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Project No. 601217-EPP-1-2018-1-BE-EPPKA2-SSA-B

CU 36: Coordinating the AM Process (Pilot)

Design for AM -setting and meeting the design brief

Prepared by: Danny Lloyd & David Wimpenny

Date: 13/01/21

Please look for slides showing - KEY INFORMATION

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Topics covered include....

- Design for AM
- Benefits of AM versus commitment
- Business case
- Functional requirements
- Commercial requirements
- Standards & legislative requirements

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Design for AM (DfAM) - Requirements capture

To support Design for AM (DfAM) we need to get more detail than for standard AM requirements capture;

1. Business case for specifying AM
2. Part function
3. Commercial requirements
4. Standards & legislative requirements
5. Scope for redesign
6. Material requirements
7. Customer management requirements

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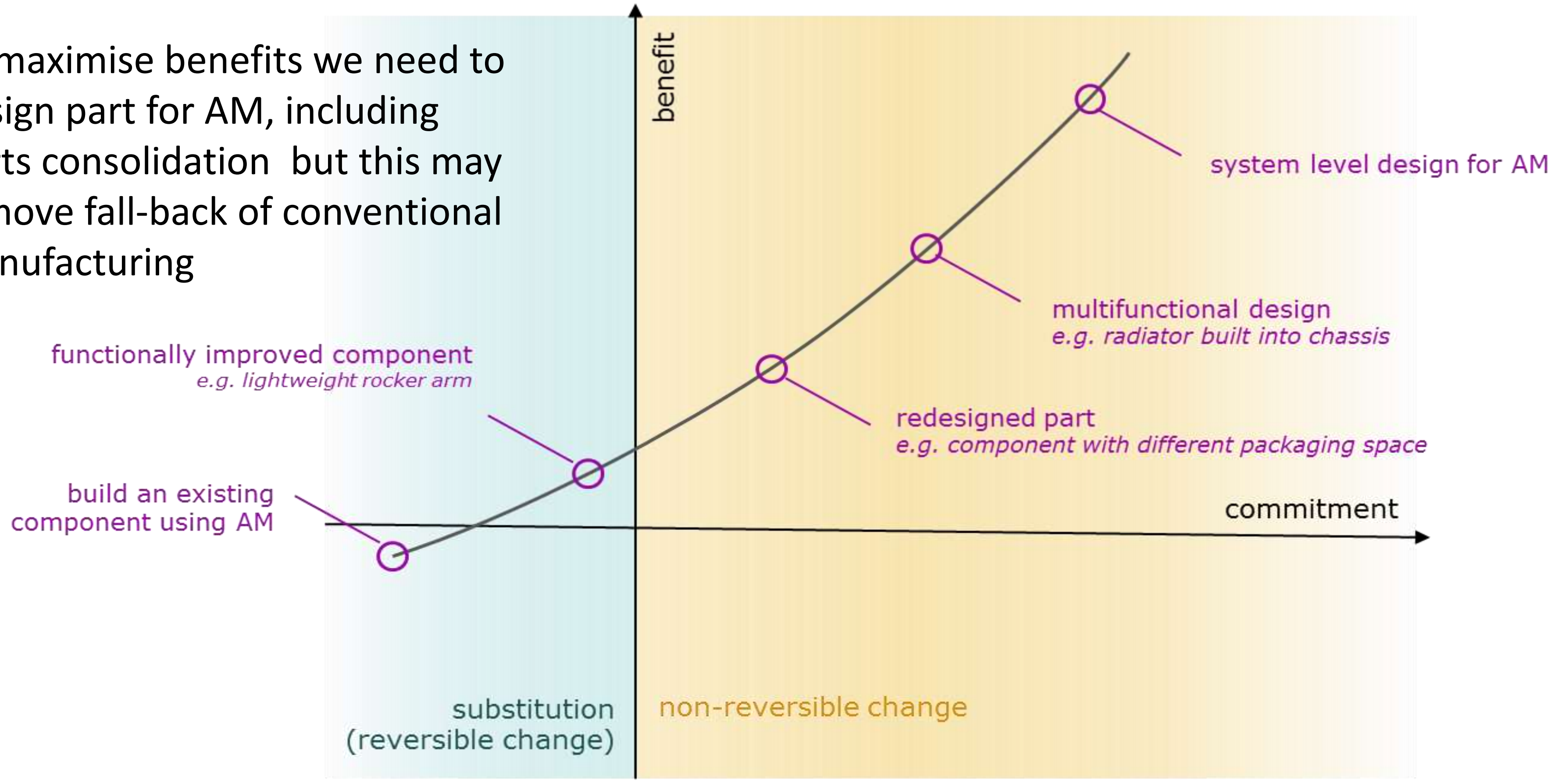
Benefit/Risk vs commitment to AM

To maximise benefits we need to design part for AM, including parts consolidation but this may remove fall-back of conventional manufacturing



Based on a graphic by Neil Mantle, Rolls-Royce

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Business case for specifying AM

- **Why is the customer considering AM for this part:**
    - *Are they properly informed about AM? (AM isn’t a miracle manufacturing method).*
    - *Are they hoping for short lead time, lower cost, improved quality?*
    - *Is it a legacy component with no drawings or CAD files?*
    - *Is their old supply chain no longer viable?*

- AM is best used for low volume production runs. If the customer requires a higher volume, AM may not be the best manufacturing method.

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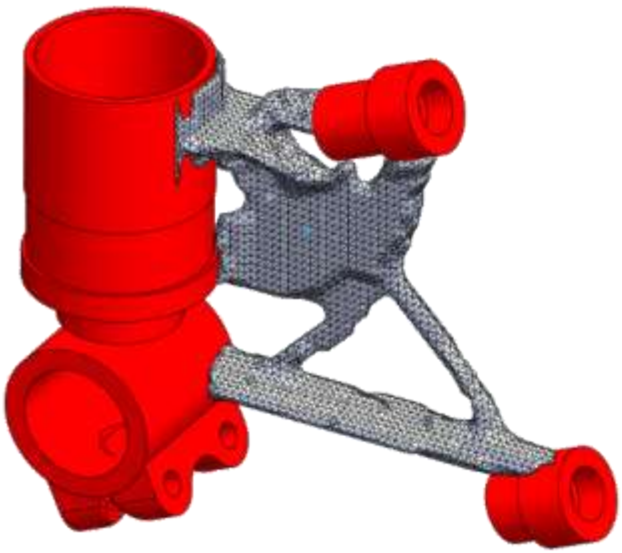
Business Case cont.

- **What value is the customer seeking for AM:**
  - *Are the customer hoping to achieve improvements in lead time, cost, quality, weight, or sustainability?*



- Knowing this will define the design philosophy.
- Not understanding the value the part is getting from AM risks proposing solutions that are not economical or deliver full value.

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Business Case cont.

- **Current manufacturing process:**
  - *What is the current manufacturing process?*
  - *What additional steps are there after the component manufacture?*

- Help to understand the current process defined design limitations and where AM can add value.
- Any additional assembly or manufacturing steps need to also be captured. Parts may undergo a coating process that requires some inherent bonding properties, or access to certain features.

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Part Function – what does the part do ?

- **Purpose of the component/assembly:**
  - *What does the part/assembly do?*
  - *What are the critical functional requirements?*
  - *What are the design drivers?*
  - *How does it interact with adjacent components?*

- Capturing this information will ensure that, if met, the final part will be fit for purpose.
- It also helps to identify where AM can add value.

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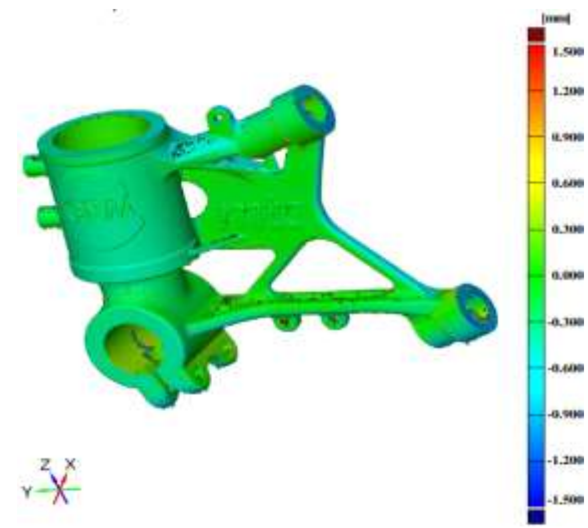
Accuracy & Surface finish

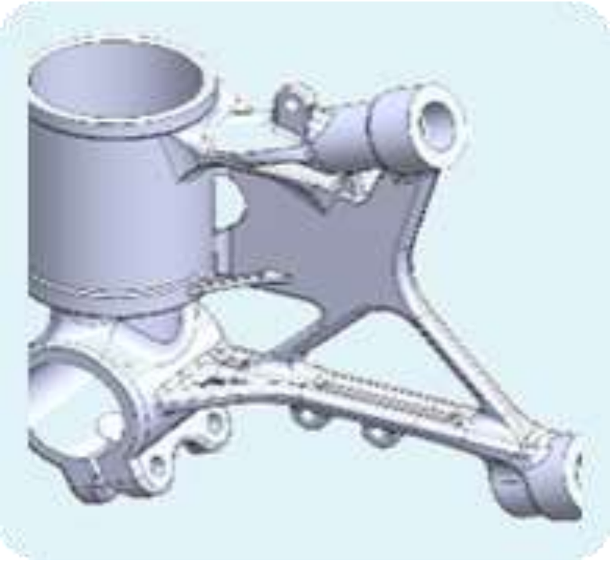
- **Dimensional accuracy and tolerances:**
  - *What accuracy is required?*
  - *What surface tolerances are required?*
  - *Are all these essential, or only specific ones?*

- Accuracy and surface finish can restrict process choice, or post processing choices.
- Understanding the actual surface finish requirements can save a lot of post processing if they are only required on critical surfaces, such as mating faces in assemblies.
- Reducing the number of critical tolerances can speed up printing and reduce the amount of post processing required, bringing down cost.



Existing Design Data/Files

- **CAD files/drawings of components/assembly and relevant adjacent files:**
  - *Size and complexity of the file*
  - *Have all the required parts of the assembly been delivered?*
  - *Has the function of all the files in assembly been understood?*
  - *Are all the CAD files/drawings available?*



- In some cases, files may not be available, such as in legacy components, or a part that was made from a discontinued tool. This will require an element of reverse engineering instead.

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Commercial Requirements – cost

- **Cost target:**
  - *Does the customer have cost target for the parts? Overall or cost per part?*
  - *Has the customer considered all the aspects of the AM process beforehand? Design, simulation, printing, post processing, inspection, quality, and value add?*

- This will ensure the parts are economically viable, and also help give the customer a better appreciation of the full AM process, as well as the value added to the part by using AM.

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Commercial Requirements – lead time

- **Lead time:**
    - *Does the customer have a target lead time for the part?*
    - *Have they considered the full AM process?*
    - *Is there time to effectively improve the parts, or simply recreate them?*

- Due to the number of steps involved, there's lots of places delays can be stacked up. This should be considered when providing a lead time to the customer. Efficient scheduling and project management will help with this.

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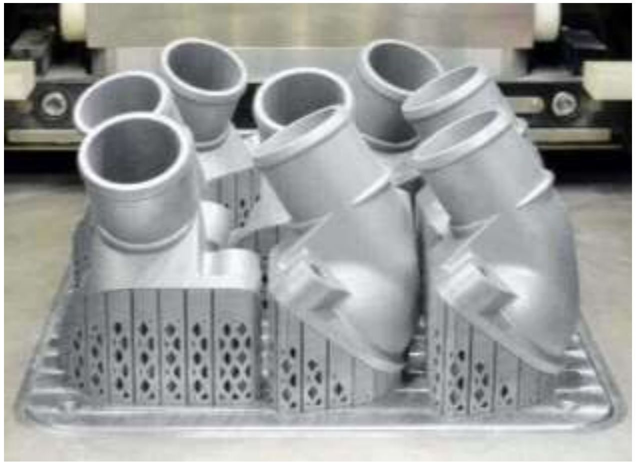
Commercial Requirements – production volume

- **Production volume:**
    - *How many parts does the customer need?*
    - *Are there variations in the parts?*



- AM is best used for low volume production runs. If the customer requires a higher volume, AM may not be the best manufacturing method.

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Standards & Legislative Requirements

- **Legislative requirements:**
  - *Different sectors have different legal requirements.*
  - *Have all the standards and compliances been clearly defined?*
  - *Can AM meet the legislative requirements?*
  - *Are there health and safety requirements?*

- This will help avoid problems with qualification and certification.
- These will likely impact all stages of manufacturing: design, process, materials
- Inspection and reporting standards

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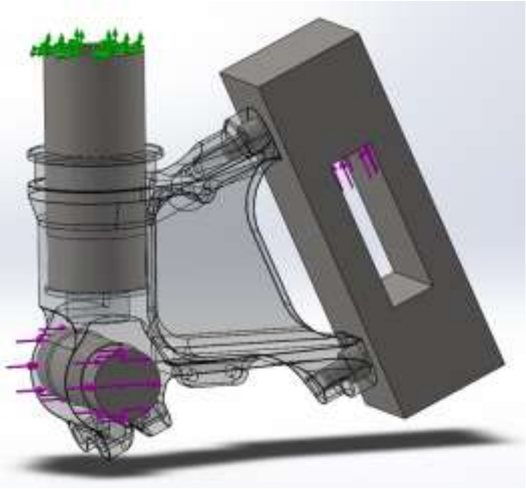
Capture Scope for Redesign

- **Determine the openness to redesign for AM:**
  - *How much of the design are the customer willing to change?*
  - *If there are strict limitations on design, are they willing to allow for*

  potential defects as a result?



- It is highly likely, unless designed from scratch, parts will be designed for a different manufacturing process. They will therefore require – as a minimum – some redesign for AM.
- Depending on the process and component, this redesign could be significant, and therefore a limiting factor in process and material selection.
- In some cases alternative manufacturing routes may be more beneficial

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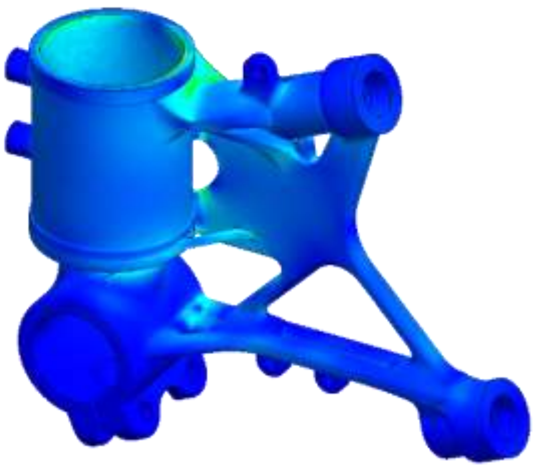
Capture Scope for Redesign

- **Consider the impact of redesign:**
  - *Are AM features such as lattices or organic structures going to add value?*
  - *What skins and surfaces are essential?*
  - *What features require access?*



- Some things will not be able to change, such as adjacent part mating surfaces. Some information on those parts will not be sharable, or changeable.
- Lattices and organic surfaces make the part harder to inspect. The level of inspection may be a limiting factor and therefore it might be more beneficial to avoid certain design techniques in certain parts of the component.

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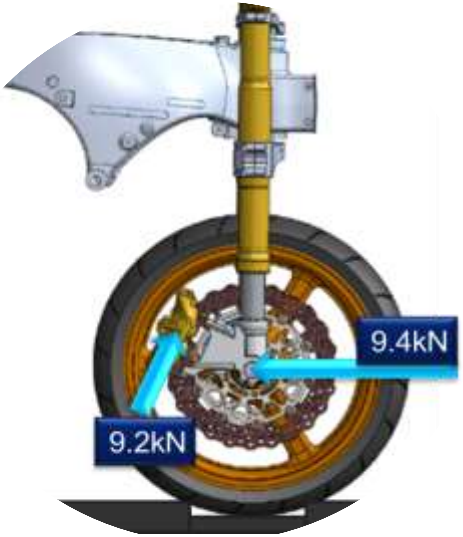
Capture Material Requirements

- **Current component material:**
  - *What is the current component material(s)?*
  - *Why has that material been chosen?*
  - *What are the mechanical requirements?*
  - *What are the chemical requirements?*
  - *What are the temperature requirements?*
  - *What are the fatigue requirements?*
  - *What are the loading requirements?*
  - *What are the elastic requirements? Etc.*



- This will compliment the understanding of the part in general, and will begin to help identify AM equivalents.
- Not all the data on AM materials may be available, so testing may be required to validate suitability.

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Capture Material Requirements

- **AM material equivalent suitability:**
    - *Is the current material available for AM?*
    - *What material equivalents are there?*
    - *Is that the best material for the job?*
    - *Will alternative materials do a good enough, equivalent, or better job?*

- The specific or general material used in the current part may not be available in AM. Therefore an equivalent AM material may have to be chosen and assessed for its suitability.
- The material chosen by the customer may not be the best for the job. Either materials available to AM, or properties achieved through redesign, may allow for an alternative material to be chosen.
- This can add value, such as light weighting by using a less dense metal or swapping out metal entirely for a polymer or composite.
- Some materials may require post processing to achieve the desired material performance. Such as heat treatment for fatigue, or coating for chemical resistance.

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Capture Material Requirements

- **Any other AM value add:**
  - *Can AM add value through materials in any other way?*

- Some processes are able to manufacture in multi material, multi colour, or functional grading. These are unique to AM and may be available to the component/assembly to add value.

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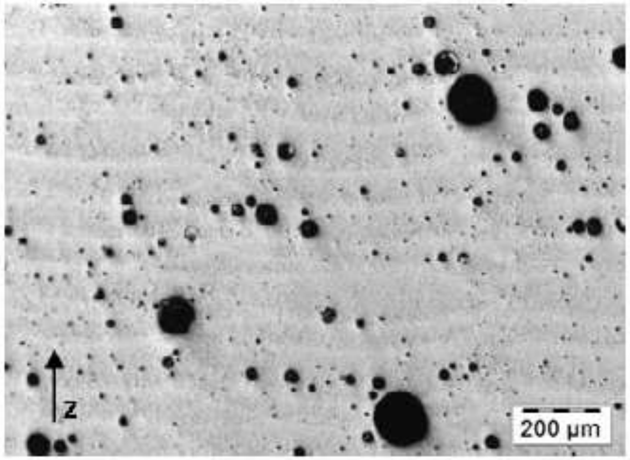
Capture Material Requirements

- **Material integrity requirements:**
  - *What level of defects are acceptable?*
  - *What is the target density?*
  - *Can these be mitigated through post processing?*



- Many AM processes suffer from defects such as porosity, voids, and other defects. These need to be communicated and acceptable levels captured.
- While some of these defects can be improved with post processing, that needs to be fully considered in the design stage, as well as cost.

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Capture Material Requirements

- **Gate reviews and customer feedback:**
  - *How involved does the customer want to be in the process?*
  - *Should the customer approve design changes throughout?*
  - *Do prototypes need to be made?*

- The customer may want to be hands off or directly involved in the entire process.
- Visual or functional prototypes may need to be made for the customer to evaluate aesthetics, fit in an assembly, or performance.

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Capture Material Requirements

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Requirements Capture - Example

A customer has a visual prototype and a CAD file for a component designed for an AM process, what things can be skipped in the requirements capture?

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Thank you

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Project No. 601217-EPP-1-2018-1-BE-EPPKA2-SSA-B

CU 36: Coordinating the AM Process (Pilot)

TOPIC 4: Controlling design data

Prepared by: Sandeep Samanthula & David Wimpenny

Date: 13/01/21

Please look for slides showing - KEY INFORMATION

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Topics covered include….

- Why design data control is critical
- Challenges for AM data management
- File formats and tolerancing
- Beyond design data – the digital tread
- Role of PLM/MES
- Data security and export control

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Why Design Data Control is critical?

- Each of the data processing steps (CAD design, tessellation, build orientation, support design, build layout, slicing, building, post processing) contribute to the finished part quality.
- Large amounts of data are generated, exchanged which need to be efficiently and securely managed.
- Data traceability is required for reproducibility, quality assurance, qualification & certification procedures

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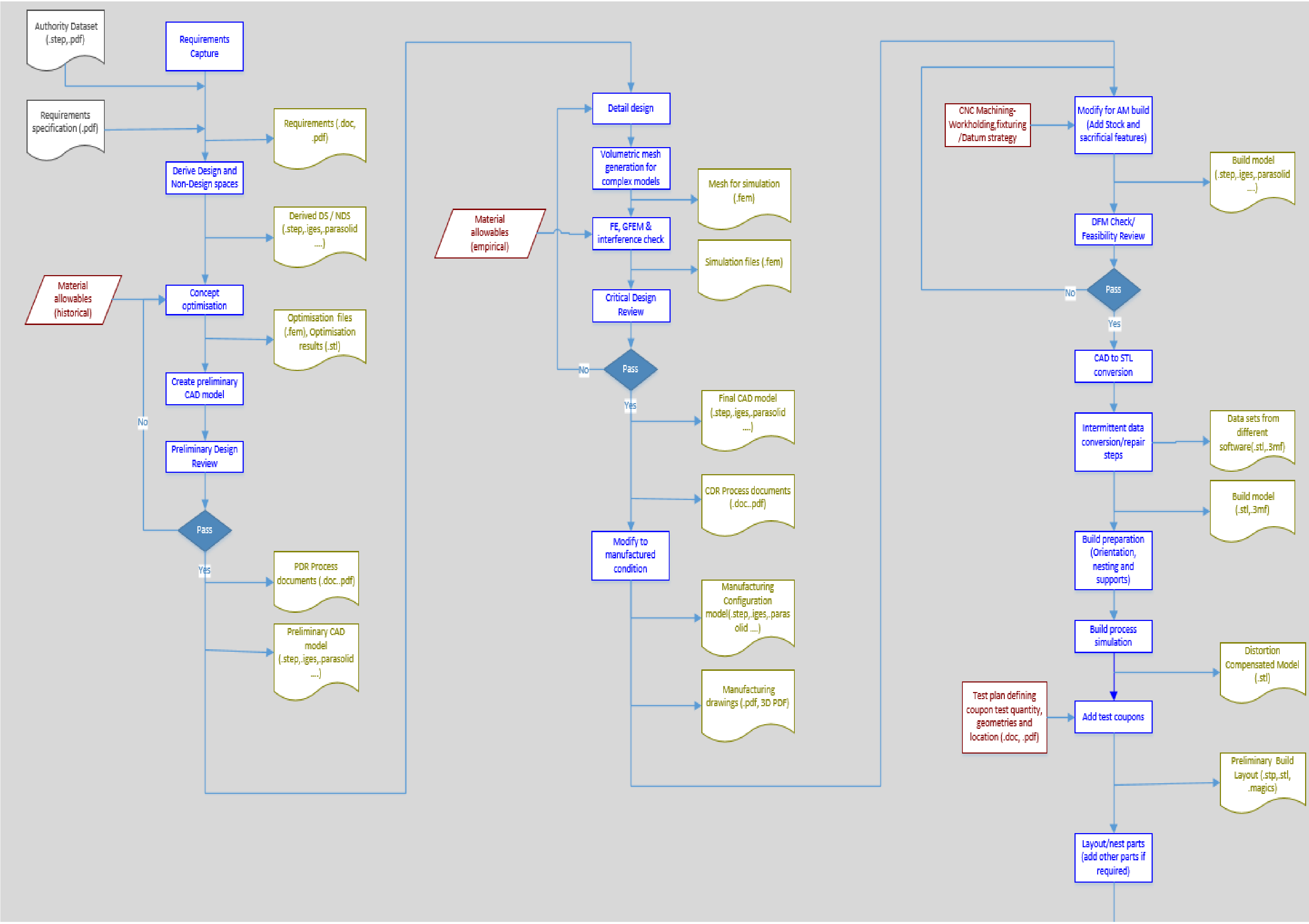

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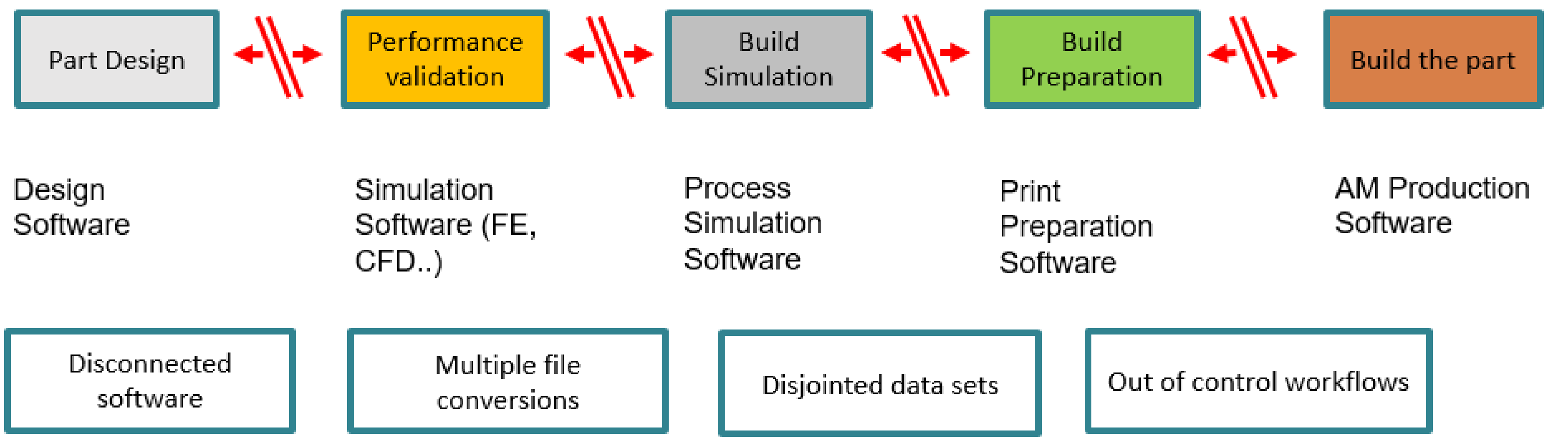
Some of the Challenges with AM Data Management include;

- Different data input formats (STL etc..or IGES,STEP or Native CAD)
- Wide variety of disconnected software packages required
- Multiple file conversions
- Lack of “standardised” data manipulation setting leads to part geometry errors



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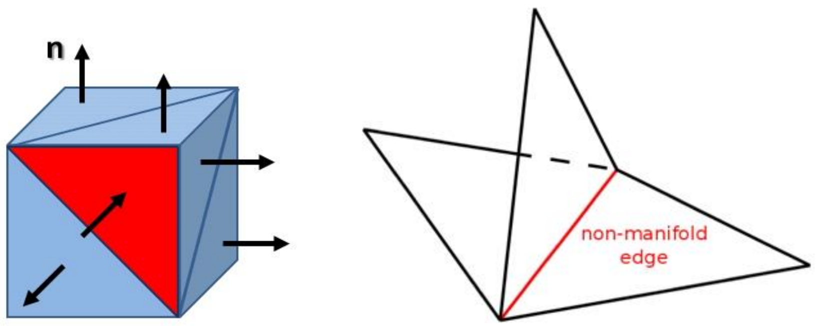
Standard Tessellation Language (STL.) Files

- Very large file sizes
- No scaling information
- Only mesh data is captures
    - No colour information
    - No material information
    - No meta data of any kind



Source: Shapeways

- Mesh errors are common
    - Inverted normals
    - Overlapping triangles
    - Holes in the mesh
    - Non-manifold edges
    - Intersections
- Errors can lead to manufacturing failures
- Errors can require manual repair

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Additive Manufacturing File (AMF) Format

- Contains five elements:
    - Object
    - Material
    - Texture
    - Constellation
    - Metadata
- Constellations copy bodies rather than the mesh
- It allows curved triangles
- Graded materials, sub-structures, microstructures, porous, and stochastic materials are possible.

Alternative File Formats

3MF

- "3D payload" contains all additional part data
- Creates instances of copied bodies rather than duplicating the mesh
- Reduced file size by 2-3x
    - Efficient storage of beam lattices
- Support structures attached to part data
- Human readable

Direct Slice

- Removes meshing format
- Greater model accuracy
- Checking and repairing routines elimination
- Pre-processing time reduction
- File size reduction
- Limited adoption in CAD packages
- Slicing time can take longer

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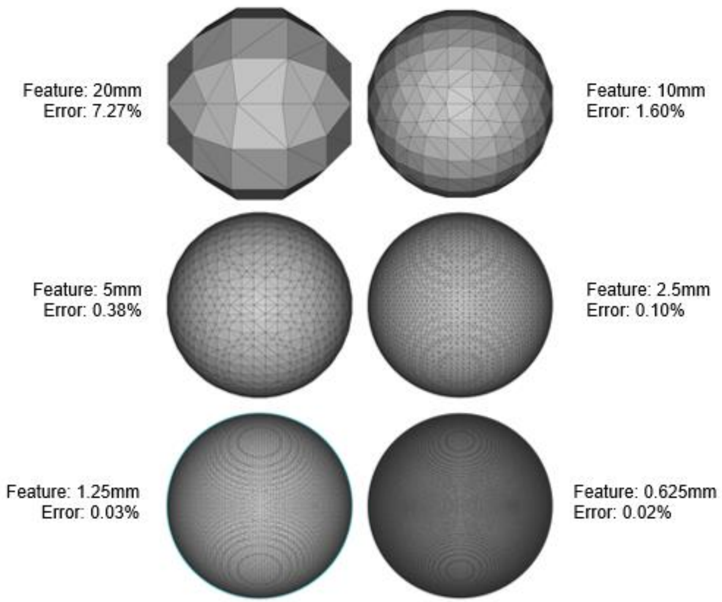
Meshing tolerances

- Converting CAD model to STL, AMF or 3MF formats risks data "degradation"
- Rule of thumb is to set the tolerance x 5 better than resolution of the AM process
- For STL file Chord height setting of 0.01 mm to 0.02 mm is recommended for most PBF processes



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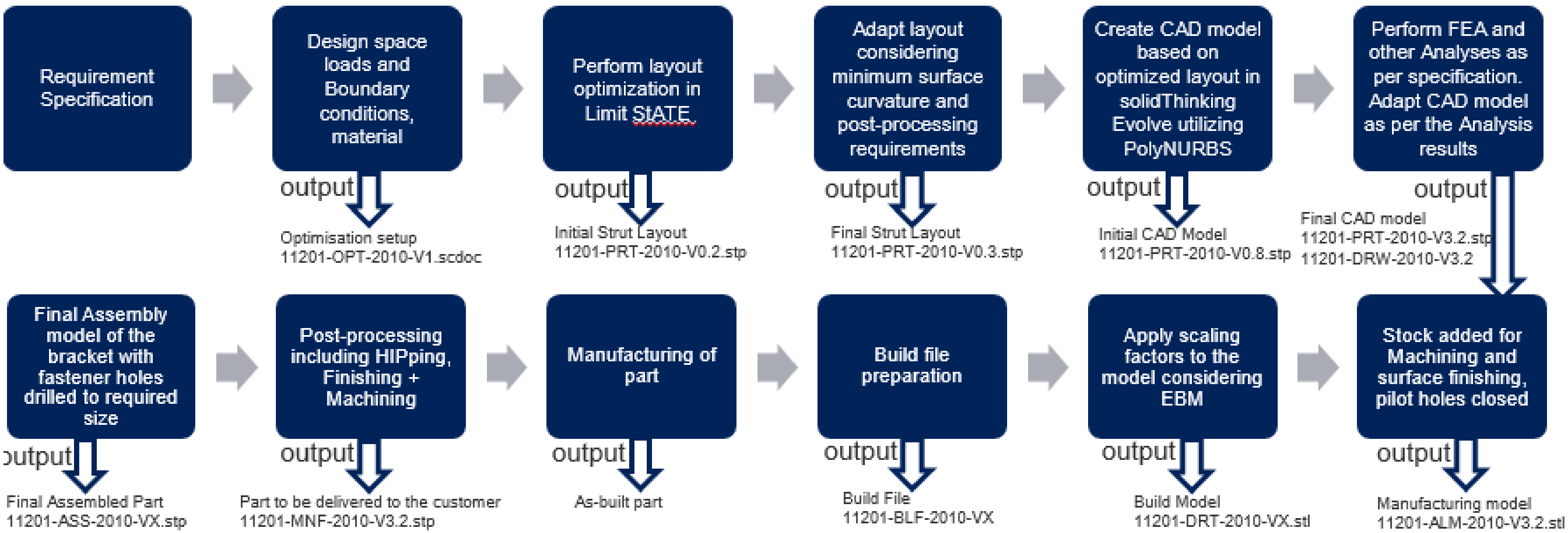
File versioning and control



File versioning example from an Aerospace component (Source: MTC)

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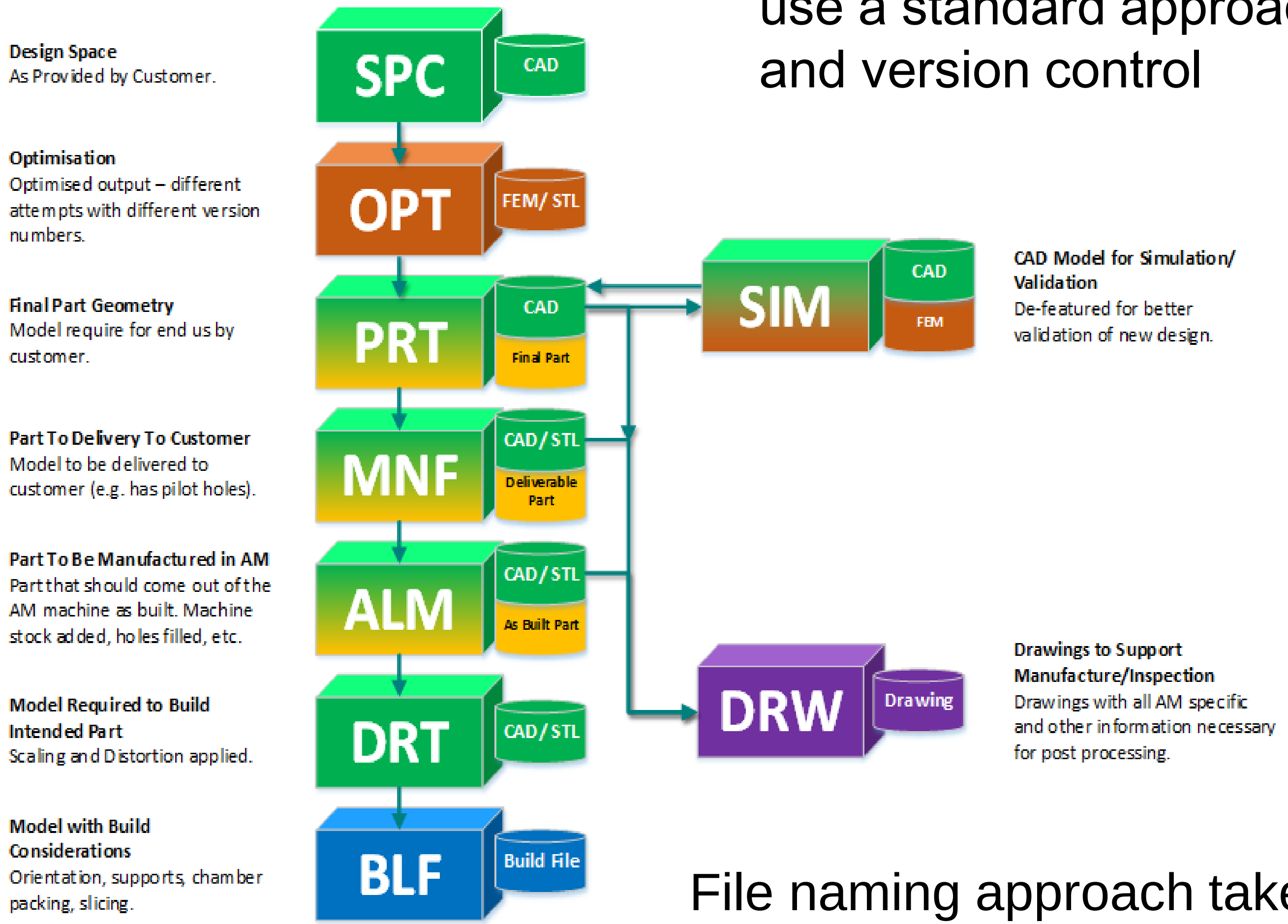
File versioning

To avoid confusion it is recommended to use a standard approach to file naming and version control



File naming approach taken at MTC

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File Management

- Quantity of data generated for a single part during AM process makes it very difficult to track and trace the files manually using model register
- Clearly specify the need for PLM/PDM system and clear definition of roles – who owns which stages of the data in the AM process?

