RAI-VLR : A NEW AIRWORTHINESS CODE FOR VERY LIGHT ROTORCRAFT

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Abstract

Scope of this article is to illustrate the contents of a new airworthiness code, RAI-VLR, specifically oriented to very light rotorcraft (VLR) whose mass does not exceed 600 Kg.
One regulatory novelty introduced by RAI-VLR is the possibility to install on the VLR rotorcraft, piston engines that not necessarily meets the JAR E/FAR 33 requirements as they must comply with the Appendix B of RAI-VLR, whose contents are essentially identical to those outlined in Subpart H of JAR 22, with some essential integration to account for the peculiar utilisation of these engines on rotorcraft such as the double ignition system.
Based on the assumption that a VLR rotorcraft is much more similar to a Very Light Aircraft from the powerplant, accessories and equipment point of view, the most of the regulatory matter introduced in the RAI-VLR, as far these disciplines are concerned, was taken directly form the JAR-VLA requirements.
However, for same specific areas such as the dynamic landing conditions and fatigue evaluation the RAI-VLR requirements are essentially based on JAR/FAR 27, even though the JAR/FAR 27 amendments taken as reference are not the present ones ma those considered more suitable for a regulation code dealing with very simple design and little manufacturer companies.

List of Symbols

A= Rotor Disc Area [m^2]
c = Blade Mean Chord [m]
Ct = Thrust Coefficient $\dfrac{T}{\rho A V_{tip}^{2}}$
Ct_w = Thrust Coefficient in level flight
Ct_{stall} = Thrust Coefficient at blade stall
Hp_{OGE} = Power required for Hovering in Out of Ground Effect [HP]
J = Rotor Inertia [Kg m^2]
N_b = Blades Number
R = Blade Radius [m]
T = Rotor Thrust [N]
Vtip= Tip Blade Velocity [m/s]
Ω=Rotor Speed at engine failure [rad/s]
ρ = Standard Sea Level Air Density [Kg/m^3]
σ = rotor solidity $\dfrac{N_b \cdot c}{\pi \cdot R}$

Introduction

In these last years we have witnessed in Italy an increasing activity related to the production of very light rotorcraft, whose low cost makes them particularly attractive for recreational flying or to operators involved in simple aerial works, such as natural park surveillance, or training.
This expanding market prompted RAI to think about a new regulation developed to ensure an adequate level of safety to the relatively simple design of these rotorcraft.
It is worth pointing out that in Italy all the flying vehicles (including rotorcraft) whose mass does not exceed 450 kg must comply with very simple, essentially operative, rules but are not bound to meet any technical requirements as those stated in ICAO Annex 8 Part II.
On the other hand the JAR/FAR 27 requirements are excessively demanding for the simple VLR rotorcraft design.
Because of this, in many cases one of the main design constraint of the VLR rotorcraft is limiting the overall mass to 450 Kg in order not to be subjected to a JAR/FAR 27 certification, this approach might raise some safety related concerns especially when the VLR designers do not necessarily belong to the aerospace community.
Acknowledging that meeting the FAR 27/JAR 27 requirements would have implied, for generally simple design and production organisations, as those represented by the manufacturer of VLR

rotorcraft, an economic burden in terms of technical solutions and costs associated to the certification tests, not compatible with the low market prices of the VLR, and recognising the necessity to introduce a technical regulation for the VLR rotorcraft, RAI decided to review the contents of the present JAR/FAR 27 requirements and adapt them to the VLR rotorcraft, following a similar approach adopted by JAA to develop the JAR-VLA code for the very light aircraft starting from FAR 23.
The result of this reviewing process is the RAI-VLR which, as being a significant improvement to the safety of the VLR rotorcraft in Italy, might be considered an useful opportunity for the manufacturers as well, in view of the inherent value related to a certified product obtained at expense of reasonable certification costs.

