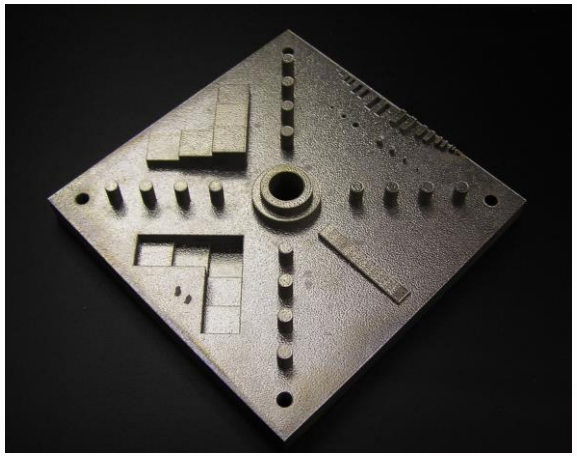
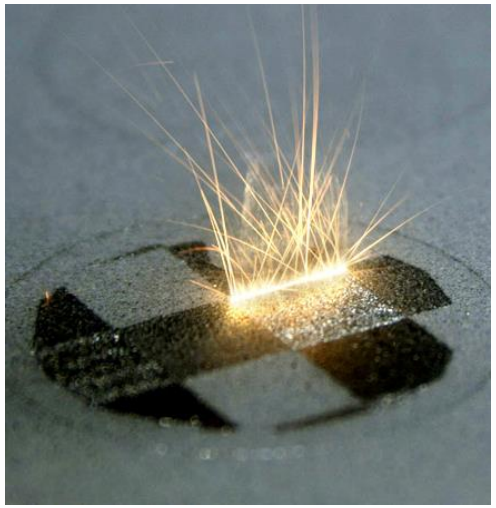
NIST Perspectives on Additive Manufacturing Standards Landscape





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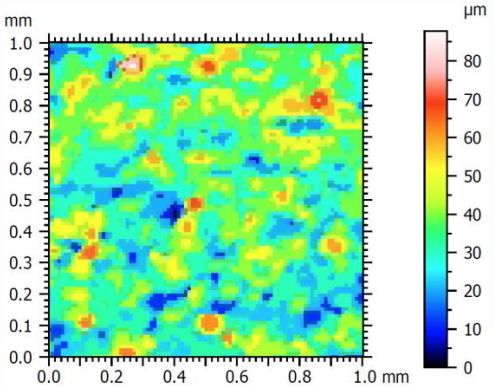

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December 9, 2020

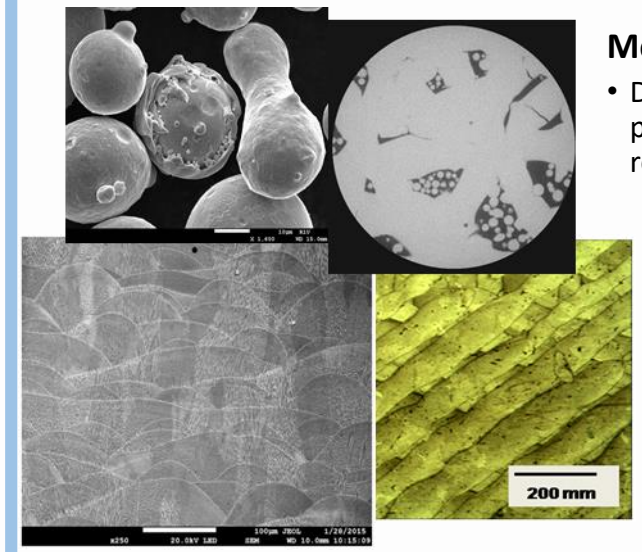
Role of Additive Manufacturing Standards

- Standards can be used for (among others):
  - specifying requirements
  - communicating guidance and best practices
  - defining test methods and protocols
  - documenting technical data
  - accelerating adoption of new technologies
  - enabling trade in global markets
  - ensuring human health and safety
- Government regulatory agencies and certifying bodies may reference publicly available standards in their regulations and procedures
- Standards development in the U.S. is conducted through voluntary participation and consensus

NIST Influence on Additive Manufacturing Standards

- Identify consensus needs and priorities for standards
  - Workshops, industry meetings, outreach events, etc.
- Conduct measurement science research to develop technical basis for standards
  - Draft content / starting point for development of documentary standards
- Serve on standards committees
  - Leadership roles
  - Technical standards development
  - Strategic planning / big picture view
- Support the coordination, facilitation, and communication among standards groups

Example NIST Measurement Science Research in Support of AM Standards



Methods to characterize metal powder

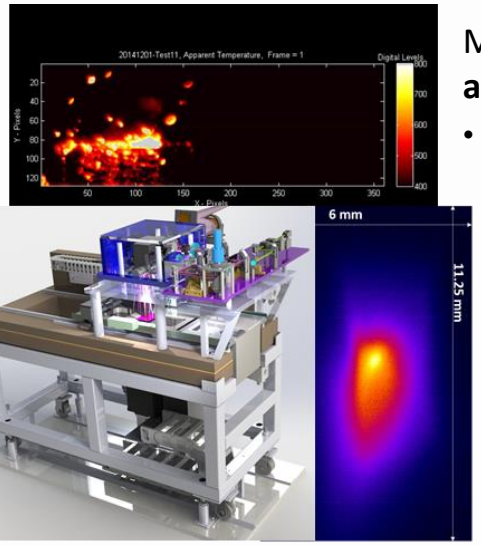
- Dimensional – mechanical – thermal – powder bed density – powder condition for recyclability

Methods to characterize built materials

- Mechanical – microstructure – porosity – density – post processing

Exemplar data

- Round robin studies – variability analyses – powder/process/material relationships



Methods enabling **in-situ process monitoring and control** to robustly predict part quality

- Process metrology – signature analysis – uncertainty quantification – AM G-Code for machine control

