

ED-295

VTOL FLIGHT CONTROL HANDLING QUALITIES VERIFICATION

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CHAPTER 1

INTRODUCTION

1.1 PURPOSE AND SCOPE

This document presents a way to collect evidence to complement the Modified Handling Qualities Rating Method (MHQRM) presented in MOC VTOL.2135 in the EASA Means of Compliance with Special Condition VTOL [1]. The intention of the application of the MHQRM is to demonstrate compliance to the stability, manoeuvrability, controllability, hence Handling Qualities (HQs) requirements presented in the Special Condition Vertical Take-Off and Landing (SC VTOL) [2]. This approach is based on presenting a list of Flight Test Manoeuvres (FTM), complemented by Specific Flights (SpFI), to cover a wide variety of possible different Flight Conditions (FltC) of MHQRM and collect evidence to confirm acceptable levels of HQs.

It is foreseen that most of this evidence will be based on flight test activity. To supplement this activity, it is foreseen that simulation could in turn be used to collect further evidence for FltCs that present flight test safety challenge (e.g., failure condition that have a high severity (Catastrophic, Hazardous) or during HQ evaluation where it must be demonstrated that the aircraft is controllable) or that can't be practically replicated in flight (e.g., some failure cases where realistic fault injection is too complex and costly).

These tests would be performed using pilot-in-the-loop simulation. Standards for the qualification of simulation devices for this purpose are beyond the scope of this document. Such standards are currently being developed in WG-112 SG4 DP008.

VTOL aircraft considered in this document are aircraft which are intended to be operated in an urban environment close to obstacles and over populated areas including transport of passengers. The VTOL-capable aircraft considered in this document correspond to the "Category Enhanced" as defined in EASA "Special Condition for small-category VTOL aircraft" [2].

For the assessment of HQs, it is assumed that there is a pilot in the loop, onboard the aircraft, with the relevant training enabling them to achieve the required level of precision to complete defined tasks. The evaluation of Remotely Piloted Aircraft Systems (RPAS) is beyond the scope of this document. Additionally, requirements for vehicle control response types or flight control systems are also beyond the scope of this document.

1.2 DEFINITIONS AND ABBREVIATIONS

AD	Atmospheric Disturbance
ADQ	Adequate
AMC	Acceptable Means of Compliance
CONOPS	Concept of Operations
CHR	Cooper Harper Rating
DVE	Degraded Visual Environment
ETL	Effective Translational Lift
FltC	Flight Conditions
FC	Failure Conditions
FCS	Flight Control System
FTM	Flight Test Manoeuvre
GVE	Good Visual Environment
HMI	Human Machine Interface

HQ	Handling Qualities
HQL	Handling Qualities Level
HQR	Handling Qualities Rating
LFE	Limit Flight Envelope
MHQR	Modified Handling Qualities Rating Method
MoE	Means of Evidence
NFE	Normal Flight Envelope
OFE	Operational Flight Envelope
SAT	Satisfactory
SpFI	Specific Flight
SFltC	Specific Flight Conditions
V _B	Design speed for maximum gust intensity
V _D	Design diving speed, the highest speed planned to be achieved in testing
V _{NO}	Maximum structural cruising speed or maximum speed for normal operations
V _H	Maximum speed in level flight at continuous power
V _{NE}	Never exceed speed
VisC	Visual Cue
VTOL	Vertical Take-Off and Landing
h ₁	Low hover height
h ₂	High hover height
D	D-value
V _{FTO}	Final Take-off Speed
GPA	Glide Path Angle

1.3

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CHAPTER 2

ASSUMPTIONS

2.1 VTOL HANDLING QUALITIES (HQ)

The Handling Qualities (HQ) will be the result of a combination of:

- The general aerodynamics and inherent stability and control characteristics of the aircraft;
- The propulsion concept, including transition phases, if any (e.g., rotating parts);
- Onboard pilot assistance provided by the Flight Control System (FCS) and the controllers provided and their mechanical characteristics;
- The atmospheric environment;
- The kind of operations;
- The visual cue environment;
- Pilot interfaces.

2.2 VEHICLE ARCHITECTURE

Multiple different VTOL vehicle architecture are possible. The document does not make any assumptions regarding the vehicle architecture. The HQ demonstration manoeuvres proposed are, as far as possible, intended to be independent of the vehicle concept.