who	date	filename including extension	geometry type	component / feature	based on (parent)	setup summary	material version	comment
Layout files								
RB	15/04/17	Scenario 1-design space constraint v7.scdoc	LS CAD	8pt design (2LCs)	Acciturri Issue 4 spec	2 LCs	Ti64 - B	Definition of tabs position
RB	24/04/17	Scenario 1-design space constraint v7.1.scdoc	LS CAD	8pt design (2LCs)	Scenario 1-design space constraint v7.scdoc	2 LCs	Ti64 - B	Removed simulation results
RB	~~17/04/17~~	~~ewira 7.1.x_t~~	Parasolid	8pt design (2LCs)	Scenario 1-design space constraint v7.1 LS CAD	2 LCs	Ti64 - B	sent to AT & Nick G for FEM
RB	04/04/17	Scenario 1-design space constraint v7.1.scdoc.3dm	Rhino file	8pt design (2LCs)	Scenario 1-design space constraint v7.1 LS CAD Modified to adapt to the tabs	2LCs	N/A	
RB	19/05/17	11201-PRT-204	PRT/STP	8pt design (2LCs)	renamed ewira 7.1.x_t	2LCs	Ti64 - B	This is the thickened strut output from the model Rob set up
RB	19/05/17	11201-PRT-205	PRT/STP	8pt design (2LCs)	11201-PRT-204	-	N/A	bracing struts across the skin support tabs removed. This is the geometry sent to Paco for checking
~~AH~~	~~16/05/17~~	~~EWIRA_8PointStrut_Spring_Reactions.inp~~	fem					
AH	16/05/17	11201-SIM-205-v1.0.inp	fem		Renamed EWIRA_8PointStrut_Spring_Reactions.inp			Spring deflections and reaction forces in other output folder. Sent to Paco as EWIRA_8PointStrut_Spring_Reactions.inp
~~MF~~	~~17/05/17~~	~~11201-ag-208.scdoc~~	LS CAD	8pt design (16LCs)	Renamed "Scenario 1-design space constraint v8_mig.scdoc"	16 LCs	Ti64 - B	
Tom LS	18/05/17	11201-ag-208_LSMODd.scdoc	LS CAD	8pt design (16LCs)	Scenario 1-design space constraint v8_mig LS CAD	16 LCs		sent to AT & F
							Ti64 - B	sent to LS to check
MF	24/05/17	11201-PRT-208-V1.scdoc	LS CAD	8pt design (16LCs)	renamed "11201-ag-208"	16 LCs	Ti64 - B	
MF	24/05/17	11201-PRT-206-v7.1.3dm	Rhino file	8pt strut design (2LCs)	Scenario 1-design space constraint v7.1.scdoc.3dm	2LCs	N/A	Removed vertical struts between tabs of secondary loads to comply with the geometry of 11201-PRT-205
MF	16/04/18	11201-PRT-206-v8- With thinner Struts.3dm	Rhino file	8pt strut design (2LCs)	11201-PRT-206-v7.1.3dm		N/A	Added thinner struts between various points of lugs. Created only for renders showing the workflow
MF	24/05/17	11201-PRT-207-v0.1.x_t	Parasolid	8pt design (2LCs)	11201-PRT-206-v7.1.3dm	2LCs	N/A	Merged struts to reduce blend points
MF	24/05/17	11201-PRT-207-v0.2.x_t	Parasolid	8pt design (2LCs)	11201-PRT-207-v0.1.x_t	2LCs	N/A	Improved simmetry between upper and bottom
MF	31/05/17	11201-PRT-207-v0.4.x_t	Parasolid	8pt design (2LCs) blended	11201-PRT-207-v0.2.x_t	2LCs blending auto	N/A	Inb&Outb Tabs adapted to Build volume, sec. loads tabs rounded. Blending auto from Tsplines
MF	30/05/17	11201-PRT-207-v0.4.2.stl	Stl file	8pt design (2LCs) blended	11201-PRT-207-v0.4.x_t	2LCs blending auto	N/A	Eyes blending added sculpting
MF	30/05/17	11201-PRT-207-v0.4.dxf	dxf file	8pt design (2LCs)	11201-PRT-207-v0.4.3dm (Scratch folder)	2LCs	N/A	Half wireframe of struts distribution for Sandeep FEA
MF	02/06/17	11201-PRT-207-v1.0.stl	Stl file	8pt design (2LCs) blended	11201-PRT-207-v0.5.3dm (Scratch folder)		N/A	Mesh smoothing. Sent to EBM build
MF	02/06/17	11201-PRT-207-v1.0.x_t	Parasolid	8pt design (2LCs) blended	11201-PRT-207-v0.5.3dm		N/A	**PDR model**. Used for meeting with CT and AT
MF	05/06/17	11201-PRT-207-v1.1.stl	Stl file	8pt design (2LCs) blended	11201-PRT-207-v1.0.stl		N/A	Anchor nuts satellite holes added. Sent to polymer print
MF	06/06/17	11201-PRT-207-v1.2.stl	Stl file	8pt design (2LCs) blended	11201-PRT-207-v0.5.1.3dm		N/A	0.5mm offset (struts 4mm). Satellite holes added. For polymer and eBM print. (05/05/2018)Sent for GOM validation
AH	07/06/17	11201-PRT-207-v0.4.4-boolean	NX Prt and stp	8pt design (2LCs) blended	11201-PRT-207-v0.4.3.x_t		N/A	Used for preliminary beam stress checks
MF	08/06/17	11201-PRT-400-v3- issue3Hinge.stl	Stl file	Hinge Issue 3			N/A	Sent to polymer print
MF	09/06/17	11201-PRT-207-v1.3-axisNpoints.stp	Step file	8pt design (2LCs) blended tappered	11201-PRT-207-v1.0.x_t	Tappered version	N/A	Tappered, thickened according to AH struts stress checks. Sent to to

Model Register used to track the file versioning and exchange in one of the internal projects (Source: MTC)

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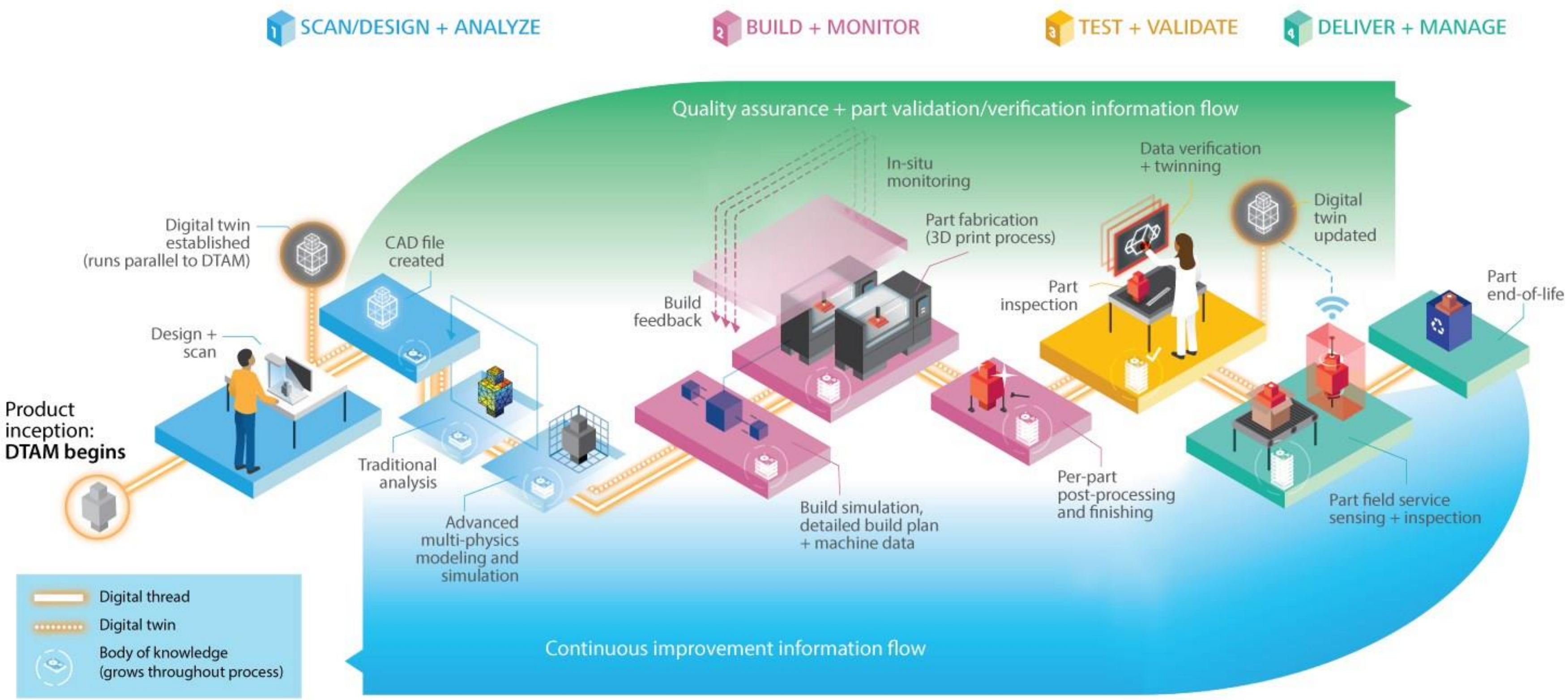
Digital Thread in AM

Digital data management goes beyond design data and AM build files



Source: https://www2.deloitte.com/insights/us/en/focus/3d-opportunity/3d-printing-digital-thread-in-manufacturing.html

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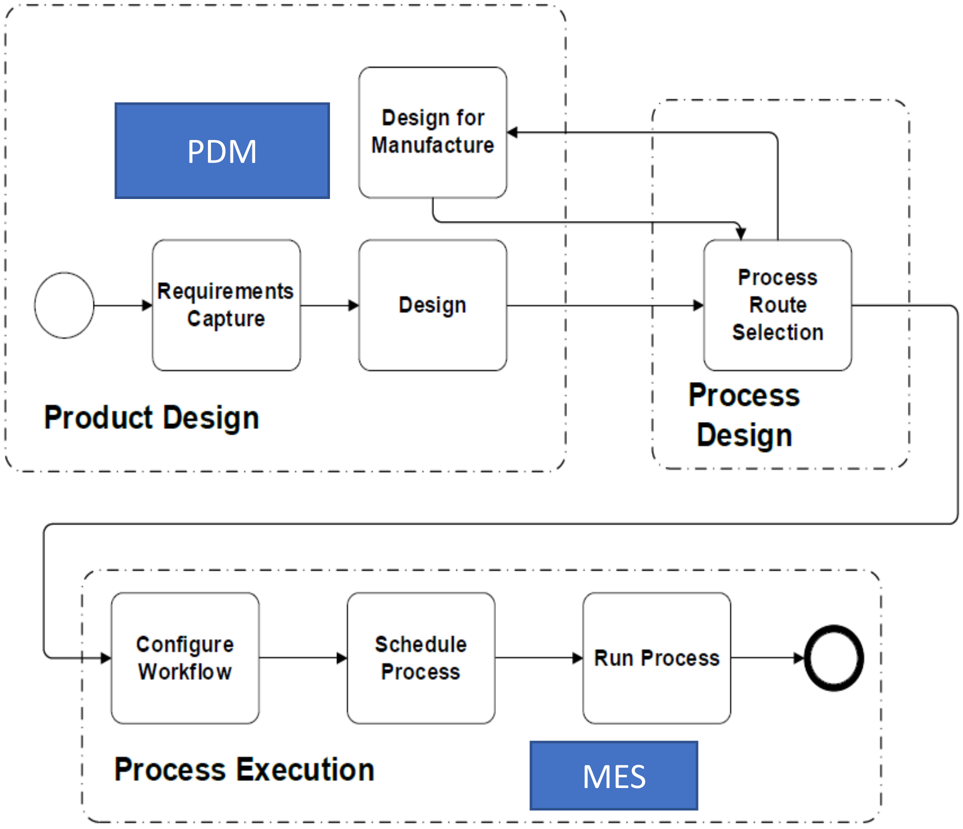
PDM/PLM and MES systems

Generic Product Data Management (PDM) and **Product Life cycle Management (PLM)** systems might not consider all aspects of AM workflow

Manufacturing Execution Systems (MES) track and document components/assemblies through the manufacturing process. Enable scheduling of resources (people/machines), provide traceability, can feed into stock management, and can update people not involved in the manufacture of the status of the part.



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PDM/PLM and MES systems for AM

PDM/PLM Systems (not exhaustive)

SIEMENS
Ingenuity for life

ptc
Windchill®

DASSAULT SYSTEMES
The 3DEXPERIENCE® Company

- MES Systems (not exhaustive)

3D TRUST

3YOURMIND

AMFG / Autonomous Manufacturing

AM-FLOW

Astroprint™

AUTHENTISE

Atlas

LINK3D

GROW

DNA am

Materialise Streamics

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Data Security

- Most data supplied about a new product is commercially sensitive to the customer
- Customer may stipulate that data transfer process can only be performed using secure platforms /software
- Penalties for breach as well as loss of reputation
- In some cases information is commercially sensitive and also has national security implications too!

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National Security

You may expect this if you are dealing with..

- Armed forces
- Police
- Security services
- Defence companies

https://military.com

https://www.hampshire.police.uk/

https://www.neweurope.eu

SECRET INTELLIGENCE SERVICE MI6

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National Security

Be wary if you receive an email or other communication marked OFFICIAL , SECRET, TOP SECRET

OFFICIAL	SECRET	TOP SECRET
The majority of information that is created or processed by the public sector. This includes routine business operations and services, some of which could have damaging consequences if lost, stolen or published in the media, but are not subject to a heightened threat profile.	Very sensitive information that justifies heightened protective measures to defend against determined and highly capable threat actors. For example, where compromise could seriously damage military capabilities, international relations or the investigation of serious organised crime.	HMG's most sensitive information requiring the highest levels of protection from the most serious threats. For example, where compromise could cause widespread loss of life or else threaten the security or economic wellbeing of the country or friendly nations.

Government Security Classifications May 2018 Version 1.1 – May 2018

If you don't hold the appropriate level of security clearance do not oper

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Export Control – What is it for ?

- Export control regulations are in place to prevent exchange of dangerous data, materials, or goods. Reasons include:
  - National and global security
  - Non proliferation and terrorism
  - International legal obligations
  - Human rights and internal repression

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Export Control - Legislation

- The main laws are:
  - EU:
    - EC Regulation 428/2009
  - UK:
    - UK Export Control Act 2002
    - UK Export Control Order 2008
  - USA
    - International Traffic in Arms Regulations (ITAR)
    - Export Administration Regulations (EAR)
  - Other countries' governments have similar arrangement to the UK.

NOTE: ITAR regulations apply to companies outside of the USA !!

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Export Control – Penalties for breaking

- For the individual:
  - Prosecution of company employees and directors
  - Up to 10 years in prison
  - Dismissal from employment
- For the company
  - Program delays and additional costs
  - Business trading restrictions and sanctions
  - Fines of up to $1m per violation
  - Reputational damage

https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.ppic.org

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Export Control – what is covered

- Export control affects the ‘export’ of any tangible (physical) or intangible (electronic) goods
- This could be hardware, technical information, drawings, CAD files, source code, software, or technical ‘know how’.
- Exporting controlled items including data usually requires an export licence

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Export Control - Classification

- Export control focuses on two categories of controlled items:
  - Military Use
    - Specifically designed or modified for military use
  - Dual Use
    - Utilised in both military and civilian applications but not adapted for military use.
  - Any component that could be used as Weapons of Mass Destruction or in chemical, biological, or nuclear weapons, or items capable of destroying them.

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EXAMPLE – MTC GUIDELINES

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What Must A Company Do To Comply With Export Control Laws?

Export Control Terms & Conditions in Contracts
Ensure clauses included in contracts and agreements to identify and mitigate commercial and legal export control risks

Screening & Embargo Checks
Trading Parties / Staff screening against individual, business entity and country specific lists

Establishing Intended End Use
Providing / obtaining necessary End User Certificates

Export Licences & Authorisations
Obtaining all necessary UK, US, EU & other export and re-transfer authorisations and meeting all licence conditions

Segregating & Labelling
Marking & control of export controlled hardware & technical data

Maintaining Records
Retention of company, transactional , project & functional records for Government & / or Client formal audits

Physical & IT Access Controls
Access controls on site and to applications, data systems and servers

Internal Compliance checks
Internal Compliance Checks Regular assessment of the company export compliance & adherence to policy & process

Training & Awareness
Provision of training & guidance materials to employees within Induction, regular Refresher, Project & Function

Legislation Updates & Management of Impacts
Keeping abreast of changes in laws, embargoes/ sanctions & licensing

Classification
Hardware, Software, Source Code, Technical Information & sometimes technical know is classified in Control Lists:

- External companies must advise MTC of the classification rating of its supplies
- MTC is responsible for classifying anything that is intended for export.

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EXAMPLE – MTC GUIDELINES

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Export Control could impact all aspects of our business. Special attention should be paid when working within a Project Lifecycle involving the following activities:

MTC Project Lifecycle

Travel overseas

- Permits required if carrying company IT equipment overseas even if personal travel
- Licences needed if export controlled data being held on equipment or being accessed or shared whilst overseas
- Some destinations/ technical data may require licence processing of several months

Technical document creation

- Need to mark document if export controlled & control distribution & access during & after creation
- Need to know if using export controlled data – contact Export Control immediately if USA ITAR/ EAR or for classification guidance

Material in, access & use

- Identify export controlled materials received typically via Supplier Dispatch note/ PO) or document cover notes
- Liaise with Export Control to manage appropriate physical segregation, labelling, access control & tracking
- If ITAR/ EAR items, restrictions or approvals may apply on access by specific nationalities or exhibition/ display

Contracts

- Need to ensure that MTC includes export control clauses in Sales & Purchase Orders & Agreements
- Request export control classification from providers of hardware, technology, etc
- Lookout for export control terms or references within external contracts/ documentation & notify Export Control immediately

Shipping overseas

- All tangible exports, even those being hand-carried, require completion of Dispatch Note via Shipping function
- Specific information, certifications, licences required potentially taking weeks to process

Technical data access & exchange

- Control on transfer/exchange via email, phone/ video call or shared data systems
- Documents containing export controlled data must be classified, marked, tagged & tracked
- External export controlled data should be pre-advised as such prior to upload to MTC servers
- Access to ITAR/ EAR data requires strict company specific and nationality control
- Export Control approval required before exporting any technical data & strict record keeping required

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Useful further reading

- ISO/ASTM 52915:2016(E) Standard Specification for Additive Manufacturing File Format (AMF)
- ISOASTM52911-1-AM-Design-Part1_Laser-based powder bed fusion of metals
- Tolerancing from STL data: A Legacy Challenge
- https://www.sciencedirect.com/science/article/pii/S221282712030946X
- Digital Thread for Additive Manufacturing (DTAM)
- https://www2.deloitte.com/us/en/pages/public-sector/articles/digital-   thread.html
- Building a digital twin for additive manufacturing through the exploitation of blockchain: A case analysis of the aircraft industry https://www.sciencedirect.com/science/article/pii/S0166361518308741
- Government Security Classifications May 2018 Version 1.1 – May 2018

https://www.gov.uk/guidance/uk-strategic-export-control-lists-the-consolidated-list-of-strategic-military-and-dual-use-items

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www.skills4am.eu

Questions ?
& Thank you

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Project No. 601217-EPP-1-2018-1-BE-EPPKA2-SSA-B

CU 36: Coordinating the AM Process (Pilot)

TOPIC 10: Complying with Standards

Prepared by: David Wimpenny

Date: 13/01/21

Please look for slides showing - KEY INFORMATION

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Topics covered include…

- What are standards and why they are important
- Role of standards in AM
- Standards development for AM
- Standards organisations
- Examples of AM standards
- AM Standards gaps
- ASTM AM Centre of Excellence
- Sector specific standards

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What are standards ?

A standard is a document that provides requirements, specifications, guidelines or characteristics that can be used consistently to ensure that materials, products, processes and services are fit for their purpose.

- Full blown standards
- Best practice Guides

https://www.nena.org/page/Standards

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Why are standards important

- Help to ensure safety, durability, and market equivalence
- Provide common language to measure and evaluate performance
- Help to ensure technology works seamlessly and establish trust
- Make interoperability of components and systems made by different companies possible.

National Institute of Standards & Technology, U.S. Department of Commerce, NIST

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Role of standards in AM

- AM represents a dramatic change in the way products are designed, manufactured and supplied
- If AM is adopted in a "free for all" way this risks failure which can lead to loss of confidence and perhaps even loss of life
- Standards provide a framework for new manufacturing methods, materials and designs to be introduced
- Will eventually lead to improved reliability of equipment, processes
- Enable critical interoperability – design data, software and data from process monitoring etc..

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Challenge of standards development for AM

- Dramatic shift from established manufacturing processes
- Rapidly developing technology
- Rush to introduce the technology
- Lack the experience to fully understand the benefits and limitations
- New approach affects so many aspects;
    - Product design
    - Material technology
    - Equipment, software, design data
    - Control of information
    - Inspection
    - Supply chains
    - Qualifications & training
    - Design and operation of facilities

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How are standards developed

1. Area requiring a new standard is put forwards as a new work item
2. Checks performed to ensure that standards don't already exist or a standard is not already in development
3. Work item approved and lead (convener) is selected
4. Standards committee is assembled
5. Meet to agree the scope of the standard
6. Draft text for standard is prepared
7. Sent for ballot
8. If changes are required these are made
9. Standard is approved
10. Standard is published
11. Future revisions may be required

THIS PROCESS CAN TAKE YEARS !

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Types of standards

- National standards – for example BSI in the UK
- International standards – for example ISO
- Sector specific standards

Sector specific standards take precedent

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Standards organisations include……

American Society for Testing and Materials (ASTM)

American Society of Mechanical Engineers (ASME)

Association for the Advancement of Medical Instrumentation (AAMI)

American Welding Society (AWS)

CEN CENELEC

Digital Imaging and Communications in Medicine

Institute for Electrical and Electronics Engineers (IEEE)

International Organisation for Standardisation (ISO)

Medical Imaging Technology Alliance (MITA)

Metal Powder Industries Federation (MPIF)

National Electrical Manufacturers Association (NEMA)

SAE International (SAE)

British Standards

The Association Connecting Electronics Industries (IPC)

American National Standards Institute (ANSI)

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ASTM F42 / ISO T261 joint committee

- Established in 2013
- Aim is to use the limited pool of experts to generate more standards, quickly and avoid unnecessary duplication

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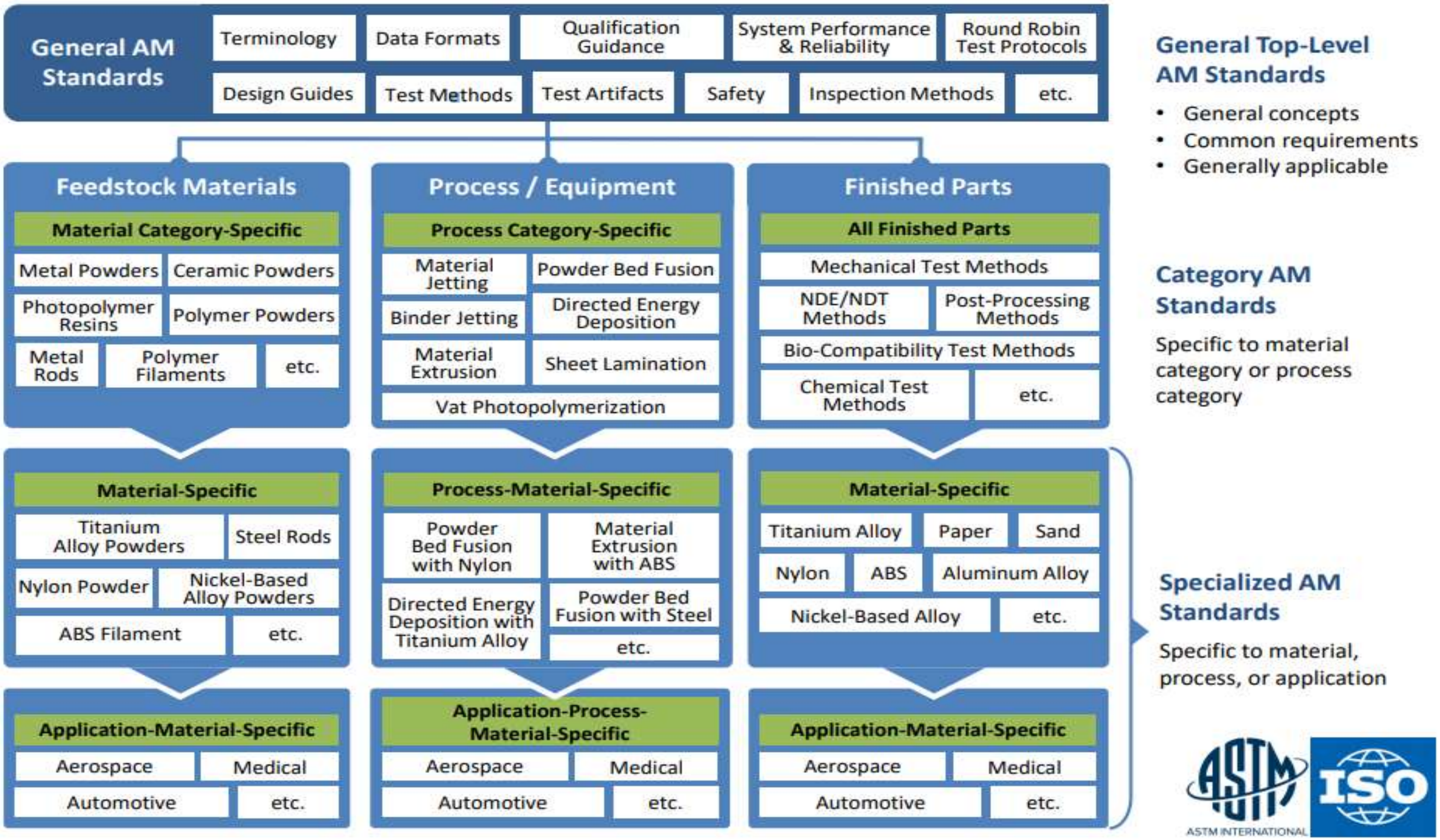
Additive Manufacturing Standards Structure



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List of AM standards developed by ASTM

ASTM INTERNATIONAL

Applications

Designation	Title
ISO / ASTM52942 - 20	Additive manufacturing — Qualification principles — Qualifying machine operators of laser metal powder bed fusion machines and equipment used in aerospace applications
ISO / ASTM52941 - 20	A… m…

Design

Designation
F3413 - 19
ISO / ASTM5291…
ISO / ASTM52911… 19
ISO / ASTM52911… 19
ISO / ASTM5291…

ISO / ASTM52941 - 20

Additive manufacturing — System performance and reliability — Acceptance tests for laser metal powder-bed fusion machines for metallic materials for aerospace application

Active Standard ISO / ASTM52941 | Developed by Subcommittee: F42.07

Book of Standards Volume: 10.04

Format	Pages	Price	
PDF	8	$52.00	ADD TO CART
Hardcopy (shipping and handling)	8	$52.00	ADD TO CART

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Materials and Processes

Designation	Title
F2924 - 14	Standa… Powde…
F3001 - 14	Standa… Low In…
F3049 - 14	Standa… Manuf…
F3055 - 14a	Standa… Fusion…
F3056 - 14e1	Standa… Fusion…
F3091 / F3091M - 14	Standa…
F3184 - 16	Standa… Powde…
F3187 - 16	Standa…

ASTM F3001 - 14

Standard Specification for Additive Manufacturing Titanium-6 Aluminum-4 Vanadium ELI (Extra Low Interstitial) with Powder Bed Fusion

Active Standard ASTM F3001 | Developed by Subcommittee: F42.05

Book of Standards Volume: 10.04

	Format	Pages	Price	
	PDF	6	$52.00	ADD TO CART
	Hardcopy (shipping and handling)	6	$52.00	ADD TO CART
	Standard + Redline PDF Bundle	12	$62.00	ADD TO CART

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Materials and process continued

ASTM INTERNATIONAL

F3213 - 17	Standard for Additive Manufacturing – Finished Part Properties – Standard Specification for Cobalt-28 Chromium-6 Molybdenum via Powder Bed Fusion
F3301 - 18a	Standard for Additive Manufacturing – Post Processing Methods – Standard Specification for
F3302 - 18	
F3318 - 18	
F3434 - 20	
ISO / ASTM52901 - 16	
ISO / ASTM52904 - 19	
ISO / ASTM52903 - 20	
ISO / ASTM52903 - 2 - 20	Additive manufacturing — Material extrusion-based additive manufacturing of plastic materials — Part 2: Process equipment

ISO / ASTM52904 - 19

Additive Manufacturing – Process Characteristics and Performance: Practice for Metal Powder Bed Fusion Process to Meet Critical Applications

Active Standard ISO / ASTM52904 | Developed by Subcommittee: F42.05

Book of Standards Volume: 10.04

Format	Pages	Price	
PDF	11	$58.00	ADD TO CART
Hardcopy (shipping and handling)	11	$58.00	ADD TO CART

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Terminology

Designation	Title
ISO / ASTM52	

Test Meth

Designat
F2971 - 13
F3122 - 14
ISO / ASTM52 19
ISO / ASTM52 13(2019)
ISO / ASTM52 19

ISO / ASTM52907 - 19

Additive manufacturing — Feedstock materials — Methods to characterize metallic powders

Active Standard ISO / ASTM52907 | Developed by Subcommittee: F42.01

Book of Standards Volume: 10.04

	Format	Pages	Price	
	PDF	14	$58.00	ADD TO CART
	Hardcopy (shipping and handling)	14	$58.00	ADD TO CART

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ASTM Roadmap and committees

ASTM INTERNATIONAL

Additive Manufacturing

F42 AM Technologies

F42.07.01 Aviation

F42.07.02 Spaceflight

F42.07.03 Medical/Biological – E34

F42.07.04 Transportation/Heavy Machinery – F45, F48

F42.07.05 Maritime – F41

F42.07.06 Electronics – F01

F42.07.07 Construction – C01/C09, D35

F42.07.08 Oil/Gas – D02

F42.07.09 Consumer – F15, F08

Applications

E55 Manufacture of Pharmaceutical and Biopharmaceutical Products

F04 Medical and Surgical Materials and Devices

F07 Aerospace and Aircraft

F25 Ships and Marine Technology

F37 Light Sport Aircraft

F38 Unmanned Aircraft Systems

F44 General Aviation Aircraft

Test Methods

E07 Nondestructive Testing

E08 Fatigue and Fracture

E28 Mechanical Testing

E37 Thermal Measurements

E57 3D Imaging Systems

G01 Corrosion of Metals

Feedstock Materials

A01 Steel, Stainless Steel and Related Alloys

B09 Metal Powders and Metal Powder Products

D20 Plastics

D30 Composite Materials

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Additive manufacturing standards committee

https://www.ansi.org/portal/amsc/AMSC-Gaps-Design

List of **gaps** in current standards provision covering;

- Design
- Precursor materials
- Process control
- Post-processing
- Finished material properties
- Non destructive evaluation
- Maintenance and repair
- Qualification & certification

GAP D22: IN-PROCESS MONITORING

There is a lack of standards for validated physics - and properties-based predictive models for AM that incorporate geometric accuracy, material properties, defects, surface characteristics, residual stress, microstructure properties, and other characteristics (NIST, 2013). No standardized data models or documentation have been identified for in-process monitoring and analytics. Given the current state of the technology, this is not surprising.

R&D Needed: Yes. R&D is needed to understand what in-process monitoring data is needed for verification and validation of the part. Research efforts have been undertaken that are devoted to the development of predictive computational models and simulations to understand the dynamics and complexity of heat and phase transformations. Although computational models and simulations are promising tools to understand the physics of the process, lack of quantitative representation of their prediction accuracy hinders further application in process control and optimization. Due to this reason, it is very challenging to select suitable models for the intended purpose. Therefore, it is important to study and investigate the degree of accuracy and uncertainty associated with AM models.

Recommendation: Develop standards for predictive computational modeling and simulation tools that link measured in-process monitoring data with product properties, quality, and consistency, as an important aspect of innovative structural design (NIST, 2013). See also Gap PC16 on in-process monitoring to obtain a layer-by-layer (3D) file or quality record showing the as-built part is defect-free or contains no critical flaws, or exhibits an in-family (nominal) response when interrogated during the build.

Priority: Medium

Organization: ASTM F42, ASME, IEEE-ISTO PWG

Status of Progress: Green

Update: Office of Naval Research (ONR) is also researching this through their Quality Made program. NIST is developing a publically available schema for metals that may apply.

10/17/2019, LY: (In addition to ONR Quality Made Program) NIST and Pennsylvania State University are leading an AM Data Management working group. This working group is developing a Common Data Dictionary to facilitate the exchange of AM data, including process monitoring information. Data models for process monitoring and simulation can be found here: https://ammd.nist.gov and here: https://www.nist.gov/ambench.

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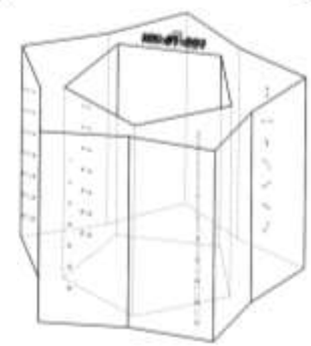
Inspection for AM Standards

- No comprehensive inspection standards for AM
- ISO/TC 261– ASTM F42 NDT For AM Parts (JG59)
  - Draft is under review, covering different sectors, lead by Ben Dutton ,MTC
  - Best practice guide based on existing standards capable of covering some of the AM defect types.
  - For AM only defects, not covered by current standards, it presents NDT methods verified potential to detect defects through star artefacts with seeded defects.
  - It then describes and provides an example for an à la carte framework to follow for a specific AM part geometry.



- ASTM E07 Non-Destructive Testing (WK47031)
  - Draft is under review focused on aerospace sector, effort lead by NASA.
  - Considers the selection and application of established and emerging NDT procedures for AM metal parts throughout their life cycle.
- Standards groups linked, also interact through common consortium members.

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ASTM AM CoE

CENTER of EXCELLENCE
RESEARCH TO STANDARDS
Additive Manufacturing

Center Goals:

1. Accelerate standardisation and close standards gaps in AM
2. House and facilitate R&D in its partners laboratories
3. Create strong global partnerships among AM developers, users and stakeholders
4. Support education, training, proficiency testing, and certification programs
5. Host professional events, workshops, and symposia featuring subject matter experts and practitioners

EWI mtc NASA NIAR NAMIC AUBURN

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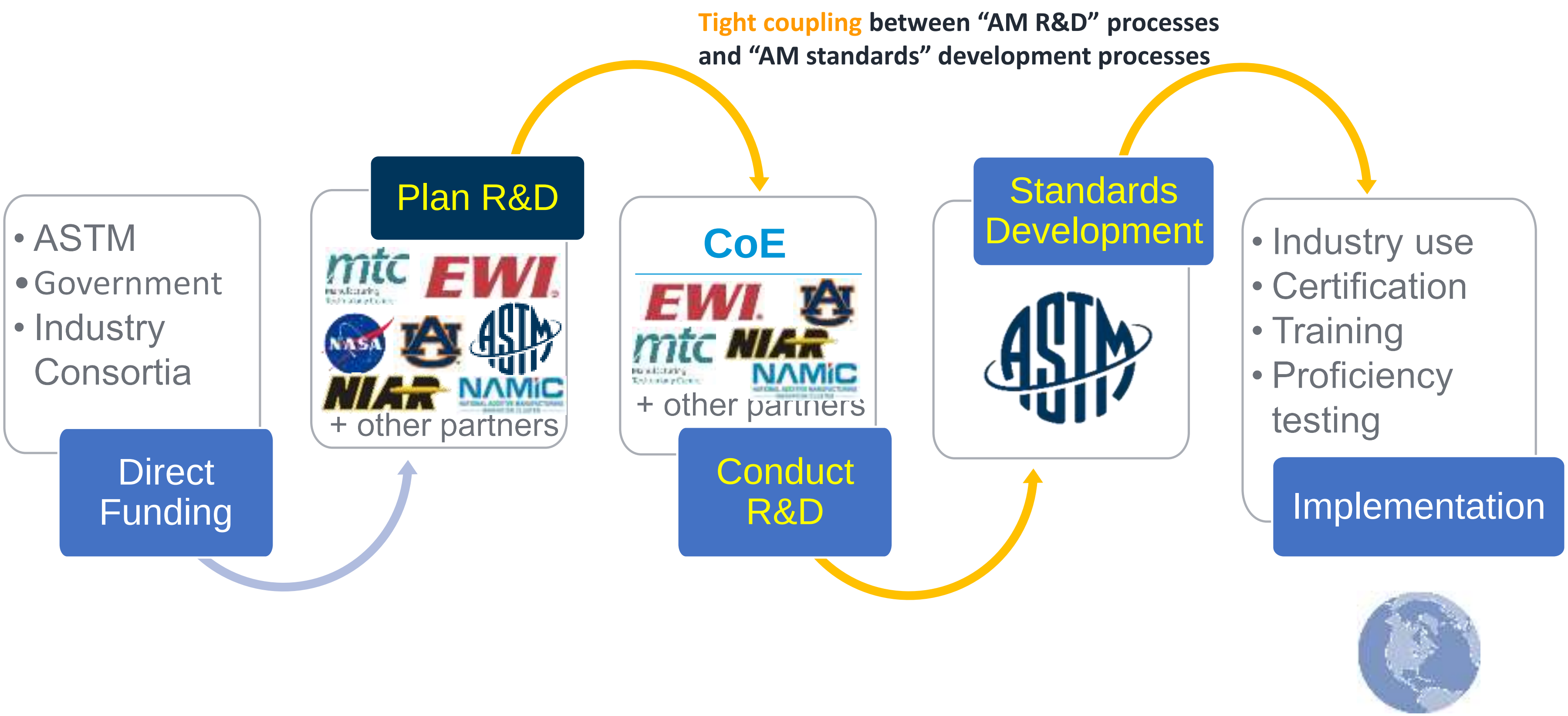
Research and Development (R&D) Progress: How it works



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CENTER of EXCELLENCE Research to Standards

COVID-19 ABOUT R&D TRAINING CONSORTIA & COLLABORATION

Just Released!

