RoCS D2.1 – IDENTIFICATION OF CSRFA TOPICS

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TABLE OF CONTENTS

Executive Summary

The aim of Work Package (WP) 2 is to identify the list of Certification by Simulation for Rotorcraft Flight Aspects (CSRFA) topics that the rotorcraft industry, in this project represented by Leonardo Helicopters (LH), and the certification authority (EASA) agree can be complemented or substituted by off-line or piloted physics-based flight simulation in a standardised process. The WP has developed general criteria to decide if an airworthiness specification requirement is of interest as CSRFA.

WP2 started at RoCS project initiation and was concluded 31 January 2020. This report provides the results and conclusion of the WP.

Flight simulation fidelity assessment has been the topic of much research in recent years. Typically, this research has been in the context of flight simulation for training purposes. The application of flight simulation in lieu of flight testing for certification has historically been limited, with authorities restricting its use.

In order to allow for an increased use of flight simulation for certification, a process has been determined to evaluate if and how simulation could potentially be used effectively and safely as a means of compliance for airworthiness specification requirements related to rotorcraft flight aspects. This includes a scoring process to identify the most promising candidate CSRFA topics.

A process has been determined to evaluate CS-29 requirements that could be candidates for certification by simulation. The conclusion reached applies as well to all parts that are similar in scope and methodologies currently used as Means of Compliance for CS-27 and certification requirements for tiltrotor. The results have also been used to evaluate as far as possible interesting simulation cases for a tiltrotor, based on LH and EASA experience. Unless specifically noted, all candidates identified for helicopters will be considered applicable also to tiltrotors.

Based on these results, four scenarios, one specific for tiltrotor and three for generic rotorcraft, have been developed in more detail, which will be used as input for WP3 and WP4. A fifth scenario for a tiltrotor was identified as well, but could not be further detailed within the timeframe of WP2, as it required further discussion with LH and EASA. Work will start on the other scenarios, and, if possible, the fifth scenario will be further developed as soon as more information will be made available to the project partners. If this is not feasible for a tiltrotor, a rotorcraft case will be considered.

The scenarios have been assigned to RoCS partners. The scenarios and their assignment are the following:

ID	***Scenario description***	***Lead***
1	*Category A RTO, helicopter*	*NLR*
2	*Power-off landing, tiltrotor*	*POLIMI*
3	*Hover with 17 kts wind from all azimuths, helicopter*	*NLR*
4	*IFR – Dynamic stability, helicopter, nominal AFCS*	*UoL, LJMU*
5	*IFR – Stability Augmentation System (SAS) failures, helicopter or tiltrotor*	*POLIMI*

1 Introduction

The aim of Work Package (WP) 2 is to identify the list of Certification by Simulation for Rotorcraft Flight Aspects (CSRFA) topics that the rotorcraft industry, in this project represented by Leonardo Helicopters (LH), and the certification authority (EASA) agree can be complemented or substituted by off-line or piloted physics-based flight simulation in a standardised process. The WP has developed general criteria to decide if an airworthiness specification requirement is of interest as CSRFA. WP2 started at RoCS project initiation and was concluded 31 January 2020. This report provides the results and conclusion of the WP.

Flight simulation fidelity assessment has been the topic of much research in recent years. Typically, this research has been in the context of flight simulation for training purposes. The application of flight simulation in lieu of flight testing for certification has historically been limited, with authorities limiting the application to cases where it can be accurately validated.
In order to allow for an increased use of flight simulation for certification, a process has been determined to evaluate if and how simulation could potentially be used effectively and safely as a means of compliance for airworthiness specification requirements related to rotorcraft flight aspects. This includes a scoring process to identify the most promising candidate CSRFA topics.

The process is described in Chapter 2 of this report. The results of the evaluation are discussed in Chapter 3. Finally, Chapter 4 determines a sub-selection of CSRFA candidates that will be further investigated in the RoCS programme, based on available time and resources. It must be stressed that those selections have been based on some hypothesis on data and simulation capabilities that are part of the assessments to be performed in WP3 and WP4. It may be possible that out of the experience gained in those WPs the selection presented here will be updated or modified.

2 Process for determination of CSRFA candidates

This chapter describes the process used to evaluate if and how simulation could be used as a means of compliance for airworthiness specification requirements related to rotorcraft flight aspects. Section 2.1 provides an overview of the airworthiness specification requirements that have been evaluated. The determination of the foreseen simulation approach for each potential candidate requirement is explained in section 2.2. The criteria used to select potential candidates for further investigation are identified in section 2.3. Finally, section 2.4 describes the scoring system used to accept or reject and rank potential candidates, and describes additional considerations that have been taken into account.

2.1 Airworthiness Specification Requirements to be considered

The requirements to be evaluated are a subset of the CS-29 requirements (ref-[1]). A selection was made in accordance with ref-[2], and has been complemented by several related requirements that are depending on the same compliance demonstration. The requirements that have been evaluated are presented in Table 1. It must be stressed that similar requirements of CS-27 can be investigated using the same approach. So, the analysis of CS-27 paragraphs has not been repeated here but similar conclusions can be drawn in that case too.

Table 1 Overview of CS-29 requirements evaluated for RoCS

Requirement ID	Requirement title	Added
29.51	Take-off data: General	X
29.53	Take-off: Category A	
29.55	Take-off Decision Point: Category A	
29.59	Take-off Path: Category A	
29.60	Elevated heliport take-off path: Category A	
29.61	Take-off distance: Category A	
29.62	Rejected take-off: Category A	
29.75	Landing: General	
29.77	Landing Decision Point: Category A	
29.79	Landing: Category A	
29.81	Landing distance (ground level sites): Category A	
29.85	Balked landing: Category A	
29.143	Controllability and manoeuvrability	
29.151(b)	Flight controls	
29.173	Static longitudinal stability	
29.175	Demonstration of static longitudinal stability	
29.177	Static directional stability	
29.181	Dynamic stability: Category A rotorcraft	
29.251	Vibration	
29.671	Control Systems - General	
29.672	Stability augmentation, automatic, and power-operated systems	
29.695	Power boost and power-operated control system	
29.1329(d)	Automatic pilot system	X
App B Part IV	Static longitudinal stability	X
App B Part V	Static lateral-directional stability	
App B Part VI	Dynamic stability	
App B Part VII	Stability augmentation system (SAS)	

It was initially foreseen to also evaluate several requirements from the certification basis of the AW609 tiltrotor. Currently the certification basis is still under development. An extract of the FAA certification basis under development was shared by Leonardo Helicopter with the partners of RoCS. Of course, many paragraphs of this certification basis are similar to the corresponding CS-29 paragraphs. For those cases the analysis of the CS-29 has been considered valid and applicable to tiltrotor too. The additional requirements identified in ref-[2] are presented in Table 2.

The provided extract of the certification basis covers the requirements TR.45 up to and including TR.255 (ref [4]). This extract became available late in the timeframe planned for WP2. Once available, the review of the requirements showed that the parts that are not substantially coincident with CS-29 were difficult to interpret for the WP2 partners. The certification knowledge and experience of the RoCS partners is in the area of rotorcraft. If the peculiar TR requirements were to be assessed in accordance with the same process as used for the CS-29 requirements, this would have required more in-depth analysis and discussions with LH and EASA. No time and opportunity was available to do such an assessment within the timeframe for

WP2, so it was decided to use as baseline the analysis of CS-29 wherever applicable. Furthermore, it was decided to choose two candidates based on LH and EASA experience with the AW609.

Table 2 Overview of tiltrotor requirements for RoCS

Requirement ID	Requirement title
TR.145	Longitudinal and lateral control
TR.147	Closed-loop handling qualities
TR.191	Transition: General
TR.201	Stall demonstration
TR.203	Stall characteristics
TR.251	Vibration and buffeting
TR.253	High-speed characteristics
TR.255	Out-of-trim characteristics

2.2 DETERMINATION OF FORESEEN SIMULATION APPROACH

For each requirement, the following process was followed:

1) First, a brief description is provided of what actually needs to be demonstrated, without reference to a specific means of compliance.

2) The next step is to choose a possible scope of compliance by simulation. The scope indicates what the foreseen role or purpose of the simulation will be in the compliance demonstration for that requirement. The scope reflects the *level of ambition* with regards to the application of simulation and will affect the scoring attached to the requirement. There is more than one possibility per requirement; the scopes analysed in this WP reflect what the RoCS partners think should be achievable in the short term (i.e. with the technologies used/developed within RoCS). Three categories are defined:

   a) <u>Critical point/condition analysis</u>: compliance flight testing is restricted to the critical points in the envelope and/or conditions of helicopter configuration (e.g. weight & centre of gravity), which have been identified by means of simulation.
   b) <u>Extrapolation of demonstrated envelope</u>: compliance flight testing is performed for a specific envelope and, e.g., altitude and/or weight extension is based on simulation.
   c) <u>Complete or partial replacement of compliance flight test</u>: a manoeuvre or an event is partially or fully demonstrated by means of simulation instead of a flight test. In both cases, another type of flight test is needed for validation purposes.

3) The following step is to identify the so-called Demonstration Parameters, that is, all parameters that are used to show compliance with that specific requirement. Examples are 'power margins', 'control margins', 'helicopter position' or 'workload & ergonomics'. Parameters should be independent from each other and measurable, so that clear acceptance criteria can be defined. For qualitative parameters, a method of evaluation agreed with EASA should be available. Each parameter belongs to a specific compliance area (e.g. flight performance, controllability, human factors, loads), which is also identified.

4) For each Demonstration Parameter, the Means of Compliance are then identified, that is, the type of simulation tool that is expected to be used to assess that parameter. Two types are defined:

   a) Desktop Simulation;
   b) Flight Simulator (engineering simulator or training simulator).

5) In the last step, the foreseen use of the Means of Compliance is developed in more detail, to be able to determine the characteristics and validation data needed for the simulation tools.

In this process, requirements were grouped together when:

- Following step 1), it appears that the demonstration activity is linked to another requirement;
- Following steps 2) to 5), it appears that the simulation activity is covered by another requirement.

For the leading requirements of a group, and for each Demonstration parameter, the simulation tool characteristics are described that are needed to accurately capture that parameter. Simulation challenges, if any, that would make it difficult to attain the required fidelity, are also indicated. In addition, the type of data needed or desired for model development and validation of metrics is described, with emphasis on data that may require flight testing and/or may not be readily available.

2.3 IDENTIFICATION OF CRITERIA FOR SELECTION OF CANDIDATES

To select a candidate requirement for Certification by Simulation, the following three criteria have been considered:

- Simulation Feasibility (SF): based on the needed simulation tool characteristics, identified simulation challenges (if any) and the type of (validation) data needed or desired. This considers the current State of the Art simulation methods that are used by research institutes.

- Flight Test Risk Reduction (FTRR): based on the reduction in flight test risk that is obtained if, for that specific Demonstration Parameter, the simulation approach as proposed is adopted. The score definition is related to the risk classification of the *original* flight testing required for demonstration of compliance compared to the *residual* flight testing that is either required for compliance demonstration and/or validation.

- Demonstration Cost Reduction (DCR): based on the cost reduction obtained when compared to the original situation where the simulation as proposed for that specific Demonstration Parameter is not used. Both the costs of setting up the simulation as well as the costs of any validation flight tests should be taken into account.

These three criteria are independent. The SF criterion captures the (current) ability to achieve the goal, which is of special interest when a final selection is performed taking into account the constraints of the RoCS project. The FTRR and DCR criteria capture the primary reasons behind stimulating the use of simulation tools for the reduction of compliance flight testing. It is noted that the scoring of these criteria necessarily requires assumptions to be made regarding the flight test approach, as well as the availability of flight test data and simulation tools at the applicant.

A fourth criterion was identified as well: Design Risk Reduction (DRR).

This criterion has not been taken into account in the scoring system, as it is not part of the compliance demonstration phase, which is the scope of this research project. Moreover, design organizations already use simulation tools for design risk and cost reduction (impact of design choices to be made, sensitivity analyses, flight test preparation).

The criterion is nevertheless evaluated for requirements that have a good score on SF but low scores on FTRR and DCR. This ensures that requirements that may not be so interesting from the point of view of cost or flight test risk reduction, might still be interesting from the point of view of reducing design risks, and, by extension, costly and/or lengthy design and certification iterations.
The process for the selection of candidates could be adapted to score DRR along with SF, FTRR and DCR, so that it has an additional role in determining interesting simulation candidates, but, as explained before, this has not been done for the RoCS selection process.

2.4 Scoring System

The three criteria have been scored in accordance with the scales and associated definitions as provided in Table 3.

Two phases are identified that lead to different scores: Initial Type Certification (ITC) and Post Type Certification (PTC). After the evaluation of the first set of requirements, it became clear that simulation scenarios in the PTC phase are usually more interesting potential candidates for Certification by Simulation than in the ITC phase. More flight test data for validation is available and a training simulator is often available as well. Moreover, the nature of PTC changes is such that the gap between what has been previously demonstrated and what needs to be demonstrated is often not as large as what would be foreseen for ITC. Note that this may not be entirely the case for design organizations that pursue Supplemental Type Certificates (STC), as they would need proprietary data from the original manufacturer. The tools, engineering data and flight test data a STC applicant has access to will vary from applicant to applicant, which makes scoring in a general case difficult. In any case, if potential candidates are chosen based on ITC, the PTC phase will anyhow benefit from the result. For these reasons it was decided to concentrate in the selection process on ITC only, as the most challenging cases to be demonstrated. However, exactly the same approach could be followed for PTC, leading of course to a different amount of potential candidates (typically larger).

Demonstration Parameters are all scored separately, but if one or more parameters are assessed in the same simulation activity, they are grouped together. For SF, the lowest Demonstration Parameter score applies to the group, as this will determine the feasibility of the simulation activity. For FTRR and DCR, the highest Demonstration Parameter score applies to the group; even if only one Demonstration Parameter has a high score, it is still an interesting potential candidate.

Potential candidate selection is performed in accordance with the following rules (see also Figure 1):

- If a Demonstration Parameter group scores at least 3 for SF, evaluate FTRR and DCR:
  - If a Demonstration Parameter group scores at least 3 for FTRR or at least 2 for DCR, the group is a potential candidate;
  - If a Demonstration Parameter group scores lower than 3 for FTRR and lower than 2 for DCR, evaluate the potential for significant DRR:
    - i) If no significant DRR could be achieved, the group is not a potential candidate;
    - ii) If significant DRR could be achieved, the group is a potential candidate.
- If a Demonstration Parameter group scores lower than 3 for SF, the group is not a potential candidate at this point in time.

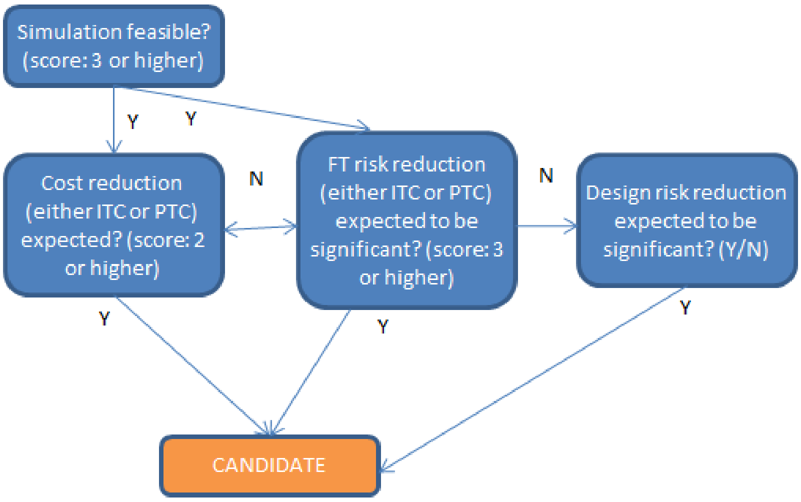

Figure 1 Potential candidate selection process

Table 3 Score definitions per criterion and boundaries for selection

Score	SF	FTRR	DCR
0			Simulation potentially and significantly more costly.
1	Key physical phenomena not captured in State-of-the-Art (SoA) simulation methods.	No reduction: flight test risk does not change	No (significant) change in sim / flight test costs
2	Simulation fidelity not expected to be sufficient with current SoA.	Risk reduction from Low to No Test, Medium to Low	Limited reduction: a subset of flight tests are still needed, high sim effort
3	Achieving the required simulation fidelity is technically challenging.	Risk reduction from High to Medium or Medium to No Test	Considerable reduction: a subset of flight tests are still needed, low sim effort
4	No major technical challenges foreseen to achieve adequate simulation fidelity.	Risk reduction from High to Low	High reduction: No flight test needed anymore, high sim effort
5	Capability already available and has been demonstrated before.	Risk reduction from High to no flight test	Maximum reduction: No flight test needed anymore, low sim effort

Scores are not further processed and presented in a matrix format, so that it remains visible why a Demonstration Parameter group is a potential candidate (due to which criterion).