2.3 FLIGHT CONTROL SYSTEM (FCS)

It is expected that the aircraft is equipped with an electronic FCS, which provides advanced control capability to fly the aircraft.

When the FCS provides assistance through dedicated computers, the FCS implements flight control laws that might offer different levels of augmentation from “Rate Command response type” to “Fully Automatic Flight”. Other possible response types, e.g., Rate Command (RC), Attitude Command Attitude Hold (ACAH) and Translational Rate Command (TRC) are described in the ADS-33 standard [Ref. 3].

This document covers the manual piloting phase, including the FCS assistance when available. The manual piloting phase deals with pilot actions on the inceptors. Pilot assistance provided by the FCS can provide some automatic features activated automatically or after a pilot request during portions of flight.

Fully automatic flight performed by the FCS alone without a pilot input on the aircraft flight controls is beyond the scope of this document.

2.4 FLIGHT ENVELOPES

In accordance with SC VTOL [2] three flight envelopes are identified; Normal Flight Envelope (NFE), Operational Flight Envelope (OFE), and Limit Flight Envelope (LFE). These are discussed in the following subsections, based on the guidance provided in MOC VTOL.2135 Issue 2. Furthermore, a synthesis of the flight envelopes is shown in Figure 2-1.

2.4.1 Normal Flight Envelope (NFE)

The NFE corresponds to the normal use of the VTOL aircraft according to its Concept of Operations (CONOPS). There are no specific limitations when the aircraft is inside the NFE.

An example of one of the boundaries of the NFE could be the V_{NO} , which represents the maximum speed for Normal Operations.

2.4.2 Operational Flight Envelope (OFE)

This flight envelope contains the NFE, but covers also excursions beyond the NFE caused by:

- Effects of wind and Atmospheric Disturbances (AD).

- Transients due to failures and malfunctions.
- Intentional or unintentional action by the crew: this can occur during normal operations and/or emergency manoeuvres (e.g., terrain avoidance).

An example of one of the boundaries of the OFE could be the V_{NE} , which is the velocity which must not be exceeded during operations. From the Human Machine Interface (HMI) point of view, an alert must be raised when reaching the boundary of OFE, unless the FCS adequately provides envelope protections that prevents the aircraft from operating outside the operation envelope or requires positive control from the crew so that the pilot is aware that he/she is exerting a command against an envelope protection.

2.4.3 Limit Flight Envelope (LFE)

This flight envelope contains the OFE and presents the structural boundaries or the design limits of the aircraft. From an operational point of view, it is not expected that the aircraft will fly beyond the OFE, even when considering the wind envelope for which the aircraft will be authorised to be operated within the OFE.

The LFE envelope will cover excursions of the aircraft after failure when flying at the boundary of the OFE with a severe impact on the aircraft behaviour and/or trajectory. A recovery phase performed by the pilot and/or the FCS after the failure can be performed transiently inside the LFE.

An example of one of the boundaries of the LFE is the V_D , which represents the velocity demonstrated in flight in order to define the V_{NE} (boundary of the OFE): $V_{NE} \leq 0.9 V_D$.

2.4.4 Envelope Boundary Synthesis

Figure 2-1 shows the proposed high airspeed flight envelope synthesis for VTOL in the context of Handling Qualities demonstration:

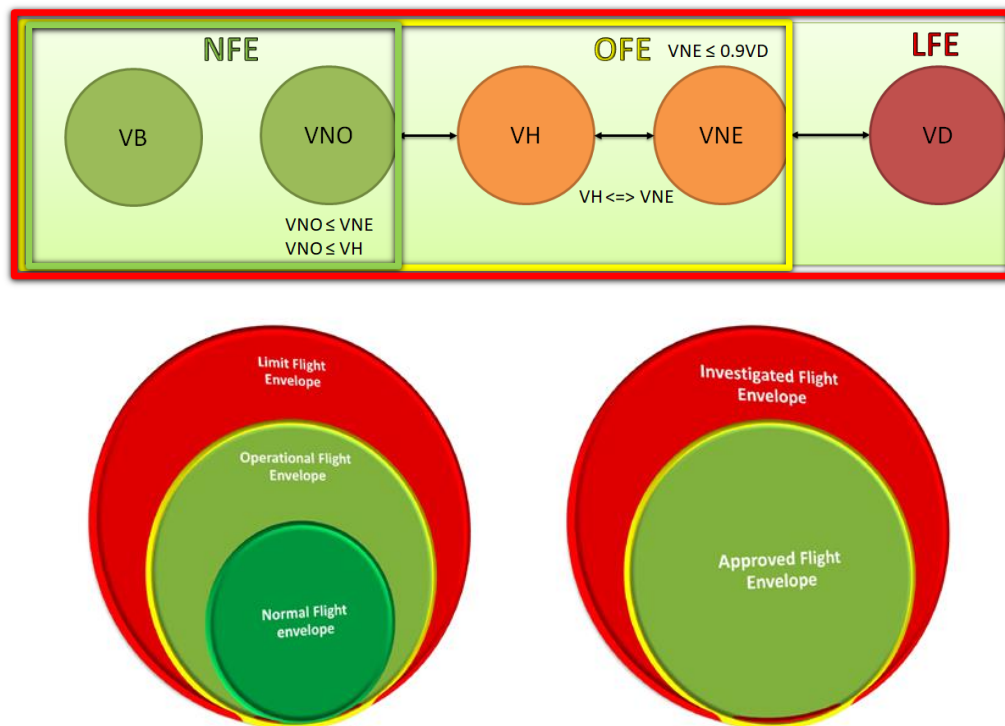


FIGURE 2-1: FLIGHT ENVELOPES SYNTHESIS

- With no failures, aircraft behaviour is demonstrated up to the boundary of the OFE (regardless of probabilistic considerations). In some pre-defined cases, the LFE boundary is investigated (e.g., $1.1V_{NE}$ flight demonstration).
- Failures (transient phase): the transient due to the failure may cause an NFE or OFE excursion. There is no deliberate attempt to reach the OFE or LFE “boundary” during demonstration.

- Failures (continuation of flight): aircraft behaviour is investigated to check if there is a degradation of controllability/HQ, but no further than the boundary of the OFE.

2.5

ATMOSPHERIC DISTURBANCES

This section is reserved for future iterations and aims to address probabilities of exceedance of moderate or severe atmospheric disturbances, as well as quantitative metrics for the definition of moderate and severe atmospheric disturbances, within an Urban Environment.

CHAPTER 3

HANDLING QUALITIES EVALUATION

3.1 HANDLING QUALITIES OBJECTIVES

The objective is to collect evidence to demonstrate the HQs based on the MHQRM process outlined in [1], Subpart B – Flight, MOC VTOL.2135. This includes evaluations both of normal and degraded handling qualities as a consequence of failure condition. These are performed using both quantitative approach which uses FTMs to quantify HQs through pilot ratings, as well as qualitative approach which is based on specific dedicated flights when the FTM approach is not applicable or practical.

In both quantitative and qualitative cases, flight tests and/or simulations can be used in order to substantiate the demonstration. A synthesis of the means of demonstration is presented in [1] according to the flight envelope, failures, and atmospheric disturbances.

3.1.1 Cooper Harper Rating Approach

This combined quantitative and qualitative approach uses the so-called Flight Test Manoeuvres (FTMs). It is intended that subjective feedback is given using the Cooper Harper Rating (CHR) Scale [3]. These evaluations should be performed by qualified pilots under a rigorous testing methodology.

Trained and experienced test pilots of minimum CAT 2 can be accepted as qualified pilot for HQ evaluations. However, VTOL manufacturer can provide evidence of sufficient training to nominate a pilot as qualified pilot. This evidence of training has to be agreed upon with the certification authority.

3.1.2 Qualitative Demonstration Approach

The qualitative approach is based on specific dedicated flights when the FTM approach is not applicable or practical. A qualitative evaluation by the qualified pilot is required. Examples may include some failure effect evaluations, behaviour with gusts, or flight in the OFE or LFE.

For failure demonstrations where pilot intervention is required, the pilot must be able to recover the trajectory of the aircraft after a defined pilot reaction time depending on the flight condition. Flight after the failure must be performed safely and should meet the appropriate requirements set in SC-VTOL. VTOL aircraft that are certified in the Category Enhanced would have to meet requirements for continued safe flight and landing and be able to continue to the original intended destination or a suitable alternate vertiport after a failure. It is important to demonstrate that the pilot is able to recover control of the aircraft safely and continue the flight without excessive pilot workload.

