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INDUSTRIALISATION OF ADDITIVE MANUFACTURING: STANDARDS DEVELOPMENT AND KEY CHALLENGES

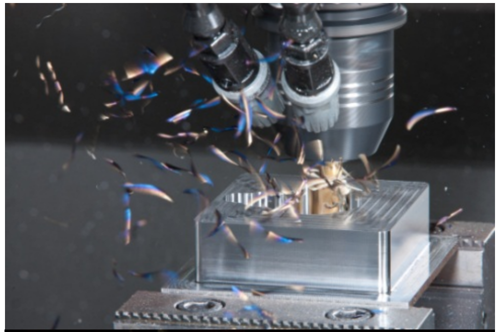
Klas Boivie, Ph.D.

Senior Research Scientist, SINTEF Manufacturing,
Chairman SIS/TK563 Additiv tillverkning, Convener ISO/TC261 WG1 Terminology,
Convener ISO/ASTM JG51 Terminology, Chair ASTM F42.91 Terminology,
ASTM International Board of Directors

IN PERSPECTIVE:

Principal methods of shaping materials:

- Subtractive shaping: Shaping a raw material by successive subtraction of pieces of the original block of material; i.e. machining, grinding drilling
- Formative shaping: Shaping a raw material by the application of pressure to the material; i.e. forging, pressing, bending, casting, etc.
- Additive shaping: Shaping by the successive addition of material(s); i.e. Additive Manufacturing technologies



Let's take a step back:

Additive Manufacturing; shaping objects by successive addition of material…
-New Technology?

A scallop

First modern system: *Stereo Lithography*, patent 1986, first machine sold in 1987
-The technology may be fairly new, but the principle is just natural and ancient!

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Where does AM-technology come from?

Early applications and corresponding concepts:

"Rapid Prototyping": several systems launched through the late 1980s and the early 1990s

"Rapid Tooling" (1990's to early 2000's) ; producing tools based on "RP" technology ex. Keltool, Wibatool, early DMLS…

"Rapid Manufacturing" (late 1990's to mid 2000's): producing end-use parts based on "RP"- technology,

-found some applications but did not really take off

-Well, perhaps it wasn't that "Rapid" after all…

-What is the *meaning* of "additive manufacturing" (AM):

Definition by ISO/ASTM 52900:2015

2.1.2
additive manufacturing, noun
AM
process of joining materials to make *parts* (2.6.1) from 3D model data, usually *layer* (2.3.10) upon layer, as opposed to subtractive manufacturing and formative manufacturing methodologies

Note 1 to entry: Historical terms: additive fabrication, additive processes, additive techniques, additive layer manufacturing, layer manufacturing, solid freeform fabrication and freeform fabrication.

Note 2 to entry: The meaning of "additive-", "subtractive-" and "formative-" manufacturing methodologies are further discussed in Annex A.

- AM is enabled by the creation and communication of a 3D model data file
  - The 3D model is, in practice, a specification for the parts made by an AM process
- An AM process is characterized by how the material is added:
  - Mechanism for delivering the feedstock material
  - Mechanism for joining the feedstock – *Subject to the laws of physics and chemistry!*

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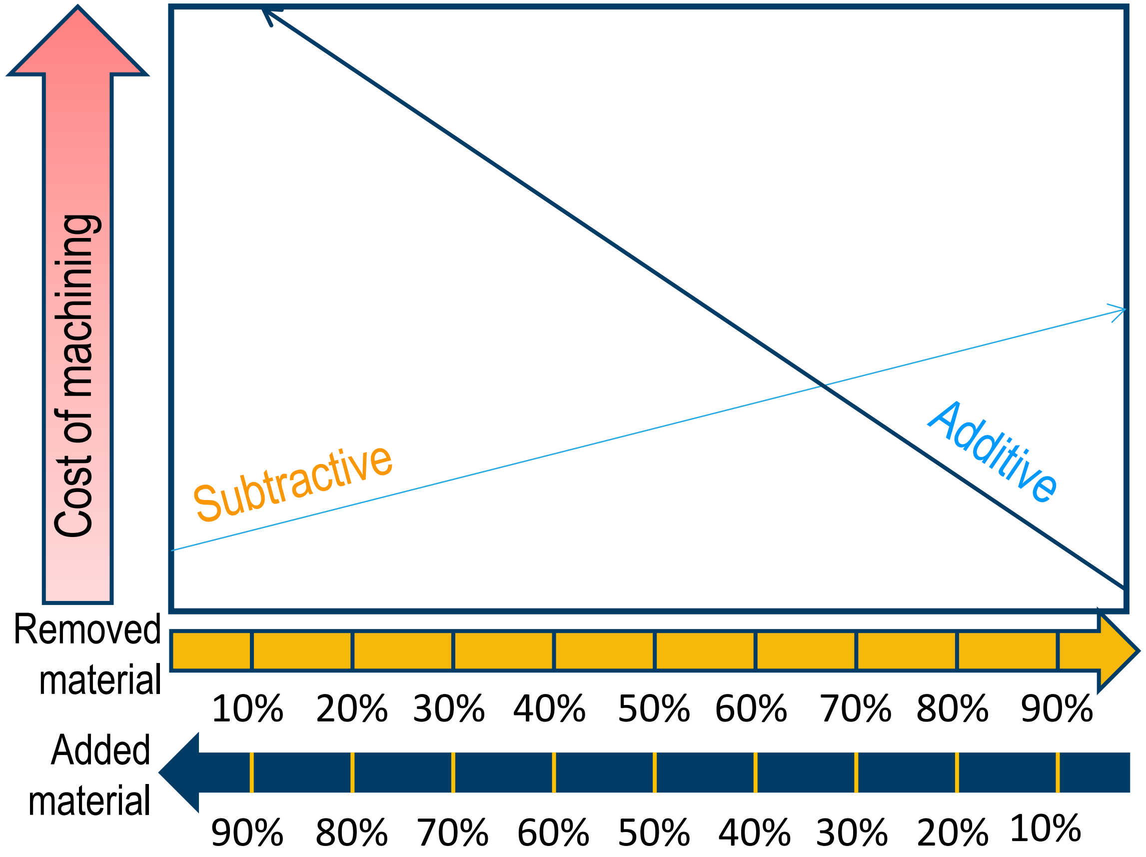
Why AM? -Some fundamentals

Operation by successive addition of material...

