DESIGN AND CERTIFICATION OF ADDITIVE MANUFACTURED PARTS IN COMMERCIAL AVIATION

Lappeenranta–Lahti University of Technology LUT

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ABSTRACT

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Design and certification of additive manufactured parts in commercial aviation

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This thesis investigates the potential of implementing additive manufacturing (AM) in the design and certification processes of no- and low-critical aircraft interior parts within commercial aviation. The study was conducted from the perspective of a Design Organization Approval holder, with Finnair Technical Operations serving as the case study organization. The motivation originates from increasing supply chain challenges in aviation, which have encouraged operators to explore AM as a means to improve spare part availability, reduce lead times, and enhance operational resilience.

The study combines recent literature, regulatory analysis, and authority input, with particular focus on guidance material provided by the European Aviation Safety Agency (EASA). As part of the research, the aspects were demonstrated by producing a prototype of an aircraft interior component, intended for benchmarking the potential of AM compared to the existing regulation and guidelines.

The key results include the identification of regulatory boundaries, documentation requirements, and competence needs for AM adoption. Based on these findings, a five-phase roadmap was proposed as guidance for design organization in implementing AM capability for aircraft interiors. The findings contribute to bridging the gap between regulatory expectations and practical implementation.

TIIVISTELMÄ

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Tämä työ tutkii lisäävän valmistuksen käyttöönoton mahdollisuuksia kaupallisessa ilmailussa suunnitteluorganisaation näkökulmasta, keskittyen lentokoneen matkustamon ei-kriittisten osien suunnittelu- ja hyväksyntäprosesseihin. Tutkimus toteutettiin Finnair Technical Operations organisaatiolle. Tutkimuksen taustalla on ilmailualan kasvavat toimitusketjuhaasteet, jotka ovat saaneet toimijat selvittämään lisäävän valmistuksen hyödyntämistä varaosien saatavuuden parantamiseksi, toimitusaikojen lyhentämiseksi ja toiminnan joustavuuden lisäämiseksi.

Tutkimus tarkastelee nykytilannetta yhdistämällä ajankohtaisia tieteellisiä julkaisuja, sääntelyanalyysiä ja viranomaisten näkemyksiä, keskittyen erityisesti Euroopan lentoturvallisuusviraston (EASA) tarjoamaan ohjeistukseen. Osana tutkimusta valmistettiin prototyyppi valikoidusta lentokoneen matkustamon osasta, jonka avulla arvioitiin lisäävän valmistuksen potentiaalia suhteessa voimassa olevaan sääntelyyn ja ohjeisiin.

Keskeisinä tuloksina tunnistettiin lisäävän valmistuksen käyttöönottoon liittyvät sääntelyn rajat, dokumentointivaatimukset sekä kyvykkyystarpeet. Tulosten pohjalta laadittiin viisiportainen etenemissuunnitelma lisäävän valmistuksen kyvykkyyden kehittämiseen suunnitteluorganisaation tueksi. Tutkimuksen löydökset auttavat kaventamaan kuilua viranomaisodotusten ja käytännön toteutuksen välillä.

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Above all, I want to thank my partner Rasmus. Despite the unexpected hardships we faced this year, he has showed such gratitude and resilience, which I deeply admire. His mentoring and continuous support gave me the motivation to finish this thesis.

ABBREVIATIONS

ABS	Acrylonitrile butadiene styrene
AM	Additive manufacturing
ASTM	American Society for Testing and Materials
BASA	Bilateral Aviation Safety Agreement
BJT	Binder Jetting
CAD	Computer Aided Design
CFRP	Carbon Fibre reinforced polymer
DED	Directed Energy Deposition
DMLS	Direct Metal Laser Sintering
DOA	Design Organization Approval
DOH	Design Organization Handbook
EASA	European Union Aviation Safety Agency
EBM	Electron Beam Melting
FAA	Federal Aviation Administration
FDM	Fused Deposition Modeling
FHA	Functional hazard assessment
FMECA	Failure modes, effects and criticality analysis
FTO	Finnair Technical Operations
ICAO	International Civil Aviation Organization
ISO	International Organization for Standardization
MEX	Material Extrusion
MJT	Material Jetting
MRO	Maintenance repair organization

OEM	Original equipment manufacturer
PBF	Powder Bed Fusion
PCD	Process control documentation
PEKK	Polyether ketone ketone
PEEK	Polyether ether ketone
PEI	Polyetherimide
PLA	Polylactic acid
POA	Production Organization approval
PSU	Passenger Service Unit
RAS	Reliability assessment studies
SHL	Sheet Lamination
SLA	Stereolithography
SLM	Selective Laser Melting
SLS	Selective Laser Sintering
VPP	VAT Photopolymerization

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DECLARATIONS

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The originality of this thesis has been reviewed with the Turnitin similarity checking service.

AI usage

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Responsibility

The author, Soila Korhonen, takes full responsibility for the content of this thesis and has reviewed and edited any content generated by AI tools.

1 Introduction

Additive manufacturing (AM) has demonstrated its attractiveness among traditional manufacturing technologies across various industries. In the aviation sector, AM has found increasing use, though its application remains subject to certain limitations. This thesis explores how AM can be effectively integrated into certified aircraft part production, focusing on its application to no- and low-critical aircraft interior components from a design organization perspective.

1.1 Motivation and background

Since the COVID-19 pandemic, the aviation industry has been facing increasing challenges regarding spare parts shortage, jeopardizing efficient, seamless and effective airline operations worldwide. Recent global geopolitical tensions have further led to logistical challenges, and material shortages aggravating the supply chain issues. These factors have accumulated to a point that the whole aviation industry, including maintenance repair organizations (MRO) as well as original equipment manufacturers (OEM) have been struggling with their inventories. Lack of essential spare parts can lead to delays in aircraft maintenance and repairs, even grounding of the aircraft, which may have significant negative financial impacts. (Dube, 2023, p.1-2.)

To mitigate these challenges, airlines and MRO providers have begun exploring alternative approaches to strengthen spare part availability. One potential solution involves leveraging Design Organization Approval (DOA) and Production Organization Approval (POA) capabilities to produce retrofit parts as alternatives to OEM components. DOA authorization allows certified companies to design and approve aircraft components, meanwhile POA enables production of the certified parts. In the European context, these approvals are governed by the European Union Aviation Safety Agency (EASA) under EASA Part 21 Subpart J (EASA, 2024). Although the use of DOA/POA frameworks cannot entirely eliminate supply chain challenges, particularly for high-criticality components, they provide valuable means of alleviating shortages in non-critical applications. By establishing alternative production channels, organizations can

reduce financial dependency on OEMs, shorten lead times, and maintain operational resilience.

1.2 Research problem

AM has been acknowledged among aviation industry as a potential pathway to enhance product design and to relieve the supply chain issues. AM enables localized production, eliminating the need for lengthy and complex supply chains and reduces lead times and costs, especially for unconventional or obsolete parts (Wawryniuk et al., 2024, p. 3083). AM has already been proven to offer several unique advantages that are appealing for the aviation industry, such as ability to produce highly individualized parts without increasing costs, to create complex shapes without need to invest in expensive and dedicated dies and tools, to implement lattice structures to save material and reduce weight, to combine assemblies into a single part, and to reduce overall costs. The largest airframe manufacturers in commercial aviation, Boeing and Airbus, have already integrated AM into their production lines for several years, even for critical parts, but utilization of AM in larger scale among commercial operators are yet limited. (Stolt et al., 2020, p. 490.)

AM is particularly attractive when designing aircraft interior parts. Many of the interior parts can be classified as non- or low-critical, meaning that failure of these components does not affect flight safety nor safety of passengers, employees, or other equipment (EASA, 2024). While AM offers substantial potential for aircraft interiors, its implementation is hindered by insufficient regulatory guidance and the absence of standardized qualification processes. DOA holders face uncertainty in demonstrating compliance and consistent quality, from material selection to final part approval. These regulatory and procedural gaps have constrained broader AM adoption within the aftermarket sector. (Singamneni et al., 2019, p. 8.)

1.3 Objective

During the past few years many of the aviation operators, including Finnair, have increased interest in exploring the possibilities provided by AM. However, large gaps between the knowledge around the approval process and practices that would enable the integration of

AM as part of the organizational operations has been identified. The main objective of this thesis is to investigate the opportunities and limitations of AM from the perspective of a DOA holder, specifically within the context of Finnair. Consequently, the objectives of this thesis have been derived from the issues mentioned above, and are defined as follows:

1. Examine the current status and potential of AM in commercial aviation in general.
2. Map the current boundaries for the design and certification of AM parts for non- or low-critical applications according to up-to-date standards, aviation authority specifications and guidance material (CM-S-008) published by EASA.
3. Explore how design and certification requirements could be practically achieved from a DOA holder perspective.
4. Propose guidelines that could be utilized to develop a process description for certifying AM parts for aircraft interior.

1.4 Research questions

To fulfil the objectives, the following research questions are addressed:

1. What is the current status and applicability of AM within commercial aviation?
2. What regulatory frameworks and standards govern the certification of AM parts for non- or low-critical components?
3. How can a DOA holder effectively meet these requirements in practice?
4. What general guidelines or process models could facilitate the certification of AM parts for aircraft interiors?

1.5 Research methods

Inductive and deductive reasoning was employed as a methodology for this study. The inductive phase involved qualitative data collection and review of industry practices, certification cases, and expert insights to identify key challenges and requirements in the design and certification of AM parts for aircraft interior. Based on these findings, a

conceptual framework was pursued. In the deductive phase, that framework was applied to an example case study of a floor fitting cover, manufactured with material extrusion (MEX) and an advanced polyetherimide (PEI) thermoplastic material (FDM® and ULTEM 9085 material™). This real-world example demonstrated the opportunities, challenges and uncertainties on the certification process.

1.6 Scope

The scope of this research is limited to the design and certification of non- or low-critical AM parts intended for aircraft interiors. The study emphasizes EASA regulatory frameworks and focuses on the European aviation context. The topic was further narrowed down to technical aspects of the capability implementation; hence assessment of economic viability falls beyond the scope of this thesis.

1.7 Contribution

This study contributes to the increasing interest in understanding the current potential of AM in aviation, by providing a structured assessment of its feasibility from a DOA perspective. It bridges the gap between theoretical understanding and practical application by proposing a process-oriented approach to certify AM parts for aircraft interiors. The findings of this thesis are aimed to provide further guidance for aviation stakeholders, including airlines and MROs, with the pursue of improving approval processes, and ultimately accelerating AM adoption within the aviation aftermarket.

2 Literature review

The development of AM related technologies e.g. lasers, computers, controllers began in the early 1980s. During year 1984 several patents were filed in different parts of the world (Japan, France and USA) with similar concept of fabricating 3D objects by adding material selectively layer-by-layer. Charles Hull is considered as one of the most influential creators of AM technology, being the inventor of stereolithography and commercializing AM for the public stakeholders. American companies, such as Stratasys, Z Corp, and 3D Systems have been pioneers in AM since mid-1980. However, most of the newer companies in the market are currently based outside of the US. The primary reason for this is that many of the original patents for AM processes have already expired, which have enabled the spread of AM technologies, machines, processes, and competition worldwide. (Gibson et al., 2021, p.45.)

Over the decades, more advanced, alternative AM technologies have emerged. This has led to remarkable advances concerning applicable materials and manufacturing processes. Meanwhile, AM is becoming more accessible throughout various industries, not only because of the expired original patents, but also because of reductions in costs combined with improved availability of the equipment (Bharat et al., 2023, p. 95). The attractiveness of AM can be acknowledged through the rapid increase in monetary investments within the industries, simultaneously as AM has been increasingly popular among the academic communities. This has led to further development and deployment of alternative production techniques. (Oliveira & Espadinha-Cruz, 2025, p. 893.)

AM processes are generally categorized based on existing standards. The most widely known standards are defined by International Organization for Standardization (ISO) or American Society for Testing and Materials (ASTM). These standards classify the different AM technologies based on three parameters: layer manufacturing process, material, and feed type. The most commonly used categories are Powder Bed Fusion (PBF), Directed Energy Deposition (DED), Material Jetting (MJT), Binder Jetting (BJT), Material Extrusion (MEX), Sheet Lamination (SHL), and VAT Photopolymerization (VPP). The state of the feedstock can be solid, powder or liquid, depending on the chosen AM technique. The typical materials consist of metals, polymers, ceramics or hybrids. Figure 1 depicts an overview of the

feedstock types and principles necessary to ensure successful implementation of the selected AM process. (Alami et al., 2023, p.8-9.)

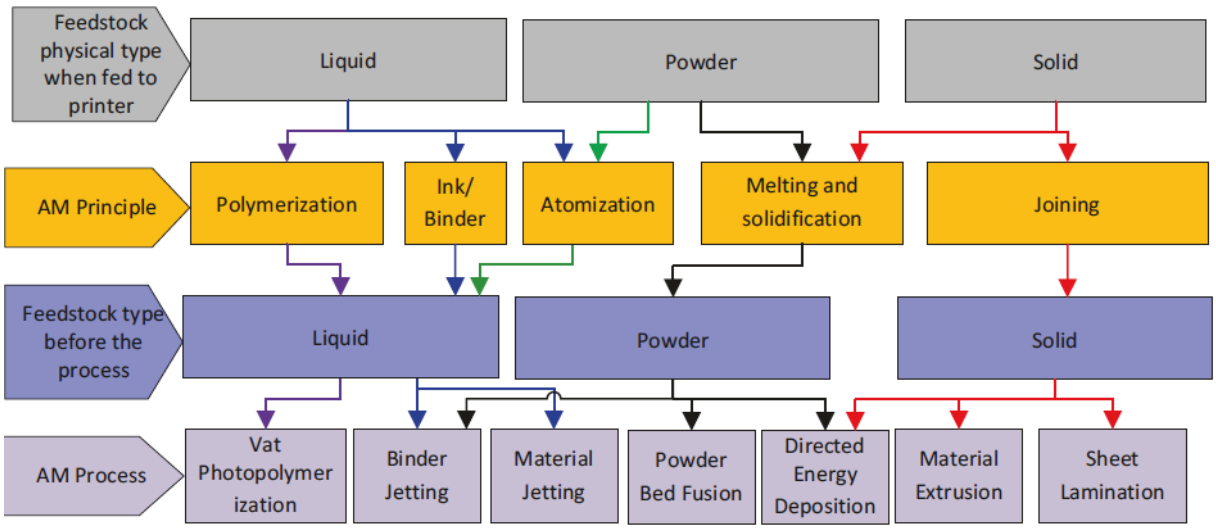

Figure 1. Relations between feedstock types and the principles for AM processes.

