Fourth Publication of Means of Compliance with the Special Condition VTOL

The document at hand, Doc. No. MOC-4 SC-VTOL, contains the fourth publication of MOCs with the Special Condition VTOL. It proposes new MOCs, as well as supplements and amendments to the ones already published with Docs. No. MOC SC-VTOL, MOC-2 SC-VTOL and MOC-3 SC-VTOL. All MOC publications will continue to be consolidated in a single document in the Easy Access Rules (EAR) format for general convenience.

Statement of Issue

EASA has received a number of requests for the type certification of vertical take-off and landing (VTOL) capable aircraft (VCA), 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-capable aircraft (SC-VTOL) 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 VCA 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 SC-VTOL establishes the safety and design objectives. This approach, previously utilised for the development of CS-23 Amendment 5, is also used for VCA 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) in the different EASA publications address the applicants´ 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 defined 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 VCA. 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.

In May 2021, EASA completed the first publication of MOCs with the Special Condition VTOL in Doc. No. MOC SC-VTOL, Issue 2. This document considered all comments received during the public consultation of Issue 1, which were furthermore individually responded in an associated Comment Response Document, also published.

In December 2022, the second publication of MOCs was finalised with Doc. No. MOC-2 SC-VTOL issue 3. This publication introduced new MOCs, as well as amendments to some of those already published with Doc. No. MOC SC-VTOL, Issue 2. All comments received during the public consultation of Issue 1 were considered and individually responded in an associated Comment Response Document, also published.

In June 2023, EASA concluded the third publication of MOCs with Doc. No: MOC-3 SC-VTOL issue 2. This publication added a new MOC to the ones already published with the two previous publications. All comments received during the public consultation of Issue 1 were considered and individually responded in an associated Comment Response Document, also published.

These three publications already include the most urgently needed material for compliance demonstration with the SC-VTOL.

The fourth publication presented in this document introduces additional MOCs as well as corrections and amendments to some of the previously introduced MOCs. The majority of the content has been reviewed and discussed with industry standardisation working groups.

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.

The first issue of this document was subject to a public consultation on the EASA Comment-Response Tool (CRT) between 18 December 2023 and 01 March 2024.

Log of issues

Issue	Issue date	Change description
1	18/12/2023	First Issue for Public Consultation
2	11/07/2025	Second Issue for Final Publication MOC VTOL.2545 appears as "[Reserved]"; an extensive revision has been drafted and will be subject to a new public consultation.

Fourth Publication of Means of Compliance with the Special Condition VTOL

Contents

MOC - SUBPART A – GENERAL

MOC VTOL.2000 Applicability and definitions

Note:

The following new Section is added to MOC VTOL.2000 in Doc. No. MOC SC-VTOL Issue 2, dated 12 May 2021.

12. Conventional Take-off and Landing (CTOL) Capability

By definition, all VTOL-capable aircraft are able to take-off and land vertically. Some of them may also have the additional capability to take-off or land as conventional aeroplanes, accelerating and/or decelerating on a runway, also named CTOL or "conventional take-off and landing".

This mode of operation should be specifically considered in the definition of the applicable ground load conditions. It should be also addressed in the definition of the "emergency landing" and "survivable emergency landing" design cases (refer to Section 4 of this MOC), as the associated ground impact conditions are different than those of aircraft limited by design to a vertical take-off and landing.

Indeed, the associated MOCs already include specific provisions to address CTOL aircraft:

- MOC VTOL.2220 Ground and water load conditions
- MOC VTOL.2270(a) and (c) Emergency landing conditions: General considerations
- MOC VTOL.2270(b)(1) Emergency landing dynamic conditions
- MOC VTOL.2270(e) Cargo and baggage compartments
- MOC VTOL.2325(a)(4) Fire Protection - Energy storage crash resistance

The question now arises, when is the CTOL operation so significantly different from the VTOL operation to require the use of the additional and/or more stringent CTOL design conditions defined in the above MOCs.

From a review of the limitations applicable to already certified CS-27/29 rotorcraft types, it is evident that rotorcraft are permitted to land with a significant speed component in forward direction.

The highest emergency landing forward speed value for an EASA TC-approved rotorcraft is 60 kts. It is also considered normal practice for some rotorcraft to land with a forward speed, in accordance with the flight manual procedures, without additional certification considerations or maintenance actions.

As these rotorcraft have not been certified considering the additional landing cases or crashworthiness requirements beyond the CS-27/29 requirements, it is reasonable to allow the same for VTOL-capable aircraft designs.

Furthermore, emergency landing dynamic conditions are not required for aircraft certified under CS-VLA. One criterion for the applicability of CS-VLA, is that the aircraft must have a stalling speed in the landing configuration of not more than 83 km/h (45 knots CAS).

Considering the above and for the sole purpose of ascertaining the applicability of the additional and/or more stringent CTOL design conditions for crashworthiness and landing, the following definition is established:

(a) An aircraft is considered as having as CTOL capability if either of the following applies:

(1) Lift-off and touchdown forward speeds exceed 45 kts(A). For Category Enhanced this should include those compliant with the continued safe flight and landing requirement SC VTOL.2005.

(2) Maximum forward speeds at touch down for an emergency landing exceeds 60 kts(A).

For Category Basic this includes CEL.

Note (A): These speeds are ground speeds at touchdown.

MOC – SUBPART B – FLIGHT

MOC VTOL.2100 Mass and Centre of Gravity

This requirement aims at establishing the mass and centre of gravity limits for which certification is sought. To show compliance with this requirement, the applicant should determine two masses: the maximum certificated mass and the minimum certificated mass.

To determine the maximum and minimum certificated mass, the empty mass should be defined first.

1. Empty Mass

(a) The empty mass consists of the airframe, lift thrust units (LTUs), and all items of operating equipment that have fixed locations and are permanently installed (including both required and optional equipment) in the aircraft. It includes fixed ballast, unusable fuel, other unusable fluids, and full operating fluids, if applicable.

(b) 'Full operating fluids' such as oils used in an LTU, auxiliary power unit, main and auxiliary gearboxes, and hydraulic systems are considered "closed fluid systems" typically filled to a 'full mark' indicator level. Fluids necessary for the operation of non-permanently installed equipment (i.e., carry-on equipment) are not considered part of the empty mass.

(c) The empty mass does not include the removable Energy Storage System (ESS) components, when applicable.

(d) A ballast is fixed when made a permanent part of the aircraft as a means of controlling the empty mass centre of gravity (CG).

(e) Installed equipment is any approved equipment attached to the aircraft with hardware and, as a result, becomes an integral part of the aircraft. Compliance with VTOL.2100 (c) is accomplished using an equipment list specifying the installed equipment at the time of weighing and the mass arm and moment of the equipment.

2. Maximum Certificated Mass

(a) The maximum certificated mass is the maximum mass for which all certification requirements are met.

(b) The maximum mass should not be less than the empty mass.

(c) For the maximum mass calculations, a mass of 77 kg for each occupant including the crew, up to the maximum occupancy, should be considered. The applicant may select a lower occupant mass, if accepted by EASA and relevant limitations are established.

3. Minimum Certificated Mass

(a) The minimum certificated mass is the minimum mass for which all certification requirements are met.

(b) The minimum certificated mass should not be more than the sum of the following:
- empty mass of point 1 above;
- the mass of the minimum crew necessary to operate the aircraft, of point 3.(c);
- In case of removable ESS, the minimum required removable ESS for operation of the aircraft.

(c) For the minimum mass calculations, a mass of not more than 77 kg for each crew member should be considered. The applicant may select a lower occupant mass, if accepted by EASA.

4. Certificated longitudinal and lateral centre of gravity (CG) limits

(a) The certificated longitudinal and lateral CG limits should be established for the maximum and minimum certificated mass, and for any intermediate mass with a more severe centre of gravity.

(b) Compliance with all certification requirements should be met for all critical combinations of mass and CG.

(c) The applicant should establish the operational mass and centre of gravity limitations to be published in the AFM, which should not lie beyond the certificated mass and CG limitations.

(d) The effects of mass and CG limits on flight requirements of the SC-VTOL should be substantiated through flight test or, where agreed by EASA, through a combination of flight test and other means of compliance.

(1) The applicant's flight test plan should consider all the areas for which mass and CG are limiting factors and include the most critical combinations of mass and CG for each area under investigation.

(2) The following general tolerances are allowed during flight testing for mass and CG. However, greater tolerances may be allowed in particular tests, if agreed by EASA:

Item	Tolerance
Mass	+3%, –1%
CG	±7% total travel

5. Aircraft Flight Manual (AFM)

(a) The following information should be published in the limitations section of the AFM:

(1) the maximum and minimum certificated mass, and

(2) the longitudinal and lateral CG envelopes.

(b) For aircraft in the Category Enhanced, the AFM should publish as a function of the ambient conditions (density altitude, or other ambient parameters that influence the performance) the mass, up to the maximum selected by the applicant, at which a safe take-off and landing can be performed with the certified minimum performance (CMP) that considers the event of a critical failure for performance (CFP).

(c) For aircraft in the Category Basic, the AFM should publish the combinations of mass and ambient conditions for which a controlled emergency landing (CEL) is achievable. The maximum certificated mass should not be higher than the mass for which a critical failure for performance (CFP) along the take-off and landing path results in a CEL at ISA SL.

6. Removable ballast

CS 23.31 Amdt. 4 or CS 27.31 Amdt 7 with their related AMC are accepted means of compliance.

MOC VTOL.2105 Performance Data

1. Introduction

The requirement VTOL.2105 defines the conditions under which the Subpart B performance requirements must be met and the performance data that should be published. The performance data can be classified in the following categories:

(a) Regulatory performance data. This is the set of performance data which must be published in the AFM (see VTOL.2170 and VTOL.2620). The regulatory performance data includes:

(1) Airfield performance, which encompasses the take-off and landing performance, such as the climb gradients in the nominal case and with a Critical Failure for Performance (CFP), the take-off and landing distances, etc.;

(2) Climb/descent performance;

(3) Any other performance depending on the aircraft characteristics, such as the performance in hovering at h_1 and (if applicable) h_2 heights, the energy consumption and the 'State of function' (SoF) characteristics in relation to a flight profile (refer to EUROCAE ED-309 "Compliance methodologies for VTOL energy level information display to the crew", paragraph on in-flight prediction), etc.

(b) Minimum performance data. This is the set of performance data which describe the minimum performance certificated in Category Basic and Category Enhanced; for example, the minimum gradients that are achieved during a take-off.

(c) Non-regulatory performance data. This is the set of additional performance data which is not approved by EASA and the applicant deems useful for operational purposes. Non-regulatory performance data should be published in the non-approved part of the AFM. This MOC is not intended to provide guidance for determination and publication of non-regulatory performance data.