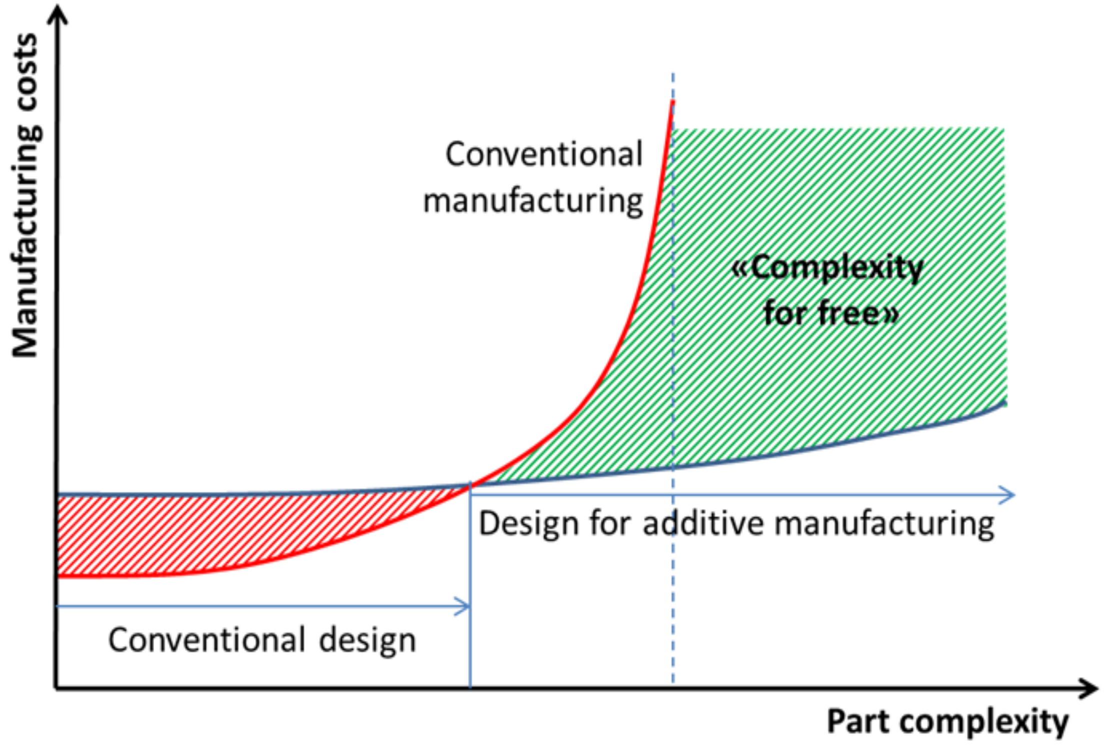
- The additive process builds a material in the shape of a product
    - Properties depend on the process conditions
- In conventional machining, succesive removing of material cost time and money
- In AM, successive addition of material cost time and money



AM is an enabling technology:

Successive addition of material brings new opportunities

- Individual variation at (almost) no additional cost
- More complex geometries- reduced number of components and operations
- More intelligent designs and improved functionalities
- Minimized material consumption
- Game changer” for materials technology



Industrialization:

AM – More than a new technology!

A new paradigm for manufacturing

A different manufacturing principle changes the rules of the game:

- New geometries
- New materials
- New production chains

Flexibility, variability, but also a new way of thinking:

- Design
- Material: is formed, -and can therefore be manipulated during the manufacturing process
- Product development...!
- Intellectual Property Rights (IPR)
- The value creation in products and services

From "Rapid Prototyping“ to industrial manufacturing

Need for a different perspective:

- This is NOT a single process (-or technology for that matter…)
  - 7 different process categories identified….
- AM does not produce final products in a single process step
  - Prototyping processes (Custom manufacturing) v.s. Industrial manufacturing processes
    - A prototyping process, essentially custom manufacturing, includes everything from concept idea to the delivery of the physical prototype. Requirements are ad-hoc and settled by agreement between service provider and customer.
    - An industrial manufacturing process consists of a series of sub-processes, with defined interfaces and specified requirements. Consistency, predictability, traceability and quality control… Predetermined product requirements!
- AM as a part of a larger manufacturing system: the AM-enabled process chain

Successful applications:

Standardized complex shapes

Orthopaedical implants:

- Trabecular Structures may built in to the part and optimized for improved primary fit and osseointegration by allowing you to tailor:
  - Pore geometry, Pore size, Relative density, Roughness
- A growing number of CE-certified and FDA-cleared implants produced by AM on the market

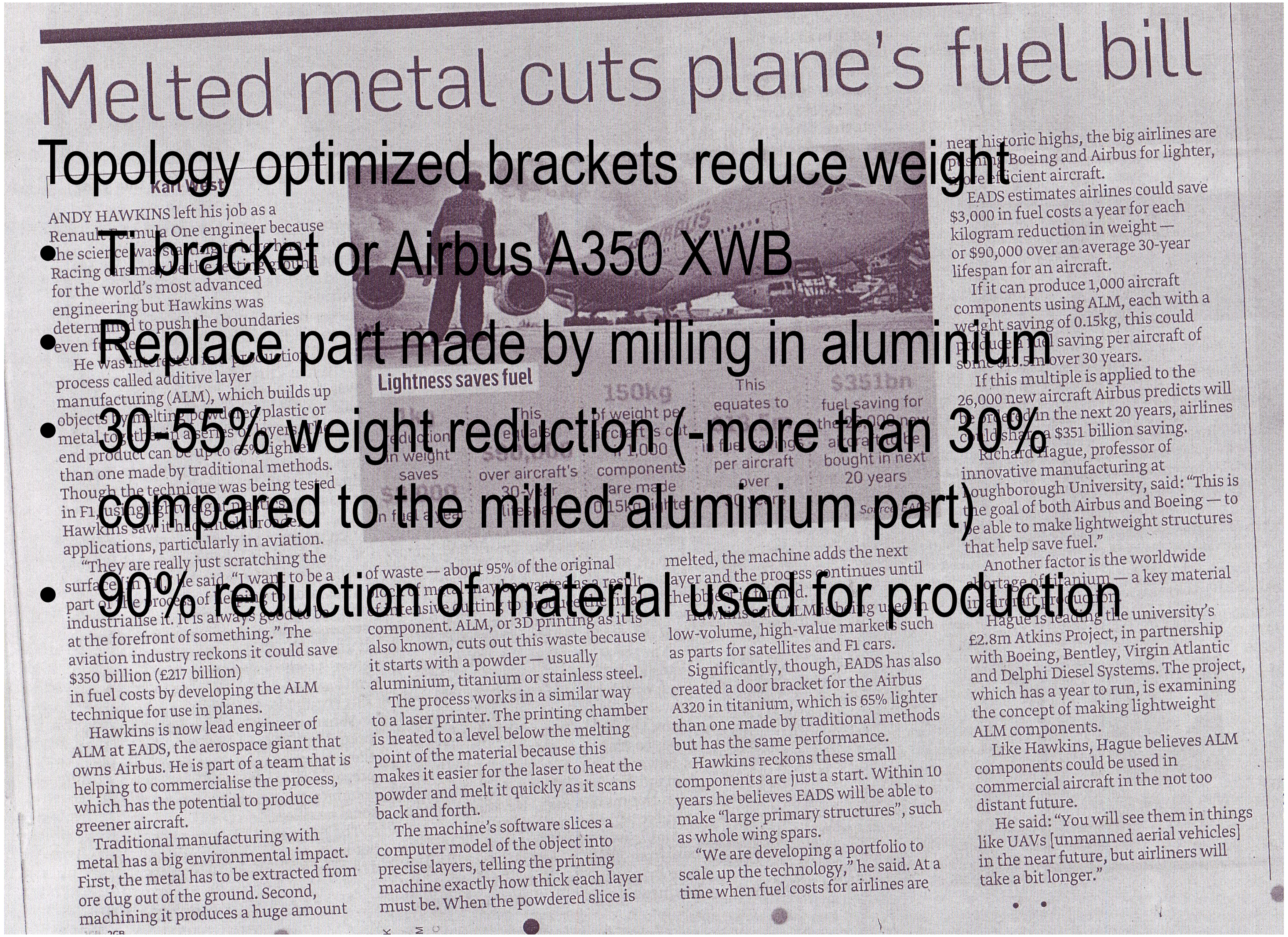
Successful applications:

Reducing the number of components

IT'S IN THE AIR..!