According to a study conducted by Alami et al. (2023, p.1), roughly 33% of the total annual revenue within the whole AM sector is received from aerospace and automotive industries. Consequently, those two industries are the fastest evolving AM markets by reported 1-2% annual growth. (Alami et al., 2023, p.1.) The revenue from the total AM industry was estimated at $2.7 billion in 2016 and has been projected to surpass $100 billion during the next two decades. Notably, the aerospace industry is expected to grow most rapidly of all AM sectors (Najmon et al., 2019, p. 7).

Boeing began incorporating polymer AM components for non-critical applications already as early as in mid-1990s. By 2019, Boeing had already produced over 200 unique AM part designs for 16 different aircraft types, with tens of thousands of AM parts installed to both military and commercial aircraft. (Najmon et al., 2019, p.7.) Correspondingly, competitors such as Airbus have invested heavily in AM during past decade. In 2015, Airbus A350 XWB model had over 1000 different AM part designs implemented, nearly all of them being polymer based interior parts. In 2017, Airbus announced that the first titanium AM component (a bracket) was installed on a serial production aircraft, with a formal approval

of EASA. As a specific example of advantages gained with AM, Airbus has been utilizing metal PBF process to manufacture latch shafts for A350 aircraft doors. The introduction of these AM based latch shafts has reduced the parts production costs by 25%, simultaneously being 45% lighter compared to conventionally produced parts, total weight savings being more than 4kg per aircraft. (Gibson et al., 2021, p. 532.)

While aircraft manufacturers continue to independently develop internal AM capabilities, a growing number of collaborations have emerged among aerospace companies, aftermarket AM machine vendors, part suppliers, and material providers, and this trend is expected to persist. Vendors are forming strategic partnerships with aircraft manufacturers and airlines to improve their capabilities to produce, supply, and replace aircraft interior parts. For example, a company named Materialise has collaborated with Airbus to produce flight-ready components by utilizing laser sintering technology, while Stratasys has formed a strategic partnership with SIA Engineering, aiming to accelerate the adoption of AM parts in commercial aviation. (Gibson et al., 2021, p. 532.)

Aircraft engine manufacturers, such as General Electric, Rolls Royce, Honeywell, and Pratt & Whitney have achieved significant advancements through the adoption of metal AM. One well-known example is an AM-produced fuel nozzle for the LEAP engine by General Electric. The nozzle design combined 18-20 components into a single part, reduced weight by 25%, and improved durability by approximately fivefold by removing welded and brazed joints. Similarly, Rolls-Royce has announced that AM will play an important role in its next-generation engine programs, aiming to reduce engine weight, lower emissions, and enhance fuel efficiency through advanced design and manufacturing flexibility. (Gibson et al., 2021, p. 533.)

These advancements have been made possible not only by design innovations, but also by the growing availability of AM-compatible materials for aerospace applications. While the material selection for the aviation industry is relatively limited compared to the broader AM sector, there are already a variety of materials available, tailored to specific applications. Aluminum alloys, titanium alloys, stainless steel, and nickel-based superalloys are the most common metal materials, primarily utilized with PBF or DED processes. For polymer-based parts, PEI, PEEK, and Nylon based materials are common choices, typically processed using MEX or PBF printing methods. An overview of the main processes and materials in aerospace applications are presented in Table 1. (Alami et al., 2023, p. 3-11.)

Table 1. AM processes and materials in aerospace applications (Alami et al., 2023).

Generic process name	Most known Registered/ Commercial name	Material Type	Common Materials	Properties	Aerospace Applications
PBF (LB-PBF/M, EB-PBF/M, LB-PBF/P)	SLM, DMLS, EBM	Metal Alloys	Ti-6Al-4V, Inconel 718, AlSi10Mg, Stainless Steel (316L)	High strength, heat & corrosion resistance	Turbine blades, engine components, structural brackets
	SLS	Polymers & Composites	Nylon 11, Nylon 12, PA 12-CF, PEEK, PEKK	Durable, lightweight, complex geometries	Ducting, housings, clips, non-structural parts
DED	LENS, DMD, WAAM	Metal Wires/Powders	Titanium, Inconel, Stainless Steel	High-strength, repair & remanufacturing	Turbine blade repair, large structural parts, Landing gear components
VPP	SLA	Photopolymers & Ceramics	High-temp resins, Ceramic Composites	High precision, smooth surfaces	Wind tunnel models, casting molds, tooling
MEX (FFF)	FDM	Polymers & Composites	PEI (Ultem 9085™, Ultem 1010™), PEEK, PEKK, ABS, ASA	Lightweight, impact-resistant	Cabin interiors, ducts, enclosures, brackets
	FDM with High-Performance Composites	Carbon Fiber-Filled Thermoplastics	Carbon Fiber PEKK (Vega™), PEKK (Antero 800NA™)	Extreme strength, high-temp resistance	Structural aerospace brackets, lightweight aircraft components
	CFF	Fiber-Reinforced Composites	Carbon Fiber reinforced nylon (Onyx FR™), Kevlar, Fiberglass	High strength-to-weight ratio, stiff, impact-resistant	UAV frames, aerospace tooling, structural brackets
BJT	ExOne, Voxeljet	Metal Powders	Stainless Steel, Inconel, Ti-6Al-4V	Cost-effective, complex geometries	Prototyping, non-critical engine parts

As shown in Table 1, AM offers diverse possibilities in aviation, from rapid prototyping to the production of complex, lightweight polymer components and even large, high-strength metal parts such as engine- or landing gear components. The following chapters, *2.1 Processes* and *2.2 Materials*, provide a more in-depth examination of the key AM technologies and materials currently employed in aerospace applications. In this thesis, the AM processes and materials are often referred to by their commercial or trademark names, rather than their generic equivalents. The reason for that is that commercial names are widely recognized within the aviation industry and most of the cited studies, equipment specifications, and case examples specifically use these registered terms.

2.1 Processes

AM consists of a wide variety of processes that are selected based on the specific application. These processes are used in the aviation industry for prototyping, rapid tooling, production, and repair of end-use components. This chapter provides an overview of the main PBF process categories, together with other types of AM techniques commonly adopted in aviation and examines their key applications.

2.1.1 Powder Bed Fusion

PBF was among the first AM technologies to be commercialized and remains one of the most versatile and extensively used AM methods. PBF is primarily suited for printing metals and polymers. It can also be applied to ceramics to some extent, but the commercial use of ceramics in aviation remains in its early stages and it is therefore not reviewed in this study. (Gibson et al., 2021, p. 125). The fundamental principle of PBF involves using a laser or electron beam to selectively melt and fuse powder material layer by layer. As illustrated in Figure 2, the process begins with the formation of a powder bed, created by spreading the powder across the work area with a roller, which is then melted or sintered according to the computer generated design (CAD) model. To mitigate oxidation risks, PBF processes typically operate in vacuum chambers or under inert gas environments. PBF technologies are further divided into subcategories, based on the energy source and raw material used to LB-PBF/M (laser metal), LB-PBF/P (laser polymer), and EB-PBF/M (electron beam metal), as standardized by ISO/ASTM 52900. In aviation industry, these processes are more commonly known by their commercial names: Selective Laser Melting (SLM®), Direct Metal Laser Sintering (DMLS®), Selective Laser Sintering (SLS®), and Electron Beam Melting (EBM®). (Alami et al., 2023, p. 10.)

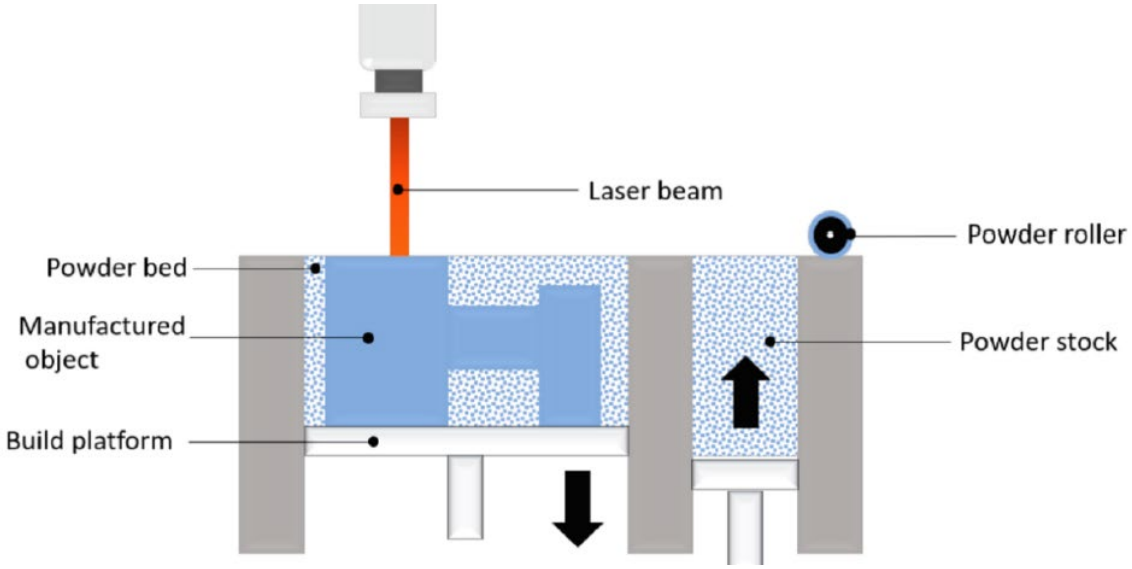

Figure 2. A schematic diagram of L-PBF process (Alami et al., 2023).

LB-PBF/M (SLM®, DMLS®) is the most matured AM process for producing superior functional metal components. LB-PBF/M technology has enabled new design possibilities in aerospace by allowing solid sections to be replaced with optimized lightweight structures (lattice or topology). (Stolt et al., 2020, p. 489.) As an example, researchers successfully fabricated a complex helicopter component from 316L stainless steel featuring internal lattice geometries, achieving a 50% weight reduction compared to the original part. Similarly, a significant weight reduction was achieved when a large nose landing gear fitting was produced through a collaboration between Safran and SLM Solutions. LB-PBF/M has also been employed in the production of Airbus A350 cabin bracket connectors, structural aerospace brackets, and even critical components such as turbine blades. (Khan et al., 2024, p. 16-23.)

LB-PBF/P (SLS®) is a method, in which the powder is selectively sintered by heating the material to a point where it can be fused without melting. It is a well-known technique to create durable components with exquisite mechanical properties. Additionally, no support structures are needed in this method, which makes the post-processing remarkably easier and allows creation of more complex internal structures and unified assemblies. LB-PBF/P (SLS®) is currently one of the most widely adopted PBF processes for aircraft interior applications. (Singh et al., 2023, p. 2124.)

EB-PBF/M (EBM®) differs from the previously mentioned PBF methods by the power source. Instead of laser, it utilizes electron beam for melting. Compared to laser melting, EB-PBF/M is better in respect to lower residual stress, energy efficiency and manufacturing speed, but generally provides poorer surface quality. (Stolt et al., 2020, p. 490.)

2.1.2 Other methods

Alongside PBF, other types of AM technologies are employed in aerospace applications, such as DED, VPP, MEX, and BJT. With DED technology the feedstock (powder or wire) is deposited directly into the melt pool through a nozzle. The melt pool can be created by laser, electron beam or a plasma arc. Since DED is not limited by a powder bed platform, even very large components can be created with this method. Alongside geometrical freedom, higher deposition rate is a benefit on DED compared to PBF. The downside of DED is that the surface quality is generally poorer, and therefore DED printed components require more post-processing. In aviation, DED is ideal for component repair such as turbine blades, or repair of larger structural parts. (Blakey-Milner et al., 2021, p.5.)

VPP, also known as Stereolithography (SLA®), refers to an AM technique in which a photosensitive liquid resin is exposed to a laser light source that selectively starts a photopolymerization process, resulting in a solid part. The polymerization process is repeated by each layer until complete part has been created. In aviation industry VPP (SLA®) is mainly used for prototyping, or manufacturing interior parts, such as console control components or panels. (Tuli et al., 2024, p. 9.)

MEX, also known as Fused deposition modeling (FDM®), is a widely adopted AM method in the aviation industry, especially with polymer-based parts. It is particularly well-suited for manufacturing aircraft interior components. This method involves heating and melting of a filament, which is then extruded onto a heated built platform through a nozzle. The filament cools down and solidifies layer by layer, enabling fabrication of complex shapes. MEX (FDM®) is a relatively simple and affordable process, making it a feasible choice for rapid prototyping, but also for manufacturing functional end-use parts. The main drawback in this method is that parts require lot of post-processing to achieve smoother finish, due to low printing resolution and need for support structures. (Wawryniuk et al., 2024, p. 3086.)

Continuous Fiber Fabrication (CFF®) is a specialized variation of MEX that incorporates continuous fiber reinforcement (e.g., carbon fiber, Kevlar, fiberglass) within a thermoplastic matrix. The reinforcement significantly enhances the strength, stiffness, and durability of the printed parts, making them comparable to metal components in some cases. (Xu et al., 2025, p. 12.)

BJT process requires a powder-based material and a liquid binder that acts as an adhesive. In this method a nozzle moves along XY-axis of the printer, depositing binding material and powder in alternate layers. Since this method is based on binding, it is not suitable for structural parts in aviation, but it is mainly used for prototyping AM components. (Alami et al., 2023, p. 10.)

