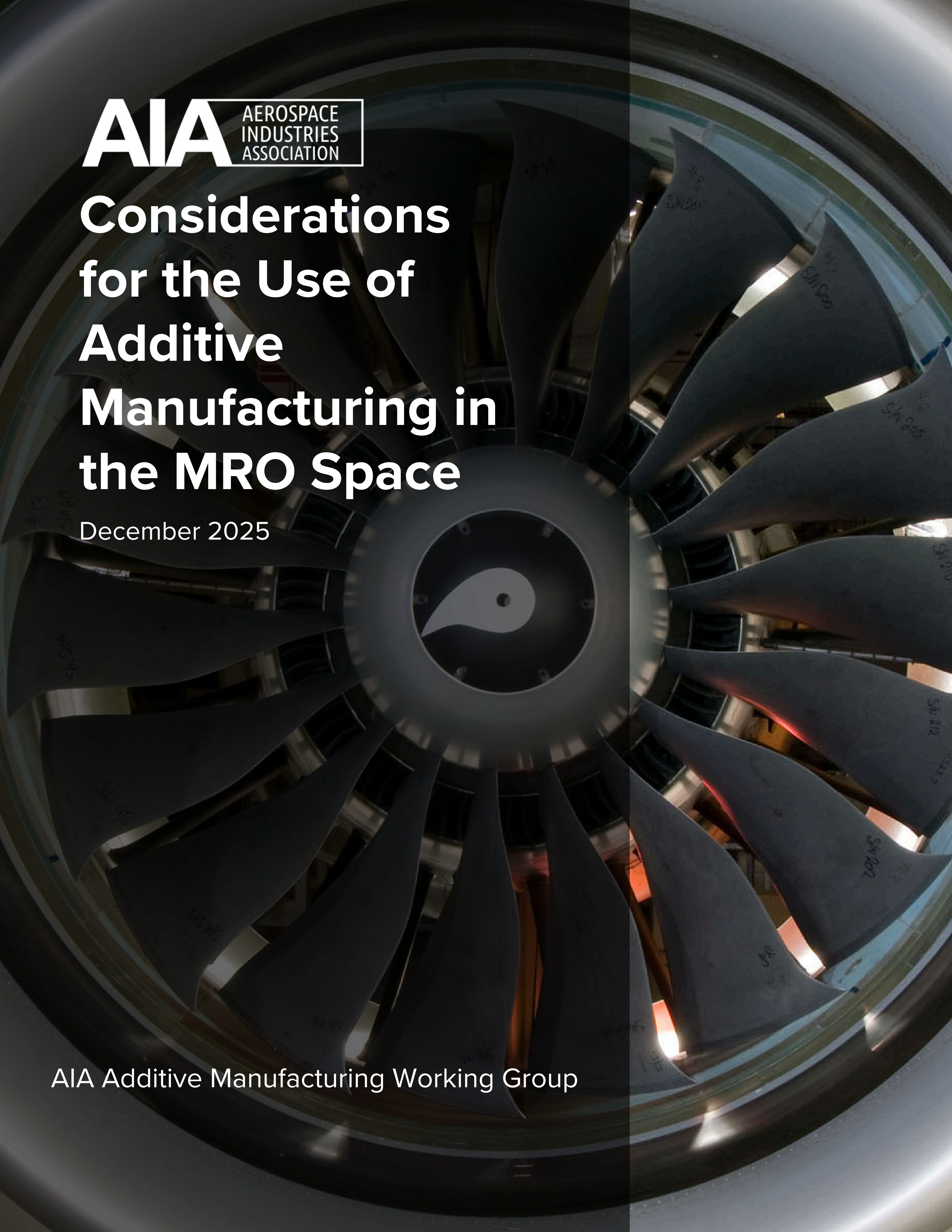

AIA AEROSPACE INDUSTRIES ASSOCIATION

Considerations for the Use of Additive Manufacturing in the MRO Space

December 2025

AIA Additive Manufacturing Working Group

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Considerations for the Use of Additive Manufacturing in the MRO Space

I. Executive Summary

Additive Manufacturing (AM) technologies continue to mature and expand for Original Equipment Manufacturer (OEM) applications. This development and expansion are also seen in Maintenance and Repair Organizations (MRO) with polymer and metallic processes for repair applications of flight hardware in addition to longstanding use as a maintenance shop aid. This document provides specific information about MRO processes and applications related to 14 CFR Part 43 (FAA) and Part 145 (FAA) and the potential use of AM therein. Additionally, it is intended to supplement the Aerospace Industry Association (AIA) "Recommended Guidance for Certification of AM Components" document which contains general guidance on current industry best practices in the areas of material/process development, part/system qualification, and development of material allowables and design values. Examples will be provided regarding differences between the OEM part design and approval processes and the limited authority given to MROs who act under the aegis of the airlines' approved maintenance programs, OEM instructions for continued airworthiness, and regulatory bodies.

The authors of this document are aerospace maintenance and repair organization certificate holders and industry Design Approval Holders (DAHs) and hence provide an experienced and qualified perspective on these issues. This document is a compilation of relevant requirements and guidance materials, coupled with a descriptive map of the MRO processes, all of which may be useful reference material when developing a compliance approach for use of AM in repair or replacement applications. It is worth reminding the reader that any proposed repair or alteration (whether incorporating Additive Manufactured parts or not) must ensure airworthiness requirements are met throughout the life of the product.

II. Industry Need

Additive manufacturing is an innovative technology that has potential in the aerospace industry. There is increasing usage in both design and production, given the opportunities for weight savings, design flexibility, "fail fast/learn fast" prototypes, reduced development time, potential rapid resolution of supply chain challenges, and potential cost savings. AM is also seen as advantageous by MROs seeking opportunities to address similar material, installation, operation, and operational variabilities. In addition to the traditional OEM design and certification standards and processes, AM applications in repair must also meet a detailed MRO certification process, which defines criticality and demonstrates suitability as a component within the airline operational system.

A. Scope

This document outlines key activities that MRO organizations should undertake when seeking regulatory certification of components repaired using AM. Specifically, it focuses on the considerations for additively manufactured parts as a repair for use in commercial aviation applications. Regulatory oversight of component repairs for commercial aviation applications is variable depending on the component criticality, application (e.g., airframe, engine, appliance), repair station location, and registration of the end use system (depending on who has oversight - FAA, EASA, CAAS, etc.). For purposes of simplicity and to illustrate the general principles involved without getting tied up in the nuances of regulatory differences, this document relies primarily on references to FAA regulations. References to other regulatory guidance (e.g., EASA) are made when there is additional benefit or uniquely useful information. This was done for readability and to illustrate the processes that the users of AM technologies must follow for the repair of aerospace components but does not imply that the FAA regulations are the only required regulations.

Furthermore, this document focuses on AM processes for use in repairs as defined by ISO/ASTM 52900:2021 as well as overwhelming industry interest and focus on Directed Energy Deposition (DED) and powder-based processes. “Cold spray” is not listed as an AM technology in the ISO/ASTM reference, though it has long been used by MROs as a way of restoring surface profiles, wear surfaces, etc. Cold spray has not traditionally been used to restore structural capability. Accordingly, it is not treated as an “Additive Manufacturing” process in this document, though the industry continues to develop this restoration and repair technique.