Topology optimized brackets reduce weight

- Ti bracket or Airbus A350 XWB
- Replace part made by milling in aluminium
- 30-55% weight reduction (-more than 30% compared to the milled aluminium part)
- 90% reduction of material used for production



Melted metal cuts plane's fuel bill

Karl West

ANDY HAWKINS left his job as a Renault Formula One engineer because the science was … Racing cars … for the world's most advanced engineering but Hawkins was determined to push the boundaries even f…

He was interested in a production process called additive layer manufacturing (ALM), which builds up objects by melting powdered plastic or metal together in a series of layers … end product can be up to 65% lighter than one made by traditional methods. Though the technique was being tested in F1 … Hawkins saw it had potential in … applications, particularly in aviation.

"They are really just scratching the surface," he said. "I want to be a part of the process of … industrialise it. It is always good to be at the forefront of something." The aviation industry reckons it could save $350 billion (£217 billion) in fuel costs by developing the ALM technique for use in planes.

Hawkins is now lead engineer of ALM at EADS, the aerospace giant that owns Airbus. He is part of a team that is helping to commercialise the process, which has the potential to produce greener aircraft.

Traditional manufacturing with metal has a big environmental impact. First, the metal has to be extracted from ore dug out of the ground. Second, machining it produces a huge amount of waste — about 95% of the original … component. ALM, or 3D printing as it is also known, cuts out this waste because it starts with a powder — usually aluminium, titanium or stainless steel.

The process works in a similar way to a laser printer. The printing chamber is heated to a level below the melting point of the material because this makes it easier for the laser to heat the powder and melt it quickly as it scans back and forth.

The machine's software slices a computer model of the object into precise layers, telling the printing machine exactly how thick each layer must be. When the powdered slice is melted, the machine adds the next layer and the process continues until the …

Hawkins said ALM is being used in low-volume, high-value markets such as parts for satellites and F1 cars.

Significantly, though, EADS has also created a door bracket for the Airbus A320 in titanium, which is 65% lighter than one made by traditional methods but has the same performance.

Hawkins reckons these small components are just a start. Within 10 years he believes EADS will be able to make "large primary structures", such as whole wing spars.

"We are developing a portfolio to scale up the technology," he said. At a time when fuel costs for airlines are near historic highs, the big airlines are … Boeing and Airbus for lighter, more efficient aircraft.

EADS estimates airlines could save $3,000 in fuel costs a year for each kilogram reduction in weight — or $90,000 over an average 30-year lifespan for an aircraft.

If it can produce 1,000 aircraft components using ALM, each with a weight saving of 0.15kg, this could produce a fuel saving per aircraft of some $13.5m over 30 years.

If this multiple is applied to the 26,000 new aircraft Airbus predicts will be needed in the next 20 years, airlines could share a $351 billion saving.

Richard Hague, professor of innovative manufacturing at Loughborough University, said: "This is the goal of both Airbus and Boeing — to be able to make lightweight structures that help save fuel."

Another factor is the worldwide shortage of titanium — a key material …

Hague is leading the university's £2.8m Atkins Project, in partnership with Boeing, Bentley, Virgin Atlantic and Delphi Diesel Systems. The project, which has a year to run, is examining the concept of making lightweight ALM components.

Like Hawkins, Hague believes ALM components could be used in commercial aircraft in the not too distant future.

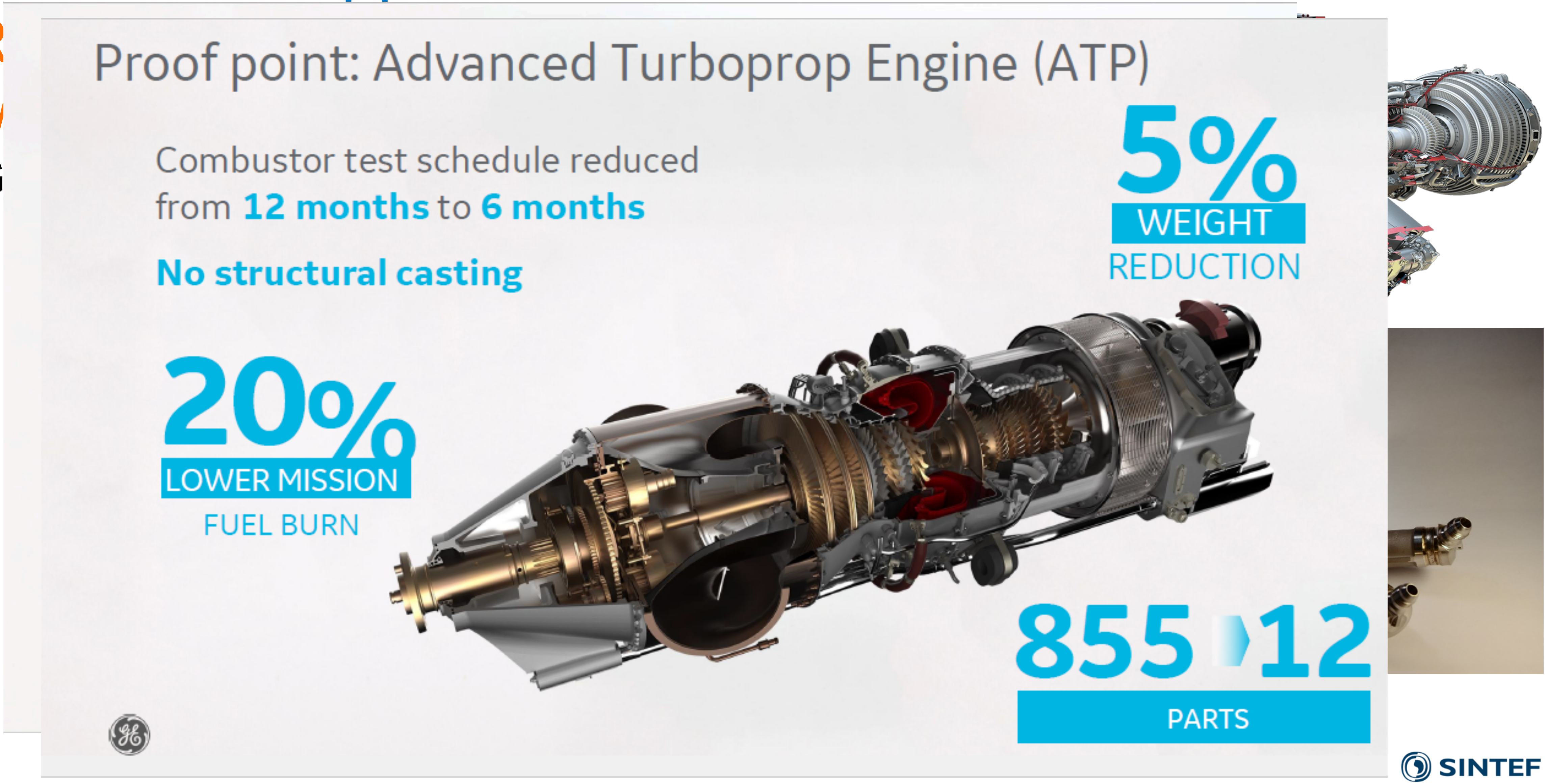
He said: "You will see them in things like UAVs [unmanned aerial vehicles] in the near future, but airliners will take a bit longer."