Reference data identifying correlations to enable intelligent controller design

- Process parameters ←→ Process signatures ←→ Part quality

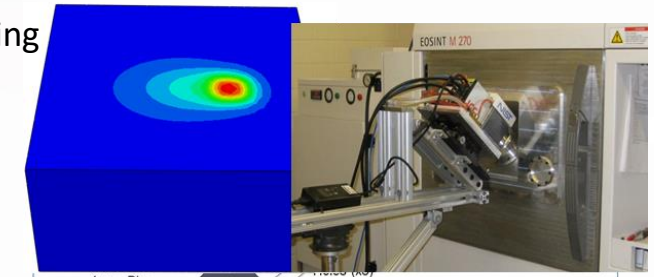
Additive Manufacturing Metrology Testbed (AMMT)

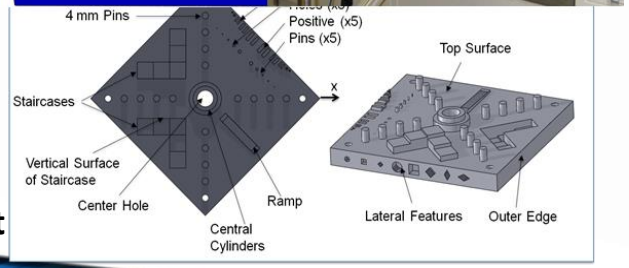
Reference data to be used by modeling community to improve model inputs and validate model outputs

- Temperature – Microstructure – Residual Stress

Pre-process and post-process test methods to characterize performance and assess part quality

- Machine performance characterization – XCT of AM parts





NIST AM Test Artifact

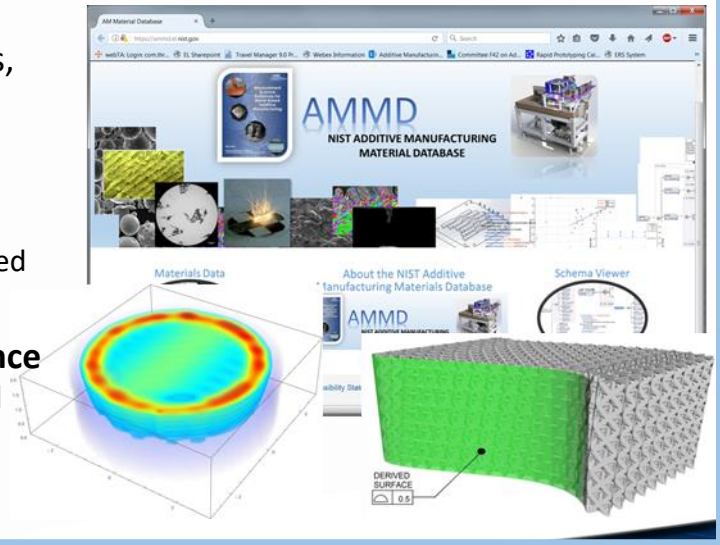
AM information systems architecture, including metrics, information models, and validation methods

Public AM Material Database

- AM schema/ database –- populated with round robin data

Product definition and tolerance representation (GD&T) for AM

AM design rules and their fundamental principles



Multiple Standards Bodies are Relevant to Additive Manufacturing

- ASTM Committee F42 on Additive Manufacturing Technologies
- ISO Technical Committee 261 on Additive Manufacturing
- SAE Aerospace Material Specifications for Additive Manufacturing (AMS-AM)
- ASME Y14.46 on Geometric Dimensioning & Tolerancing (GD&T) Requirements for Additive Manufacturing
- ASME B46 Project 53, Surface Finish for AM
- AWS D20 on Additive Manufacturing
- ISO TC184 / SC4, STEP-based data representation for AM
- <others – the **AM Standards Landscape continues to grow**!>

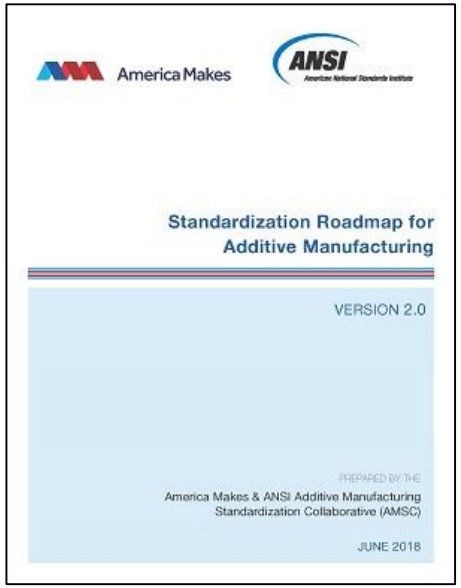
NIST Contributes to All of These Efforts

Challenges Due to the Growing AM Standards Landscape

- Increased risk of duplication of efforts and overlapping content
- Potential for inconsistencies or even contradictions
- Conflicting standards create ambiguity and confusion
- Increased requirements for communication and coordination
- Increased needs for liaisons
- Limited resources available for standards development

Additive Manufacturing Standards Collaborative (AMSC)

- ***Purpose:*** coordinate and accelerate development of additive manufacturing standards consistent with stakeholder needs and facilitate growth of the additive manufacturing industry
- AMSC launched in March 2016 following two planning meetings
- Facilitated by American National Standards Institute (ANSI) through cooperative agreement with America Makes; experts from many industry sectors identified AM standards gaps and priorities
- Standardization Roadmap for Additive Manufacturing / AMSC Standards Landscape, Version 2.0 (June 2018)
  - Identifies published and in-development standards and specifications, assesses gaps, makes recommendations for priority areas where there is a perceived need for additional standardization



www.ansi.org/amsc

ANSI American National Standards Institute

Additive Manufacturing Standards Collaborative (AMSC)