III. Industry and Regulatory Relationships

To think through the potential use of additive manufacturing in the aftermarket, it is required to understand the relationship between the OEMs and/or Design Approval Holders (DAH), the air carriers, and MRO organizations. Figure 1 below shows how all three entities are linked together in maintaining the aircraft.

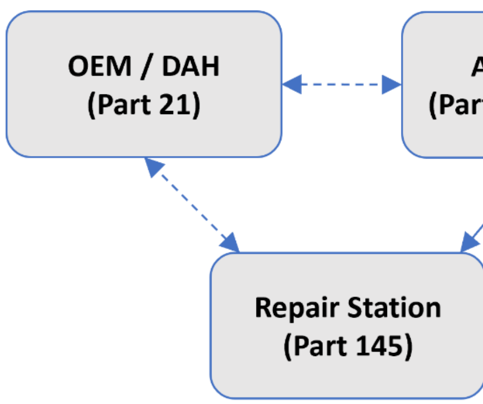


Figure 1: The Relationship Between the Three Main Aerospace Industry Entities

- The OEM/DAH designs a product and applies for a Type Certificate (TC); once the TC is approved and issued by the FAA, the OEM is referred to as a TC holder. The TC holder must establish a set of Instructions for Continued Airworthiness (ICA); this data is often, but not exclusively, published in maintenance manuals and provided to the air carrier. For a more thorough description of this relationship, please refer to Advisory Circular (AC) 120-77A Sections 7 and 9.
- The air carrier is responsible for all maintenance performed on an aircraft and maintaining airworthiness. The Instructions for Continued Airworthiness (ICA) are part of the basis for
- developing a Continuous Airworthiness Maintenance Program (CAMP) per AC 120-16; additional instructions come from regulations such as 14 CFR 91, 121 or 43.

- Additionally, a CAMP is created under 14 CFR Part 135 or 121 and is a means of compliance to the guidance of Advisory Circular (AC) 120-16. Under a CAMP program, air carriers may allow the use of Designated Engineering Representative (DER)-approved repairs and/or alterations to aid in maintaining airworthiness, *creating an opportunity for the introduction of additively manufactured components and/or parts in the aftermarket.* It is therefore imperative that the DER be cognizant of the process-sensitive nature of AM part manufacturing as outlined in the AIA “Recommended Guidance for Certification of AM Components” document, EASA CM-S-008 Issue 3, and other emerging regulatory framework documents.

- The repair station (MRO facility) is required to adhere to all requirements of the CAMP. This includes having the OEM/DAH-generated ICA flow down to the repair station for execution of the maintenance or repair activity. The repair station may request and receive further information from the OEM/DAH through the air carrier or from the OEM/DAH directly.

IV. Guidance for Additive Manufacturing of Component Repair and Alteration

This section provides an overview of existing regulatory guidance on the required processes for the introduction of any replacement part on a U.S. type-certificated product. MRO organizations looking to fabricate, procure, and install aircraft parts (including AM, though the ACs are process agnostic) should understand FAA AC 20-62 and 43-18, which are outlined below and linked directly in Table 5. The FAA has also released AC 33.15-3, which covers the use of the specific powder bed fusion AM technology in turbine engine design. Also note that in 2025, EASA released AM guidance documentation in the form of an EASA Certification Memorandum on Additive Manufacturing (CM-S-008 Issue 3), which, coupled with the incipient release of Revision H of CMH-17, Volume 3, Chapter 3, “AIRCRAFT STRUCTURE CERTIFICATION AND COMPLIANCE” gives good overall guidance to AM specific or process-sensitive certification processes and procedures for the certification of parts by an applicant.

A. FAA Advisory Circular 20-62

FAA AC 20-62 provides information and guidance for aircraft operators, maintenance organizations, and maintenance personnel in determining the quality, eligibility, and traceability of aeronautical parts and materials intended for installation on U.S. Type Certificated (TC) products. Within this AC, the FAA defines what an approved part is: a part or parts that already have approved data.

Furthermore, AC 20-62 describes five types of parts that may be acceptable for installation on a type certificated product. For those seeking to introduce AM parts through repair, the below four types from AC 20-62 could be pathways for AM parts to be used by an MRO.

1. Parts produced by an owner or operator for maintaining or altering their own product and are shown to conform to FAA-approved data.
2. Parts for which inspections and tests have been accomplished by appropriately certificated persons authorized to determine conformity to FAA-approved design.
3. Parts fabricated by an appropriately rated certificate holder with a quality system and consumed in the repair or alteration of a product or article in accordance with Part 43.
4. A commercial part as defined in Part 21.1.
    - NOTE: the fifth part type (“standard parts” - nuts and bolts) is not a candidate for AM

B. FAA Advisory Circular 43-18

As described in FAA AC 43-18 and paraphrased below, acceptable methods of compliance for the fabrication of aircraft parts by maintenance personnel must ensure that parts fabricated during maintenance and alterations have an equivalent level of safety as those parts produced under the original design approval holder's authority. Furthermore, their implementation must be accomplished in such a manner that the condition of the aircraft, airframe, aircraft engine, propeller, or appliance will be at least equal to its original or properly altered condition. AC 43-18 also provides information on the determination of parts categories, required manual procedures, design data approval, and applicable authority involvement for part creation and usage. All the stipulations require adequate amounts of data and proof of process controls for maintenance parts made with the various additive manufacturing technologies, as outlined in the AIA "Recommended Guidance for Certification of AM Component" document and described herein. With that, many elements and choices affect the processes and extent of requirements needed to fabricate, repair, or replace parts while performing maintenance and/or an alteration.

Repair or replacement parts design data (including any for Additive Manufactured parts) may be approved under Part 21.8(d) and fabricated under Part 43.13(a and b), provided the fabricator installs the part onto or within the product or part thereof while it is undergoing repair or alteration. A fabricator who intends to sell fabricated parts would need to obtain a PMA (refer to Part 21.9(a) and Part 21.303(a)).

C. Part Criticality

Per AC 43-18 and as quoted below, parts are categorized into one of three categories (abbreviated to CAT), depending on their potential systemic effect on airplane safety; they are listed on a Category Parts List (CPL) in Appendix 1 and 2 from AC 43-18. The purpose of categorization is to establish the extent of regulatory approval of the design data, such that the degree of compliance rigor can be made commensurate with the criticality of the application.

- CAT 1 Part: A fabricated part, the failure of which could prevent continued safe flight and landing; resulting consequences could reduce safety margins, degrade performance, or cause loss of capability to conduct certain flight operations.
- CAT 2 Part: A fabricated part, the failure of which would not prevent continued safe flight and landing but would reduce the capability of the aircraft or the ability of the flight crew to cope with adverse operating conditions or subsequent failures.
- CAT 3 Part: A fabricated part, the failure of which would have no effect on the continued safe flight and landing of the aircraft.