ASTM International Supports Eight New Re[search to Standards Projects for Additive] Manufacturing

READ NOW

ASTM International Supports Eight New Research to Standards Projects for Additive Manufacturing

September 15, 2020

Today, global standards developer ASTM International announced it's third round of funding to support research that helps expedite standards in additive manufacturing (AM). This investment which includes additional in-kind contributions will support the ASTM International Additive Manufacturing Center of Excellence (AM CoE) goal of aligning technical standardization with the rapidly evolving AM industry.

"We are thrilled to support these crucial and high-impact research projects in additive manufacturing that seek to accelerate standardization," said Dr. Mohsen Seifi, ASTM International's director of global additive manufacturing programs. "These eight projects will join the 14 existing projects that address the AM CoE's high-priority research areas for standardization, including design, data, modeling, feedstock, processes, post processing, testing, and qualification." Each of these projects will address one or more standardization gaps listed in the AMSC (Additive Manufacturing Standardization Collaborative) roadmap published by ANSI/America Makes.

This year, over 60 ideas for projects were submitted by ASTM International members for consideration. After a thorough review, eight high-impact ideas were approved by the ASTM executive section focused on research and innovation (F42.90.05) within the committee on additive manufacturing technologies (F42).

The AM CoE partners will conduct these projects, covering a broad range of topics:

- Auburn University will develop a standard coupon design for evaluating lattice structures in metal AM under compressive loading. This work will improve reliability of lattice structures used in applications ranging from bone ingrowth for medical implants to weight reduction in transportation structures.
- Applied technology developer EWI will develop a common data exchange format (CDEF) for powder characterization. This standard will enable efficient data sharing throughout the AM supply chain by serving as a link between different data management systems.
- The UK-based Manufacturing Technology Centre (MTC) will develop standard guidance for evaluating polymer powders during recycling and re-use in AM. This guidance aims to improve confidence for manufacturing with recycled powders.
- MTC will also lead a project to develop guidance on metal powder feedstock sampling and recycling strategies. This research will identify strategies currently used for sampling and recycling powder feedstock and provide guidance on the suitability of these methods for AM processes, materials, and end-use applications.
- NAMIC – Singapore's National Additive Manufacturing Innovation Cluster – and the Singapore Institute of Manufacturing Technology (SIMTech) will develop standard sub-sized tensile specimens for witness testing of metal AM. These specimens will reduce the time and material costs of witness testing, a method of monitoring build quality by testing a coupon printed alongside the components in an AM build.
- NAMIC and A*Star's National Metrology Centre of Singapore will develop standard guidance for volume traceability of non-destructive testing for metal components produced with powder bed fusion and binder jetting. This project will assess components made with both processes and will provide guidance for use in assessing part quality.
- NAMIC and the Singapore University of Technology and Design (SUTD) will conduct a study of maraging steel, an alloy commonly used by the automotive, aerospace, sports, and tooling industries, among others. This work will provide a basis for developing a material specification for this class of alloys in AM applications.
- NASA and Auburn University will design a series of test components and a methodology to assist validation of process parameters for powder bed fusion. The proposed test components will enable manufacturers to confirm that a parameter set is robust and produces suitable part quality across a variety of local thermal conditions by incorporating challenging geometries.
- Wichita State University's National Institute for Aviation Research (NIAR) will continue two previous projects started in round two. The first project will provide guidance for polymer design values in additive manufacturing, while the second project establishes coupon-part property relationships for dynamic testing of additively manufactured polymers.

For more information and details on each project, visit the center's website at www.amcoe.org.

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Sector Specific Standards

- Aerospace
- Space
- Medical
- Marine
- Defence

Sector specific standards may refer to generic standards but they take precedence over them

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Aerospace Specific International standards

The four aerospace additive manufacturing technical standards are:

- AMS7000: Laser-Powder Bed Fusion (L-PBF) Produced Parts, Nickel Alloy, Corrosion and Heat-Resistant, 62Ni - 21.5Cr - 9.0Mo - 3.65Nb Stress Relieved, Hot Isostatic Pressed and Solution Annealed
- AMS7001: Nickel Alloy, Corrosion and Heat-Resistant, Powder for Additive Manufacturing, 62Ni - 21.5Cr - 9.0Mo - 3.65Nb
- AMS7002: Process Requirements for Production of Metal Powder Feedstock for Use in Additive Manufacturing of Aerospace Parts
- AMS7003: Laser Powder Bed Fusion Process

ASTM is developing four aerospace specific standards cover feedstock materials (WK67454), finished part properties (WK67461), system performance and reliability (WK67484), and qualification principles (WK67485)

ISO/ASTM 52941:2020

Additive manufacturing — System performance and reliability — Acceptance tests for laser metal powder-bed fusion machines for metallic materials for aerospace application

ISO/ASTM 52942:2020

Additive manufacturing — Qualification principles — Qualifying machine operators of laser metal powder bed fusion machines and equipment used in aerospace applications

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Space Specific International standards

ECSS Standards

The European Cooperation for Space Standardization (ECSS) is an initiative established to develop a coherent, single set of user-friendly standards for use in all European space activities.

ECSL

European Centre for Space Law (ECSL) The ECSL was founded in 1989 on the initiative of the European Space Agency. Its objectives are the improvement in space law research, education and practice in Europe.

CCSDS Recommendations

The Consultative Committee for Space Data Systems (CCSDS) is an international voluntary consensus organization of space agencies and industrial associates interested in mutually developing standard data handling techniques to support space research, including space science and applications.

ISO Standards

The International Standards Organization Standards (ISO) catalogue.

IEEE Standards

The Institute of Electrical and Electronics Engineers (IEEE) standards.

ESCIES System

The European Space Components Information Exchange System (ESCIES) is a repository for EEE parts information hosted by ESA, on behalf of the Space Components Steering Board, as part of the European Space Components Coordination.

EPPL Listing

The European Preferred Parts List (EPPL) is a list of preferred and suitable components to be used by European manufacturers of spacecraft hardware and associated equipment.

EUROPEAN COOPERATION ECSS FOR SPACE STANDARDIZATION

Hoping to collaborate with NASA

https://www.esa.int/About_Us/Business_with_ESA/Space_Related_Standards2

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www.skills4am.eu

Questions ?
& Thank you

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Project No. 601217-EPP-1-2018-1-BE-EPPKA2-SSA-B

CU 36: Coordinating the AM Process (Pilot)

TOPIC 2: AM system and Operator scheduling

Prepared by: Sean Anthony Smith, William Morisson, David Wimpenny

Date: 13/01/21

Please look for slides showing - KEY INFORMATION

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Topics covered include....

- Overview of scheduling
- Machine utilisation
- Effective deployment of staff
- Consider the entire end to end process
- Managing risk and disruptions
- Automated scheduling software

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Scheduling

Aim of effective scheduling is to;

- Achieve the desired level of machine utilisation
- Ensure efficient use of staff
- Consider the entire end-to-end process

+

Manage risks/disruption

+

Meet customer delivery times

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Machine utilisation

- Depreciation of equipment often accounts for a significant proportion of the cost of manufacture
- Maximise machine utilisation helps to reduce piece price and thus stimulates demand

BUT…

- **High machine utilisation can lead to longer lead times and may not be acceptable for some end-use sectors.**

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Efficient deployment of staff

- Manpower costs are a significant factor
- Managing workload is important for part quality, staff moral and safety

Challenges with AM…….

Machine changeover – currently manual operation on most AM machines > Think about when changeover will take place.

AM is a Batch production process – leads to feast/famine as well as extended lead times

Weekends are different than weekdays

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Consider the entire end-to-end process

- End-to-end AM process can be very complex
- Mix of batch and continuous processes
- Often conflicting requirements
- Changes to one part of the process can have major impact elsewhere
- Bottlenecks can easily occur;
  - Upstream -for example powder testing and file preparation)
  - Downstream – heat treatment, wire EDM, finishing, inspection

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Manage risks/disruption

- AM processes can be unreliable – build failures/ scrap parts (overall yield can be <60% for some parts)
- Risk of failure increases with;
- Build time
- Challenging geometry
- Difficult materials
- Certain machine types

This risk needs to be factored into the cost and also the scheduling

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Meet customer delivery times

- Need to manage expectations…
- Tight delivery costs more
- Increased flexibility may be encouraged with lower pricing

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Daily Production Scheduling Review

- Daily review needed for dynamic and agile scheduling
- Visible and live production boards are a necessity
- Actual plan may differ from weekly plan against
- Different AM machine types and process adds complexity
- Need to judge results based on performance

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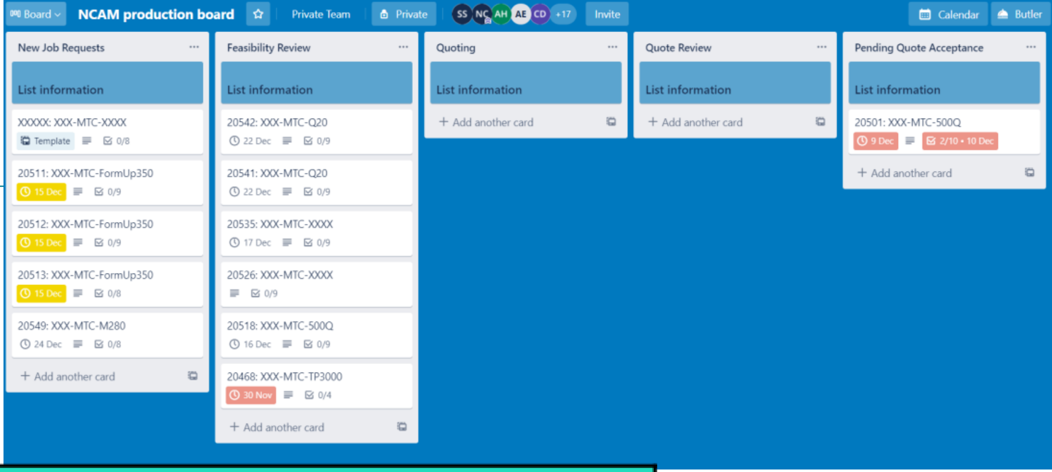
Planning boards;
Production board
Machine schedule



Weekly machine schedule (Planned)							
	Mon	Tue	Wed	Thu	Fri	Sat	Sun
	AM PM	AM PM	AM PM	AM PM			
M400-4	De-build	Setup & build CRP 2	Build	De-build	Non Work Day	Non Work Day	Non Work Day
M280	De-build & setup	Build - Sigma labs build 1	De-build	Idle - Waiting on manufacturing information			
AM250	Setup & build	build monitoring	build monitoring	De-build pm with customer			
Matsuura	Material changeover						
Solukon	Material changeover	Repair		Build			
Q20	Idle - waiting on manufacturing information & results from previous build						
AM500Q	Setup & start CRP 1	De-build, setup & build CRP 2	De-build, setup & build CRP 3	De-build			
Trumpf	Idle - waiting on results from previous build						
Addup	Service						
Other	post processing	EBM trophies post processing					

Weekly machine schedule (Actual)							
	Mon	Tue	Wed	Thu	Fri	Sat	Sun
	AM PM	AM PM	AM PM	AM PM			
M400-4	De-build	Setup & start CRP 2	De-build - rake crash	Idle - waiting on decision for CRP 3	Non Work Day	Non Work Day	Non Work Day
M280	Build stopped - started again	Build	Build completion & de-build	Setup & build & de-built sigma labs 1			
AM250	Setup & build	Build monitoring	Build completion	De-build			
Matsuura	Material changeover						
Solukon	Material changeover	Repair & clean down	Build				
Q20	Idle - waiting on manufacturing information & results from previous build						
AM500Q	Setup & start CRP 1	De-build, setup & build CRP 2 - machine issue	Down	Down - Powder re-circ pump inverter issue			
Trumpf	Idle - results from previous build			Setup & build			
Addup	Service						
Other	post processing						

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Automated scheduling systems include;

- https:https://amfg.ai/
- https://www.3yourmind.com/agile-mes
- https://www.materialise.com/en/software/streamics

Sven Hinrichs (sven.h@amfg.ai) will present on the AMFG automated scheduling system

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Project No. 601217-EPP-1-2018-1-BE-EPPKA2-SSA-B

CU 36: Coordinating the AM Process (Pilot)

TOPIC 1: Introduction

Prepared by: David Wimpenny

Date: 10/01/21

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Contents

- Welcome
- Introduction of the participants
- Outline of the SAM project
- Overview of the course
- What we need from you

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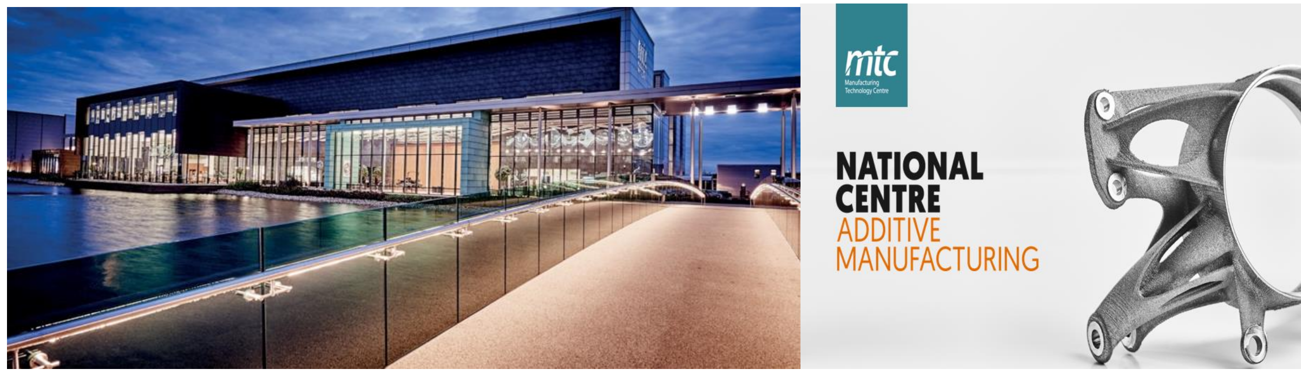
SAM
SECTOR SKILLS STRATEGY IN ADDITIVE MANUFACTURING

Co-funded by the Erasmus+ Programme of the European Union

Welcome



<u>Trainers</u>

David Wimpenny – Chief Technologist, NCAM-MTC

Danny Lloyd – Research Engineer, NCAM-MTC

Aneta Chrostek-Mroz – Research Engineer, NCAM-MTC

Sven Hinrichs – AMFG

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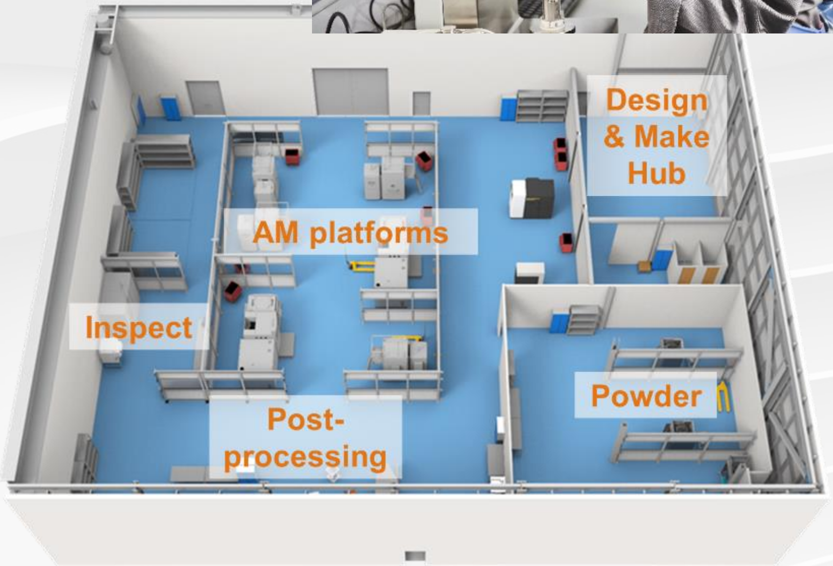
MTC Manufacturing Technology Centre

NATIONAL CENTRE ADDITIVE MANUFACTURING

How we can help you…..



- R&D projects
- Advisory Services
- Knowledge Hub
- Events
- Training
- Funding support

KNOWLEDGEHUB

knowledgehub.the-mtc.org

Introduction of participants

- Each participant to introduce themselves.. Including experience with AM and role in organisation

~30 seconds max (please)

Organisation	Attendees
JLR	Luke Fox
Croft Filters	Neil Burns
HiETA	Alex Owen
Croom Precision	Connor Byrnes
Croom Precision	Patrick Byrnes
Cobham	Matthew Walker
Cobham	Samuel Barton
3D step	Tuomo Liukku
3D step	Mira Federley
ITSEM	Jorge Abel Arámburo López
-	Rúben Paulo
SENTRES	Cem Özateş
MTC	Martin Dury
MTC	Colin Bancroft
MTC	Harald Egner

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Sector Skills Strategy in AM - **SAM Project**

Developing an effective system to identify and deliver skills the AM sector needs for sustainable and inclusive growth ;

- Assessing current and anticipated gaps and shortage of skills in AM
- Devising an AM sector skills strategy
- Support the development of the AM European Qualification System
- Design professional profiles according to the industry requirements
- Develop specific relevant qualifications to be delivered for the AM Sector

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SAM plays a critical role in establishing…

International Additive Manufacturing Qualification System

IAMQS

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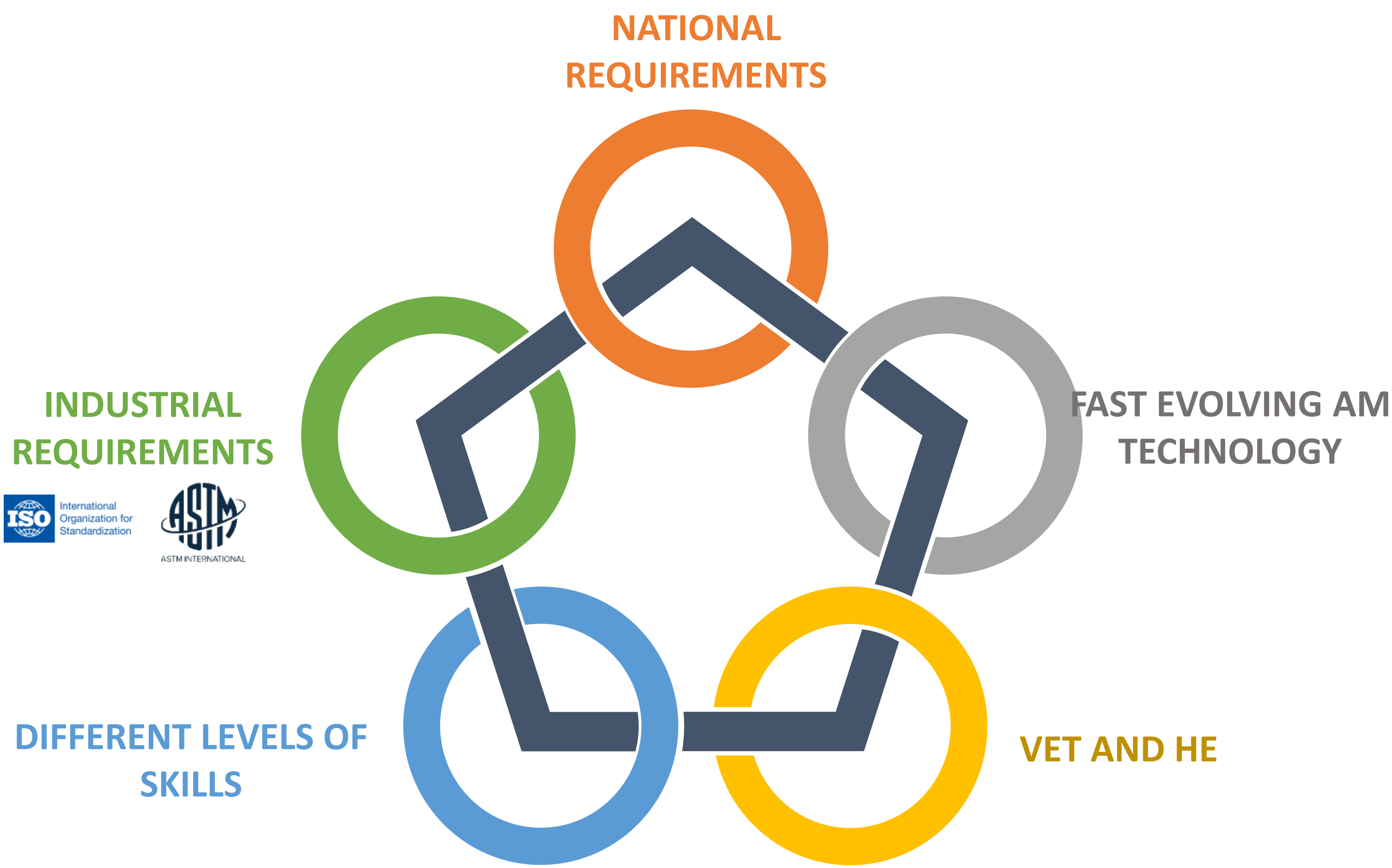
Qualifications in AM



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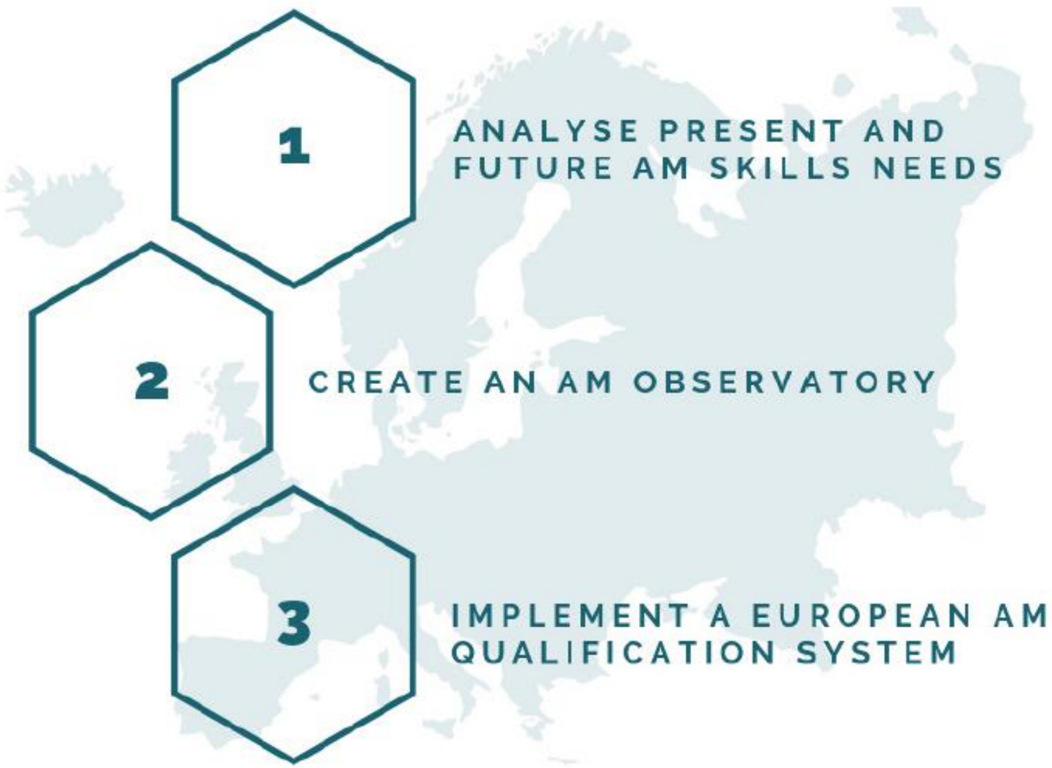
Objectives and Expected Results



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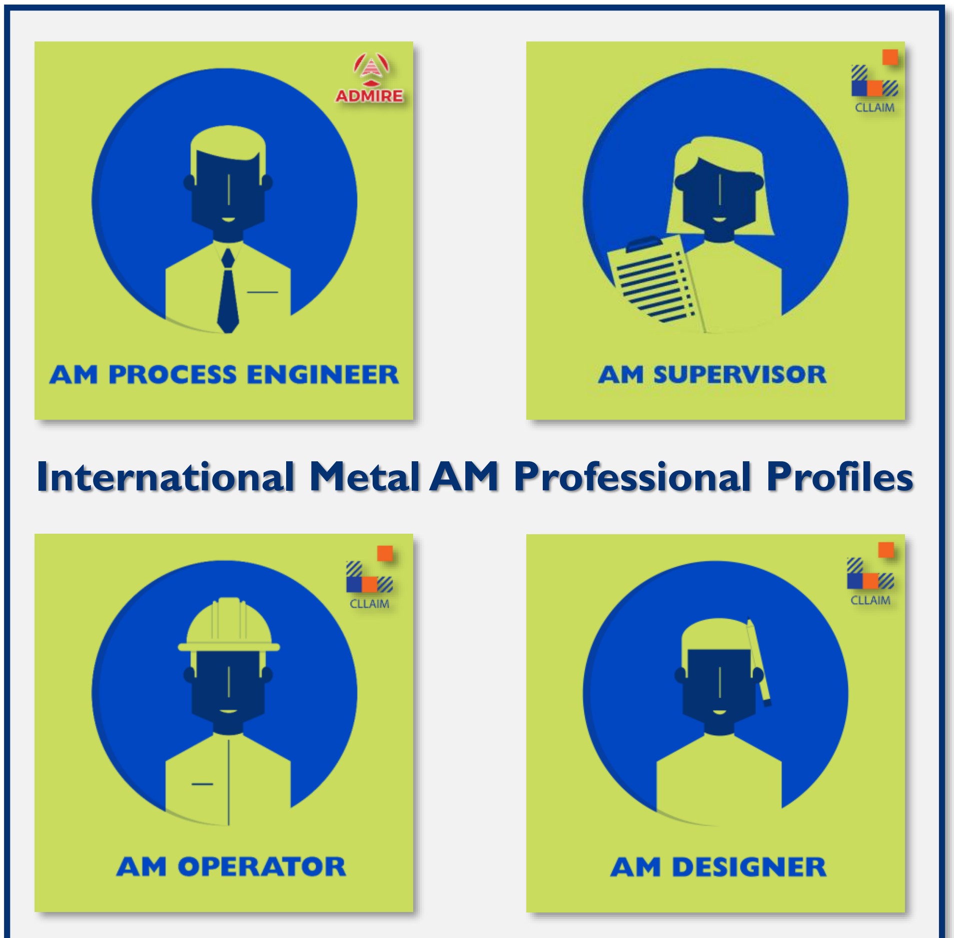
International AM Qualifications... and future qualifications



Qualification framework which reflects the requirements of different roles and also AM different technologies.

Each qualification is comprised of a combination of compulsory and elective competence units (teaching modules).

Each competence unit is being piloted with a "select" audience to gain feed-back on the content /structure

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Competence unit 36 – "Coordination of AM" process

Focuses on the management of the end-to-end AM process to ensure parts are produced which satisfy **customer expectations** as well as complying with the **producers quality management system** and meet the **prevailing external standards**

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Course covers.....

- How to ensure clear communication across the process chain.
- Capturing client requests and preparing quotations.
- Design for AM and how to develop a robust design brief.
- Implementing a quality system and quality control documentation.
- Devising a comprehensive Additive Manufacturing Procedure Specification.
- Effective scheduling of AM systems and personnel.
- Traceability and control of documentation.
- Complying with standards.
- Checking part quality before dispatch.
- Dealing with non-conformance issues.

Tuesday 12th January (9:00am – 12:30pm and 1:00pm to 4:30pm)

Wednesday 19th January (9:00am – 12:30pm and 1:00pm to 4:30pm)

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Objectives of the day….

- We need to cover the entire course (in ~ 7 hours)
- There will be time for questions..at the end of each slide for urgent but brief questions, as well as time at the end of each 30min session
- Apart from 30min for lunch we don't have any scheduled breaks so you will have to take the opportunity at the end of each presentation

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What we need from you - PLEASE

- This is the first running of this course we need your views on the content/structure and delivery – you will be given time to complete the course questionnaire
- ALSO - we would like you to complete a brief skills questionnaire
- Finally – there is a short 10 min assessment for the course

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Time Table (19.01.21)

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START TIME (GMT)	CONTENT	
9:00	Introduction to the course	DW
9:30	TOPIC 1: Capturing client requests and preparing quotations	DW
10:00	TOPIC 2: AM system and Operator scheduling	DW+SH
10:30	10min break	-
10:40	TOPIC 3. Design for AM - Setting and meeting the design brief	DL
11:10	TOPIC 4: Controlling design data	DW
11:40	TOPIC 5: Quality system and quality control documentation	DW
12:10	LUNCH BREAK	
1:00	TOPIC 6: Additive Manufacturing Procedure Specification	DW
1:30	TOPIC 7:Assessing part quality	DW
2:00	TOPIC 9:Traceability and control of documentation	ACM
2:10	10 min break	-
2:40	TOPIC8: Dealing with non-conformance issues	DW
3:10	TOPIC 10:Standards	DW
3:40	Complete afternoon schedule feed-back	
4:00	COURSE ASSESSMENT (10mins- multiple choice)	

Trainers;
David Wimpenny (DW) – Chief Technologist, NCAM-MTC
Danny Lloyd (DL)– Research Engineer, NCAM-MTC
Aneta Chrostek-Mroz (ACM) – Research Engineer, NCAM-MTC
Sven Hinrichs (SH) - AMFG

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Please Note

This is not one of MTC standard training courses which is prepared by the AMTC profession team of educators – the material used has been prepared by the MTC's research engineers with some material supplied from the Admire project.

More information on Admire go to; https://admireproject.eu/

ADMIRE

For more information on MTCs portfolio of professional training courses go to; https://the-amtc.co.uk/training/our-courses/

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Project No. 601217-EPP-1-2018-1-BE-EPPKA2-SSA-B

CU 36: Coordinating the AM Process (Pilot)

TOPIC 6: Additive Manufacturing Process Specification

Prepared by: Sean Anthony Smith, William Morrison & David Wimpenny

Date: 13/01/21

Please look for slides showing - KEY INFORMATION

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Topics covered include…

- What is the AM process specification
- Examples of AMPs

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Additive Manufacturing Process Specification (AMPS)

- AMPS defines the entire end-to-end process which must be followed to ensure that a part meets the required quality.
- Essential step in process certification for some applications
- Moving away from part to process certification – this will accelerate the adoption of AM – particularly in safety critical applications.
- Close link to standards

AMPS gets into the detail of the process

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AM Process Specification - Examples (Non-Exhaustive List)

- NASA 3717 for metallurgical control
- NASA 3716 for manufacture of spaceflight hardware
- ASTM F3303 Standard for Additive Manufacturing
- AMS 7003 Laser Powder Bed Process

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KEY INFORMATION

AMPS Encompasses…(1)

- **Facility specification**; layout plan, people and material workflow and segregation, climate control for temperature and humidity
- **EH&S specification;** PPE measures, barriers/partitions, closed rooms, local exhaust ventilation, risk assessments and safe working practice, material COSHH…
- **People and skills specification;** approved users, roles and responsibilities, skills and training matrix
- **Equipment;** performance validation(FATS), installation, commissioning (SATS), servicing, maintenance calibration for AM machine and other equipment used in the process

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AMPS Encompasses…(2)

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- **Design data;** ID registers, version control, validation of fidelity.
- **Material/feedstock specification;** for metal powder the definition of alloy, form/shape, size range, size distribution, chemical weighting, interstitial content.
- **Specification of other consumables;** compressed air type, inert gas type, filter grade, alcohol cleaning grade, build plate specification and drawings
- **Operation specification;** Work instruction, guidelines, check sheets, route cards, manufacturing packs with control plans/process record sheets + process parameters

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KEY INFORMATION

AMPS Encompasses…(3)

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- **KPVs and Process Window Control;** process variable measurement against necessary output criteria and fix setting/range by control plan

- **Inspection specification;** Part drawings and detailed inspection plans

Note: Where possible reference machine manufacturer instructions /manual. This avoids the need to duplicate this information, also ensures that the latest guidance is being used.

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KEY INFORMATION

NASA AM Standards/Specs

Co-funded by the Erasmus+ Programme of the European Union

MEASUREMENT SYSTEM IDENTIFICATION: METRIC/SI (ENGLISH) UNITS

National Aeronautics and Space Administration

MSFC-SPEC-3717
BASELINE
EFFECTIVE DATE: October 18, 2017

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

EM20

MSFC TECHNICAL STANDARD

SPECIFICATION FOR CONTROL AND QUALIFICATION OF LASER POWDER BED FUSION METALLURGICAL PROCESSES

Approved for Public Release; Distribution is Unlimited

CHECK THE MASTER LIST — VERIFY THAT THIS IS THE CORRECT VERSION BEFORE USE

MSFC-SPEC-3717

FEEDS INTO

MSFC-STD-3716

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

MSFC TECHNICAL STANDARD

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

Approved for Public Release; Distribution is Unlimited

CHECK THE MASTER LIST — VERIFY THAT THIS IS THE CORRECT VERSION BEFORE USE

MSFC-SPEC-3717 is an applicable document to **MSFC-STD-3716**.

It defines procedural requirements for **foundational aspects of process control** in L-PBF: definition and qualification of the L-PBF metallurgical process; maintenance, calibration, and qualification of L-PBF equipment and facilities; and training of personnel for L-PBF operations.

