Contents

General Comments -

comment 1 comment by: *Swedish Transport Agency, Civil Aviation Department (Transportstyrelsen, Luftfartsavdelningen)*

Thank you for the opportunity to comment on NPA 2022-2076 'Third Publication of Proposed MoC with SC VTOL - MOC-3 SC-VTOL - Issue 1'. Please be advised that there are no comments from the Swedish Transport Agency.

response Noted.

comment *43* comment by: *Kevin Bruce*

This MOC should be written to cover the full battery system design and installation of the battery system into the aircraft compliance methods. After the statement of issue the title notes Lift/Thrust system installation and then the next title states battery thermal runaway. It does not make sense that this MOC only covers thermal runaway as this is only one aspect of the design standard requirements and for electric propulsion systems there is no other MOC's available.

The MOC refers to layers of protection 13 times, but it does not really define them. If there are multiple layers of protection built in how do these affect the testing requirements. Let's say I can show the layers of protection have a reliability of 10^{-14} against thermal runaway. Is containment or propagation protection still required? To add the details of these multiple layers of protection and how to use them in this MOC would not be difficult or make this MOC to hard to read. It would help to address the former question. It will provide the full MOC to subpart E and F for the battery system. It will also help determine where the compliance can or should be shown – at the battery system level or the aircraft level.

response Not accepted.

As stated in the MOC: *"This Means of Compliance is not addressing neither superseding other tests needed for the certification of propulsion battery systems (i.e. external short circuit, available system capacity and energy, protections testing, battery system crashworthiness tests…)."*
Therefore, other MOCs will need to be developed to address these aspects.

EASA is working to develop MOCs either internally or in collaboration with EUROCAE for the following mitigation and protection layers (non-exhaustive list):

Cell level:

- Quality cells from robust suppliers (Under POA of the OEM).
- Cell incoming inspection and testing (Uniformity, reduction of manufacturing defects).
- Cell thermal runaway variabilities characterization to identify the wort-cases conditions.
- Reliability requirements for the cell failure derived from defined safety requirements (2 or more cells in thermal runaway is considered Catastrophic).

Battery Level:

- RTCA DO-311A section 2.1 "General requirements" (design, quality, maintenance requirements…)
- Safety objectives and DALs for the control and protective functions derived from defined safety requirements (2 or more cells in thermal runaway is considered CAT)
- Ageing of the cells and degradation of the battery during operational lifetime considered.
- Set of Non-propagation tests: Battery or submodule able to safely manage a single cell in Thermal Runaway in the worst-cases of test conditions combinations.
- Set of containment tests: Determine the worst-cases of test conditions combinations, triggering a thermal runaway in at least the 20% of the cells in the battery or submodule, that shall be safely managed at battery level or installation ensuring a continued safe flight and landing.

Installation level:

- RTCA DO-311A section 3 "Installation Consideration" to be evaluated.
- Isolation Monitor to detect any decrease on isolation of the High Voltage system.
- Venting and draining provisions at A/C level.
- Crashworthiness tests.

It is important to highlight that demonstrating compliance with the set of tests of non-propagation and containment, does not alleviate the other protection layers.

Also, for various reasons (new and constantly evolving battery cell technology, novel application, inexistent or very limited in-service experience) component failure rate is subject to significant uncertainties, and due to that both set of tests are required independently of the estimated reliability of the layers of protection.

comment 77 — comment by: *Diamond Aircraft Industries GmbH*

This MOC should be written to cover the full battery system design and installation of the battery system into the aircraft compliance methods. After the statement of issue the title notes Lift/Thrust system installation and then the next title states battery thermal runaway. It does not make sense that this MOC only covers thermal runaway as this is only one aspect of the design standard requirements and for electric propulsion systems there is no other

	MOC's available. The MOC refers to layers of protection 13 times, but it does not really define them. If there are multiple layers of protection built in how do these affect the testing requirements. Let's say I can show the layers of protection have a reliability of 10-14 against thermal runaway. Is containment or propagation protection still required? To add the details of these multiple layers of protection and how to use them in this MOC would not be difficult or make this MOC to hard to read. It would help to address the former question. It will provide the full MOC to subpart E and F for the battery system. It will also help determine where the compliance can or should be shown – at the battery system level or the aircraft level. Recommendation: The MOC should be revised to cover the full system requirements.
response	No accepted. See response to comment 43.

comment	*94* comment by: *Voltaero* This MOC seems to be directly linked to specific cell types, chemistries, and integration. It may inhibit the possibility to develop and integrate new technologies and advanced chemistries as cell technology progresses. These new technologies dedicated to next generation of propulsion batteries are crucial for the development of electric and hybrid-electric aircraft
response	Partially accepted. The MOC is intended to be technology-agnostic for the cell types, chemistries, and integration, that can be found in the market today and therefore for the current projects in certification or pre-application. To address the next generation of propulsion batteries, once defined and proposed to EASA, this MOC could be revised or a new MOC could be developed. It is not possible to already establish a MOC that will be valid for any unknown future technologies. It will be included in the MOC a clarification in that regard: "This means of Compliance is predicated on battery technologies and chemistries that are currently known and ready for use. Future technologies and chemistries might require additional or alternative considerations, that should be first established at project level."

comment	*129* comment by: *Electric Power Systems Inc* While this forms a specific means of compliance for battery certification, it introduces multiple sources of ambiguity which will require significant amount of regulator judgment. Applying cell to cell propagation mitigation as a primary safety mechanism requires the much more extensive yet subjective cell and module level characterization discussed in this document. Insufficient guidance is provided to account for the complex interplay between independent considerations that affect cell to cell propagation (variability of cell TR inception, position of cell intern short circuit, variability in cell energy release, variability in cell construction, variability in cell manufacturing and conformity, position of the cell in the module). Absent extensive standardization in cell, cell-to-cell, module, and system testing, such complexities leads to little comfort that any potential test executed during represent the worst case scenario and would be accepted for certification. Thermal runaway containment represents a more demonstrable means for TR protections. While this MOC may be suitable for specific cell types and chemistries, it is also not certain how application of this MOC will impact the ability to adopt advanced chemistries as cell technology advances. Universal application of the MOC may lead to detrimental impacts inhibiting the introduction of new technologies. This in turn will harm the adoption of electric aircraft technologies.
response	Partially accepted. Both mitigations are requested, Thermal Runaway propagation prevention (non-propagation test) and Thermal Runaway containment. For the non-propagation test, due to the variability of designs, general guidelines are proposed to support applicants to characterize and assess their design at different levels and define tests that capture all these possible variabilities and worst-case conditions. On top of that, margins are included to ensure non-propagation, and a second protection layer (containment) is requested. The MOC is intended to be technology-agnostic for the cell types, chemistries, and integration, that can be found in the market today and therefore for the current projects in certification or pre-application. To address the next generation of propulsion batteries, once defined and proposed to EASA, this MOC could be revised or a new MOC could be developed. It is not possible to already establish a MOC that will be valid for any unknown future technologies. It will be included in the MOC a clarification in that regard: “This means of Compliance is predicated on battery technologies and chemistries that are currently known and ready for use. Future technologies and chemistries might require additional or alternative considerations, that should be first established at project level.”

comment	*140* comment by: *The Boeing Company* The Boeing Company appreciates the opportunity to review and provide comments on the proposed Means of Compliance concerning propulsion batteries thermal runaway. This is a significant and important building block in establishing the foundation for the certification of electric and hybrid VTOL aircraft. This proposed MOC is a valuable start to addressing the robust challenge of thermal runaway mitigation. However, Boeing believes additional work is needed to provide a comprehensive compliance approach for high voltage batteries intended for VTOL application. Additional testing and analysis, beyond what is covered in the MOC, may be necessary to support the appropriate level of thermal runaway testing, which could potentially be addressed by additional or updated consensus standards. Industry collaboration would be beneficial to achieving a more comprehensive approach to battery qualification for electric aircraft. We encourage EASA to work with electric aircraft OEMs and SDOs to develop additional appropriate testing standards that considers the particularities of very large propulsion battery systems needed to power electric and hybrid aircraft. We have reviewed the document and have identified areas of recommended change. The enclosed comments contain the details of our suggested revisions
response	Noted.

comment	*155* comment by: *General Aviation Manufacturers Association (GAMA)* **RATIONALE / REASON / JUSTIFICATION** This MOC is mostly focused on thermal runaway and yet there are many factors to consider in a complinace demostration for a battery system. Additionally, the MOC refers to the multiple layers of protection several times but does not expand on them. This can cause issues in design development where an applicant will not fully understand these multiple layers. In order to achieve the proper safety level the multiple layer approach is needed. **PROPOSED TEXT/ACTION** GAMA proposes to add details about the multiple layers, whether it is something new or point to other guidance.
response	Noted. See response to comment 43. Whenever the development of the additional guidance and MOCs listed in the response to comment 43 has been completed, this MOC will be amended to point at them as proposed.

comment	*156* comment by: *General Aviation Manufacturers Association (GAMA)* **RATIONALE / REASON / JUSTIFICATION** It is possible that the Battery system can be viewed as a self-contained system as we already do for complex avionics units or other pieces of equipment. As such, the MOC should be divided between what is required to be done at the battery system level and what is required at the installation level. This would also prepare things for a future TSO on a battery system. **PROPOSED TEXT/ACTION** EASA to review the guidance and determine what should be done or can be done at the battery system level as well as split this out into a separate sectio7n from the installation requirements.
response	Not accepted. Propulsion Batteries are complex, critical, and novel systems, with very limited in-service experience. EASA, at this stage, is not considering developing an ETSO for propulsion batteries as the MOCs are still in development and first they need to be exposed to certification projects for maturation and consolidation.

comment	*182* comment by: *General Aviation Manufacturers Association (GAMA)* **RATIONALE / REASON / JUSTIFICATION** The use of the phrase 'Propulsion Battery System' seems to not correspond to any of the definitions layed out on §2 (page 5), hence it does not ensure a consistent and harmonised language throughout the document and provides a basis for misinterpretation for what a propulsion battery system is. **PROPOSED TEXT/ACTION** EASA to use the terms "A propulsion battery…." or "A propulsion battery and battery system…." as these are terms that have already been defined in § 2, page 5. This should be changed, specially, in § 3 (a) (1), § 4a and § 5a.
response	Accepted. All definitions have been reviewed and modified for more clarity.

comment	*189* comment by: *General Aviation Manufacturers Association (GAMA)* **RATIONALE / REASON / JUSTIFICATION** This MOC only describes a single battery safety concept (cell to cell propagation mitigation) which is not the only one meeting the safety objective of thermal runaway containment. Other

battery safety concepts e.g. module to module propagation mitigation/thermal runaway containment, should also be described in this MOC.

PROPOSED TEXT/ACTION

GAMA suggests to restate § 3(a)(1)(i)(v) as follows: *"Performing thermal runaway non-propagation tests following the guidelines described in the following sections (b) or (c) …"* ; and create (c) for alternate battery safety concepts, e.g. battery module to module non-propagation/containment test. Alternatively, EASA should generalize the proposed § 3 (b), 4., 5., to not prescribe a single design solution/safety concept and allow other suitable solutions to make the MOC proof for other, future battery design solutions and technologies.

response

Not accepted.

The MOC does not describe a single battery concept based on cell-to-cell propagation mitigation. It is based on different protection and mitigation layers from cell level to battery level and to installation level. These mitigations encompass to include and test non-propagation measures, and containment of realistic worst-cases of thermal runaway.

Non-propagation tests are not defining/prescribing a particular solution, as containment tests are not defining/prescribing a particular solution. Both safety layers/measures are requested, and for both, the applicant can propose different solutions.

This approach intends to foster innovation and development of new solutions for these battery system protection layers, instead of only placing over-reliance on containment mitigations. EASA's approach is consistent with modern, accepted industry practice, where these protection and mitigation layers are incorporated in batteries used in critical sectors as space and satellite applications (NASA/TM-2009-215751 Guidelines on Lithium-Ion battery use in Space Applications, Aerospace report No. TOR-2007 (8583)-2 Acquisition Standard for Lithium-Ion Based Launch Vehicle Batteries)

comment

245 comment by: *Vertical Aerospace*

Vertical Aerospace appreciates the extensive efforts by EASA to introduce the third publication of MOCs with the Special Condition VTOL. While Vertical Aerospace embraces several aspects of the MOC, Vertical Aerospace respectfully expresses its dissenting opinion on a number of instances via the comments provided accordingly and requests more clarification on technical aspects that feels should not be neglected. More importantly, Vertical Aerospace does not feel comfortable that it is possible to guarantee that thermal runaway events can be prevented for every possible scenario or that the safest method of prevention is through stopping the propagation itself. Instead, a robust safety assessment towards ensuring that the pack/system is capable of managing a thermal event and subsequent propagation is deemed to allow more flexibility towards meeting the safety objective (dependent on the design itself).

response	Not accepted. The MOC does not state that it is possible to guarantee that thermal runaway events can be prevented for every possible scenario or that the safest method is a cell-to-cell propagation mitigation. The MOC proposes different protection and mitigation layers, from cell level to battery level, and to installation level. These mitigations encompass to include and test non-propagation measures, and containment of realistic worst-cases of thermal runaway, on which the focus is clearly placed.

Statement of Issue	p. 1

comment	*30* comment by: *Collins Aerospace/Pratt & Whitney* Comment: Delete "critical" in last sentence of section. Justification: It is unclear what defines a "critical" thermal runaway, or how it would differ from any other thermal runaway.
response	Accepted.

comment	*44* comment by: *Kevin Bruce* This section should have clear and detailed information to properly define the issue. It currently makes general statements about the issue. However, in order to find the best solution, the background and details of the issue should have sufficient detail such that the reader can make some conclusions as to the effectiveness of the MOC. In particular it may be beneficial to define the typical failures that are possible. There is a list of issues, but these are not necessarily directly related to failures from the design standpoint. The list of issues presented here in this section are not completely covered in the proposed MOC. Each if these items should have some details as to an appropriate MOC. As stated in the fourth paragraph, “with proper design…..” the issues can be prevented therefore the MOC should include acceptable means for all areas of the battery system design and installation. One point should be made about the battery system design and installation. We should write the MOC to separate the MOC for the battery system design and then a separate section for the battery system installation. While not all applicants will use a battery system that is designed and manufactured by a supplier to the applicant this is likely the path that most will take and the battery system should be able to be approved as a stand alone system under a TSO. There are many aspects of the battery system design that can be dealt with regardless of the aircraft platform. Comments made through out this paper will provide further clarification of this point. The other benefit to this approach is that it will make it easier to distinguish which tests and analysis need to be completed at the aircraft level. The first sentence of the last paragraph of this section is not clear. What does the “considerable part of the weight of the aircraft” have to do with properly defining test requirements and ensuring adequate safety? The second sentence is also difficult to read. This last paragraph in this section should be a concluding statement that leads to the proposed MOC. The last sentence talks about a critical thermal runaway. Unprotected all thermal runaways are critical. However, given a system design a thermal runaway may not be critical. Therefore,

	it may be better to change the language in this document to refer to uncontained thermal runaway. We need to be careful about how this section is written and not take information from unrelated events, or events that have already been learned from as a basis for the MOC. The 787 battery issue resulted in the FAA AC 20-24 and there is info in here that can assist this MOC. The fact that there is higher energy in the propulsion battery system needs to be accounted for properly, but it does not mean what we have already learned from the current lithium battery installations cannot be used. Consider the fact that there is a similar amount of energy in the fuel stored on board today's aircraft and we have built protections systems around this. But have not made it onerous.
response	Partially accepted. The "Statement of issue" section is an introduction of the problem and a justification on the need of issuing a MOC. Guidelines are provided for the proper design, manufacturing, installation, operation, and maintenance (RTCA DO-311A sect. 2.1 "General Requirements" and section 3 "Installation Considerations") As stated in the MOC: *"This Means of Compliance is not addressing neither superseding other tests needed for the certification of propulsion battery systems (i.e. external short circuit, available system capacity and energy, protections testing, battery system crashworthiness tests…)."* Therefore, other MOCs will need to be developed to address these aspects. EASA is working to develop MOCs either internally or in collaboration with EUROCAE for the following mitigation and protection layers (non-exhaustive list): Cell level: - Quality cells from robust suppliers (Under POA of the OEM). - Cell incoming inspection and testing (Uniformity, reduction of manufacturing defects). - Cell thermal runaway variabilities characterization to identify the wort-cases conditions. - Reliability requirements for the cell failure derived from defined safety requirements (2 or more cells in thermal runaway is considered Catastrophic). Battery Level: - RTCA DO-311A section 2.1 "General requirements" (design, quality, maintenance requirements…) - Safety objectives and DALs for the control and protective functions derived from defined safety requirements (2 or more cells in thermal runaway is considered CAT) - Ageing of the cells and degradation of the battery during operational lifetime considered.

- Set of Non-propagation tests: Battery or submodule able to safely manage a single cell in Thermal Runaway in the worst-cases of test conditions combinations.
- Set of containment tests: Determine the worst-cases of test conditions combinations, triggering a thermal runaway in at least the 20% of the cells in the battery or submodule, that shall be safely managed at battery level or installation ensuring a continued safe flight and landing.

Installation level:

- RTCA DO-311A section 3 "Installation Consideration" to be evaluated.
- Isolation Monitor to detect any decrease on isolation of the High Voltage system.
- Venting and draining provisions at A/C level.
- Crashworthiness tests.

It is important to highlight that demonstrating compliance with the set of tests of non-propagation and containment does not alleviate the other protection layers.

Regarding ETSO: Propulsion Batteries are complex, critical and novel systems, with very little service experience. EASA at this stage is not considering developing an ETSO for propulsion batteries as the MOCs are still in development and need first to be exposed to certification projects for maturation and consolidation.

Regarding uncontained thermal runaway: The MOC clearly states that a Battery Thermal runaway (defined as the thermal runaway of two or more cells within a battery) is considered catastrophic and is not alleviated by complying with the test approaches defined in the MOC.

The word "Critical" is deleted.

comment | *78* | comment by: *Diamond Aircraft Industries GmbH*

This section should have clear and detailed information to properly define the issue. It currently makes general statements about the issue. However, in order to find the best solution, the background and details of the issue should have sufficient detail such that the reader can make some conclusions as to the effectiveness of the MOC. In particular it may be beneficial to define the typical failures that are possible. There is a list of issues, but these are not necessarily directly related to failures from the design standpoint.
The list of issues presented here in this section are not completely covered in the proposed MOC. Each if these items should have some details as to an appropriate MOC. As stated in the fourth paragraph, "with proper design….." the issues can be prevented therefore the MOC should include acceptable means for all areas of the battery system design and installation. One point should be made about the battery system design and installation. We should write the MOC to separate the MOC for the battery system design and then a separate section for the battery system installation. While not all applicants will use a battery system that is designed and manufactured by a supplier to the applicant this is likely the path that most will

	take and the battery system should be able to be approved as a stand alone system under a TSO. There are many aspects of the battery system design that can be dealt with regardless of the aircraft platform. Comments made through out this paper will provide further clarification of this point. The other benefit to this approach is that it will make it easier to distinguish which tests and analysis need to be completed at the aircraft level. The first sentence of the last paragraph of this section is not clear. What does the "considerable part of the weight of the aircraft" have to do with properly defining test requirements and ensuring adequate safety? The second sentence is also difficult to read. This last paragraph in this section should be a concluding statement that leads to the proposed MOC. The last sentence talks about a critical thermal runaway. Unprotected all thermal runaways are critical. However, given a system design a thermal runaway may not be critical. Therefore, it may be better to change the language in this document to refer to uncontained thermal runaway. We need to be careful about how this section is written and not take information from unrelated events, or events that have already been learned from as a basis for the MOC. The 787 battery issue resulted in the FAA AC 20-24 and there is info in here that can assist this MOC. The fact that there is higher energy in the propulsion battery system needs to be accounted for properly, but it does not mean what we have already learned from the current lithium battery installations cannot be used. Consider the fact that there is a similar amount of energy in the fuel stored on board today's aircraft and we have built protections systems around this. But have not made it onerous. This section should be revised.
response	Partially accepted. See response to comment 43.

comment	*130* comment by: *Electric Power Systems Inc* Motivation for the change in MOC is to eliminate undue packaging overhead. We share this desire to reduce packaging overhead, but the approach discussed in this document is not the only way to get to reduced mass. Also, no definition or guidance on suitable protective layers/measures for the battery system are defined. Certainly cell-to-cell propagation mitigation constitutes a protective layer. However, what additional layers are acceptable means for TR protection (software, containment, module to module propagation mitigation, resitlient installation, etc...)?
response	Not accepted. See response to comment 43.

comment	*138* comment by: *Ampaire Inc* We were unable to use the CRT editor to place comments in "General Comments" so we are placing our general comments here. We believe the intent of the two choices of MoC approaches is that Approach #1 is chosen when the result of a thermal runaway event could be catastrophic and Approach #2 can be chosen as an option when the result of a thermal runaway event is not catastrophic and ensuing continued safe flight and landing in accordance with EASA MOC VTOL.2330 can be managed. Approach #2 does not require the strict containment and venting requirements of DO-311A. Assuming we are interpreting the above correctly, then we agree with these two approaches except as noted within the individual sections. We do recommend that the Introduction section should include a rationale for the two approaches and when an applicant might chose one or the other for clarity.
response	Not accepted See response to comment 47.

comment	*174* comment by: *Rolls-Royce plc* Page 1 Section/Paragraph Statement of Issue **RATIONALE / REASON / JUSTIFICATION for the Comment** Some of them can be prevented with proper design, manufacturing, installation, operation, and maintenance, while others cannot be completely avoided (i.e., cell internal short-circuit due to latent manufacturing defects), therefore, their effect should be properly mitigated. **PROPOSED TEXT** Suggest changing language around risk mitigation: Some of them can be mitigated through proper adoption of processes throughout design, manufacture, intallation, operation and maintenance. Others cannot be completely avoided (i.e. cell internal short-circuit due to latent manufacturing defects) and their effect should be mitigated in-service.
response	Accepted.

comment	*215* comment by: ***Heart Aerospace AB*** In the last paragraph, what is meant by critical thermal runaway, and what is the difference from any other thermal runaway event? Assuming there's no difference, Heart Aerospace recommends using consistent wording across the document to define similar events, and in case there's a difference, we recommend adding these definitions in section 2, Definitions.
response	Accepted. "Critical" is deleted.

1. Introduction **p. 4**

comment | *2* | comment by: *AIRBUS HELICOPTERS*

In the second sub-paragraph of the paragraph : "*1. Introduction*", with regard to the sentence : "*However, its "Thermal runaway containment test" in section 2.4.5.5, was developed for lithium batteries that provide power to other aircraft systems or equipment, without considering the particularities of* ***very large*** *propulsion battery systems needed in electric and hybrid aircraft*"

COMMENT :
The definition of "very large propulsion battery system" should be provided Energy/power range should be considered to classify the propulsion battery (see similar proposal in DO311A paragraphe 1.4.1).

JUSTIFICATION :
The introduction refers to very large propulsion battery systems without providing definition of "very large".
What is the difference between very large, large, small ?

response | Partially accepted.

"very large" is deleted. The MOC does not intend to differentiate propulsion batteries in terms of size, but in terms of functions.

comment | *15* | comment by: *AIRBUS HELICOPTERS*

COMMENT :
An additional approach is proposed with the following

Approach #3: RTCA DO-311A Section 2.4.5.5. Battery Thermal Runaway Containment Test
(a) Propulsion Battery Systems are considered to properly fulfil verification aspects of propulsion battery system thermal runaway conditions when compliance is demonstrated with:
(1) Section 3. "Prerequisites" of this document limited to (a) General considerations, and (b)
(ii) A full characterisation of thermal runaway behaviour at cell level and
(2) Requirements of RTCA DO-311A section 2.2.2.4 when tested in accordance with section 2.4.5.5 Battery Thermal Runaway Containment Test, and
(3) Evidence that at least 100% of the cells achieved thermal runaway.

JUSTIFICATION:

	This third approach with different conditions and acceptance criteria provides an equivalent level of safety to the other approaches #1 and #2 proposed in the MoC
response	Not accepted. Both mitigations are requested, Thermal Runaway propagation prevention (non-propagation test) and Thermal Runaway containment. For the non-propagation test, due to the variability of designs, general guidelines are proposed to support applicants to characterize and assess their design at different levels and define tests that capture all these possible variabilities and worst-case conditions. On top of that, margins are included to ensure non-propagation, and a second protection layer (containment) is requested.

comment	*31* comment by: *Collins Aerospace/Pratt & Whitney* Comment: In document heading, change "TRHUST" to "THRUST" Justification: Spelling correction Comment: Delete or clarify "extreme" in paragraph 3. Justification: It is unclear what what is meant by "extreme"? Does extreme mean unlikely or impossible, or does it just mean severe (without accounting for likelihood)? Comment: In last paragrph, replace "not addressing neither superseding" with "neither addressing nor superseding". Justification: Grammar correction
response	Accepted.

comment	*45* comment by: *Kevin Bruce* The first paragraph identifies several sections of CS-23 then states that each of these requires demonstrating that the hazards from a fire are mitigated. 23.2325 is about fire protection but is not mentioned. 23.2440 mentions fire and heat and in some way is a repeat of 2325 and 2330. 2400, 2425 and 2430 do not mention fire (they do mention hazards and again there is redundancy in all of these paragraphs, i.e. the same MOC details is used for all or part of each of them). 2510 and 2525 is about the SSA or reliability (the old 1309). While in the SSA one would account for fire in the FHA and common cause analysis it is not clear that this MOC covers anything different in the AMC for these two paragraphs. The second paragraph of this section states that the DO-311A testing was developed for other aircraft systems. An explanation of why this is an issue for propulsion batteries should be provided. The fact that there is more energy needed for propulsion in of itself is not what the issue is. There should be a full explanation of what the issues are. Then we are able to

	see when, where and why other MOC's are needed. Whether it is a small system battery of 2A or the full propulsion battery the proper level of protection is needed for how it is used. If I create a battery system that has multiple modules, where each module is within the energy level envisioned in DO-311A why is the testing identified in DO-311A not sufficient? The third paragraph first sentence is awkward. What is trying to be stated here. The fact that the system energy/weight ration is decreased is not the responsibility of the regulations and the MOC's associated with them. It is up to the designer to solve this while meeting the minimum safety requirements. If the statement here is intended to demonstrate that the testing in DO-311A is too onerous and will lead to unnecessary protections and weight penalties than this should be stated more clearly. Additionally, proof should be provided that this is the case. As a matter of fact, we do have information to show that the reverse is actually true. There is a design solution that will allow for a battery module to meet the DO-311A testing at a much lower weight than cell to cell propagation protection. In the fourth paragraph it is mentions that EASA is proposing alternative methods to promote best industry practices, however the content of this MOC is developed around one solution to a propulsion battery system design. Paragraphs (a), (b), (c) and (d) contain information but not clear information. More background is required in these paragraphs to ensure the reader can see the full picture of the stated issues. It seems that some of the detail in this section is related to the Statement of Issue rather than the introduction to the MOC. If we treat this MOC like any other AMC typically there is an introduction which is a brief statement of the standard that needs to be met and the reasons why, then you have some background to set the stage for why the MOC is written they way it is. In other words, how does this MOC meet the standard and the stated issues. The last paragraph of this section does not make sense. This MOC should cover in full the methods for the battery system compliance, both from the design of the system standpoint and then the installation. Unless it is planned that another MOC is will be prepared. As stated earlier whatever is prepared, we should separate clearly what is covered under the battery system design level and the aircraft installation level.
response	Partially accepted. Propulsion Batteries are part of lift/thrust system installation as per VTOL.2400 (a): *"For the purpose of this Subpart, the aircraft lift/thrust system installation must include each component that is necessary for lift/thrust, affects lift/thrust safety, or provides auxiliary power to the aircraft. "* Therefore VTOL.2440 is a more appropriate requirement for fire in Propulsion Batteries than VTOL.2525.

The MOC is not only related to fire effects, but also to fire prevention in terms of battery design and installation through DO-311A guidelines, so requirements: VTOL.2425(a), VTOL.2430(a)(1)(5), (b)(2), (c)(3) are covered.

Requirements VTOL.2430(a)(2)(6)(7) and (b)(3) will be deleted.

Regarding VTOL.2510 and VTOL.2525, this MOC defines some safety requirements ("Battery thermal runaway" is catastrophic) that should be used by applicants to specify the reliability requirement for the cell failure, as well as the safety objectives of the control and protective functions.

An explanation why the DO-311A is not sufficient is already provided in the MOC.

The MOC does not prescribe any design solution. Non-propagation tests are not defining/prescribing a particular design solution, as containment tests are not defining/prescribing a particular design solution. Both safety layers/measures are requested, and for both, the applicant can propose different design solutions, therefore fostering innovation and bringing more safety in the long term, in opposition to relying only on containment.

The objective of the MOC is clearly stated in the document, other MOCs or standards will be developed as needed to cover other areas of Propulsion batteries certification.

comment	*203* comment by: *Vertical Aerospace* ".. was developed for lithium batteries that provide power to other aircraft systems or equipment, without considering the particularities of very large propulsion battery systems needed in electric and hybrid aircraft." - Clearly introduce the distinction between batteries used for auxiliary power vs propulsion batteries and reword accordingly, i.e. ".. was developed for lithium batteries that provide auxiliary power to other aircraft systems or equipment; therefore the standard did not necessarily consider the particularities of very large battery systems intended to be used for electric and hybrid aircraft propulsion." It could also be the case for a generic statement within Section 1 Introduction of the document to be introduced, such as the following: "This MOC applies to Battery Systems intended to be used for electric and hybrid aircraft propulsion."
response	Accepted.

comment	*204* comment by: *Vertical Aerospace* "...because of placing the focus on the containment of an extreme thermal runaway event…" Which condition does the word "extreme" refer to? Replace the term "extreme" with "unprecedented".
response	Accepted.

comment	*216* comment by: *Heart Aerospace AB* DO-311A, Appendix C, proposes an alternative to the "Thermal Runaway Containment Test" in section 2.4.5.5. It is important that EASA clarifies why Appendix C was not considered an acceptable alternative for large propulsion battery systems used in electric and hybrid aircraft.
response	Not accepted. EASA is not accepting Appendix C because unlike Appendix C test, two protection layers are requested: Thermal Runaway propagation prevention (non-propagation test) and Thermal Runaway containment. For the non-propagation test, due to the variability of designs, general guidelines are proposed to support applicants to characterize and assess their design at different levels and be able to propose tests that capture all these possible variabilities and worst-case conditions (DO-311A Appendix C is not capturing these variabilities). On top of that, margins are included to ensure non-propagation, and a second protection layer (containment) is requested.

