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Certification Requirements to Additive Manufactured Parts Used in Airframe Primary Structures

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Abstract. Paper introduces review and defines the main requirements of regulations and standards relating to certification of airframe primary structural parts made by additive manufacturing (AM), i.e. 3D printing. The aim of paper was to classify requirements to certification tests in compliance with airworthiness regulations. Paper gives a base for design of an experimental program supporting certification of the selected part of a structure. The paper is focused mainly on application in a military service. Requirements are specified in compliance with EASA (European Union Aviation Safety Agency) and EMACC (European Military Airworthiness Certification Criteria) regulations.

Introduction

Additive manufacturing (AM) is a form of manufacturing, which is subsequently derived from a rapid prototyping technology since the 1990's. Application of AM is still not extensively used technology in the Czech aerospace industry for principle structural elements of airframes. On the other side it can be stated that the certification practises are not fully proceeded in the world until now. In this sense, the main aim of this paper is to provide a review of airworthiness regulations and standards with the scope for definition of an experimental programme for certification of selected primary aircraft structure part in compliance with airworthiness regulations.

Airworthiness regulations base

CS (Certification Specification) issued by EASA (European Union Aviation Safety Agency), FAR (Federal Aviation Regulations) issued by FAA (Federal Aviation Administration), and MASAAG (Military Aircraft Structures Airworthiness Advisory Group) regulations for airworthiness of structures are fundamental.

Requirements of each regulation differ according to type and size of structure and according to scope of service. In case of a primary structural part of the airframe certification, it is relevant to apply the requirements of CS-23 (Certification Specifications for Normal-Category Aeroplanes) [1], or CS-25 (Large Airplanes) [2] valid in EU (European Union), or their equivalents FAR-23 [3] a FAR 25 [4] issued by FAA. Requirements in detail and ways for their complying are defined in a row of supporting and mandatory ruling, such as FAA a EASA Advisory Circulars (AC), Acceptable Means of Compliance (AMC), Certification memo (CM), Guidance Material (GM) a others standards, recommendations and handbooks – for example MMPDS (Metallic materials properties Development and Standardization), CMH (Composite Material Handbook), Joint service Specification Guides (JSSG), Defence Standards (DEF-

STAN), NATO STANAG (NATO Standardization Agreement), European Military Airworthiness Certification Criteria (EMACC), American Society for Testing and Materials (ASTM standards), etc.

From the material and manufacturing process application and certification point of view, the following paragraphs are critical CS-25 (Amendment 23, 2019) paragraphs:

- CS 25.603 Materials and fabrication (for composite materials AMC 20-29):
- CS 25.605 Manufacturing processes:
- CS 25.613 Material strength properties and material design values:

The regulation defines statistical base of characteristics/material properties A, or B. Properties „A“ a „B“ are defined in „The Metallic Materials Properties Development and Standardization (MMPDS) handbook“ or ESDU 00932 „Metallic Materials Data Handbook.“

Formulations with similarly meaning can be find in CS-23 (or FAR23 and FAR25) regulation although the new version of C-23 regulation reformulates and renumbers individual paragraphs. The new version formulates discussed requirements in paragraph CS 23.2260.

Test specimens used in certification process must be manufactured from materials manufactured based on certified manufacturing procedures. Specimens form and testing methods must:

(i) comply to worldwide recognized standards, or

(ii) comply to requirements described in detail in appropriate handbooks, or

(iii) be realized in compliance with approved testing plan which contains test specimen definitions and definition of testing.

Additionally, CS 25.571 Damage Tolerance and fatigue properties (see AMC 25.571) must be taking into account for principle elements and structures. In compliance with CS25.571 paragraph the Damage Tolerance philosophy application is impractical, it is allowed to apply Safe Life philosophy. This structure must be proved by analyses supported by experiments. Experiments must prove that the structure sustains repeated loads expected in the service without detection of any cracks. Appropriate safety factor must be applied in this case. Additional NDI (non-destructive inspection) procedures must be defined.

Number of tests for experimental certification

Material, structural parts and full-scale structures strength values have to be defined based on knowledge of “Engineering characteristics”, which are influenced by material, technology, manufacturing procedure and assembly. From these reasons the certification of structure must be complex and have to consist of tests pyramid from small coupons up to full scale structures – so called „Building block Diagram (BBD)” – see Fig. 1.

The three static statistic values for material characterisation are recognized by MMPDS standard [5]. A-, B- and S-basis of material characteristics are defined. Relationship between them depends on used data analysis (Normal, Weibull, Pearson or Non-parametric distribution), size of specimens, asymmetry, etc. In general, MMPDS defines number of 100 specimens for A- and B-basis design values as the smallest allowable number of specimens, whereas these values have to be evaluated from 10 heats and 10 lots. Minimum number of 299 specimens must be tested in case of the nonparametric data evaluation is required.

The A-basis means 95% confidence of 99% exceedance. The B-basis values mean 95% confidence of 90% exceedance. An S-basis value is taken from a specification (issued by industrial institutions or standardization groups as for example SAE Aerospace Material, ASTM, etc.) or federal or military standards (MIL-STD-970 [6]). According to MMPDS minimum number of 30 specimens is required for S-basis value definition.