2. Minimum Performance Data

Minimum performances are likely to be those sizing the certificated mass and the operational flight envelopes. Failure to meet the minimum Subpart B performance requirements could result in a limitation in the operational flight envelopes (see VTOL.2110) and/or of the certificated mass and Centre of Gravity (CG) limits (see VTOL.2100).

(a) For an aircraft in the Category Basic, the minimum performance needs to be met only in still air at sea level in standard conditions (ISA SL).
In order to provide a set of operationally relevant data, the applicant is encouraged to determine the minimum performance considering wind limits and altitudes appropriate for the intended operations.

(b) For an aircraft in the Category Enhanced, the minimum performance must be met for all the ambient conditions included in the operational flight envelope (see VTOL.2105 (a) (2) (ii)). Therefore, the applicant should carefully define the target boundaries of the operational flight envelope before starting the performance flight test campaign.

3. Regulatory Performance Data

The regulatory performance must be determined and published for all the ambient conditions that define the operational flight envelope (see VTOL 2105(b), VTOL.2170, VTOL.2620). Therefore, the applicant should carefully define the target boundaries of the operational flight envelope before starting the performance flight test campaign.

(a) Range and endurance determination:
[*reserved*]

4. Parameters affecting Minimum and Regulatory Performance

Performance data should account for the flight envelopes to which they are referred.

Applicants should consider the following parameters when developing a plan to establish the aircraft performance data (where applicable, distinction is made between Categories Enhanced and Basic):

(a) Altitude and temperature effects

The applicant should consider altitude and temperature effects (density effects) when determining the minimum performance for category Enhanced, and when developing the regulatory performance data for Basic and Enhanced.

(1) two altitudes should be published in the AFM to define the flight envelopes of an aircraft: the maximum operating (or maximum cruise) altitude and the maximum take-off and landing altitude.

(i) Normal and operational flight envelopes may have different altitudes.
(ii) The maximum take-off and landing and the cruise altitudes are limited by the Outside Air Temperature (OAT).
(iii) A maximum and minimum OAT should be established to avoid any unsafe design feature inside the operational flight envelope for which certification is sought.

(2) Applicants may derive the performance from:
a. Flight test data, possibly complemented by data established using acceptable inter-/ extrapolation criteria
b. A performance prediction tool validated by actual flight test data, or
c. A combination of a. and b.
or derive them entirely from test data. In the absence of validated tools and agreed extrapolation criteria, performance should be based on test data acquired at the extremes of the altitude and OAT envelopes (high temperature/high altitude and low temperature/low altitude combinations).

(i) Compressibility effects at high altitude and low OAT should be investigated whenever of concern.
(ii) The performance test plan should allow gathering sufficient data to validate both the take-off and landing and the cruise envelopes. Test data should be gathered at least at the lowest and at the highest altitudes of both take-off and landing and cruise altitudes.
(iii) Medium altitude test points may be required for the take-off and landing depending on the extension of the altitude envelope.

(3) Acceptable interpolation and extrapolation criteria of flight test data for the altitude and temperature effects should be agreed with EASA.

(b) Mass and Centre of Gravity (CG)

(1) The applicant should establish the performance for the most critical combination of mass and CG, including lateral CG (if affecting performance).

(2) The applicant should determine the most critical CG condition for each performance data, which may vary depending on the VTOL design.

(3) Mass should span from the minimum mass up to the maximum mass as defined in VTOL.2100.

(c) Wind conditions

Wind conditions can significantly affect airfield performance (e.g. take-off and landing distances and climb gradients…) and hovering at h1 and h2. Therefore, when determining this performance, the applicant should take into account the wind conditions for which certification is required. The following chapters/paragraphs aim at providing guidance for Enhanced and Basic Category for airfield and minimum performance. For additional guidance on the wind effects on climb and hovering performance see also MOC VTOL.2125.

(1) Category Enhanced

(i) The airfield performance and the minimum performance data should be developed with the most critical wind condition for which certification is sought. When limitations to the wind intensity and azimuths are proposed to reduce the number of allowable wind conditions (e.g. no tail winds on take-off), the proposed limitations should be operationally feasible. In addition:

(A) In case of a Conventional Take-Off (ConvTO) (see MOC VTOL.2115) or a Conventional Landing (ConvL) (see MOC VTOL.2130), the applicant should select a maximum crosswind component not less than the highest of 0,2 V_{TOSS} and 0,2 V_{REF}. This maximum crosswind condition should be demonstrated by flight test

(B) In cases other than (A), the take-off and landing mass cannot be higher than the mass established to ensure controllability in accordance with SC VTOL.2135 (a)(6). However, the effect of crosswind on take-off and landing procedures should be assessed through flight test to confirm that the proposed procedures can be flown without requiring exceptional piloting skill.

(2) Category Basic

(i) When determining the minimum performance, the applicant may refer to still air and ISA sea level conditions (see VTOL. 2105 (a)(1)).

In order to provide a set of operationally relevant data, the applicant is encouraged to determine the minimum performance considering wind limits appropriate for the intended operations.

(ii) The airfield performance should be developed considering the most critical wind condition for which certification is sought.

(d) Energy Storage System characteristics and accessible power

(1) The applicant should consider the effects on performance of electric propulsion, which poses different challenges than traditional propulsion by internal combustion.

(2) The features of the Energy Storage System (ESS) that may affect the performance include, but are not limited to, the battery ageing, the battery thermal limits, and the variation of accessible energy in relation to the power demand profile during flight.

(3) The characteristics of the ESS should be known along with the critical parameters and associated limits that may affect the accessibility to the stored energy.

(4) When determining the minimum and regulatory performance, the applicant should consider the effect of the State of Function of the ESS (See EUROCAE Standard ED-289), which includes:

(i) Ageing of the ESS
(ii) State of charge of the Energy Storage System (ESS)
(iii) ESS cooling/heating effects

(e) Effects of installation losses, downwash and other demands of energy

(5) The applicant should consider the following elements that may affect minimum and regulatory performance:

(i) Lift Thrust Units (LTU) installation and cooling/heating losses: these losses are typically consequence of the LTU installation, and may reduce the rated thrust, or of the required power, in order to keep the temperature within the operating limits. In order to determine the minimum and regulatory performance, the cooling/heating systems should be set in the position that maintains the temperature of the LTU components within the established limits.
(ii) Downwash effects (see MOC VTOL.2400);
(iii) Additional power needed for the environmental protection systems (pitot heating, windshield defogging, icing protection);
(iv) Cockpit and cabin heating and cooling;
(v) Other demands of energy (e.g., the energy required for the avionics and flight control system, cockpit and cabin lights, external and landing lights).

(6) Special care should be given to hybrid power solutions, where the available energy may be impacted by other variables.

(f) Configuration

(1) The performance data should clearly describe the configuration to which they refer.

(2) The configuration description should include at least**:**

(i) the landing gear position (extended or retracted);
(ii) the setting of secondary aerodynamic surfaces such as flaps/slats;
(iii) the LTU position or range of positions, depending on whether they are directly controlled by the crew or are set to a fixed value.

(3) For the definition of the LTU configuration, refer to MOC VTOL.2435 (g).

(g) Failure conditions

(1) For Category Basic and Category Enhanced the certified minimum performance should be determined and met considering the Critical Failure for Performance (CFP).
(2) Reserved.

MOC VTOL.2125 Climb Information

1. General

(a) In order to determine the climb/descent and (where applicable) the hovering performance, an applicant may choose the most appropriate flight-testing technique for its design.
(b) Prediction tools may be used as well, provided that the results are validated with a suitable number of flight test points.

2. Category Basic

(a) The climb/descent performance in the normal flight envelope should be determined up to the extremes of the cruise altitude.
(b) The climb/descent performance data should be published for the best climb speed, with:

(1) the landing gear retracted, and
(2) the configuration required for climb, and
(3) not more than the take-off power in nominal conditions.

(c) Applicants are encouraged to also publish the climb/descent performance data for the operational envelope.
(d) When applicable, the hovering performance at h_1 and h_2 should be determined and the corresponding performance data published:

(1) up to the extremes of the take-off and landing density altitudes, and
(2) either considering at least 17 kts of steady wind from all azimuths, or
(3) considering zero wind or wind coming from a selected quadrant.

3. Category Enhanced

(a) The climb/descent performance data should be determined for the Operational Flight Envelope (OFE) up to the extremes of the maximum cruise density altitude.
(b) The climb/descent performance data should be published for the best climb speed, with:

(1) the landing gear retracted, and
(2) the configuration required for climb, and
(3) not more than the take-off power, considering the Critical Failure for Performance (CFP).

(c) When applicable, the hovering performance at h_1 and h_2 should be determined and the corresponding performance data published:

(1) up to the maximum cruise density altitude.
(2) considering at least 17 kts of steady wind from all azimuths.

MOC VTOL.2160 Vibration

1. Explanation

According to VTOL.2160, each part of the VTOL must be free from excessive vibration throughout the limit flight envelope. This should be understood as including each appropriate configuration, speed, power, and rpm conditions.

2. General

VTOL.2160 'Vibration' is a flight requirement and includes the effect on crew and occupants, and associated effects in handling qualities and controllability.

The effect of vibration on structure and equipment are addressed in the following requirements:

- Airframe structure and equipment installations: VTOL.2215(b)
- Lift/thrust units: VTOL.2400(c)(4)
- Systems and equipment: VTOL.2500(b)

3. Procedures

(a) The procedures described in FAA AC 27.251 apply. However, the specificities of VTOL aircraft having Lift/Thrust Units with variable rpm should be considered for the selection of the rpm ranges, including the effect of combinations of harmonic and phases, as well as the different configurations of the Lift/Thrust Units.

(b) The airspeed and rotor speed limits should be investigated and established under VTOL.2170, VTOL.2200, and also considering VTOL.2615.

MOC VTOL.2165 Flight in icing conditions

For showing of compliance with VTOL.2265 (b), (c) for eVTOL aircraft not certified for icing, EUROCAE standard ED-314 'Compliance Methodologies for VTOL Certification in Inadvertent Icing and Snow Operation' is acceptable.

~~MOC VTOL.2220 Ground and water load conditions~~

~~**Note:**~~ ~~The below new text is added to MOC VTOL.2220 in Doc. No. MOC SC-VTOL Issue 2, dated 12 May 2021. Modifications are highlighted in blue colour for the reader's convenience.~~

~~4. Landing conditions~~

~~(a) For the landing gear and its attachment structure only, spin-up and spring-back-up landing cases should be considered, taking into account the maximum touchdown speed and the recommended forward speed for emergency touchdown, if applicable. CS 29.479 (b)(3) is accepted as means of compliance for the spin-up case. The spring-back case should be consistent with the spin-up condition.~~

MOC – SUBPART C – STRUCTURES

MOC VTOL.2215b Flight Load Conditions: Vibration and buffeting

1. Explanation

VTOL.2215(b) requires that vibration and buffeting must not result in structural damage up to the dive speed and within the limit flight envelope. This should be understood as including each appropriate configuration, speed, power, and rpm conditions.