1.(a) Amount of additional external energy **p. 4**

comment	*177* comment by: *General Aviation Manufacturers Association (GAMA)* **RATIONALE / REASON / JUSTIFICATION** The following statement in § 1(a): *"The amount of additional external energy put into the battery system for this test is far in excess of energies used in service"* may be true for an in-flight use where the battery is not connected to a charging source. However, it is not clear whether the MOC require consideration for a scenario where the eVTOL is on the ground being recharged with personnel seated inside the aircraft. If yes, then the battery system could be exposed to charging sources that are "far in excess". Ground recharge is expected during the 'service' and 'maintenance' of the eVTOL. **PROPOSED TEXT/ACTION** EASA to clarify whether the "in service" claim would include ground service cases (such as recharge).
response	Not accepted. The “in service” includes ground service cases (such as recharge), as the energy is limited by fail-safe protection layers and adoption of processes throughout design, manufacturing, installation, operation, and maintenance.

1.(a)(1) Overcharging levels and chemical and thermal instability **p. 4**

comment	*16* comment by: *Andrea Marinovich* Where is the evidence for this statement? The high energy densities required by aerospace cells tend to have more exact charging requirements than lower energy density ones.
response	Noted. The statement is based on research and tests performed in projects in the last years, and it is referring to the overvoltage levels needed to trigger thermal runaway.

comment	*110* comment by: *Rolls-Royce plc* Page 4 Section/Paragraph 1 **RATIONALE / REASON / JUSTIFICATION for the Comment** However, the "Thermal runaway Containment Test" in section 2.4.5.5, was developed for lithium batteries that provide power to other aircraft systems or equipment, without considering the particularities of very large propulsion battery systems needed in electric and hybrid aircrafts. This MoC should distinguish between very large propulsion battery and other than very large propulsion battery like the one that can be used for hybrid propulsion. Some hybrid aircraft could install small batteries compared with the full electric ones. **PROPOSED TEXT** Introduce different requirements for different size of batteries to maintain the proportionality between risks and protection features.
response	Partially accepted. "very large" is deleted in the second paragraph of "Section 1. Introduction". The MOC does not differentiate batteries in terms of size, but in terms of function. Proportionality will be introduced by aircraft category (VTOL, CS-23, LSA, Sailplanes…).

comment	*121* comment by: *Rolls-Royce plc* Page 4 Section/Paragraph 1 **RATIONALE / REASON / JUSTIFICATION for the Comment** and to foster innovation and development of new solutions for these battery system protection layers, instead of relying only on containment mitigations. **PROPOSED TEXT** The EASA proposal should be based on safety considerations. Development of new solutions costs time, resources and money that not all the applicants may have available.
response	Not accepted. To foster innovation and develop of new solutions is not the main objective of the MOC, but a secondary objective, as innovation has demonstrated to increase safety in the history of aviation. The first objective is clearly stated in the previous sentence: *"In this Means of Compliance, EASA proposes an alternative method for propulsion lithium batteries, to promote best industry practices, robust designs, and protection layers strategies for the entire propulsion battery system."*

comment	*159* comment by: *Rolls-Royce plc* Page 4 Section/Paragraph 1 **RATIONALE / REASON / JUSTIFICATION for the Comment** However, the "Thermal runaway Containment Test" in section 2.4.5.5, was developed for lithium batteries that provide power to other aircraft systems or equipment, **PROPOSED TEXT** If this is the case, than a distinction should be made between propulsion batteries based on cell size, nr. of cells, and energy. Controlling propagation of 2 small cells within a module housing 10000 cell is very different to controlling propagation of 2 large cells in a 10 cell module. In the latter, the propagation of TR would already result in overstepping the 20% containment requirement!
response	Partially Accepted.

The MOC is modified to only request the triggering of 1 cell. Since the worst-case conditions of aging, temperature, trigger method, SOC, positions of the heater, position of the cell, orientation… are requested to maximize the potential for propagation, the tests will provide already enough margin in comparison with other single cell trigger tests (i.e., RTCA DO-311A 2.4.5.4, NASA EP-19-001 Interpretation Memo for the Battery TR Propagation requirements in JSC-20793 Rev D.). The modularization of the battery is a way to make easier the managing of thermal runaway situations, so bringing more or at least the same safety in terms of containment. However, over-modularize the battery in very small modules, could lead to a huge number of external wires between the modules (i.e. for HV power provision, temperature and voltage sensing…) creating additional reliability risks. Therefore, it is expected solutions that propose reasonable modularization level.

1.(a)(2) Heating of the whole battery **p. 4**

comment | *178* comment by: *General Aviation Manufacturers Association (GAMA)*

RATIONALE / REASON / JUSTIFICATION

In relation to the statement in § 1(a)(2):

"Heating the whole battery could compromise the validity of the test results due to mechanical and thermal effects created by preheating the whole battery structure, materials, and components to high temperatures."

The use of the term *"could compromise the validity of the test"* reads as an argument against heating the battery before a TR test and appears to be a critique of DO-311A Section 2.4.5.5 for its absence of requiring the battery to be heated before the thermal runaway test is performed. The intent of this 1(a)(2) paragraph could not be resolved by reviewing this MOC's section 4 and 5.

In this MOC's Section '4. Approach #1: RTCA DO-311A Section 2.4.5.5.', it references Section '3 Prerequisites' where paragraph 3(b)(ix) states that *"The temperature of the battery before triggering the cells should be always stabilized at 55degC or the maximum operating temperature, whichever is higher."* Section '5. Approach #2: Battery Thermal Runaway Containment for Continued Safe Flight and Landing' also includes paragraph 5(b)(2)(ix) *"The temperature of the battery before triggering the cells should be always stabilized at 55degC or the maximum operating temperature, whichever is higher."*

PROPOSED TEXT/ACTION

GAMA recommends clarifying paragraph 1(a)(2) on whether this MOC opposes preheating the battery prior to TR test or if it supports preheating the battery prior to TR test.

GAMA also recommends aligning 3(b)(ix) and 5(b)(2)(ix) to match this MOC's position. If the intent is to require heating for the full battery TR test after heating the battery, recommend using the procedure in DO-311A, Section 2.4.5.4. that allows removal of the battery from the temperature chamber before initiating TR to minimize contamination of the temperature chamber (see 2.4.5.4.1.g "After temperature statbilization, the EUT may be removed from teh temperature chamber (if used) to avoid contamination of the chamber....")

response | Not accepted.

1(a)(2) paragraph is not referring to the pre-heating of the battery before the test, as this temperature can be reached in normal operation of the battery. It is referring to DO-311A, Section 2.4.5.5.2 (d) where the whole battery is heated up to reach a thermal runaway, what will drive, in most of the cases, the entire battery or module (all cells) into thermal runaway by overcharging or overheating the entire battery pack or module.

Overcharging or overheating a propulsion battery system to the point of thermal runaway does not represent a realistic case of field failure. In fact, this test represents an extreme condition never encountered in-service, that will often drive a near-simultaneous failure of all cells in the battery, versus single cell initiation-propagation scenarios which have been experienced in service:

1. NTSB Incident Report NTSB/AIR-14/01, PB2014-108867 "Auxiliary Power Unit Battery Fire, Japan Airlines Boeing 787-8, January 7th, 2013".

   Section 1.2.4: *"The JTSB's report on the TAK incident stated that heat generation **in a single cell** "was probably caused by [an] internal short circuit" which developed into "thermal propagation to other cells, [which] consequently damaged the whole battery."*

2. JSTB Incident Report AI2014-4, Japan Transportation Safety Board "Auxiliary Power Unit Battery Fire, All Nippon Airways Boeing 787-8, Japan January 16th, 2013".

   Probable causes: *"Internal heat generation **in cell #6** very likely developed into venting, making it the initiating cell, resulting in cell-to-cell propagation and subsequent failure of the main battery"*

3. AAIB Accident Report 2/2015, UK Air Accidents Investigation Branch. "Emergency Locator Transmitter fire, Ethiopian Airlines Boeing 787-8, July 12th, 2013".

   Summary: "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 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."

1.(b) Overcharging or overheating the whole battery **p. 4**

comment	*17* comment by: *Andrea Marinovich* In-flight overcharging in a hybrid aircraft is certainly a feasible failure mode.
response	Not Accepted. The MOC provides guidelines for the proper design of the battery to preclude overcharge under any circumstance based on RTCA DO-311A section 2.1 “General Requirements”. Successful implementation is verified through testing. The design of electronics for critical aviation applications has been practiced for decades in the industry and demonstrated as highly effective for the safe operation of aircraft when consistent with appropriate industry practices, as requested in the MOC (SAE ARP 4761, EASA AMC 20-115, EASA AMC 20-152).

comment	*18* comment by: *Andrea Marinovich* Where is the evidence to support this statement?
response	Noted. Based on the experience collected in projects and in service over the last years.

comment	*217* comment by: *Heart Aerospace AB* Overheating or overcharging will usually not lead to nearly simultaneous failures. Heart Aerospace recommends rewording this section as: "In few cases, overcharging (if feasible) or overheating the whole battery can drive a near-simultaneous failure of all cells in the battery, which would not represent a realistic in-service field failure, but an extreme condition not encountered in service, even in batteries where reliable and tested protection layers were not implemented."
response	Partially accepted. It will be reworded as: “In some cases..” There is not enough testing data to support any quantification, especially with so many different designs and variability in test outcomes.

1.(c) Undertest of the propulsion battery containment **p. 4**

comment	*218* comment by: *Heart Aerospace AB* Many of the arguments listed herein are common practice for other standards also intended to verify equipment performance in aviation. DO-160 qualification, for instance, is performed with a single test / single test article per section, and manufacturing variations, degradation and aging effects, its impacts on equipment performance and compliance with the applicable tests are not required to be evaluated or justified. It is important that EASA clarifies why this common practice is no longer being considered acceptable for large propulsion battery systems used in electric and hybrid aircraft.
response	Not accepted. Propulsion batteries are not comparable to other aircraft equipment, due to their novel use, criticality, significant fire hazard and lack of service experience. Neither thermal runaway tests can be compared with DO-160 qualification tests, due to the variability in the outcome of the tests (due to cell variability, TR initiation criteria, temperature, SOC..) and its novelty and lack of testing experience.

comment	*179* comment by: *General Aviation Manufacturers Association (GAMA)* **RATIONALE / REASON / JUSTIFICATION** The indicated text seems to contain grammatical incorrections. **PROPOSED TEXT/ACTION** EASA to strike the word 'neither' as proposed: "This Means of Compliance is not addressing ~~neither~~ or superseding other tests needed for the certification of propulsion battery systems...."
response	Accepted. I will be modified as: *"This Means of Compliance is <u>neither</u> addressing <u>nor</u> superseding other tests needed for the certification of propulsion battery systems (i.e. external short circuit, available system capacity and energy, protections testing, battery system crashworthiness tests…)."*

1.(c)(2) Thermal runaway behaviour at cell level **p. 5**

comment	*131* comment by: *Electric Power Systems Inc* This limitation of DO-311A is due to the means by which safety is achieved. By instituting an extreme test (including external heating or overcharge and high temperature modules) the TR behavior of an individual cell is not particularly impactful. The bulk behavior of the complete stored energy induced into Thermal runaway drives the ability to contain per DO-311A not the behavior of an individual cell.
response	Not accepted. DO-311A containment tests may lead to undertest the propulsion battery containment, since only one test article is tested, and there could be variabilities or defective cells within the battery system that lead to trigger very few cells. As the power to the heating device may be removed once a thermal runaway has initiated, only those very few cells might enter into thermal runaway. Furthermore, the containment could be tested only in a brand-new battery (no aging or degradation considered). The thermal runaway behavior of an individual cell is thus particularly impactful: As the pass/fail criteria accept that only 2 cells enter into thermal runaway, the containment could be undertested (with only these 2 or very few cells in thermal runaway).

1.(c)(3) Variability in the cells or defective cells **p. 5**

comment	*132* comment by: *Electric Power Systems Inc* This limitation of DO-311A is due to the means by which safety is achieved. By instituting an extreme test (including external heating or overcharge and high temperature modules) the TR behavior of an individual cell is not particularly impactful. The bulk behavior of the complete stored energy induced into Thermal runaway drives the ability to contain per DO-311A not the behavior of an individual cell. Looking at this from a system safety perspective, DO-311A fundamentally makes the assumption that TR will happen and propagation will be occur. This assumption stems from the complexity associated with providing demonstrable evidence that TR can be avoided, or that propagation at the cell to cell level can be universally achieved. Therefore, with containment in place per DO-311A, regardless of the trigger mechanism, or temperature of the triggered event, containment is in place to mitigate the true hazard being loss of thermal containment.
response	Not accepted. DO-311A containment tests may lead to undertest the propulsion battery containment, since only one test article is tested, and there could be variabilities or defective cells within the battery system that lead to trigger very few cells. As the heating device power may be removed once the thermal runaway is initiated, only those very few cells might enter into thermal runaway. Furthermore, the containment could be tested only in a brand-new battery (not aging or degradation considered). The thermal runaway behavior of an individual cell is particularly impactful: As the pass/fail criteria accept that only 2 cells enter into thermal runaway, the containment could be undertested (with only these 2 or very few cells in thermal runaway). This MOC does not state that it is possible to guarantee that thermal runaway events can be prevented for every possible scenario or that the safest method is a cell-to-cell propagation mitigation. The MOC proposes different protection and mitigation layers, from cell level to battery level, and to installation level. These mitigations encompass to include and test non-propagation measures, and containment of realistic worst-cases of thermal runaway, on which the focus is clearly placed.

comment	*219* comment by: *Heart Aerospace AB* This same issue would happen when trying to fail 20% of the cells in the pack. There is variability of the cells, hence over-temperature and overvoltage levels that would lead to thermal runaway would be different, even when cells are not defective. It is important that EASA clarifies why proposing to fail 20% of the cells in the pack is considered an acceptable alternative and mitigates this cell variability concern for large propulsion battery systems used in electric and hybrid aircraft.
response	Not accepted. Unlike in the DO-311A, the test in EASA MOC for thermal runaway containment requests to individually target and trigger at least the 20% of the cells, and to consider all the variabilities identified at cell level, battery level (position, aging, degradation with environment) and installation level.

1.(c)(4) Heating device power removed **p. 5**

comment	*220* comment by: *Heart Aerospace AB* This same issue would happen when trying to fail 20% of the cells in the pack. There is variability of the cells, hence over-temperature and overvoltage levels that would lead to thermal runaway would be different, even when cells are not defective. It is important that EASA clarifies why proposing to fail 20% of the cells in the pack is considered an acceptable alternative and mitigates this cell variability concern for large propulsion battery systems used in electric and hybrid aircraft.
response	Not accepted. Unlike in the DO-311A, the test in EASA MOC for thermal runaway containment request to individually target and trigger at least the 20% of the cells, and to consider all the variabilities identified at cell level, battery level (position, aging, degradation with environment) and installation level.

1.(d) Designed protections reliability and overall risk	**p. 5**

comment | *157* comment by: *Rolls-Royce plc*

Page 5 Section/Paragraph 1 (d)

RATIONALE / REASON / JUSTIFICATION for the Comment

The design of electronics for critical aviation applications has been practiced for decades in the industry and has been demonstrated to be highly effective in the safe operation of aircraft when consistent with appropriate industry practices. Therefore, as for any other system in the aircraft, if designed protections are shown to be reliable the overall risk testing should consider those protections and their reliability

Due to the novelty of the application the risk is that it is difficult to prove the protections reliability therefore after having implemented them the thermal runaway test will be still extreme.

PROPOSED TEXT

Clarify what is expected to demonstrate the protections are reliable. E.g. reference to Industy Standards or other recognised guidance material.

response | Noted.

In section 3. (a) (1) of the MOC the following guidance material/standard is requested:

(ii) Evidence that critical functions including control and protective functions that include software have been designed and validated, as per the applicable revision of EASA AMC 20-115, to appropriate design assurance level.

(iii) Evidence that critical functions including control and protective functions that include airborne electronic hardware have been designed and validated, as per the applicable revision of EASA AMC 20-152, to appropriate design assurance level.

(iv) Evidence that a propulsion battery System Safety Assessment (SSA) has been performed as per the applicable revision of SAE ARP 4761, addressing the hazards leading to thermal runaway, including […]

comment	*19* comment by: *Andrea Marinovich* This is equally true of Li-ion system batteries yet DO-311A does not take this into consideration, and is a source of conflict with industry at this time. The 787 battery incidents show the difficulties of proving the efficacy of protection systems in preventing thermal runaway. I think because of this, if relaxation of DO-311A testing is being proposed, very strong evidence will need to be provided by industry that the thermal propagation events witnessed in these small batteries either a) do not scale to a large one, and b) the electronic protection measures are reliable enough to work effectively at the required criticality level.
response	Not accepted. The MOC is not relaxing the DO-311A tests or approach, only having a different approach focusing on prevention (protections measures, non-propagation measures and tests, installation guidelines…), and mitigation of a more realistic worst case where several cells go to thermal runaway and there is propagation. These tests (non-propagation and containment) do not relax other critical mitigations/protections as stated in the Note in (3)(a)(1). DO-311A standard includes useful guidelines for design, testing, manufacturing, installation, operation, and maintenance of rechargeable lithium battery systems. However, this document was developed to support the certification of smaller batteries that provide auxiliary power to other aircraft systems or equipment and already includes dissenting opinions from several stakeholders regarding the document approach for thermal runaway safety. The prescribed thermal runaway containment test methods in DO-311A goes beyond forcing multiple cells into thermal runaway and will drive, in most of the cases, the entire battery or module (all cells) into thermal runaway by overcharging or overheating the entire battery pack or module. Overcharging or overheating of a propulsion battery system, as requested in DO-311A, to the point of thermal runaway does not represent a realistic worst case field failure. In fact, this test represents an extreme condition never encountered in service, that will drive a near-simultaneous failure of all cells in the battery with far more energy than used in service, versus single cell initiation-propagation scenarios which have been experienced in service, as in the mentioned Boeing 787-8 incidents in 2013: 1. NTSB Incident Report NTSB/AIR-14/01, PB2014-108867 “Auxiliary Power Unit Battery Fire, Japan Airlines Boeing 787-8, January 7th, 2013”. Section 1.2.4: *“The JTSB’s report on the TAK incident stated that **heat generation in a single cell** “was probably caused by [an] internal short circuit” which developed*

into "thermal propagation to other cells, [which] consequently damaged the whole battery."

2. JSTB Incident Report AI2014-4, Japan Transportation Safety Board "Auxiliary Power Unit Battery Fire, All Nippon Airways Boeing 787-8, Japan January 16th, 2013"

   Probable causes: *"**Internal heat generation in cell #6** very likely developed into venting, making it the initiating cell, resulting in cell-to-cell propagation and subsequent failure of the main battery"*

3. AAIB Accident Report 2/2015, UK Air Accidents Investigation Branch. "Emergency Locator Transmitter fire, Ethiopian Airlines Boeing 787-8, July 12th, 2013"

   Summary: "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 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."

However, in other cases, this test may lead to undertest the propulsion battery containment, since only one test article is tested, and there could be variabilities or defective cells within the battery system, that lead to trigger very few cells. As the heating device power may be removed once initiated the thermal runaway, it could lead to have only those very few cells into thermal runaway testing the containment in a brand-new battery (not aging or degradation considered).

Moreover, the DO-311A does not encourage best industry practices and robust designs for all mitigation layers for the entire propulsion battery system, and places over-reliance on containment mitigations, alleviating some protection layers such as:

- Single cell non-propagation measures (non-propagation tests not requested).
- Safety objectives and DALs for the control and protective functions.
- Reliability requirements for the cell failure.

EASA approach for propulsion batteries safety is based on different protection and mitigation layers from cell level to battery level and to installation level and considering the particularities of Electric and Hybrid aviation.

This approach intends to foster innovation and development of new solutions for these battery system protection layers, instead of only placing over-reliance on containment mitigations. EASA's approach is consistent with modern, accepted industry practice, where these protection and mitigation layers are incorporated in batteries used in critical sectors, for example in space and satellite applications:

1. NASA/TM-2009-215751 Guidelines on Lithium-Ion battery use in Space Applications.
2. Aerospace report No. TOR-2007 (8583)-2 Acquisition Standard for Lithium-Ion Based Launch Vehicle Batteries.

EASA is working to develop MOCs either internally or in collaboration with EUROCAE for the following mitigation and protection layers (non-exhaustive list):

Cell level:

- Quality cells from robust suppliers (Under POA of the OEM).
- Cell incoming inspection and testing (Uniformity, reduction of manufacturing defects).
- Cell thermal runaway variabilities characterization to identify the wort-cases conditions.
- Reliability requirements for the cell failure derived from defined safety requirements (2 or more cells in thermal runaway is considered Catastrophic).

Battery Level:

- RTCA DO-311A section 2.1 “General requirements” (design, quality, maintenance requirements…)
- Safety objectives and DALs for the control and protective functions derived from defined safety requirements (2 or more cells in thermal runaway is considered CAT)
- Aging of the cells and degradation of the battery during operational lifetime considered.
- Set of Non-propagation tests.
- Set of containment tests.

Installation level:

- RTCA DO-311A section 3 “Installation Consideration” to be evaluated.
- Isolation Monitor to detect any decrease on isolation of the High Voltage system.
- Venting and draining provisions at A/C level.
- Crashworthiness tests.

It is important to highlight that demonstrating compliance with the set of tests of non-propagation and containment, does not alleviate the other protection layers.

2. Definitions **p. 5**

comment	*32* comment by: *Collins Aerospace/Pratt & Whitney* Comment: Hierarchy of battery configuration is not clear, and in conflict with definitions from other standard bodies such as SAE. Recommend hierarchy of battery cell/battery module/battery system.
response	Accepted. All definitions have been reviewed and modified for more clarity.

comment	*46* comment by: *Kevin Bruce* You cannot define a word use the same word in a definition. Additionally, the definition of a battery cell should be included as it is used in this MOC. Also, throughout the MOC a review should be done to ensure that when the term battery is used it means battery, when cell is used it means cell, etc. Proposed definitions: Battery - a container consisting of one or more cells, in which chemical energy is converted into electricity and used as a source of power. *(In this case we should stick with the standard definition and not create something new. Batteries have been around a long time)* Battery Cell (or Cell) - a device containing electrodes immersed in an electrolyte, used for current-generation or electrolysis. Battery Module - means a group of interconnected cells ***or batteries*** in series and/or parallel arrangement contained in a single enclosure that ensures that no fluids, flames, gasses, smoke, or fragments enter other modules during normal operation or failure conditions. *(the term battery module may be more suited to use in this MOC than just battery however the term battery should still be defined)* Battery String – a collection of batteries or battery modules that are segregate and independent of another collection of batteries or battery modules. Battery System - means a collection of batteries **or battery modules** plus any protective, monitoring, alerting circuitry or hardware inside or outside of the battery, its packaging, and the designed venting provisions.

	Propulsion Battery System – means a battery system used for propulsion applications *(a point of clarity here – in many cases the propulsion battery system will also be the primary electrical power for other systems on the aircraft like the avionics – this should be considered here in the definition as well as in the MOC. Additional considerations are needed to be looked at when the propulsion battery system also feeds a low voltage system)* There may be a need to define other words such as thermal runaway.
response	Partially accepted. All definitions have been reviewed and modified for more clarity.

comment	*79*	comment by: *Diamond Aircraft Industries GmbH*
	Battery module definition vague. It is not clear what the relation is between a 'battery' and 'battery module'. For example, can a battery system be composed out of multiple battery modules? Or is a set of battery modules automatically referred to as a battery. What is the difference between a battery system containing multiple battery modules vs a battery system containing multiple batteries? The definition of a battery cell should be included as it is used in this MOC Additionally, you cannot define a word use the same word in a definition. Also, throughout the MOC a review should be done to ensure that when the term battery is used it means battery, when cell is used it means cell, etc. Elaborate definition of battery module. Illustrate the difference in definition to a multi battery module battery system and a multi-battery battery system. Proposed definitions: Battery - a container consisting of one or more cells, in which chemical energy is converted into electricity and used as a source of power. (In this case we should stick with the standard definition and not create something new. Batteries have been around a long time) Battery Cell (or Cell) - a device containing electrodes immersed in an electrolyte, used for current-generation or electrolysis. Battery Module - means a group of interconnected cells or batteries in series and/or parallel arrangement contained in a single enclosure that ensures that no fluids, flames, gasses, smoke, or fragments enter other modules during normal operation or failure conditions. (the term battery module may be more suited to use in this MOC than just battery however the term battery should still be defined) Battery String – a collection of batteries or battery modules that are segregate and independent of another collection of batteries or battery modules. Battery System - means a collection of batteries or battery modules plus any protective, monitoring, alerting circuitry or hardware inside or outside of the battery, its packaging, and	

	the designed venting provisions. Propulsion Battery System – means a battery system used for propulsion applications (a point of clarity here – in many cases the propulsion battery system will also be the primary electrical power for other systems on the aircraft like the avionics – this should be considered here in the definition as well as in the MOC. Additional considerations are needed to be looked at when the propulsion battery system also feeds a low voltage system) There may be a need to define other words such as thermal runaway.
response	Partially accepted. All definitions have been reviewed and modified for more clarity.

comment *141* — comment by: *The Boeing Company*

COMMENT #1 of 14			
Type of comment (check one)	***Non-Concur***	***Substantive*** ***X***	***Editorial***
Affected paragraph and page number	Page: 5 Paragraph: *Section 2 "Definitions" (whole section)*		
What is your concern and what do you want changed in this paragraph?	**THE PROPOSED TEXT STATES:** - **REQUESTED CHANGE:** We recommend that each definition in Section 2 "Definitions" be modified to match the definitions in the recently published ARP 8676 "Nomenclature and Definitions for Electrified Propulsion Aircraft", including succinct definitions for non-propagation and containment.		
Why is your suggested change justified?	**JUSTIFICATION:** Use of definitions from an industry-accepted standard, when available, are an industry best practice. Definitions for non-propagation and containment will help the applicants understand the differences between the test approaches, as EASA intends them.		

response

Partially Accepted.

All definitions have been reviewed and modified for more clarity.

Non-propagation and containment are defined by the test pass/fail criteria, but objective evidences or unambiguous markers that demonstrate that a cell achieved thermal runaway are included in definitions.

comment *205* comment by: *Vertical Aerospace*

It is understood that definitions are of certain importance for ensuring consistency throughout the document and need to be architecture agnostic; however, the current definitions create some level of ambiguity. An example would be the multiple use of the term "propulsion battery system" within the document (although not part of Section 2 Definitions) which is implied to be the same as "battery system".
Consider keeping the Battery System definition (both within definitions and throughout the document) and provide a Generic note at the beginning of the document to state that this MOC applies only to Battery Systems intended to be used for electric and hybrid aircraft propulsion. Therefore, use of the term Propulsion battery (system) will not be needed any more. Note that the term is currently being used 29 times throughout the document.

response

Accepted.

All definitions have been reviewed and modified for more clarity.

2.(a) "Battery"	p. 5

comment	*27* comment by: *Andrea Marinovich* Is battery a synonimous of cells?
response	Accepted. Definition of “battery cell” will be included.

comment	*33* comment by: *Collins Aerospace/Pratt & Whitney* Comment: Delete entire definition Justification: Redundant and creates confusion - "battery module" and "battery system" definitions sufficiency address levels of the battery system.
response	Partially Accepted. All definitions have been reviewed and modified for more clarity.

comment	*56* comment by: *Electric Power Systems Inc* A more fundamental set of definitions need to be established. Using the term "battery" in the definition of "battery" is insufficient. Consider more complete set of definitions of cell, module, system, and installation. Clarity on these definitions provides the fundamental basis for the recommendations and requirements provided in this document.
response	Accepted. All definitions have been reviewed and modified for more clarity.

comment	*95*	comment by: *Voltaero*
	The specific wording used in this MOC needs to be better define. A lack of clarity in this set of define will lead to subjective interpretation of the recommendations and requirements provided in this document.	
response	Accepted. All definitions have been reviewed and modified for more clarity.	

comment	*181*	comment by: *General Aviation Manufacturers Association (GAMA)*
	RATIONALE / REASON / JUSTIFICATION The indicated text seems to contain grammatical incorrections and not provide enough clarity as tu ensure proper interpretation of the text. **PROPOSED TEXT/ACTION** EASA to consider striking the word 'to' as proposed: "Battery" means a stand-alone battery or ~~to~~ a battery that is part of a battery system.	
response	Accepted. All definitions have been reviewed and modified for more clarity.	

comment	*206*	comment by: *Vertical Aerospace*
	The current definition excludes embedded batteries (as per the DO-311A use of the terms "stand-alone" and "embedded" batteries). Remove the word "stand-alone".	
response	Accepted. All definitions have been reviewed and modified for more clarity.	

comment	*207*	comment by: *Vertical Aerospace*
	Is the current term "Battery" considered to be equivalent to a "Battery Subpack"? It is suggested to reword to state that a Battery is considered to be a subsystem of the Battery System.	

