Regulatory Considerations for AM Qualification and Status of FAA AM Roadmap

Federal Aviation Administration

Presented at:

ADDITIVE MANUFACTURING FOR REACTOR MATERIALS & COMPONENTS

PUBLIC MEETING

November 28-29, 2017

North Bethesda, MD

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Disclaimer

The views presented in this talk are those of the author and should not be construed as representing official Federal Aviation Administration position, rules interpretation or policy

Outline

- **Industry Trends**
- **Regulatory Considerations**
- **Recent FAA Developments**

AM is Not a Single Process…

… a *partial* list of metal AM technologies

3-D Printing

Powder Bed Fusion (PBF)

Electron Beam Melting (EBM)

Additive Layer Manufacturing (ALM)

Directed Energy Deposition (DED)

Direct Metal Laser Sintering (DMLS)

Selective Laser Melting (SLM)

Rapid Plasma Deposition (RPD)

Laser Engineered Net Shaping (LENS)

Laser Freeform Manufacturing Technology (LFMT)

Laser Cladding Technology (LCT)

Laser Deposition Technology (LDT)

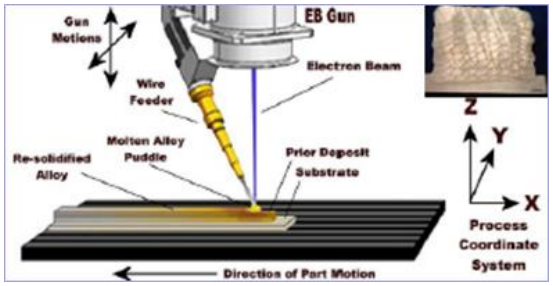
Wire + Arc AM (WAAM)

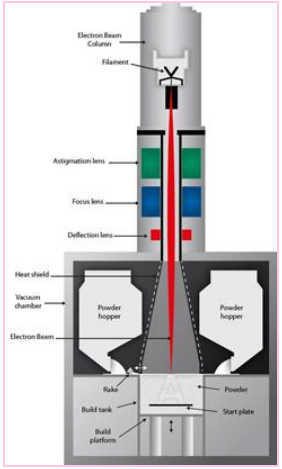
Ultrasonic Additive Manufacturing (UAM)

- **Different physics → different Q&C considerations**
- **Lack of common terminology (e.g. L-PBF / SLM / DMLM / DMLS)**

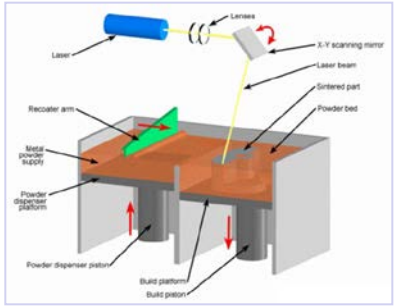
Diversity of AM Processes and Certification Domains

By Source of Material:
Powder vs. Wire





By Source of Energy:
Laser vs. e-Beam vs. Plasma Arc



New Type and Production Certificates

Repair and Overhaul (MROs)

Aftermarket Parts (PMAs)

Business Drivers for AM

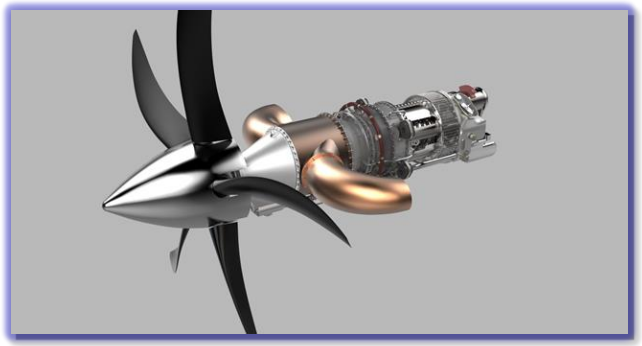
- **Part count reductions**
- **Producibility / machinability issues**
  - ***e.g. thin-wall castings***
- **More complex geometric designs**
  - ***Weight reduction***
  - ***Design optimization***
- **Single Source alternatives**
- **Production of low volume / legacy parts**
- **PMA business model (reverse engineering)**
- **Low barrier to entry for smaller businesses**

Business Drivers Can Be Good *Predictors* Of *Technology Trends*

Examples of Expanding Use of AM

- **"GE *Advanced Turboprop* is the first Aviation product to fully utilize additive tools…"**
  - **It has 30% fewer parts (from 800+ to *15 parts*), and will be completed with a 50% reduction in cycle time**

