	<p>Means of Compliance with the Special Condition VTOL</p>	<p>Doc. No: MOC SC-VTOL Issue: 2 Date: 12 May 2021</p>
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Means of Compliance with the Special Condition VTOL

Statement of Issue

EASA has received a number of requests for the type certification of vertical take-off and landing (VTOL) aircraft, which differ from conventional rotorcraft or fixed-wing aircraft. In the absence of suitable certification specifications for the type certification of this type of product, a complete set of dedicated technical specifications in the form of a Special Condition for VTOL aircraft was developed. The Special Condition addresses the unique characteristics of these products and prescribes airworthiness standards for the issuance of a type certificate, and changes to this type certificate, for a person-carrying VTOL aircraft in the small category, with lift/thrust units that are used to generate powered lift and control.

This Special Condition was subject to a public consultation process and finally issued by EASA in July 2019.

The Special Condition VTOL establishes the safety and design objectives. This approach, previously utilised for the development of CS-23 Amendment 5, is also used for VTOL designs in order not to limit technical innovation by describing prescriptive design solutions as certification standards. The Special Condition does not contain the means that are possible to demonstrate compliance with the safety and design objectives.

The Means Of Compliance (MOC) contained within this document address the applicant's requests for clarification of EASA's interpretation of these objectives and of possibilities how to demonstrate compliance with them. Some of these MOCs contain material which should be considered to be guidance material to assist the applicant with an understanding of the objective rather than providing a definitive means of compliance.

In the preparation of these MOCs EASA has followed the same principles, and pursued the same objectives, as with the Special Condition. First, to provide sufficient flexibility to address different architectures and design concepts, although it is acknowledged that all possible cases cannot be considered in these MOCs and alternatives can be proposed by applicants to address some particular design features. In addition, the proposed MOCs should enable an equal treatment of all applicants, by establishing a level playing field and ensuring that a comparable level of safety in the compliance with the objectives of the Special Condition is achieved by all designs.

EASA is committed to continue supporting the industry in the development of safe VTOL aircraft. To this end EASA has decided to prioritise the publication of MOC with the Special Condition VTOL and to issue them in a sequential manner. This approach will allow EASA to focus its resources where the greatest safety impact will be achieved and where the need for clarity is more urgently required. It will furthermore allow the industry to gain an early insight into EASA's interpretation and expectations from the design objectives of the Special Condition which could have an important effect in the design decisions, instead of waiting until exhaustive guidance for the Special Condition is developed.

Consequently, the first issue of the MOCs mostly concerns subjects that are considered to drive basic design choices and have a higher safety impact on the overall VTOL aircraft architecture. **The comment response document published alongside the issue 2 of this document collects all comments received during public consultation of issue 1 and the detailed responses provided by EASA. It should serve as an important source of information to clarify the correct interpretation of this document.**

Successive issues of this MOC document will include new MOCs as well as supplements to the existing ones. **They may recognise available industry standards.**

Finally, it is recognised that the experience gained during the certification of these new products and their entry into service will allow to increase the knowledge in their certification. It is possible that a better insight into the particular characteristics of these products is gained, which might result in modifications of particular elements of the first MOCs that are issued. EASA will do so considering first and foremost the safety of the European citizens but also mindful of the effects on all stakeholders.

Note: For ease of interpretation, grey shading has been used in this document to indicate where additions or substitutions have been made to the text of the proposed means of compliance (issue 1). Deleted text is only marked through the revision bars on the left-hand side of the document.

Log of issues

Issue	Issue date	Change description
1	25/05/2020	First Issue for Public Consultation
2	12/05/2021	Modified in consideration of the comments received in the public consultation that was open from May 25, 2020 to July 27, 2020. Refer to the published CRD for the details.

Means of Compliance with the Special Condition VTOL

Contents

Statement of Issue.....	1
Log of issues.....	2
MOC – SUBPART A – GENERAL	5
MOC VTOL.2000 Applicability and definitions.....	5
MOC VTOL.2005 Certification of small-category VTOL aircraft.....	8
MOC VTOL.2010 Accepted Means of compliance	8
MOC – SUBPART B – FLIGHT	10
MOC VTOL.2135 Minimum Acceptable Handling Qualities Rating.....	10
MOC – SUBPART C – STRUCTURES	18
MOC VTOL.2200 Structural design envelope.....	18
MOC VTOL.2215 Flight load conditions	19
MOC VTOL.2220 Ground and water load conditions	22
MOC VTOL.2230 Limit and ultimate loads.....	23
MOC VTOL.2235 Structural strength.....	23
MOC VTOL.2240(d) High Energy Fragments – Particular Risk Analysis	24
MOC VTOL.2250(c) No catastrophic effect from structural single failures in the Category Enhanced	26
MOC VTOL.2250(f) Aircraft capability after bird impact	27
MOC VTOL.2270(a) and (c) Emergency landing conditions: General considerations.....	29
MOC VTOL.2270(b)(1) Emergency landing dynamic conditions	29
MOC VTOL.2270(e) Cargo and baggage compartments	30
MOC – SUBPART D – DESIGN AND CONSTRUCTION.....	31
MOC 1 VTOL.2300 Fly-by-Wire control systems: Definition and Scope.....	31
MOC 2 VTOL.2300 Acceptability of ASTM standard F3232/F3232M-20 for Fly-by-Wire flight control systems	31
MOC 3 VTOL.2300 Validation of Electronic Flight Control Laws (FCL) in Fly-by-Wire flight control systems.....	33
MOC VTOL.2300(a)(1) Function and operation of Fly-by-Wire flight control system	35
MOC VTOL.2300(a)(2) Protection against likely Hazards for Fly-by-Wire flight control systems.....	37
MOC VTOL.2300(a)(3) Control margin awareness.....	42
MOC 4 VTOL.2300 Common Mode Failures and Errors in Fly-by Wire Flight Control Functions.....	42
MOC 5 VTOL.2300 Hidden Failures in Fly-by-Wire flight control systems.....	43

MOC VTOL.2320(a)(2) Occupant physical environment	44
MOC VTOL.2325(a)(4) Fire Protection - Energy storage crash resistance	45
MOC VTOL.2325(b)(1) and (b)(2) Fire Protection: fire extinguishers and design of interiors	49
MOC VTOL.2335 Lightning Protection	49
MOC – SUBPART E –LIFT/THRUST SYSTEM INSTALLATION	50
MOC VTOL.2400(b) Accepted Specifications for Electric/Hybrid Lift/Thrust Units	50
MOC VTOL.2430(a)(2) Protection of the fuel system against lightning	50
MOC VTOL.2430(a)(6) Energy retention capability in an emergency landing	50
MOC – SUBPART F –SYSTEMS AND EQUIPMENT	51
MOC 1 VTOL.2500(b) Intended function of systems and equipment	51
MOC 2 VTOL.2500(b) Electromagnetic compatibility	51
MOC 3 VTOL.2500(b) Airworthiness Security in the Category Enhanced	52
MOC VTOL.2510 Equipment, systems, and installations	53
MOC VTOL.2515 Electrical and electronic system lightning protection	65
MOC VTOL.2520 High-intensity radiated fields (HIRF) protection	75
MOC VTOL.2555 Installation of recorders	85

MOC – SUBPART A – GENERAL**MOC VTOL.2000 Applicability and definitions****1. General considerations**

When this document quotes CS-27, CS-29, CS-23 or CS-25 paragraphs, unless otherwise indicated, the terms referring to aeroplanes, rotorcraft and their architecture **should** be replaced by those corresponding to VTOL aircraft and their architecture.

Unless otherwise specified, the following replacements should be assumed:

- (a) "Rotorcraft" or "aeroplane" **should** be replaced by "VTOL aircraft"
- (b) "Engine", "Turbine", "Powerplant" and "Rotor" **should** be replaced by "Lift/thrust system"
- (c) "Autorotation" **should** be replaced by "Controlled Emergency Landing"
- (d) "Fuel" **should** be replaced by "Energy"
- (e) "Fuel tank" **should** be replaced by "Energy storage device"

VTOL aircraft present an intrinsic capability to take-off and land vertically. Some VTOL aircraft may additionally be able to take-off or land as conventional aeroplanes, accelerating and/or decelerating on a runway. This mode of operation as conventional aeroplanes, also named CTOL or "conventional take-off and landing", is also specifically addressed, when relevant, in the Means of Compliance described in this document.

2. Continued Safe Flight and Landing

For Category Enhanced aircraft, as detailed in MOC VTOL.2510, the aircraft must be able to perform a continued safe flight and landing after any single failure or combination of failures that are not classified as catastrophic.

All failures **directly or indirectly** affecting continued safe flight and landing should be considered and evaluated. The lift/thrust system loss is not the only type of failure of this system that could affect safe flight and landing; other types of failures may also be critical, for example a frozen RPM command to a lift/thrust unit or a flight control system actuator **failure**.

The continued safe flight and landing includes **any** transition phase **between** horizontal **and** vertical flight, if **included in the applicable procedure**, and the ground phase up to the complete stop of the aircraft and evacuation of the occupants.

It is acceptable to use emergency procedures during the continued safe flight and landing following a failure, for example emergency ratings of the lift/thrust units.

In order to assess the VTOL's ability to perform a continued safe flight and landing, any changes in aircraft performance that affect the capability of the aircraft (e.g. range, expected height loss, remaining rate of climb) to continue the flight and perform a landing after a single failure or combination of failures not **extremely improbable should be considered (see section 10 in this MOC, Certified Minimum Performance (CMP)). The characteristics of **diversion** vertiports that could be used after such failures can differ from the vertiport of intended landing. In this case, the necessary information on the required **diversion** vertiports should be established and decided prior to the flight to be able to plan the flight accordingly (e.g. distance required for a running landing, load carrying capability, dimensions). Additionally:**

- (a) The remaining energy reserve following a failure condition should be no less than the sufficient reserve accepted for compliance with VTOL.2430(b)(4).

- (b) The performance and obstacle margins should be no less than the minimum accepted for compliance with VTOL.2115, VTOL.2120 and VTOL.2130.
- (c) The continued safe flight and landing should not require exceptional piloting skills, alertness, or strength. The Handling Qualities can be evaluated considering the Modified Handling Qualities Rating Method in MOC VTOL.2135.
- (d) The procedures for continued safe flight and landing should be designed so as to not injure occupants or people on the ground and should not introduce additional damages to the aircraft due to the landing.

Explanatory Note: The Means of Compliance above mirror CS-27 Category A rotorcraft. It is expected that flight tests will be performed to determine the best repeatable technique(s) for a particular aircraft over the range of mass, centre of gravity, altitude, temperature and other operational limits for which certification is requested. Any landing which results in permanent deformation of the aircraft structure or landing gear beyond allowable maintenance limits is considered an unsatisfactory test point.

3. Controlled Emergency Landing

For Category Basic aircraft, as detailed in MOC VTOL.2510, the aircraft must be able to perform a controlled emergency landing after any single failure or combination of failures not classified as catastrophic. For Category Enhanced, controlled emergency landing procedures could also be published for catastrophic failure conditions.

A controlled emergency landing should be performed under control; in particular it should be possible to steer the aircraft towards a touchdown area with the remaining lift/thrust units. Therefore this objective cannot be met by the use of non-steerable parachutes.

While the objective is similar to a controlled glide or autorotation, some damage to the aircraft to absorb the impact forces can be accepted. Active systems could also be acceptable if they meet the safety requirements of VTOL.2510.

The procedures for a controlled emergency landing should be designed so as to not injure occupants if landing is achieved on a flat solid surface.

The controlled emergency landing includes the transition phase from horizontal to vertical flight, if applicable, and the ground phase up to the complete stop of the aircraft and evacuation of the occupants.

The operational context in which the aircraft is certified should be taken into account when defining the controlled emergency landing: The capability to steer the aircraft should be evaluated based on the gliding distance and the external visual cues necessary in case of a possible loss of instruments or information in the cockpit. In particular, if the aircraft is certified for IFR, the applicant should either demonstrate that the controlled emergency landing can be carried out in IMC, or specify the minimum height required to complete the manoeuvre once the visual references have been regained.

4. Emergency Landing and Survivable Emergency Landing

As opposed to “Continued Safe Flight and Landing” and “Controlled Emergency Landing”, “Emergency Landing” and “Survivable Emergency Landing” do not correspond to design objectives but rather to design cases. They address the ultimate consequences at aircraft level of an uncontrolled landing which would be survivable by the occupants if appropriate design features are incorporated.

These design cases are consequently bound by the physical conditions within which a normal occupant would be reasonably expected to survive after contact of the aircraft with the ground (e.g. impact velocity, time exposure to a given acceleration level, etc.).

Depending on the severity of this ground contact and its consequences, the following definitions are established:

- **Emergency Landing:** Impact (crash) where the occupants are given every reasonable chance of escaping serious injury. The occupants should be able to evacuate the vehicle without assistance. The impact conditions are detailed in VTOL.2270 and associated MOC.
- **Survivable Emergency Landing:** Impact (crash) which is potentially survivable, even with serious injuries to the occupants. The occupants should be protected from post-impact hazards as described in VTOL.2325(a)(4), VTOL.2430(a)(6) and associated MOC.

Accordingly, these design cases should be considered irrespective of their probability of occurrence at least in the definition of: features for the structural protection of occupants (VTOL.2270), means of egress and emergency exits (VTOL.2315), features to minimise the initiation a fire (VTOL.2325) and features to ensure energy retention and minimisation of hazards by the lift/thrust system (VTOL.2430).

Due to their low probability of occurrence, emergency procedures for these design cases are not mandatory and would not need to be demonstrated for compliance with VTOL.2620. Nevertheless, EASA recommends the definition of such procedures when this would contribute to the survivability of occupants (VTOL.2620).

5. Person-carrying

An aircraft is considered person-carrying if it carries crew, passengers or both.

6. Lift/thrust unit

A lift/thrust unit is considered to be any engine that directly contributes to providing lift or thrust and includes its controller, the connected effector (e.g. rotor, propeller, fan) and any related actuators (e.g. pitch change, tilting, vectoring).

7. Lift/thrust system

The lift/thrust system is composed of the lift/thrust units and their related energy storage, distribution and management systems as well as any other related ancillary systems (e.g. lubrication, cooling or transmission).

8. Flight control system

The flight control system is composed of the pilot controls, computers, wiring, actuators, sensors, and all those elements necessary to control the attitude, speed and flight path (trajectory) of the aircraft. The lift/thrust units can be functionally considered to be actuators of the flight control system and therefore part of the flight control function.

In reference to the lift/thrust unit definition provided in Section 6 of this MOC, any engine directly contributing to providing lift or thrust, its controller, and fans shall comply with applicable engine certification provisions (e.g. SC-EHPS) while the other elements (rotors, propellers, and related actuators) shall comply with SC VTOL.

9. Exceptional piloting skills

The term “exceptional piloting skills” is usually recalled when addressing the Handling Qualities requirements. The Handling Qualities should be such that the aircraft can be operated “without exceptional piloting skills”, which means that the flight crew is expected to have an “average” competency and currency to carry out the task. To ensure that the competency and currency that will be subjectively evaluated by the applicant correspond to the expected “average”, the evaluation should be carried out by more than one flight crew with final verification of the compliance finding by EASA. The Operational Suitability Data (OSD) certification will

establish the minimum syllabus of pilot type rating training to ensure that pilots are properly trained to the required level of proficiency.

10. Certified Minimum Performance (CMP)

The Certified Minimum Performance (CMP) is the set of performance data obtained by considering the effect of single failures and combinations of failures that are not extremely improbable on the nominal performance parameters. The CMP should also take into account the effects of the fires that are considered in VTOL.2330.

Depending on the aircraft architecture, the CMP for different performance parameters may be the result of different failures. For example, for a given aircraft, the range may be the most degraded as a result of a battery failure while the best rate of climb may be the most degraded by an electric engine failure. The failure of the battery and of the electric engine would then become, for the respective flight phase and performance parameter, the critical failure for performance (CFP, see section 11 in this MOC).

The CMP is part of the type data and is associated with limitations on the continued safe flight and landing for Category Enhanced and on the controlled emergency landing for Category Basic, to be established in accordance with VTOL.2510 and VTOL.2620.

11. Critical Failure for Performance (CFP)

A critical failure for performance (CFP) is a failure or combination of failures that results in the maximum degradation for a given flight phase and performance parameter. The set of critical failures for performance is used to establish the Certified Minimum Performance and as part of the safety assessment process of VTOL.2510.

MOC VTOL.2005 Certification of small-category VTOL aircraft

Aircraft can be certified in both categories Basic and Enhanced by using different Aircraft Flight Manual (AFM) supplements and different configurations.

It is also possible to certify an aircraft initially in the Category Basic and later on in the Category Enhanced, subject to the respective compliance demonstration.

The definitions of Continued Safe Flight and Landing and of Controlled Emergency Landing are provided in sections 2 and 3 of MOC VTOL.2000.

MOC VTOL.2010 Accepted Means of compliance

The Means of Compliance (MOC) in this document are a way to facilitate the completion of the necessary certification activities to be conducted by the applicant and verified by EASA during the compliance demonstration.

Each MOC in this document, when followed in its entirety, is considered an acceptable means for the applicant to demonstrate compliance with the related objectives of the Special Condition for the currently foreseen VTOL architectures and technologies.

The MOC in this document may not yet include appropriate means to demonstrate compliance for the certification of all possible designs and/or technologies, including the new and novel application of existing technologies.

Consequently, for these cases, the MOC in this document cannot be considered by default as being acceptable or appropriate for the certification of a particular design. The use of other means to demonstrate compliance with the special condition may be required to be proposed by the applicant and subsequently accepted by EASA.

The MOCs in this document may be updated with any necessary complement or modification, while additional MOCs with different objectives in the Special Condition may also be incorporated in this document as required. In the course of these revisions, EASA may recognise available industry standards as accepted Means of Compliance with the Special Condition VTOL.

EASA may also accept other means to demonstrate compliance with the objectives contained in the special condition during the certification of a particular design. In doing so, EASA will thoroughly evaluate all proposals of MOC and analyse their merits and associated justification. Subsequently EASA will establish whether the proposed MOC will ensure that the relevant safety objective in the special condition can be demonstrated as being fully met by it. The ultimate goal being to provide flexibility in the design of the VTOL whilst ensuring that the objectives of the special condition are satisfied and demonstrated by the applicant.

MOC – SUBPART B – FLIGHT**MOC VTOL.2135 Minimum Acceptable Handling Qualities Rating****1. Background and Introduction**

The aircraft needs to be controllable and manoeuvrable to cope with adverse weather conditions and to avoid late detected obstacles or traffic appropriate to the type. The control and manoeuvring of the aircraft requires a certain amount of physical and/or mental workload from the crew. Satisfactory Handling Qualities (HQ) give the opportunity for the crew to better manage high workload situations, and allow them to operate safely for longer periods, and to be able to deal with aircraft system failures and contingencies. Degraded HQ lead to an increased crew attentional demand for aircraft control, hence reduced high workload capacity for other tasks and for Situational Awareness.

The following is a method of determining and evaluating, for compliance demonstration, the HQ for VTOLs in the Category Enhanced in normal and abnormal/emergency conditions. The Category Basic VTOLs may also elect to use this method; however, the Minimum Acceptable Handling Qualities Rating section 4 will need to be adapted. The focus is on the crew task of flight path/trajectory control. All the other characteristics of the flight controls such as number of inceptors, size and mechanical forces (friction, breakout etc.) are out of scope of this MOC. These other characteristics however will influence the achievable HQ, so they will be indirectly assessed.

This method is different from CS-23 and CS-27, since in those certification specifications, the HQ of an aircraft are suitably assessed on the addition of the compliance to static or dynamic stability requirements along with other requirements for controllability and average piloting skills. HQ are evaluated without any specific generally recognised method, and are mainly evaluated to measure the workload to determine the minimum crew in respect to the kind of operations. Usually the Cooper Harper Handling Qualities Rating Scale (CHR) is used to measure the Handling Qualities, while the Bedford rating scale (or NASA Task Load Index as alternative) is used to measure the workload. However, each applicant can choose the methodology to determine the HQ and/or workload.

This Modified Handling Qualities Rating Method (MHQRM) is an accepted means of compliance with VTOL.2135, and can also be used to assess compliance, fully or in part, with the following SC VTOL requirements that require a determination of HQ: VTOL.2110 Flight Envelopes, VTOL.2115 Take-off performance, VTOL.2130 Landing, VTOL.2135 Controllability, VTOL.2140 Control forces, VTOL.2145 Flying qualities, VTOL.2150 Stall characteristics and stall warning, VTOL.2160 Vibration, VTOL.2300 Flight control systems and VTOL.2305 Landing gear systems.

This method should not be considered to be the only method. Applicants may propose alternative methods or deviations based on the characteristics of their design, or on their compliance determination strategy. Unless otherwise specified in a special condition, the HQRM does not replace or override any of the systems and equipment requirements of §§ VTOL.2500, VTOL.2505 and VTOL.2510.

2. List of Acronyms

AD	Atmospheric Disturbance
ADQ	Adequate
AFM	Aircraft Flight Manual
CHR	Cooper Harper Rating Scale

CON	Controllable
CONOPS	Concept of Operations
EFCS	Electronic Flight Control System
FC	Failure Conditions
FE	Flight Envelope
FEP	Flight Envelope Protection
FHA	Functional Hazard Assessment
FltC	Flight Condition
GNSS	Global Navigation Satellite System
HQ	Handling Qualities
HQR	Handling Qualities Rating
HQRM	Handling Qualities Rating Method
IMC	Instrument Meteorological Conditions
LFE	Limit Flight Envelope
MHQRM	Modified Handling Qualities Rating Method
MTE	Mission Task Elements
NFE	Normal Flight Envelope
NVIS	Night Vision Imaging System
OFE	Operational Flight Envelope
SAT	Satisfactory
SC	Special Condition
TBD	To be determined
VFR	Visual Flight Rules
VisC	Visual cues
VTOL	Vertical Take Off and Landing

3. MHQRM Process

The overall process is derived from the FAA Advisory Circular 25-7D Appendix E, which was intended mainly to define a method for evaluating Failure Conditions (FCs). In particular, the principle of determining the minimum HQR based on the probability of being in a given Flight Condition (FltC) was adopted. The “tool” to evaluate and show compliance with the minimum acceptable HQR will be derived from ADS-33E. The Mission Task Elements (MTE) manoeuvres of this military standard will be adapted to the SC VTOL based on the Concept of Operations (CONOPS) for VTOL that is being produced by industry. There will be also provisions on the competences of the

test pilots (fixed wing or rotary wing background) and on the minimum number of evaluators. This tool is being developed together with industry and research centres, and will be published at a second stage.

This MHQRM starts by determining the minimum acceptable HQR for each phase of the flight and for a given FltC, defined as a combination of the Flight Envelope (FE) and the level of Atmospheric Disturbance (AD), relative to the Nominal State of the aircraft systems, or the probability of the FC being evaluated. A pre-requisite to start the MHQRM process is thus to have Functional Hazard Assessment (FHA) available and have preliminary quantitative assessments for the FCs to be analysed in the MHQRM. If this MHQRM process is intended for validating FC classification in the Aircraft FHA, early coordination with EASA is advised.

The methodology developed in this MOC is aimed at identifying which FCs need to be considered in the handling quality assessment. One possible outcome of the HQ assessment is that the failure condition classification of a given FC needs to be increased.

To limit the risk of iterations of the FHA content and the subsequent side effects on the MHQRM, early coordination with EASA on the safety assessment outputs (FHAs, preliminary quantitative analysis) is also advised.

The visual environment, or the quality of the Visual Cues (VisC), is not defined, and the assumption is that the VisC, in terms of external visual environment and displays/sensors feedback, are sufficient to allow the crew to perform their tasks and be able to achieve and assess Desired and Adequate HQ performance criteria. The most conservative external visual environment (Day, Night, IMC, NVIS) should be used for each phase of flight for which certification is requested. For example, if the aircraft is intended to be certified for flight in Night VFR, the climb, cruise, descent and approach phases of flight should be evaluated by using an appropriate external visual environment, while the take-off and landing phase may use a better external visual environment. The VisC will be defined in the evaluation document and should be agreed with EASA on a case by case basis.

To apply this method it is first necessary to divide the profile of the aircraft into different phases of flight, e.g. taxi (if applicable), take-off (including rejected take-off), climb, cruise, descent, approach and landing (including landing following a failure condition and bailed landing). The classification for each phase of flight is done because there could be failure conditions at aircraft level that affect HQs only in one particular phase of flight, as for example the loss of Global Navigation Satellite System (GNSS) could result in a reduced accuracy in the Translational Rate Command FCS mode in low airspeed, or a failure condition (i.e. multiple electric engine failures) could result in less precise turn coordination in cruise.

For each phase of flight, the different FltCs that have a probability of being encountered of greater than 10^{-9} per hour are then identified. Special care should be given also to the transition between different phases of flight and aircraft configuration changes (if any). The FltCs probability is given by combining (multiplying) the probability of the aircraft being in a specific FE, the probability of the aircraft having a FC that affects HQ (not only flight control system failures, but any other, including lift/thrust system failures) and the probability of an AD being experienced.

When there is an interrelationship between the different probabilities, the FE probability will be adjusted to take this into account. For each FltC, the minimum HQR level is assigned based on the requirements derived from SC VTOL. The applicant should then show compliance by using an approved rating tool in actual flight test, or in a simulator that has been validated and shown to be representative for the test.

4. Minimum ACCEPTABLE HQR

Table 1 describes the different Handling Qualities Rating (HQR) levels and compares them to the System Failure Classification that is contained in MOC VTOL.2510, and to the Cooper Harper Rating Scale.