	Also, consider consistent use of the term with/without capital letters (battery Vs Battery).
response	Accepted. For the purpose of the MOC, “Battery” and “Battery System” is considered to be equivalent. All definitions have been reviewed and modified for more clarity.

comment	*221* comment by: *Heart Aerospace AB* Heart Aerospace suggests replacing the proposed battery of this document by the battery definition in DO-311A or ARP8676.
response	Partially accepted. All definitions have been reviewed and modified for more clarity.

2.(b) "Battery system" **p. 5**

comment	*34* comment by: *Collins Aerospace/Pratt & Whitney* Comment: Replace "a battery plus any" with "a battery module plus any". Replace "the battery," with "the battery module,". Justification: clarify relationship between various levels of the battery system
response	Partially accepted. All definitions have been reviewed and modified for more clarity.

comment	*57* comment by: *Electric Power Systems Inc* This definition includes major functions which the battery performs but does not provide guidance on segmentation of the battery system when considering the 20% TR progagation requirement
response	Accepted. All definitions have been reviewed and modified for more clarity.

comment	*208* comment by: *Vertical Aerospace* Is the current term "Battery System" considered to be equivalent to the "Electrical Energy Storage System" term? If applicable, introduce the equivalency of the two terms to ensure consistency with other SC-VTOL requirements.
response	Accepted. All definitions have been reviewed and modified for more clarity. A note has been included to introduce the equivalency between the two terms.

comment	*222* comment by: *Heart Aerospace AB* Heart Aerospace suggests rewording as:

	" "Battery system" means a battery plus any protective, monitoring, alerting circuitry or hardware required for the battery to meet its intended function when installed in a given application." Or instead, using the definition of ARP8676.
response	Partially Accepted. All definitions have been reviewed and modified for more clarity.

2.(c) "Propulsion battery"	p. 5

comment	*35* comment by: *Collins Aerospace/Pratt & Whitney* Comment: Replace: "Propulsion battery" means a battery or battery system with: "Propulsion battery system" means a battery system Justification: Clarify system relationships
response	Partially Accepted. All definitions have been reviewed and modified for more clarity.

comment	*180* comment by: *General Aviation Manufacturers Association (GAMA)* **RATIONALE / REASON / JUSTIFICATION** The indicated text seems to not provide enough clarity as tu ensure proper interpretation of the text. **PROPOSED TEXT/ACTION** EASA to consider clarifying the following sentence by adding the word 'electric' as follows: "“Propulsion battery” means a battery or battery system used for **electric** propulsion applications."
response	Partially Accepted. All definitions have been reviewed and modified for more clarity.

comment	*209* comment by: *Vertical Aerospace* As per Comment 205
response	Accepted. All definitions have been reviewed and modified for more clarity.

2.(d) "Battery Module"	**p. 5**

comment	*3* comment by: *AIRBUS HELICOPTERS* With regard to paragraph (d) : *"Battery Module" means a group of interconnected cells in series and/or parallel arrangement contained in a single enclosure that ensures that no fluids, flames, gasses, smoke, or fragments enter other modules during normal operation or failure conditions.*" It is suggested to change the definition of a "Battery Module" as follows : **PROPOSED TEXT:** *"Battery Module" means a group of interconnected cells in series and/or parallel arrangement contained in a single enclosure that ensures that* ***no thermal runaway is propagated from one module to the others*** *during normal operation or failure conditions.*" **JUSTIFICATION :** It is suggested that the "Battery Module" definition be only performance-based. Indeed, the "Battery Module" definition with the wording " *[...] single enclosure that ensures that no fluids, flames, gasses, smoke, or fragments enter other modules during normal operation ...*" is giving detailed design requirements and therefore is considered as solution-prescriptive. See as well the comment #4 about the need of consistency between the battery module definition in paragraph 2.(d). and the note on page 11.
response	Partially Accepted. Modularization solution is just one solution accepted to relax the test from battery level to module level, and to do so, a clear definition of module is needed. Other solutions (i.e. not modularization) are also accepted. The sentence will include "no thermal runaway propagation from one module to the others", but the clear definition of a module is kept: *"Battery Module" means a group of interconnected cells in series and/or parallel arrangement contained in a single enclosure that ensures that no fluids, flames, gasses, smoke, or fragments enter other modules, and that no thermal runaway is propagated from one module to the others during normal operation or failure conditions.*

comment	*58* comment by: *Electric Power Systems Inc* This definition is valuable but not adequately accounted for in the MOC. Since uncontained TR is the fundamental risk, containment at the module level should be fundamental to the battery MOC.
response	Not accepted. Both mitigations requested, Thermal Runaway propagation prevention (non-propagation test) and Thermal Runaway containment and no propagation to other modules or batteries, are fundamental in EASA's safety approach.

comment	*76* comment by: *Bilge Atici* **Comment summary 2.d page 5** As pointed in Section.1, the purpose of this MOC is to provide alternative methods to containment test like protection layers strategies. Therefore, an update in "Battery Module" definition will provide opportunities for more alternatives. **Suggested resolution** Changing the definition of "Battery Module" as follows: "(d) "Battery Module" means a group of interconnected cells in series and/or parallel arrangement contained in sub module(s), enclosure(s) or compartment(s) that ensures that no fluids, flames, gasses, smoke, or fragments enter other module(s)/sunmodule(s), enclosure(s) or compartment(s), during normal operation or failure conditions."
response	Not accepted. The definition of Battery Module uses the term "Enclosure" that is a generic term meaning: "An area that is surrounded by a barrier", so the term "enclosure" could be a sub-module or compartment provided that no fluids, flames, gasses, smoke, or fragments enter the other modules and that there is no propagation to other modules.

comment	*223* comment by: *Heart Aerospace AB* Heart Aerospace suggests rewording as: " "Battery Module" means a group of interconnected cells in series and/or parallel arrangement contained in a single enclosure." Or instead, using the definition of ARP8676.

response	Not accepted. The MOC definition is an extension of the definition included in ARP8676, suited to this MOC, and defining conditions to accept the relaxation of Thermal runaway tests from Battery level to module level.

3. Prerequisites	**p. 5**

comment | *47* | comment by: *Kevin Bruce*

It does not seem to make sense to have a section identified as prerequisites in an MOC. We should just have the MOC. This section should be retitled. However, prior to doing so all comments on this section need to be addressed, a rewrite completed, and the layout of the sections determined.

The first note in this section is note inappropriate. The FHA is the place to determine the failure classification and to just define a battery thermal runaway as catastrophic may not be appropriate for all design solutions. The proper term to be used here is uncontained thermal runaway similar to what we already do on a gas powered engine – uncontained fire.

(a)(1)(iv) – ARP 4761 is a good recommendation but for some classes of aircraft it is an overkill at the aircraft level. Level 1 and 2 aircraft are not typically complex enough or highly integrated in their system and the use of 4761 is onerous.

(b) – the term cell is used in this section which may be appropriate if the battery system is designed with all the cells connected in a way that cell to cell propagation mitigation is required. However, if a battery module is designed that prevents an uncontained thermal runaway this should be allowed and the non-propagation test section re written to account for either design solution (cell to cell protection or module to module protection). In the end the goal is to prevent an uncontained thermal runaway and the designer should be able to show that the system design provides the proper protections against thermal runaway.

(b)(2) – Section 2.1 of DO-311A is not really about propagation prevention, it is more about all the other factors to design for to have a safe battery system. This paragraph should just state that section 2.1 of DO-311 should be met.

(b)(3)(ii) – while this is probably a good idea from the design standpoint to understand your cells better is it necessary of an MOC. The reasons this is needed should be made clear here. This sounds more like sound design advice rather than an MOC.

(b)(3)(ii)(B) this paragraph needs to be re written – the grammar is not good. Therefore, it is not clear on the intent.

(b)(3)(v) thru ((ix) – these sections refer to the battery system. Suggesting the full battery system as installed on an aircraft requires thermal runaway propagation testing does not properly account for all proposed design solutions. There should be guidance provided to help one determine at which level the non propagation test should happen and the provide the guidance on what factors to consider when conduction the test. There is examples of battery

	modules that fully contain a thermal runaway of all cells within the module (including temperature characterization of the module casing and thermal runaway "exhaust" allowing for the airframer to protect against these). b)(3)(xi) - this requirement may not be possible as the high temp event in a thermal runaway is somewhat unpredictable. Even when characterizing individual cells on thermal runaway once in the module it is hard to get multiple cells to go to thermal runaway in a given time.
response	Partially accepted. The purpose of this note in 3(a)(1) and definitions section is to define what is considered a "battery thermal runaway": o Thermal runaway of two cells that thermally affect at least one common adjacent third cell within the same battery or, for modularized batteries, within the same module. o Thermal runaway of any three or more cells within the same battery or, for modularized batteries, within the same module. The whole EASA safety strategy is based in a multi-layer approach, where the reliability of the cells and the control and protective functions play a key role in EASA safety approach for the battery, and shouldn't be relaxed due to: • Propulsion batteries are not comparable to other aircraft equipment/Systems, due to their novel use, criticality, significant fire hazard and lack of service experience. • Neither thermal runaway tests can be compared with other qualification tests, due to the variability in the outcome of the tests (due to cell variability, TR initiation criteria, temperature, SOC..) and its novelty and lack of testing experience. Therefore, EASA is setting safety requirements ("battery thermal runaway" is catastrophic) that should be used by the applicants to specify the reliability requirement for the cell failure as well as the safety objectives of the control and protective functions. This activity is complementary to the tests. This MOC is currently not applicable to CS23 aircraft, the MOC is only applicable to VTOL in the category enhanced as clearly stated. Other MOCs for CS23 aircraft, based on this SC-VTOL MOC and applying proportionality, will be developed and published for comments after. Both mitigations are requested, Thermal Runaway propagation prevention (non-propagation test) and Thermal Runaway containment. For the non-propagation test, due to the variability of designs, general guidelines are proposed to support applicants to characterize and assess their design at different levels and define tests that capture all these possible variabilities and worst-case conditions. On top of that, margins are included to ensure non-propagation, and a second protection layer (containment) is requested. Non-propagation tests are not defining/prescribing a particular solution, as containment tests are not defining/prescribing a particular solution. Both safety layers/measures are

	requested, and for both the applicant can propose different solutions, therefore fostering innovation and bringing more safety in the long term, in opposition to relying only on containment. Section 3(a)(1)(i) is modified as follows: *"Evidence that RTCA DO-311A section 2.1 Requirements have been considered and successfully implemented and section 3 Installation Considerations has been evaluated."* The section 3(b)(2) modified as: *"(2) The applicant should define, in coordination with EASA, a set of tests at battery system level to demonstrate that the propagation prevention mechanisms have been successfully implemented."* Section 3.(b)(3)(ii) will be modified as follows, including the reason why it is requested, and moved to 6.(a)(3)(ii): *" A full characterisation of thermal runaway behaviour at cell level should be performed by the applicant to identify the potential worst-cases for cell-to-cell propagation at battery system level tests, combining the following parameters:"* Section 3.(b)(3)(ii) (B) will be modified as follows, including the reason it is requested, and moved to 6.(a)(3)(ii)(B) : *"Different State of Charge (SOC). Low SOC leads to more material remaining in the cell hence increasing the probability of cell-to-cell propagation. However higher SOC leads to a thermal runaway more explosive and energetic with more material expelled outside the cell."* Section 3(b)(3)(xi) is completely removed, only one cell is required to be triggered in thermal runaway.

Comment	*80* comment by: *Diamond Aircraft Industries GmbH* It does not seem to make sense to have a section identified as prerequisites in an MOC. We should just have the MOC. This section should be retitled. However, prior to doing so all comments on this section need to be addressed, a rewrite completed, and the layout of the sections determined. Revisit the title of each section after the disposition of all comments and a revision to the MOC
response	Not accepted. Prerequisites section sets the conditions for the use of this MOC as a framework that applies to both approaches.

3.(a) General considerations	p. 5

comment	*211* comment by: *G Cherouvrier SEP* In the paragraph: "Note: Demonstrating compliance with one of the test approaches defined in this MOC does not alleviate the classification of the failure condition "battery thermal runaway" (i.e. the thermal runaway of two or more cells within a battery) considered catastrophic." With a safe* aircraft and propulsion architecture, a contained** battery thermal runaway failure condition, assuming the definition below should not be considered as Catastrophic event. Proposition: "Note: Demonstrating compliance with one of the test approaches defined in this MOC does not alleviate the classification of the failure condition "battery thermal runaway" (i.e. the thermal runaway of two or more cells within a battery) considered catastrophic unless it is demonstrated that flight and landing can be safely managed". **safe means: be able to continue flight and safely landing* ***contained means:* *No rupture of the battery system.* *No release of fragments outside the battery system* *No escape of flames outside of the battery system.* *No escape of emissions outside the battery system, except through the designed venting provisions.* *No compromise of warning signals and safety functions (e.g., battery automatic disconnect function).*
Response	Not accepted. See response to comment 47. Both mitigations are requested, Thermal Runaway propagation prevention (non-propagation test) and Thermal Runaway containment. For the non-propagation test, due to the variability of designs, general guidelines are proposed to support applicants to characterize and assess their design at different levels and define tests that capture all these possible variabilities and worst-cases conditions. On top of that, margins are included to ensure non-propagation, and a second protection layer (containment) is requested.

3.(a)(1) RTCA DO-311A and multiple layers of mitigation mechanisms **p. 5**

comment	*36* comment by: *Collins Aerospace/Pratt & Whitney* Comment: Replace "should" with "shall" four places Justfication: Change wording to reflect mandatory requirement. Comment: In note following section (iii), delete entire note. Justification: This note is not appropriate here. Whether or not a battery thermal runaway (either contained or not) is a catastrophic hazard is determined by aircraft SSA and not by whether a particular test sequence is passed. Comment: In section (iv), replace "hazards leading to thermal runaway" with "hazards leading to, during, and following a thermal runaway" Justification: SSA must not just address what leads to the runaway, but how the battery system reacts to it. Comment: In section (v) replace "battery" with "battery module". Justification: Wording clarification. Comment: In section (vi), replace "non-propagation" with "containment" and replace "propagation prevention" with "containment". Justification: Containment of the failure within the battery system is the need at the aircraft level. Specifying non-propagation defines a particular technical solution approach.
response	Partially accepted. EASA SC-VTOL MOCs always use the term “should” instead of “shall” as they are not requirements. See response to comment 47. Section (iv) will be modified. Section (v) is mainly related to control and protective functions that are normally allocated in the battery. Section (vi): Non-propagation tests are not defining/prescribing a particular solution, as containment tests are also not defining/prescribing a particular solution. Both safety layers/measures are requested, and for both, the applicant can propose different solutions.

comment	*59* comment by: *Electric Power Systems Inc* 3.a.1 There are different ways of implementing "multiple layers of mitigation." This MOC provides guidance on only one of these layers. Vehicle, architecture, and platform specific system safety assessments should inform the implementation of mitigation mechanisms. An overly prescriptive set of MOC will inhibit innovations in battery safety and lead to long term reductions in battery safety. 3.a.1 (note) More than two cells within the battery does not equal catastrophic. A catastrophic failure has a very specific meaning during vehicle system safety analysis. 2 cells or more in TR in no way rises to the level of a catastrophic failure. A catastrophic failure must be considered as loss of thermal containment applied at the system level that leads to loss of aircraft / life. The only reason this failure scenario may be considered catastrophic is potential uncertainty in the relationship between cell and system level failures. This is only the case for cell to cell propagation resistant designs. 3.a.1.vi Not all battery safety approaches require the condition that cell to cell propagation is mitigated. Different methods for redundant layers of protection can be applied to which may deviate for this requirement.
response	Not accepted. Both mitigations are requested, Thermal Runaway propagation prevention (non-propagation test) and Thermal Runaway containment. For the non-propagation test, due to the variability of designs, general guidelines are proposed to support applicants to characterize and assess their design at different levels and define tests that capture all these possible variabilities and worst-case conditions. On top of that, margins are included to ensure non-propagation, and a second protection layer (containment) is requested. Non-propagation tests are not defining/prescribing a particular solution, as containment tests are not defining/prescribing a particular solution. Both safety layers/measures are requested,

and for both, the applicant can propose different solutions, therefore fostering innovation and bringing more safety in the long term, in opposition to relying only on containment.

See response to comment 47.

EASA is working to develop MOCs either internally or in collaboration with EUROCAE for the following mitigation and protection layers (non-exhaustive list):

Cell level:

- Quality cells from robust suppliers (Under POA of the OEM).
- Cell incoming inspection and testing (Uniformity, reduction of manufacturing defects).
- Cell thermal runaway variabilities characterization to identify the wort-cases conditions.
- Reliability requirements for the cell failure derived from defined safety requirements (2 or more cells in thermal runaway is considered Catastrophic).

Battery Level:

- RTCA DO-311A section 2.1 "General requirements" (design, quality, maintenance requirements…)
- Safety objectives and DALs for the control and protective functions derived from defined safety requirements (2 or more cells in thermal runaway is considered CAT)
- Aging of the cells and degradation of the battery during operational lifetime considered.
- Set of Non-propagation tests.
- Set of containment tests.

Installation level:

- RTCA DO-311A section 3 "Installation Consideration" to be evaluated.
- Isolation Monitor to detect any decrease on isolation of the High Voltage system.
- Venting and draining provisions at A/C level.
- Crashworthiness tests.

It is important to highlight that demonstrating compliance with the set of tests of non-propagation and containment does not alleviate the other protection layers.

comment *81* comment by: *Diamond Aircraft Industries GmbH*

3(a)(1)(iv)

ARP 4761 is a good recommendation but for some classes of aircraft it is an overkill at the aircraft level. Level 1 and 2 aircraft are not typically complex enough or highly integrated in their system and the use of 4761 is onerous.

Revise to indicate that the use of ARP 4761 is good practice but not required.

response

Not accepted.

This MOC is only applicable to VTOL in the category enhanced.

comment

97

comment by: *Volocopter GmbH*

Comment to note:
Note: *Demonstrating compliance with one of the test approaches defined in this MOC does not alleviate the classification of the failure condition "battery thermal runaway" (i.e. the thermal runaway of two or more cells within a battery) considered catastrophic.*

Comment:
There is no consideration for the physical or temporal separation of the two cell events, that may allow the two events to be considered independent from each other.

Proposed wording:
"Demonstrating compliance with one of the test approaches defined in this MOC does not alleviate the classification of the failure condition "battery thermal runaway" (i.e. the thermal runaway of two or more cells that directly (physically) and overlappingly (timing wise) thermally affect at least one common third cell) considered catastrophic."

response

Partially Accepted.

It will be modified as:

(a) Definitions:
(b) "Battery Thermal Runaway" is defined as:

(1) *Thermal runaway of two cells that thermally affect at least one common adjacent third cell within the same battery or, for modularized batteries, within the same module.*

(2) *Thermal runaway of any three or more cells within the same battery or, for modularized batteries, within the same module.*

3(a)(1)(iii)

Note:
Demonstrating compliance with one of the test approaches defined in this MOC does not alleviate the classification of the failure condition "battery thermal runaway" (as defined in 3.(g)), which is considered catastrophic.

The safety of the propulsion battery is based in a multi-layer approach, where the reliability of the cells and the control and protective functions play a key role and should not be alleviated, since:

- Propulsion batteries are not comparable to other aircraft equipment/systems, due to their novel use, criticality, significant fire hazard and lack of service experience.
- Thermal runaway tests are not comparable to other qualification tests, due to the variability in the outcome of the tests (due to cell variability, TR initiation criteria, temperature, SOC..) and their novelty and lack of testing experience.

Therefore, this safety requirement should be used by the applicants to specify the reliability requirement for the cell failure, as well as the safety objectives of the control and protective functions.

comment | *124* | comment by: *H55_FSU*

System Safety Assessment, 3 (a)(iv):
The depth of analysis should be consistent with the failure classification. The proposed text suggests complete analysis also for minor failure consitions.

Quantitative assessment is missing in the list.

response | Partially accepted.

As a preliminary remark, failure conditions related to thermal runaway are usually not considered minor due to the failure effects at aircraft level (e.g. reduction in safety margin, performance Impact) and the effects on the crew (e.g. increase in workload).

Quantitative and qualitative assessment is included in the list and expected to be performed in line with the depth of analysis agreed at project level.

comment | *133* | comment by: *Ampaire Inc*

Regarding this text in (iii) Note:
Note: Demonstrating compliance with one of the test approaches defined in this MOC does not alleviate the classification of the failure condition “battery thermal runaway” (i.e. the thermal runaway of two or more cells within a battery) considered catastrophic.

We are not sure what was intended by this note but have an interpretation and suggested revision. A propulsion battery system thermal runaway event is not necessarily catastrophic.

That depends on many factors and should be driven by the appropriate SSA and FHA for the given application. For example, in a hybrid electric propulsion aircraft you can lose the entire battery system, properly contain and vent the thermal runaway event consequences and still safely fly and land the aircraft. A Catastrophic Failure condition is one which would result in multiple fatalities, usually with the loss of the airplane.

Suggested revision:
"Note: The classification of the failure condition “battery thermal runaway” (i.e. the thermal runaway of two or more cells within a battery) whether classified as catastrophic, hazardous, or other through the SSA, FHA, and other safety reports is established with the understanding that the applicant has demonstrated compliance with one of the test approaches defined in this MOC."

response Not accepted.

See response to comment 47.

comment *183* comment by: *General Aviation Manufacturers Association (GAMA)*

RATIONALE / REASON / JUSTIFICATION
The referenced DO-311A Section 3 is "Installation Considerations" and expressly states "This section has no design requirements", but this MOC's Section 3(a)(1)(i) includes it in a statement about requirements.

PROPOSED TEXT/ACTION
GAMA Recommends changing the wording from "*Evidence that RTCA DO-311A section 2.1 and section 3 requirements have been considered and are successfully implemented*" to "*Evidence that RTCA DO-311A section 2.1* ***requirements have been successfully implemented and section 3 installation considerations have been evaluated.***"

response Accepted

comment *184* comment by: *General Aviation Manufacturers Association (GAMA)*

RATIONALE / REASON / JUSTIFICATION
In relation to the following note:

Note: Demonstrating compliance with one of the test approaches defined in this MOC does not alleviate the classification of the failure condition “battery thermal runaway” (i.e. the thermal runaway of two or more cells within a battery) considered catastrophic.

There is no consideration for the physical or temporal separation of the two cell events that may allow the two events to be considered independent from each other.

PROPOSED TEXT/ACTION
EASA to consider the proposed wording:

"Note: Demonstrating compliance with one of the test approaches defined in this MOC does not alleviate the classification of the failure condition "battery thermal runaway" (i.e. the thermal runaway of two or more cells **that directly (physically) and overlappingly (timing wise) thermally affect at least one common third cell**) considered catastrophic."

response

Partially Accepted.

It will be modified as:

(c) Definitions:
(d) "Battery Thermal Runaway" is defined as:

(1) Thermal runaway of two cells that thermally affect at least one common adjacent third cell within the same battery or, for modularized batteries, the same module.

(2) Thermal runaway of any three or more cells within the same battery or, for modularized batteries, the same module.

3(a)(1)(iii)

Note 1:

Demonstrating compliance with one of the test approaches defined in this MOC does not alleviate the classification of the failure condition "battery thermal runaway" (as defined in 3.(g)), which is considered catastrophic.
The safety of the propulsion battery is based in a multi-layer approach, where the reliability of the cells and the control and protective functions play a key role and should not be alleviated, since:

- Propulsion batteries are not comparable to other aircraft equipment/systems, due to their novel use, criticality, significant fire hazard and lack of service experience.
- Thermal runaway tests are not comparable to other qualification tests, due to the variability in the outcome of the tests (due to cell variability, TR initiation criteria, temperature, SOC..) and their novelty and lack of testing experience.

Therefore, this safety requirement should be used by the applicants to specify the reliability requirement for the cell failure, as well as the safety objectives of the control and protective functions.

comment	*185* comment by: *General Aviation Manufacturers Association (GAMA)* **RATIONALE / REASON / JUSTIFICATION** References in § 3(a)(1)(i)(iv) A,B, C,D are not hazards but safety analyses which support an SSA or are part of a SSA. The intent is not clear of what EASA is trying to communicate in this paragraph. **PROPOSED TEXT/ACTION** EASA to consider adding a period after "SAE ARP 4761". Then, replacing the text after the comma with: "The following analyses may support the SSA:"
response	Partially accepted. Text has been updated to clarify EASA intent. This step corresponds to the usual safety assessment activities: *"(iv) Evidence that a safety assessment of the propulsion battery system has been performed as per the applicable revision of SAE ARP 4761, addressing the hazards leading to, during, and following a thermal runaway. This safety assessment should include:"*

comment	*186* comment by: *General Aviation Manufacturers Association (GAMA)* **RATIONALE / REASON / JUSTIFICATION** With respect to reference (iv)(D), a CCA can only be a CMA, PRA, ZSA. There shouldn't be anything else to add. **PROPOSED TEXT/ACTION** EASA to consider deleting the "…"
response	Accepted.

comment	*187* comment by: *General Aviation Manufacturers Association (GAMA)* **RATIONALE / REASON / JUSTIFICATION** Text as proposed in § 3(a)(1)(i)(v) does not clarify whether only catastrophic failures conditions are considered "critical" or if hazardous failure conditions also fall into that category. Furthermore, the addition of the phrase "critical functions" seems to add no value and may increase confusion or misinterpretation. **PROPOSED TEXT/ACTION**

	EASA to clarify the scope of 'critical', and consider striking the sentence 'of the citical functions' as proposed: "...and not result from a single failure ~~of the citical functions~~ of the propulsion battery system,..."
response	Accepted.

comment	*188* comment by: *General Aviation Manufacturers Association (GAMA)* **RATIONALE / REASON / JUSTIFICATION** Text as proposed in § 3(a)(1)(i)(v) does not make sure that the DAL supports RTCA DO-311A. The effects of the FHA drive the DAL, but there are some cases where the severity may not align with a DAL. This has occurred with a EEC or FADEC on a single engine aircraft-where the effects were less than CAT and the DAL requirement was A. **PROPOSED TEXT/ACTION** EASA to consider adding a line about a required DAL which should state that the DAL from the RTCA DO-311A takes precedence over what the FHA states.
response	Not accepted. The intent is not to have systematically the RTCA-DO-311A taking precedence over the DAL allocation derived from the failure condition classification (“Battery Thermal runway” Catastrophic). Applicants may elect to comply with RTCA DO 311A Appendix C DAL A requirement, but this is not the only one way to fulfill this MOC: The DAL of items contributing to a battery thermal runaway failure condition may also for instance be allocated as per the ARP4754A process.

comment	*210* comment by: *Vertical Aerospace* Section 3.(a)(1) states the following: "Propulsion battery systems should follow the design, manufacturing, installation, operation, and maintenance guidance provided in RTCA DO-311A section 2.1". However, DO-311A is not sufficient for high-voltage batteries and in some cases may not be fully applicable for propulsion batteries, i.e. handles. Thus, add reference to 'where applicable', suggest the minimum applicability of DO-311A being met but make clear that additional capabiltiy, signage, considerations etc. will be required.
response	Partially accepted.

	Wording in Section 3.(a)(1) "should follow" and in 3(a)(1)(i) "have been considered" introduce already the needed flexibility, in case prescriptive requirements are not applicable to a specific design, but the intent is covered differently. Last paragraph in section 1. of this MOC is updated as follows: *"This Means of Compliance is neither addressing nor superseding other tests and considerations needed for the certification of propulsion battery systems (i.e. external short circuit, available system capacity and energy, protections testing, battery system crashworthiness tests, HV signage…)."*

comment	*230* comment by: *Heart Aerospace AB* A thermal runaway of two or more cells in a battery, as described in DO-311A, section 2.1.2, as an isolated even, cannot be deemed a catastrophic failure. An uncontained thermal runaway that cannot be mitigated at installation level has historically been considered by the industry as a catastrophic failure, and Heart Aerospace recommends using this definition in this paragraph.
response	Not accepted. See response to comment 47.

3.(b) Thermal Runaway Non-Propagation Tests	**p. 6**

comment	*37* comment by: *Collins Aerospace/Pratt & Whitney* Comment: In title , replace "non-propagation" with "containment". Justification: Containment of the failure within the battery system is the need at the aircraft level. Specifying non-propagation defines a particular technical solution approach.
response	Not accepted. Both mitigations are requested, Thermal Runaway propagation prevention (non-propagation test) and Thermal Runaway containment. For the non-propagation test, due to the variability of designs, general guidelines are proposed to support applicants to characterize and assess their design at different levels and define tests that capture all these possible variabilities and worst-case conditions. On top of that, margins are included to ensure non-propagation, and a second protection layer (containment) is requested. Non-propagation tests are not defining/prescribing a particular solution, as containment tests are not defining/prescribing a particular solution. Both safety layers/measures are requested, and for both, the applicant can propose different solutions, therefore fostering innovation and bringing more safety in the long term, in opposition to relying only on containment.

comment	*82* comment by: *Diamond Aircraft Industries GmbH* The term cell is used in this section which may be appropriate if the battery system is designed with all the cells connected in a way that cell to cell propagation mitigation is required. However, if a battery module is designed that prevents an uncontained thermal runaway this should be allowed and the non-propagation test section re written to account for either design solution (cell to cell protection or module to module protection). In the end the goal is to prevent an uncontained thermal runaway and the designer should be able to show that the system design provides the proper protections against thermal runaway. Look at finding an MOC that fits all design solutions
response	Not accepted. Both mitigations are requested, Thermal Runaway propagation prevention (non-propagation test) and Thermal Runaway containment. For the non-propagation test, due to the variability of designs, general guidelines are proposed to support applicants to characterize and assess their design at different levels and define tests that capture all these possible variabilities and

	worst-case conditions. On top of that, margins are included to ensure non-propagation, and a second protection layer (containment) is requested. Non-propagation tests are not defining/prescribing a particular solution, as containment tests are not defining/prescribing a particular solution. Both safety layers/measures are requested, and for both, the applicant can propose different solutions, therefore fostering innovation and bringing more safety in the long term, in opposition to relying only on containment.

comment	*106* comment by: *Volocopter GmbH* Comment to: 5 (b) (1) ... *for a time that covers at least the detection of the fire at the most adverse operation condition and an ensuing continued safe flight and landing in accordance with EASA MOC VTOL.2330 Fire Protection in designated fire zones* Comment: Final MOC VTOL.2330 released in June 2022 does not mention any time criteria anymore, but just the ability to ensure continued safe flight and landing (for enhanced category only). Also it seems to be a circular reference, as MOC VTOL.2330 refers to MOC VTOL.2440 when mentioning the duration of the thermal runaway test "The conditions in (f)(3)(i) and (ii) should be fulfilled for the complete duration of an accepted Thermal Runaway Test as per MOC VTOL.2440."
response	Partially Accepted. It is modified as follows: Experience has demonstrated that, although very unlikely, more than a cell could go into thermal runaway due to an unforeseen failure mode. Therefore, the applicant should define in coordination with EASA, a set of tests to demonstrate that realistic worst-cases of thermal runaway in more than a cell can be managed at propulsion battery system level and installation level (Battery Explosive Fire Zone) ensuring continued safe flight and landing in accordance with EASA MOC VTOL.2330 “Fire Protection in designated fire zones”.