From GE 2016 Annual Report

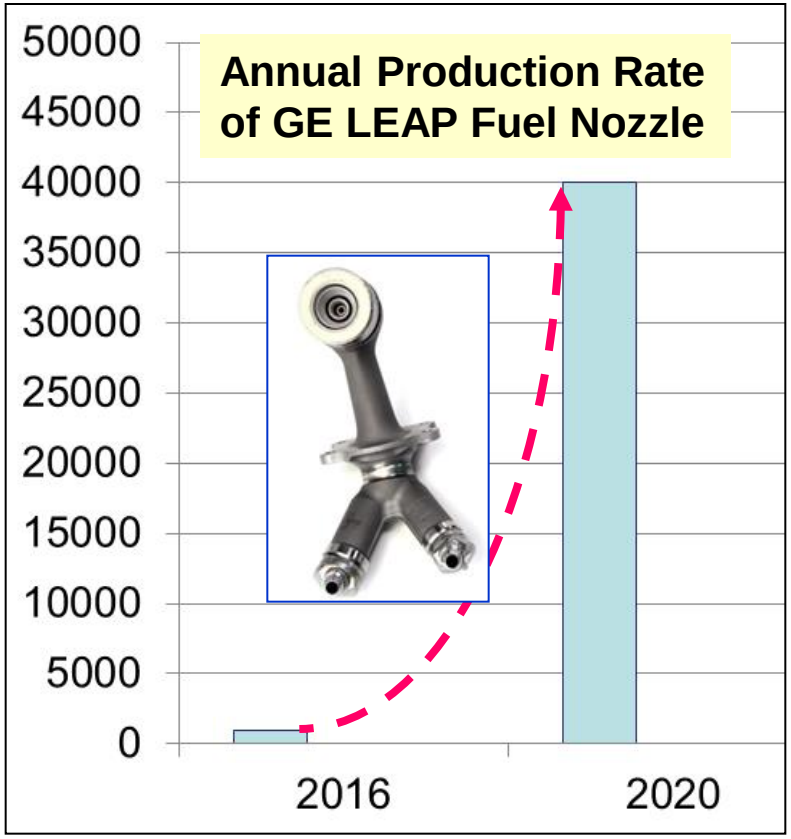


"By 2018 Airbus expects to print about *30 tons of metal AM parts every month*, according to a company statement…"

http://www.3dcadworld.com/manufacturers-turn-additive-made-metal-parts/

Example: Moving Towards Full-Scale Production

"GE Aviation Selects Auburn, AL for High Volume Additive Manufacturing Facility"



"Production will ramp up quickly over the next five years, going from 1,000 fuel nozzles manufactured annually to more than 40,000 by 2020".

Reference: http://www.geaviation.com/press/other/other_20140715.html

Example: Moving Towards "Part Family" Qualification

Families for qualification

Successful qualification can be used to qualify a number of similar parts

Separate qualification of each AM part is not necessary.

To be considered as a 'family', the parts shall satisfy the following criteria:

- Same material and post processing conditions
- Same classification of part and part function
- Same manufacturing and inspection programme
- Similar geometry and section thickness

Qualification of a number of similar parts = qualification by 'families'

15 29th August 2017 AIRBUS

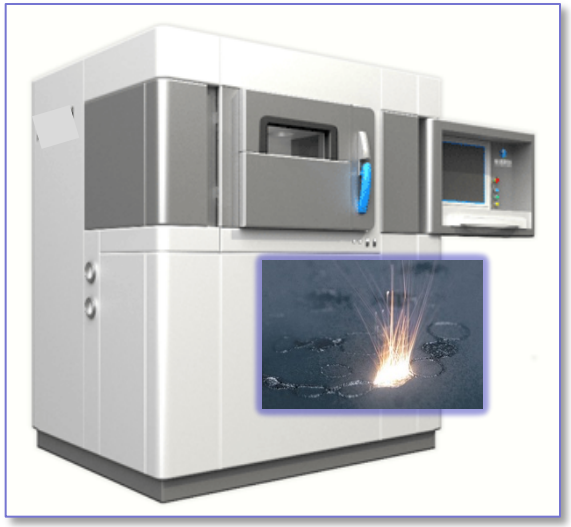
Presented by J. van Doeselaar (Airbus) at the 2017 Joint FAA – AFRL AM Qual & Cert Workshop, Dayton, OH.

Additive Manufacturing – New Paradigm:

Manufacturing Capabilities Ahead of Design Vision..?

