EASA

European Aviation Safety Agency

EASA

Additive Manufacturing

update

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EASA Rotorcraft Structures Workshop

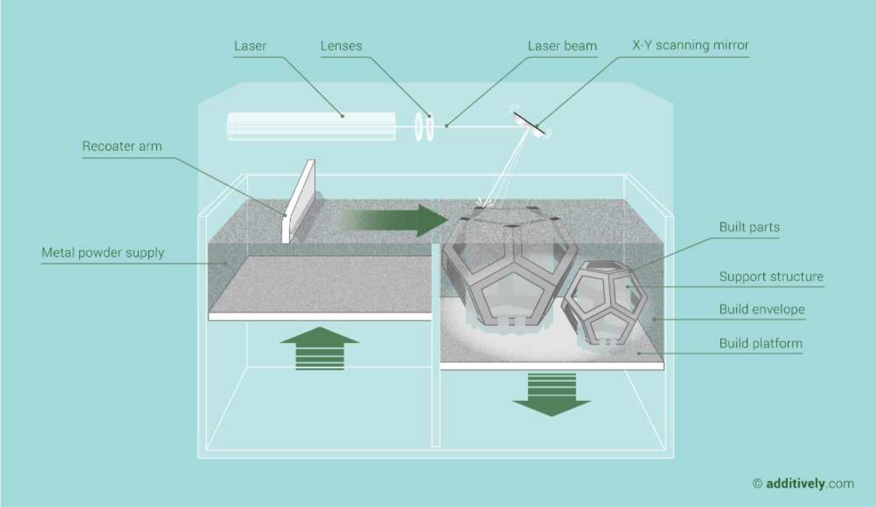
February 2019, Koeln

Your safety is our mission.

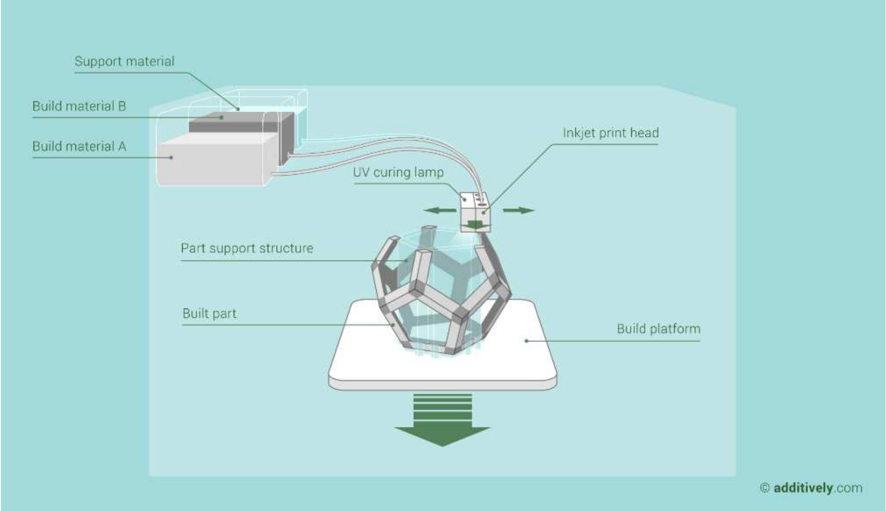
Additive Manufacturing – many methods, and definitions:

'… make objects…layer upon layer…'

Laser-melting



Photopolymer-jetting



Illustrations courtesy of additively
your access to 3D printing

- metallic/non-metallic
- single material, multi-material, + fillers,
- hybrid processes, e.g. icw convention methods

- **significant potential commercial benefits**, e.g. rapid prototype evolution, reduced part count, weight reduction etc

AM ‘Engineering Properties’ are:

- defined by the ‘material <u>and</u> process’
- built directly into the part or repair

a challenge:

- ‘complex parts’ – base pyramid coupon data may not represent the complex part properties (although stable simple base pyramid data is essential…otherwise, how can the higher pyramid work be trusted?)
- ‘sensitive processes’ – a major challenge if completing production activities in a more challenging maintenance environment

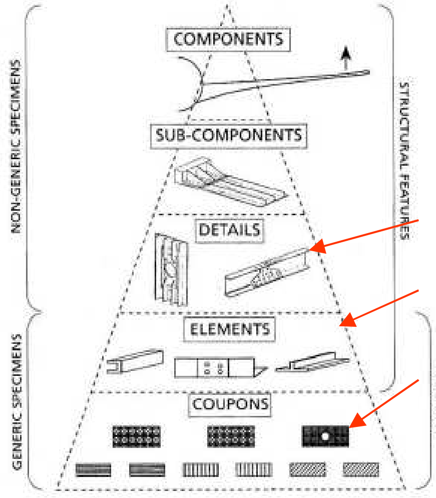
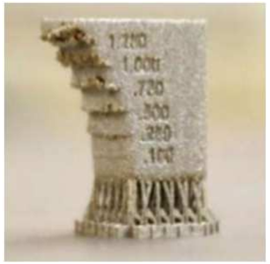


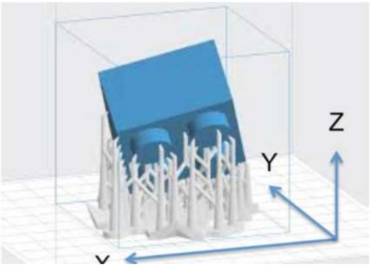
Figure 1 - Schematic diagram of building block tests for a fixed wing.

representative ‘engineering properties’ developed here?

e.g. AM, composites, bonded joints



e.g. no access to free edges – fatigue issue?



e.g. support structure on the build platform

EASA - AM

AM – EASA Regulator's Perspective (see support slides and EASA Workshop presentations and CM)

- rapidly increasing number of materials, processes, and applications, i.e. baseline applications and repair
- potential safety considerations
  - 'engineering properties', e.g. anisotropic, new and competing damage modes
  - repeatability - many variables (materials, processes, products), etc
  - changes in relationship between design, production, continued airworthiness (CAW), more integrated than many typical metallic processes (some similarities wrt composites)
  - increasing process driven quality (relative to inspection)
  - pressure for utilisation in increasingly critical applications
  - **industry and regulator knowledge base and training**
    - are changes required in rules and/or guidance?