3.(b)(1) Propagation to adjacent cells **p. 6**

comment	*28*	comment by: *Andrea Marinovich*
	In my opinion the propagation from a battery module to another module shall be avoided (assuming that a single module can be lost)	
response	Accepted. That is the intent of the MOC: to avoid propagation from cell to cell (non-propagation test) and from module to module (containment tests). The definition of module is updated to make the intent clearer, as: (a) *"Battery Module" means a group of electrically interconnected cells in series and/or parallel arrangement contained in a single enclosure that ensures that no fluids, flames, gasses, smoke, or fragments enter other modules, and that no thermal runaway is propagated from one module to the others during normal operation or failure conditions."*	

comment	*38*	comment by: *Collins Aerospace/Pratt & Whitney*
	Comment: Delete entire last sentence "Therefore, propagation to adjacent cells in the battery would be properly prevented to avoid a chain reaction". Justification: Containment of the failure within the battery system is the need at the aircraft level. Specifying non-propagation defines a particular technical solution approach.	
response	Not accepted. Both mitigations are requested, Thermal Runaway propagation prevention (non-propagation test) and Thermal Runaway containment. For the non-propagation test, due to the variability of designs, general guidelines are proposed to support applicants to characterize and assess their design at different levels and define tests that capture all these possible variabilities and worst-case conditions. On top of that, margins are included to ensure non-propagation, and a second protection layer (containment) is requested. Non-propagation tests are not defining/prescribing a particular solution, as containment tests are not defining/prescribing a particular solution. Both safety layers/measures are requested, and for both, the applicant can propose different solutions, therefore fostering innovation and bringing more safety in the long term, in opposition to relying only on containment.	

comment	*60*	comment by: *Electric Power Systems Inc*
	Relying on cell-to-cell propagation mitigation requires very robust mechanisms for ensuring cell manufacturing conformity. This approach necessitates that cell manufacturers provide extensive visibility into their supply chains, design features which drive TR performance, provide adequate notice of chain (preferably preemptory), and material guarantees. If these are not provided, the cell TR performance characterization which underpins the certification approach should be replicated by the applicant to ensure that cell-to-cell propagation mitigation is retained throughout the product life cycle. These requirements significantly impact the ability of the industry to adopt new cell chemistries due to this MOC's narrow perception of battery safety. While this is accurate, it is important to note that "should" and "properly" are the correct words to be used. This denotes design judgment but not universal necessity. This is particularly true in battery designs in which cell-to-cell propagation mitigation is not necessitated by the system safety assessment.	
response	Noted. For the non-propagation test, EASA expects the applicants to characterize and assess their design at different levels and be able to propose tests that capture all possible variabilities and worst-case conditions. On top of that, margins are included in the MOC to ensure non-propagation, and a second protection layer (containment) is requested. This Means of Compliance considers the battery technology and chemistries proposed in the different projects currently in certification and in future projects of which EASA is already aware. If new chemistries are proposed in the future that could have a different behaviour impacting this MOC, other MOC could be proposed at the time of application.	

comment	*134*	comment by: *Ampaire Inc*
	Regarding this text: "Therefore, propagation to adjacent cells in the battery should be properly prevented to avoid a chain reaction." We disagree with this statement. Non-propagation is a specific design choice to achieve the battery system safety objectives. It is not the only choice. Suggested revision: "Therefore, battery system safety requirements must be met assuming an unpreventable internal short circuit at cell level will occur. Typical methods include preventing cell to cell	

	propagation, controlling the rate of propagation, and/or safe containment and venting with full propagation." Alternate revision: Delete the sentence entirely
response	Not accepted. Both mitigations are requested, Thermal Runaway propagation prevention (non-propagation test) and Thermal Runaway containment. For the non-propagation test, due to the variability of designs, general guidelines are proposed to support applicants to characterize and assess their design at different levels and define tests that capture all these possible variabilities and worst-case conditions. On top of that, margins are included to ensure non-propagation, and a second protection layer (containment) is requested. Non-propagation tests are not defining/prescribing a particular solution, as containment tests are not defining/prescribing a particular solution. Both safety layers/measures are requested, and for both, the applicant can propose different solutions, therefore fostering innovation and bringing more safety in the long term, in opposition to relying only on containment.

comment	*142* comment by: *The Boeing Company*

COMMENT #2 of 14			
Type of comment (check one)	***Non-Concur***	***Substantive*** ***X***	***Editorial***
Affected paragraph and page number	Page: 6 Paragraph: Section 3(b)(1)		
What is your concern and what do you want changed in this paragraph?	**THE PROPOSED TEXT STATES:** "Therefore, propagation to adjacent cells in the battery should be properly prevented to avoid a chain reaction." **REQUESTED CHANGE:** "Therefore, propagation **beyond where the applicant defines their full-containment capability** ~~**to adjacent cells**~~ in the battery should be properly prevented to avoid a chain **reaction** **that would prevent continued safe flight and landing**."		
Why is your suggested change justified?	**JUSTIFICATION:** Based on their design, the applicant should be able to define the boundary of their containment, through which propagation will not exceed. Requiring non-propagation at the cell-level may be over-burdensome for applicants and not be necessary to meet EASA's		

	safety intent. Ensuring that propagation does not affect continued safe flight and landing will ensure no thermal runaway is catastrophic.

response Not accepted.

Both mitigations are requested, Thermal Runaway propagation prevention (non-propagation test) and Thermal Runaway containment. For the non-propagation test, due to the variability of designs, general guidelines are proposed to support applicants to characterize and assess their design at different levels and define tests that capture all these possible variabilities and worst-case conditions. On top of that, margins are included to ensure non-propagation, and a second protection layer (containment) is requested.

Non-propagation tests are not defining/prescribing a particular solution, as containment tests are not defining/prescribing a particular solution. Both safety layers/measures are requested, and for both, the applicant can propose different solutions, therefore fostering innovation and bringing more safety in the long term, in opposition to relying only on containment.

comment *224* comment by: *Heart Aerospace AB*

The statement in DO-311A, section 2.1.7, is meant to highlight that internal cell failures (i.e., short-circuit) cannot be assumed to be fully prevented by design, nor to be mitigated by internal or external protection means, and therefore should not be disregarded nor minimized during the safety development process.

Most of the documented thermal runaway events in automotive and aviation have happened due to poor pack design practices.

Heart Aerospace suggests replacing the statement "... becomes the most likely scenario for thermal runaway. Therefore, propagation to adjacent cells in the battery should be properly prevented to avoid a chain reaction." for "is a failure mode that must be addressed during the safety development process, and adequate design mitigations should be provisioned to guarantee the system would reach a safe state after a thermal runaway is initiated".

response Not accepted.

Both are requested:

- Propagation should be prevented
- Failure mode must be addressed during the safety development process (section (3).(a).(1).(iv)).

comment	*233*	comment by: *Vertical Aerospace*
	"Due to this, having an internal short circuit at cell level in propulsion battery systems with thousands of cells, becomes the most likely scenario for a thermal runaway". This statement is not fully accurate since the most likely cause of a cell failure is battery component failure and not individual cell internal short-circuit failures. Remove reference to 'most likely'.	
response	Accepted. Although in aviation, the few failures which have been experienced in service, are all related to a single cell failure: 1. NTSB Incident Report NTSB/AIR-14/01, PB2014-108867 "Auxiliary Power Unit Battery Fire, Japan Airlines Boeing 787-8, January 7th, 2013". Section 1.2.4: *"The JTSB's report on the TAK incident stated that heat generation **in a single cell** "was probably caused by [an] internal short circuit" which developed into "thermal propagation to other cells, [which] consequently damaged the whole battery."* 2. JSTB Incident Report AI2014-4, Japan Transportation Safety Board "Auxiliary Power Unit Battery Fire, All Nippon Airways Boeing 787-8, Japan January 16th, 2013" Probable causes: *"Internal heat generation **in cell 6** very likely developed into venting, making it the initiating cell, resulting in cell-to-cell propagation and subsequent failure of the main battery"* 3. AAIB Accident Report 2/2015, UK Air Accidents Investigation Branch. "Emergency Locator Transmitter fire, Ethiopian Airlines Boeing 787-8, July 12th, 2013" Summary: "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 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."	

3.(b)(2) Tests to demonstrate the propagation prevention mechanisms) **p. 6**

comment	*39* comment by: *Collins Aerospace/Pratt & Whitney* Comment: Replace "should" with "shall" Justification: Reflect mandatory requirement. Comment: Replace "propagation prevention" with "containment". Justification: Containment of the failure within the battery system is the need at the aircraft level. Specifying non-propagation defines a particular technical solution approach.
response	Not accepted. EASA SC-VTOL MOCs always uses the term “should” instead of “shall” as they are not requirements. Non-propagation tests are not defining/prescribing a particular solution, as containment tests are not defining/prescribing a particular solution. Both safety layers/measures are requested, and for both, the applicant can propose different solutions.

comment	*61* comment by: *Electric Power Systems Inc* This guidance introduces excessive subjectivity. Consistency in the application of this process between applicants will be challenging, especially when integration of the cells within the module may represent vastly different critical behavioral sensitivities for cell thermal runaway in different designs.
response	Noted. This is the reason why EASA’s approach for propulsion batteries safety is based on independent and redundant protection and mitigation layers from cell level to battery level and to installation level, and all the variabilities shall be assessed to identify the worst cases combinations. Safety margins are included on top of that. Moreover, demonstrating compliance with the set of tests of non-propagation and containment does not alleviate the other protection layers.

comment	*83* comment by: *Diamond Aircraft Industries GmbH* Section 2.1 of DO-311A is not really about propagation prevention, it is more about all the other factors to design for to have a safe battery system. This paragraph should just state that section 2.1 of DO-311 should be met. Revise accordingly
response	Partially accepted. As compliance with section 2.1 of DO-311A is already included in 3(a)(1)(i): *"Evidence that RTCA DO-311A section 2.1 requirements have been considered and successfully implemented and section 3 installation considerations have been evaluated."* Section 3(b)(2) is modified as: *"(2) The applicant should define, in coordination with EASA, a set of tests at battery system level to demonstrate that the propagation prevention mechanisms have been successfully implemented."*

comment	*135* comment by: *Ampaire Inc* Regarding this text: "The applicant should define, in coordination with EASA, a set of tests at battery system level to demonstrate that the propagation prevention mechanisms described in RTCA DO-311A section 2.1 "General requirements", have been successfully implemented." The entire Section 2.1 of DO-311A as noted in the first sentence of the standard is specifically for 'general equipment requirements that do not require compliance verification via the tests within this standard". The term 'minimize' regarding propagation is used throughout Section 2.1. There is no requirement to 'prevent' as written in this draft MoC. Suggested revision: Delete the entire sentence
response	Partially accepted. As compliance with Section 2.1 of DO-311A is already included in 3(a)(1)(i):

"Evidence that RTCA DO-311A section 2.1 requirements have been considered and successfully implemented and section 3 installation considerations have been evaluated."

Section 3(b)(2) is modified as:

"(2) The applicant should define, in coordination with EASA, a set of tests at battery system level to demonstrate that the propagation prevention mechanisms have been successfully implemented."

comment 143 — comment by: *The Boeing Company*

COMMENT #3 of 14			
Type of comment (check one)	***Non-Concur***	***Substantive*** ***X***	***Editorial***
Affected paragraph and page number	Page: 6 Paragraph:		
What is your concern and what do you want changed in this paragraph?	**THE PROPOSED TEXT STATES:** (2) The applicant should define, in coordination with EASA, a set of tests at battery system level to demonstrate that the propagation prevention mechanisms described in RTCA DO-311A section 2.1 "General requirements", have been successfully implemented. **REQUESTED CHANGE:** We recommend the following changes: adding "battery system level" in the "Definitions" section; providing a baseline list of tests that should be standardized for each applicant; and adding a specific reference to the sub-section being referred to within DO-311A.		
Why is your suggested change justified?	**JUSTIFICATION:** Providing a baseline list of tests to expect, for each applicant, will ensure that there are no rigor-related gaps between different certification efforts. A definition of "battery system level" is needed to assist in the understanding of intent. DO-311A Section 2.1 is a very large section; applicants would benefit from a more precise section-reference.		

response	Partially accepted. The definitions section is updated for clarification. This MOC is only assessing Thermal runaway tests, as stated in the introduction: *"This Means of Compliance is neither addressing nor superseding other tests needed for the certification of propulsion battery systems (i.e. external short circuit, available system capacity and energy, protections testing, battery system crashworthiness tests…)."* Subsection reference removed: "The applicant should define, in coordination with EASA, a set of tests at battery system level to demonstrate that the propagation prevention mechanisms have been successfully implemented."

comment	*214* comment by: *G Cherouvrier SEP* In the paragraph: "(iii) A thermal runaway in at least 20% of the cells in the propulsion battery system should be caused by overheating and/or overcharging as determined by the previous cell characterisation." It is not clear if the 20% of the cells shall be the triggered cells (ie. triggered cells = targeted cells = 20% of the cells) or if it is acceptable to start a smaller amount of cells in thermal runaway as long as 20% of the cells have been in thermal runaway ? If yes, is it acceptable to deactivate once the trigered cells are in thermal runway as long as 20% of the cell are in thermal runway in the end ? Could you clarify please?
response	Noted. 20% of the cells shall be the triggered cells (triggered cells = targeted cells = 20% of the cells) and within approximately 1 minute. Once the 20% or the targeted cells reached thermal runaway the heater(s) can be deactivated.

comment	*225*	comment by: *Heart Aerospace AB*
	The reference to DO-311A, section 2.1, seems incorrect, and should be replaced either by a reference to section 2 (General Requirements) or section 2.2.2 (Safety Requirements).	
response	Not accepted. Sections 2.2 and 2.2.2. include performance and safety requirements, to be compliant with (pass/fail criteria) when testing in accordance to section 2.4. All these tests will be defined in other documents, as explained in the MOC: *“This Means of Compliance is neither addressing nor superseding other tests needed for the certification of propulsion battery systems (i.e. external short circuit, available system capacity and energy, protections testing, battery system crashworthiness tests…).”* Section 2.1 are general requirements, including design guidelines to prevent propagation or thermal runaway in multiple cells.	

3.(b)(3) Guidelines for the development of Thermal Runaway Non-Propagation tests **p. 6**

comment	5 comment by: *AIRBUS HELICOPTERS* Same comment than comment #6. With regard to the paragraph 3.(b).(3).(xiv).(A) on page 8 : *"The battery system tested should be monitored for 8 hours after the initial thermal runaway event, and during this time comply with the following:* *(A) No propagation to other cells"* **COMMENT :** In case of approach #1, the acceptance criteria for thermal runaway should be the paragraph 3.(b).(3).(xiv).(A) AND paragraph 4.(a).(3) as written in the document **JUSTIFICATION :** For approach #1, paragraph 4.(a) is listing the three acceptance criteria to comply with: 4.(a).(1) AND 4.(a).(2) AND 4.(a).(3). Paragraph 3.(b).(3).(xiv).(A) specifies that "No propagation to other cells." Is allowed during the Thermal Runaway event, nor 8h after the Thermal Runaway event with a test procedure launching the Thermal Runaway on 2 cells. This is contradictory with paragraph 4.(a).(3) which requires at least 20% of cells that achieved a Thermal Runaway. For a battery system having one hundred cells, the two acceptance criteria are not aligned for approach #1.
Response	Partially Accepted. Both mitigations are requested, Thermal Runaway propagation prevention (non-propagation test) and Thermal Runaway containment. For the non-propagation test, due to the variability of designs, general guidelines are proposed to support applicants to characterize and assess their design at different levels and define tests that capture all these possible variabilities and worst-cases conditions. On top of that, margins are included to ensure non-propagation, and a second protection layer (containment) is requested. Clarification has been added that criterion 4(a)(3) applies only to test requested in 4(a)(2). Therefore, the acceptance criteria for the test requested in 4(a)(2) are: 1) To be in compliance with DO-311A section 2.2.2.4., **AND** 2) To be in compliance with 4(a)(3)

comment	*20*	comment by: *Andrea Marinovich*
	For subpara (3)(ii) (A) to (D) : Is there a consensus view held within industry that is accurate enough to allow quantitative metrics to be created for these parameters? I'm not sure that there is yet.	
Response	Noted. The MOC is based on acquired knowledge from projects, research, working groups… Currently there are no other parameters proposed to be included in the public consultation. EASA is open to discuss this possibility if there would be any proposal.	

Comment	*21*	comment by: *Andrea Marinovich*
	subpara (vi) : Can we clarify exactly what 'different installations' means. Will this mean if the battery design is the same (eg same part number) but the ECS inlet is slightly different that both need to be tested or just the least ideal installation eg only the worst-case?	
Response	Noted. Justification can be done through installation analysis (i.e. differences in orientation, venting provisions) and/or testing. If during the analysis/tests it is demonstrated that the differences in the different installations have no impact in the test outcome or the worst-case is identified and tested, the tests would not need to be repeated for each installation.	

Comment	*22*	comment by: *Andrea Marinovich*
	subpara (ix) : please, clarify what Trigger Mechanism shall be used	
response	Partially accepted. MOC is modified to clarify this point: *"(ii) A full characterisation of thermal runaway behaviour at cell level should be performed by the applicant to identify, and include at battery system level tests, the potential worst-cases for cell-to-cell propagation at battery system level tests combining the following:* *(A) Thermal Runaway Trigger Method. When it is possible to overcharge the cell to force a thermal runaway, the behaviour of the cell between overcharging and overheating may lead to different outcomes."*	

Comment	*23*	comment by: *Andrea Marinovich*
	Subpara (xi) : the 30 second limit is very demanding. Consider a longer time	
response	Noted. Only 1 cell in thermal runaway will be requested. This condition is deleted.	

Comment	*29*	comment by: *Andrea Marinovich*
	Subpara (ii)(e) : I suggest also time to get thermal runway from trigger	
response	Accepted.	

comment	*40*	comment by: *Collins Aerospace/Pratt & Whitney*
	Comment: Replace "should" with "shall" (21 places) Justification: Reflect mandatory requirement. Comment: Replace "non-propagation" with "containment". Justification: Containment of the failure within the battery system is the need at the aircraft level. Specifying non-propagation defines a particular technical solution approach. Comment: In section (i) replace "batteries" with "battery systems" (two places) Justification: Clarify what needs to be aged prior to being tested. Comment: In section (ii)(E), add (f) Initiation State of Charge Justification: Quantify initiation point for characterization (ii)(B) Comment: In section (iii) replace "battery" with "battery system" Justification: Clarify scope that needs to be considered. Comment: In section (iii), replace "overheating and/or overcharging" with "the worst-case combination of test conditions" Justification: Current wording implies optionality as opposed to mandating worst case. Comment: In section (xiv) delete criteria "(A) No propagation to other cells" Justification: Containment of the failure within the battery system is the need at the aircraft level. Specifying non-propagation defines a particular technical solution approach.	
response	Partially Accepted.	

Comment #1: Not accepted.

EASA SC-VTOL MOCs use “should” instead of “shall” as Means of Compliance are not requirements.

Comment #2: Not accepted.

Having an internal short circuit at cell level in propulsion battery systems with thousands of cells becomes the most likely scenario for a thermal runaway. Therefore, propagation to adjacent cells in the battery should be properly prevented to avoid a chain reaction.

On top of that a second protection layer (containment) is requested at battery/module level.

Non-propagation tests are not defining/prescribing a particular solution, as containment tests are not defining/prescribing a particular solution. Both safety layers/measures are requested, and for both, the applicant can propose different solutions.

Comment #3: Accepted, section (i) is modified accordingly.

Comment #4: Accepted, section (ii)(e) is modified accordingly.

Comment #5: Accepted, section (iii) is modified accordingly.

Comment #6: Accepted, section (iii) is modified accordingly.

Comment #7: Not accepted. See reply to comment #2 with regards to section (xiv)(A).

comment | *62* | comment by: *Electric Power Systems Inc*

3.B.3.i

End of life testing does represent a deviations from current DO-311A. Inadequate guidance available to justify what cell aging is required to replicate worst case. For a fully containing module using DO-311a, overtest characteristics of DO-311A discussed in this document does represent a significant level of conservatism which represents a remedy for this.

3.B.3.ii
Only required if the 3.a.iv holds and cell to cell propagation mitigation is a key element in the battery safety strategy.

Each of these categories A through D should be considered in combination as well as in isolation. The worst case trigger method may be vary based on SOC, the position of the TR, and the heating rate. Considering the effects of these variables in isolation is insufficient to fully determine worst case cell TR performance.

Additionally, no consideration or commentary is provided regarding the size of the cell or and the amount of energy released. Formulating MOC test requirements in this manner has a potentially detrimental impact on the timeline for adoption of advanced cells and prescribed design approaches regarding cell capacity selected.

3.B.3.ii.C
Guidance required to assess and replicate during test. Compounding affects also exist with the position of the internal short circuit with the location of the cell in the module (5.b.2.iv.b & 3.b.3.iv.b)).

Full characterization is challenged by the need to adequately conform the cells from the supplier and capture the manufacturing manufacturing lifecycle impacts of internal short circuit variability on TR behavior. These considerations are hampered by fact that most mass cell manufacturers which have the ability to build cells at relevant volumes and drive cell prices to required levels will not guarantee the provision of COC, will not sign up to the NOC requirements, and are not material incentivized to accept quality flowdowns and liabilities typically required by aerospace.

3.B.3.ii.F
The subjective nature of this requirement will lead to challenges in consistent implementation between applicants.

Additionally, the number of replicates should represent the total manufacturing variable expected during cell manufacturing lifecycle. These tests should include cell replicates from different lots, manufactured on different dates, from different manufacturing sites if applicable. This sample must represent all expected cell variabilities that are anticipated in in the life of the product.

3.B.3.iii
Adjacent cells in TR do not always represent the worst case scenario for battery safety. Considerations regarding vent path obstructions and associated management, potential heating due to secondary short circuiting, as well as other installation considerations should be considered when determining the cells to be put into TR.

The chaotic event within the module does not always result in adjacent cells being the only cells put at risk. Mechanical debris, induced deformation of materials within the battery may cause other risks of propagation.

Additionally, the position of cells relative to each other within the module, as well as the position of the target TR cells to other module features may also affect the worst case scenario for cell TR.

3.B.3.iv.B
This activity must be coordinated with 3.b.3.ii

	Passive propagation mitigation necessitates the consideration of managing cell TR directionality (top, bottom side), cell TR behavior (burst, breech, contained), cell spacing and heat sinking, secondary short circuit management, ejecta path management, and flame control. The worst case cell TR variability at the cell level must also be considered depending on the position of the cells within the installation. Each position may exhibit highly sensitive installation effects which vary the conclusion on the worst determination performed during cell characterization which impact which TR behavior must be induced during the test campaign. In order to demonstrate propagation mitigation is achieved, all of these considerations must be covered by the tests which are performed at the battery system level. 3.B.3.vi What constitutes a battery "installation." Does this require the application of the "battery module" definition. A single battery system that is electrically connected may be distributed in different aircraft location. On the other hand, there may be batteries which are electrically independent but which my be in close physical proximity. More guidance on contiguous installation, modularization, and functional dependency are required to fully consider this requirement. 3.B.3.xi.B The 30 second trigger timing delta seems somewhat arbitrary. Does this represent or replicate the worst case propagation scenario considering debris management, deformations, and secondary short circuit behaviors? 3.B.3.xiv.A Only applicable to designs which rely on cell to cell propagation as a primary means for vehicle safety.
response	Partially accepted. EUROCAE ED-289 is referred to for the definition of the aging profile. On top of that, there are other conservatism/margins introduced in the MOC. Both mitigations are requested, Thermal Runaway propagation prevention (non-propagation test) and Thermal Runaway containment Point (ii) is modified as:

"(ii) A full characterisation of thermal runaway behaviour at cell level should be performed by the applicant to identify, and include at battery system level tests, the potential worst-cases ***for cell-to-cell propagation*** *at battery system level tests, combining the following parameters:"*

The MOC is providing high level guidance due to the possibility of very different solutions.

Point 3.B.3.iv.B is modified as:

"(B) The battery system configuration, installation location, and point 3.(b).(3).(ii) should be assessed to justify the selection of cells with the potential to become worst cases (e.g. centre, wide face, narrow face, corner, edge…)."

Definitions section updated to make it clearer.

3.B.3.xi.B deleted as only 1 cell in TR is requested.

comment *67* comment by: *Bilge Atici*

Comments summary 3.b page 6
Exclusion of non-propagation in the case of full containment.
For small modules such as a 6-cell compartment, if a 2-cell trigger propagates to the entire module and can be successfully contained using worst-case conditions of cell/environment characterization, all non-propagation pre-requisite testing can be waived (3.b).
Suggested resolution
Exclusion of non-propagation in the case of full containment.

response Not accepted.

Both mitigations are requested, Thermal Runaway propagation prevention (non-propagation test) and Thermal Runaway containment. For the non-propagation test, due to the variability of designs, general guidelines are proposed to support applicants to characterize and assess their design at different levels and define tests that capture all these possible variabilities and worst-cases conditions. On top of that, margins are included to ensure non-propagation, and a second protection layer (containment) is requested.

comment *68* comment by: *Bilge Atici*

Comment summary 3.b.3.ix **page 8 and 5.b.2.ix page 10*;***
Regarding parag The temperature of the battery system before triggering the cells should be always stabilized at 55°C or the maximum operating high temperature, whichever is higher." The maximum temperature can be below 55 deg C when substantiated by a detailed thermal analysis, demonstrating scenarios based on nominal, limit, and ultimate conditions.
Suggested resolution

With a design-specific and validated thermal analysis looking at a range of thermal load cases, the maximum starting temperature of the cell for thermal runaway non-propagation and containment can be well predicted. The additional level of safety between the expected level and 55 deg C is accounted for by the validated thermal analysis at the aircraft level. This should be provided as an option in the relevant section.

response

Not accepted.

This point from DO-311A ensures margins to cover the variabilities in the cells and tests outcomes, and the very limited thermal runaway tests and in-service experience.

comment

69 comment by: *Bilge Atici*

Comment summary 3.b.3.ii.A page 7
Exclude the overcharge trigger at the module and cell level. No mechanism in the cell to prevent overcharge; however, the electrical architecture of the battery module excludes overcharge of individual cells in the presence of the battery management system.
Suggested resolution
If the overcharge is not possible due to the design of the Electrical Power System not due to the cell technology, the overcharge triggering method should be excluded. The wording of the paragraph A should be revisited to address different triggering methods.

response

Partially accepted.

It will be modified as:

"Thermal Runaway Trigger Method. When it is possible to overcharge the cell to force a thermal runaway, the behaviour of the cell between overcharging and overheating may lead to different outcomes."

comment

70 comment by: *Bilge Atici*

Comment summary 3.b.3.ii.A page 7
For an eVTOL which is powered only by battery systems, an overcharge condition can only occur during charging on ground.
The catastrophic outcome of an overcharging condition can be mitigated either by functional means (e.g. preventing overcharge or containing a thermal runaway) or by operational means (e.g. charging without passengers on board)
This operational means shall also become a potential means of compliance beside the functional means described in the document.
Suggested resolution
The sub-paragraph shall be updated as follow:

	Thermal Runaway Trigger Method. When overcharging the cell to force a thermal runaway is possible (no internal cell protections) ***and operationally leading to a catastrophic outcome,*** cell thermal runaway behaviour between overcharging and overheating ***shall be well understood and considered at the battery system level testing.***
response	Partially accepted. It is modified as: *"Thermal Runaway Trigger Method. When it is possible to overcharge the cell to force a thermal runaway, the behaviour of the cell between overcharging and overheating may lead to different outcomes."*

comment	*71* comment by: *Bilge Atici* **Comment summary 3.(b).(3).ii,iii,iv,ix page 7 and 8** 2-cell trigger at worst-case conditions of aging, temperature, and trigger method is overly conservative given the stated assumption in MOC-3 that any 2-cell trigger is "very unlikely". **Suggested resolution** Combinations of conditions and triggering with 1 vs. 2 cells. Use 1-cell trigger versus 2-cell when more than 1 worst case condition is used. Examples to achieve an equivalent level of safety. When considering end of life: 1 cell at operational max temperature When considering new cells: 1 cell at emergency max temperature or 2 cells at operational max temperature
response	Partially Accepted. The MOC will be modified to only request the triggering of 1 cell for the non-propagation tests, since it is requested to identify and test the worst-cases conditions of aging, temperature, trigger method, SOC, positions of the heater, position of the cell, orientation… that maximize the potential for propagation. Therefore, the 1 cell non-propagation tests will provide already enough margin in comparison with other single cell trigger tests (i.e. RTCA DO-311A 2.4.5.4, NASA EP-19-001 Interpretation Memo for the Battery TR Propagation requirements in JSC-20793 Rev D.).

comment	*72* comment by: *Bilge Atici* **Commnet summary 3.b.3.xiv page 8** As proposed by commnet 67 by Lilium, for full containment strategy the non-propagation criteria should be applicable for adjacent submodules, enclosures or compartments. **Suggested resolution** Point (A) tshould be updated as follows; No propagation to other cells in the adjacent compartments.
response	Not accepted. Both mitigations are requested, Thermal Runaway propagation prevention (non-propagation test) and Thermal Runaway containment. For the non-propagation test, due to the variability of designs, general guidelines are proposed to support applicants to characterize and assess their design at different levels and define tests that capture all these possible variabilities and worst-cases conditions. On top of that, margins are included to ensure non-propagation, and a second protection layer (containment) is requested. Regarding no propagation between modules, the definition of module is updated as: "Battery Module" means a group of electrically interconnected cells in series and/or parallel arrangement contained in a single enclosure that ensures that no fluids, flames, gasses, smoke, or fragments enter other modules, <u>and that no thermal runaway is propagated from one module to the others during normal operation or failure conditions.</u> Regarding no propagation to adjacent batteries, enclosures or compartments, it is covered in EASA MOC VTOL 2330.

comment	*84* comment by: *Diamond Aircraft Industries GmbH* 3(b)(3)(ii) While this is probably a good idea from the design standpoint to understand your cells better is it necessary of an MOC. The reasons this is needed should be made clear here. This sounds more like sound design advice rather than an MOC. Revise accordingly 3. (b) (3)(ii) (B)

"Normally, low SOC lead to more material remaining in the cell hence increasing the probability of cell-to-cell propagation." It is not fully understood why a higher material content will increase the cell-to-cell propagation probability or why a higher SOC influences it.