2.2 Materials

The AM materials in aviation can generally be classified based on used feedstock. The main categories are polymers, polymer-based composites, or metals. The given feedstock is primarily selected depending on the criticality of the parts. The overall capabilities of metal AM systems have evolved significantly within aerospace, but real applications for flying parts in commercial aviation are still rather limited compared to polymers. Polymer based components have numerous practical examples of production-certified flying parts already in use and steadily increasing beyond just prototyping. (Gasman, 2019, p. 334.)

2.2.1 Polymers

Polymer AM parts in aircraft are mainly used for low- or non-critical interior applications. The choice of AM materials in aviation industry is currently relatively limited, because polymers are often highly flammable and can emit smoke and toxic gases when burned. There are few flame-retardant polymer materials such as Polyether ketone-ketone (PEKK), Polyether ether ketone (PEEK), Polyetherimide (PEI) and treated nylons which are commercially available for AM processes. (Lv et al., 2020, p. 3223.)

PEI, also referred to as its brand name ULTEM™, is a high-performance thermoplastic commonly utilized in aviation for its strength, durability, and resistance to high temperatures.

There are two ULTEM™ types that are exceptionally well suited for aerospace applications and certified for its use: ULTEM 1010™ and ULTEM 9085™. ULTEM 1010™ has superior tensile strength out of all FDM® filaments and therefore it can be used to create durable and strong components. It is most often used for semi-structural parts and can be utilized for food-related applications due to its biocompatibility. ULTEM 9085™ on the other hand is most often used for aircraft interior components, where weight reduction is possible, but strength is still required. Both ULTEM 1010™ and ULTEM 9085™ provide excellent stress crack and fatigue resistance, dimensional stability, have inherent flame-retardant properties, low smoke generation, and are resistant to a wide range of chemicals. Due to these properties, they are ideal materials for demanding aerospace environments with critical reliability and performance. (Boado-Cuartero et al., 2024, p. 2.)

PEEK is a natural polymer with a semi-crystalline structure, known for its high-performance mechanical and thermal properties. PEEK offers advantages such as low flammability, creep resistance (resistance to deformation under stress), and the ability to withstand high levels of radiation. It is also highly durable in the presence of high-pressure steam and water, maintaining its integrity without degradation. PEEK can function at temperatures up to approximately 230 °C and produces minimal toxic gas and smoke when exposed to fire. (Rahman et al., 2023, p.12.)

Nylon is a commonly used material for AM due to its affordability and decent strength properties. Conventional Nylon is rather flammable, making it unsuitable for environments with strict fire safety standards. However, the material can be treated by adding halogen- and phosphorus-based compounds to nylon powders to enhance its flame-retardant properties, while aiming to preserve the material's physical characteristics and processability. Additive manufacturing companies like EOS and 3D Systems have introduced flame-retardant nylon variants, such as PA2210FR™, PA2241FR™, and DuraForm FR1200™, to fulfil the safety requirements. (Lv et al., 2020, p. 5722.)

In addition to end-use parts, polymers in aviation are widely used for prototyping and rapid tooling, e.g. for creating fixtures, molds, or dies. These applications typically have less stringent material requirements, allowing for greater flexibility in material selection. Polymers such as acrylonitrile butadiene styrene (ABS), polylactic acid (PLA), various grades of nylons, and photopolymers are commonly used for these purposes. (Alami et al., 2023, p. 3.)

In applications where increased mechanical performance is required, polymers can be reinforced with materials such as carbon fiber. Currently, two principal carbon fiber-reinforced polymer (CFRP) AM methods are employed: chopped fiber and unidirectional (continuous) fiber reinforcement. Chopped CFRP, developed as a lightweight alternative to certain metal components, offers improved stiffness and strength over unfilled polymers but remains mechanically inferior to composites reinforced with continuous fibers. By contrast, unidirectional CFRP technology involves the alignment of continuous carbon fibers in a single direction, significantly enhancing both strength and stiffness. This method enables the production of lightweight components with mechanical properties that can rival those of aluminum alloys, while achieving substantial weight reductions compared to metal parts of equivalent strength. Figure 3 illustrates the CFRP additive manufacturing process using FDM®, along with representative parts. (Xu et al., 2025, p. 12.)

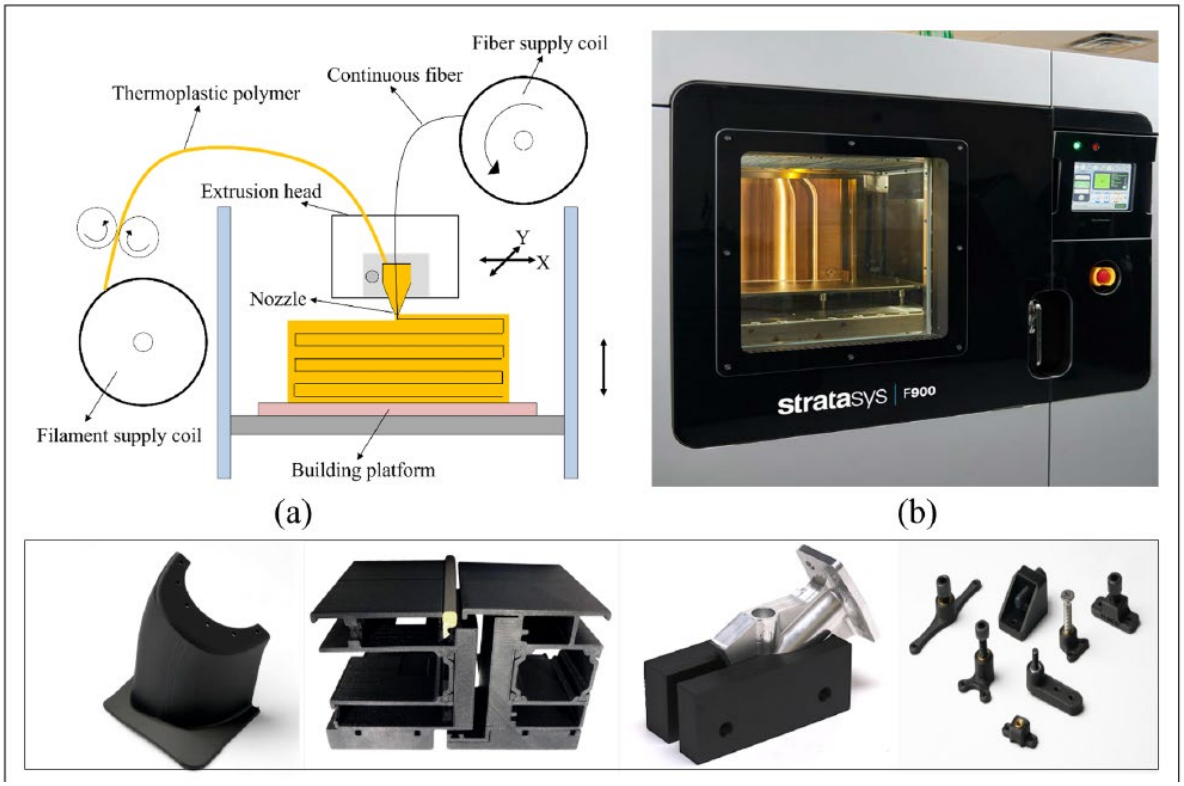

Figure 3. An example illustration of CFRP additive manufacturing process using FDM® (Xu et al., 2025).

As a notable example, Markforged has developed high-performance carbon fiber-filled polymer materials tailored for AM in aerospace. These include Vega™, an ultra-high-performance PEKK composite filled with carbon fiber, and Onyx FR™, a flame-retardant nylon reinforced with micro carbon fibers. Both materials demonstrate potential for use in structural or semi-structural aerospace components due to their strength-to-weight efficiency and compliance with industry performance standards. (Gibson et al., 2021, p. 190.)

2.2.2 Metals

While metals (and metal-polymer hybrids) are not specifically in the scope of this study, it is important to understand their position and usage with aircraft AM based interior applications. Metal AM bring great potential for technical and commercial advantages in aerospace applications, such as lightweight designs with complex geometries, as well as enhanced mechanical performance. Metals can also be used in combination with polymers to reduce weight of the part without compromising the structural integrity. In aerospace applications, the spectrum of AM metals includes aluminum alloys, titanium alloys, stainless steel, iron-and nickel-based superalloys, copper alloys, cobalt alloys, among others. Most of the metals in AM are used in pre-alloyed powder forms, or in wire, depending on the applicable printing process. (Blakey-Milner et al., 2021, p. 5.)

While metal AM in the aviation industry is more commonly associated with critical structural and engine components, the utilization for aircraft interior applications is expected to see broader adoption in the future, when the technologies advance, and the regulation is further streamlined. One of the earliest examples of metal AM part being used for the interior of commercial aircraft is a cabin bracket connector of Airbus A350 XWB. The bracket was manufactured with laser PBF method from Titanium alloy (Ti-6Al-4V). Topology optimization was exploited with this part as shown in Figure 4. (Blakey-Milner et al., 2021, p. 10.)

Figure 4. Topology optimization is utilized for Airbus A350 XWB cabin bracket connector manufactured with AM. Copyright Airbus.

As previously mentioned, component performance can be further enhanced through multi-material design. Figure 5 illustrates this process: the original metal bracket (A) has undergone topology optimization process to reduce unnecessary material while maintaining essential structural integrity (B). In the final iteration (C), material optimization was applied by replacing selected regions of the solid metal part with continuous carbon fiber-reinforced polymer, creating a hybrid component.

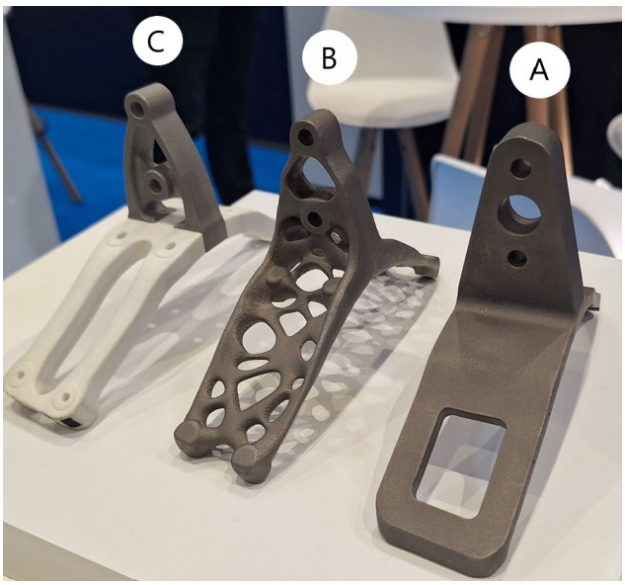

Figure 5. Topology optimization (B) and combination of materials (C) can be utilized to reduce overall part weight, while still maintaining the required strength criteria. (Aircraft interior expo Hamburg 2025, Materialise stand).

This hybrid approach not only ensures that the part meets the required strength and stiffness criteria but also achieves a substantial reduction in overall weight, highlighting the advantages of combining topology and material optimization in advanced component design.

2.3 AM for aircraft interiors – Current status

For aircraft interior applications, Stratasys and EOS currently stand out as the two leading industrial providers of AM solutions. Stratasys specializes in FDM® technology, particularly using ULTEM 9085™. In contrast, EOS focuses on SLS® process, primarily utilizing flame retardant nylon PA2241FR™. These two methods are illustrated in Figure 6, while the processes were described in more detail on previous chapter 2.1.

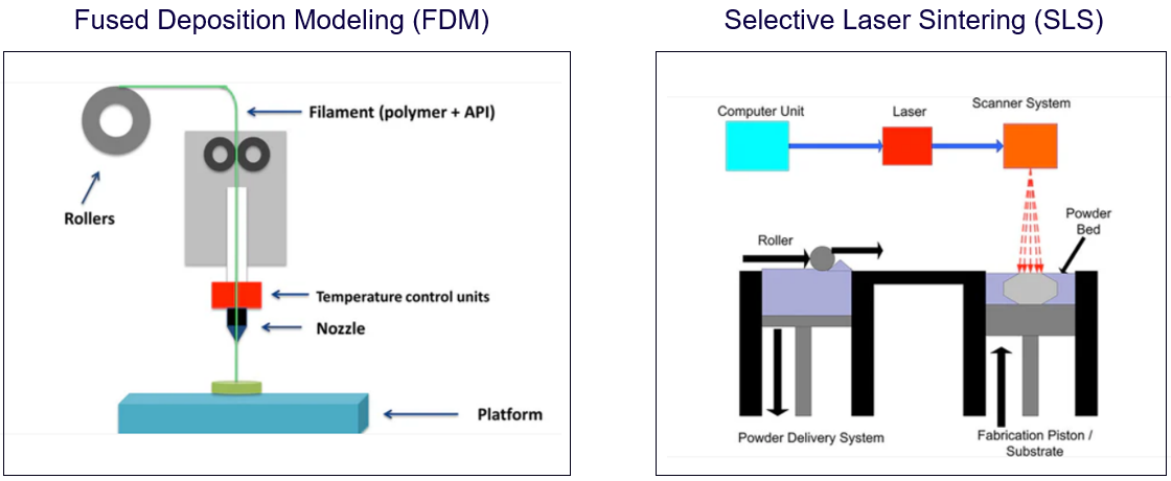

Figure 6. FDM® utilizes filament as feedstock, while SLS® is a powder-based printing method.

Both FDM® and SLS® technologies offer distinct advantages, making the choice between them highly dependent on the specific design criteria, performance requirements, and regulatory considerations of the component in question. Table 2. below provides a comparative overview of the key characteristics of FDM® and SLS® technologies, highlighting their respective strengths and limitations.

Table 2. Comparison of FDM® and SLS® methods (Derad et al., 2025).