Exceptional piloting skills should not be required for the achievement of any HQ performance criteria. The evaluation should assess whether Desired or Adequate criteria are met, and the associated workload in terms of physical and/or mental compensation required by the crew.

Table 1: Handling Qualities Ratings definition (Example for Cruise)

Handling Qualities Rating (HQR)	Description	MOC VTOL.2510 Failure Conditions Classifications	Cooper Harper Rating Scale (CHR)
Satisfactory (SAT)	Handling Qualities allow achievement of desired performance criteria without exceptional piloting skills and with no or minimal pilot compensation.	Up to Minor	1-3
Adequate (ADQ)	Handling Qualities allow achievement of desired performance criteria or adequate performance criteria without exceptional piloting skills and with moderate to extensive pilot compensation.	Major	4-6
Controllable (CON)	Handling Qualities DO NOT allow achievement of adequate performance criteria WITHOUT exceptional piloting skills. Allows however continued safe flight and landing, without exceptional piloting skills , after a transient condition or reconfiguration to retain control, if necessary.	Hazardous	7-9

Table 2 is an example for the Cruise phase of flight, and shows the minimum HQR for each FltC, defined as a combination of the FE and the level of AD, relative to the probability of the FC being evaluated. Similar tables could be created for the other phases of flight, as the type of FC, most critical from a HQs point of view, could vary depending on the phase of flight. The minimum HQR for each table will not vary across the different tables, but, since the FC, FE and AD levels may vary depending on the phase of flight, including the probabilities of occurrence, it might be beneficial to have different tables or groups of tables depending on the phase of flight.

The different FE are (Table 3): Normal Flight Envelope (NFE), Operational Flight Envelope (OFE) and Limit Flight Envelope (LFE).

The AD level (Table 4) can be Light, Moderate or Severe.

The FC probabilities (Table 5) are in accordance with the aircraft level MOC VTOL.2510 quantitative probability values. Probability values for Probable up to Remote Failure Conditions have been grouped together for table readability reasons, as the minimum HQR would be the same.

It is important to highlight that NOT every combination of AD, FC and FE should be tested.

Table 2 Minimum Acceptable Handling Qualities Rating

Phase of flight: CRUISE (Example)									
FltC $X_{FE} * X_{FC} * X_{AD}$	Atmospheric Disturbance (AD)								
	Light			Moderate			Severe		
	Flight Envelope (FE)								
Failure Condition (FC)	NFE	OFE	LFE	NFE	OFE	LFE	NFE	OFE	LFE
Nominal Condition	SAT	SAT	CON	SAT	SAT	CON <small>NOTE 1</small>	SAT	ADQ <small>NOTE 1</small>	CON <small>NOTE 1</small>
Probable up to Remote Failure Conditions:	SAT	ADQ	CON	SAT	ADQ <small>NOTE 1</small>	CON <small>NOTE 1</small>	ADQ	CON <small>NOTE 1</small>	CON <small>NOTE 1</small>
Extremely Remote Failure Conditions:	ADQ	ADQ	CON	ADQ	CON <small>NOTE 1</small>	NOTE 2	CON	NOTE 2	NOTE 2

NOTE 1: This is considered to be a transient condition, and it is expected that better HQR will be achieved when the AD level is decreased. Likewise it should be demonstrated that better HQRs are achieved in the more favourable Flight Envelopes: such transition should be relatively quick and without requiring exceptional piloting skills.

NOTE 2: This FC is shaded in red as it could possibly have a related probability lower than Extremely Improbable, and should not be considered. If the FC probability is greater than Extremely Improbable, then the minimum HQR should be CON.

The probabilities in Tables 3, 4 and 5 apply when they are considered separately. When obvious interrelationships exist due to the design or the intended or expected operation of the aircraft, the way to address this within MHQRM is to modify the FE probability value. For example, for FltCs with Moderate and Severe AD levels in CRUISE and APPROACH, an atmospheric (windshear) event may require an escape operational procedure that results into entry in the LFE, resulting in a LFE probability of 10^0 (i.e. 1 or certain). Similarly, an aircraft flying at the boundaries of the NFE, may experience overspeed due to a gust and fall into the OFE, hence the modified FE would be 10^0 (i.e. 1 or certain). This probability adjustment concept would also apply to FCs where, for example, a loss of warnings or a loss of envelope protection might contribute to excursions outside the NFE or OFE, in which case the flight envelope probability should be increased appropriately. In this latter case, the change of probability will be evaluated case by case and should be agreed with EASA.

5. Probability definitions and determination

(a) Flight Envelope (FE)

The flight envelope probabilities will depend on the aircraft architecture. The automatic envelope protection provisions (if available) and the cues to the crew will be the determining factors.

The flight crew should operate the aircraft by definition in the NFE. Excursions into the OFE and LFE are determined by AD, by transient conditions due to failures (that can have different probabilities based on the design), or by expected human errors.

These probabilities should be adjusted to account for the interrelationship between AD and FC events (section 4).

Applicants should provide probabilities based on the evidence that they have available to substantiate them, and based on their aircraft characteristics.

Visual and aural warnings, or specific aircraft characteristics at the boundaries of the envelopes (vibrations, noise) could grant credits for increasing the probability of remaining within a given FE.

The probability values proposed by the applicant should be substantiated with actual flight test data.

Table 3: Probability of Occurrence of the Flight Envelope (FE)

Flight Envelope	Notes	Probability X_{FE}
Normal Flight Envelope (NFE)	Generally associated with routine operational and/or prescribed conditions. At the boundaries of this envelope there could be means to raise the awareness of the crew (cautions).	10^0
Operational Flight Envelope (OFE)	The crew should be aware that the operation occurs outside the NFE. At the boundaries of the OFE, warnings and/or EFCS envelope protection means could be present. The Aircraft Flight Manual (AFM) limitations should be consistent with the boundaries of the OFE. When considering airspeed to define the envelope, the high speed boundaries of the OFE would be the current V_{ne} .	TBD
Limit Flight Envelope (LFE)	The crew should never operate in this envelope; a return should be made at least to the OFE. This is the maximum extent in terms of envelope that needs to be investigated from a HQ point of view but should not be included in the AFM. The boundaries of the LFE are associated with aircraft limits.	TBD

(b) Atmospheric Disturbance (AD)

The atmospheric disturbance level ranges from the complete absence of any disturbance up to the atmospheric disturbance level (gusts) that are considered for the structural limits of the aircraft. The AD considered could be different depending on which phase of flight is being evaluated.

Additional steady state relative winds values, for the most critical azimuth, are established to show compliance with the applicable requirements when the aircraft is operating based on ground references (e.g. Take-off, Hover, Landing).

The amplitude of the gusts to be considered for the structural design will be defined in MOC VTOL.2215 "Flight Load Conditions". Non-symmetric gust cases should be considered when evaluating HQ. The shapes of the gusts may also be a critical factor for HQ and should be evaluated.

The steady state relative wind values are derived from the experience from CS-27, and have been identified as being 17 kt. This value is the minimum to be used for airworthiness approval; applicants may choose higher steady wind values based on market requirements.

The steady wind value should be evaluated only in the phases of flight that are close to the ground. The controllability in steady winds should be demonstrated for all FC in Light AD level (without gusts and turbulence).

The exact values of the gusts are currently not defined for each AD level. Even the related probabilities (X_{AD}), which are modified in respect to Appendix E to AC25-7D to account for the Urban Environment, will need to be verified by recorded data which are currently not available.

Table 4: Probability of Occurrence Guidelines of Atmospheric Disturbance (AD)

Atmospheric Disturbance	Notes	Probability X_{AD}
Light:	No appreciable turbulence and steady state winds less than 3 kt with no appreciable gusts.	10^0
Moderate:	Light to moderate turbulence. Changes in altitude and/or attitude occur. Usually causes variations in indicated airspeed.	TBD
Severe:	Turbulence that causes large, abrupt deviations in altitude and/or attitude. Usually causes large variations in indicated airspeeds.	TBD

(c) Aircraft or System Failure Condition affecting HQ (FC)

The Failure Condition probabilities (X_{FC}) relate to the probability of encountering a Failure Condition which affects HQs. This may include, but is not limited to, the FCS or lift/thrust system. The MHQRM should be linked to the Safety Assessment Process at aircraft level. Feedback should be provided into the different Safety Assessment Elements, such as the Functional Hazard Assessment (FHA), Preliminary System Safety Assessment (PSSA), Fault Tree Analysis (FTA), System Safety Assessment (SSA) or Failure Mode and Effect Analysis (FMEA), and vice versa to check if the assumptions of these Safety Assessment Elements in terms of effect (when the driving factor are HQ) are confirmed by the MHQRM evaluation.

Table 5: Probability of Occurrence Guidelines of Failure Condition affecting HQ (FC)

Failure Condition	Notes	Probability X_{FC}
Nominal Operation:	No failures	10^0
Up to Major Failure conditions:	Failures with an effect on HQR not more severe than MAJOR.	NOTE 3
Hazardous Failure conditions:	Failures with a HAZARDOUS effect on HQR.	$\leq 10^{-7}$ NOTE 3

NOTE 3: The applicant may use any value derived from the safety assessment process, provided it meets the safety objectives. Allowable quantitative probabilities for "probable", "remote" and "extremely remote" are defined in MOC VTOL.2510 §8

MOC – SUBPART C – STRUCTURES**MOC VTOL.2200 Structural design envelope**

The following design values and limitations should be established to show compliance with the structural requirements of this Subpart, for each aircraft configuration or flight mode, as appropriate:

(Note: Failure conditions need not be taken into account when defining these design values and limitations.)

- (a) The design maximum and design minimum weights.
- (b) The lift/thrust units design rpm ranges with power on and power off, if applicable. These design values should provide adequate margin to accommodate the variations in rpm speed occurring in any manoeuvre.
- (c) Design Airspeeds:
 - (1) *Maximum level flight speed, V_H* . The maximum level flight speed at maximum continuous power;
 - (2) *Maximum Design speed, V_D* .
 - (3) *Never-Exceed speed, V_{NE}* . V_{NE} should not be greater than 0.9 times V_D .
 - (4) *Velocity of Normal Operations, V_{NO}* is the maximum structural cruising speed. V_{NO} should be defined by the applicant and should be less than or equal to V_H and V_{NE}
 - (5) *Maximum design rearward and sideward flight speeds*. The maximum design rearward and sideward speeds should be defined to be no less than 1.11 times the maximum permitted rearward and sideward speeds.
 - (6) *Design speed for maximum gust intensity, V_B (for Category Enhanced)*. For V_B , the following applies:
 - (A) V_B should not be less than the speed determined by the intersection of the line representing the maximum positive lift $C_{N\ MAX}$ and the line representing the rough air gust velocity on the gust V-n diagram, or $V_{S1}V_{n_g}$, whichever is less, where –
 - (a) n_g the positive aircraft gust load factor due to gust, at speed V_{NO} , and at the particular weight under consideration; and
 - (b) V_{S1} is the stalling speed with the flaps retracted at the particular weight under consideration.
 - (B) V_B need not be greater than V_{NO} .
 - (C) If loss of control due to stall is not possible, or definition of V_B in accordance with (A) is not applicable, V_B should be defined according to the VTOL operating limit for flight in turbulent conditions.
- (d) The centre of gravity limits corresponding to the configuration of the aircraft.
- (e) The rotational speed ratios between each lift/thrust unit and each connected rotating component, as applicable.
- (f) The positive and negative limit manoeuvring load factors should be defined based on the maximum capability of the aircraft, taking into account the flight control system (without failure cases), for which:
 - (1) The probability of being exceeded is shown by analysis to be extremely improbable within the design altitude and temperature range;

- (2) The selected values are appropriate to each weight condition between design maximum and minimum weights and associated critical centres of gravity; and
- (3) The positive load factor is not less than 2.0 and the negative limit manoeuvring load factor is not less than -0.5.

Note: An absolute maximum positive and negative limit manoeuvring load factor may be proposed for acceptance by EASA, as appropriate for the aircraft operation and consistent with current Certification Specifications (e.g. CS 23.337 and CS 27.337).

- (g) Ranges of altitudes and temperature for which certification is requested.
- (h) Ranges of position of adjustable elements of lift/thrust units and control devices, if applicable.

MOC VTOL.2215 Flight load conditions

The following flight load conditions specify a set of flight conditions to be evaluated to conservatively cover the most extreme manoeuvring capability of the aircraft. They should be analysed with the aircraft in the most critical flight phases and flight configurations, in accordance with the design limitations as defined in MOC VTOL.2200. The flight load cases may be simulated or defined by combining conservative combinations of parameters, or a combination of these approaches. Full control input ranges should be considered when determining the flight load cases. The limitations imposed by the flight control system, without failure cases, may be taken into account.

Failure conditions need not be considered, except as specified in paragraph (g) of this MOC.

If automation systems, such as autopilot upper modes, or a Detect and Avoid system can generate higher control loads than pilot inputs, the corresponding loads should be taken into account.

Suddenly. For the purposes of this MOC, 'suddenly' is defined as the time interval for complete control input based on a rational analysis, supported by test. For conventional pilot controls, such as stick and pedal, 'suddenly' may be assumed as 0.2 seconds for complete control inputs.

- (a) Symmetrical Flight Load Conditions: To produce these flight load conditions, the airspeeds should be set at V_D in forward, rearward and sideward flight. The normal load factor should be unity.
- (b) Symmetrical pull-up and recovery: To produce these flight load conditions, with the aircraft in an initial trim condition at forward speeds:
 - (1) Displace the input control suddenly in order to achieve a nose up motion, to the maximum deflection as limited by the control stops;
 - (2) Maintain the maximum input control displacement to allow the aircraft to pitch upwards and achieve the specified positive manoeuvring load factor; and
 - (3) Return the input control suddenly to that required for level flight.

The most critical initial trim forward speeds should be evaluated, up to and including V_D . This flight load condition should be evaluated in both power on and power off rpm ranges, if applicable.

The intention of the symmetric pull-up and recovery manoeuvre is to achieve maximum pitch acceleration, maximum positive normal load factor and maximum aircraft nose-up angle-of attack.

- (c) Symmetrical Pushover and Recovery:

To produce these flight load conditions, with the aircraft in an initial trim condition at forward speed :

- (1) Displace the input control suddenly, in order to achieve a nose down motion, to the maximum deflection as limited by the control stops;
- (2) Maintain the maximum input control displacement to allow the aircraft to pitch downwards and achieve the specified negative manoeuvring load factor; and
- (3) Return the input control suddenly to that required for level flight.

The most critical initial trim forward speeds should be evaluated, up to and including V_D .

The intention of the symmetric pushover and recovery manoeuvre is to achieve maximum pitch acceleration, maximum negative normal load factor and maximum aircraft nose-down angle-of-attack.

(d) Rolling Flight Conditions (Rolling pull-up and recovery):

To produce these flight load conditions, with the aircraft in an initial trim condition at forward speed:

- (1) Displace the input control suddenly, in order to achieve a nose up and rolling moment, to the maximum deflection as limited by the control stops, or that necessary to achieve a positive load factor of not less than two-thirds that specified in paragraph (b);
- (2) Maintain the control displacements to allow the aircraft to pitch, roll and achieve a positive manoeuvring load factor of at least two-thirds that specified in (b); and
- (3) Return the controls suddenly to those required for level flight.

The maximum rate of roll and the load factor should occur simultaneously. The most critical initial trim forward speeds should be evaluated, up to and including V_D .

The intention of the rolling pull-up and recovery manoeuvre is to achieve maximum pitch acceleration, maximum roll acceleration with two-thirds of the maximum positive normal load factor.

(e) Yawing Conditions:

To produce these flight load conditions, with the aircraft in an initial trim condition, with zero yaw, at forward speeds and in the hover:

- (1) Displace the input control suddenly, in order to achieve a yawing motion, to the maximum deflection as limited by the control stops;
- (2) Maintain the input control displacement to allow the aircraft to yaw to the maximum transient sideslip angle;
- (3) Allow the aircraft to attain the resulting sideslip angle; and
- (4) Return the directional control suddenly to neutral.

Both right and left yaw conditions should be evaluated. The most critical initial trim forward speeds should be evaluated, from zero up to and including V_{NE} or V_H , whichever is less.

Yawing conditions in the hover (spot turns) should be evaluated in both in ground effect (IGE) and out of ground effect (OGE).

The intention of the yawing condition is to achieve maximum yaw acceleration and maximum aircraft sideslip angles.

(f) Gust Conditions:

- (1) The aircraft should be designed to withstand, at each critical airspeed up to V_D , including hovering, the loads resulting from vertical and horizontal gusts of 9.14 metres per second (30 ft/s).
- (2) The aircraft should be designed to withstand, at each critical airspeed up to V_H or V_{NE} , whichever is lower, including hovering, the loads resulting from vertical and horizontal gusts of 15.24 metres per second (50 ft/s).
- (3) For Category Enhanced, the aircraft should be designed to withstand, at each critical airspeed up to V_B including hovering, the loads resulting from vertical and horizontal rough air gusts of 20.12 m/s (66 ft/s)
- (4) The aircraft should be designed to withstand 100% of the vertical gust condition of (1) acting on one side of the aircraft.
- (5) The following assumptions should be made:

- (i) For wing structures, the shape of the vertical gust is –

$$U = \frac{Ude}{2} \left(1 - \cos \frac{2\pi s}{25\bar{C}} \right)$$

Where –

s = Distance penetrated into gust (ft);

\bar{C} = Mean geometric chord of wing (ft) if applicable, or other dimension rationally derived; and

Ude = Derived gust velocity referred to in paragraphs (1) to (3)

- (ii) For other structures, and for horizontal gusts, either sharp-edged (instantaneous) gusts or sharp-edged gusts modified by an alleviation (attenuation) factor may be used for calculating aerodynamic loads for the aircraft and any installed stabilizing surfaces.

(g) Take-off from sloping ground

- (1) The aircraft should be designed for take-off from level ground and up to the maximum slope and aircraft orientation combinations permitted for operation
- (2) Vertical lift/thrust should be the maximum achievable for the take-off configuration of the aircraft
- (3) This condition should be evaluated in both in ground effect (IGE) and out of ground effect (OGE)

(h) Unsymmetrical loads due to lift/thrust unit failure:

- (1) The aircraft should be designed for unsymmetrical loads resulting from the failure of the critical lift/thrust unit, including blade release, at speeds up to V_D including hover.
- (2) The timing and magnitude of the probable pilot or automated corrective action should be conservatively estimated, considering the characteristics of the particular lift/thrust unit and aircraft combination.
- (3) In the case of no corrective action being automatically performed, pilot corrective action, may be assumed to be initiated at the time maximum pitching, rolling or yawing velocity is reached, but not earlier than 2 seconds after the lift/thrust unit failure.
- (4) Characterisation of the lift/thrust failure may be considered using analysis in lieu of an instantaneous loss of lift/thrust if appropriate, but should be done in a rational and conservative manner, and appropriately verified by test.

MOC VTOL.2220 Ground and water load conditions

Explanatory Note: In this issue, this MOC addresses ground conditions only; water load conditions will be defined in a later issue of this MOC.

1. General

(a) *Loads and equilibrium.* For limit ground loads –

- (1) The limit ground loads obtained in this MOC should be considered to be external loads applied to the aircraft structure as if it were acting as a rigid body; and
- (2) If significant, the structural dynamic response of the airframe should be taken into account **considering all critical mass distributions**; and
- (3) In each specified landing condition, the external loads should be placed in equilibrium with linear and angular inertia loads in a rational or conservative manner.

(b) *Critical centres of gravity.* The critical centres of gravity within the range for which certification is requested should be selected.

2. Ground load conditions and assumptions

- (a) For specified landing conditions, all weights should be considered up to the maximum weight. Total lift may be assumed to act through the centre of gravity throughout the landing impact. This lift may not exceed two-thirds of the design maximum weight.
- (b) Unless otherwise prescribed, for each specified landing condition, the aircraft should be designed for a limit load factor of not less than the limit inertia load factor substantiated under MOC VTOL.2235 “*Limit drop test*”.

3. Tyres and shock absorbers

CS 27.475 Amdt. 6 is accepted as a means of compliance

4. Landing conditions

(a) The following landing conditions apply depending on the configuration of the VTOL

- (1) The following landing conditions apply to landing gear with two wheels aft, and one or more wheels forward, of the centre of gravity:
 - (i) The level landing conditions in CS 27.479 Amdt. 6 are accepted as means of compliance.
 - (ii) The tail-down landing conditions in CS 27.481 Amdt. 6 are accepted as means of compliance.
 - (iii) The one-wheel landing conditions in CS 27.483 Amdt. 6 are accepted as means of compliance.
 - (iv) The lateral drift landing conditions in CS 27.485 Amdt. 6 are accepted as means of compliance.
 - (v) The braked roll conditions in CS 27.493 Amdt. 6 are accepted as means of compliance.
- (2) The ground loading conditions for landing gear with tail wheels in subparagraphs (a) to (h) of CS 27.497 Amdt. 6 are accepted as means of compliance.
- (3) The ground loading conditions for landing gear with skids in CS 27.501 Amdt. 6 are accepted as means of compliance.

(b) CTOL aircraft should be designed for the additional loading conditions specified in this paragraph. In showing compliance with this paragraph, the following apply:

- (1) The level landing conditions in CS 23.479(a) and (b) Amdt. 4 are accepted as a means of compliance.
- (2) The tail down landing conditions in CS 23.481 Amdt. 4 are accepted as a means of compliance.
- (3) The one-wheel landing conditions in CS 23.483 Amdt. 4 are accepted as a means of compliance.
- (4) The sideload conditions in CS 23.485 Amdt. 4 are accepted as a means of compliance.
- (5) The braked roll conditions in CS 23.493 Amdt. 4 are accepted as a means of compliance.
- (6) The supplementary conditions for tail wheels in CS 23.497 Amdt. 4 are accepted as a means of compliance.
- (7) The supplementary conditions for nose wheels in CS 23.499 Amdt. 4 are accepted as a means of compliance.
- (8) The supplementary conditions for ski-planes in CS 23.505 Amdt. 4 are accepted as a means of compliance.

(c) The ski landing conditions in CS 27.505 Amdt.6 are accepted as a means of compliance.

5. Taxiing Condition

- (a) CS 27.235 Amdt. 6 is accepted as a means of compliance.
- (b) In addition, for aircraft with conventional take-off and landing (CTOL) capability the aircraft should be designed to withstand the loads that would occur when take-offs and landings are performed on unpaved runways having the roughest surface that may be expected in normal operation.

MOC VTOL.2230 Limit and ultimate loads

The combination of CS 27.301(a) Amdt. 6 and CS 27.303 Amdt. 6 is accepted as a means of compliance.

MOC VTOL.2235 Structural strength

Explanatory Note: At this issue, this MOC addresses landing gear drop test requirements only. Additional MOC will be added in future issues to address, for example, allowable damages to the aircraft for the Category Basic controlled emergency landing.

- (a) *Shock absorption tests:* CS 27.723 Amdt. 6 is accepted as a means of compliance.
- (b) *Limit drop test:* CS 27.725 Amdt. 6 is accepted as a means of compliance.
- (c) *Reserve energy absorption drop test:* CS 27.727 Amdt. 6 is accepted as a means of compliance. In addition:
 - (1) Shock absorbing devices, such as oleos, should not “bottom” during the reserve energy drop test. “Bottoming” occurs when displacement of the device no longer occurs with increasing load. (for further guidance see FAA AC 27.727(a)(3) in FAA AC 27-1B Change 7, which is the EASA AMC as per Book 2 of CS-27 Amdt. 6)

Notes:

- (1) The proper attitude for the aircraft after the reserve energy absorption drop test is an attitude which allows for permanent deformation of landing gear elements but provides for adequate egress from the aircraft (for further guidance see FAA AC 27.727A (b)(1) in FAA AC 27-1B Change 7, which is the EASA AMC as per Book 2 of CS-27 Amdt. 6).
- (2) External accessories that may not impact the landing surface during drop testing include devices such as externally mounted fuel tanks or accessories that are likely to cause post-landing fires. Cameras, loudspeakers, and search lights may be damaged during deformations resulting from reserve energy drop tests if electrical connections are sufficiently protected to preclude electrical fires and the devices are not likely to penetrate fuel tanks and other energy sources. The expendable accessories, if installed, should also be designed to not have “hard points” that would unacceptably damage the aircraft structure under landing impacts by penetration into the occupied areas or fuel tanks. These expendable accessories should be designed with frangible fittings, frangible devices, or comparable design features. Also, these devices should be designed to not significantly alter the energy absorbing ability or design features of the landing gear (for further guidance see FAA AC 27.727A (b)(2) in FAA AC 27-1B Change 7, which is the EASA AMC as per Book 2 of CS-27 Amdt. 6).
- (3) External accessories may not contact a level landing surface after “limit landing load” deflection of the landing gear, i.e. the deflection resulting from the limit drop test described in paragraph A of this MOC.

MOC VTOL.2240(d) High Energy Fragments – Particular Risk Analysis

The objective of VTOL.2240(d) and this particular risk analysis apply to lift/thrust unit or rotating-machinery failures, such as propellers, rotors that provide lift, compressor and turbine rotors of turbine engines and APUs and, electric engine rotor and cooling fans. Service experience of conventional aircraft has shown that damages due to high-energy fragments, for example following uncontained compressor and turbine rotor failures, continue to occur. VTOL aircraft have no service experience while the introduction of new technology and architectures means that VTOL aircraft cannot directly use conventional aircraft service experience to determine the likelihood and effects of failures. For Category Enhanced the failure of a lift/thrust unit or other rotating-machinery should therefore be assumed and the corresponding risk should be assessed, in line with the objective of VTOL.2250(c), with specific considerations for simultaneous or cascading effects presented in this Particular Risk Analysis. For Category Basic, a lower safety objective, in line with VTOL.2510, is accepted.

