Certification of "Small" UAV Systems

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ABSTRACT

It is widely recognised that Unmanned Air Vehicle Systems are the natural evolution of the manned aircraft for aerospace usage, performing the well-known 3D missions, i.e. dull, dirty or dangerous, that usually constrain to a not effective usage of pilot and flight crew. Additionally, it is to consider that these Systems in many different operation's theatres are already used for day-by-day military missions, reducing the risk as much as possible in the lead of safety of the operators and saving many lives.

Whilst the military has been successful using UAV Systems operationally for some time in limited roles, it has not been possible to exploit these systems commercially or even fly military aircraft in transit flights through un-segregated airspace, mainly due to qualification and certification issues, as up to now an ad-hoc regulation for UAV does not exist. If UAV Systems are to be more than a niche product, both in civil and military applications, then they must be authorized to operate over populated areas and in airspace alongside other manned or unmanned aircraft.

UAV Systems are ready to exploit their true market potential, nevertheless a major barrier is the ability to integrate with other airspace users. The current regulatory perspective is to develop, through a consultative process involving both Industries and Authorities, a regulation for UAV Systems, allowing those with a weight above 150 kg to operate as a normal file-and-fly aircraft, but this process is likely to take some years before being completed.

Small UAV Systems have their own peculiarity, such as the use in reduced and limited areas, even within buildings, also by a non-pilot operator. A typical military application can be infra-theatres operations for battle field reconnaissance; on the other side, a typical civil application is for fire-fighting operations, accommodating a camera, as payload. Therefore, it is possible to consider for these Systems a specific approach, as reasonable flight limitations could be introduced, allowing their use in the short timeframe.

In order to provide a response to the market demand, a method has been identified and will be proposed for adoption in the certification process of the Small UAV Systems and their subsequent operation in suitable portions of the airspace.

1.0 INTRODUCTION

This paper is based on the activities of a joint working group between Alenia Aeronautica and D.G.A.A. (Italian Military Certification Authority). The group was formed, taking into account the wide experience of both parties, in terms of Certification activities performed over the past decades and of UAV operations, which Alenia Aeronautica is specializing into. It should be considered that these Systems are not in the remits of EASA and that the National Authorities, both Civil and Military, have not yet established a standard process to implement the applicable requirements. Furthermore all the European on-going activities, in terms of different working groups, are not taking into account these Systems.

Therefore in 2006, Alenia Aeronautica and DGAA decided together to create a full procedure allowing the use, within the Italian Armed Forces, of “Small” UAV, i.e. total weight lower than 150 kg. Furthermore this procedure will enable DGAA to certify small UAV to be used within the Armed Forces.

Comprehensive analyses have been carried out to identify the current Bibliography to be used as starting point for developing of the new methodology, as well as to consider the several on-going activities on the “bigger” UAV Systems, both European and US.

A general concern is that flying with unmanned aircraft in controlled airspaces over populated area shall not endanger the safety of other airspace users as well as of the people on ground. For such a reason, in the past, the use of UAV Systems has been always bounded in restricted areas, such as flight test or segregated areas.

A requirement to regulate the development, the type certification and the operations of UAVs rise up in the last years, following the wide spread of these Systems, the development of new UAV-related technologies (to guarantee both better performances and higher safety levels) and the interest showed by Institutional Operators to use “Small” UAVs.

This paper provides new elements, identified during the joint working group between Alenia Aeronautica and DGAA, specific to the “SMALL UAV”, unmanned aircraft with a total weight below 150 kg, that could be considered and introduced in the already existing National regulation, disciplining the use by the Italian Armed Forces.

Moreover, this paper contains indications for the proper operational use of these Systems, assuring the safe use of these aircraft during the training and the operative phases from the Institutional end-user.

Furthermore, at the end of this study, some instructions have been provided to allow the use of the minimum operational control volumes and the methodology to identify them for day-by-day operations of “Small" UAV” Systems.

2.0 KINETIC ENERGY LIMITS AT IMPACT

In this paragraph some technical parameters (MTOW, V_D, etc.), related to the "SMALL UAV", have been identified, in order to define a selection criteria based on the value of Kinetic Energy at impact on ground of the System. This criteria has been developed considering National and International Policy on the same subject [ref. 1-10].

These parameters allow the evaluation of a preliminary safety level to study further in depth, in order to set the appropriate requirements, in terms of airworthiness, during the Type Certification process.

