CASE STUDIES TO ILLUSTRATE THE ROTORCRAFT CERTIFICATION BY SIMULATION PROCESS; CS 29/27 DYNAMIC STABILITY REQUIREMENTS[1]

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Abstract

Introduction

A newly developed aircraft must be certified before entering service by demonstrating compliance with the safety requirements set by certification authorities. Both the structure of the certification process and the means to demonstrate compliance with the regulations must be reached with agreement between the manufacturer, or more generally the applicant, and the authority. The compliance demonstration is usually performed through flight and ground tests that are usually the lengthiest and most expensive part of the certification process. Moreover, certain compliance flight tests could pose safety issues such as those related to flight control system or engine failures. To reduce the scope of flight test activities, and thus reduce the cost and time consumption, and lower the potential risk, advanced analysis-based methods of compliance, such as flight simulation, are being explored. For instance, Leonardo Helicopters used simulation in the certification of the engine-off landings for the AW189 [1], and tail rotor loss of effectiveness for the AW169 [2]. Both EASA's CS-27 and CS-29 Subpart B define the term "analysis-based" methods of compliance as "*calculations*" in the clause of *"tests upon a rotorcraft of the type for which certification is requested, or by calculations based on, and equal in accuracy to, the results of testing"* [3], [4]. Federal Aviation Administration (FAA) Advisory Circular AC-29.21(a) states "calculation" includes flight simulation [5]. FAA's AC 25-7D §3.1.2.6 defines the general principles under which flight simulation may be proposed as an acceptable alternative to flight testing for large aeroplanes [6]. With the increase in fidelity of physics-based rotorcraft flight simulation models, it is foreseeable that the usage of flight simulation to replace flight testing through a virtual-engineering process will become more dominant, as the industry pursues efficiency, low cost, increased safety, and low energy consumption [7]. The team of the European CleanSky2 funded project, Rotorcraft Certification by Simulation (RoCS), has the aim to explore the possibilities, limitations, and guidelines for best practices for the application of flight simulation to demonstrate compliance with the airworthiness regulations related to helicopters and tiltrotors [8].

Under the framework of the RoCS project, preliminary Guidance for the application of (rotorcraft) flight modelling and simulation has been developed in support of certification for compliance with standards CS-27/29, PART B (Flight) and other flight-related aspects (e.g. CS-29, Appendix B, Airworthiness Criteria for Helicopter Instrument Flight) [9]. The Guidance follows a requirements-based approach and is presented in the form of a structured process for Rotorcraft Certification by Simuation (RCbS). The process starts with the selection of 'applicable certification requirements' (ACRs) for the application of RCbS, with judgements on a matrix of factors of Influence (how the RCbS process will be applied), Predictability (extent of interpolation/extrapolation, and Credibility (confi-

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dence in results), in line with a comprehensive description of the assembly of flight simulation requirements. Case Studies drawn from selected ACRs are conducted to demonstrate the efficacy of aspects of the process, and include example fidelity metrics and tolerances for fidelity sufficiency and credibility analysis. This paper presents the results from the case study on Dynamic Stability (DS), CS 29.181 and CS 27.171 plus Appendix B Instrument Flight Rule (IFR) flight, to illustrate the application of the Guidance.

Fidelity Assessment and Uncertainty Quantification for Dynamic Stability

The Guidance for the RCbS process is organised into three main subsequent, but iterative, phases [9]:

1) requirements-capture and build;
2) flight simulation model (FSM) development (2a), flight simulator (FS) development (2b) and Flight Test Measurement System (FTMS) development (2c);
3) Credibility assessment and Certification.

Phase 1 consists of three subtasks for a chosen ACR – selected Influence and Predictability levels, selected simulation types and critical features, and domain descriptions. Phase 2 describes how the FSM/FS/FTMS development meets the requirements, Verification, Validation and Fidelity assessment, and updating. Phase 3 focuses on extrapolation, credibility assessment and certification. Some results from cited studies of Phases 2 and 3 are included in this abstract.

An example of the requirements in the Dynamic Stability paragraphs of CS-29 relating to VFR flight are stated as [4],

> *"CS 29.181 Dynamic stability: Category A rotorcraft; Any short period oscillation occurring at any speed from V_Y (best rate of climb) to V_{NE} (never exceed speed) must be positively damped with the primary flight controls free and in a fixed position."*

The DS boundaries for both CS27 and CS29 including IFR flight are shown in Figure 1 in the format of the frequency-damping chart; note that there are no stability requirements for VFR flight in CS-27. The Handling Qualities boundaries from ADS-33 standards [10] are included for comparison, together with data points for the 'bare-airframe' (no stability augmentation) RCbS AW109S TREKKER lateral-directional oscillation (LDO), the chosen case study on Dynamic Stability. For reference, the TREKKER is certified according to the CS27 requirements.