Applicability

The RAI-VLR airworthiness code prescribes standards for issuance of a type certificate for a rotorcraft with a single engine having not more than 2 seats and with a maximum take off weight of 600 Kg.
While limiting the applicability of this code only to the single engine piston driven engines is mainly due to the need of considering very simple design, the 600 Kg maximum weight is mainly aimed to account for the following factors :

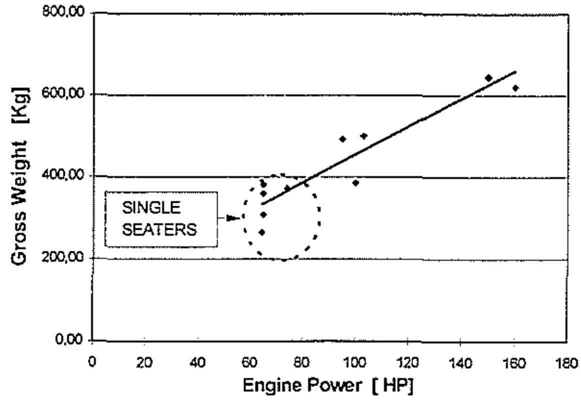
- Rotorcraft configuration that, consistently with JAR-VLA, might envisage 2 occupants.

- Rotorcraft designs meeting some basic airworthiness requirements without adopting unusual or not well proven engineering solutions.

- Fuel tank installation of suitable capacity to allow flight duration of three hours or more.

Currently the weights of potential RAI-VLR rotorcraft, including home-built helicopter, range between 250 Kg of the simplest single seat configurations and 500 Kg for the two occupant versions with engine power below 100 HP.
However, as it can be seen in the following figure, in which are plotted the weight and engine power of the most popular ultralight rotorcraft, an increase of the installed engine power , typically more than 140 HP, cause the maximum take off weight to be well above 600 Kg , even for home-built rotorcraft.

Figure 1



As a consequence, considering that meeting the RAI-VLR requirements might imply an increase of the initial not certified rotorcraft weight that varies between 10-20 %, the 600 Kg upper limit represents a good margin considering the possible developments and changes of these rotorcraft configuration once they are granted with a VLR certification (e.g engine power increase).

Flight

Subpart B of RAI-VLR is similar to JAR/FAR 27.
Obviously differences arise in order to account for the different types of usage of VLR rotorcraft as well as the limited performances of powerplant systems installed.
Because of that, one of the basic assumptions taken in RAI-VLR is that an adequate and complete performance assessment can be conducted at sea level conditions.
As a matter of fact a long and very time consuming flight test campaign in correspondence of all altitudes for which certification is requested, as suggested in JAR/FAR 27, beyond representing an excessive economic burden for the manufacturer, might not be very meaningful, with respect to the data acquired at sea level, in view of the low altitudes which these very simple rotorcraft can fly.
It is worth pointing out that this same consideration are assumed in JAR-VLA.
Obviously for such specific topics such as take-off or hovering capabilities a deeper investigation must be conducted; particularly paragraph RAI-VLR 73 prescribes a minimum altitude of 3000 ft

in correspondence of which hovering performances should be demonstrated.
It is our opinion that 3000 ft might represent a very reasonable assumption when compared to the 4000 ft value, as suggested in FAR/JAR 27, which is considered a suitable minimum altitude for rotorcraft by far more powerful than the VLR ones.
Similarly as far the height-speed envelope is concerned, RAI-VLR 79 states a reference altitude of 6000 ft instead of 7000 ft as suggested in FAR/JAR 27.
Additional main differences with JAR/FAR 27 can be found in controllability and manoeuvrability section.
In JAR/FAR 27 143 (c) is explicitly required a minimum wind velocity of 17 knots to be considered for near ground operations; conversely in RAI VLR 143(c) this minimum wind velocity is not prescribed but it should be determined on a case by case basis through flight test.
Even though RAI-VLR is a simplification of JAR/FAR 27 , there are some requirements such as RAI-VLR 143(d), concerning the controllability after an engine failure, that are fully taken from JAR/FAR 27, which results particularly critical for the VLR rotorcraft.
As a matter of fact, being the VLR rotorcraft pilots not necessarily very experienced, it is important to assure that the controllability of the rotorcraft must be granted even in the case of a complete engine failure, this point might be stressed even further in view of the fact that the VLR rotorcraft are generally powered by fully rated engines and possible rotors with low inertia.
Because of this latter consideration RAI-VLR, includes a specific Advisory Circular in which is required that compliance should be demonstrated by considering a corrective action time delay for the cruise failure not below 1 second or normal pilot reaction time, whichever is greater.
Additionally, based on similar formulations found in [1] and [2], before starting flight tests the rotorcraft design must be such that the following parameter, which represents a measure of rotor speed decay after that engine power is lost , must be at least equal to 1.3 seconds.