The grammar needs to be improved. As it is right now, it is not clear on the intent.

Rephrase / clarify

response Accepted.

Section 3.b.3.ii will be modified as follows, including the reason it is requested:
" A full characterisation of thermal runaway behaviour at cell level should be performed by the applicant to identify the potential worst-cases for cell-to-cell propagation at battery system level tests, combining the following parameters:"

Section 3.b.3.ii (B) will be modified as follows, including the reason it is requested:
"State of Charge (SOC). Low SOC usually leads to more material remaining in the cell, hence increasing the probability of cell-to-cell propagation. However, higher SOC usually leads to a more explosive and energetic thermal runaway with more material expelled outside the cell."

comment *85* comment by: *Diamond Aircraft Industries GmbH*

3(b)(3)(v) thru ((ix)

30 seconds might be too short of a time in practice to trigger two cells simultaneously, resulting in costly retests. For clarity, consider adding a definition that defines the exact moment a cell can be assumed to be in thermal runaway. For example, when the measured cell temperature rate of change increases.

Provide a rational why 30seconds is a realistic trigger time delta and be consistent with timing requirement in 5.(b)(2)(xi)(B). Add the definition of when it can be assumed that a cell has entered thermal runaway.

response Accepted.

It will be included in the definition of "Cell thermal runaway" the following:

"Cell Thermal Runaway" is a rapid self-sustained heating of a battery cell driven by exothermic chemical reactions of the materials within the cell. Examples of objective evidence or unambiguous markers that demonstrate that a cell achieved thermal runaway are:

(1) A sharp increase in temperature and pressure and a drop in cell voltage.

(2) Measured peak temperature at least 80% of the typical peak temperature reached during thermal runaway for a given chemistry, per test or per literature reports.
(3) Melted metallic components of cells (other than lithium).
(4) Decomposed active materials / Oxidized metallic lithium.
(5) Pyrolyzed (charred) cell contents

Section 3(b)(3)(xi) is removed, only one cell in thermal runaway is required.

comment *86* comment by: *Diamond Aircraft Industries GmbH*

3. (b) (3)(xi)(B)

"No compromise of warning signals and safety functions" in the 8 hours after the initial thermal runaway event. It is implied that the battery monitoring system will need to be fully operational during and after a thermal runaway event and long after the aircraft has landed. It is probably that this event will cause some damage to local circuitry/thermocouples and therefore the loss of some monitoring capability. It should be acceptable that after the successful triggering of a safety function (for example battery disconnect) that the functioning afterwards shall not need to be demonstrated.

Suggest removing this item, or rephrasing it that should only be applicable for a time that covers at least CSFL.

response Not accepted.

For Non-Propagation test, the pass/fail criteria is aligned with DO-311A 2.1.4.1 Battery Protective features:

“Protective circuits, including the battery disconnect function, should be suitably protected from cell failure conditions within the battery such that the safety function is not compromised.”

And with DO-311A 2.1.4.2 Battery Warning features:

“Warning circuits should be suitably protected from cell failure conditions within the battery system such that the warning signal is not compromised.”

comment *96* comment by: *Voltaero*

Ref to subpara (b)-Thermal runaway Non-Propagating Test / Point (3) (vi):

	What is meant by properly justified and how the worst-case installation is evaluated What kind of justification is required in this case? Is a safety assessment (SSA) applicable for demonstration of compliance? So, if applicable, should an additional battery test be performed anyway?
response	Noted. The justification can consist of an installation analysis (i.e. differences in orientation, venting provisions) and/or testing. If during the analysis/tests it is demonstrated that the different installations have no impact in the test outcome or the worst-case is identified, the tests would not need to be repeated for each installation.

comment	*98* comment by: *Voltaero* Ref. to subpara (b)-Thermal runaway Non-Propagating Test / Point (3) (iv)(B): This criterion for selection the triggered cells seems to be dependent on the specific battery system configuration and installation. This means that the A/C manufacturer should identify these configurations through a safety assessment (qualitative/quantitative…) in conjunction with the battery manufacturer. A better clarification on this should be requested in order to understand also if there could be used a theoretical approach to identify the worst case or a multiple scenario with different choice of the triggered cells should be tested (???).
response	Not accepted. Yes, the selection of the cells is dependent on the specific battery system configuration and installation, therefore the MOC does not specify the locations of the cells to be tested. The selection of these locations will need to be justified, and it will be necessary to test different locations (“worst-cases”).

comment	*99* comment by: *Voltaero* Ref. to subpara (b)-Thermal runaway Non-Propagating Test / Point (3) (vi): This point seems to clarify the Para 3- Prerequisite / Subpara (b)-Thermal runaway Non-Propagating Test / Point (3) (iv)(B) but for this latter a clarification should be necessary in case of a battery pack system is installed in a well identified zone of the a/c (either wide or not)
response	Not accepted.

Point (3)(iv)(B) is specific to the location of the 1 cell to be triggered within the battery, requesting different positions of the cell within the battery.

Point (3)(vi) requests to do an assessment of the possible influence in the outcome of the tests in the case that the battery is installed in different locations (i.e., with differences in orientation, venting provisions).

comment | *100* | comment by: *Volocopter GmbH*

Comment to *point iii) A thermal runaway in at least a pair of adjacent cells in the Propulsion Battery should be caused by overheating and/or overcharging as determined by the previous cell characterisation.*
This does not consider the case where two non-adjacent cells thermally impact a common third cells and cause it to go into thermal runaway.

Proposed wording:
"a pair of adjacent cells, or a pair of cells that directly thermally affect at least one common third cell"
Alternatively, rephrase simply to "...in at least two cells...", and rely on the following (iv)(A) to select cell positions that "maximize the potential for propagation"

response | Noted.

The MOC will be modified to only request the triggering of 1 cell. Since the worst-case conditions of aging, temperature, trigger method, SOC, positions of the heater, position of the cell, orientation… are requested to maximize the potential for propagation, and the tests will provide already enough margin in comparison with other single cell trigger tests (i.e. RTCA DO-311A 2.4.5.4, NASA EP-19-001 Interpretation Memo for the Battery TR Propagation requirements in JSC-20793 Rev D.).

comment | *101* | comment by: *Volocopter GmbH*

Comment to: *(vii) The tested battery system should not be modified to such an extent that the method of propagation can be significantly different than in a non-modified battery system.*

Comment:
Suggestion to add a note that the electrical connection between cells should not be modified for the overcharging trigger method, as it also provides a thermal and electrical interface between them, whose absence may influence the propagation behavior.

response | Not accepted.

Modifications in the electrical connection between cells in parallel configurations could be needed, to isolate and overcharge only the targeted cells.

It will be requested to justify any modification in the battery system or cells to perform the tests and its potential impact in the test outcome, as per:

"(v) The tested battery system should be representative of the in-use application, and should include cooling, configuration into the aircraft, designated venting provision, and any other design configuration or variable that could impact the test outcome."

"(vii) The tested battery system should not be modified to such an extent that the method of propagation is not anymore representative of that for a non-modified battery system."

"(viii) The cells should not be modified in any way that changes the composition or mechanical properties of the cell itself (including the external cell case)."

Comment *103* comment by: *Volocopter GmbH*

Comment:
Taking into consideration that the cell thermal runaway behavior is known, worst-case trigger methods are selected, and the additional containment safety layer is in place, SOC-temperature pairs that can occur during usage would be more appropriate.

Proposed wording:
"… should always be stabilized at the maximum possible operating temperature that the cells can reach during any flight at the defined test SOC level, increased by 5 °C"

response Not accepted.

This requirement is maintained from DO-311A to include margins to cover the variabilities in the cells and tests outcomes, and the very limited thermal runaway tests and in-service experience.

comment *104* comment by: *Volocopter GmbH*

Comment to: *(xiv) (C) and (D)*
No release of fragments outside the battery system
No escape of flames outside of the battery system

Comment:
Please add "except through the designed venting provisions." to both (C) and (D) points.

response

Partially Accepted.

Ejecting fragments off-board an eVTOL is not acceptable, only flames and emissions are allowed to be vented off-board.

comment

112

comment by: *boeing -Royce plc*

Page 6 Section/Paragraph 3(a)(iii)

RATIONALE / REASON / JUSTIFICATION for the Comment

Note: Demonstrating compliance with one of the test approaches defined in this document do not alleviate the classification of the failure condition “Battery Thermal Runaway” (Thermal Runaway of two or more cells within a battery) considered Catastrophic.

No regulation or guidance material have classified the Thermal Runaway of two or more cells within a battery as Catastrophic. If it is meant to be done in this document maybe an explanation is necessary instead of a note.

PROPOSED TEXT

Proposal is to consider a requirement for Battery thermal runaway similar to the CS 25.933 Reversing systems for Large aircraft:

Each Propulsion battery systems must be designed so that either:
(1) The aeroplane can be shown to be capable of continued safe flight and landing during and after any battery thermal runaway; or
(ii) It can be demonstrated that any battery thermal runaway complies with VTOL.2510 Equipment, systems, and installations.

Where Uncontrolled Battery Thermal Runaway shoul be classified CAT, not just the Thermal Runaway event in itself.

response

Not accepted.

See response to comment 47.

comment *113* comment by: *Rolls-Royce plc*

Page 6 Section/Paragraph 3.(b)(2)

RATIONALE / REASON / JUSTIFICATION for the Comment

"The applicant should define, in coordination with EASA, a set of tests at battery system level to demonstrate that the propagation prevention mechanisms described in RTCA DO-311A section 2.1 "General requirements", has been successfully implemented.

RTCA DO-311A Section 2.1 General Requirements
Section 2.1 contains general equipment requirements that do not require compliance verification via the tests within this standard. Performance and safety requirements that require test verification are included in Section 2.2.

DO-311A section 2.1 "General requirements" is not supposed to be demonstrated by tests

PROPOSED TEXT

Please clarify if the intent of this section is to only accept "a set of tests at battery system level" to demonstrate that the RTCA DO-311A section 2.1 propagation prevention mechanisms requirements have been considered and successfully implemented.

response Partially Accepted.

This section is modified as:

"(2) The applicant should define, in coordination with EASA, a set of tests at battery system level to demonstrate that the propagation prevention mechanisms have been successfully implemented."

comment *114* comment by: *Rolls-Royce plc*

Page 7 Section/Paragraph 3.(b)(3)(ii)(A)

RATIONALE / REASON / JUSTIFICATION for the Comment

ii) A) Thermal Runaway Trigger Method. When overcharging the cell to force a thermal runaway is possible (no internal cell protections), cell thermal runaway behaviour between overcharging and overheating lead to different outcomes. These differences should be well understood and considered at battery system level testing.

Are the two test methods described in the section 2.4.5.4.1 Overcharging and 2.4.5.4.2 Overheating, but limited to a single cell, an acceptable procedure for the single cell test to induce a thermal runaway?

PROPOSED TEXT

Please define which existing DO-311A proposed methodology, if any, is acceptable by EASA as test procedure.

response

Not accepted.

Test procedure shall be proposed by the applicant based on the guidelines proposed in this MOC. DO-311A test 2.4.5.4.1 and 2.4.5.4.2 are not acceptable for non-propagation tests as they do not consider aging of the cells and the battery or module, different SOCs, different positions of the heater on the cell case, different heating rates and different positions of the cell in the battery or module.

comment

115 comment by: *Rolls-Royce plc*

Page 7 Section/Paragraph 3.(b)(3)(iii)

RATIONALE / REASON / JUSTIFICATION for the Comment

iii) A thermal runaway in at least a pair of adjacent cells in the Propulsion Battery should be caused by overheating and/or overcharging as determined by the previous cell characterisation.

Is the 2.4.5.4 Single Cell Thermal Runaway Containment Test (Paragraph 2.2.2.3) procedure extended to 2 cells acceptable to induce a thermal runaway in a pair of adjacent cells?

PROPOSED TEXT

Please define which existing DO-311A proposed methodology, if any, is acceptable by EASA as test procedure.

response

Not accepted.

Test procedure shall be proposed by the applicant based on the guidelines proposed on this MOC. DO-311A test 2.4.5.4 is not acceptable for non-propagation tests as it does not consider aging of the cells and the battery or module, different SOC, different positions of the heater on the cell case, different heating rates and different positions of the cell in the battery or module.

comment *125* comment by: *H55_FSU*

Thermal runaway non-propagation test guidelines section 3. (b)(3)(iii):

It is not clear from the stated text wether those tests specified are individual tests to be performed independently prior to the battery thermal runaway containment test or guidelines to be considered while performing the tests as described in section 4(a)(1) and 5(a)(1).

response Noted.

Section (3).(b).(3). provides guidelines to develop non-propagation tests for both approaches in 4. And 5.

comment *144* comment by: *The Boeing Company*

COMMENT #4 of 14			
Type of comment (check one)	***Non-Concur***	***Substantive*** ***X***	***Editorial***
Affected paragraph and page number	Page: 6-7 Paragraph: *Section 3(b)(3)(i) 'Aging and environmental'*		
What is your concern and what do you want changed in this paragraph?	**THE PROPOSED TEXT STATES:** (i) Aging and environmental conditions during operation may result in degradation of the protection layers **REQUESTED CHANGE:** "(i) Aging and environmental conditions during operation may result in degradation of the **electro-chemical properties and** protection layers **for each battery**"		
Why is your suggested change justified?	**JUSTIFICATION:** Aging affects the entire composition of the battery, which further affects performance. The change demonstrates the actual property-based aging effect that is relevant to what is being addressed.		

response Accepted.

comment | *145* | comment by: *The Boeing Company*

COMMENT #5 of 14		
Non-Concur	***Substantive*** ***X***	***Editorial***
Page: 6-7 Paragraph: *Section 3(b)(3)(i) 'Aging and environmental'*		
THE PROPOSED TEXT STATES: Therefore, to test the worst-case condition during the life of the propulsion battery system, these tests should also be performed with batteries that have experienced loading that could lead to such degradation, i.e. vibrations, thermal cycling and electrical cycling, either on separate test articles or sequentially on the same test articles. Batteries used for RTCA DO-160/EUROCAE ED-14 environmental tests or aging cycle tests can be used as test samples. Alternatively, batteries that have gone through equivalent accelerated life tests can be used. **REQUESTED CHANGE:** We recommend providing clarification or guidance on a standardized approach to age (or to select aged) cells, rather than providing a few options.		
JUSTIFICATION: The variation in approaches for aging can result in pitfalls in certification rigor across different programs. Establishing a notional baseline for aging the cells used in these tests will ensure standardization across all applicants, regardless of design.		

response

Partially Accepted.

Reference to EUROCAE ED-289 for guidelines to define the aging profile is included.

comment | *146* | comment by: *The Boeing Company*

COMMENT #6 of 14			
Type of comment (check one)	***Non-Concur***	***Substantive*** ***x***	***Editorial***
Affected paragraph and page number	Page: 8 Paragraph: *Section 3(b)(3)(xi)(B)*		

What is your concern and what do you want changed in this paragraph?	**<u>The proposed text states</u>:** (B) The two triggered cells have entered thermal runaway within 30 seconds of each other. **<u>REQUESTED CHANGE</u>:** (B) The two triggered cells have entered thermal runaway within ~~30 seconds~~ **<u>a reasonable amount of time (approximately 30 seconds, if possible)</u>** of each other.
Why is your suggested change justified?	**<u>JUSTIFICATION</u>:** We recommend providing an approximate goal, rather than a strict time requirement. Thermal runaway is very inconsistent due to differences in cell/test manufacturing

response

Partially accepted.

Non-propagation test will request to only trigger 1 cell, so section 3(b)(3)(xi) has been deleted.

comment *147* comment by: *The Boeing Company*

COMMENT #7 of <u>14</u>		
Non-Concur	***Substantive*** ***x***	***Editorial***
Page: 8 Paragraph: *Section 3(b)(3)(xiv)(A)*		
<u>The proposed text states</u>: (A) No propagation to other cells. **<u>REQUESTED CHANGE</u>:** (A) No propagation ***<u>beyond where the applicant defines their full-containment capability</u>*** ~~**to other cells**~~.		
<u>JUSTIFICATION</u>: Based on their design, the applicant should be able to define the boundary of their containment, through which propagation will not exceed. Requiring non-propagation at the cell-level may be over burdensome for applicants, especially considering the added weight implications, and may not be necessary to meet EASA's safety intent.		

response

Not accepted.

Both mitigations are requested, Thermal Runaway propagation prevention (non-propagation test) and Thermal Runaway containment. For the non-propagation test, due to the variability of designs, general guidelines are proposed to support applicants to characterize and assess their design at different levels and define tests that capture all these possible variabilities and worst-case conditions. On top of that, margins are included to ensure non-propagation, and a second protection layer (containment) is requested.

Non-propagation tests are not defining/prescribing a particular solution, as containment tests are not defining/prescribing a particular solution. Both safety layers/measures are requested, and for both the applicant can propose different solutions, therefore fostering innovation and bringing more safety in the long term, in opposition to relying only on containment.

It has been proven in several projects under development, that there are viable solutions in terms of mass.

comment *160* comment by: *Rolls-Royce plc*

Page 6 Section/Paragraph 3(a)(iii)

RATIONALE / REASON / JUSTIFICATION for the Comment

Note: Demonstrating compliance with one of the test approaches defined in this document do not alleviate the classification of the failure condition “Battery Thermal Runaway” (Thermal Runaway of 2 or more cells within a battery) considered Catastrophic.

PROPOSED TEXT

The statement mixes system safety with technical requirement.
A failure should be categorized by the caused effect.
Even if Thermal Runaway is uncontrolled, as long as it is contained within the enclosure - which is the rational of this document - it will not necessary lead to a catastrophic outcome, assuming the fire does not spread to other parts of the aircraft.
Suggestion to add Uncontained to "Battery Thermal Runaway" to justify the CAT classification

response

Not accepted

See response to comment 47.

comment	*161* comment by: *Rolls-Royce plc* Page 6 Section/Paragraph 3(a)(iv) **RATIONALE / REASON / JUSTIFICATION for the Comment** d. Evidence and/or documents showing that a propulsion battery System Safety Assessment (SSA) has been performed as per latest version of SAE ARP 4761, addressing the hazards leading to thermal runaway, and including: **PROPOSED TEXT** Suggestion to change latest version to "applicable version", or "applicable version at the time of application". FHA is not part of SSA. Suggesting including the following safety deliverables: FHA, SSA and FMECA.
response	Partially Accepted. Paragraph has been clarified as indeed FHA are not systematically included in the SSA. This section is referring to SAE ARP 4761, this ARP is not referring to FMECA, only to FMEA/FMES. The intent here is to describe the usual safety assessment process applied to the propulsion battery system. Out of consistency, we referred in this section to FMEA and not FMECA.

comment	*162* comment by: *Rolls-Royce plc* Page 6 Section/Paragraph 3(b)(2) **RATIONALE / REASON / JUSTIFICATION for the Comment** "The applicant should define, in coordination with EASA, a set of tests at battery system level to demonstrate that the propagation prevention mechanisms described in RTCA DO-311A section 2.1 “General requirements”, has been successfully implemented. **PROPOSED TEXT** DO311A - 2.1 covers design requirements, which do not have to be demonstrated by tests. What would be the way to demontrate compliance with design requirements? Documentation?

	Is the guidance for tests tests described in DO311A - 2.4 abeing referred to here, and is it acceptable MOC by EASA?
response	Partially Accepted. This Section is modified as: *"The applicant should define, in coordination with EASA, a set of tests at battery system level to demonstrate that the propagation prevention mechanisms have been successfully implemented."* The test procedure shall be proposed by the applicant based on the guidelines proposed on this MOC. DO-311A tests in 2.4 are not acceptable for non-propagation tests as they do not consider aging of the cell and the battery or module, different SOC, different positions of the heater on the cell case, different heating rates and different positions of the cell in the battery or module.

comment	*163* comment by: *Rolls-Royce plc* Page 7 Section/Paragraph 3(b)(ii) **RATIONALE / REASON / JUSTIFICATION for the Comment** None **PROPOSED TEXT** Is it needed to specify the amount of samples used for the characterization testing? Is a single representative test sufficient? Are mutiple tests required, and if so how many?
response	Noted. The MOC is providing high level guidance due to the variability and possibility of very different solutions. Regarding the variability in cell level tests, the MOC is already requesting: *"Due to the high variability in cell level tests, the applicant should define, in coordination with EASA, an appropriate number of replicates to ensure a representative sample for the cell thermal runaway characterization in (ii). This sample should represent all expected cell variabilities that are anticipated in the life of the product, and should include cell replicates from different lots, manufactured on different dates and from different manufacturing sites (if applicable)."*

comment	*164* comment by: *Rolls-Royce plc* Page 7 Section/Paragraph 3(b)(3)(ii)(A) **RATIONALE / REASON / JUSTIFICATION for the Comment** 2) Thermal Runaway Trigger Method. When overcharging the cell to force a thermal runaway is possible (no internal cell protections), cell thermal runaway behaviour between overcharging and overheating lead to different outcomes. These differences should be well understood and considered at battery system level testing. **PROPOSED TEXT** Are the tests described in DO311A 2.4.5.4.1 Overcharging and 2.4.5.4.2 Overheating acceptable MOC for EASA? Please define which existing, if any, DO-311A proposed methodology is acceptable by EASA as test procedure.
response	Not accepted. The test procedure shall be proposed by the applicant based on the guidelines proposed on this MOC. DO-311A tests 2.4.5.4.1 and 2.4.5.4.2 are not acceptable for non-propagation tests as they do not consider aging of the cell and the battery or module, different SOC, different positions of the heater on the cell case, different heating rates and different positions of the cell in the battery or module.

comment	*165* comment by: *Rolls-Royce plc* Page 7 Section/Paragraph 3(b)(3)(iii) **RATIONALE / REASON / JUSTIFICATION for the Comment** 3) A thermal runaway in at least a pair of adjacent cells in the Propulsion Battery should be caused by overheating and/or overcharging as determined by the previous cell characterisation. **PROPOSED TEXT** Is the test described in DO311A Appendix C - Alternate Test Method for Battery Thermal Ruanway Test, C.2 acceptable MOC for EASA (for initiating a pair of adjacent cells)?

	Is the 2.4.5.4 Single Cell Thermal Runaway Containment Test (Paragraph 2.2.2.3) procedure extended to 2 cells acceptable to induce a thermal runaway in a pair of adjacent cells?
response	Noted. The MOC is modified to request the triggering of only 1 cell. The guidelines of this MOC shall be used to develop the non-propagation tests, based on DO-311A but including lessons-learnt and knowledge acquired after DO-311A was published and some variabilities that were not included in DO-311A tests (e.g. aging, different SOC, position of the heater, different heating rates…) that can lead to different outcomes.

comment	*166*	comment by: *Rolls-Royce plc*
	Page 8 Section/Paragraph 3(b)(xiv) **RATIONALE / REASON / JUSTIFICATION for the Comment** 13) The battery system tested should be monitored for 8 hours after the initial thermal runaway event, and during this time comply with the following requirements: [...] e) No escape of emissions outside the battery system. **PROPOSED TEXT** Clarify if the DO-311A pass fail criteria of "Escape of emissions shall comply with the declared venting category (see Sections 1.4.2 and 2.1.8)" is accepted? (e) No escape of emissions outside the battery system. To be deleted in this case)	
response	Accepted. This condition is modified to include: “except through the designed venting provisions”	

comment	*167* comment by: *Rolls-Royce plc* Page 6 Section/Paragraph 3(a)(1)(iii) **RATIONALE / REASON / JUSTIFICATION for the Comment** None **PROPOSED TEXT** There might be a need for an FMECA as well.
response	Not accepted. The purpose of section 3(a)(1)(iii) is to define the design assurance activities that are expected. Note that in section 3(a)(1)(iv) the usual safety assessment activities are expected, which includes a FMEA/FMES. See also response to comment 161.

comment	*168* comment by: *Rolls-Royce plc* Page 8 Section/Paragraph 3(b)(3)(xiv) **RATIONALE / REASON / JUSTIFICATION for the Comment** No propagation to other cells. **PROPOSED TEXT** Since thermal runaway propagation is not necessarily catastrophic, this requirement is not supported. This requirement will not result in comparable results. Some battery modules consist of 10 x 40 Ah cells, others of 100 x 4 Ah cells so propagation of 2 cells might be catastrophic in the first instance (already over 20%), but most likely won't have any safety effect in the latter. This requirement handicaps modules built out of small format cells (which would naturally result in safer battery, as the energy is quantized into smaller sections)

	Also, this requirement does not take into account Side Wall Rupture, if 2 side wall ruptures are initiated - which is the worst kind of failure, and the most conservative approach to our knowledge - it is highly unlikely anyone is able to stop propagation completely, rather control propagation which should eventually be stopped. Explosion of pouch batteries would lead to the same outcome. If this document only considers "conventional failure", it might be strict against TR propagation but it does not necessarily gives guidance on developing a robust and safe design.
response	Not accepted. The MOC is modified to only request the triggering of 1 cell. Since the worst-case conditions of aging, temperature, trigger method, SOC, positions of the heater, position of the cell, orientation… are requested to maximize the potential for propagation, the tests will provide already enough margin in comparison with other single cell trigger tests (i.e. RTCA DO-311A 2.4.5.4, NASA EP-19-001 Interpretation Memo for the Battery TR Propagation requirements in JSC-20793 Rev D.). The MOC does not state that it is possible to guarantee that thermal runaway events can be prevented for every possible scenario or that the safest method is a cell-to-cell propagation mitigation. The MOC proposes different protection and mitigation layers, from cell level to battery level, and to installation level. These mitigations encompass to include and test non-propagation measures, and containment of realistic worst-cases of thermal runaway, on which the focus is clearly placed. It has been proven in several projects under development that there are viable solutions. The purpose of the note in 3(a)(1) and definitions section is to define what is considered a "battery thermal runaway": o Thermal runaway of two cells that thermally affect at least one common adjacent third cell within the same battery or, for modularized batteries, the same module. o Thermal runaway of any three or more cells within the same battery or, for modularized batteries, the same module. The whole EASA safety strategy is based in a multi-layer approach, where the reliability of the cells and the control and protective functions play a key role in EASA safety approach for the battery, and shouldn't be relaxed due to: • Propulsion batteries are not comparable to other aircraft equipment/Systems, due to their novel use, criticality, significant fire hazard and lack of service experience. • Neither thermal runaway tests can be compared with other qualification tests, due to the variability in the outcome of the tests (due to cell variability, TR initiation criteria, temperature, SOC..) and its novelty and lack of testing experience.

	Therefore, EASA is setting safety requirements ("battery thermal runaway" catastrophic) that should be used by the applicants to specify the reliability requirement for the cell failure as well as the safety objectives of the control and protective functions. This activity is complementary to the tests.

comment	*175* comment by: *Rolls-Royce plc* Page 8 Section/Paragraph 3 (b) (vii) **RATIONALE / REASON / JUSTIFICATION for the Comment** (vii) The tested battery system should not be modified to such an extent that the method of propagation can be significantly different than in a non-modified battery system. **PROPOSED TEXT** Is the level of acceptable modification clear from this comment? Would it be better to say that the method of propogation should be representative of that for a non modified system rather that not significantly different?
response	Accepted. This condition is modified as: *"The tested battery system should not be modified to such an extent that the method of propagation is not anymore representative of that for a non-modified battery system."*

comment	*176* comment by: *Rolls-Royce plc* Page 8 Section/Paragraph 3(b)(3) (xi) (A) **RATIONALE / REASON / JUSTIFICATION for the Comment** (xi) It should be proven for each test that: (A) The trigger method setup aims to trigger both cells at the same time. **PROPOSED TEXT** Is it sufficient to say that you need to prove a test aims to achieve simultaneous triggering? Would suggest the second point which is time bound is the neccesary requirement here?
response	Noted

Point (ix) is deleted, as will only be requested to trigger one cell.

comment 190 comment by: *General Aviation Manufacturers Association (GAMA)*

RATIONALE / REASON / JUSTIFICATION

The paragraph in § 3(b)(3)(i) describes the need to test the worst-case condition during the life of a battery and then identifies batteries with prior testing history that may be acceptable for the non-propagation tests. It states: *"Batteries used for RTCA DO- 160/EUROCAE ED-14 environmental tests...can be used as test samples."* However, although DO-311A Section 2.3/Table 2-1 identifies the DO-160 tests to be performed, it does not require that any single EUT be tested in more than 1 DO-160 test. Therefore, a battery previously used in a single DO-160 environmental test (e.g. Section 15 Magnetic Effect) appears to meet this Sect 3(b)(3)(i) EUT criterion. Some DO-160 tests do not create adequate ageing or degradation in the cells.

