Unmanned Aircraft System (UAS) Airworthiness Certification

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ABSTRACT

In order to fly with military Unmanned Aircraft Systems (UAS) in The Netherlands, the UAS needs to be certified. An airworthiness certification shall be completed successfully. The intended operational usage will largely dictate the extent of this process. The objective of the airworthiness certification process is to demonstrate safe operations of the UAS for the intended operational usage that will reflected in the Military Type Certificate (MTC) issued by the Military Airworthiness Authority (MAA).

As part of the airworthiness certification process, airworthiness requirements are drafted and related Means of Compliance (MOC) codes to show compliance to these requirements are defined. Flight tests can be used as a MOC code. These MOC codes Flight Test shall be grouped together and together with an description and interpretation of the requirement these shall be integrated in a structured manner in the flight test plan (FTP). The flight test plan shall be executed and results shall be reported in the flight test report (FTR). In this FTR, compliance claims for all those requirements where the MOC code Flight Test was proposed are reported. At a higher level, they support the certification compliance report wherein all the supporting evidence is collected in order to arrive at compliance for all the airworthiness requirements. This paper will outline this process in more detail, will indicate how flight tests are embedded in this process and will give examples on different aspects of the certification process.

UAS AIRWORTHINESS CERTIFICATION

1 INTRODUCTION

Although airworthiness certification may not be of concern for every country, for densely populated areas in Europa, like the Netherlands, it is. Based on the intended operational usage, the UAS needs to be certified and a Military Type Certificate (MTC) must be in place before the operations can start. Such an airworthiness certification process is an extensive, complex and challenging process and can take years to complete. But the good news is that when you have the MTC available, it offers a very good selling argument for the manufacturer. An overview of an airworthiness certification process from a flight test perspective - and how this can be integrated - will be presented.

The paper starts by selecting the proper airworthiness standards and requirements for the UAS to be certified. Since the Military will have their own functional and performance based requirements, these will be integrated or combined with the airworthiness requirements. The next step is to define the certification basis containing the applicable airworthiness requirements. For showing compliance to these requirements, various Means of Compliance codes are at hand. In this paper, the focus is on the Flight test as Means of Compliance. The compliance plan containing the applicable requirements and the Means of Compliance codes for each requirements will be followed by the compliance demonstration. For those requirements where a flight test is demanded, these requirements are grouped together in the flight test plan. Flight tests will be conducted and findings are reported in the flight test report. The airworthiness

certification process is concluded with the Certification report that should lead to the Military Type Certificate for the UAS to be certified. At the end of this paper some examples of UAS flight test observations will be presented.

This paper focusses on Military UAS certification processes. No detailed UAS design information and flight tests experiences were releasable for this paper.

2 CERTIFICATION STANDARDS AND REQUIREMENTS

When an airworthiness certification process has to be completed, certification standards for UAS do apply. In the early days of military UAS certification, in the early nineties, such standards did not exist and were not readily available. Therefore, such requirements had to be drafted by the applicant himself/herself based on similar standards for manned aircraft and for newly introduced elements to operate an UAS, additional requirements had to be formulated. These requirements relate to the so called 'command line' of the UAS.

What is needed to operate the UAS? E.g. An Aerial Vehicle (AV), an Ground Control Station, a data link, a launch and recovery unit. While for the AV it is obvious what has to be taken into account during airworthiness certification, for a launcher for example it is of primary concern that a sufficient and safe lift off speed shall be realized at all times under the intended conditions.

During the second half of the nineties, harmonization started and standards for UAS certification became available evolving during many years ever since. Certification Standards like e.g. NATO STANAG (Standard NATO Agreement) 4671 USAR for UAS up to 12.500 lbs or STANAG 4703 for light UAS are now available when an airworthiness has to be completed.

Initially, the terminology Unmanned Aerial Vehicle (UAV) was used for certification. This refers to the flying vehicle only. It requires more system elements to keep the UAV flying. Then, the wording UAV system was introduced. Now, these are referred to as Unmanned Aircraft System (UAS) to keep phrasing in line with other existing airworthiness regulations.

First, the airworthiness standard with the requirements shall be clear, then the next step is to apply these for your own certification process and indicate how UAS flight testing will become part of this process.