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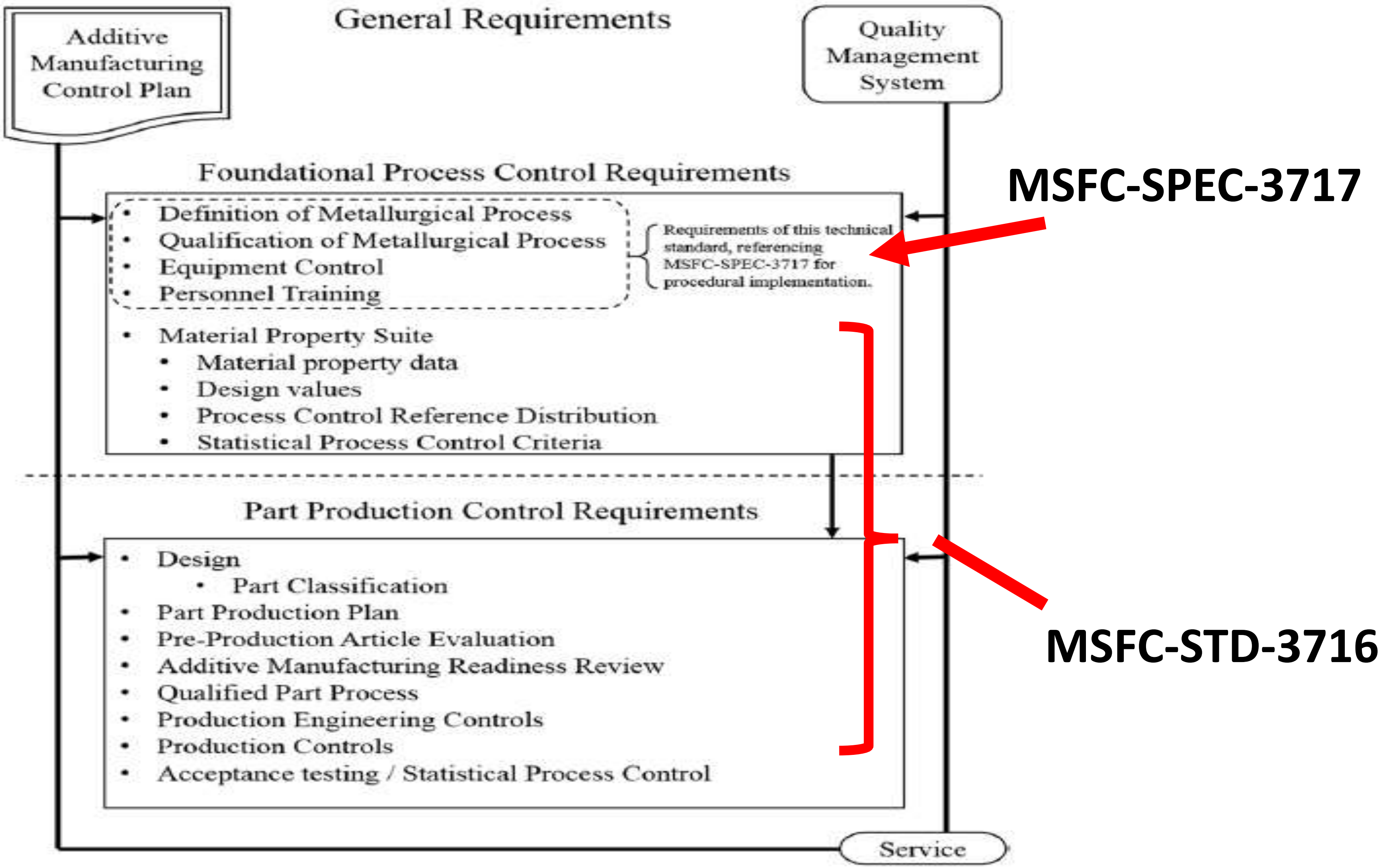

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Nasa Standard - MSFC-SPEC-3717

S4M SECTOR SKILLS STRATEGY IN ADDITIVE MANUFACTURING

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Title: Specification for Control and Qualification of Laser Powder Bed Fusion Metallurgical Processes	Document No.: MSFC-SPEC-3717	Revision: Baseline
	Effective Date: October 18, 2017	Page 4 of 58

MEASUREMENT SYSTEM IDENTIFICATION METRIC/SI (ENGLISH) UNITS

NASA

National Aeronautics and Space Administration

MSFC-SPEC-3717
BASELINE
EFFECTIVE DATE: October 18, 2017

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

EM20

MSFC TECHNICAL STANDARD

SPECIFICATION FOR CONTROL AND QUALIFICATION OF LASER POWDER BED FUSION METALLURGICAL PROCESSES

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Nasa Standard - MSFC-SPEC-3717

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4.1.1 Powder Feedstock

4.1.1.1 Virgin Powder Requirements

[PCQR-2] A configuration controlled material specification used in all powder feedstock acquisition shall levy comprehensive requirements that ensure consistent performance in the L-PBF process and govern, at a minimum, the following aspects of virgin powder production and procurement:

a. Requiring powder producers and suppliers to operate under a QMS conforming to AS9100, or an equivalent approved by the CEO,
b. Specifying unambiguously the method of powder manufacture,
c. Specifying powder chemistry requirements, including acceptable methods of measurement and tolerance,
d. Specifying particle size distribution (PSD) requirements and the acceptable methods of powder sampling and determining the PSD, including explicit limits in weight percent on the quantity of coarse and fine particles outside the PSD range,
e. Specifying, at least qualitatively, the mean particle shape (powder morphology) and limits on satellite particles
f. Controlling the blending of powder heats into powder lots by requiring each blended powder heat individually meet all requirements of the feedstock specification
g. Prohibiting post-production additions to the powder lot for control of PSD or chemistry, (doping)
h. Providing requirements for powder cleanliness and contamination control,
i. Providing requirements for powder packaging, labeling, and environmental controls,

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Nasa Standard - MSFC-SPEC-3717

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DEFINITION AND QUALIFICATION OF L-PBF METALLURGICAL PROCESSES

4.1.3 Thermal Processing

[PCQR-6] The thermal process for the candidate metallurgical process shall be defined with all steps needed to manage microstructural evolution from the as-built state to the final microstructure, including a mandatory hot isostatic pressing (HIP) step for application of the metallurgical process to Class A parts.

[Rationale: This MSFC Specification requires post-build thermal processes to evolve part microstructure toward a uniform and orderly state to mitigate risks, known and unknown, associated with material performance due to the complex as-built microstructure from the L-PBF process.]

A typical L-PBF thermal process includes stress relief, HIP, and post-HIP heat treatments appropriate to the alloy, such as annealing or a solution treatment and aging cycle.

Stress relief thermal cycles are not mandatory for a L-PBF metallurgical process. HIP is mandatory for all L-PBF metallurgical processes that are used to produce Class A parts per MSFC-STD-3716, thus use restrictions for the metallurgical process are needed when HIP is not included in the thermal process. HIP conditions are chosen to provide a time and temperature appropriate to fully homogenize and recrystallize the as-built microstructure as well as to close the majority of microporosity present from the build process. Further heat treatment following HIP is performed as required to achieve the proper final microstructure for the alloy.

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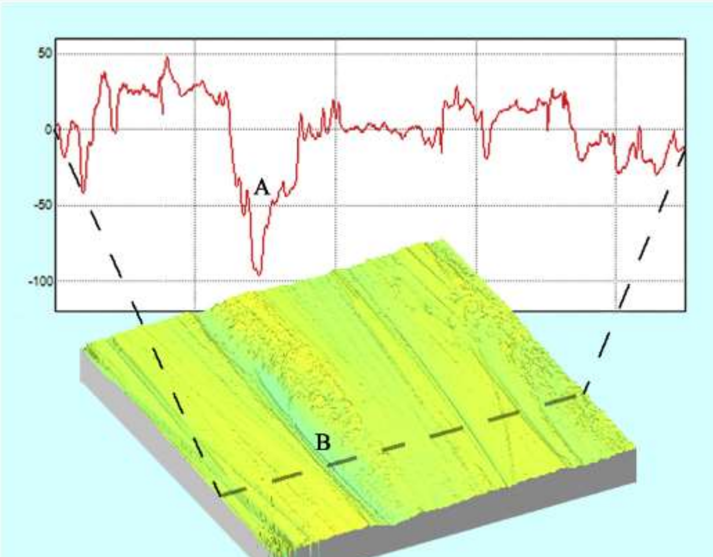
4.2.4 Surface Texture and Detail Resolution Metrics (Reference Parts)

[PCQR-17] Surface texture and detail resolution capability of the L-PBF process shall be evaluated using Reference Part(s) from a minimum of two locations in the build area:

a. The near center of the build area,
b. The furthest location for beam reach or other location identified with reduced build quality.

[Rationale: Rendering capability of the L-PBF process is commonly not uniform across the build area due to influences such as laser incidence angle. These two evaluation locations are intended to bound the process capability.]

This MSFC Specification does not levy specific quality metrics for surface texture and detail resolution for purposes of qualifying a metallurgical process. The Master QMP should be

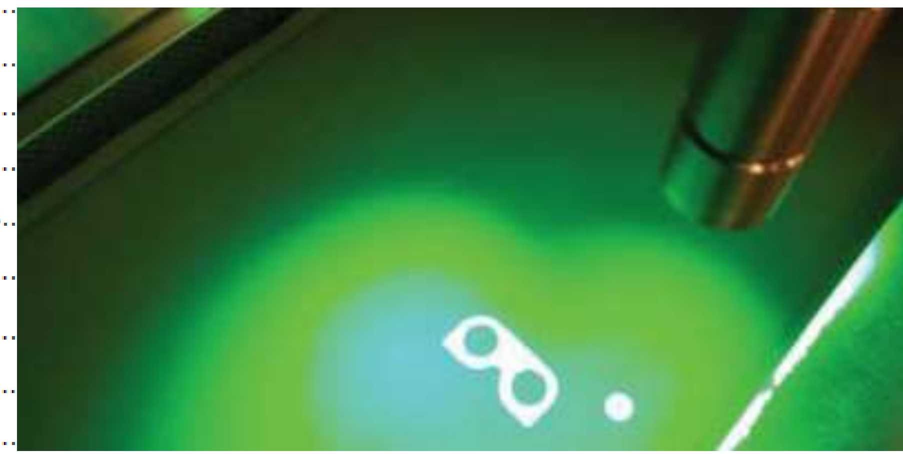


Precision Engineering 46 (2016) 34–47Contents lists available at ScienceDirectPrecision Engineeringjo ur nal homep age: www.elsevier.com/

4.5 Equipment and Facility Process Control

[PCQR-23] The equipment control requirements of this section shall be in place and verifiable through the QMS of the L-PBF Process Vendor prior to production of L-PBF parts under auspices of MSFC-STD-3716.

[Rationale: Controlled part production can only occur once equipment and facility controls are in place and enforced.]



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4.6.1 Training Program

[PCQR-45] An active operator training program shall be defined, maintained, and implemented to meet the following objectives:

a. Provide a consistent framework for training and certification requirements
b. Provide clear delineations of abilities and responsibilities associated with granted certifications
c. Provide operators with all necessary skills, knowledge, and experience to execute the responsibilities of their certification safely and reliably
d. Provide for operator evaluations that demonstrate adequacy in skills, knowledge, and experience to grant certifications to personnel, ensuring only properly trained and experienced personnel have appropriate certifications
e. Incorporate content regarding the importance, purpose, and use of the QMS for all certifications.

[Rationale: Operator certifications are only meaningful if granted from a properly structured and adequate training program.]

The CEO and L-PBF Process Vendors are jointly responsible for the adequacy of the implemented training program.

There is currently no openly defined system for operator certifications in AM technologies. The intent of this requirement is to ensure appropriate depth in the knowledge and skills of the AM workforce involved in the production of aerospace parts per these MSFC Technical Standards. Programs are developing within the industry and if suitable may be used in lieu of an internally structured program.

https://www.google.com/url?sa=i&url=https%3A%2F%2Ftwitter.com

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NASA Standard -MSFC-STD-3716

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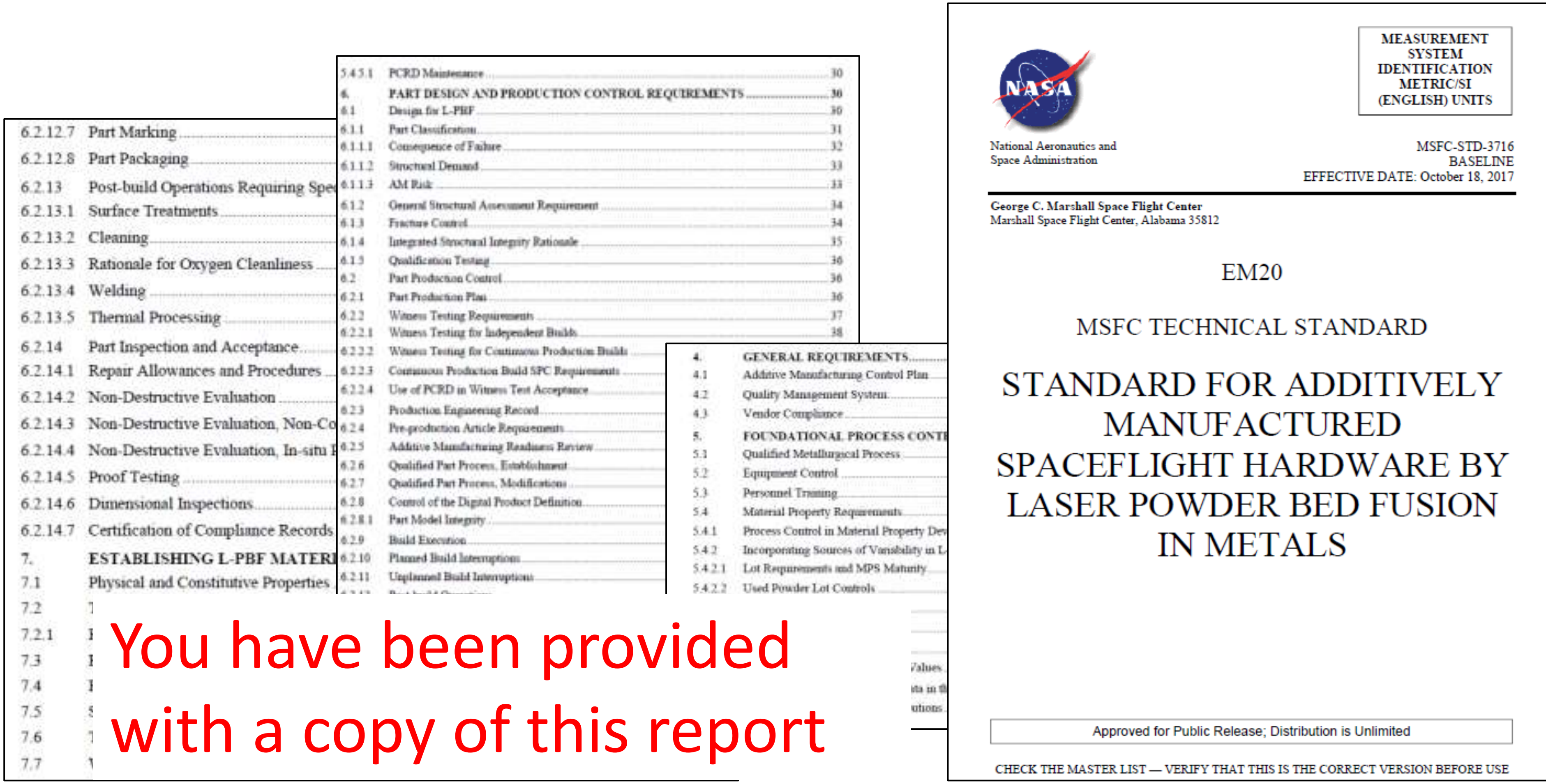
KEY INFORMATION

..provides a framework for implementation of L-PBF AM parts into spaceflight applications requiring high reliability…



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Organisational

Foundation process control

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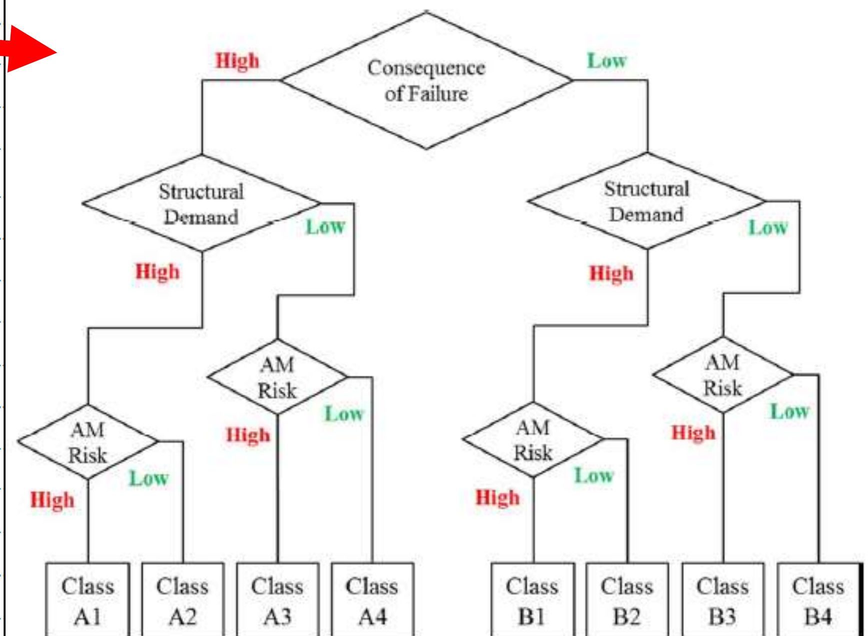

FIGURE 4. Part classification

TABLE III. Witness specimen quantities for stand-alone acceptance

Class	A1	A2	A3	A4	B1	B2	B3	B4
Tensile	6	6	6	6	6	6	6	6
FH Contingency	1	1	1	1	1	1	-	-
Metallography	2	2	1	1	1	1	-	-
Chemistry	1	1	-	-	-	-	-	-
HCF	2	2	2	2	2	-	-	-
Low Margin Point	A/R	A/R	-	-	-	-	-	-
Witness sub-article	A/R	-	A/R	-	A/R	-	-	-
Witness article	1 for 6	-	-	-	-	-	-	-
CQMP	A/R	A/R	A/R	A/R	A/R	A/R	-	-

Notes:

FH Contingency = Full-height contingency specimen

A/R = As required when specified in the PPP/QPP

TABLE IV. Witness specimen acceptance methods for stand-alone acceptance

Class	A1	A2	A3	A4	B1	B2	B3	B4
Tensile	PCRD	PCRD	PCRD	PCRD	PCRD	PCRD	PCRD	PCRD
FH Contingency	A/N	A/N	A/N	A/N	A/N	A/N	-	-
Metallography	Comp	Comp	Comp	Comp	Comp	Comp	-	-
Chemistry	A/S	A/S	-	-	-	-	-	-
HCF	PCRD	PCRD	PCRD	PCRD	PCRD	-	-	-
Low Margin Point	DV Min	DV Min	-	-	-	-	-	-
Witness sub-article	Comp	-	Comp	-	Comp	-	-	-
Witness article	Comp	-	-	-	-	-	-	-
CQMP	A/S	A/S	A/S	A/S	A/S	A/S	-	-

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6.2.8.1 Part Model Integrity

[AMR-36] A methodology for verifying the integrity of part models throughout all stages of the digital part definition associated with the L-PBF process shall be documented and enforced through the AMCP.

[Rationale: To ensure the certified design intent is reflected in the part, the integrity of the part design must be verified at the original CAD, then maintained throughout the process of geometry conversion to render a complete build file for the L-PBF part.]

Just as standard processes exist to confirm part drawings properly specify final part configuration prior to release, a similar process is required to check the integrity of solid models and any associated information containing design intent. Design integrity must be maintained throughout the AM-related manipulations of the post-design electronic data such as error-free creation of stereolithography (STL) files with proper resolution, and generation of L-PBF platform-specific slice files.

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6.2.12.2 As-Built Part Inspections

[AMR-41] Immediately upon build completion and removal from the powder bed, all parts shall receive, at minimum, full visual inspection for any indications of build anomalies prior to processes that may alter the as-built state of the part, such as bead or grit blasting, with all anomalies recorded in detail in the QMS.

[Rationale: Many indicators of L-PBF process quality are best evaluated prior to further part processing, including many indicators, such as coloration or support damage, that may be eliminated during further part processing.]

Build anomalies include, but are not limited to, witness lines on the part surface (see definition), unusual discoloration, laminar defects such as cracks or tears, separation of part from support structures, and geometric distortion.

At this time, the L-PBF machine should receive an inspection for any anomalies. Any damage or nicks in the edge of the recoater blade should be noted.

High quality photographs to document the as-built part inspection process is recommended, particularly unusual observations or anomalies.

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6.2.14.7 Certification of Compliance Records

[AMR-58] The production engineering record shall contain a list of all records needed to establish part compliance with the requirements of the QPP, with all such records maintained within the QMS.

> *[Rationale: For proper L-PBF part traceability, it is important that the production engineering record unambiguously define what records are required to establish the complete production data package for the part. Without such accounting, data packages for parts may go incomplete, resulting in parts with insufficient quality rationale.]*
>
> *In accordance with NRRS 1441.1, NASA Records Retention Schedules, contract and QMS requirements, all part records are archived for the prescribed period and remain fully traceable, including those provided by external vendors for operations such as heat treating, machining, or inspection. All witness specimen test results and records as well as non-conformance documentation are included in the certification of compliance records for the part. When complete, it is recommended that a final, summarized certification of conformance record be generated demonstrating all requirements have been met, all non-conformances resolved, and that the part is fit for service.*

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7.3 Fatigue

[AMR-61] As required for structural assessment, or at customer discretion, the MPS for any given L-PBF product shall include fatigue properties developed in accordance with the following policies:

a. The process for developing design fatigue curves from the test data is described as part of the MUA substantiating the MPS methodology per section 5.4 of the main body;

b. Fatigue initiation life properties are developed in the form of stress-life or strain-life curves;

c. All fatigue design curves are labeled with their basis, e.g., typical or bounding;

d. Fatigue properties are subject to the lot requirements of section 5.4.2.1 of the main body;

e. Ten or more tests are used to define a fatigue curve for a given condition and, for HCF, a minimum of four tests are within 10% of the stress defined as the fatigue limit; (See the definition of fatigue limit for this MSFC Technical Standard.)

f. If the MPS fatigue design curves are applied to Class A parts with cycle counts $\geq 10^8$, fatigue test data are acquired to substantiate the design curve in this regime, except for Class B parts, where an analytical methodology for predicting such fatigue limits may be employed when properly documented;

g. Effects of surface textures rendered by the L-PBF process, and surface improvement treatments, are included in the fatigue design curves of the MPS as follows:

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- ASTM AM CoE partners, including MTC Working with NASA to develop generic internal standard based on the space standards heritage

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Additive Manufacturing

ASTM INTERNATIONAL

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Sources of information

- National/international standards
- Sector specific guidelines
- Other sources…….

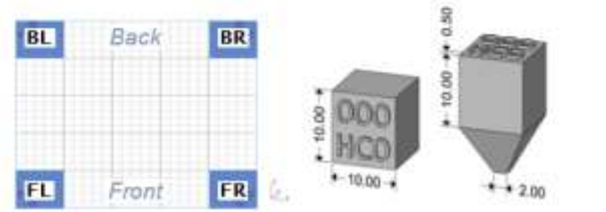

Figure 1. At the UK's National Centre for Additive Manufacturing, we put a block in every such corner of our metal powder bed fusion builds - see plan view of the build chamber on the left with corners labelled back left (BL), back right (BR), front left (FL) and front right (FR). The geometry of the block is also shown - plan view (middle) and side view (right). It is a 10 mm cube with an inverted pyramid below it. The letters on top are a unique identifier that are used to trace them back to the build and location on the bed. The blocks are removed from the build plate and tested to monitor the performance of the machine.

This process is mandatory at the National Centre for all M-PBF machine builds, with the exception of the following scenarios:

- For parameter development builds, or when a standard material melt-theme does not exist
- On externally prepared builds files which do not permit internal additions and alterations
- When the addition of cubes is physically impossible, due to the geometry of primary parts e.g. for large-spanning primary parts which cover the entire surface of the build platform

KHUB-AM-0007-Selecting buying commissioning an MPBF system-v2.0

Guide - Considerations when Selecting, Commissioning and Maintaining a Metal Powder Bed Fusion System

November 2020

- Validation of process capability - where you identify a candidate machine and process parameters to achieve the required build quality
- Installation and commissioning
- Maintenance, servicing and upgrades
- Measurement of M-PBF Machines

KNOWLEDGEHUB

http://knowledgehub.the-mtc.org/knowledge-hub/

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Recommended Guidance for Certification of AM Components
AIA Additive Manufacturing Working Group

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Recommended Guidance for Certification of AM Components
AIA Additive Manufacturing Working Group

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https://www.aia-aerospace.org/wp-content/uploads/2020/02/AIA-Additive-Manufacturing-Best-Practices-Report-Final-Feb2020.pdf

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Process Control Documents

Infrastructure

- Facility Control Plan
- Operator Training and Qualification Plan
- Work Instruction Plan
- Software Configuration Control Plan

Machine Qualification Plans

- Key Process Variable (KPV) Plan
- Machine Configuration Plan
- Preventative Maintenance Plan
- Machine Calibration Plan
- Machine Requalification Plan

Feedstock Control Plan

- Feedstock Lot Control Plan
- Feedstock Handling Plan
- Powder Feedstock Re-use Plan
- Machine and Material Alloy Change
- Contamination Avoidance Plan

Part Production Plans

- Engineering Requirements Plan
- Manufacturing Part Definition Plan
- Machine Parameters Plan
- Build Interruption Plan
- Quality Control Plan
- In-Process Monitoring Inspection Plan
- Record Keeping Plan

Post-Process Plans

- Powder Removal Plan
- Stress Relief Plan
- Hot Isostatic Press (HIP) Plan
- Heat Treatment Plan
- Build Plate Removal Plan
- Support Removal Plan
- Surface Enhancement Plan

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Case study

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See additional slides not presented during training session


Inspiring Great British Manufacturing

Report Title: **D1 - Guidance on Validation of the Electron Beam Powder Bed Fusion Process for Aerospace**

Version Number: 1.0

Project Title: 32296-12-11 DRAMA Metron Process Validation Support Package

Prepared For: Metron Advanced Equipment Ltd.

Author: Nick Cruchley

Thank you to Metron allowing this information to be shared with you

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Definitions of terminology used in within the context of production of components for the aerospace industry

Term	Quoted Definition	Definition Source	Reference
Certification	"A procedure by which a third party gives written assurance that a product, process or service conforms to a specified requirement."	MAASAG Paper 124 Issue 1	(Lunt, et al., 2018)
Qualification	"The demonstration that the product, process or service conforms to a specified requirement."	MAASAG Paper 124 Issue 1	(Lunt, et al., 2018)
Validation	"Activities performed to demonstrate that a product is capable of meeting the requirements for the specified application or intended use." Note: Validation can also apply to a manufacturing process.	SABRe Supplier Management System Requirements Definition	(Rolls-Royce, 2019)
Verification	"Verification uses objective evidence to confirm that specified requirements have been met."	SABRe Supplier Management System Requirements Definition	(Rolls-Royce, 2019)

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Product Design & Development	Requirements capture	Product design	Review design for manufacturability and assembly		
Process Design & Development	Establish process flow	Identify process operating windows	Establish process capability – geometry	Establish process capability – material properties 32296-12-11 D1 & D2	Process control plan 32296-12-11 D1
Machine Qualification	Machine installation qualification	Machine operation qualification	Machine performance qualification		
Product & Process Validation	Process validation	Product Validation			
Quality Control	Quality control plan				

Description of the stages of new production introduction from design to qualified process and product

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Airworthiness Regulations

- **CAA/ EASA:** the regulatory bodies which oversee the safety of the aerospace sector
- **Design Organisation:** "responsible for the design of products, parts and appliances or for changes or repairs" …… likes of Boeing, Airbus, Rolls-Royce, GE Aviation and Pratt and Whitney.
- **Production Organisation:** "responsible for the manufacture of products, parts and appliances" … must demonstrate its capability in accordance with Annex 1 (Part 21), Subpart J of the regulation (European Union, 2012)… must (amongst other things) have agreement in place with Design Organisation; demonstrate a robust Quality System; and have a nominated independent owner of quality management.
- Obtaining these approvals **can take years**….includes visits from National Aviation Authority (the CAA for the UK) and so the lead time can, in part, depend upon the availability of the National Aviation Authority

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Subcontracting

- Design Organisation or Production Organisation can subcontract to another company but legal responsibility for the airworthiness of the products remains with them (ie you can not subcontract the responsibility)

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Working to standards

- AS9100D is the aerospace industry accepted standard for quality management systems.
- Special processes (including some metal powder bed additive processes) are audited by an organisation called Nadcap (National Aerospace and Defense Contractors Accreditation Program).
- Nadcap checklist exists for a specific manufacturing process, it is a good place to start to understand requirements
- Aerospace organisations still impose their own specific requirements

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SECTOR SKILLS STRATEGY IN ADDITIVE MANUFACTURING

Manufacturing Process Approval

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- Even if the appropriate baseline accreditations and approvals are in place, the supplier still has to prove **production readiness for each new product introduced**. This can include demonstrating that the "engineering requirements are properly understood and verified" and that "manufacturing quality and rate potential exists" (Rolls-Royce, 2013).
- Requirements for process approval may be different for each component, depending on e.g. their processing route or criticality.
- Design Organisation will provide detailed material and process specifications….may even prescribe certain elements of the manufacturing process such the supplier that the powder feedstock is purchased from.
- Qualification process has to be undertaken for **each product** supplied to each aircraft type. The Design Organisation may permit learning to be 'read across' from one product to another or from one process to another.
- For metal AM the material is formed at the same time as the geometry and we do not have a good understanding of when we can read across between similar materials, geometries and process parameters.

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Guidance for Aerospace Process Control

- Guidance on the processes and requirements for the introduction of new products to aerospace is freely available in the form of: Rolls-Royce SABRe 3 Production Part Approval Process (Rolls-Royce, 2015)

and

- SAE Requirements for Advanced Product Quality Planning and Production Part Approval Process (SAE International, 2016).

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Table 2: Reviewed documents referencing to specific EB-PBF process tasks

	Reviewed Documents										
	NADCAP Audit Criteria For Laser and Electron Beam Metallic Powder Bed Additive Manufacturing	MASAAG Paper 124 Guidance Note On the Qualification and Certification of Additive Manufactured Parts for Military Aviation	AIA - Recommended Guidance for Certification of AM components	FAA Job Aid for Evaluating Additive Manufacturing Facilities and Processes	NASA MSFC-STD-3717 Specification For Control and Qualification of Laser Powder Bed Fusion Metallurgical Processes	ASTM F2924 Standard Specification for Additive Manufacturing Titanium-6 Aluminium-4 Vanadium with Powder Bed Fusion	ASTM F3049 Standard Guide for Characterizing Properties of Metal Powders Used for Additive Manufacturing Processes	ASTM F3301 Standard for Additive Manufacturing – Post Processing Methods – Standard Specification for Thermal Post-Processing Metal Parts Made Via Powder Bed Fusion	ASTM F3303 Standard for Additive Manufacturing – Process Characteristics and Performance: Practice for Metal Powder Bed Fusion Process to Meet Critical Applications	AMS 2801B Heat Treatment of Titanium Alloy Parts	AMS7003 Laser Powder Bed Fusion Process
Powder specification	X		X		X	X			X		
Powder Receipt	X			X							
Powder handling	X	X		X	X						
Powder Storage	X	X		X	X				X		X
Powder blending		X			X	X					X
Powder recycling		X			X	X			X		
Powder testing						X	X				
Key process variables		X	X								X
Machine operation	X	X	X						X		
Build Monitoring		X		X							
Build pauses	X	X			X						X
Machine maintenance	X	X		X	X				X		X
Support removal	X		X								
Thermal post processing	X	X	X		X	X		X		X	
Surface Finishing		X									
Machining											
Inspection	X	X	X	X							

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4.1 Powder

4.1.1 Specification

The sources reviewed containing information on the specification of powder being procured and for continual testing is displayed in Table 2. Based on the information reviewed the MTC suggests that Metron's processes must include the following:

- Powder suppliers are to hold AS9100 or an equivalent accreditation
- A clear powder specification is used when procuring powder feedstock including acceptable limits, methods of sampling, methods of testing and acceptable testing tolerances on the following metrics:
    - Chemistry
    - Particle size distribution (PSD)
    - Powder morphology (at least qualitative requirements)
    - Flowability
    - Contamination requirements
- In addition to this the powder specification should:
    - Explicitly state the powder manufacturing method (incl. atomising gas)
    - Place controls on the blending of powder heats into powder lots (i.e. requiring each blended heat to meet the feedstock specification)
    - State the requirements for feedstock packaging (incl. environmental controls) that by design explicitly prevent moisture from entering.

Note: Multiple standards (ASTM F3303) explicitly prohibit the placing of desiccants or other materials in contact with the feedstock materials.

- A certificate of conformance (CoC) to the supplied specification
    - Identifiers of powder heat and blended lot with date and location of production allowing traceability back to the specific heat.
- Powder should be verified against this specification prior to use

4.1.7 Testing

The sources reviewed provided little guidance on the procedures and methods for powder testing, however, ASTM F3049-14 can provide some guidance on this. Together with this standard the MTC recommends following the test standards for verifying the powder feedstock metrics displayed in the table below.

Table 3: Test standards governing the relevant metallic powder test methods employed for the suggested material purchasing specification

Property	Test	Governing standard
Powder sampling	Sampling method	ASTM B215
Particle size determination*	Sieve analysis	ASTM B214
	Light scattering method	ASTM B822
Morphology	Morphology definitions only**	ASTM B243
Chemical composition	Inert gas fusion	ASTM E1447
	Combustion Analysis	ASTM E1941
	Inductively Coupled Plasma Atomic Emission Spectrometry	ASTM E2371
	Wavelength Dispersive X-ray fluorescence	ASTM E539
Flowability	Hall flow	ASTM B213 & B855
	Carney flow	ASTM B964
Contamination	N/a	No current governing standard or commonly accepted test method
Density	Hall flow	ASTM B212
	Carney flow	ASTM B417
	Scott volumeter	ASTM B329
	Arnold meter	ASTM B703
	Tap Density	ASTM B527
	Skeletal density	ASTM B923

* Non standardised light scattering methods may be applicable

** Only defines definitions of powder shapes – no standard for qualification of powder morphology currently exists

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4.2.2 Machine operation

The sources reviewed containing information on procedures for machine set up is displayed in Table 2. Based on the information reviewed the MTC suggests the following advice.

Note: It is strongly suggested by multiple standards and the MTC that a machine is allocated to a single material as the changing over of materials in the context of validation or qualification for aerospace is too high risk and runs a large amount of machine requalification effort.

All operators shall be suitably trained or qualified to operate the equipment and a documented record of operator for each stage of the manufacturing process should be kept. The operator may be considered a KPV and if so should be controlled accordingly.

The equipment/machinery to be used during manufacture (including pre and post processing) should be defined and documented at a minimum to the following level:

- Machine, make and model
- Serial number
- Date of machine configuration
- Software and hardware version numbers
- Recoater configuration, material and condition
- Recoater speed
- Build platform material and configuration
- Preheating temperature
- Powder dosing range
- Gas composition/grade
- Vacuum quality
- Oxygen limits
- Temperature limits
- Dew point and moisture control

Documented procedures should be in place to ensure that the quality of the all build plates are controlled, this includes:

- Build plate cleanliness and condition
- Build plate is free from contamination and defects
- Traceability between manufactured component and build plate
- Tolerances and material requirements of the build plate including: flatness, finish, thickness, and alloy
- Visual inspection of build plates is carried out and that non-conforming build plates are disregarded

Similar process control could be consider for other key consumables such as recoaters and process gases.

Work instructions & route cards cover….

ensure a documented procedure (e.g. work instructions and route cards) that ensures the following:

- Maintenance record is checked and correct
- Qualification status of the machine
- Powder quantity loaded is sufficient and correct
- Build platform serial number matches the route card/manufacturing plan
- Installation of build plate
- Proper recoater installation
- Platform and recoater are fully inspected prior to build
- Ensure correct type, function and cleanliness of all auxiliary systems
- Check chiller temperature and flow of fluid
- Record chiller temperature prior to each build
- Ensure no gas flow restrictions
- Gas type and flow meets specifications
- Ensure build parameters are correct for build
- Beam powder shall be measured and documented immediately prior to each build and following each build
- Ensure build file matches intended build file
- Ensure machining stock is in accordance with manufacturing plan
- Powder sampling
- Qualified procedures for part production are established and undertaken
- Material changeover procedure before new powder is introduced (machine and ancillaries).
- Route card should include operations that control manufacturing and inspection procedures during set up and include sign off
- Route card should include all essential manufacturing information (ID number, powder batch number, thermal cycle designations)
- Fully defined operation sheets and build programmes that fully define all KPVs and conditions related to the build process.
- Route cards, operation sheets and build programmes need to be fully traceable back to the job sheet and purchase order.
- Traceability and control of recovered powder post build
- Removal of components from the build volume for post processing

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www.skills4am.eu

Thank you

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Project No. 601217-EPP-1-2018-1-BE-EPPKA2-SSA-B

CU 36: Coordinating the AM Process (Pilot)

TOPIC 7: Product verification & Quality

Prepared by: Aneta Chrostek-Mroz and David Wimpenny

Date: 13/01/21

Please look for slides showing - KEY INFORMATION

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Introduction to Part verification & Quality

- Quality enables a user to characterize and determine which product is better than the other
- The quality level of products and services indicates not only their intended function and performance but also their perceived value and benefit to the customer
- In the AM industry, organizations are required to have a quality framework that addresses the new concerns specific to AM, in addition to adopting and committing to the approaches and expectations defined in quality management standards, such as ISO 9001:2015

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Part verification & Quality criteria

The part quality requirements may be defined by;

- Requirements by customer
- Requirements by organization
- Requirements by statutory and regulatory bodies
- Contract / orders requirements

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Part verification & Quality

essential step not only to ensure that parts meets customer expectations but also as a critical aspect of process control

NASA Standard -MSFC-STD-3716

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Assessing AM parts can be challenging…..