3 Results of the CSRFA candidate selection process

This chapter presents the results of the evaluation process described in the previous chapter. Section 3.1 provides an overview of the scores for all Demonstration Parameter groups that have been identified, and discusses special cases. Section 3.2 discusses more detailed scenarios that were developed for a selection of high ranking potential candidates, as identified in the previous section, and for a tiltrotor.

On December 6, 2019 a meeting was held at EASA premises to discuss the results. Comments on the results of the evaluation process and the developed scenarios have been taken into account in the final results presented in this report. The Minutes of Meeting of the EASA meeting are included in Appendix 2.

3.1 Overview and discussion of Demonstration Parameter group scores

The process presented in Chapter 2 has been developed in an Excel file that contains the full analysis for all the CS paragraphs considered. This Excel file is included in Appendix 4. A summary of the results in Appendix 4 is shown in Appendix 1.

There are only two Demonstration Parameter groups that are not potential candidates in the ITC phase. Those are the following:

- Category A requirements: “Flying qualities” and “workload & ergonomics”: This is due to the fairly high cost of developing a flight simulator that is representative enough to accurately evaluate flying qualities and workload (in ITC, normally no training simulator is available). In addition, no design risks have been identified that would require a simulator activity, and cannot be mitigated by other means.
- Controllability and manoeuvrability, including AFCS/SAS failures: “ergonomics”: This is mainly due to the fact that a flight test is not needed anyway to demonstrate this aspect. In addition, no design risks have been identified that would require a simulator activity, and cannot be mitigated by other means.

For the Category A requirements this situation changes in the PTC phase. A training simulator, or in any case sufficient experience with the aircraft, would be available, which is expected to be accurate enough to assess workload and ergonomics, especially if the simulator model would use the flight simulation model developed in the ITC phase.

For the first part of the controllability & manoeuvrability requirement 29.143(a) (excluding the power-off landing), scope b) “extrapolation of demonstrated envelope” is foreseen. However, the requirement being rather generic, and covering many flight conditions, multiple scenarios could be defined resulting in different scores. It was decided to not further develop this particular requirement. After developing all other requirements, it appeared that most activities envisaged for other requirements will also allow use for this particular case.

Potential candidates that have either DCR ≥ 3 and FTRR ≥ 2 <u>or</u> FTRR ≥ 3 and DCR ≥ 2 are considered ‘interesting’ cases and are shown in Table 4. The white candidates only comply with either the FTR or the DCRR criterion while yellow candidates comply with both criteria for FTR and DCRR following the selection process shown in Figure 1. The orange potential candidate did not only comply with <u>both</u> criteria for FTR and DCRR following the selection process shown in Figure 1 (so DCR ≥ 2 and FTRR ≥ 3), but also with <u>both</u> criteria for the selection of ‘interesting’ cases for Table 4 (so DCR ≥ 3 and FTRR ≥ 3).

Table 4 'Interesting' cases for ITC: Potential candidates with DCR ≥ 3 & FTRR ≥ 2 or FTRR ≥ 3 & DCR ≥ 2

Case ID	Req ID	Scope of Compliance by Simulation	Parameter group	Simulation tool
1	Category A Rejected Take-Off (RTO)	c) Complete or partial replacement of compliance flight test	Power & control margins, landing loads, H/C position	Desktop virtual pilot simulation
2	Controllability & manoeuvrability: power-off landing	c) Complete or partial replacement of compliance flight test	Control & power margins & NR control	Desktop simulation (trim conditions) and engineering simulator (dynamic manoeuvres)
			Flying qualities	Engineering simulator
3	Controllability & manoeuvrability: 17 kts wind from all azimuths	b) Extrapolation of demonstrated envelope	Control & power margins	Desktop virtual pilot simulation
4	AFCS/SAS failure recovery	c) Complete or partial replacement of compliance flight test	Failure recovery & workload	Engineering simulator
		b) Extrapolation of demonstrated envelope	Aircraft response hands-off	Desktop simulation
5	IFR – Dynamic stability	c) Complete or partial replacement of compliance flight test	Aircraft responses: time to half/double amplitude	Desktop simulation (excitation by defined control input or simulated turbulent gust)

3.2 Scenarios for a selection of potential candidates

The most interesting cases identified in the previous section will be discussed in more detail in this section. To aid this discussion, specific scenarios have been developed.

At this point, only application to rotorcraft was considered. However, from past LH and EASA experience it became clear that the power-off landing and the simulation of AFCS/SAS failures are very attractive cases for tiltrotor certification by simulation. It was, therefore, decided to develop scenarios for cases 1, 3 and 5 based on the rotorcraft requirements but considering them applicable also to tiltrotor, and develop scenarios for cases 2 and 4 considering the associated tiltrotor requirements as the main focus. However, the tiltrotor scenario for case 4 has not been developed within the timeframe of WP2, because it required further discussion with LH and EASA, but it will be pursued and evaluated within WP3 and 4. In any case, work will start on the other scenarios.

The following sections will explain the scenarios defined for cases 1, 2, 3 and 5. Note that, following discussion with EASA, the scenario for case 1 is different from the scenario used for the initial evaluation in Appendix 4, because it was identified as a valuable scenario and more feasible. However, this does not impact the result shown in Table 4, except that the scope of compliance by simulation is type b) (extrapolation of demonstrated envelope) instead of c) (complete or partial replacement of compliance flight test).

3.2.1 Scenario 1: Rejected Take-Off (RTO) Category A

3.2.1.1 Requirement

The application to RTO is taken as an example to establish an initial scenario, since it is expected to be the most challenging from the simulation point of view. It can be possible that other portions of Cat. A, like continuous take off or balked landing are the limiting factor for the specific aircraft at hand. In that case the same approach presented here will be applied to the other cases.

The requirements for this scenario are the following:

§29.51 Take-off data: General
(a) The take-off data required by CS 29.53, 29.55, 29.59, 29.60, 29.61, 29.62, 29.63 and 29.67 must be determined:
(1) At each weight, altitude, and temperature selected by the applicant; and
(2) With the operating engines within approved operating limitations.
(b) Take-off data must:
(1) Be determined on a smooth, dry, hard surface; and
(2) Be corrected to assume a level take-off surface.
(c) No take-off made to determine the data required by this paragraph may require exceptional piloting skill or alertness, or exceptionally favourable conditions.

§29.53 Take-off: Category A
The take-off performance must be determined and scheduled so that, if one engine fails at any time after the start of take-off, the rotorcraft can:
(a) Return to and stop safely on, the take-off area; or

3.2.1.2 Assumptions

The Applicant is the helicopter manufacturer and the certification activity is for Initial Type Certification. The helicopter could be a CS-29/27 dual-engine helicopter, with an irreversible flight control system and a conventional tail rotor. The pilot reaction time to be demonstrated has been defined (f.i. 1 sec).

3.2.1.3 Scope of simulation activities

The selected scope is b), "extrapolation of demonstrated envelope" with the following activities:

- A RTO procedure is developed prior to flight testing;
- "Abuse cases" are simulated to reduce compliance flight testing;
- Flight test demonstration of cross-wind take-off and landing (20 knots from port/starboard);
- Extrapolation to the maximum take-off/landing capability to replace high-altitude compliance testing.

3.2.1.4 Data and hardware presumed to be available

The following non-exhaustive list of helicopter design information is presumed to be available for simulation development:

- Installed power f(OAT,PA) and accessory powers
- Cockpit HMI incl. instruments, inceptors, FoV, etc.
- AFCS architecture incl. FADEC

The following flight test data is presumed to be available for validation:

- Low-altitude Category A test data incl. HQ assessment
- SID test data at/below VTOSS
- Ground effect test data as per CS-FSTD(H)
- IGE hover in cross-wind (low altitude)

Both a desktop simulation tool as well as a generic engineering simulator is presumed to be available.

3.2.1.5 Targeted simulation approach

The targeted simulation approach is the following:

- Virtual pilot simulation of RTO procedure to demonstrate performance aspects (power margins, NR control, control margins, H/C position), including variations in piloting procedure (e.g., take-off rate of climb, climb angle, reaction time).
- Piloted simulation in an engineering simulator for handling qualities, workload & ergonomics assessment, and to confirm virtual pilot simulation results.
- Compliance with landing gear and drive system structural limits is demonstrated through specification of constraints on touchdown conditions and power-off transient rotor speed.

3.2.1.6 Modelling and simulation challenges

The following challenges are identified:

- Power margins & NR control, H/C position: Ground effect (if included) and low-speed rotor wake interference (download factor);
- Control margins, H/C position: Main rotor wake interference on empennage, tail rotor effectiveness in crosswind;
- Structural loads: Hub/mast loads with rapid cyclic movement (if limits not defined by flapping angles);
- Flying qualities, workload & ergonomics: Flight dynamics simulation fidelity, adequate representation of cockpit HMI, adequate cueing (haptic, aural/visual, vestibular, vibratory, instruments), in particular to perform the landing flare.

3.2.1.7 Scores

The scores for the virtual pilot simulation are the following:

- SF: 3 (challenging): Simulation of torque effects due to low-speed interference and of control margin effects due to interference is challenging;
- FTRR: 1 (no reduction): OEI landing test still performed, but for limited number of conditions;
- DCR: 3 (considerable): Limited dedicated flight testing (no need to test corners of envelope), modest cost of simulation.

The scores for the piloted simulation in an engineering simulator are the following:

- SF: 3 (challenging): For representative flying qualities: doable, but likely to be more difficult to fly in the simulator than in aircraft (conservative);
- FTRR: 1 (no reduction): OEI landing test still performed, but limited number of conditions;
- DCR: 0 (negative): Limited flight testing required anyway and a training-quality simulator would be needed to replace flight tests. Again, it is stressed that for PTC this scoring could be significantly different.

3.2.1.8 Conclusion
CS 29.53(a) is a promising candidate for certification by (desktop) simulation with emphasis on performance aspects. Simulation is useful to reduce scope of testing and to support compliance demonstrations for higher altitude, crosswind or alternate configurations. Human factor aspects should be addressed by limited flight testing.

3.2.2 Scenario 2: Controllability & manoeuvrability: power-off landing (tiltrotor)

3.2.2.1 Requirement
For this scenario, all requirements that are relevant for the power-off landing have been identified:

<u>§29.33 Main rotor speed and pitch limits</u>
(a) Main rotor speed limits. A range of main rotor speeds must be established that:
(2) With power off, allows each appropriate autorotative manoeuvre to be performed throughout the ranges of airspeed and weight for which certification is requested.

<u>§29.75 Landing: General</u>
(a) For landing data required by this subpart –
(1) The corrected landing data must be determined for a smooth, dry, hard, and level surface;
(2) The approach and landing must not require exceptional piloting skill or exceptionally favourable conditions; and
(3) The landing must be made without excessive vertical acceleration or tendency to bounce, nose over, ground loop, porpoise, or water loop.
(b) The landing data required by §29.77, <u>29.79</u>, 29.81, 29.83 and 29.85 must be determined—
(1) At each weight, altitude, and temperature for which landing data are approved;
(2) With each operating engine within approved operating limitations; and
(3) With the most unfavourable centre of gravity.

<u>§TR.79 Landing performance (one engine inoperative)</u>
<u>[…]</u>
(b) It must be possible to make a safe landing on a prepared landing surface after complete power failure occurring during normal cruise.

<u>§TR.143 Controllability and manoeuvrability</u>
(g) For aircraft operating in the VTOL/Conversion mode for which a VCON (power-off) is established under §TR.1505, compliance must be demonstrated with the following requirements with critical weight, critical centre of gravity, and critical proprotor rpm:

1) *The aircraft in the VTOL/Conversion mode must be able to safely transition from OEI power-on VCON to power-off VCON without exceptional pilot skill after the last operating engine is made inoperative at the OEI power-on VCON.*
2) *In the VTOL/Conversion mode, there must be satisfactory pitch, roll, and directional control at a speed of 1.1VCON (power-off).*

(h) The control forces necessary to meet the requirements of this subpart must be determined by quantitative tests. In no case may the control forces of this section exceed the following -
(1) For temporary application; 60 pounds in pitch, 30 pounds in roll, and 150 pounds in yaw.
(2) For prolonged application; 10 pounds in pitch, 5 pounds in roll, and 20 pounds in yaw.

3.2.2.2 Assumptions

The Applicant is the helicopter manufacturer and the certification activity is for Initial Type Certification. The aircraft is a dual-engine tiltrotor with an irreversible control system, with a certification base as shown in ref-4.

3.2.2.3 Scope of simulation activities

The selected scope is c), “complete or partial replacement of compliance flight test”, with the following activities:

- Autorotative landing procedure development prior to validation flight testing;
- Replacement of compliance flight test (actual power-off landing).

3.2.2.4 Data and hardware presumed to be available

The following helicopter design information is presumed to be available for model development:

- Cockpit HMI incl. instruments, inceptors and FoV

The following flight test data is presumed to be available for validation:

- Flare effectiveness (OGE)
- Power-off SID test data (frequency domain)
- Stabilized autorotation manoeuvres

Both a desktop simulation tool as well as a generic engineering simulator is presumed to be available.

3.2.2.5 Targeted simulation approach

The targeted simulation approach is the following:

- Trim and piloted simulation of steady flight, appropriate manoeuvres, transitions and landing (power-off) to demonstrate adequate power and control margins, and adequate NR control.
- Piloted simulation of power-off landing with representative tiltrotor behaviour in a representative cockpit environment to verify acceptable workload and handling qualities for the pilot (possibly using Cooper-Harper applied to this specific manoeuvre), including visibility, control forces, and possible stick interference.
- Compliance with landing gear and drive system structural limits demonstrated through specification of constraints on touchdown conditions and power-off transient rotor speed.

3.2.2.6 Modelling and simulation challenges

The following challenges are identified:

- Power margins & NR control, control margins: Rotor inflow and interference rotor/wing
- Flying qualities, workload & ergonomics: Flight dynamics simulation fidelity, adequate representation of cockpit HMI, adequate cueing (haptic, aural/visual, vestibular, vibratory, instruments), in particular to perform the landing flare.

3.2.2.7 Scores

For the rotorcraft (i.e., helicopter) case, the two Demonstration Parameter groups “Control & power margins & NR control” and “Flying qualities” score high on FTRR (4), because a risky power-off landing demonstration is replaced by flare effectiveness flight tests, which are considerably less risky. Their score on DCR is not very high (2), because one flight test is replaced by a high-effort (and therefore high-cost) simulation activity. This rationale applies to helicopters and tiltrotors. The Demonstration Parameter "Ergonomics" has a low score (1) for both criteria, due to the fact that no flight test is needed anyway. This applies to the tiltrotor case too.

3.2.2.8 Conclusion

The simulation of power-off landing for a tiltrotor is a promising candidate for certification by simulation. Simulation is useful to replace demonstration of risky power-off landings during flight tests.

3.2.3 Scenario 3: Controllability & manoeuvrability: 17 kts wind from all azimuths

3.2.3.1 Requirement

The requirements for this scenario are the following:

<u>§29.141 Flight Characteristics: General</u>
(a) Characteristics required by CS <u>29.143</u>, 29.151, 29.161, 29.171, 29.173, 29.175, 29.177, 29.181 must be determined:
(1) at the approved operating altitudes and temperatures;
(2) for each critical loading conditions for weight and CG for which certification is requested;
(3) for power-on operations: under any speed, power, rpm for which certification is requested;
(4) for power-off operations: under any speed, rpm for which certification is requested

<u>§29.143 Controllability and manoeuvrability</u>
(c) Wind velocities from zero to at least 31 km/h (17 knots), from all azimuths, must be established in which the rotorcraft can be operated without loss of control on or near the ground in any manoeuvre appropriate to the type (such as crosswind take-offs, sideward flight, and rearward flight), with:
(1) Critical weight;
(2) Critical CG;
(3) Critical rpm; and
(4) altitude from standard sea-level to max take-off and landing altitude capability of the rotorcraft
(d) Wind velocities from zero to at least 31 km/h (17 knots), from all azimuths must be established in which the rotorcraft can be operated without loss of control out-of-ground effect, with:
(1) weight selected by the applicant;
(2) critical CG;
(3) rotor rpm selected by the applicant;
(4) altitude from standard sea-level to max take-off and landing altitude capability of the rotorcraft.