- Open Gaps in Standards Landscape

Section	High (0-2 years)	Medium (2-5 years)	Low (5+ years)	Total
Design	4	15	6	25
Precursor Materials	1	4	4	10
Process Control	4	8	4	16
Post-processing	0	4	3	7
Finished Material Properties	3	1	0	4
Qualification & Certification	4	8	3	15
Nondestructive Evaluation	2	4	2	8
Maintenance & Repair	0	7	1	8
Total	18	51	24	93

  - 65 gaps need Research & Development

ASTM Committee F42 on Additive Manufacturing Technologies

ASTM INTERNATIONAL

Quick facts

- **Formed:** 2009
- **Current Membership:** 1000+ members (Over 30% outside the US)
- **Standards:** 30+ approved, 45+ in development (Jointly with ISO)
- **Meet twice a year, next meeting:** March 2021, Colorado School of Mines
- **Global Representation, including:**

Argentina	Germany	Norway	Switzerland
Australia	India	Puerto Rico	Taiwan
Austria	Italy	Russian Federation	United Kingdom
Belgium	Japan	Singapore	United States
Canada	Korea	South Africa	
China	Mexico	South Korea	
Czech Republic	Netherlands	Spain	
France	Nigeria	Sweden	

http://www.astm.org/COMMITTEE/F42.htm

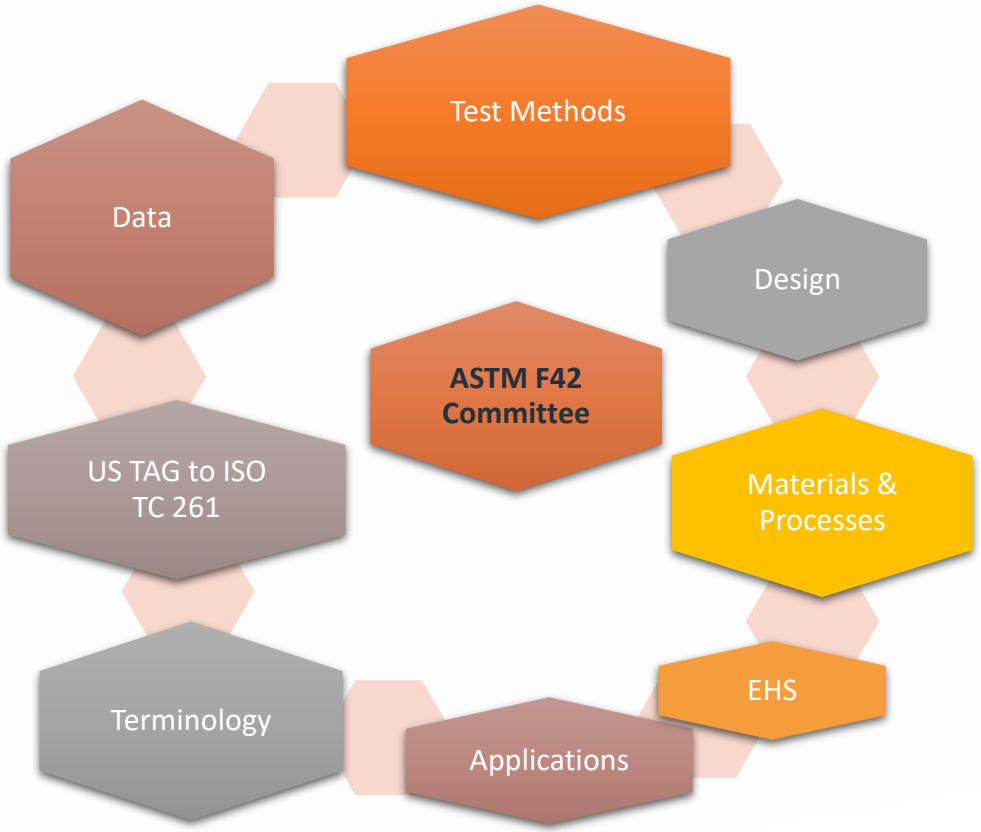
ASTM Committee F42 Structure

Standards under the jurisdiction of F42 (https://www.astm.org/COMMIT/SUBCOMMIT/F42.htm)

Subcommittees *address specific segments within the general subject area covered by the technical committee.*

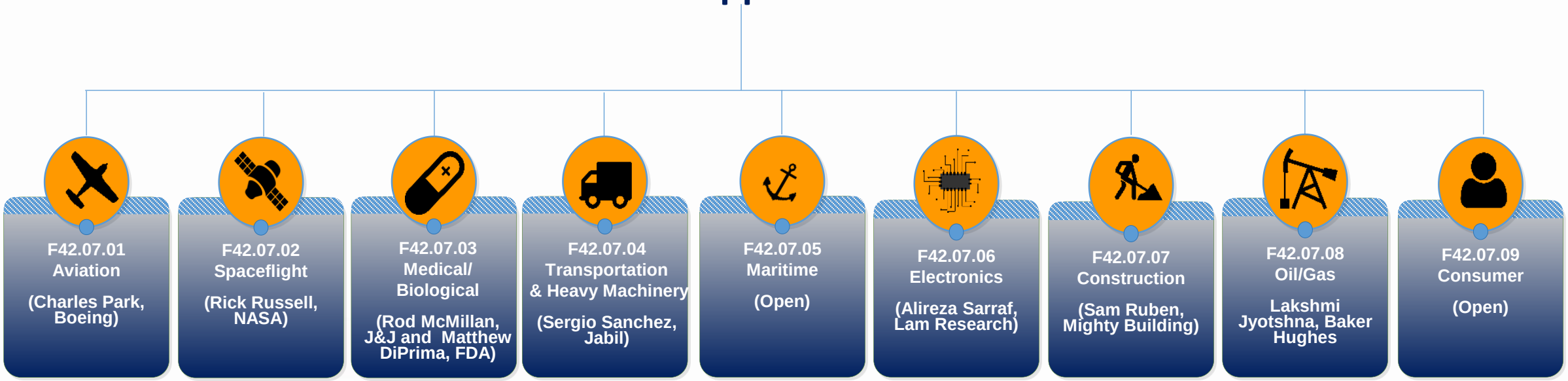
- **F42.01 Test Methods** – Jesse Boyer, Pratt & Whitney
- **F42.04 Design** – David Rosen, GA Tech
- **F42.05 Materials and Processes** – Frank Medina, UTEP/Tim Shinbara, AMT
- **F42.06 Environment, Health, and Safety** – Francoise Richard, P&W Canada
- **F42.07 Applications** – Shane Collins, Additive Industries
- **F42.08 Data –** Alex Kitt, EWI
- **F42.90 Executive** – John Slotwinski, JHU/APL
- **F42.90.05 Research and Innovation** – Matt Donovan, Jabil
- **F42.91 Terminology** – Klas Boivie, Sintef
- **F42.95 US TAG to ISO TC 261** – Stacey Clark, US Army

