On the Development of Fatigue and Damage Tolerance Framework for Additively Manufactured Parts

Michael Gorelik

Chief Scientist for Fatigue and Damage Tolerance

Federal Aviation Administration, Scottsdale, AZ, USA

The use of metal additive manufacturing (AM) in commercial and military aviation continues to expand at a rapid pace. This expansion is accompanies by a number of important trends, including transition to full-scale production, topological optimization, development of advanced process controls, rapid evolution of AM supply chain, development of public domain specifications and standards, etc. One trend that needs to be acknowledged in particular is fast progression towards safety-critical AM applications. This trend is not unique to AM as a new technology. In fact, as discussed in [1], while it may take 10 to 20+ years to develop and establish a new material system for non-critical components, it typically takes 4 years or less to expand the use of such technology to safety-critical applications.

While any safety-critical applications in civil aviation are subject to fatigue and damage tolerance (F&DT) certification requirements, metal AM, being a relatively new and process-intensive technology, with no significant prior full-scale production or field experience, may invoke a number of technology-specific considerations [2, 3]. Historically, meeting F&DT related qualification and certification (Q&C) requirements has been one of the most significant challenges for new material and manufacturing technologies in aerospace, and AM is no exception. A considerable body of work has been dedicated to addressing F&DT related technical considerations for AM, both by the leading companies (typically in a proprietary environment), and in the public domain. Significant progress has been made in this area over the past few years; however, most of the presenters at [4] have agreed that the tools, data and methods are not fully mature yet to address this area from the Q&C perspective.

The objective of this paper is to outline the framework and the specific set of technical considerations that, in the author's opinion, will need to be addressed in order to mature the key elements of the F&DT framework for Q&C of metal AM parts in aviation. These technical considerations are discussed from the perspective of the "system-level" approach to F&DT (*Figure 1*). Examples of the areas discussed in the paper include (but are not limited to):

- Parts criticality considerations and tailoring of requirements
- Considerations for development of design allowables, including "knockdown factors"
- Characterization of AM defects and anomalies, and their effect on fatigue
- Testing considerations for AM, including coupon to part properties correlation
- NDI and in-situ process monitoring
- Effect of post-processing on fatigue and fracture properties
- Zoning considerations for AM parts, and potential use of probabilistic assessment [5]
- Part family considerations
- Role of public standards
- Potential R&D efforts, including seeded defects studies

Discussion of some of the above topics is based, in part, on the output of several workshops and meetings co-organized by the author, including 2016 - 2017 joint FAA – USAF Workshops on Q&C of AM Parts ([6], [7]), 2018 Joint FAA – EASA AM Q&C Workshop, and 2018 Technical Interchange Meeting (TIM) on the use of probabilistic fracture mechanics for assessment of AM parts.

Note: This paper is not intended to offer regulatory guidance for F&DT assessment of metal AM parts; rather, it is aimed at promoting the discussion and potential collaboration between the industry, regulators and standards organizations to further mature the key elements of F&DT framework for metal AM parts of high criticality in order to support their safe introduction in commercial and military aviation.

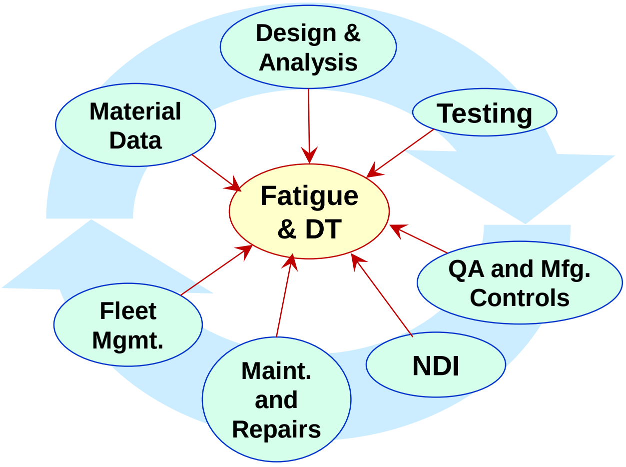

Figure 1. "System-level" view of F&DT discipline. All elements need to be addressed for new technologies like AM to ensure safe implementation.

References

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Keywords: Fatigue, Damage Tolerance, Structural Integrity, Qualification, Certification, Additive Manufacturing, Non-Destructive Inspections.