A new industry standard defining part criticality is ASTM F3572-22. AC 43-18 is definitive, whereas F3572-22 provides additional reference information with industry consensus. As seen in Table 1, F3572-22 defines 4 levels of criticality that are similar to the above three layers with an additional fourth layer "D" that is already encompassed by the CAT 3 definition from AC 43-

18. The distinction provides additional opportunity to tailor the substantiation package to be commensurate with criticality. Consult your local regulatory authority for guidance as needed.

TABLE 1 Part Classifications

Classification	Consequence of Failure	Non-exhaustive Examples
A	High	Part whose failure can directly affect continued safe flight and landing Part whose failure can result in serious or fatal injury to passengers or cabin crews Part whose failure requires exceptional piloting skill of flight crew to compensate
B	Medium	Part whose failure can indirectly affect continued safe flight and landing Part whose failure can result in minor injury to flight crew, passengers, or cabin crews Part whose failure can result in significant increase in workload of flight crew
C	Low	Part whose failure has no effect on continued safe flight and landing Part whose failure has no effect on flight crew, passengers, or cabin crew Part whose failure can result in slight reduction in operational/functional capabilities Part whose failure can result in slight increase in workload of flight crew
D	Negligible or No Effect	Part whose failure would pose no risk of damage to other equipment or injury to the ground personnel Parts not affecting operational/functional capabilities

Table 1: ASTM F3572-22 Criticality Definitions

D. Use of Part Criticality for AM Substantiation

Once criticality is defined, this helps determine the different types and quantities of substantiating data required as part of an approval package. The AIA "Recommended Guidance for Certification of AM Component" document developed and summarized considerations and current industry best practices in the areas of material/process development, part/system qualification, and development of material design allowables and design values for AM parts. Table 2 below gives appropriate cross-reference information for CAT 1 and 2 parts, with different considerations for CAT 3 in the trailing paragraph.

For CAT 1 and CAT 2 parts, the following design data is required for FAA approval:

Required Design Data (CAT 1 and 2)	AIA "Recommended Guidance for Certification of AM Component" Document Section References
Drawings and specifications necessary to show the configuration of the fabricated part	Section 6 (Development Process)
Information on materials, dimensions, and processes (including special manufacturing processes) necessary to define the structural strength or other critical characteristics of the fabricated part (e.g., fatigue strength if/when needed)	Section 6 (Development Process) Section 8 (Material Allowables and Design Values Development)
Inspection and test procedures	Section 14 (Inspection)
Substantiating data (test reports, analysis, computations, and assessments) necessary to show that the design data used to fabricate the part for a repair or alteration meets the applicable airworthiness standards and that no detrimental consequences will result in degradation to the next higher-level subassembly or assembly, or to the product	Section 8 (Material Allowables and Design Values Development) Section 9, 10, 11, 12, 13 (Design Value Qualification / Detailed Design Qualification / System Qualification / Production Process Quality Controls / Build Quality Plans)
Airworthiness limitations, as applicable	N/A

ICA/maintenance instructions if the application for design approval is sought for a product or article in which the fabricated part is eligible for installation (and was filed on or after Jan. 28, 1981)	N/A
Fabricated part marking	N/A

Table 2: Required Design Data (CAT 1 and 2) for FAA Approvals with AIA Cross-References

For CAT 3 parts, although the level of detail needed may be less, there is still a need to provide information to show compliance. This information is defined as: data acceptable to the administrator (defined in an operator's CAMP), which is required to substantiate that the fabricated part is consumed within the repair or during the alteration, and which returns the product to its original or properly altered condition (e.g., AC 43.13-1B, Service Bulletins (SB), component maintenance manual (CMM), service history, or prior service experience, etc., in accordance with Part 43.13(b)).

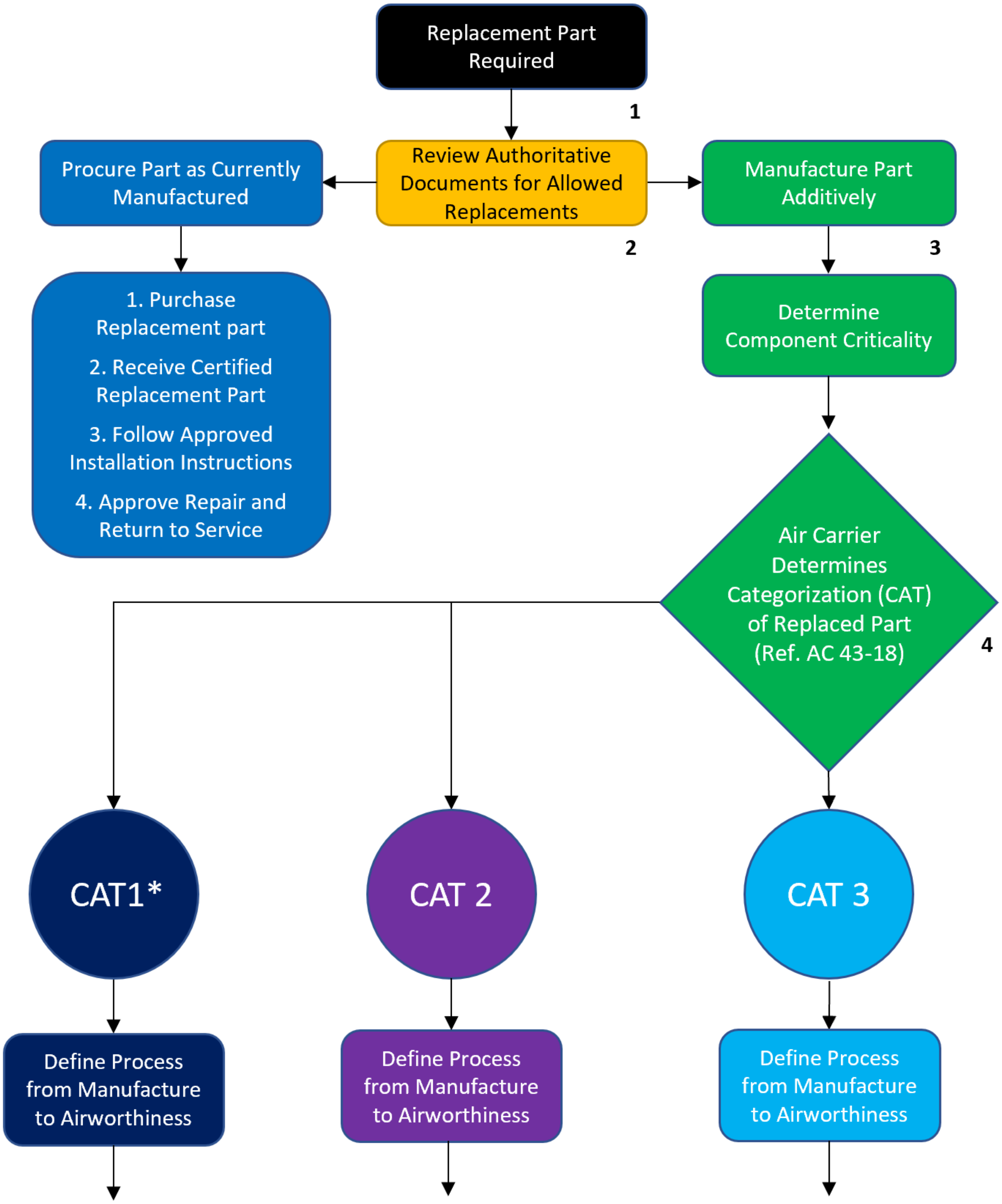
Note 1: All fabrication repairs of parts must be accomplished in accordance with methods, techniques, and practices in AC 43.13(a).