8 Subcommittees and Focus



Sub-Committee F42.07 on Applications

F42.07 Applications



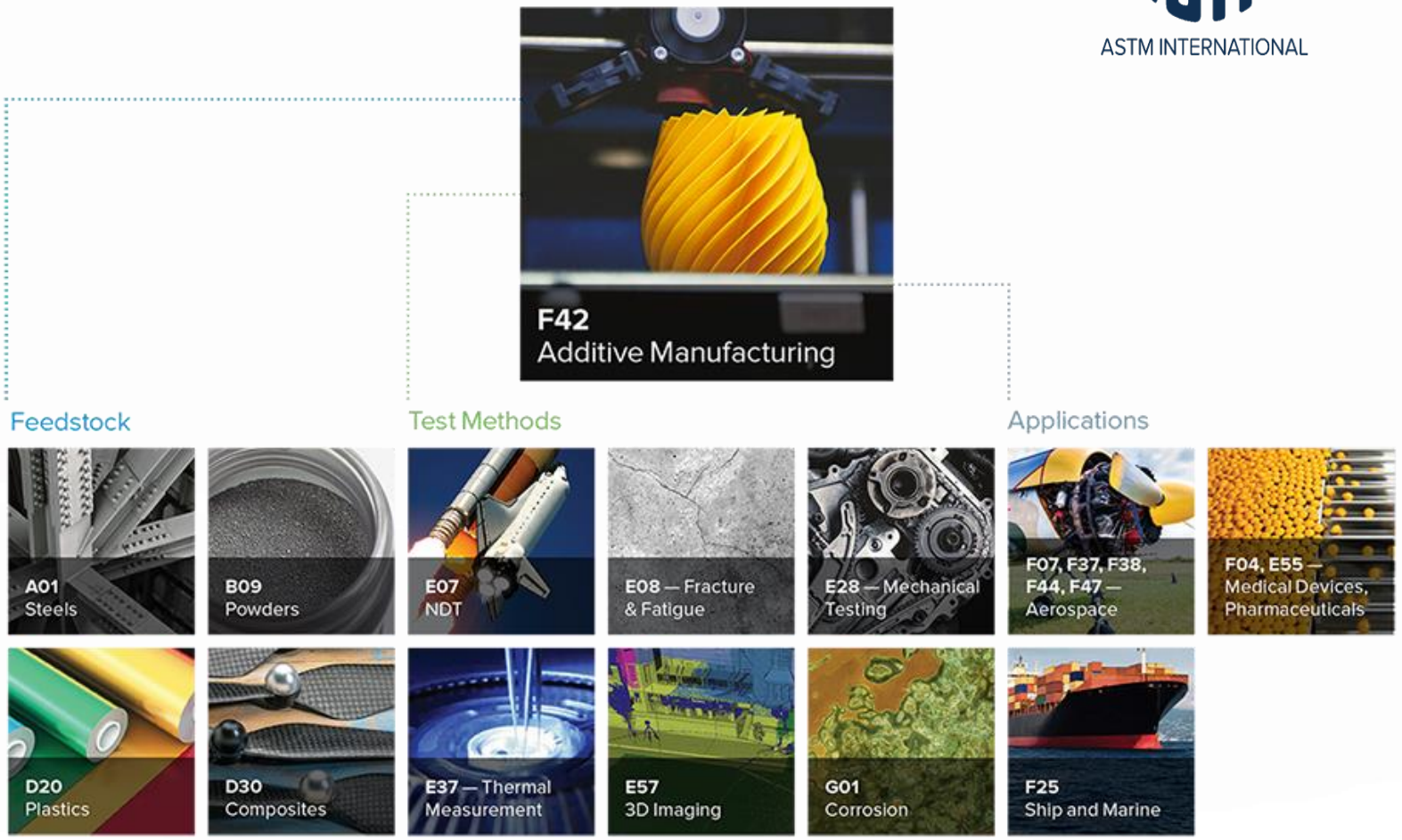
Scope

- The development of **standards for additive manufacturing** in a variety of industry-specific applications, settings, & conditions.
- The work of this subcommittee will be coordinated with other F42 subcommittees, ASTM technical committees, and national/international organizations having mutual or related interests.

ASTM: AM Footprint Across Committees

ASTM INTERNATIONAL

- **Breadth**
  - More than 20 AM relevant Committees
  - 1000+ standards applicable to AM
  - 2000+ technical experts
- **Collaboration**
  - PSDO – ISO TC261 (CEN TC438)
  - MOU & Membership – America Makes
  - MOU – SME
  - Liaison Agreement – 3MF
  - Strategic Relationships – NIST, NASA, FAA, FDA, DOD, ….