3.2.3.2 Assumptions

The Applicant is the helicopter manufacturer and the certification activity is for Initial Type Certification. The helicopter is a CS-29 dual-engine helicopter, with an irreversible flight control system and a conventional tail rotor.

3.2.3.3 Scope of simulation activities

The type of scope is b), "extrapolation of demonstrated envelope" with the following foreseen activities:

- Identification of critical configurations prior to flight testing;
- Interpolation of wind azimuths to reduce required flight test points (OGE and IGE);
- Extrapolation to partially replace high-altitude compliance flight testing;

- Extrapolation to replace flight testing at critical weight, rpm and CG.

3.2.3.4 Data and hardware presumed to be available

The following helicopter design information is presumed to be available for model development:

- Installed power f(OAT,PA) and accessory powers
- Cockpit HMI incl. instruments, inceptors, FoV, etc.
- AFCS architecture incl. FADEC

The following flight test data is presumed to be available for validation:

- IGE take-off and hover in cross-wind (low altitude)
- SID test data for OGE hover without cross-wind (frequency domain)
- Ground effect test data as per CS-FSTD(H)
- Sideward, rearward low speed flights (low altitude)

Both a desktop simulation tool as well as a generic engineering simulator is presumed to be available.

3.2.3.5 Targeted simulation approach

The targeted simulation approach is the following:

- Virtual pilot desktop simulation of OGE/IGE hover and quartering flight (trim and transitions): Assessment of control and power margins;
- Virtual pilot desktop simulations of hover, take-off and landing manoeuvres at high altitude: to demonstrate sufficient directional authority to affect recognizable yaw response with wind from critical azimuth, by assessment of control and power margins;
- Piloted simulation of relevant manoeuvres in an engineering simulator: to verify A/C controllability and flying / handling qualities as affected by visibility, control forces, stick interference.

3.2.3.6 Modelling and simulation challenges

The following challenges are identified:

- Control and power margins: Main rotor interference;
- Control and power margins: Tail rotor effectiveness (wake interference and vortex ring state);
- Flying / handling qualities: Adequate simulation cueing (haptic, aural, vestibular, vibratory, instruments).

3.2.3.7 Scores

The scores for the virtual pilot simulation are the following:

- SF: 3 (challenging): High-altitude, main rotor interference, tail rotor effectiveness;
- FTRR: 2 (limited reduction): flight testing is still performed but the corners of the envelope and configurations are demonstrated by simulation;
- DCR: 3 (considerable): Extensive high-altitude flight testing is replaced by simulation with modest cost.

The scores for the piloted simulation in an engineering simulator are the following:

- SF: 3 (challenging): For representative flying qualities: highly dynamic manoeuvre, cues;

- FTRR: 2 (limited reduction): flight testing still performed, corners of the envelope and configurations demonstrated by sim;
- DCR: 2 (limited): Cost of simulation is high.

3.2.3.8 Conclusion

CS 29.143(c)(d) is a promising candidate for certification by (desktop) simulation with emphasis on control margins. Simulation is useful to reduce scope of testing and to support compliance demonstrations for higher altitude or alternate configurations. Human factor aspects should be addressed by limited flight testing.

3.2.4 Scenario 4: IFR – Dynamic stability

3.2.4.1 Requirement

The requirements for this scenario are the following:

<u>CS-29 Appendix B Paragraph VI Dynamic stability</u>
(a) Any oscillation having a period of less than 5 seconds must damp to ½ amplitude in not more than one cycle.
(b) Any oscillation having a period of 5 seconds or more but less than 10 seconds must damp to ½ amplitude in not more than two cycles.
(c) Any oscillation having a period of 10 seconds or more but less than 20 seconds must be damped.
(d) Any oscillation having a period of 20 seconds or more may not achieve double amplitude in less than 20 seconds.
(e) Any aperiodic response may not achieve double amplitude in less than 9 seconds.

3.2.4.2 Assumptions

The Applicant is the helicopter manufacturer and the certification activity is for Initial Type Certification. The helicopter is a CS-29 dual-engine helicopter, with an irreversible flight control system and a conventional tail rotor. IFR VNE is the same as for VFR.

3.2.4.3 Scope of simulation activities

The type of scope is b), “extrapolation of demonstrated envelope” with the following activities:

- Desktop simulation of aircraft response after perturbation from trim (with nominal and degraded AFCS), replaces dedicated flight tests;
- Extrapolation in altitude of all manoeuvres under this paragraph from VMINI to VNE.

3.2.4.4 Data and hardware presumed to be available

The following helicopter design information is presumed to be available for model development:

- AFCS sensor and actuator data (e.g., transfer functions) as needed for control law development;
- AFCS descriptions: nominal and degraded status.

The following flight test data is presumed to be available for validation:

- Compliance flight test data for all manoeuvres under this paragraph at low altitude up to and including VNE;
- SID test data from 0.9 VMINI up to and including VNE.

A desktop simulation tool is presumed to be available.

3.2.4.5 Targeted simulation approach

The targeted simulation approach is the following:

- Desktop simulation with excitation by defined control input or simulated turbulent gust and IFR-appropriate levels of stability augmentation (AFCS model): period and time to half/double amplitude of any oscillation in any axis is assessed.

3.2.4.6 Modelling and simulation challenges

The following challenges are identified:

- Real-time unsteady rotor/fuselage/empennage/fin rotor wake interference at various airspeeds up to VNE and service ceiling;
- Roll-pitch coupling and Dutch roll damping and frequency.

3.2.4.7 Scores

The scores for the desktop simulation are the following:

- SF: 3 (challenging): Due to VNE and service ceiling;
- FTRR: 2 (limited: low risk test to no test): Low risk flight test is replaced by simulations;
- DCR: 4 (considerable): high cost of simulation due to VNE and service ceiling but no dedicated flight tests are needed (use of VFR flight test data). Even though the flight test required for this paragraph is not a high-cost flight test, the simulation activity can also cover paragraph IV, which might require a considerable amount of flight tests.

3.2.4.8 Conclusion

CS 29 Appendix B paragraph VI is a promising candidate for certification by desktop simulation, due to reduction of the flight test effort (including no dedicated high altitude testing needed).

4 Conclusion on CSRFA candidates for RoCS

A process has been determined to evaluate CS-29 requirements that could be candidates for certification by simulation. The results have also been used to evaluate as far as possible interesting simulation cases for a tiltrotor, based on LH and EASA experience.

Based on these results, four scenarios, one for tiltrotor and three for rotorcraft, have been developed in more detail, which will be used as input for WP3 and WP4. A fifth scenario for a tiltrotor was identified as well, but could not be further detailed within the timeframe of WP2, as it required further discussion with LH and EASA. Work will start on the other scenarios, and, if possible, the fifth scenario will be further developed and evaluated within WP3 and 4. If this is not feasible for a tiltrotor, a rotorcraft case will be considered.

The scenarios have been assigned to RoCS partners. The scenarios and their assignment are presented in Table 5.

Table 5 Scenarios for WP3 and WP4

ID	Scenario description	Lead
1	Category A RTO, helicopter	NLR
2	Power-off landing, tiltrotor	POLIMI
3	Hover with 17 kts wind from all azimuths, helicopter	NLR
4	IFR – Dynamic stability, helicopter, nominal AFCS	UoL, LJMU
5	IFR – Stability Augmentation System (SAS) failures, helicopter or tiltrotor	POLIMI

5 References

[1] "Certification Specifications and Acceptable Means of Compliance for Large Rotorcraft", CS-29, European Aviation Safety Agency, Amendment 6, 17 December 2018.

[2] "Grant Agreement for Partners Number 831969 ITD/IADP/TA – FRC IADP Project Title – RoCS", H2020-CS2-CFP08-2018-01, 8 March 2019.

[3] "Certification of Transport Category Rotorcraft", AC 29-2C Change 7, 6 February 2016.

[4] "Certification Basis for the AW609 Tiltrotor – FAA Project # TC3419RC-R", 609A0000P001 Issue A, Leonardo Helicopters, AgustaWestland Philadelphia, 11 August 2016.

APPENDIX 1 – OVERVIEW OF SCORES

	Scope of compliance by simulation	Parameter group	Feasibility	ITC FT Risk Reduction	ITC Cost Reduction	PTC FT Risk Reduction	PTC Cost Reduction	Candidate? Y/N	If "N": design risk reduction? (Y/N/NA)	Candidate? Y/N
29.51, **29.53a**, 29.55, 29.59-29.61, 29.77, 29.85	c. Replacement (partial) of compliance flight test	Power & control margins, landing loads, H/C position	3	2	3	3	5	Y	NA	Y
		Flying qualities	3	2	0	3	5	Y (PTC)	NA	Y (PTC)
		Workload & ergonomics	4	2	0	3	5	Y (PTC)	NA	Y (PTC)
29.53b, 29.55, 29.62, 29.75, 29.77, 29.79, 29.81	c. Replacement (partial) of compliance flight test	Power & control margins, H/C position	4	1	3	2	5	Y	NA	Y
		Flying qualities	4	1	0	2	5	Y (PTC)	NA	Y (PTC)
		Workload & ergonomics	4	1	0	2	5	Y (PTC)	NA	Y (PTC)
29.143a(1)(2)(i)-(v), 29.672c, App B Par VIIa, 29.143(e)(f)	b. Extrapolation of demonstrated envelope	Control & power margins & NR control								
		Flying qualities								
		Ergonomics								
29.143a(2)(vi), 29.672c	c. Replacement (partial) of compliance flight test	Control & power margins & NR control	5	4	2			Y	NA	Y
		Flying qualities	5	4	2			Y	NA	Y
		Ergonomics	5	1	1			N	N	N
29.143b	c. Replacement (partial) of compliance flight test	Control margins	3	2	2			Y	NA	Y
29.143c, **29.143d**, 29.672c App B Par VIIa	b. Extrapolation of demonstrated envelope	Control & power margins	3	2	3			Y	NA	Y
		Flying qualities	3	2	2			Y	NA	Y
		Ergonomics	5	1	1			N	N	N
29.173, 29.175, 29.672c, App B Par VIIa	b. Extrapolation of demonstrated envelope	Longitudinal cyclic versus airspeed	See 29.143(b)							
29.175, **29.177**, 29.672c, App B Par VIIa	c. Replacement (partial) of compliance flight test	Pedal control position & lateral cyclic force	3	2	2			Y	NA	Y
29.181, 29.672c	c. Replacement (partial) of compliance flight test	Damping of aircraft states	3	2	2			Y	NA	Y
29.672a, **29.672b**, 29.672c, App B Par VIIa	c. Replacement (partial) of compliance flight test	Failure recovery & workload	3	3	4			Y	NA	Y
		Ergonomics	5	1	1			N	N	N
	b. Extrapolation of demonstrated envelope	Aircraft response (hands-off)	4	2	4			Y	NA	Y
29.1329(d) App B Par VIIb	c. Replacement (partial) of compliance flight test	Flight path & structural loads	See 29.143 but in autopilot degraded mode: so see also 29.672(a)(b)							
App B Par IV	b. Extrapolation of demonstrated envelope	Longitudinal cyclic force versus airspeed	See App B Par VI							
App B Par Vb, App B Par VIIa	c. Replacement (partial) of compliance flight test	Dihedral & damping aircraft states & longitudinal trim	3	2	1 or 3			Y	NA	Y
App B Par VI, App B Par VIIa	c. Replacement (partial) of compliance flight test	Aircraft responses: Time to half/double amplitude	3	2	4			Y	NA	Y

APPENDIX 2 – MINUTES OF MEETING WITH EASA 06-12-2019

<table>
<tr><td colspan="2">9.30 Status of the project: where we are, delays, deliverables, next major milestones (15 m, POLIMI)</td></tr>
<tr><td colspan="2">GQ briefly introduced the partners and EASA to the status of the project, delays etc….</td></tr>
<tr><td colspan="2">9:45 WP2: Introduction to the methodology used for CSRFA evaluation (NLR)</td></tr>
<tr><td>NM briefed EASA about the excel table defined within WP2
• The scoring approach was explained to give the partners an understanding on how the most promising scenarios have been selected
• FP noted that we should consider cases where it is impossible to perform a flight test. For instance, not all failures of a FBW system can be tested (because they are too risky or simply impossible to reproduce in flight). Those are candidates
• SvH noted that those are by default candidates, so they don’t need to be scored. In any case they are already tackled by simulation so there does not seem to be added value in scrutinizing those cases
• FP noted that RoCS can provide also for those cases a robustness framework
• FP Ergonomics is typically checked before FT on mock-ups (FT will probably be too late)
• FP App B par IV return to trim capability is extremely important for IFR and drives the choice of minimum speed for IFR Vmini (and in some cases IFR VNE), which may be a function of altitude, CoG, etc.
• FP Identification of Vmini is a great challenge and requires a lot of testing to identify the critical conditions and may be difficult to identify it exactly
• FP if the simulator is good to identify the Vmini it will probably be able to simulate all App B requirements
• Return to trim is a controls-free maneuver (in same cases pedals are not free)
• A big question (long discussions) when you talk about stability is always how to perform the tests. What has to be switched off (autopilot on or off. Should be off but you do not fly AP off); how to inject disturbance (doublet steps); 1in, 2in etc...; single axis, or multi-axes; feet off or feet on to keep the heading?
• Reduction of time to prepare a test could be considered a significant cost reduction.
• In simulation, the disturbance can be modelled as a gust instead of pilot input (no modelling of AFCS mechanical characteristics).
• NM indicated that App B par IV was not identified in the RoCS proposal as one of the potential candidates to be evaluated, but it will be added.
• Working up test manoeuvres is an important part of the certification</td>
<td>Actions
1 - Action: NLR – Add Appendix B par IV in the CSRFA evaluation. Deadline: 31/12/19
2 - Action: NLR – Add “ergonomics aspects dealt with by ground test in early design stage” to scenarios. Deadline: 31/12/19</td></tr>
</table>

process as it identifies limiting factors and this should be considered in RoCS.	
WP2 Scenario1 Cat-A (NLR)	
• FP: The definition of the procedure is often part of the certification work. It is necessary for the certificatory to understand how the procedure was developed and work to fix it with the applicant • FP: The NR variability and the associated energy is crucial. Models have to keep this aspect into account • High altitude Cat-A testing is very risky so models may help to significantly reduce such risk. There have been situations where cat-A maneuvers have been repeated more than 40 times ending with H/C damaged • FP: the manoeuvre itself is changed at high altitude • HS: Perform high altitude tests to validate models is way less risky than performing Cat-A testing in those conditions • HS: The HQs at high altitude are different. There is more lag of the helicopter at high altitude the pilot has to anticipate more. . There is also more effort in rotor speed management. Finally, the TAS will be different for the same IAS. • HS: In some cases, it is not so difficult to "abuse" too much. A simulator may help a lot in reducing the risk allowing the pilot to test different pilot variation to identify those that are critical, understand what are the parameters that should be followed more tightly. So the simulator can help on selecting appropriate abuse test cases • FP: Specs of the installed engine are important and engine model should be very reliable. It important to have a model of the installed power (of the minimum-spec engine) and not the one provided by engine manufacturer. OEM perform test to identify installed power models as a function of ambient conditions, incl. high-altitude. What kind of data can we get form LH? • FP: Why limiting to rejected take off? In some cases, is Continuous take off or balked landing the limiting performance • NM clarifies that only the presentation of this scenario limits itself to rejected take-off, because this is the most challenging to simulate. • HS: Limitation in rejected TO are often related to missing cues, so this could be an issue in flight simulators • MW: Project should identify what simulation features are needed in order to apply RoCS approach to future, possibly more capable simulators	**Actions** **1 - Action**: POLIMI – Check with LH what type of engine installed specs and data we will be able to get. Deadline: 31/12/19
WP2 Scenario 29.143 low speed controllability (NLR)	
• FP: Extrapolation allowed up to 2000 ft within the demonstrated range of GW/sigma, always with the applicant that has to show a reliable methodology to extrapolate. Extrapolation is not allowed for NOTAR helicopters.	**Actions**

