mapping was developed, from the acceptance of a booking, to transporting and offloading the batteries at the destination.
- The following seven key actors in the supply chain were identified:
  - Cell/Battery Manufacturer
  - Packer
  - Shipper
  - Freight Forwarder
  - Ground Handling Agent
  - Operator
  - Aircraft Manufacturer

Task 5: Step 2

- Based on the data collected from the detailed mapping, a questionnaire was created in preparation for the Sabatair Risk Assessment for the Air Transport of Battery Consignments Workshop held in Brussels 6^{th} to 7^{th} June 2019.

- Several EU stakeholders from the lithium cell air transport supply chain (operators, ground handling agents, lithium battery experts, aircraft manufacturers …) attended the workshop

- The outcomes from the two-day workshop can be found in the project deliverables.

Task 5: Step 2

Questions	Responses
When designing a cell, does the manufacturer consider the hazards of the chemistry chosen and the potential risks this may pose in the supply chain?	• Batteries are designed for a specific purpose. • Manufacturers only work with the classification system. •Not generally considered for transport but consider final use. • UN 38.3 tests are mandatory. The operator and other stakeholder in the supply chain can request a copy of the UN38.3 Test Summary from the manufacturer or subsequent distributor. • It the batteries are counterfeit, the manufacturer will have no concern for any of the regulatory requirements.
Do cell, battery and device manufacturers consider the implications in transport for the return of batteries/devices containing batteries subject to recalls or warranty returns (whether specifically related to the cell/battery or the device)?	• Really need to know the reason for the recall – Not all reasons for a recall are safety related. For example, a battery that does not charge does not necessarily indicate this is a safety issue. • Consideration needs to be given as to where the batteries are being shipped from and by whom (e.g. members of the public or by companies). • There were comments that the regulations make it clear that batteries recalled for safety reasons are forbidden in air transport
As a mitigation measure to consider for the transport of freshly manufactured cells, a minimum 'wait-and-see' latency period could be defined of at least several days between the conclusion of the formation cycling and carriage by air to allow for the emergence of cell heating, possibly leading to thermal runaway. Is this a practical proposition?	• Having a latency period is standard practice for battery manufacturers, who must operate under a quality management system. • To implement this would require a change in transport regulations. • Currently the UN38.3 Tests are deemed to be sufficient.

Task 5: Step 3

- The risk assessment guidance was created based on the outcome of the workshop.

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Deliverable D6:

Air Transport Operators Generic Safety Risk Assessment Guidance for the Safe Transport of Lithium Battery Consignments as Cargo

Task	**5**	Risk Assessment for the Air Transport of Battery Consignments

Task 5: conclusions

- SABATAIR guidance on the transport of lithium batteries complements ICAO's guidance on transport of dangerous goods

- Although not all the hazards, risks and mitigating measures that are addressed in the Guidance may be relevant for every operator, reviewing the document will certainly contribute to raising the level of awareness of the existence of certain hazards, and may give useful indications of how the associated risks may be mitigated to an acceptable level.

- These safety risk assessment guidance do not focus on or recommend the use of a specific risk assessment model or tool. Whichever model the operator chooses, the capabilities and limitations of the model need to be taken into account, including aspects such as ease of use, accessibility, analytical rigour and adaptability.

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Main Results:

- Performed tests to improve and validate the packaging standard developed by the SAE G27
- Assessed and proposed additional mitigating measures to prevent the involvement of batteries in an external cargo fire
- Developed guidance to operators to perform risk assessments for the transport of lithium batteries as cargo

Final report and project deliverables published in December 2020 on the project website

(https://sabatair.vito.be/en/reports)

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European Union Aviation Safety Agency

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