This criteria is based on the hypothesis that the quantity of damage, caused by an aircraft to third parties, is proportional to its Kinetic Energy at impact on ground. Only two operational scenarios have been considered significant for this calculation:

- Free fall from 400 ft [1];
- Loss of control.

For each scenario, the corresponding Kinetic Energy at impact has to be calculated using the formulas in the following paragraphs.

The results must then be compared with a limit value of the allowable energy for the general flight safety (defined in Table 2) and relative to the corresponding MTOW of the aircraft. These values, generally, shall be lower than the limit one, indicated in Table 2.

1 *Limit altitude authorised within the test area during the training phase.*

2.1 FREE FALL

A free fall is the event caused by a failure condition (or a failures combination) that determines the incapacity of the aircraft of keeping a determined altitude, causing the impact on ground.

The following parameters have to be considered for the calculation of kinetic energy at impact:

- MTOW [kg] - Maximum Take Off Weight;
- V_D [kts] - Maximum Dive Speed;
- c - Non-dimensional coefficient of aerodynamic drag, (=0,9);
- h_{max} - Maximum Operational Altitude (as indicated in the flight envelope of the System).

Hence:

if $h_{max} > 400$ ft then $h = 400$ ft

if $h_{max} \leq 400$ ft then $h = h_{max}$

$$\textit{Theoretic speed at impact}[kts] = V_{imp\,teor} = \sqrt{2 \cdot c \cdot \mathrm{g} \cdot \mathrm{h}}$$

This speed ($V_{imp-teor}$) is only "theoretical", as it corresponds to the speed that the aircraft would have if it fells down from the cruise altitude h. In the reality, the aircraft could achieve, during the free fall, a speed at impact higher than the maximum allowable dive speed (V_D); in such a case, the aircraft structure will collapse probably as soon as the dive speed is reached, therefore the "real" speed (V) to consider in the kinetic energy calculation is the V_D.

Summarising:

- If $V_{imp-teor} > V_D$ then $V=V_D$
- If $V_{imp-teor} \leq V_D$ then $V=V_{imp-teor}$

Having determined the speed V, as above described, it is then possible to calculate the value of Kinetic Energy at impact for the scenario of Free fall, using the following formula:

$$\text{Ec [KJ]} = \frac{1}{2} \cdot \text{MTOW} \cdot \text{V}^2 \cdot CSA$$

where CSA is a measure of aerodynamic drag, bound to the maximum cross-section area of the aircraft. The value is extracted from Table 1:

MAXIMUM CROSS-SECTION AREA OF AIRCRAFT [m^2]	CSA
Area < 0,5	1
0,5 ≤ Area < 1	0,66
1 ≤ Area < 1,5	0,58
Area ≥ 1,5	0,51

Table 1: Aerodynamic drag coefficient

2.2 LOSS OF CONTROL

The loss of control is subsequent to a failure condition (or a combination of failures) that determines the aircraft loss of control with an impact on ground at high speed.

For the kinetic energy calculation, the parameters to be considered are:

- MTOW [kg] - Maximum Take Off Weight;
- V [kts] - 1,4 x V_{mo} (Maximum Operating Speed).

and the energy is:

$$\text{Ec [KJ]} = \frac{1}{2} \cdot \text{MTOW} \cdot \text{V}^2$$

2.3 CRITERIA APPLICATION

In order to preliminarily identify the design requirements for the System and considered in the certification basis the kinetic energy values at impact, calculated for both scenarios, shall be lower than the allowable limit values, reported in Table 2, depending on the class of "SMALL UAV".

These values can be considered as alarm values for the preliminary choice of technical standard to be used in the design and in the type certification of the aircraft.

SMALL UAV	MICRO	MINI	LIGHT
$E_{K\ limit}$ [KJ]	*2*	*25*	*95*

Table 2: Limit values for preliminary analysis for Type Certification

In case the values would be above the limit, then it is required an official agreement with the Certification Authority, in order to better identify the necessary mitigation factor.

3.0 SMALL UAV SYSTEMS REQUIREMENTS

3.1 REGULATORY, SAFETY TARGET AND HYBRID APPROACH

Taking into account the existing International Policy, the possible certification approaches, relative to the "SMALL UAV" Systems category, are reported in Table 3:

CATEGORY	*APPROACH*	*PARAGRAPH*
MICRO	*SAFETY TARGET*	*3.3*
MINI	*SAFETY TARGET*	*3.3*
LIGHT	*HYBRID*	*3.4*

Table 3: Type Certification Approach for different "SMALL UAV" categories

3.2 REGULATORY

The Regulatory approach for the certification of manned/unmanned aircraft consists of applying defined airworthiness codes (Certification Specifications in the EASA system, FAR, MIL…), based on long lasting experience, to the design of any aircraft. Recognition of compliance with those requirements is given by the granting of a type-certificate for the approved design and certificates of airworthiness to individual aircraft. The airworthiness requirements, sometimes supplemented by special conditions, address all aspects of the design which may affect the airworthiness of the aircraft.