2. General

(a) VTOL.2215(b) is a structural requirement and addresses the effect of vibration on the structure and installations of equipment. The effects of vibration on the aircraft and other equipment are addressed in the following requirements:

(1) Crew and occupants, and associated effects in handling qualities and controllability: VTOL.2160

(2) Lift/thrust units: VTOL.2400(c)(4)

(3) Systems and equipment: VTOL.2500(b)

(b) The aircraft should be designed to withstand any vibration and buffeting that might occur in any likely operating condition up to VD.

(c) The following are typical Means of Compliance for Vibration compliance demonstration. Combination of these MoC can be selected:

a. Impulse hammer test

b. Instrumented Flight test & Flight loads survey

c. Validated Simulation

3. Procedures

The demonstration includes one of the following or a combination

(1) Dynamic test (e.g. Impulse hammer or shake test) for natural frequencies determination of structural components, assemblies or equipment installation.

This test may be combined with flight test campaign as needed.

For rotorcraft, the main sources of vibration are the main rotor, the tail rotor and the engine. However, for VTOL aircraft having multiple Lift/Thrust Units with variable rpm, it should be considered that they could generate a greater range of harmonic frequencies with potentially different phases between LTUs. The effect of these combinations of harmonic, phases and natural frequencies should be investigated.

The demonstration is as follows:

Determination of the natural frequencies of the structure or equipment installation by instrumented ground vibration testing, e.g. impulse hammer test or shake test and comparison with the relevant sources of vibration. If the natural frequencies are within the source vibration ranges, additional substantiation such as instrumented flight test should be performed to determine the level of vibration and resulting loading on the structure or equipment installation.

(2) Instrumented Flight test & Flight loads survey.
Flight test is relevant to address VTOL.2215 at the global aircraft level.
The flight test demonstration as required by VTOL.2160 or the flight load survey for VTOL.2240, may be used to evaluate the level of vibration and buffeting. Flight tests should be performed over representative flight phases and configurations. Instrumentation, e.g. accelerometers, strain-gauges, may be necessary to quantify the level of vibration.

(3) Validated Simulation (for airframe, rotor and drive system), code MC 2
Note. Simulation can't be selected in isolation and should be used to support for example the location of the sensors or the configurations to select for the bong or flight test.

If the resulting load levels can generate structural damage to structure, a fatigue evaluation as per VTOL.2240 is necessary with potential maintenance procedure to prevent structure failure.

MOC VTOL.2220 Ground and water load conditions

Note:
The below new text is added to MOC VTOL.2220 in Doc. No. MOC SC-VTOL Issue 2, dated 12 May 2021. Modifications are highlighted in blue colour for the reader's convenience.

4. Landing conditions

(b) Aircraft that meet the CTOL criteria of MoC VTOL.2000 point 12 a (1) should be designed for the additional loading conditions specified in this paragraph (Note: aircraft that meet the CTOL criteria a(2) only, need not consider these additional loading conditions).
In showing compliance with this paragraph, the following apply: […]

(d) For the landing gear and its attachment structure only, spin-up and spring-back-up landing cases should be considered, taking into account the maximum touchdown speed and the recommended forward speed for emergency touchdown, if applicable. CS 29.479 (b)(3) is accepted as means of compliance for the spin-up case. The spring-back case should be consistent with the spin-up condition.

MOC 1 VTOL.2235 Structural Strength: Strength and Deformation

(a) CS 27.305 (a) and (b) Amdt. 6 are accepted as means of compliance with VTOL.2235 regarding strength and deformation characteristics.

(d) Where structural flexibility is such that any rate of load application likely to occur in the operating conditions might produce transient stresses appreciably higher than those corresponding to static loads, the effects of this rate of application must be considered.

(e) CS 27.307 Amdt. 6 is accepted as a means of compliance with VTOL.2235 regarding the proof of structure. MOC 2 VTOL.2235 offers different certification approaches with regards to the need for and extent of testing, considering a proposed classification of the structure and the consequences of a structural failure for the integrity of the VTOL aircraft and the safety of its occupants.

MOC 2 VTOL.2235 Structural Strength: Methods of Compliance for Proof of Structure

1. Scope

This guidance proposes methods of compliance with VTOL.2235 regarding the proof of structure. It is also applicable to VTOL.2230 for the same subject.
According to VTOL.2210, compliance with the strength and deformation requirements VTOL.2230, VTOL.2235 and VTOL.2240 must be shown for each critical loading condition.
Structural analysis may be used only if the structure conforms to that for which experience has shown this method to be reliable. In other cases, substantiating tests must be made to load levels that are sufficient to verify structural behaviour up to loads specified in VTOL.2240.

2. Definitions

(a) *Detail*. A structural element of a more complex structural member (e.g. joints, splices, stringers, stringer run-outs, lugs, or access holes). This definition includes also mechanical parts (e.g. gear teeth, shafts).
(b) *Subcomponent.* A major three-dimensional structure which can provide complete structural representation of a section of the full structure (e.g., stub-box, section of a spar, blade or beam, wing panel, wing, rib, body panel, frames). Gears and mechanical parts of the rotor should also be considered.
(c) *Component*. A major section of the airframe structure (e.g., wing, body, fin, horizontal stabiliser, main rotor hub assembly, cabin, tail boom, fin, horizontal stabiliser or transmission/upper deck, pylon, blade), which can be tested as a complete unit to qualify the structure. It includes also mechanical assembly (e.g. main gearbox assembly, rotor elements).
(d) *Full-Scale.* Dimensions of test article are the same as design; fully representative test specimen (not necessarily complete airframe).
(e) *New Structure*. Structure for which behaviour is not adequately predicted by analysis supported by previous test evidence. Structure that utilises significantly different structural design concepts such as details, geometry, structural arrangements, and load paths or materials from previously tested designs.
(f) *Similar New Structure*. Structure that utilises similar or comparable structural design concepts such as details, geometry, structural arrangements, and load paths concepts and materials to an existing tested design.
(g) *Derivative/Similar Structure*. Structure that uses structural design concepts such as details, geometry, structural arrangements, load paths, stress levels and materials that are nearly identical to those on which the analytical methods have been validated.
(h) *Previous Test Evidence*. Testing of the original structure that is sufficient to verify structural behaviour in accordance with VTOL.2235.

3. Introduction

As required by VTOL.2235, the structure must be shown to comply with strength and deformation requirements, and as such it must:

(a) be able to support limit loads without detrimental or permanent deformation, and,
(b) be able to support ultimate loads without failure.

This implies the need of a comprehensive assessment of the external loads (addressed by VTOL.2210 and VTOL.2215), the resulting internal strains and stresses, and the structural allowables.

According to VTOL.2210, compliance for each critical loading condition must be established. Compliance can be shown by analysis supported by previous test evidence, analysis supported by new test evidence or by test only.

As compliance by test only is impractical in many cases, a large portion of the substantiating data will be based on analysis.

There are a number of standard engineering methods and formulas which are known to produce acceptable, often conservative results, especially for structures where load paths are well defined.

Those standard methods and formulas, applied with a good understanding of their limitations, are considered reliable analyses when showing compliance with VTOL.2235 (limit and ultimate loads demonstration). Conservative assumptions may be considered in assessing whether or not an analysis may be accepted without test substantiation.

The application of methods such as Finite Element Method or engineering formulas to complex structures in VTOL aircraft is considered reliable only when validated by full scale tests (ground and/or flight tests). Experience relevant to the product in the utilisation of such methods should be considered.

4. Classification of Structure

(a) The structure of the product should be classified into one of the following three categories:

(1) New Structure
(2) Similar New Structure
(3) Derivative/Similar Structure

(b) Justifications should be provided for classifications other than New Structure. Elements that should be considered are:

(1) Accuracy/conservatism of the analytical methods, and,
(2) Comparison of the structure under investigation with previously tested structure.

(c) Considerations should include, but are not limited to the following:

(1) external loads (bending moment, shear, torque, etc.);
(2) internal loads (strains, stresses, etc.);
(3) structural design concepts such as details, geometry, structural arrangements, load paths;
(4) materials;
(5) test experience (load levels achieved, lessons learned);
(6) deflections;
(7) deformations;
(8) extent of extrapolation from test stress levels.

5. Need and Extent of Testing

(a) The following factors should be considered in deciding the need for and the extent of testing including the load levels to be achieved:

(1) the classification of the structure (as per 4. (a));
(2) the consequence of failure of the structure in terms of the overall integrity of the VTOL aircraft;
(3) the consequence of the failure of interior items of mass and the supporting structure to the safety of the occupants.

(b) Relevant service experience may be included in this evaluation.

6. Certification Approaches

The following certification approaches may be selected:

(a) Analysis, supported by new strength testing of the structure to limit and ultimate load.

(1) This is typically the certification approach followed for 'New Structure'.

(2) Substantiation of the strength and deformation requirements up to limit and ultimate loads normally requires testing of subcomponents, full scale components or full-scale tests of assembled components (such as a nearly complete airframe). The entire test program should be considered in detail to assure the requirements for strength and deformation can be met up to limit load levels as well as ultimate load levels.

(3) Sufficient limit load test conditions should be performed to verify that the structure meets the deformation requirements of VTOL.2235 and to provide validation of internal load distribution and analysis predictions for all critical loading conditions.

(4) Because ultimate load tests often result in significant permanent deformation, choices will have to be made with respect to the load conditions applied. This is usually based on the number of test specimens available, the analytical static strength margins of safety of the structure and the range of supporting detail or subcomponent tests. An envelope approach may be taken, where a combination of different load cases is applied, each one critical for a different section of the structure.

(5) These limit and ultimate load tests may be supported by detail and subcomponent tests that verify the design allowables (tension, shear, compression) of the structure and often provide some degree of validation for ultimate strength.

(b) Analysis validated by previous test evidence and supported with additional limited testing.

(1) This is typically the certification approach followed for 'Similar New Structure'.

(2) The extent of additional limited testing (number of specimens, load levels, etc.) will depend upon the degree of change, relative to the elements of paragraphs 4.(b)(1) and (2).
For example, if the changes to an existing design and analysis necessitate extensive changes to an existing test-validated finite element model (e.g. different rib spacing) additional testing may be needed. Previous test evidence can be relied upon whenever practical.

(3) Additional limited tests may be further supported by detail and subcomponent tests that verify the design allowables (tension, shear, compression) of the structure, and often provide some degree of validation for ultimate strength.

(c) Analysis, supported by previous test evidence.

(1) This is typically the certification approach followed for Derivative/ Similar Structure.

