Commercial Airplanes

Boeing Design Approval Holder Update for 7th Joint EASA-FAA AM Workshop

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Boeing Design Approval Holder Update

Boeing Global AM

- 20 Boeing AM Sites Worldwide
  - US
  - Canada
  - Australia
  - UK
- Multiple Innovation Cells Nationwide

Flight Hardware

- 140,000+ AM Parts Flying on Enterprise Platforms
- Metal and Polymer
  - Commercial Aircraft
  - Defense Platforms
  - Vertical Lift
  - Satellites
  - Autonomous
- Complex Assemblies
- Building on decades of Experience in AM

Value Stream Capabilities

- Printing, Post Processing, Inspection & Qualification
- Metal:
  - Laser powderbed, E-Beam Powder bed, DED wire, DED powder
- Polymer:
  - FFF, SLS, SLA, Large Area Polymer
- Flight Hardware, Production Tooling, Shop Aids, Rapid Prototyping, Mockups

Digital Integration

- End-to-End Value Stream:
  - Digital Twin, Digital Thread for quality and scale
  - Data analytics, Machine Learning
  - Model Based Engineering
  - Build File Development & Simulation

A Holistic View of Boeing Additive Manufacturing (BAM)

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Boeing Additive Manufacturing Polymer Timeline

1990

Stereolithography (SLA)
- Engineering Models
- Wind Tunnel Models
- Tooling

1995

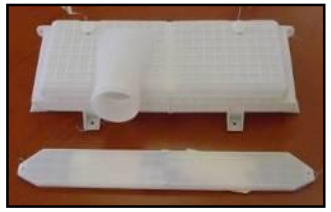
Selective Laser Sintering (SLS)
- F/A-18 & F15
- Production Parts & Tooling

2000

Production Aircraft Delivered with SLS Parts
- F/A-18, F-15, & P-8
- ~1500 SLS Parts / Year

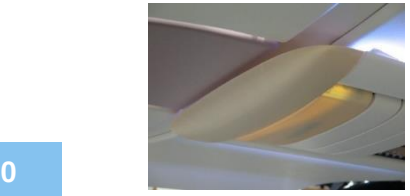
2005

Fused Filament Fabrication (FFF)
- Tooling
- Engineering Models



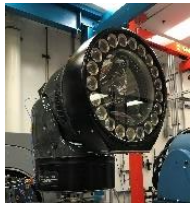
2010

SLS Nylon for BCA
- 787 & 777
- Filter Box Assembly



2015

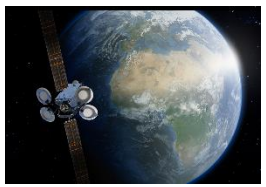
FFF ULTEM 9085
- First Production BCA Parts
- 777 Interior Parts