"Additive manufacturing is the new frontier. It has taken the shackles off the engineering community, and gives them a clean canvas…"

Mr. David Joyce, GE Aviation President and CEO



Regulatory Considerations for AM

- **New Material and Process Space**
  - *Common consideration for new material or manufacturing technology introduction*
- **New Design Space**
  - *Unique to Additive Manufacturing..?*

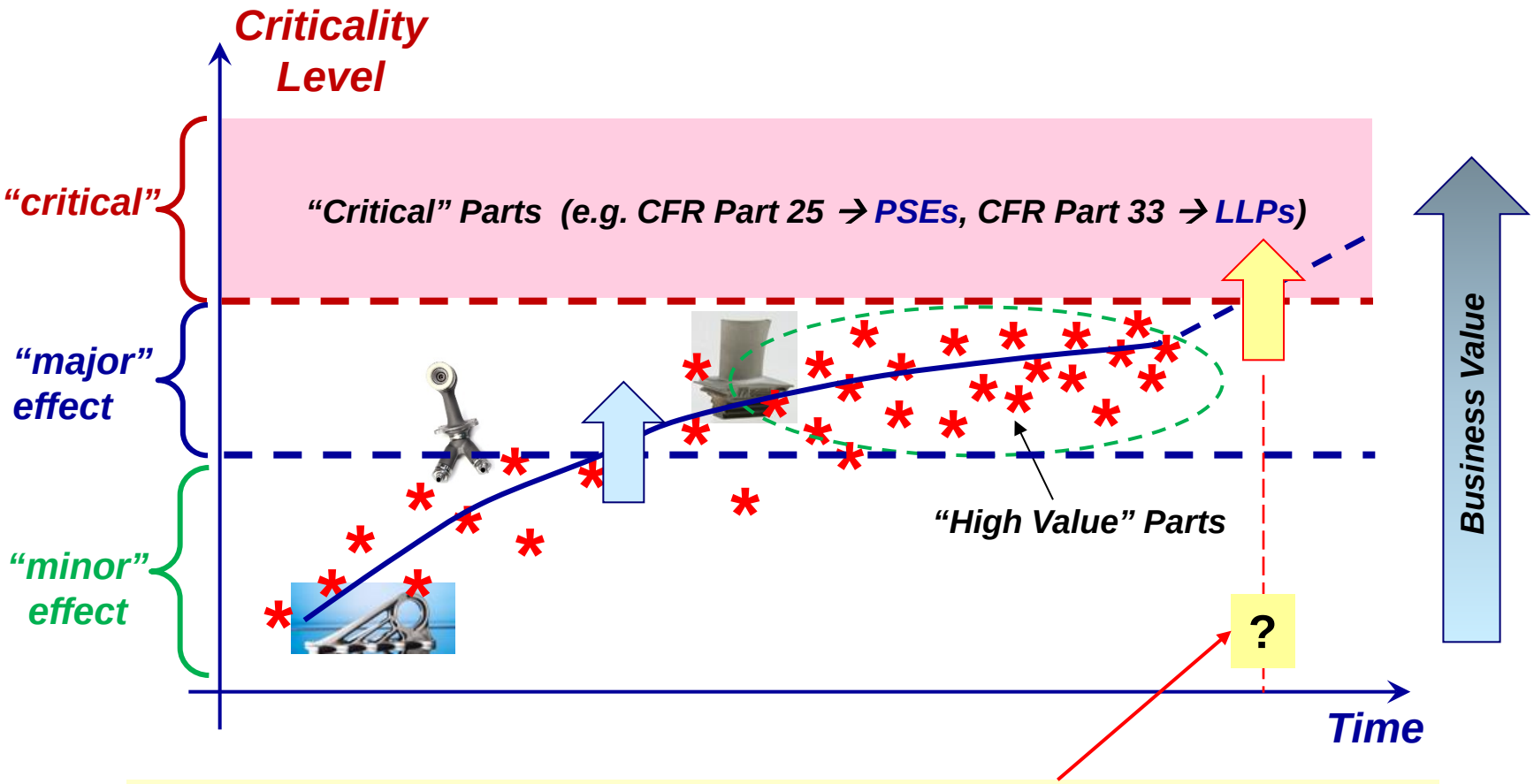
Topological Optimization Using AM

Common Claim: "*Complexity is Free…*"

- ***… But is it really?***
  - **High number of Kt features**
  - **Inspectability challenges**
  - **Location-specific properties**
  - **Surface quality of hard-to-access areas**
    - **may need to live with as-produced surface**

Need a Realistic Assessment of Technical Challenges / Risks Associated with a Business Case

Evolution of Criticality of AM Parts



Transition to "safety-critical" applications in aviation will occur sooner than initially expected