Applicants for either Basic or Enhanced category who wish to utilize means to shut down or stop individual rotor systems to mitigate hazards considered under this risk analysis should ensure that sufficient and reliable indications, control means and operational procedures are included in the design to allow for correct identification of a failed or hazardous lift/thrust unit and effective means to meet the analysis assumptions of imbalance exposure herein (see also MOC VTOL.2425 (b)).

1. For Category Basic:

The methodology from existing AMC such as AMC 20-128A is accepted for fragment size and trajectory. The lift/thrust unit or rotating-machinery probability of failure should be compatible with its severity, in accordance

with VTOL.2510. All consequences of a failure should be considered including possible cascading effects taking into account the overall probability of failure (Figure 1).

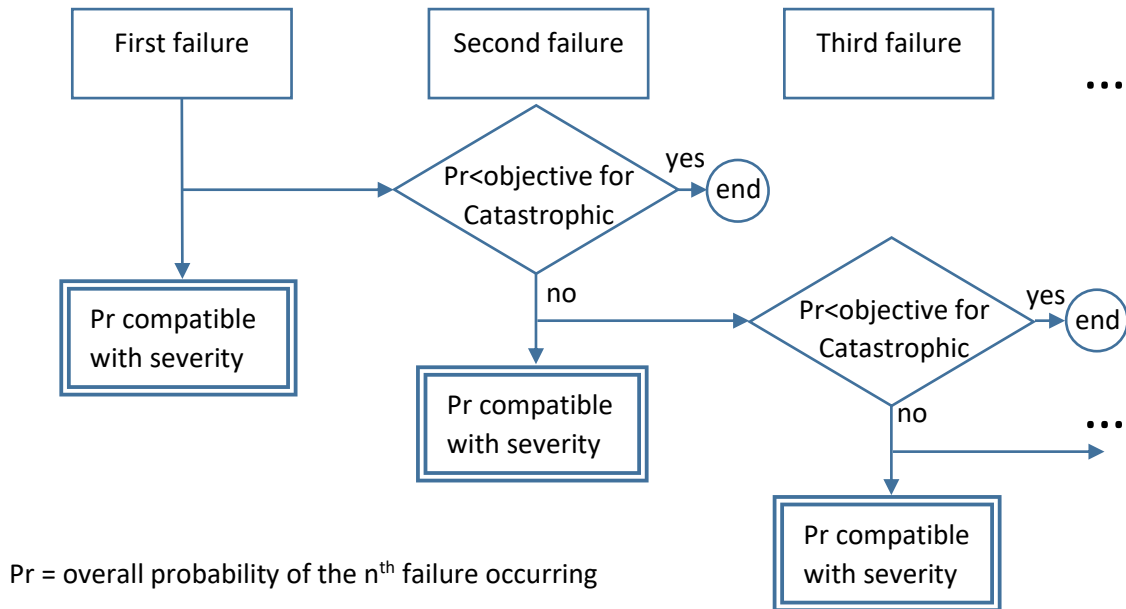


Figure 1: Methodology for the cascading failure evaluation for Category Basic

2. For Category Enhanced:

(a) Fragments to consider:

A failure of a lift/thrust unit or other rotating-machinery should be assumed. The Safety Analysis should consider all fragments released with residual energy. For propellers this could be the complete blade from the aerofoil surface to the retention and any component attached to the blade/hub. This could include counterweights, clamps, erosion shields, cuffs, de-ice boots, and pitch change pins.

(b) Path and size of fragments:

For turbine engines, the paths and sizes of fragments described in AMC 20-128A and AMC 25.963(e) in Book 2 of CS-25 Amdt. 24 can be used. For propellers and other types of fragments the impact area should be established based on test, analysis, or both. Applicants may use data from propellers with similar physical and operating characteristics to establish the impact area.

(c) Hazards:

Hazards from the failure of a lift/thrust unit or other rotating-machinery to be considered should include damage due to the impact of the high-energy fragments and the imbalance created by such failure. Further guidance material on engine imbalance, including windmilling considerations, can be found in AMC 25-24. Applicants may utilize design means of control and stoppage of those lift/thrust units, for which the probability of failure of those control means is shown to be commensurate with the objectives of VTOL.2510, and must rationally consider the environment of operation under the expected imbalance conditions.

(d) Safety Analysis:

It should be assessed that the failure of a lift/thrust unit or rotating-machinery does not have a catastrophic effect as defined in MOC VTOL.2510. The assessment should include aircraft systems, structures (including energy storage), occupants and other lift/thrust units. Due to the distributed propulsion, the failure of a lift/thrust unit may, for some architectures, potentially cause other lift/thrust failures in a chain reaction. Specifically the assessment of simultaneous or cascading failures of lift/thrust units can use the following methodology:

The first failure shall not have an immediate catastrophic effect.

It may however have a catastrophic effect by cascading events if extremely improbable. This is determined as follows: If the first failure can cause a second failure of a lift/thrust unit, the probability of the second failure should be evaluated. In the determination of this probability, consideration can be given to the probability of occurrence of the first failure and the probability of chain reaction (incl. hazardous trajectory probability and associated second failure probability). If this overall probability is less than 10^{-9} per flight hour, the hazards can be considered to have been minimised and the analysis can stop there. If it is higher, the effect of the second failure should be assessed and should not be catastrophic. The probability of the third failure should then be evaluated.

The analysis should continue until the overall probability of the next failure is less than 1×10^{-9} per flight hour or all lift/thrust units have been assessed (Figure 2).

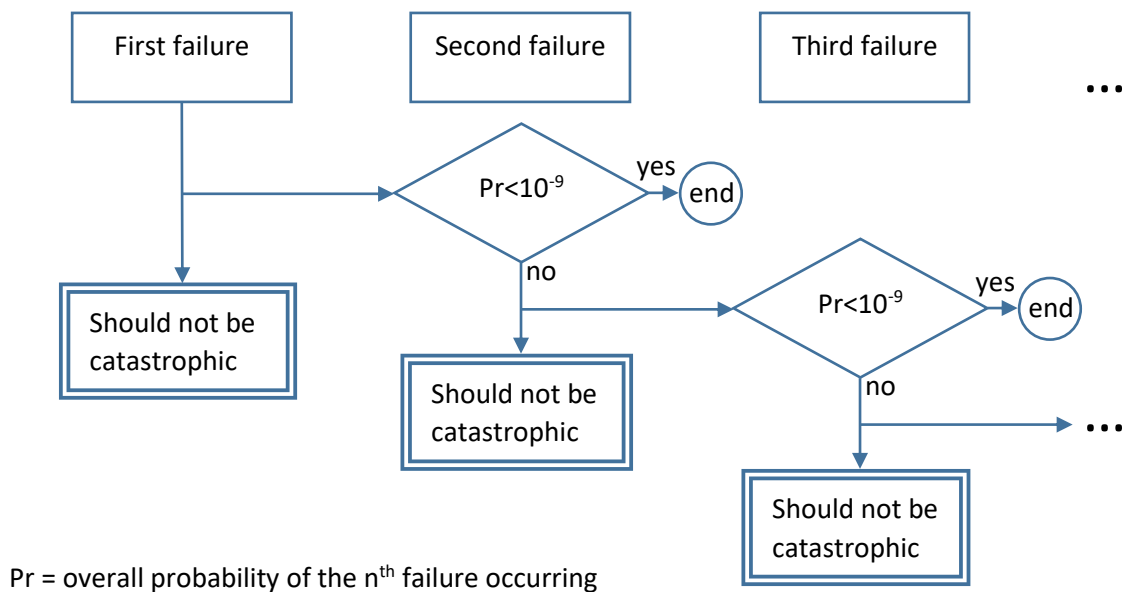


Figure 2: Methodology for the cascading failure evaluation for Category Enhanced

MOC VTOL.2250(c) No catastrophic effect from structural single failures in the Category Enhanced

The following method is accepted for compliance with VTOL.2250(c) in the Category Enhanced for structural elements and parts:

- (a) To demonstrate that no single failure has catastrophic consequences per design, a Safety Assessment should be performed that includes the following steps:

- (1) a complete and comprehensive list of structural elements or parts and their interfaces should be provided;
 - (2) the functions that the structural elements or parts perform should be identified; and
 - (3) a safety assessment should be performed to identify all structural elements and parts for which failure could lead to Catastrophic consequences. All reasonably anticipated and conceivable failures modes should be taken into account, and all the stages of flight and operating conditions should be considered.
 - (4) The conclusions of the Safety Assessment should demonstrate the non-catastrophic classifications of all single failures and thereby show direct compliance with VTOL.2250 (c).
 - (5) If any single failure is identified that can lead to a catastrophic consequence:
 - (i) a structural redesign or vehicle re-configuration should be considered.
 - (ii) For simply loaded static elements⁽¹⁾ that are not involved in a system function, if redesign or reconfiguration is impractical or adds excessive design complexity that would impair the overall safety objective, it should be demonstrated that catastrophic consequences from any single failure are extremely improbable applying a combination of the compensating provisions in accordance with paragraph (b).
Note ⁽¹⁾: Simply loaded static elements are typically airframe components. They are not high cycle fatigue loaded, non-rotating and not complexly loaded such as control surfaces or blades.
- (b) For structural elements or parts and failure modes identified in (a)(5)(ii), compensating provisions acceptable to EASA may be selected from the non-exhaustive list below:
- (1) Design features; (e.g., safety factors, part-derating criteria, etc.)
 - (2) Fatigue tolerance evaluation
 - (3) Operational limitations
 - (4) An inspection or check that would detect the failure mode or evidence of conditions that could cause the failure mode
 - (5) A preventive maintenance action to minimise the likelihood of occurrence of the failure mode, including replacement actions and verification of serviceability of items which may be subject to a dormant failure mode
 - (6) Special assembly procedures or functional tests for the avoidance of assembly errors which could be safety critical
 - (7) Other safety devices

MOC VTOL.2250(f) Aircraft capability after bird impact

This MOC provides methods to demonstrate the remaining capability of the aircraft after a bird impact as required by VTOL.2250(f).

It is applicable to VTOL Aircraft in the Category Basic designed to carry 7 to 9 passengers and in the Category Enhanced.

1. Single bird strike evaluation:

- (a) In accordance with VTOL.2250(f), VTOL aircraft must be designed to ensure the capability of a controlled emergency landing in the Category Basic with a maximum of 7 or more seats, or of a continued safe flight and landing in the Category Enhanced, after impact of a 1.0-kg (2.2-lb) bird. This should be ensured

in the most critical configuration for the corresponding velocity of the VTOL (relative to the bird along the flight path of the vehicle) up to the maximum speed in level flight with maximum continuous power, at operating altitude up to 2438 m (8,000 ft.).

- (b) Compliance should be shown by tests or by analysis based on tests carried out on sufficiently representative structures of a similar design.
- (c) The following parts should be evaluated for a single bird strike:
- (1) The windshield directly in front of occupants and the supporting structures for these panels should be capable of withstanding a bird impact without penetration for maximum speeds above 50kt.
 - (2) Other structures, systems and equipment should also be evaluated. The selection of the areas to be substantiated should be the result of a comprehensive hazard analysis based on:
 - (i) Exposed areas of the structure and internal equipment and systems inside of these exposed areas in case of bird penetration or shock loads; and
 - (ii) Their criticality and their ability to ensure continued safe flight and landing (for Category Enhanced) or controlled emergency landing (for Category Basic).
- (d) When performing the hazard analysis, direct and induced effects of a bird strike should be considered:
- (1) "Direct Effects": to ensure the integrity of the structure and functionality of systems or equipment (including consideration of shock loads) which are critical for continued safe flight and landing (for Category Enhanced) or controlled emergency landing (for Category Basic).
 - (2) "Induced Effects": to examine the possible consequences of the ejection of pieces from structures, systems or equipment which are struck by a bird on other structures and systems. For a bird impact on the lift/thrust system, the guidance in MOC VTOL.2240(d) can be followed, when relevant, in the demonstration of compliance mentioned in paragraph (a) of this section.

2. Multiple bird strike evaluation:

- (a) VTOLs are generally equipped with redundant systems and structures. To ensure continued safe flight and landing (for Category Enhanced) or controlled emergency landing (for Category Basic) following a multiple bird strike, an evaluation should be performed of the effects of such multiple bird strike in the most critical configurations for the corresponding velocity of the VTOL up to the maximum speed in level flight with maximum continuous power, within the range of airspeed for normal operation up to 4000ft MSL (Mean sea level).
- (b) The applicant should consider potentially vulnerable redundant systems and structures and their effective exposed area (wing, lift surfaces, rudder, ailerons...).
- (c) An acceptable approach is to show that there is no loss of function of the element that is impacted after a single impact with a medium sized bird of 0.450 kg. Alternatively, scenarios evaluating multiple bird impacts distributed across each structure or system can be proposed by the applicant considering medium birds and small birds according to the MOC VTOL.2400 guidance (see Figure 1). Multiple bird strike evaluation is not required for the windshield.

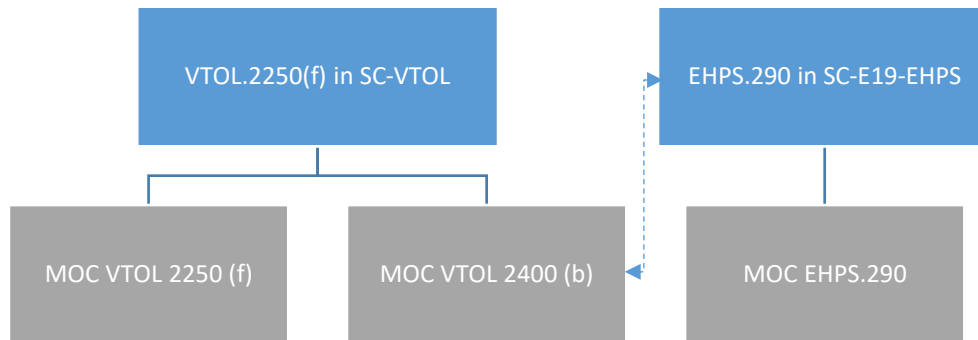


Figure 1- Overview of the Airframe and Propulsion System guidance interaction for compliance to bird strike

MOC VTOL.2270(a) and (c) Emergency landing conditions: General considerations


This MOC provides a set of general design conditions that, when used in their entirety, are accepted to ensure adequate protection of occupants against injuries that would prevent egress in an emergency landing.

- (a) CS 27.561(a) Amdt. 6 is accepted as a means of compliance.
- (b) CS 27.561(b) Amdt. 6 is accepted as a means of compliance with the addition under subparagraph (3)(ii) of a 18 g ultimate inertial load factor in the forward direction for CTOL aircraft.
- (c) CS 27.561(c) Amdt. 6 is accepted as a means of compliance replacing “rotors, transmissions and engines” by “lift/thrust units, transmissions and energy storage systems”.
- (d) CS 27.561(d) Amdt. 6 is accepted as a means of compliance replacing “fuel tanks” by “energy storage systems”.
- (e) For CTOL, CS 23.561(d) Amdt. 4 is accepted as a means of compliance.

MOC VTOL.2270(b)(1) Emergency landing dynamic conditions

This MOC provides a set of general design conditions that, when used in their entirety, are accepted to ensure adequate protection of occupants against injury in dynamic conditions that are likely to occur in an emergency landing.

- (a) CS 27.562(a) Amdt. 6 is accepted as a means of compliance.
- (b) CS 27.562(b) Amdt. 6 is accepted as a means of compliance under the following conditions:
 - (1) CS 27.562(b)(1) Amdt. 6 is accepted as a means of compliance, noting that the 30 g at seat attachment level was based upon the typical underfloor structure of a conventional rotorcraft. Therefore the 30 g is only valid if the structure underneath the seats has equal or better damping characteristics than a conventional rotorcraft. If specific design features are integrated, less than 30g at the seat may be acceptable based on analysis supported by tests
 - (2) CS 27.562(b)(2) Amdt. 6 is accepted as a means of compliance with the following addition: For CTOL peak floor deceleration should occur in not more than 0.05 seconds after impact and should reach a minimum of 26 g. For CTOL seat/restraint systems not being in the first row, peak deceleration should occur in not more than 0.06 seconds after impact and should reach a minimum of 21 g.
 - (3) CS 27.562(b)(3) Amdt. 6 is accepted as a means of compliance.
- (c) CS 27.562(c) Amdt. 6 is accepted as a means of compliance.

 <p>European Union Aviation Safety Agency</p>	Means of Compliance with the Special Condition VTOL	Doc. No: MOC SC-VTOL Issue: 2 Date: 12 May 2021
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(d) CS 27.562(d) Amdt. 6 is accepted as a means of compliance.

MOC VTOL.2270(e) Cargo and baggage compartments

The following provisions provide a set of design criteria that, when used in their entirety, are accepted to ensure compliance of the baggage compartment design with VTOL.2270(e):

- (a) CS 27.787 Amdt. 6 is accepted as a means of compliance.
- (b) CS 27.855(b) Amdt. 6 is accepted as a means of compliance.
- (c) For CTOL, in addition to (a) and (b), CS 23.787 Amdt. 4 is accepted as a means of compliance

MOC – SUBPART D – DESIGN AND CONSTRUCTION**MOC 1 VTOL.2300 Fly-by-Wire control systems: Definition and Scope**

The definition of flight control system is provided in MOC VTOL.2000.

Due to the distributed propulsion, most VTOL configurations have a closer integration of engines and flight controls than other types of aircraft. To address this specificity, a number of lift/thrust system and flight control system objectives are included in Subpart F – Systems and equipment objectives.

While some definitions are proposed in this MOC to facilitate common references, they do not imply limits in the scope of analyses. For example, in most configurations, the lift/thrust units play a role in the flight control function and should thus be integrated in any related safety analyses (e.g. MOC VTOL.2510, MOC 4 VTOL.2300).

Scope and certification approach covering both engines and flight controls for each project should be proposed by the Applicant for acceptance by EASA.

MOC 2 VTOL.2300 Acceptability of ASTM standard F3232/F3232M-20 for Fly-by-Wire flight control systems**1. Status and comments**

The ASTM F3232/F3232M-20 standard is the Standard Specification for Flight Controls in Small Aircraft. As this standard was prepared with the assumption of traditional (i.e. mechanical) primary flight controls, it can only be accepted as a means of compliance with VTOL.2300 for Fly-by-Wire (FbW) control systems with some explanations (see below), adaptations and additions (see Section 2) .

The definitions provided in §3 of ASTM F3232/F3232M-20 are only applicable insofar as the concept exists for VTOL aircraft and has not been defined otherwise. For instance: “aircraft type code” is not a valid concept for VTOL and “Continued Safe Flight and Landing” has been specifically defined for VTOL aircraft in MOC VTOL.2000.

Similarly, any reference in ASTM F3232/F3232M-20 to standards or methods for the determination of Handling Qualities should be considered to be replaced by a reference to MOC VTOL.2135.

Lastly, while this standard addresses conventional architecture elements such as flaps and stall barrier systems, different considerations may apply for other architectures in VTOL aircraft.

The following table provides the status of the acceptability of the ASTM F3232/F3232M-20 standard as a means of compliance with VTOL.2300 for Fly-by-Wire (FbW) control systems. Later revisions of ASTM F3232/F3232M or alternative standards may also be proposed by the applicant and agreed with EASA as acceptable means of compliance in a particular certification project.

ASTM F3232/F3232M-20	VTOL status/comments
§4.1.1, §4.1.2	Accepted
§4.1.3, §4.1.3.1	Accepted
§4.2	This ASTM standard paragraph is an accepted means of compliance. Nevertheless, additional means of compliance are required for FbW, as proposed in this MOC.
§4.3	Accepted
§4.4	Accepted
§4.5	Accepted
§4.6	Accepted
§4.7	This ASTM § was developed for traditional flight control systems. It is accepted as with some additions, see Section 2 below .
§4.8	Accepted
§4.9	Typo in the ASTM standard: "flight" instead of "light". Accepted
§4.10	Accepted
§4.11	Accepted
§4.12	Accepted
§4.13	Accepted
§5.1	Accepted
§5.2	Accepted with some additions to address FbW
§5.3 Artificial Stall Barrier System	Accepted

2. Adaptations/additions to ASTM standard F3232/F3232M-20 linked to Fly-by-Wire implementation

(a) Operation tests

To be considered an accepted means of compliance with VTOL.2300(a)(1) and (2), paragraph §4.7 of ASTM standard F3232/F3232M-20 should be adapted and complemented as follows:

(1) Adaptation of ASTM F3232/F3232M-20 standard

4.7 Operation Tests:

4.7.1 *It must be shown by operation tests that, when the controls are operated from the pilot compartment with the system loaded to the maximum actuation system forces (i.e. loads and torques), the system is free from jamming, excessive friction, excessive deflection, or any combination thereof.*

NOTES:

- (i) It is acceptable to reduce the load slightly to enable movement of the actuator throughout its range.
- (ii) This requirement applies to primary and secondary flight controls that move surfaces and flight controls that move or redirect lift/thrust units. It does not apply to fixed propulsion units that vary RPM, blade angle, or thrust for flight control.

(2) Addition to ASTM F3232/F3232M-20 standard

One method, but not the only one, for demonstrating the Operational Tests is as follows:

Conduct the control system operational tests by operating the controls from the pilot's compartment with the entire system loaded so as to correspond to the limit control forces established by the regulations for the control system being tested. The following conditions should be met:

(i) Under limit load, check each control surface/effector for travel and detail parts for deflection. This may be accomplished as follows:

- (A) Support the control surface/effector being tested while positioned at the neutral position.
- (B) Load the surface using loads corresponding to the limit control forces established in the SC VTOL.
- (C) Load the pilot's control until the control surface is just off the support.
- (D) Determine the available travel which is the amount of movement of the surface/effector from neutral when the control is moved to the system stop. It is acceptable to reduce the load slightly to enable movement of the actuator throughout its range.
- (E) The above procedure should be repeated in the opposite direction.
- (F) The minimum control surface/effector travel from the neutral position in each direction being measured should be 10 percent of the control surface travel measured with no load on the surface.

Regardless of the amount of travel of the surface when under limit load, the aircraft should have adequate flight characteristics as specified in Subpart B. Any derivative aircraft of a previous type certificated aircraft need not exceed the control surface travel of the original aircraft; however, the flight characteristics should be flight tested to ensure compliance.

(ii) Under limit load, no signs of jamming or of any permanent set of any connection, bracket, attachment, etc. may be present.

(iii) Friction should be minimised so that the limit control forces and torques specified by the regulations may be met.

MOC 3 VTOL.2300 Validation of Electronic Flight Control Laws (FCL) in Fly-by-Wire flight control systems

Compliance of the electronic flight control laws should be considered satisfactory when an adequate substantiation of validation activities is shown and formalised in the compliance documents.

(a) Formalisation of compliance demonstration strategy

In order to demonstrate compliance with an adequate level of formalisation, the following should be performed and captured within compliance documents:

- (1) Determination of flight control characteristics that require a detailed and specific validation strategy for VTOL.2135, VTOL.2145, VTOL.2300, VTOL.2500, VTOL.2510 compliance and Modified Handling Qualities Rating Method (MHQRM) demonstration;

- (2) Substantiation of the proposed validation strategy (e.g. analyses, simulator tests, flight tests) covering the characteristics and features determined above.

(b) Validation activities

For the substantiation of the proposed validation strategy, the applicant should perform the following activities:

- (1) Identify the objectives (intended function) of each function.
- (2) Check proper integration of each FCL function in the EFCS (Electronic Flight Control System) against objectives (e.g. rig-test, offline/piloted simulation, flight test, ...).
- (3) Check compatibility of each function with other functions acting on the same control surface/actuator:
 - (i) Identify potential interface problems with other functions,
 - (ii) Define test conditions (e.g. rig-test, offline/piloted simulation, flight test, ...),
 - (iii) Particular consideration should be given to actuator limitations and the resulting coupling of the remaining control authority between different control functions.
- (4) Check compatibility of each function in all applicable modes with other functions at aircraft level:
 - (i) Identify potential interface problems with other functions on aircraft level,
 - (ii) Define test conditions (e.g. rig-test, offline/piloted simulation, flight test, ...).
- (5) Analyse failure conditions for each function:
 - (i) Identify failure conditions and classify the severity of failures in accordance with VTOL.2510,
 - (ii) Define test conditions for verification of failure conditions severities (e.g. rig-test, offline/piloted simulation, flight test, ...).
 - (iii) Where functions are acting on the same control surface/actuators, particular consideration shall be given to coupling of failures in these functions (including control margin dependencies) as well as the overall redundancy management between these functions (including actuator limitations).
- (6) Document all steps.

(c) Characteristics

For the validation activities identified by the paragraphs (b) (2) to (5) above, the following should be covered in particular:

- (1) Definition of priorities between FCL functions acting on the same control surface / actuator (e.g. priorities, mixing-laws, ...),
- (2) Multi-objective optimisation (e.g. trajectory, energy consumption, passenger comfort), including trading one criterion (e.g. airspeed) vs others in extreme conditions,
- (3) Transition between different FCL modes with and without failures (e.g. blending, fading-in/fading-out, smoothness of transition, ...),
- (4) Effects of erroneous input data (e.g. air data, aircraft configuration, ...),
- (5) Discontinuities and non-linearities,
- (6) Control law interfaces,

- (7) Voting mechanisms,
- (8) Protections priorities (e.g. entry/exit logic conditions not symmetrical),
- (9) Determination of critical scenario for multiple failures.