- Complex part geometry
- Poor surface finish which varies across the part
- Material properties are process and orientation dependant
- Part quality can depend on part orientation, build location (for example in PBF-LB flow of argon can affect part quality)
- Some defects are "unique" to AM

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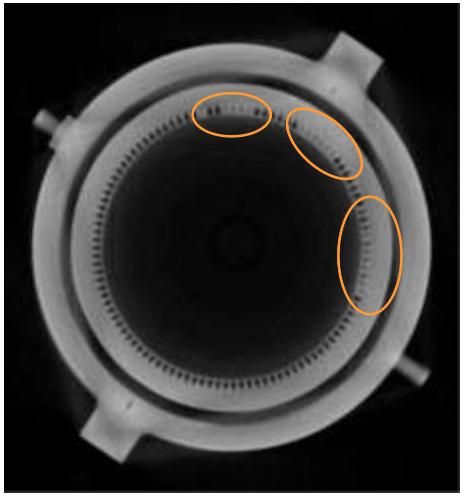
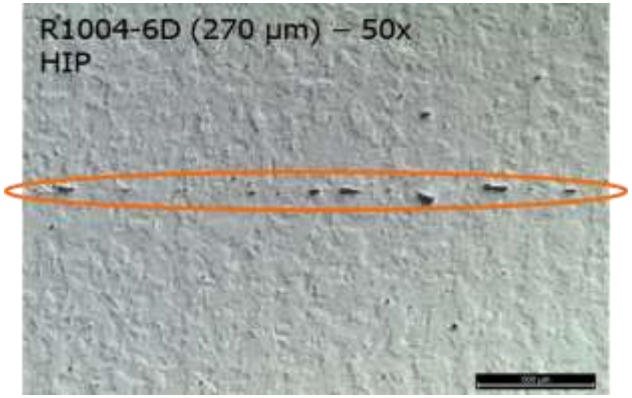
"Unique" AM Defects

- **Specific AM defects** – Layer defects (horizontal LOF), cross-layer defect (vertical LOF), unconsolidated powder and trapped powder

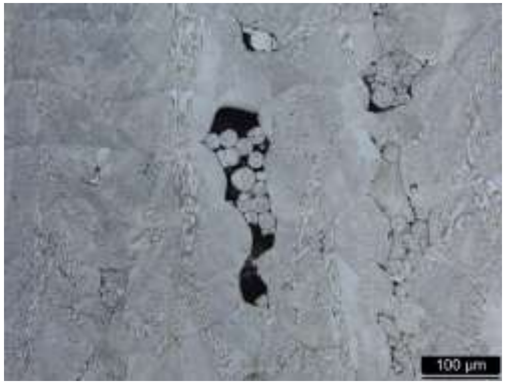


Trapped powder



Layer defect (horizontal LOF)

Cross-layer defect (vertical LOF)



Unconsolidated powder

Courtesy ISO/ASTM JG59 DTR 52905, 'Additive Manufacturing — Non-Destructive Testing and Evaluation — Standard Guideline for Defect Detection in Metallic Parts', Submitted for balloting.

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When to measure part quality ?

We tend to think this is the last step in the process before we ship parts to customers but in reality we need to assess part quality throughout the process chain

- After critical process steps
- During processing - increasingly in-process inspection methods are being employed to "measure as we make"

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Assessing parts quality after critical process steps …for example

- As built
- After stress relieving
- After base plate removal
- After support removal
- After heat treatment
- After finishing

Using this approach we can;

- Avoid incurring costs in downstream processes
- Enable replacement parts to be scheduled
- Identify the source of problem and prevent it affecting future parts

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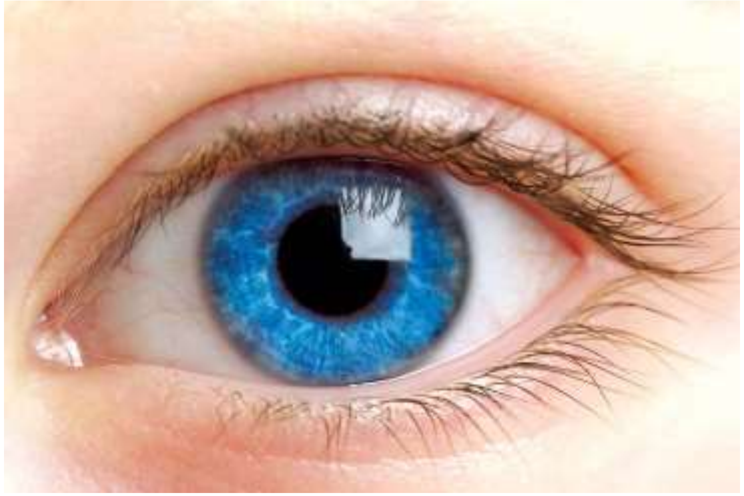
Inspection technique….?



- Widely available
- No capital investment
- No calibration
- Limited training
- Huge amount of data can be collected and processed very quickly

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How to assess part quality after process steps

Visual assessment can provide a lot of useful information and is quick if rather subjective to perform

Look for

- Distortion/swelling
- Delamination
- Poor surface finish
- Discolouration

Also worth checking overall dimensions (particularly for large parts)

NASA Standard -MSFC-STD-3716

6.2.12.2 As-Built Part Inspections

[AMR-41] Immediately upon build completion and removal from the powder bed, all parts shall receive, at minimum, full visual inspection for any indications of build anomalies prior to processes that may alter the as-built state of the part, such as bead or grit blasting, with all anomalies recorded in detail in the QMS.

> *[Rationale: Many indicators of L-PBF process quality are best evaluated prior to further part processing, including many indicators, such as coloration or support damage, that may be eliminated during further part processing.]*
>
> *Build anomalies include, but are not limited to, witness lines on the part surface (see definition), unusual discoloration, laminar defects such as cracks or tears, separation of part from support structures, and geometric distortion.*
>
> *At this time, the L-PBF machine should receive an inspection for any anomalies. Any damage or nicks in the edge of the recoater blade should be noted.*
>
> *High quality photographs to document the as-built part inspection process is recommended, particularly unusual observations or anomalies.*

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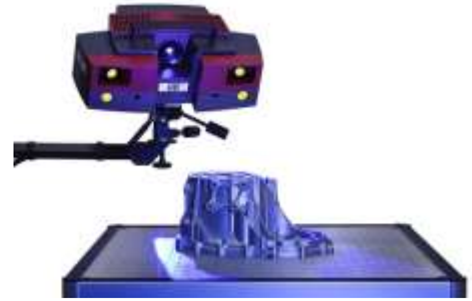
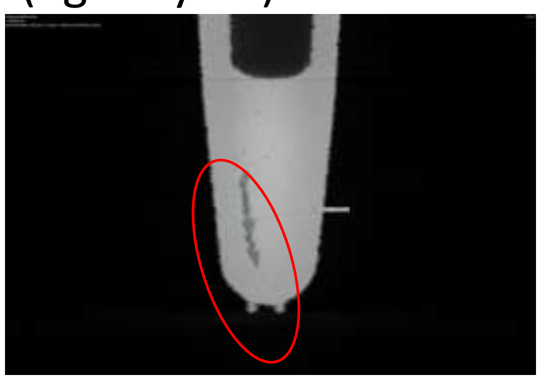
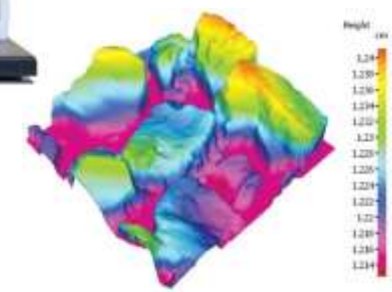
Final part quality assessment



- **Part accuracy** - hand held measurement tools, CMM +touch trigger probe (TTP) but increasingly using optical techniques (such as photogrammetry / structured light / laser strip)
- **Surface finish** – optical measurement of area (Sa,SZ) rather than linear profile lines
- **Integrity** - NDT (eg Xray CT)





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Assessing part integrity by Non Destructive Testing (NDT)

Mainly for reference but please READ

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X-ray Imaging

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KEY INFORMATION

NDT Technique	Physical Phenomena	Fundamentals	Applications
Radiographic Testing	Electromagnetic radiation (ionizing)	Requires the incidence and penetration of radiation energy on and through an inspected material, which is absorbed homogeneously by the material, except in the regions where thickness, density variations or defects arise. The radiation that passes through material impinges an image in a sensing medium revealing the defects.	Detect deep or embedded defects (virtually no limits); Poor sensibility for defects perpendicular to the radiation direction; Poor sensibility for small defects compared to the sample dimension; Not suitable for on-line inspection. Human health concerns.
X-ray Backscatter	Electromagnetic radiation (ionizing)	Backscatter X-ray detects the radiation that reflects from the target as opposed to conventional X-rays.	Detect deep or embedded defects (virtually no limits); It can operate even if only one side of the target is available; Inspecting times can be unacceptably long.
Computed Tomography	Electromagnetic radiation (ionizing)	Method of forming reliable three-dimensional (3D) representations of an object by taking many x-ray images around an axis of rotation and using algorithms to reconstruct a 3D model.	Detect deep or embedded defects (virtually no limits); Not suitable for online inspections. Time-consuming and size limitations.

ADMIRE
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Ultrasound

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KEY INFORMATION

NDT Technique	Physical Phenomena	Fundamentals	Applications
Conventional Pulse-echo Ultrasonic Testing	Mechanical vibration	A beam of high-frequency sound waves is introduced into a material, travel through it and are reflected at interfaces or defects. The reflected sound is analyzed to identify the presence and location of defects.	Can be used for flaw detection, location and measurement; It cannot be used for high-temperature inspection (typically > 300 °C); Surface treatment dependent. Not adequate for locally non-planar surfaces.
Phased Array Testing	Mechanical vibration	PA systems utilize multi-element probes, which are individually excited under computer control. By exciting each element in a controlled manner, a focused beam of ultrasound can be generated. Software enables the beam to be steered. Two and three-dimensional views can be generated.	Can be used for flaw detection, location and measurement; Fast inspection times; Able to penetrate thick sections; Cannot work at high temperatures; Requires coupling; May require several probes.
Immersion Ultrasonic Testing	Mechanical vibration	Immersion or water-column (squirt) US techniques allow a more efficient coupling between the US probe and the inspected material. It facilitates the automation of the inspection process providing C-scan images of the test pieces.	Improved probability of detection of the smallest defects; More accurate sizing and location of subsurface flaws; Good results independents of the geometry complexity; Cannot be used on-line and under high temperature; Requires immersion of the part.
Electromagnetic Acoustic Transducer (EMAT)	Mechanical vibration and Electromagnetic induction	This inspection method uses an electromagnetic acoustic (EMA) way of ultrasound excitation and reception.	Can be used for flaw detection, location and dimensional measurements. Contactless and couplant independent but requires proximity; Suitable for high temperatures; Geometry constrained. Low sensibility for small defects.
Laser Ultrasonic Testing	Thermal expansion and optical measurement	A laser pulse is directed to the surface, heating it and inducing an ultrasonic pulse that propagates into the sample. This ultrasonic pulse may interact with a defect and then returns to the surface. A separate laser receiver detects the displacement that is generated when the pulse reaches the surface.	Can be used for flaw detection, location and measurement; Capable of detecting very small flaws (virtually no limits); Contactless and couplant independent; Can be used on complex geometries, curved or difficult to access areas; Can be used at very high temperatures.

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Electromagnetic

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KEY INFORMATION

NDT Technique	Physical Phenomena	Fundamentals	Applications
		when the pulse reaches the surface.	
Potential Drop	Electrical current	Measurement of the potential drop by an increase in the electric resistant between two measurement electrodes in a presence of a discontinuity.	Very good at estimating surface cracks depth; Penetration depth of few mm; Surface roughness reduces the accuracy of the sized cracks. Can be used at high temperature.
Eddy Currents	Electromagnetic induction	A coil (probe) is excited with an alternating electrical current, producing an alternating magnetic field around a conductive test piece. Eddy currents are induced in the materials, but defects cause a change in eddy current, corresponding to a change in the impedance coil, allowing the identification of the defects.	Can be used for surface and subsurface flaw detection; Penetration depth of few mm (1/2 mm); Very sensitive to small defects. Contactless but requires proximity; Limited to conductivity materials.
Magnetic Particle Testing	Magnetic field	The inspected material is magnetized. The presence of a surface or subsurface defect allows the magnetic flux to leak. Then magnetic (ferrous) particles are applied on material surface and attracted to the flux leak zone, indicating the presence of a defect.	Limited to ferromagnetic materials; Can detect subsurface defects. Not adequate for online inspection.

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Thermography

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KEY INFORMATION

NDT Technique	Physical Phenomena	Fundamentals	Applications
Infrared Thermography	Electromagnetic radiation	Infrared thermography aims at the detection of subsurface features, owing to temperature differences (DT) observed on the investigated surface during monitoring by an infrared camera.	Can detect subsurface defects; Risk-free (no radiation); Suitable for online monitoring; Requires heated working material; Large areas can be scanned fast.
Laser Thermography	Electromagnetic radiation	A high-power laser source is used for external heat delivery and the energy will diffuse in the specimens' surface making discontinuities detectable with the analysis of the temperature distribution near the laser spot.	Can detect subsurface defects; Suitable for online monitoring; Contactless and requiring no surface finishing;
Vibro Thermography	Electromagnetic radiation and mechanical vibrations	An ultrasonic transducer generates elastic waves within the test specimen. These waves will interact with the irregularities present in the object and due to the friction, energy will be dissipated in heat form and later detected by an IR camera.	Can detect subsurface defects; Requires contact; Very short measurement time (seconds). Difficult to apply in heated surfaces.
Eddy Current Thermography	Electromagnetic induction and radiation	Use of induced EC to heat the sample and defect detection is based on the changes of the induced eddy currents flows revealed by thermal visualization captured by an infrared camera.	Can detect subsurface defects. May require time to deposit enough energy in the material; Suitable for online monitoring.

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SECTOR SKILLS STRATEGY IN ADDITIVE MANUFACTURING

Other

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KEY INFORMATION

NDT Technique	Physical Phenomena	Fundamentals	Applications
Penetrant Testing	Capillary action	Components are wetted with a fluorescent penetrant and penetrant soak into a surface defect. The penetrant excess is removed, and a developer is applied to the surface, drawing penetrant from defects out, forming a visible indication of the defect.	Cannot detect interior defects; Cannot be implemented on-line; It is time-consuming (> 20 min).
Acoustic Emission	Mechanical vibration	Elastic waves that are emitted in a medium due to crack can be captured by suitable piezoelectric sensors on the surface of a specimen.	Can be used for flaw detection and location; Perfect for parts in operation; Not suitable for post-manufacture inspection (prior to service). Not adequate for online inspection.

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Measurement of quality "by proxy"

- Witness samples produced alongside/joined to components
- Can be subjected to destructive testing including;
  - Metallurgical assessment – microstructure / density
  - Mechanical properties
  - Chemical composition (including interstitial contamination)
  - Other properties

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In process measurements

- As well as in-process monitoring of KPVs the development of in-process inspection methods can be used to assess the accuracy and integrity of parts
- As well as providing timely information it enables a directly link between KPVs and potential defects to be investigated
- Systems under development include Ultrasonic and eddy current NDT heads for DED to identify potential defects in-situ

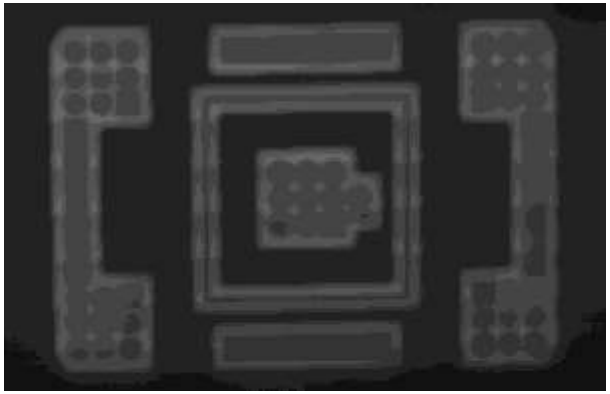

Image of a layer obtained using the near-infrared thermal imaging camera on the Arcam Q20 at MTC

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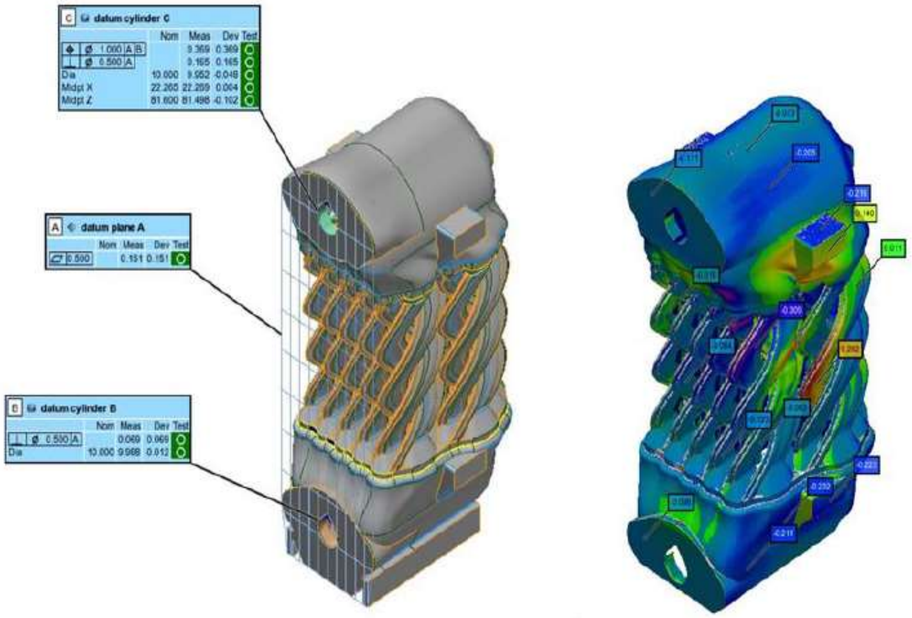
Product verification

Case study – KHUB-AM-0005 planning for product verification
Heat exchanger produced by Metal PBF-L
(you have been supplied with this report)

Product verification is important aspect of manufacturing, used to ensure product meets required design specifications and therefore performs as intended.



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Planning for Product Verification

- Should start at the design concept and process planning stages
- Has significant impact on product quality, manufacturing process and cost
- Final inspection of product at the end of manufacturing process is most common method of verifying product quality

BUT

- Components which are complex or require multiple manufacturing operations it may be better to verify as manufacturing progresses to;
  - Avoid incurring cost /time for downstream process
  - Take time corrective action (such as rebuild)
  - Identify the cause of the problem (for example geometrical inaccuracy)
  - Enable access to features (for example assembled/welded parts)

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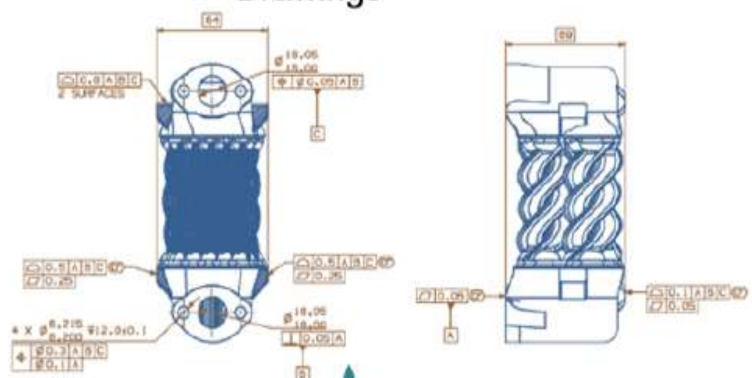
Strategy for Product Verification

Documents relating to product verification against key product lifecycle steps

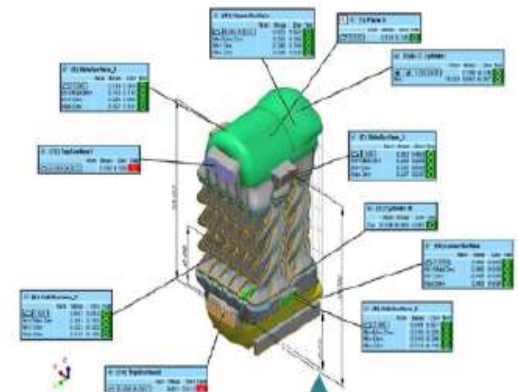
- Functionality statements

Functional requirement	Interpretation	Characteristic type
The component must not interfere with surrounding parts at maximum material condition.	Bounding envelope / maximum material condition.	Form
The interfaces must achieve a strong connection and a good seal.	Threaded flange interface. Control datum features.	Fit
The component must achieve the minimum heat transfer characteristics within its operating volume and conditions.	Heat transfer of xx. Surface area of xx.	Function
The component must achieve the desired hydraulic performace at operating conditions through its life.	Pressure drop vs flow characteristic curve at operating envelope.	Function
Component integrity must be maintained through its life at nominal conditions and at worst operating conditions for a short period.	Operating conditions for xx hours and/or xx heat/cool cycles. Max temperature/pressure for xx hrs. Surface finish of xx worst case for fatigue.	Function

- Drawings



- Inspection programs
- Inspection reports & data



Functionality definition → Process design → Part definition → Inspection planning → Inspection execution

Functional requirements	Verification routes					
	Dimensional	NDT	Condition of supply control	Manufacturing process control	Functional test	In-service history
The component must not interfere with surrounding parts at maximum material condition.	Green	Red	Red	Amber	Amber	Red
The interfaces must achieve a strong connection and a good seal.	Amber	Amber	Amber	Amber	Amber	Red
The component must achieve the minimum heat transfer characteristics within its operating volume and conditions.	Amber	Amber	Amber	Amber	Green	Amber
The component must achieve the desired hydraulic performace at operating conditions through its life.	Red	Red	Red	Amber	Green	Amber
Component integrity must be maintained through its life at nominal conditions and at worst operating conditions for a short period.	Amber	Amber	Red	Amber	Green	Amber

- Verification matrices

Feature	Drawing ref	Sheet/grid ref	System type	Point strategy	Reporting strategy	Feature construction	Comments
1	[⏥ 0.05]Ⓒ▶–[A] 2 SURFACES	1-E12	CMM with scanning tactile probe	Scan around each large hole. 2 scans total.	Report 1 flatness value.	Least squares fit for plane. Treat as continuous feature.	Primary datum feature
2	Ø16.05/16.00▶–[B]	1-D10	CMM with scanning tactile probe	2 scans at 1/3 and 2/3 depths.	Report 1 diameter. Report 1 roundness for info.	Least squares fit.	Secondary datum feature
3	[⊥ 0.05 A]▶–[D]	1-D10	CMM with scanning tactile probe	Measured above.	Report 1 perpendicularity.	Software mode set to ASME Y14.5	Secondary datum feature
4	Ø16.05/16.00▶–[C]	1-H10	CMM with scanning tactile probe	1 scan at middle depth.	Report 1 diameter. Report 1 roundness for info.	Least squares fit.	Tertiary datum feature
5	[⌖ Ø0.05 A B]▶–[C]	1-H10	CMM with scanning tactile probe	Measured above.	Report 1 position.	Software mode set to ASME Y14.5	Tertiary datum feature
6-9	4xØ6.215/6.200	1-D6	CMM with scanning tactile probe	1 scan at middle depth.	Report diameter values. Hole at 6 o'clock is no 1 then number holes clockwise.	Least squares fit.	

- Inspection plans

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Functionality statements

Recommended that document with the following minimum information is created:

1. **Functional requirements**: high level qualitative statements of the intended part function;
2. **Interpretation**: high level quantitative expressions of how the functional requirements will be translated into specifications;
3. **Characteristic type:** whether the functional requirement relates to form, fit or function;
4. **Criticality:** an assessment of relative criticality or importance

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Some of the functional requirements for heat exchanger…

Functional requirement	Interpretation	Characteristic type	Criticality
The component must not interfere with surrounding parts at maximum material condition.	Bounding envelope / maximum material condition.	Form	
The interfaces must achieve a strong connection and a good seal.	Use threaded flange interface. Make mating surfaces datum features.	Fit	Critical
The component must achieve the minimum heat transfer characteristics within its operating volume and conditions.	Minimum heat transfer coefficient. Minimum surface area.	Function	Critical
The component must achieve the desired hydraulic performance at operating conditions through its life.	Pressure drop vs flow characteristic curve at operating envelope.	Function	Critical

Verification matrix

Description of the method of assessing each requirements is met;

- Dimensional inspection or non-destructive testing (NDT), e.g. measuring a feature using manual gauging;
- Condition of supply checks, e.g. ensuring a valid and traceable CoC (certificate of conformity) has been provided, as the supplier might be responsible for carrying out the inspection;
- Manufacturing process controls, e.g. ensuring the process is stable or capable, or locking and using correct versions of programs;
- Functional testing;
- Leveraging data, e.g. from in-service history or on-going statistical analysis.
- An assessment of how adequate each method would be, This can be as simple as stating whether the requirement would be fully or partially met, or a more advanced assessment could include the RPN score (risk priority number) from a DFMEA (design failure mode and effect Analysis).

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Verification matrix for heat exchanger

different colours represent the different methods, and the icons represent whether a requirement is fully or partially met.

Functional requirements	Possible verification routes					
	Dimensional	NDT	Condition of supply	Manufacturing	Functional test	In-service history
The component must not interfere with surrounding parts at maximum material condition.	Measure linear dimensions or profile of external surface.			Prove process is capable.	Go/nogo fixture. Assembly success/failure.	
The interfaces must achieve a strong connection and a good seal.	Thread go/nogo gauge. Measure mating surfaces.	Visually check thread damage. Presence of correct sealant.	Verify screws / inserts are in spec.	Torque settings locked. Calibrated wrenches.	Leak test. Fatigue / vibration test.	
The component must achieve the minimum heat transfer characteristics within its operating volume and conditions.	Measure profile of a surface.	Measure surface area. Measure Sa of internal & external surfaces.	Verify powder is in spec.	Process proved stable. KPVs controlled.	Power test.	Use proven part family design elements.
The component must achieve the desired hydraulic performace at operating conditions through its life.				Process proved stable. KPVs controlled.	Pressure test.	Use proven part family design elements.
Component integrity must be maintained through its life at nominal conditions and at worst operating conditions for a short period.	Verify wall thickness.	Sa of internal & external surfaces. Defect / porosity allowances.	Verify powder is in spec. Material spec.	Lock down build programs.	Accelerated fatigue test. Max temperature test. Max pressure test.	Use historical data from part family if available.
The component's internal surfaces must have antifouling properties to avoid performance degradation.		Sa or feature based characteristics of internal surfaces.		Prove at FAIR and lock down.	Chemical lab tests for product family	Use historical data from part family if available.
The component's external surfaces must be self-cleaning to avoid		Sa or feature based characteristics of		Prove at FAIR and lock down.	Chemical lab tests for product family	Use historical data from part family if available.

- Choosing the appropriate combination of verification routes from the matrix, should be based on minimising risk, or maximising the component's functionality, within the given cost and practicality constraints.
- For the heat exchanger example, we can see that, as a minimum, functional testing, X-ray computed tomography, and 3D structured light methods should be used to verify the component. It is notable that verification in this case will be heavily reliant on functional testing.

Legend:

Manual gauging / visual	C
3D Structured Light	F
X-Ray CT	T

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Part definition and inspection planning

- Part definition refers to the creation of drawings and GD&T (geometric dimension & tolerancing) , following from the definition of the general geometry.
- For a single component the following drawings could be created:
  - Stage drawing for the component in as-built condition;
  - Stage drawing following the removal of support structures;
  - Stage drawing for the post-heat treated condition;
  - Stage drawing following surface processing (e.g. polishing);
  - Stage drawing(s) for the machining operations;
  - Part drawing for the component in its finished-machined condition;
  - Inspection drawings;
  - Drawings for any machining and inspection fixtures;
  - Drawing for any nested parts on the build plate.

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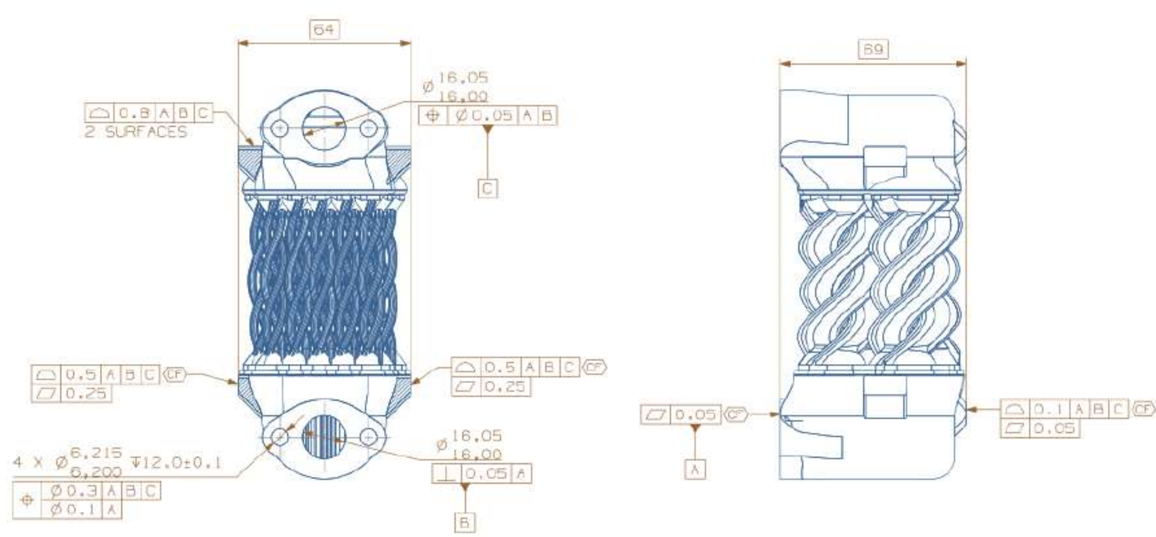
generating full set of drawings is advisable as it will help highlight issues early, for example any potential issues with datum transfers and tolerance stack ups.

Downside is multiple drawings will have to be updated when changes are made to the design or the process.

For this reason an c
definition practices
towards the use of
CAD.

Technical drawing for the heat exchanger with Geometric Dimensions and Tolerances



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Inspection planning

creating the overall strategy for the inspection of every feature or requirement in the drawing (such as drawing notes or referenced specifications)

The inspection plan should include the following information:

- Part number;
- Drawing name and version;
- Feature description and feature grid reference or number;
- Inspection system to be used;
- Measurement strategy to be used;
- Feature construction strategy or algorithm to be used;
- Feature reporting strategy.

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Part of the inspection plan for the heat exchanger

Document	12352-INSP-PRT-V1.1						
Description	Dimensional inspection plan for DRAMA heat exchanger test case in as-built condition						
Created by:	E.Chatzivagiannis	Date:	21/03/2019				
Drawing ref.	12352-PRT-101-V1.0						
Feature	Drawing ref.	Sheet/grid ref.	System type	Point strategy	Reporting strategy	Feature construction strategy	Comments
1	[FLAT|0.05]<CF> (2 SURFACES) [A]	1-E12	CMM with scanning tactile probe	Scan around each large hole. 2 scans total.	Report 1 flatness value.	Least squares fit for plane. Treat as continuous feature.	Primary datum feature
2	DIA16.05/16.00 [B]	1-D10	CMM with scanning tactile probe	2 scans at 1/3 and 2/3 depths.	Report 1 diameter. Report 1 roundness for info.	Least squares fit.	Secondary datum feature
3	[PURP|0.05|A] [B]	1-D10	CMM with scanning tactile probe	Measured above.	Report 1 perpendicularity.	Software default strategy, using evaluation as per ASME 14.5.	Secondary datum feature
4	DIA16.05/16.00 [C]	1-H10	CMM with scanning tactile probe	1 scan at middle depth.	Report 1 diameter. Report 1 roundness for info.	Least squares fit.	Tertiary datum feature
5	[POSN|DIA0.05|A|B] [C]	1-H10	CMM with scanning tactile probe	Measured above.	Report 1 position.	Software default strategy, using evaluation as per ASME 14.5.	Tertiary datum feature
6,7,8,9	4xDIA6.215/6.200	1-D6	CMM with scanning tactile probe	1 scan at middle depth.	Report diameter values. Hole at 5 o'clock is no.1 then number holes clockwise.	Least squares fit.	
10,11,12,13	4xDPTH12.0+/-0.1	1-D6	CMM with scanning tactile probe	TBD by inspector.	Report 4 depths. Numbering as above.	TBD by inspector.	
14,15,16,17	[CPOS|DIA0.3|A|B|C]	1-D6	CMM with scanning tactile probe	Measured above.	Report 4 positions to upper FCF.	Software default strategy, using evaluation as per ASME 14.5.	Part of composite positional tolerance
18,19,20,21	[CPOS|DIA0.1|A]	1-D6	CMM with scanning tactile probe	Measured above.	Report 4 positions to lower FCF.	Software default strategy, using evaluation as per ASME 14.5.	Part of composite positional tolerance
22	[SPRF|0.5|A|B|C]<CF>	1-E6	CMM with scanning tactile probe	Scan a square loop on each pad. 2 scans total.	Report 1 profile value. Report 1 max dev value for info. Report 1 min dev for info. Report 1 min zone value for info.	Least squares fit. Treat as continuous feature.	
23	[FLTN|0.25]<CF>	1-E6	CMM with scanning tactile probe	Measured above.	Report 1 flatness value.	Least squares fit. Treat as continuous feature.	
24	[SPRF|0.5|A|B|C]<CF>	1-E11	CMM with scanning tactile probe	Scan a square loop on each pad. 2 scans total.	Report 1 profile value. Report 1 max dev value for info. Report 1 min dev for info. Report 1 min zone value for info.	Least squares fit. Treat as continuous feature.	
25	[FLTN|0.25]<CF>	1-E11	CMM with scanning tactile probe	Measured above.	Report 1 flatness value.	Least squares fit for plane. Treat as continuous feature.	
26,27	[SPRF|0.8|A|B|C] (2 SURFACES)	1-H7	CMM with scanning tactile probe	Scan a loop on each pad.	Report 2 profile values.	Least squares fit. Do no treat as continuous feature.	
28,29	2xDIA6.215/6.200	1-H23	CMM with scanning tactile probe	1 scan at middle depth.	Report 2 diameter values. Bottom hole is no.1 top is no.2.	Least squares fit.	

Grouping Inspection Requirements

Multiple inspection plan documents will need to be created for the different manufacturing operations. It might be preferable to group inspection requirements of a single inspection operation (example above) or it might be preferable to separate out the requirements for different systems (example below which separates out the XCT inspection requirements).

Inspection plan that groups inspection requirements for multiple inspections.

Document:	12352-NDT-PRT-V1.0				
Description	Integrity requirements for DRAMA heat exchanger test case in finished machined condition				
Created by:	E.Chatzivagiannis	Date:	03/05/2018		
Drawing ref.	12352-PRT-101-V1.0				
No.	Defect type	Acceptance criteria			
1	Cracks (internal and external)	None allowed			
2	External surface pores	50µm² maximum pore size		Maximum of 5 pores per 50mmx50mm area	
3	External witness marks, weld tracks	Allowed as long as they are removed by maching and finishing, and as long as surface finish requirements are met			
4	Internal porosity - core	25µm² maximum pore section area		5µm maximum pore length	100µm³ maximum pore volume
5	Internal porosity - solid areas	400µm² maximum pore section area			
6	Inclusions	None allowed			
7	Unconsolidated powder / lack of fusion	None allowed			

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Acknowledgments

• The National Centre Additive Manufacturing (NCAM) is the UK's independent body to accelerate the uptake of AM in the UK. NCAM is managed by the Manufacturing Technology Centre (MTC), a part of the High Value Manufacturing Catapult. NCAM is grateful to **Evangelos Chatzivagiannis** for writing this document, to Innovate UK for funding this work and to all contributors and reviewers.

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Questions ?
& Thank you

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Project No. 601217-EPP-1-2018-1-BE-EPPKA2-SSA-B

CU 36: Coordinating the AM Process (Pilot)

TOPIC: Traceability and Control of Documentation

Prepared by: **Aneta Chrostek-Mroz**

Date: 07/01/21

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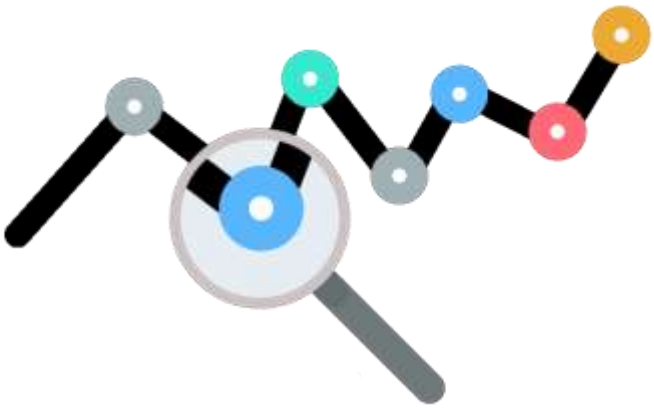
Topics covered include…

- What is traceability and why is it important
- Definition of traceability
- Traceability in AM
- AM process chain
    - Focus on feedstock
    - Part production
- Traceability check list



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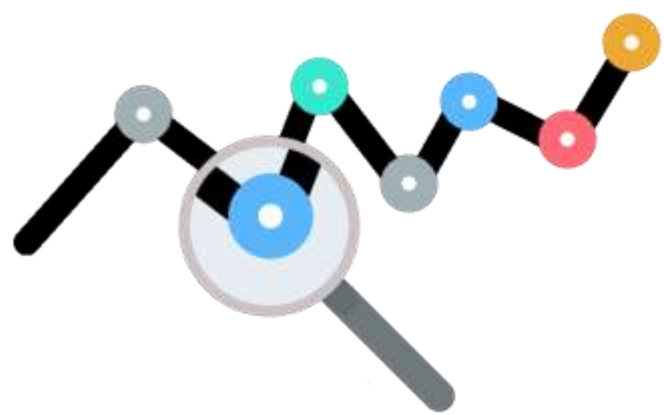
What is Traceability?