Note 2: AC 43-18 provides information regarding the definition of a "part" which states, "For the purposes of this AC, [a part] is an article that could be produced under the provisions of 14 CFR part 21 and is eligible for installation on a certificated aircraft without further manufacturing processes. Additionally, the definition of a part for the purposes of this AC would *not* include raw materials or repair segments being utilized for the repair or alteration of a part (i.e., sheet metal stock, sealants, lubricants, raw forgings, or castings, billet material, etc.)". This would logically extend to precursor feedstock for any AM process (powder, wire, polymer filament, etc.).

Note 3: Until AM becomes widespread and industry-standard, it is recommended that AM repair segments of CAT 1 and CAT 2 parts be identified in the repair paperwork for easy traceability.

E. MRO Part Replacement Decision Flow

To aid in understanding, flow charts illustrating the processes of substantiation and acceptance of a part replacement activity based on the three categories of criticality (as defined by AC 43-18) are provided in Figures 2 and 3. The flow charts depict the two common pathways of either procuring and/or manufacturing replacement parts (by AM in this case). Two examples follow the figures to enhance the understanding of the process steps shown.



*Suggest caution regarding the use of AM on CAT 1 replacement parts due to maturity of technology and the increased amount of substantiating data and proof of controls that will need to be provided (Ref. AIA "Recommended Guidance for Certification of AM Components")

Figure 2: MRO Part Replacement Decision Tree

**It is recommended to include the air carrier in discussions on classification of repair/alteration as major/minor for purposes of ACO/ECO approval (beyond repair categorization). Note: ACO/ECO now called Certification Branch

Figure 3: MRO Part Replacement Decision Tree (Continued)

F. Examples

1. Category 2 (CAT 2) Part: Auxiliary Pump

Introduction: A component within the Auxiliary Pump has been replaced with a spare unit. The inventory consists of conventional and the potential for an Additively Manufactured (AM) part.

Note: The AM process is not used to create the entire assembly. For the purposes of this example, it is assumed the housing is non-repairable and needs to be replaced.

This case study walks through the process of developing a repair using an AM part with the intent of the part becoming a line stock item.

Box 1: It has been determined that the part has failed and needs replacement. This then is a repair by replacement of the housing.

Box 2: Authorizing documents, including the Illustrated Parts Catalog (IPC), are reviewed and it is determined that the failed part is a replaceable item.

Box 3: An AIA MRO industry survey showed that there are multiple reasons to consider additive: speed, cost, and customization. For this case study, the AM process is being pursued because a new cast housing is no longer procurable.

Box 4: The housing in this scenario is considered to have a Category 2 criticality based on Appendix 2 of AC 43-18. Category levels are as defined in the previous section AC 43-18 Paragraph 7.b. AC 43-18 is definitive; however, ASTM F3572-22 is an additional reference that does have industry consensus. Consult your local regulatory authority for guidance.

Box 6: The MRO and/or airline engineering team works in conjunction with the geographic Certification Branch (formerly ACO/ECO), and/or DER to define a viable substantiation document approach. These conversations are likely to occur at several points throughout the process.

For new and novel technologies (such as AM), it is recommended to initiate a familiarization meeting with the geographic Certification Branch (formerly ACO/ECO) to raise awareness about the technology and project proposal.

The MRO and/or airline engineering team do not typically have access to the OEM designs. Therefore, reverse engineering is often utilized to determine the properties of the current component. See Section V.A of this document for more information on reverse engineering. In summary, the engineering team reviews the part to determine material type, treatment, and finishes. An additive material of equal or better properties and chemistry, plus all relevant post processing steps for the application are selected (using guidelines from the AIA document, “Recommended Guidance for Certification of AM Components”).

The component then needs to be analyzed to define the dimensional requirements and tolerances. The best practice is to have multiple original components available to determine dimensional tolerances for the reverse engineered part. Additionally, the mating components may be analyzed to determine the appropriate fit in lieu of having multiple assets available for review.

The resultant analysis should be converted into drawings, specifications, materials data, inspection/test methods and substantiation data, airworthiness limits, ICA, and part marking requirements to support the part manufacturing.

Importantly, once a repaired part is selected to be designed using AM, the substantiating data needs to include test evidence to validate the design. The data should include factors unique to additive manufacturing such as the effect of orientation during the production process, effect of AM surface roughness, or the impact of NDI capability. Testing may include destructive methods for verifying material properties, fit checks with mating components, Qualification Test Procedures (QTP) and first article inspection requirements (as well documented in Sections 8 – 12 of the AIA "Recommended Guidance for Certification of AM Component" document.) Additionally, the additively manufactured component requires part marking for future identification.

The airworthiness limits will also be created as the part is fully designed and substantiated. This information includes an ICA for continued service and operation as well as component specific part marking requirements. If the new AM part requires new instructions for continued airworthiness, a Design Approval Holder (such as an airline) will be required to create and approve this new ICA. In this example, the pump housing does not have an airworthiness limitation but does have instructions for continued airworthiness that include dimensional and NDI during service at specified intervals. Be aware that a detailed discussion on airworthiness limitations is out of scope for this document.

Box 7: The MRO or airline engineering team has finished the development of an additively manufactured pump housing and submitted the package (including particular AM specifications, serial number(s), and M&P specifications for example) to the geographic Certification Branch (formerly ACO/ECO) for review and approval.

Box 9: The Certification Branch agrees that the component is rated Category 2. They reserve the right to approve or delegate to a DER.

Box 10: Airline engineering approval is granted for the design and installation occurs per the existing procedures.

Box 11: An FAA 8130-3 or Certificate of Conformity (if owner/operator) is issued to certify the work as completed. EASA requires Form 1 or equivalent as described in the EU/US Maintenance Annex Guidance.

2. Category 3 (CAT 3) Part: Tray Table Bracket

Box 1: It has been determined that the part has failed and needs replacement.

Box 2: Authorizing documents, including the IPC, are reviewed and it is determined that the failed part is a replaceable item.

Box 3: An AIA MRO industry survey showed that there are multiple reasons to consider additive: speed, cost, and customization. For this case study, AM is being pursued because the tray table bracket is out of stock and not available.

Box 4: The tray table bracket for this scenario is considered to have a Category 3 criticality based on the definition in AC 43-18 Paragraph 7.b.(3). Category levels are as defined in the previous section AC 43-18 Paragraph 7.b. AC 43-18 is definitive; however, ASTM F3572-22 is an additional reference and has industry consensus. Consult your local regulatory authority for guidance.