CF-PEKK (SLS)
- CH-47
- High Intensity Searchlight

2020

CF-PEKK (SLS)
- CST-100 Starliner
- 170 Interior Parts



CF-PEKK (SLS)
- International Space Station (ISS)
- ATA Carrier Pallet

FFF PEKK Adopted
- MQ-25 & T-7A
- Environment & Control Systems

LSAM Qualification
- Large Application Polymer Tooling

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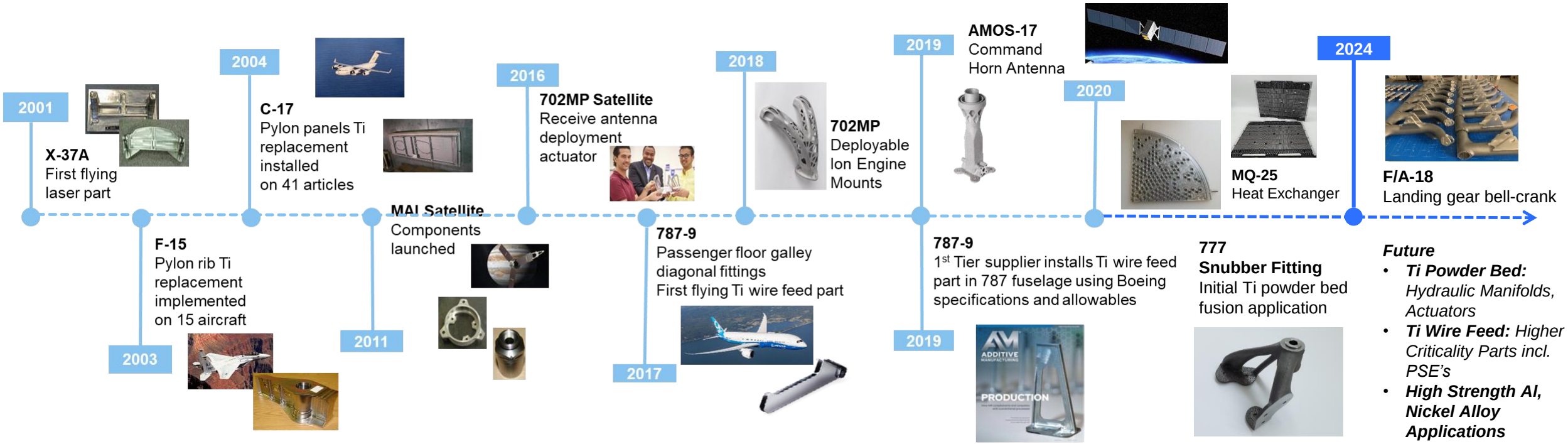
Boeing Additive Manufacturing Metallic Timeline



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Metallic AM Components for BCA

Material, AM type	Applications	Part Criticality (ASTM F3572)	Benefit / Motivation	Material & Process Control	BCA Status
Ti Wire Directed Energy Deposition	Structural Components	Class B and below primary, secondary structures (non-PSE) **Future:** Class A, PSE parts	Buy-to-fly cost savings (reduced material and machining cost)	Internal specifications (requires PCD)	▪ Value proposition realized for cost reduction and sustainability benefits ▪ Developed general allowables beyond point-design applications ▪ DED processes addressed in MMPDS Volume II guidelines ▪ Research toward improved fatigue and damage tolerance performance
Ti Powder Bed Fusion **Future:** High Strength Al & Inconel Alloys	Systems Components / Complex Geometries	Class B and below **Future:** Systems components with fatigue requirements	Improved performance & efficiency (reduced part volume & weight, higher performance design features)	Internal specifications (requires PCD) **Future:** Industry specifications for lower criticality parts without fatigue requirements	▪ Initial point design application on the 777 program ▪ Shaping JMADD Ti LPBF bulk material allowables development ▪ Sponsoring AMS 7028 for Ti LPBF & recently released AMS7030 for AlSi10Mg

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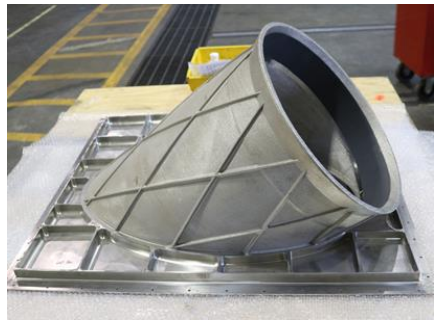
Metallic AM Components for BCA

Flight Test



- **777-200 ecoD APU Exhaust Duct (2022)**
- ***Ti Powder Feed DED***

- **777-200 ecoD Engine Overheat Detection Bracket (2022)**
- ***Inconel 718 Laser Powder Bed***

- **777-200 ecoD Engine Bleed Air Duct (2025)**
- ***Inconel 718 Laser Powder Bed***

Certified / Production

- **787 Passenger Floor Aft Galley Fitting (2017)**
- ***Ti Wire DED***

- **787-9 Back-up Fitting (2019)**
- **Tier 1 suppliers (Sprit AeroSystems and Leonardo) using Boeing specs & allowables**
- ***Ti Wire DED***

- **Currently 1500+ Ti Wire DED parts in service**

- **777 APU Snubber Fitting (Qualification In-Work)**
- **Ti Laser Powder Bed**

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Guidance Documents and Industry Standards