"ability to trace all processes from procurement of raw materials to production, supply, use, maintenance and disposal" - **when, where** and **how**

- Critical part of an effective quality management system
- Collecting information vital
- Evidence of effective traceability underpins certification



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Traceability for AM: Manufacturing History

Any controlled manufacture process would have been developed through experimental workings. The found process would be documented as procedures/ specifications as per topic 6 AMPS. This should form the basis of manufacturing history where by known steps were carried out with the details of how and when and why they were carried out.

The process chain must be defined and recorded as per specification so it can be repeated for volume production but also to allow approval of production with known history and manufacturing information – ***any anomalies can then be identified that could deem scrap or warrant further inspection to approve***

Additive Manufacture provides the opportunity to gain significant amount of manufacturing information – ***you get information for each component layer processed in AM***

BUT

AM also poses the challenges on dealing with large amounts of data sets (Terabytes from single process run)

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Definition of Traceability: **ISO 9001**

- The quality management system of the International Organization for Standardization (ISO) is generally called the ISO 9000 series or ISO 9000 family and ISO 9001 is the most important standard in this family. A quality management system (QMS) is defined as "part of a management system intended to lead and manage an organization regarding quality."
- ISO 9001 is an international standard based on the essence extracted from many successful cases regarding business improvement. Its purpose is to maximize profits by promoting business based on consistent rules concerning not only manufacturing processes or products, but also throughout the business from purchase to manufacturing, shipment, and service. We can say that it is the best guideline for improving routine work by eliminating problems such as inefficient procedures or repeated mistakes. By obtaining ISO 9001 certification, the company can also achieve social credibility and increase the trust of customers.

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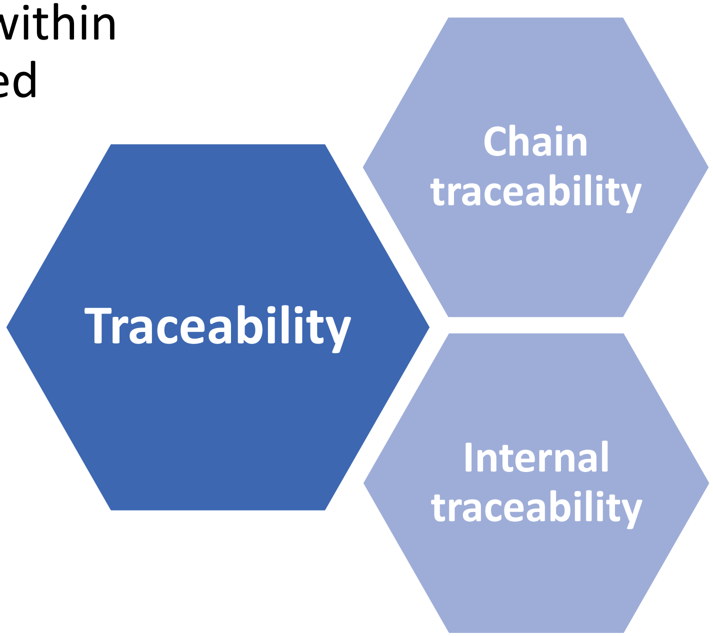
What is Traceability in Additive Manufacturing

Chain traceability – Movement of products in multiple processes (between different departments e.g. Additive Manufacturing , Materials Characterisation Lab, Metrology, Metallurgy)

Internal traceability – Movement of products within a single process that can be monitored (a limited specific area in a whole process, e.g. Additive Manufacturing)



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Traceability for AM

- For the AM process and all stages of a process from feedstock procurement to production of AM parts, post processing, part testing, distribution or disposal need to be traceable.

- Lack of traceability can result in an increase in error and non-conformance

- For an AM facility both chain and internal traceability need to be considered

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KEY INFORMATION

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Importance of Traceability for AM

- Error and non-conformance reduction
- **Component failure investigation**
- Cost saving
- Quality improvement
- Customer confidence
- Cost saving
- Business protection
- Reputation

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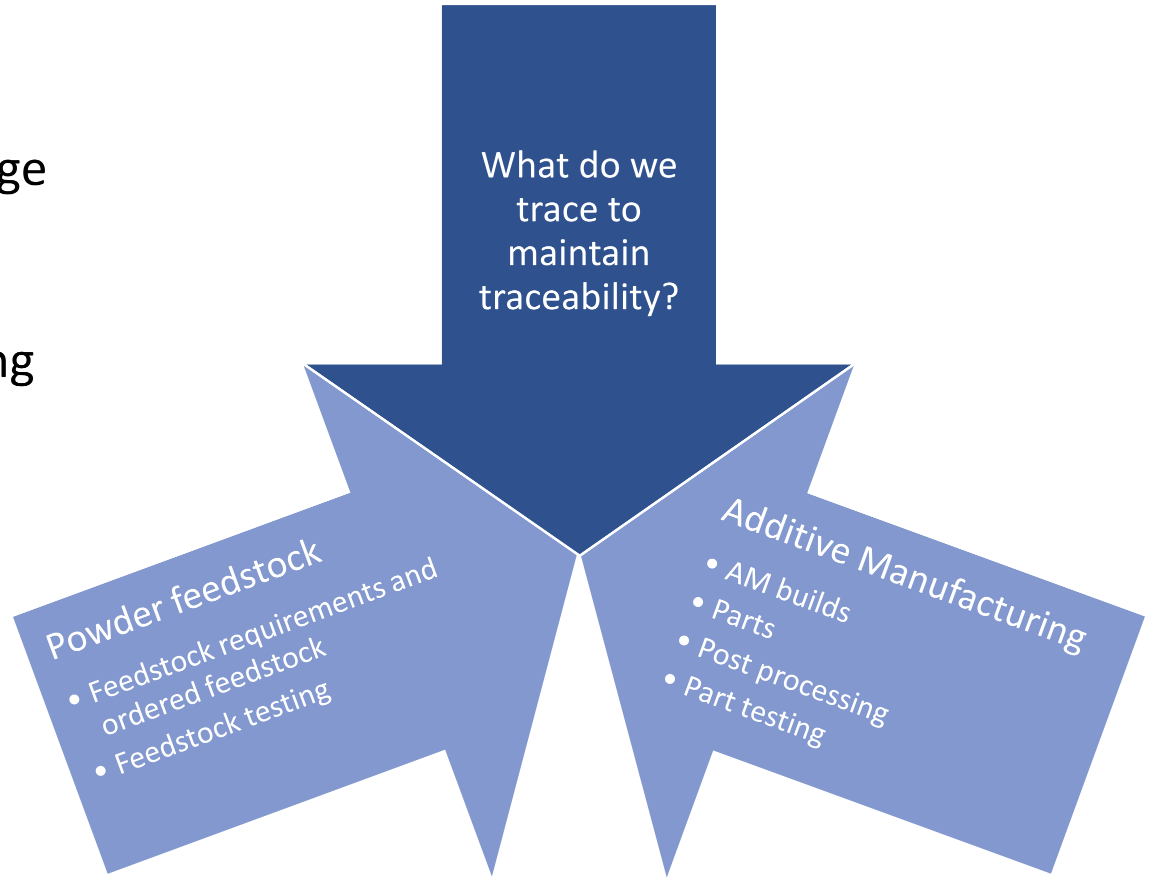
Chain Traceability in Additive Manufacturing

- Feedstock procurement
- Feedstock receipt and storage
- Feedstock testing

- Production & post processing



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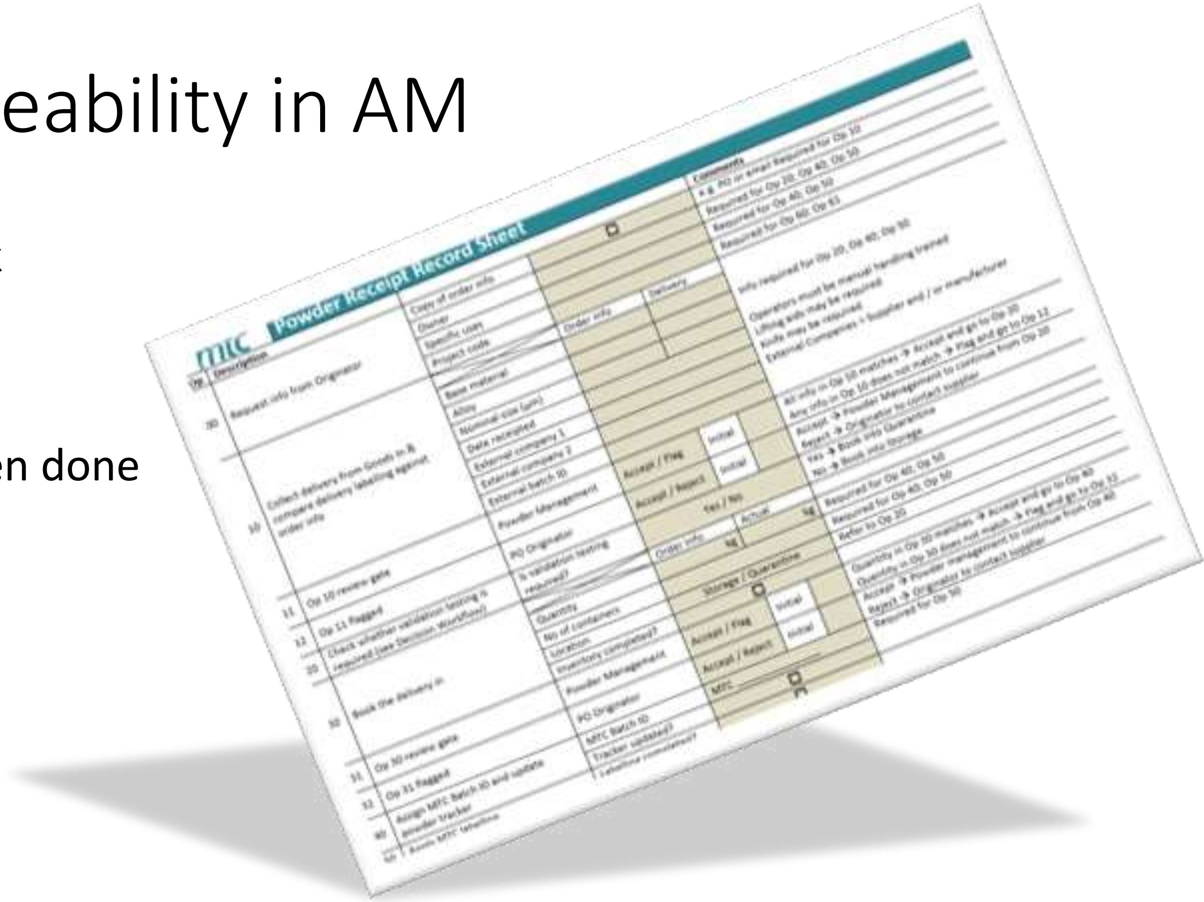
Tools Allowing Traceability in AM



Documentation of intended work

- Templates
- Processes

Record Keeping of what have been done

- Completed forms
- Record sheets
- Drawings
- Parts
- Samples
- Machine logs
- Data

Documentation and record keeping requirements are to be determined based on business needs

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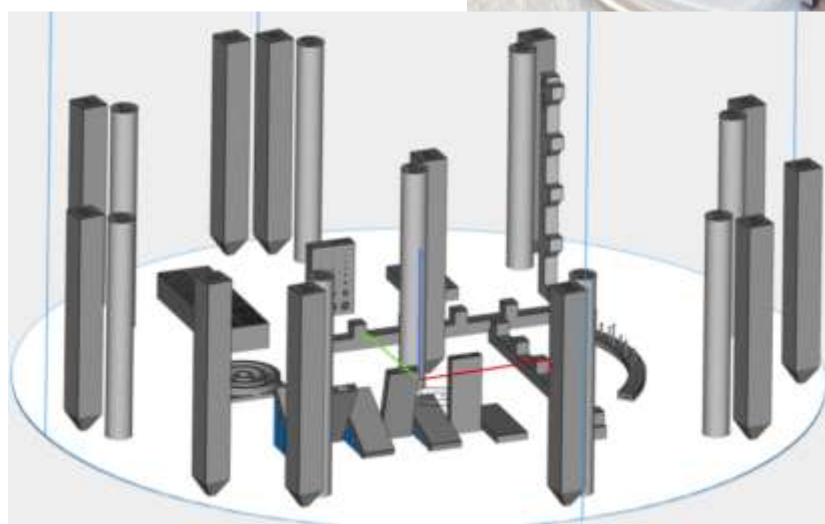
Not Just About Documentation and Data

You may need to retain samples:

Witness samples

Powder samples



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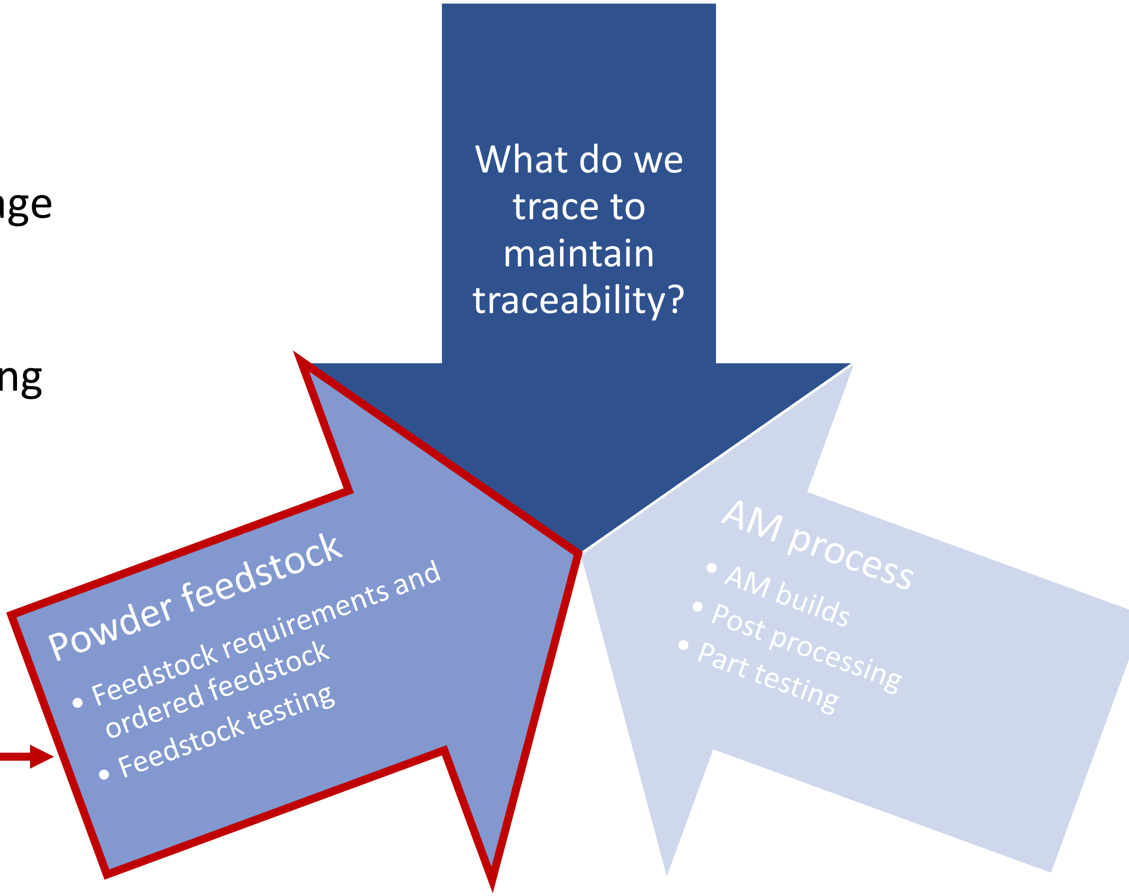
Chain Traceability in Additive Manufacturing

- Feedstock procurement
- Feedstock receipt and storage
- Feedstock testing

- Production & post processing

We will focus on powder feedstock to show the depth of information



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Feedstock procurement

- Feedstock requirements need to be retained (a proposal, copies of emails, excel spreadsheet)

Procurement e-form and **purchase order** are evidence of the conformity of the ordered feedstock to specified requirements

Information captured:

- Supplier details
- Product description
- Material type
- Alloy name
- Alloy specification
- Quantity
- Nominal particle size
- Customer purchase order

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KEY INFORMATION

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Feedstock receipt and storage

Certificate of Conformity (CoC)

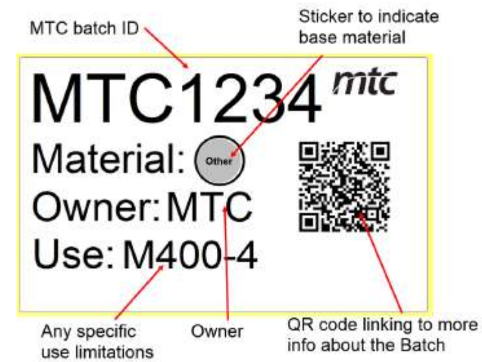
Information captured:

- Supplier
- Customer Purchase Order
- Alloy name
- Supplier batch number
- Dispatch number
- Weight
- Nominal particle size
- Alloy specification
- Number of certificate of analysis

Powder tracker is a log of all powder batches in stock

Information captured:

- MTC batch ID
- Supplier batch number
- Date receipted
- Manufacturer
- Initial weight and a number of containers
- Current weight and a number of containers
- Location
- Material type, alloy name, nominal particle size
- AM process, AM machine
- Feedstock status (active, retired, top-up, quarantined, exhausted, not in use, contaminated)



	Base Material
Al	Aluminium
Fe	Iron/Steel
Ni	Nickel
Ti	Titanium
CONF	CONFIDENTIAL
Other	Other

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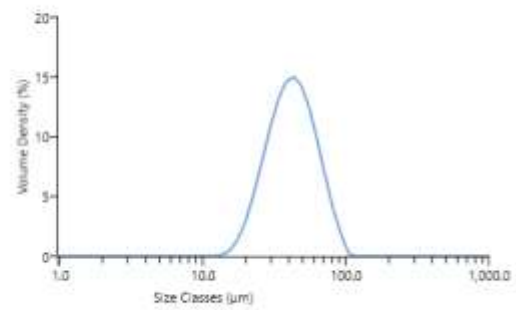
Feedstock testing

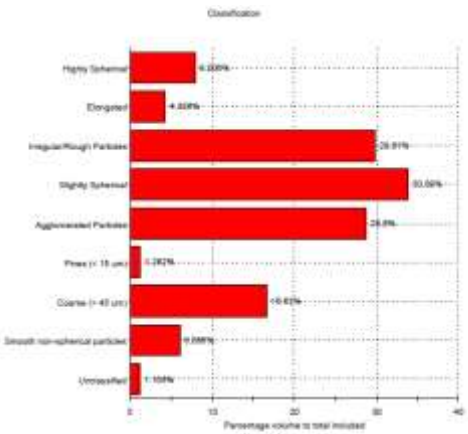


Sample testing log

- The log of all powder samples tested

  Information captured:

  - Materials Lab Sample ID
  - MTC batch ID/supplier batch number
  - Sample description (e.g. project name, project code, build ID)
  - Material
  - Alloy name
  - Weight
  - Date
  - Additional information



- All samples and material test data are labelled in a standardised way and can be identified using the Materials Lab Sample ID

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KEY INFORMATION

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Chain Traceability in Additive Manufacturing

- Feedstock procurement
- Feedstock receipt and storage
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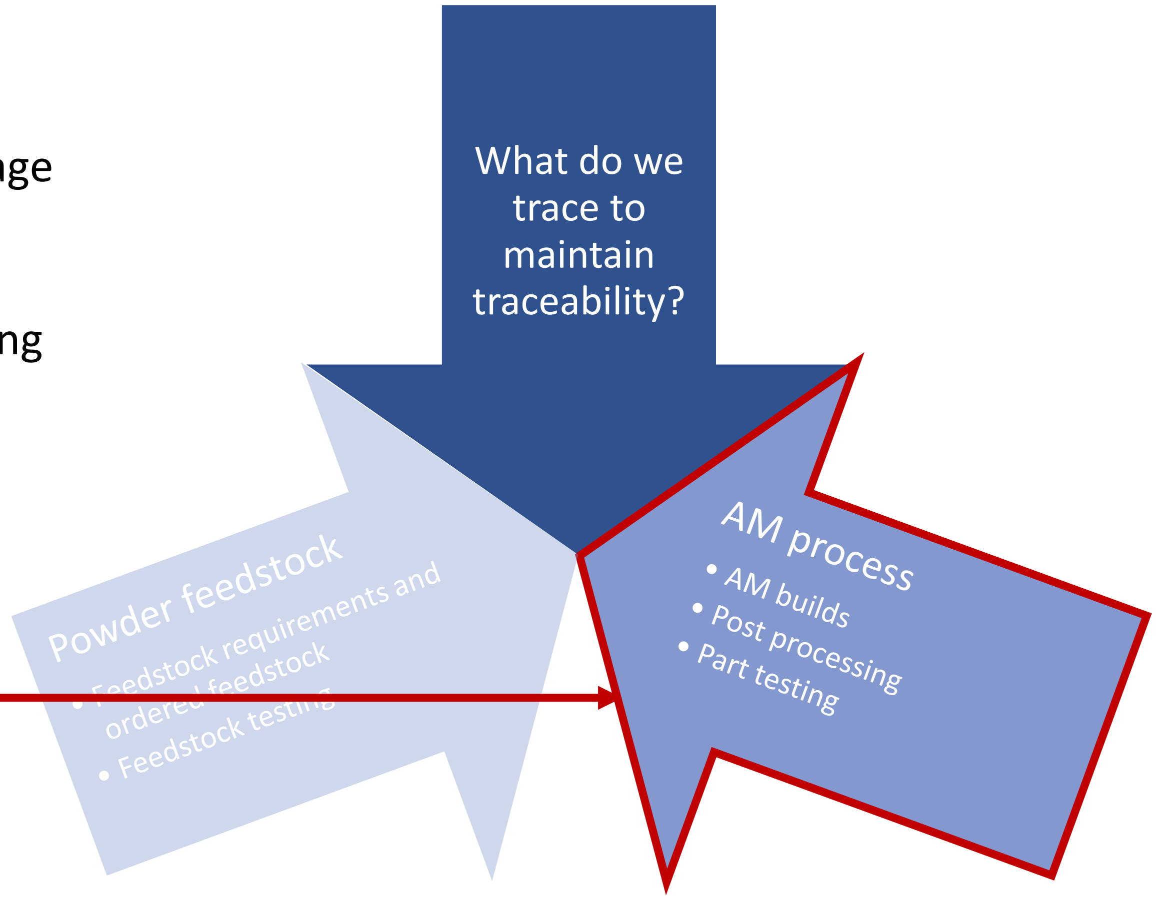
We will focus on AM process to show the depth of information



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Production & Post processing: Data Register for Process Chain

	Matrix	Data Register							
Project	34930-01	34930-01							
Customer									
AM Machine	RenAM500Q								
Material	Ti6Al4V								
MTC Job Request Reference		20004		20024		20081		20203	
Folder No.	Zipped Folder	Build 1		Build 2		Build 3		Build 4	
	Data Category	Data Description	Data/Folder ID	Data Description	Data/Folder ID	Data Description	Data ID	Data Description	Data ID
1	Powder	CoC		CoC		CoC		CoC	
	MTC Powder Batch	MTC Powder Batch Validation	MTC0152 validation report	MTC Powder Batch Validation	MTC0152 validation report	MTC Powder Batch Validation	MTC0152 validation report	MTC Powder Batch Validation	MTC0152 validation report
2	CAD design	25mm2x1mm Plate	1mm Plate_V1.0						
	Part Drawing	n/a	n/a						
3	AM Build Requirements	Build and process requirement definition		Build and process requirement definition		Build and process requirement definition		Build and process requirement definition	
4	AM Build Model	STL of all parts and support	14-MTC-AM500Q-STLs	STL of all parts and support	15-MTC-AM500Q-STLs	STL of all parts and support	16-MTC-AM500Q-STLs	STL of all parts and support	18-MTC-AM500Q-STLs
		Magics Project File	14-MTC-AM500Q	Magics Project File	15-MTC-AM500Q_UPDATED	Magics Project File	16-MTC-AM500Q	Magics Project File	18-MTC-AM500Q
5	E-stage parameters	E-stage Parameters		E-stage Parameters		E-stage Parameters		E-stage Parameters	
6	Melt Theme	AM500Q Ti 60 micron Default	AM500Q_Ti64_60micron_V1.0	AM500Q Ti 60 micron Default	AM500Q_Ti64_60micron_V1.0	AM500Q Ti 60 micron Default	AM500Q_Ti64_60micron_V1.0	AM500Q Ti 60 micron Default	AM500Q_Ti64_60micron_V1.0
7	QuantAM File	QuantAM File	14-MTC-AM500Q.amx	QuantAM File	15-MTC-AM500Q.amx	QuantAM File	16-MTC-AM500Q.amx	QuantAM File	18-MTC-AM500Q.amx
8	Machine File	MTT Machine File	14-MTC-AM500Q_S.mtt	MTT Machine File	15-MTC-AM500Q_Quad.mtt	MTT Machine File	16-MTC-AM500Q_2laser	MTT Machine File	18-MTC-AM500Q_2laser
9	Heat Treatment	Furnace Thermocouple Data from Cycle	20004_HT Cycle Data_14-MTC-AM500Q	Furnace Thermocouple Data from Cycle	20024&20081_HT Cycle Data_15&16-MTC-AM500Q	Furnace Thermocouple Data from Cycle	20024&20081_HT Cycle Data_15&16-MTC-AM500Q	Furnace Thermocouple Data from Cycle	20224-HT Cycle Data-18-MTC-AM500Q
10	Metallurgy Inspection	Density measurement on carrier specimens	MTC Build Quality Assurance_RenAM500Q	Density measurement on carrier specimens	MTC Build Quality Assurance_RenAM500Q	Density measurement on carrier specimens	MTC Build Quality Assurance_RenAM500Q	Density measurement on carrier specimens	MTC Build Quality Assurance_RenAM500Q
								Hardness Testing Control Plan and Results	Hardness testing control plan_V1.0 & 20224-X
11	Metrology Inspection In-situ with Build Plate	n/a	n/a	GOM Report		GOM Report		GOM Report	
	Metrology Inspection of parts	GOM Report	Sean-Anthony Smith 34930-01 scan 1 Report	GOM Report		GOM Report		GOM Report	
		CMM Report	n/a	CMM Report		CMM Report	1/2/3/4_-_08_07__27_08_2020	CMM Report	
12	Visual Inpsection of build and part	Images of build and processing of parts	14-MTC-AM500Q-Build&Part Images	Images of build and processing of parts	15-MTC-AM500Q-Build&Part Images	Images of build and processing of parts	16-MTC-AM500Q-Build&Part Images	Images of build and processing of parts	18-MTC-AM500Q-Build&Part Images
13	Simulation	n/a	n/a	Magics Files and Simulation Images	Magics Files & Images	Magics Files and Simulation Images	Magics Files & Images	Magics Files and Simulation Images	Magics Files & Images

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Chain Traceability in Additive Manufacturing

AM build requirements are defined and retained in **AM Build Requirements Capture Sheet**

Build Log

- Dedicated for each AM platform
- Contains documentation for all AM builds (build file, production pack, machine logs)

Each AM build has a unique *AM build ID* that allows the build identification

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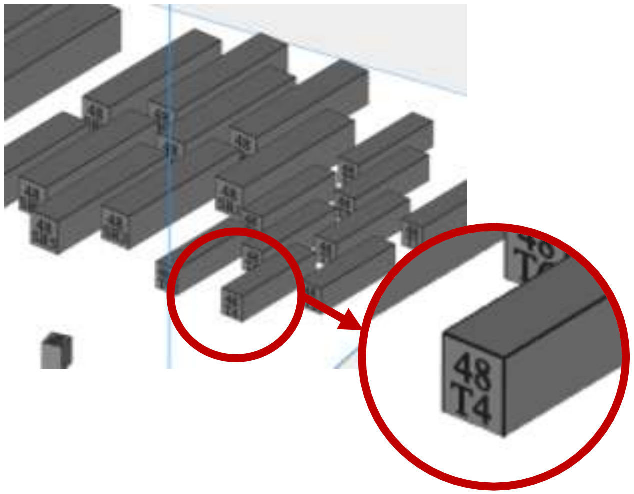
Chain Traceability in Additive Manufacturing

Production Pack

- Contains the **AM Route Card** and **Process Record Sheets** dedicated for each operation specified in the AM Route Card

Information captured in the AM Route Card:

- Materials Lab Sample ID
- Issuer
- Powder batch
- Project
- Job number
- Build number
- Date issued and delivery date



AM Route Cards and Process Record Sheets

- Allow to trace operations; process and machine conditions; Work Instructions and procedures that have been followed for each operation; post processing and part testing

Build file allows part identification for the build and tracing a part location on the build plate

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Traceability for AM: Layer History Opportunity vs Challenge

As components build up layer by layer in AM each layer process needs a specification and record to capture manufacturing history – **Layer validation in AM**

This forms the basis of key challenges in AM:

- How do I confidently **capture, store and then analyse thousands of layer data** sets to validate production run
- How do I **prove and then control consistency of each** layer and resulting component

However the layer information is advantageous:

- **Material evolution information** can be sought to **manipulate and control material evolution** in a single component
- **Anomalies and single point defects** once a given process window is found can be **identified on each layer** of a given component with correlation of layer information to part quality information
- The opportunity of layer **signal processing and machine learnin**g could lead to significant advancements in driving **efficient production yield and cost saving**

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Traceability for AM: In-Process Monitoring Available for AM

AM Process	Machine Manufacturer	'Module' name	Failure Mode Monitored	Parameter Altered	Equipment
Electron Beam Powder Bed Fusion	Arcam	LayerQam™	Porosity	N/A	Camera
Laser Powder Bed Fusion	B6 Sigma, Inc. (specialist)	PrintRite3D® INSPECT™	Unknown	N/A	Thermocouple and high speed camera
Laser Powder Bed Fusion	Concept Laser	QM melt pool	Melt pool monitoring	Laser Power	High-speed CMOS-camera
Laser Powder Bed Fusion	EOS	N/A	Unknown	N/A	Camera
Direct Energy Deposition	DEMCON	LCC 100	Melt pool monitoring	Laser Power	Camera
Direct Energy Deposition	DM3D Technology	DMD closed-loop feedback system	Melt pool monitoring and build height	Laser Power	Dual-colour pyrometer and three high-speed CCD cameras
Direct Energy Deposition	Laser Depth	LD-600	Depth measurement	Laser Power	Inline coherent imaging
Direct Energy Deposition	Promotec	PD 2000	Melt pool monitoring	N/A	CMOS-camera
Direct Energy Deposition	Promotec	PM 7000	Melt pool monitoring	N/A	1D photo detector
Direct Energy Deposition	Stratonics	ThermaViz system	Melt pool temperature	Laser Power	Two-wavelength imaging pyrometer

Source: KHUB-AM-0010-Correlation of IPM Data to XCT Inspection -v1.0

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Traceability for AM: In-Process Monitoring Available for AM

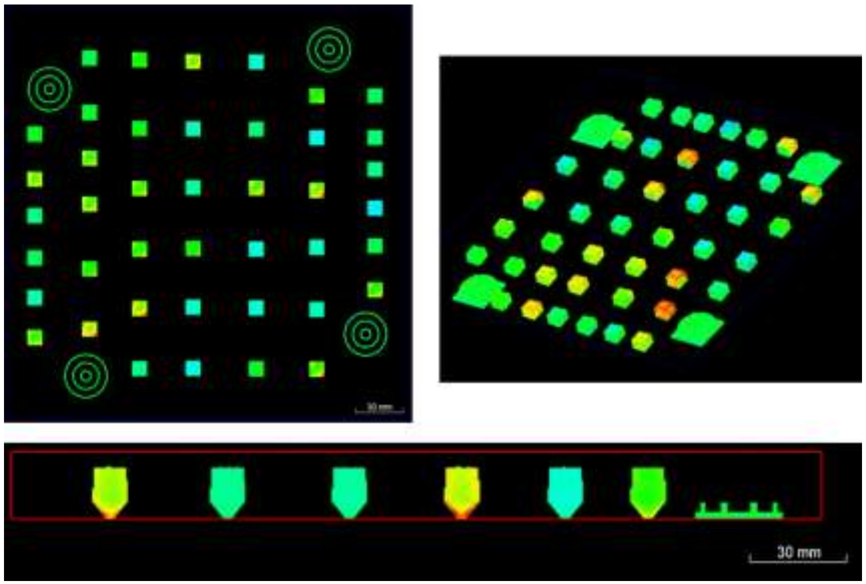

Figure. IPM data representation in the Renishaw InfiniAM Spectral software generated by MTC.

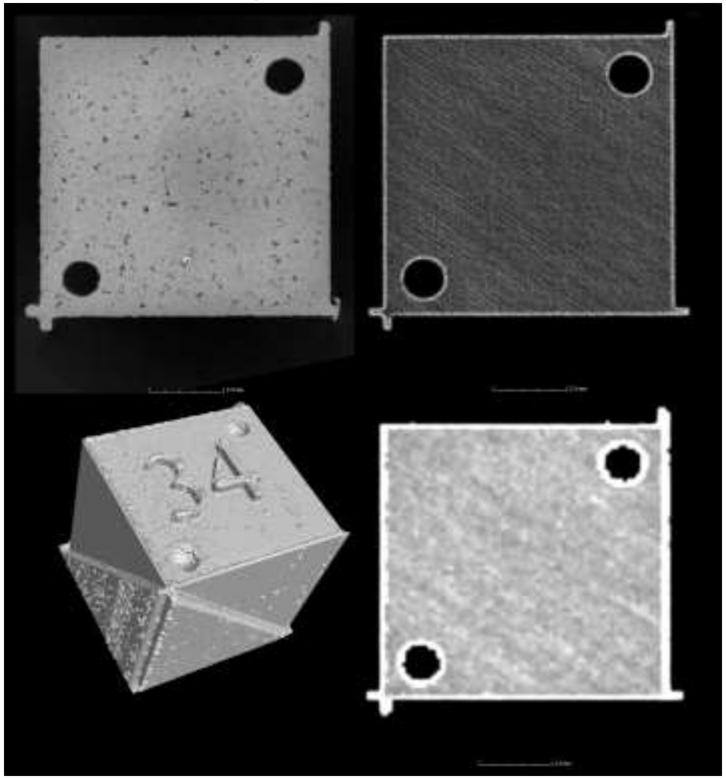

Figure. IPM data representation for single layer against XCT image for the same sample and layer

Source: KHUB-AM-0010-Correlation of IPM Data to XCT Inspection -v1.0

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Tools enhancing Traceability in AM

- Enabling data management of metal powders, parts, conditions across multiple locations, multiple machines and processes, providing audit trial and full traceability.

	3rd party software	**DIY software**
Advantages	• Expert software developers • Regular updates • Customer support • Ease of implementation • Designed for this application • Automatic data input • Entire product lifecycle management	• No additional licensing costs • Completely customisable • Ease of use • Can implement in phases
Limitations	• Licensing cost • Less customisable • Need to learn new software • Need to align with production style • Tied into production • Links into other system software systems	• Likely to be complex spreadsheets • Time consuming to set up and maintain • Software capability will be limited • Links into other software systems

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Questions ?
& Thank you

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Project No. 601217-EPP-1-2018-1-BE-EPPKA2-SSA-B

CU 36: Coordinating the AM Process (Pilot)

TOPIC 1: Capturing client requests and preparing quotations

Prepared by: Sean Anthony Smith, Danny Lloyd, David Wimpenny

Date: 13/01/21

Please look for slides showing - KEY INFORMATION

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Content

- Sales order process
- Things to watch out for
- Communication
- Overview of requirement capture
- Educating customers & managing expectations
- Level 2 questions
- Managing risk
- Examples of quotation system

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Sales-order process

1. Requirements capture
2. Quote
3. Receive order
4. Acknowledge order
5. Schedule build
6. Make, deliver and get paid……

Sounds easy !

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Some of the things to watch out for

- Quote is wrong (incomplete, inaccurate, open to interpretation…).
- Order arrives "out of the blue" months after quoting (need to generate new price and timing)
- Purchase order does not match the quote.
- Acknowledging order means acceptance of customer T&Cs which include unacceptable terms (including ownership of parameters)
- Check the part file received with order before progressing in case part file is significantly different than part you quoted for.

