

CERTIFICATION OF COMPOSITES IN CIVIL ROTORCRAFT CURRENT APPROACH AND THE WAY AHEAD

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ABSTRACT

This paper is intended to highlight, other than a sintetic overview of the philosophy underlain the certification of primary rotorcraft structures as adopted in Italy by RAI and in Europe in recent certification programmes (in particular for the civil certification of the EH 101), some peculiar aspects of composite relevant to helicopter structures.

A number of issues that should be addressed in the certification process will also be discussed with a view to helicopter structures compared to the fixed wing experience. In addition , some safety related issues typical of the composite technology which have been more recently addressed in the U.S. Federal Aviation Administration Advisory Circular A.C.21.26 "Quality Control for manufacture of composite structures" issue 1 dated 26-1-90 or are going to be introduced by amending the existing Advisory Material (reference is made to the JAA Notice of Proposed Amendment NPA-25D-256) will be treated with particular emphasis on the integrated nature of the composite design compared to conventional metal structures.

A number of relatively new topics will also be described regarding how the interaction of different disciplines and areas of specialisation involved in the design, construction and qualification of composites have imposed appropriate evaluation by the Constructors and the Civil Certification Authorities.

In conclusion , an attempt will be made to identify some key points for success of composite material applications which , in the author's opinion and in the light of JAR 21 and related Design Organisation Approval (D.O.A.) implementation, should constitute the next challenge for a cooperative effort between European Constructors and the Joint European Authorities in the common perception of working together for safety.

INTRODUCTION

The gradual process of pressing into service composite technology for both fix and rotary wing civil aircraft has today achieved a level of maturity ; the use of advanced composite materials ,infact ,has been extended to a wide range of primary structure applications.

In Europe the helicopter industry also followed this process with the first applications to main rotor hubs

and blades certified in the mid eighties up to the more recent SA 332 MK2 composite fuselage and EH101 composite applications which include main and tail rotor hubs and blades, the complete tail unit , the forward cabin, some flight control rods.

In parallel with the said gradual process, some specific topics unique of composite materials had to be addressed during the certification of safety of flight structures ; consequently guidelines and advisory material were published by the Civil Certification Authorities .

The U.S. Federal Aviation Administration firstly published on october 1978 the Advisor Circular A.C. 20.107 " Composite Aircraft Structures " which was subsequently revised as result of a joint FAA and JAA effort and of the experience meanwile gained in U.S.A. and in Europe.

The revised A.C.20.107A (equivalent JAA guidance paper ACJ 25.603) was issued in april 1984 and contains acceptable means of complying with the pertinent requirements of the FAR/JAR 23,25 for small and large airplanes and FAR/JAR 27,29 for rotorcrafts.

OVERVIEW OF THE COMPOSITE CERTIFICATION FOR HELICOPTER STRUCTURES

The key issues for certification of composite aircraft structures were identified since the FAA Advisory Circular AC 20.107 was firstly issued and have then been discussed in a number of papers [Ref.1,2,3,4] as far as experience has been gained. These issues were identified to provide guidance material on the means of complying with the existing design requirements in consideration of the differencies between composites and metals.

Althought the approach for certification of fixed wing composite structure should be the same as for rotorcrafts, some peculiar aspects which give raise to differencies in the compliance philosophy demonstration are here after discussed :

Material and Fabrication Development

Developing design allowables for rotary wing structures does not differ from fixed wing; however it has to be recognised that if a safe life design is proposed for certification this would impose the use of A-basis design allowables.

The long term exposure to severe environmental conditions of composite structures and the associated moisture absorption into the laminates has been of concern to the Airworthiness Authorities.

In most cases rotorcraft structures, especially dynamic components, are thicker than fixed wing structures.