$$t / k = \frac{J\Omega^2 - J\Omega^2 \cdot \dfrac{(Ct_w / \sigma)}{0.8 \cdot (Ct_{stall} / \sigma)}}{(746 \cdot Hp_{OGE})}$$

Subpart C Structure

RAI-VLR Subpart C requirements are fundamentally the same as in JAR 27.
The main differences can be found in the evaluation of the emergency landing condition loads, the fatigue substantiation of structures and the introduction of new coefficients for the limit torque, to include also the two-strokes engines, taken directly form JAR-VLA 361.
With reference to the emergency landing condition accelerations, RAI-VLR 561, it should be considered that in these last decades the applicable requirements have been considerably modified in all airworthiness codes.
The adoption in RAI-VLR of values currently used in JAR/FAR 27 would have meant, for the design of a light helicopter, emergency landing loads higher than those against which most of the present operating helicopter were certified.
As a consequence, intermediate values between the present values of JAR/FAR 27 and those in force in CAM6 or FAR 27 before amendment 25 (see tables below), has been adopted.

Table 1.

Supporting Structure	VLR	CAM6	JAR 27
up	1.5	1.5	1.5
fwd	8	4	8
side	2	2	2
down	4	4	4

Table 2.

Occupant & Item of mass	VLR	CAM6	JAR 27
up	3	1.5	4
fwd	9	4	16
side	3	2	8
down	9	4	20

In addition the crashworthiness/dynamic conditions prescribed in JAR/ FAR 27.562 were not deemed appropriate for the design of this class of helicopter and not introduced in RAI-VLR.
Nevertheless, RAI intend to issue some advisory material regarding this latter subject whose main task is to provide, following the same approach adopted in the glider regulation JAR 22, the basic design criteria to ensure safety levels of

crashworthiness; these criteria might include also static test.
Finally as far structure fatigue evaluation is concerned, it was deemed appropriate, irrespective of weight and operative limitation, to follow as much as possible the contents of JAR/FAR 571.
Namely a flight test campaign must be conducted for the determination of flight loads and special care should be given to the assessment of the GAG cycles.
The only difference from JAR/FAR requirements is that the current damage tolerance criteria have not been included in RAI-VLR 571 because it is assumed that the level of engineering background lying behind such kind of analysis is generally far beyond the capabilities of VLR designers.

Subpart D Design and Construction

Subpart D of RAI-VLR is similar to JAR/FAR 27 as far peculiar helicopter components such as fasteners, rotors, landing gear, control system are concerned.
Conversely, RAI-VLR requirements dealing with fabrication methods or material allowable determination are taken directly from JAR-VLA.
The reason leading to that decision is based on the small industrial organisation of VLR helicopters manufacturers who, under this respect, are very similar to the VLA aircraft manufacturers.

Subpart E Powerplant

Because of the type of engine used on VLR helicopters, in Subpart E the main differences between RAI-VLR and JAR/FAR 27 can be found.
The first important novelty of RAI-VLR is in RAI-VLR 903, where the installation of engines certified according the requirements reported in appendix B of RAI-VLR regulation is permitted.
From a practical standpoint these requirements are the same as Part H of JAR-22 regulation with some differences related to the driven shaft configuration and from the different usage of these engines with respect to the VLA aircraft.
Double ignition and, consistently with the requirements of FAR 33.49 for engines to be installed on helicopters, an integration of the engine endurance test with the conditions and additional time of operation as outlined in RAI-VLR 923, are required.
The contents of RAI-VLR 923 are identical to JAR/FAR 27.923 requirements.