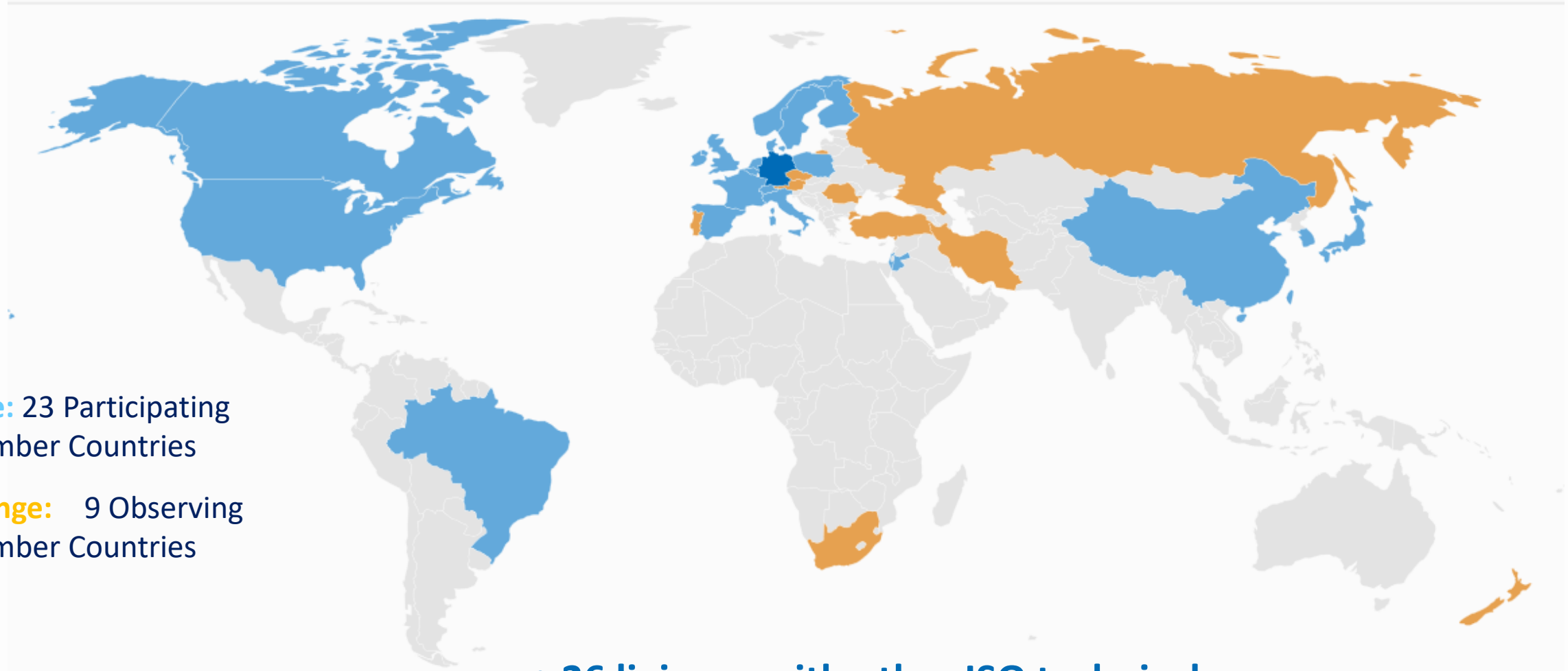


ISO Technical Committee 261 on Additive Manufacturing

- TC261 Working Groups established for:
  - WG1 – Terminology
  - WG2 – Processes, Systems, and Materials
  - WG3 – Test Methods and Quality Specifications
  - WG4 – Data and Design
  - WG6 – Environment, Health, and Safety
  - JWG10 (with ISO TC44) – AM in Aerospace Applications
  - JWG11 (with ISO TC61) – AM for Plastics

https://www.iso.org/committee/629086.html

ISO TC 261: Participating (P) and Observing (O) Members



- **Blue:** 23 Participating Member Countries
- **Orange:** 9 Observing Member Countries

+ 26 liaisons with other ISO technical committees for cooperation

Formal Agreement Established between ASTM F42 and ISO Technical Committee 261

- Formal collaboration established between ASTM and ISO (first of its kind!) for joint development of AM standards
- Results in dual-logo ISO and ASTM standards (same content, no need for future harmonization)
- Guiding principles and specific procedures for how ASTM and ISO will cooperate and work together are defined in the “Joint Plan for Standards Development”

Some Details of the F42 / TC261 Collaboration

- New Work Items offered to the partner body
- If accepted, draft standards developed by Joint Groups and reviewed by both organizations
- Parallel ASTM and ISO ballots
  - ISO/TC 261: "Draft International Standard" (DIS) ballot; 3-month balloting cycle, an FDIS ballot may be needed…
  - ASTM F42: Final balloting; 30-days balloting cycle
- Editorial changes are allowed; comments resulting from ASTM balloting can be submitted into the ISO balloting process
- Separate (new) fast-tracking process allowed within ISO
- Publication, copyright, and commercial arrangements