Up to now, it is a common philosophy of these airworthiness requirements that, as far as practicable, they avoid any presumption of the purposes for which the aircraft will be used in service.

The Regulatory approach is considered not usable for the "SMALL UAV" Systems, since it would require safety levels only achievable with a full ~~sub~~systems redundancy (hydraulic, electric, etc.), that in such small Systems is very difficult. Nonetheless this approach is used partially in the "Hybrid" approach (ref. par. 3.4).

3.3 *SAFETY TARGET*

The "Safety Target" approach consists of setting an overall safety objective for the aircraft within the context of a defined mission and operating environment. The "Safety Target" methodology is a top-down approach which focuses on safety critical issues which could affect achievement of the safety target, and allows potential hazards to be addressed by a combination of design and operational requirements.

This approach is considered valid for the demonstration of safe conditions for the "SMALL UAV Systems with a weight lower than 20 kg.

3.4 *HYBRID*

The "Hybrid" approach is based partially on "Safety Target" methodology, consisting of fixing an overall safety objective to be achieved within the envelope of pre-defined missions and/or operational scenarios, and partially on the "Regulatory" approach for all those aspects that could comply to the already existing, or modified, requirements. This new approach, applying an amount of engineering judgment, ensures an adequate overall safety level. Furthermore, it does not penalize UAV characteristics and fits as much as possible the mission profile and the operational limitations. Ultimately it offers a reduced time frame for the issue of a Military Type Certificate for the "SMALL UAV" Systems, in LIGHT category. In fact, it is believed that these aircraft could present adequate design solutions to allow partial redundancies of critical ~~sub-~~systems, guarantying safety levels much higher.

3.5 *SAFETY ANALYSIS AND OBJECTIVES*

When applying for "SMALL UAV" Type Certification, the SDR (System Design Responsible) Company shall conduct a safety analysis and provide the results expressed in terms of UAV System cumulative probability for a catastrophic[2] event per flight hour, caused by technical problems to the System and its Sub-systems.

For the UAV Systems, a catastrophic event is defined as the loss of the System associated to the probability to hit people on ground, combining the inherent System reliability (Loss of UAV probability) with the population

[2] *Catastrophic definition for "SMALL UAV" in AER.P-2 is: "Failure condition that can cause the loss of the APR or a part of it combined with the possibility that the aircraft could wound or kill one or more persons. Failure condition that can cause the deviation from the planned course combined with the collision with another aircraft with people on board. Failure condition that can cause the fatal wounding of the operators during operations on ground."*

density and the debris area (depending on the kinetic energy of the aircraft):

$$p_{catastrophic} = p_{\substack{UAV \\ System \\ Loss}} \times p_{\substack{Hitting \\ People}} =$$

$$= p_{\substack{UAV \\ System \\ Loss}} \times \left(DP_{\substack{Density \\ Population}} \times A_{debris} \right)$$

This approach allows to maintain an high safety level towards third parties, without compromising the design flexibility. The design then will have safety objectives even one or two order of magnitude lower than the values present in the equivalent category (in terms of weight) for the manned aircraft, due to the impossibility to achieve such values on the unmanned systems. But these lower values combined with the population density then will give an overall safety level comparable to that one of the manned aircraft.

The "Safety" requirement, defined in the Product Specification, shall be lower than the values indicated in Table 4:

WEIGHT	*Catastrophic*	*Loss of System*
below 2kg (MICRO)	*≤ 1x10-5*	*≤ 1x10-3*
between 2kg and 20 kg (MINI)	*≤ 5x10-6*	*≤ 1x10-4*
between 20 kg and 150 kg (LIGHT)	*≤ 1x10-6*	≤ 5x10-5

Table 4: Safety Objectives

3.6 GUIDELINES FOR SAFETY ANALYSIS

In accordance with the recommendations and guidelines of the ARP-4761 and ARP-4754 and of the Annex "G" to the AER.P-2 rule, starting from the first design phases, the Company shall submit the project to a Safety Analysis that includes:

- a Top-Down approach qualitative evaluation and severity category classification of hazards generated by the loss or malfunction of the aircraft main functions ("Functional Hazard Assessment");
- a Bottom-up approach qualitative analysis FMECA ("Failure Mode Effects and Criticality Analysis");
- at least for the Catastrophic and Hazardous severity categories, a Top-Down approach quantitative analysis of the probability that a hazard event happens at aircraft level, due to single or multiple failures ("Fault Tree Analysis");
- the evaluation of each hazard condition acceptability, according to the Hazard Risk Index matrix in accordance with MIL-STD-882 method;
- the identification of safety devices, warning systems and any appropriate and consolidated procedure to mitigate the risk.

The critical Sub-systems, whose failures could cause the UAV System loss, are:

- Propulsion System Failure;
- Flight Control System (including Flight Control Computer, Actuators, etc.);
- Ground Control Station (GCS);
- Data Link.

For each UAV System category, the SDR Company will be in charge of identifying the critical Sub-systems for flight operations.

If necessary, the design will be modified in such a way to foresee the necessary redundancies to reduce the probability of catastrophic failures and to avoid that a single failure can cause the loss of aircraft.

3.7 GUIDELINES FOR SOFTWARE DEVELOPMENT AND QUALIFICATION

The software shall be developed with an approach based on its reliability, defined as: *“the probability that the software does not cause a Sub-system failure for a determined timeframe and under specific conditions”*.

The procedure, defined in par.3.9, shall be used for the software functions, whose bugs could lead to catastrophic or critical failures.

3.8 IMPORTANT PARAMETERS FOR S/W DEVELOPMENT AND IMPLEMENTATION

The software shall be developed and implemented, in order to ensure an high level of reliability, considering the following parameters:

- Type of application (real-time control systems, technical application, information management, etc.);
- Development Environment (development methodology and tools available);
- Anomalies management;
- Traceability;
- Insertion of Quality Review results in the developed software;
- Software Language;
- Program dimensions;
- Modularity;
- Complexity;
- SLOC (Source Lines Of Code);
- Already developed software quantity;
- Insertion of the Standard Review results.

3.9 SAFETY CRITICAL SOFTWARE

The software integrity and the functionalities availability are requested for all those software components that have an impact on safety, and shall be guaranteed through the use of software development processes in accordance with RTCA-DO-178B requirements, ref. [10], with the exception of UAV Systems with a weight below 20 kg, that establishes the adequate software class depending on the safety analysis results. The software functions that could lead to catastrophic or critical conditions shall be identified through a System Safety Assessment.

3.10 GUIDELINES FOR PLD (PROGRAMMABLE LOGICAL DEVICES) DEVELOPMENT AND QUALIFICATION

The development of the on-board electronics, i.e. “Application Specific Integrated Circuits” (ASICs) and “Programmable Logic Devices”, shall follow applicable methodologies and processes in accordance with the existing regulations.

RTCA/DO-254 “*Design Assurance Guidance for Airborne Electronic Hardware*” represents a set of best practices for the quality of the on-board electronics design and shall be used as preferential guideline, ref. [9].

If present, the firmware shall be classified in advance as hardware or as software and consequently analysed.

The methodology described in par.3.12 is applicable for those hardware functionalities, the failure of which could lead to catastrophic or critical conditions at System level.

3.11 HARDWARE COMPLEXITY

The hardware shall be analysed hierarchically at different levels, in order to estimate the complexity:

integrated circuit Liner Replaceable Unit (LRU); moreover, also the functions, which could not be testable, shall be considered.

The hardware, containing components such as ASIC or PLD, could be considered simple if, through a set of exhaustive deterministic tests and appropriate analysis at criticality level, it is possible to ensure a correct work in every operational condition, without any anomalies.

If the criteria above listed are not verified, then the hardware shall be considered complex.

It is strongly recommended to keep the level of hardware as simple as possible.

3.12 SAFETY CRITICAL HARDWARE

The hardware functionalities that could lead to catastrophic or critical conditions shall be identified through a System Safety Assessment in order to adopt a proper strategy in the hardware design.

RTCA/DO-254 App. B recommends some specific development methods. Therefore the SDR Company will be in charge of implementing these methodologies or to suggest some equivalent ones to the Certification Authority for their acceptance.

4.0 OPERATIONAL INSTRUCTIONS

Operational procedures shall be defined, in order to guarantee adequate safety levels. It is also necessary to make a distinction between different scenarios in which the UAV System could be used. In particular, this paper focused on training and routine operations. Hence, in case of operations during crisis or conflict time, all these procedures could be superseded on the basis of national safety considerations.