NAVAIR News Release
NAVAIR Headquarters
Patuxent River, MD

July 29, 2016

NAVAIR marks first flight with 3-D printed, safety-critical parts

Safety-Critical AM Parts are Coming…

An MV-22B Osprey equipped with a 3-D printed titanium link and fitting inside an engine nacelle maintains a hover as part of a July 29 demonstration at Patuxent River Naval Air Station, Maryland. The flight marked Naval Air System Command's first successful flight demonstration of a flight critical aircraft component built using additive manufacturing techniques. (U.S. Navy photo)

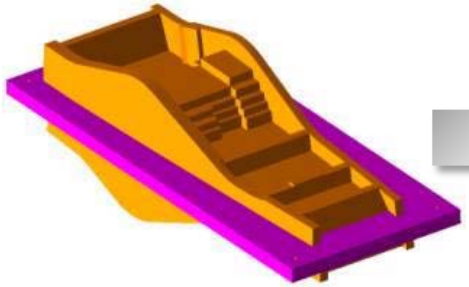
F-15 Pylon Rib Insertion Success Story

Courtesy of AFRL

Issue: -7075 Al Forging, Pylon Rib, Corrosion Fatigue Cracking
-Decision to move to Ti 6-4 forging already made
Long lead time for Ti forging ~1 year

Solution: -Replace with Ti 6Al-4V Additive
-To meet urgent need for aircraft in depot
- Quality issues lessened because of high margin for Ti in this application.

RX Role: -Provided Technical Leadership to Acquisition
-Executed Technology Demonstration Project
-Worked Attachment Issues (bushings, fasteners,etc...)



Results: -Additive Substitution Certified for use in Structural A
-Parts Manufactured and Qualified
-Prior to Insertion
-Ti forging cost
Provided Forgings
to competition

First structural AM part introduced in 2003

What Causes Aircraft Failures?

Frequency of Failure Mechanisms *)

(mechanical failures only)

Failure Mechanism	% Failures *(Aircraft Components)*
Fatigue	55%
Corrosion	16%
Overload	14%
Stress Corrosion Cracking	7%
Wear / abrasion / erosion	6%
High temperature corrosion	2%

**) Source: Why Aircraft Fail, S. J. Findlay and N. D. Harrison, in Materials Today, pp. 18-25, Nov. 2002.*

- **Some of the most challenging requirements *for new material systems such as AM* are related to F&DT**

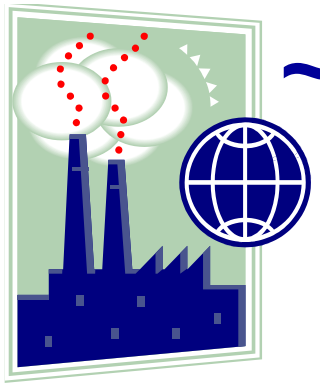
AM - “Barrier to Entry”