ISO TC261 / ASTM F42 – Guiding Principles for Standards Development

01

Trusted

One set of AM standards to be used all over the world

02

Similarity

Common roadmap and organizational structure for AM standards

03

Don't reinvent the wheel

Use and build upon existing standards, modified for AM when necessary

04

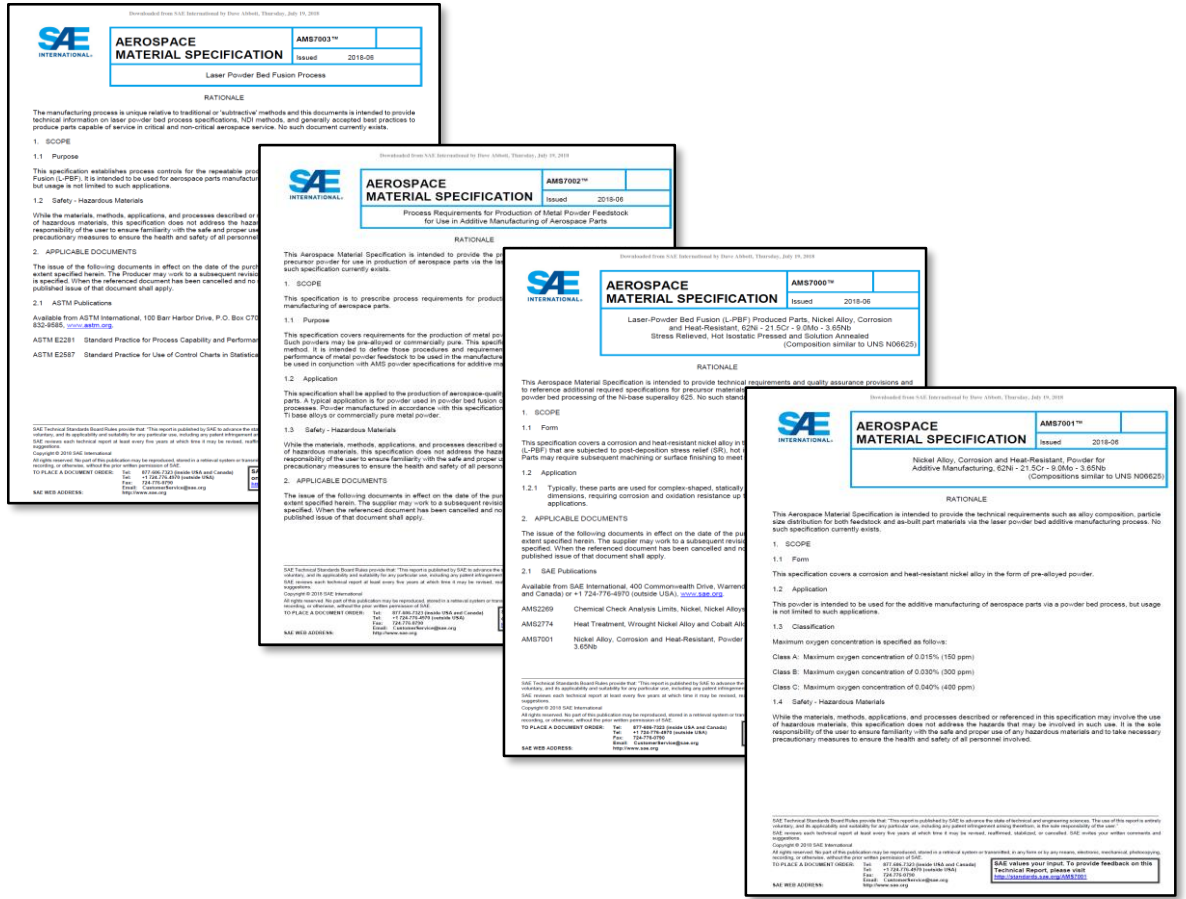
Partnerships

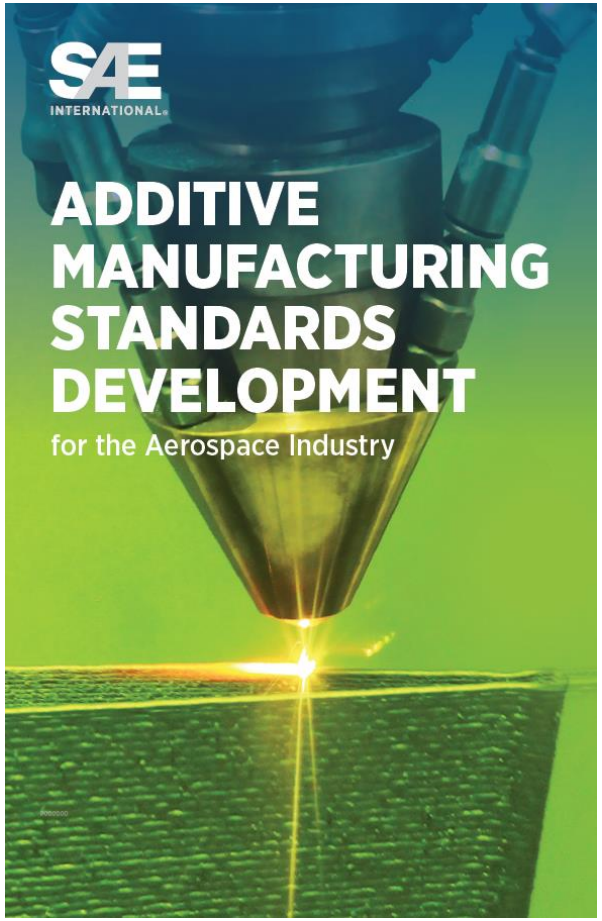
Emphasis on joint standards development, co-located meetings, etc.

SAE International: Aerospace Material Specifications for Additive Manufacturing (AMS-AM)

Committee Scope

To develop and maintain aerospace material and process specifications for additive manufacturing…





