Fatigue in Additive Manufactured aircraft: the long way to make it fly

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Manufacturing of metallic products is currently facing a historic revolution driven by a group of innovative technologies clustered under the name of Additive Manufacturing (AM) or, more colloquially, 3D-printing.
As opposed to the conventional subtractive manufacturing methodologies, AM is able to create net-shaped products by means of the addition, layer by layer, of the needed material.
The biggest benefit of the AM in respect to the conventional manufacturing technologies is the substantial freedom the technology gives to the product designers in frame of the product development.
Due to the relaxed geometrical constraints, complex parts characterized by optimized shapes can be realized (Figure 1). This can be translated in development of lighter and more cost-efficient parts and assemblies hitting two of the most important targets of the aeronautical industry.

Figure 1. Secondary Structure (Bracket) developed by Premium Aerotec GmbH. Conventional design (milling plus riveting) compared with topologically optimized design developed for the Additive Manufacturing (53% weight saving, 40% cost saving).

Despite the high investments, the AM still finds a limited applicability for the manufacturing of primary aircraft components (Table 1).
This is also due the challenges relative to the fulfilment of the Fatigue and Damage Tolerance (F&DT) requirements, prescribed by the airworthiness authorities.

Table 1. Examples of primary structures as reported in the FAA Advisory Circular AC 25.571-1D of interest for the applicability of AM.

Wing and empennage	Control surfaces, slats, flaps, and their mechanical systems and attachments (hinges, tracks, and fittings)
	Integrally stiffened plates
	Primary fittings
Fuselage	Circumferential frames
	Door latches
	Window frames
Landing gear	Landing gear and their attachments
Engine mounts.	Engine mounts and their attachments

In this paper, the strict F&DT requirements on primary aeronautical structures will be reviewed together with the challenges they set on AM processes.

The goal of this paper is to present the state of art of the AM technology implemented in one of the leading companies specialized in manufacturing of large aircraft components and to offer a potential way-forward toward the wider exploitation of AM technology potentials.
An overview of the F&DT performances of the produced AM parts will be presented together with the most significant characteristics of the AM parts affecting their F&DT performances.
The main steps of the AM process currently in-place for the production of aircraft secondary structures will be described and the limitations of this process in controlling the aforementioned characteristics of the produced AM parts will be then highlighted.
As a consequence of these limitations, not optimized secondary structures designed with extremely high safety factors to cover the "certainties of the uncertainties" are produced. Furthermore, constrained by strict F&DT requirements, the production and installation of aircraft primary structures using AM is currently not feasible.
In line with currently applicable Airworthiness regulations, a way-forward in order the overcome the current limitations of wider use of AM will be proposed, made of:

- Investigations aimed to get more complete understanding of the process, structure, roughness, F&DT performances relations;

- Development of AM products in a context of structural integrity.

According to authors' perspective, following this strategy will support the development of more weight and cost effective AM secondary structures and start to move towards the vision of the development of AM primary structures.

Keywords: Additive Manufacturing, Fatigue and Damage Tolerance, Primary and Secondary Structures