Optimistic →

Equipment acquisition

~ $1M

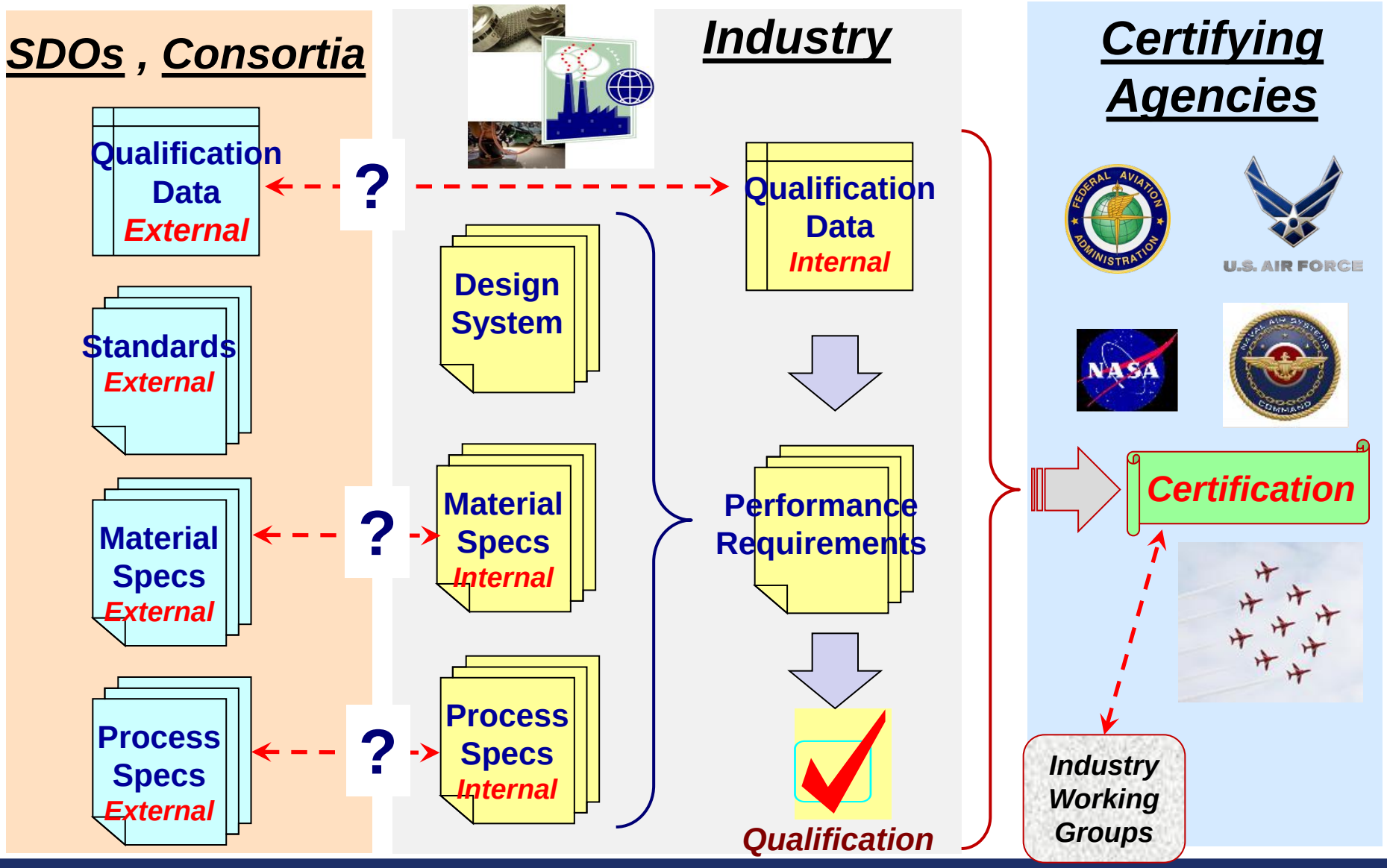
Realistic →



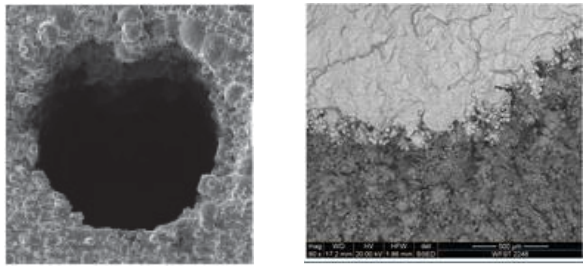
~ $10’s of M

- **Process development**
- **Process qualification**
- **Process controls**
- **Material characterization**
- **Design data**
- **QA / NDI**
- **etc.**

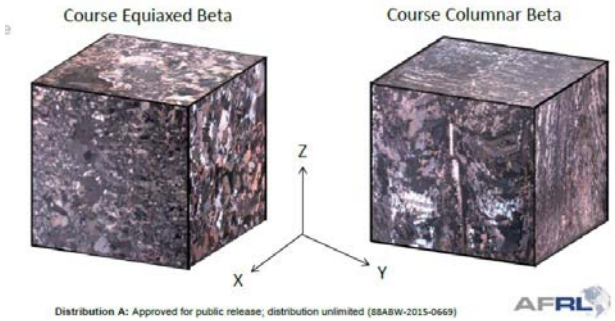
Evolving Specs and Standards Landscape



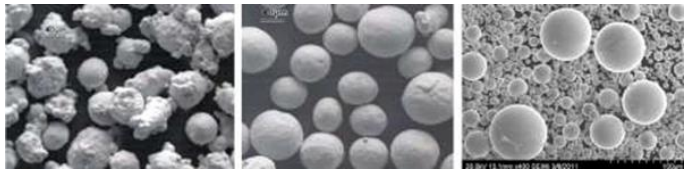
Examples of Risk Factors for AM



Surface Quality



Microstructure Variability

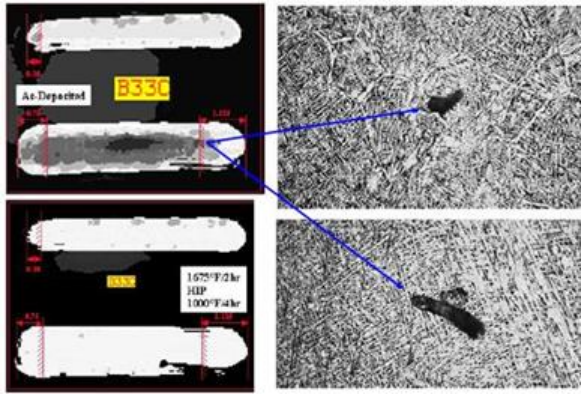


Powder Control

Powder feed rate (g/min)
Laser Power (W)
Scan speed (in/min)
Laser spot size (in)
Substrate temp (ºF)
Hatch spacing (% of calculated)