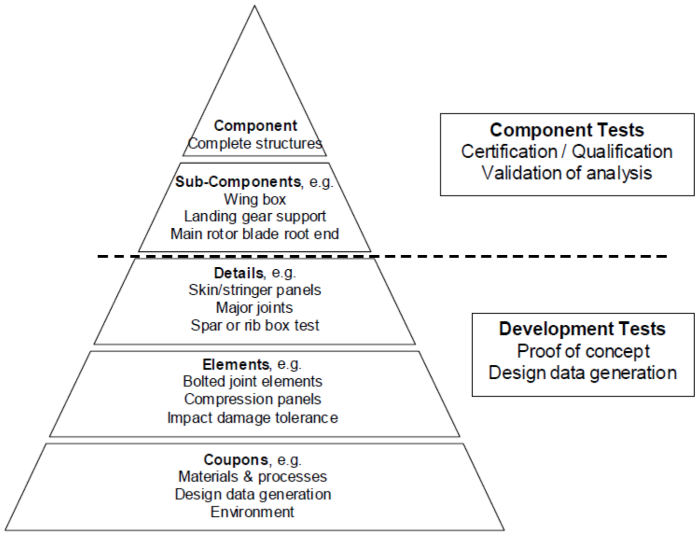

Fig. 1: Schematic BBD for certification purposes

Fundamental requirements for AM in the military field are specified namely in DEF-STAN 00-970 [7], MASAAG - Guidance Note on the Qualification and Certification of Additive Manufactured Parts for Military Aviation [8], EMACC Handbook [9] and ISO and ASTM standards. Regulations DEF STAN 00-970 Part 3, Part 4 or Part 5 are very similar to CS-23 or CS-25. MASAAG [8] deals with qualification and certification of AM metal parts labelled as Grade A. Any of part manufactured by AM have to go through certification procedure as a significant change of the original structure. This is caused by the fact that AM represents both manufacturing process and material change and often also design change. A-, B- and S-basis is defined similarly to MMPDS, only the basis is named as Grade A or Grade B structure. Moreover, US JSSG 2006 [10] guide defines that A-basis is strictly required for design of critical parts of the structure.

Generally, the B-basis for each failure mode should be evaluated in compliance with DEF STAN 00-932 [11]. This requirement could be severe and impractical. For this case, material characteristic could be evaluated based on at least 15 specimens. Then, the values must be evaluated under the worst environment in case of these conditions significantly influenced strength. In case of 15 specimens, 3 batch of materials must be used with minimum number of 5 specimens from each supplier. Exceptionally, it is acceptable to classify allowable values for particular material batches in case of mean value is changing in each batch and together coefficient of variation remains the same. Then B-value for individual batch must be decreased as compared to reference value. The B-value increase is not allowed.

Allowable stress or strength must be defined for each Grade A structure part. The strength is usually defined as B-basis [7]. Allowable of strength has not to be higher than 1.5-fold of design limit load. At the same time, no undesirable deformations are allowed under load level at least of 75% design limit load [7].

Variability of AM process have to be analysed also from fatigue behaviour point of view. As well definition of part resistance to environmental degradation (corrosion, stress corrosion, etc.) and part protection against these effects.

Specific requirements for AM

Special standards focused especially on AM technology were published by US National Institute of Standards and Technology (NIST), namely:

- NISTIR 7847 [12] and NISTIR 7873 [13] – review of ASTM and ISO test methods
- NISTIR 8005 [14] - summary of ASTM standards and general.

ASTM society published several standards focused especially for AM. These standards can be sorted to following basic groups:

- Terminology (ISO/ASTM52900-15, ISO/ASTM 52921).
- Design (ISO/ASTM 52915-16 a 52910-18).
- Materials and procedures (ASTM standards: F2924-14, F3001-14, F3049-14, F3055-14a, F3056-14e1, F3091/F3091M-14, F3184-16, F3187-16, F3213-17, F3301-18a, F3302-18, F3303-18 and F3318-18, ISO/ASTM52901-16).
- Experimental methods (ASTM standards F2971-13 and F3122-14, ISO/ASTM52921-13).

Mechanical properties of AM parts depend on manufacturing plan, build platform, build directions, origin point, part location, part orientation, etc. in generally. Based on this coordinate system, building plan and type of bounding box with positioning of test specimens shall be designed and manufactured. Fig. 2 shows an example of various specimen orientation.