SAE AMS-AM By the Numbers – October 2020

16 Standards

2 Data Submission Guidelines

14 Metals AMS Published

2 Non-metals AMS Published

30 Works in Progress

5 in revision

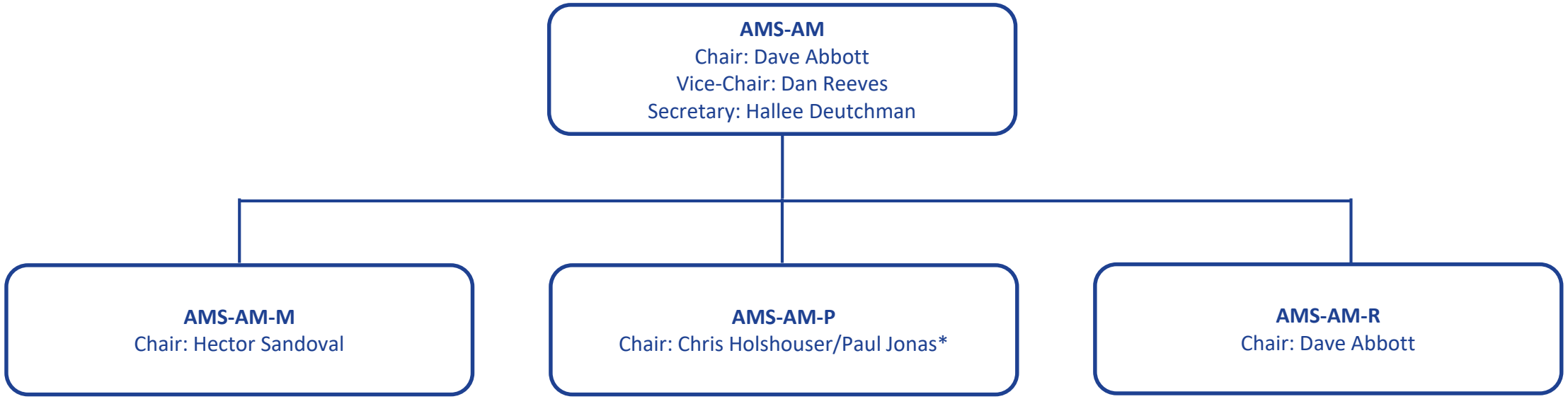
500+ Members

24 Countries

- Established in 2015 to develop and maintain aerospace material and process specifications for additive manufacturing
- Membership is representative of global aerospace sector and supply chains
- Assists U.S. Federal Aviation Administration in developing guidance for AM certification

Bi-annual meetings include both North American and European locations

AMS-AM Committee – Top Level



Metals Subcommittee

Non-Metals Subcommittee

Repair Applications Subcommittee

Each subcommittee includes both Materials and Process technical tracks

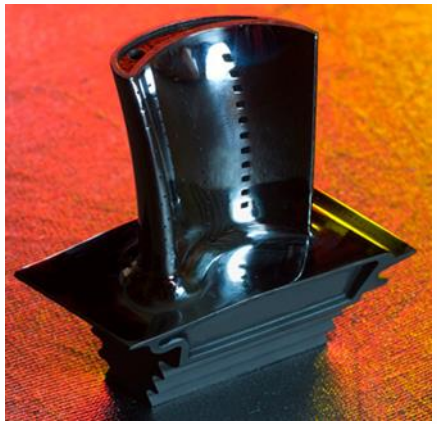
Current SAE Specification Framework

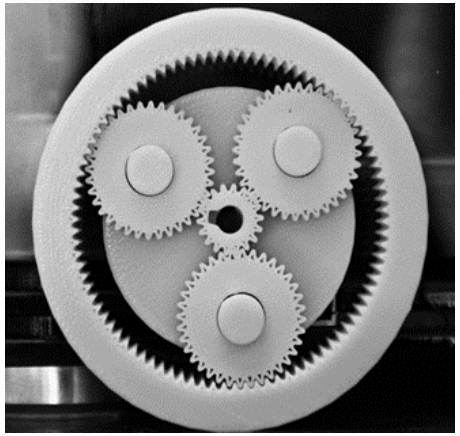
- Hierarchical framework
- Defines requirements and establishes controls
- Framework combines Performance-based and Pseudo-prescriptive (establish controls and provide substantiation)

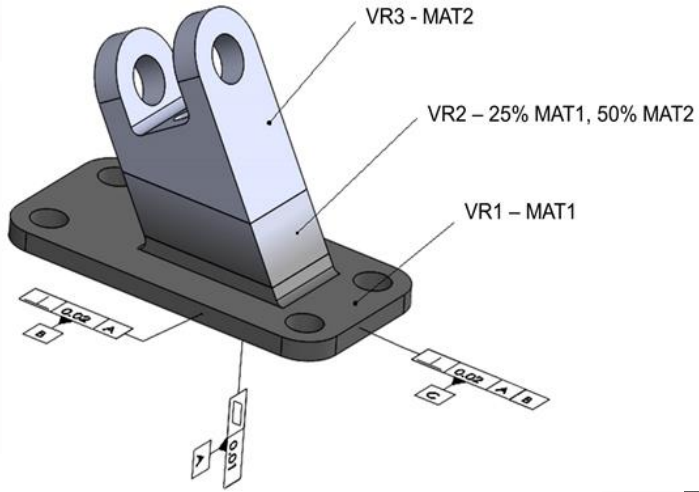
Control = Quality + Consistency

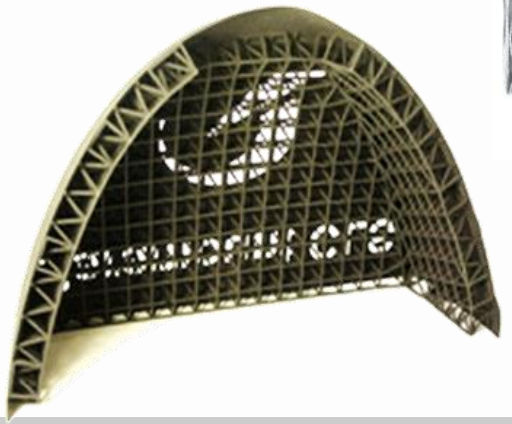
ASME Y14.46 Standards Committee

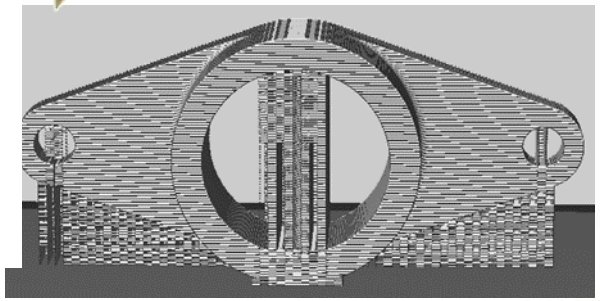
- ASME Y14.46-2017, Product Definition for AM
- Geometric Dimensioning & Tolerancing (GD&T) requirements that are *unique to additive manufacturing*
  - free-form complex surfaces; internal features; lattice structures; support structures; as-built assemblies; build-direction dependent properties; multiple / functionally-gradient materials, etc.
- GD&T: the language for communicating geometric tolerance specification and design intent from designers to manufacturing / quality engineers