over 100 process parameters identified

Process Controls



HIP Effectiveness

Many More Identified by Experts…

AM Challenges To Be Addressed

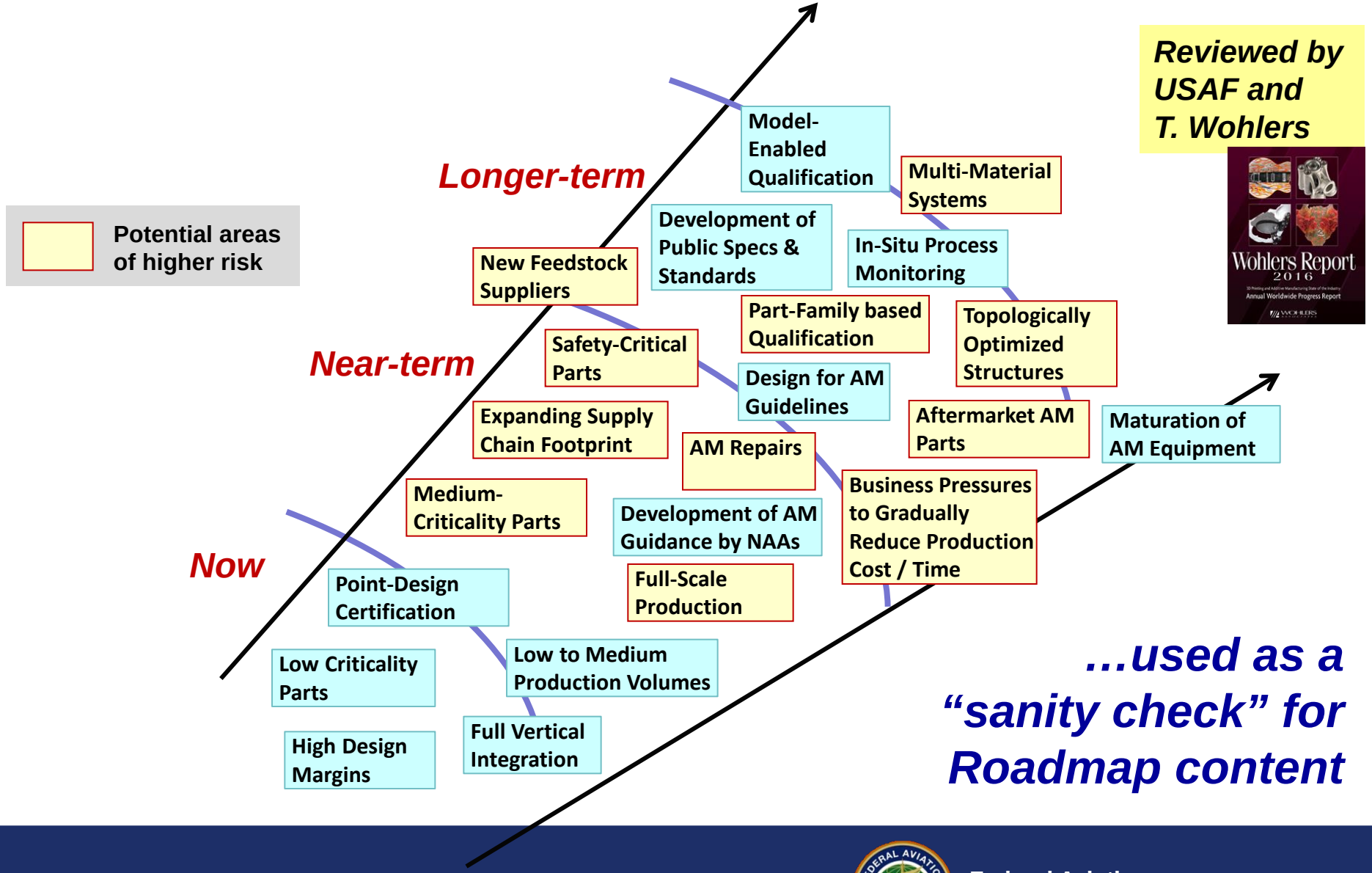
- **Limited understanding of acceptable ranges of variation for key manufacturing parameters**
- **Limited understanding of key failure mechanisms and material anomalies**
- **Lack of industry databases / allowables**
- **Development of capable NDI methods**
- **Lack of industry specs and standards**
- **New design space**