	FDM®	**SLS®**
Main industrial provider	Stratasys	EOS
Materials	ULTEM 9085	Flame-retardant nylon (PA2241FR)
Mechanical properties	Anisotropic. FDM® printed parts are weaker in layer bonding direction (Z-axis).	Isotropic
Surface finish	Lower quality, visible layer lines	Better finish, finer resolution
Weight Optimization	Good for solid/lightweight structures	Excellent, support complex lattice structures
Complex geometry	Limited—requires support structures	Excellent—no supports needed, ideal for internal cavities
Cost (per part)	Lower for simple, low-volume parts	Higher upfront, better for high-mix low-volume
Post-processing needs	Support removal, surface smoothing	Powder removal (must be taken into consideration with the design), surface finishing
Dimensional accuracy	Moderate, can warp with large parts	High, more stable and precise

Both materials, ULTEM 9085™ and PA2241FR™, meet the FAR 25.853 fire, smoke and toxicity requirements and are well suited for aircraft interior applications. The main advantage of the SLS® method is the isotropic mechanical behavior and the possibility to print complex geometries without support structures. That provides better surface quality with little to no post-processing. Additionally, it enables greater design freedom and possibly simplifies the certification process, when part orientation and potential warping due to anisotropy does not have to be taken into consideration. On the other hand, Stratasys FDM® method is widely established in the aviation sector offering consistent and well-documented material properties supported by existing qualification databases. This makes FDM® a potentially more straightforward path for regulatory approval for non- and low-critical components. Additionally, FDM® is often preferred for low-volume production due to its more favorable cost-efficiency.

2.3.1 Regulations

The aviation industry is highly regulated to ensure safe and efficient global air travel. International Civil Aviation Organization (ICAO) sets and develops international standards and recommended practices and policies for aviation safety, which are implemented and controlled in their respective jurisdictions. EASA serves as the aviation safety regulator in Europe, while in the USA the equivalent authority is Federal Aviation Administration (FAA). Alongside EASA and FAA, numerous other civil aviation authorities operate worldwide. Each have developed their own set of regulations, which are based on the shared international guidelines set by ICAO. To promote collaboration between authorities, Bilateral Aviation Safety Agreements (BASAs) are established. For instance, the BASA between EASA and FAA facilitates the mutual recognition of regulatory competences and certifications. This arrangement significantly enhances the efficiency of trade and operational activities in the aviation sector while minimizing duplication of regulatory efforts. (Barrera, 2022, p. 3-9.)

EASA Part 21 is a regulatory document that covers common technical and administrative procedures for the environmental certification and airworthiness of products, parts, and appliances related to aircraft. Part 21 Subparts G and J specify regulatory framework related to DOA and POA activities. (EASA, 2024.) Certification of components are set in the EASA main document CS-25, which provides certification specifications requirements and applicable means of compliance for large aircraft (aircraft more than 19 passengers or a maximum take-off weight more than 5700kg). Although CS-25 does not include specific provisions for AM, all components regardless of the manufacturing method must comply with the applicable certification requirements. The compliance of AM parts with CS-25 is always assessed on a case-by-case basis, considering their unique characteristics and intended applications. Some of the key aspects to consider during this evaluation are outlined in Table 3.

Table 3. An overview of AM regulations applied in CS-25 (EASA CS-25, 2023).

Structural Integrity and Load-Bearing Components	**Criteria**
CS 25.301: Loads	AM parts must demonstrate their ability to withstand specified load conditions without failure.
CS 25.303: Factor of Safety	A safety factor must be applied to account for material variability and potential defects in AM components.
CS 25.305: Strength and Deformation	AM parts must meet the strength and deformation requirements for the intended application.
CS 25.307: Proof of Structure	The structure must be tested or analytically verified to ensure it meets design requirements.
Emergency landing conditions	
CS 25.561: General	AM parts must maintain structural integrity and occupant protection during emergency landings, preventing catastrophic failure under specified loads.
CS 25.562: Dynamic conditions	AM parts must withstand dynamic impact loads from emergency landings without fragmentation or loss of structural integrity.
Materials and Manufacturing Processes	
CS 25.601: Design features	No hazardous or unreliable design features are allowed. The suitability of each questionable design detail and part must be established by tests.
CS 25.603: Materials	All materials used, including AM powders and filaments, must meet approved specifications (traceability, consistency, and quality control).
CS 25.605: Fabrication Methods	The AM manufacturing process must ensure consistent quality and reliability. This includes adherence to standardized processes, post-processing, and inspection requirements.
CS 25.609: Protection of Structure	AM components must be protected from environmental factors, such as corrosion and temperature extremes, that could compromise integrity.
Fire Protection and Cabin Safety	
CS 25.853: Compartment Interiors	AM parts used in aircraft interiors must comply with flammability, smoke, and toxicity standards.
Systems and Equipment	
CS 25.1301: Function and Installation	AM parts integrated into systems must function as intended and be properly installed, with failure consequences identified.
CS 25.1309: Equipment, Systems, and Installations	Any AM component contributing to system functionality must meet reliability and safety requirements.
Testing and Validation	
CS 25.1529: Instructions for Continued Airworthiness	Maintenance and inspection guidelines for AM parts must be developed to ensure continued airworthiness.

As specific guidance to AM, EASA has published a certification memorandum CM-S-008, which provides non-binding explanatory and interpretation material on how to achieve compliance with the CS-25 requirements. The most recent finalized version, Issue 4, was published in September 2025. The issue 4 introduces several significant updates to existing guidance, especially addressing the use of AM parts for non-critical applications. It emphasizes a certification effort that is proportionate to the criticality of the AM part, which allows components classified as low- or non-critical to undergo a more streamlined certification process. As DOAs adopt AM technologies, they should demonstrate compliance with the updated guidance outlined in CM-S-008, particularly in relation to the proportionality of certification efforts. DOAs must assess the criticality of each AM part and provide appropriate substantiation for its safety and airworthiness. This includes performing safety assessments, validating material properties, and ensuring that quality control measures are in place throughout the AM production process. Additionally, DOAs are responsible for ensuring that all AM processes adhere to the same certification requirements as traditional manufacturing methods, with any deviations being thoroughly documented and justified. This responsibility extends to ensuring that the design, testing, and qualification procedures for AM parts are aligned with the established certification specifications, thereby ensuring that the final products maintain the required safety, performance, and reliability standards. (EASA, 2024.)

Furthermore, ISO and ASTM are continually developing standards for AM which provide detailed guidance to support the fulfilment of design and certification requirements within the aviation sector (Khan & Riccio, 2024, p. 25). For example, SFS-EN ISO/ASTM 52910:2019 *"Additive manufacturing. Design. Requirements, guidelines and recommendations"*, SFS-EN ISO/ASTM 52911-2:2019 "*Additive manufacturing. Design. Part 2: Laser-based powder bed fusion of polymers*" and SFS-EN ISO/ASTM 52924:2023 "*Additive manufacturing of polymers. Qualification principles. Classification of part properties*" can be utilized to validate design methodologies and establish quality assurance processes for non-critical aircraft interior components manufactured using AM.

2.3.2 Current boundaries

One of the main challenges in the certification of AM components for aerospace applications is the limited availability of public and industrial data, compared to the information available from traditional manufacturing processes. This is a direct consequence of a highly competitive industry, combined with the lack of a properly streamlined regulation.

Unlike conventional manufacturing methods, AM introduces high variability in part properties due to differences in feedstock quality, build parameters, and post-processing techniques, making consistency and repeatability more difficult to achieve. This process variability complicates the qualification and validation of AM components. Furthermore, there is a notable shortage of long-term performance data, which is essential for building confidence among regulatory authorities and part manufacturers. Although institutions such as ASTM, and ISO have made progress in developing AM-specific standards, comprehensive and harmonized certification frameworks are still under development. Regulatory bodies including the FAA and EASA have introduced preliminary guidance, but that guidance is still mainly focused on what to control, not exactly how to control it. (Wawryniuk et al., 2024, p. 3094-3096.)

2.3.3 Future insights

As aviation industry is one of the fastest-growing sectors in AM, also new processes are being developed, and new materials are emerging that are more sustainable or more advanced in performance. Newer high-performance materials like Vega™ (carbon fibre-filled PEKK) and Antero 800NA™ (a high-performance thermoplastic) offer exceptional strength and flame-retardant properties.

From a sustainability perspective, the limited recyclability and non-biodegradability of current high-performance polymers, such as ULTEM 9085™, present significant challenges. To address these limitations, research is advancing toward sustainable flame-retardant alternatives, including bio-based polymers (e.g., Bio-PEEK, Bio-Nylon) and ceramic matrix composites (CMCs), which offer improved environmental performance and durability for

aerospace applications. (Rahman et al., 2023, p.2-3). In metals, closed-loop recycling of powders and the adoption of more abundant or lower-carbon alloys can further reduce the ecological footprint of AM. As the aerospace industry moves toward net-zero targets, sustainable AM materials, combined with lightweight design and part consolidation, will be essential in minimizing emissions and resource consumption across aircraft production and operation. (Gonçalves et al., 2023, p.306.)

3 AM at Finnair

Finnair Technical Operations (FTO) is part of Finnair Corporation, with its operations and maintenance base located at Helsinki-Vantaa Airport, Finland. Main responsibility of FTO is to ensure aircraft maintenance operations and continuing airworthiness management for the Finnair fleet and Finnair group airlines, in compliance with regulatory requirements, as well as the company's internal policies, priorities, and standards. The Finnair fleet consists of approximately 80 aircraft, the majority of which are manufactured by Airbus. Fleet includes wide-body aircraft (Airbus A330/A350), narrow-body aircraft (Airbus A319/A320/A321) and smaller aircraft used mainly on domestic or short distance European flights (Embraer 190, ATR-72).

While continuous airworthiness management is the main priority for the operation, FTO also holds a DOA, which authorizes it to design and approve certain modifications and repairs for the fleet. AM has been recognized as an interesting alternative to be explored from DOA perspective, especially for aircraft interior upgrades and for tackling lead time issues. In addition to interior parts, potential AM applications at Finnair could possibly include tools, aircraft loose items, or catering equipment.

Since 2023, FTO has already gained experience related to AM through a project that was carried out in collaboration with AM craft (POA provider) and an external DOA provider. 17 of Finnair's Airbus A320 aircraft were modified by replacing heavy, outdated flip-down video monitors in the Passenger Service Units (PSUs) with lightweight, 3D-printed blanking panels (Figure 7). The primary objectives of this modification were threefold: to reduce aircraft weight, minimize maintenance associated with onboard monitors, and to enhance the overall passenger experience. The implementation resulted in substantial weight reductions, which translates to significant annual fuel cost savings, underscoring the economic and environmental benefits of the modification.

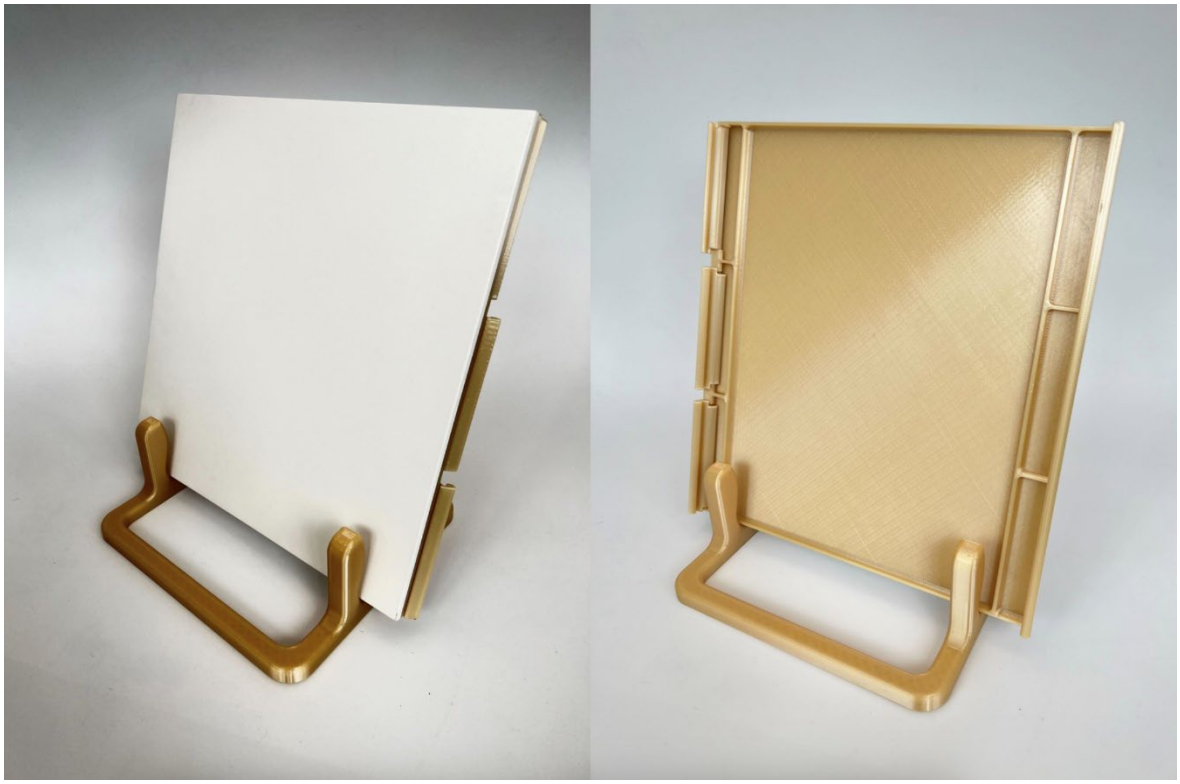

Figure 7. PSU panels manufactured by FDM® process with ULTEM 9085™ filament.

In this project, the PSU panel design and certification was outsourced to an external DOA provider, while AM Craft served as the POA. AM Craft successfully manufactured over 300 of these panels by utilizing FDM® technology and ULTEM 9085™ filament. To ensure smooth finishing and a cohesive appearance with the surrounding cabin, each panel underwent post-processing, including sanding and coating. The project was considered successful because it effectively demonstrated the viability of AM in specific applications, particularly for producing low-to-medium volume customized components.

For design and certification of AM parts, the primary limitation for Finnair DOA is the novelty. To fully understand both the opportunities and limitations of the technology, designers must acquire and maintain an appropriate level of knowledge and training throughout all stages of design and service activities of AM. Such expertise is essential to critically assess potential applications of AM within the domain.