• GQ: RoCS will not examine Fenestron or NOTAR configurations. However, RoCS should present generalised guidelines and standards. These should be suitable for all rotorcraft types, and consideration at least for the problems for other H/C should be considered and not directly dismissed. • FP: Do we have enough historical data to confirm that this extrapolation limit is correct? To be honest no, especially now that H/C configuration can be significantly different from those used to define those numbers • FP: The idea that in those hover cases wind is always beneficial is not true • FP: Flight tests have shown that the pace car method is not always equivalent to hover in wind. Care should be taken when validating models. The pace car method remains an AMoC. • HS: performance is difficult to test if you do not have the pace car to drive the speed. However simulation may offer the possibility to test at altitudes where there is no runway where the pace car and additional visual reference that can be used. • Take a look at 29.1587 related to what should go in the flight manual • FP: Never seen a case where controllability is limited by power. Usually, tail rotor effectiveness is the limiting factor for low speed controllability • FP HS noted that controllability AND control power are the elements to measure. They raised issue of nonlinearity of response in the last 10% of control authority range. So control margin with the assumption of linearity may not be considered sufficient to evaluate control power. • FP: the "original" FT risk is very high. Testing is considered risky because it is performed close to the ground (possibly inside hV-diagram) at considerable bank angle. • FP, HS: Re-ingestion of exhaust gasses and compressor stall is sometimes observed during cross-wind hover testing, particularly at high altitude. Moreover, if it does not happen during the compliance flight test, this doesn't mean it can't happen. • SvH: Re-ingestion of exhaust gasses and compressor stall is not captured by simulation. Such aspects will require flight test evaluation.	
WP2 Scenario 3: Dynamic stability VFR and IFR (NLR)	
• FP: The maximum speed in IFR will typically not be lower than VNE, except for flight in degraded AFCS state. In any case, think of a reduction of at most 20%. It will mostly be driven by helicopter behaviour in case of AFCS failures. • SvH: Even a reduction of only 20% is already significant for simulation validation purposes. Nevertheless, the scoring of the scenarios should consider the worst-case scenario where VNE_IFR = VNE_VFR. • FP: Regarding data available, for IFR, the minimum speed is Vmini,	Actions **1 - Action**: NLR – Adjust the scenario according to discussions. Deadline: 31/12/19

which will be lower than VY. You have to show stability also on descent flights. • FP: Return to trim is an aspect of App B par IV, not for dynamic stability. • FP: Note that "VFR dynamic stability" requirements only apply to Cat A aircraft. • FP: Noted the difficulty in standardizing and developing the test technique needed and this would be good to examine in simulation. Section of the correct way to inject perturbation is important during flight test. • FP: test conditions are usually the same for longitudinal, lateral, dihedral and dynamic stability • HS: if piloted simulations are necessary, control loading (friction, breakout, etc.) is very important. In addition, control chain elements may influence the possibility of controls to go back to trim MW correct use of control loading may lead to correct reproduction of these elements	
WP2 Scenarios on Tiltrotors (POLIMI)	
• Power off landing and helicopter behaviour with AFCS failures are possible scenarios to investigate for tiltrotors. However, we do not yet have input from LH to evaluate scenarios in more detail. Tiltrotor certification basis is difficult to interpret. • FP: You do not need detailed TR requirements / guidance to start working on those two cases; the helicopter requirements are defined at a high level and are a good starting point for that. • FP: consider also the possibility to investigate TO scenarios (e.g. manoeuvres/procedures optimization w.r.t. effect of nacelle angle)	Actions
14:00 WP3 model metrics (NLR)	
• The concept of the predictive fidelity metrics was briefly presented based on the cross-wind hover example. • HS: CS-FSTD is not a good reference for defining tolerances; substantiation is missing. Could be still be a good starting point where no other indications are available. • HS: From a performance perspective, pitch and roll angle are not very important for cross-wind hover. • MW noted they might not be, but are good indicators as to whether the model is correct, if we can't get trim correct this will cause problems using the model for other tests. • HS: ADS-33 is a good basis for quantifying HQs, even if tolerances may be hard to define and possibly dependent on nominal HQ level. • SvH: Extrapolation of sim vs test error based on historical data (in RoCS: AW109) and/or UQ-type sensitivity analysis. • SvH: EASA review of D3.1 will be requested in Q1 2020.	Actions
14:30 WP4 perceptual metrics (DLR)	
• The concept of pilot-in-the-loop testing in RoCS was discussed. • Collaborative test campaigns would need to be planned to give EASA	Actions **1 - Action**: DLR – formal plan for

3-6 months' notice • FP: Suggested that Summer is not a good time for EASA/test pilots, due to FT requirements	first simulator tests in 2020. Deadline: 02/2020 **2 - Action**: DLR, POLIMI – formally request the participation of EASA/LH test pilots in test campaigns.02/2020
15:00 AoB, Wrap-Up (5 m, POLIMI)	
● For WP2, the deliverable 2.1 needs to be completed in the coming period. Delivery is delayed compared to the original schedule and foreseen to be end of January 2020. ● M12 Meeting May 2020 ● M24 meeting at EASA.	Actions **1 - Action**: NLR – Draft report layout and determine contributions from WP2 partners. Deadline: 31/12/19 **2 - Action**: POLIMI –Prepare a doodle for next meeting in Milano Deadline: 31/12/19

APPENDIX 3 – ACRONYMS & ABBREVIATIONS

AFCS	Automatic Flight Control System
CG	Centre of Gravity
CS	Certification Specification
CSRFA	Certification by Simulation for Rotorcraft Flight Aspects
DCRR	Demonstration Cost Reduction
DLR	German Aerospace Centre
DRR	Design Risk Reduction
EASA	European Aviation Safety Agency
FAA	Federal Aviation Administration
FADEC	Full Authority Digital Engine Control
FoV	Field of View
FSTD	Flight Simulation Training Device
FTRR	Flight Test Risk Reduction
H/C	Helicopter
HMI	Human Machine Interface
HQ	Handling Qualities
IFR	Instrument Flight Rules
IGE	In Ground Effect
ITC	Initial Type Certification
JU	Joint Undertaking
LH	Leonardo Helicopters
LJMU	Liverpool John Moore University
NR	Main rotor speed
NLR	Royal Netherlands Aerospace Centre
OAT	Outside Air Temperature
OEI	One Engine Inoperative
OGE	Out of Ground Effect
PA	Pressure Altitude

POLIMI	Politécnica de Milano
PTC	Post Type Certification
RoCS	Rotorcraft Certification By Simulation
RTO	Rejected Take-Off
SAS	Stability Augmentation System
SF	Simulation Feasibility
SID	System Identification
UoL	University of Liverpool
VCON	Conversion speed (tiltrotor)
VFR	Visual Flight Rules
VMINI	Minimum speed in IFR
VNE	Never Exceed speed
VTOL	Vertical Take-Off and Landing
VTOSS	Take-Off Safety Speed
WP	Work Package

APPENDIX 4 – EXCEL FILE

CS REQUIREMENT (AMDT 6 17 December 2018)		COMPLIANCE DEMONSTRATION	POSSIBLE USE OF SIMULATION								SIM TECHNICAL FEASIBILITY		RISK & EFFORT REDUCTION Initial TC				RISK & EFFORT REDUCTION Post-TC (config & envelope changes)				
ID	**Description**	**Demonstration requirements**	**Scope of compliance by simulation**	**Demonstration parameters**	**Means of Compliance**		**Foreseen simulation approach**	**Model and flight simulator characteristics assumed to be required for approach**	**Simulation challenges**	**Data needed/desired for model development and validation/metrics**	**Sim feasibility**	**Group score: sim feasibility**	**Flight test risk reduction**	**Demonstration cost reduction**	**Group score: risk reduction**	**Group score: cost reduction**	**TRNG sim available?**	**Flight test risk reduction**	**Demonstration cost reduction**	**Group score: risk reduction**	**Group score: cost reduction**
		What needs to be demonstrated to show compliance?	a. Critical point/condition analysis b. Extrapolation of demonstrated envelope c. Replacement (partial) of compliance flight test	Parameters used to determine compliance ([compliance area] - [parameter name])	Dekstop sim	Flight sim (any kind)				Bold face: dedicated flight testing required	Score from 1-5	Group parameters that are assessed in the same simulation (lowest score is leading).	Score from 1-5	Score from 0-5	Group parameters that are assessed in the same simulation (highest score is leading).		Y/N (only at rows with MOC = Flight Sim)	Score from 1-5	Score from 0-5	Group parameters that are assessed in the same simulation (highest score is leading).	
29.51	Take-off data: General (a) The take-off data required by CS 29.53, 29.55, 29.59, 29.60, 29.61, 29.62, 29.63 and 29.67 must be determined: (1) At each weight, altitude, and temperature selected by the applicant; and (2) With the operating engines within approved operating limitations. (b) Take-off data must: (1) Be determined on a smooth, dry, hard surface; and (2) Be corrected to assume a level take-off surface. (c) No take-off made to determine the data required by this paragraph may require exceptional piloting skill or alertness, or exceptionally favourable conditions.	See referenced requirements.	Covered by 29.53-29.62																		
29.53(a)	Take-off: Category A: The take-off performance must be determined and scheduled so that, if one engine fails at any time after the start of take-off, the rotorcraft can: (a) Return to and stop safely on, the take-off area; or	For specific h/c configurations (weight, c.g., external equipment) and flight envelope (altitude, temperature, wind, icing conditions): Controllable take-off and transition to OEI (full stop) landing for a smooth, dry, hard level surface, with criteria i.a.w. 29.62 and loads and NR within limits. No tail wind components. Port and starboard quarter crosswinds up to 20 kts. Reaction time to be demonstrated: 1 sec	c. Replacement (partial) of compliance flight test	Performance - power margins & NR control	X		Virtual pilot simulation of defined rejected take-off (RTO) procedure incl. possible variations (in reaction time, and as determined by available cues) to determine MTOW for all foreseen H/C configurations and the applicable flight envelope, taking into account OEI power ratings and limitations in available power.	Nonlinear flight dynamics model with low-order engine dynamics and hi-fi rotor wake able to predict: - Steady installed power/torque limits and transient OEI torque response - OGE/IGE low-speed power required in (cross)wind at NR≤100%	- Ground effect (if included) - Low-speed rotor wake interference (download factor)	- OGE/IGE power with wind (incl. descent) at/below VTOSS - Power available f(OAT,PA) incl. installation effects - Ground effect validation test data as per CS-FSTD(H) - Total accessory power & drive system inertia (especially rotor speed dynamics at high altitude)	**3**: simulation of torque effects of low-speed interference challenging		**1**: no change in the risk of required flight testing	**1**: no reduction in flight testing foreseen, test data available, modest cost of simulation			N/A	**2**: low-risk performance test replaced by simulation (validated with data available for ITC config and envelope)	**5**: no flight test, low sim effort		
				Flight characteristics - control margins	X		Virtual pilot simulation of defined RTO procedure incl. possible variations (in reaction time, and as determined by available cues) to determine available pilot control margins.	Nonlinear flight dynamics model with hi-fi rotor wake able to predict: - Rotor speed dynamics - Main and tail rotor control authority (hub forces and moments)	- Main rotor wake interference on empennage - Tail rotor effectiveness in crosswind	- Ground effect validation test data as per CS-FSTD(H) - Pilot control rigging - Relevant AFCS features - Attitude & control positions crosswind HIGE (especially at high altitude).	**3**: simulation of control margin effects due to interference challenging		**1**: no change in the risk of required flight testing	**1**: no reduction in flight testing foreseen, test data available, modest cost of simulation			N/A	**3**: medium-risk control margin test replaced by simulation (validated with data available for ITC config and envelope)	**5**: no flight test, low sim effort		
				Structural loads - landing gear / airframe and drive system	X		Virtual pilot simulation of defined RTO procedure incl. possible variations (in reaction time, and as determined by available cues) to determine min/max NR and touchdown conditions. Compliance with LG load limits demonstrated by landing parameter constraints (e.g., touchdown sink rate, ground speed, lift-over-weight, h/c attitude, etc.). Drive system loads compliance through demonstration of rotor speed within steady and transient limits and simulation of flapping angles & hub/mast loads.	Nonlinear flight dynamics model with low-order LG model able to predict: - Transient rotor speed dynamics - Flapping angles or hub/mast loads with rapid cyclic movement - Ground contact conditions (WoW)	- Hub/mast loads with rapid cyclic movement (if not monitoring flapping angles) - If piloted sim: cueing to determine flare height	**- Simulated OEI rejected take-off at sea level conditions (with power recovery?)** - Drive system rotational inertia (especially at high altitude) - Landing gear geometry	4: simulation of power-off NR and landing entry conditions proven on AW189 certification, so OEI rejected takeoff should be possible too.	3	**2**: OEI landing test (medium risk) replaced by simulated OEI test (low risk)	**3**: limited dedicated flight testing, no need to test corners of envelope, modest cost of simulation	2	3	N/A	**3**: OEI landing test (medium risk) replaced by simulation (validated with ITC data)	**5**: no flight test, low sim effort	3	5
				Performance - H/C position	X		Virtual pilot simulation of defined RTO procedure incl. possible variations (in reaction time, and as determined by available cues) to determine landing position spread (inside FATO), ensure limit ground speed that ensures that you come to a stop within the FATO, and rejected take-off height loss (for obstacle clearance).	Nonlinear flight dynamics model with adjustable pilot model able to predict/model: - OEI height loss - Pilot strategy/aggression	See power and control margin	- Simulated OEI rejected take-off at sea level conditions (height loss)	4: simulation of rejected TO trajectory also used for piloting procedure development		**2**: OEI landing test (medium risk) replaced by simulated OEI test (low risk)	**3**: limited dedicated flight testing, no need to test corners of envelope, modest cost of simulation			N/A	**3**: low altitude OEI testing (medium risk) replaced by simulation (validated with ITC data)	**5**: no flight test, low sim effort		
				Human factors - Flying qualities		X	Piloted simulation of Category A RTO procedure with representative helicopter behaviour to verify acceptable handling qualities for the pilot (possibly using Cooper-Harper applied to these specific manoeuvres)	Piloted flight simulation with: - Rotor speed dynamics OEI FADEC (e.g. yaw and heave dynamics) and rotor speed dynamics power-off - High flight dynamics simulation fidelity (representative HQ, low adaptation) - AFCS architecture (possibly HITL) - Adequate cueing (haptic, aural, vestibular, vibratory, instruments)	- Flight dynamics simulation fidelity - Adequate cueing (haptic, aural/visual, vestibular, vibratory, instruments)	- AFCS architecture - SID test data **at/below VTOSS** (frequency domain) - Qualitative pilot assessment of the manoeuvres (e.g. Cooper-Harper).	3: likely to be more difficult to fly in the sim than in aircraft (conservative)	3	**2**: medium-risk OEI flight test replaced by low-risk test for sim validation	**0**: no flight test, but sim effort is high (if no training sim available)	2	0	Y	**3**: medium-risk OEI flight test replaced by simulation validated with ITC data (if not demonstrated by similarity)	**5**: no flight test, low sim effort (TRNG sim available)	3	5
				Human factors - workload & ergonomics		X	Piloted simulation in representative cockpit environment and operational scenario to confirm A/C controllability and verify pilot workload, HMI, visibility of FATO, and overall piloting procedure, including variations.	Piloted flight simulation with: - High flight dynamics simulation fidelity (representative HQ, low adaptation) - AFCS architecture incl. control loading (possibly HITL) - Representative cockpit HMI (controls, displays, ergonomics, FoV)	- Flight dynamics simulation fidelity - Adequate representation of cockpit HMI - Adequate cueing to perform the flare	- A/C HMI description - Cockpit window layout - AFCS architecture - SID test data at/below VTOSS (frequency domain)	**4:** when focussing on initial recovery after OEI	4	**2**: medium-risk OEI flight test replaced by low-risk test for sim validation	**0**: no flight test, but sim effort is high (if no training sim available)	2	0	Y	**3**: medium-risk OEI flight test replaced by simulation validated with ITC data (if not demonstrated by similarity)	**5**: no flight test, low sim effort (TRNG sim available)	3	5
29.53(b)	Take-off: Category A: The take-off performance must be determined and scheduled so that, if one engine fails at any time after the start of take-off, the rotorcraft can: (b) Continue the take-off and climb-out, and attain a configuration and airspeed allowing compliance with CS 29.67(a)(2). *29.67(a)(2): The steady rate of climb without ground effect, 305 m (1 000 ft) above the take-off surface, must be at least 46 m (150 ft) per minute, for each weight, altitude, and temperature for which take-off data are to be scheduled with:* *(i) The critical engine inoperative and the remaining engines at maximum continuous power including continuous OEI power, if approved, or at 30-minute OEI power for rotorcraft for which certification for use of 30-minute OEI power is requested;* *(ii) The landing gear retracted; and* *(iii) The speed selected by the applicant.*	For specific h/c configurations (weight, c.g., external equipment) and flight envelope (altitude, temperature, wind, icing conditions): Controllable take-off and transition to OEI fly-away for a smooth, dry, hard level surface, with margins from take-off surface and obstacles compliant with 29.59 and 29.60, and rate-of-climb compliant with 29.67(a)(2). No tail wind components. Port and starboard quarter crosswinds up to 20 kts. Reaction time to be demonstrated: 1 sec	c. Replacement (partial) of compliance flight test	Performance - power margins & NR recovery	X		Virtual pilot simulation of defined CTO procedure incl. possible variations (in reaction time, and as determined by available cues) up to climb-out at VY to determine MTOW for all foreseen H/C configurations and the applicable flight envelope, taking into account OEI power ratings and limitations in available power.	Nonlinear flight dynamics model with low-order engine dynamics and hi-fi rotor wake able to predict: - Steady installed power/torque limits and transient OEI torque response - OGE power required up to VY at 100% NR	No particular challenges	- OGE climb power up to VY - Power available f(OAT,PA) incl. installation effects - Total accessory power & drive system inertia (especially rotor speed dynamics at high altitude)	**4**: no particular challenge for climb at VTOSS-VY @ 100% NR		**1**: no change in risk of required flight testing	**2**: no reduction in flight testing foreseen, test data available, modest cost of simulation			N/A	**2**: low-risk performance test replaced by simulation (validated with data available for ITC config and envelope)	**5**: no flight test, low sim effort		
				Flight characteristics - control margins	X		Virtual pilot simulation of defined CTO procedure incl. possible variations (in reaction time, and as determined by available cues) to determine available pilot control margins.	Nonlinear flight dynamics model with hi-fi rotor wake able to predict: - Rotor speed dynamics - Main and tail rotor control authority (hub forces and moments)	No particular challenges	- Pilot control rigging - Relevant AFCS features - Attitude & control positions MTOW climb at VY (especially at high altitude).	**4**: not control margin limited	4	**1**: no change in risk of required flight testing	**1**: no reduction in flight testing foreseen, test data available, modest cost of simulation	1	3	N/A	**2**: low-risk control margin test replaced by simulation (validated with data available for ITC config and envelope)	**5**: no flight test, low sim effort	2	5
				Structural loads - drive system	X		Virtual pilot simulation of defined CTO procedure incl. possible variations (in reaction time, and as determined by available cues) to determine min/max NR during fly-away. Drive system loads compliance through demonstration of rotor speed within steady and transient limits.	Nonlinear flight dynamics model able to predict: - Transient rotor speed dynamics	No particular challenges	- Simulated OEI transient NR, sea level: backing-up climb to fly-away - Drive system rotational inertia (especially at high altitude)	4: simulation of power-off NR proven on AW189 certification, so OEI continued takeoff should be possible too.		**1**: OEI fly-away test already performed at safe altitude	**3**: limited dedicated flight testing, no need to test corners of envelope, modest cost of simulation			N/A	**2**: OEI fly-away test (low risk) replaced by simulation (validated with ITC data)	**5**: no flight test, low sim effort		
				Performance - H/C position	X		Virtual pilot simulation of defined CTO procedure incl. possible variations (in reaction time, and as determined by available cues) to demonstrate height loss and take-off distance (for obstacle clearance).	Nonlinear flight dynamics model with adjustable pilot model able to predict/model: - OEI height loss during fly-away - Pilot strategy/aggression	No particular challenges	- Simulated OEI height loss, sea level: backing-up climb to fly-away	4: simulation of continued TO trajectory also used for piloting procedure development		**1**: OEI fly-away test already performed at safe altitude	**3**: limited dedicated flight testing, no need to test corners of envelope, modest cost of simulation			N/A	**2**: OEI fly-away test (low risk) replaced by simulation (validated with ITC data)	**5**: no flight test, low sim effort		