Additional level of complexity – some of these areas are inter-dependent…

Other considerations

- ***Lack of robust powder (feedstock) supply base***
- ***OEM-proprietary vs. commodity type technology path***
- ***Low barrier to entry for new (inexperienced?) suppliers***

Expected Evolution of AM Landscape…



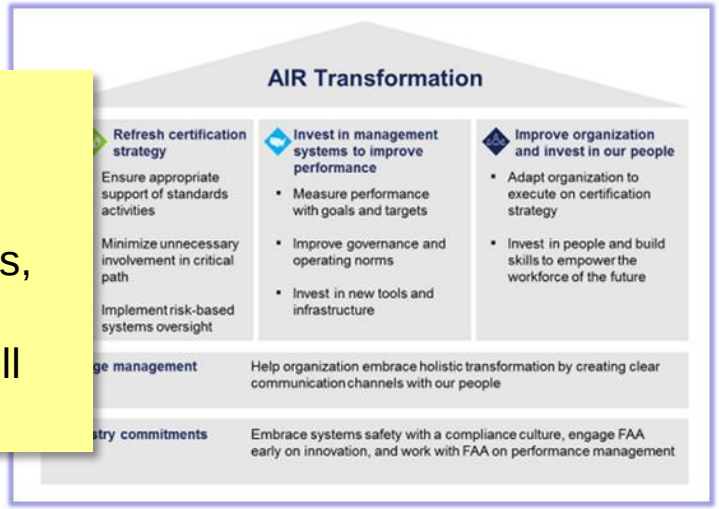
…used as a "sanity check" for Roadmap content

AIR Transformation *(effective 7-23-17)*

Aircraft Certification Service (AIR)

- **Policy and Innovation**
- **Compliance and Airworthiness**
- **System Oversight**
- **Organizational Performance**
- **Foundational Business**

The **Policy & Innovation Division** *supports aerospace innovation* by creating novel means of compliance, develops and maintains AIR regulations, manages the CSTA (chief scientists) program and overall fleet safety, as well as educational outreach.



Public-facing AIR Transformation Web Site:

https://www.faa.gov/about/office_org/headquarters_offices/avs/offices/air/transformation/

Excerpts from National Team's Charter

(Oct. 2015)

- **AIR-100 management *requested the development of a roadmap for determining the needs for policy and guidance along with any training for certifying projects utilizing AM parts*.**
- **The *roadmap will be developed and implemented by the Additive Manufacturing National Team* (AMNT) which will require resources, input, and support from AIR Directorates, Flight Standards and offices.**
- **The roadmap *will identify FAA concerns and recommendations to insure application of robust and consistent safety standards* for design, manufacture and field management of AM products.**
- **The development of this roadmap *will require coordination with other government agencies, academia and industry organizations*.**

Focus on AM Roadmap Development

AM Roadmap – Main Focus Areas ("swimlanes")

(1) *Engineering Certification*

(2) *Production / QA*

(3) *Maintenance / MROs*

(4) *COS (continued operational safety)*

"regulatory"

Enablers:

(5) *Workforce Education (FAA + Designees + Industry)*

(6) *R&D*

AM Roadmap Timeline

Projected AM Roadmap Span

(notional timeline – will be populated as feasible)

2017	2018	2019	2020	2021	2022	2023	2024	2025

Prioritization of Roadmap tasks

FY18-20 **"tactical" project plan**

Key Elements of the AM Roadmap Content

(4 regulatory swimlanes)

- **Key Risk Factors**
- **Regulatory gap analysis**
- **Proposed new or revised documents (policies, ACs, …)**
  - ***No rule changes expected***
- **Key Tasks and Project Plan (high level)**
- **"Inter-dependencies" between the 4 swimlanes**
- **Input into R&D and Training swimlanes**

Note:

- ***It is recognized that we may not currently have sufficient internal knowledge and experience to address some of the longer-term Roadmap items*** → ***see next page***

Mechanisms to Address Knowledge Gaps

- **Industry engagement (AIA, GAMA, MARPA, …)**
- **Engagement with SDOs (SAE, ASTM, AWS, …)**
- **Government engagement (USAF, NAVAIR, NASA, NIST, America Makes…)**
- **R&D (internal & external)**
- **CSTA (chief scientist) and other targeted workshops**
- **FAA AM certification projects benchmarking**
- **Manufacturing surveillance**
- **Site visits to production facilities (outreach)**
- **Coordination with other national authorities (NAAs)**