EASA - AM

- EC No 216/2008 annex
  1.a.**Structures and materials**: the **integrity of the structure** must be **ensured throughout, and sufficiently beyond, the operational envelope for the aircraft,** including its **propulsion system**, and **maintained for the operational life of the aircraft.**
  1.c.3. Systems and equipment…

...gulatory Framework (moving towards **performance based regulations**)

Basic Regulation

EC 2018/1139

EU Parliament
EU Council

...ing rules

...1702/2003

...and environmental certification of aircraft and related products, parts and appliances, as well as for the certification of design and production organisations.

- **21A.31 Type design …** shall consist of:
  - 2. Information on **materials and processes** and on **methods of manufacture and assembly** of the product necessary to ensure the conformity of the product

EU Commission

GM 21.A.147(a) Changes to the approved production organisation – Significant changes
1 …to be approved by the competent authority include:
 - significant changes to production capacity or methods…

•Binding

•Non-Binding

Acceptable Means of Compliance (AMC) and Guidance Material (GM) for

PART 21

Certification Specifications

Airworthiness Codes, e.g. CS 23, 25, 27, 29 et...

PART 145 – Maintenance organisation approvals

PART 66 – Certifying staff

Part 147 – Training organisations requirements

EASA

- **Certification Specifications: Limited 'Material and Process', e.g.**
  CS 2x.603: Materials… 'suitability and durability … based upon experience/test… conform to specifications… consider environment
  CS 2x.613: Mechanical Strength Properties and Design Values Materials. (a) … design values based upon a statistical basis

CS 2x.605: Fabrication Methods

(a) The methods of fabrication used must produce a consistently sound structure. If a **fabrication process** (such as gluing, spot welding, or heat treating) **requires close control** to reach this objective, the process **must be performed under an approved process specification.**

(b) Each **new aircraft fabrication method must be substantiated by a test programme**

CS 2x.613: Mechanical Strength Properties and Design Values Materials

(a) **Material strength properties** must be based on enough tests of material meeting approved specifications to establish design values on a **statistical basis**. *(A and B-basis)*

.... limited to specific machine serial number
... avoid using different materials in the same machine until variability/equivalence is better understood

ASA - AM

Additive Manufacturing: What is new to manufacturing regarding AM?

raw materials	e.g. handling, transport, storage, preparation etc	many existing standards and practices apply
build process	e.g. preparation, processing, process monitoring etc	many (TCH) methods... few existing standards
post build processing	e.g. removal from equipment, heat treatment, machining etc	many existing standards and practices apply
inspection & testing	e.g. chemical, physical, NDI, visual etc	many existing standards and practices apply

access to complex part surfaces?

Develop and maintain Design Allowables?

AM relative to The Regulations – EASA priorities and resources:

- **priority is safety**… **'do not reduce the existing level of safety'**
- **prioritise activities with respect to <u>novelty and criticality</u>**

e.g. AM within scope of LoI (Opinion 07/2016 + NPA 2017-20, due Autumn 2019)

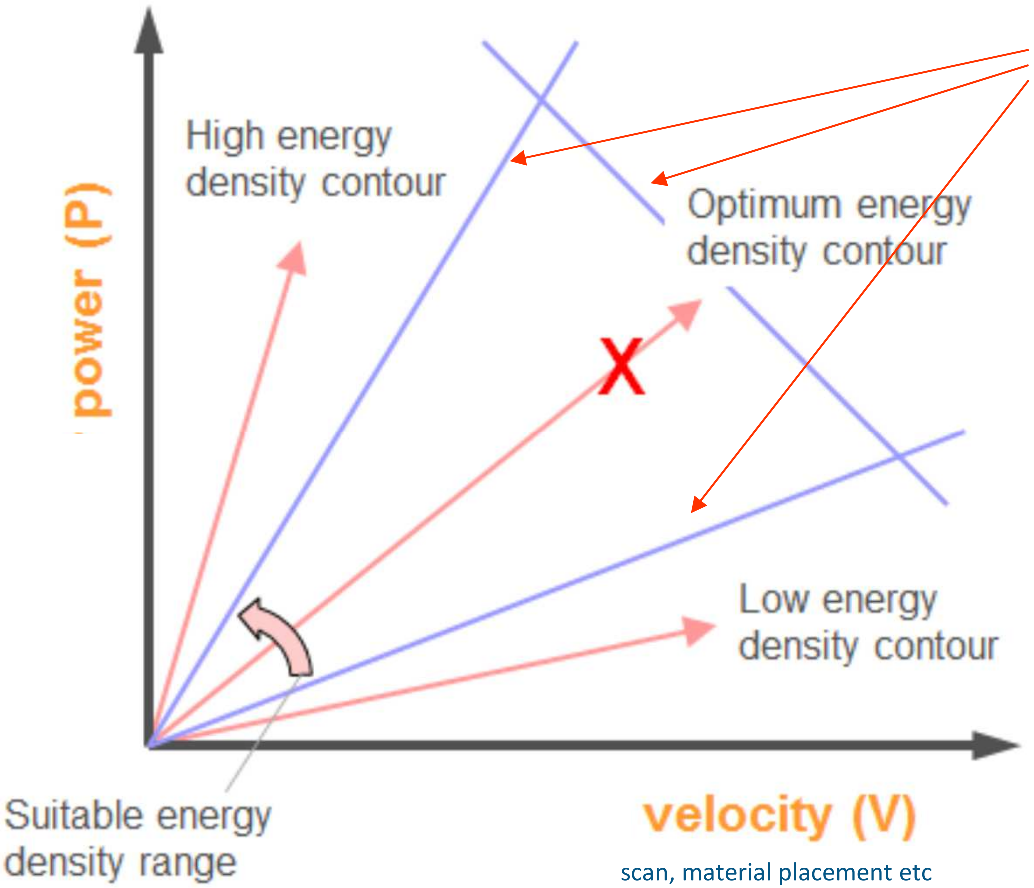
21.B.100 Level of Involvement (LoI)