CS REQUIREMENT (AMDT 6 17 December 2018)		COMPLIANCE DEMONSTRATION	POSSIBLE USE OF SIMULATION								SIM TECHNICAL FEASIBILITY		RISK & EFFORT REDUCTION Initial TC				RISK & EFFORT REDUCTION Post-TC (config & envelope changes)				
ID	**Description**	**Demonstration requirements**	**Scope of compliance by simulation**	**Demonstration parameters**	**Means of Compliance**		**Foreseen simulation approach**	**Model and flight simulator characteristics assumed to be required for approach**	**Simulation challenges**	**Data needed/desired for model development and validation/metrics**	**Sim feasibility**	**Group score: sim feasibility**	**Flight test risk reduction**	**Demonstration cost reduction**	**Group score: risk reduction**	**Group score: cost reduction**	**TRNG sim available?**	**Flight test risk reduction**	**Demonstration cost reduction**	**Group score: risk reduction**	**Group score: cost reduction**
		What needs to be demonstrated to show compliance?	a. Critical point/condition analysis b. Extrapolation of demonstrated envelope c. Replacement (partial) of compliance flight test	Parameters used to determine compliance ([compliance area] - [parameter name])	Dekstop sim	Flight sim (any kind)				Bold face: dedicated flight testing required	Score from 1-5	Group parameters that are assessed in the same simulation (lowest score is leading).	Score from 1-5	Score from 0-5	Group parameters that are assessed in the same simulation (highest score is leading).		Y/N (only at rows with MOC = Flight Sim)	Score from 1-5	Score from 0-5	Group parameters that are assessed in the same simulation (highest score is leading).	
				Human factors - Flying qualities		X	Piloted simulation of Category A CTO procedure with representative helicopter behaviour to verify acceptable handling qualities for the pilot (possibly using Cooper-Harper applied to these specific manoeuvres)	Piloted flight simulation with: - Rotor speed dynamics OEI FADEC (e.g. yaw and heave dynamics) - High flight dynamics simulation fidelity (representative HQ, low adaptation) - AFCS architecture (possibly HITL) - Adequate cueing (haptic, aural, vestibular, vibratory, instruments)	- Flight dynamics simulation fidelity - Adequate cueing (haptic, aural/visual, vestibular, vibratory, instruments)	- AFCS architecture - SID test data at/below VTOSS (frequency domain) - Qualitative pilot assessment of the manoeuvres (e.g. Cooper-Harper).	4: simulation of HQs and cockpit HMI not so challenging for fly away	4	**1**: low-risk OEI flight test replaced by low-risk test for sim validation	**0**: no flight test, but sim effort is high (if no training sim available)	1	0		**2**: low-risk OEI flight test replaced by simulation validated with ITC data (if not demonstrated by similarity)	**5**: no flight test, low sim effort (TRNG sim available)	2	5
				Human factors - workload & ergonomics		X	Piloted simulation in representative cockpit environment and operational scenario to confirm A/C controllability and verify pilot workload, HMI, visibility of FATO, and overall piloting procedure, including variations.	See 29.53(a)	See 29.53(a)	See 29.53(a)	4: simulation of HQs and cockpit HMI not so challenging for fly away	4	**1**: low-risk OEI flight test replaced by low-risk test for sim validation	**0**: no flight test, but sim effort is high (if no training sim available)	1	0	Y	**2**: low-risk OEI flight test replaced by simulation validated with ITC data (if not demonstrated by similarity)	**5**: no flight test, low sim effort (TRNG sim available)	2	5
29.55	Take-off Decision Point: Category A (a) The take-off decision point (TDP) is the first point from which a continued take-off capability is assured under CS 29.59 and is the last point in the take-off path from which a rejected take-off is assured within the distance determined under CS 29.62. (b) The TDP must be established in relation to the take-off path using no more than two parameters, such as airspeed and height, to designate the TDP. (c) Determination of the TDP must include the pilot recognition time interval following failure of the critical engine.	For specific h/c configurations (weight, c.g., external equipment) and flight envelope (altitude, temperature, wind, icing conditions): TDP as a function of airspeed and/or height that fulfills the demonstration criteria presented for 29.53 and 29.62, and showing that a suitable pilot recognition time has been taken into account.	Covered by 29.53																		
29.59	Take-off Path: Category A (a) The take-off path extends from the point of commencement of the take-off procedure to a point at which the rotorcraft is 305 m (1000 ft) above the take-off surface and compliance with CS 29.67(a)(2) is shown. In addition: (1) The take-off path must remain clear of the height-velocity envelope established in accordance with CS 29.87; (2) The rotorcraft must be flown to the engine failure point at which point the critical engine must be made inoperative and remain inoperative for the rest of the take-off; (3) After the critical engine is made inoperative, the rotorcraft must continue to the TDP, and then attain VTOSS. (4) Only primary controls may be used while attaining VTOSS and while establishing a positive rate of climb. Secondary controls that are located on the primary controls may be used after a positive rate of climb and VTOSS are established but in no case less than 3 seconds after the critical engine is made inoperative; and (5) After attaining VTOSS and a positive rate of climb, the landing gear may be retracted. (b) During the take-off path determination made in accordance with sub-paragraph (a) and after attaining VTOSS and	For specific h/c configurations (weight, c.g., external equipment) and flight envelope (altitude, temperature, wind, icing conditions): take-off paths with associated h/c airspeed and vertical speed histories, engines rpm or torque histories, and associated use of primary/secondary controls, resulting from fulfilling the demonstration criteria presented for 29.53, and shown to comply with the criteria in 29.59	Covered by 29.53																		
29.60	Elevated heliport take-off path: Category A (a) The elevated heliport take-off path extends from the point of commencement of the take-off procedure to a point in the take-off path at which the rotorcraft is 305 m (1 000 ft) above the take-off surface and compliance with CS 29.67(a)(2) is shown. In addition: (1) The requirements of CS 29.59(a) must be met; (2) While attaining VTOSS and a positive rate of climb, the rotorcraft may descend below the level of the take-off surface if, in so doing and when clearing the elevated heliport edge, every part of the rotorcraft clears all obstacles by at least 4.6 m (15 ft); (3) The vertical magnitude of any descent below the take-off surface must be determined; and (4) After attaining VTOSS and a positive rate of climb, the landing gear may be retracted. (b) The scheduled take-off weight must be such that the climb requirements of CS 29.67(a)(1) and CS 29.67(a)(2) will be met.	For specific h/c configurations (weight, c.g., external equipment) and flight envelope (altitude, temperature, wind, icing conditions): take-off paths with associated h/c airspeed and vertical speed histories, engines rpm or torque histories, and associated use of primary/secondary controls, resulting from fulfilling the demonstration criteria presented for 29.53, and shown to comply with the criteria in 29.60	Covered by 29.53																		
29.61	Take-off distance: Category A (a) The normal take-off distance is the horizontal distance along the take-off path from the start of the take-off to the point at which the rotorcraft attains and remains at least 11 m (35 ft) above the take-off surface, attains and maintains a speed of at least VTOSS; and establishes a positive rate of climb, assuming the critical engine failure occurs at the engine failure point prior to the TDP. (b) For elevated heliports, the take-off distance is the horizontal distance along the take-off path from the start of the take-off to the point at which the rotorcraft attains and maintains a speed of at least VTOSS and establishes a positive rate of climb, assuming the critical engine failure occurs at the engine failure point prior to the TDP.	For specific h/c configurations (weight, c.g., external equipment) and flight envelope (altitude, temperature, wind, icing conditions): take-off distances as derived in accordance with 29.61 from the take-off paths determined for 29.59 and 29.60	Covered by 29.53																		
29.62	Rejected take-off: Category A The rejected take-off distance and procedures for each condition where take-off is approved will be established with: (a) The take-off path requirements of CS 29.59 and 29.60 being used up to the TDP where the critical engine failure is recognised, and the rotorcraft landed and brought to a stop on the take-off surface; (b) The remaining engines operating within approved limits; (c) The landing gear remaining extended throughout the entire rejected take-off; and (d) The use of only the primary controls until the rotorcraft is on the ground. Secondary controls located on the primary control may not be used until the rotorcraft is on the ground. Means other than wheel brakes may be used to stop the rotorcraft if the means are safe and reliable and consistent results can be expected under normal operating conditions.	For specific h/c configurations (weight, c.g., external equipment) and flight envelope (altitude, temperature, wind, icing conditions): take-off paths, and distances derived from those paths, with associated h/c airspeed and vertical speed histories, engines rpm or torque histories, and associated use of primary/secondary controls, resulting from fulfilling the 'OEI landing' criterion presented for 29.53, and shown to comply with the criteria in 29.62	Covered by 29.53																		
29.75	Landing: General (a) For each rotorcraft: (1) The corrected landing data must be determined for a smooth, dry, hard and level surface; (2) The approach and landing must not require exceptional piloting skill or exceptionally favourable conditions; and, (3) The landing must be made without excessive vertical acceleration or tendency to bounce, nose over, ground loop, porpoise, or water loop. (b) The landing data required by CS 29.77, 29.79, 29.81, 29.83 and 29.85 must be determined: (1) At each weight, altitude and temperature for which landing data are approved: (2) With each operating engine within approved operating limitations: and (3) With the most unfavourable centre of gravity.	See referenced requirements.	Covered by 29.53																		
29.77	Landing Decision Point: Category A (a) The landing decision point (LDP) is the last point in the approach and landing path from which a balked landing can be accomplished in accordance with CS 29.85. (b) Determination of the LDP must include the pilot recognition time interval following failure of the critical engine.	For specific h/c configurations (weight, most unfavoraluable c.g., external equipment) and flight envelope (altitude, temperature, wind, icing conditions), scope is Category A landing only: TDP as a function of airspeed and/or height that fulfills the demonstration criteria presented for 29.79 and 29.85, and showing that a suitable pilot recognition time has been taken into account.	Covered by 29.53																		
29.79	Landing: Category A (a) For Category A rotorcraft: (1) The landing performance must be determined and scheduled so that if the critical engine fails at any point in the approach path, the rotorcraft can either land and stop safely or climb out and attain a rotorcraft configuration and speed allowing compliance with the climb requirement of CS 29.67(a)(2); (2) The approach and landing paths must be established with the critical engine inoperative so that the transition between each stage can be made smoothly and safely; (3) The approach and landing speeds must be selected for the rotorcraft and must be appropriate to the type of rotorcraft; and (4) The approach and landing path must be established to avoid the critical areas of the height-velocity envelope determined in accordance with CS 29.87. (b) It must be possible to make a safe landing on a prepared landing surface after complete power failure occurring during normal cruise.	For specific h/c configurations (weight, most unfavoraluable c.g., external equipment) and flight envelope (altitude, temperature, wind, icing conditions), scope is Category A landing only (29.79(a)): Controllable OEI landing shown to comply with the criteria in 29.79 with loads and NR within limits and, controllable OEI fly-away with margins from landing surface and obstacles compliant with 29.85, and rate-of-climb compliant with 29.67(a)(1)(2). No tail wind components. Port and starboard quarter crosswinds up to 20 kts.	Covered by 29.53																		

CS REQUIREMENT (AMDT 6 17 December 2018)		COMPLIANCE DEMONSTRATION	POSSIBLE USE OF SIMULATION								SIM TECHNICAL FEASIBILITY		RISK & EFFORT REDUCTION Initial TC				RISK & EFFORT REDUCTION Post-TC (config & envelope changes)				
ID	**Description**	**Demonstration requirements**	**Scope of compliance by simulation**	**Demonstration parameters**	**Means of Compliance**		**Foreseen simulation approach**	**Model and flight simulator characteristics assumed to be required for approach**	**Simulation challenges**	**Data needed/desired for model development and validation/metrics**	**Sim feasibility**	**Group score: sim feasibility**	**Flight test risk reduction**	**Demonstration cost reduction**	**Group score: risk reduction**	**Group score: cost reduction**	**TRNG sim available?**	**Flight test risk reduction**	**Demonstration cost reduction**	**Group score: risk reduction**	**Group score: cost reduction**
		What needs to be demonstrated to show compliance?	a. Critical point/condition analysis b. Extrapolation of demonstrated envelope c. Replacement (partial) of compliance flight test	Parameters used to determine compliance ([compliance area] - [parameter name])	Dekstop sim	Flight sim (any kind)				Bold face: dedicated flight testing required	Score from 1-5	Group parameters that are assessed in the same simulation (lowest score is leading).	Score from 1-5	Score from 0-5	Group parameters that are assessed in the same simulation (highest score is leading).		Y/N (only at rows with MOC = Flight Sim)	Score from 1-5	Score from 0-5	Group parameters that are assessed in the same simulation (highest score is leading).	
29.81	Landing distance (ground level sites): Category A The horizontal distance required to land and come to a complete stop (or to a speed of approximately 5.6 km/h (3 knots) for water landings) from a point 15 m (50 ft) above the landing surface must be determined from the approach and landing paths established in accordance with CS 29.79.	For specific h/c configurations (weight, most unfavorauble c.g., external equipment) and flight envelope (altitude, temperature, wind, icing conditions): landing distances as derived in accordance with 29.81 from the approach and landing paths determined for 29.79	Covered by 29.53																		
29.85	Balked landing: Category A For Category A rotorcraft, the balked landing path with the critical engine inoperative must be established so that: (a) The transition from each stage of the manoeuvre to the next stage can be made smoothly and safely; (b) From the LDP on the approach path selected by the applicant, a safe climbout can be made at speeds allowing compliance with the climb requirements of CS 29.67(a)(1) and (2); and (c) The rotorcraft does not descend below 4.6 m (15 ft) above the landing surface. For elevated heliport operations, descent may be below the level of the landing surface provided the deck edge clearance of CS 29.60 is maintained and the descent (loss of height) below the landing surface is determined.	For specific h/c configurations (weight, most unfavorauble c.g., external equipment) and flight envelope (altitude, temperature, wind, icing conditions): balked landing paths with associated h/c airspeed and vertical speed histories, engines rpm or torque histories, resulting from fulfilling the demonstration criteria presented for 29.79, and with margins from landing surface and obstacles compliant with 29.85, and rate-of-climb compliant with 29.67(a)(1)(2)	Covered by 29.53																		