Most of These Mechanisms Are Already Engaged

Benchmarking of Composites ACs

(AC – Advisory Circular)

- **Parallels between Composites and AM:**
  - **Process-intensive technology subject to manufacturing variability**
  - **Material is being created at the same time as the part is being built**
- **Three ACs from the "Early Days" of Composites**
  - **Composite aircraft structure → AC 20-107A (1984)**
  - **Composite manufacturing quality control → AC 21-26 (1989)**
  - **Repair Stations for Composite and Bonded Aircraft Structure → AC 145-6 (1996)**

These And Similar Documents Have Been Considered by AMNT

Examples of *External* Benchmarking

MEASUREMENT SYSTEM IDENTIFICATION METRIC/SI (ENGLISH) UNITS

National Aeronautics and Space Administration

MSFC-STD-3716
BASELINE
EFFECTIVE DATE: October 18, 2017

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

EM20

Just Released

MSFC TECHNICAL STANDARD

STANDARD FOR ADDITIVELY MANUFACTURED SPACEFLIGHT HARDWARE BY LASER POWDER BED FUSION IN METALS

America Makes

Driven by… NCDMM

America Makes
Technology Roadmap 2.0

Final Report

Department of Defense Additive Manufacturing Roadmap

Report Released 30 November 2016

Dr. Jennifer Fielding, Technical Advisor, Structures, Propulsion and Manufacturing Enterprise Branch,

These And Similar Documents Have Been Considered by AMNT

Prioritization Considerations

- **Safety impact**
  - Expected increase in criticality of applications
    - "minor effect" → "major effect" → "safety-critical" / timeline?
  - Various industry segments (e.g. OEMs, Tier 1, PMAs, MROs…)
- **Certification process**
  - Breadth of application (e.g. multiple categories of parts / multiple product types)
  - Industry deployment timeline (e.g. current TRL / MRL levels)
  - Regulatory gaps (applicability of current policies / advisory materials)
  - Current experience level (development / full-scale production / field)
- **Other considerations**
  - Availability of industry specs and standards (materials, processes)
  - Availability of industry design / properties data

Strategic AM Roadmap *Draft*
Submitted for Internal Review (*end of FY17*)

D R A F T

FAA
Aviation Safety (AVS)

Developed by the FAA AM National Team (AMNT)

FAA AVS Strategic Metal AM Roadmap

Executive Summary

The FAA AVS Strategic Metal Additive Manufacturing (AM) Roadmap provides a multi-year plan for

Note:

- **Due to the FAA's mission, AM Roadmap is *focused on certification and safety* aspects of AM, and therefore is significantly different in scope and content from other well publicized AM roadmaps (e.g. by DoD or America Makes)**
- **The term "Strategic" is used in the context of the agency's mission (i.e. it is not a "Technology" roadmap)**

Informal AM Roadmap Review Meetings

- **Government:**
  - ***NASA / US Army – July 19, 2017***
  - ***USAF – Sept. 1, 2017***
- **Industry:**
  - ***AIA AM Working Group – Aug. 28, 2017***

<u>Note</u>: The final *draft* roadmap document has not been shared externally at this time of this presentation.

Summary

- **Expect rapid expansion of AM in Aviation and increase in the levels of AM parts criticality**
  - ***High criticality applications are not limited to Aerospace***
- **A number of AM-specific risk factors identified by experts → *appropriate regulatory (Q&C) framework is a key enabler***
- **First FAA AM Certification Roadmap *draft* developed**
  - **Provides a sequence of regulatory documents (policy, guidance, …) to be developed over the next few years**
  - ***No rule changes are envisioned at this time***
  - **Roadmap is a living document - will be updated *annually***

➢ ***Industry, agencies and societies collaboration is needed to ensure safe introduction of AM in major industry sectors***

References


International Journal of Fatigue 94 (2017) 168–177

Contents lists available at ScienceDirect

International Journal of Fatigue

journal homepage: www.elsevier.com/locate/ijfatigue

Additive manufacturing in the context of structural integrity

Michael Gorelik

Federal Aviation Administration, Scottsdale, AZ, United States

https://doi.org/10.1016/j.ijfatigue.2016.07.005


Progress Towards Metal Additive Manufacturing Standardization to Support Qualification and Certification

Mohsen Seifi, Michael Gorelik, Jess Waller, Nik Hrabe, Nima Shamsaei, Steve Daniewicz & John J. Lewandowski

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Additive Manufacturing

https://link.springer.com/article/10.1007/s11837-017-2265-2

Questions…

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