For this thesis, a range of public sources and scientific literature was explored. A critical gap was identified in the availability of publicly accessible yet essential data, and the body of scientific research directly supporting the advancement of AM-related DOA processes was

found to be limited. Where relevant data was available, much of it could not be directly applied to the present work due to differences or lack of internal company standards. The guidelines issued by EASA (CM-S-008), as discussed earlier, provide general direction; however, their broad and non-specific nature leaves uncertainty regarding how commercial aviation operators should build the competence and readiness required for independent AM part certification. CS-25 defines the DOA process for conventional parts in detail with respect to airworthiness. Nevertheless, the novelty of AM introduces uncertainties about which aspects of certification apply to individual and unique AM projects. These factors, together with the potential economic benefits, highlight the need for comprehensive study. Such a study could establish internal guidelines and a roadmap for implementing the most appropriate methods to advance AM within normal service operations at a commercial aviation operator such as Finnair.

4 Methods

This study combined inductive and deductive research methods to explore the design and certification process of AM parts for aircraft interior applications. The study was structured into five steps, as illustrated in Figure 8. The purpose was that each step would produce individual outputs, which ultimately support both exploratory analysis and practical application.

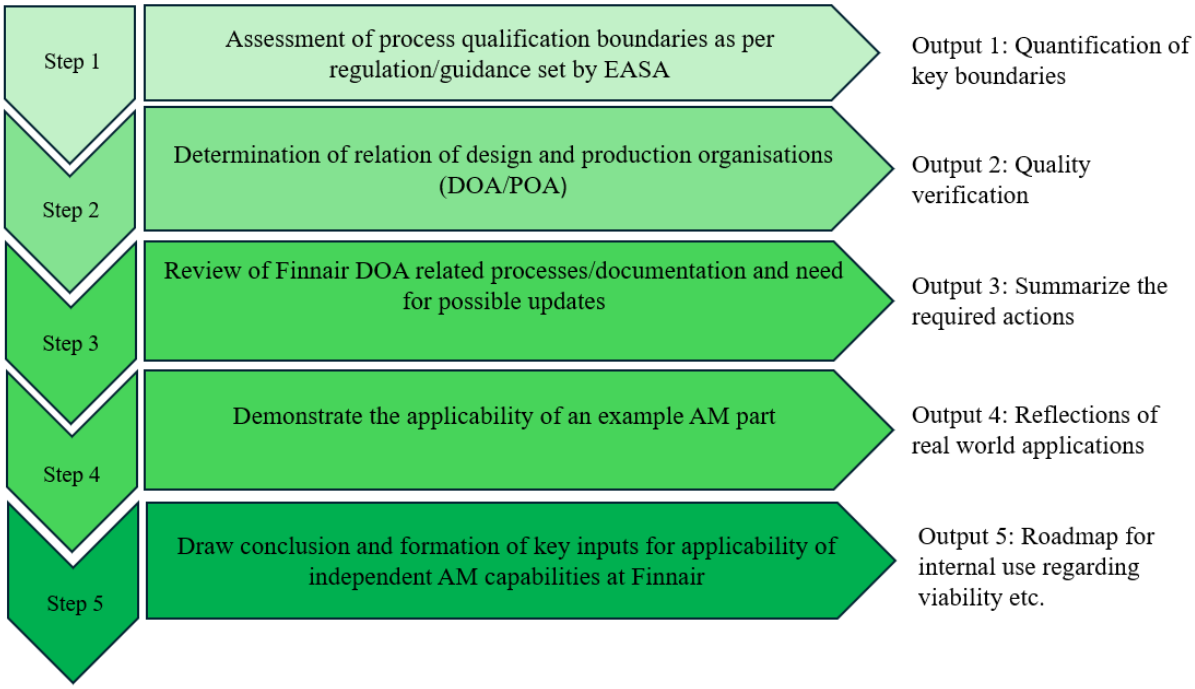

Figure 8. The methodology is described as a step-by-step process.

In the inductive phase, qualitative methods were used to gather and analyze data from industry practices, regulatory guidelines, expert interviews, and existing certification cases. Additional information was collected from professional workshops, and discussions with subject-matter experts representing both DOA and POA organizations, which were realized during organized events. The information was analyzed qualitatively by comparing the contents and by identifying recurring themes related to certification, process qualification, and organizational responsibilities. The inductive phase aimed to identify the organizational

boundaries, that must be considered when adopting AM in commercial aviation operation. The process began with an assessment of the key features, which are required for process qualification as per EASA regulations and guidance (step 1), leading to a quantification of the key regulatory boundaries. Next, the relationship between DOA-POA practices were evaluated (step 2), resulting in a quality verification framework. This was followed by an internal review of Finnair's DOA-related documentation and processes (step 3) to identify any necessary updates, and to produce a summary of required actions for internal alignment.

Based on insights from the inductive analysis, a conceptual framework was developed to guide the integration of AM technologies into existing internal guidelines and organizational structures. The framework defined the interactions between DOA-POA, and regulatory oversight, highlighting documentation interfaces, approval responsibilities, and the flow of compliance evidence required for certification.

In the deductive phase, the conceptual framework, which was developed from the inductive analysis, was applied to a real-world case study (step 4): the design and certification considerations for a floor fitting cover manufactured using FDM® with ULTEM 9085™. The feasibility and certification pathway of the example part were examined, resulting in reflections of real-world applications, including observed opportunities, limitations, and areas of uncertainty in the certification process. The aim of the demonstration was, however, not to go through a real certification but rather act as proof of concept.

Finally, a practical integration roadmap was developed (step 5) for Finnair's use, assessing the viability of AM adoption for non-critical aircraft interior components. Each step is described in more detail below:

Step 1. Identification of process qualification boundaries

The first step on the AM design and certification capability implementation path was to identify the key boundaries for process qualification within the regulatory framework. These boundaries define the possible limitations, and compliance requirements governing the use of AM in aircraft part production.

The requirements were derived primarily from a comprehensive review of relevant literature, with particular reference to EASA CM-S-008 Issue 4. More in-depth insights were obtained

through participation in the EASA Part 21 Workshop and Certification Conference held in Cologne, Germany in autumn 2024, and participation in the "Leading Minds Forum" organized by Materialise in Leuven, Belgium in April 2024. These events brought together engineers and other experts from across the aviation industry to promote cross-industry collaboration and to discuss current challenges, best practices, and opportunities associated with AM implementation. The information gathered from these events was summarized in separate memorandums. Together with the literature review, these materials were used to map the key process qualification boundaries and to establish the regulatory and organizational context for the subsequent steps of this study.

Step 2. DOA-POA coordination

In traditional manufacturing, DOA and POA processes are often quite separated. With AM however, material properties, geometry, and performance are tightly linked to the process parameters and therefore the scope and responsibilities of the collaboration between the DOA and POA should be clearly defined.

Essentially, DOA is responsible for design data compliance and for ensuring that AM processes are adequately defined and controlled. The DOA performs the analysis for part criticality and classification (e.g. C or D for low- non-critical parts) and ensures that all required specifications are transferred to the POA. The POA must ensure conformity to the approved design data and is responsible for manufacturing the actual part (CAAS, 2023). Finnair Design Organization Handbook (DOH) is an internal compliance document (non-public), which describes the general organizational policies and procedures related to DOA-POA cooperation. The existing guidance was reviewed to find out whether AM implementation would trigger any need for updates. Additionally, AM specific literature regarding DOA-POA relations was reviewed (CAAS, 2023) and summarized into a quality-verification framework.

Step 3. Finnair related processes and documentation

The implementation of AM capability requires both updating of existing internal documentation and creation of new documents to ensure regulatory compliance and effective

process control. In this step, the key company documents were reviewed to assess the impact of AM on organizational procedures and design processes.

1. Design organization handbook (DOH)

   DOH is a formal document maintained by the DOA holder to define the organization's structure, responsibilities, procedures, and internal processes related to aircraft design and certification activities. It serves as a comprehensive reference for both internal personnel and regulatory authorities, demonstrating compliance with EASA Part 21 Subpart J (Regulation EU No. 748/2012). The design documentation structure consists of the design data, certification and compliance documents and supporting data. The categories with their related documents (focusing on minor modifications) are presented in Table 4.

Table 4. Design documentation categories for minor modifications/repairs (Finnair DOH).

Category	**Core purpose**	**Main documents**
Design data	Defines the product's technical content and approves the modification/repair	1. Engineering Order 2. Technical drawings/3D models 3. Part manufacturing instructions 4. Installation instructions
Certification and compliance documents	Proves conformity to standards and regulations	1. Change/repair classification 2. Change/repair approval 3. Analysis reports (Test plans, Test reports)
Supporting data	Provides additional evidence and background information that supports the main design and certification materials.	1. Material properties data 2. EASA/FAA publications 3. Maintenance manuals

Finnair's DOH (Rev. 44) and associated design documentation was reviewed for this thesis to determine whether the implementation of AM capability would necessitate updates to the handbook or the supporting documents. The review further aimed to clarify how AM processes might interface with current design practices.

2. Process specification documentation

   Design process specification documents shall be developed by the DOA organization to ensure that design and manufacturing processes are standardized, sufficiently repeatable, and compliant with EASA AMC 21.A.31. Additionally, specific internal guidance material may be required to support the effective implementation of AM, particularly in areas such as 3D-modelling practices, technical drawing standards, and competence development through both initial and recurrent training programs for design engineers. The key process specifications for AM were compiled based on recognized industry standards, including the ISO/ASTM 52900 series, which provide guidance on design principles and process control. Additional regulatory and technical guidance was drawn from EASA CM-S-008 Issue 4 and AIA Additive Manufacturing Working Group (February 2020).

Step 4. Example demo part

A demo part was applied in this thesis to demonstrate the applicability of AM within the design and certification framework. The demonstration was not intended as a real certification project but served as an example to showcase process requirements in a real-world context and thus acting as proof-of-concept for internal evaluation of the feasibility. The chosen demonstration part was a galley floor fitting cover from a Finnair A350 aircraft (Figure 9). Its function is to protect the galley floor attachment fittings from debris or liquids that could potentially cause contamination in the area.

Figure 9. OEM floor fitting cover from A350 galley.

1. Design and modelling process

   The part was initially selected as a potential case by the Finnair DOA, after which the original OEM component was provided to an external POA organization for evaluation. The POA conducted 3D-modelling based on the supplied physical geometry and reference data. In the redesigned version, two separate OEM components were integrated into a single part to simplify the structure and reduce assembly complexity. A prototype of the cover was manufactured by the POA and returned to the DOA for test fitting and further evaluation.

2. Manufacturing process

   The POA maintains a strategic partnership with Stratasys and utilizes FDM® machinery and ULTEM 9085™ material to produce aircraft interior parts. Through this partnership, the POA can implement certified process parameters, datasets, materials, and workflows established by Stratasys, to support traceability, process consistency, and reproducibility

in production. These measures facilitate the validation of the manufacturing process and contribute to streamlining the overall certification pathway.

3. Evaluation and certification approach

   The certification approach for the demo part followed the structure of supplemental document to EASA CM-S-008 Issue 4, which introduces examples from early applications of AM parts of no- or low-criticality. The examples in the document are provided as practical guidance, to illustrate the main aspects that should be taken into consideration during the certification. Through the demo part, the applicability of AM to non-critical aircraft interior components was assessed, along with the documentation and process requirements necessary for potential future certification.

Step 5. Integration roadmap development

The final step was to consolidate key findings from the previous phases into a practical roadmap for Finnair's internal use. The roadmap outlined the key actions which are necessary to establish AM capability for non-critical aircraft interior components within the DOA framework. The roadmap was developed based on steps 1 to 4, and it takes into account the following aspects:

1. Initiation and alignment for AM adoption
2. Competence and infrastructure development
3. Process development and documentation
4. Pilot certification project and validation
5. Operational integration and continuous improvement

The roadmap highlights the alignment of organizational objectives, the development of necessary competencies and infrastructure, and the establishment of compliant processes. Implementation of a pilot certification project enables practical validation before full operational integration, while continuous monitoring and improvement support the adoption of AM.

5 Results

The results presented in this chapter are concluded from publicly available data related to AM research and documents published by EASA. These sources were compared to Finnair internal documentation and consolidated to form the study's results. The required procedures and results are presented in steps, corresponding to the methodology described in Chapter 4. Each step summarizes the key findings, identified requirements, and observations relevant to the implementation AM capabilities within Finnair DOA.

Step 1. Identification of process qualification boundaries

Based on the regulatory review, industry input, and workshop discussions, the following process qualification boundaries were identified:

1. DOA

   The organization must hold a valid DOA. Furthermore, it must be verified with EASA whether the existing DOA authorization covers AM activities, or if a specific AM expansion is required.

   Based on email correspondence with EASA, the approach must be discussed and coordinated with the EASA team leader responsible for overseeing the organizations (in this case Finnair's) DOA. The EASA team leader will determine the most appropriate investigation method, which may include desk reviews, interviews, on-site audits, and/or the involvement of subject matter experts.

2. Competence and training of personnel

   Personnel involved in the design, analysis, and approval of AM parts must demonstrate an appropriate level of knowledge of materials, processes, and applications, as outlined in EASA CM-S-008 Issue 4.

   Discussions during the EASA Part 21 Conference in Cologne confirmed that the "appropriate level of knowledge" should be proportional to the criticality, novelty, and complexity of the part and process. Although no specific AM training programs are

mandated by EASA, generic competence needs for designers are summarized in the conference memorandum (Appendix 1).

For non-critical applications, the required competence may be achieved through basic training in relevant AM technologies, potentially organized in collaboration with POA partners. The memorandum from the leading minds forum (Appendix 2) presents an example of such training content. As part of this thesis, Finnair engaged with several POAs and received structured training proposals covering AM qualification processes and adoption strategies for DOA organizations. These discussions indicated that the pilot certification project could be integrated into the training, thereby supporting capability development and offering mutual benefit to both parties.