The validation strategy should include but should not be limited to operational scenarios. The determination that an adequate level of validation of the FCL design has been achieved should be based on engineering judgment.

(d) Documentation to be provided

The applicant should prepare a checklist with a defined set of test cases based on experience, and provide the FCL Validation methodology and strategy for verification by EASA.

(e) Auditing

The Applicant should perform adequate auditing and EASA may define a related Level of Involvement in such audits.

Compliance should be shown in conjunction with the following requirements: VTOL.2135, VTOL.2145, VTOL.2500 and VTOL.2510.

MOC VTOL.2300(a)(1) Function and operation of Fly-by-Wire flight control system

(a) Flight crew awareness of the modes of operation

- (1) If the design of the flight control system has multiple modes of operation (e.g. hover, transition, cruise modes) and/or includes degraded modes following failures, a means should be provided to indicate to the crew any mode that significantly changes or degrades the handling or operational characteristics of the aircraft.
- (2) The sub-modes of operation (both in nominal and degraded mode) and the transition between them should be smooth, and should be evaluated to determine whether or not they are intuitive. If these sub-modes or the transition between them are not intuitive, an indication to the flight crew may be required. This indication may be different from the classic "failure alerting".
- (3) In case of several flight control modes, limitations should be clearly annunciated and the definition of a Training Area of Special Emphasis (TASE) in the Flight Crew Data (FCD) may need to be established during the certification of the Operational Suitability Data (OSD).

Compliance should be shown in conjunction with other paragraphs (such as VTOL.2445), where failures could lead to flight control mode degradation.

(b) Flight envelope protection

If Flight Envelope Protection (FEP) features are implemented, then these should follow the following principles:

- (1) Onset characteristics of each envelope protection feature should be smooth, appropriate to the phase of flight and type of manoeuvre; and not be in conflict with the ability of the pilot to satisfactorily change the aircraft flight path (e.g. speed, attitude) within the approved flight envelope.

- (2) Limit values of protected flight parameters (and if applicable, associated warning thresholds) should be compatible with:
 - (i) the aircraft structural limits;
 - (ii) the required safe and controllable manoeuvring of the aircraft;
 - (iii) the margins to critical conditions;
 - (iv) dynamic manoeuvring, airframe and system tolerances (both from manufacturing and in-service), and non-steady atmospheric conditions - in any appropriate combination and phase of flight - should not result in a limited flight parameter beyond the nominal design limit value that would cause unsafe flight characteristics;
 - (v) the rotor rotational speed limits;
 - (vi) the blade stall limits;
 - (vii) the engine and transmission torque limits; and/or
 - (viii) any other operation limitations for the aircraft and lift/thrust system installation.
- (3) The aircraft should be responsive to pilot commanded dynamic manoeuvring within a suitable range of the parameter limits that define the approved flight envelope.
- (4) The FEP system and any failure condition not shown to be extremely improbable should be analysed per MOC VTOL.2135 MHQRM (including the effect on flight envelope probabilities) and VTOL 2510.
- (5) When simultaneous envelope limiting is active this should not result in adverse coupling or adverse priority (e.g. if two or more envelope limitations could exist simultaneously, this consequence should not be a wrong priority).

Adherence to the above principles should be shown in conjunction with the demonstration of compliance with the following requirements: VTOL.2110, VTOL.2425(a), VTOL.2500, VTOL.2510(a)(b) and VTOL.2135 with MOC VTOL.2135.

(c) Flight control and critical displays:

The following apply at all attitudes and in all modes of operation:

- (1) The flight control system should be designed to continue to operate and not hinder aircraft recovery from any attitude.
- (2) Control systems for essential services should be designed so that when a movement to one position has been selected, a different position can be selected without having to wait for the completion of the initially selected movement, and the system should arrive at the finally selected position without further attention. The movements that follow and the time taken by the system to allow the required sequence of selection should not be such as to adversely affect the airworthiness of the aircraft.
- (3) Compliance should be shown by evaluation of the closed loop flight control system. This evaluation is intended to ensure that there are no features or unique characteristics (including numerical singularities) which would restrict the pilot's ability to recover from any attitude. The intent is not to limit the use of envelope protection features or other systems that augment the control characteristics of the aircraft.
- (4) The following conditions that might occur due to pilot action, system failures or external events should be considered:
 - (i) Abnormal attitude (including the aircraft becoming inverted);
 - (ii) Excursion of any other flight parameter; and

- (iii) Flight conditions that may result in higher than normal pitch, roll or yaw rates.
- (5) For each of the conditions in (c)(4):
 - (i) The flight control system should continue to operate;
 - (ii) The design of the flight control laws, including any automatic protection function should not hinder aircraft recovery; and
 - (iii) Critical flight displays should continue to provide accurate indications and any other information that the pilot may require to execute recovery from the unusual attitude and/or arrest the higher than normal pitch, roll or yaw rates.

MOC VTOL.2300(a)(2) Protection against likely Hazards for Fly-by-Wire flight control systems

(a) Control Signal Integrity

Perturbations, as referred to in this MOC, are described as signals that result from any condition that is able to modify the command signal from its intended characteristics. They can be categorised into the following categories:

- (1) Internal causes that could modify the command and control signals. These include but are not limited to:
 - (i) loss of data bits, frozen or erroneous values,
 - (ii) unwanted transients,
 - (iii) computer capacity saturation,
 - (iv) processing of signals by asynchronous microprocessors,
 - (v) adverse effects caused by transport lag,
 - (vi) poor resolution of digital signals,
 - (vii) sensor noise,
 - (viii) corrupted sensor signals,
 - (ix) aliasing effects,
 - (x) inappropriate sensor monitoring thresholds,
 - (xi) structural interactions (such as control actuator compliance or coupling of structural modes with control modes), that may adversely affect the system operation or structural stability and integrity.
- (2) External causes that could modify the command and control signals. These include but are not limited to:
 - (i) Lightning,
 - (ii) EMI effects (e.g., electric engine interference, aircraft's own electrical power and power switching transients, smaller signals if they can affect flight control, transients due to electrical failures),
 - (iii) High Intensity Radiated Fields (HIRF)
 - (iv) Single Event Effects (SEE)
- (3) Spurious signals and/or false data, that are a consequence of perturbations in either of the two categories above, may result in malfunctions that produce unacceptable system responses equivalent to those of conventional systems such as limit cycle/oscillatory failures, runaway/hardover conditions, disconnection, lockups and false indication/warning

that consequently present a flight hazard. It is imperative that the command signals remain continuous and free from internal and external perturbations and common cause failures. Therefore special design measures should be employed to maintain system integrity at a level of safety at least equivalent to that which is achieved with traditional hydro-mechanical designs. These special design measures can be monitored through the System Safety Analysis (SSA) process provided specific care is directed to development methods and on quantitative and qualitative demonstrations of compliance.

- (4) An evaluation of the following should be conducted:
- (i) The flight control system should continue to perform its intended function (even in a degraded mode), regardless of any malfunction from sources in the integrated systems environment of the aircraft.
 - (ii) Any system in the aerodynamic loop which has a malfunction should not produce an unsafe level of uncommanded motion and should automatically recover its ability to perform critical functions upon removal of the effects of that malfunction.
 - (iii) Malfunctions of systems in the aerodynamic loop should not adversely affect the ability to perform a safe flight and landing.
 - (iv) Any disruption to an individual unit or component as a consequence of a malfunction, and which requires annunciation and crew action, should be identified to and approved by EASA to ensure that:
 - (A) the failure can be recognised by the crew, and
 - (B) the crew action can be expected to result in continued safe flight and landing in the Category Enhanced or in a controlled emergency landing in the Category Basic.
 - (v) An automatic change from a normal to a degraded mode that is caused by spurious signal(s) or malfunction(s) should meet the probability requirements associated with the functional hazard assessment (FHA) established per VTOL.2510(a), (e.g. a failure condition assessed as major should be remote).
 - (vi) Exposure to a spurious signal or malfunction should not result in a hazard with a probability greater than that allowed by the criteria of VTOL.2510(a) and associated MOC. The impact on handling qualities and structural loads should also be evaluated.
 - (vii) Interaction of flight control functions and actuator control loops
 - (viii) The flight control system should operate appropriately when considering other systems. The applicant should ensure the compatibility of automatic functions that may dynamically interact or affect flight control in both normal and anticipated abnormal operating conditions and ensure that such interactions (either by aircraft response or by data transfer) do not result in inappropriate flight control responses. This should include any potential for adverse coupling of the dynamics of one automated flight function with another (e.g., coupling between automated power and flight control functions).
- (5) The complexity and criticality of the FbW flight control system (if utilised) necessitates additional laboratory testing beyond that required as part of individual equipment validation and software verification.
- (6) It should be shown that either the FbW flight control system signals cannot be altered unintentionally (i.e. what is received by the effector/actuator is what was transmitted by the computer), or that altered signal characteristics meet the following criteria:

- (i) Stable gain and phase margins are maintained for all flight control closed loop systems. Pilot control inputs (pilot in the loop) are excluded from this requirement.
 - (ii) Sufficient pitch, roll, yaw and lift/thrust control power is available to provide control for continued safe flight and landing in the Category Enhanced or for controlled emergency landing in the Category Basic, considering all the FbW flight control system signal malfunctions that are not extremely improbable.
 - (iii) The effect of spurious signals on the systems which are included in the aerodynamic loop should not result in unacceptable transients or degradation of the aircraft's performance. Specifically, signals that would cause a significant uncommanded motion of a control surface/effector actuator should be readily detected and deactivated or the surface motion should be arrested by other means in a satisfactory manner. Small amplitude residual system oscillations may be acceptable, if justified.
 - (iv) Establishment of a Validation and Verification process for the development of the flight control monitors, for example following SAE ARP 6539 Validation and Verification Process Steps for Monitors Development in Complex Flight Control and Related Systems.
- (7) It should be demonstrated that the output from the control surface closed loop system does not result in any uncommanded, sustained oscillations of flight control surfaces/actuators. The effects of minor instabilities may be acceptable, provided that they are thoroughly investigated, documented, and understood. An example of an acceptable condition would be one where a computer input is perturbed by spurious signals, but the output signal remains within the design tolerances, and the system is able to continue in its selected mode of operation unaffected by that perturbation.
- (8) In the context of showing and demonstrating these system characteristics an accepted Means of Compliance includes:
- (i) Systematic laboratory validation which includes a realistic representation of all relevant interfacing systems, and associated software, including the control system components which are part of the lift/thrust system. Closed loop aircraft simulation/testing will be necessary in this laboratory validation.
 - (ii) Laboratory or aircraft testing to demonstrate unwanted coupling of electronic command signals (over the spectrum of operating frequencies) and their effects on the mechanical actuators and interfacing structure.
 - (iii) Analysis or inspection to substantiate that separation/segregation are utilised to minimize any potential hazards.
- (9) A successful demonstration of signal integrity should include all elements, which contribute to command and control signals to the "aerodynamic closed loop" that actuate the flight controls. The "aerodynamic closed loop" should be evaluated for the normal and degraded modes. Elements of the integrated "aerodynamic closed loop" may include for example; digital or analogue flight control computers, power control units, control feedback, major data busses, and the sensor signals including; air data, acceleration, rate gyros, commands to the surface position, and respective power supply sources. Autopilot systems (including feedback functions) should be included in this demonstration if they are integrated with the FbW flight control system.

Compliance should be shown in conjunction with VTOL.2510 and SC EHPS (Electric and Hybrid Propulsion System).

(b) Pre-flight check

A means should be provided to allow a check of full range of movement to their commanded position of all primary lift/thrust controls (i.e. pilot controls, control surfaces) prior to flight, or a means should be provided that will allow the pilot to determine that full control authority is available prior to flight.

Some checks of the engine power and power control (e.g. engine RPM at least at idle thrust) should also be provided.

Compliance should be shown in conjunction with the following requirements VTOL.2425(a), VTOL.2435(f) (g) and VTOL.2615.

(c) Precautions against maintenance error / incorrect assembly

Experience has shown that maintenance errors should be assumed to occur and should be considered in the system design in order to reduce their likelihood.

The flight control system should be designed to physically prevent incorrect assemblies having significant safety effects and/or critical repercussions (i.e. catastrophic, hazardous, or major). Distinctive and permanent marking should only be used if the prevention of incorrect assembly by design is impractical, and EASA accepts the justification provided.

Significant safety effects may include an out-of-phase action, reversal in the sense of the control, faults introduced due to improper rigging, interconnection of the controls between two systems where this is not intended and loss of function.

(d) Flight Control Jams

The aircraft, pilot controls and its movable control system and/or surfaces should be designed to prevent a jam from occurring (refer to ASTM F3232/F3232M-20 standard §4.7 and 4.8) and should be tolerant to any jam, as far as practicable, and demonstrate continued safe flight and landing in the Category Enhanced or controlled emergency landing in the Category Basic. This may include the need for jam alleviation means.

The detachment of a part (e.g. control surface) should not be used as an alleviation means.

(1) Definition of Jam:

A Jam is a failure or event such that a control (e.g. control surface), pilot control, or component is fixed in one position.

Causes of a jam may include corroded bearings, interference with a foreign or loose object, control system icing, seizure of an actuator, or a disconnection that results in a jam by creating an interference. Jams of this type should be assumed to occur and should be evaluated at positions up to and including the normally encountered positions defined in (2) below.

All other failures that result in a fixed control (e.g. a control surface), pilot control, or component are addressed via the safety analysis process in accordance with VTOL.2300 and VTOL.2510. Depending on system architecture and the location of the failure, some jam failures may not always result in a fixed control surface or pilot control.

(2) Determination of Control System Jam Positions.

The flight phases required to be addressed should cover all flight phases (e.g. vertical takeoff, transition, in-flight (climb, cruise, normal turns, descent, and approach), transition and, vertical landing). Additional phases specific to the aircraft, such as hover should also be considered.

(3) Methodology:

When showing compliance with VTOL.2300(a)(2), the applicant should:

- (i) provide a summary of the design features that are intended to prevent a jam from occurring, due to failure or physical interference (jam prevention means),
- (ii) provide a summary of the means by which a jam could be alleviated (jam alleviation means),

Note: if credit is taken from a jam alleviation device (e.g. jam breakout or override, disconnect means, alternate surface control, alternate power source, or alternate cable paths), then the conditional probability of failure of the jam alleviation device, given that jam has occurred, should be less than 1×10^{-3} .

(iii) For each axis and flight phase:

(A) determine the 'normally encountered position'.

This 'normally encountered position' is the maximum position resulting from reasonably expected manoeuvres, gust/manoeuvre load alleviation function commands and wind & gust conditions.

As an example, assuming a jam to be approximately 1×10^{-6} to 1×10^{-7} per flight hour, a reasonable definition of normally encountered positions would represent the range of control surface deflections (from neutral to the largest deflection) expected to occur in 1000 random operational flights, without considering other failures, for each of the flight segments identified in the rule. This assumption should be supported by FMEA/SSA expected failure rates for jams.

NOTE 1:

If there is significant uncertainty regarding the control surface positions during 1000 random operational flights, it is acceptable to use the control surface stop or to propose another position based on conservative assumptions for acceptance by EASA.

NOTE 2:

Similarly to NOTE 1 above, the 1000 random operation flights is based on the assumption of a jam to be approximately 1×10^{-6} to 1×10^{-7} per flight hour. This is actually dependent on the actuator technology, installation, aircraft manufacturer and supplier experience. The Applicant should therefore propose a conservative analysis to cover the risk that is foreseen.

- (B) evaluate the jam at positions up to and including the normally encountered position, and demonstrate continued safe flight and landing in the Category Enhanced or controlled emergency landing in the Category Basic including structural strength capability.

NOTE 3: Only the aircraft rigid body modes need to be considered when evaluating the aircraft response to manoeuvres, wind/gust conditions and continued safe flight to landing.

- (iv) to identify the remaining possible jamming conditions, and demonstrate to EASA that all precautions have been taken and that the probability of occurrence is consistent with the hazard classification. If it is needed, it should be discussed with and accepted by EASA.

NOTE 4: Compliance should be shown in conjunction with MOC VTOL.2215 Flight Load Conditions for wind/gust conditions.

MOC VTOL.2300(a)(3) Control margin awareness

- (a) A suitable annunciation or indication should be provided to the crew for any flight condition in which commands (e.g. control surfaces, engine RPMs) are approaching their limits (whether or not it is pilot commanded) and that returning to normal flight and/or continuation of safe flight requires a specific crew action.
- (b) There should be a direct feedback of the control margin to the flight crew at any time in flight, in nominal and in a failure condition. This control margin is the remaining control available, related to the type of control laws (e.g. attitude command) and the means of control (e.g. torque provided by lift/thrust units). For systems that provide combined thrust and vector control, information should be provided to the crew about which amount of remaining control is available to allow them to take the required actions to fly the aircraft.
- (c) In the case of different control margin priorities, they should be clearly indicated to the crew for the current condition (e.g. height hold vs airspeed hold vs bank angle).
- (d) It should be taken into account that some pilot-demanded manoeuvres (e.g., rapid roll) are necessarily associated with intended full performance, which may saturate the control. Therefore, simple alerting systems should function in both intended and unexpected flight control-limiting situations and should be properly balanced between the necessary crew-awareness and nuisance alerting. Nuisance alerting should be minimised by proper setting of the warning threshold.
- (e) Depending on the application, suitable annunciations may include cockpit flight control position, force, annunciator light, or control position indicators. The term “suitable” indicates an appropriate balance between nuisance and necessary operation. Furthermore, this MOC applies at the limits of flight control authority, not necessarily at the limits of any individual control travel.

Compliance should be shown in conjunction with VTOL.2445 (a), (b), (c), (f) and (g).

MOC 4 VTOL.2300 Common Mode Failures and Errors in Fly-by Wire Flight Control Functions

To demonstrate compliance with VTOL.2300, in line with VTOL.2510, specific attention should be paid to common mode failures and errors in flight controls. The considerations on common modes in Section 9 (b) of MOC VTOL.2510 apply, supplemented by the following for fly-by-wire flight controls:

- (a) Full reliance on Development Assurance and Quality Assurance as sole mitigation of a common mode failure or error leading to a total loss of flight controls function shall be avoided as far as practicable. Additional architectural mitigations that provide functional independence and/or item development independence should be provided.

- (b) It is recognized that dissimilarity in the High-level specifications of Flight Control Laws in a Command/Monitoring (COM/MON) architecture may not be easy to implement. Monitoring of the Flight Control Laws may be a possible mitigation means against common mode errors in such case.

MOC 5 VTOL.2300 Hidden Failures in Fly-by-Wire flight control systems

To demonstrate compliance with VTOL.2300, in line with VTOL.2510, and to reach an acceptable level of safety, specific attention should be paid to latent failures.

The objective is to obtain a design with a minimum number of significant latent failures. Each significant latent failure should be highlighted in the system safety assessment and subject to review by EASA.

In addition to the general considerations in Section 12 of MOC VTOL.2510, the following applies for fly-by-wire flight control systems:

(a) Definitions:

- (1) Latent = dormant = hidden for more than one flight.
- (2) A failure is latent until it is made known to the flight crew or maintenance personnel.
- (3) A significant latent failure is one, which would in combination with one or more specific failures, or events result in a Hazardous or Catastrophic Failure Condition.
- (4) A significant failure condition is one which is classified Hazardous or Catastrophic and contains one or more significant latent failures.

(b) The following approach should be followed:

- (1) Double failures, with either one latent, that can lead to a Catastrophic Failure Condition should be avoided as far as practicable in system design. Deviations should be presented and accepted by EASA.
- (2) Latent failures that contribute to Hazardous or Catastrophic effects at aircraft level should be avoided in system design.
- (3) The use of periodic maintenance or flight crew checks to detect significant latent failures when they occur is undesirable and should not be used in lieu of practical and reliable failure monitoring and indications.
- (4) It is recognised that, on occasion, it would be impracticable to meet (1) and (2). In such cases:
 - (i) The remaining latent failures should be recorded and justified in the PSSA/SSA and reviewed during the design review process for compliance,
 - (ii) Compliance should be based on both previous experience and sound engineering judgement and should assess:
 - (A) the failure rates and service history of each component,
 - (B) the inspection type and interval for any component whose failure would be latent, and
 - (C) any possible common cause of cascading failure modes.
 - (iii) The integrity of the evident part of the significant failure condition should meet a minimum standard:

- (A) For Catastrophic failure combinations comprising of only one evident failure, the probability per flight hour of the evident part should be:
- $\leq 10^{-5}/\text{Fh}$ for Category Enhanced and Basic 7 to 9 passengers or
 - $\leq 10^{-4}/\text{Fh}$ for Category Basic below 7 passengers.
- (B) For Hazardous failure combinations comprising of only one evident failure, the probability per flight hour of the evident part should be:
- $\leq 10^{-4}/\text{Fh}$ for Category Enhanced and Basic 7 to 9 passengers or
 - $\leq 10^{-3}/\text{Fh}$ for Category Basic below 7 passengers.
- (iv) In addition, a Specific Risk calculation should be performed to demonstrate compliance with the presence of a latent failure. For each combination composed of one evident failure and latent failures and leading to a Catastrophic Failure Condition the probability of the latent part of the combination (e.g. "Sum of the products of the failure rates multiplied by the exposure time" of any latent failure) should be on average equal to or less than 1×10^{-3} ($=1/1000$).
- (v) The periodic maintenance checks, which may result from the compliance to this Specific Risk criterion in (b)(4)(iv)), should be considered as candidates for required maintenance tasks, in addition to the candidates for required maintenance tasks already selected for compliance to VTOL.2510.

MOC VTOL.2320(a)(2) Occupant physical environment

A hazard that originates from high energy should be understood to cover all possible serious injury mechanisms involving one or more of the aircraft's energy sources. This might involve, for example, contact with a high speed rotating part, with a high temperature surface, with a high velocity and/or temperature gas jet, or with an electrically live conductor.

With the aircraft in its normal pre-take-off/post-landing attitude on the ground it should be substantiated that no person in contact with the ground or entering/exiting the aircraft can place any part of their body in a position where serious injury could occur.

This may be achieved by the provision of physical barriers, designed to prevent contact with aircraft parts or reduce the risk of inadvertent movement into dangerous areas, design precautions to prevent the aircraft presenting identified hazards when flight is not intended, or an appropriate combination of both. The complete range of human anthropometry, including children, should be considered.

In the case of physical barrier means, all possible positioning of persons should be considered, without any assumptions of likelihood of a person taking up such a position. However, if full prevention is not feasible, for example against movement into a high velocity and/or temperature gas jet, a partial barrier solution may be acceptable. In such a case, precautions such as highly visible markings, pre-flight briefings to passengers, a requirement for trained ground personnel to be present, etc. might be considered by EASA to provide a comparable level of safety. Furthermore, the possibility of persons becoming distracted by one potential hazard and moving into another hazardous area, including in the case of darkness, should be considered.

In the case of a design precaution to prevent the presence of high energy at a critical location, the reliability of the precaution should be commensurate with its failure to function as intended being classified as catastrophic. Appropriate mechanical, electrical or software interlocks could form the basis of design precautions, using inputs

such as proximity detection of objects around the aircraft, exit locking status, etc. If design precautions based on passivating or shutting down systems are used to protect occupants while entering/exiting the aircraft, these must be supplemented by other design provisions or physical barriers to protect people on the ground.

The chosen means of protection should also cover the case where at the end of flight a passenger immediately opens an exit and egresses the aircraft.

"Serious Injury" should be taken to mean any injury which involves one or more of the following;

- (1) hospitalisation for more than 48 hours, commencing within 7 days from the date the injury was received;
- (2) a fracture of any bone (except simple fracture of fingers, toes, or nose);
- (3) laceration which causes severe haemorrhages, nerve, muscle, or tendon damage;
- (4) injury to any internal organ;
- (5) second- or third-degree burns, or any burns affecting more than 5 percent of the body surface; or
- (6) verified exposure to infectious substances or harmful radiation.

(Source: ICAO, Annex 13 to the Convention on International Civil Aviation)

MOC VTOL.2325(a)(4) Fire Protection - Energy storage crash resistance

1. Introduction and scope:

VTOL.2325 (a)(4) requires that the energy storage system and its installation in the aircraft are designed to minimise the risk of post-crash fires in survivable emergency landings. The ultimate goal is to provide occupants with sufficient time to evacuate or be extracted from the aircraft following such events.

The similarity of VTOL aircraft and small rotorcraft justifies the consideration of the design and test criteria as being comparable and therefore applicable. These criteria, mainly contained in CS 27.952 Amdt. 6 and CS 27.561 Amdt. 6, have proven to be successful in a large number of accidents in preventing or delaying the onset of post-crash fires, thus maximising the occupant escape time after survivable emergency landings.

The main concern in small rotorcraft are crash-induced fuel leaks that quickly come in contact with ignition sources during or after impact. It is recognised that there are many possible energy sources in VTOL aircraft (fuel, electricity, gas) that require the need to consider other forms of fire initiation. However, they do not invalidate the defined emergency landing conditions for which the design needs to show its capability to minimise the risk of fire initiation.

The following accepted means of compliance with VTOL.2325(a)(4) therefore builds on the design and test criteria contained in CS 27.952 Amdt. 6 and CS 27.561 Amdt. 6, complementing or adapting them, whenever necessary to account for different energy sources.

In addition, this MOC also constitutes an accepted means of compliance with VTOL.2430(a)(6) regarding the energy retention capability of the energy storage and distribution system during a survivable emergency landing on land. Specific considerations for the demonstration of compliance with VTOL.2430(a)(6) of VTOL aircraft intended to be used for operations on water, emergency flotation or ditching as per VTOL.2310 or over water are provided in MOC VTOL.2430(a)(6).