The artificial ageing of test specimens is therefore a crucial step in the compliance demonstration due to the long time exposure needed for such a scope. The time constraints for certification could result, in some cases, in calendar life limitations to be imposed on the thickest components in accordance with the partially aged state reached by the certification test specimens. Obviously the mentioned limitations could be removed as soon as successful test results are gathered from moisture conditioned specimens at the prescribed equilibrium level representative of the requested worst case service life. It has to be reminded that the increase of temperature to increase the rate of water diffusion into fiber/epoxy laminates could be beneficial for saving artificial ageing exposure time but should be exercised with care in consideration of the possible induced effect of producing micro-cracks into the matrix. This effect could lead to an unrealistic water absorption mechanism into the laminates. Artificial ageing temperatures higher than 80°C, for 180°C cure systems, should be justified as not producing micro-cracks into the laminates, nor inducing post-curing to the composite material.

Proof of Structure Static

The building block approach [Ref. 4, 5] is considered the best way for the compliance demonstration also for helicopter structures especially for built-up structures of complex geometry such as fins, stabilizers, fuselages.

For dynamic components the principle is still valid ; the pyramid of testing, however, looks more compacted in terms of type of application level specimens while the number of tests needed to address all the different issues should not differ significantly.

The static test strength demonstration of dynamic components and fins, for which rigidity requirements are of paramount importance, assumes a peculiar significance with respect to the displacement monitoring to be implemented during the tests in order to check any stiffness change.

It is almost impossible to analytically predict the resulting stiffness changes associated with the combined effects of acceptable manufacturing discrepancies (usually built into the test specimens), barely visible impact damages, thermal and moisture absorption effects, without disregarding those of repeating loads, if significant, and how they interact with the others . This latter issue is unique to composites while asking ultimate static strength demonstration at the end of lifetime. The issue is explained by the composite material strength behaviour :

- after impact, with drastic reduction in residual static strength

- under severe environmental conditions, with matrix stiffness properties degradation and possible change in the failure mechanism of the laminates, having into consideration that a reduction of the static strength safety factor during the service life of the component cannot be admitted as well as a reduction in flutter margins.

Proof of Structure Fatigue

The Regulatory Requirements

The Airworthiness standards for Transport Category Rotorcraft established by FAR 29 were amended in October 1989 with Amendment 29-28 by adding flaw tolerance requirements to the existing ones for fatigue evaluation of structures and by extending the requirements for fatigue evaluation to all critical structures, not only flight structures.

Even before Am. 29-28, for composite helicopter structures, the use of guidelines provided by AC.20.107A was worth in providing an acceptable and achievable damage tolerance level and could be considered as an anticipation of the compliance demonstration to the more updated requirements introduced in the rules after Am. 29-28 was published.

In order to assess composite material peculiarities with respect to fatigue in accordance with AC 20.107A , a level of tolerance to damages should be impaired to the design of helicopter structures ,as a minimum ,for the following aspects :

- Manufacturing discrepancies up to the maximum level allowed in production.
- Impact damages induced in production and in service
- Environmental effects
- Effects of lightning strikes

Safe life versus damage Tolerance

Depending on the specific components and on the particular design , since the first composite structural applications there was concern , at least in Italy , to adopt a new certification approach and ,from the constructor perspective, to abandon well proofed and experienced design practices.

It was recognised the risk of using a fairly new approach leaving the previous safe life which ,with some restrictions, was judged to be well proofed for metals.

The risk was not only related to safety issues but also, from the constructor 's perspective, to commercial and planning issues.

In addition , based on fatigue design experience with low fracture toughness metal alloys , there was some conviction that a flaw tolerant design would have not been easily achieved for helicopter structure, with a potential for losing past experience [Ref. 6]

A precautional approach was therefore judged the most appropriate so, once more, a stepped up substantiation activity was considered the most effective .

The composite structure fatigue substantiation - while tailored to demonstrate an enhanced safe life with full accountability of the already mentioned composite related issues - was also supported by a careful estimation of the inherent composite material variability for the most critical failure modes in order to validate load and/or life scatter factors to be used for the enhanced safe life determination.

The experimental activity carried out at constant amplitude fatigue loading has also been useful for substantiating the truncation level of the spectrum fatigue testing carried out on subcomponent and component level test articles to properly investigate damage tolerance capability of the structures. In the latter case clearly visible impact damages, if realistic, have to be investigated.