3. Change management and safety assessment

The introduction of AM must follow appropriately structured processes to ensure regulatory compliance and operational safety. The general quality and safety compliance are based on the corresponding procedure as shown in Figure 10. As per CM-S-008 Issue 4, it is expected that the initial adoption of AM will lead to higher level of involvement from EASA in compliance verification. Specific audits may be scheduled to evaluate the integration and use of AM within the design organization's audit cycle. These audits may be conducted concurrently with the review of AM applications, rather than solely after their approval, to ensure regulatory oversight throughout the implementation process.

Figure 10. General structure to illustrate safety and quality compliance on organizational level.

The scope of a design safety assessment conducted on a component level aims to identify and demonstrate the part criticality, including potential new damage and failure modes

introduced by AM. This evaluation should be supported by appropriate threat analyses and design safety assessments, such as Functional Hazard Assessment (FHA) and Failure Modes, Effects and Criticality Analysis (FMECA). Both top-down (system-level) and bottom-up (component-level) safety assessments should be applied to ensure that it can be clearly demonstrated to EASA that the AM part does not adversely affect safety. The demonstration should consider all likely defects, damage, and failure modes, relative to conventional manufacturing technologies used for comparable applications, and must account for potential non-conformities and their impact on structural and system functions. The chart shown on Figure 11 depicts the design safety assessment to support no/low criticality classification.

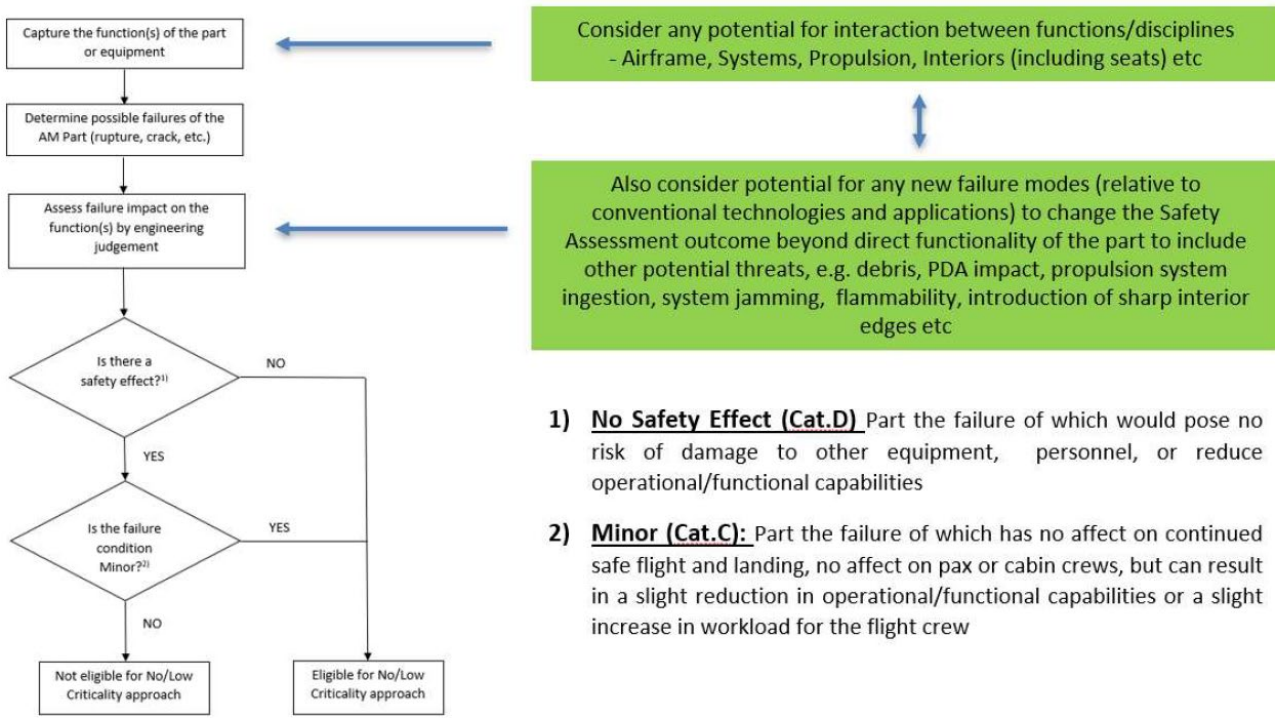

Figure 11. Design safety assessment chart to support no or low criticality classification (CM-S-008 Issue 4).

For each individual design certification project, safety and non-criticality analysis is performed as per CS-25 applicable paragraphs e.g. listed on Table 3, and those aspects are to be declared on certification and compliance documentation (Table 4). In order to

fulfil the certification requirements, all related aspects should also be appropriately justified.

4. Coordination between DOA and POA

   All AM-specific process owners must be designated within the DOA and POA and the AM-related processes must be formalized, documented, and controlled within the organization's quality system. The coordination framework for these activities is discussed further in Step 2.

5. Internal standards, procedures and guidance updates

   Internal design and production manuals must be checked and verified that the content complies with AM and is revised as necessary. Organizational standards shall be created to include AM-specific design guidelines, process qualification criteria, non-conformance management for AM, approval routes and reporting obligations etc. This is reviewed in further detail in Step 3.

6. Early engagement with authorities

   It is emphasized by EASA that the competent authority must be proactively engaged by the organization during early stage of the AM capability implementation. Within this work, the EASA team leader was contacted by email to receive further guidance and practical information regarding the early engagement. However, no response was received within the timeframe of this work, hence the specifics remain currently unclear.

Step 2. DOA-POA coordination

EASA Part 21 Subpart J (Regulation EU No. 748/2012) requires that the DOA- and POA processes are properly aligned and coordinated. The process for DOA-POA coordination for any component, regardless of the manufacturing method, is defined in Finnair DOH, but the description within the handbook remains at a rather general level. The existing procedures in DOH can be applied to AM production. Nevertheless, since the DOH does not include descriptions of specific manufacturing methods, AM-related production details should be defined separately. It is important that the development and verification of certain AM process-specific elements are accounted for at an early stage. While these details are not

required to be integrated into the DOH itself, they should be standardized as supplementary procedures dedicated to AM. The content of existing required processes described in Finnair DOH, and the AM specific procedures can be summarized as follows:

1. Existing process in accordance with Finnair DOH (general level)

    a. Formal DOA-POA arrangement:

        The arrangement between DOA and POA must be formalized and signed by both organizations. Responsibilities, points of contact, and references to interface procedures should be provided, either as extracts or as the full handbook.

    b. Transfer of design data:

        The DOA is responsible for providing up-to-date design data (e.g. drawings, specifications, manufacturing processes, surface treatments, post-processing, and quality requirements) to the POA. The POA ensures that manufacturing activities align with the approved design data. Continuous communication between DOA and POA must be maintained throughout the design, certification, and production phases.

    c. Feedback system for non-conformances:

        The POA is required to provide feedback on any potential non-conformances, errors, or deficiencies in design, which shall be addressed and resolved by the DOA.

2. AM specific elements to be verified between DOA-POA

    a. Process qualification and control:

        AM-specific material and process specifications, together with process control documents, shall be developed in cooperation with design and production. The POA implements the AM processes in accordance with approved design data, maintains process stability, and ensures the qualification of machines and processes. This is reviewed in further detail in Step 3.2.

b. Knowledge transfer and training:

Both DOA and POA personnel must possess sufficient competence in design, production, and inspection to understand AM-specific risks and controls. The DOA shall establish a training program for AM, including initial and recurrent training, to ensure that designers and other relevant personnel acquire the necessary knowledge and skills to perform their responsibilities effectively. The training of the designers should be established in cooperation with POA (e.g. appendix 2) to support consistent AM implementation across organizations; however, it is noted that such training may also be obtained from other external providers when appropriate. Training and qualifications shall be specific to the AM processes and materials employed.

The processes described and their connections are illustrated in more detail in Figure 12.

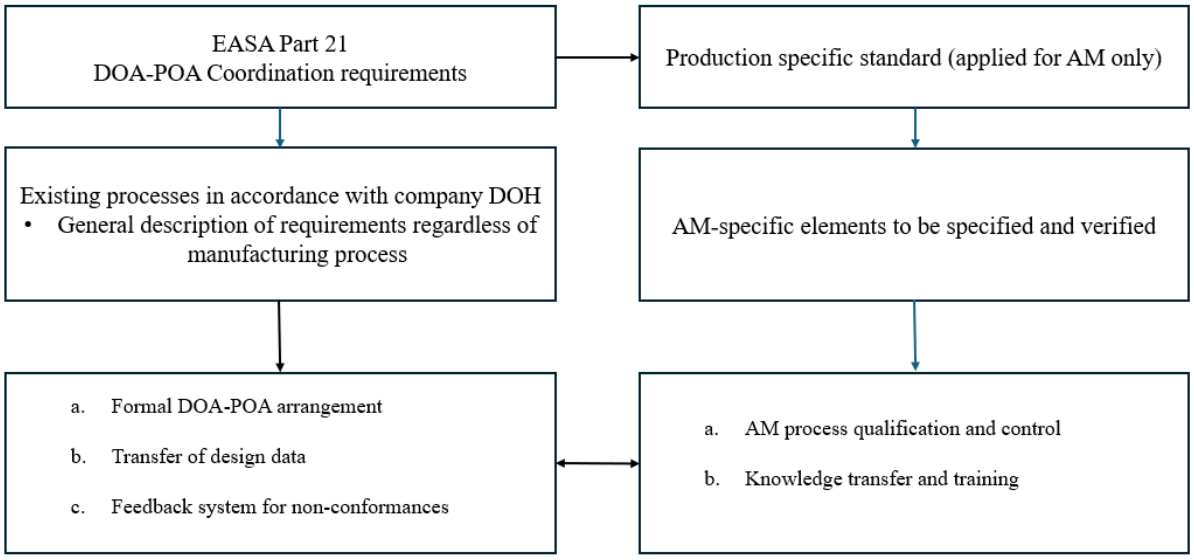

Figure 12. DOA-POA coordination.

Step 3. Finnair related processes and documentation

The implementation of AM capability within Finnair's DOA framework may necessitate updates to internal documentation and procedures to ensure regulatory compliance and effective process control. Beyond DOA–POA coordination, potential revisions to the DOH

were identified, along with the creation of new AM-specific documents. These aspects were reviewed in this step.

1. Design organization handbook

   After reviewing Finnair DOH (Rev 44.), the following chapters were identified for further evaluation and potential revision:

   a. Scope of work: Confirm with EASA whether AM capability should be mentioned in the scope of work chapter, e.g. with following content: “AM technologies for polymer parts are included in cabin scope.”

   b. Training policy and requirements for designers and Compliance Verification Engineers (CVEs): Assess whether provisions for initial and recurrent training related to AM technologies should be established and documented in this chapter.

   c. Description of used equipment: For the design tools the DOH currently states the following: “AutoCAD (Computer Assisted Design) system is used for drafting and design work.” If new design software for AM is introduced, this section should be updated accordingly.

   d. Manufacturing instructions: A dedicated manufacturing instruction template should be created for AM processes. Consider whether that should be mentioned in this chapter.

   e. The design document templates: The templates listed earlier in Table 4 were also reviewed as they are included as appendix of DOH. While most remain applicable, technical drawing templates may require updates to accommodate AM-specific parameters. Additionally, the Change/Repair Classification Template, used to determine whether a modification is major or minor, should be carefully reviewed with the Finnair CVE (and EASA Team Leader) to determine whether AM implementation as a new manufacturing method could influence classification criteria in any checklist items.

2. Process specification documentation

   The process specification documentation ensures that AM design and manufacturing activities are performed under controlled and repeatable conditions, providing a

verifiable link between design intent, process execution, and airworthiness compliance. The process specifications should be created by the DOA, in cooperation with the POA, to form the basis for Process Control Documents (PCDs) established by the POA. Once the process is qualified, the PCD is frozen, and any subsequent change requires re-qualification before being implemented in production.

Based on CM-S-008 Issue 4, relevant ISO/ASTM standards, and AIA Additive Manufacturing Working Group (February 2020) the key process specification areas for qualified process are identified as follows:

a. Design requirements and validation: Design intent must specify functional criteria, geometric features, and dimensional tolerances, with AM-specific features such as layer orientation, support structures, potential distortion, and surface finish. Design values may be defined through AM machine operational and process performance qualification, supported by relevant material property data. Validation for low- or non-critical components may rely on dimensional checks, comparison with existing components, or functional verification rather than extensive structural testing, reflecting the reduced criticality of the parts. From existing standards, ISO/ASTM 52910 can be utilized as a general AM design guidance and ISO/ASTM 52911-2 for process-specific design advice for PBF of polymers. Standardized description of part position/orientation should follow ISO 17295.

b. Material specifications: All AM feedstock, whether filament or powder, must have documented properties and traceability. The DOA must ensure that material certificates of conformity are obtained, and that storage and handling conditions are maintained by POA (e.g. by on-site audits) to prevent degradation, contamination, or changes in performance. ISO/ASTM 52925 (polymer PBF) and 52903-1 (polymer MEX) can be used as further guidance on material specifications.

c. Process parameters/machine control: The DOA in cooperation with POA must specify critical process parameters such as layer thickness, build orientation, laser power or print speed, infill, and pre- or post-heat conditions. Machines used for production must be qualified, calibrated, and maintained under controlled

conditions. The manufacturing approval is usually valid only for one specific AM printer. The Machine Type and Serial number must be specified within the PCD. Process parameters and allowable tolerances should be documented, and any deviation from these parameters must trigger an evaluation to ensure continued compliance. ISO/ASTM 52903-2 provides specific descriptions for process and equipment qualification topics.

d. Build preparation: Correct file preparation, including metadata and slicing parameters, must be ensured. The orientation strategy and support structures should be defined to achieve consistent mechanical performance and surface quality, and any instructions for post-processing should be clearly documented. ISO 17295 provides comprehensive instructions for AM general manufacturing principles, while ISO/ASTM 52915 provides more specific guidance related e.g. metadata and slicing parameters.

e. Post-processing, inspection & testing: The DOA must provide guidance on the removal of support structures, heat treatment, surface finishing, and cleaning processes. Certification of compliance with CS-25 is expected to be achieved by test, or analysis supported by test. According to CM-S-008 Issue 4, it has been increasingly requested by industry to replace physical testing with modelling and simulation, but that has been seen challenging by EASA, due to e.g. anisotropy and competing damage modes, which can lead to lower safety margins if not properly understood and modelled. For low- or non-critical parts, visual inspections, dimensional measurements, and functional checks (e.g. coupon level testing) are generally sufficient to verify compliance. Flammability tests are essential even for non-critical parts. Development with non-metallic AM parts has shown that flammability depends on manufacturing factors such as infill and print orientation. Therefore, a supplier's certificate of conformity for feedstock is not sufficient to proof flammability requirements without some testing of an article printed at the production facility. ISO/ASTM 52903-2, 52910, 52911-2, and 52927 and CS-25 Appendix F, FAR 25.853 can be used as further guidance on these items.

f. Qualification and change control: The AM process must be demonstrated to consistently produce parts that meet design requirements. Once qualified, the

associated PCDs are frozen, and any subsequent changes to materials, machines, software, or parameters require re-qualification. Change management procedures ensure that modifications do not compromise part quality or regulatory compliance. ISO/ASTM 52920 specifies criteria for AM processes and quality-relevant factors across the production chain and can be used as a baseline for process qualification and change control in industrial AM in parallel with ISO/ASTM 52930 (AM qualification principles).

g. Documentation and record-keeping: This area includes the maintenance of design data such as technical drawings and 3D models, certification and compliance evidence such as approval records and change classifications, and supporting data including material certificates, inspection reports, and supplier information. Alongside documentation, the competence and training of personnel must be addressed. Implementation of AM would require creation of new internal instruction material for designers related to 3D-modelling practices, technical drawing standards, and competence development. ISO/ASTM 52910 can be utilized for this purpose. ISO/ASTM 52915 defines AM file format as a standardized interchange format for 3D models, metadata, and build parameters and that information can be used to ensure consistent digital records for design data.