Box 5: The MRO and/or airline engineering team has gathered all required part configuration and manufacturing data. Since this is a Category 3 (non-critical) part, the team will not need to contact the Aircraft Flight Standards Service (AFSS) aviation safety inspector unless the air carrier/owner-operator requires it. For Category 1 or 2 parts, contacting the AFSS is necessary. For a Category 3 part, since the repair/alteration is considered "Minor," the MRO and/or engineering team will create a substantiation package to demonstrate compliance to the applicable airworthiness regulations. This would be considered "acceptable data" and could be used to return the aircraft to service after the repair/alteration is complete. Ref. 14 CFR Part 43.13.

Box 6: It is assumed that material performance requirements may be less stringent for Category 3 components. That said, for new and novel technologies like AM, the air carrier needs to be part of the evaluation and airworthiness process.

The MRO and/or airline engineering team have gathered dimensional data from a pre-existing component and verified the installation requirements; in addition to gathering data sufficient to establish that the AM replacement part will meet all performance requirements. This data may contain drawings, specifications, and test data. Note: the additively manufactured component requires part marking for future traceability.

An internal substantiation package is created for review by the air carrier or DAH.

Boxes 9, 10: Airline engineering approval is granted for the design, and installation occurs per the existing procedures. The MRO is responsible for contacting the airline to approve use prior to installation.

Box 11: An FAA 8130-3 or Certificate of Conformity (if owner/operator) is issued to certify the work as completed. EASA requires Form 1 or equivalent as described in the EU/US Maintenance Annex Guidance.

V. MRO Regulatory Considerations for Each Use Case

What follows are the existing guidance and/or regulations that govern existing repair needs for MROs, most of which are not AM-specific. There is no analogous guidance for repairs of engine or airframe by AM techniques; it is recommended that the regulatory bodies publish such guidance for use by the repair stations and air carriers.

- FAA AC 20-62: provides information and guidance for use in determining quality, eligibility and traceability of aeronautical parts and materials intended for installation on US type-certificated products and articles, and to enable compliance with the applicable regulations.
- FAA Part 43: provides the rules for maintenance, preventative maintenance, rebuilding, or alteration of any aircraft, airframe, engine, or component of such aircraft that holds a U.S. airworthiness certificate or certain foreign registered civil aircraft. Consult Appendix A of Part 43 for detailed examples on the different types of major alterations, major repairs, and preventative maintenance items. Furthermore, Appendix B provides guidance on proper record keeping and communication required for major repairs and major alterations.
- EASA CM-S-008 Issue 03: provides certification guidance regarding the introduction and use of AM technologies across a broad range of products, parts and appliances subject to EASA regulations. Note: this guidance document is a valuable reference for the user even if the repair or replacement part is not certified by EASA.
- FAA Order 8900.1: provides guidance to Flight Standards personnel regarding the use of AM technology to fabricate a part by aircraft owners, air agencies, and air operators when performing maintenance and alterations of type certified products and associated appliances. It is provided here as reference only for non-flight standards parties in order to give insight and clarity into what FAA Flight Standards personnel would be evaluating for AM-specific repairs or replacement parts.

The use of additive manufacturing in the MRO space requires individuals to have knowledge covering a wide array of reference materials, design approaches, and best practices for techniques not often employed by the OEM. The following sections are designed to provide awareness of a few of those major considerations including reverse engineering, repairs, and performing alterations of aircraft products.

A. Reverse Engineering

Reverse engineering is the process of capturing the design of an article as outlined in FAA 14 CFR Part 21.303(a)(3) with relevant AC 21.303-4 (Section 26). Additional information on reverse engineering for turbine engines can be found in AC 33-8 (Section 7). Reverse engineering is often used for Parts Manufacturing Approval (PMA) but can also be utilized to develop a repair or alteration, especially when the complete original design data package is not available or accessible to the aftermarket; it could also involve an additive component. Reverse engineering may be adequate to duplicate and substantiate the functional design of the approved part <u>with appropriate care</u> (ranging from exact margin calculations based on exhaustive data to a simplified part comparison of material properties, strength equivalence, etc.). When reverse engineering a part, the design actions include developing:

(i) Drawings and specifications necessary to show material and part pedigree and control the configuration of the article
(ii) Information on dimensions, materials, and processes necessary to define the structural performance of the article and mating substructure (which will be more complex for AM than with standard manufacturing processes)

Reverse engineering of a component may result in an alteration (and a new part number) based on the material properties and/or varying manufacturing process changes required when using AM.

Additionally, when fabricating a replacement part using AM technology, it may be considered a major design change and not just reverse engineering when a major repair/alteration is reviewed against the Major Repair and Alteration Data Approval Online Job Aid that is associated with FAA Order 8300.16. Additional information can be found in AC 43-201A.

B. Repair

Both major and minor repair situations will require substantiating data packages. 14 CFR Part 1.1 provides clarity on the meaning of major and minor repairs, with additional definitions found in AC 120-77, which are reproduced below.

> 1. A major repair is repair that if improperly done, might appreciably affect weight, balance, structural strength, performance, powerplant operation, flight characteristics, or other qualities affecting airworthiness; or
> 2. A repair that is not done according to accepted practices or cannot be done by elementary operations.
>
> Note: A minor repair is any repair that is not categorized as "major" as per the above.

Note that the development of various AM processes and equipment (powder and wire-based) has enabled improvements in the adjacent welding repair processes. As such, AM equipment can be used to repair components via traditional weld repair processes (again, powder and wire-based). Traditional weld repair users may benefit from the process variability assessment and controls used to address AM parts and validation approaches outlined in this report, but traditional weld repairs use well-defined and well-established welding repair procedures that do not necessarily overlap with the nascent AM repair infrastructure. A detailed discussion about AM-enabled "enhanced weld repairs" is outside the scope of this document.