2. Energy Storage crash resistance:

- (a) Unless other means that are acceptable to EASA are employed to minimise the hazard to occupants caused by energy storage systems following an otherwise survivable impact (crash landing), the energy storage system should incorporate the design features of this MOC
- (b) These systems should be shown to be capable of sustaining the static and dynamic deceleration loads of this MOC, considered as ultimate loads acting alone, measured at the system component's centre of gravity without structural damage to the energy storage system or their attachments that could cause any fire other than the contained battery fire allowed in point 3.(f)(2)(ii) of this MOC.
- (c) In addition, no harmful amounts of liquids or toxic fumes or gases should enter an occupied area or the evacuation path.

3. Drop test requirements.

Each energy storage system, or the most critical energy storage system, should be subject to a drop-test using the following methodology:

- (a) the drop height should be at least 15.2 m (50 ft);
- (b) the drop impact surface should be non-deforming;
- (c) the energy storage system should be charged or filled to its most critical condition expected during a crash;
- (d) the energy storage system should be enclosed in a surrounding structure representative of the installation unless it can be established that the surrounding structure is free of projections or other design features likely to contribute to rupture of the energy storage system;
- (e) the energy storage system should drop freely in an orientation that is representative of a typical installation on the aircraft and impact in a horizontal position $\pm 10^\circ$ with regards to the horizontal axis of the VTOL; and
- (f) after the drop test there should be no risk of post-crash fire or other harmful release within a time frame compatible with the rescue of seriously injured occupants.
 - (1) For liquid or gaseous fuels: no leakage of flammable fluids or gases.
 - (2) For batteries:
 - (i) structural damage should not lead to a fire, leakage of harmful fluids, fumes or gases; or
 - (ii) any fire or leakage of harmful fluids, fumes or gases should be contained for at least 15 minutes in non-occupied areas and outside the evacuation path.
 - (3) Any projectile release should not lead to serious injury to occupants or persons on ground.

4. Energy storage system load factors.

- (a) Except for energy storage systems located so that structural damage to the energy storage that could cause fire, leakage of harmful or flammable fluids or gases, or toxic fumes in occupied areas or the evacuation path is extremely remote, each energy storage system should be designed and installed to retain its contents under the following ultimate inertial load factors, acting alone.
- (b) For energy storage systems in the cabin:
 - (1) Upward – 4 g.
 - (2) Forward – 16 g. (18 g for CTOL)
 - (3) Sideward – 8 g.

- (4) Downward – 20 g.
 - (5) Rearward – 1.5 g.
- (c) For energy storage systems located above or adjacent the crew or passenger compartment that, if loosened, could injure an occupant in an emergency landing:
- (1) Upward – 1.5 g.
 - (2) Forward – 12 g.
 - (3) Sideward – 6 g.
 - (4) Downward – 12 g.
 - (5) Rearward – 1.5 g.
- (d) For energy storage systems in other areas:
- (1) Upward – 1.5 g.
 - (2) Forward – 4 g.
 - (3) Sideward – 2 g.
 - (4) Downward – 4 g.

5. Energy storage system isolation means.

- (a) For liquid or gaseous fuel systems, self-sealing isolation means should be installed unless hazardous relative motion of energy storage system components to each other or to local aircraft structure is demonstrated to be extremely improbable or unless other means are provided.
- (b) The isolation means, such as fuses, couplings or equivalent devices should be installed where structural deformation could lead to a hazard to the occupants due to high energy release or release of harmful amount of fluids or gases.
- (c) For liquid or gaseous fuel systems, the design and construction of the isolation means for fuel tank to fuel line connections, fuel tank to fuel tank interconnects, and other points in the fuel system should incorporate the following design features:
 - (1) the load necessary to separate a breakaway coupling should be between 25 and 50% of the minimum ultimate failure load (ultimate strength) of the weakest component in the fuel-carrying line. The separation load should in no case be less than 1334 N (300 lb), regardless of the size of the fuel line;
 - (2) a breakaway coupling should separate whenever its ultimate load (as defined in subparagraph 5(c)(1)) is applied in the failure modes most likely to occur;
 - (3) all breakaway couplings should incorporate design provisions to visually ascertain that the coupling is locked together (leak-free) and is open during normal installation and service;
 - (4) all breakaway couplings should incorporate design provisions to prevent uncoupling or unintended closing due to operational shocks, vibrations, or accelerations; and
 - (5) no breakaway coupling design may allow the release of liquid or gaseous fuel once the coupling has performed its intended function.
- (d) For electrical energy storage systems:
 - (1) During a crash landing in which structural damage could lead to the release of high energy, an isolation means should ensure that no energy can be released from the energy storage system which could lead to serious injury to occupants or persons on ground. Its activation should be:

- (i) automatic, unless this is demonstrated to be impractical, in which case other means acceptable to EASA may be employed.
 - (ii) indicated to the flight crew and rescue personnel.
- (2) A manual isolation means has to be safely accessible for the rescue personnel and be clearly marked.
- (e) All individual isolation means, such as fuses, emergency stop, breakaway couplings, coupling fuel feed systems, or equivalent means should be designed, tested, installed and maintained so that inadvertent activation in flight is minimised to the maximum extent practicable. It should be ensured that the isolation means are not degrading beyond an acceptable level in accordance with the reliability requirements for systems and the fatigue requirements for structural installations.
 - (f) Alternatively, for gaseous or liquid fuels, equivalent means to the use of breakaway couplings should not create a survivable impact-induced load on the fuel line to which it is installed greater than 25 to 50% of the ultimate load (strength) of the weakest component of the line and should comply with the fatigue requirements of CS 27.571 Amdt. 6 without leaking.

6. Frangible or deformable structural attachments.

- (a) Frangible or locally deformable attachments of energy storage system components to local aircraft structure should be used unless hazardous relative motion of energy storage system components to local aircraft structure is demonstrated to be extremely improbable in an otherwise survivable impact,.
- (b) The attachment of energy storage system components to local aircraft structure, whether frangible or locally deformable, should be designed such that separation or relative local deformation of the attachment of energy storage system components will occur without rupture or local tear-out of energy storage system components that will could cause leakage or high energy release.
- (c) The load required to separate a frangible energy storage system components attachment from its support structure, or to deform a locally deformable attachment relative to its support structure, should be between 25% and 50% of the minimum ultimate load (ultimate strength) of the weakest component in the attached system. In no case should the load be less than 1330 N (300 lbs).
- (d) A frangible or locally deformable energy storage system components attachment should separate or locally deform as intended whenever its ultimate load (as defined in sub-paragraph 6(c)) is applied in the modes most likely to occur.
- (e) All frangible or locally deformable energy storage system components attachments should comply with the fatigue requirements of CS 27.571 Amdt. 6.

7. Separation of flammable fluids or gases and ignition sources.

To provide maximum crash resistance, flammable fluids or gases should be located as far as practicable from all occupiable areas and from all potential ignition sources.

8. Other basic mechanical design criteria.

Battery system components, electrical wires, and electrical devices should be designed, constructed and installed, as far as practicable, to be crash resistant.

9. Rigid or semi-rigid fuel tanks.

Rigid or semi-rigid fuel tank or bladder walls should be impact and tear resistant.

MOC VTOL.2325(b)(1) and (b)(2) Fire Protection: fire extinguishers and design of interiors**1. Category Basic**

- (a) Fire Extinguishers: CS 23.851(a), (b)(1), (c) Amdt. 4 are accepted as a means of compliance
- (b) Compartment interiors: CS 27.853 Amdt. 6 is accepted as a means of compliance.
- (c) Cargo and baggage compartment: CS 27.855 Amdt. 6 is accepted as a means of compliance.

2. Category Enhanced

For Category Enhanced the means of compliance accepted for Category Basic should be completed with the following provisions:


- (a) Compartment interiors: CS 29.853(a), (b) and (d) Amdt. 7 are accepted as a means of compliance.
- (b) Baggage compartment:

A baggage compartment that is located where the presence of a fire would not easily be discovered by a pilot while at his station should:

- (1) Have ceiling and sidewall liners and floor panels constructed of materials that have been subjected to and meet the 45° angle test of Appendix F to CS-23 Amdt. 4. The flame should not penetrate (pass through) the material during application of the flame or subsequent to its removal. The average flame time after removal of the flame source should not exceed 15 s, and the average glow time should not exceed 10 s. The compartment should be constructed to provide fire protection that is not less than that required of its individual panels; or
- (2) Be constructed and sealed to contain any fire within the compartment or have a device to ensure detection of fires or smoke by a crew member while at his station and to prevent the accumulation of harmful quantities of smoke, flame, extinguishing agents, and other noxious gases in any crew or passenger compartment.

MOC VTOL.2335 Lightning Protection

- (a) In order to demonstrate that the exposure to lightning is “unlikely”, the same operational limitations as defined in MOC VTOL.2515 “Electrical and electronic system lightning protection” are accepted.
- (b) CS 27.610 Amdt. 6 is accepted as a means of compliance.
- (c) As an alternative to CS 27.610 Amdt. 6, paragraph 17.1 of ASTM F3061/F3061M-19 “Standard Specification for Systems and Equipment in Small Aircraft” is also accepted as a means of compliance.

 <p>European Union Aviation Safety Agency</p>	<p>Means of Compliance with the Special Condition VTOL</p>	<p>Doc. No: MOC SC-VTOL Issue: 2 Date: 12 May 2021</p>
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MOC – SUBPART E –LIFT/THRUST SYSTEM INSTALLATION

MOC VTOL.2400(b) Accepted Specifications for Electric/Hybrid Lift/Thrust Units

EASA Special Condition E-19 on Electric/Hybrid Propulsion System is an accepted specification to be met by electric/hybrid lift/thrust units that are installed in VTOL aircraft.

MOC VTOL.2430(a)(2) Protection of the fuel system against lightning

For the protection of a conventional fuel system against lightning:

- (a) CS 27.954 Amdt. 6 is accepted as means of compliance
- (b) As an alternative to CS 27.954, the paragraph 17.2 of ASTM F3061/F3061M-19 “Standard Specification for Systems and Equipment in Small Aircraft” is also accepted as a means of compliance.

MOC VTOL.2430(a)(6) Energy retention capability in an emergency landing

1. General:

MOC VTOL.2325(a)(4) provides an accepted means of compliance with VTOL.2430(a)(6) regarding the energy retention capability of the energy storage and distribution system during a survivable emergency landing on land.

2. Specific considerations for VTOL aircraft with an electrical energy storage and distribution system:

In addition to Section 1 of this MOC, the following applies for VTOL aircraft with an electrical energy storage and/or distribution system:

- (a) For VTOL aircraft that are certified as per VTOL.2310 for intended operations on water, for emergency flotation or for ditching, MOC VTOL.2325(a)(4) with the following changes constitutes an accepted means of compliance with VTOL.2430(a)(6) regarding the energy retention capability of the energy storage and distribution system during a survivable emergency landing on water:
 - (1) In Section 3(b) of MOC VTOL.2325(a)(4): the drop impact surface should be water. Conservatively a non-deforming surface may be used.
 - (2) In Section 5 (d)(1) of MOC VTOL.2325(a)(4): persons on ground include all persons in contact with the VTOL, including persons in the water. The electrical energy storage and distribution system should retain the stored electrical energy for at least 15 minutes.
- (b) For VTOL aircraft certified for continued operations over water without meeting the flotation categories under VTOL.2310, MOC VTOL.2325(a)(4) with the following change constitutes an accepted means of compliance with VTOL.2430(a)(6) regarding the energy retention capability of the energy storage and distribution system during a survivable emergency landing on water:
 - (1) In Section 3(a) of MOC VTOL.2325(a)(4): the drop height may be reduced to 6 m

MOC – SUBPART F –SYSTEMS AND EQUIPMENT**MOC 1 VTOL.2500(b) Intended function of systems and equipment****1. Considerations on Safety Assessment and Development Assurance**

- (a) Compliance with VTOL.2500(b) is intrinsically linked with VTOL.2510 and should therefore be addressed simultaneously.
- (b) In particular, the safety assessment and development assurance processes described in paragraph §9 and §10 of MOC VTOL.2510 are part of the accepted means of compliance with VTOL.2500(b).

2. Operating and environmental conditions

VTOL.2500(b) covers the equipment and systems installed to meet a regulatory requirement, or whose improper functioning would lead to a hazard. Such systems and equipment are required to “be designed and installed so that they perform their intended function throughout the operating and environmental limits for which the aircraft is certified”. The aircraft operating and environmental conditions include:

- (a) the full normal envelope of the aircraft, as defined by the Aircraft Flight Manual, with any modification to that envelope associated with abnormal or emergency procedures;
- (b) any anticipated external aircraft environmental conditions:
 - (1) external environmental conditions such as atmospheric turbulence, HIRF, lightning, and precipitation, which the aircraft is reasonably expected to encounter, with severities limited to those established by certification standards and precedence;
- (c) any anticipated internal aircraft environmental conditions:
 - (1) the environmental effects within the aircraft, including vibration and acceleration loads, variations in fluid pressure and electrical power, and fluid or vapour contamination due to either the normal environment or accidental leaks or spillage and handling by personnel; and
- (d) any additional conditions where equipment and systems are assumed to “perform their intended function.”

For lift/thrust system, compliance with VTOL.2400 can be used to support the compliance demonstration with VTOL.2500(b) regarding the Electric Hybrid Propulsion System (EHPS) scope defined in the Special Condition E-19 EHPS.

MOC 2 VTOL.2500(b) Electromagnetic compatibility**1. Introduction and scope**

This MOC provides an accepted means of compliance related to Electromagnetic Compatibility (EMC) between different equipment and also between equipment and its interconnecting cabling. It is applicable to VTOL Aircraft in Categories Basic and Enhanced.

2. Electromagnetic compatibility

Electromagnetic compatibility tests should be conducted on the ground and in-flight as necessary. Any electromagnetic interference (EMI) noted on the ground should be repeated in-flight at the frequency at which the EMI occurred on the ground, unless the problem could be analysed and resolved beforehand. Since some systems are difficult to operate on the ground (e.g. air data system, etc.), the effects of EMI should be evaluated with all systems operating in-flight to verify that no adverse effects are present in the engine, energy supply system control, battery management, brake antiskid and other systems.

When electromagnetic interference and radio frequency interference (EMI and RFI) protection is required, special attention should be paid to the termination of individual and overall shields. Back shell adapters that are designed for shield termination, connectors with conductive finishes, and EMI grounding fingers are available for this purpose as are many other suitable solutions.

Electromagnetic interferences can exist between systems, but also between wires, and between wires and systems. Electromagnetic interference can be introduced into aeroplane systems and wiring by coupling between electrical cables or between cables and coaxial lines or other aeroplane systems. The correct functioning of systems should not be affected by EMI generated by adjacent wires. EMI between wiring which is a source of EMI and wire susceptible to EMI increases in proportion to the length of parallel runs and decreases with greater separation. Wiring of sensitive circuits that may be affected by EMI should be routed away from other wiring interference, or provided with sufficient shielding to avoid system malfunctions under operating conditions. Regardless of the function performed, the equipment and its interconnecting wiring will unavoidably generate and be exposed to various types of electrical transients, electrical and magnetic fields, and spurious noise, spanning over a wide range of frequencies and amplitudes. For sure, EMI should be limited to negligible levels in wiring related to systems that are necessary for continued safe flight, landing and egress. A comprehensive victim and source testing is typically expected to ensure the proper functioning of the systems on the aircraft (unless another way is agreed with EASA). The following sources of interference should be considered:

- (a) Conducted and radiated interference caused by electrical noise generation from apparatus connected to the busbars.
- (b) Coupling between electrical cables or between cables and aerial feeders.
- (c) Parasitic currents and voltages in the electrical distribution and grounding systems, including the effects of lightning currents or static discharge.
- (d) Different frequencies between electrical generating systems and other systems.

EUROCAE ED-248 is an accepted means of compliance with VTOL.2500(b) concerning electromagnetic compatibility, except that the note in its Table 3, paragraph 6.2, for helicopters or small aircraft with HF radio transmitters installed does not apply to VTOL aircraft.

MOC 3 VTOL.2500(b) Airworthiness Security in the Category Enhanced

Airworthiness Security is the protection of the airworthiness of an aircraft from intentional unauthorised electronic interaction: harm due to human action (intentional or unintentional) using access, use, disclosure, disruption, modification, or destruction of data and/or data interfaces. This also includes the consequences of malware and forged data and of access of aircraft systems from ground systems but does not include physical attacks or electromagnetic disturbance.

Improper functioning of equipment and systems can be caused by intentional unauthorised electronic interaction (IUEI). The applicant should consider cybersecurity threats as possible sources of ‘improper functioning’ of equipment and systems:

- (a) The equipment, systems and networks of Category Enhanced VTOL aircraft, considered separately and in relation to other systems, should be protected from intentional unauthorised electronic interactions that may result in catastrophic or hazardous effects on the safety of the aircraft. Protection should be ensured by showing that the security risks have been identified, assessed and mitigated as necessary.
- (b) When required by paragraph (a), the applicant should make procedures and instructions for continued airworthiness (ICA) available that ensure that the security protections of the aircraft equipment, systems and networks are maintained.

AMC 20-42 – Airworthiness Information Security Risk Assessment is an accepted means of compliance with VTOL.2500(b) for Airworthiness Security aspects.

MOC VTOL.2510 Equipment, systems, and installations

1. Purpose

This MOC describes an accepted means for showing compliance with the requirements VTOL.2510(a) and VTOL.2510(b). These means are intended to supplement the engineering and operational judgement that should form the basis of any compliance demonstration.

Whilst this MOC details “what” should be addressed for showing compliance with the requirement VTOL.2510(a), it does not provide detailed guidance on the implementation of development assurance and safety assessment processes. Detailed guidance and recommended practices may be found in the standards that are recognised through the list of reference documents in §3 below.

In general, the extent and structure of the analyses required to show compliance with VTOL.2510(a) and VTOL.2510(b) will be greater when the system is more complex and the effects of the Failure Conditions are more severe.

2. Applicability

As specified in VTOL.2500(a), paragraph VTOL.2510 is intended as a general requirement that should be applied to any equipment or system as installed, in addition to specific systems requirements, considering the following:

- (a) General - If a specific SC VTOL requirement exists which predefines systems safety aspects (e.g., redundancy level or criticality) for a specific type of equipment, system, or installation, then the specific SC VTOL requirement will take precedence. This precedence does not preclude accomplishment of a system safety assessment. For example, requirement VTOL.2430 predefines a required level of redundancy in the energy storage and distribution systems.
- (b) Subpart B, C and D - While VTOL.2510 does not apply to the performance and flight characteristics of Subpart B and structural requirements of Subparts C and D, it does apply to any system on which compliance with any of those requirements is based. For example, it does not apply to an aircraft's inherent stall characteristics, but it does apply to a stall warning system used to enable compliance with VTOL.2150.
- (c) Subpart E - In certain VTOL configurations, the lift/thrust system is closely integrated with other systems, such as the flight control system, and will also affect “continued safe flight and landing” or the “controlled emergency landing”. Therefore the “lift/thrust control systems” and “lift/thrust system

installation hazard assessment” will be addressed through the requirements VTOL.2500 and VTOL.2510 of Subpart F.

This MOC does not cover “Airworthiness Security” aspects. Interactions and interfaces between the system safety assessment process and the security assessment process exist however. Therefore, should a function be implemented or a system/equipment installed on the aircraft as a result of the airworthiness security assessment process, this function or system/equipment needs to undergo the system safety assessment process.

3. Reference Documents

The following references are quoted in different sections of this MOC as a source of additional guidance:

- (a) EUROCAE ED-79A/ARP4754A, Guidelines for development of civil aircraft and systems
- (b) SAE ARP4761, Guidelines and methods for conducting the safety assessment process on civil airborne systems and equipment.
- (c) AMC 20-115(), Airborne Software Development Assurance Using EUROCAE ED-12 and RTCA DO-178.
- (d) AMC 20-152(), Development Assurance in Airborne Electronic Hardware (AEH)
- (e) AMC 20-189(), Management of Open Problem Reports.
- (f) AMC 25-19 Amdt. 24, Certification Maintenance Requirements

4. Definitions

- (a) Complexity: An attribute of functions, systems or items which makes their operation, failure modes or failure effects difficult to comprehend without the aid of analytical methods. (Source: ED-79A/ARP4754A).
- (b) Continued Safe Flight and Landing: see MOC to VTOL.2000 Applicability and definitions.
- (c) Controlled emergency landing: see MOC to VTOL.2000 Applicability and definitions.
- (d) Commercial-Off-The-Shelf (COTS) software: Commercially available applications that are sold by vendors through public catalogue listings. COTS software is not intended to be customised or enhanced. Contract-negotiated software developed for a specific application is not COTS software (Source: ED-12C/DO-178C).
- (e) Derived requirements: Additional requirements resulting from design or implementation decisions during the development process which are not directly traceable to higher-level requirements and/or specify behaviour beyond that specified by the higher level requirements (Source: adapted from ED-79A/ARP4754A and ED-12C/DO-178C).
- (f) Development Assurance: All of those planned and systematic actions used to substantiate, at an adequate level of confidence, that errors in requirements, design and implementation have been identified and corrected such that the system satisfies the applicable certification basis. (Source: ED-79A/ARP4754A).
- (g) Development Assurance Level (DAL): the level of rigor of development assurance tasks necessary to demonstrate compliance with paragraphs VTOL.2500 and VTOL.2510 (Source: adapted from ED79A/ARP4754A). The DALs are determined by the system safety assessment process.

Two types of development assurance levels are identified in this document:

- (1) FDAL: Development Assurance Levels for aircraft functions, systems and equipment
- (2) IDAL: Development Assurance Levels for software and electronic hardware items

- (h) Error: An omission or incorrect action by a flight crew member or maintenance personnel, or a mistake in requirements, design, or implementation.
Note: Errors may cause failures, but are not considered to be failures (Source: adapted from AMC 25.1309 in Book 2 of CS-25 Amdt. 24).
- (i) Event: An occurrence which has its origin distinct from the aircraft, such as atmospheric conditions (e.g. gusts, temperature variations, icing and lightning strikes), runway conditions, conditions of communication, navigation, and surveillance services, bird-strike, payload fire. The term is not intended to cover sabotage. (Source: adapted from AMC 25.1309 in Book 2 of CS-25 Amdt. 24)
- (j) Failure: An occurrence that affects the operation of a component, part, or element such that it can no longer function as intended (this includes both loss of function and malfunction). (Source: adapted from AMC 25.1309 in Book 2 of CS-25 Amdt. 24)
- (k) Failure Condition: A condition having an effect on the aircraft, its occupants and/or third parties, either direct or consequential, which is caused or contributed to by one or more failures or errors, considering flight phase and relevant adverse operational or environmental conditions, or external events. (Source: adapted from AMC 25.1309 in Book 2 of CS-25 Amdt. 24)
- (l) Latent failure: A failure is latent until it is made known to the flight crew or maintenance personnel. (Source: adapted from AMC 25.1309 in Book 2 of CS-25 Amdt. 24)
- (m) Malfunction: Failure of a system, subsystem, unit, or part to operate in the normal or usual manner. The occurrence of a condition whereby the operation is outside specified limits. (Source: AC 23.1309-1E)
- (n) Open-source software: describes software that comes with permission to use, copy and distribute, either as is or with modifications, and that may be offered either free or with a charge. The source code should be available. (Source: Gartner)
- (o) Significant latent failure: A significant latent failure is one, which would in combination with one or more specific failures, or events result in a Hazardous or Catastrophic Failure Condition. (Source: adapted from AMC 25.1309 in Book 2 of CS-25 Amdt. 24).

5. Abbreviations

- (a) AEH – Airborne Electronic Hardware
- (b) COTS – Commercial Of The Shelf
- (c) CMA – Common Mode Analysis
- (d) (F)/(I)DAL – Function / Item Development Assurance Level
- (e) PRA – Particular Risk Analysis

6. Principles of Fail-Safe design concept

The requirements of SC-VTOL incorporate the objectives and principles or techniques of the fail-safe design concept, which considers the effects of failures and combinations of failures in defining a safe design.

- (a) The following basic objectives pertaining to failures apply:
 - (1) In any system or subsystem, the failure of any single element, component, or connection during any one flight should be assumed, regardless of its probability. Such single failures should not be catastrophic.
 - (2) Subsequent failures of related systems during the same flight, whether detected or latent, and combinations thereof, should also be considered.
- (b) The fail-safe design concept uses the following design principles or techniques in order to ensure a safe design. The use of only one of these principles or techniques is seldom adequate. A combination of two or more is usually needed to provide a fail-safe design, i.e. to ensure that major failure

conditions are remote, hazardous failure conditions are extremely remote, and catastrophic failure conditions are extremely improbable:

- (1) Designed Integrity and Quality, including Life Limits, to ensure intended function and prevent failures.
- (2) Redundancy or Backup Systems to enable continued function after any single (or other defined number of) failure(s); e.g. two or more engines, hydraulic systems, flight control systems, etc.
- (3) Isolation and/or Segregation of Systems, Components, and Elements so that the failure of one does not cause the failure of another.
- (4) Proven Reliability so that multiple, independent failures are unlikely to occur during the same flight.
- (5) Failure Warning or Indication to provide detection.
- (6) Flight Crew Procedures specifying corrective action for use after failure detection.
- (7) Checkability: the capability to check a component's condition.
- (8) Designed Failure Effect Limits, including the capability to sustain damage, to limit the safety impact or effects of a failure.
- (9) Designed Failure Path to control and direct the effects of a failure in a way that limits its safety impact.
- (10) Margins or Factors of Safety to allow for any undefined or unforeseeable adverse conditions.
- (11) Error-Tolerance that considers adverse effects of foreseeable errors during the VTOL aircraft's design, test, manufacture, operation, and maintenance.