(2) Justification should be provided for this approach by demonstrating how the previous static test evidence validates the analysis and supports showing compliance for the structure under investigation. Elements that need to be considered are those defined in paragraphs 4. (b)(1) and (2).
For example, if the changes to the existing design and test-validated analysis are evaluated to assure they are relatively minor and the effects of the changes are well understood, the original tests may provide sufficient validation of the analysis and further testing may not be necessary. As an illustration of this general example, in a case where a mass increase results in higher loads, along with a corresponding increase in some of the element thickness and fastener sizes, while the materials and geometry (overall configuration,

spacing of structural members, etc.) remain generally the same, the revised analysis could be considered reliable based on the previous validation.

(d) Test only.

(1) Sometimes no reliable analytical method exists, and testing must be used to show compliance with strength and deformation requirements. In other cases, it may be elected to show compliance solely by tests even if there are acceptable analytical methods. In either case, testing by itself can always be used to show compliance with the strength and deformation requirements of SC VTOL Subpart C.

(2) In such cases, the test load conditions should be selected to assure all critical design loads are encompassed.

(3) If tests only are used to show compliance with strength and deformation requirements for single load path structure which carries flight loads (including pressurisation loads), the test loads must be increased to account for variability in material properties, as required by VTOL.2260 (c). In lieu of a rational analysis, a factor of 1.15 applied to the limit and ultimate flight loads may be used for metallic materials.

(4) If the structure has multiple load paths, no material correction factor is required.

7. Interpretation of Data

(a) The interpretation of the substantiation analysis and test data requires an extensive review of:

(1) the representativeness of the loading;
(2) the instrumentation data;
(3) comparisons with analytical methods;
(4) the representativeness of the test article(s);
(5) the test set-up (fixture, load introductions);
(6) the load levels and conditions tested;
(7) the test results.

(b) Testing is used to validate analytical methods except when showing compliance by test only.

(1) If the test results do not correlate with the analysis, the reasons should be identified and appropriate action taken.

(2) This should be accomplished whether or not a test article fails below ultimate load.

(c) Should a failure occur below ultimate load, an investigation should be conducted for the product to reveal the cause of this failure.

(1) This investigation should include a review of the test specimen and loads, analytical loads, and the structural analysis.

(2) This may lead to adjustment in analysis/modelling techniques and/or part redesign and may result in the need for additional testing.

(3) The need for additional testing to ensure ultimate load capability, depends on the degree to which the failure is understood and the analysis can be validated by the test.

The approach described above is valid for static justification. However, a similar approach can be extended for compliance with fatigue, dynamic and crashworthiness requirements. For these applications, the criteria and the classification have to be accepted by and agreed with the authority.

MOC 3 VTOL.2235 Structural strength: Landing Gear Drop Test

Note:

The following text fully replaces MOC VTOL.2235 in Doc. No. MOC SC-VTOL Issue 2, dated 12 May 2021. Changes and additions are highlighted in blue colour for the reader's convenience.

(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, with the following modification:

The drop height must be that resulting in a drop contact velocity equal to the greatest probable sinking speed likely to occur at ground contact in normal landings, but not less than 0.20 m (8 in).

(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).

Note 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).

Note 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).

Note 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.

(d) Unless shown to be extremely improbable, failure conditions or malfunctions of systems that could affect the aircraft sinking speed should be treated in accordance with the following criteria. For Category Enhanced, landings should include the Continued Safe Flight and Landing procedures.

(1) System in the failure condition. For the aircraft, in the system failed state and considering any appropriate reconfiguration and flight limitations, the following apply:

(i) Limit drop test: as defined in CS 27.725 Amdt. 6, with the following modification: The drop height must be that resulting in a drop contact velocity equal to the greatest probable sinking speed likely to occur at ground contact with the system in the failed state.

(ii) Reserve energy absorption drop test: as defined in CS 27.727 Amdt. 6, with the following modifications: The drop height must be that specified for the limit drop test in the system failed state multiplied by an appropriate factor of safety that is related to the probability of occurrence of the failure. The factor of safety (F.S.) is defined in Figure 1 where 10^{-X} is equal to the probability associated to Extremely Improbable for the aircraft Category and number of passengers in accordance with MOC VTOL.2510. Lift from the lift/thrust units may not exceed 1.5 times the lift allowed under the limit drop test.

Note: The most critical limit drop test and the most critical reserve energy drop test should be performed. These may not necessarily result from the same failure condition.

(iii) Landing loads: The loads derived from the limit ground conditions specified in MOC VTOL.2220 should be determined. Unless otherwise prescribed, for each specified landing condition, the aircraft should be designed for a limit load factor of not less that the limit inertia load factor substantiated under the limit drop test with the system in the failed state defined in subparagraph (d)(1)(i).

(iv) Static strength substantiation: Each part of the structure should be able to withstand the landing loads in subparagraph (d)(1)(iii) multiplied by a factor of safety depending on the probability of occurrence of the failure. The factor of safety is defined in Figure 1 where 10^{-X} is equal to the probability associated to Extremely Improbable for the aircraft Category and number of passengers in accordance with MOC VTOL.2510 (Figure 1).

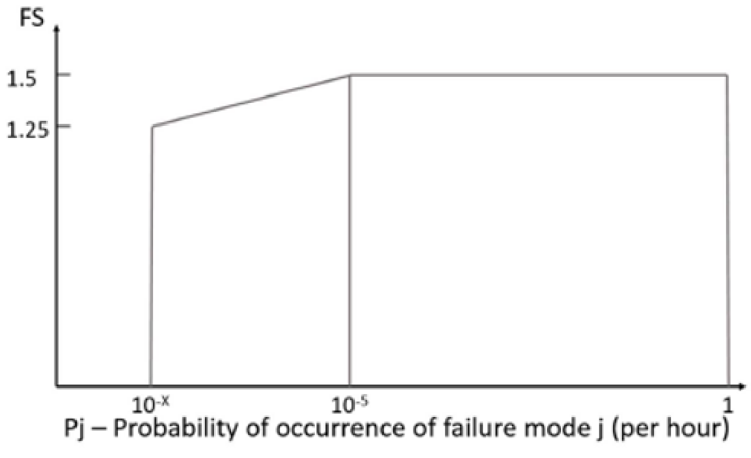

Figure 1: Factor of safety for the landing condition

(e) In addition, for aircraft with CTOL capability, when substantiating the criteria of MOC VTOL.2220 4.(b), i.e. CTOL additional ground conditions, the following are accepted as a means of compliance,:

(1) Shock absorption tests: CS 23.723 Amdt. 4
(2) Limit drop tests: CS 23.725 Amdt. 4
(3) Ground load dynamic tests: CS 23.726 Amdt. 4
(4) Reserve energy absorption drop tests: CS 23.727 Amdt. 4

MOC VTOL.2270 (c) Seats, berths, safety belts, and harnesses

CS 27.785 Amdt. 6 is accepted as a means of compliance with regards to seats, berths, safety belts, and harnesses providing protection for occupants in the VTOL aircraft.

The applicability of the content of paragraphs CS 27.561, CS 27.562 and CS 27.625 referenced therein shall be understood as laid out in MOC VTOL.2270 (a) and (c), in MOC VTOL.2270 (b)(1), and in MOC VTOL.2265, respectively.

MOC – SUBPART D – DESIGN AND CONSTRUCTION

MOC VTOL.2315 (a) Means of Egress and Emergency Exits

Note: The following text is added to MOC VTOL.2315 (a) in Doc. No. MOC-2 SC-VTOL, Issue 3, dated 22 December 2022.

2. Means of egress and emergency exits for landing on land

(a) EUROCAE ED-307 'Guidance on the demonstration of acceptable occupant safety – emergency egress' is accepted as a means to demonstrate that the aircraft is designed to facilitate rapid and safe evacuation of the aircraft in conditions likely to occur following an emergency landing on land required by VTOL.2315 (a)(1), with the following addition after sub-paragraph 3::

2.2.2 Intuitive use and opening effort, sub-paragraph 3:

Tests on the aircraft should also be carried out to evaluate the effort required to open the emergency exit. This may be carried out at ambient temperature.

(b) In addition:

(1) Each emergency exit, including a flight crew emergency exit, must have means to permit viewing of the conditions outside the exit when the exit is closed. The viewing means may be on or adjacent to the exit provided no obstructions exist between the exit and the viewing means. A subjective outside viewing test can be conducted to determine if the exterior viewing means provides an adequate view to allow identification of possible hazards in the evacuation path.

(2) CS 27.783 (a) Amdt.6 is accepted as a means of compliance regarding external doors.

MOC – SUBPART E – LIFT/THRUST SYSTEM INSTALLATION

MOC VTOL.2400 (c)(3) Hazards to Crew, Passengers and Ground Personnel by Electromagnetic Fields generated by High Voltage

Adherence to the 'Guidelines for limiting exposure to electromagnetic fields (1 Hz to 100 kHz and 100 kHz to 300 GHz)' issued by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) is accepted as a means to comply with VTOL.2400 (c)(3) regarding the protection for humans against adverse health effects from exposures to radiofrequency electromagnetic fields from 1 Hz to 300 GHz generated in the aircraft.

MOC VTOL.2415 Lift/thrust system installation ice protection

For showing of compliance with VTOL.2415 (a) for eVTOL aircraft not certified for icing, EUROCAE standard ED-314 'Compliance Methodologies for VTOL Certification in Inadvertent Icing and Snow Operation' is acceptable.

Note:

The EUROCAE standard ED-314 is in the process of publication by EUROCAE. It will become publicly available during the consultation period of this fourth publication of MOC.

MOC 5 VTOL.2500 (b) Flight guidance systems

1. Purpose

This MOC describes an accepted means for showing compliance with VTOL.2500 (b) for Flight Guidance Systems (FGS). It is intended to supplement the engineering and operational judgment that forms the basis of any compliance demonstration.

2. Terminology and Applicability

An FGS may have several subfunctions, whose denomination and meaning may vary depending on whether it is installed on an aeroplane or on a rotorcraft (e.g., flight director, autopilot, thrust director, auto-thrust, altitude hold, engaging, disengaging, coupling, uncoupling). Vertical Take-Off and Landing (VTOL) aircraft encompass a broad range of diverse designs (e.g., vectored thrust, multicopter, lift + cruise), and their FGS may resemble or differ from both aeroplane and rotorcraft design. In order to cover potential future concepts, the previously mentioned nomenclature of subfunctions will not be used in this MOC.

This MOC applies to FGS, if installed, which consist in functions that can be activated or deactivated, engaged or disengaged, and that when activated/engaged provide workload alleviation to the flight crew by displaying targets to follow on the flight display and/or by automatically controlling the aircraft on one or several axes, thus facilitating hands-on flight or enabling hands-off flight.

FGS usually consist in one or more of the following functions:

(a) FGS outer loops: based on targeted flight parameters selected from a flight crew control panel and/or from ground navaids and/or from a flight management system and based on aircraft state obtained from various sensors, provide commands to the FGS inner loops and/or the flight guidance cues to capture and/or track the targeted flight parameters.

(b) FGS inner loops: based on commands from the FGS outer loops and based on aircraft state and configuration, provide commands and actuation, and/or provide commands to flight and/or lift/thrust control laws to control the aircraft, and achieve the FGS outer loops commands.