Successful applications:

R

W

G



Successful applications:

Weight reduction, performance and process material

GE Avio, TiAl LPT blades AM for the LEAP, GEnx, GE90 and GE9X jet engines

- 40% weight reduction compared to casting
- Significant reduction in machining
- New plant built for production in 2013:
  - 12 000 sqft (optional x2)
  - Up to 60 AM machines qualified for aerospace production
  - Gas atomization system

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Successful applications:

Repair: reduced lead times

Siemens Turb

- Material: H
- Conventio
  - Lead tin
- AM repair
  - Lead tin
  - AM sec
- Siemens r

  are preser
- Invested €

  for AM pro

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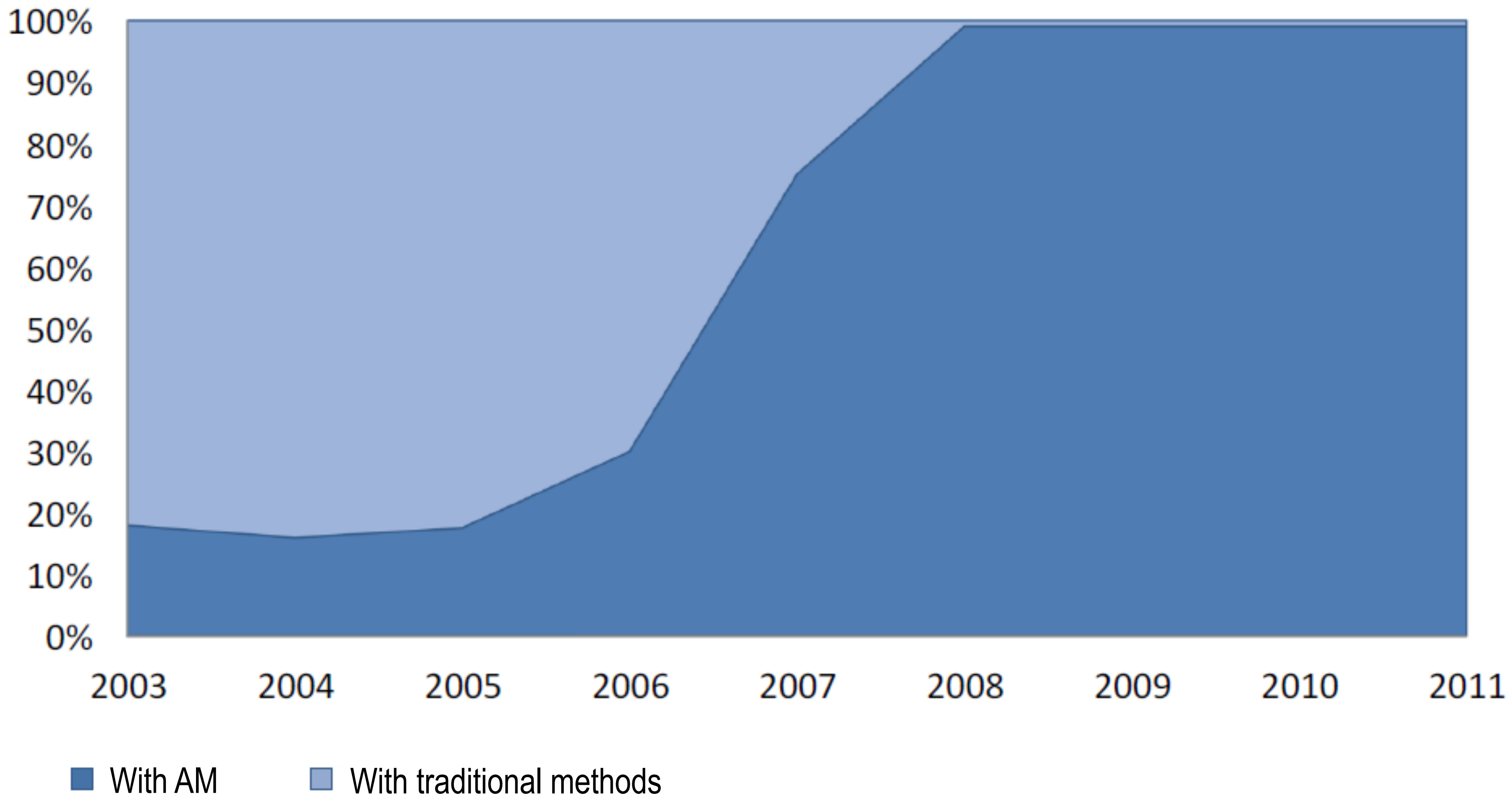
AM application and market impact

Hearing aids: % of the market made with AM



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Great expectations - Many challenges

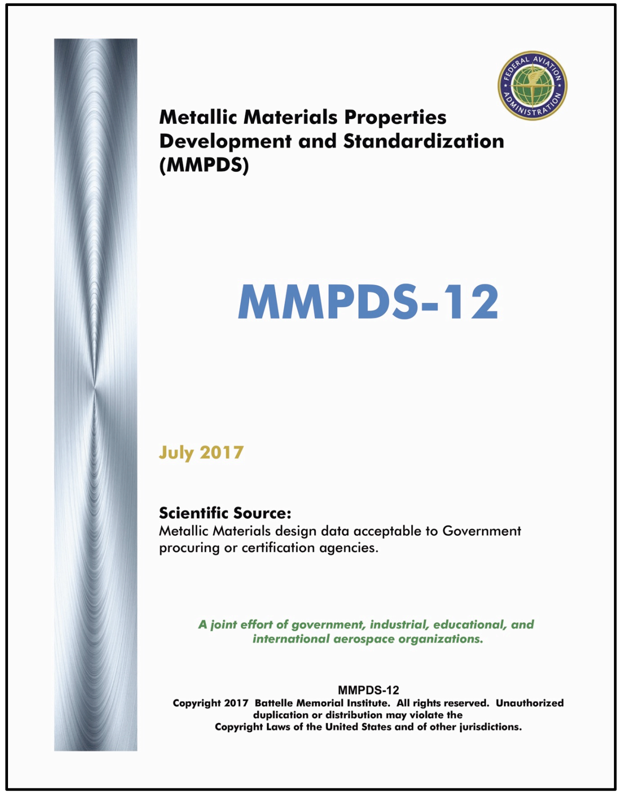
Process and material are more coupled than conventional processes

- Multiple variables and parameters
  - Different machine systems, different set-ups, different calibrations, and different conditions produces different results…,
  - Need for predictability, stability and traceability!
- Quality management, traceability, inspection and verification
- Certification and qualification requires testing and evaluation under specified conditions
- Producers and customers: purchasing process, roles and responsibilities, communication…

Predictable material properties:
The MMPDS Handbook

MMPDS: Metallic Materials Properties Development and Standardization)

- Providing a source of statistically based design values for commonly used metallic materials and joints
- Recognized for certification purposes, by the FAA, by all departments and agencies of the Department of Defence (DoD) and by NASA
- Current edition MMPDS-12 (2017)
- Ongoing effort to include statistically based design values for material formed by AM in future editions
  - Rules for determining statistically based design values for parts made by AM…