CS REQUIREMENT (AMDT 6 17 December 2018)		COMPLIANCE DEMONSTRATION	POSSIBLE USE OF SIMULATION								SIM TECHNICAL FEASIBILITY		RISK & EFFORT REDUCTION Initial TC				RISK & EFFORT REDUCTION Post-TC (config & envelope changes)				
ID	**Description**	**Demonstration requirements**	**Scope of compliance by simulation**	**Demonstration parameters**	**Means of Compliance**		**Foreseen simulation approach**	**Model and flight simulator characteristics assumed to be required for approach**	**Simulation challenges**	**Data needed/desired for model development and validation/metrics**	**Sim feasibility**	**Group score: sim feasibility**	**Flight test risk reduction**	**Demonstration cost reduction**	**Group score: risk reduction**	**Group score: cost reduction**	**TRNG sim available?**	**Flight test risk reduction**	**Demonstration cost reduction**	**Group score: risk reduction**	**Group score: cost reduction**
		What needs to be demonstrated to show compliance?	a. Critical point/condition analysis b. Extrapolation of demonstrated envelope c. Replacement (partial) of compliance flight test	Parameters used to determine compliance ([compliance area] - [parameter name]) Note: parameter = measurable	Dekstop sim	Flight sim (any kind)				Bold face: dedicated flight testing required	Score from 1-5	Group parameters that are assessed in the same simulation (lowest score is leading).	Score from 1-5	Score from 0-5	Group parameters that are assessed in the same simulation (highest score is leading).		Y/N (only at rows with MOC = Flight Sim)	Score from 1-5	Score from 0-5	Group parameters that are assessed in the same simulation (highest score is leading).	
29.143(a)(1)(2)(i)-(v)	Controllability and manoeuvrability The rotorcraft must be **safely controllable and manoeuvrable**: (1) During steady flight; and (2) During **any manoeuvre appropriate to the type**, including: (i) Take-off, (ii) Climb; (iii) Level flight; (iv) Turning flight; (v) Autorotation; and	For specific h/c configurations (weight, c.g., external equipment) and flight envelope (altitude, temperature): Definition of applicable flight conditions and manoeuvres and showing that these can be flown without loss of control, including transition from one condition / manoeuvre to the other. Requirement includes demonstration of adequate control margins after single AFCS failures (with possible control stick interference in cockpit): as required by CS29.672.	b. Extrapolation of demonstrated envelope	Controllability - control margins	X	X	Trim and piloted simulation of steady flight, appropriate manoeuvres (power on) and transitions to demonstrate adequate control margins, incl. small allowance for moderate turbulent gust control, with most adverse control rigging production tolerance. Cyclic control authority in autorotation must be sufficient to allow adequate flare capability.	Nonlinear flight dynamics model with hi-fi rotor and fuselage aero able to predict: - Main and tail rotor control authority (hub forces and moments at given control positions)	- Trim matching across the flight envelope (incl. power and lateral cyclic) - High-speed phenomena as function of altitude (stall, drag divergence) - Main rotor wake interference on empennage	- Trim controls/attitudes in part of flight envelope (as available) - Controls/attitudes during identified appropriate maneuvres in available part of envelope											
				Performance - power margins & NR control	X	X	Trim and piloted simulation of steady flight, appropriate manoeuvres and transitions to demonstrate adequate power margin to ensure controllability (i.e., when not control margin limited).	Nonlinear flight dynamics model able to predict/simulate: - Steady installed power/torque - Engine failure, autorotation and power off scenarios (except landing)	- High-speed phenomena as function of altitude (stall, drag divergence) - Main rotor wake interference on empennage	- Available installed power accross envelope - Trim and maneuvre torque/NR in part of flight envelope (as available)											
				Human factors - flying qualities		X	Piloted simulation of relevant manoeuvres with representative helicopter behaviour to verify acceptable handling qualities for the pilot (possibly using Cooper-Harper applied to these specific manoeuvres)	Piloted flight simulation with: - Rotor speed dynamics power on FADEC (e.g. yaw and heave dynamics) and rotor speed dynamics power-off - High flight dynamics simulation fidelity (representative HQ, low adaptation) - AFCS architecture (possibly HITL) - Adequate cueing (haptic, aural, vestibular, vibratory, instruments)	- Flight dynamics simulation fidelity - Adequate cueing (haptic, aural, vestibular, vibratory, instruments)	- AFCS architecture - SID test data (frequency domain) - Qualitative pilot assessment of the manoeuvres (e.g. Cooper-Harper).											
				Human factors - ergonomics		X	Piloted simulation of relevant manoeuvres in representative cockpit environment to verify A/C controllability as affected by visibility, control forces, and stick interference.	Piloted flight simulation with: - Representative cockpit HMI (controls, displays, ergonomics, FoV)	- Adequate representation of cockpit HMI	- A/C HMI description											
29.143(a)(2)(vi)	Controllability and manoeuvrability The rotorcraft must be safely controllable and manoeuvrable: (2) During any manoeuvre appropriate to the type, including: (vi) **Landing (power on and power off).**	For specific h/c configurations (weight, c.g., external equipment) and flight envelope (altitude, temperature) and AFCS single failures: Showing that power off landing can be flown without loss of control.	c. Replacement (partial) of compliance flight test	Controllability - control margins	X	X	Trim and piloted simulation of landing (power on and off) and transitions to demonstrate adequate control margins, incl. small allowance for moderate turbulent gust control, with most adverse control rigging production tolerance. Cyclic control authority in autorotation must be sufficient to allow power-off landing.	Nonlinear flight dynamics model with hi-fi rotor wake able to predict: - Rotor speed dynamics (power-off) - Main and tail rotor control authority (hub forces and moments) - AFCS impact on control margins	- Trim matching across the flight envelope (incl. power and lateral cyclic) - Main rotor inflow	- Trim controls/attitudes in part of flight envelope (as available) - Controls/attitudes during identified appropriate maneuvres in available part of envelope - Power-off landing: control travel and attitudes during flare effectiveness demonstrations	**5**: Refer AW189 certification	5	**4**: power off landing demonstration replaced by flare efectiveness flight tests	**2**: one flight test is replaced by high effort sim	4	2					
				Performance - power margins & NR control	X	X	Trim and piloted simulation of steady flight, appropriate manoeuvres (power on and off) and transitions to demonstrate adequate power margin and power-off NR control to ensure controllability (i.e., when not control margin limited).	Nonlinear flight dynamics model able to predict/simulate: - Steady installed power/torque - Engine failure, autorotation and power off scenarios	- Main rotor inflow	- Available installed power accross envelope - Trim and maneuvre torque/NR in part of flight envelope (as available) - Power-off landing: NR during flare effectiveness demonstrations	**5**: Refer AW189 certification		**4**: power off landing demonstration replaced by flare efectiveness flight tests	**2**: one flight test is replaced by high effort sim							
				Human factors - flying qualities		X	Piloted simulation of power on and power off landing with representative helicopter behaviour to verify acceptable handling qualities for the pilot (possibly using Cooper-Harper applied to this specific manoeuvre)	Piloted flight simulation with: - High flight dynamics simulation fidelity (representative HQ, low adaptation) - AFCS architecture incl. control loading (possibly HITL) - Adequate cueing (haptic, aural, vestibular, vibratory, instruments)	- Flight dynamics simulation fidelity - Adequate cueing (haptic, aural, vestibular, vibratory, instruments)	- AFCS architecture - SID test data (frequency domain) - Qualitative pilot assessment of the flare effectiveness in flight test (e.g. Cooper-Harper).	**5**: Refer AW189 certification	5	**4**: power off landing demonstration replaced by flare efectiveness flight tests	**2**: one flight test is replaced by high effort sim	4	2					
				Human factors - ergonomics		X	Piloted simulation of power on and power off landing in representative cockpit environment to verify A/C controllability as affected by visibility, control forces, and stick interference.	Piloted flight simulation with: - Representative cockpit HMI (controls, displays, ergonomics, FoV)	- Adequate representation of cockpit HMI	- A/C HMI description (esp. control system)	**5**: Refer AW189 certification	5	**1**: no flight test needed anyway for this task	**1**: No change, as no flight test was needed, and if activity is combined with piloted sim for flying qualities	1	1					
29.143(b)	Controllability and manoeuvrability The margin of cyclic control must allow satisfactory roll and pitch control **at VNE** with: (1) **Critical** weight; (2) **Critical** centre of gravity; (3) **Critical** rotor rpm; and (4) **Power off** (except for helicopters demonstrating compliance with sub-paragraph (f)) and power on. For RoCS: May be extended to 1.1VNE as risk-reduction for 29.251 flight test.	For specific h/c configurations (critical weight, critical c.g., external equipment) and flight envelope (altitude, temperature): Pitch & roll cyclic control histories during flight at VNE with critical rotor rpm and power off and during flight at VNE with critical rotor rpm and power on, showing sufficient cyclic control margin.	c. Replacement (partial) of compliance flight test	Controllability - control margins	X		Open-loop control response simulation to demonstrate sufficient control authority at VNE in critical configuration for clearly positive nose-down pitching moment and 30 deg bank turns with reasonable turn rates (incl. control reversals and out of trim sideslip conditions).	Nonlinear flight dynamics model able to predict main rotor control authority (hub forces and moments) in the presence of dynamic stall (or at least able to predict stall onset) in level and turning steady flight, and compressibility effects (table look-up).	- Advancing blade compressibility (gradual yet steep increase in profile power) - Retreating blade stall (sudden and unsteady hub and control loads)	- VNE test data obtained for loads/vibration substantiation (different weight, cg, rpm).	**3**: if needed, non-realtime coupled CSD-CFD for trim/open-loop response	3	**2**: VNE flight test in control-critical config not required (low-risk because mitigated by prior VNE testing for loads, vibrations, etc.)	**2**: VNE flight test in control-critical config not required, simulation challenging	2	2					
29.143(c)	Controllability and manoeuvrability Wind velocities from zero to at least 31 km/h (17 knots), **from all azimuths**, must be established in which the rotorcraft can be operated **without loss of control** on or **near the ground** in **any manoeuvre appropriate to the type** (such as crosswind take-offs, sideward flight, and rearward flight), with: (1) Critical weight; (2) Critical centre of gravity; (3) Critical rotor rpm; and (4) Altitude, from standard sea-level conditions to the **maximum take-off and landing altitude capability** of the rotorcraft. Assumption: irreversible control system & conventional tail rotor	For specific h/c configurations (critical weight, critical c.g., external equipment) and flight envelope (altitude, temperature) and AFCS single failure conditions: Definition of applicable flight conditions and manoeuvres on or near the ground, and showing that these can be executed / flown stable with critical rotor rpm and without reaching / exceeding control limits, in winds from zero to at least 17 knots from all azimuths (no lateral gusts). Temperature taken into account for required data in FM (29.1587)	b. Extrapolation of demonstrated envelope	Controllability - control margins	X		Trim and virtual pilot simulation of IGE hover and quartering flight (trim), as well as appropriate take-off and landing manoeuvres accross the temperature and altitude envelope with wind from all azimuths, to demonstrate adequate control authority/margin incl. 'recognizable yaw'.	Nonlinear flight dynamics model with hi-fi rotor wake able to predict main and tail rotor control authority (hub forces and moments) in the presence of wake interference effects and wind from critical azimuth.	- Main rotor interference on fuselage, tail planes and tail rotor IGE. - Tail rotor effectiveness (wake interference and vortex ring state).	- Cross-wind IGE hover control positions data at critical azimuth(s) and sea level conditions - Ground effect validation test data as per CS-FSTD(H)	**3**: tail rotor interference effects challenging	3	**2**: corners of envelope (high altitude) (risky flight test) demonstrated by simulation	**3**: high-altitude testing replaced by low effort sim	2	3					
				Performance - power margins	X		Trim and virtual pilot simulation of steady flight and appropriate manoeuvres in cross-wind to demonstrate adequate power margin to ensure controllability (i.e., when not control margin limited).	Nonlinear flight dynamics model with hi-fi rotor wake able to predict power required in the presence of wake interference effects.	- Prediction of interference effects on power required	- Cross-wind IGE hover torque data at critical azimuth(s) and sea level conditions - Ground effect validation test data as per CS-FSTD(H)	**3**: tail rotor interference effects challenging		**2**: corners of envelope (high altitude) (risky flight test) demonstrated by simulation	**3**: high-altitude testing replaced by low effort sim							
				Human factors - flying qualities		X	Piloted simulation of relevant manoeuvres with representative helicopter behaviour to verify acceptable handling qualities for the pilot (possibly using Cooper-Harper applied to these specific manoeuvres)	Piloted flight simulation with: - High flight dynamics simulation fidelity (representative HQ, low adaptation) - AFCS architecture incl. control loading (possibly HITL)	- Flight dynamics simulation fidelity - Adequate cueing (haptic, aural, vestibular, vibratory, instruments)	- AFCS architecture - SID test data for hover without cross-wind (frequency domain) - Qualitative pilot assessment of the manoeuvres (e.g. Cooper-Harper).	3: highly dynamic manoeuvre makes simulation challenging	3	**2**: corners of envelope (high altitude) (risky flight test) demonstrated by simulation	**2**: high-altitude testing replaced by high effort sim	2	2					
				Human factors - ergonomics		X	Piloted simulation of relevant manoeuvres in representative cockpit environment to verify A/C controllability as affected by visibility, control forces, and stick interference.	Piloted flight simulation with: - Representative cockpit HMI (controls, displays, ergonomics, FoV)	- Adequate representation of cockpit HMI	- Control system HMI description and cockpit geometry	**5**: control forces/travel determined by feel system (irreversible hydraulic controls)	5	**1**: no flight test needed anyway for this task	**1**: No change, as no flight test was needed, and if activity is combined with piloted sim for flying qualities	1	1					
29.143(d)	Controllability and manoeuvrability Wind velocities from zero to at least 31 km/h (17 knots), from all azimuths, must be established in which the rotorcraft can be operated without loss of control **out-of-ground effect**, with: (1) Weight selected by the applicant; (2) Critical centre of gravity; (3) Rotor rpm selected by the applicant; and (4) Altitude, from standard sea-level conditions to the **maximum take-off and landing altitude capability** of the rotorcraft.	29.143(c) OGE	Covered by the above, but including also OGE hover.																		