….(a) **The Agency shall determine its involvement** in the verification of the compliance demonstration activities and data related to the application for a type-certificate etc… and **consider at least the following elements**:

1. the **novel or unusual features** of the certification project, including operational, organisational and knowledge management aspects…

3. the **criticality of the design or technology** and the related safety and environmental risks, including those identified on similar designs; and…

What needs to be understood? P-V diagrams – acceptable properties



Metallic/non-metallic and many processes:

- **Boundary definitions?**
- **Key parameter definition**?
- **Competing defect/damage modes**?
- **Statistical credentials** (A, B-Basis etc)?
- **Sensitivity** (% change in 'engineering properties' wrt boundaries and key parameters?)

- 100+ control parameters
20, 30, 40….'key parameters'?

e.g. does a static part remain a static part if produced using AM?

EASA AM Strategy - current activities: Certification Memo (CM)

EASA CM–S-008 Issue 01: Additive Manufacturing: **simple message to industry…**

share intent early with EASA in order to support integration within existing regulatory framework,

e.g. POA, DOA audits etc

- responsibilities shared within EASA via subject contacts, identified in CM, and internal EASA AM WG meetings etc

- Cert. Directorate (Chief Expert - Airframe)	R. Minter – richard.minter@easa.Europa.eu
- Structures	S. Waite (AM WG chair) – simon.waite@easa.europ.eu
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- Propulsion	M. Mercy - matthew.mercy@easa.europa.eu
	O. Kastanis - omiros.kastanis@easa.europa.eu
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	O. Tribout - olivier.tribout@easa.europa.eu
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- Maintenance	R. Tajas - rosa.tajes@easa.europa.eu
- ETSO	TBD

* changes in progress since CM published – new subject contacts 'red text'

Conclusions:

- no/very limited Rule changes expected
- some harmonised guidance and knowledge transfer activities expected to be important (training, workshops etc), e.g.
- generic awareness, education, currency, and standardisation workshops

  +

- focus development workshops

Regulator Workshops
- FAA - EASA 21-24/8/18
- EASA - CAAS 15-16/10/18

Focused Regulator Workshops
- EASA 28-29/6/18

'Knowledge Transfer'

Conclusions:

- interaction with other stakeholders

e.g. AIA, SAE AM-M and AM-P, ASTM

- use existing strategies and 'lessons learned' from existing technologies, when applicable, e.g. composites, … necessary to mitigate potentially more rapid introduction into service

- revise EASA Cert Memo EASA CM–S-008 Issue 01: Additive Manufacturing

- improve audit efficiency – adapt to POA, DOA, and Certification changes

- CMH-17*: new non-metallic AM volume proposed

* CMH-17 Composite Materials Handbook- 17

Conclusions:

- Developing Standardisation Body Activities (metallic and non-metallic): SAE, ASTM, PRI etc

- NCAMP: shared database activity extending to include AM (initially non-metallic/low criticality applications, e.g. Ultem 9085)

- EASA R&D Strategy developing in conjunction with Clean Sky 2, Horizon 2020, and iaw NBR (increasing AM project involvement expected)

- Performance based regulation – consider other mitigating actions, e.g. sampling, fleet leader programmes

Next EASA-FAA AM Workshop:
- EASA - FAA 5-7/11/19 Koeln (TBC)

AM – EASA Perspective (EASA Workshop presentations)

EASA Workshop 2016:
http://www.easa.europa.eu/system/files/dfu/WORKSHOP%20Additive%20Manufacturing%20-%20Presentations.zip

EASA Safety Conference 2016:
https://www.easa.europa.eu/event-type/annual-safety-conference

EASA Workshop 2017:
http://www.easa.europa.eu/newsroom-and-events/events/2017-easa-workshop-additive-manufacturing

EASA Certification Memo:
https://www.easa.europa.eu/sites/default/files/dfu/EASA%20CM-S-008%20Additive%20Manufacturing.pdf

EASA Knowledge Transfer Workshop 2018:
https://www.easa.europa.eu/newsroom-and-events/events/additive-manufacturing-workshop-machine-knowledge-and-training

FAA – EASA AM (metallic) Workshop August 21-23rd 2018
https://www.niar.wichita.edu/niarfaa/WorkshopRegistration/FAAAdditiveManufacturingWorkshop.aspx

Questions?