2.1 Example

If the launcher is for example mounted on a military truck, the wheels and the cabin of the truck are not part of the command line and do not deserve attention during the airworthiness process. Such aspects are covered by other military regulations and standards.

3 FUNCTIONAL REQUIREMENTS & PERFORMANCE-BASED REQUIREMENTS

In general, the military have their own functional requirements regarding the acquisition of a new system for their inventory. The intended operational and environmental conditions shall be specified. Where shall the UAS be deployed? Under which conditions? Also, performance figures like climb time to a particular altitude, ceiling, time on target, wind conditions, and temperature domain shall become clear. Such functional requirements are closely related to the certification requirements which are normally defined in a more generic way in order to leave some interpretation for the manufacturer.

3.1 Example

While the certification requirements may state the intended operational and environmental conditions for which the UAS shall be certified must be clear, this does not give guidance on the exact conditions that

shall be taken into account. Then, the functional requirements are of help and shall be integrated into the certification requirements. It will become clear which detailed requirements needs to be taken into account in the certification process and those requirements that shall be taken into account during UAS flight testing. Another standard can be used to specify these environmental conditions.

4 PREPARING THE CERTIFICATION BASIS

Based on the selected Airworthiness standard that has been considered applicable for the UAS to be certified, the next step is to indicate for each requirement of that standard, if it applies or not. If it is considered not applicable, a brief rationale shall be given. In the end, an applicability matrix will result presenting an overview of all applicable and non-applicable (sub) requirements. If considered not applicable, a brief rationale shall be added. The resulting certification basis will be submitted to the Military Airworthiness Authority for their approval.

Note that sometimes it may appear that the entire requirement may not apply but only parts of it. Then the requirement may be tailored, modified, to cope with the specific design features that are part of the UAS design to be certified.

The next step is to go into more detail on the applicable requirements, that is, to indicate how these requirements can be demonstrated by indicating which Means of Compliance (MOC) code applies. For example, is a flight test needed to do or will is an analysis and a ground test be considered to be sufficient?

4.1 Example

The stalling speed will be used as an example. In the USAR 4671 set of airworthiness requirements for USAR 49, stalling speed, a detailed requirement is presented for each specific engine design configurations. If the UAS to be certified has a reciprocating engine, that requirement applies while the requirement for the turbine requirement is not.

STANAG 4671: USAR.49 Stalling Speed
(a) VS0 and VS1 are the stalling speeds or the minimum steady flight speed, in knots (CAS), at which the UAV is controllable with

(1) For reciprocating engine-powered UAV, engine(s) idling, the throttle(s) closed or at not more than the power necessary for zero thrust at a speed not more than 110% of the stalling speed; and
(2) For turbine engine-powered UAV, the propulsive thrust may not be greater than zero at the stalling speed, or, if the resultant thrust has no appreciable effect on the stalling speed, with engine(s) idling and throttle(s) closed;
(3) Propeller(s) in the take-off position;
(4) The UAV in the condition existing in the test or calculation in which VS0 and VS1 are being used;
(5) Centre of gravity in the position which results in the highest value of VS0 and VS1; and
(6) Weight used when VS0 or VS1 are being used as a factor to determine compliance with a required performance standard.

(b) VS0 and VS1 must be determined by

(1) ***analysis*** *based on a calculation method agreed with the Certifying Authority, or*
(2) by ***flight tests*** *using the procedure and meeting the flight characteristics specified in USAR.201.*

In this example, already some guidance on possible means of compliance is presented as well. This will be discussed in the next section.

By going through the entire standard or set of airworthiness requirements, the applicability matrix will result. For each requirement and each sub-requirement(s), it's indicated if the requirement applies or not. If not, a brief rationale shall be added. In this way, the airworthiness authorities get a decent understanding on what has been done in order to arrive at the certification basis where the applicable requirements for the UAS to be certified are presented. The next section provides an example.

5 DEFING THE MEANS OF COMPLIANCE

For each of the selected requirement, it shall be indicated how the requirement can be demonstrated by the intended Means of Compliance (MOC) code. Here the focus is on the flight test. Having the UAS design finalized, the choice can be for example to apply an analysis and a flight test. The horizontal distance travelled in the air to fly over a 50 ft obstacle can – and shall - be calculated first, but the next step is to demonstrate it in real flight to verify if the predictions are accurate and reliable. Then, MOC code Flight test is selected and shall be included in the preparation of the Certification Plan.