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Keeping in mind the pitfalls….lets work through the process of requirements capture and quoting

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Effective communication is critical …

- Engagement with the customer and capturing their requirements is the first link in the communication chain
- Need to adopt a consistent structured approach to requirements capture
- Avoid making assumptions
- Get the background as well as the specifics for the particular enquiry

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Requirements Capture includes;

- Part function
- Commercial requirements/Business case
- Scope for redesign
- Material requirements
- Customer management requirements

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First 3 questions ….

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Q1 – Has customer used AM before ?

Helps to understand the level of additional customer "education" and managing expectations you have to do

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KEY INFORMATION

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Q2 – what do they want (hope to)to get out of the current project

- Improved part performance through;
  - Use of alternative material
  - Design for AM
- Reduced assembly operations by part consolidation
- Flexible production to enable low volume/customisation
- Reduced lead time
- Reduced cost

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Q3 – What do you want to make ?

- Name of part > this is very helpful
- Function of the part > again very helpful
- Part geometry > fixed or redesigned for AM?
- Material > is this fixed or alternatives possible?
- Number of parts / when required > flexibility for scheduling ?
- Accuracy /surface finish requirements ?
- Any specific heat treatment/ infiltration/surface coating ?
- The level of detail in the requirements capture can be reduced if it's a simple, low risk, non critical job

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Perfect AM part characteristics

- Low production volume
- Complex geometry
- Small in size
- Thin walled
- Material which is easy or difficult to process using conventional manufacturing methods

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Educating & Managing Expectations

- AM can be slow and expensive
- To maximise benefits of AM parts should be redesigned
- Accuracy +/- 50µm up to +/-5mm
- Surface finish – PBFLB typical RA 10-30µm but it can vary depending on machine, material, location orientation
- Limited range of proven materials for AM
- Properties are often anisotropic
- Choosing a cheap material may not affect the cost significantly
- Build failure and part defects are high compared to many conventional automated processes
- Specifications may have room to for change, especially if they're designed around a conventional manufacturing process.

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"Level 2" questions include….

Is the part subject to particular security and export control issues ?

- Commercially sensitive
- UK- Government national security classification
- Export control/ITAR

Answer "don't know" is <u>not</u> acceptable

Needs to be a clear YES or NO

If YES then this will impact on the cost of undertaking the project and dictate how/if the project can be progressed

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Requirements Capture Guide -1

1. Part / assembly information and functionality		
Component and project goals – high level requirements and AM benefits to be realised		
Component name		
CAD files of the component(s) and relevant assemblies and adjacent parts	Provide accurate information about the existing or proposed component or assembly. (e.g. size and complexity of the geometry)	If there is a possibility of consolidation, it's important to capture the requirements for the combined / consolidated part also.
Purpose/function of component or assembly	Describe the functionality of the component or assembly Identify and record critical functional requirements. Identify the design drivers of the component (e.g. load-driven, fatigue-driven, frequency-driven etc.)	This is a very important step. If we don't capture this we might end up designing a component which isn't fit for the purpose/application. In addition, we might also miss the opportunity of getting maximum benefit from AM
Goal of the AM build or redesign task and the priority of goals	Determine why Additive Manufacturing was chosen for this part? What is the value the customer is seeking by choosing the AM route? Determine openness to options of redesign for AM.	If we don't understand the value we are getting with AM we could risk proposing solutions that are not economical, or that don't deliver full value. In some cases an alternate manufacturing route might be cheaper and quicker than AM.
Legislative requirements	Legislative requirements are application and sector specific, and all legal standards and compliance requirements must be clearly defined at the start. e.g. CE mark, aerospace standards etc.	We need to ask: Can we demonstrate compliance using AM for this part? It is important to understand the legislative requirements beforehand especially for critical components to avoid problems with qualification and certification of the AM part.
Cost target	Determine whether the customer has a realistic cost target for the component, and how well the AM-specific elements have been considered in the overall cost goals.	Here we determine the likely possibility of meeting cost target with AM. Solutions and proposals need to demonstrate that they meet the cost target. Developing a superior AM part that is not viable economically is likely to be rejected.
Production volume	To verify if the intended production volume is suited to current AM economic models. Currently, AM is most suitable for low-volume production.	If the production volume is high it is challenging to provide a positive business case for AM. There might be alternate manufacturing methods which are more economical.

2. Material, functional and performance requirements		
Material considerations		
Component material	Identify the required material and the rationale for selecting it. Determine whether a suitable/ equivalent material can be used for AM.	The material used in an existing component may not be available to use with AM. Material choice can drive AM process decision, while material attributes and bulk material properties are important factors in AM part design.
Alternative/equivalent material acceptability	Determine whether a different material would be acceptable, if the original material proposed cannot deliver the required function, or cannot be used in AM.	Alternative materials may deliver better performance with AM, however, it is also likely that a redesign for that chosen material is necessary to achieve the added value that is required.
Linear or non-linear material **Plastic deformation**	For polymers, these properties may be critical for functionality or assembly.	AM can offer the option of functionally graded parts, where different materials are used for different parts of the component to optimise function, weight and cost
Dimensions & accuracy required.	Different AM processes have different capabilities in terms of dimensional accuracy. Determining dimensional accuracy is important for the machine as well as the build parameters used.	This is critical. If we don't capture this we may end up choosing wrong AM process or will need to spend a lot of time and effort on post-processing (finishing and machining) to reach acceptable tolerances.
Ra requirements and definition of surface function	Define the required Ra Define the reasons for the particular requirements.	Ra specifications may be difficult to achieve with AM on particular surfaces. Finishing and machining post-build steps can be costly for AM parts, so it's important to define where they are most critical so that the AM process and build steps can be optimised to meet cost targets.
Residual powder considerations	For established AM standards, it is necessary to record any specific requirements for powder recycling e.g. minimum percent of new powder vs. recycled.	Meeting required industry standards will ensure that the part can be certified/qualified. The level of powder control will have an impact on the production cost.
Functional requirements		
Material integrity requirements	Acceptable internal / external defects, and levels of porosity, density, and anisotropy.	Some properties of AM parts may need to be defined that wouldn't apply in conventional manufacturing due to the effects of building in layers and from powder particles.
Fatigue and damage tolerance requirements	Determine extent to which fatigue properties are critical Define surface finish requirements that affect fatigue properties.	There is a possibility of improving the fatigue properties of a part with HIPing after part is manufactured with AM. This information is important to define the appropriate post-processing steps which are significant for overall cost.

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CAD files of the component(s) and relevant assemblies and adjacent parts	Provide accurate information about the existing or proposed component or assembly. (e.g. size and complexity of the geometry)	If there is a possibility of consolidation, it's important to capture the requirements for the combined / consolidated part also.

- What consequences are there of not receiving the component CAD files?
- What consequences are there of not receiving the *adjacent component* CAD files?
- 3 minute discussion

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Internal job request system at MTC

- Process semi-automated and enables requirements to be captured
- Information feeds directly into the job quotation and scheduling system
- However, communication with the customer is still essential

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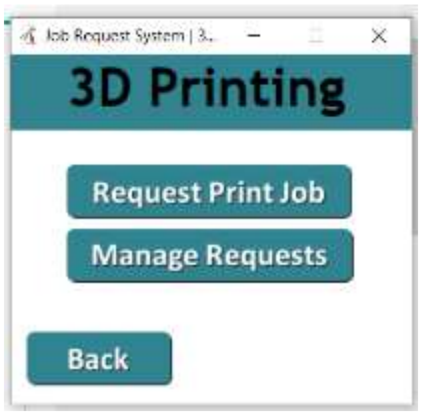
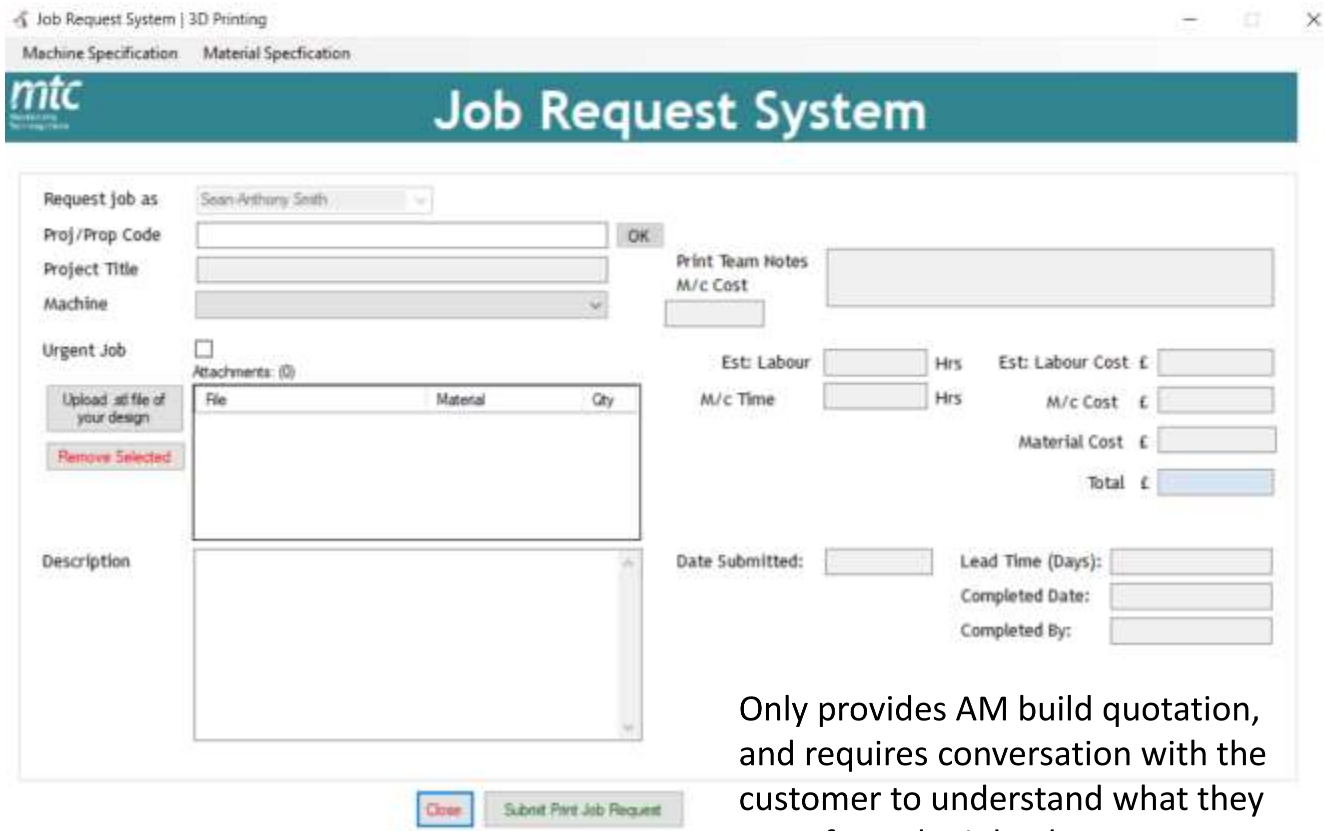
AM Quoting: MTC Polymer AM Job Request System





For any polymer prints, quoting and component manufacture requests follow MTC workshop job request system in accordance or auditable to ISO9001

Links through to scheduling too

Only provides AM build quotation, and requires conversation with the customer to understand what they want from the job. The part may require redesign, and/or post processing.

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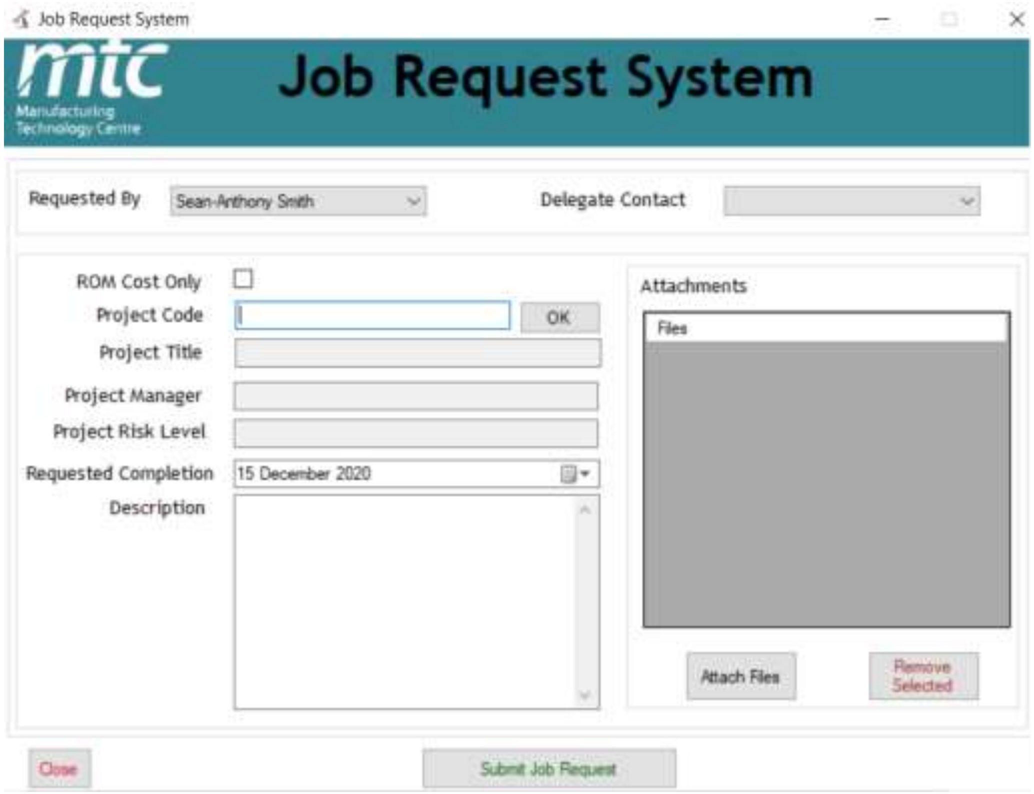
AM Quoting: MTC Metal AM Job Request System

For any metal prints the component manufacture requests and quotation follow MTC workshop job request system in accordance or auditable to ISO9001

Request is logged and quoting is completed offline using tool from BMS by relevant resource.

Metal AM part processing is too complex for the current system



Design
- Build model preparation and simulation
- Software and licensing

Method of Manufacture (MoM)
- Drawing creation
- Control plan creation
- Record sheets and production packs
- Inspection plan
- Route card

Manufacture
- **AM Build**
- Heat Treatment
- Wire EDM/ Bandsaw
- Support Removal
- Surface dressing
- Blasting or tumbling
- Machining Cost
- Cleaning

Inspection
- Metallurgy evaluation
- Dimensional inspection by metrology
- Internal integrity inspection by metrology
- Surface profile and finish by metrology

Validation
- Mechanical testing
- Fit, form and function testing

Quote for Full Process Chain

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MTC's approach to external quotations

- Extremely comprehensive and risk adverse
- Involves all of the stakeholders within the process chain
- This increases the time it takes to complete quotations but reduces the risk of a major problem downstream

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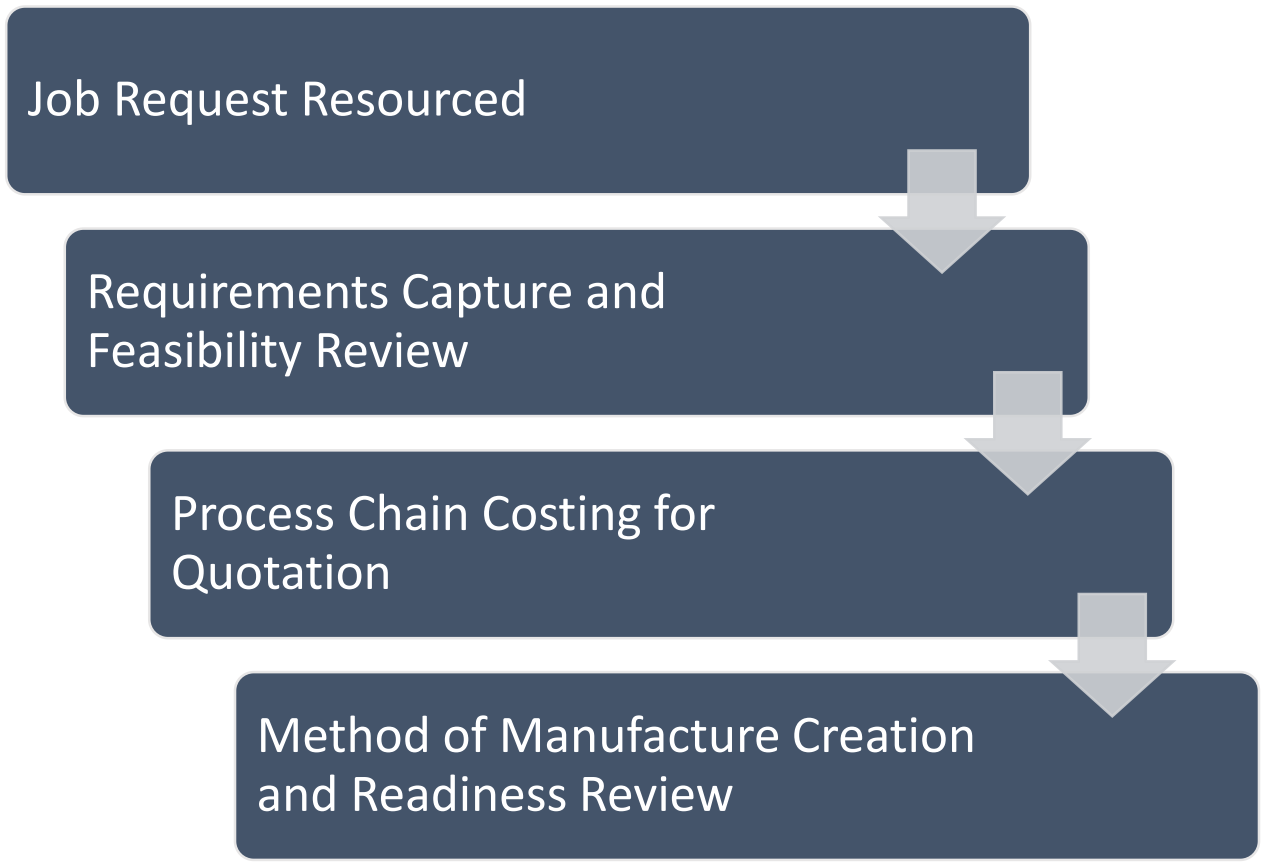
AM Quoting:

The job request is resourced to carry out requirements capture and feasibility review with customer before quoting. The relevant process chain stakeholders then provide customer with quotation and lead time.



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AM Quoting: Manufacture Considerations

- Part Data/Receipt
- Part Specification
- Material Specification
- AM Part Build Specifics
- AM Manufacture Route
- Other info and approvals

=

Ready for Quoting

mtc Manufacturing Technology Centre

AM Build Requirements Capture Sheet AM-003-F2 (V2)

Part Model/Build Model

Images of model/DWG (ISO/TOP) etc.

COMPONENT DEFINITION		
	Customer Requirement	**MTC proposed**
Project code		
Build/part/drawing name including version numbers		
Number of parts to be manufactured		
Part description and intended end use		
Component tolerances: -Surface finish -Dimensional -Porosity spec - Mechanical strength		
Final data expected		
Required completion date		

MATERIAL		
Parameter	**Customer Requirement**	**MTC proposed**
Alloy type		
Specific alloy requirements		
Melt theme		
Size fraction		
Batch number		
Powder testing requirements		

PART SPECIFICS		
Parameter	**Requirement**	**MTC Process/ Process Limit**
Machine(s)		
Number of parts		
Build file prep required?		
Part orientation		
Can the build(s) be shared with other parts?		

MANUFACTURING ROUTE		
Ops	**Description (example ops in Red)**	**Equipment**
Op1	Build file prep	
Op2	Build	
Op3	Powder removal	
Op4	Quality check	
Op5	washing	
Op6	heat treatment	
Op7	WEDM	
Op8	Support removal	
Op9	Blasting	
Op10	Baseplate recovery	
Op11	Machining	
Op12	Inspection	

Attach any additional manufacturing information (DWG, STL, cut plan etc.) with this document

OTHER PROJECT SPECIFIC REQUESTS

for example, requirement to collect monitoring data or log files etc.

SIGN OFF

Customer requirements captured and agreed by all parties?

ACCEPT REJECT

Customer	
Name	
Signature	
Date	

MTC Lead	
Name	
Signature	
Date	

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AM Quoting: Managing Risk

- Try to avoid a combination of difficult process + difficult material + difficult part geometry !

- Identifying "problem" features and see if they can be designed out

or

- conduct process simulation and/or undertake test builds of these features

Part failure is bad for both the customer and the supplier

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AM Quoting: Managing Risk

Higher risk needs to be reflected in the quotation
Customer may agree to "time & materials" rather than a fixed price
or
"Best endeavours"

If not the price quoted needs to factor in the risk

Prototypes

low value material/ parts

- High risk x3
- Medium risk x2
- Low risk x1.5

Performance Critical Parts/ Supporting Production

high value material and /or parts

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AM Quoting: Cost Categories (Non-Exhaustive List)

Materials/Consumables:
- AM Machine Feedstock; powder/wire..
- Blasting and polishing media
- Material containers
- Machine consumables; base-plates, filters,
- Powder test consumables
- CNC fixture and tooling
- Hand tools; files, grit paper, dremmel tools..

Machine Time:
- Powder Lab/Test Equipment
- Blender and Sieve
- AM machine
- Furnace
- Wire EDM/Bandsaw
- CNC
- Blasting or polishing equipment
- Metrology equipment
- Metallurgy equipment

Labour:
- MoM creation and AM build model generation
- Material preparation
- AM machine operations
- Powder Removal
- Furnace operations
- Wire EDM/Bandsaw operations
- Support removal
- CNC operations
- Component surface dressing
- Blasting or polishing operations
- Metrology operations
- Metallurgy operations
- Visual inspection at each step

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Automated quotation system

- Quoting is time consuming, requires expertise, can be subjective and if not undertaken correctly losses work or loose money on jobs
- In recent year automated quotation systems have been developed which allow customer to receive quotes 24/7
- BUT these tend to be more reliable for simple polymer processing ….

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AM Quoting: Best in Class (Non-Exhaustive List)

- https://www.materialise.com/en/software/solutions-for-data-preparation/quoting
- https://www.protolabs.co.uk/services/3d-printing/
- https://amfg.ai/
- https://proto3000.com/3d-printing-rapid-prototyping-additive-manufacturing-services-quote/
- https://www.3tamp.com/polymer-ordering-portal

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Project No. 601217-EPP-1-2018-1-BE-EPPKA2-SSA-B

CU 36: Coordinating the AM Process (Pilot)

TOPIC 5: Quality systems & Quality Control Documentation

Prepared by: David Wimpenny & Sean Anthony Smith (MTC)

Date: 13/01/21

Please look for slides showing - KEY INFORMATION

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Topics covered include…

- Quality & quality management
- Quality management systems
- How QMS can be applied within a AM activity
- ISO9001
- Certification / registration
- Kanban boards & cards
- Total quality management

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Quality & Quality management

- Quality must reflect all the features of a product (or service) which are required by the customer.
- Quality management means what the organization does to;
  - ensure that its products or services satisfy the customer's quality requirements

  and
  - comply with any regulations applicable to those products or services.

REF: Overview of ISO 9001 and ISO 14001 by Roger Frost e-mail frost@iso.org Manager, Communication Services2009-01-08

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Quality Management System

- To be really efficient and effective, the organization can manage its way of doing things by systemising it.
- Nothing important is left out.
- Everyone is clear about who is responsible for doing what, when, how, why and where.
- Management system standards provide the organization with an international, state-of-the-art model to follow.

REF: Overview of ISO 9001 and ISO 14001 by Roger Frost e-mail frost@iso.org Manager, Communication Services2009-01-08

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What is a Quality Management Systems?

Collection of policies, procedures, plans, resources, processes, practices, and the specification of responsibilities and authority of an organization designed to achieve product and service quality levels, customer satisfaction and company objectives.

Ref:https://www.academia.edu/19670615/Dave_John_Mike_Quality_Management_Systems_PPT_03

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Quality Management Systems (QMS) systems: Relevant Sector Standards/ Accreditations

ISO 9001 - quality management system industry generic

AS 9100 – quality management system for aviation space and defence

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Processes, not products

QMS standards concern the way an organization goes about every aspect of its work;

- Not product standards.
- Not service standards.
- They are process standards.
- Can be used by product manufacturers and service providers.

REF: Overview of ISO 9001 and ISO 14001 by Roger Frost e-mail frost@iso.org Manager, Communication Services2009-01-08

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Principles of the ISO 9001 Standard

1. **Customer Focus** – understand needs, meet requirements, exceed expectations

2. **Leadership** – unity of purpose, organizational direction, empowerment, achieve objectives

3. **Involvement of People** – fully involved employees, to benefit the organization

4. **Process Approach** – accomplishments by processes, resources must be managed

Ref:https://www.academia.edu/19670615/Dave_John_Mike_Quality_Management_Systems_PPT_03

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Principles of the ISO 9001 Standard – Cont.

5. **System Approach to Management-** processes managed as system

6. **Continual Improvement** – permanently applied to the organization, its people, their processes, their systems and their products

7. **Factual Approach to Decision Making** – decisions based on analysis of accurate, relevant and reliable data

8. **Mutually Beneficial Supplier relationships** – organization and suppliers benefit from each other's resources and knowledge

Ref:https://www.academia.edu/19670615/Dave_John_Mike_Quality_Management_Systems_PPT_03

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Quality System Documentation Overview

https://advisera.com/9001academy/knowledgebase/how-to-structure-quality-management-system-documentation/

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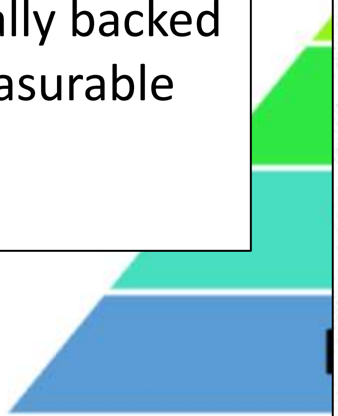
Quality System Documentation Overview

Policy

Clear statement of commitment to quality, ideally backed up with measurable objectives



https://advise
quality-manag

Protea
technology leadership in measurement solution

Protea Limited (Protea) is committed to satisfying the requirements of its customers in the areas of analyser systems design, manufacture, supply and servicing, and working at all times in accordance with stated methods, and to a consistently high standard of professional practice.

Protea will deliver a high standard of service and the aim of the Quality System is to ensure that this is consistently achieved.

Protea aims to develop and grow its services and establish, through Management Review, a system for setting and reviewing objectives and to ensure that the IMS is still effective and appropriate.

The Management Team shall ensure the quality policy is communicated and understood by all members of Protea's staff, who will in turn actively support it by taking personal responsibility for their work.

Protea is committed to comply with the requirements of ISO 9001:2015 and BS EN 15267-2:2009 and to respond to the information generated by the IMS to invoke continual improvement.

In addition, Protea Peterborough is committed to comply with the requirements of ISO / IEC 80079-34:2011.

Andrew Toy

Managing Director

Date: 12th February 2018

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Quality System Documentation Overview

Manual

Clearly states the company's intentions for operating the processes within the quality management system. It can include policies for all areas of the business that affect ability to make high-quality products and meet customers and ISO 9001 requirements

https://isoconsultantkuwait.com

https://advisera.com/9001academ
quality-management-system-docu

Quality Manual Contents

- Introduction & Scope
- Quality Management Principles
- References and Definitions
- Context of the Organization
- Leadership
- Management System Planning
- Support
- Operation
- Performance Evaluation
- Improvement
- Appendices

https://www.iso-9001-checklist.co.uk/quality-manual-template-gbp.htm

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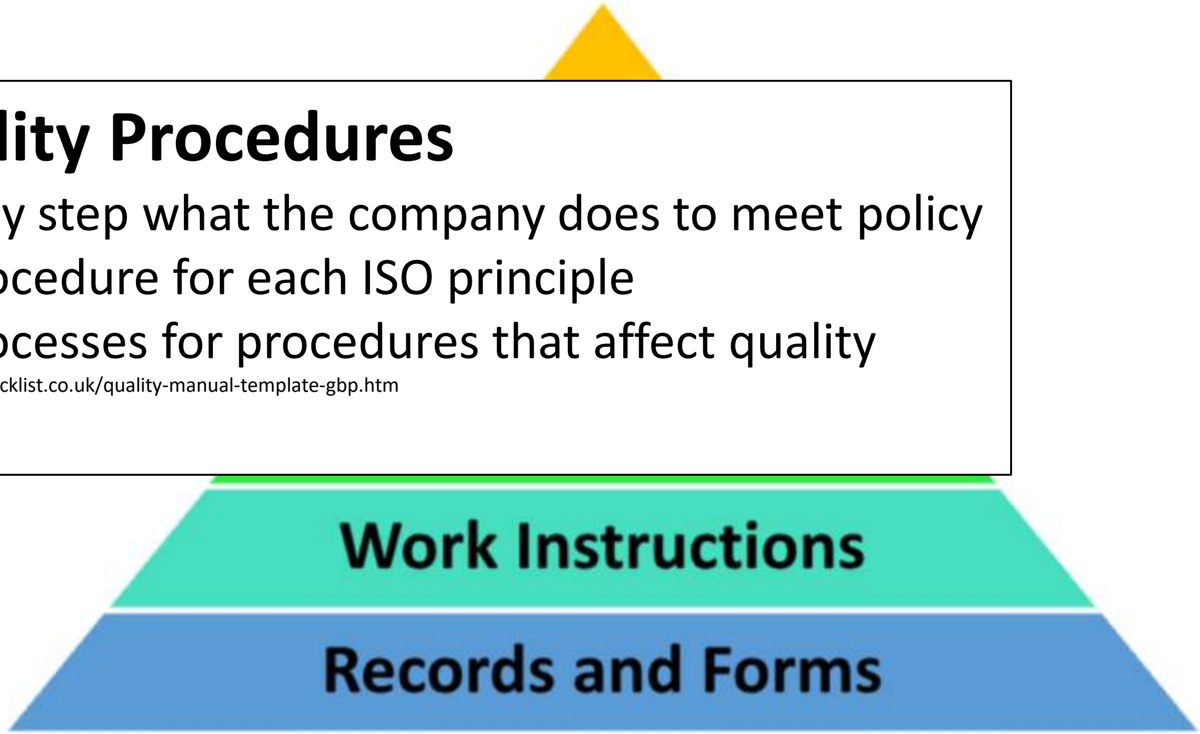
Quality System Documentation Overview

Quality Procedures

Step by step what the company does to meet policy

- Procedure for each ISO principle
- Processes for procedures that affect quality

https://www.iso-9001-checklist.co.uk/quality-manual-template-gbp.htm



https://advisera.com/9001academy/knowledgebase/how-to-structure-quality-management-system-documentation/

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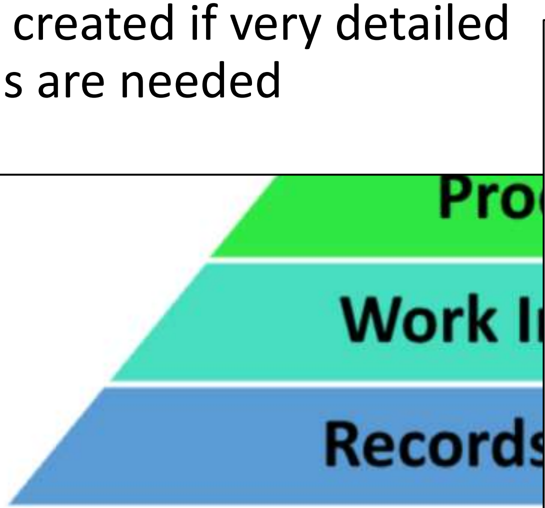
Work Instructions

Document containing detailed instructions that specify exactly what steps to follow to carry out an Activity. A work instruction contains much more detail than a Procedure and is only created if very detailed instructions are needed



https://advisera.com/9001
quality-management-syste

9 "Rules" for work instructions

1. Know exactly how to do the task.
2. Plan how to write steps in order.
3. Write instructions beginning with verb.
4. Write each step as a small piece.
5. Include warnings as pre-steps.
6. Write the steps in logical order.
7. Review and edit instructions carefully.
8. Express steps in the positive.
9. Avoid expressing opinions, preferences, or choices.

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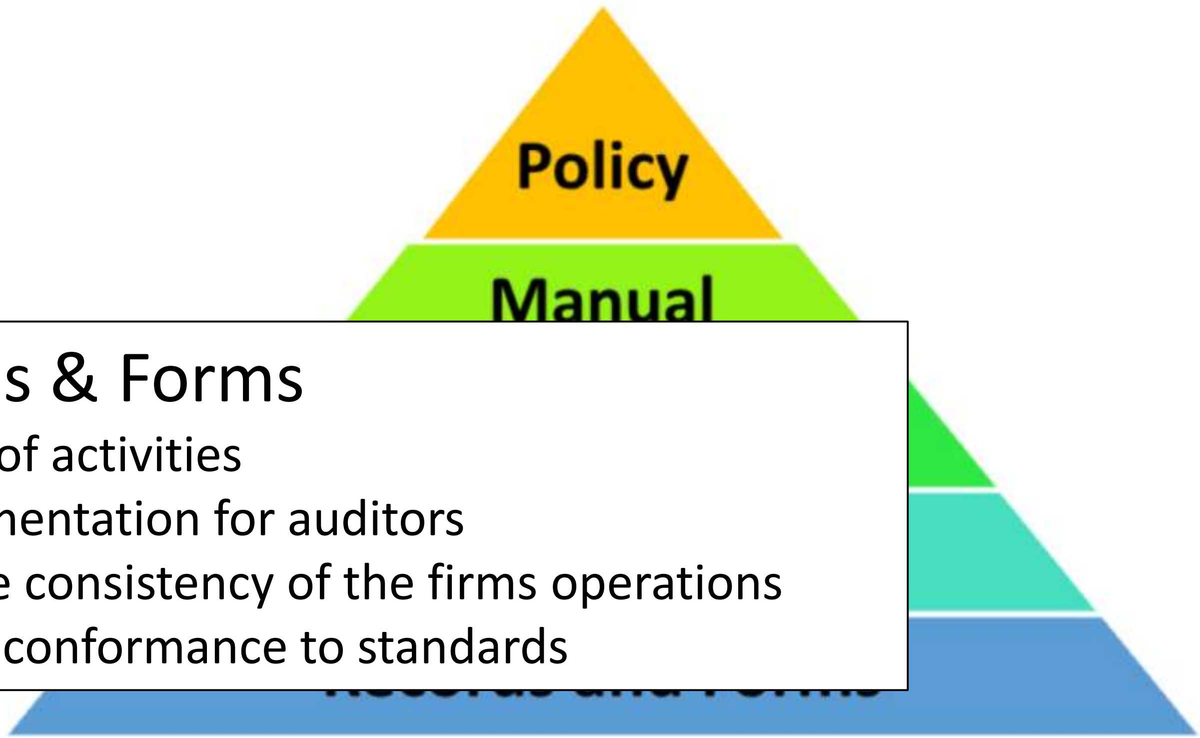
Quality System Documentation Overview



Records & Forms

- Proof of activities
- Documentation for auditors
- Ensure consistency of the firms operations
- Verify conformance to standards

https://advisera.com/9001academy/knowledgebase/how-to-structure-quality-management-system-documentation/

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Certification and registration

- Certification is known in some countries as registration.
- Means independent, external body has audited QMS and verified it conforms to requirements of the standard
- Certification gives more credibility in world marketplace

But

- Organisations can implement for internal benefits without spending money on a certification programme but cannot claim to “hold” ISO 9001 without passing an external audit.