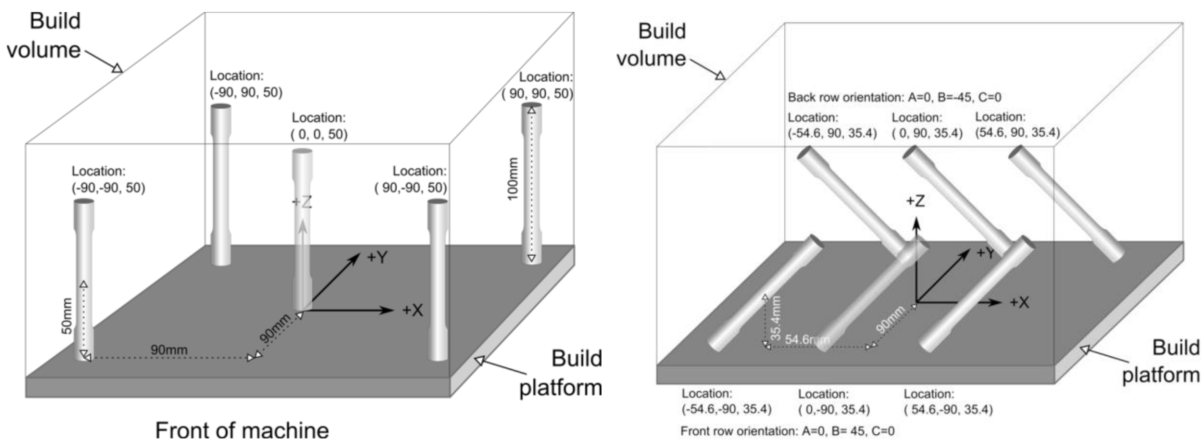

Fig. 2: Part location and orientation: round bar specimens with Z Orientation (left) and round bar specimens oriented at B+45 from Z and B–45 from Z (right)

It can be stated that up to now no complex standard for valuation of AM exists as compared to ordinary manufacturing processes or normalization of AM characteristics with respect to optimized selection of manufacturing parameters (print parameters, laser moving, surface treatment, etc.). Also, no manual for specification of design processes exists.

No complex qualification or certification procedure for AM in aviation industry is available. Some examples of qualification systems designed for selected manufacturing processes are listed in NASA MSFC-STD-3716, „Standard for Additively Manufactured Spaceflight Hardware by Laser Powder Bed Fusion in Metals“ [15] and in the new AWS D20.1 standard [16] (requirements for qualification of machines, manufacturing processes, operators, planning and inspection personnel).

For Class (grade) A components, a minimum of four witness specimens shall be distributed through the model. Three of the witness specimens are to be tested [20]. The console can be classified as Grade B structure. Then, at least of two parts must be put into the build model [20] (i.e. process including part design, orientation/area/build arrangement, including surrounding structure, resources for manufacturing and demonstrative specimens).

The tension test specimens in each standard qualification build shall include the following orientations: the tensile axis within the X-Y plane, the tensile axis along the Z axis, and the tensile axis at angle 45° (±15) from the Z axis (see Fig. 3). For Class (Grade) A and Class (Grade) B components, 54 tension test specimens are required at minimum. These 54 specimens shall be comprised of tension test specimens from each of the eight corners (or at four, equallyspaced extremes at the edges of the build platform and four at the top of the build volume) and in the centre of the build volume to be qualified [16]. The specimens are designed in compliance with ASTM E8 (Standard Test Method for Tension Testing of Metallic Materials) standard. All post-manufacturing processes, with exception of machining and surface polishing, have to satisfy to actual procedures.

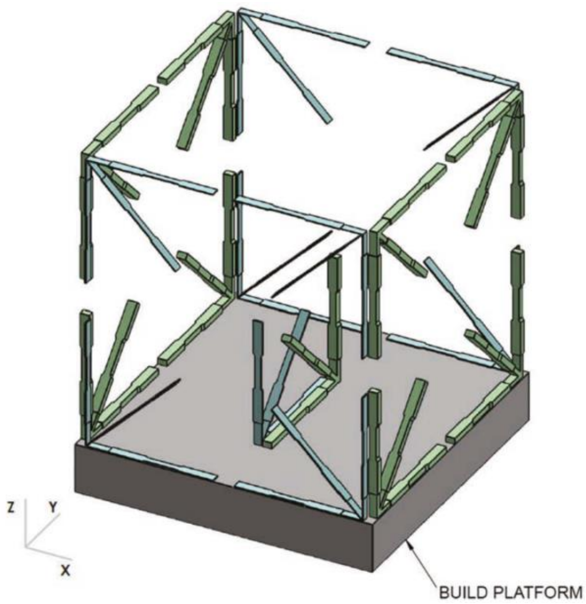

Fig. 3: Design example of a standard qualification build for „Powder Bed Fusion“ [16]

Conclusions

Paper reviews and summarizes airworthiness regulation and standard requirements related with certification of parts and structures made by AM technology (3D printing) for aerospace applications. The aim of paper was to classify and define requirements for certification tests in compliance with EASA and EMACC regulations. Paper gives a base for design of experimental program supporting certification of a structure part made by AM. In the field of static characterisation, it will be necessary to prove the Young modulus of elasticity, tensile strength, yield strength and ductility for various orientations in the building block. Minimum number of 300 specimens should be manufactured and tested. Fatigue behaviour of AM part have to be investigated for the orientation and placement in building block with worst expected characteristics. Number of tested fatigue test specimens has to be in compliance with requirements of ASTM standard. Both as build and machined specimens are designed.

Acknowledgement

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