(c) Flight guidance cues: based on commands from the FGS outer loops, provide indications to the flight crew on flight displays to capture and/or track the targeted flight parameters.

FGS also encompass other functionalities such as indications (e.g. flight mode annunciator, target readouts, bugs) and alerting.

Each one of the FGS outer loops, FGS inner loops, and flight guidance cues may refer to functions dealing with any of the aircraft axes. Flight director and autopilot for roll and pitch axes, autothrust for speed or thrust typical of aeroplanes, and two-axes or four-axes autopilot, collective coupling typical of rotorcraft; all are aimed at being covered by the functions defined above.

Stability augmentation systems, envelope protection, or control laws parts of the Flight Control System (FCS), which are present full-time, are not deactivated/disengaged together with the FGS outer or inner loops, and do not enable hands-off flight, are out of scope of this MOC (e.g. for architectures using the same control laws for manual and FGS inner loop commands, the FGS inner loop perimeter stops at the input to FCS control laws; FCS inner loops are out of scope). Manual trim systems are part of the FCS and are out of scope of this MOC. The interfaces and integration with all those FCS functions are however to be considered.

The long-term trajectory management (i.e. planning from start to landing) from the Flight Management Systems (FMS) is out of scope of this MOC, which focuses on systems providing short/medium-term trajectory control.

The interfaces and integration with the FMS are however to be considered, and the steering orders sent by the FMS for area navigation are considered part of the short/medium-term trajectory control within the FGS outer loops. Interfaces and integration with all dependent systems/equipment are to be considered, which may include –but not be limited to– displays, alerting system, control panel, inceptors, sensors, control laws.

The level of rigor and the efforts in the demonstration of compliance may vary depending on the complexity of the FGS, the category of the VTOL aircraft, and the types of operations.

Additional considerations and means of compliance may be applicable depending on the technology used (e.g. touchscreens, Head-Up Display (HUD)), the operational cases and flight phases during which the FGS is aimed at being usable (e.g., take-off and landing, go-around, Performance-Based Navigation (PBN)), or on the modes and couplings implemented (e.g., windshear escape, Airborne Collision Avoidance System (ACAS), Terrain Avoidance and Warning System (TAWS)).

Explanatory Note:

Due to significant differences between aeroplanes and rotorcraft flight guidance systems, and due to novelties brought by the eVTOL aircraft, this MOC proposes updated definitions for the SC VTOL, bringing them at a higher concept level and less specific-design-oriented.

3. Related Documents

Additional information may be found in the following references.

(a) EASA CS-23 Amdt. 5 AMC/GM Issue 1 and subsequent, AMC2 23.2500 line 23.1329;
(b) EASA CS-25 Amdt. 26 and subsequent, AMC1 and AMC2 to CS 25.1329;
(c) EASA CS-27 Amdt. 6 and subsequent, MG 23;
(d) EASA CS-29 Amdt. 6 and subsequent, MG 23.

These references are offered for additional guidance, but are not in themselves acceptable means of compliance with SC VTOL. Some of their content may not be applicable due to the design or operational use of the VTOL FGS, or be too demanding depending on the VTOL category. However, they contain useful information, either themselves (AMC 25.1329) or by referring to FAA advisory circulars and RTCA documents (Flight Test Guide for Certification of CS-23 Aeroplanes (Amdt. 4) Chapter 5 paragraph 307 'Paragraph 23.1329 Automatic Pilot System', AMC 27 'General', AMC MG 23 'Automatic Flight Guidance and Control Systems installation in CS-27 Rotorcraft', AMC 29 'General', AMC MG 23 'Automatic Flight Guidance and Control Systems installation in CS-29 Rotorcraft').

Explanatory Note:

The proposed CS amendment levels are purposefully not aligned with the date of publication of SC-VTOL-01 (i.e., 2017-07-02), but are chosen so that they contain the applicable guidance (e.g. for CS-29 and CS-27 the MG 23, and for CS-25 the latest AMC1 25.1329).

4. Definitions

(a) Activation: A state change of the FGS outer loops, which get in gear.
(b) Arming: A state change of the FGS outer loops, which prepare to get in gear. The intent to transition to a new mode or state has been established but the condition necessary to make that transition has not been satisfied.
(c) Deactivation: A state change of the FGS outer loops, which are released from activation.
(d) Disengagement: A state change of the FGS inner loops, which are released from engagement.
(e) Engagement: A state change of the FGS inner loops, which get in gear.

(f) External environmental condition: A set of physical conditions external to the aircraft such as steady wind (any direction, including crosswind), wind gradient, gust, windshear, turbulence, icing, precipitations, temperature. They may be encountered at different levels of amplitude, such as light, moderate, and severe. Their encounter likeliness may be categorised as normally encountered or rarely (infrequently) encountered. (Source: adapted from MOC 1 VTOL.2500 (b) and refined for FGS.)

(g) Failure condition: Refer to the definition in MOC VTOL.2510 section 4, and to the classifications (i.e., no safety effect, minor, major, hazardous, catastrophic) in MOC VTOL.2510 section 7.

(h) FGS inner loops: Based on commands from the FGS outer loops and based on aircraft state and configuration, provide commands and actuation, and/or provide commands to flight and/or lift/thrust control laws to control the aircraft and achieve the FGS outer loops commands.

(i) FGS outer loops: Based on targeted flight parameters selected from a flight crew control panel and/or from ground navaids and/or from a flight management system and based on aircraft state obtained from various sensors, provide commands to the FGS inner loops and/or the FGS flight guidance cues to capture and/or track the targeted flight parameters.

(j) Field of view: Refers to areas that are visible by the flight crew. It may concern the area enabling the flight crew to look outside and acquire external references, but in present context it especially concerns the field of view for head-down displays. It is decomposed into the optimum field of view and the maximum field of view. They correspond to optimum and maximum vertical and horizontal visual fields from the design eye reference point that can be accommodated with eye rotation only. Refer to CS ACNS.A.GEN.005.

(k) Flight envelope: Refer to MOC VTOL.2135, including for normal flight envelope, operational flight envelope, limit flight envelope.

(l) Flight guidance cues: Based on commands from the FGS outer loops, provide indications to the flight crew on flight displays to capture and/or track the targeted flight parameters.

(m) Flight guidance system: A system consisting of one or more of the following elements:

  (1) FGS outer loops;
  (2) FGS inner loops;
  (3) FGS flight guidance cues.

(n) Hardover: A type of functional failure mode where a command or indication goes to full displacement in a brief period of time.

(o) Human performance issue: A deficiency or undesired outcome that affects human's ability to perform tasks as the result of various factors, including human interaction with the machine, the environment or other involved stakeholders. It can manifest in different ways, such as human errors, but also encompasses other kind of shortcomings, e.g., suboptimal strategies, difficulty in finding information, inappropriate levels of workload, etc., or may also include any other observable item that cannot be considered to be a human error, but still reveals a flight deck design, flight crew training or operational procedures-related concern. (Source: CM-21.A-A-003 section 3.4.)

(p) Interlock: A condition or set of conditions preventing a function to be activated or engaged when undesired.

(q) Mode: System state that corresponds to a single (or set of) FGS outer loops behaviour(s).

(r) Override: An action taken by the flight crew intended to prevent, oppose, or alter an operation being conducted by the FGS inner loops, without first disengaging them.

(s) Parameter: A measurable variable (e.g., airspeed, heading, flight path angle), which in scope of this MOC may be used as a target for the FGS outer loops, and whose presentation is typically required by SC VTOL.2615.

(t) Reversion: A state change of the FGS outer loops, which automatically return to a previously active mode or to a predetermined 'default' mode for that condition. This may occur due to several reasons, such as specific criteria becoming satisfied or because the FGS cannot perform the currently selected operation. This type of mode change is not requested by the flight crew and therefore may be unexpected.

(u) Slowover: A type of functional failure mode where a command or indication moves away from the correct value over a relatively long period of time.

(v) Transient: A disturbance in the control or flight path of the aircraft that is not consistent with response to flight crew inputs or current external environmental conditions.

(1) Slight transient: a transient that would lead to a slight reduction in safety margins, a slight increase in flight crew workload, some physical discomfort to passengers.

(2) Significant transient: a transient that would lead to a significant reduction in safety margins, a significant increase in flight crew workload, physical discomfort to the flight crew, physical distress to passengers possibly including injuries.

(3) Large transient: a transient that would lead to a large reduction in safety margins, an excessive increase in flight crew workload, physical distress to the flight crew, physical distress to passengers possibly including serious injuries for Category Enhanced or fatal injury for Category Basic.

(w) Transition: A state change of the FGS outer loops, which pass from one mode to another.

5. Acronyms

Acronyms	Definition
ACAS	Airborne Collision Avoidance System
AFM	Aircraft Flight Manual
ATC	Air Traffic Control
FCOM	Flight Crew Operating Manual
FCS	Flight Control System
FDR	Flight Data Recorder
FGS	Flight Guidance System
FMEA	Failure Modes and Effect Analysis
FMS	Flight Management System
GNSS	Global Navigation Satellite System
HUD	Head-Up Display
ICA	Instruction for Continued Airworthiness
ILS	Instrument Landing System
MC	Means of Compliance (as defined in Part 21 Appendix A to AMC 21.A.15(b))
MEH	Minimum Engagement Height
MUH	Minimum Use Height
NFE	Normal Flight Envelope
PBN	Performance-Based Navigation

Acronyms	Definition
TAWS	Terrain Avoidance and Warning System

6. System Description

The applicant should provide a clear, detailed, and comprehensive description of the FGS and its interfaces. The description should encompass –but not be limited to– the aspects listed below. It should include diagrams and images to illustrate the descriptions.

(a) Functions performed by the system.
(b) Architecture; including equipment hosting the FGS functions, their interfaces, their locations, as well as all the other equipment and functions with which the FGS is interacting/interfaced.
(c) Modes of operation; including their objective, the flight procedures they support, the inputs they are using, the outputs they are producing, their arming and activation and deactivation and reversion conditions, the related indications to the flight crew.
(d) Cockpit interface; including all the controls and displays for the flight crew.
(e) Alerts; including their classification, their visual, aural, and tactile components, and their inhibitions.
(f) Operational use cases, decomposition per flight phase, minimum use height.
(g) Interlocks, conditions for engagement and disengagement, manual and automatic.
(h) Interfaces with other functions/systems; e.g., sensors, FMS, FCS, maintenance, Flight Data Recorder (FDR), power supply.
(i) Coupling with other functions/systems; e.g., PBN, ACAS, TAWS, emergency descent, windshear detection, envelope protection.
(j) Monitoring within the FGS.
(k) Inputs and outputs management; e.g., selecting, voting, blending, fault detection.
(l) Degraded conditions; e.g. failure within the FGS, failure of other functions/systems.
(m) Self-test and maintenance.