The chart shows data points for the FLIGHTLAB predictions for the TREKKER at 120kts airspeed and two altitudes. For this case study, the validation process at one (altitude-velocity) point (3000 ft, 120kts) revealed that the FSM prediction for the LDO was just outside the CS-27/29 boundary (red x), while estimates (*) from flight test showed the LDO to be just inside the boundary. The 'renovation' process developed in Ref. [11] determined that an FSM-update involving a 10% increase in the yaw damping was sufficient to bring the fidelity metric (red +) into the sufficiency range, defined in this example as a 10% (blue-dashed) 'box' around the mean flight test point. The figure also shows uncertainty boxes wrapped around the flight test and simulation test points, based on the varying computations of frequency and damping using different sections of the pedal doublet-induced yaw response test data, subject to different control input magnitudes.

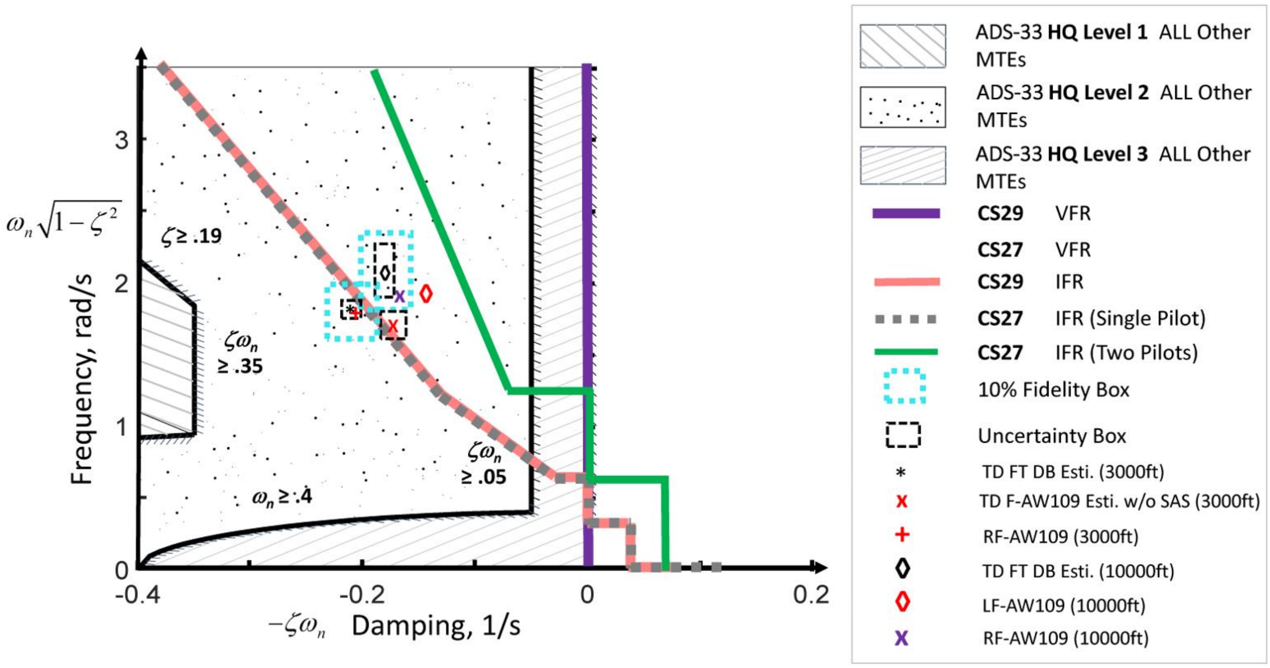

Figure 1 Comparisons of LDO stability from flight test and simulation; including FSM renovation to achieve sufficient fidelity for the dynamic stability frequency/damping metrics

For the high altitude, 10k ft, case, the same renovation process brought the FSM prediction just inside the 10% fidelity box of the flight test point. If the flight test data did not exist and the high-altitude case was being considered in the domain of extrapolation, the applicant might claim high confidence in the application of the FSM update at 10k ft that was successful at low altitude. The applicant might argue that there were no significant differences in the two cases to justify a more extensive update, but they would, of course, need to offer explanations for the damping deficiency.

In the above case, the renovations, or model updates, were made using a single ‘delta’ derivative, augmenting the nonlinear FSM yaw damping with a 10% increase in N_r. A plausible physical explanation for this is that the wind tunnel tests on the fuselage/empennage did not capture the interference/blockage effects correctly, both statically and dynamically. In addition, there are uncertainties regarding the modelling of the blockage effects on the tail rotor in the FSM. Uncertainty analysis could include varying interference modelling parameters, to explore sensitivities, coupled with additional CFD analysis to compare with the wind tunnel test data.

The above-cited contents provide a glimpse of results from the areas of Phases 2 and 3 for the Dynamic Stability Case Study. The complete story will be elaborated on in the full manuscript that will include the application process in three phases of the Guidance, with particular emphasis on credibility assessment for points at surrounding flight conditions and aircraft weight and balance configurations.

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