Ref:https://www.academia.edu/19670615/Dave_John_Mike_Quality_Management_Systems_PPT_03

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Kanban System

- Devised in 1940s by Taichi Ohno for Toyota
- Expediting the manufacturing processes through continuous improvement.
- remove obstacles and keeping team communication clear by standardizing and refining the processes.
- This further helped in waste reduction and ultimately, maximized value.
- Kanban forms a critical part of Lean Thinking

https://productivityland.com/what-is-kanban-board/

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Kanban is really about improved visualisation

- Visualise work
- Limit work in progress
- Manage flow
- Make policies explicit
- Implement feedback loops
- Improve collaboratively, evolve experimentally

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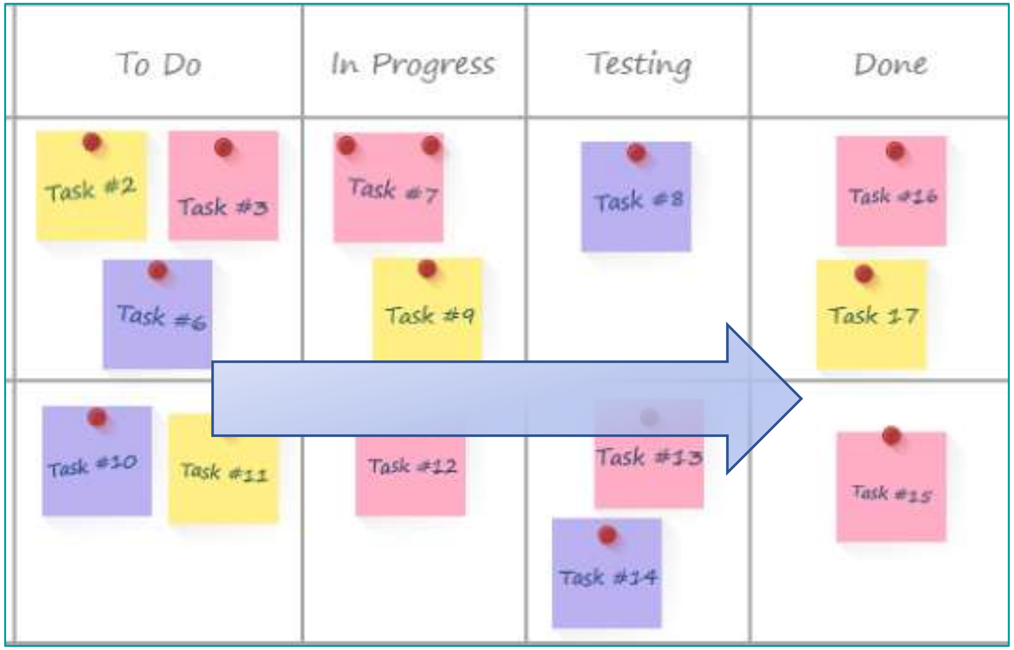
Kanban Board

- Columns represent workflow stages
- Cards move left to right across horizontal “swimlanes”
- Easy visualization of project status



https://productivityland.com/what-is-kanban-board/

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Physical Kanban board and cards

https://tcardsdirect.co.uk/

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Computer generated Kanban board

https://blog.planview.com/8-kanban-board-examples-for-engineering-manufacturing-organizations/

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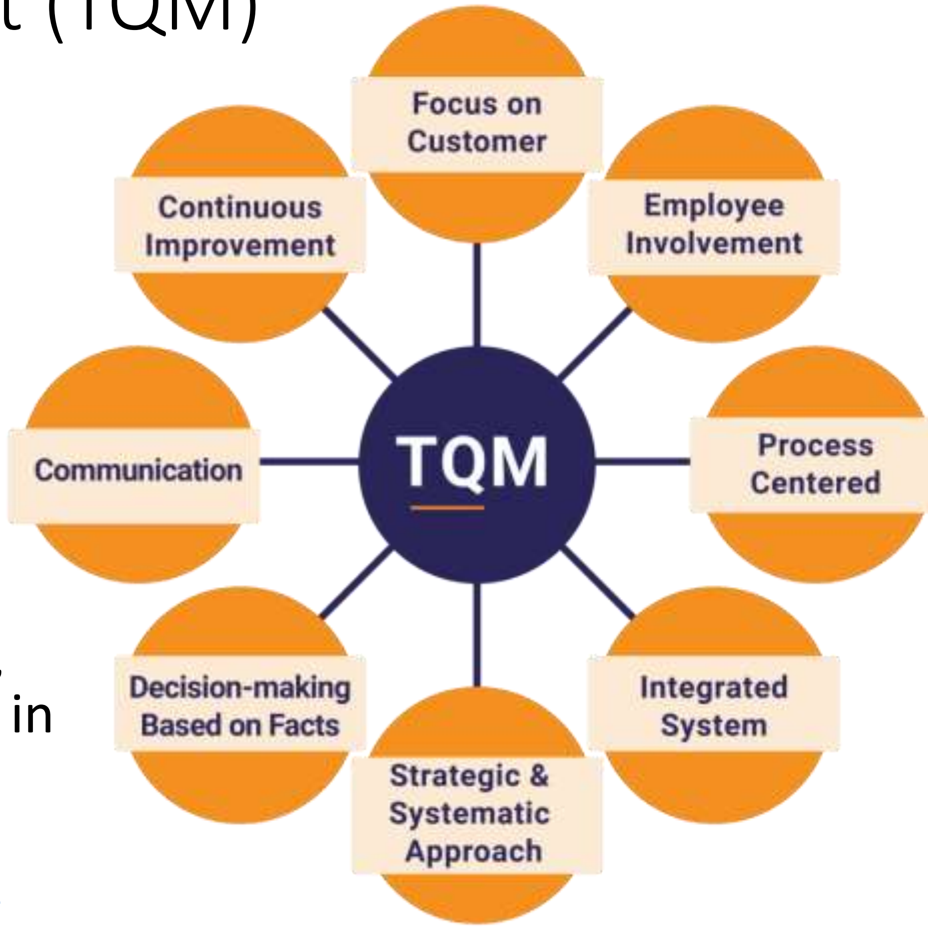
Total Quality Management (TQM)

- Principles developed in Japan to compete in the international marketplace.

- Approach to long-term success through customer satisfaction.

- All members of an organization participate in improving processes, products, services, and the culture in which they work.



[REF: Total Quality Management (TQM): What is TQM? | ASQ asq.org]

https://www.juran.com/blog/what-is-total-quality-management/

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TQM Versus ISO9001

- ISO 9001 and TQM not interchangeable
- ISO 9001 is compatible with, and is viewed as a subset of TQM
- ISO 9001 can be implemented in an non-TQM environment
- ISO 9001 and TQM are not in competition

Ref:https://www.academia.edu/19670615/Dave_John_Mike_Quality_Management_Systems_PPT_03

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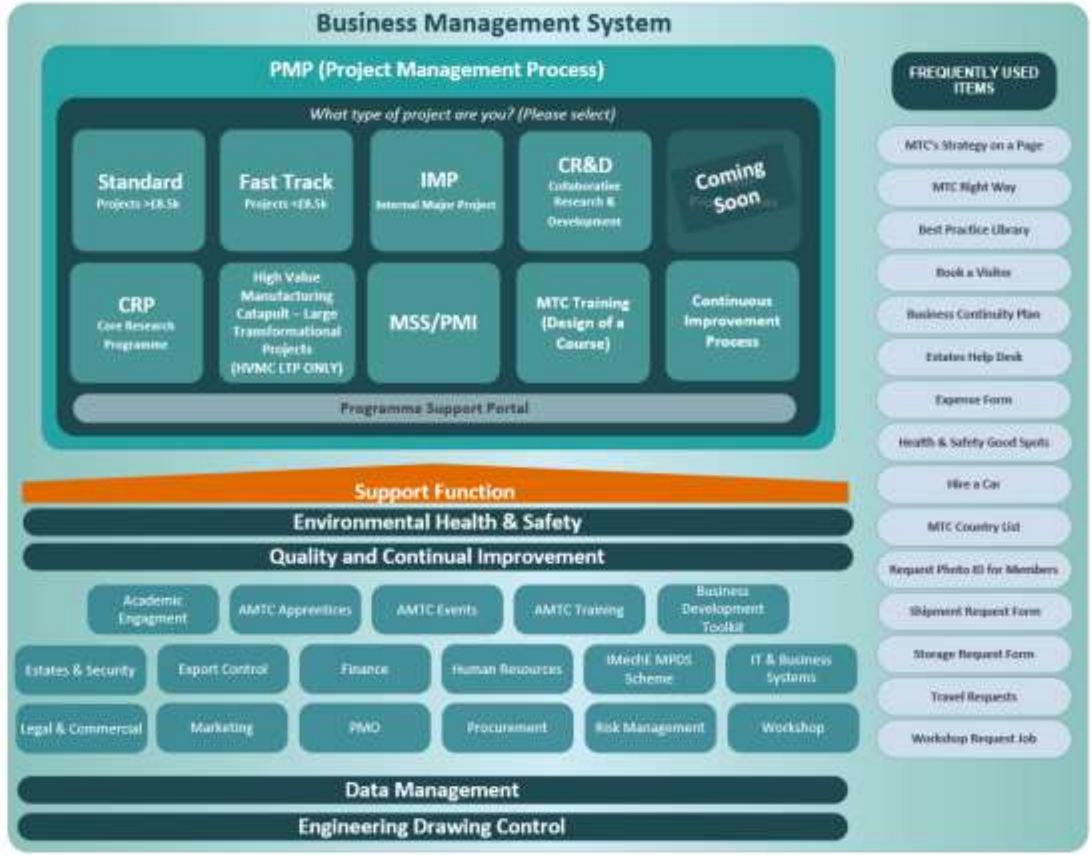
QMS: Implementation to AM @ MTC

- AM must align to the rest of your business and follow system for management of quality and business objectives
- The MTC has centralised project and operations control supporting ISO 9001 and Quality Management System across our manufacturing operations including AM as part of National Centre for Additive Manufacturing (NCAM)



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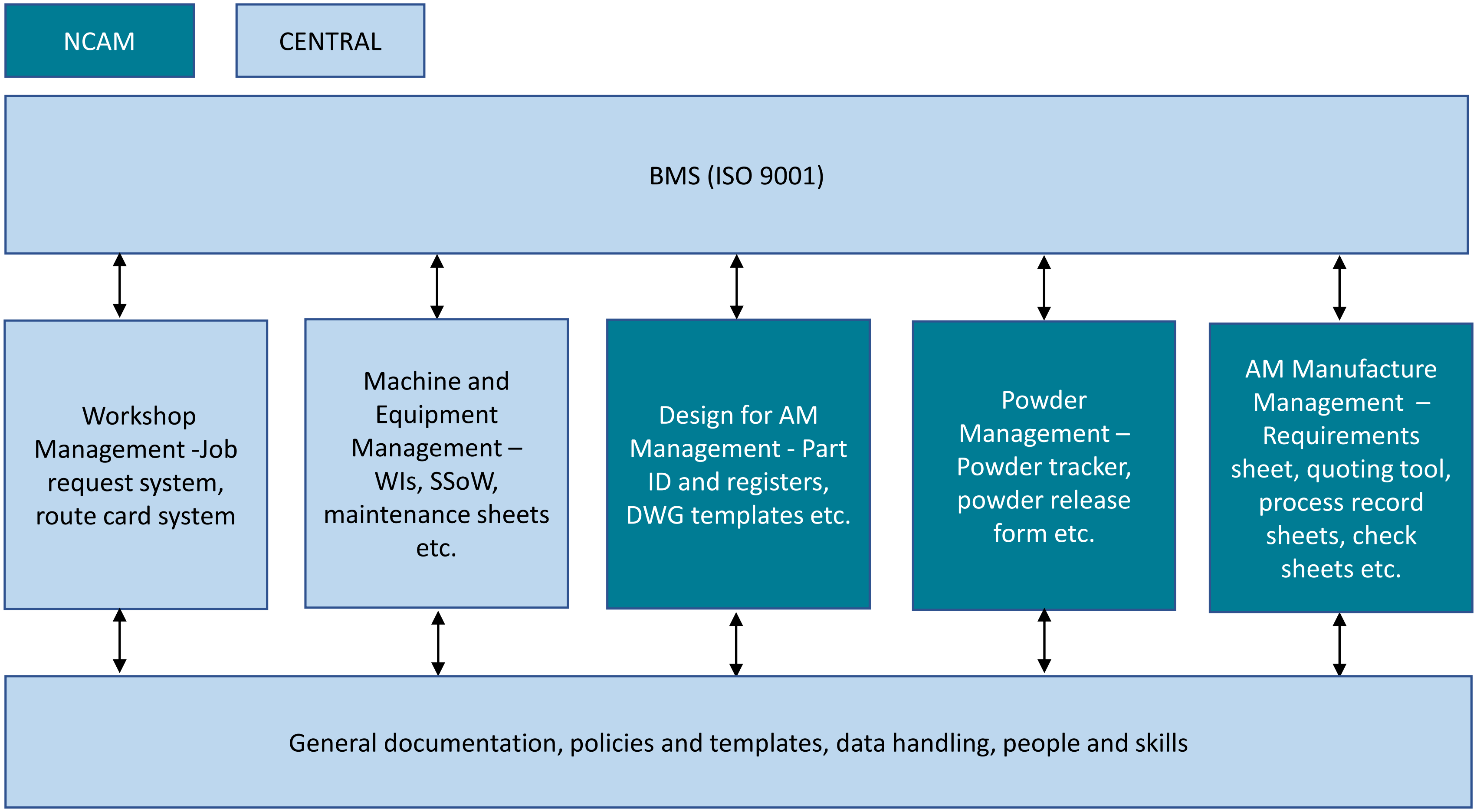
QMS: MTC Quality System Approach for AM



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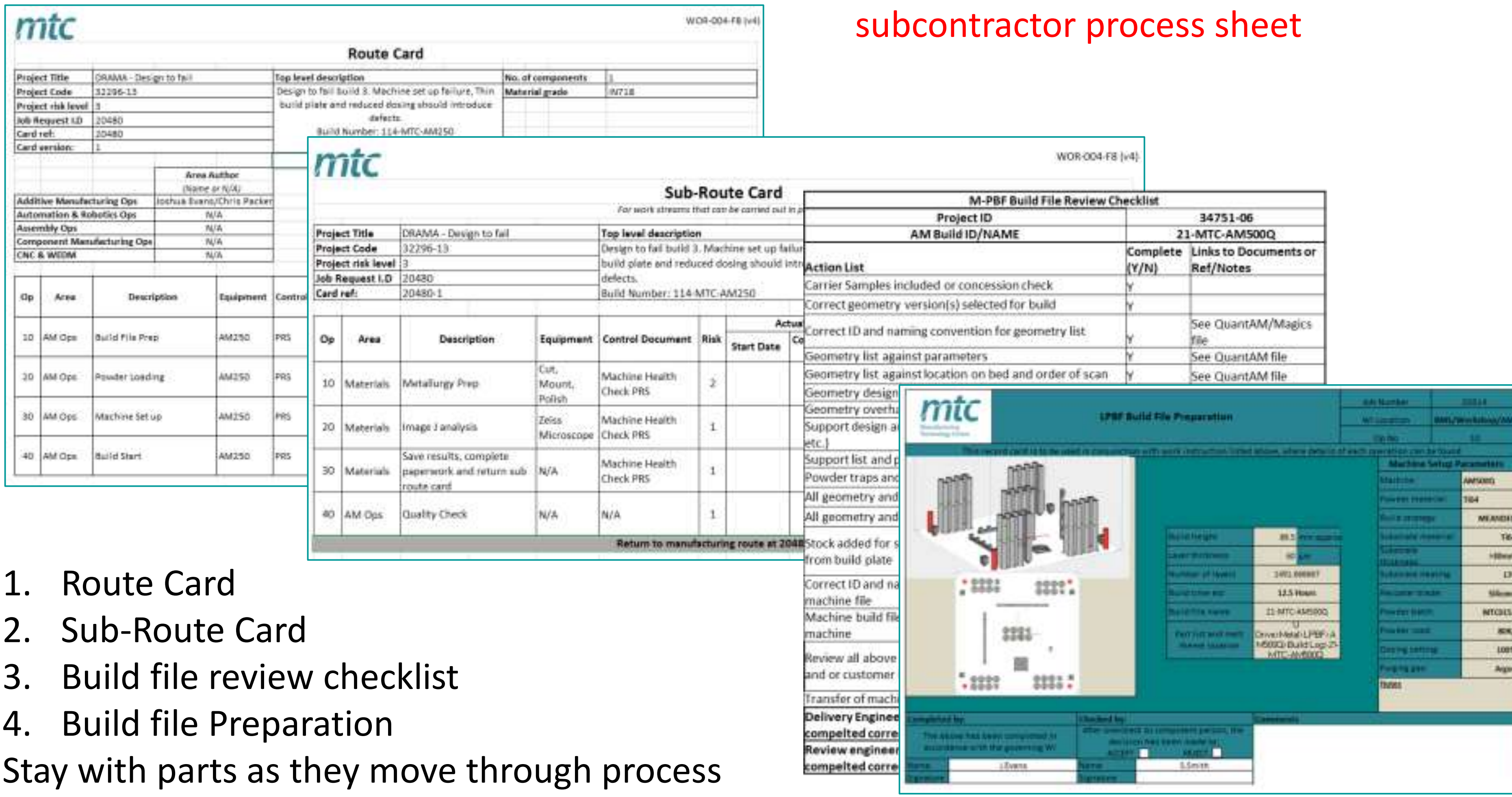
AM Production Pack

Also Job card and subcontractor process sheet



1. Route Card
2. Sub-Route Card
3. Build file review checklist
4. Build file Preparation

Stay with parts as they move through process

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1.Route Card

- **Manufacture operation workflow**
- **Operation workflow control gates**

mtc

WOR-004-F8 (v4)

Route Card

Project Title	DRAMA - Design to fail	**Top level description**		**No. of components**	1
Project Code	32296-13	Design to fail build 3. Machine set up failure, Thin build plate and reduced dosing should introduce defects. Build Number: 114-MTC-AM250		**Material grade**	IN718
Project risk level	3				
Job Request I.D	20480				
Card ref:	20480				
Card version:	1				

	Area Author *(Name or N/A)*		**Area Author** *(Name or N/A)*
Additive Manufacturing Ops	Joshua Evans/Chris Packer	**Maintenance**	N/A
Automation & Robotics Ops	N/A	**Materials Labs**	N/A
Assembly Ops	N/A	**Metrology Lab**	N/A
Component Manufacturing Ops	N/A	**Customer**	Llyr Jones
CNC & WEDM	N/A		

Op	Area	Description	Equipment	Control Document	Risk	Actual		Outcome *(tick one)*		Completion Stamp	Notes / Progress Stamps / Overcheck Stamps
						Start Date	Completion Date	C	H		
10	AM Ops	Build File Prep	AM250	PRS	3						
20	AM Ops	Powder Loading	AM250	PRS	2						
30	AM Ops	Machine Set up	AM250	PRS	3						
40	AM Ops	Build Start	AM250	PRS	2						

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2.Sub-Route Card

- **Material and part flow/planning through manufacture**

WOR-004-F8 (v4)

Sub-Route Card

For work streams that can be carried out in parallel

Project Title	DRAMA - Design to fail	**Top level description**	**No. of components**	4
Project Code	32296-13	Design to fail build 3. Machine set up failure, Thin build plate and reduced dosing should introduce defects. Build Number: 114-MTC-AM250	**Material grade**	IN718
Project risk level	3		**List component IDs**	
Job Request I.D	20480		HC1, HC2, HC3, HC4	
Card ref:	20480-1			

Op	Area	Description	Equipment	Control Document	Risk	Actual Start Date	Actual Completion Date	Outcom (tick one) C	Outcom (tick one) H	Completion Stamp	Notes / Progress Stamps / Overcheck Stamps
10	Materials	Metallurgy Prep	Cut, Mount, Polish	Machine Health Check PRS	2						
20	Materials	Image J analysis	Zeiss Microscope	Machine Health Check PRS	1						
30	Materials	Save results, complete paperwork and return sub route card	N/A	Machine Health Check PRS	1						
40	AM Ops	Quality Check	N/A	N/A	1						
Return to manufacturing route at 20480 110											

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3.Build File Review Checklist

- Key operation step information and data capture
- Operation peer review and approval

M-PBF Build File Review Checklist		
Project ID	**34751-06**	
AM Build ID/NAME	**21-MTC-AM500Q**	
Action List	**Complete (Y/N)**	**Links to Documents or Ref/Notes**
Carrier Samples included or concession check	Y	
Correct geometry version(s) selected for build	Y	
Correct ID and naming convention for geometry list	Y	See QuantAM/Magics file
Geometry list against parameters	Y	See QuantAM file
Geometry list against location on bed and order of scan	Y	See QuantAM file
Geometry design and build-ability	Y	
Geometry overhang check	Y	
Support design and connection to geometry (teeth design etc.)	N/A	
Support list and parameters	N/A	
Powder traps and powder removal possible	N/A	
All geometry and support within build envelope	Y	
All geometry and supports connected to build plate	Y	
Stock added for support or sacraficial material removal from build plate	Y	See control plan (AM CRP Project Workshop Requirement Spec)
Correct ID and naming convention for build model and machine file	Y	
Machine build file settings correct on build file and machine	Y	
Review all above against AM build requirements capture and or customer build specification	Y	Stress relief cycle defined by standard SAT/FAT
Transfer of machine build file to machine	Y	JE to complete
Delivery Engineer Signiture that all above has been compelted correctly	J Evans - 05/11/2020	
Review engineer Signiture that all above has been compelted correctly	S Smith - 05/11/2020	

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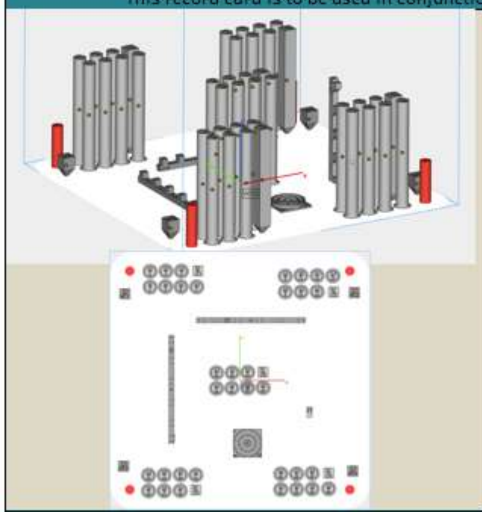
4.Build File Preparation Sheet

mtc Manufacturing Technology Centre

LPBF Build File Preparation

Job Number	20314
WI Location	BMS/Workshop/AM
Op No	10

This record card is to be used in conjunction with work instruction listed above, where details of each operation can be found



Build height	89.5	mm approx
Layer thickness	60	µm
Number of layers	1491.666667	
Build time est	**12.5 Hours**	
Build file name	21-MTC-AM500Q	
Part list and melt theme location	Drive>Metal>LPBF>AM500Q>Build Log>21-MTC-AM500Q	

Machine Setup Parameters	
Machine:	**AM500Q**
Powder material:	**Ti64**
Build strategy:	**MEANDER**
Substrate material:	**Ti64**
Substrate thickness:	**>30mm**
Substrate heating:	**170**
Recoater blade:	**Silicone**
Powder batch:	**MTC0152**
Powder load:	**80Kg**
Dosing setting:	**100%**
Purging gas:	**Argon**
Notes	

Completed by:		**Checked by:**		**Comments**
The above has been completed in accordance with the governing WI		After overcheck by compotent person, the decision has been made to: ACCEPT ☐ REJECT ☐		
Name	J.Evans	Name	S.Smith	
Signature		Signature		

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Subcontract Process Sheet

If parts leave MTC for external operations (for example heat treatment);

- Production pack is retained at MTC
- Subcontract process sheet is supplied with the part showing the precise processing operations, supporting evidence required and key contact points

This mirrors what is in the PO to the company but helps to ensure that it is followed !!!

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References

- Quality Management for Organizational Excellence – Introduction to Total Quality – Groetsch and Davis
- Origin Of ISO 9000 Standards - http://www.youtube.com/watch?v=igMS5uuX4rI
- ISO 9000 Certification Dance - http://www.youtube.com/watch?v=Ipq82fL1xyQ

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www.skills4am.eu

Thank you

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Project No. 601217-EPP-1-2018-1-BE-EPPKA2-SSA-B

CU 36: Coordinating the AM Process (Pilot)

TOPIC 8: Dealing with non conformance

Prepared by: David Wimpenny

Date: 13/01/21

Please look for slides showing - KEY INFORMATION

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Things can go wrong……

- End-to-end AM process is very complex and build failures and defective parts are very common.
- If system for monitoring the process and part quality works properly the problem will be spotted very quickly.
- Avoid defective parts being sent to customer.
- Changes made to the manufacturing schedule.
- But then rapid and concerted action needs to take place to identify the nature of the problem, the **root cause** and **corrective action** taken.

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Root cause analysis

- "root cause" refers to the primary reason for the problem (build failure, defective parts etc.)

- Common examples of root cause analysis in manufacturing include methodologies such as **"Fishbone"** diagram and the **"5 Whys".**

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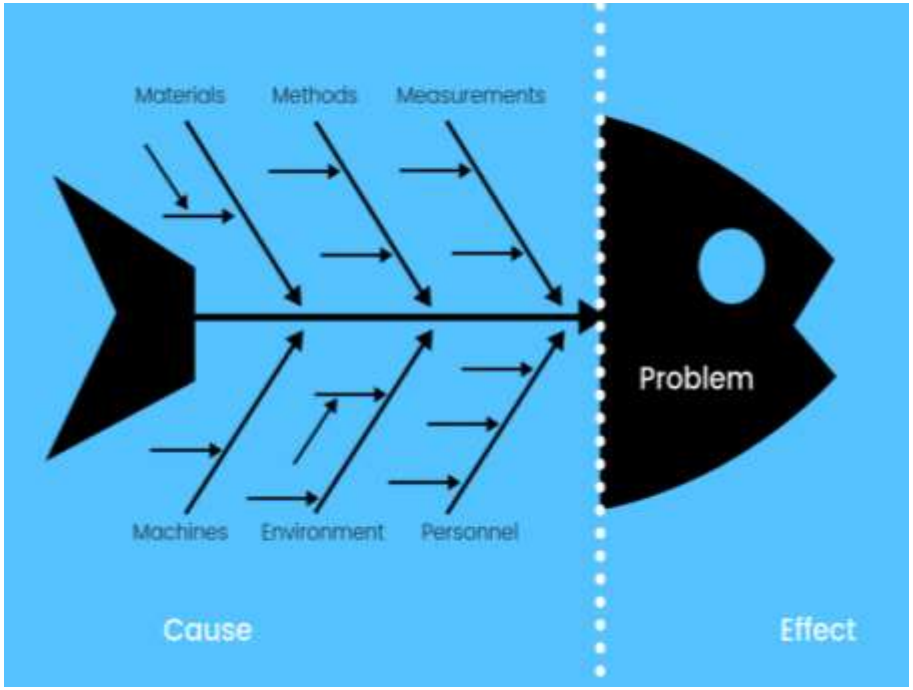
Fish Bone Diagram

- Identifies possible causes of a problem through a structured approach.
- Once the potential reasons have been identified there is still work to do to identify the actual cause of the problem.



blob:https://videos.asq.org/96de6f51-f636-480d-94ca-6674b7549daa

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KEY INFORMATION

Fish Bone Diagram

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- Agree on a problem statement (effect). Write it at the center right of the flipchart or whiteboard. Draw a box around it and draw a horizontal arrow running to it.
- Brainstorm the major categories of causes of the problem. If this is difficult use generic headings:
    - Methods
    - Machines (equipment)
    - People (manpower)
    - Materials
    - Measurement
    - Environment
- Write the categories of causes as branches from the main arrow.
- Brainstorm all the possible causes of the problem. Ask "Why does this happen?" As each idea is given, the facilitator writes it as a branch from the appropriate category. Causes can be written in several places if they relate to several categories.
- Again ask "Why does this happen?" about each cause. Write sub-causes branching off the causes. Continue to ask "Why?" and generate deeper levels of causes. Layers of branches indicate causal relationships.

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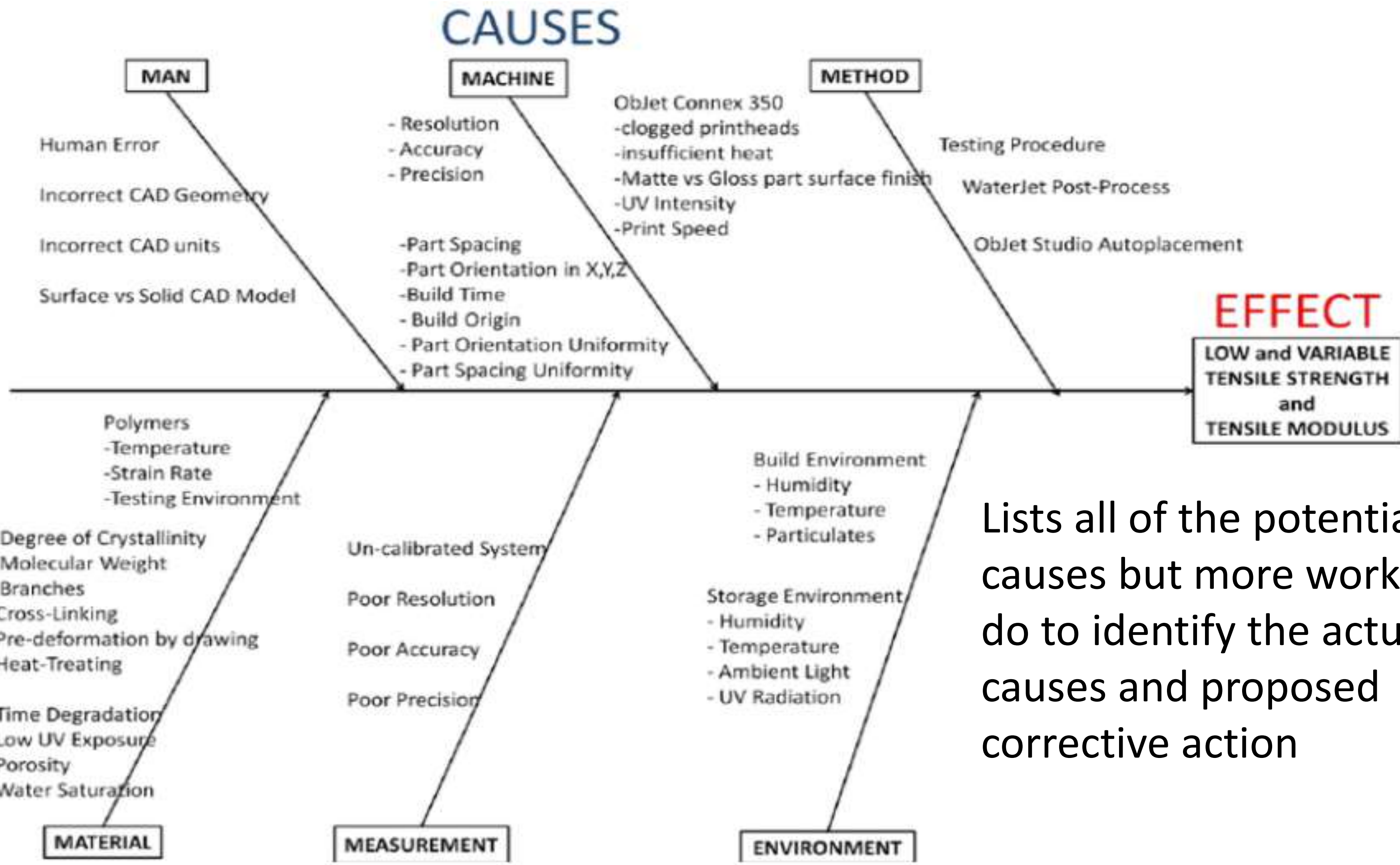

Lists all of the potential causes but more work to do to identify the actual causes and proposed corrective action

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5 Whys

- simple and effective **tool** for identifying the root cause of a problem ….by asking a sequence of "**Why**" questions. ...
- Once you have identified the root cause then corrective action to prevent reoccurrence can take place.

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Example:

Caught speeding ….

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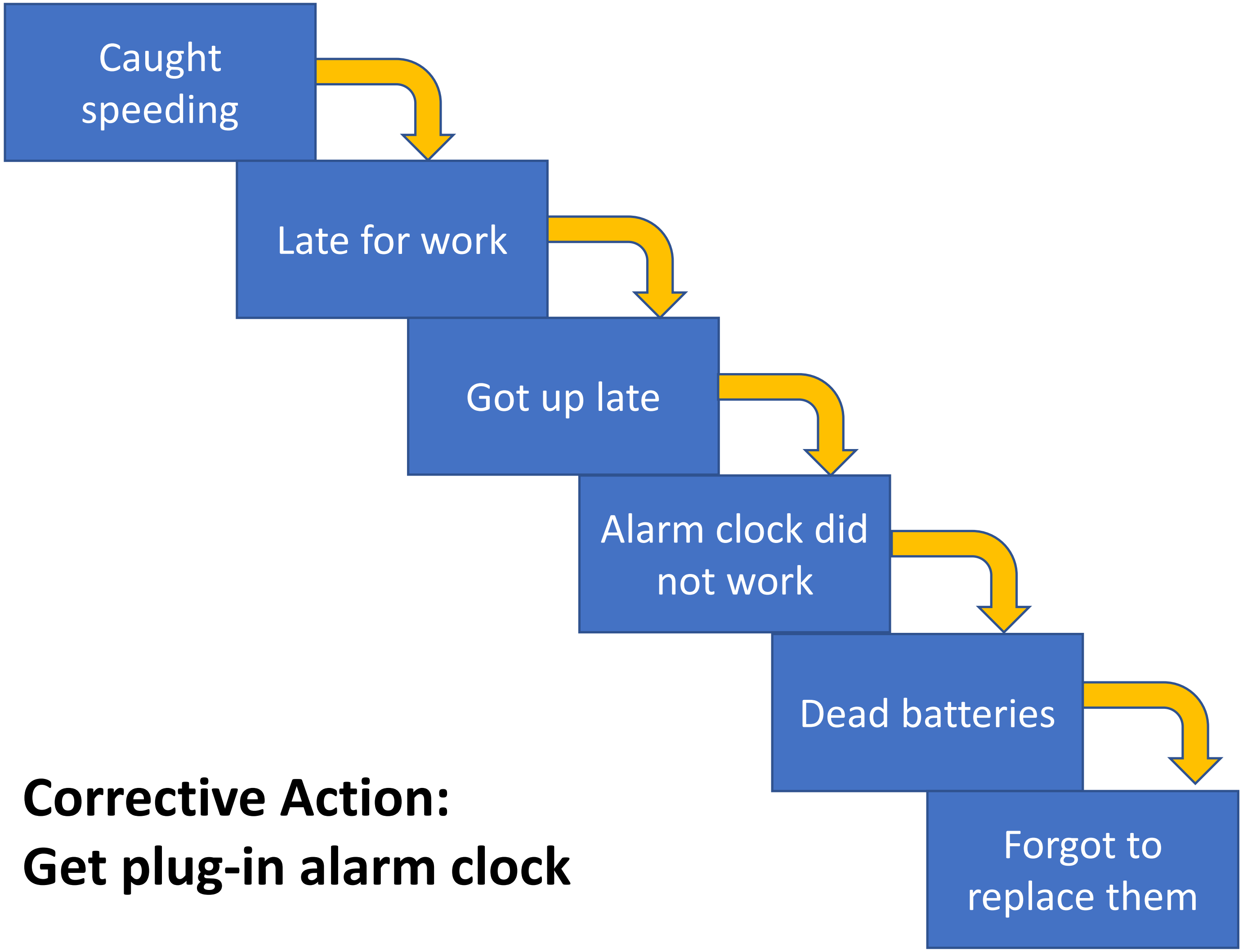

Corrective Action:
Get plug-in alarm clock

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Dealing with Recurring Problems

- One of the most time-consuming (and potentially expensive) problems is when a nonconformance continues to occur. When the same issue happens more than once, it indicates a problem in the corrective action process. When corrective action Additive Manufacturing processes fail, it’s typically because of one of two reasons:

1. Investigation failed to uncover the actual root cause that led to the defect.
2. Corrective action taken was ineffective in solving the problem.

https://www.bright-am.com/corrective-action-additive-manufacturing/

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5 Steps for Effective Corrective Action Additive Manufacturing Managements

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1. Identify the problem

First - identify the problem and most likely

Some corrective actions don't require a full-blown investigation. There may be obvious solutions that can resolve the issue. Others may take an in-depth analysis to find the root cause.

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2. Identify the root cause

In any manufacturing operation, avoid treating just the symptoms. You need to treat the underlying problem. That said, you'll likely need to take a deep dive to uncover and identify the patterns. Examine each step in the process. You may find that you need to make changes in processes, training, raw materials, or suppliers.

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3. Execute the Corrective Action Additive Manufacturing Plan

- Once you've identified the root cause and created the plan to address the underlying problem, you need to put the plan in motion and document the changes. Your audit trail should capture what changes are made, and all paperwork needs to be updated so the information stays current on the production floor.
- Many Additive Manufacturers will do all of the above processes but fail to take the next crucial step: checking for effectiveness.

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4. Check for Effectiveness

- Once your corrective action plan has been put in place, it's crucial to continue to evaluate results against performance goals. If the problem hasn't been fixed, you'll need to stop again and reassess risk.

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5. Standardize and Document

- After you have confirmed that the corrective action has done its job and eliminated the nonconformance, you need to make sure to standardize your procedures, update your documentation, and communicate it to everyone involved in the production process. Changes made through corrective actions need to be part of your standard operating procedures going forward.
- These five steps will work as a framework for you to diagnose, implement, and measure your corrective action. Depending on your compliance needs, you may need to follow an even more formal process.

https://www.bright-am.com/corrective-action-additive-manufacturing/

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