At this regard it has to be noticed that the impact energy cutoff value of 50 Joules - commonly accepted in Europe for fixed wing composite structures - for substantiating Barely Visible Impact Damages induced on thick laminates has also been agreed for substantiation of helicopter structures. In addition, if shown to be realistic for the particular application, higher impact energy values should be used as part of the damage tolerance substantiation.

Flight by flight fatigue spectrum testing of composite helicopter structures is considered an unsubstitutable and practical evidence for the compliance demonstration of the flaw tolerant design requirements applicable to rotorcraft structures.

The use of hybrid metal-composite structures implies an increased number of testing deemed necessary to validate fatigue strength of the concerned component under conflicting fatigue behaviours of the constituent materials in respect of the fatigue test spectrum definition.

On the other hand experimental evidence has shown excellent damage tolerant capability of hybrid metal-composite dynamic component under fatigue spectrum testing tailored for the composite part in presence of large cracks affecting the metal .

However the question remains about how significant is, for such structures, the weight penalty if compared to a purely composite structure.

Fatigue spectrum definition

With respect to fixed wing aircraft, helicopter structures are subjected to significantly higher frequencies of fatigue load cycles with a relatively higher variability in helicopter flight spectrum. Moreover the relatively flat S-N curve shape exhibited by composites in the frequency range of interest impose a careful assessment

of the truncation level proposed for fatigue spectrum testing of helicopter structures.

The fatigue spectrum development for composite structures has been the subject of numerous investigations confirming the significance of loads of high amplitude - even if of low frequency - in composite fatigue, so also evidencing the mentioned conflicting fatigue behaviours of hybrid metal-composite structures [Ref. 5,7,8].

The importance of accurately simulating start-stop cycles and their percentage of occurrence in fatigue tests of composite rotorcraft structures is, consequently, explained as well as the need for including into fatigue test spectra the loads associated with failure states of systems interacting with structures.

Particular attention should be paid in monitoring possible fretting effects induced during accelerated fatigue testing which constitute one of the limits to the objective of reducing testing time. An undue temperature increase associated with fretting could, in fact, affect the material behaviour in fatigue giving unconservative results especially while conducting flaw growth test verifications.

Lightning Strike

Lightning strike substantiation of composite structures involves demonstration by analysis and tests that the structure is capable of dissipating lightning strike electrical charges.

Lightning test results provide to the structure analyst the necessary data to perform structural strength assessment once the evidenced lightning induced damages are judged as tolerable by the structure. In such case it has to be demonstrated that the structure, in presence of the lightning induced damages, is capable of sustaining the expected loads for continued safe flight and landing.

Structural strength verification should cover all aspects associated with the continuation of flight:

- capability to sustain the fatigue loads for the time period from the lightning event to the safe land of the rotorcraft multiplied by appropriate life or load factors or a combination of the two

- residual strength verification at the end of the time interval above

- flutter substantiation to cope with any eventual stiffness reduction - or change in mass distribution - associated with the lightning strike damages.

Referring to the last point, service experience has shown that a lost piece of a tail rotor blade due to lightning strike, even if sustainable for the strength and stiffness characteristics of the blade, could produce an

unacceptable change of his vibration characteristics, as consequence of the mass change, resulting in a resonant frequency excitation of the tail rotor hub and seems to have caused the loss of the tail rotor.

Service experience has also shown the importance of establishing detailed repairing procedures for composite structures which should include provisions for restoring not only the structural strength of the structure but also the pre-existing lightning protection so as to avoid lightning damages to the repaired structures higher than those evidenced during certification tests.

Indications regarding the execution of a final electrical continuity check should be included in the repair schemes affecting those areas of composite structures to be protected, by design, against the effects of lightning strikes.

INTERACTION OF SYSTEMS AND STRUCTURES

The availability of computer controlled systems has offered to the designers the opportunity of making profit of these advancements in flight control technology by using active flight control systems capable of providing automatic responses to external inputs from sources other than pilots.