7. System Design and Development – General considerations

(a) The applicant should design and develop the FGS in accordance with:

~~(1) MOC VTOL.2510 regarding safety and development assurance aspects.~~
~~(1) MOC 3 VTOL.2500 (b) 'Airworthiness Security in the Category Enhanced', when certification for Category Enhanced is sought.~~
(1) VTOL.2165 'Flight in Icing Conditions'.
(2) MOC VTOL.2205 'Interaction of Systems and Structures' for taking into account its effects on structures.
(3) MOC 1 VTOL.2500 (b) 'Intended Function of Systems and Equipment' so that it is qualified for the operating and environmental conditions for which the aircraft is certified.
(4) MOC 2 VTOL.2500 (b) 'Electromagnetic Compatibility'.
(5) MOC VTOL.2515 "Electrical and Electronic System Lightning Protection".
(6) MOC 3 VTOL.2500 (b) 'Airworthiness Security in the Category Enhanced', when certification for Category Enhanced is sought.
(7) MOC VTOL.2510 regarding safety and development assurance aspects.
(8) MOC VTOL.2520 "High-Intensity Radiated Fields Protection".
(9) MOC VTOL.2600 "Flight Crew Compartment" as regards controls, indications, alerts, and behaviour.

(10) MOC VTOL.2605 "Installation and Operating Information" as regards its indications and alerts.

(11) VTOL.2610 "Instrument Markings, Control Markings and Placards" as regards its controls and instruments.

(12) VTOL.2615 'Flight, Navigation, and Lift/Thrust System Instruments' as regards the provided information.

(b) The applicant should record adequate FGS parameters in accordance with MOC VTOL.2555.

The following sections 8 to 11 address the design and development of the control means, the FGS behaviour, the FGS envelope, and the indicating and alerting means. Section 12 provides specific guidance on the safety assessment and section 13 focuses on the integration aspects.

8. Control Means

(a) The means provided to the flight crew to interact with the FGS, such as arming or activating or deactivating a mode of the FGS outer loops, displaying or removing the flight guidance cues, engaging or disengaging the FGS inner loops should enable the flight crew to safely perform their tasks associated with the intended function of the system.

(b) Quick disengagement controls of the FGS inner loops should be provided to the flight crew on the relevant flight control inceptors. They should be readily accessible to the flight crew while operating the flight control inceptors.

(c) Override capability should be provided for the flight crew to safely take control of the aircraft, and be designed in a manner consistent with the urgency of the takeover. The design of such capability should minimise the risk of unintended override.

Explanatory Note:

Point (a) provides consistency with MOC VTOL.2600 section 2 and the referenced CS 27.1302.

Point (b) is intended to be flexible (not 'autopilot quick disconnect pushbutton on control wheel / side stick' and 'autothrottle quick disconnect on throttle levers') to cope with different designs (e.g., single engagement/disengagement for roll/pitch/yaw and power, different inceptors).

Point (c) allows the applicant to decide whether to automatically disengage the FGS inner loops upon an override, or not disengage but ensure safe behaviour for example. Also, the threshold for an automatic disengagement and behaviour prior to the disengagement might depend on the balance between the immediateness of the need to take control versus the risk of inadvertent disengagement through unintended physical interference between the pilot and the inceptors. It also provides consistency with MOC VTOL.2600 section 2 and the referenced CS 27.1302 (b)(2).

As mentioned in section 2, additional considerations related to specific technologies, such as the use of touchscreens (problematics of vibration, arm/hand/finger stabilisation means, commonality introduced between loss of display and of many controls, etc.), may be required.

9. FGS Behaviour

(a) The FGS should provide track keeping accuracy and precision commensurate with the intended operations.

(b) The FGS outer and inner loops should provide smooth guidance and control, without perceptible sustained nuisance oscillations.

(c) The flight guidance cues should provide smooth target display, appropriately damped to achieve satisfactory control task performance without pilot compensation or excessive workload.

(d) Responses and transient responses of the FGS affecting the aircraft control or flight path, and producing loads on the aircraft, may occur upon engagement or disengagement of the FGS inner loops, upon activation, transition, or reversion of FGS outer loops modes, upon change of target parameter or value, upon system reconfiguration, upon failure condition (of the FGS or of any relevant other system), upon external condition, etc.

(1) The FGS should generate responses and transient responses commensurate with the likeliness of the encountered conditions, namely:

(2) the FGS should generate normal or not more than slightly degraded responses, and no transients or not more than slight transients in the Normal Flight Envelope (NFE), under normally encountered external environmental conditions, or under minor failure conditions;

(3) the FGS should generate not more than significantly degraded responses, and not more than significant transients upon momentary excursions outside the NFE, under rarely encountered external environmental conditions, or under major failure conditions;

(4) the FGS should generate safe responses, and not more than large transients under hazardous failure conditions;

(5) the applicant should also address FGS generation of responses and transient responses under relevant combinations of flight envelope conditions, external environmental conditions, failure conditions and any other relevant conditions (e.g., combinations of excursions outside the NFE with rarely encountered external environmental conditions or with failure conditions, combinations of failure conditions with rarely encountered external environmental conditions);

(6) the applicant should assess all those FGS generation of responses and transient responses under all applicable aircraft configurations (e.g., mass, centre of gravity) and change of configuration during flight (e.g., rotor tilting);

(7) the applicant should assess the effects of the FGS responses and transient responses effects on structures, under normal system conditions and under failure conditions, in accordance with MOC VTOL.2205 'Interaction of Systems and Structures'.

(e) The several FGS outer loops modes and FGS inner loops engagement status between different axes should be compatible with each other, or otherwise made impossible to be active/engaged simultaneously.

Explanatory Note:

Point (a) intends to not only ensure adequate accuracy, but also to ensure it is clearly specified by the applicant, so that it can be verified.

Point (d) introduces a relationship between the likeliness of a condition and the admitted level of effects on the FGS outputs.

10. Flight Envelope

(a) The applicant should define the FGS flight envelope.

(b) The Minimum Use Height (MUH) should be compatible with the FGS architecture, the FGS performance, the worst-case attitude change and flight path deviation under failure condition and intended operations. The minimum use height concerns not only the approach and landing phase for FGS inner loops disengagement, but also the take-off and initial climb phase for FGS inner loop engagement (in such case sometimes called 'Minimum Engagement Height' (MEH)), as well as enroute, and go-around/missed approach phases.

(c) The applicant should assess the safety implications of the flight crew attempting to activate the FGS outer loops or engage the FGS inner loops outside the FGS normal flight envelope, and where necessary provide safety mitigations.

(d) The applicant should consider the implementation of interlocks to prevent unintended (manual or automatic) activation of FGS outer loops or engagement of FGS inner loops in relevant conditions (e.g., during ground phases).

(e) The FGS inner loops control authority should be commensurate with the intended operations.

(f) The applicant should consider the implementation of FGS envelope protection with FGS inner loops engaged in order to ensure flight crew awareness and avoidance of potentially incoming unsafe conditions with regards to the aircraft attitude and speed, for example Vortex Ring State.

Explanatory Note:

Point (b) mentions the 'FGS architecture' as having a potential impact on the MUH: for example, an FGS architecture enabling fail-operational outer and inner loops may have a different demonstrated MUH than a fail-passive or than a not-failure-protected one.

Point (f): the FGS envelope protection is potentially different than the FCS envelope protection. This is related to the difference in authority and awareness between manual and automatic flights. FGS envelope protections usually trigger sooner than the FCS ones, i.e., comprise additional margins. FGS envelope protections may be limited to alerts, for flight crew awareness and recovery.

11. Indicating and Alerting Means

(a) The visual components of the indications and alerts related to the FGS should be positioned in the flight crew field of view in accordance with their intended use and safety implications (e.g., optimum field of view for mode annunciators and for caution and warning alerts such as FGS inner loops disengagement alert).

(b) Means should be provided to indicate to the flight crew:

(1) the FGS behaviour in a clear, predictable, and unambiguous way in order to minimize the risk of flight crew errors and confusion.

(2) The arming, activation, transition, and reversion of FGS outer loops modes, the engagement status of the FGS inner loops. Selector switch position or status is not acceptable as the sole means of indication.

(3) The sources and targets provided to the FGS.

(4) Which FGS outer and inner loops are active or engaged among redundant ones, if applicable and relevant.

(c) When operationally relevant, indications for FGS outer loop mode transitions and reversions should be emphasized, and potentially supported by an alert, in accordance with the expected flight crew awareness and response (e.g., altitude capture, loss of approach mode).

(d) Disengagement of FGS inner loops should be annunciated through an alert composed of both visual and aural attention-getting cues, and be prioritized based on the urgency of the flight crew awareness and response. The applicant should consider the implementation of a time-critical warning alert for the disengagement of FGS inner loops. The alert should continue until acknowledged by the crew.

(e) Conditions that may result in a significant transient at disengagement (e.g., FGS controlling at the limit of its authority), whether the latter is manual or automatic, should be annunciated through an alert, commensurate with the urgency of the situation.

(f) If applicable, envelope protection alerts should activate with suitable margins to the condition to avoid, while not resulting in nuisance activations. They should be prioritized based on the urgency of the flight crew awareness and response.

Explanatory Note:

Point (b)(3) aims at providing sufficient awareness to the flight crew, with regard to whether the FGS is coupled with the guidance panel in basic modes, or with ground navaids such as an ILS, or with a PBN function using ground navaids, or GNSS, or inertial data, barometric data; and which are the targets that the FGS outer loops are enslaved to.

As mentioned in section 2, specific technologies, such as the use of HUD, may require additional considerations, which may be project-specific or perhaps lead to the definition of dedicated additional MOCs.