3.1.3 Usage of Handling Quality Rating Definitions

It is important to note the HQR definitions and CHR scores outlined in MOC VTOL.2135 do not directly relate to certification pass fail criteria when performing FTMs as they do not necessarily represent certification boundaries. If an aircraft does not meet the assigned HQR criteria while performing a FTM, then the applicant can further establish if the aircraft can be operated safely without exceptional piloting skill and the associated workload in terms of physical and/or mental compensation required by the crew, against mission related criteria based on the intended operation of the aircraft.

3.1.4 Objective Criteria

In addition to the quantitative and qualitative approaches introduced here, HQ evaluation can also be performed using objective criteria, both in the time and frequency domains. These analyses are based on the physical response of the vehicle, with specific tailored approaches dependent upon control axes and possible deficiencies. The use of these criteria and approaches may be considered in addition to the FTM and SpFI introduced in this document. However, the definition of recommended objective tests is beyond the scope of this document.

3.2 QUANTITATIVE APPROACH – FLIGHT TEST MANOEUVRES (FTM)

3.2.1 Definition

The scope of each FTM is to quantify the HQs according to the pilot workload representative of expected operations. FTMs are designed to identify HQ deficiencies of the aircraft and to ensure that the operations can be performed without exceptional piloting skills. For such quantitative evaluation, no specific limitation of the aircraft must be encountered to be able to identify HQ deficiencies. For this reason, evaluation is normally performed inside the NFE with no wind (or only very light wind) in order to precisely evaluate the HQs without the influence of AD or limitations of the aircraft.

Two main FTM families can be identified:

- Hover & Low speed → Piloting with visual references to ground & obstacles.
- Forward Flight → Piloting with visual reference to distant references (e.g., horizon) or with instruments.

The intention of the FTM description is to:

- Set realistic operational desired and adequate tolerances commensurate with the concept of operations of the aircraft to verify adequate handling qualities (e.g., FTM Hover, FTM Hovering Turn, FTM Take-Off & Landing, FTM Cruise Turn, FTM Approach go-around) while meeting minimum manoeuvrability parameters. Here the aim is to create pilot compensation and workload demands similar to that expected during nominal operations. In this context handling qualities are a combination of pilot workload, pilot compensation effort and aircraft capability.
- Set challenging desired and adequate tolerances to deliberately stress test the flight control system beyond the concept of operations to magnify & expose potential handling qualities deficiencies (e.g., PIOs). This relates primarily to handling qualities during unexpected near-earth obstacle avoidance manoeuvring (e.g., FTM Slalom, FTM Pirouette, FTM Deceleration to Hover, FTM Lateral manoeuvre). The rationale is that the pilot should not run into handling quality cliff edges during non-nominal manoeuvring in highly congested urban environments.
- Ensure a repeatable process so that all flight qualified pilots achieve proficiency in the manoeuvre in order to be able to assess the balance between workload and aircraft capability in a meaningful way.

The CHRs are awarded following completion of an FTM by a minimum of three different qualified pilots. These individual ratings are averaged in order to obtain an overall CHR, which corresponds to HQRs indicating either satisfactory (SAT), adequate (ADQ), or controllable (CON). Although the CHR is not a linear interval scale, an overall CHR may be represented by an average of ratings if those ratings are within the same HQ level or are within a reasonable range. As the evaluation aims to identify the potential deficiencies of the aircraft, initial evaluations should be conducted with no AD. Therefore, the focus is on the response of the closed-loop system (pilot + vehicle + FCS). To perform hover and low speed FTMs, a dedicated test area should be used with specific cues enabling the pilot to monitor performance parameters. A set of proposed FTMs are presented in Appendix 1 of this document.

3.2.2 Scaling Principles of FTM

The desired and adequate performance criteria prescribed for Hover and Low speed FTMs should be consistent with the operational requirements applicable for the aircraft. It is envisaged that the accuracy of VTOL aircraft handling, in particular close to the ground, will vary significantly based on the aircraft size, which could vary considerably for different VTOLs. For this reason, some FTMs proposed in this document have been designed using scaling techniques defining the targets for the aircraft's handling performance and precision in relation to its size. The decision to scale FTMs based upon the size in the Hover & Low Speed FTMs is taken due to the expectation that the size of the VTOL aircraft will be considered to enable operations from a given vertiport with defined obstacle clearance criteria.