Active control systems have been expanded to a number of functions increasing their effectiveness and reliability up to fly by wire flight controls which are becoming standard equipments on large transport aeroplanes.

Certification of aircrafts with these systems has been achieved by issuance of special conditions for relevant projects and by using guidelines provided by Advisory Circular issued by the Federal Aviation Administration (A.C. 25.672-1) in November, 1983 for Stability Augmentation Systems (SAS), Load Alleviation Systems (LAS) and Flutter Control Systems (FCS).

In Europe the Joint Aviation Authorities in cooperation with the FAA and other American and European aerospace industry organisation, began a process to harmonise the airworthiness requirements of Europe and of the United States applicable in this field to large aircrafts which is now close to be finalised.

In the helicopter industry some peculiar applications begin to be utilized: undesired vibratory levels could be reduced, as an example, by simply superimposing out of phase forced vibrations induced by computer controlled jack actuators at the points where the undesired vibrations are generated.

The controlling parameter being the acceleration induced in one or more selected point of the helicopter structure, it is possible to adapt the requested out of phase actuators input so as to reduce at a minimum the total vibratory level. The link with the recorded structural vibration is managed by computer in a feedback logic. This is one of the numerous possibilities that could be installed, nowadays, on rotorcrafts to achieve a specific desired improvement.

From an airworthiness stand point the problem to face with these relatively new aspects of the helicopter structure certification is basically to guarantee an acceptable level of safety taking into account that current requirements do not provide an adequate basis to address them. The certification experience of aeroplanes, in this respect, has been of help in defining acceptable levels of safety and how to achieve them.

The rotorcraft design standards identified in JAR/FAR29 besides calling for acceptable controllability and vibration level also, in general, call for substantiation to both static and fatigue criteria to defined flight envelopes. As part of the structural substantiation, the use of systems interacting with structures impose consideration regarding :

- The system operative
- The system inoperative or degraded
- Failure cases including recovering from failure.

The substantiation of the structures affected by the system implies, therefore, that all possible failure modes not shown to be extremely remote [i],[Ref. 9] should be taken into account in developing representative or conservative loading during the recovery phase and suitable restrictions on operation with the system failed. The considerations should be addressed on :

Static substantiation: developing loads occurring after the failure including transient.

Fatigue substantiation: developing fatigue spectrum consistent with the demonstrated probability of failure of the systems. At this regard particular attention should be paid, for composites, to those peak loads generated in certain failure states which could affect the fatigue strength of composite structure even if they are associated with a low number of occurrences based on the concerned probability of failure of the system. These peak loads should not be omitted in the fatigue spectrum developed for composite structures unless shown to have negligible effect due to their low amplitude.

Controllability substantiation: showing that after the failure of the system the recovery of the rotorcraft is possible in association with pilot corrective actions.

Flutter substantiation: showing freedom from flutter in the failure condition up to the same speeds and power conditions provided under system operative.

[i]:According to Ref. 9 defined as " Unlikely to occur to each aeroplane during his total life but which may occur several times when considering the total operational life of a number of aeroplanes of the type "; the associated probability ranges between 10e-7 to 10e-9

The static and fatigue assessment should also demonstrate that the system failure will not contribute to significantly reduce the stiffness of the concerned structure, under any appropriate reconfiguration and flight limitation for continuation of flight, behind acceptable limits.

As it can be seen the adoption of such new technologies and improvements that are not appropriately addressed in the current requirements impose a review of the safety standard which usually lead to a multi disciplinary effort.

Moreover, the certification substantiation approaches typical of fixed wing damage tolerant structures are even more familiar to helicopter designers .

The reasons, among others, could be searched in the technology novelties themselves or in the increased complexity of the designs associated to the maturity achieved by the technology which justify the adoption of new rules.

The concerned certification work produces a regulatory harmonisation " in fieri " of the requirements themselves:

many specialists with different backgrounds, experiences and approaches are forced to work together to identify a complete and congruent set of requirements to address interface problems which influence more than one discipline.