12. Safety Assessment

(a) Part of the safety assessment is to determine failure conditions, their effects and their severity classifications, taking into account different types of functional failure modes (e.g., loss of function, malfunction), flight crew awareness (e.g., annunciated, unannunciated), flight phases (e.g., cruise, approach), operational and environmental events, etc. In performing the safety assessment, the applicant should consider the following non-exhaustive lists of elements characteristic of the FGS:

(1) Functional failure modes:

(i)	partial loss of FGS outer loops
(ii)	total loss of FGS outer loops
(iii)	FGS outer loops output hardover
(iv)	FGS outer loops output slowover
(v)	FGS outer loops output oscillations
(vi)	inadvertent FGS outer loops mode activation or transition
(vii)	loss of FGS inner loops engagement capability
(viii)	partial loss of FGS inner loops disengagement capability
(ix)	total loss of FGS inner loops disengagement capability
(x)	annunciated loss of or inadvertent disengagement of FGS inner loops
(xi)	unannunciated loss of or inadvertent disengagement of FGS inner loops
(xii)	FGS inner loops output hardover
(xiii)	FGS inner loops output slowover
(xiv)	FGS inner loops output oscillations
(xv)	inadvertent engagement of FGS inner loops
(xvi)	inadvertent engagement of FGS inner loops in combination with loss of FGS inner loops disengagement capability
(xvii)	jamming or increased/modified friction/forces of pilot inceptors
(xviii)	loss of envelope protection

(xix)	erroneous envelope protection
(xx)	inadvertent activation of envelope protection
(xxi)	loss of flight guidance cues
(xxii)	erroneous flight guidance cues
(xxiii)	inadvertent display of flight guidance cues

(2) Operational, environmental, external events:

(i)	all phases from ground to ground, through take-off, transition, climb, cruise, descent, landing
(ii)	go-around
(iii)	sustained out-of-trim conditions
(iv)	lift/thrust degradation/asymmetry
(v)	control surfaces degradation/asymmetry
(vi)	external environmental conditions
(vii)	incorrect speed management
(viii)	impending stall condition

(3) Effects on:

(i)	FGS
(ii)	cockpit
(iii)	other systems
(iv)	aircraft attitude
(v)	flight path
(vi)	performance
(vii)	handling qualities
(viii)	control surfaces
(ix)	lift/thrust
(x)	aeroelastic stability
(xi)	structural strength
(xii)	flight crew
(xiii)	passengers
(xiv)	maintenance and ground personnel

(b) The applicant should include combinations of functional failure modes when relevant. This may consist in –but not be limited to– combining failures of different axes of the FGS, or combining with failures from dependent/mitigating systems.

(c) The applicant should assess failure conditions of other systems with foreseen operational combinations of FGS activation/engagement (e.g., FGS outer loops solely active or with FGS inner loops engaged, single axis or multiple axis, including speed), in different aimed operations (e.g., cruise, approach, PBN), in order to determine the potentially different effects and severity classifications.

(d) The applicant should use the failure conditions of FGS and of other systems to determine adequate flight crew recognition means, adequate flight crew recovery actions procedures, and to design a safe behaviour of the FGS in those conditions.

(e) The applicant should clearly identify and describe mitigation means for which credit is taken in the safety assessment. This may include –but not be limited to– interlock, monitoring, fault detection and diagnosis, fault tolerance, reconfiguration, redundancy, authority limiting, alerting, flight crew recognition and recovery.

(f) The applicant should use the guidance introduced in MOC VTOL.2510 "Equipment, Systems, and Installations" to capture and manage FGS design needs identified from the safety assessment.

(g) For Category Enhanced, the applicant should identify portions and equipment of the FGS whose failure may contribute to hazardous or catastrophic consequences, and which are thus subject to the in-service monitoring process, in order to support the showing of compliance with VTOL.2510 (c).

Explanatory Note:

The safety assessment is covered on a general basis by MOC VTOL.2510, referenced in section 7 of this MOC. The objective of this section is to remind some points and highlight specificities related to the FGS, aiming to ensure that applicants will consider these key aspects.

The validation aspects of the failure conditions are addressed in section 18 of this MOC.

13. Integration

The potential complexity of the FGS organisational, functional, and physical integration may have a bearing on the aircraft safety, by introducing higher risks of development errors, or combined failures affecting several (sub)functions and (sub)systems at a time.

(a) The applicant should clearly establish, describe, and assure the following:

(1) roles and responsibilities of the stakeholders (e.g., applicant and their different teams, suppliers);

(2) detailed functional and physical integration;

(3) detailed interfaces within the FGS and with dependent systems;

(4) requirement and assumption management, within the FGS, with dependent systems, with all stakeholders, from aircraft level to system, software, and hardware levels.

(b) The applicant should carefully address the integration and interaction with the FCS and the lift/thrust system, whether direct or indirect. This may include –but not be limited to– the implementation of the FGS inner loops in flight control computers and the blending in the control laws, the mechanical interface between an FGS actuator and pilot control inceptors, the interactions between the FGS envelope protection and other protections, the effect of pilot trimming control, the effect of pilot control on an axis not covered by the FGS, the effect of the stability augmentation systems and of their loss, the effect of normal and degraded control laws, the effect of surface/lift/thrust actuation normal and degraded conditions, the effect of different lift/drag configurations.

(c) The applicant should carefully address the interface with sensors and sources (e.g., control panel, air data, inertial data, ground navaids, GNSS, FMS, or even the FGS outer loops for the FGS inner loops). This may include –but not be limited to– redundant signal management and source selection, mode reversion in case of failure, closing the loop on steering orders, ensuring compatible resolutions, frequencies, rates, and limits.

(d) When performing the safety assessment, the applicant should give specific attention to failures having combined effects on the FGS and other systems introduced by the integrated architecture. The applicant should perform a bottom-up safety analysis (e.g., system functional Failure Modes and Effect Analysis (FMEA)), addressing failure modes within the FGS but also from the dependent systems, addressing not only single failures but also relevant combinations of failure modes, and including consideration of cascading effects.

(e) The applicant should give specific attention to design-related human performance issues. They may arise from the potentially high number of modes and engagement combinations, involving multiple sources depending on the operation, themselves being manually or automatically selected, and the potentially high number of controls and indications related to the use of the FGS, potentially implemented on multifunction control and display means, and the potentially high number of different failure scenarios. The applicant should assess the FGS both in isolation and in combination with other cockpit systems, to ensure that the flight crew is able to detect, reverse, or recover from any human performance issues.

14. Compliance Demonstration – General considerations

(a) The applicant should predicate the showing of compliance with the requirements from the SC VTOL on a combination of Means of Compliance (MC) as defined in Part 21 Appendix A to AMC 21.A.15 (b). This includes especially MC1 design review, MC2 calculation/analysis, MC3 safety assessment, MC4 laboratory tests, MC5 ground tests, MC6 flight tests, MC7 design inspection/audit, MC8 simulation, MC9 equipment qualification.

(b) Testing is an important part of the showing of compliance. The applicant should ensure the representativeness of the test means when using MC4, MC5, MC6, and MC8. In particular, the applicant should show compliance with MOC 4 VTOL.2500 (b) 'Certification Credit for Simulation and Rig Tests' when using MC4 or MC8.

The following Sections 15 to 18 provide specific guidance to adequately substantiate compliance of the FGS functionalities, performance, human factors, and failure conditions.

15. Functionalities

(a) When demonstrating that the FGS performs its intended functions, in addition to providing a thorough description of the system, the applicant should exhaustively test all functionalities of the FGS and the interfaces with dependent systems.

(b) To accomplish this exhaustiveness, the applicant may take credit of tests performed at several levels (e.g., software level, equipment level, system level, aircraft level) and may use a combination of MC4, MC5, MC6, and MC8. However, the applicant should perform a minimum as MC6.

(c) The applicant should consider the following non-exhaustive list of elements to be tested:

(1)	each FGS outer loops mode arming
(2)	each FGS outer loops mode activation
(3)	each FGS outer loops modes transition
(4)	each FGS outer loops modes reversion
(5)	each FGS outer loops modes deactivation
(6)	each FGS inner loops engagement
(7)	each FGS inner loops disengagement (manual and automatic)
(8)	each flight guidance cues display
(9)	each flight guidance cues removal
(10)	each flight crew control
(11)	each flight crew indication
(12)	each flight crew alert
(13)	each protection means
(14)	each interlock

(15)	each authority limit
(16)	each monitor
(17)	each built-in-test
(18)	each redundancy priority logic
(19)	each interface between FGS equipment
(20)	each FGS output
(21)	each input to the FGS (e.g., from sensors –air data, inertial, GNSS, radio altimeter–, from the inceptors, from the control panel, from the FMS, from the FCS, from the thrust/lift system, from the landing gear system)
(22)	each relevant failure of the inputs to the FGS
(23)	each relevant failure within the FGS
(24)	each relevant failure of the outputs of the FGS
(25)	each relevant FGS reconfiguration

(d) The applicant should provide traceability between all the FGS functionalities and the test points. The applicant may use the requirement engineering process introduced in MOC VTOL.2510 'Equipment, systems, and installations' to provide this traceability and to justify the coverage of the testing activities.

16. Performance

(a) The applicant should use testing/simulation (together with calculation/analysis) as part of the demonstration of the performance of the FGS. The performance demonstration concerns all functions of the FGS, from the FGS outer loops to the FGS inner loops through the flight guidance cues, for each mode of the FGS outer loops, and involves adequateness of the gains, the proportional, integral, and derivative controllers, and the filters of the control loops.

(b) The applicant should consider the following non-exhaustive list of attributes:

(1)	track keeping accuracy and precision
(2)	stability
(3)	transitions (mode change, capture of leg/target)
(4)	transients
(5)	oscillations
(6)	loads
(7)	accelerations
(8)	smoothness of cues

(c) The applicant should take into account the following in the demonstration:

(1)	all applicable flight phases
(2)	all applicable types of operations
(3)	all applicable manoeuvres
(4)	all applicable operational combinations of FGS activation/engagement (e.g., FGS outer loops solely active or with FGS inner loops engaged, single axis or multiple axis, including speed)
(5)	all applicable tolerances of the system (internal, e.g., servo clutch, sensors, and external, e.g., ground navaids, GNSS)
(6)	all applicable aircraft configurations (e.g., mass and centre of gravity, landing gear, flaps, rotor tilt)

(7)	all applicable aircraft degraded condition (e.g., partial loss of lift/thrust, partial loss of control surfaces)
(8)	all applicable external environmental conditions
(9)	all applicable portions of the flight envelope

(d) Especially, about the flight envelope and the external environmental conditions, consistently with sections 9.(d) and 11.(e):

(1) the applicant should assess and determine the external environmental conditions (both normally encountered and rarely encountered, as defined in paragraph 4.(f)) applicable to the aircraft, in relation to the concept of operations;

(2) the applicant should show that the FGS meets the normal performance requirements in the NFE, and under normally encountered external environmental conditions, allowing for slight transients at worst;

(3) the applicant should show that the FGS has potentially degraded but acceptable performance during momentary excursions outside the NFE, and under rarely encountered external environmental conditions, which may involve significant transients, and in case of reaching authority limit or impending automatic disengagement: timely annunciation to the flight crew;

(4) if relevant, the applicant should assess the performance of the FGS under rarely encountered external environmental conditions combined with excursions outside the NFE, especially considering that those two conditions may not be independent;

(5) The applicant should test/simulate/analyse each flight phase, mode, and operation a sufficient number of times in varying conditions, commensurately with the specificities and criticality of the situation, in order to reach an adequate confidence level in the performance assessment.

(6) The applicant may use a combination of means of compliance for the demonstration of performance. However, the applicant should perform a minimum of the tests as MC6, especially in the NFE and with normally encountered external environmental conditions. The applicant may use MC2 MC4/MC5/MC8, especially outside the NFE and with rarely encountered external environmental conditions, for practical and safety reasons.