7. Failure conditions classifications and probability terms

(a) Failure Conditions Classifications.

Failure Conditions are classified according to the severity of their effects as follows:

- (1) No Safety Effect: Failure Conditions that would have no effect on safety; for example, Failure Conditions that would not affect the operational capability of the aircraft or increase crew workload.
- (2) Minor: Failure Conditions which would not significantly reduce aircraft safety, and which involve crew actions that are well within their capabilities. Minor Failure Conditions may include, for example, a slight reduction in safety margins or functional capabilities, a slight increase in crew workload, such as routine flight plan changes, or some physical discomfort to passengers.
- (3) Major: Failure Conditions which would reduce the capability of the aircraft or the ability of the crew to cope with adverse operating conditions to the extent that there would be, for example, a significant reduction in safety margins or functional capabilities, a significant increase in crew workload or in conditions impairing crew efficiency, physical distress to occupants, possibly including injuries, or physical discomfort to the flight crew.
- (4) Hazardous: Failure Conditions, which would reduce the capability of the aircraft or the ability of the crew to cope with adverse operating conditions to the extent that there would be:
 - (i) a large reduction in safety margins or functional capabilities, or

- (ii) physical distress or excessive workload such that the flight crew's ability is impaired to where they could not be relied on to perform their tasks accurately or completely, or
 - (iii) for Category Enhanced, possible serious injury to an occupant other than the flight crew, but no fatality reasonably expected, or
 - (iv) for Category Basic, serious or fatal injury to an occupant other than the flight crew.
- (5) Catastrophic:
- (i) For Category Enhanced, failure conditions, which are expected to result in one or more fatalities, or incapacitation of a flight crew member, usually with the loss of the aircraft. Failure conditions that would prevent continued safe flight and landing of the aircraft are also considered catastrophic.
 - (ii) For Category Basic, failure conditions, which are expected to result in multiple fatalities, or incapacitation or fatal injury to a flight crew member, usually with the loss of the aircraft. Failure conditions that would prevent a controlled emergency landing of the aircraft are also considered catastrophic.

Explanatory Note: The Categories Basic and Enhanced were introduced in the Special Condition to allow proportionality in safety objectives. The highest safety levels of Category Enhanced apply for the protection of third-parties when flying over congested areas or when conducting commercial air transport of passengers. Different levels of performance are also requested through the performance objectives of Continued Safe Flight and Landing and of Controlled Emergency Landing. This issue of the MOC adds considerations for incapacitation, serious injuries and fatalities in the definitions of Hazardous and Catastrophic failure conditions. For Category Basic, the definitions are similar to AC 23.1309-1E. For Category Enhanced fatalities are excluded in the definition of Hazardous failure conditions due to the high number of operations anticipated and the public safety expectations in the air taxi/urban air mobility context. This also aligns with the expected approach for RPAS where a fatality (on the ground) would be classified Catastrophic.

When referring to "fatalities": passengers, flight crew and people on ground are considered.

(b) Qualitative Probability Terms.

When using qualitative analyses to determine compliance with VTOL.2510(a), the following descriptions of the probability terms used in VTOL.2510 and this MOC have become commonly accepted as aids to engineering judgment:

- (1) Probable Failure Conditions are those that are anticipated to occur one or more times during the entire operational life of each aircraft.
- (2) Remote Failure Conditions are those that are unlikely to occur to each aircraft during its total life, but which may occur several times when considering the total operational life of a number of aircraft of the type.
- (3) Extremely Remote Failure Conditions are those that are not anticipated to occur to each aircraft during its total life but which may occur a few times when considering the total operational life of all aircraft of the type.

- (4) Extremely Improbable Failure Conditions are those so unlikely that they are not anticipated to occur during the entire operational life of all aircraft of one type.

8. Safety Objectives

The objective of VTOL.2510(a) is to ensure an acceptable safety level for equipment and systems as installed on the aircraft. A logical and acceptable inverse relationship must exist between the average probability per flight hour and the severity of failure condition effects.

- (a) Safety Objectives per aircraft category and failure condition classification:

The safety objectives for each failure condition are:

Table 1: Safety Objectives

		Failure Condition Classifications			
		Minor	Major	Hazardous	Catastrophic
		Allowable Qualitative Probability			
		Probable	Remote	Extremely Remote	Extremely Improbable
		Allowable Quantitative Probability (Note C and D) Development Assurance Level			
Category	Maximum Passenger Seating Configuration	$\leq 10^{-3}$ FDAL D (see Note B)	$\leq 10^{-5}$ FDAL C	$\leq 10^{-7}$ FDAL B	$\leq 10^{-9}$ FDAL A
Enhanced	-	$\leq 10^{-3}$ FDAL D (see Note B)	$\leq 10^{-5}$ FDAL C	$\leq 10^{-7}$ FDAL B	$\leq 10^{-9}$ FDAL A
	7 to 9 passengers (Basic 3)	$\leq 10^{-3}$ FDAL D (see Note B)	$\leq 10^{-5}$ FDAL C	$\leq 10^{-7}$ FDAL B	$\leq 10^{-9}$ FDAL A
	2 to 6 passengers (Basic 2)	$\leq 10^{-3}$ FDAL D (see Note B)	$\leq 10^{-5}$ FDAL C	$\leq 10^{-7}$ FDAL C (see Note A)	$\leq 10^{-8}$ FDAL B (see Note A)
Basic	0 to 1 passenger (Basic 1)	$\leq 10^{-3}$ FDAL D (see Note B)	$\leq 10^{-5}$ FDAL C	$\leq 10^{-6}$ FDAL C (see Note A)	$\leq 10^{-7}$ FDAL C (see Note A)

[Quantitative safety objectives are expressed per flight hour]

Note A: no considerations of the system architecture for a DAL reduction are acceptable, as the FDAL classification already constitute a proportionate approach.

Note B: Alleviation in software development assurance for IDAL D as per section 10(c) is possible.

Note C: It is recognised that, for various reasons, component failure rate data may not be precise enough to enable accurate estimates of the probabilities of Failure Conditions. This results in some degree of uncertainty. When calculating the estimated probability of each Failure Condition, this uncertainty should be accounted for in a way that does not compromise safety.

Note D: The applicant is not expected to perform a quantitative analysis for minor failure conditions.

Note E: An average flight profile (including flight phases duration) and an average flight duration should be defined.

(b) Single failure and common cause failure considerations:

According to VTOL.2510(a)(1), a catastrophic failure condition must not result from the failure of a single component, part, or element of a system. Failure containment should be provided by the system design to limit the propagation of the effects of any single failure to preclude catastrophic failure conditions. In addition, there must be no common-cause failure, which could affect both the single component, part, or element, and its failure containment provisions. A single failure includes any set of failures, which cannot be shown to be independent from each other. Common-cause failures (including common mode failures) and cascading failures should be evaluated as dependent failures from the point of the root cause or the initiator. Errors in development, manufacturing, installation, and maintenance can result in common-cause failures (including common mode failures) and cascading failures. They should, therefore, be assessed and mitigated in the frame of the common –cause and cascading failures consideration.

Protection from multiple failures should be provided when the first failure would not be detected during normal operations of the aircraft, which includes pre-flight checks.

Sources of common cause and cascading failures include development, manufacturing, installation, maintenance, shared resource, event outside the system(s) concerned, etc. The ARP4761 describes types of common cause analyses, which may be conducted, to ensure that independence is maintained (e.g. particular risk analyses, zonal safety analysis, common mode analyses), see also Section 9(b).

While single failures should normally be assumed to occur, experienced engineering judgment and relevant service history may show that a catastrophic failure condition by a single failure mode is not a practical possibility. The logic and rationale used in the assessment should be so straightforward and obvious that the failure mode simply would not occur unless it is associated with an unrelated failure condition that would, in itself, be catastrophic.

Analyses should always consider the application of the fail-safe design concept as described in section 6, and give special attention to ensuring the effective use of design techniques that would prevent single failures or other events from damaging or otherwise adversely affecting more than one redundant system channel or more than one system performing operationally similar functions

Early coordination with EASA on these aspects is advised.

9. Safety assessment process

(a) Overview

The Safety Assessment process aims at demonstrating that systems and components are designed and installed in a way that occurrence probabilities of failure conditions are commensurate with their classification and that no catastrophic failure condition results from a single failure. It consists of several objectives, listed below in no particular order:

- (1) Examine aircraft and system functions to identify potential functional failures and classify the hazards associated with specific failure conditions.
- (2) Establish the safety requirements for the aircraft, its systems and items and validate these safety requirements.
- (3) Verify that system architecture and design meets the corresponding safety requirements and the safety objectives, including the single failure criterion.

- (4) Establish and verify physical and functional separation, isolation and independence requirements between systems and items, and verify that these requirements have been met.

Guidance on how to perform the Safety Assessment process can be found in ED-79A/ARP4754A and ARP4761. The applicant may propose other guidance for the Safety Assessment process, which should be agreed with EASA in conjunction with the overall proposed Development Assurance process.

The depth and scope of the analyses are dependent on the system criticality and/or complexity.

The safety assessment process is an iterative process, requiring preliminary assessment steps to ensure that the proposed system architecture(s) can reasonably be expected to meet the safety objectives, as well as regular coordination with EASA on the different process steps.

When identifying the aircraft and system functions and classifying the hazards associated with the Failure Conditions, the applicant will have to substantiate the effects of failure conditions with consideration to operational conditions and events. Guidance on the handling qualities assessment can be found in MOC VTOL.2135.

Any assumptions made during the safety assessment process need to be justified and validated.

(b) Common mode considerations

Common mode analysis (CMA) is an analytical method to define independence principles and associated requirements, and verify that those independence requirements have been implemented sufficiently. The CMA serves also as a tool to identify any lack of independence and to develop mitigation means to reduce the likelihood or the effect of a common mode failure resulting from a lack of independence.

The CMA should be performed early in the safety assessment process, because it has an impact on the definition of the safety requirements as well as on the system architecture.

Sources of common mode failures include development, manufacturing, installation, maintenance, shared resource, event outside the system(s) concerned, etc. When identifying mitigation means for specific common modes, the means should be appropriate to the common mode failure/error.

It is important to note that even Items that are developed to IDAL A may be subject to development error. Such error may simultaneously affect several instances of the same item with potential functional or safety consequences. EASA has experienced cases, where a development error in IDAL A item has even resulted in simultaneous failures of all affected equipment. Therefore, it should not be assumed that IDAL A items are protected from such development errors and consequently they should be included in the scope of the common mode analysis irrespective of the FDAL/IDAL of the system/item.

The following structured approach is accepted to accomplish a common mode analysis:

- (1) Establish program-specific checklists (for common mode types, sources, and resulting failures/errors). ARP4761 paragraph K.3.1 can be followed for this purpose. These checklists should be used to detect elements that may defeat the redundancy or independence principles within the design.

The following Common Modes are examples of common mode types, sources, and resulting failures/errors to be considered:

- (i) Software development errors
- (ii) Hardware development errors
- (iii) Hardware failures
- (iv) Production/repair flaws
- (v) Stress related events (e.g., abnormal flight conditions, abnormal system configurations)
- (vi) Installation errors
- (vii) Requirement errors
- (viii) Environmental factors (e.g., temperature, vibration, humidity, etc.)
- (ix) Cascading faults
- (x) Common external source faults
- (xi) General Common Modes are further detailed in the ARP4761 table K1.

- (2) Identify the independence principles and requirements. ARP4761 paragraph K.3.2 can be followed for this purpose.

These Failure Conditions should cover both the availability (i.e. loss) and integrity of functions and protections.

- (3) Analyse the design to ensure it meets the principles and requirements identified in paragraph (2) above. ARP4761 paragraph K.3.3 can be followed for this purpose.

The analysis of the design:

- (i) should be conducted not just at system level but also at item level (Airborne Electronic Hardware items including architecture and Software items including architecture), and
- (ii) should address both the availability (i.e. loss) and integrity of functions and protections.

- (4) Document the results of the above steps of the CMA process. ARP4761 paragraph K.4 can be followed for this purpose.

Additional considerations may be appropriate for some specific systems and functions. In particular for Fly-by-wire Flight Control Functions, MOC 4 VTOL.2300 applies.

10. Development Assurance process

Any analysis necessary to show compliance with VTOL.2510(a) should consider the possibility of development errors.

For simple systems, which are not highly integrated with other aircraft systems, errors made during the development of systems may still be detected and corrected by exhaustive tests conducted on the system and its components, by direct inspection, and by other direct verification methods capable of completely characterising the behaviour of the system. Such items may be considered as meeting the DAL A rigor when they are fully assured by a combination of testing and analysis, however requirements for these items should be validated with the rigor corresponding to the FDAL of the function. **Systems which contain software and/or complex electronic hardware items, cannot be considered simple.**

For more complex or highly integrated systems, exhaustive testing may either be impossible because all of the system states cannot be determined or impractical because of the number of tests which should be accomplished. For these types of systems, compliance may be shown by the use of development assurance. The

level of development assurance should be commensurate with the severity of the failure conditions the system is contributing to.

(a) Development Assurance Level (DAL) allocation

The development assurance level of a function or of an item is assigned depending on the classification of the failure conditions it contributes to.

Initial FDAL allocation is performed in accordance with Section 8(a) in this MOC.

Guidelines, which may be further used for the allocation of development assurance levels to aircraft and system functions (FDAL) and to items (IDAL), are described in the document ED-79A/ARP4754A, section 5.2.

In the absence of agreed guidelines on FDAL/IDAL allocation, the FDAL should be commensurate with those applicable to the category of aircraft as per Section 8(a) in this MOC and the IDAL of all components contributing to a given function should be equal to the FDAL of that function.

(b) Aircraft/System development assurance

For the aircraft and for systems of FDAL A, B, C or D, this MOC recognises the ED-79A/ARP4754A as acceptable guideline for establishing a development assurance process from aircraft and systems levels down to the level where software/ Airborne Electronic Hardware (AEH) development assurance is applied.

The extent of application of ED-79A/ARP4754A to substantiate functional development assurance activities may vary depending on the complexity of the systems and on their level of interaction with other systems. Early concurrence with EASA is essential.

(c) Software development assurance

This MOC recognises AMC 20-115() as an accepted means of compliance with requirement VTOL.2510(a).

For Commercial-Off-The-Shelf (COTS) software items and open-source software, in addition to the provisions of AMC20-115(), this MOC recognises guidance from DO-278A/ED-109A section 12.4 as an alternative that could be generally applied beyond the limits of CNS/ATM systems. In this case, the association between ED-12C/DO-178C software level and ED-109A/DO-278A AL (Assurance Level) can be found in DO-278A / ED-109A table 2-2 of section 2.3.3 'Assurance Level Definitions'.

Alleviation for software items of IDAL D contributing to Minor Failure Conditions:

- (1) For Category Basic 1 and Basic 2 (c.f. Table 1: Safety Objectives), it is possible to alleviate the software-level development assurance, relying on system-level development assurance processes, provided that:
 - (i) the equipment is one piece of equipment; and
 - (ii) the equipment is developed with an acceptable development assurance process.
- (2) For Category Basic 3 (see Table 1: Safety Objectives) and Enhanced, the software-level development assurance may be alleviated provided that:
 - (i) the software high-level requirements are defined and are verified to be captured in the systems requirements as described in ED-79A/ARP4754A section 5.4; and

- (ii) if some are ‘derived requirements’, a mechanism is in place to properly identify, validate and verify those derived software high-level requirements as described in ED-79A/ARP4754A section 5.4.

Note: In both cases, the system-level processes are not considered to be software development assurance processes.

- (d) Airborne Electronic Hardware development assurance

This MOC recognises AMC 20-152() as accepted means of compliance for requirement VTOL.2510(a).

- (e) Open Problem Report management

This MOC recognises AMC 20-189() as accepted means of compliance for establishing an open problem report management process for the system, software and AEH domains.

- (f) Considerations on derived requirements

ED-79A/ARP4754A section 5.3.1.4 adequately addresses the concerns related to potential for errors introduced by derived requirements while designing and implementing the systems

However, if ED-79A/ARP4754A section 5.3.1.4 defines the derived requirements as those that “may not be uniquely related to a higher-level requirement”, the definition could create an ambiguity as it is limited to “Additional requirements resulting from design or implementation decisions during the development process which are not directly traceable to higher-level requirements”.

Requirements that trace to a higher-level requirement and add a behaviour that is not specified at a higher level should also be considered as derived.

As a consequence, the definition from ED-79A/ARP4754A is superseded by the definition provided in Section 4 of this document.

11. Considerations for highly integrated systems

- (a) Generic guidance

- (1) When aircraft functions are provided by a combination of systems, the relevant requirements of those systems should be validated together, including the following activities:

- (i) Analysis of the potential interactions and interferences between systems,
(ii) Planning of dedicated activities at system and aircraft levels to ensure validation of those requirements that are affected by interactions or interference.

- (2) When incorporating multiple functions into the same system or equipment, applicability of AMC 20-170 should be considered. For architectures with no partitioning, particular care should be taken in the analysis of interactions between functions.

- (b) Additional Considerations for the Lift/Thrust system

For most VTOL aircraft designs, the Flight Control System and the Lift/Thrust system are highly integrated, i.e. the propulsion system directly contributes to the controllability of the aircraft. Therefore the development of the Lift/Thrust system should take into consideration the safety objectives of Section 8 and should follow the provisions of VTOL.2510 and associated guidance.

12. Latent failure considerations

The use of periodic maintenance or flight crew checks to detect significant latent failures when they occur is undesirable and should not be used in lieu of practical and reliable failure monitoring and indications. Significant latent failures are latent failures that would, in combination with one or more specific failure(s) or event(s), result in a Hazardous or Catastrophic failure condition and should be avoided in system design.

Within the frame of the no single failure criterion, dual failure combinations, with either one latent, that can lead to a Catastrophic Failure Condition should be avoided in system design. Any such combinations should be highlighted in the relevant SSA and discussed with EASA as early as possible after identification.

Additional considerations may be appropriate for some specific systems and functions. In particular for Fly-by-wire Flight Control Functions, MOC 5 VTOL.2300 applies.

13. Flight Crew and Maintenance considerations

(a) Flight Crew actions

When assessing the ability of the flight crew to cope with a failure condition, the information that is provided to the flight crew and the complexity of the required action should be considered. If the evaluation indicates that a potential failure condition can be alleviated or overcome during the time available without jeopardizing other safety related flight crew tasks and without requiring exceptional pilot skill or strength, credit may be taken for correct and appropriate corrective action for both qualitative and quantitative assessments. Similarly, credit may be taken for correct flight crew performance if overall flight crew workload during the time available is not excessive and if the tasks do not require exceptional pilot skill or strength. Unless flight crew actions are accepted as normal airmanship, the appropriate procedures should be included in the EASA-approved AFM or in the AFM revision or supplement. The AFM should include procedures for operation of complex systems such as integrated flight guidance and control systems. These procedures should include proper pilot response to cockpit indications, diagnosis of system failures, discussion of possible pilot-induced flight control system problems, and use of the system in a safe manner.

(b) Maintenance actions

Credit may be taken for the correct accomplishment of maintenance tasks in both qualitative and quantitative assessments if the tasks are evaluated and found to be reasonable. Required maintenance tasks, which mitigate hazards, should be provided for use in EASA-approved ICA. Annunciated failures that will be corrected before the next flight or a maximum duration should be established before a maintenance action is required. If the latter is acceptable, the analysis should establish the maximum allowable interval before the maintenance action is required. A scheduled maintenance task may detect latent failures. If this approach is taken, and the failure condition is hazardous or catastrophic, then a maintenance task should be established. The process for the identification and selection of these scheduled maintenance tasks requires early coordination and agreement with EASA. Guidance may be found in AMC 25-19.

Credit could be given to tests performed due to mean time between failures (MTBF) to detect the presence of hidden failures, if it can be ascertained that the equipment is removed and inspected at a rate much more frequent than the safety analysis requires. This credit should be substantiated in the relevant SSA. The means of detection of the hidden failures should be clearly identified, either at the opportunity of the acceptance tests performed before the equipment enters service or leaves the manufacturer, or at the opportunity of test of system integrity when it is installed back on the aircraft. This substantiation should be

recorded in the relevant SSA. In case of double failures, with either one or both hidden, that can lead to Catastrophic or Hazardous Failure Condition, no credit should be taken from MTBF for failure detection, and the maintenance task enabling detection of the hidden failure should be identified as a required maintenance task.

MOC VTOL.2515 Electrical and electronic system lightning protection

1. Unlikely Exposure to Lightning

It is stated in VTOL.2515 that sub paragraphs (a) and (b) are applicable “unless it is shown that the exposure to lightning is unlikely”. The demonstration on this condition should be based on reliable meteorological reports and/or on-board means to detect lightning, directly or indirectly (e.g. Lightning Detector, Weather Radar). Therefore, an accepted means to avoid the compliance demonstration with electrical and electronic system lightning protection requirements is to establish the following operational limitations:

- (a) VFR Day with reliable weather reports stating the absence of significant clouds before and/or during the flight for departure, enroute, terminal and diversion vertiports, or
- (b) VFR with means to detect lightning or storm cells via a certified onboard system, and/or ground base support plus appropriate communication with the pilot. The qualification of such ground-based system should be ensured by the operator.

When VTOL.2515 (a) and (b) are applicable, this MOC proposes simplified methods for addressing the Indirect Effects of Lightning (IEL) compliance demonstration on VTOL aircraft. These methods vary depending on the VTOL Aircraft categories; Basic 1 (0 to 1 passenger), Basic 2 (2 to 6 passengers), Basic 3 (7 to 9 passengers) and Enhanced.

2. Reference Documents

The following references are quoted in different sections of this MOC as a source of additional information or to provide accepted methods and practices:

(a) Industry Standards

- (1) ASTM
 - F3061/F3061M Specification for Systems and Equipment in Small Aircraft
 - F3230 Standard Practice for Safety Assessment of Systems and Equipment in Small Aircraft
 - F3309 Standard Practice for Simplified Safety Assessment of Systems and Equipment in Small Aircraft
- (2) EUROCAE/SAE/RTCA
 - ED-81/ARP5413A Certification of an Aircraft Electrical/Electronic Systems for the Indirect Effect of Lightning
 - ED-84/ARP5412B Aircraft Lightning Environment and Related Test Waveforms
 - ED-91/ARP5414B Aircraft Lightning Zoning
 - ED-105/ARP5416A Aircraft Lightning Test Methods

ED-158/ARP5415B	User/s Manual for Certification of Aircraft Electrical/Electronic Systems for the Indirect Effect of Lightning
ED-14()/DO-160()	Environmental Conditions and Test Procedures for Airborne Equipment

(b) Authorities Guidance

(1) FAA

PS-ACE-23-10	HIRF/Lightning Test Levels and Compliance Methods for 14 CFR Part 23 Class I, II, and III Aircraft <i>Note: only partially recognised by EASA</i>
AC 23.1309-1E	System Safety Analysis and Assessment for Part 23 Aircraft
AC 20-136B	The Certification of Aircraft Electrical and Electronic Systems for Operation in the High-intensity Radiated Fields (HIRF) Environment

(2) EASA

MOC VTOL.2515	Acceptable Means of Compliance for VTOL System Safety Analysis and Assessment
AMC 20-136	Aircraft Electrical and Electronic System Lightning Protection

3. Definitions

For the purpose of this MOC the following definitions apply:

- (a) **Actual Transient Level (ATL):** The level of transient voltage or current that appears at the equipment interface circuits due to the external environment. This level may be less than or equal to the transient control level, but should not be greater.
- (b) **Adverse Effect:** A response of a system that results in an undesirable and/or unexpected operation of an aircraft system, or undesirable and/or unexpected operation of the function performed by the system.
- (c) **Ceiling And Visibility are OK (CAVOK):** statement in meteorological report indicating that there are no clouds below 5000 ft AGL (or Minimum Sector Altitude whichever is greater), no presence of Towering Cumulus (TCU) and/or Cumulonimbus (CB) and visibility above 10 km.
- (d) **Equipment:** A component of an electrical or electronic system with interconnecting electrical conductors.
- (e) **Equipment Transient Design Level (ETDL):** The peak amplitude of transients to which equipment is qualified.
- (f) **Hazard related to lightning exposure:** Comparison between the probability to be struck by Lightning and the failure from another internal cause.
- (g) **IEL Group:** Group of VTOL categories having the same methodology for their Indirect Effects of Lightning compliance demonstration. 3 Groups have been identified; Group I for VTOL Category “Basic 1” (0-1 passenger), Group II for VTOL Category “Basic 2” (2-6 passengers) and Group III for VTOL Categories “Basic 3” (7-9 passengers) and Enhanced.
- (h) **Immunity:** Capacity of a system or piece of equipment to continue to perform its intended function, in an acceptable manner, in the presence of an electrical transient.
- (i) **Indirect effects:** Electrical transients induced by lightning in aircraft electrical or electronic circuits.