Obviously this work implies also to review the historical background of the requirements which often belongs to a restricted number of persons without mentioning the unique opportunity to share opinions and definitively understand the need for and the importance of a common approach with a compulsory set of standard and commonly accepted definitions

QUALITY ASSURANCE

The multidisciplinary aspects of composite design

The integrated nature of composite technology from the design and conception point of view suggests to the designers and to the Certification Authorities to pay special attention to those aspects of the design and manufacturing which by their nature cannot be considered separately.

Quality assurance and control for composite production should not only be regarded as a mean to guarantee that the structures , once manufactured, meet the specified type design standard but also as a crucial step in the engineering design evaluation process which could highly contribute to conceive a sound design.

This aspect, in reality, is not new to aerospace industry however it is emphasized for composite.

A design assessment which takes into account the number of topics associated with the manufacturing since the beginning, including repairs and quality control, will ease the certification process and will also be worth to cope with in service problems.

The mentioned topics are :

- Accessibility for inspecting, manufacturing, repairing.
- Producibility
- Repairability (in production and in service)
- Readiness of the technology in terms of availability of qualified material, proofed technological process, inspection techniques and related standards.

The certification work, in parallel, has to embrace those manufacturing and quality control process aspects strictly linked with the engineering design in an effort to evaluate and anticipate possible future problem areas.

The challenge here, where a multidisciplinary experience is invaluable, is to make sure that the proposed certification substantiation is congruent with the "real world" of production and manufacturing. This means that manufacturing discrepancies proposed to be substantiated against the applicable structural requirements (i.e. static, fatigue, flutter.....) are consistent, in terms of location, type, number and size with those expected in production. The resulting evaluation should include :

- The materials utilised and their expected response to the complete production process
- The shop environments in particular those of the lay-up areas
The build-up structural concept and tools utilised
- The inspection techniques intended to be used and their implementation at the different production steps
- The number and type of destructive and non destructive evaluation carried out on the structure or on travellers obtained from sacrificial areas of the production structures.

Each one of this areas of investigation will lead to a common engineering effort the result of which has to be finalized in establishing and approve :

- A set of specifications, production requirements, engineering data and drawings which define the type design standard.
- The test articles to be used for certification testing as representative of the worst production structure.

Basically, these design and certification objectives could interact so as one could drive the other or viceversa depending on the previous experience gained by the constructor and by the amount of novelties introduced into the design and manufacturing without mentioning commercial aspects that sometime justify a design with respect to another, the use of a material and associated process instead of another.

From an airworthiness stand point at the time of type certification, based on the substantiation test results, the type design standard should be frozen and, for composite, the factual aspect would be the approved acceptance-rejection criteria and standards.

Material Change

The definition of a type design standard regarding composites includes a number of additional precautions, with respect to metals, to be taken into account in order to freeze the certified type design. The reasons for this difference is mainly related to the intrinsic characteristics of composite materials which are able to perform their structural properties at the end of the production process (their mechanical properties are so called " process dependent ").

The raw materials, in addition, are extremely sensitive to a number of parameters which, if not completely under control, can contribute to affect the final expected performances of the structure.

In lack of standardised material classification, the materials used for supporting the type certification activity and hence candidates for the Type Design Standard, have to be identified by their brand name in the set of applicable type design drawings.

Usually, economical reasons lead to a type design standard based on a single source of approved materials for each application [Ref. 4]

The problem of a composite material change as a significant change to the original type design has been recently addressed in a Notice of Proposed Amendment to the Joint Aviation Requirements, JAR 25, NPA25-D256 refers , proposing to add guidance material to the existing one about this subject.

Hereafter some related issues are discussed:

The case of existing materials and related procurement specifications proposed for new applications

For composite material applications to critical safety of flight structures, the concerned material specifications and the associated acceptance test values should be defined for the specific application and for each qualified material even if the selected materials are already covered by existing in house material specification.

The reason is mainly related to the use ,in the past, of composite material specifications covering more than one qualified material with ,in some cases, quite significant differences in their performances.