Support Slides

baseline structures **and repairs**

CS25.571: Damage-tolerance & fatigue evaluation *of structure*

Note: Recent Amendments CS25 amdt.19

*'(a) General. An evaluation of the strength, detail design, and fabrication must show that catastrophic failure due to fatigue, **manufacturing defects**, **environmental deterioration**, or accidental damage will avoided throughout the operational life of the aeroplane…'*

'(3)…..inspections or <u>other procedures</u> must be established as necessary to prevent catastrophic failure, and must be included in the Airworthiness Limitations Section of the Instructions for Continued Airworthiness required by CS 25.1529'

Does not need to be visual,
…or an inspection
Note: 80-90% of inspections are visual
ref. also CS25.611

need to find, define, and bound damage…

CS29.573: **Damage tolerance and fatigue evaluation of composite rotorcraft structures**:

similar intent other CSs

'(d) Damage Tolerance Evaluation…

(2) The damage tolerance evaluation must include PSEs of the airframe, main and tail rotor drive systems, main and tail rotor blades and hubs, rotor controls, fixed and movable control surfaces, engine and transmission mountings, landing gear, and any other detail design points or parts whose failure or detachment could prevent continued safe flight and landing…

(iv) A Threat Assessment for all structure being evaluated that specifies the locations, types, and sizes of damage, considering fatigue, environmental effects, intrinsic and discrete flaws, and impact or other accidental damage

(including the discrete source of the accidental damage that may occur during manufacture or operation…)'

EASA - AM

Writing guidance for the many materials and processes will be a **resource challenge**…

Guidance documents… EASA priorities and resources:

Example AM challenge - Guidance (what is the appropriate level of detail)?

- FAA *Memorandum AIR100-16-130-GM18 'Engineering Considerations for Powder Bed Fusion (PBF) Additively Manufactured Parts'

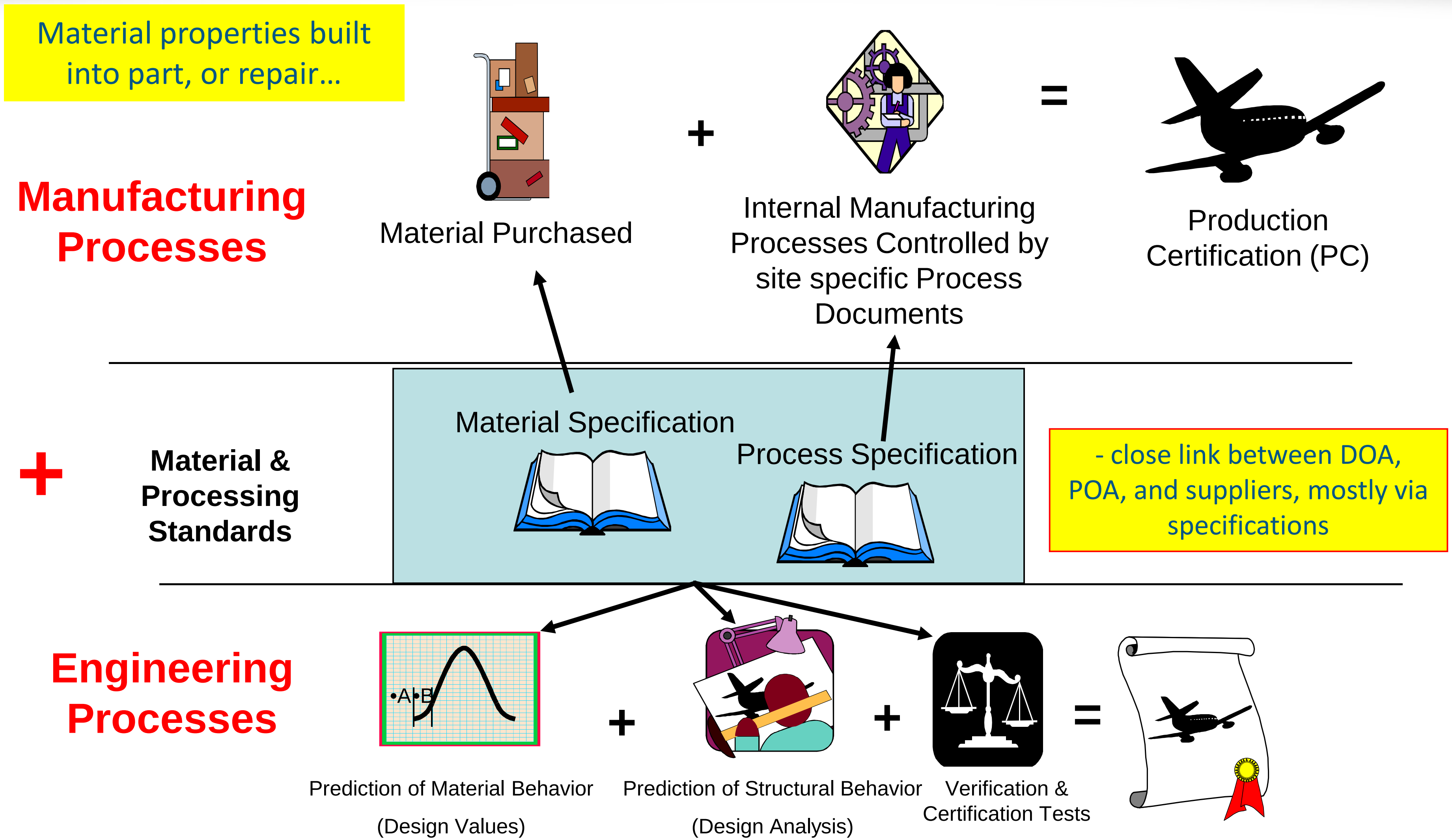
…addresses one method, PBF, which refers to (but does not address in detail) *'100 control parameters… '**

many variables – materials, process, configurations…
Who is going to do this for each material and process…? What level of detail?