CS REQUIREMENT (AMDT 6 17 December 2018)		COMPLIANCE DEMONSTRATION	POSSIBLE USE OF SIMULATION								SIM TECHNICAL FEASIBILITY		RISK & EFFORT REDUCTION Initial TC				RISK & EFFORT REDUCTION Post-TC (config & envelope changes)				
ID	**Description**	**Demonstration requirements**	**Scope of compliance by simulation**	**Demonstration parameters**	**Means of Compliance**		**Foreseen simulation approach**	**Model and flight simulator characteristics assumed to be required for approach**	**Simulation challenges**	**Data needed/desired for model development and validation/metrics**	**Sim feasibility**	**Group score: sim feasibility**	**Flight test risk reduction**	**Demonstration cost reduction**	**Group score: risk reduction**	**Group score: cost reduction**	**TRNG sim available?**	**Flight test risk reduction**	**Demonstration cost reduction**	**Group score: risk reduction**	**Group score: cost reduction**
		What needs to be demonstrated to show compliance?	a. Critical point/condition analysis b. Extrapolation of demonstrated envelope c. Replacement (partial) of compliance flight test	Parameters used to determine compliance ([compliance area] - [parameter name]) Note: parameter = measurable	Dekstop sim	Flight sim (any kind)				Bold face: dedicated flight testing required	Score from 1-5	Group parameters that are assessed in the same simulation (lowest score is leading).	Score from 1-5	Score from 0-5	Group parameters that are assessed in the same simulation (highest score is leading).		Y/N (only at rows with MOC = Flight Sim)	Score from 1-5	Score from 0-5	Group parameters that are assessed in the same simulation (highest score is leading).	
29.143(e)	Controllability and manoeuvrability The rotorcraft, **after failure of one engine**, in the case of multi-engine rotorcraft that meet Category A engine isolation requirements, or c**omplete power failure** in the case of other rotorcraft, must be **controllable** over the **range of speeds and altitudes for which certification is requested** when such power failure occurs with maximum continuous power and critical weight. No corrective action time delay for any condition following power failure may be less than: (1) For the cruise condition, one second, or normal pilot reaction time (whichever is greater); and (2) For any other condition, normal pilot reaction time.	For specific h/c configurations (critical weight) and flight envelope (altitude) and AFCS single failures: Controllable (transition to) OEI (Cat A) or power off (Cat B) flight at all applicable flight conditions (hover, cruise, climb, speeds up to VNE, takeoff at VY) considering normal pilot reaction time for the appropriate flight condition. Failure occurs at engine or transmission maximum continuous power or take-off power, where appropriate to the condition. Normal pilot reaction time can be assumed to be 3 seconds.	See 29.143(a) (1)(2)(i)-(v)																		
29.143(f)	Controllability and manoeuvrability For helicopters for which a VNE (power- off) is established under CS 29.1505(c), compliance must be demonstrated with the following requirements with critical weight, critical centre of gravity, and critical rotor rpm: (1) The helicopter must be safely slowed to VNE (power-off), without exceptional pilot skill after the last operating engine is made inoperative at power-on VNE. (2) At a speed of 1.1 VNE (power-off), the margin of cyclic control must allow satisfactory roll and pitch control with power off.	For specific h/c configurations (critical weight, critical c.g.) and flight envelope (altitude) and AFCS single failures: Controllable transition from VNE power-on to VNE power-off after all engines out and at critical rotor rpm, and sufficient cyclic control margins at 1.1 VNE power off, with normal pilot reactions and skill. No controllability requirement for stabilized power-off flight at speeds above 1.1 VNE (power-off) when VNE power-off is established per § 29.1505(c). Normal pilot reaction time can be assumed to be 3 seconds.	See 29.143(a) (1)(2)(i)-(v)																		
29.173	Static longitudinal stability (a) The longitudinal control must be designed so that a rearward movement of the control is necessary to obtain an airspeed less than the trim speed, and a forward movement of the control is necessary to obtain an airspeed more than the trim speed. (b) Throughout the **full range of altitude** for which certification is requested, with the throttle and collective pitch held constant during the **manoeuvres specified in CS 29.175(a) through (d)**, the **slope of the control position versus airspeed curve** must be positive. However, in limited flight conditions or modes of operation determined by the Agency to be acceptable, the slope of the control position versus airspeed curve may be neutral or negative if the rotorcraft possesses flight characteristics that allow the pilot to maintain airspeed within ±9 km/h (±5 knots) of the desired trim airspeed without exceptional piloting skill or alertness.	For specific h/c configurations (critical weight, critical c.g., external equipment, landing gear) and flight envelope (altitude) and AFCS single failures: Forward motion of the cyclic control must produce increasing speeds and aft motion must result in decreasing speeds. The slope of longitudinal control position versus airspeed with throttle and collective fixed must be positive in climb, cruise, level flight around VNE, and autorotation as defined in 175(a)-(d).	b. Extrapolation of demonstrated envelope	Stability - longitudinal cyclic versus airspeed	X		Desktop simulation of aircraft response after rearward and forward control motion with throttle and collective pitch held constant during climb, cruise, VNE and autorotation as specified in 29.175(a) to 29.175(d)	Same as for 29.143(b)													
29.175(a)	Demonstration of static longitudinal stability **Climb.** Static longitudinal stability must be shown in the climb condition at speeds from Vy - 19 km/h (10 knots) to Vy + 19 km/h (10 knots), with: (1) Critical weight; (2) Critical centre of gravity; (3) Maximum continuous power; (4) The landing gear retracted; and (5) The rotorcraft trimmed at VY.	For specific h/c configurations (critical weight, critical c.g., external equipment) and flight envelope (altitude) and AFCS single failures: Forward motion of the cyclic control must produce increasing speeds and aft motion must result in decreasing speeds. The slope of longitudinal control position versus airspeed with throttle and collective fixed must be positive in	Condition used for 29.173 and 29.177																		
29.175(b)	Demonstration of static longitudinal stability **Cruise.** Static longitudinal stability must be shown in the cruise condition at speeds from **0.8 VNE - 19 km/h (10 knots) to 0.8 VNE + 19 km/h (10 knots)** or, if VH* is less than 0.8 VNE, from VH - 19 km/h (10 knots) to VH + 19 km/h (10 knots), with: (1) Critical weight; (2) Critical centre of gravity; (3) Power for level flight at 0.8 VNE or VH, whichever is less; (4) The landing gear retracted; and (5) The rotorcraft trimmed at 0.8 VNE or VH, whichever is less. *: Level flight speed at MCP	For specific h/c configurations (critical weight, critical c.g., external equipment) and flight envelope (altitude) and AFCS single failures: Forward motion of the cyclic control must produce increasing speeds and aft motion must result in decreasing speeds. The slope of longitudinal control position versus airspeed with throttle and collective fixed must be positive in	Condition used for 29.173 and 29.177																		
29.175(c)	Demonstration of static longitudinal stability **VNE**. Static longitudinal stability must be shown at speeds from **VNE – 37 km/h (20 knots) to VNE** with: (1) Critical weight; (2) Critical centre of gravity; (3) Power required for level flight at VNE – 19 km/h (10 knots) or maximum continuous power, whichever is less; (4) The landing gear retracted; and (5) The rotorcraft trimmed at VNE – 19 km/h (10 knots).	For specific h/c configurations (critical weight, critical c.g., external equipment) and flight envelope (altitude) and AFCS single failures: Forward motion of the cyclic control must produce increasing speeds and aft motion must result in decreasing speeds. The slope of longitudinal control position versus airspeed with throttle and collective fixed must be positive in climb, cruise, level flight around VNE, and autorotation.	Condition used for 29.173 and 29.177																		
29.175(d)	Demonstration of static longitudinal stability **Autorotation**. Static longitudinal stability must be shown in autorotation at: (1) Airspeeds from the minimum rate of descent airspeed – 19 km/h (10 knots) to the minimum rate of descent airspeed + 19 km/h (10 knots), with: (i) Critical weight; (ii) Critical centre of gravity; (iii) The landing gear extended; and (iv) The rotorcraft trimmed at the minimum rate of descent airspeed. (2) Airspeeds from the best angle-of-glide airspeed – 19 km/h (10 knots) to the best angle-of-glide airspeed + 19 km/h (10 knots), with: (i) Critical weight; (ii) Critical centre of gravity; (iii) The landing gear retracted; and (iv) The rotorcraft trimmed at the best angle-of-glide airspeed	For specific h/c configurations (critical weight, critical c.g., external equipment, landing gear) and flight envelope (altitude) and AFCS single failures: Forward motion of the cyclic control must produce increasing speeds and aft motion must result in decreasing speeds. The slope of longitudinal control position versus airspeed with throttle and collective fixed must be positive in autorotation at critical NR.	Condition used for 29.173 and 29.177																		
29.177	Static directional stability (a) The directional controls must operate in such a manner that the sense and direction of motion of the rotorcraft following control displacement are in the direction of the pedal motion with throttle and collective controls held constant at the **trim conditions specified in CS 29.175 (a), (b), (c) and (d)**. Sideslip angles must increase with steadily increasing directional control deflection for sideslip angles up to the lesser of: (1) ±25 degrees from trim at a speed of 28 km/h (15 knots) less than the speed for minimum rate of descent varying linearly to **±10 degrees from trim at VNE**; (2) The steady-state sideslip angles established by CS 29.351; (3) A sideslip angle selected by the applicant which corresponds to a sideforce of at least 0.1g; or (4) The sideslip angle attained by **maximum directional control input**. (b) Sufficient **cues must accompany the sideslip to alert the pilot when approaching sideslip limits**. (c) During the manoeuvre specified in sub-paragraph (a) of this paragraph, the sideslip angle versus directional control position curve may have a negative slope within a small range of angles around trim, provided the desired heading can be maintained **without exceptional piloting skill or alertness**.	For specific h/c configurations (critical weight, critical c.g., external equipment, landing gear) and flight envelope (altitude) and AFCS single failures: Demonstrate that the direction of motion is in the direction of the pedal input up to the indicated sideslip limit, with throttle and collective fixed, in climb, cruise, level flight around VNE, and autorotation. Structural sideslip limits are determined under 29.351. Note that (4) is not taken into account, as it is a requirement for the slip ball system.	c. Replacement (partial) of compliance flight test	Stability - control position (pedal)		X	Piloted flight simulation with AFCS features, including initial trim and subsequent yaw excursions and retrim to demonstrate pedal travel and yaw response.	Nonlinear flight dynamics model with accurate airframe aerodynamics and hi-fi rotor wake able to predict main and tail rotor control authority (hub forces and moments) in the presence of wake interference effects at large sideslip angles and airspeeds up to VNE.	- Real-time unsteady main-tail rotor wake interference at various sideslip angles and airspeeds up to VNE.	- Flight test data from 29.351 loads test: level flight up to VNE, trim up to 10 deg sideslip	**3**: challenging due to large AoS and VNE	3	**2**: low-risk flight test replaced by sim	**2**: sim only for climb and autorotation, sim effort high due to VNE	2	2					
				Human factors - lateral cyclic force		X	Piloted flight simulation with possibly AFCS HITL to demonstrate acceptable lateral cyclic force for trim (pilot judgement).	Nonlinear flight dynamics model as described above, coupled with control system HITL in piloted simulation.	If hydraulic irreversible system: no particular challenge. If reversible system: challenge to predict control surfaces forces and the mechanical chain / transfer function.	Control system force characterization needed.	**5**: control forces/travel determined by feel system (assuming irreversible hydraulic controls)		**2**: low-risk flight test replaced by sim	**1**: if irreversible: no change, no flight test needed anyway							

CS REQUIREMENT (AMDT 6 17 December 2018)		**COMPLIANCE DEMONSTRATION**	**POSSIBLE USE OF SIMULATION**								**SIM TECHNICAL FEASIBILITY**		**RISK & EFFORT REDUCTION Initial TC**				**RISK & EFFORT REDUCTION Post-TC (config & envelope changes)**				
ID	**Description**	**Demonstration requirements**	**Scope of compliance by simulation**	**Demonstration parameters**	**Means of Compliance**		**Foreseen simulation approach**	**Model and flight simulator characteristics assumed to be required for approach**	**Simulation challenges**	**Data needed/desired for model development and validation/metrics**	**Sim feasibility**	**Group score: sim feasibility**	**Flight test risk reduction**	**Demonstration cost reduction**	**Group score: risk reduction**	**Group score: cost reduction**	**TRNG sim available?**	**Flight test risk reduction**	**Demonstration cost reduction**	**Group score: risk reduction**	**Group score: cost reduction**
		What needs to be demonstrated to show compliance?	a. Critical point/condition analysis b. Extrapolation of demonstrated envelope c. Replacement (partial) of compliance flight test	Parameters used to determine compliance ([compliance area] - [parameter name]) Note: parameter = measurable	Dekstop sim	Flight sim (any kind)				Bold face: dedicated flight testing required	Score from 1-5	Group parameters that are assessed in the same simulation (lowest score is leading).	Score from 1-5	Score from 0-5	Group parameters that are assessed in the same simulation (highest score is leading).		Y/N (only at rows with MOC = Flight Sim)	Score from 1-5	Score from 0-5	Group parameters that are assessed in the same simulation (highest score is leading).	
29.181	Dynamic stability: Category A rotorcraft Any short period **oscillation** occurring at any speed from **VY to VNE** must be **positively damped** with the primary flight controls free and in a fixed position. Assumption: irreversible control system	For specific h/c configurations (weight, c.g., external equipment) and flight envelope (altitude) and AFCS single failures: Demonstrate positive damping for short-period (<5 sec) oscillations in any axes, with the cyclic, collective and directional controls held in the desired test condition or released by the pilot, during climb, cruise and descent, from VY to VNE, with minimum approved stability augmentation.	c. Replacement (partial) of compliance flight test	Stability - damping of aircraft states	X		Desktop simulation of short-term aircraft response after perturbation from trim.	Nonlinear flight dynamics model with AFCS model. Aerodynamic model suitable for VNE.	Configuration of the control loading system. Aerodynamic model.	- Flight test data (control responses) - AFCS sensor and actuator data (e.g., transfer functions) as needed for control law development.	**3**: challenging due to VNE	3	**2**: low-risk flight test replaced by sim	**2**: limited flight test needed, sim effort high due to VNE	2	2					