The key process specifications, with requirements and example acceptance criteria, are summarized in table 5, including their relevant standards. Each area should be addressed by using the relevant ISO/ASTM standards as guidance, along with applicable EASA documents. Collaboration with major industrial AM system providers (e.g., Stratasys, EOS, or equivalent, depending on the selected technology) is also recommended to ensure alignment with best practices and equipment-specific criteria. Establishing this cooperation early in the qualification process supports data exchange, equipment calibration consistency, and conformity with both industry and regulatory expectations.

Table 5. The key process specification areas of relevant ISO-standards that should be applied to the integration of AM process.

Specification	Requirement	Standard/Reference	Acceptance Criteria
Material (Powder)	Define chemical composition, particle size distribution, moisture content, and reuse criteria	ISO/ASTM 52925 (AM of polymers. Feedstock materials. Qualification of materials for L-PBF parts)	Meets chemical and physical property limits
Material (Filament)	Define filament diameter tolerance, ovality, moisture control, and storage conditions	ISO/ASTM 52903-1 (AM. MEX-based additive manufacturing of plastic materials. Part 1. Feedstock materials)	Meets chemical and physical property limits
Machine Qualification	Qualification of polymer AM machines including calibration and environmental control	ISO/ASTM 52903-2 (AM. MEX based additive manufacturing of plastic materials. Part 2. Process equipment), OEM Guidelines	IQ/OQ/PQ completed, calibration records available
Build Process Parameters	Define critical process parameters (temperature, layer thickness, scan speed, cooling) and control limits	ISO/ASTM 52911-2 (AM. Design. Part 2. Laser-based powder bed fusion of polymers), ISO 17295	Parameters within validated range
Post-Processing	Define requirements for depowdering, annealing, surface finishing, and inspection	ISO/ASTM 52910 (AM. Design. Requirements, guidelines and recommendations), ISO/ASTM 52911-2	Post-processing steps completed per specification
Inspection and Testing	Define dimensional checks, density verification, e.g. testing methods for polymers	ISO/ASTM 52927 (AM. General principles. Main characteristics and corresponding test methods, ISO/ASTM 52903-2	All parts meet dimensional and mechanical property requirements
Flammability	Perform flammability tests for cabin interior parts per CS-25 Appendix F	CS-25 Appendix F, FAR 25.853	Pass/fail per burn length and time criteria
Static Strength	Perform static load tests for structural polymer parts	CS-25, ISO/ASTM 52927, ASTM D638, ASTM D790	Ultimate load achieved without failure
Environmental and Functional Tests	Perform humidity, temperature cycling, and chemical resistance tests	ISO/ASTM 52900, ISO/ASTM 52910, ISO/ASTM 52920	No degradation beyond allowable limits
Documentation and Traceability	Ensure traceability of polymer batches, build files, and process data	ISO/ASTM 52924 (AM of polymers. Qualification principles. Classification of part properties), ISO/ASTM 52915	Full traceability maintained in PCD

Step 4. Example demo part

The demo part was applied to benchmark the specification requirements and evaluate the practical implications of AM certification within the DOA framework. The purpose was not

to execute a real certification project but to simulate the process and identify gaps, challenges, and opportunities for future implementation.

1. Part description and design drivers

   The selected part was a galley floor fitting cover from an Airbus A350 aircraft. A prototype of the redesigned AM part was manufactured by the POA, replicating the physical geometry to the OEM cover, as shown on Figure 13.

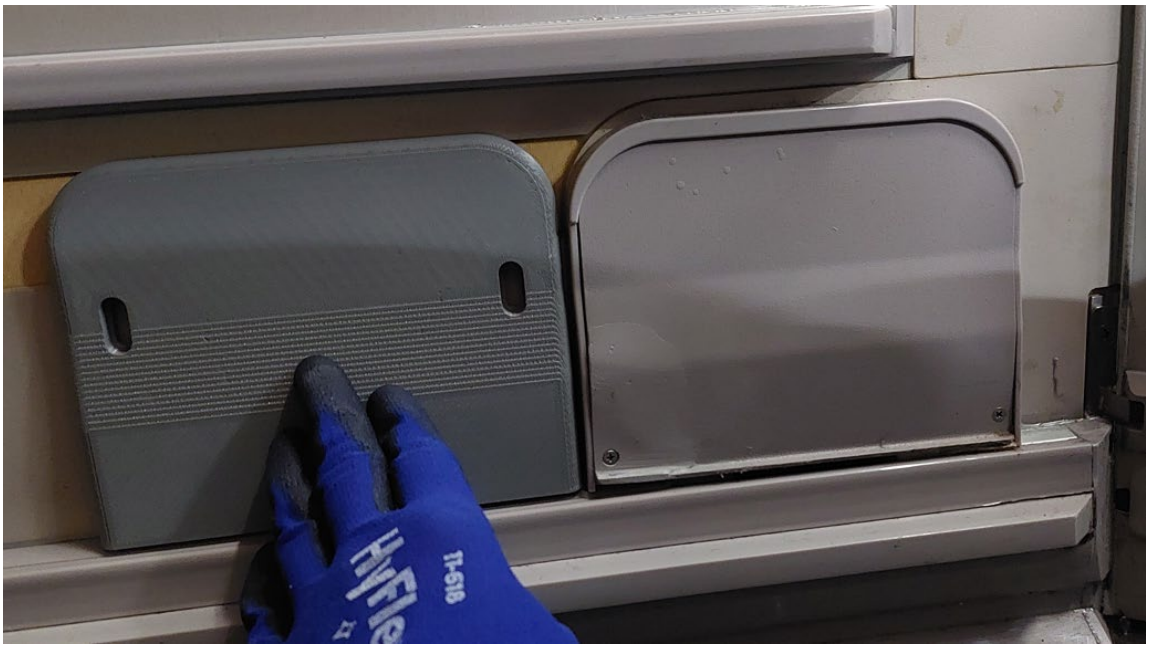

Figure 13. AM part (left) consolidating the original two-piece OEM cover (right) into a single component.

The OEM design consists of two separate components: a frame secured to the wall using two quick-release fasteners, and a cover attached to the frame with two small screws. In the redesigned AM version, these elements were consolidated into a single part to simplify assembly and enhance durability. To ensure proper sealing in the new configuration, aircraft-grade silicone sealant would be applied around the perimeter of the cover during installation.

While reducing part count and enhancing durability were relevant objectives, the primary design drivers were the cost and limited availability of the OEM components, factors that often represent the most critical constraints in such projects.

Based on the initial quotation received from the POA, it was determined that the lead time could be shortened from several months to a matter of weeks, and the component cost significantly lowered by replacing the OEM part with an AM alternative. Additionally, possible weight reduction of the part could serve as an important design driver, resulting in further cost-savings.

2. Criticality and safety assessment

   According to EASA CM-S-008 Issue 4, components with a mass below 0,45 kg (or 0,15 kg if attached to a seat) and not associated with any safety equipment may be considered candidates for no- or low-criticality classification. The weight of the cover produced was less than 0,45kg and it is not related to any safety equipment or seats. Based on these criteria, and with reference to the EASA design safety assessment chart presented in Figure 11, the floor fitting cover qualifies as a candidate for no- or low-criticality component. Determining whether the part should be classified as Category C (low-critical) or Category D (non-critical) would require more thorough evaluation in collaboration with the CVE and, for initial certification projects, potentially with EASA to ensure alignment with regulatory expectations.

3. Material and manufacturing process

   The POA operates under a strategic partnership with Stratasys, utilizing ULTEM™ 9085 material and the FDM® process for aircraft interior part production. This partnership provides a significant advantage in process control, as all critical parameters, datasets, materials, and workflows are predefined and validated by Stratasys. By adhering to these established specifications, the manufacturing process achieves a higher degree of consistency and traceability, which in turn facilitates process validation and compliance verification by the DOA. PCD must include specifications for material handling (e.g. batch traceability) and storage (e.g. temperature, humidity) and machine qualification. The manufacturing approval is only valid for one specific AM printer. The Machine Type (Stratasys Fortus 900mc) and Serial number (S/N) must be specified within the PCD.

4. Post-processing and inspection

   Post-processing and inspection are conducted in accordance with PCD. For the floor fitting cover, finishing operations would be limited to the removal of support

structures and cleaning of the part, as the component is not visible to passengers. Consequently, no additional surface treatments, such as sanding or coating, would be mandated. Any deviations from the defined process must be documented and subjected to formal approval prior to implementation.

5. Testing and compliance

   The required tests must be specified case by case along with their acceptance criteria. Testing in this case could include e.g. the following:

   Static Strength: Component-level tests conducted to validate retention and cyclic impact loads. Failure modes compared to the OEM part.

   Flammability: Coupon-level flammability tests performed to confirm compliance with CS-25 Appendix F and FAR 25.853.

   Other Considerations: The final part to be visually inspected at each processing step, as per AM process specifications and drawings.

Step 5. Roadmap for design and certification capability for AM parts

The final step consolidates the outcomes into a roadmap for developing AM design and certification capability within Finnair's DOA. The roadmap provides a practical framework to guide Finnair through a phased implementation of AM activities for non-critical aircraft interior parts, ensuring compliance with EASA Part 21 Subpart J. The roadmap (Figure 14) illustrates the sequential development of the design- and process capability. However, several activities should overlap to ensure efficient resource utilization and continuity of development. The process is divided into five progressive phases, each representing an individual stage in the readiness.

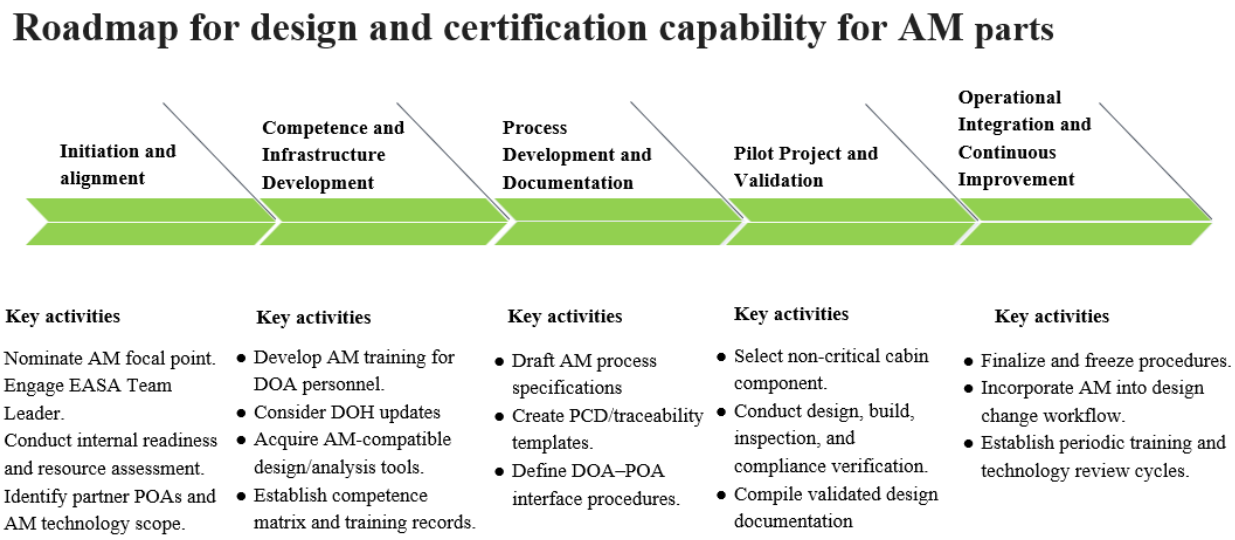

Figure 14. Roadmap for AM capability implementation.

1. Initiation and Alignment

   The first phase establishes the foundation for AM capability development by aligning Finnair's internal objectives with regulatory requirements and strategic priorities. The main focus is to verify clear governance and early engagement with EASA. Activities include the nomination of an AM focal point within the DOA, conducting an internal readiness assessment, and identifying appropriate AM technologies and potential production partners (POAs). This phase aims to provide a clear understanding of the regulatory framework (EASA Part 21, Subpart J) and to define the boundaries of the initial implementation scope. The output of this phase is a documented AM implementation plan, authority communication record, and a preliminary risk and capability assessment.