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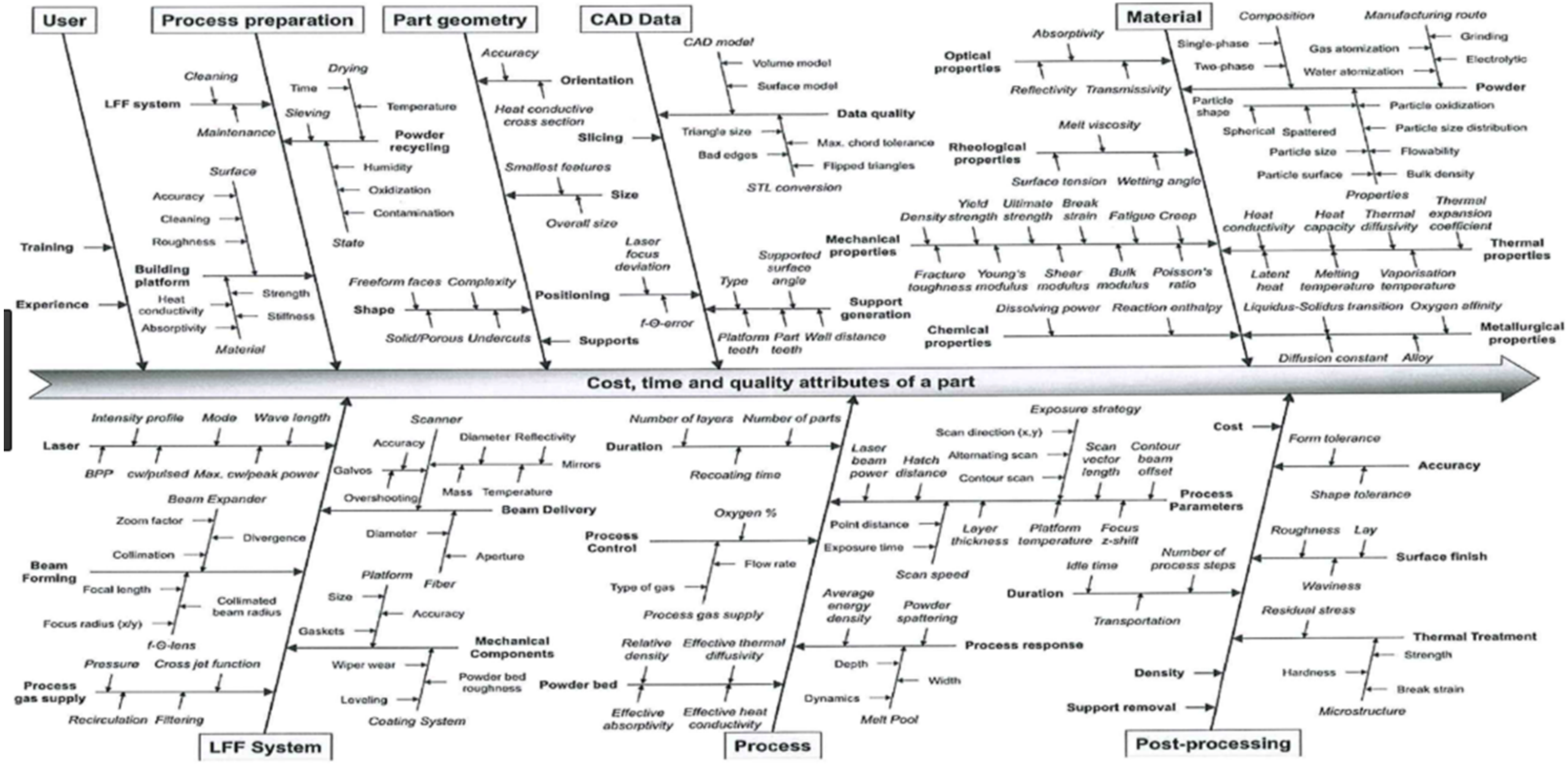
Need for certification

Increase and verification of reliability in personell, processes and parts

- Many parameters and variability in the outcome of the AM-process makes this particularily critical for AM
  - FAA have identified over 200 different parameters that influence the process!
- Certification of personell – quality of parts and EHS issues
- Certification for AM providers
  - Involvement of internatioanlly recognized Certification organizations
  - Involvement of National cerification labs
  - Involvement of industry specific certification organizations

Parameters influencing AM part quality:



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Certification guides for metallic parts by AM: DNV-GL

- DNV-GL have developed a new classification guideline for the approval of AM parts (2017), approval of manufacturers (2018), and type approval of feedstock (2019)
- Provides support when AM manufacturers aim to qualify their premises and technology for broad acceptance
- Offers approval and certification services according to agreed performance specifications for AM processes as well as for AM parts


DNV·GL

CLASS GUIDELINE

DNVGL-CG-0197 Edition November 2017

Additive manufacturing - qualification and certification process for materials and components


DNV·GL

CLASS PROGRAMME

Approval of manufacturers

DNVGL-CP-0267 Edition July 2018

Additive manufacturing

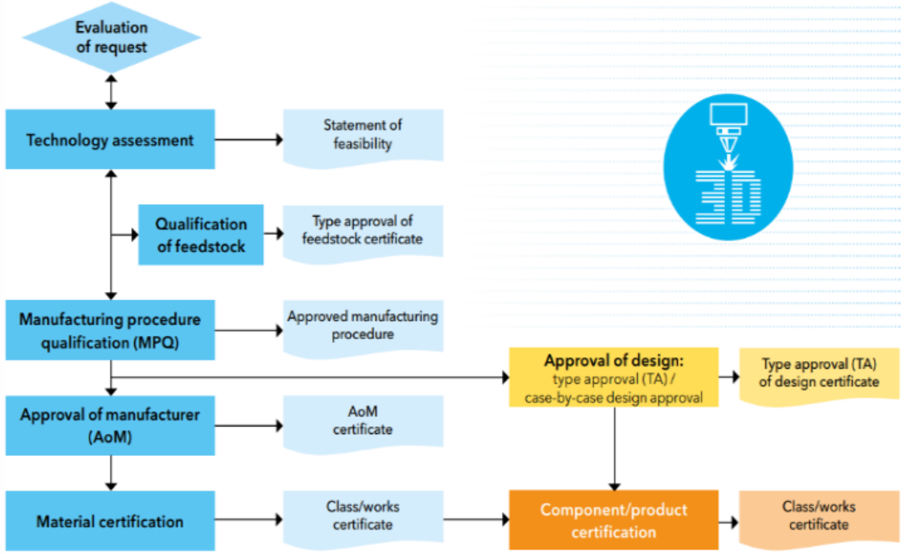

DNV·GL

CLASS PROGRAMME

Type approval

DNVGL-CP-0291 Edition June 2019

Additive manufacturing feedstock



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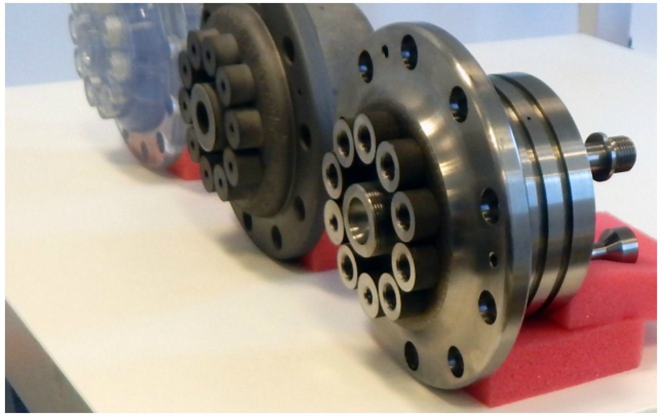
Certification guides for metallic parts by AM: Lloyd's Register

- Lloyd's Register (LR) in collaboration with TWI has developed an AM part certification service for "all industries", from marine to oil and gas, upstream and downstream
- Services include:
  - Independent assurance of additive manufacturing feedstock
  - Assurance for AM production facilities
  - Certification of parts:
    - Plug gateway manifold for Oil and gas industry