While this paragraph also mentions that batteries that have *"experienced loading that could lead to such degradation, i.e. vibrations, thermal cycling and electrical cycling"*, each environmental condition would result in degradation of different types (vibration leading to part looseness or cell chafing; thermal cycling in open circuit could result in negligible degradation or dendrite formation; electrical cycling at low rates and low depths of discharge could result in negligible degradation).

This section appears to accommodate applicants with the prospect of minimizing cost by using previously tested batteries. But, by allowing batteries with varying test history for these TR non-propagation tests, the variation in cell degradation in each battery may be different and yield variations in the volatility of the TR responses.

PROPOSED TEXT/ACTION

EASA to consider:

a) Deleting the allowance to use batteries of various test histories.

b) Defining either a method to achieve an aged battery from a new test article or defining a specific test history that would be acceptable for representation as an aged battery.

c) Defining just one of the following test history for the TR Non-Propagation test:

1. Use a battery that has completed DO-160 Section 4 Ground Survival High Temp and Short- Time Operating High Temp; Ground Survival Low Temp and Short-Time Operating Low Temp; Operating High Temp; (Altitude; Decompression if pouch cells); and Temp Variation; or
2. Use a battery that has completed salt fog, humidity, and vibration; or

	3. Use a battery that has been repeatedly overdischarged and recharged at high current for X cycles at low temp).
response	Partially accepted. The MOC is providing high level guidance to allow for flexibility in the proposals, but the applicant will have to demonstrate a proper aging and degradation due to environmental conditions (iaw operation expected) in coordination with EASA. DO-160 and EUROCAE ED-289 are documents that can be used for these proposals. The MOC will be modified to include "…when the applicant demonstrates a proper aging and degradation".

comment	*191* comment by: *General Aviation Manufacturers Association (GAMA)* **RATIONALE / REASON / JUSTIFICATION** § 3(b)(3)(ii) is identifying a number of considerations that would need test procedures developed to minimize test method variability between applicants. **PROPOSED TEXT/ACTION** GAMA recommends that test procedures be defined to enable better review and comment.
response	Not accepted. The MOC is providing high level guidance due to the variability and possibility of very different solutions. Regarding the variability in cell level tests, the MOC will request: *"Due to the high variability in cell level tests, the applicant should define, in coordination with EASA, an appropriate number of replicates to ensure a representative sample for the cell thermal runaway characterization in (ii). This sample should represent all expected cell variabilities that are anticipated in the life of the product, and should include cell replicates from different lots, manufactured on different dates and from different manufacturing sites (if applicable)"*

comment	*192* comment by: *General Aviation Manufacturers Association (GAMA)* **RATIONALE / REASON / JUSTIFICATION** The requirement in point (3)(ii)(A) seems ambiguous. When the requirement states *"…differences should be fully understood and considered….."* it is not clear what the tester should be considering. Is the tester looking for a worst case event? If so, what is meant

by "worst case"? Maximum generated heat, or maximum expansion, or maximum gas emission or maximum explosive force, etc.?

PROPOSED TEXT/ACTION

EASA to specify what properties need to be considered.

response Partially Accepted.

Point (ii) modified as:

"(ii) A full characterisation of thermal runaway behaviour at cell level should be performed by the applicant to identify the potential worst-cases ***for cell-to-cell propagation*** *at battery system level tests, combining the following parameters:"*

comment *193* comment by: *General Aviation Manufacturers Association (GAMA)*

RATIONALE / REASON / JUSTIFICATION

In relation to this statement in § 3(b)(3)(ii)(B) :

"Different State of Charges (SOC). Normally, low SOC lead to more material remaining in the cell hence increasing the probability of cell-to-cell propagation. However, higher SOC lead to a thermal runaway more explosive and energetic with more material expelled outside the cell."

The end objective is to identify the worst case failure of the cell. In Section 3(b)(3)(i), it allows for the use of batteries that had been previously used in tests to include aging and environmental effects. However, dendrite formation through over-discharge (<0%SOC) and high current recharge (100%SOC) are known to result in thermal runaway. Cycling between over-discharge and high current recharge could produce the aging needed for these cells.

This paragraph does not provide clarity on what is considered low SOC and high SOC. Different cell manufacturers can also define their own end point voltage and charge voltages that effectively sets their value of 0%SOC and 100%SOC with sufficient margin on either end. Whereas, the 0%SOC and 100%SOC for the battery may define 0%SOC based on the minimum motor voltage and the 100%SOC based on the maximum battery charger voltage; these voltage values may not perfectly align with the cell's defined 0%SOC and 100%SOC values.

PROPOSED TEXT/ACTION

GAMA recommends defining low SOC and high SOC where low SOC is the value that a battery can be overdischarged to while sitting on the shelf for an extended period uncharged and high SOC is the value that the battery can be fully charged before the overvoltage protection trips.

response Not accepted.

§ 3(b)(3)(ii)(B) provides high level guidance to allow flexibility for each applicant to define LOW and HIGH SOC, depending on the specific design solution and operation.

comment *194* comment by: *General Aviation Manufacturers Association (GAMA)*

RATIONALE / REASON / JUSTIFICATION
The requirement in point § 3(b)(3)(ii)(D) seems ambiguous. When the requirement states *"...differences should be fully understood and considered....."* it is not clear what the tester should be considering. What behaviors is the applicant to consider at the battery level? Maximum smoke, max flames, max heat, max explosive pulse, max cell expansion?

PROPOSED TEXT/ACTION
EASA to specify what properties need to be considered.

response Partially accepted.

Point (ii) modified as:

*"(ii) A full characterisation of thermal runaway behaviour at cell level should be performed by the applicant to identify the potential worst-cases **for cell-to-cell propagation** at battery system level tests, combining the following parameters:"*

comment *195* comment by: *General Aviation Manufacturers Association (GAMA)*

RATIONALE / REASON / JUSTIFICATION
Point § 3(b)(3)(ii)(E)(b) does not specify which energy type it is refering to (i.e. thermal energy, explosive energy, etc.). Although it is assumed the desire is for thermal energy since this is the thermal runaway test, it should be clarified.

PROPOSED TEXT/ACTION
EASA to consider changing the wording to "Average total thermal energy release expressed in joules"

response Accepted.

comment	*196* comment by: *General Aviation Manufacturers Association (GAMA)* **RATIONALE / REASON / JUSTIFICATION** In relation to the following requirement in § 3(b)(3)(xiv): *"The temperature of the battery system before triggering the cells should be always stabilized at 55°C or the maximum operating high temperature, whichever is higher"* Taking into consideration that the cell thermal runaway behavior is known, worst-case trigger methods are selected, and the additional containment safety layer is in place, SOC-temperature pairs that can occur during usage would be more appropriate. **PROPOSED TEXT/ACTION** EASA to consider the following proposal: "… should always be stabilized **at the maximum possible operating temperature that the cells can reach during any flight at the defined test SOC level, increased by 5 °C**"
response	Not accepted. This point from DO-311A ensures margins to cover the variabilities in the cells and tests outcomes, and the very limited thermal runaway tests and in-service experience.

comment	*197* comment by: *General Aviation Manufacturers Association (GAMA)* **RATIONALE / REASON / JUSTIFICATION** In relation to the statement in § 3(b)(3)(xiv) *"The battery system tested should be monitored for 8 hours…."*, it is not clear whether the 8 hours are defined to represent the maximum use of the propulsion battery in-flight or if it is intended to determine if the aircraft remains a hazard on the ground to adjacent aircraft. In automotive, there have been reports of batteries that have gone into a full battery runaway weeks after a battery was damaged in a collision. **PROPOSED TEXT/ACTION** GAMA recommends "16 hours" to align with DO-311A which represents a reasonable overnight monitoring period after completion of the test or, alternatively, restate as "a minimum of 8 hours" to allow applicant to monitor for a longer period (including to align with work shift hours).
response	Partially accepted. It is modified as: “a minimum of 8 hours”.

The 8 hours' time is a compromise between:

- Time to have a very high confidence that all the potential chemical reactions in any cell are fully stopped, and there will not be propagation.
- Time to make the test execution easier and practical (in opposition to the 16h requested in the DO-311A, for large aeroplanes longer flights). For example, a first test could be done early in the morning, and a second one in the late afternoon (as already discussed with some applicants).
- Proportional to VTOL operation when compared to large airplanes.

comment | *212* | comment by: *G Cherouvrier SEP*

In the paragraph:
"(xiv) The battery system tested should be monitored for 8 hours after the initial thermal runaway event, and during this time comply with the following: (A) No propagation to other cells. (B) No rupture of the battery system. (C) No release of fragments outside the battery system. (D) No escape of flames outside of the battery system. (E) No escape of emissions outside the battery system, except through the designed venting provisions F) No compromise of warning signals and safety functions (e.g., battery automatic disconnect function)."

It seems difficult to expect no flames and no fragments outside the battery system.

Proposition: "(C) No release of fragments outside the battery system, except through the designed venting provisions. (D) No escape of flames outside of the battery system, except through the designed venting provisions."

response | Partially Accepted.

Ejecting fragments off-board an eVTOL is not acceptable, only flames and emissions are allowed to be vented off-board.

comment | *213* | comment by: *G Cherouvrier SEP*

In the paragraph:"(xiv) The battery system tested should be monitored for 8 hours after the initial thermal runaway event, and during this time comply with the following: (A) No propagation to other cells."

This is a critical requirement that would lead to a massive mass and volume increase in order to guarantee over the battery lifetime that in any case a cell in thermal runaway will ever initiate another cell in vicinity. It should be acceptable that a vicinal cell initiate a thermal runway if in the end the thermal runaway is contained (ie. no rupture, no flames except by venting provisions, no release of fragments except by veting provision, no emisions except by

	venting provision..) and stop at intended level. for exemple, A battery system may be modularized in order to stop any thermal runaway to propagate at the full battery and to be contained at module level. Proposition: suppression of " (A) No propagation to other cells."
response	Not accepted. Both mitigations are requested, Thermal Runaway propagation prevention (non-propagation test) and Thermal Runaway containment. For the non-propagation test, due to the variability of designs, general guidelines are proposed to support the applicants to characterize and assess their design at different levels and define tests that capture all these possible variabilities and worst-cases conditions. On top of that, margins are included to ensure non-propagation, and a second protection layer (containment) is requested. It has been proven in several projects under development, that there are viable solutions in terms of mass and volume.

comment	*226* comment by: *Heart Aerospace AB* *Comment 1* Proper understanding at cell level is a good practice, but there is no agreed methodology to consistently conform a test article to reflect design / production variability and field degradation / aging in aviation. These issues have historically been covered by employing industry agreed test methodologies that slightly overtest equipment / systems, considering either normal operating conditions or failure combinations not shown to be extremely improbable. This can be seen in standards like DO-297, DO-227, DO-311 and DO-160. The guidelines proposed by EASA in this paragraph will lead to safer battery systems, but at a significant and desproportional economic impact to the electrical aviation community. In order to cover the concerns highlighted by EASA in this paragraph, Heart Aerospace recommends focusing on developing an industry agreed internal cell failure prediction standard (which is work already being performed by Eurocae WG-112), that should then be used to determine the worst case failure combinations of every design that cannot be shown to be extremelly improbable and should be addressed by the safety development process, and used to define the most suitable test configuration in all associated test standards. All references to aging and variability contained in the document should be maintained, but directed to awareness and considerations in the safety development process, and used as the rationale to substantiate the proposal of a standardized and unique test methodology that would replace what is currently proposed in DO-311A, section 2.4.5.5.

	Comment 2 Would there be an acceptable limit for propagation if intentionally designed for? For example: in a small number of cells which are in contact (eg: 8) there is propagation, but it is self extinguished and the remaining cells within the battery does not suffer any thermal runaway. Is this acceptable?
response	Not accepted. EASA agrees that the MOC will lead to safer battery systems but disagrees that it will bring a significant and disproportional economic impact to the electrical aviation community. It has been proven in several projects under development, that there are viable solutions. The MOC will request to trigger 1 cell in the worst cases combinations, and avoid propagation to any other cell, so the case proposed won't be acceptable to comply with this MOC.

comment	*234* comment by: *Vertical Aerospace* Section 3.(b)(3)(ii)(A): Reference to "no internal cell protections" is ambiguous. Remove the "no internal cell protections" reference as the System Safety Assessment will define the scope of any protections, whether they sit at cell or system or at a different level.
response	Accepted.

comment	*235* comment by: *Vertical Aerospace* Section 3(b)(3)(ii)B: "Normally,...cell-to-cell propagation". This may be true for some cell designs, however, for certain cell designs the tabs or other components can act as fuses that stop the event from occurring; in comparison, at lower SoC the cell can maintain short-circuit current for longer periods of time and therefore generate more heat and ultimately be more unsafe than high SoC conditions. Therefore, it is requested to remove the term "normally" and focus on conducting test at different SoC.
response	Partially Accepted.

comment	*236* comment by: *Vertical Aerospace* Section 3(b)(3)(iv): Does that consideration also extend to other components that could be significantly more damaging than just propagation itself? Clarification is required.

response

Noted.

More clarification is needed to fully understand the concern. However, if the battery system has other components that could be significantly more damaging than just propagation itself, applicant will also have to address those potential cases.

comment

237 comment by: *Vertical Aerospace*

Section 3(b)(3)(xii): In some cell chemistries e.g., lithium-titanate the capability of the cell to ignite is severely reduced by the cell chemistry itself; also, some cells may implement methods to stop the propagation occurring in the first instance from the cell - Clarification is required as this would penalise these safer systems.

response

Noted.

This Means of Compliance considers the battery technology and chemistries proposed in the different projects currently in certification and in future projects of which EASA is already aware.

If new chemistries are proposed in future that could have a different behaviour impacting this MOC, other MOC could be proposed at the time of application.

comment

238 comment by: *Vertical Aerospace*

Section 3(b)(3)(xiv): "The battery system tested should be monitored for 8 hours..." Clarification is requested on the rationale of the above time duration.

response

Noted.

The 8 hours' time is a compromise between:

- Time to have a very high confidence that all the potential chemical reactions in any cell are fully stopped, and there will not be propagation.
- Time to make the test execution easier and practical (in opposition to the 16h requested in the DO-311A). For example, a first test could be done early in the morning, and a second one in the late afternoon (as already discussed with some applicants).
- Proportional to VTOL operation when compared to large airplanes.

comment	*239* comment by: *Vertical Aerospace* Section 3(b)(3)(i): "Aging and environmental conditions...". Ageing seldom creates more reactive cells unless it is specifically fast charging or cold temperature usage. An analysis for worst case scenario should take these into account; therefore, it is requested to add an additional example conditional of 'cold charging & extended fast charging' as these will reduce the failure temperature of cells and increase likelihood of propagation in li-ion.
response	Partially accepted. The MOC now includes a reference to the aging cycle to be in accordance with EUROCAE ED-289, where the definition of the aging profile includes charging and operational lower temperature and current limits.

comment	*240* comment by: *Vertical Aerospace* Section 3(b)(3)(viii): Does cell 'can' refer only to cylindrical or prismatic cells? It is requested to replace 'can' with 'case'.
response	Accepted.

comment	*241* comment by: *Vertical Aerospace* Section 3(b)(3)(xiv)(A): "No propagation to other cells": Clarification is required for what exactly "propagation" means in this instance. Monitoring for additional heat ramps on top of heat transfer from failed cells will not be practical.
response	Partially accepted. The definition of cell thermal runaway is updated to include several objective evidence: "Cell Thermal Runaway" is a rapid self-sustained heating of a battery cell driven by exothermic chemical reactions of the materials within the cell. Examples of objective evidence or unambiguous markers that demonstrate that a cell achieved thermal runaway are: (1) A sharp increase in temperature and pressure and a drop in cell voltage.

(2) Measured peak temperature at least 80% of the typical peak temperature reached during thermal runaway for a given chemistry, per test or per literature reports.

(3) Melted metallic components of cells (other than lithium).

(4) Decomposed active materials / Oxidized metallic lithium.

(5) Pyrolyzed (charred) cell contents

The following is also requested to be recorded during the test:

(C) The temperatures of the cells nearest to the cells being triggered.

4. Approach #1: RTCA DO-311A Section 2.4.5.5. Battery Thermal Runaway Containment Test p. 9

comment	*12* comment by: *AIRBUS HELICOPTERS* **COMMENT :** Acceptance criteria for each approach are hidden in the text. It is suggested to restructure the document in order to clearly show what are the acceptance criteria for Approaches #1 and #2 in a dedicated section or paragraph.
response	Partially accepted. Document has been restructured and criteria made clearer.

comment	*24* comment by: *Andrea Marinovich* Will this also be linked to the drop test as obviously the same requirements will need to be met once it has survived the drop test? Or is this covered elsewhere?
response	Not accepted. Drop test is not covered in this MOC as stated in the introduction: *"This Means of Compliance is neither addressing nor superseding other tests needed for the certification of propulsion battery systems (i.e. external short circuit, available system capacity and energy, protections testing, battery system crashworthiness tests…). "* Drop test requirements are defined in "EASA MOC VTOL.2325(a)(4) Fire Protection - Energy storage crash resistance". EUROCAE WG 112 SG-1 DP001 "Process Standard for Crashworthiness Test of Battery Systems for EVTOL Applications" is currently under development to provide additional guidance.

comment	*48* comment by: *Kevin Bruce* As noted before Section 3 is not properly titled and a rework of the MOC is need. In the end this section should be retitled as well as Section 5. Additionally, it may make more sense to create a section in which it states that one of the following shall be done. The overall approach to this MOC needs to be re thought. The goal is to prevent an uncontained thermal runaway and in the event one or more modules has a thermal runaway event, the aircraft can land safely. If one chooses to design a system where cell to cell

	propagation is protected against and then the thermal runaway contained at the cell level this MOC should address this. If the design is such that cell to cell propagation is not protected against within the module but the module contains the event and module to module propagation is protected against this MOC should address this also. The MOC should be written in such a way that the design solution is not suggested. This MOC is written considering only a system where the protection is designed at the cell level. Or it is assumed that protections effective at the aircraft level cannot be built into a module design. The 20% requirement – where did this come from and again this may not be appropriate for the given design solution. In a battery module all cells should go to thermal runaway – this is worst case. How the test is conducted should be left at the specific program level to determine to be sure it meets the intent of the MOC.
response	Not accepted. Both tests are requested, Thermal Runaway propagation prevention (non-propagation test) and Thermal Runaway containment. Having an internal short circuit at cell level in propulsion battery systems with thousands of cells becomes the most likely scenario for a thermal runaway. Therefore, propagation to adjacent cells in the battery should be properly prevented to avoid a chain reaction. On top of that a second protection layer (containment) is requested at battery/module level. Non-propagation tests are not defining/prescribing a particular solution, as containment tests are not defining/prescribing a particular solution. Both safety layers/measures are requested, and for both, the applicant can propose different solutions. Regarding the rationale of the requested percentage of cells, see response to comment #118.

comment	*63* comment by: *Electric Power Systems Inc*
response	Comment empty

comment	*87* comment by: *Diamond Aircraft Industries GmbH* As noted before Section 3 is not properly titled and a re work of the MOC is need. In the end this section should be retitled as well as Section 5. Additionally, it may make more sense to create a section in which it states that one of the following shall be done. The overall approach to this MOC needs to be re thought. The goal is to prevent an uncontained thermal runaway and in the event one or more modules has a thermal runaway event, the aircraft can land safely. If one chooses to design a system where cell to cell

	propagation is protected against and then the thermal runaway contained at the cell level this MOC should address this. If the design is such that cell to cell propagation is not protected against within the module but the module contains the event and module to module propagation is protected against this MOC should address this also. The MOC should be written in such a way that the design solution is not suggested. This MOC is written considering only a system where the protection is designed at the cell level. Or it is assumed that protections effective at the aircraft level cannot be built into a module design. Revise accordingly
response	Not accepted. Both tests are requested, Thermal Runaway propagation prevention (non-propagation test) and Thermal Runaway containment. Having an internal short circuit at cell level in propulsion battery systems with thousands of cells becomes the most likely scenario for a thermal runaway. Therefore, propagation to adjacent cells in the battery should be properly prevented to avoid a chain reaction. On top of that a second protection layer (containment) is requested at battery/module level. Non-propagation tests are not defining/prescribing a particular solution, as containment tests are not defining/prescribing a particular solution. Both safety layers/measures are requested, and for both, the applicant can propose different solutions.

comment	*126* comment by: *H55_FSU* **Time constraint for Battery thermal runaway containment test:** It should be clarified wether or not a time constraint for triggering the thermal runaway event should be considered (e.g. 30 seconds as per section 3(xi) or 1 minute as per section 5).
response	Partially Accepted. 3.(b)(3)(xi)(B) is removed as only 1 cell is requested to trigger the thermal runaway. 5.(b)(2)(xi)(B) will be modified as follows: *"(B) All triggered cells have entered into thermal runaway within a reasonable amount of time (approximately 1 minute)."*

4.(a) Compliance with verification aspects of propulsion battery system thermal runaway conditions	p. 9

comment	*105* comment by: *Volocopter GmbH* Comment to: *(a) (3) Evidence that at least 20% of the cells achieved thermal runaway. This percentage could be reduced (not below 15%) with the concurrence of EASA, based on the design, protection layers, installation and testing robustness proposed by the applicant.* Comment: If design, protection layers, installation and testing robustness are so well-executed as to warrant a reduction of the initial load, the battery system should have no trouble at all passing the test with 20% of the cells in thermal runaway. Therefore, the reduction is not needed and does not create a level playing field. Suggestion to remove.
response	Accepted.

comment	*116* comment by: *Rolls-Royce plc* Page 9 Section/Paragraph 4(a) and 5(a) **RATIONALE / REASON / JUSTIFICATION for the Comment** Propulsion Battery Systems are considered to properly fulfil verification aspects of propulsion battery system thermal runaway conditions when compliance is demonstrated with: (1)...... (2)...... ...... Does this set of tests provide full or partial compliance with VTOL 2330 ? **PROPOSED TEXT** Please clarify to which requirements the testing is providing compliance.

	MOC VTOL.2330 Fire Protection in designated fire zones (f) Explosive firewall (1) Each EESS should be isolated by an Explosive firewall [..] (2) Each opening in the Explosive Firewall should be sealed with close-fitting as grommets, bushings, or fittings able to withstand the heat and pressure created by a thermal runaway of battery. (3) Each Explosive Firewall and shroud should be: (i) constructed so that no hazardous quantity of fluid, corrosive gases, smoke, soot, particulate, liquid metal or flame can pass from any EESS compartment to other parts of the VTOL aircraft, DO-311A 2.2.2.4 Battery Thermal Runaway Containment When a battery is subjected to a thermal runaway condition wherein multiple cells are forced into a thermal runaway, the battery system shall comply with the following requirements: a. No release of fragments outside of the battery system. b. No escape of flames outside of the battery system, except through the designed venting provisions. c. Escape of emissions shall comply with the declared venting category (see Sections 1.4.2 and 2.1.8).
response	Noted. This MOC and its tests provide partial compliance to requirement VTOL.2330. MOC VTOL.2330 and this MOC VTOL.2440 shall be addressed together, as MOC VTOL.2330 defines the Explosive Firewall and sets the path for compliance for containment tests in accordance with MOC VTOL.2440. Compliance can be demonstrated at Propulsion Battery level (the Explosive Firewall is the battery enclosure) or the demonstration requires the battery to be installed in the aircraft, in this case, the Explosive Firewall is the aircraft compartment that contains the battery. Section/Paragraph 4(a) (Approach #1 based on DO-311A) can be followed with the Propulsion Battery being the Explosive Firewall. Section/Paragraph 5(a) (Approach #2) could be followed in both ways, with the Battery case directly being the Explosive Firewall or with the compartment walls building the Explosive Firewall. EUROCAE WG 112 SG 2, with involvement of EASA, is developing the DP “Designated Fire Zones for VTOL” to provide additional guidance.

4.(a)(1) Section 3. "Prerequisites" **p. 9**

comment *41* comment by: *Collins Aerospace/Pratt & Whitney*

Comment: This wording implies that two tests must be successfully run to satisfy the MOC. Recommend single acceptance criteria.
Justification: Is this the regulatory intent?

response Not accepted.

Yes, two tests should be successfully run to follow the MOC, and each of the test has its specific pass/fail criteria defined in the document.

comment *65* comment by: *Electric Power Systems Inc*

The value of this propagation mitigation requirement at the cell level has minimal impact when considering the system level safety analysis. With containment provided per DO-311A, cell to cell propagation has little impact on the fundamental safety of the aircraft.

Containment currently remains the sole method for objective, representative, and demonstrable manner of battery safety testing. This is reflected in the requirements in 3.b.3.xiv

response Not accepted.

Both tests are requested, Thermal Runaway propagation prevention (non-propagation test) and Thermal Runaway containment.

Having an internal short circuit at cell level in propulsion battery systems with thousands of cells becomes the most likely scenario for a thermal runaway. Therefore, propagation to adjacent cells in the battery should be properly prevented to avoid a chain reaction.

On top of that a second protection layer (containment) is requested.

comment *148* comment by: *The Boeing Company*

COMMENT #8 of 14			
Type of comment (check one)	***Non-Concur***	***Substantive*** ***x***	***Editorial***

Affected paragraph and page number	Page: 9 Paragraph: *Section 4(a)(1)*
What is your concern and what do you want changed in this paragraph?	**<u>The proposed text states</u>:** (1) Section 3. "Prerequisites" of this document, and . **<u>REQUESTED CHANGE</u>:** (1) Section 3. "Prerequisites" 3 (a) of this document, and .
Why is your suggested change justified?	**<u>JUSTIFICATION</u>:** We recommend providing information on the intent of the two tests proposed so that applicants can choose between the non-propagation test or containment test, based on their design.

response

Not accepted.

Both tests are requested, Thermal Runaway propagation prevention (non-propagation test) and Thermal Runaway containment. For the non-propagation test, due to the variability of designs, general guidelines are proposed to support applicants to characterize and assess their design at different levels and define tests that capture all these possible variabilities and worst-case conditions. On top of that, margins are included to ensure non-propagation, and a second protection layer (containment) is requested.

4.(a)(3) At least 20% of the cells in thermal runaway **p. 9**

comment	*6* comment by: *AIRBUS HELICOPTERS* Same comment than comment #5. **COMMENT :** In case of approach #1, the acceptance criteria for thermal runaway should be the paragraph 3.(b).(3).(xiv).(A) AND paragrap 4.(a).(3) as written in the document **JUSTIFICATION :** For approach #1, paragraph 4.(a) is listing the three acceptance criteria to comply with: 4.(a).(1) AND 4.(a).(2) AND 4.(a).(3). Paragraph 3.(b).(3).(xiv).(A) specifies that "No propagation to other cells." is allowed during the Thermal Runaway event, nor 8h after the Termal Runaway event with a test procedure launching the Thermal Runaway on 2 cells. This is contradictory with paragraph 4.(a).(3) which requires at least 20% of cells that achieved a Thermal Runaway. For a battery system having one hundred cells, the two acceptance criteria are not aligned for approach #1.
response	Partially Accepted. Added clarification that criteria 4(a)(3) applies only to the test requested in 4(a)(2). Therefore, the acceptance criteria for test requested in 4(a)(2) is: - To be compliant with DO-311A section 2.2.2.4., **AND** - To be compliant with 4(a)(3)

comment	*8* comment by: *AIRBUS HELICOPTERS* **COMMENT :** Clarify the rationale of the requested percentage of cells that have achieved a thermal runaway. **JUSTIFICATION :** Should the percentage of cells in thermal runaway be adapted to size of the battery or module ? Refer as well to comment #2 : very Large battery, large battery, small battery ? Refer as well to similar comment #11 about paragraph 5.(b).(2).(iii).

response

Not accepted

The MOC does not differentiate battery sizes. Nevertheless, referring to a percentage of the cells within the battery or module instead of a fixed number of cells, it is already accounting for the different sizes.

Regarding the rationale of the requested percentage of cells, see response to comment #118.

comment

14 comment by: *AIRBUS HELICOPTERS*

COMMENT :
A clarification is requested about which test case should be carried out with regard to the acceptance critera 4.(a).(3) ?
Is it the test defined in section 5.(b).(2).(iii) defined for approach #2 also to be used for approach #1 ?

JUSTIFICATION :
A test case about the acceptance critera 4.(a).(3) seems missing.
With the current content of the document, it appears that the 4.(a).(3) acceptance criteria is alone and is not linked to any test of paragraph 3 and section 4.

response

Accepted.

A clarification is added that the criterion 4(a)(3) applies only to the test requested in 4(a)(2).

comment

25 comment by: *Andrea Marinovich*

Scope of the Test is not clear.

For a safety point of view is it not better to minimize the % of cell that fail in thermal runaway?

response

Not accepted.

The test objective is to determine the effectiveness of the Battery system to manage the resulting effects when multiple cells are forced into thermal runaway as explained in DO-311A or section 5(b)(1) of this MOC.

The test is not related to the minimization of the cells that could fail in thermal runaway, and safety objectives are not relaxed due to this test, as clearly stated in 3.(a)(1):

"Demonstrating compliance with one of the test approaches defined in this MOC does not alleviate the classification of the failure condition "battery thermal runaway" which is considered catastrophic."