The relatively low criticality of the designs allowed the Constructors to establish acceptance values capable of being met by materials exhibiting different performances in some characteristics.

The increased demand of accurate and efficient design together with the increased number of critical applications have nowadays prompt the Certification Authorities and the Constructors to differentiate one material from another, one application from another.

The acceptance values included in the material specifications should reflect the real performances of each single qualified material ; in doing so, assurance will be given that in production the supplied materials conform to those originally used for the manufacture of the certification test articles.

In cases where the certification process would evidence the peculiar criticality of a new design with respect to already approved ones or of one material characteristic for a specific application, it would be advisable to include in the acceptance material standards those testing requirements appropriate for the case (as an example : impact testing, open hole testing.....). This is particularly applicable to those characteristics which reflects critical point designs.

The quality standards applicable to helicopter structures are usually more stringent than those of fixed wing structures : typically, specimens cutted from sacrificial area of each production item are destructively tested ; a complete production item could also be destructively tested in accordance with approved sampling plans. Nevertheless the change of composite material should be regarded as a significant change to the type design definition and all possible precautions taken to avoid the risk of entering into service a potentially large number of production items deviating from the original approved type design standard.

Production process change

Production experience has also shown the importance of each single step in the manufacturing process of composites.

Even apparently small or not significant variations to the production process , if not appropriately supported by experimental process change verification and engineering evaluation, could lead to undesired and unexpected responses of the materials, once cured.

A pessimistic approach during the certification phase, entitling larger than expected manufacturing discrepancies for strenght substantiation, could be extremely worth in anticipating the " real world " of production and would enable to cover, without further showing, those unexpected production mistakes or deviations occurring after type certification , as the experience sometime suggests.

SPECIAL TOPIC

Helicopter post crash investigation has drawn to the attention of the involved Authorities that the Civil Emergency Services were unaware of the danger posed by composite material post an accident, suggesting to promote a campagne to improve the general level of awareness regarding the potential danger associated with composite materials, especially following fire.

Althought not strictly related to safety of flight, the issue is reported in the convincement that it will contribute to reduce the risks evidenced by the investigation team.

CONCLUSIONS

From the experience gained in recent civil rotorcraft certification programmes , this paper has highlighted some issues which have been relevant for the compliance demonstration of composite rotorcraft structures such as :

- the compliance demonstration with respect to fatigue requirements including damage tolerance evaluation

- the adopted requirements to cope with new design features including systems the failure of which could affect the strength of structures,with emphasis on the need for coordinating the certification work involving many disciplines

- quality assurance issues and related peculiar aspects of composites which, if addressed in an enlarged perspective since the very early stage of the projects , would highly contribute to support and ease the certification effort with significant cost saving.

The success of composite applications to rotorcraft structures , provided the technology can be today considered mature, is mainly related to the capability of the Constructors in conceiving their design and verification tasks in a comprehensive approach through :

- A design review management capable of assuring an efficient , cooperative and coordinated involvement of all related functions of the design cycle for composites

- A research and development activity which supportsthe engineering design and the test laboratories together with the production and the maintenance of the structures,in particular in the field of non destructive testing ,which is susceptible of large improvements in the near future for composites,with concurrent safety and economic benefits.

In this respect the new flaw tolerant requirements for helicopter structures cannot be considered as separated but implies a new frontier in " seeing the invisible " at economically feasible costs.

- Investements in education and training initiatives in all fields to enlarge the confidence and the consciousness at the different responsibility levels about composite applications

- Participation to cooperative projects and to research activities with an early involvement of Certification Authorities

- Establishing an independent Design Assurance System to monitor and integrate the internal policies and procedures for good design praticies and verification.This would be highly reccomended taking into account the recent tendency outlined by the JAA in the JAR 21 rules , in particular the part related to the Design Organisation Approval.

In parallel ,the Airworthiness Authorities have to face with the increased demand for specialised personnel with sound multidisciplinary background partecipating to the numerous, statutory or not ,projects,researchs, international meeting initiatives and are also urged to devote increasing budgeting resources for training and education,as the recent experience at RAI demonstrates.

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