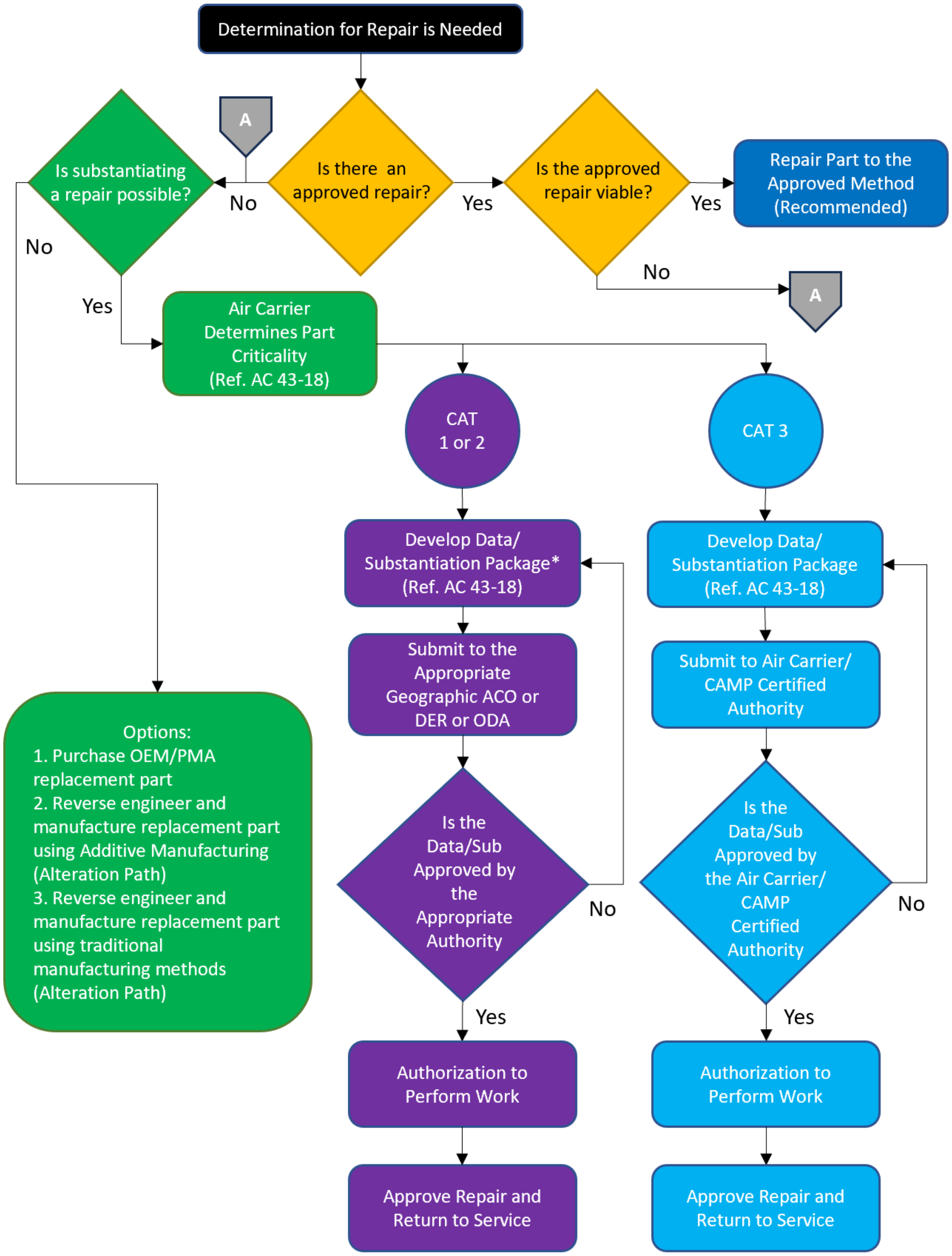
As mentioned, "traditional" aerospace repairs may utilize well-established data sources and processes, whereas additive repair processes are not yet as well developed. Examples of existing repair techniques include standard machining, bolted repairs, and weld repair using established industry-standard wire arc processes. Caution should be taken with automated weld-like DED wire feed processes such as Wire Arc Additive Manufacturing (WAAM), CMT and plasma wire feed processes. There may not be adequate data to substantiate all kinds of weld repairs using these technologies.

Maturing AM processes that need further investigation for use in repair due to their novelty include Laser/Electron beam powder bed fusion, laser metal deposition powder/wire, and electron beam metal deposition (EBAM).

Therefore, when considering the use of AM in repairs (as part of the overall repair process flow illustrated below in Figure 4), the amount and type of substantiating data and associated controls for additive processes will be much higher than required with conventional repair techniques (including welding) and may therefore require additional development time and substantiating data.

Furthermore, repair development classification requires a repair compatibility assessment to be performed. This assessment is designed to verify that any new repairs will not negatively impact any currently published maintenance data. Important considerations for additively manufactured parts versus conventionally manufactured parts include, but are not limited to, the material differences after welding/thermal operations are performed, joint strength of joining methods for additively manufactured sections, basic static strength, and possible impact on fatigue strength.

Lastly, AC 43-210, “Standardized Procedures for Obtaining Approval of Data Used in the Performance of Major Repairs and Major Alterations”, describes and elaborates on the type of data that can be provided for substantiation, acceptable data, pre-approved data, ODA approvals, etc. It also provides a useful flowchart and checklist (AC 43-210A, page 13 and 14) for the determinations and process of field repairs vs. alterations.



*It is recommended to include the air carrier in discussions on classification of repair as major/minor for purposes of Certification Branch approval (beyond repair categorization).

Figure 4: Repair Process Decision Flow

C. Alteration

Alterations follow a similar substantiation process to that of a standard repair (see Figure 4) and are also classified as major or minor. A major alternation is defined as a change that is not listed in the aircraft, aircraft engine, or propeller specifications: that might appreciably affect weight, balance, structural strength, performance, powerplant operation, flight characteristics, or other qualities affecting airworthiness (Ref. AC 120-77). As referenced in AC 43-210, when performing an alteration (even possibly CAT 3), the use of additive manufacturing may be classified as a major alteration as it is not yet an accepted practice and cannot be done by elementary operations. For example, machines for additive manufacturing are not currently off the shelf units that can be used without the characterization of material properties, effects of print orientation, gas flow, etc. (See Section 6 of the "AIA Recommended Guidance for Certification of AM Component" document).

The part alteration path may be required due to limitations in the replacement part supply chain, i.e., no supplier, excessive lead time, tooling no longer available due to wear or loss, etc. An alteration may also be required when a replacement part design requires a deviation from the current Type Certificate (TC) or Supplemental Type Certificate (STC) configuration. The alteration action converts the aircraft from an approved configuration to a new configuration. Table 3 has additional information describing the level of change and associated approvals required.

Major / Minor	Approval Method
Major – Resulting in major change in type design (alterations only)	STC (existing or apply for new - Part 21 process)
Major	DER / ODA / CB / Field Approval
Minor	Acceptance Data

Table 3: Design Change Classification and Approval by Non-Type Certificate Holders

Additive manufacturing may be used to implement a material or performance-based change (form or function) to the replacement part definition. This could be required when components may no longer be available from the supply chain, such as casting that is no longer manufactured. Additively manufactured components (a casting replacement component in this case) will have a similar configuration but are produced by a different process. Substantiating data establishing equivalency for this type of change will need to be developed and shared with the cognizant repair DER by the airline and MRO authority.

As described in the previous section for repairs, AC 43-210A describes and elaborates on the type of data that can be provided for substantiation: acceptable data, pre-approved data, ODA approvals, etc. It also provides a useful flowchart and checklist (AC 43-210A, page 13 and 14) for the process of field repairs or alterations.

Whether considering the use of additive technologies for reverse engineering, part repair, or alteration, process stability, controls and common definitions for part criticality must be established. The next section will highlight documents that are published in the industry to help provide such guidance and stability.

VI. Relevant Reference Standards and Guidance Documents

There are many Standards Development Organization (SDO) specifications published and more in work, covering a variety of Additive Manufacturing topics. The MRO sub-team reviewed many of them and proposed several with MRO-relevant content as shown in Table 4; the list is current as of time of publication and is not exhaustive.