- (j) **Internal environment:** The potential fields and structural voltages inside the aircraft that are produced by the external environment.
- (k) **Lightning Certification Level (LCL):** Level of an electrical or electronic system performing a function whose most critical Failure Condition is catastrophic, hazardous or major.
- (l) **Margin:** The difference between the equipment transient design levels and the actual transient level.
- (m) **No Significant Cloud (NSC):** statement where CAVOK information is not met but ensures no presence of Towering Cumulus (TCU) and/or Cumulonimbus (CB).
- (n) **Normal Operation:** A status where the system is performing its intended function. When addressing compliance with VTOL.2515 (a) (2), the function whose failure would prevent the continued safe flight and landing for Category Enhanced or a controlled emergency landing for Category Basic should be in the same undisturbed state than before exposure to the Lightning threat. Other functions, performed by the same system, subject to VTOL.2515 (b), are not required to be recovered.
- (o) **System:** An electrical or electronic system includes all electrical and electronic equipment, components and electrical interconnections that are required to perform a particular function.
- (p) **Transient Control Level (TCL):** The maximum allowable level of transients that appear at the equipment interface circuits because of the defined external environment.
- (q) **Upset:** Impairment of system operation, either permanent or momentary. For example, a change of digital or analogue state that may or may not require a manual reset.

4. Means of Compliance:

(a) Minimum Design Considerations

- (1) In order to utilise the methods described in this practice, the following minimum design considerations should be addressed. If deviations from these minimum design considerations are desired, the acceptability of the methods described should be agreed by EASA.
- (2) The airframe should incorporate low impedance electrical conductors to allow lightning current to flow through the aircraft. The low impedance conductors should be incorporated into the basic structure of the aircraft.
 - (i) For aircraft with primarily metal structure, the metal skin provides a low impedance electrical conductor. Standard rivets and bolts should provide adequate electrical bonding between permanent structural joints. Electrical bonding straps or jumpers should be installed on moving parts or for removable panels or parts.
 - (ii) For aircraft with primarily carbon fibre or fiberglass structure, metal mesh, metal foil, or expanded metal foil should be incorporated onto the external surfaces of the aircraft composite structure. This mesh or foil should be joined together electrically and provide a continuous electrical conductor between the extremities of the aircraft. Metallic components that are internal to the structure of the aircraft may also be used to provide similar shielding for equipment and its wiring.
 - (iii) For aircraft constructed of tube and fabric, the tube skeleton can be considered to be the low impedance electrical path through the aircraft. The bonding also may be achieved by the use of bonding straps or jumpers where required to electrically bond other metallic sub-structure that might be relied upon to provide bonding for equipment.
- (3) Electrical bonding specifications and verifications should be developed and implemented on the production drawings and instructions for continued airworthiness.

Additional considerations for wiring protection can be found in ED-158 A (User's Manual for certification of aircraft electrical/Electronic Systems for the Indirect Effect of Lightning).

(b) IEL Group Determination

The IEL Group should be identified by using Table 1; the relevant Group will determine the IEL Compliance Verification method given in paragraph (d).

	VTOL Categories			
	Basic (max passenger seating configuration)			Enhanced
	0-1	2-6	7-9	
IEL Group	I	II	III	III

Table 1 – IEL Group Allocation

(c) IEL Safety Assessment

- (1) Aircraft systems that require an IEL Safety Assessment should be identified. The elements of the system that perform a function should be defined, considering redundant and/or backup equipment that constitutes the system. The process used for identifying these systems should be similar to the process used for showing compliance with VTOL.2510. This requirement addresses any system failure that may cause or contribute to an effect on the safety of flight of an aircraft. The effects of a Lightning Strike should be assessed to determine the degree to which the aircraft and its systems safety may be affected. The operation of the aircraft systems should be assessed separately and in combination with, or in relation to, other systems. This assessment should cover:
 - (i) All normal aircraft operating modes, stages of flight, and operating conditions;
 - (ii) All failure conditions and their subsequent effect on aircraft operations and the flight crew; and
 - (iii) Any corrective actions required by the flight crew.

- (2) A safety assessment related to IEL should be performed to establish and classify the equipment or system failure condition. Table 2 provides the corresponding Failure Condition classification and system IEL certification level for VTOL.2515. The IEL safety assessment determines the consequences of failures, due to IEL, for the aircraft functions that are performed by the system. The Lightning Certification Level (LCL) classification assigned to the system and functions can be different from the Design Assurance Levels assigned for equipment function and/or item (software, and complex electronic hardware). This is because operation in Lightning environment can cause common cause effects. The term 'Design Assurance Level' should not be used to describe the Lightning Certification Level because of the potential differences in assigned classifications for software, complex electronic hardware, and equipment function

IEL Requirements VTOL.2515	MOST CRITICAL FAILURE CONDITION OF THE FUNCTION	SYSTEM LIGHTNING CERTIFICATION LEVEL (LCL)
<p>Unless it is shown that exposure to lightning is unlikely:</p> <p>(a) Each electrical or electronic system that performs a function, the failure of which would prevent continued safe flight and landing for Category Enhanced, or a controlled emergency landing for Category Basic, must be designed and installed such that:</p> <p>(1) The function at the aircraft level is not adversely affected during and after the time the aircraft is exposed to lightning; and</p> <p>(2) The system recovers normal operation of that function in a timely manner after the aircraft is exposed to lightning unless the system's recovery conflicts with other operational or functional requirements of the system.</p>	Catastrophic	A
<p>(b) Each electrical and electronic system that performs a function, the failure of which would reduce the capability of the aircraft or the ability of the flight crew to respond to an adverse operating condition, must be designed and installed such that the system recovers normal operation of that function in a timely manner after the aircraft is exposed to lightning.</p>	Hazardous/Major	B/C

Table 2 – IEL Failure Conditions and System Lightning Certification Level

- (i) The IEL safety assessment should consider all potential adverse effects due to system failures; loss, malfunctions or misleading information caused by IEL threat. The IEL safety assessment may show some systems have different failure conditions in different phases of flight; therefore, the LCL corresponds to the most critical Failure Condition
- (ii) In addressing the Failure Condition in Table 2, the nature of IEL should be considered. The potential for common cause of failures across multiple equipment/systems performing the same or different functions due to the simultaneous exposure to the IEL threat should be considered. Additionally, the inherent immunity of mechanical systems with no electrical circuitry should also be considered.
- (iii) In addressing the Failure Condition in Table 2, the indirect effects of lightning should not be combined with random failures that are not the result of the IEL threat.
- (iv) Due to the similar approach in the safety assessment process related to IEL and HIRF, the System Certification Levels for HIRF and Lightning are usually the same.

(d) IEL Compliance Verification

- (1) Unless operational limitations are implemented to only allow operation in VFR Day with reliable weather reports on the absence of significant clouds, or the Operation in VFR is permitted with certified VTOL systems to detect the lightning strike or storm cells, then the likelihood of exposure to lightning in VMC condition has to be considered (see Figures 1 and 2 in Section 5). Nevertheless, the Hazard related to this exposure on VTOL aircraft could be assessed by comparing the Rate of lightning strike to Aircraft and the Safety objectives at Aircraft Level (see Table 3 in Section 5); in some cases, the probability of having a lightning strike to an aircraft is lower than the probability of having a failure from another technical cause. In such cases, the Hazard associated with a lightning strike can be considered to be unlikely and therefore for lower IEL Groups and the IEL Groups operating in VFR, VTOL.2515 (b) is not applicable for Level B and/or C systems that can be removed from the verification (see Section 6).
- (2) IEL Group I
 - (i) For level A Systems (Display and Non-Display)
 - (A) Follow the AMC 20-136; or
 - (B) Conduct Equipment/System testing using the following categories:
 - (a) According to the VTOL aircraft primary structure and wiring type, choose the appropriate Category/Waveform at Level 3 in EUROCAE ED-14G section 22.
 - (b) Fail/Pass Criteria: when subjected to the Lightning Environment, it could be acceptable that equipment is/are subject to adverse effect, provided that the Level A function is maintained at the aircraft level and all the Equipment/Systems that are required in normal operation recover manually or automatically, in a timely manner, this function after the threat.
 - (ii) For Level B Systems on aircraft approved for IFR Operation
Conduct Equipment/System testing using the following categories:
 - (A) According to the VTOL aircraft primary structure and wiring type, choose the appropriate Category/Waveform at Level 2 in EUROCAE ED-14G 22.
 - (B) Fail/Pass Criteria; when submitted to the Lightning Environment, it could be acceptable that redundant equipment is/are subject to adverse effect, provided that the Level B function is recovered manually or automatically, in a timely manner, after the threat.
- (3) IEL Group II
 - (i) For level A Systems (Display and Non-Display)
 - (A) Follow the AMC 20-136; or
 - (B) Conduct Equipment/System testing using the following categories:
 - (a) According to the VTOL aircraft primary structure and wiring type, choose the appropriate Category/Waveform at Level 3 in EUROCAE ED-14G section 22.

(b) Fail/Pass Criteria; when submitted to the Lightning Environment, it could be acceptable that equipment is/are subject to adverse effect; provided that the Level A function is maintained at the aircraft level and all the Equipment/System, required in normal operation, recover manually or automatically, in a timely manner, this function after the threat.

(ii) For Level B Systems

Conduct Equipment/System testing using the following categories:

- (A) According to the VTOL aircraft primary structure and wiring type, choose the appropriate Category/Waveform at Level 2 in EUROCAE ED-14G 22.
- (B) Fail/Pass Criteria; when submitted to the Lightning Environment, it could be acceptable that redundant equipment is/are subject to adverse effects, provided that the Level B function is recovered manually or automatically, in a timely manner, after the threat.

(4) IEL Group III

(i) For Level A Non-Display Systems:

- (A) Follow the AMC 20-136; or
- (B) Determine the aircraft Actual Transient Level (ATL) (by test, analysis, combination of both or by similarity); and
- (C) Conduct Equipment/System testing using the following categories:
 - (a) According to the VTOL aircraft primary structure and wiring type, choose the appropriate Category/Waveform at Level 3 or 4 in EUROCAE ED-14G section 22.
 - (b) Fail/Pass Criteria; when submitted to the Lightning Environment, it could be acceptable that equipment is/are subject to adverse effect, provided that the Level A function is maintained at the aircraft level and all the Equipment/Systems that are required in normal operation, recover manually or automatically, in a timely manner, this function after the threat.
 - (c) Verify the positive margin between the default levels applied during the Equipment/System testing (EDTL as defined in (a)) and the Transient Control Level (TCL, maximum expected aircraft ATLs). If a positive margin is not established, corrective measures should be implemented in line with AMC 20-136.

(ii) For level A Display Systems:

Conduct Equipment/System testing using the following categories:

- (A) For VTOL aircraft with primarily metal structure, EUROCAE ED-14G section 22 category A3J3L3.
- (B) For VTOL aircraft with primarily carbon fibre, fiberglass or non-conductive material structure, EUROCAE ED-14G section 22 category B3K3L3.

- (C) Fail/Pass Criteria; when submitted to the Lightning Environment, it could be acceptable that equipment is/are subject to adverse effect, provided that the Level A function is maintained at the aircraft level and all the Equipment/Systems required in normal operation recover manually or automatically, in a timely manner, this function after the threat.
- (iii) For level B Systems:
Conduct Equipment/System testing using the following categories:
- (A) For VTOL aircraft with primarily metal structure, EUROCAE ED-14G 22 category A2J2L2.
- (B) For VTOL aircraft with primarily carbon fibre, fiberglass or non-conductive material structure, EUROCAE ED-14G section 22 category B2K2L2.
- (C) Fail/Pass Criteria; when submitted to the Lightning Environment, it could be acceptable if redundant equipment is/are subject to adverse effect, provided that the Level B function is recovered manually or automatically, in a timely manner, after the threat.
- (iv) For Level C Systems on aircraft approved for IFR Operation:
Conduct Equipment/System testing using the following categories:
- (A) For VTOL aircraft with primarily metal structure, EUROCAE ED-14G 22 category A1J1L1.
- (B) For VTOL aircraft with primarily carbon fibre, fiberglass or non-conductive material structure, EUROCAE ED-14G section 22 category B1K1L1.
- (C) Fail/Pass Criteria; when submitted to the Lightning Environment, it could be acceptable that redundant equipment is/are subject to adverse effect, provided that the Level C function is recovered manually or automatically, in a timely manner, after the threat.
- (5) IEL Testing for Level A Systems considerations;
- (i) The Test Levels for upper IEL Group could also be used for lower IEL Group; for instance, the use of the level for Level A Non-Display System for IEL Group III can be used for Level A System of IEL Groups I/II.
- (ii) Equipment testing is acceptable when it is shown that the interdependencies between equipment performing a function are understood and each equipment is tested and monitored to verify there is no unacceptable upset of the function.
- (iii) If similar equipment are used to perform the same function, the test can be limited to a single equipment.
- (6) Level A System architecture consideration: when a level A system is composed of redundant channels/equipment that perform the same level A function, it is permitted to limit the system to the channels/equipment that are required in normal operation provided that they are not susceptible when they comply with VTOL.2515(a); for instance if it is demonstrated that the primary channels comply with VTOL.2515(a) without the support of the back-up channel, the equipment of this channel is/are not required to be qualified to Level 3/4, however this back-up channel should be considered to be as a level B system (Level 2).

5. Rate of Lightning strike to small aircraft and Failure Condition Likelihood

(a) Rates of Lightning strike in General Aviation

Research on lightning strikes to aircraft has shown that the rate of lightning strikes per flight cycle is closely correlated to several parameters: the size, the cruise altitude and the ratio of VMC/IMC conditions. This correlation provides a method for estimating the likelihood of lightning strikes to smaller aircraft.

Table 3 provides estimated small aircraft lightning strike rates based on this correlation.

A/C Class	Class I	Class II	Class III
Percentage of operations in instrument meteorological conditions	10%	27%	38%
Rate of lightning strikes per flight cycle	$7 \cdot 10^{-6}$	$2 \cdot 10^{-5}$	$7 \cdot 10^{-5}$
Hours per flight cycle	0.73	0.80	1.41
Rate of lightning strikes per flight hour	10^{-5}	$3 \cdot 10^{-5}$	$5 \cdot 10^{-5}$

Table 3 - Estimated small aircraft lightning strike rates

(b) Environmental Condition and Aircraft Position

A Lightning strike database has been established for the FAA; it compiles all the lightning strikes reports involving small aircraft.

Figure 1 shows, from this Lightning Strike database shows the position of the aircraft when it was struck by lightning. It can be seen from this figure that this mainly occurs when the aircraft is in clouds where intra-clouds flashes are intercepted by the Aircraft. In a few cases, below clouds, it is possible that Cloud-to-ground Lightning strikes are intercepted or triggered by the Aircraft.

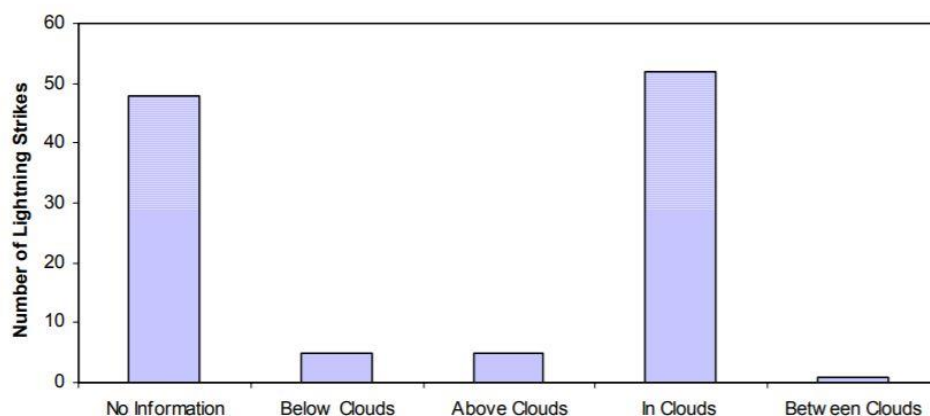


Figure 1 - Number of Lightning Strikes vs Aircraft Position

Figure 2 shows, from this Lightning strike database, the environmental conditions of the aircraft when it was struck by lightning. It can be seen from this figure that Lightning Strike mainly occurs under rain or hail conditions but in 30% of the cases there was no precipitation.

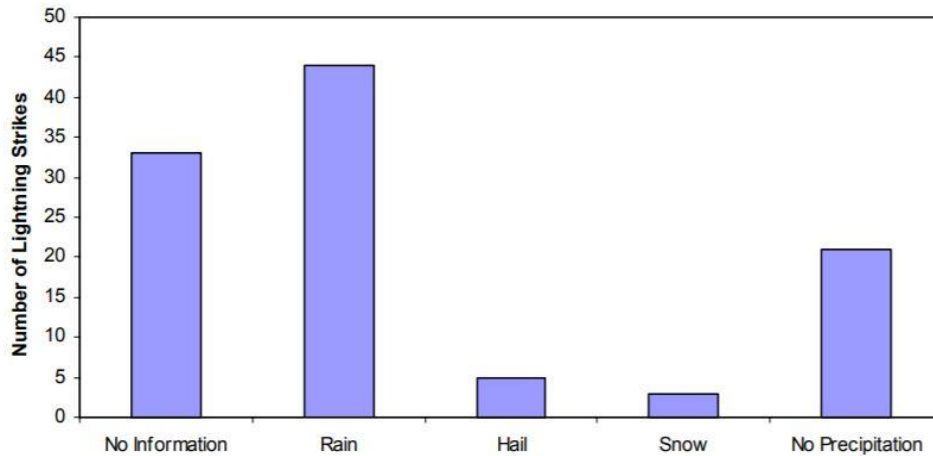


Figure 2 - Number of Lightning Strikes vs Environmental Conditions

Table 4 presents the Rates of lightning strike to Aircraft according to the IEL Group; these Rates are the results of the data from the Table 1 and Figures 1 and 2 extrapolated to VTOL Groups.

A/C Group	IEL Group I VFR ⁽¹⁾⁽²⁾	IEL Group I IFR ⁽¹⁾⁽²⁾	IEL Group II VFR ⁽¹⁾⁽²⁾	IEL Group II IFR ⁽¹⁾⁽²⁾	IEL Group III VFR ⁽¹⁾⁽²⁾	IEL Group III IFR ⁽¹⁾⁽²⁾
R Lightning Strike /FH	$5 \cdot 10^{-6}$	$5 \cdot 10^{-5}$	$8 \cdot 10^{-6}$	$8 \cdot 10^{-5}$	10^{-5}	10^{-4}

Table 4 - IEL Group Lightning Strike Rates

⁽¹⁾ For simplification it has been assumed that aircraft flying under VFR are in VMC and aircraft flying under IFR are in IMC for 50% and VMC for 50% of the flight time (so same order of magnitude between IMC and IFR)

⁽²⁾ A factor 10^{-1} has been applied to the Rate of Lightning Strike to aircraft between IFR and VFR operations (according to data from Figures 1 and 2).

(c) Hazard on VTOL aircraft

By comparing the Rate of Lightning Strike and the Safety Objective at Aircraft Level, we can determine its associated Hazard category.

Table 5 provides the likelihood of the Hazard due to Lightning Strike for a given IEL Group.

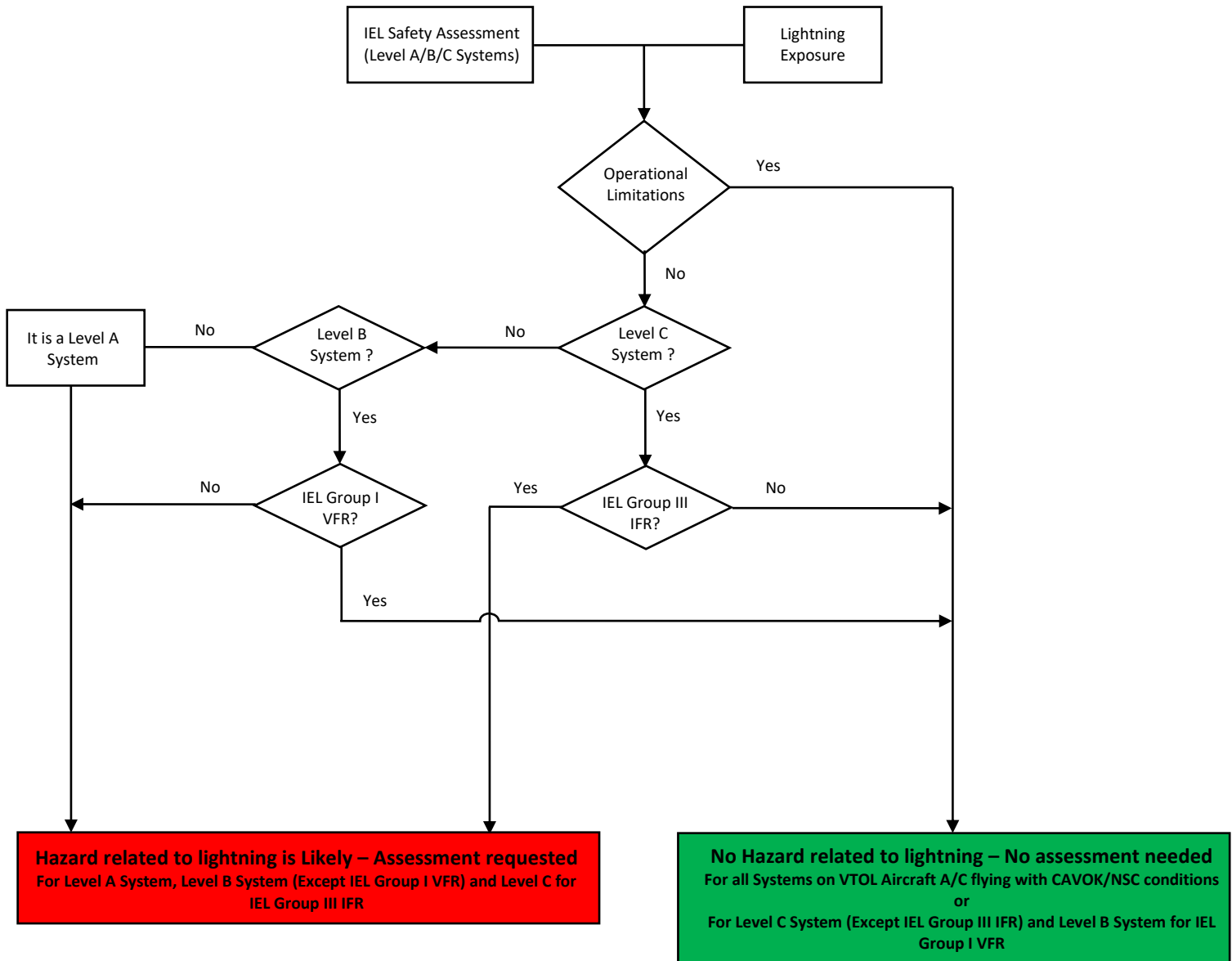
Failure Condition A/C Group	Catastrophic (Level A)	Hazardous (Level B)	Major (level C)
IEL Group I VFR	Likely (Safety Objectives 10^{-6})	Unlikely (Safety Objectives 10^{-5})	Unlikely (Safety Objectives 10^{-4})
IEL Group I IFR	Likely (Safety Objectives 10^{-6})	Likely (Safety Objectives 10^{-5})	Unlikely (Safety Objectives 10^{-4})
IEL Group II VFR	Likely (Safety Objectives 10^{-7})	Likely (Safety Objectives 10^{-6})	Unlikely (Safety Objectives 10^{-4})
IEL Group II IFR	Very Likely (Safety Objectives 10^{-7})	Likely (Safety Objectives 10^{-6})	Unlikely (Safety Objectives 10^{-4})
IEL Group III VFR	Very Likely (Safety Objectives 10^{-8})	Likely (Safety Objectives 10^{-6})	Unlikely (Safety Objectives 10^{-4})
IEL Group III IFR	Very Likely (Safety Objectives 10^{-8})	Likely (Safety Objectives 10^{-6})	Likely (Safety Objectives 10^{-4})

Table 5 - Likelihood of Hazard due to Lightning Strike

$P_{\text{Hazard}} = R_{\text{Lightning Strike}} / S_{\text{Safety Objective}}$

$P_{\text{Hazard}} < 1$: Hazard is Unlikely, $1 \leq P_{\text{Hazard}} \leq 10^2$: Hazard is Likely, $P_{\text{Risk}} > 10^2$: Hazard is Very Likely

6. Decisional Flow Chart on the Hazard related to Lightning Exposure to Aircraft



MOC VTOL.2520 High-intensity radiated fields (HIRF) protection

1. Scope of this MOC

This MOC proposes simplified methods for addressing High Intensity Radiated Fields (HIRF) compliance demonstration on VTOL aircraft. These methods depend on the VTOL Aircraft Category; Basic 0 to 1 passenger, Basic 2 to 6 passengers, Basic 7 to 9 passengers and Enhanced.

The topics covered within this MOC are: Minimum Design Requirements, HIRF Group Determination, HIRF Safety Assessment and HIRF Compliance Verification.

2. Reference Documents

The following references are quoted in different sections of this MOC as a source of additional information or to provide accepted methods and practices:

(a) Industry Standards

(1) ASTM

F3061/F3061M	Specification for Systems and Equipment in Small Aircraft
F3230	Standard Practice for Safety Assessment of Systems and Equipment in Small Aircraft
F3309	Standard Practice for Simplified Safety Assessment of Systems and Equipment in Small Aircraft

(2) EUROCAE/SAE/RTCA

ED-107A/ARP 5583A	Guide to Certification of Aircraft in a High Intensity Radiated Field (HIRF) Environment
ED-14()/DO- 160()	Environmental Conditions and Test Procedures for Airborne Equipment

(b) Authorities Guidance

(1) FAA

PS-ACE-23-10	HIRF/Lightning Test Levels and Compliance Methods for 14 CFR Part 23 Class I, II, and III Airplanes <i>Note: only partially recognised by EASA</i>
AC 23.1309-1E	System Safety Analysis and Assessment for Part 23 Airplanes
AC 20-158A	The Certification of Aircraft Electrical and Electronic Systems for Operation in the High-intensity Radiated Fields (HIRF) Environment

(2) EASA

MOC VTOL.2510	Means of Compliance for VTOL Equipment Systems and installations
AMC 20-158	Aircraft Electrical and Electronic System High-intensity Radiated Fields (HIRF) Protection

3. Definitions

For the purpose of this MOC the following definitions apply:

- (a) Adverse Effect: A response of a system that results in an undesirable and/or unexpected operation of an aircraft system, or undesirable and/or unexpected operation of the function performed by the system.
- (b) Attenuation: Term used to denote a decrease in electromagnetic field strength in transmission from one point to another. Attenuation may be expressed as a scalar ratio of the input magnitude to the output magnitude or in decibels (dB).