2. Competence and Infrastructure Development

   Second phase focuses on developing the foundational competence and infrastructure necessary for AM design and certification activities. Initial training programs should be introduced for design engineers, and for CVEs, covering AM principles, design rules, materials, process control, and regulatory aspects. Simultaneously, the existing company documentation, such as DOH, should be reviewed and updated as necessary to reflect AM-related responsibilities. The need for appropriate software tools must also be assessed, and access should be ensured. By the end of this phase, Finnair's

DOA will have the internal competence and digital infrastructure, which is required to manage AM-related design tasks in compliance with regulatory expectations.

3. Process Development and Documentation

   Once the necessary competence and infrastructure have been established, the next phase focuses on formalizing the processes required to perform and control AM design activities. This involves defining and documenting AM-specific procedures related to design and production. Process specifications should be created in co-operation with POA, in accordance with EASA CM-S-008 Issue 4 and ISO/ASTM standards. Key elements include PCD, material traceability procedures, and inspection templates. Furthermore, the DOA–POA interface must be refined to ensure effective communication of design data and manufacturing feedback. Phase 3 concludes with internal verification of the applicable documents to confirm readiness for EASA oversight.

4. Pilot Project and Validation

   Pilot project serves as the practical validation of all developed procedures and documentation through the execution of a representative AM project. A non-critical aircraft cabin component should be selected for the pilot certification project e.g. the galley floor fitting cover. The DOA will perform the design activities in cooperation with POA, after which the POA will execute the manufacturing process under controlled conditions. Verification and compliance will be demonstrated according to the applicable requirements of CS-25 and pre-determined acceptance criteria. The outcome of this phase is a fully validated design documentation package and conformity verification evidence, which collectively forms the basis for procedural refinement and internal approvals.

5. Operational Integration and Continuous Improvement

   After successful validation, AM-specific procedures are finalized, approved, and fully integrated into the existing design change and modification workflows. At this stage, the plan for continuous improvement process is established, including recurring training updates, audits, and process reviews. Lessons learned from both production and in-service operations should be systematically captured to refine design rules, process control criteria, and quality assurance. Continued engagement

with EASA ensures that procedures remain compliant and up to date with evolving requirements. Completion of this phase signifies that DOA has achieved a self-sustaining AM design and certification capability.

6 Discussion

The results provide an overview of the design and certification requirements for AM parts in commercial aviation for non- or low-critical aircraft interior components. The findings confirm that while AM can offer significant potential benefits, such as reduced lead times, cost savings, and design flexibility, its integration into certified aviation workflows remains relatively complex. As stated in CM-S-008 Issue 4, current EASA requirements for some applications of no or low criticality may be considered excessively conservative due to immaturity or lack of experience and data. Development and refinement of the requirements are expected in the upcoming years once confidence and experience with AM is better established.

The results of this study correspond for the most part with the purpose and research questions outlined in the introduction. The first research question, concerning the current status and applicability of AM in commercial aviation, was addressed through a comprehensive literature review. The second question, focused on regulatory frameworks and standards, was answered by mapping EASA Part 21, CS-25, and CM-S-008 Issue 4 guidance, alongside relevant ISO/ASTM standards, to define process qualification boundaries for non- and low-critical parts. The third question, regarding practical implementation for DOA, was addressed through the five-step methodology, which provide actionable measures for competence development, DOA–POA coordination, and documentation updates. Finally, seeking guidelines or process models was fulfilled by consolidating key requirements into a roadmap, offering a practical model for Finnair for AM design and certification capability implementation. It must be emphasized that the example demo part was created solely by design engineer point of view, and the validity of the results would need to be officially verified and thus, further specified if applied as a real certification project. In real life, the AM certification would require input and cooperation between several stakeholders, including Finnair DOA members, POA, and EASA Team Leader.

In fact, the most challenging aspect of AM implementation lies in the process specification and qualification. Current regulatory guidance clearly defines what must be controlled but provides limited direction on how these controls should be applied in practice. This part of the process places a considerable burden on DOA holders to interpret and implement

appropriate standards, often requiring case-by-case justification and close engagement with authorities.

To illustrate the identified aspects influencing AM design capability implementation under Finnair DOA, a SWOT analysis was performed (Figure 15).

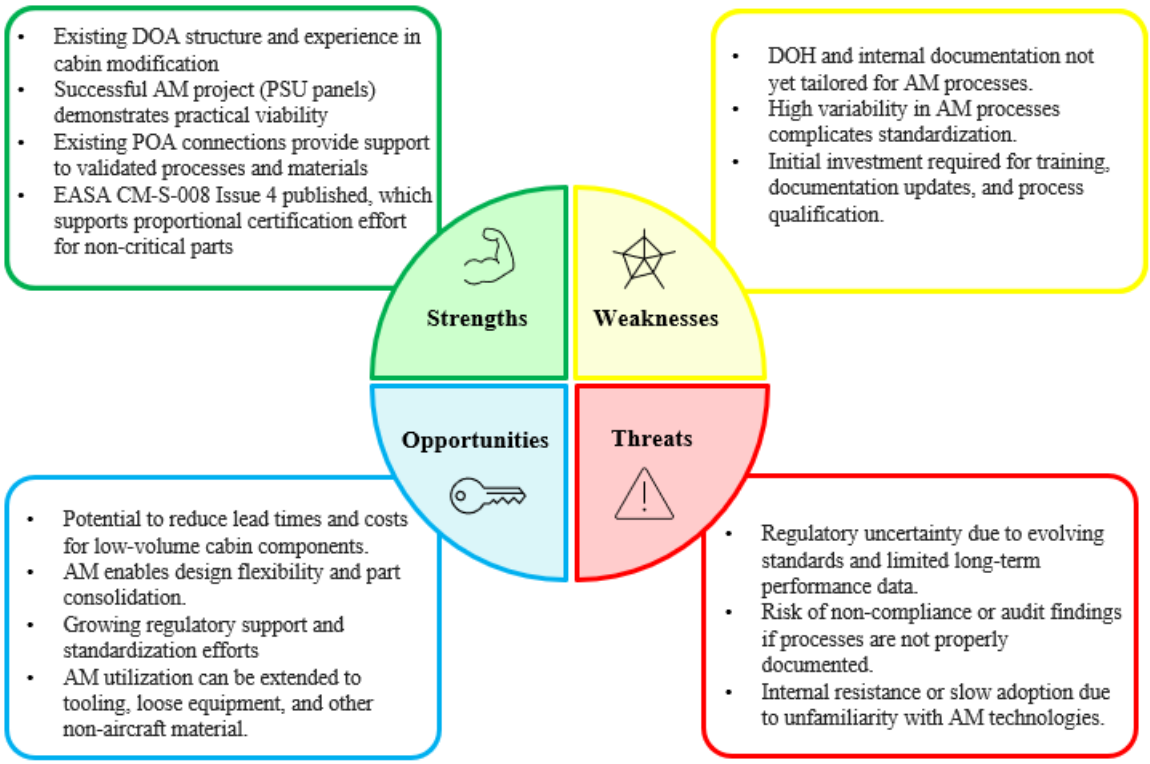

Figure 15. SWOT analysis for AM design capability implementation under Finnair DOA.

AM presents potential for innovation, cost savings, and efficiency in cabin modification, that are supported by emerging regulatory frameworks. As discussed before, the challenges remain in process standardization, documentation, and regulatory confidence. To mitigate risks and ensure successful implementation, thorough management and training is required. Due to regulatory concerns, AM can sometimes be seen more as a threat instead of an opportunity, which can slow down the adoption of the technology.

From a business perspective, the main driver of AM implementation relates to the cost and availability of the parts. Traditional procurement of OEM components often involves extended delivery cycles, which can range from several months to even more than a year in

some cases, and result in significant operational delays and increased maintenance costs. AM capability can potentially enhance operational resilience and reduce dependency on OEM suppliers. Although the unit cost of AM parts is typically remarkably lower than for OEM components, the initial investment required to implement and maintain AM capability within a DOA is substantial. It includes costs associated with acquiring specialized design tools, updating internal documentation, training personnel, and establishing process qualification frameworks. A comprehensive evaluation would be required to determine whether it is economically viable for Finnair to develop in-house AM design capability or would outsourcing remain the more cost-effective option. The decision would largely depend on the expected utilization rate of the capability. However, this study was focused on the technical aspects of the capability implementation, and the economic viability fall beyond the scope.

Even if Finnair would not intend to pursue AM capability under its DOA, it might yet be advantageous for design engineers to gain at least basic level knowledge and experience in AM through training programs. Familiarity with AM principles enables designers to identify potential applications and value drivers, even when design and manufacturing are outsourced. Furthermore, AM could be utilized beyond aircraft interior components, for example, in producing specialized tools, jigs, or non-aircraft materials such as catering equipment and loose items, which can offer additional operational efficiency and cost savings.

7 Conclusions

The research confirms that AM can offer considerable benefits for commercial aviation, including reduced lead times, enhanced design flexibility, and production cost savings. These advantages are particularly relevant in the context of supply chain management and the increasing demand for customized cabin solutions.

The study also highlights the challenges and obstacles of the adoption of AM in aviation due to a relatively complex workflow. The regulatory environment is evolving, but it still lacks detailed procedural guidance, placing significant responsibility on DOA holders to interpret and implement standards appropriately. The CM-S-008 Issue 4 by EASA provides a foundational framework for the certification, but case-by-case substantiation and close coordination with authorities is still needed, due to its non-binding nature and generality.

The methodology applied in this thesis, covering regulatory boundary identification, DOA-POA coordination, internal documentation review, demonstration part evaluation, and roadmap development, has provided a structured approach to assess the feasibility of AM integration. The demo part acted as a proof-of-concept to illustrate the practical implications of AM adoption.

The findings suggest that successful implementation of AM capability requires early engagement with regulatory authorities, clear definition of internal processes and responsibilities, development of AM-specific documentation and training programs, close collaboration between DOA and POA, and potentially a pilot certification project to validate procedures and build organizational confidence.

While AM is still sometimes perceived with caution in aviation industry due to regulatory uncertainties, its potential to transform aircraft interior design and aftermarket operations is evident. With continued development of standards, increased regulatory clarity, and accumulation of operational experience, AM is expected to become a mainstream solution for certified aviation components among other manufacturing methods.

8 Future studies

The process qualification in aviation remains one of the most complex aspects of AM implementation. Future research should focus on developing standardized qualification protocols, particularly for polymer-based processes. Comparative studies between different machine models, feedstock batches, and build strategies could help to establish the qualification criteria.

In addition to physical qualification, simulation and virtual testing offer opportunities to streamline certification processes. Modelling tools, which can predict anisotropic behavior, residual stresses, and failure modes could reduce dependency on extensive physical testing for non-critical components, even if these models must be validated through empirical data to ensure accuracy and reliability.

Sustainability is another topic that requires attention. Current high-performance polymers, such as ULTEM™ 9085, cause challenges in recyclability and environmental impact. Research into bio-based flame-retardant polymers and closed-loop recycling systems for AM feedstock could help to reduce the ecological footprint of AM adoption.

Finally, economic and operational aspects would require further exploration. Cost-benefit analyses comparing in-house AM capability with outsourcing models and scalability could guide strategic decisions for airlines and MROs.

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Appendix 1.

MEMORANDUM

Date: 26.11.2024

Subject: EASA Part 21 Workshop – Side Meeting 4: Additive Manufacturing

Location: EASA Headquarters, Cologne, Germany

Facilitator: EASA

Participants: Representatives from EASA and aircraft MROs, Design & Production Organizations, and AM Industry Experts

Agenda Summary:

The workshop focused on revision changes to CM-S-008 Issue 4 and discussed the regulatory framework for AM under EASA Part 21. Key topics included certification challenges, material standards, production oversight, and future guidance. Participants engaged with EASA DOA experts on specific concerns.

Key Highlights:

1. CS-25 revisions.

2. Certification proportionality: Draft tables presented to align certification effort with part criticality.

3. Material and standards: Emphasis on repeatability, traceability and use of ASTM/ISO standards.

4. Design and production oversight: Importance of early engagement, DOA/POA interfaces, and change management under Part 21.A.147.

5. Industry collaboration: EASA encouraged ongoing dialogue to refine standards and certification pathways.

6. Training requirements: No specific training mandated for DOA designers, generic needs indicated in CM-S-008. Non exhaustive list:

- DOA/POA Interface (e.g. proper transfer of information to POA and understanding of the meta data and AM file transport)
- Technological understanding of the process to be used
- Technological understanding of the characteristics of the machine model to be used (e.g. laser type, laser interactions if multiple lasers, etc.)
- Use of material specs.

Appendix 2.

MEMORANDUM

Date: 17.-18.04.2024

Subject: Leading minds forum

Location: Materialise Headquarters, Leuven, Belgium

Facilitator: Materialise

Participants: Engineering representatives from aircraft manufacturer (Airbus), Production Engineers (Materialise), Design Engineers and Management from aircraft MROs.

Agenda Summary:

The purpose of this forum was to foster cross-industry collaboration and accelerate the adoption of AM in aerospace through expert-led discussions, breakout sessions, and networking. Key theme was AM cabin applications for airlines.

Key Highlights:

1. Networking with industry partners and stakeholders.
2. Factory tour providing new insights about SLS and FDM manufacturing in aviation.
3. Discussions on certification, supply chain resilience, and industrialization of AM.
4. Training for DOA in cooperation with POA. Example of AM for Aero 2-day training program:
   Day 1: AM Awareness & landscaping
   - Introduction to AM technologies and their aerospace applications.
   - Design guidelines and value drivers for AM.
   - Case studies and practical examples of AM in prototyping and serial production.
   - Familiarization with production facilities

   Day 2: AM process optimization, certification & quality
   - Historical context and strategic value of AM in aerospace.
   - Deep dive into qualification of flying parts and DOA processes.
   - Lessons on industrializing FDM and SLS parts in compliance with aerospace standards (e.g. 21.G).
   - Certification and quality management frameworks, including EASA's role.