Document	Title	Notes
AIA Report	Recommended Guidance for Certification of AM Components	Prepared by AIA Additive Manufacturing Working Group (under CARS committee)
ISO/ASTM 52900:2021	Additive Manufacturing – General Principles - Terminology	This document establishes and defines terms used in AM technology, which applies the additive shaping principle and thereby builds physical three-dimensional (3D) geometries by successive addition of material.
SAE AMS Docs	Link to All Published and In-Progress AMS SAE Additive Manufacturing documents	Link takes users to SAE AMS AM, additive manufacturing public forum area.
SAE ARP7042	Recommended Practice: Development Planning for Design of Additive Manufactured Components in an Aircraft System	This SAE Aerospace Recommended Practice (ARP) is intended to provide an airframe manufacturer or system supplier guidance for planning to use AM in developing an aircraft development program and is intended as a comprehensive plan pertaining to the development of the am components in the aircraft system.
SAE AIR7352	Additively Manufactured Component Substantiation	This Aerospace Information Report (AIR) was prepared to provide users with an overview of the scope of tasks and requirements associated with substantiating additively manufactured components. This document is informational only and not formal guidance.
ASTM F3572	Standard Practice for Additive Manufacturing – General Principles – Part Classifications for Additive Manufactured Parts Used in Aviation	Standard practice for AM – general principles – part classifications for AM parts used in aviation. Produced by the ASTM F42 committee.
ASTM ISO/ASTM 52910	Additive manufacturing - Design - Requirements, guidelines and recommendations	This document gives requirements, guidelines, and recommendations for using AM in product design.
ASTM ISO/ASTM 52901	Standard Guide for Additive Manufacturing - General Principles - Requirements for Purchased AM Parts	It is applicable for use as a basis to obtain parts made by AM that meet minimum acceptance requirements.
EASA CM-S-008 Issue 3	Final Certification Memorandum ref. CM-S-008 Issue 3 on "Additive Manufacturing"	The purpose of this certification memorandum is to provide guidance regarding the introduction and use of AM technologies across a broad range of products
CMH-17 Rev. H	Polymer Matrix Composites: Materials, Usage, Design and Analysis	The third volume of this six-volume compendium provides methodologies and lessons learned for the design, analysis, manufacture, and field support of fiber-reinforced, polymeric-matrix composite structures. Chapter 3 primarily addresses composite civil airframe structures, however, many of the themes discussed are applicable to other composite material forms, such as Ceramic Matrix Composites (CMCs), Metal Matrix Composites (MMCs) and, some Additively Manufactured (AM) structures
FAA 8900.1	Volume 6, Chapter 11, Sec. 29	Describes the use of AM technology to fabricate a part by aircraft owners, air agencies, and air operators when performing maintenance and alterations of type certified products and associated appliances. (parts 91, 121, 135, and 145)

FAA AC 33.15-3	Powder Bed Fusion Additive Manufacturing Process for Aircraft Engine Parts	Describes an acceptable means for demonstrating compliance with Title 14, Code of Federal Regulations (14 CFR) 33.15 for aircraft engine parts with materials produced by the Powder Bed Fusion (PBF) AM process. Guidance is also presented on closely related design and manufacturing aspects associated with AM.

Table 4 List of Informational and Guidance Material for MRO Consideration

The above standards are part of the larger framework of industry and SDO-created specifications and controls required to produce stable and repeatable additive parts both for OEM and MRO needs. Lastly, additional process controls such as a Process Control Document (PCD) may be required to produce stable and repeatable parts as outlined in the AIA's "Recommended Guidance for Certification of AM Components" document.

VII. Regulatory References (Non-Additive Specific)

Table 5 below provides other regulatory references that are useful to review and understand. This list is current as of time of publication and is not exhaustive.

Document	Title	Notes
14 CFR Part 1	Definitions and Abbreviations	Chapter 1, Subchapter A, Part 1
14 CFR Part 21	Certification Procedures for Products and Articles	Various definitions of Parts and Approvals required, ex. 21.8, 21.9 etc.
14 CFR Part 43	Maintenance, Preventive Maintenance, Rebuilding, and Alteration	Describes rules governing the maintenance, preventive maintenance, rebuilding, and alteration of any (1) Aircraft having a U.S. airworthiness certificate; (2) Foreign-registered civil aircraft used in common carriage or carriage of mail under the provisions of Part 121 or 135 of this chapter; and (3) Airframe, aircraft engines, propellers, appliances, and component parts of such aircraft with some exceptions…
FAA AC 20.62E	Eligibility, Quality, & Identification of Aeronautical Replacement Parts	Provides information and guidance for use in determining the quality, eligibility and traceability of aeronautical parts and materials intended for installation on U.S. type-certificated (TC) products and articles
AC 21.303-4	Application for Parts Manufacturer Approval Via Tests and Computations or Identicality	This advisory circular (AC) updates the Federal Aviation Administration's (FAA) guidance to applicants for parts manufacturer approval (PMA) of articles via tests and computations or identicality without a license agreement.
FAA AC 33-8	Guidance for Parts Manufacturer Approval of Turbine Engine and Auxiliary Power Unit Parts under Test and Computation	This advisory circular (AC) provides guidance for developing substantiation data to support the design approval of critical and complex turbine engine and auxiliary power unit (APU) parts produced under parts manufacturer approval (PMA).
FAA AC 33-9	Developing Data for Major Repairs of Engine Parts	This guidance will help persons developing major repair data meet the requirements of Title 14 of the Code of Federal Regulations (14 CFR) part 43 to restore the engine to at least equal to its original or properly altered condition.
FAA AC 43-18	Fabrication of Aircraft parts by Maintenance Personnel	This advisory circular (AC) ensures that parts fabricated during maintenance and alteration have an equivalent level of safety as those parts produced under the original design holder's production certificate.
FAA AC 43-210A	Standardized Procedures for Obtaining Approval of Data Used in the Performance of Major Repairs and Major Alterations	This advisory circular (AC) describes a standardized procedure for requesting approval of technical data associated with major repairs/major alterations.

FAA AC 120-16G	Air Carrier Maintenance Programs	This advisory circular (AC) explains what the term "maintenance program" means. Our explanation describes the scope and content of air carrier aircraft maintenance programs.
FAA AC 120-77A	Maintenance and Alteration Data	This advisory circular (AC) provides one means, but not the only means, of ensuring that the contemplated maintenance, alteration, or continue-in-service condition is in compliance with applicable regulations and existing policy.

Table 5: List of Regulatory Guidance for MRO Consideration

VIII. Areas of Future Work / Recommendations

The AIA AM working group has developed a list of recommended research and development objectives and investments to industrial, governmental, and standards development organizations (SDOs) to help meet the needs of Additive Manufacturing in the maintenance, repair, and overhaul environment.