- *need to standardise strategy to identify **key parameters and manage sensitivity**?*
- *failure modes wrt hazard analysis?*
- *other mitigating factors?… e.g. batch mixing in multi-load path structure etc*

* one of a number of useful developing FAA AM documents

EASA - AM



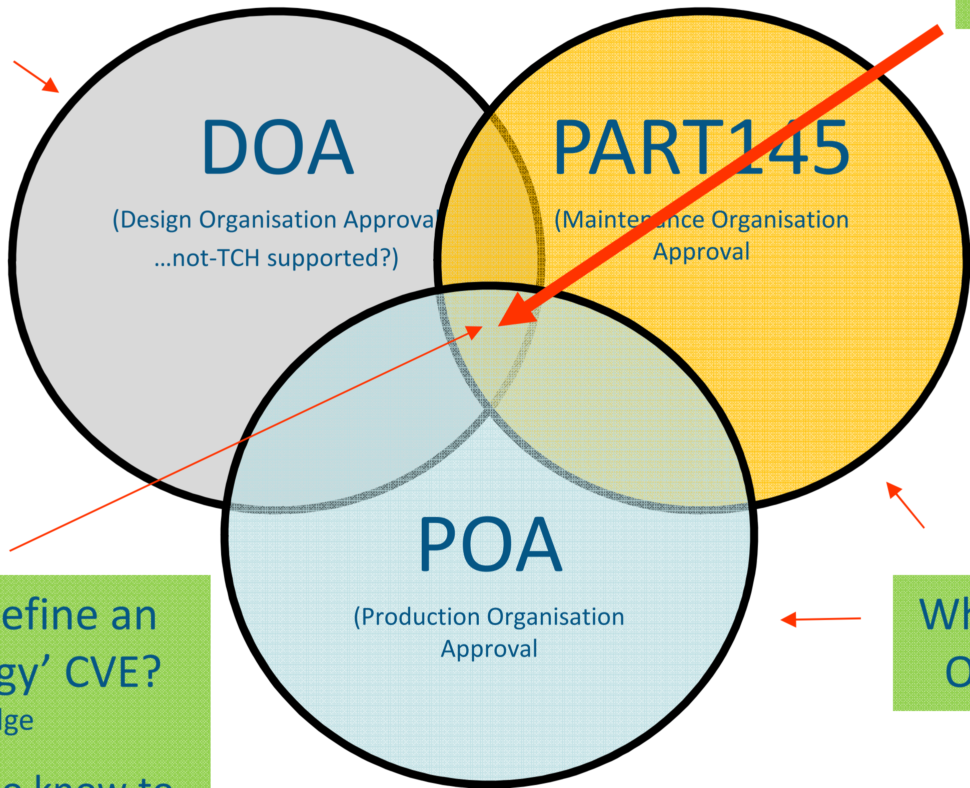
Note: slide from a CMH-17 composite tutorial – similar for AM

EASA - AM

Knowledge Transfer – What needs to be transferred to whom in order to support defining appropriate training?:

- The AM Machine…

What does an AM Design Engineer need to understand about the machine and its operation wrt design allowables/values?



Large TCH needs and organisation process different to MRO!

What does an AM Machine Operator need to know?

Does EASA need to define an 'Integrated Technology' CVE?
…Materials, POA, DOA knowledge

What does EASA need to know to fairly regulate the industry?

AM relative to The Regulations – EASA priorities and resources:

EASA Risk Matrix (RM) elements:

- Scope, definition, and associated AM terminology not standardised
- Current RULES ineffective (Low risk… existing rules are high level and generic)
- Current GUIDANCE ineffective (Low risk… however some additional supporting guidance is expected to be necessary)
- Design Certification - Engineering Properties
- DOA related
- POA related
- Repairs and Maintenance
- DOA/POA/Maintenance and Cert interfaces
- EASA DESIGN CERT interface with EASA DOA, POA, Maintenance
    - DOA - POA interface
    - DOA - Maintenance interface
    - POA - Maintenance interface
    - EASA - Industry interface
- Bogus Parts/Non-Compliant parts

Common RM elements:
- *Knowledge transfer*
- *Training*
- *Workforce awareness*

Focus for Workshops…

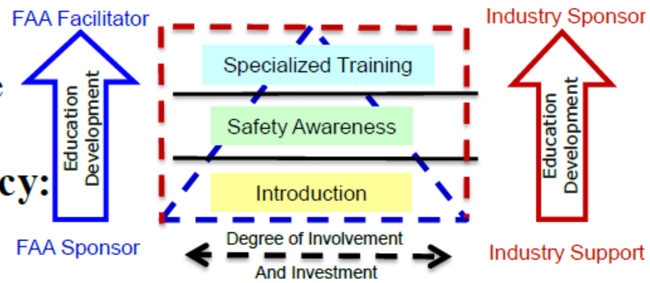
Knowledge Transfer – What needs to be transferred to whom in order to support appropriate training?:

Is this an appropriate model? If not, why not?