- **EASA CM-S-008 R4 draft**

			Material and Process control	Design Values / Material soundness	Static Strength	Fatigue / Damage Tolerance	Powerplant	Systems
Requirements for Structures, Equipment and Installations	Large Aeroplanes		CS 25.603 Materials CS 25.605 Fabrication methods	CS 25.613 Material strength properties and Material Design Values	CS 25.305 Strength and deformation CS 25.307a Proof of structure	CS 25.571 Damage tolerance and fatigue evaluation of structure	CS25.901c and 25.903c Sustained Engine Imbalance (windmilling)	CS 25.1309 Equipment, systems and installations CS25.1435 Hydraulic systems
Part Classification (see new ASTM-F42 standard)	A	(CAT)	X	X (3)	X (4)	X	(6)	As required (8)
		(HAZ)	X	X (3)	X (4)	N(9)	(6)	As required (7)
	B	(MAJ)	X	X (3)	X (4)	N(9)	(6)	As required (7)
	C	(MIN)	S (2)	S(5)	S (4)	N(1)	N(1)	As required (7)
	D	(NSE)	N (1)	N(1)	N(1)	N(1)	N(1)	N(1)

Table 2a: CERTIFICATION EFFORT PROPORTIONALITY TO PART CRITICALITY – Large Aeroplanes (table key above)

ASTM F3572-22	Systems (FHA)	Structures
Class A	Hazardous or Catastrophic	Principle Structural Element (PSE)
Class B	Major	Other Primary Structure
Class C	Minor	Secondary Structure
Class D	No Safety Effect	Non-Structural

System criticality definitions do not map well to structural applications. Boeing suggests also providing structural definitions to the classifications

787 Passenger Floor Aft Galley Fitting

- **Other Primary Structure (ASTM F3572 Class B)**
- Primary structural support for the passenger floor under the aft galley.

777 APU Snubber Fitting

- **Secondary Structure (ASTM F3572 Class C)**
- Part used to hold open APU. Maintenance Doors for on-the-ground work. Does not operate in flight.

787 Overboard Vent Tube

- **FHA = Minor (ASTM F3572 Class C)**
- Provides support for the vacuum waste system vent tube at the fuselage skin, and allows venting of the vacuum waste system for operation on the ground and in-flight.

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Needs to Support AM Roadmap - Guidance Documents, Industry Standards & Supply Chain

- **Working well**
  - FAA/EASA Working Group discussions provide a common forum for discussion & alignment on key topics.
  - Ability to leverage available data for our internal use (polymer AM in particular).
  - Generally addressing critical needs (e.g. powder contamination risks & detection techniques).
- **Could be improved**
  - Coordination between the various Standards Development Organizations (SDO) on overlapping topics.
  - We are working to drive alignment between SDO activities and Boeing/aerospace industry interests, but bandwidth is limited. Feedback on what activities we should be aware of, or prioritize would be helpful.
  - More coverage needed to address machine/hardware controls.
  - Additional work to address powder contamination risks & detection techniques (additional development of practical techniques and including these in specs/standards).
  - Release of key guidance documents that we use as a basis for developing our certification plans and approaches
    - E.g., the “Applicant Specific Guidance Memorandum for Additive Manufactured Parts for Transport Airplanes” – not released, only in draft form.
  - Further expansion of supply chain and machine options within the aerospace industry
  - Adoption of a common framework for evaluation of machine performance, mechanical screening test (fatigue in particular)

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R&D Needs

- **General areas of interest (Multiple CRAD proposals in-work for DED/LPBF are aligned to these):**
  - Evaluation and characterization of new AM machine types
  - Machine equivalency approaches
  - Qualification approaches
  - Delta Qual program – performance based vs. process control
  - Allowables / Data generation
  - New Materials
- **Joint Advanced Materials & Structures (JAMS) AM Project Ideas shared in 2023 related to:**
  - Effects of Defects
  - Powder Sustainability, Contamination
  - Microstructure Definitions
  - HIP Contamination
  - Coatings/Finishes and Flammability for Polymer AM
- **Ongoing Needs for DED Processes:**
  - Expansion of supply chain and machine options within the aerospace industry
  - Understanding of key process parameters & in-process monitoring for any systems
  - Development of new alloy chemistries tailored for DED processes
  - Continued research into solidification process parameters, microstructural characterization, defect conditions, etc. to further aerospace opportunities