See response to comment 47.

comment	*42* comment by: *Collins Aerospace/Pratt & Whitney* Comment: There is no clear criteria to justify the use of 15% versus 20% for the test. Recommend using a single 20% value. Justification: Requirement is ambiguous and open to subjective interpretation.
response	Accepted.

comment	*64* comment by: *Electric Power Systems Inc* This requirement is arbitrary and subjective. Additional clarity must be provided regarding what is meant by 15 or 20% of the cells. This is significantly challenged by the insufficient definitions for battery in this MOC. Does this requirement refer to all cells in the aircraft, all the cells in a functionally independent battery system, in a contiguous collocated cells, within a module, or some other grouping of cells. How is this influenced by considerations of cell, module, and system energy content?
response	Partially Accepted. The definitions are updated to clarify he terms "battery system" and "module". *"Battery Module" means a group of electrically interconnected cells in series and/or parallel arrangement contained in a single enclosure that ensures that no fluids, flames, gasses, smoke, or fragments enter other modules, and that no thermal runaway is propagated from one module to the others during normal operation or failure conditions.* *"Battery system" means an assembly of electrically interconnected battery modules (modularized battery) or cells in series and/or parallel, plus any protective, monitoring, alerting circuitry or hardware inside or outside of the battery, its packaging, and the designed venting provisions.* The following Note in the Approach #2 is updated as well: ***Note 2:*** *Since propulsion battery systems have much higher capacity and size than conventional battery systems, it may not be feasible to design a battery system, that complies with the previous test approaches with a reasonable weight penalty. The applicant may propose a modularized battery system design composed out of battery modules, to comply at*

	battery module level, instead of at battery system level, with any of the test approaches defined in this document. And point 4(a)(3) is updated as: *At least 20% of the cells in the battery system achieved thermal runaway in the test in previous point [4.(a)(2)].* The 20% of the cells shall be selected to test the potential worst cases in accordance with (5)(b)(2)(iv): (iv) Triggered cells should be selected as follows: (A) To maximize the potential for propagation to other cells, the spacing and heat transfer characteristics between cells should be assessed. (B) The battery system configuration and installation location should be assessed to justify the selection of cells that have potential to be worst cases to be tested (e.g. centre, wide face, narrow face, corner, edge, subgroup of triggered cells in different sides, …) The possibility to reduce to 15% of the cells instead of 20% is removed.

comment	*73* comment by: *Bilge Atici* **Comment summary 4.a.3 page 9** A clarification on the first sentence is required. In contrast to the Approach#2, for which it is clearly expressed that a thermal runaway in at least 20% of the cells in the propulsion battery system should be caused, here the expression “Evidence that at least 20% of the cells achieved thermal runaway” may lead misunderstanding. Also the propulsion battery system reference is not quite clear. Is it asking the 20 percent of the cells for the whole system level or for battery module level which has defined as gas tight enclosures. **Suggested resolution** The expression can be changed as: “Evidence that at least 20% of the battery module cells go into thermal runaway and meet with test pass fail criteria defined in DO 311A.” The propulsion battery system reference should be replaced with battery module.
response	Partially Accepted. The definitions are updated to clarify “battery system” and “module”. *(a) “Battery Module” means a group of electrically interconnected cells in series and/or parallel arrangement contained in a single enclosure that ensures that no fluids, flames, gasses, smoke, or fragments enter other modules, and that no thermal runaway is propagated from one module to the others during normal operation or failure conditions.*

(b) *"Battery system" means an assembly of electrically interconnected battery modules (modularized battery) or cells in series and/or parallel, plus any protective, monitoring, alerting circuitry or hardware inside or outside of the battery, its packaging, and the designed venting provisions.*

The following Note in the Approach #2 is updated as well:

> ***Note 2:*** *Since propulsion battery systems have much higher capacity and size than conventional battery systems, it may not be feasible to design a battery system, that complies with the previous test approaches with a reasonable weight penalty. The applicant may propose a modularized battery system design composed out of battery modules, to comply at battery module level, instead of at battery system level, with any of the test approaches defined in this document.*

And point 4(a)(3) is updated as:

> *At least 20% of the cells in the battery system achieved thermal runaway in the test in previous point [4.(a)(2)].*

comment | *88* | comment by: *Diamond Aircraft Industries GmbH*

It is unclear whether the 20% refers to the total amount of cells in the entire battery system, battery, or battery module. Further it is unclear why 20% (or 15%) is chosen as a minimal limit.

Rephrase / clarify

response | Partially Accepted.

The definitions are updated to clarify "battery system" and "module".

(c) *"Battery Module" means a group of electrically interconnected cells in series and/or parallel arrangement contained in a single enclosure that ensures that no fluids, flames, gasses, smoke, or fragments enter other modules, and that no thermal runaway is propagated from one module to the others during normal operation or failure conditions.*

(d) *"Battery system" means an assembly of electrically interconnected battery modules (modularized battery) or cells in series and/or parallel, plus any protective, monitoring, alerting circuitry or hardware inside or outside of the battery, its packaging, and the designed venting provisions.*

The following Note in the Approach #2 is updated as well:

> ***Note 2:** Since propulsion battery systems have much higher capacity and size than conventional battery systems, it may not be feasible to design a battery system, that complies with the previous test approaches with a reasonable weight penalty. The applicant may propose a modularized battery system design composed out of battery modules, to comply at battery module level, instead of at battery system level, with any of the test approaches defined in this document.*

And point 4(a)(3) is updated as:

> *At least 20% of the cells in the battery system achieved thermal runaway in the test in previous point [4.(a)(2)].*

comment | *136* | comment by: *Ampaire Inc*

The only requirement should be that the trigger cells achieve thermal runaway. If the applicant's design prevents propagation then there will be no more cells that achieve thermal runaway.

Suggested revision:
Evidence that all the trigger cells achieve thermal runaway. The number and location of trigger cells, and number of tested trigger cell positions, will be developed with concurrence of EASA, based on the design, protection layers, installation and testing robustness proposed by the applicant.

response | Partially accepted.

Section 4(a)(3) is updated to clarify that it is only referring to point (2) “DO-311A Thermal runaway containment test” (overheating all the cells), and not to section (1) (non-propagation test).

comment | *149* | comment by: *The Boeing Company*

COMMENT #9 of 14			
Type of comment (check one)	***Non-Concur***	***Substantive*** x	***Editorial***
Affected paragraph and page number	Page: 9 Paragraph: *Section 4(a)(3)*		
What is your concern and what do you want	**The proposed text states:** Evidence that at least 20% of the cells achieved thermal runaway. This percentage could be reduced (not below 15%) with the		

changed in this paragraph?	concurrence of EASA, based on the design, protection layers, installation and testing robustness proposed by the applicant. **REQUESTED CHANGE:** We recommend adding "20% of the cells in the Propulsion Battery System" to the Definitions section with clarification on where these specific percentages come from, and at what design/test level the percentages are enforced.
Why is your suggested change justified?	**JUSTIFICATION:** Based on the provided definitions in Section 2, it is not clear whether this requirement for 20% of cells in the Propulsion Battery System entering thermal runaway is enforced at the aircraft level (i.e. 20% of all cells on the aircraft that provide energy for propulsion) or the individual battery level.

response

Partially Accepted.

The definitions are updated to clarify "battery system" and "module".

(e) "Battery Module" means a group of electrically interconnected cells in series and/or parallel arrangement contained in a single enclosure that ensures that no fluids, flames, gasses, smoke, or fragments enter other modules, and that no thermal runaway is propagated from one module to the others during normal operation or failure conditions.

(f) "Battery system" means an assembly of electrically interconnected battery modules (modularized battery) or cells in series and/or parallel, plus any protective, monitoring, alerting circuitry or hardware inside or outside of the battery, its packaging, and the designed venting provisions.

The following Note in the Approach #2 is updated as well:

> **Note 2:** Since propulsion battery systems have much higher capacity and size than conventional battery systems, it may not be feasible to design a battery system, that complies with the previous test approaches with a reasonable weight penalty. The applicant may propose a modularized battery system design composed out of battery modules, to comply at battery module level, instead of at battery system level, with any of the test approaches defined in this document.

And point 4(a)(3) is updated as:

> *At least 20% of the cells in the battery system achieved thermal runaway in the test in previous point [4.(a)(2)].*

comment *198* comment by: *General Aviation Manufacturers Association (GAMA)*

RATIONALE / REASON / JUSTIFICATION
The statement in § 4(a)(3) *"Evidence that at least 20% of the cells achieved thermal runaway"* creates a conflict with the aim of § 3(b) which appears to have an end goal of achieving non-propagation of cell failures.

Establishing a minimum number of cells that have gone into a thermal runaway beyond the initial number of cells that were forced into thermal runaway prevents the applicant from working towards a design that prevents propagation.

Furthermore, if design, protection layers, installation and testing robustness are so well-executed as to warrant a reduction of the initial load, the battery system should have no trouble passing the test with 20% of the cells in thermal runaway. In consequence, the reduction does not seem to be nedeed and could be detrimental to achieving a level playing field.

PROPOSED TEXT/ACTION
GAMA suggests removing this requirement. Alternatively, GAMA would propose to replace *"Evidence that at least 20% of the cells achieved thermal runaway."* with *"Objective evidence, confirmed by post-test inspection, that at least the two trigger cells achieved thermal runaway…."* from DO-311A, 2.4.5.5.1.

response Partially Accepted.

Clarification is added that the criterion 4(a)(3) applies only to the test in 4(a)(2).

The possibility to reduce to 15% of the cells instead of 20% is removed.

The following is included as definition of "Cell thermal runaway":

> "Cell Thermal Runaway" is a rapid self-sustained heating of a battery cell driven by exothermic chemical reactions of the materials within the cell. Objective evidence or unambiguous markers that demonstrate that a cell achieved thermal runaway are:
>
> (1) A sharp increase in temperature and pressure and a drop in cell voltage.
>
> (2) Measured peak temperature at least 80% of the typical peak temperature reached during thermal runaway for a given chemistry, per test or per literature reports.
>
> (3) Melted metallic components of cells (other than lithium).
>
> (4) Decomposed active materials / Oxidized metallic lithium.
>
> (5) Pyrolyzed (charred) cell contents

comment	*231* comment by: *Heart Aerospace AB* The minimum number of cells that are required to reach thermal runaway within a battery at the end of a show compliance test should be equal to the number of cells agreed in the test plan to be initially induced into thermal runaway (which is already described in 3(b)(3)(xi)(B) and (xii) - the same cells chosen to be triggered should be shown to reach thermal runaway). Any failure propagation, and a certain minimum number of cells that should additionaly reach thermal runaway, should be a consequence of the battery system design, and assessed as part of the pass-fail criteria (which is already described in 3(b)(3)(xiv)). Heart Aerospace suggests deleting item 4(a)(3).
response	Partially accepted. Clarification is added that the criterion 4(a)(3) applies only to the test in 4(a)(2).

comment	*242* comment by: *Vertical Aerospace* The scope of requesting 20% of the cells achieving thermal runaway is highly questionable and no rationale/audit trail exists to substantiate the use of this percentage. It should be two cells or the entire pack/system or more sensibly to be based on the safety assessment performed by the applicant. As such, either removal of the requirement or a full description on the conditions that encompass the 20% figure is requested.
response	Not accepted. See response to comment #118.

comment	*243* comment by: *Vertical Aerospace* Does this refer to a monolithic block of cells or spread across the pack? Clarification is requested.
response	Noted. The 20% of the cells shall be selected to test the potential worst cases in accordance with (5)(b)(2)(iv): (iv) Triggered cells should be selected as follows: (A) To maximize the potential for propagation to other cells, the spacing and heat transfer characteristics between cells should be assessed. (B) The battery system configuration and installation location and point 6.(b).(2).(iii) [A thermal runaway in at least 20% of the cells in the propulsion battery system should be caused by the worst-cases of test conditions combinations as determined in previous point (ii)] should be assessed to justify the selection of cells that have potential to be worst cases to be tested (e.g. centre, wide face, narrow face, corner, edge, subgroup of triggered cells in different sides, …)

5. Approach #2: Battery Thermal Runaway Containment for Continued Safe Flight and Landing (CSFL) time Tests	p. 9

comment	*13*	comment by: *AIRBUS HELICOPTERS*
	COMMENT : Acceptance criteria for each approach are hidden in the text. It is suggested to restructure the document in order to clearly show what are the acceptance criteria for Approaches #1 and #2 in a dedicated section or paragraph.	
response	Partially accepted. Document has been restructured and criteria made clearer.	

comment	*49*	comment by: *Kevin Bruce*
	Simalar comments as for Section 4.	
response	Noted.	

5.(a)(1) Section 3. "Prerequisites"	**p. 9**

comment	*51* comment by: *Collins Aerospace/Pratt & Whitney* Comment: This wording implies that two tests must be successfully run to satisfy the MOC. Recommend single acceptance criteria. Justification: Is this the regulatory intent?
response	Not accepted. Yes, two tests should be successfully run to follow the MOC, and each of the test has its specific pass/fail criteria defined in the document.

5.(a)(2) Test guidelines in section (b)	**p. 9**

comment	*52*	comment by: *Collins Aerospace/Pratt & Whitney*
response	Comment empty.	

5.(b) Thermal Runaway Containment for CSFL time Tests **p. 9**

comment	*158* comment by: *Rolls-Royce plc* Page 9 Section/Paragraph 5(b)(1) **RATIONALE / REASON / JUSTIFICATION for the Comment** […] a set of tests to demonstrate that a realistic worst-case of thermal runaway in more than 2 cells can be safely managed at propulsion battery system level or installation level (Battery Explosive Fire Zone). Does this mean that, if the battery is part of the propulsion system TC application, these set of tests can consider the installation level features as part of the test article? **PROPOSED TEXT** The SC E-19 requires the propulsion system applicant to identify the intended aircraft application. Therefore the fire/explosion installation level protection are expected to be considered in the propulsion system tests. Please confirm.
response	Noted. This MOC and its tests provide partial compliance to requirement VTOL.2330. MOC VTOL.2330 and this MOC VTOL.2440 shall be addressed together, as MOC VTOL.2330 defines the Explosive Firewall and sets the path for compliance for containment tests in accordance with MOC VTOL.2440 containment tests. Compliance can be demonstrated at Propulsion Battery level (the Explosive Firewall is the battery enclosure) or the demonstration requires the battery to be installed in the aircraft, in this case, the Explosive Firewall is the aircraft compartment that contains the battery. Section/Paragraph 4(a) (Approach #1 based on DO-311A) can be followed with the Propulsion Battery being the Explosive Firewall. Section/Paragraph 5(a) (Approach #2) could be followed in both ways, with the Battery case directly being the Explosive Firewall or with the compartment walls building the Explosive Firewall. EUROCAE WG 112 SG 2 with involvement of EASA, is developing the DP “Designated Fire Zones for VTOL” to provide additional guidance.

comment	*169* comment by: *Rolls-Royce plc* Page 9 Section/Paragraph 5(b)(1) **RATIONALE / REASON / JUSTIFICATION for the Comment** […] a set of tests to demonstrate that a realistic worst-case of thermal runaway in more than 2 cells can be safely managed at propulsion battery system level or installation level (Battery Explosive Fire Zone). **PROPOSED TEXT** If the batteries are housed individually, (therefor the battery module enclosure is also the explosive firewall) do we still have to consider the installation level features as part of the test article?
response	Noted. The battery module can be the test article and EASA MOC VTOL.2330 followed at module level as stated in Section/Paragraph 5(b)(2) (xv) and the final note.

comment	*170* comment by: *Rolls-Royce plc* **Page 10 Section/Paragraph 5(b)(2)(iii)** RATIONALE / REASON / JUSTIFICATION for the Comment 3) A thermal runaway in at least 20% of the cells in the propulsion battery system should be caused by overheating and/or overcharging as determined by the previous cell characterisation. **PROPOSED TEXT** If the thermal runaway of 2 cells is considered catastrophic, what is the rational behind containment of 20%? This approach would suggest either we consider TR propagation catastrophic, or even the containment of 20% non catastrophic! Tests with a thermal runaway in at least 20% of the cells seems too demanding compared with the scope of the tests "worst-case of thermal runaway in more than 2 cells"
response	Not accepted.

	See response to comment #118.

comment	*171* comment by: *Rolls-Royce plc* Page 9 Section/Paragraph 5(b)(1) **RATIONALE / REASON / JUSTIFICATION for the Comment** 13) During the test it should be demonstrated that the thermal runaway can be safely managed at propulsion battery system level or installation level (Battery Explosive Fire Zone) for a time that covers at least the detection of the fire at the most adverse operation condition and an ensuing continued safe flight and landing in accordance with EASA MOC VTOL.2330 Fire Protection in designated fire zones. **PROPOSED TEXT** What is the pass/fail criteria? Is "Escape of emissions shall comply with the declared venting category" accepted?
response	Noted. The pass-fail criteria are as per EASA MOC VTOL.2330 (published in June 2022) as stated in Section/Paragraph 5(b)(2) (xv).

comment	*244* comment by: *Vertical Aerospace* Section 5.(b)(2)(iii): As per comment#242.
response	Not accepted. See response to comment #118.

5.(b)(1) Tests for Thermal Runaway in more than 2 cells.	**p. 9**

comment	*9*	comment by: *AIRBUS HELICOPTERS*
	With regard to the sentence : "*can be **safely** managed at propulsion battery system level or installation level (Battery Explosive Fire Zone) for a time that covers at least the detection of the fire at the most adverse operation condition **and an ensuing continued safe flight and landing** in accordance with EASA MOC VTOL.2330 Fire Protection in designated fire zones.*" It is suggested to change this sentence as follows : **PROPOSED TEXT :** "*Therefore, the applicant should define in coordination with EASA, a set of tests to demonstrate that a realistic worst-case of thermal runaway in more than 2 cells can **be managed** at propulsion battery system level or installation level (Battery Explosive Fire Zone) for a time that covers at least the detection of the fire at the most adverse operation condition **and ~~an~~ ensuring continued safe flight and landing** in accordance with EASA MOC VTOL.2330 Fire Protection in designated fire zones.*" **JUSTIFICATION :** The wording "*safely managed*" is too generic and therefore it is suggested to remove this criteria as the CSFL objective is already specified at the end of the sentence. The wording "*thermal runaway in more than 2 cells can be safely managed*" coudl otherwise be understood as success criteria.	
response	Partially Accepted. It will be modified as follows: *"Therefore, the applicant should define in coordination with EASA, a set of tests to demonstrate that realistic worst-cases of thermal runaway in more than a cell can be managed at propulsion battery system level and installation level (Battery Explosive Fire Zone) ensuring continued safe flight and landing in accordance with EASA MOC VTOL.2330 Fire Protection in designated fire zones"*	

comment	*10*	comment by: *AIRBUS HELICOPTERS*
	With regard to the sentence : "*Therefore, the applicant should define in coordination with EASA, a set of tests to demonstrate that a realistic worst-case of thermal runaway in more than 2 cells can be safely managed at propulsion battery system level or installation level (Battery Explosive Fire Zone) **for a time that covers at least the detection of the fire** [...]* " **PROPOSED TEXT :**	

	"Therefore, the applicant should define in coordination with EASA, a set of tests to demonstrate that a realistic worst-case of thermal runaway in more than 2 cells can be safely managed at propulsion battery system level or installation level (Battery Explosive Fire Zone) for a time that covers at least the detection of a ***thermal runaway*** *[...]* " **JUSTIFICATION :** The link between fire definition and thermal runaway is not fully clear in the wording "for a time that covers at least the detection of the fire". A thermal runaway event may not generate systematicaly a fire.
response	Partially Accepted. Reference to fire has been removed, as the information is contained in EASA MOC VTOL.2330 “Fire Protection in designated fire zones”.

comment	*53* comment by: *Collins Aerospace/Pratt & Whitney* Comment: Replace "should" with "shall" Justification: Reflect mandatory requirement.
response	Not accepted. EASA SC-VTOL MOCs always use the term “should” instead of “shall” as they are not requirements.

comment	*66* comment by: *Electric Power Systems Inc* This requirement is subjective and arbitrary and may lead to issues with consistent application between applicants. Worst case is extremely challenging to fully identify and also extremely challenging to reliably emulate / demonstrate. Allowing for a time based approach to continued flight and evacuation without details regarding impact of on the airframe post evac will have undesirable impacts of the perception of electric propulsion within the industry. Accepting loss of airframe as an acceptable consequence of TR may be unpalatable to operators, leasing companies, and insurers.
response	Not accepted. The MOC provides guidelines to implement several safety layers: - Prevent root causes of thermal runaway. - Identify the worst-cases for propagation between cells with margins. - Identify the worst-cases for containment with margins.

There will be other guidance materials for the post-evacuation, the vertiport and the handling of fires on ground.

comment *199* comment by: *General Aviation Manufacturers Association (GAMA)*

RATIONALE / REASON / JUSTIFICATION
In relation to the following sentence in § 5(b)(1):

"Experience has demonstrated that, although very unlikely, it cannot be fully discarded that more than 2 cells could go into thermal runaway due to an unforeseen failure mode."

The text *"it cannot be fully discarded"* adds confusion.

PROPOSED TEXT/ACTION
GAMA recommends deleting *"it cannot be fully discarded"* and restate as: *"Experience has demonstrated that, although very unlikely, more than 2 cells could go into thermal runaway due to an unforeseen failure mode."*

response Accepted.

comment *200* comment by: *General Aviation Manufacturers Association (GAMA)*

RATIONALE / REASON / JUSTIFICATION

In relation to this statement:

"Therefore, the applicant should define in coordination with EASA, a set of tests to demonstrate that a realistic worst-case of thermal runaway in more than 2 cells can be safely managed…."

While testing with 2 cells going into thermal runaway has been included in test standards for large batteries, some may argue that it is as speculative as forcing an entire battery of cells into a thermal runaway or requiring that at least 20% of the cells achieve thermal runaway.

This paragraph's requirement to demonstrate a realistic worst-case in more than 2 cells needs to be based on a scenario identified by a more formal analysis (e.g. Sec 3(a)(1)(iv)-SSA, FHA, FTA, FMEA, etc) otherwise the scenario may be just as speculative as a scenario where only two or all cells are forced into a thermal runaway.

PROPOSED TEXT/ACTION

	GAMA recommends restating as: *"Therefore, the applicant should define in coordination with EASA,* ***one or more tests to demonstrate the worst-case battery failure modes identified in the analyses of Section 3(a)(1)(iv) can be safely managed at the propulsion battery level or installation level....****"*
response	Not accepted. See response to comment #118.

comment	*232* comment by: *Heart Aerospace AB* The minimum number of cells that are required to reach thermal runaway within a battery at the end of a show compliance test should be equal to the number of cells agreed in the test plan to be initially induced into thermal runaway (which is already described in 5(b)(1), 5(b)(1)(xi)(B) and 5(b)(1)(xii) - the same cells chosen to be triggered should be shown to reach thermal runaway). Any failure propagation, and a certain minimum number of cells that should additionaly reach thermal runaway, should be a consequence of the battery system design, and assessed as part of the pass-fail criteria (which is already described in 5(b)(1)(xv)). Heart Aerospace suggests deleting item 5(b)(2)(iii).
response	Not accepted. See response to comment #118.

5.(b)(2) Guidelines for the development of Thermal Runaway Containment for CSFL time Tests	p. 9

comment	*11*	comment by: *AIRBUS HELICOPTERS*
	With regard to the paragraph 5.(b).(2).(iii) on page 10 : "*A thermal runaway in **at least 20% of the cells** in the propulsion battery system should be caused by overheating and/or overcharging as determined by the previous cell characterisation.*" **COMMENT :** Clarify the rationale of the requested percentage of cells that are in a thermal runaway condition **JUSTIFICATION :** In the Proposed Means of Compliance with the Special Condition VTOL, there is no technical rationale linked to the requested percentage of cells in thermal runaway. Should the percentage of cells in thermal runaway be adapted to size of the battery or module ? Refer as well to comment #2 : very Large battery, large battery, small battery ? Refer as well to similar comment #8 about paragraph 4.(a).(3).	
response	Not accepted. The MOC does not differentiate battery sizes. Nevertheless, using a percentage of the cells within the battery o module, instead of a fix number of cells, it is already accounting for the different sizes. Regarding the rationale of the requested percentage of cells, see response to comment #118.	

comment	*26*	comment by: *Andrea Marinovich*
	Subpara (xi) : the 1 minute requirement is very demanding. Consider a longer time.	
response	Partially Accepted. 5.(b)(2)(xi)(B) is modified as follows: *"(B) All triggered cells have entered into thermal runaway within a reasonable amount of time (approximately 1 minute)."*	

comment	*54* comment by: *Collins Aerospace/Pratt & Whitney* Comment: Replace “should” with “shall” (13 places) Justification: Reflect mandatory requirement. Comment: In section (ii), replace “Non-Propagation” with “Containment”. Justification: Containment of the failure within the battery system is the need at the aircraft level. Specifying non-propagation defines a particular technical solution approach. Comment: In section (iii), replace “overheating and/or overcharging” with “the worst case combination of test conditions” Justification: Current wording implies optionality as opposed to mandating worst case. Comment: In section (iii), there is no clear criteria to justify the use of 15% versus 20% for the test. Recommend using a single 20% value. Justification: Requirement is ambiguous and open to subjective interpretation. Comment: In section (v), add “(worst case flight cooling conditions)” after “cooling”. Justification: The MOC states that cooling shall be included, but does not specify if (or how) that cooling system shall be operating during the test. Comment: In section (xv), include definitive pass/fail criteria (suggest criteria B-E from paragraph 3.xiv) Justification: Current wording “safely managed” does not provide any objective pass/fail criteria.
Response	Partially accepted. Comment #1: Not accepted. EASA SC-VTOL MOCs use “should” instead of “shall” as Means of Compliance are not requirements. Comment #2: Not accepted. Having an internal short circuit at cell level in propulsion battery systems with thousands of cells becomes the most likely scenario for a thermal runaway. Therefore, propagation to adjacent cells in the battery should be properly prevented to avoid a chain reaction. On top of that, a second protection layer (containment) is requested at battery/module level. Non-propagation tests are not defining/prescribing a particular solution, as containment tests are not defining/prescribing a particular solution. Both safety layers/measures are requested, and for both, the applicant can propose different solutions. Comment #3: Partially accepted, the text is modified in the requested sense.

Comment #4: Accepted, the possibility to reduce to 15% of the cells instead of 20% is removed.

Comment #5: Partially accepted. "Cooling" is deleted and included in any other design configuration or variable that could impact the test outcome. It would be assessed on a case-by-case basis.

Comment #6: Not Accepted, the pass-fail criteria is to comply with EASA MOC VTOL.2330 (published in June 2022) as stated in Section/Paragraph 5(b)(2) (xv). The word "safely" is removed.

comment *74* comment by: *Bilge Atici*

Commnet summary 5.b.2.iii page 10
For an integrated propulsion battery system housing hundreds of cells and composed of several modules/enclosures/compartments, the requirement of thermal runaway in at least 20% of the cells will be a very high rate and not likely to perform CSFL with 20% energy loss. A change in battery module definition as requested in comment # 5 along with a modification here as battery module would cover different kind of design alternatives.
Suggested resolution
The sub-paragraph can be updated as follow:
"A thermal runaway in at least 20% of the cells in the **battery module** should be caused by overheating and/or overcharging as determined by the previous cell characterisation. This percentage could be reduced (not below 15%) with the concurrence of EASA, based on the design, protection layers, installation and testing robustness proposed by the applicant"

response Partially Accepted.

The definitions have been modified for clarification. The test is requested at battery system level. However, where the applicant demonstrates a proper modularization (iaw battery module definition), the test can be performed at module level. Moreover, there could be applicants proposing batteries without modularization.

comment *75* comment by: *Bilge Atici*

Comment summary 5.b.2.i.ii.iii.iv.ix page 9 and 10
20% of module cells trigger at worst-case conditions of aging, temperature, and trigger method is overly conservative given the stated assumption in MOC-3 that any 2-cell trigger is "very unlikely".
Suggested resolution
Combinations of conditions and triggering with 20% or less should be modified.

	Use 10% versus 20% when more than 1 worst case condition is used. Examples to achieve an equivalent level of safety. All use worst-case trigger. When considering end of life: 10% of module at operational. · When considering new cells: 10% of module at emergency max temperature or 20% of module at operational max temperature.
response	Not accepted. See response to comment #118.

comment	*89* comment by: *Diamond Aircraft Industries GmbH* 5.(b)(2)(ii) Wrong reference to Non-propagation tests paragraph. Change. Should be 3.(b)(3)(ii)
response	Accepted.

comment	*90* comment by: *Diamond Aircraft Industries GmbH* 5.(b)(2)(xi)(B) When a large quantity of trigger cells are needed to comply with the requirement 5.(b)(2)(iii), then the 1 minute time delta might not be practically achievable. Furthermore not in line with 3. (b) (3)(xi)(B). Consider removing this as a fail criteria for such battery systems, or add an exemption when it can be demonstrated that a longer time does not significantly influence the overall test result (Thermal runaway containment).
response	Partially Accepted. 3.(b)(3)(xi)(B) is removed, as only 1 cell is requested to trigger the thermal runaway. 5.(b)(2)(xi)(B) is modified as follows: *"(B) All triggered cells have entered into thermal runaway within a reasonable amount of time (approximately 1 minute)."*

comment	*102* comment by: *Voltaero* Ref to Subpara (b) / Point (2) (iv)(B): See the same comment in the point Para 3- Prerequisite / Subpara (b)-Thermal runaway Non-Propagating Test / Point (3) (iv)(B)
response	Not accepted. Point (5)(b)(2)(iv)(B) is specific to the location of the cells to be triggered within the battery, requesting different positions of the cells within the battery. Point (5)(b)(2)(vi) requests to do an assessment of the possible influence in the outcome of the tests in the case that the battery is installed in different locations (i.e., differences in orientation, venting provisions).

comment	*107* comment by: *Volocopter GmbH* Comment to: *5 (b) (2) (iii) A thermal runaway in at least 20% of the cells in the propulsion battery system should be caused by overheating and/or overcharging as determined by the previous cell characterisation. This percentage could be reduced (not below 15%) with the concurrence of EASA, based on the design, protection layers, installation and testing robustness proposed by the applicant.* Comment: If design, protection layers, installation and testing robustness are so well-executed as to warrant a reduction of the initial load, the battery system should have no trouble at all passing the test with 20% of the cells in thermal runaway. Therefore, the reduction is not needed and does not create a level playing field. Suggestion to remove.
response	Accepted.

comment	*108* comment by: *Volocopter GmbH* Comment: Suggestion to add a note that the electrical connection between cells should not be modified for the overcharging trigger method, as it also provides a thermal and electrical interface between them, whose absence may influence the propagation behavior.

response

Not accepted.