- (c) Equipment: Component of an electrical or electronic system with interconnecting electrical conductors.
- (d) External High-intensity Radiated Fields Environment: Electromagnetic RF fields at the exterior of an aircraft.
- (e) Field Strength: Magnitude of the electromagnetic energy propagating in free space expressed in volts per meter (V/m).
- (f) High-intensity Radiated Fields (HIRF) Environment: Electromagnetic environment that exists from the transmission of high power RF energy into free space.
- (g) High-intensity Radiated Fields (HIRF) Test level: The level of Field Strength applied during the Equipment/System Test, it may vary according the RF Band.
- (h) HIRF Certification Level (HCL): The level of an electrical or electronic system that performs a function whose worst Failure Condition classification is catastrophic, hazardous or major.
- (i) HIRF Group: Group of VTOL categories having the same methodology for their HIRF compliance demonstration. 3 Groups have been identified; Group I for VTOL Category “Basic 1” (0-1 passenger), Group II for VTOL Category “Basic 2” (2-6 passengers) and Group III for VTOL Categories “Basic 3” (7-9 passengers) and Enhanced.
- (j) Immunity: The capacity of a system or piece of equipment to continue to perform its intended function, in an acceptable manner, in the presence of RF fields.
- (k) Internal HIRF Environment: RF environment inside an airframe, equipment enclosure, or cavity. The internal RF environment is described in terms of the internal RF field strength or wire bundle current.
- (l) Normal Operation: A state of the system where the system is performing its intended function. When addressing compliance with VTOL.2520 (a) (2), the function whose failure would prevent the continued safe flight and landing for Category Enhanced or a controlled emergency landing for Category Basic should be in the same undisturbed state than before exposure to the HIRF threat. Other functions, performed by the same system, subject to VTOL.2520 (b), are not required to be recovered.
- (m) Radio Frequency (RF): Frequency useful for radio transmission. The present practical limits of RF transmissions are roughly 10 kilohertz (kHz) to 100 gigahertz (GHz). Within this frequency range, electromagnetic energy may be detected and amplified as an electric current at the wave frequency.
- (n) System: The piece of equipment connected via electrical conductors to another piece of equipment, both of which are required to make a system function. A system may contain pieces of equipment, components, parts, and wire bundles.
- (o) Transfer Function: The ratio of the electrical output of a system to the electrical input of a system, expressed in the frequency domain. For HIRF, a typical transfer function is the ratio of the current on a wire bundle to the external HIRF field strength, as a function of frequency.
- (p) Upset: An impairment of system operation, either permanent or momentary. For example, a change of digital or analogue state that may or may not require a manual reset.

4. Means of Compliance

(a) Minimum Design Considerations

- (1) In order to utilise the methods described in this practice, the following minimum design considerations should be addressed. If deviations from these minimum design considerations are desired, the acceptability of the methods described should be agreed to by EASA.
- (2) The airframe should incorporate low impedance electrical conductors to allow induced current to flow through the aircraft. The low impedance conductors should be incorporated into the basic structure of the aircraft.

- (i) For aircraft with primarily metal structure, the metal skin provides a low impedance electrical conductor. Standard rivets and bolts should provide adequate electrical bonding between permanent structural joints. Electrical bonding straps or jumpers should be installed on moving parts or for removable panels or parts.
- (ii) For aircraft with primarily carbon fibre or fiberglass structure, metal mesh, metal foil, or expanded metal foil should be incorporated onto the external surfaces of the aircraft composite structure. This mesh or foil should be joined together electrically and provide a continuous electrical conductor between the extremities of the aircraft. Metallic components that are internal to the structure of the aircraft may also be used to provide similar shielding for equipment and its wiring.
- (iii) For aircraft constructed of tube and fabric, the tube skeleton can be considered to be the low impedance electrical path through the aircraft. The bonding also may be achieved by the use of bonding straps or jumpers where required to electrically bond other metallic sub-structure that might be relied upon to provide bonding for equipment.

- (3) Electrical bonding specifications and verifications should be developed and implemented on the production drawings and instructions for continued airworthiness.

(b) HIRF Group Determination

The HIRF Group should be identified by using Table 1; the relevant Group will determine the HIRF Compliance Verification method given in paragraph (d).

	VTOL Categories			
	Basic (max passenger seating configuration)			Enhanced
	0-1	2-6	7-9	
HIRF Group	I	II	III	III

Table 1 – HIRF Group Allocation

(c) HIRF Safety Assessment

- (1) The VTOL aircraft systems that require a HIRF Safety Assessment should be identified. The elements of the system that perform a function should be defined, considering the use of redundant and/or backup equipment that constitutes the system. The process used for identifying these systems should be similar to the process used for showing compliance with VTOL.2510. This requirement addresses any system failure that may cause or contribute to an effect on the safety of flight of a VTOL aircraft. The effects of a HIRF encounter should be assessed to determine the degree to which the aircraft and its systems safety may be affected. The operation of the aircraft systems should be assessed separately and in combination with, or in relation to, other systems. This assessment should cover:
 - (i) All normal VTOL aircraft operating modes, stages of flight, and operating conditions;
 - (ii) All failure conditions and their subsequent effect on VTOL aircraft operations and the flight crew; and
 - (iii) Any corrective actions required by the flight crew
- (2) A safety assessment related to HIRF should be performed to establish and classify the equipment or system failure condition. Table 2 provides the corresponding Failure

condition classification and system HIRF certification level for VTOL.2520. The HIRF safety assessment determines the consequences of failures, due to HIRF, for the aircraft functions that are performed by the system. The HIRF Certification Level (HCL) classification assigned to the system and functions can be different from the Design Assurance Levels assigned for equipment function and/or item (software, and complex electronic hardware). This is because HIRF is an environment that can cause common cause effects. The term ‘Design Assurance Level’ should not be used to describe the HIRF Certification Level because of the potential differences in assigned classifications for software, complex electronic hardware, and equipment function

HIRF Requirements VTOL.2520	MOST CRITICAL FAILURE CONDITION OF THE FUNCTION	SYSTEM HIRF CERTIFICATION LEVEL (HCL)
(a) Each electrical and electronic system that performs a function, the failure of which would prevent continued safe flight and landing for Category Enhanced, or a controlled emergency landing for Category Basic, must be designed and installed such that: (1) The function at the aircraft level is not adversely affected during and after the time the aircraft is exposed to the HIRF environment; and (2) The system recovers normal operation of that function in a timely manner after the aircraft is exposed to the HIRF environment, unless the system’s recovery conflicts with other operational or functional requirements of the system.	Catastrophic	A
(b) Each electrical and electronic system that performs a function, the failure of which would reduce the capability of the aircraft or the ability of the flight crew to respond to an adverse operating condition, must be designed and installed such that the system recovers normal operation of that function in a timely manner after the aircraft is exposed to the HIRF environment.	Hazardous/Major	B/C

Table 2 – HIRF Failure Conditions and System HIRF Certification Level

- (3) The HIRF safety assessment should consider all potential adverse effects due to system failures; loss, malfunctions or misleading information caused by a HIRF threat. The HIRF safety assessment may show some systems have different failure conditions in different phases of flight; therefore, the HCL corresponds to the most critical Failure Condition.
- (4) In addressing the Failure Condition in Table 2, the nature of HIRF should be considered. The potential for common causes of failures across multiple equipment/systems performing the same or different functions due to the simultaneous exposure to the HIRF threat should be considered. Mechanical systems can be considered inherently immune to HIRF and may be used in the safety assessment.
- (5) In addressing the Failure Condition in Table 2, the effects of HIRF should not be combined with random failures that are not the result of the HIRF threat.

- (6) Due to the similar approach in the safety assessment process related to IEL and HIRF, the System Certification Levels for HIRF and Lightning are usually the same.

(d) HIRF Compliance Verification

- (1) By applying the 'Net Safety Benefit' approach¹ on the lower HIRF Group, VTOL.2520 (b) is not applicable for level C system of HIRF Groups I and II, it could be removed from the Compliance Verification.

- (2) HIRF Groups I and II

(i) For Level A Non-Display Systems:

(A) Follow AMC 20-158; or

(B) Conduct Equipment/System testing using the following default levels:

- (a) Conducted susceptibility testing with the Generic transfer function for aircraft (according to VTOL shape and size) extrapolated to the HIRF Environment III (as defined in Section 5) corresponding to the EUROCAE ED-14G section 20 categories Y or W.
- (b) Radiated Susceptibility testing with Generic attenuation curves (depending on equipment location) extrapolated to the HIRF Environment III (as defined in Section 5) corresponding to the EUROCAE ED-14G section 20 categories L, G or F
- (c) Fail/Pass Criteria; when subjected to the HIRF Environment, it could be acceptable that redundant equipment is/are subject to adverse effects, provided that the Level A function is maintained at the aircraft level and all the Equipment/Systems that are required in normal operation recover manually or automatically, in a timely manner, this function after the threat.

(ii) For Level A Display Systems:

(A) Follow the AMC 20-158; or

(B) Conduct Equipment/System testing using the following default levels:

- (a) Conducted susceptibility testing with the Generic transfer function for aircraft (according to VTOL shape and size) extrapolated to the HIRF Environment I (as defined in Section 5) corresponding to the EUROCAE ED-14G section 20 categories O or M.
- (b) Radiated Susceptibility testing with Generic attenuation curves (depending on equipment location) extrapolated to the HIRF Environment I (as defined in Section 5) corresponding to the EUROCAE ED-14G section 20 categories G, F or D.
- (c) Fail/Pass Criteria; when subjected to the HIRF Environment, it could be acceptable that redundant equipment is/are subject to adverse effects, provided that the Level A function is maintained at the aircraft level and all the Equipment/Systems that are required in normal operation

¹ For additional information, refer to the EASA Proposed Certification Memorandum CM-SA-001 published in the EASA Website: [Proposed Certification Memorandum CM-SA-001 - Net Safety Benefit - Issue 01 | EASA \(europa.eu\)](#)

recover manually or automatically, in a timely manner, this function after the threat.

(iii) For Level B Systems:

- (A) Follow the AMC 20-158 (by using Equipment HIRF Test Levels 1 or 2 as defined in Section 5); or
- (B) Conduct Equipment/System testing as defined in (d) (2) (ii) (B) (a) and (b); when submitted to the HIRF Environment, if the Equipment/System subject to adverse effects does not to recover its level B function after the threat, the method proposed by the AMC 20-158 for Level B systems in (d) (2) (iii) (A) can be used as an alternatively.

(3) HIRF Group III

(i) For Level A Non-Display Systems:

- (A) Follow the AMC 20-158; or
- (B) Conduct Equipment/System testing using the following default levels:
 - (a) Conducted susceptibility testing with the real transfer function of the aircraft (determined by Low Level coupling test, analysis, combination of both or similarity) extrapolated to the HIRF Environment III (as defined in Section 5).
 - (b) Radiated Susceptibility testing with real attenuation curves (determined by Low level Testing, analysis, combination of both or similarity) extrapolated to the HIRF Environment III (as defined in Section 5).
 - (c) Fail/Pass Criteria; when submitted subjected to the HIRF Environment, it could be acceptable that redundant equipment is/are subject to adverse effects, provided that the Level A function is maintained at the aircraft level and all the Equipment/Systems that are required in normal operation recover manually or automatically, in a timely manner, this function after the threat.

(ii) For Level A Display Systems:

- (A) Follow the AMC 20-158; or
- (B) Conduct Equipment/System testing using the following default levels:
 - (a) Conducted susceptibility with the Generic transfer function for aircraft (according to VTOL shape and size) extrapolated to the HIRF Environment I (as defined in Section 5) corresponding to the EUROCAE ED-14G section 20 categories O or M.
 - (b) Radiated Susceptibility with Generic attenuation curves (depending on equipment location) applied HIRF Environment I (as defined in Section 5) corresponding to the EUROCAE ED-14G section 20 categories G, F or D.
 - (c) Fail/Pass Criteria; when subjected to the HIRF Environment, it could be acceptable that redundant equipment are subject to adverse effect,

provided the Level A function is maintained at the aircraft level and all the Equipment/Systems required in normal operation recover manually or automatically, in a timely manner, this function after the threat.

(iii) For Level B Systems:

- (A) Follow the AMC 20-158 (by using Equipment HIRF Test Levels 1 or 2 as defined in Section 5); or
- (B) Conduct Equipment/System testing as defined in (d) (3) (ii) (a) and (b); when submitted to the HIRF Environment, if the Equipment/System, subject to adverse effects, does not to recover to its level B function after the threat, the method proposed by the AMC 20-158 for Level B systems in (d) (3) (iii) (A) can be used as an alternative.

(iv) For Level C Systems:

- (A) Follow the AMC 20-158 (by using Equipment HIRF Test Level 3 as defined in Section 5); or
- (B) Conduct Equipment/System testing as defined in (d) (3) (ii) (a) and (b); when submitted to the HIRF Environment, if the Equipment/System, subject to adverse effects, does not to recover to its level C function after the threat, the method proposed by the AMC 20-158 for Level C systems in (d) (3) (iv)(A) can be used as an alternative.

(4) HIRF Testing for Level A systems considerations;

- (i) The Test Levels for upper HIRF Group can also be used for lower HIRF Groups; for instance the use of real transfer function and attenuation curves and/or more severe External HIRF Environment can be used for Level A Systems of HIRF Groups I/II.
- (ii) Equipment testing is acceptable when it is shown that the interdependencies between equipment performing a function are understood and each equipment is tested and monitored to verify that there are no unacceptable upsets of the function.
- (iii) If similar equipment are used to perform the same function; the test can be limited to a single equipment.

(5) Level A System architecture consideration; when a Level A system comprises redundant channels/equipment that perform the same level A function, it is permitted to limit the system to the channels/equipment that are required in normal operation provided that they are not susceptible when they comply with VTOL.2520(a); for instance if it is demonstrated that the primary channels comply with VTOL.2520(a) without the support of the back-up channel, this channel is not requested to be exposed to the HIRF Environment I/III, however this back-up channel should be considered to be a level B system.

5. HIRF Environments and Equipment HIRF Test Levels

This Section specifies the HIRF environments and equipment HIRF test levels for electrical and electronic systems under VTOL.2520.

(a) HIRF environment I is specified in the following Table 3:

Table 3 — HIRF Environment I

FREQUENCY	FIELD STRENGTH (V/m)	
	PEAK	AVERAGE
10 kHz - 2 MHz	50	50
2 MHz - 30 MHz	100	100
30 MHz - 100 MHz	50	50
100 MHz – 400 MHz	100	100
400 MHz – 700 MHz	700	50
700 MHz - 1 GHz	700	100
1 GHz - 2 GHz	2000	200
2 GHz - 6 GHz	3000	200
6 GHz - 8 GHz	1000	200
8 GHz - 12 GHz	3000	300
12 GHz - 18 GHz	2000	200
18 GHz - 40 GHz	600	200

In this table, the higher field strength applies at the frequency band edges.

(b) HIRF environment II is specified in the following Table 4:

Table 4 — HIRF Environment II

FREQUENCY	FIELD STRENGTH (V/m)	
	PEAK	AVERAGE
10 kHz – 500 kHz	20	20
500 kHz - 2 MHz	30	30
2 MHz - 30 MHz	100	100
30 MHz – 100 MHz	10	10
100 MHz – 200 MHz	30	10
200 MHz - 400 MHz	10	10

FREQUENCY	FIELD STRENGTH (V/m)	
	PEAK	AVERAGE
400 MHz - 1 GHz	700	40
1 GHz - 2 GHz	1300	160
2 GHz - 4 GHz	3000	120
4 GHz - 6 GHz	3000	160
6 GHz - 8 GHz	400	170
8 GHz - 12 GHz	1230	230
12 GHz – 18 GHz	730	190
18 GHz - 40 GHz	600	150

In this table, the higher field strength applies at the frequency band edges.

(c) HIRF environment III is specified in the following Table 5:

Table 5 — HIRF Environment III

FREQUENCY	FIELD STRENGTH (V/m)	
	PEAK	AVERAGE
10 kHz – 100 kHz	150	150
100 kHz - 400 MHz	200	200
400 MHz - 700 MHz	730	200
700 MHz – 1 GHz	1400	240
1 GHz - 2 GHz	5000	250
2 GHz - 4 GHz	6000	490
4 GHz - 6 GHz	7200	400
6 GHz - 8 GHz	1100	170
8 GHz - 12 GHz	5000	330
12 GHz – 18 GHz	2000	330

FREQUENCY	FIELD STRENGTH (V/m)	
	PEAK	AVERAGE
18 GHz - 40 GHz	1000	420

In this table, the higher field strength applies at the frequency band edges.

(d) Equipment HIRF Test Level 1.

Equipment Level Test ED-14G (or later Revision) Cat R for both conducted and radiated susceptibility.

(e) Equipment HIRF Test Level 2.

Equipment HIRF test level 2 is HIRF environment II in table 4 of this Section reduced by acceptable generic aircraft transfer function and attenuation curves. Testing should cover the frequency band of 10 kHz to 8 GHz.

(f) Equipment HIRF Test Level 3.

Equipment Level Test ED-14G (or later Revision) Cat T for both conducted and radiated susceptibility.

MOC VTOL.2555 Installation of recorders

This MOC is applicable to each recorder installed to comply with VTOL.2555.

(a) General:

The recorder should have an ETSO authorisation against one of the following ETSOs or a later equivalent:

- (1) ETSO-C123b; or
- (2) ETSO-C124b; or
- (3) ETSO-2C197

(b) Recorder installation:

The container of the recording medium should be located and mounted so as to minimise the probability of the container rupturing or the recording medium being destroyed as a result of impact with the Earth's surface or of heat damage caused by a post-impact fire.

The structural provisions within the aircraft for the mounting of the recorder should be able to withstand the loads resulting from severe vibration (such as those resulting from rotor imbalance). In addition, the strength of the local attachments should be able to withstand the crash safety loads in CS 27.561(b)(3).

If the recorder has an erasure device or function, the installation must be designed to minimise the probability of inadvertent operation and actuation of the erasure device or function during crash impact.

(c) Recorder identification:

A high proportion of the area of the outer surfaces of the container of the memory medium should be coloured bright orange.

The height, width and depth of the container of the memory medium must each be 4 cm (1.5 inches) or greater

(d) Recorder characteristics:

The recorder should:

- (1) Permit quick downloading of the flight parameters without having to remove the recorder;
- (2) Be capable of retaining the flight parameters that are recorded during at least the preceding 5 hours and the audio recording during at least the preceding 2 hours;
- (3) Automatically start to record as early as possible after power-on and in any case prior to the aircraft being capable of moving under its own power;
- (4) Continue to record until the termination of the flight when the aircraft is no longer capable of moving under its own power;
- (5) If the recorder has a recording duration of less than 25 hours, have a means for the flight crew to stop the recording upon completion of the flight in such a way that re-enabling the recording is only possible by a dedicated manual action.

(e) Flight Parameters and audio recording:

The recorder, or the combination of recorders installed to comply with VTOL.2555, should:

- (1) Record the flight parameters required to accurately determine the flight path, speed, attitude, engine power, operation and configuration of the VTOL aircraft. The minimum list of flight parameters to be recorded is provided in paragraphs (h) and (j). All recorded parameter values should be accurately time-stamped according to a common time reference and be recorded at a rate not below 4 Hz;
- (2) For aircraft with a minimum flight crew of two pilots, simultaneously record, on separate channels and with reference to a timescale:
 - (i) The aural environment of the cockpit (area microphone);
 - (ii) Pilots' headset audio, including but not limited to voice communications, audio signals for navigation aids, aural alerts.

(f) Maintenance instructions:

- (1) When developing the ICA for the recorder systems, the applicant should address all the failures that may affect their correct functioning or the quality of the recorded information. Note: 'Recorder systems' designates the recorders and their dedicated equipment (e.g. dedicated sensors or transducers, dedicated data buses, dedicated power source...).
- (2) Examples of failures (indicative and non-exhaustive list):
 - (i) Loss of the recording function or of the acquisition function of the recorder;
 - (ii) Failure of a means to facilitate the finding of the recording medium after an accident (e.g. an underwater locating device or an emergency locator transmitter attached to the recorder);
 - (iii) Failure of a means to detect a crash impact (for the purpose of stopping the recording after a crash impact, or for the purpose of deploying the recorder if it is deployable);
 - (iv) Failure of any power source dedicated to the recorder (e.g. dedicated battery);
 - (v) Failure of the start-and-stop function;

- (vi) Failure of a sensor dedicated to the recorder system;
- (vii) For flight parameters recording, when any required parameter is missing, or is not correctly recorded;
- (viii) For audio recording (if applicable):
- (ix) Any required audio signal is missing, or is recorded with an audio quality that is rated 'poor' (refer to the example of audio quality rating provided in Section 9 of AMC 25.1459);
- (x) Failure of a transducer or amplifier dedicated to the recorder system (e.g. failure of the cockpit area microphone).

(g) Data transmission & ground recording: [Reserved]

(h) The following flight parameters should as a minimum be recorded with a recording resolution at least as high as specified in EUROCAE Documents ED-155 or ED-112:

- (1) Time
- (2) Altitude
- (3) Latitude
- (4) Longitude
- (5) Indicated airspeed or calibrated airspeed
- (6) Groundspeed
- (7) Outside Air Temperature (OAT)
- (8) Heading (magnetic or true)
- (9) Track
- (10) Vertical speed
- (11) Pitch attitude
- (12) Roll attitude
- (13) Longitudinal acceleration (body axis)
- (14) Normal acceleration
- (15) Lateral acceleration
- (16) Roll rate or Roll acceleration
- (17) Pitch rate or Pitch acceleration
- (18) Yaw rate or yaw acceleration
- (19) If electric engines are used:
 - (i) Electric Engines: rotation speed of each rotor (in RPM)
 - (ii) Electric Engines: health status of each electric engine controller
 - (iii) Electric Engines: temperature of each electric engine
 - (iv) Electric Engines: temperature of each electric engine controller
 - (v) Electric Engines: measured electrical current for each electric engine
 - (vi) For liquid cooled electric engines: pressure and temperature of the cooling liquid
- (20) Flight controls
 - (i) Pilot input positions on all axis and corresponding flight control,
 - (ii) Outputs (e.g. target RPM for each electric engine, flight surface positions, ...)
- (21) Status of each flight control computer
- (22) Wings angle (if applicable)
- (23) Nacelles angles (if applicable)

- (24) Propeller pitch (for each variable pitch propeller)
 - (25) Air-Ground status such as Weight on Wheels or equivalent parameter
 - (26) Alerts (including master warning and master caution status)
 - (27) Manual voice transmission keying (if voice communications are used)
 - (28) For each battery used for propulsion and/or flight controls:
 - (i) Health status, State Of Charge (SOC), voltage, temperature, current flow,
 - (ii) if available:
 - (A) State of Power (SOP); or
 - (B) Calculated remaining flight time.
 - (29) Health status of each electrical distribution unit (e.g. distribution units, converters) contributing to the propulsion and/or flight controls
 - (30) Status of the battery management system (if any)
 - (31) If combustion engine(s) are used:
 - (i) Fuel parameters;
 - (ii) Oil pressure and oil temperature;
 - (iii) Parameters required to determine propulsive thrust or power delivered;
 - (iv) Turbine RPM (if applicable);
 - (v) FADEC health status (if applicable);
 - (vi) Aircraft inputs used by the FADEC (if applicable);
 - (vii) Any electrical current generation; and
 - (viii) Any other parameter subject to a limitation
- (i) In addition, the following flight parameters should be recorded if they are used by the aircraft systems or are available for use by the pilot to operate the aircraft. They should be recorded with a recording resolution at least as high as specified in EUROCAE Documents ED-155 or ED-112:
- (1) Active AFCS mode
 - (2) Radio altitude or terrain elevation
 - (3) Current navigation source,
 - (4) Vertical and lateral deviation with respect to current active navigation path
 - (5) DME 1 & 2 distances
 - (6) Drift angle
 - (7) Wind speed
 - (8) Wind direction
 - (9) Landing gear position
 - (10) Ice: ice detection, status of de-icing or anti-icing system
 - (11) Electric Engine: vibration level
 - (12) Traffic advisories or alerts, if installed (e.g. ADS-B IN, ACAS...)
 - (13) Obstacle and terrain alerts, if installed (e.g. TAWS, ...)
- (j) If the VTOL aircraft has datalink communication capabilities, the following should be recorded:
- (1) data link communication messages to and from the aircraft, including messages applying to the following applications:
 - (i) data link initiation and termination,

- (ii) controller-pilot communication,
 - (iii) addressed surveillance,
 - (iv) flight information, including weather data (if required for operation),
 - (v) aircraft broadcast surveillance,
 - (vi) aircraft operational control data, and
 - (vii) graphics.
- (2) information that enables correlation to any associated records related to data link communications and stored separately from the helicopter; and
- (3) information on the time and priority of data link communications messages, taking into account the system's architecture.