#	Title/Segment	Objective	Investment	Comments
1*	SDOs, Government	Create materials databases with a cross reference to traditional material properties. Example: Cast Al (A365) vs. AM Al (type and process)	Regulator and Industry Working Group cooperation to drive consensus on correct control framework for future capital and intellectual investment.	Define the list of industry specifications and controls available for use, or gaps to that need. Collaboration with the regulators and SDOs on requirements for use in showing compliance to provide confidence in the AM as a maturing technology.
2*	SDOs	Create a process for showing how to establish equivalency between new or alternate machines and those used to create industry standards.	Investment of time to achieve industry consensus.	Note: MMPDS community has approved guidelines for showing equivalency to published (public) static allowables. Suggest following that MMPDS framework as a model.
3*	SDOs (specifically AWS)	Investigate if additive parts can be repaired or joined using welding processes. Develop altered material properties for the welded locations.	Spend time and money to develop the controls and data required to extend the existing weld repair framework to AM.	How does the existing weld repair infrastructure exclude AM? In other words, what additional controls need to be developed to "tack on to" the existing weld repair specs to allow AM to be used there too.
4*	SDOs	Define all process controls for the quality management approach to be used by AM providers.	Time to develop a shared understanding of common controls valuable to industry and not conflicting with IP concerns.	Need specific and prescriptive guidelines written into the existing (or new) specification controls for raw material, process key variables, post-processing, etc. Consider a generic industry wide PCD (or PCD framework) by AM process and machine. Something to add to the ASTM 52930 framework but for the whole AM creation chain of action, not just machine setup and qualification
5*	FAA / EASA / etc.	Publish harmonized guidance for AM part certification and return to service.	Time and focused investment to develop guidance	Publish guidance "map" of all relevant regulations controlling AM part creation and certification. Would apply to both OEM and MRO usage

6	SDOs	Create a document that compares industry specifications and/or standards. Defines their relationship to each another	Time to review current released specifications and create document.	Something analogous to the ASTM F3572-22.
7	FAA / EASA / etc.	Increase awareness and create opportunity for DERs and ODA UMs (Unit Members) in the additive space.	Time and focused investment to develop courses and knowledge base.	Ensures that regulatory organizations and more DERs and ODA UMs have the requisite knowledge around process sensitivity and controls related to the wide array of AM processes.
8	Failure Analysis Industry	Failure analysis labs need to be prepared for additive manufactured parts and how to recognize them.		Look at how to incorporate additive manufactured parts into the standard checklist when evaluating. Industry training and capability of microstructural detection is needed
9	FAA / EASA / Industry	Create a new specialized approval process (ie. ops spec and/or rating) for General AM processes expertise.	Organizational Investment in AM (Housing, Facilities, Tooling, Equipment, Materials, Training, Design & Production responsibilities, Quality functions, etc.)	A new Operations Specification or Rating would help the maintenance and repair facilities advertise their expertise and standardize level of excellence.
10	FAA / EASA / etc.	It is recommended that the regulatory bodies publish Airframe guidance for repairs.		Guidance analogous to 33.15-3 but for Airframe.
11	FAA / Military MCO Office	Create guidance further defining the MCO office process for AM insertion in MRO applications	Time and focused investment to develop guidance	Publish guidance "map" of all relevant regulations controlling AM part creation and certification, and clearly define where the AM certification process differs or can differ from standard FAA guidance and requirements when applied to Military owned and operated Commercial Derivative Aircrafts.
12	FAA / EASA / etc.	Create guidance for other additive manufacturing processes than LPB for repairs and alterations.		Something analogous to 33.15-3 for other processes (all systems). Wire or powder-based DED

*Greatest near-term enablers for the MRO infrastructure

Table 6: Areas of Future Work / Recommendations

IX. Conclusion / Take-Aways

This document has been created to help guide the user through the MRO repair and/or alteration pathways to demystify the processes for those not already familiar. It also shows that the use of AM parts does not require a host of new regulations, but rather merely use the existing rules in a way that is responsive to the process-sensitive needs of the maturing AM technologies. Additionally, the document can serve as an entry point into the AM-specific concerns for those who are familiar with the MRO world, but who are unfamiliar with AM technologies. A few key takeaways include:

- Most airplanes in use today (2025) do not have any metallic AM parts from the OEM, and therefore any metals application of AM for repairs will need to provide rigorous levels of substantiating detail.
- MROs can explore polymer AM with fewer barriers to substantiation/certification by using the existing regulatory framework for aircraft part fabrication and approval, given that most polymer parts would likely be CAT 3.
- The amount of AM data required to show compliance within existing regulatory framework will be larger than required by conventional repair techniques. However, with proper attention and detail, the existing framework is seen to be sufficient for the incorporation of AM in:
    - Repair parts
    - Alterations
    - Reverse engineered parts
- This is a rapidly evolving technology and there remains much work to be done; investments in either time or money by industry, government, academia, and standards development organizations (SDOs) are needed to help meet the future needs of the maintenance, repair, and overhaul environment.

X. Acronyms

AC	Airworthiness Certificate; Advisory Circular
ACO	Aircraft Certification Office (part of the FAA)
AFSS	Aircraft Flight Standard Service
AIA	Aerospace Industries Association
AIR	Aerospace Information Report
AM	Additive Manufacturing
AMOC	Alternate Means of Compliance
AMS	Aerospace Material Specification
ARP	Aerospace Recommended Practice
ASTM	American Society for Testing and Materials
AWS	American Welding Society
CAMP	Continuous Airworthiness Maintenance Program
CAT	Category
CB	Certification Branch (formerly ACO)
CFR	Code of Federal Regulations
CMM	Component Maintenance Manual
CPL	Category Parts List
DAH	Design Approval Holder
DED	Directed Energy Deposition
DER	Designated Engineering Representative
DOA	Design Organization Approval
EASA	European Union Aviation Safety Agency
EBAM	Electron Beam Metal Deposition
ECO	Engine Certification Office
FAA	Federal Aviation Administration
GAMA	General Aviation Manufacturers Association

ICA	Instructions for Continued Airworthiness
IPC	Illustrated Parts Catalog
LPB	Laser Powder Bed
M&P	Materials and Process
MIDO	Manufacturing Inspection District Office
MMPDS	Metallic Materials Properties Development and Standardization
MRO	Maintenance Repair and Overhaul (or Organization)
NADCAP	National Aerospace and Defense Contractors Accreditation Program
NDI	Non-Destructive Inspection
ODA	Organizational Delegated Authority
OEM	Original Equipment Manufacturer
PBF	Powder Bed Fusion
PC	Production Certificate
PCD	Process Control Document
PMA	Parts Manufacturer Approval
POA	Production Organization Approval
QTP	Qualification Test Procedure
SAE-AMS	Society of Automotive Engineers Aerospace Manufacturing Standard
SB	Standards Body
SDO	Standards Development Organization
STC	Supplemental Type Certificate
TC	Type Certificate
TSO	Technical Standard Order
TSOA	Technical Standard Order Authorization
UM	Unit Member
US	United States
WAAM	Wire Arc Additive Manufacturing

XI. CONTRIBUTING INDIVIDUALS AND ORGANIZATIONS

Organization	**Representative**
Boeing	Eric Sager (WG Co-Chair)
Boeing (guest)	Aric Turner
Delta Air Lines	Drew Korte (sub WG Chair)
Delta Airlines	Mitch Rife
Honeywell	Matt Cenci
General Aviation Manufacturers Association (GAMA)	Joseph Sambiase
GE Aviation	Ray Martell
HEICO	Jeff Paust
Sikorsky	Kishore Tenneti
Pratt Whitney	Peter Breitzmann
Pratt Whitney	Garrett Kernozicky
Rolls-Royce	Robert Moriarty
Safran Aircraft Engines	Barton Reid
Safran	Jean Francois Fromentin
Textron	Bret Vogel