The question here is which MOC code (or codes) apply to which requirements? Sometimes, the requirement itself already gives some guidance. In fact, one might say it's not really a requirement but the MOC code is already embedded. Sometimes, guidance material is available indicating what airworthiness authorities normally expect in order to arrive at compliance. However, for most of the requirements experience with airworthiness certification processes is of paramount importance to draft all the MOC codes for each particular requirement. The MOC code shall be selected in such a way that compliance for safe flight can be anticipated on one hand, while the effort to achieve this shall be minimized. Flight tests and flight tests campaigns require quite a lot of effort to complete but are essential as they are normally considered as the proof of the pudding.

5.1 Example

For the STANAG 4671 USAR 49 Stalling speed example, already some guidance is presented in the requirement itself as analysis and flight test are mentioned as MOC codes. To present such MOC codes information in a structured manner, an example is presented below.

Requirement Nr.	Description	Applicability	Means of Compliance Code	Remarks
(a) 1	*"For reciprocating engine-powered UAV (...)"*	Yes	Design Analysis Flight test	Design implies that a system design description is available and is used for each requirement to specify the design.
(a) 2	*"For turbine engine-powered UAV (...)"*	No	Not applicable	No turbine engine featured
(a) 3	*"Propellers (...)"*	Yes	Design Analysis Flight test	
(a) 4	*"The UAV in the condition (...)"*	Yes	Design Analysis Flight test	
(a) 5	*"Centre of gravity (...)"*	Yes	Design Analysis Flight test	
(a) 6	*"Weight used (...)"*	Yes	Design Analysis Flight test	
(b) 1	*"Analysis based (...)"*	Yes	Design Analysis	

(b) 2	*"by flight tests (…)"*	Yes	Design Analysis	

6 PREPARING THE CERTIFICATION PLAN

In the Certification Plan (CP), the proposed way to conduct the certification process and to show compliance to the applicable requirements will be described. For each of the applicable requirements, the proposed MOC code or codes are described. In the main body text of the report, the major tests that are foreseen will be briefly discussed. It will indicate if a flight test campaign in foreseen and on which particular test range and when this campaign will be held.
Other relevant topics in the CP are a.o. a design description of the UAS and its elements needed to fly with it, the intended operational usage, parties involved in the certification process, planning considerations, and anticipated documentation (e.g. System Flight Manual).

It might also be the case that at this stage of the certification process, it can be anticipated that some airworthiness requirements cannot be (completely) met. This will lead to discussions with the MAA and a structured process shall be in place to present the opinions of the applicant and those of the MAA. In the end, a.o. special conditions, equivalent safety findings, exemptions, deviations or operational restrictions may result. For an immature UAV system, even denial of the certification may occur. The CP shall also be approved by the MAA.

7 CONDUCTING THE COMPLIANCE DEMONSTRATION

The UAS design to be certified shall now be frozen, both in terms of hardware and software configuration. Only then, its recommended to start the compliance demonstration phase of the process. When compliance demonstration may start too early and still modifications are being completed to the UAS design, discussions will result on the re-usability and accurateness of the results.

For showing compliance to the applicable requirements, the selected MOC codes shall be used as a start for the compliance demonstrations. A.o. test plans – either being a ground test, laboratory test or flight test - shall be prepared.

Now, the hands-on experience and real world of flight testing enters the scene. Since it has been anticipated that various requirements need to be demonstrated by means of a flight test, a flight test plan shall be prepared. Based on the CP wherein for each requirement the MOC codes are presented, all MOC codes flight tests shall be grouped as flight tests are needed for compliance demonstration.

8 FLIGHT TEST PLAN

The OEM will prepare the flight test plan based on the requirements that require a flight test as MOC code. The OEM with it experienced UAS flight testers will compile all those requirements where the MOC code flight test is selected and organize them. A step-by-step approach is followed. That is, to put them into a logical sequence during the flight and indicate the number of flights that is required to do so.

In general, quite a number of requirements shall be demonstrated by means of a flight test. All those requirements shall be inserted into the flight profile of the UAS to be certified taking into account the UAS design specifications, the endurance and the maximum range of the UAS and any flight range restrictions. Several flights may be foreseen enabling repeats of various data points.