Personnel Qualifications in Metal Additive Manufacturing

- EWF (European Federation for Welding, Joining and Cutting) is in progress of development of qualification programs for process operators and engineers in metal AM
- Professional profiles under development (so far):
  - DED (Wire + Arc) Operator
  - DED (Laser) Operator
  - PBF-LB Operator
  - Metal AM Engineer (Generic)
  - DED (Wire + Arc) Engineer (Specialized)
  - DED (Laser) Engineer (Specialized)
  - PBF-LB Engineer (Specialized)
  - Metal AM Designer

The role of standards:

Standards are used for (among others):

- Specifying requirements
- Communicating guidance
  - "What do you mean by RP, RT, RM, FFF, LF, SFF, ALM, ALF, AF, DDF, DDM, 3DP, (-and others)?"
- Documenting best practices
- Defining test methods and protocols
  - Certifying bodies typically reference publicly available standards in their procedures
- Documenting technical data
- Accelerating the adoption of new technologies

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STANDARDIZATION INITIATIVES

International market requires international standards:

ASTM International, Committee F42

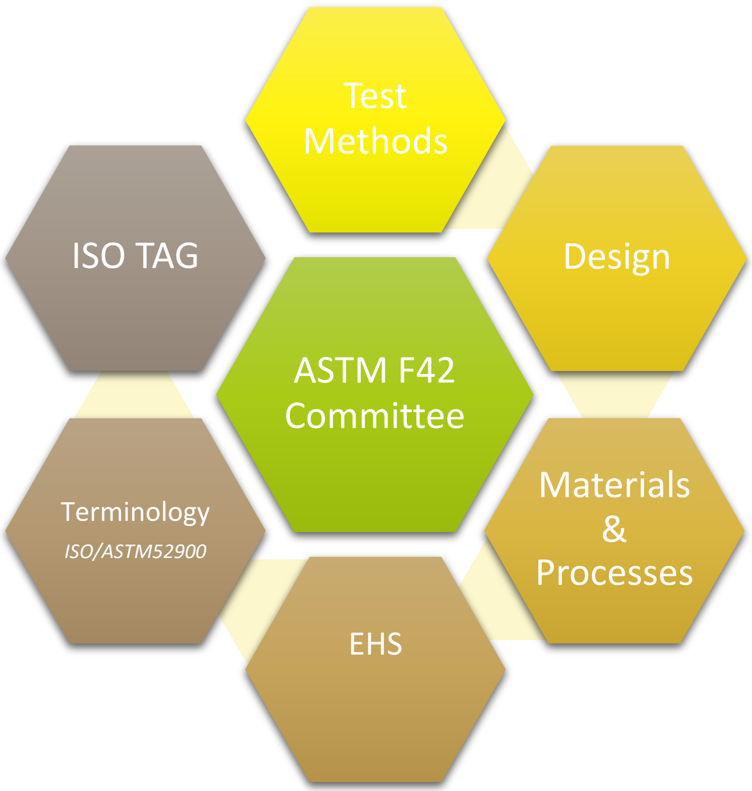
- Established 2009, -coined & defined "Additive Manufacturing"
- **Scope:** "The promotion of knowledge, stimulation of research and implementation of technology through the development of standards for additive manufacturing technologies."
- Membership is based on representation of different stake holders: companies, universities, research organisations etc.
    - 1 vote/organisation

ASTM F42 Fact Sheet 2018

Quick facts

Formed: 2009
Current Membership: 725+ members (150+ outside US)
Standards: 22 approved, 20+ in development

Subcommittees and Focus



Global Representation: 27 Countries

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

Stakeholder Representation (partial list)

Government

Air Force Research Lab (US), FAA (US), FBI (US), FDA (US), NASA (US), NAVAIR (US), NIST (US), US NRC (US)

Academia

Cornell University (US), DeMontfort University (UK), Georgia Institute of Technology (US), Milwaukee School of Engineering (US), North Carolina University (US), Norwegian University of Science and Technology (Norway), Rochester Institute of Technology (US), Texas University at El Paso (US), University of Louisville (US), University of Maryland (US), University of Nottingham (UK), University of Texas (US), Universidad de Zaragoza (Spain), University of Ulster (UK),

Industry

Airbus, Arconic (US), Arcam (Sweden), Arkema (France), Autodesk (US), BAE Systems (UK), Boeing (US), EOS (Germany), Evonik Degussa (Germany), GE (US), GKN Aerospace (US), Gulfstream Aerospace (US), Honeywell (US), Lockheed (US), Materialise (Belgium), Met-L-Flo, Inc. (US), Northrop Grumman (US), Objet Geometries (Israel), Pratt & Whitney (US), Rolls Royce (US), Schlumberger (US), Siemens (Germany), Stratasys (US)

Trade Associations

CECIMO (EU), National Center for Manufacturing Sciences (US), Rapid Product Development Association of South Africa (RSA), Society of Manufacturing Engineers (US)

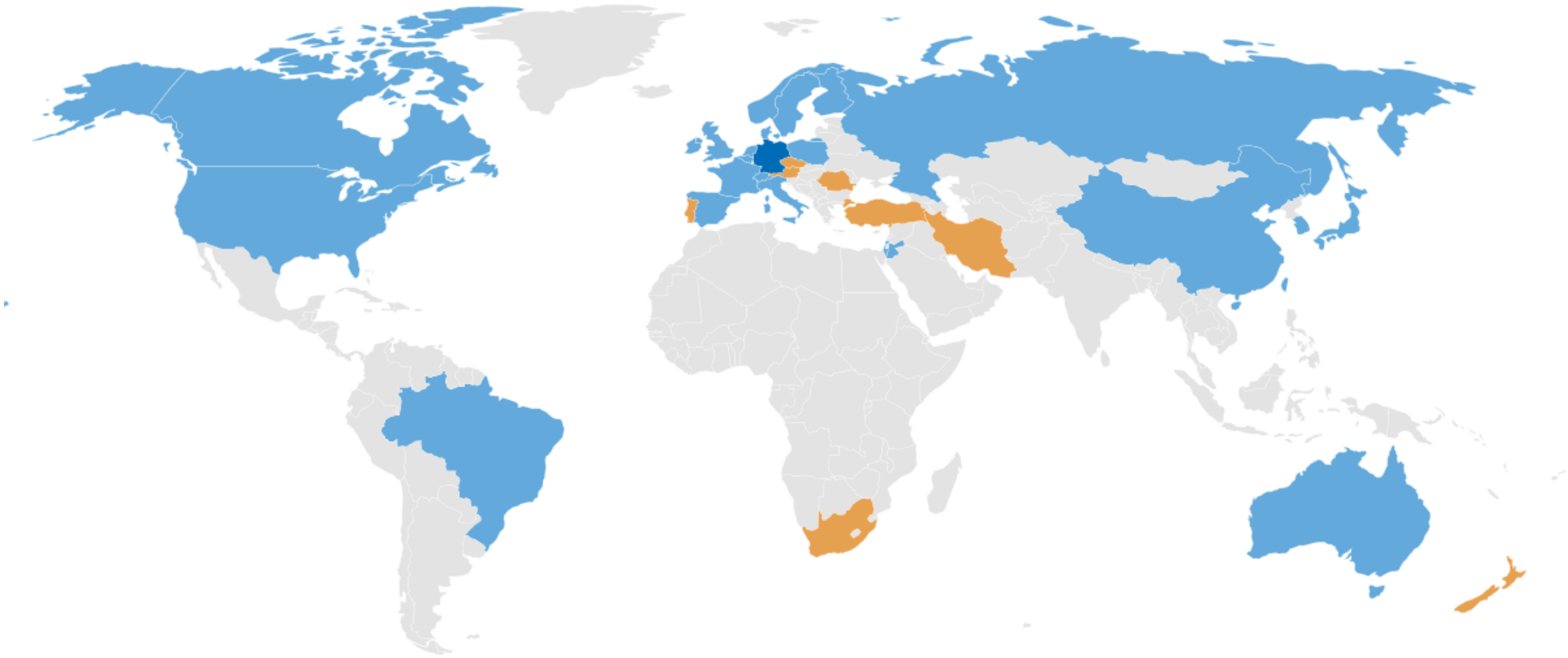
3rd party certification bodies

-EVEN MORE INTERNATIONAL…

ISO Technical Committee 261 (ISO/TC261)