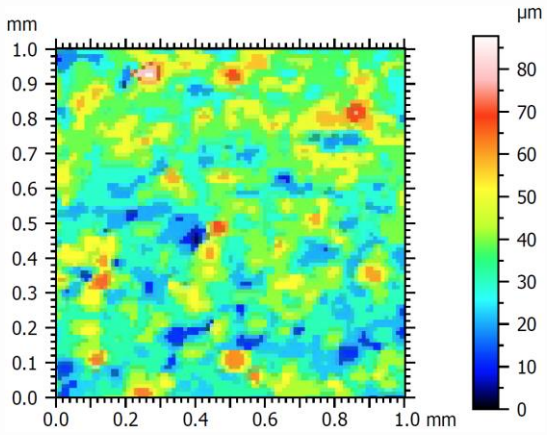






ASME B46 Project 53 - Surface Finish for AM

- Composed of surface metrology experts associated with ASME B46: Classification and Designation of Surface Qualities
- White paper and preliminary work item for surface attributes and corresponding characterization methods relevant to components made with additive manufacturing
- Several open research questions remain; no consensus at this time; associated standards are in early phase of discussion / development
  - For example: typical surface characterization parameters (such as Ra, arithmetic average of roughness profile) may not be the best approach for describing complex AM surfaces



Sample surface map

Other Related ASME Standards Activities

ASME Y14 Committee
- Y14.41-2019, Digital Product Definition Data Practices
- Y14.47-2019, Model Organization Practices
- Y14.48, Universal Direction and Load Indicators (in development)

ASME Manufacturing and Advanced Manufacturing (MAM) Standards Committee
- New subcommittee on Additive Manufacturing

ASME Model-Based Enterprise (MBE)
- Rules, guidance, and examples for the creation, use, and reuse of model-based datasets, data models, and related topics within a Model-Based Enterprise
- Starting point:
  MBE Standards Recommendation Report (Dec 2018): direction, activities, priorities, organization, roadmap for standards process

ASME Special Committee On Use Of Additive Manufacturing For Pressure Retaining Equipment
- To develop a technical baseline to support development of a proposed BPTCS standard or guideline addressing the pressure integrity governing the construction of pressure retaining equipment by additive manufacturing processes.

ASME Verification and Validation (V&V) Committee
- V&V 50, Computational Modeling for Advanced Manufacturing (launched in 2016)

ASME B89.4.23 Committee
- Performance Evaluation of Computed Tomography Systems

ASME Committee on Digital Engineering / Big Data / Digital Transformation (forming in 2021)

AWS D20 on Additive Manufacturing

- AWS D20.1/D20.1M:2019, Specification for Fabrication of Metal Components using Additive Manufacturing
- Requirements for repeatable production of metal AM components
  - *Processes*: powder bed fusion (PBF) and directed energy deposition (DED)
  - *Feedstock*: metal powder and wire
- Contents:
  - Design Requirements for AM Components
  - AM Machine and Procedure Qualification
  - AM Machine Operator Performance Qualification
  - Fabrication Requirements
  - Inspection Requirements
  - Acceptance Requirements

First revision in process: multiple-laser systems; in-process monitoring / adaptive feedback; updates to PBF powder requirements; updates to PBF qualification variables; inspection test artifact requirements

NIST Perspectives on AM Standards

- NIST continues to support and influence AM standards development through measurement science research and service on standards committees
  - Contributions to more than 40 AM standards activities across several standards bodies
  - Multiple leadership roles, including with ANSI Additive Manufacturing Standards Collaborative
- **NIST Motivations / Future Vision:**
  - High quality, technically accurate standards
  - Usable and high impact standards that meet stakeholder needs
  - Integrated and cohesive set of standards: consistent, non-contradictory, non-overlapping
  - No duplication of effort
  - Use of existing standards, modified for AM when necessary
- **Coordination**, **communication**, and **cooperation** are essential to achieve this vision and to drive consensus standards that enable trade in global markets
  - AM users, standards bodies, vendors, technology providers, regulatory agencies, etc. all play a role
  - Challenges continue to grow due to technology advancements and rapidly-changing environment
- Much progress and cooperation to-date; definitely **successes to build upon**!
  - e.g., AMSC interactions; multi-logo standards; AM standards structure; many liaisons; terminology

Your ideas, participation, expertise, and help are welcomed and appreciated!

Questions and Discussion

Contact:

Kevin Jurrens

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Key References for AM Standards Landscape

- AMSC, AM Standardization Roadmap and AM Standards Landscape: https://www.ansi.org/amsc
- ASTM F42: https://www.astm.org/COMMITTEE/F42.htm
- ASTM AM Center of Excellence: https://amcoe.org/
- ISO TC261: https://www.iso.org/committee/629086.html
- SAE: https://www.sae.org/works/committeeHome.do?comtID=TEAAMSAM
- SAE AM Data Consortium: https://www.sae-itc.com/amdc
- AWS D20: https://www.aws.org/standards/committee/d20-committee-on-additive-manufacturing-2
- ASME Y14.46: https://cstools.asme.org/csconnect/CommitteePages.cfm?Committee=100749850
- ASME MBE Standards Recommendations Report: http://go.asme.org/MBEreport
- MMPDS: https://www.mmpds.org/
- CMH-17: https://www.cmh17.org/HOME/AdditiveManufacturing.aspx
- Workshop Proceedings, Strategic Guide for AM Data Management and Schema: https://amcoe.org/rd-publications