Taxi, take-off roll, obstacle clearance, climb, level and turning flight, speeds, controllability, manoeuvrability, range, descent, and landing or recovery airworthiness requirements will define the FTP. On top of that, functional requirements that may require can be added as well in the FTP.

Flight tests cards will be prepared for each selected data point and shall be filled in precisely during the tests. Guidance may be used to (better) interpret the test conditions to be met. Pre-requisites – e.g. frozen design configuration, both in terms of hardware and software - of the test are defined at the start of the test plan. Each test point shall be recalled and it shall be observed if all went in accordance with the plan. Any anomalies shall be reported and after each data point the qualified tester shall sign the test, either passed, partial or fail. Success criteria shall be added to give the UAS tester direct insight into the flight performance and behaviour of the UAS. Repeats may be completed when flight time permits. When passed, the tester can move to the next data point. Flight data is recorded by flight test instrumentation for post flight analysis.

Of major importance is the flight mode of the UAS under test. Depending on the design, autonomous or semi- autonomous modes are quite common. Manual mode on the contrary wherein the UAS pilot flies the UAS are not always featured.

It shall be noted that the environmental conditions that occur during the flight tests have to be taken into account obviously. If for example more demanding conditions – e.g. hot and high performance, or cold operations - are required, dedicated flight test campaigns to areas where those conditions are present may be scheduled. Flight tests under those particular conditions give confidence into the UAS operating under such conditions. In the end, the demonstrated conditions during the flight tests campaigns can be listed and reported.

8.1 Example

From the example on the stalling speed requirement, it was indicated that an analysis or flight test shall be used. But the question is then, how shall the flight test be organized in such a way that the requirement could be met? The example on USAR 201 below gives the flight tester (some) guidance what the airworthiness authorities would expect to meet this requirement. It's up to the tester then to integrate these guidance into the flight test plan in a logical and structured manner.

STANAG 4671: USAR.201 Wings Level Stall

(*a) Flight tests shall be conducted in straight flight for each relevant UAV flaps configuration, with the engine at idle position and for the most appropriate combination of weight and center of gravity while reducing the speed at a decelerating rate of approximately 1kt/s*

(1) up to the time the UAV stalls, or

(2) until Vmin DEMO, if the stalling speed is not to be demonstrated in compliance with USAR.50, and,

(i) no stall tendency shall occur down to Vmin DEMO ,

(ii) Vmin DEMO shall be lower by the margin established under USAR.50 than the minimum steady flight speed (except take-off and landing) allowed by the flight envelope protection maintained by the flight control system.

(b) These flight tests may be conducted, while possibly adjusting or inhibiting flight control protection features.

When the flight test plan is ready, it shall be approved by the MAA and after approval the flight tests can be conducted. Flight tests shall be witnessed by the applicant, specific System Matter Experts (SMEs) and the MAA. The OEM shall conduct the flight tests in accordance with the FTP. Any deviation shall be discussed and reported. Both hand written observations on the successful completion of the data points shall be reported together with logging of the flight test data during all intended maneuvers. These observations shall be used to prepare the flight test report.

9 FLIGHT TEST REPORT

The results of the conducted flight tests will be reported on the flight test report. For each applicable requirement wherefore a flight test was required, it shall be explicitly stated if the requirement could be met, or could not be met or could partially be met. Some explanations on details on the conducted flight tests shall be presented. For those requirements that could not completely be demonstrated, it shall be indicated what is needed to fill in these gaps. E.g. are new flight tests needed or is a change to the flight test plan needed or is a configuration change needed? Restrictions and/or limitations may occur and these become part of the certification report and the final Military Type Certificate (MTC).

The OEM flight test organisation that completed the flight tests shall analyses each particular requirement separately. Both the flight observations and recorded flight data shall be used to come to a final statement – or declaration of compliance – that the particular requirement was met. This is of major importance.
Not all supporting analysis data will become available to the applicant due to e.g. proprietary reasons of the OEM.

9.1 Example

Detailed analysis will enable to precisely analyze and prepare the prescribed information in the requirement. The applied UAS configuration during this data point, UAV weight, center of gravity, autopilot setting, throttle setting, decreasing speed profile (observe it on the screen for a first impression during the actual flight, use recorded data to confirm), observations on stall behavior (on the screen, support this by post flight analysis) shall be considered here, analyzed and reported.