- Established 2011, after an initiative from DIN, based on VDI Guidelines on "Rapid Technologies"
- **Scope:** (Next slide please…)
- Membership is based on representation of different national standardization organization. Each member organization may nominate experts for different workgroups.
  - 1 vote/organization
- Presently: 25 participating countries +8 observers

ISO/TC 261: International participation



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COLLABORATION:

Standards are needed, but we don't necessarily need several competing standards…

ISO & ASTM have signed a Partnership Standards Development Organization (PSDO) agreement

- Fast tracking the adoption process of an ASTM International standard as an ISO FDIS (Final Draft International Standard
- Formal adoption of a published ISO standard by ASTM International
- Maintenance of published standards
- Publication, copyright and commercial arrangements

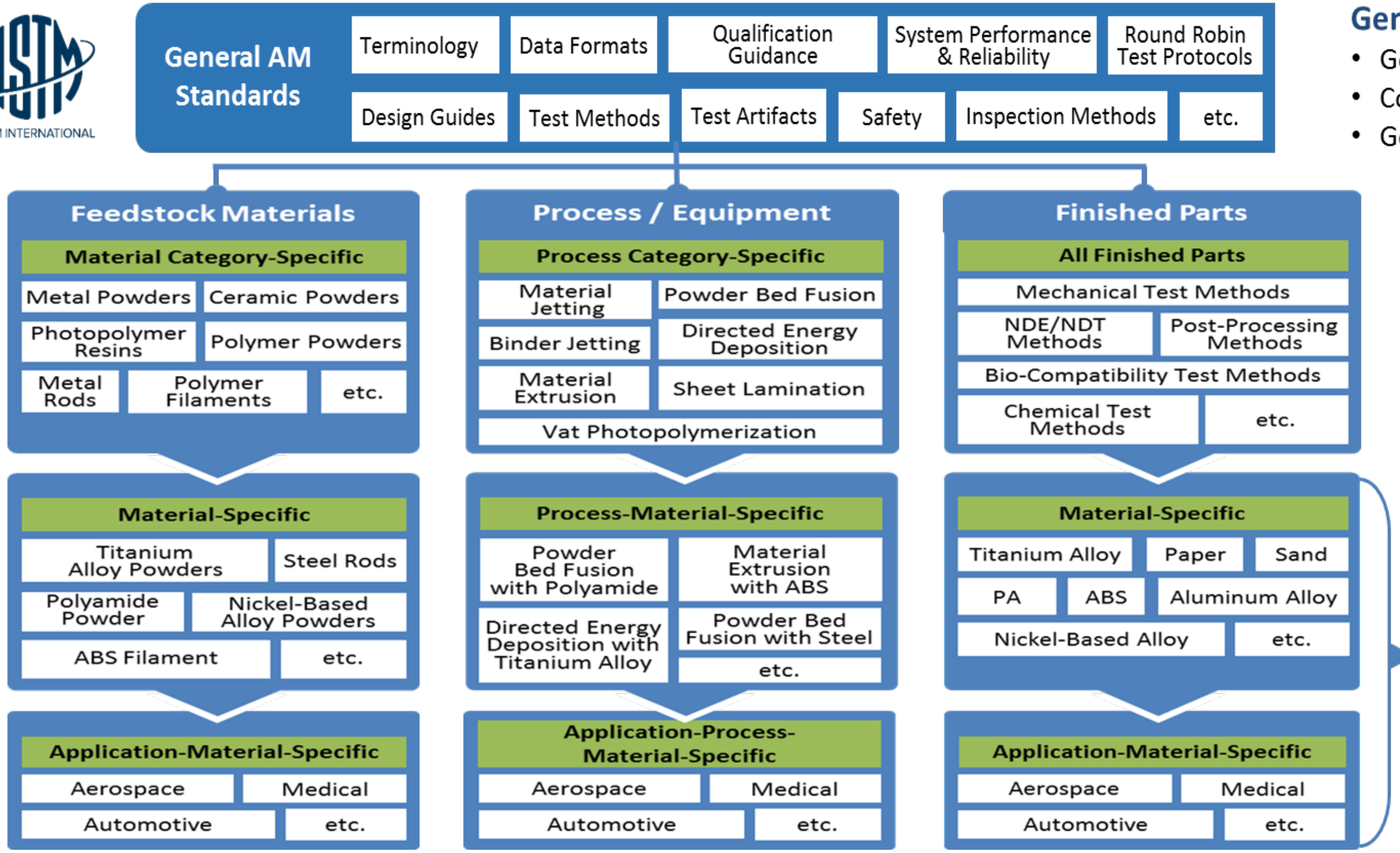
James Thomas, ASTM President, and Rob Steele, ISO Secretary-General

Guiding principles:

- One set of AM standards – to be used all over the world
- Common roadmap and organizational structure for AM standards
- Use and build upon existing standards, modified for AM when necessary
- Emphasis on joint standards development

Additive Manufacturing Standards Structure

Additive Manufacturing Standards Structure



General Top-Level AM Standards
- General concepts
- Common requirements
- Generally applicable

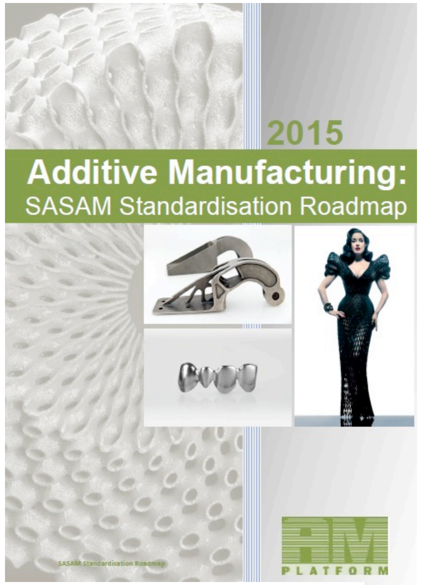
Category AM Standards

Specific to material category or process category

Specialized AM Standards

Specific to material, process, or application

EUPOPEAN INITIATIVES



- SASAM - "Support Action for Standardisation of Additive Manufacturing" EU FP7 CSA-project
  - Scoping – stakeholder's requirements
  - Roadmap for standardization of AM
  - Project completed Apr 2014, roadmap updated 2015
- STAIR-AM: Cen-CENELEC working group (STAndardization, Innovation and Research)
  - Objective: "to be a meeting point of stakeholders from the AM research, innovation community and the global standardization community." (Ended 2015)
  - Activities continued by CEN/TC438 and AM-Platform
- CEN/TC 438 (since July 2015)
  - Transform ISO/ASTM standards to EN ISO/ASTM standards
  - *CEN standards automatically replace any national standards in all member states*

HOW STANDARDS ARE DEVELOPED

Very basic:

- All standards development is based on contribution from members
  - Members are stakeholders and base their contribution on an interest in developing the standards
  - No funding or compensation provided from the SDOs
  - SDO's have all the IPR
- Consensus based!
- ASTM: experts nominated directly by stakeholder (Company, University, Professional organization, etc.)
  - Type of membership depend on the nature of the stakeholder's interest
- ISO & CEN experts nominated national SDO committees, -which is based on stakeholder memberships

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HOW STANDARDS ARE DEVELOPED:

New work item proposal

ASTM:

Submitted to Sub-committee

- Request for participation
- Sufficient commitment from members – work to develop standards documents begins
- A minimum of 60% committee participation in ballots is required for continuation of project

ISO:

Submitted to Secretariat

- Proposal circulated and submitted for ballot
- Call for experts from National mirror committees
- Work group secretariat normally appointed to the same SDO as submitted the proposal
- Draft circulated and submitted to repeated ballot processes

Joint ISO/ASTM: Each SDO may propose an item & invite the partner to join

3 - 5 experts from each SDO participate in the JG (Joint work Group)

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ASTM F42 and ISO/TC261:

Sub-Committees

- F42.01 Test Methods
- F42.04 Design
- F42.05 Materials and Processes
  - F42.05.01 Metals
  - F42.05.02 Polymers
  - F42.05.05 Ceramics
- F42.06 Environment, Health, and Safety
- F42.07 Applications*
- F42.91 Terminology

Workgroups

- ISO/TC 261/WG 01 "Terminology"
- ISO/TC 261/WG 02 "Processes, systems and materials"
- ISO/TC 261/WG 03 "Test methods and quality specifications"
- ISO/TC 261/WG 04 "Data and Design"
- JWG 05 "Joint ISO/TC 261 - ISO/TC 44/SC 14 WG; Additive manufacturing in aerospace applications
- ISO/TC 261/WG 06 "Environment, health and safety"
- JWG 07 "Joint ISO/TC 261 - ISO/TC 61/SC 9 WG; Additive manufacturing for plastics"

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*New subcommittee: F42.07 Applications

"Bridging the gap between AM standards and existing product specifications"

- F42.07.01: Aviation
- F42.07.02:Spaceflight
- F42.07.03: Medical/Biological
- F42.07.04: Transportation/Heavy machinery
- F42.07.05: Maritime
- F42.07.06: Electronics
- F42.07.07: Construction
- F42.07.08: Oil & Gas
- F42.07.09: Consumer

JOINT STANDARDS DEVELOPMENT AGREEMENT:

- Draft for review 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 the ASTM balloting can be submitted into the ISO balloting process

ISO PRINCIPLES AND RECOMMENDATIONS FOR TERMS AND DEFINITIONS

- Terms should be as general as possible, -as long as they are clear, concise and short
- <u>NO Trade Marks!</u>
- Definitions for terms should:
  - Be possible to use as a replacement for the term in a text
  - Not include any restrictions, requirements or specifications
    - Should be defined as a part of the specific standards and not in the terminology

For example:
What is the meaning of ”3D printing”?

The term "3D Printing" may apply to:

- Printing text and pictures on a 3D substrate
- An AM process based on the original patent ”Three Dimensional Printing Techniques” (Patent by MIT, 1993, trademark 1992-93, see also "binder jetting")
- An AM process based on a traditional printing operation, (such as "binder jetting" + "material jetting")
- A low cost AM system that private people can have at home, like a home printer
- A general term for the whole field of AM; -This is mainly due the recent media exposure of low cost home AM….

WHAT'S THE POINT WITH "NO TRADE MARKS"?

- For example: "Selective Laser Melting" –SLM
  - Originally developed and patented in collaboration between Fraunhofer ILT and Dr. Dieter Schwarze and Dr. Matthias Fockele from F&S Stereolithographietechnik GmbH
- SLM® is a current registered trademark by SLM Solutions GmbH
- SLM Solutions use "SLM" in their product names and marketing:
  - What if SLM Solutions decide to launch a product using:
    - An electron beam?
    - A laser, but no powder bed?
    - ...or any other product?

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TRADE MARKS AND PROCESSES

For comparison in personal vehicles: the trade mark "Volvo" means "I roll", -Is therefore all that rolls a "Volvo"?

- How about Volvo Construction Equipment, Volvo Penta, or Volvo Aero?

- Comparing "SLM" with "DMLS/DMLM" and "LaserCusing"? –Like comparing Mercedes Benz with BMW and Audi…

Clouds on the horizon….

Since 2015 many new stakeholders (International and national SDOs, different TC's within the same SDO, various industrial and professional associations) have initiated their own AM standard development

- In the US, for example:
  - ASTM E07 –Non-destructive Testing
  - ASTM E08 -Fatigue & Fracture
  - ASME Y14.46 -Geometric Dimensioning & Tolerancing
  - ASME B46 -Surface Texture
  - ASME BPVC -Welding, Brazing, Plastic Fusion
  - SAE AMS –AM Aerospace Material Specs
  - AWS D20 –AM Fabrication of Metal Components
- In ISO, for example
  - ISO TC44/SC14 Welding and brazing in aerospace
  - ISO/IEC JTC1/WG12 3D Printing and scanning
  - ISO/TC184/SC1 Physical device control
  - ISO/TC184/SC4 Industrial data

The more, the merrier?

More activity – Faster over all development?

Possibly, but lack of coordination also brings:

- High risk of duplication of efforts and overlapping content
- High risk for inconsistencies (or even contradictions)
- Conflicting standards: -creates ambiguity and confusion in the market
  - In particular critical to AM!
- Expertise spread thin over several committees

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AMSC:
Additive Manufacturing Standardization Collaborative

- US initiative, coordinated by ANSI and America Makes with the purpose:
  - "To coordinate and accelerate the development of (US) industry-wide AM standards and specifications, consistent with stakeholder needs, and thereby facilitate the growth of the AM industry"
- Principal objectives:
  - Coordinate and provide input to AM Standards Developing Organizations (SDOs)
  - Develop a (US) standardization roadmap for AM based on existing standards and specifications, as well as those in development, and identified gaps
  - As a general agreement all standards should use the same ISO/ASTM 52900 Terminology standard

The ASTM International
Additive Manufacturing Center of Excellence

CE
STANDARDS
itive Manufacturing

Founding partners

ASTM INTERNATIONAL | AUBURN UNIVERSITY | EWI | mtc | NASA

Strategic partners

NAMIC NATIONAL ADDITIVE MANUFACTURING INNOVATION CLUSTER | NIAR

A synergistic, collaborative, and efficient environment in which R&D advances technical standards, helping all aspects of additive manufacturing flourish.

www.amcoe.org | amcoe@astm.org

ASTM AM CoE
Clear Vision & Dedicated Mission

VISION

The Center facilitates collaboration and coordination between government, academia, and industry to advance AM standardization and expand ASTM and our partners' capabilities

MISSION

The Center bridges standards development with R&D to better enable efficient development of standards, education and training, certification and proficiency testing programs

Concluding remarks

International standards development

- Development of AM standards is a key element in establishing AM as a part of the industrial manufacturing system and provide an intellectual infrastructure to the market.
- International collaboration between ASTM, ISO and CEN is formally established and is growing
  - One set of standards used all over the world!
  - Common roadmap and organizational structure for AM standards
    - Use and build upon existing standards, modified for AM when necessary
  - Joint working groups are in progress
- Several standards, both common and by the individual organizations, have been published and more are on the way


It's not a tip of an iceberg we're seeing,
-we're entering a new universe in manufacturing...

Thank you for the attention!

Any Questions?

klas.boivie@sintef.no