17. Human Factors

(a) The applicant should perform a human factors assessment of the FGS in accordance with MOC VTOL.2600 section 2. The applicant should identify, analyse, and mitigate potential human performance issues, which may occur while operating the aircraft in normal and abnormal situation, including in the event of aircraft systems failure conditions. The applicant should consider the nature of the human factors objectives to select the adequate combination of MC1, MC2, MC4, MC5, MC6, and MC8 constituting the assessment.

(b) The applicant should address the following non-exhaustive list of FGS design items:

(1)	Controls, including:
(i)	engagement
(ii)	disengagement
(iii)	quick disengagement
(iv)	override
(v)	modes (activation, deactivation, transition, arming)
(vi)	targets
(vii)	trim

(viii)	flight guidance cues (display, removal)
(2)	indications
(3)	alerts
(4)	operationally relevant system behaviour
(5)	integration with other systems (controls, indications, alerts, behaviour)
(6)	automatic disengagement (e.g., due to failures, external conditions)

(c) When evaluating the FGS design, the applicant should take into account the conditions described in section 16(c) which may have an impact on human performance (e.g., demanding flight phase, dynamic conditions, external environmental conditions, aircraft degraded conditions). The applicant should also take into account operational conditions which may have an impact on human performance (e.g. communication with Air Traffic Control (ATC)).

18. Failure Conditions Validation

(a) The applicant should validate the failure conditions with care, using –depending on the effects, assumptions and associated risks of incorrect analysis– combinations of design review, analysis, desktop calculation, laboratory testing, ground testing, flight testing, pilot-in-the-loop simulation.

(b) The applicant should for example consider:

(1) MC4 or MC5 to check the effects on the system, dependent systems, and aircraft;

(2) MC6 or MC8 to check the flight crew recognition and recovery (including recognition and reaction times), and workload;

(3) MC2 to justify the effects on systems or structure, to justify the selected failure injection, to extend the validity of test points to broader conditions.

(c) The applicant should take into account all considerations from sections 12.(a)(2) and (3), 16.(b) and (c), and 17.(b) and (c).

(d) The applicant should give specific attention to aggravating factors (e.g., operational and external environmental conditions). For example, and consistently with section 9.(d), the applicant should assess the effects of the failure conditions under relevant combinations of flight envelope conditions and external environmental conditions (e.g., failure condition under rarely-encountered external environmental conditions and with potential excursions outside the NFE).

(e) The applicant should use a structured HF process to confirm the assumptions made about the expected flight crew behaviours (example can be found in the certification memorandum CM-SA-002 'Flight Crew Human Factors Assumptions in Aircraft and System Safety Assessments').

19. FGS in Icing Conditions

(a) The applicant should demonstrate that icing conditions for which the FGS is not certified to operate can be detected and avoided, and that it is possible to safely extract from unintentional entry into such icing conditions with FGS activated/engaged.

(b) The applicant should demonstrate normal performance/functioning of the FGS in icing conditions for which the FGS is requested to be certified.

(c) The applicant should address all the relevant paragraphs of present MOC for FGS in Icing Conditions, which may include for example:

(1) 7.(a)(1), 20.(b)(5);

(2) for 19.(a) specifically: 9.(d)(3), 10.(c), (d), 11.(a), (e), 12.(a)(2)(vi), 15.(c)(5), (7), (9), (11), (12), (13), (14), (16), 16.(c)(8), (d)(3), 17.(b)(2), (3), (4), (6), 18.(c), (d);

(3) for 19.(b) specifically: 9.(a), (b), (c), (d)(2), 10.(b), (e), (f), 11.(f), 12.(a)(2)(vi), 15.(c)(15), (21), 16.(c)(8), (d)(2), 17.(c), 18.(c), (d).

Explanatory Note:

Icing conditions may introduce hazards while flying with the FGS, such as – for example – ice accretion changing the aerodynamic characteristics of the aircraft, with potential consequences ranging from affecting the FGS performance, to controlling to FGS authority limit and masking the condition to the flight crew. The effects may greatly vary depending on the FGS architecture, its integration with other systems such as the FCS, the availability of anti/de-ice systems, etc, which needs to be clarified by the applicant. The icing conditions for which the FGS is aimed at being certified need to be determined, and adequate FGS behaviour need to be justified and substantiated within those conditions and upon momentary/unintentional excursions beyond those conditions.

The list provided in point (c) is an example, aiming at raising awareness on potential items to consider and highlight differences between points (a) and (b), but it actually depends on each application; the applicant is responsible for identifying and addressing all relevant considerations.

20. Limitations, Procedures, Instructions

(a) The applicant should record the FGS operating limitations, procedures, and other information necessary for the safe operation of the aircraft in the Aircraft Flight Manual (AFM), in accordance with SC VTOL.2620 ‘Aircraft Flight Manual’.

(b) This may include –but not be limited to– the following:

(1) minimum use height (for each applicable flight phase, operational procedure, FGS outer loops mode);
(2) applicable operations;
(3) flight envelop restrictions;
(4) configuration restrictions;
(5) external environmental conditions restrictions (e.g., icing, wind speed);
(6) non-normal procedures (e.g., as identified from the safety assessment);
(7) normal procedures (potentially detailed in the Flight Crew Operating Manual (FCOM) if published).

(c) The applicant should record the FGS maintenance instructions and mandatory maintenance tasks in the Instruction for Continued Airworthiness (ICA), if any, in accordance with SC VTOL.2625 ‘Instructions for Continued Airworthiness’.

(d) For Category Enhanced, the applicant should identify applicable FGS portions and equipment to be part of the instructions for the in-service monitoring, in accordance with SC VTOL.2510 (c).

MOC VTOL.2515 Electrical and electronic system lightning protection

Note:

MOC VTOL.2515 in Doc. No. MOC SC-VTOL, Issue 2, dated 12 May 2021 is updated, by upgrading all references to AMC 20-136 to AMC 20-136A.

Similarly, all references to AMC 20-158 in MOC VTOL.2520 are also upgraded to AMC 20-158A. Both AMCs should be used at release 'A' since their contents are related.

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

Note:

The original publication for comments of MOC VTOL.2520 (in Doc. No. MOC SC-VTOL, Issue 1, dated 25 May 2020) referred to DO-160E/ED 14E categories K (Cat L -6dB) and J (Cat L -12 dB) in the HIRF compliance verification for HIRF Groups I and II for non-level A display systems (Section (d)(2)(i)(B)(b)).

In the next revisions of that standard, DO-160F/ED 14F and DO-160G/ED 14G, both categories K and J disappeared.

In line with several comments received during the public consultation phase, the final publication in Doc. No MOC SC-VTOL, Issue 2, dated 12 May 2021 referred to the latest standard of DO-160G/ED-14G with categories G and F for HIRF Environment I (with 0 dB and -6 dB, respectively) as the closest to the previous categories K and J.

It is however acknowledged that, for some frequency bands, categories G and F do not rightly match with categories K and J, and therefore it is now proposed to replace them with the DO-160G/ED-14G Cat L with associated attenuations.

In addition, all references to AMC 20-158 in MOC VTOL.2520 are also upgraded to AMC 20-158A. Similarly, all references to AMC 20-136 in MOC VTOL.2515 are upgraded to AMC 20-136A. Both AMCs should be used at release 'A' since their contents are related.

The below text replaces the corresponding parts of MOC VTOL.2520 in Doc. No. MOC SC-VTOL Issue 2, dated 12 May 2021. Modifications are highlighted in blue colour for the reader's convenience.

(…)

4. Means of Compliance

(…)

(d) HIRF Compliance Verification

(1) By applying the 'Net Safety Benefit' approach[1] 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.

[1] For additional information, refer to the EASA Certification Memorandum CM-SA-001 published on the EASA Website: Final Certification Memorandum CM-SA-001 - Net Safety Benefit - Issue 01

(2) HIRF Groups I and II

(i) For Level A Non-Display Systems:

(A) Follow AMC 20-158A; 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, L-6dB or L-12dB:
(…)

MOC VTOL.2525 System power generation, energy storage, and distribution

The following are accepted as means of compliance with VTOL.2525, as applicable:

(a) CS 27.1351 (a), (b), (c) Amdt. 6, Electrical Systems – General

(b) CS 23.1331 (b) Amdt. 4, for instruments using a power source

(c) CS 27.1357 Amdt. 6, for circuit protective devices

(d) To address the hazards associated to the installation of non-propulsion Electrical Storage Devices (ESD):

(1) In normal operation or foreseeable malfunction of the ESD, no explosive, toxic, or corrosive gases or fluids should:

(i) Accumulate in hazardous quantities
(ii) Damage structures or adjacent essential equipment or systems
(iii) Endanger passengers or crew

(2) Hazardous effects on structures, occupants, essential equipment, or systems caused by the maximum amount of heat that can be generated during normal operation or probable malfunctions should be prevented.
(3) The ESD should maintain safe operating temperatures, pressures, or any other identified parameter, during normal operation (including storage, generation/discharging, refilling/recharging and / or jettisoning).
(4) The following means of information on the status of the ESD should be established:

(i) When the failure of the ESD could affect safe operation of the aircraft, means to detect the failure and alert the flight crew.
(ii) When the ESD is required for the safe operation of the aircraft, means for the flight crew and/or maintenance personnel to determine the ESD charge or status.

(5) The design and installation of the ESD should minimize likely errors during ground handling of the aircraft, the ESD, or its components, to prevent a hazardous event. To that effect:

(i) Instructions for continued airworthiness, as required by VTOL.2625, containing proper procedures including instructions on preventing the occurrence of any hazard to the ESD, to the aircraft, or to persons during refilling or recharging, and safe storage and exchange procedures of the ESD or its components if applicable.

(ii) Markings or placards should be provided as necessary.

(e) When the ESD are Lithium batteries, the use of equipment qualified according to the following standards is accepted as means of compliance in addition to (d):

(1) MOPS DO-227A or ETSO C-142b for Non–Rechargeable Lithium Batteries, complemented with a risk assessment at aircraft level (considering any limitations in the installation identified during the battery qualification).

(2) MOPS DO-311A or ETSO C-179b for Rechargeable Lithium Batteries, complemented with a risk assessment at aircraft level (considering any limitations in the installation identified during the battery qualification).

MOC VTOL.2530 External and Cockpit Lighting

Note:

The below text replaces the corresponding part of MOC VTOL.2530 in Doc. No. MOC-2 SC-VTOL Issue 3, dated 22 Dec 2022. Modifications are highlighted in blue colour for the reader's convenience.

5. Anti-collision lights

(a) The anti-collision lights are intended to attract attention to the aircraft and they should be designed and installed to ensure minimum performances in terms of intensities, flash rate, colours and fields of coverage, in order to be capable to provide sufficient visibility in a timely manner for another aircraft to avoid a collision. CS 23.1401 Amdt. 4 is accepted as means of compliance with VTOL.2530 (b) and meets this intent. Compliance with operational regulations may require a means to allow the flight crew to switch the lights off.

MOC VTOL.2545 Pressurised System Elements

[Reserved]