In the FTR, both all recorded notes during the flight tests shall be added together with supporting evidence graphs that the requirement could be met. A compliance statement by the OEM shall conclude this section.

10 PREPARING THE CERTIFICATION REPORT

With the Flight test Report available, the next step is to complete the entire certification report. For all the applicable requirements, compliance shall be indicated. Available test reports and other supporting evidence shall be included. The flight test report will become part of the Certification Data Package. The certification report together with the compliance reports serves as evidence for the Military Type Certificate (MTC) request at the Military Aviation Authority (MAA).

For each of the applicable requirements, the complete compliance assessment shall be presented. A compliance matrix will result. The requirement, any tailoring, the means of compliance code(s), the results of the compliance demonstration results for each of the indicated MOC codes (here, a reference to the flight test report with the OEM compliance statement shall be made), and a conclusion if the requirement could be met, or that non-compliance resulted that was solved or that any operational restrictions may apply.

11 MILITARY TYPE CERTIFICATE

The final goal is the Military Type Certificate (MTC) issued by the MAA. If all the requirements have been filled in as expected and that compliance could be shown, the green light is given to operate the certified UAS. The MTC goes together with the Military Type Certificate Data Sheet (MTCDS) where a.o. the design specifications, UAS elements, configuration, certification basis, compliance report, operational limitations and restrictions, UAS Flight Manual, Maintenance manual and any other data for safe operations are summarized.

The successfully completed fight tests and its observations are of major importance for the issuing the MTC. These tests give confidence in the design, safe flight operations and conforms what has been expected up-front based on detailed analysis and flight simulations.

12 FLIGHT TEST EXAMPLES

Some examples related to UAS flight testing are mentioned here. Detailed UAS design and operational information cannot be given here.

Environmental conditions: Stick to the flight test plan and the calculated wind limits. If operational flight conditions start to diverge, act accordingly. To start with wind limits above the stated limits shall be avoided, even if it goes well and an incident could be avoided. Off course, project management decisions may require a speedy flight test program without many disturbances (like to relocate the launch direction as wind direction changes) but at the end to flight test under wind conditions that are not permitted shall be avoided.

Launching: Some technical solutions to launch the UAS require additional attention, e.g. a rocket booster to lift the UAV quickly into the air. Not only during transport when more demanding logistic requirement apply, but also during pre-flight preparation. Alignment of the rocket booster is of paramount importance. Quick ignition doesn't leave time to react when a slightly downwards thrust vector has been introduced and shall be cope with during the launch phase. As a more 'practical' solution, misalignments can be mitigated by selecting a high starting point with free airspace in front, that is the top of a hill.

Solder proof design concepts are advantageous for the military. Quick deployment times, easy assembly and ruggedized design helps the commander in the field. But still the soldier in charge of launching the UAS has to stick to the procedures and make sure the pre-flight checklist has been completed accordingly. While the attachment of the horizontal stabilizer can be of simple design, the soldier shall make sure that the stabilizer has been attached properly else it may become loose resulting in a UAS without pitch control authority.

13 CONCLUSIONS

In order to fly with military Unmanned Aircraft Systems (UAS) in The Netherlands, the UAS needs to be certified. An airworthiness certification process is an extensive, complex and challenging process. The objective is to get the Military Type Certificate (MTC) granted by the Military Airworthiness Authority (MAA) offering confidence in the safe and airworthy UAS design.

Flight Tests are embedded in the airworthiness certification process. Steps to be taken to integrate flight tests in a structured manner in the certification process have been discussed. A structured process and good book keeping to address all requirements and their compliancy is required. For those requirements that require as Means of Compliance (MOC) code a Flight Test will become part of the Flight Test Plan. This plan shall be organised in a logical manner. After completion of the Flight Tests, compliance claims for the applicable requirements shall be reported in the Flight Test Report supporting the certification report. Together with the Military Type Certificate Data Sheet (MTCDS), the MTC can be applied for.

With the MTC available, intended flight operations for the intended operational conditions can start. Although it may require quite some effort and time to complete, for the OEM it offers good potential for selling their products to other countries without having to do the airworthiness certification process again.