Composite Educational Initiatives

FAA AVS Composite Training

- **FAA composite training strategy established** [Sept., 2009]
  - Courses to support airframe structural engineering, manufacturing, and maintenance functional disciplines



Incl. three levels of competency:

I) Introduction (common to all functional disciplines)
Self-study intro content for composite basics/terminology
CMH-17 Tutorial for composite certification & compliance [Aug, 2008]

II) Safety Awareness (courses for each functional discipline)
Skills needed for FAA workforce supporting composite applications (including industry focal involved in safety and certification oversight)

III) Specific Skills Building (most courses developed by the industry)
Specialized skills needed in the industry & some FAA experts
Currently dominated by industry on-the-job training/mentoring

Is an AM equivalent to AIR 5719 appropriate?

Composite Structural Engineering Technology
Module 1.0: Introduction

Click Here for Optional Slides

Federal Aviation Administration

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EASA - AM

What is a ‘key parameter/characteristic*?

- large ‘engineering property’ change relative to a parameter range (relative to machine operation tolerances/capabilities?)?

- defect/damage mode change relative to a parameter range (relative to machine operation tolerances/capabilities?)?

Many materials and processes…
How do we regulate this…

e.g. does a static part remain a static part if produced using AM?

* ‘key characteristic’ used in SAE

EASA Certification:

It will be important for the **regulators to understand the machine technologies and that appropriate knowledge, e.g. appropriate AM Machine knowledge associated with 'key parameters', is being transferred between the TCHs, machine producers, and other sub-contractors, such that the TCHs and STCHs have full and appropriate knowledge to demonstrate to the regulators full control and responsibility for their products, including maintenance considerations.**

Initial main outcomes (EASA perspective):

- successful open discussion
  - feedback – some 'light bulb' moments for some group members (good!)
  - first time all major AM Machine Manufacturers had been together at a 'working' workshop
- need for all stakeholders to be informed of roles and responsibilities in certification process
  - need for basic certification tutorial similar to composites CMH-17 'level 1'? (supplied by regulators icw TCHs?)
  - TCHs also to cascade responsibility message to sub-contractors
- need for baseline machine reference builds
  - confidence building…not design allowables….

Initial main outcomes (EASA perspective):

- need to define ‘key characteristics’
  - definition?
  - define for each material/process?
  - prioritise knowledge transfer/training wrt ‘key characteristics’?
- need to manage applications in proportion to criticality
  - appropriate guidelines (e.g. ‘low criticality AM products’ EASA Cert Memo)
- need to further process output from the Knowledge Transfer Workshop 2018:

https://www.easa.europa.eu/newsroom-and-events/events/additive-manufacturing-workshop-machine-knowledge-and-training

RECENT Focused Workshop Example:

Machine Producer/Knowledge Transfer/Training – June 28-29th 2018 Koeln

- Invited attendees - 3 groups (based upon different knowledge/different needs):

- Group 1: Machine Manufacturers
- Group 2: TCHs
- Group 3: Operator/MRO/POA/non-TCH DOA & Standardisation bodies

possible focused meeting model!

- closed group discussion and open cross group discussions:

- possible themes suggested in the invitation (repeated in support slides)

- deliberately not constrained to a matrix question/feedback format in order to allow easier identification of any issues. However, one constraint is to address the **key question**:

/Q/ What knowledge* does each group believe that it needs from the other groups (including the regulators) in order to function more efficiently and better meet its (safety) objectives?

* themes, level of detail etc, also see invitation and support slides

Maybe we will identify some common knowledge transfer priorities…

FAA – EASA AM (metallic) Workshop August 21-23rd 2018

Session 1 Debrief: "Design Data for Q&C"

(co-chairs R. Dutton, D. Wells)

- 'Part Family' definition needs standardisation – more standardised requal methodologies (major/minor etc)

'The Industry is ready to move beyond the point design scenario. Establishing an accepted framework that enables the **use of common design values is the key first step** to reducing certification burden.' - 5 step approach proposed:

STEP 1: AM Process Qualification (part agnostic, with some exceptions)

- A. Define a baseline, locked AM candidate process by machine serial number

- B. Qualify the candidate process using commonly accepted metrics (no standards yet) to an accepted and understood state of inherent, yet acceptable "discontinuities" (defect state)

- C. Characterize material performance of qualified baseline process as required for Q&C

- D. Identify AM-specific "influence factors" that may alter material performance.

FAA – EASA AM (metallic) Workshop August 21-23rd 2018

https://www.niar.wichita.edu/niarfaa/WorkshopRegistration/FAAAdditiveManufacturingWorkshop.aspx

Day 1: - Broad range of presentations (see link above)

Day 2 and 3 : - Breakout sessions

1/ "**Design Data for Q&C** – static properties characterization, part family considerations, feature-based qualification, component vs. coupon properties".

2/"**Fatigue and Fracture Considerations** – effect of defects, characterization of defects, characterization of F&DT properties, zoning considerations for F&DT".