Modifications in the electrical connection between cells in parallel configurations could be needed to isolate and overcharge only the targeted cells.

It will be requested to justify any modification in the Battery system or cells to perform the tests and its potential impact in the test outcome, as per points (v), (vii) and (viii).

comment

109 comment by: *Volocopter GmbH*

Comment1 to *5 (b) (2) (xiv) (A): The voltages of at least the cells being triggered.*

This creates a lot of effort for added instrumentation and potential to influence the test in an undefined way due to a potentially large number of cells to be monitored.
Since this is the last protection layer, and the expectation is that a fire propagation will take place, the added value of the sensors is not clear.
Proposal to remove.

Comment2 to *5 (b) (2) (xiv) (C): The temperatures of the cells nearest to the cells being triggered*

Comment:
This creates a lot of effort for added instrumentation and potential to influence the test in an undefined way due to a potentially large number of cells to be monitored.
Since this is the last protection layer, and the expectation is that a fire propagation will take place, the added value of the sensors is not clear.

Proposal to remove

response

Not Accepted.

§ 5(b)(2)(xiv)(A) refers to the voltages of the cells being triggered, that are normally measured by the BMS, so no added instrumentation should be needed for that. The cells' voltage together with the temperature, will be used to demonstrate that thermal runaway has occurred in all the cells triggered, independently of the trigger method used.

§ 5(b)(2)(xiv)(C) requests that the temperatures of the cells nearest to the cells being triggered are recorded during the test to understand either the propagation mechanisms or the margin in case there is no propagation to other cells.

A clarification is added in § 5(b)(2)(vii) regarding the test installation: "*Wires for heating, voltage, and temperature monitoring should be passed through the housing and the opening should be sealed to retain internal pressure. Suitable sealant may be high temperature RTV silicone rubber or equivalent.*"

comment	*118* comment by: *Rolls-Royce plc* Page 10 Section/Paragraph 5(b)(2)(iii) **RATIONALE / REASON / JUSTIFICATION for the Comment** iii) A thermal runaway in at least 20% of the cells in the propulsion battery system should be caused by overheating and/or overcharging as determined by the previous cell characterisation. The scope of the set of tests is limited to "demonstate that a realistic worst-case of thermal runaway in more than 2 cells can be safely managed....". [Ref. 5(b)(1)] How 20% has been defined? **PROPOSED TEXT** Tests with a thermal runaway in at least 20% of the cells seems too demanding compared with the scope of the tests "worst-case of thermal runaway in more than 2 cells"
response	Not accepted. It is essential to define requirements that ensure the adequate level of safety of the Propulsion Battery while avoiding unnecessary testing, weight penalties or, in the worst case, undertesting. The prescribed test methods in DO-311A extend beyond forcing multiple cells into thermal runaway and will drive, in most of the cases, the entire battery or module (all cells) into thermal runaway by overcharging or overheating the entire battery pack or module. In fact, this test represents an extreme condition never encountered in service, that will drive a near-simultaneous failure of all cells in the battery with far more energy than used in service, versus single cell initiation-propagation scenarios which have been experienced in service (see response to comment #178). As seen in the last years in different forums (projects, standardization working groups, research…) it has been impossible to reach a consensus of all the stakeholders for thermal runaway safety. Even in the comments provided to this MOC there are antagonistic positions. EASA decided to issue this MOC, after all these years working and discussing it with most of the main stakeholders, to provide its view in this matter. The first objective of this MOC is to prevent the most common root causes that could lead to a battery thermal runaway and which can be avoided through proper adoption of processes throughout design, manufacturing, installation, operation, and maintenance.

However, as other root causes cannot be completely avoided (i.e., cell internal short-circuit), their effect should be mitigated in-service. For these cases, EASA is requesting two additional protection/mitigation layers: non-propagation and containment.

These protection/mitigation layers (non-propagation and containment) do not relax other critical mitigations/protections as stated in the Note in (3)(a)(1) [which is moved to (4) in the final version of the MOC].

These protection layers shall be demonstrated in accordance with:

- Non-propagation tests: The worst-case conditions of aging, temperature, trigger method, SOC, positions of the heater, position of the cell, orientation… are requested to maximize the potential for propagation. The tests will provide already enough margin in comparison with other single cell trigger tests (i.e. RTCA DO-311A 2.4.5.4, NASA EP-19-001 Interpretation Memo for the Battery TR Propagation requirements in JSC-20793 Rev D.).

- Containment tests, targeting individually at least a 20% of the cells to account for the worst cases of variabilities. This fixed minimum percentage was discussed in several forums and will lead to:

    - Provide enough margin and a level playing field for all applicants (avoiding significant differences, interpretations, and pitfalls in testing across different projects).
    - In almost all the cases, it will lead to force propagation to the full battery or module, being this a more realistic case of initiation-propagation than the DO-311A containment test.
    - Not penalize the designs with very robust and well-implemented cell-to-cell non-propagation protections that prevent that the thermal runaway is propagated to the full battery or module even when 20% of the cells are triggered.

comment | *127* | comment by: *Electric Power Systems Inc*

5.b.2.ii
Only relevant to cell to cell propagation resistant designs. Reference is incorrect 3.b.3.ii. See notes on that section.

5.b.2.iii
Inconsistent language between this or 4.b.3.

What constitutes a battery "installation." Does this require the application of the "battery module" definition.

	A single battery system that is electrically connected may be distributed in different aircraft location. On the other hand, there may be batteries which are electrically independent but which my be in close physical proximity. More guidance on contiguous installation, modularization, and functional dependency are required to fully consider this requirement. 5.b.2.iv.B Should also need to consider what constitutes worst case considering cell TR behavior, location in the module, and location in the system. How do you ensure that worst case was truelly represented? See comments for section 3.b.3.iv.b 5.b.2.xi.b Inconsistent to 3.b.3.xi.b. 5.b.2.xv Allowing for a time based approach to continued flight and evacuation without details regarding impact of on the airframe post evac will have undesirable impacts of the perception of electric propulsion within the industry. Accepting loss of airframe as an acceptable consequence of TR may be unpalatable to operators, leasing companies, and insurers.
response	Partially Accepted. 5.(b)(2)(ii) and 5.(b)(2)(iii) are modified taking this comment into account. The definitions section is updated to provide additional guidance on “battery system”, “battery module” and “battery thermal runaway”. 5.(b)(2)(iv)(B): Section 3.(b)(3)(ii), referenced in 5.(b)(ii), will be modified as follows: *”A full characterisation of thermal runaway behaviour at cell level should be performed by the applicant to identify the potential worst-cases for cell-to-cell propagation at battery system level tests, combining the following parameters:”* 3.(b)(3)(xi)(b) is deleted. Only one cell is requested to be triggered into TR. 5.(b)(2)(xv) is aligned with the adopted EASA MOC VTOL.2330 that already went through public consultation. Moreover, this MOC provides guidelines to implement several safety layers: - Prevent root causes of thermal runaway. - Identify the worst-cases for propagation between cells with margins. - Identify the worst-cases for containment with margins.

There will be other guidance materials for the post-evacuation, the vertiport and the handling of fires on ground.

comment *139* comment by: *Ampaire Inc*

Regarding the text in (iii)
"A thermal runaway in at least 20% of the cells..."

The 20% seems arbitrary (as in Approach #1) and without technical foundation.

Suggested revision:
Evidence that all the trigger cells achieve thermal runaway. The number and location of trigger cells, and number of tested trigger cell positions, will be developed with concurrence of EASA, based on the design, protection layers, installation and testing robustness proposed by the applicant.

response Not accepted.

See response to comment #118.

comment *150* comment by: *The Boeing Company*

COMMENT #10 of 14			
Type of comment (check one)	***Non-Concur***	***Substantive*** ***x***	***Editorial***
Affected paragraph and page number	Page: 9 Paragraph: *Section 5(b)(2)(i) 'Aging and environmental'*		
What is your concern and what do you want changed in this paragraph?	**THE PROPOSED TEXT STATES:** (i) Aging and environmental conditions during operation may result in degradation of the protection layers **REQUESTED CHANGE:** "(i) Aging and environmental conditions during operation may result in degradation of the **electro-chemical properties and** protection layers **for each battery**"		
Why is your suggested change justified?	**JUSTIFICATION:** Aging affects the entire composition of the battery, which affects performance.		

response | Accepted

comment | *151* | comment by: *The Boeing Company*

COMMENT #11 of 14			
Type of comment (check one)	***Non-Concur***	***Substantive*** ***x***	***Editorial***
Affected paragraph and page number	Page: 9 Paragraph: *Section 5(b)(2)(i) 'Aging and environmental'*		
What is your concern and what do you want changed in this paragraph?	**THE PROPOSED TEXT STATES:** Therefore, to test the worst-case condition during the life of the propulsion battery system, these tests should also be performed with batteries that have experienced loading that could lead to such degradation, i.e. vibrations, thermal cycling and electrical cycling, either on separate test articles or sequentially on the same test articles. Batteries used for RTCA DO-160/EUROCAE ED-14 environmental tests or aging cycle tests can be used as test samples. Alternatively, batteries that have gone through equivalent accelerated life tests can be used. **REQUESTED CHANGE:** We recommend providing clarification or guidance on a standardized approach to age (or select aged) cells, rather than just stating a few general options.		
Why is your suggested change justified?	**JUSTIFICATION:** The variation in approaches for aging can result in pitfalls in certification rigor across different programs. Establishing a notional baseline for aging the cells used in these tests ensures standardization across all applicants, regardless of design.		

response

Partially Accepted.

EUROCAE ED-289 is referenced for the definition of aging cycle tests. With this addition it is deemed that the MOC guidelines already provide a reasonable level of detail to be applicable to different designs and solutions. EASA expects the development of other standards by standardization bodies to provide more detailed, standardized, and consensual guidance.

comment

152 comment by: *The Boeing Company*

COMMENT #12 of 14		
Non-Concur	***Substantive*** ***x***	***Editorial***
Page: 10 Paragraph: *Section 5(b)(2)(iii)*		

The proposed text states:
A thermal runaway in at least 20% of the cells in the propulsion battery system should be caused by overheating and/or overcharging as determined by the previous cell characterisation. This percentage could be reduced (not below 15%) with the concurrence of EASA, based on the design, protection layers, installation and testing robustness proposed by the applicant.
REQUESTED CHANGE:
We recommend providing additional information on test execution details.

JUSTIFICATION: It is not clear how to demonstrate 15-20% cells going into thermal runaway, when the applicant has already proven non-propagation in the prerequisites by only triggering 2 cells.

response

Not accepted.

Both tests are independent. The Thermal Runaway Containment for CSFL time test aims to overheat/overcharge 20% of the cells in a short period of time to demonstrate a proper containment.

The MOC guidelines are deemed to provide a reasonable level of detail, to be able to accommodate different designs and solutions.

comment | *153* | comment by: *The Boeing Company*

COMMENT #13 of 14		
Non-Concur	***Substantive*** *x*	***Editorial***
Page: 10 Paragraph: *Section 5(b)(2)(xi)(B)*		
The proposed text states: (B) All triggered cells have entered into thermal runaway within 1 minute **REQUESTED CHANGE:** (B) All triggered cells have entered into thermal runaway within **a reasonable amount of time (approximately 1 minute, if possible).** ~~1 minute~~		
JUSTIFICATION: We recommend providing an approximate goal, rather than a strict time requirement. Thermal runaway is very inconsistent due to differences in cell/test manufacturing.		

response

Partially Accepted.

It will be modified as follows:

"(B) All triggered cells have entered into thermal runaway within a reasonable amount of time (approximately 1 minute). "

comment | *201* | comment by: *General Aviation Manufacturers Association (GAMA)*

RATIONALE / REASON / JUSTIFICATION

In relation to this statement:

"A thermal runaway in at least 20% of the cells in the propulsion battery system should be caused by overheating and/or overcharging…."

Establishing a minimum number of cells that have gone into a thermal runaway beyond the initial number of cells that were forced into thermal runaway prevents the applicant from working towards a design that prevents propagation. This paragraph's requirement to force 20% of the battery into thermal runaway needs to be based on a scenario identified by a more formal analysis (e.g. Sec 3(a)(1)(iv)-SSA, FHA, FTA, FMEA, etc) otherwise the scenario may be just as speculative as a scenario where only two or all cells are forced into a thermal runaway.

If the value of 20% is intended to represent a foreseeable quantity of cells damaged from an external collision, please explain why the 20% value is used.

Furthermore, If design, protection layers, installation and testing robustness are so well-executed as to warrant a reduction of the initial load, the battery system should have no trouble passing the test with 20% of the cells in thermal runaway. In consequence, the reduction does not seem to be nedeed and could be detrimental to achieving a level playing field.

PROPOSED TEXT/ACTION
GAMA suggests removing this requirement. Alternatively, GAMA recommends restating as: *"A thermal runaway in two cells [or more cells if more cells could fail from a scenario identified in the analyses of Section 3(a)(1)(iv)] in the propulsion battery should be caused by overheating and/or overcharging…."*

response Not accepted.

See response to comment #118.

comment *202* comment by: *General Aviation Manufacturers Association (GAMA)*

RATIONALE / REASON / JUSTIFICATION
Excessive number of required instrumentation wires will make it difficult to comply with § 5(b)(2)(vii).

PROPOSED TEXT/ACTION
GAMA recommends deleting § 5(b)(2)(xiv)(A) if the trigger method is heating. Also, recommends deleting all or reducing the required number of sensors from § 5(b)(2)(xiv)(C) regardless of the trigger method.

response Partially Accepted.

§ 5(b)(2)(xiv)(A) refers to the voltages of the cells being triggered, that are normally measured by the BMS, so no added instrumentation should be needed for that. The cells' voltage together with the temperature, will be used to demonstrate that thermal runaway has occurred in all the cells triggered, independently of the trigger method used.

§ 5(b)(2)(xiv)(C) requests the temperatures of the cells nearest to the cells being triggered are recorded during the test to really understand, either the propagation mechanisms or the margin in case there is no propagation to other cells.

A clarification is added in § 5(b)(2)(vii) regarding the test installation: "Wires *for heating, voltage, and temperature monitoring should be passed through the housing and the opening* *should be sealed to retain internal pressure. Suitable sealant may be high temperature RTV silicone rubber or equivalent."*

comment *228* comment by: *Heart Aerospace AB*

Comment 1

Proper understanding at cell level is a good practice, but there is no agreed methodology to consistently conform a test article to reflect design / production variability and field degradation / aging in aviation. These issues have historically been covered by employing industry agreed test methodologies that slightly overtest equipment / systems, considering either normal operating conditions or failure combinations not shown to be extremelly improbable. This can be seen in standards like DO-297, DO-227, DO-311 and DO-160.

The guidelines proposed by EASA in this paragraph will lead to safer battery systems, but at a significant and desproportional economic impact to the electrical aviation community.

In order to cover the concerns highlighted by EASA in this paragraph, Heart Aerospace recommends focusing on developing an industry agreed internal cell failure prediction standard (which is work already being performed by Eurocae WG-112), that should then be used to determine the worst case failure combinations of every design that cannot be shown to be extremelly improbable and should be addressed by the safety development process, and used to define the most suitable test configuration in all associated test standards. This would also address EASA's statement in 5(b)(1) ("Experience has demonstrated that, although very unlikely, it cannot be fully discarded that more than 2 cells could go into thermal runaway due to an unforeseen failure mode.") in a way that doesn't penalize robust and safe design approaches for the mistakes of unsafe design implementations.

All references to aging and variability contained in the document should be maintained, but directed to awareness and considerations in the safety development process, and used as the rationale to substantiate the proposal of a standardized and unique test methodology that would replace what is currently proposed in DO-311A, section 2.4.5.5.

Comment 2

(x) Heart Aerospace suggests defining what is considered an acceptable evidence of initiation of a thermal runaway event. This would be helpful in applying uniform test standard. For example: is outgassing without any fire considered initiation of thermal runaway? Leaving the interpretation of thermal runaway initiation up to the individual test conductor can result in applicants applying different level of rigor in testing.

Comment 3

	(xiv) Heart Aerospace suggests adding measurement of vent outgas air flow rates or some pressure level measurement in the battery. This can be helpful in assessing the adequacy of the vent outlet size, and also the impact of vent outlet blockage that may occur in service.
response	Partially accepted Comment 1: EASA agrees that the MOC will lead to safer battery systems but disagrees that it will bring a significant and disproportional economic impact to the electric aviation community. It has been proven in several projects under development, that there are viable solutions. Comment 2: The following will be included in the definitions of “Cell thermal runaway”: “Cell Thermal Runaway” is a rapid self-sustained heating of a battery cell driven by exothermic chemical reactions of the materials within the cell. Objective evidence or unambiguous markers that demonstrate that a cell achieved thermal runaway are: (1) A sharp increase in temperature and pressure and a drop in cell voltage. (2) Measured peak temperature at least 80% of the typical peak temperature reached during thermal runaway for a given chemistry, per test or per literature reports. (3) Melted metallic components of cells (other than lithium). (4) Decomposed active materials / Oxidized metallic lithium. (5) Pyrolyzed (charred) cell contents Comment 3: It will be included to measure the volume and release rate of the gases at standard temperature and pressure, that exit the battery system.

5. Note: Properly modularized battery system design and compliance at module level **p. 11**

comment	*4*	comment by: *AIRBUS HELICOPTERS*
	With regard to the last sentence of the note : "*The applicant may propose a properly modularized battery system design with smaller modules, to comply at module level with any of the test approaches defined in this document*." It is suggested to change this sentence as follows : **PROPOSED TEXT:** "*The applicant may propose a properly modularized battery system design with smaller modules, to comply at module level with any of the test approaches defined in this document* ***in order to demonstrate containment at module level for thermal runaway effects without propagation/impact on adjacent modules***." **JUSTIFICATION :** There is a need to clarify the link with the definition of the "Battery module" (as per paragraph 2.(d)), otherwise to propose an alternative definition of modularized battery system linked to the need of containment at module level, e.g. thermal runaway effects without propagation/impact on neighboring modules	
response	Partially Accepted. Definition of "Battery module" updated to include: *"…that ensures…that no thermal runaway is propagated from one module to the others…".*	

comment	*50*	comment by: *Kevin Bruce*
	It is not clear what the intent here is for this note. The statement made in this not as well as other parts of this MOC make some conclusion that a designer cannot properly design a propulsion battery system light enough. Such statements are not appropriate for an MOC, AMC or any other document issued in the regulatory system. The MOC should state clearly the issue, the requirements from the design standards and then the means of compliance with proper rationale.	
response	Not accepted. The note is offering additional flexibility from which designers could benefit when faced with other specific design constraints affecting the weight.	

comment	*55* comment by: *Collins Aerospace/Pratt & Whitney* Comment: Replace "modules" with "battery module" and "module" with "battery module". Justification: Provide nomenclature consistency with earlier defintions. Comment: Add definitive statement as to what needs to be done to provide evidence of modularity. Add additional sentence "Applicant must provide evidence that battery module/battery module propagation cannot occur to allow testing on a subset of the battery system". Justification: Provide additional guidance to potential applicants.
response	Partially Accepted. The definition of "Battery module" is updated to include: *"…that ensures…that no thermal runaway is propagated from one module to the others…"* It will be required to demonstrate this via testing, unless otherwise justified, i.e. modules are totally independent (not shared venting, different locations…)

comment	*91* comment by: *Diamond Aircraft Industries GmbH* The definition of a modularized battery system needs to be improved. Is this a battery system solely constructed out of battery modules? Or is it a battery system constructed out of multiple batteries, where each battery is seen as a module? Elaborate definition of battery module. Illustrate the difference in definition to a multi battery module battery system and a multi-battery battery system.
response	Accepted. All definitions have been reviewed and modified for more clarity.

comment	*92* comment by: *Diamond Aircraft Industries GmbH* There is no mention of a module-to-module propagation failure mode or the need to demonstrate this via testing. Does this mean that this can be demonstrated alternatively? (design review, analysis, etc.) Please clarify
response	Partially Accepted. The definition of "Battery module" is updated to include: *"…that ensures…that no thermal runaway is propagated from one module to the others…"* It will be required to demonstrate this via testing, unless otherwise justified, i.e. modules are totally independent (not shared venting, different locations…)

comment	*93* comment by: *Diamond Aircraft Industries GmbH* It is not clear what the intent here is for this note. The statement made in this note as well as other parts of this MOC make some conclusion that a designer cannot properly design a propulsion battery system light enough. Such statements are not appropriate for an MOC, AMC or any other document issued in the regulatory system. The MOC should state clearly the issue, the requirements from the design standards and then the means of compliance with proper rationale.
Response	Not accepted. The note is offering additional flexibility from which designers could benefit when faced with other specific design constraints affecting the weight.

comment	*119* comment by: *Rolls-Royce plc* Page 11 Section/Paragraph 5(b)(2)(xv) **RATIONALE / REASON / JUSTIFICATION for the Comment** xv) During the test it should be demonstrated that the thermal runaway can be safely managed at propulsion battery system level or installation level (Battery Explosive Fire Zone) for a time that covers at least the detection of the fire at the most adverse operation condition and an ensuing continued safe flight and landing in accordance with EASA MOC VTOL.2330 Fire Protection in designated fire zones.

PROPOSED TEXT

Clear Pass/Fail Crireria are missing

response

Not accepted.

Pass/fail criteria are as per MOC VTOL.2330, as stated in 5(b)(2)(xv).

comment 128 comment by: *Electric Power Systems Inc*

What constitutes a properly modularized battery system design? Does this modularization have to comply with the definition above ("no fluids, flames, gasses, smoke, or fragments enter other modules during normal operation or failure conditions")? What criteria will be used to justify proper modularization. Modularization does not have adequate definition in terms of functional separation and physical separation. How does this relate and apply to the work with the 15 to 20% requirement in sections 4.1.3 and 5.b.2.iii?

This is a very subjective and has implications on all requirements expressed within the document. This represents a significant risk of misaligned application of this philosophy between specific certification projects.

Improper allocation of this note may also result in battery systems with undesirable safety performance which are "technically compliant" but which do not exhibit equivalent levels of safety compared to existing aircraft of similar assurance levels (rotorcraft / fixed wing).

response

Partially Accepted.

The Battery Module definition has been modified to include that propagation from module to module is prevented (same intent as physical separation):

"Battery Module" means a group of electrically interconnected cells in series and/or parallel arrangement contained in a single enclosure that ensures that no fluids, flames, gasses, smoke, or fragments enter other modules, and that no thermal runaway is propagated from one module to the others during normal operation or failure conditions.

The possibility to reduce to 15% of the cells instead of 20% in 5.(b)(2)(iii) is removed.

A Common Cause Analysis is requested in 3(a)(iv)(D). Separation at functional level is covered by requirement VTOL.2430(a)(1):

"be designed to provide independence between multiple energy storage and supply systems so that a failure, including fire, of any one component in one system will not result in the loss of energy storage or supply of another system."

Compliance to this requirement will be requested at system level, and it is out of the scope of this MOC (as other compliance demonstrations to other requirements).

"This Means of Compliance is neither addressing nor superseding other tests needed for the certification of propulsion battery systems (i.e. external short circuit, available system capacity and energy, protections testing, battery system crashworthiness tests…). "

comment *154* comment by: *The Boeing Company*

COMMENT #14 of 14			
Type of comment (check one)	***Non-Concur***	***Substantive*** ***x***	***Editorial***
Affected paragraph and page number	Page: 11 Paragraph: *'Note'*		
What is your concern and what do you want changed in this paragraph?	**The proposed text states:** Note: Since propulsion batteries have much higher capacity and size than conventional systems batteries, it may not be feasible to design a battery system that complies with the previous test approaches with a reasonable weight penalty. The applicant may propose a properly modularized battery system design with smaller modules, to comply at module level with any of the test approaches defined in this document. **REQUESTED CHANGE:** We recommend moving this note into Section 3 (a) 'General Considerations', and elaborating on its applicability and impact on the other tests in this proposal.		
Why is your suggested change justified?	**JUSTIFICATION:** This is an important "Note" that impacts the usability of the MOC and should be included at the beginning.		

response Not accepted.

The Note is affecting the test approaches (non-propagation and containment) defined in that section and the previous one. Section 3 include only the non-propagation test, to include it in that section could be misleading.

comment	*172* comment by: *Rolls-Royce plc* Page 11 Section/Paragraph 5(b)(2)(xv) **RATIONALE / REASON / JUSTIFICATION for the Comment** 13) During the test it should be demonstrated that the thermal runaway can be safely managed at propulsion battery system level OR installation level (Battery Explosive Fire Zone) for a time that covers at least the detection of the fire at the most adverse operation condition and an ensuing continued safe flight and landing in accordance with EASA MOC VTOL.2330 Fire Protection in designated fire zones. **PROPOSED TEXT** Proposal: replace OR with "AND" The current version of the document favours installation level containment. This might result in less safe designs. If installation level containment is considered, than propagation from module to module should be investigated, as well as, how is such large compartment capable of withstanding the Explosion Containment test, which is a necessary part of Battery Testing.
response	Accepted.

comment	*173* comment by: *Rolls-Royce plc* Page 11 Section/Paragraph NOTE **RATIONALE / REASON / JUSTIFICATION for the Comment** Since propulsion batteries have much higher capacity and size than conventional systems batteries, it may not be feasible to design a battery system that complies with the previous test approaches with a reasonable weight penalty. The applicant may propose a properly modularized battery system design with smaller modules, to comply at module level, with any of the test approaches defined in this document. **PROPOSED TEXT** Since thermal runaway propagation is not necessarily catastrophic, this requirement is not supported. This requirement will not result in comparable results. Some battery modules consist of 10 x 40 Ah cells, others of 100 x 4 Ah cells so propagation of 2 cells might be catastrophic in the first instance (already over 20%), but most likely won't have any safety effect in the latter.

This requirement handicaps modules built out of small format cells (which would naturally result in safer battery, as the energy is quantized into smaller sections)

Also, this requirement does not take into account Side Wall Rupture, if 2 side wall ruptures are initiated - which is the worst kind of failure, and the most conservative approach to our knowledge - it is highly unlikely anyone is able to stop propagation completely, rather control propagation which should eventually be stopped.

Explosion of pouch batteries would lead to the same outcome.
If this document only considers "conventional failure", it might be strict against TR propagation but it does not necessarily gives guidance on developing a robust and safe design.

response

Partially Accepted.

The MOC will be modified to only request the triggering of 1 cell. Since the worst-case conditions of aging, temperature, trigger method, SOC, positions of the heater, position of the cell, orientation… are requested to maximize the potential for propagation, the tests will provide already enough margin in comparison with other single cell trigger tests (i.e. RTCA DO-311A 2.4.5.4, NASA EP-19-001 Interpretation Memo for the Battery TR Propagation requirements in JSC-20793 Rev D.).

On top of Thermal Runaway propagation prevention (non-propagation test) a second protection layer (containment) is requested.

Moreover, demonstrating compliance with the set of tests of non-propagation and containment does not alleviate the other protection layers.

The purpose of note in 3(a)(1) and definitions section is to define what is considered a “battery thermal runaway”:

- Thermal runaway of two cells that thermally affect at least one common adjacent third cell within the same battery or, for modularized batteries, the same module.
- Thermal runaway of any three or more cells within the same battery or, for modularized batteries, the same module.

The whole EASA safety strategy is based in a multi-layer approach, where the reliability of the cells and the control and protective functions play a key role in EASA safety approach for the battery, and shouldn’t be relaxed due to:

- Propulsion batteries are not comparable to other aircraft equipment/Systems, due to their novel use, criticality, significant fire hazard and lack of service experience.
- Neither thermal runaway tests can be compared with other qualification tests, due to the variability in the outcome of the tests (due to cell variability, TR initiation criteria, temperature, SOC..) and its novelty and lack of testing experience.

Therefore, EASA is setting safety requirements ("battery thermal runaway" is catastrophic) that should be used by the applicants to specify the reliability requirement for the cell failure as well as the safety objectives of the control and protective functions. This activity is complementary to the tests.

The modularization of the battery is a way to make easier the management of thermal runaway situations, thus bringing more or at least the same safety in terms of containment. However, over-modularizing the battery in very small modules could lead to a huge number of external wires between the modules (i.e. for HV power provision, temperature and voltage sensing…) creating additional reliability risks. Therefore, it is expected to see solutions that propose reasonable modularization level.

comment *229* comment by: *Heart Aerospace AB*

(xv) Safe management of a thermal runaway event may require timely annunciation to the crew in the context of CSFL if any crew action is required. If so, timely annunciation of such critical events should be measured and included in (xiv).

response Not accepted.

The pass/fail criteria in this MOC for the test is as per EASA MOC VTOL.2330 (published in June 2022), that among other things requests the following:

(g) Detection systems

(1) Detection systems include but are not limited to: quick-acting fire, gases, overtemperature / undervoltage / overpressure sensors.

(2) For each EESS and lift/thrust unit, approved, quick-acting detectors should be provided in numbers and locations ensuring prompt detection of faults potentially leading to fire.

(3) Each detector should be constructed and installed to withstand any loads to which it would be subjected in operation.

(4) No detector should be affected by any oil, water, other fluids, or fumes, soot and corrosive gas that might be present.

(5) There should be means to allow crew members to check the functioning of each detector system electrical circuit.

(6) The wiring and other components of each detector system in an electrical energy storage system compartment should have appropriate characteristics for the associated fire zone.

(7) No detector system component for any fire zone (FWZ, DFZ or EFZ) should pass through any other fire zone, unless–

(i) It is protected against the possibility of false warnings resulting from fires in zones through which it passes; or *(ii) The zones involved are simultaneously protected by the same detector and extinguishing systems.*