CS REQUIREMENT (AMDT 6 17 December 2018)		COMPLIANCE DEMONSTRATION	POSSIBLE USE OF SIMULATION								SIM TECHNICAL FEASIBILITY		RISK & EFFORT REDUCTION Initial TC				RISK & EFFORT REDUCTION Post-TC (config & envelope changes)				
ID	**Description**	**Demonstration requirements**	**Scope of compliance by simulation**	**Demonstration parameters**	**Means of Compliance**		**Foreseen simulation approach**	**Model and flight simulator characteristics assumed to be required for approach**	**Simulation challenges**	**Data needed/desired for model development and validation/metrics**	**Sim feasibility**	**Group score: sim feasibility**	**Flight test risk reduction**	**Demonstration cost reduction**	**Group score: risk reduction**	**Group score: cost reduction**	**TRNG sim available?**	**Flight test risk reduction**	**Demonstration cost reduction**	**Group score: risk reduction**	**Group score: cost reduction**
		What needs to be demonstrated to show compliance?	a. Critical point/condition analysis b. Extrapolation of demonstrated envelope c. Replacement (partial) of compliance flight test	Parameters used to determine compliance ([compliance area] - [parameter name])	Dekstop sim	Flight sim (any kind)				Bold face: dedicated flight testing required	Score from 1-5	Group parameters that are assessed in the same simulation (lowest score is leading).	Score from 1-5	Score from 0-5	Group parameters that are assessed in the same simulation (highest score is leading).		Y/N (only at rows with MOC = Flight Sim)	Score from 1-5	Score from 0-5	Group parameters that are assessed in the same simulation (highest score is leading).	
29.151(b)	Flight controls (b) Control system forces and free play may not inhibit a **smooth, direct rotorcraft response** to control system input.	Dedicated flight test may be associated to this requirement, depending on demonstrations performed for other requirements. Since it is highly dependent on the certification project, it is not possible to dermine a generic scenario where simulations other than the ones already discussed for other requirements would provide an added value.																			
29.671	General (a) Each control and control system must operate with the ease, smoothness, and positiveness appropriate to its function. (b) Each element of each flight control system must be designed, or distinctively and permanently marked, to minimise the probability of any incorrect assembly that could result in the malfunction of the system. (c) A means must be provided to allow full control movement of all primary flight controls prior to flight, or a means must be provided that will allow the pilot to determine that full control authority is available prior to flight.	Basic characteristics tested under 29.141 -- 29.175 (not simulated).																			
29.672(a)-(b)	Stability augmentation, automatic, and power-operated systems If the functioning of stability augmentation or other automatic or power-operated system is necessary to show compliance with flight characteristics requirements of CS–29, the system must comply with CS 29.671 and the following: (a) A **warning** which is clearly distinguishable to the pilot **under expected flight conditions** without requiring the pilot's attention must be provided for any failure in the stability augmentation system or in any other automatic or power-operated system which could result in an unsafe condition if the pilot is unaware of the failure. Warning systems must not activate the control systems. (b) The design of the stability augmentation system or of any other automatic or power-operated system must allow initial **counteraction of failures** without requiring **exceptional pilot skill or strength**, by overriding the failure by moving the flight controls in the normal sense, and by **deactivating the failed system**. Assumption: irreversible control system	For specific h/c configurations (weight, c.g.): (a) Demonstrate, throughout the operating envelope of the aircraft, that the pilot is aware of the warning signal due to safety-relevant failures of stability augmentation or power operated systems (not primary control systems) but at the same time is not distracted by it in a way that comprimises her/his workload level. (b) The stability augmentation system failure must not be sudden and must allow an easy counteraction; the corrective action should be logical; easy access to deactivating means. Safe recovery must be demonstrated.	c. Replacement (partial) of compliance flight test	Human factors - failure recovery		X	Piloted simulation of in-flight AFCS failures throughout the operating envelope and for applicable configurations (weight, c.g.), in representative operational scenario, with a defined pilot reaction time, to demonstrate safe recovery and continued flight after AFCS failure with representative cueing (aural, tactile, vestibular, etc.) and w/o exceptional	Flight simulator with AFCS model including safety-relevant failure modes, failure cueing, and stick/pedal forces. May need vibration or initial acceleration cueing depending on failure mode.	Cueing based on aircraft dynamic response / acceleration If applicable: control loading forces to simulate failure in reversible part of control system. - Flight dynamics at unusual attitudes up to VNE (continued flight in degraded mode).	- **Validation flight test data of conditions/manoeuvres relevant for AFCS failures (incl. landing) (e.g. control responses)** - AFCS model including failures - Data of control chain reaction in case of boost systems failures	**3**: unusual attitudes and non-linearities and VNE (AFCS failures that have an effect on aircraft response)	3	**3**: Flight tests with AFCS failures are replaced by simulation and low risk validation flight tests (no failures)	**4**: Large number of failures simulated instead of tested	3	4					
				Human factors - workload		X	Piloted simulation of in-flight AFCS failures throughout the operating envelope and for applicable configurations (weight, c.g.) to measure pilot workload after failure (e.g. failure rating scale).	Flight simulator like above with representative cautions / warnings and possibly HMI, possibly eye tracking and force feedback systems.	- Flight dynamics at unusual attitudes up to VNE (continued flight in degraded mode). - Cueing based on aircraft dynamic response / acceleration	- Validation flight test data of conditions/manoeuvres relevant for AFCS failures (incl. landing) (e.g. control responses) - AFCS model including failures - Data of control chain reaction in case of boost systems failures - A/C HMI description incl. relevant	**3**: unusual attitudes and non-linearities and VNE (AFCS failures that have an effect on aircraft response)		**3**: Flight tests with AFCS failures are replaced by simulation and low risk validation flight tests (no failures)	**4**: Large number of failures simulated instead of tested							
				Human factors - ergonomics		X	Piloted simulation of AFCS failures with actual cockpit HMI to verify pilot physical access to supplementary controls required for corrective action (e.g., AFCS deactivation).	Flight simulator with physical or VR copy of A/C cockpit.	- Adequate representation of cockpit HMI	- A/C HMI geometric description	**5**: capability available	5	**1**: No flight test needed anyway	**1**: No change, no flight test needed anyway	1	1					
			b. Extrapolation of demonstrated envelope	Controllability - aircraft response (hands-off)	X		Desktop simulation of aircraft hands-off response after failures up to pilot reaction time. Final attitudes and rates are compared with previous flight tests.	Desktop simulation model with AFCS model including safety-relevant failure modes (flight dynamics only).	- Flight dynamics at unusual attitudes up to VNE (initial response).	Flight tests at unusual attitudes or of actual failures (aircraft responses)	**4**: desktop flight dynamics only, validation data available	4	**2**: One less risky failure flight test instead of multiple more risky failure flight tests	**4**: Large number of failures simulated instead of tested	2	4					
29.672(c)	Stability augmentation, automatic, and power-operated systems If the functioning of stability augmentation or other automatic or power-operated system is necessary to show compliance with flight characteristics requirements of CS–29, the system must comply with CS 29.671 and the following: (c) It must be shown that after any single failure of the stability augmentation system or any other automatic or power-operated system: (1) The rotorcraft is **safely controllable** when the **failure or malfunction** occurs at **any speed or altitude within the approved operating limitations**; (2) The **controllability and manoeuvrability requirements of CS–29 are** met within a **practical operational flight envelope** (for example, speed, altitude, normal acceleration, and rotorcraft configurations) which is described in the rotorcraft flight manual; and (3) The **trim and stability characteristics are not impaired below a level needed to allow continued safe flight and**	See 29.143 but in SAS degraded mode	b. Extrapolation of demonstrated envelope	See 29.143 but in SAS degraded mode	X	X	See 29.143 but in SAS degraded mode	See 29.143 but in SAS degraded mode: so see also 29.672(a)(b)													
29.1329(d)	Automatic pilot system (d) The system must be designed and adjusted so that, within the range of adjustment available to the pilot, it cannot produce **hazardous loads on the rotorcraft**, or create **hazardous deviations in the flight path**, under **any flight condition appropriate to its use**, either during normal operation or **in the event of a malfunction**, assuming that **corrective action begins within a reasonable period of time**. *According to AC 29-2C: 29.1329 scope is only automatic pilot system, not SAS. SAS is covered by 29.672.*	For specific h/c configurations (weight, c.g.) and flight envelope: Demonstrate that recovery after automatic pilot system failures at airspeeds up to 1.1 VNE, in VFR and IFR conditions, following appropriate time delay, does not result in excessive (depending on flight phase) and/or unrecoverable deviations in flight path or exceedance of limit loads on the aircraft. Pilot recognition and reaction time must be substantiated for all relevant phases of flight.	c. Replacement (partial) of compliance flight test	Performance - flight path	X	X	Destop simulation to investigate critical h/c configurations and flight envelope points. Flight simulator to confirm the flight path for critical conditions, for representative corrective action.	See 29.143 but in autopilot degraded mode: so see also 29.672(a)(b)													
				Structural loads	X	X	Destop simulation to investigate critical h/c configurations and flight envelope points. Flight simulator to confirm the flight parameters for critical conditions, for representative corrective action. Assumption: Loads can be evaluated by assessing flight parameters (f.i. accelerations).	See 29.143 but in autopilot degraded mode: so see also 29.672(a)(b)													

CS REQUIREMENT (AMDT 6 17 December 2018)		COMPLIANCE DEMONSTRATION	POSSIBLE USE OF SIMULATION								SIM TECHNICAL FEASIBILITY		RISK & EFFORT REDUCTION Initial TC				RISK & EFFORT REDUCTION Post-TC (config & envelope changes)				
ID	**Description**	**Demonstration requirements**	**Scope of compliance by simulation**	**Demonstration parameters**	**Means of Compliance**		**Foreseen simulation approach**	**Model and flight simulator characteristics assumed to be required for approach**	**Simulation challenges**	**Data needed/desired for model development and validation/metrics**	**Sim feasibility**	**Group score: sim feasibility**	**Flight test risk reduction**	**Demonstration cost reduction**	**Group score: risk reduction**	**Group score: cost reduction**	**TRNG sim available?**	**Flight test risk reduction**	**Demonstration cost reduction**	**Group score: risk reduction**	**Group score: cost reduction**
		What needs to be demonstrated to show compliance?	a. Critical point/condition analysis b. Extrapolation of demonstrated envelope c. Replacement (partial) of compliance flight test	Parameters used to determine compliance ([compliance area] - [parameter name])	Dekstop sim	Flight sim (any kind)				Bold face: dedicated flight testing required	Score from 1-5	Group parameters that are assessed in the same simulation (lowest score is leading).	Score from 1-5	Score from 0-5	Group parameters that are assessed in the same simulation (highest score is leading).		Y/N (only at rows with MOC = Flight Sim)	Score from 1-5	Score from 0-5	Group parameters that are assessed in the same simulation (highest score is leading).	
App B Part IV(a)	Static longitudinal stability (a) General. The helicopter must possess positive static longitudinal **control force** stability at critical combinations of weight and centre of gravity **at the conditions specified in sub-paragraphs IV (b) to (f)** of this appendix. The **stick force** must vary with speed so that any substantial speed change results in a stick force **clearly perceptible to the pilot**. The **airspeed must return to within 10% of the trim speed** when the control force is slowly released for each trim condition specified in sub-paragraphs IV (b) to (f) of this appendix. Assumption: irreversible control system	For specific h/c configurations (weight, c.g., external equipment) and AFCS single failures: A change in speed of 10 kts must produce a stick force that is clearly perceptible to the pilot (i.e. a discernible and quantifiable force gradient), and airspeed must return to within 10% of the trim speed when the control force is slowly released, in climb, cruise, slow cruise, descent and approach as defined in (b) to (f), and for the complete IFR	b. Extrapolation of demonstrated envelope	Stability - longitudinal cyclic force versus airspeed	X		Desktop simulation of aircraft airspeed changes and related longitudinal cyclic control forces, after rearward and forward control motion with throttle and collective pitch held constant during climb, cruise, slow cruise, descent and approach as specified in (b) to (f) (relation between cyclic control motion and force has been characterized and is included in the model). Determination of VMINI and VNEI.	See App B Par VI													
App B Part IV(b)-(f)	(b) **Climb.** Stability must be shown in climb throughout the speed range 37 km/h (20 knots) either side of trim with: (1) The helicopter trimmed at VYI ; (2) Landing gear retracted (if retractable); and (3) Power required for limit climb rate (at least 5.1 m/s (1000 fpm)) at VYI or maximum continuous power, whichever is less. (c) **Cruise.** Stability must be shown throughout the speed range from 0.7 to 1.1 VH or VNEI, whichever is lower, not to exceed ±37 km/h (± 20 knots) from trim with: (1) The helicopter trimmed and power adjusted for level flight at 0.9 VH or 0.9 VNEI, whichever is lower; and (2) Landing gear retracted (if retractable) (d) **Slow cruise.** Stability must be shown throughout the speed range from 0.9 VMINI to 1.3 VMINI or 37 km/h (20 knots) above trim speed, whichever is greater, with: (1) The helicopter trimmed and power adjusted for level flight at 1.1 VMINI; and (2) Landing gear retracted (if retractable) (e) **Descent.** Stability must be shown throughout the speed range 37 km/h (20 knots) either side of trim with: (1) The helicopter trimmed at 0.8 VH or 0.8 VNEI (or 0.8 VLE for the landing gear extended case), whichever is lower; (2) Power required for 5.1 m/s (l000 fpm) descent at trim speed; and (3) Landing gear extended and retracted, if applicable. (f) **Approach.** Stability must be shown throughout the speed range from 0.7 times the minimum recommended approach speed to 37 km/h (20 knots) above the maximum recommended approach speed with: (1) The helicopter trimmed at the recommended approach speed or speeds; (2) Landing gear extended and retracted, if applicable; and (3) Power required to maintain a 3° glide path and power required to maintain the steepest approach gradient for which approval is requested.	Description of the conditions to be demonstrated for Part IV(a)																			
App B Par V (a)	Static lateral-directional stability (a) Static directional stability must be positive throughout the **approved ranges of airspeed, power, and vertical speed**. In straight and steady sideslips up to ±10° from trim, directional control position must increase without discontinuity with the angle of sideslip, except for a small range of sideslip angles around trim. At greater angles up to the **maximum sideslip angle** appropriate to the type, increased directional control position must produce increased angle of sideslip. It must be possible to maintain **balanced flight without exceptional pilot skill or alertness**	Demonstrated as 29.177, but in IFR envelope.																			
App B Par V (b)	Static lateral-directional stability (b) During sideslips up to ± 10° from trim throughout the approved ranges of airspeed, power, and vertical speed there must be no **negative dihedral stability perceptible to the pilot through lateral control motion or force** **Longitudinal cyclic movement** with sideslip must not be excessive.	For specific h/c configurations (weight, c.g., external equipment) and AFCS single failures: Positive dihedral stability throughout majority of approved IFR loading envelope to demonstrate that sideslip excursion (w/o directional input) does not induce a roll control motion/force that further increases the sideslip angle. No significant longitudinal trim changes and short period dynamic modes which only occur in sideslip conditions.	c. Replacement (partial) of compliance flight test	Stability - dihedral		X	Piloted simulation to demonstrate that there is no roll force/motion due to sideslip (w/o directional control input) perceptible by the pilot throughout majority of approved IFR weight and c.g. envelope.	Nonlinear flight simulation with accurate interactional aerodynamics able to predict sideslip-roll coupling. Flight simulator must have adequate roll attitude and control motion/force cueing (not visual since it is IFR).	- Interactional aerodynamics affecting roll-sideslip coupling (small motions, so absolute accuracy is challenging). - Sustained level of acceleration cueing	- Flight test data in sideslipping flight in IFR envelope, level and climb/descent (control responses, diversions from trim conditions)	**3**: might 2 or 4 depending on cueing	3	**2**: Use of existing data instead of dedicated low risk flight test	**2**: might be 1 or 3 depending on required amount of flight tests	2	2					
				Stability - damping of aircraft states & longitudinal trim		X	During simulation above: check for significant longitidunal cyclic trim changes and short period dynamic modes.	As above.	As above.	- Basic (uncoordinated) trim and short-term control response flight test data.	**3**: might 2 or 4 depending on cueing		**2**: Use of existing data instead of dedicated low risk flight test	**2**: might be 1 or 3 depending on required amount of flight tests							
App B Par VI	Dynamic stability (a) Any oscillation having a period of less than 5 seconds must damp to ½ amplitude in not more than one cycle. (b) Any oscillation having a period of 5 seconds or more but less than 10 seconds must damp to ½ amplitude in not more than two cycles. (c) Any oscillation having a period of 10 seconds or more but less than 20 seconds must be damped. (d) Any oscillation having a period of 20 seconds or more may not achieve double amplitude in less than 20 seconds. (e) Any **aperiodic response** may not achieve double amplitude in less than 9 seconds.	For specific h/c configurations (weight, c.g., external equipment) and flight envelope (altitude) and AFCS single failures: Similar to 29.181; dynamic excitation to approximate turbulent gust response, response in all axes, aperiodic response up to 20 deg bank or 5 deg pitch displacement from trim	c. Replacement (partial) of compliance flight test	Stability - aircraft responses: time to half/double amplitude of any oscillation in any axis	X		Desktop simulation with excitation by defined control input or simulated turbulent gust and IFR appropriate levels of stability augmentation (AFCS model).	Nonlinear flight dynamics model with AFCS model. Aerodynamic model suitable for VNEI.	Configuration of the control loading system. Aerodynamic model (if VNEI = VNE).	- Flight test data (control responses) - AFCS sensor and actuator data (e.g., transfer functions) as needed for control law development.	**3**: challenging if VNEI = VNE, small rates/ amplitudes	3	**2**: low risk flight tests replaced by simulation	**4**: sim effort is high but no dedicated flight test needed (considers also Par IV activity)	2	4					
App B Par VII (a)	Stability augmentation system (SAS) (a) If a SAS is used, the reliability of the SAS must be related to the effects of its failure. Any SAS failure condition that would prevent continued safe flight and landing must be extremely improbable. It must be shown that, for any failure condition of the SAS which is **not shown to be extremely improbable**: (1) The helicopter is **safely controllable** when the **failure** or malfunction occurs a**t any speed or altitude within the approved IFR operating limitations**; and (2) The overall flight characteristics of the helicopter allow for prolonged instrument flight without **undue pilot effort**. Additional unrelated probable failures affecting the control system must be considered. In addition: (i) The controllability and manoeuvrability requirements in Subpart B of CS-29 must be met throughout a practical flight envelope; (ii) The flight control, trim, and dynamic stability characteristics must not be impaired below a level needed to allow continued **safe flight and landing**; (iii) For Category A helicopters, the dynamic stability requirements of Subpart B of CS-29 must also be met throughout a practical flight envelope; and (iv) The static longitudinal and static directional stability requirements of Subpart B of CS-29 must be met throughout	For specific h/c configurations (weight, c.g., external equipment), a practical flight envelope, and AFCS failures not shown to be extremely improbable: Safe flight and landing, with controllability, static and dynamic stability characteristics as per 29.143 and 29.173-29.181 and an acceptable pilot workload, considering the IFR environment.	See 29.143, 29.173-29.181 and App B Par V and VI, but in AFCS degraded mode: so see also 29.672(a)(b).The reliability part of the requirement is not assessed by flight simulation.																		
App B Par VII (b)	Stability augmentation system (SAS) (b) The SAS must be designed so that it cannot create a **hazardous deviation in flight path** or produce **hazardous loads** on the helicopter during normal operation or in the event of **malfunction or failure**, assuming **corrective action begins within an appropriate period of time**. Where multiple systems are installed, subsequent malfunction conditions must be considered in sequence unless their occurrence is **shown to be improbable**.	For specific h/c configurations (weight, c.g., external equipment) and flight envelope (altitude) and AFCS failures not shown to be improbable: Demonstrate that recovery after AFCS failures (incl. hardover) at airspeeds up to 1.1 VNE (IFR), following appropriate time delay, does not result in excessive (depending on flight phase) and/or unrecoverable deviations in flight path or exceedance of limit loads on the aircraft. Pilot recognition and reaction time (e.g., in the event of hardover) must be substantiated for all relevant phases of flight.	See 29.1329(d)					See 29.143 but in AFCS degraded mode: so see also 29.672(a)(b)													