Mini and Micro UAV Systems can be used without NOTAM and without a Communication System for the communications with the ATC. These Systems shall be limited to operate always in Line of Sight, as normally they do not have any optical sensor, which could mitigate the risk related to air collision with other airspace users (including gliders, balloons, etc.).

4.1 "SMALL UAV" SYSTEM OPERATOR QUALIFICATION

UAV System operators could be qualified through the attendance of a specific course, organised by the SDR Company (which has the design know-how). This course shall be defined together with the Staff of the Armed Forces that is the end-user of the UAV System. This common definition shall tackle all peculiar aspects of the UAV System; moreover the Armed Force, to which has been assigned the UAV, shall organise a flight operational course. Once that the operators got through all different examinations successfully then they shall get through medical test as well.

In order to keep the operator fit to UAV operations, a minimum number oh hours per year has to be establish, as well as a maximum daily hours number for training or missions.

4.2 FLIGHT AREA

The flight areas, for the LIGHT Small UAV Systems, shall be in accordance with the limitation related to the population density; instead for the MICRO and MINI UAV in volumes which must not interfere with the air traffic.

4.3 SAFETY REQUIREMENTS

The use of MINI and MICRO UAV Systems shall take into account the following requirements, ensuring in such a way an adequate safety level:

- Maximum value of population density in the over-flown area, to be determined during the type certification process;
- Operational volume, identified in such a way that avoids any interference with normal air traffic;
- Only Line of Sight operations.

The LIGHT UAV System shall comply with the following requirements:

- The operator shall be qualified in accordance with the procedures explained in par.4.1;
- NOTAM is required for the LIGHT UAV, as well as a flight plan to be inserted in the Air Tasking Order, coordinating with the Authority in charge of that; in order to mitigate the risk of mid-air collision with users not provided of Transponder, i.e. Non-cooperative aircraft, a dedicated ATC controller is auspicial;
- Verification of the full functionalities of all electrical and mechanical equipment before using the UAV System (an overall pre-flight check-list could be useful for this purpose);
- Use only authorised frequencies (for flight in Italy refers to those authorised by Italian Air Staff);
- Check that, before and during the flight, there is not electromagnetic interferences in the operational area that could interfere with a proper control of the aircraft.

5.0 AREAS IDENTIFICATION FOR SMALL UAV SYSTEMS FLIGHT TEST

Two different subsequent phases are present in this methodology. The first one aims to identify the operational minimum control volume necessary to perform a safe flight, specific to a UAV System.

Subsequently, the suitable sites are identified, from a geographical-dimensional point of view and considering as well the population density of this area, overlapping the minimum control volume to the possible existing test areas.

The suitability of the test areas shall take as well into account the cumulative probability of catastrophic event (loss of UAV System combined with death or wounding of people on ground).

5.1 OPERATIONAL MINIMUM CONTROL VOLUME IDENTIFICATION

Safety evaluations shall be performed, once having identified the final aircraft configuration, in order to identify any possible hazard, which could affect the test area characteristics, and to analyse the aircraft performances, which could affect the operational volume required for the test.

Taking into account the UAV configuration, its dimensions, the redundancies present in the main Sub-systems, the inherent UAV reliability as well as the worst case hazards, some evaluations specific to the UAV System shall be performed to identify:

- Risk area, taking into account the worst possible failure cases that can be present during take-off and landing;
- Minimum volumes, in terms of

altitude, length and width, required to perform the experimental envelope test; flight limitations and aircraft performances shall be considered in order to optimise this phase;

- Dimensions (width and length) of airways to achieve the test areas and to approach again the runway, considering possible manoeuvres of go-around and/or of immediate return to base;
- Dimensions, number and positioning of test areas where the Loiter circuits have to be performed, in case of loss of signal;
- Procedures and areas within which Flight Termination System (if present) could be activated, whenever required.

The results of the above listed analysis allow to identify the minimum operational control volumes exclusively related to a specific UAV System, to perform safely all flight test activities.

5.2 SUITABILITY OF THE OPERATIONS AREA

Overlapping this volume to properly selected geographical area, it is possible to verify the suitability from both a geographical-dimensional and population density point of view.

Following verifications in terms of operations, environment and procedures will allow a more detail analysis, ensuring that the identified area is generally suitable for the planned activities.

6.0 REFERENCES

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