3/ "**NDI Inspections and In-situ Process Monitoring** – validated NDI methods for AM (current state), flaw detection capabilities, in-situ monitoring (current and future use)"

Day 3: - Debriefs

FAA – EASA AM (metallic) Workshop August 21-23rd 2018

Session 1 Debrief: "Design Data for Q&C"

STEP 2: Establish common design value properties based upon baseline process and influence factors

STEP 3: Establish statistical process controls that maintain material quality and performance standards throughout production

STEP 4: Demonstrate Equivalent AM Material Performance

STEP 5: Maintain a strong Part Qualification process that ensures each implementation of the qualified AM process and application of properties (and influence factors) has been successful relative to the assumed material performance standards. (1stArticle cut-ups)

FAA – EASA AM (metallic) Workshop August 21-23rd 2018

Session 2 Debrief: "Fatigue and Fracture Considerations "

(co-chairs M. Gorelik, S. Waite)

- effect of defects, characterization of defects, characterization of F&DT properties, zoning considerations for F&DT

- main focus on *safety critical parts* (PSEs, LLPs)

– *tried to focus on product-neutral and agency-neutral considerations when practical*

- *Non-regulatory discussion* – intent to focus on underlying technical issues

1/ Characterization of AM defects
2/ Characterization of effect of defects
3/ Role of Fatigue and Fracture Data in Process Qualification
4/ Expectations from regulators relative to F&DT guidance for AM
5/ Recommendations for AM F&DT research topics *in the context of Q&C*

FAA – EASA AM (metallic) Workshop August 21-23rd 2018

1/ Session 2 - Characterization of AM defects

Should as-built surfaces be included in consideration –YES
- need to consider scan strategy (PBF) for exposed surfaces -may influence level of defects

Sub-surface defects very close to the surface may need a special considerations
- surface treatment may smear pre-existing surface defects

How to build notched fatigue specimens tailored to AM? - -
- machined notches, as-built notches, …

Consider potential for *defects interaction* (e.g. porosity near LOF)

Are conventional measures of roughness in AM adequate for correlating to fatigue debits?

What is the pre-requisite / level of process readiness for generating detailed defect data?
- process maturity, but for inherent anomalies –don't expect data sharing in the foreseeable future (too many company-specific proprietary settings)
- - Note: the answer will likely be different for rogue defects (data sharing may be required; at the moment an Unknown Unknown for AM)Ref: RISC / RoMan activities

FAA – EASA AM (metallic) Workshop August 21-23rd 2018

1/ Session 2 - Characterization of AM defects... cont.

How do we define rogue defects? (in ref. to previous bullet)

External reference: ASTM draft document –"catalog of defects" WK47031

Need to distinguish between as-built vs. post-processing defects

Types of defects for LPBF/ EPBF:

LOF, gas porosity, keyholing, contamination, inclusions, micro-cracks, surface roughness / surface connected features, localized Alpha post-HIP (Ti64), unmelted particles, abnormal microstructure (e.g. abnormal grain growth, ALA grains), support structure "interaction" with part's surface, software-induced defects, cross-layer and layer defects (collinear arrays of defects linked to scan strategy), local non-uniform chemistry

Types of defects for Wire DED:

LOF, interface defects, gas porosity, contamination, inclusions, residual surface defects (not fully removed by machining), cracks, abnormal microstructure (e.g. abnormal grain growth, ALA grains)

Characterization of inherent defects / anomalies

- need to understand the range of practical interest (min size)

Methods: CT + image analysis s/w (e.g. VolumeGraphics), metallography / sectioning, fractography, EBSD(contamination), profilometry, digital X-ray

Frequency charact. –mostly CT, potentially in-situ monitoring

3D characterization may be needed, depending on the application , defect types, criticality, …

Starting with 1-parameter (1D) size distribution may be adequate, …need to treat it as location-specific property

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2/ Session 2 - Characterization of effect of defects

Effect of as-built roughness on fatigue –similar or different from other conventional alloy forms?

S-N Curves

If using conventional S-N curve approach, will have high scatter due to *potential variability* in material properties and defect rates / population; may need to consider alternative methods

May depend on how S-N curves are used; consider that we create material and part at the same time.

With so many machines, configurations, etc. – how many S-N curves would we need?

Need to consider specimen size effect.

Can't address rogue defects

For inherent anomalies – should be adequate, if the frequency is such that we have representative set of anomalies within the gage section volume

May get unconservative assessment if fatigue bar's volume is too small compared to parts

Need to generate significant volumes of data to better understand fatigue and fracture behavior (in public domain)

Getting the right pedigree data may be more challenging for AM

Challenge area –highly topologically optimized parts (not enough representative volume)

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2/ Session 2 - Characterization of effect of defects… cont.

Alternative methods to quantify effect of defects

DT assessment, probabilistic approach allows to account for size distribution and frequency of defects
- Don't need to use *probabilistic* approach if we don't have to –deterministic
- DT is much faster and less expensive

Benchmarking – inherent defects that are not detectable by NDI

Conventional (regulatory) DT assessment –any changes for AM?

Need to modify the approach for topologically optimized parts

Do we need a higher level of FCG material characterization for AM?
Depends on the framework the company uses for conventional materials
Potential for location-specific properties, but may be similar to other material systems
May need new test procedures for special features, e.g. thin walls

Can quantify effect of defects (e.g. on Kth and LCF) by artificially generating defects in test coupons

May need to revisit initial flaw size assumptions (for some cases) Deterministic or probabilistic approach?

Need to consider residual stresses

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3/ Session 2 - Role of Fatigue and Fracture Data in Process Qualification

Fatigue and fracture data are more sensitive to process variation, harder to hit acceptable window

- Process changes are easier to detect than with static properties
- Fatigue properties may be different for the same static properties (not unique to AM)
- FCG properties are less sensitive to process variation than LCF
- Anisotropy – no different than for other materials (e.g. single crystal blades)

4/ Session 2 - Expectations from regulators relative to F&DT guidance for AM

Configuration control is a MUST for safety-critical hardware

- Q: By default, it's OEMs responsibility. How can regulators help?