It is evident that the possibility of adopting these types of propulsion system involves some design simplification that, apart from obvious considerations related to the piston single engine, must be necessarily reflected at regulation standard too.
Particularly as regards tanks, filters of the fuel system and engine control system, RAI-VLR requirements take their inspiration from JAR-VLA requirements which are deemed more adequate than JAR/FAR 27 for this type of installation.
However it should be pointed out that implementation of JAR-VLA requirements is essentially limited to the above mentioned areas of the engine system, while it was considered advisable to keep paragraphs of JAR/FAR 27, suitably adapted, for all that concerns specific problems of helicopters (rotor drive system, gear box, powerplant fire protection, induction system, engine vibration).
Finally as regards the certification of the engine itself the requirements of Appendix B of RAI-VLR are based on the assumption that an adequate investigation of the engine performances might be carried out without using very complex and costly test procedures, as in FAR 33, that, although deemed necessary on more sophisticated and powerful engines, add an unduly burden to the certification of these simple engines.

Subpart F Equipment

RAI-VLR Subpart F is based on the consideration that many instruments installed on JAR 27 certified helicopters are not essential for VLR helicopters, because of the greater simplicity of the systems as well as to the limited performance of these rotorcraft: relatively low speed, low ceiling and short flight time. In view of the above, JAR-VLA requirements were deemed to be more adequate to be implemented in RAI-VLR. Nevertheless, for those particular instruments and components typical of helicopters, JAR 27 requirements have been adopted in RAI-VLR. The differences between RAI-VLR and JAR 27 for this subpart are mainly restricted to the powerplant instruments, batteries installation and test and electrical equipment.
In particular in RAI-VLR, for powerplant instruments, these indicators are not required :

- Cylinder head temperature; a minimum-maximum cylinder head temperature warning device is needed

- Fuel filter contamination indicator

Given the similar characteristics of the battery installation systems, the requirement dealing with this area (RAI-VLR 1353) has been taken directly from JAR-VLA. However, demonstrations of correct functioning under the conditions shown in JAR-VLA 1353 b(1), b(2), b(3) are not included.
In a similar way, as for static pressure sources, magnetic direction indicators and gyroscopic instruments, the applicable RAI-VLR requirements (1325, 1327, 1331) are the same as in JAR-VLA.
The same approach has been followed in RAI-VLR to set the standards for switches and electric cables (see RAI-VLR-1361, 1365, 1367), safety equipment (RAI-VLR-1413) and miscellaneous equipment (RAI-VLR-1431, 1436).
However, among the miscellaneous equipment of FAR/JAR 27, there are some which are peculiar for helicopters such as the JAR/FAR 27.1436 (high energy rotors) in this case these requirements were entirely embodied in RAI-VLR.

Subpart G Operating Limitations and Information

The requirements included in this part are basically the same as those in JAR/FAR regulations with obvious exemptions of those sections covering turbine engines, multi-engine configurations or retractable landing gear.

Conclusion

RAI-VLR is a new airworthiness code that fully comply the ICAO Annex 8 part II standards.
RAI would be legitimated to issue Standard CoA for VLR rotorcraft, certified against RAI-VLR, however RAI interpretation of the "Arrangements concerning the development and the implementation of Aviation Requirement", through which a number of Authorities (. RAI included) committed themselves to adopt the present and future JAR's as their only codes, is that such Authorities cannot issue a Standard CoA for a product, whose certification basis is not a JAR code, when the application date has been made after the adoption of JAR's as codes.
Finally RAI-VLR has been taken as reference code by the JAA Subgroup, set up by the JAA HASG, whose objective is the drafting of a new JAA-VLR code to be submitted to the JHWG members for evaluation by the end of 1997.

References

1. Johnson, W., "Helicopter Theory", Princeton, USA, Princeton University Press, 1980

2. Newman, S., " The foundations of helicopter flight ", Bury St.Edmunds, UK, Edward Arnold, 1994

Acknowledgement

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