Guidance for owner-produced parts?

- New FAA policy for ASIs is in the works. Plan is to educate ASIs and DERs.

What would be regulatory response to discovering a rogue flaw in AM critical part?

FAA DAR (Designated Airworthiness Representative), DER (Designated Engineering Representative) , ASI (Aviation Safety Inspectors)

FAA – EASA AM (metallic) Workshop August 21-23rd 2018

5/ Session 2 - Recommendations for AM F&DT research topics *in the context of Q&C*

Defect populations and sizes –needs to be developed as a structured study

Seeded defects study (leveraging process maps, e.g. P-V maps) – to understand process boundaries and fatigue behavior of defects

Understanding of the fatigue behavior of defects below the NDI detectability threshold

Understanding of crack nucleation mechanisms for key types of AM anomalies

Correlating in-situ process monitoring with actual defects formation *(need to cross-reference w/NDI and Process Monitoring Session)*

Note: need to capture different process families in the above research areas

Parking Lot:

- Use of sub-scale part models for evaluating full-scale part integrity? May not work for all cases (process scaling issue)
- Can manufacturing credits (similar to AC 33.70-2) be defined for AM?
- How sensitive is near-threshold FCG behavior to AM-specific materials attributes?
- R&D topic –probabilistics based process optimization
- R&D in support of the feasibility of static AM factors

FAA – EASA AM (metallic) Workshop August 21-23rd 2018

Session 3 Debrief: ""NDI Inspections and In-situ Process Monitoring"

(co-chairs , E. Lindgren, M. Mercy)

NDE & Process Monitoring in Defect Management

Design for AM –best practise and design rules
- Part geometry can limit inspection capability - design with inspection in mind

Machine validation and process baseline - starting point for capturing potential defects of concern, more effective use of NDE / Process Monitoring

Facilitators:

Min baseline standard for machines (defect capability)
- More uniform processes and defect behaviour, known variability between machines

Process parameters identified with tolerance (there will be process variance)

Preventative maintenance programme, pre and post run health check, maintain system in control

Decrease variability, but ……will not eliminate the occasional rogue defect!

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A Structured Approach using NDE / Process Modelling/Process Monitoring

Defect characterisation (stochastic and rogue)
- source of anomalies (key process parameters and influencers)
- impact of anomalies (e.g. lack of fusion, residual stress)

Mitigate your anomalies types based upon part criticality and product requirements

Anticipate defects through process modelling & residual stress modelling
- capture accepted operation and measure manufacturing deviations
- predictive indication of variance

In situ NDE

Post process NDE
– leveraging technologies from casting and welding
- existing technologies may have limitations (surface condition)

Customised coupons representative of part features (not NDE, but ……)
- destructive evaluation to infer part behaviour

mix and match approach for material, process, and application combinations

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Areas for future NDE development, group perspective……

Cost effective defect resolution during the build

For as deposited parts NDE limitations exist - as built, as machined, as delivered….

Need for AM specific standards

CT time constraints

Better understanding of anomaly effects

Conversion of in-situ data measurements (e. g. melt pool) into effective diagnostic / preventative tools

Transfer functions
- between defects and measurables
- seeded defect and naturally occurring defects

Structured analysis / decomposition of gaps and / or needs for certification
- system blockers to progress this area

Recent related activities:

PRI: Bodies of knowledge:

- *Process Operator/Technician*
- *Process Planner*
- *Process Owner*

FAA Workshop 2017:
http://www.tc.faa.gov/its/worldpac/techrpt/tc18-3.pdf

SAE ('operator training' – Norway April 2018)

Possible knowledge transfer themes might include (see invitation):

- Who are the key functionaries, e.g. machine operator, CVE, design staff, production staff, training staff, etc. and where does the technical knowledge exist,
  - what background knowledge do they need (theory/practical)
  - what do they need to know?
- what timescales are expected for training of each functionary?

- Knowledge base for CVEs (and/or other key staff members) addressing AM? (EASA understands that knowledge relating to materials, POA, DOA, systems etc may all be necessary to appropriately address the integrated link between design, production, and maintenance)

- Machine producer interface with industry (from the TCH, machine manufacturer, MRO, or other sub-contractor basis)
  - what does the TCH/STCH need to know from the machine producer to clearly demonstrate control and responsibility for the product
  - how does this change in the maintenance environment

Questions?

EASA AM: Strategy:

1 - Understand the technology / process / product and its actual, planned or potential uses.

2 - Identify potential safety / environmental risks.

3 - Define and implement means to mitigate risks working closely with industry and NAAs.

4 - Monitor evolution of technology / product / process and effectiveness of mitigation.

5 - Review and revise implementation of strategy as necessary.

Design philosophy changes:

Do not reduce the existing Level of Safety

- show ‘equivalence’ to existing technologies
- result of: experience, R&D, ‘engineering judgement’, reaction to incidents and accidents, and regulations existing at the time of certification, Type Certificate Holder in-house design practice

Maintain robust ‘aircraft level’ design concept

- address all identified threats, e.g. manufacture, in-service
- similar to established metallic structure, e.g. T. Swift philosophy etc
- local damage may be different, but structural level failure may be driven by the similar failure mode, e.g. buckling