NATIONAL CENTRE ADDITIVE MANUFACTURING

mtc Manufacturing Technology Centre

Challenges of manufacturing a layout optimised EB-PBF component for aerospace flight

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HIGH VALUE MANUFACTURING CATAPULT

NATIONAL CENTRE ADDITIVE MANUFACTURING

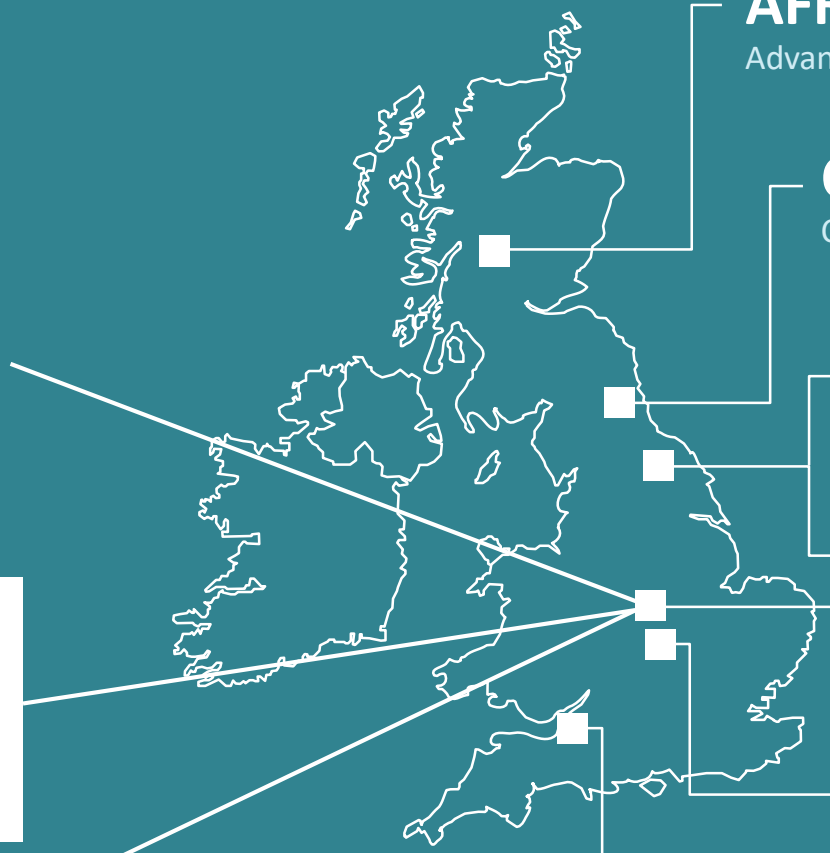
>800 employees
>100 engineers focussed on AM projects

esa

MTC hosts the European Space Agency (ESA) AM Benchmarking Centre since May 2017

ASTM INTERNATIONAL

MTC selected as European partner in ASTM AM Centre of Excellence in April 2018



AFRC
Advanced Forming Research Centre

CPI
Centre for Process Innovation

NAMRC
Nuclear Advanced Manufacturing Research Centre

AMRC
Advanced Manufacturing Research Centre

MTC
Manufacturing Technology Centre

WMG
Warwick Manufacturing Group

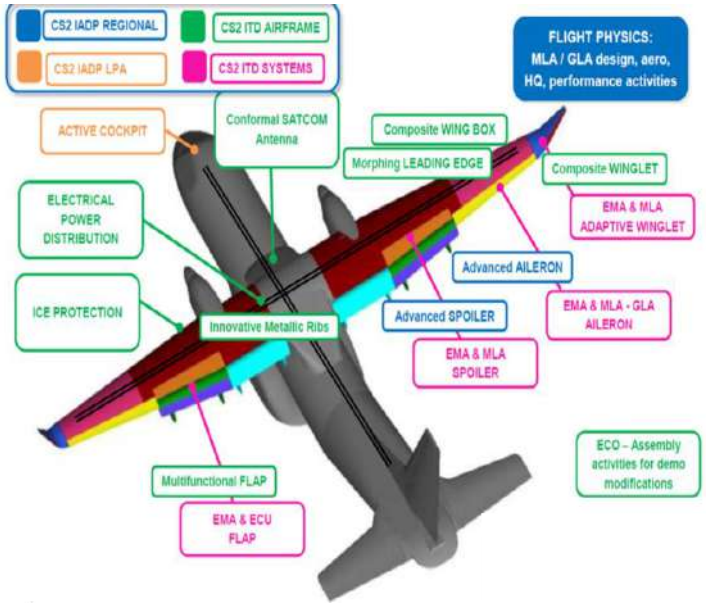
NCC
The National Composites Centre

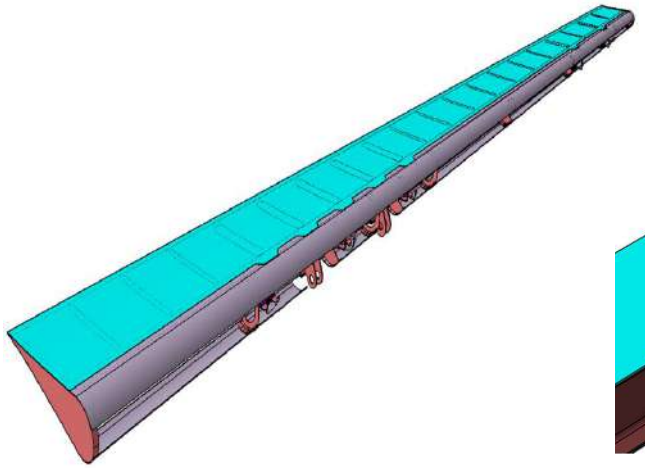
mtc Manufacturing Technology Centre

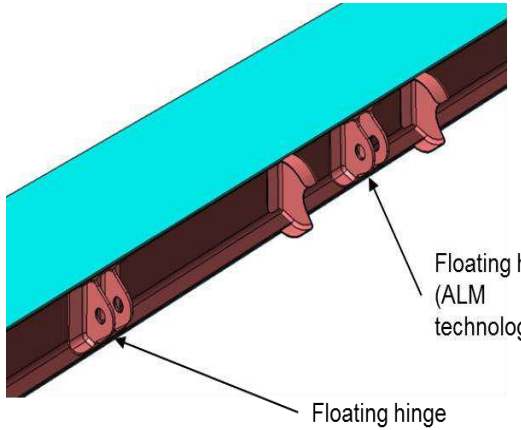
CATAPULT High Value Manufacturing

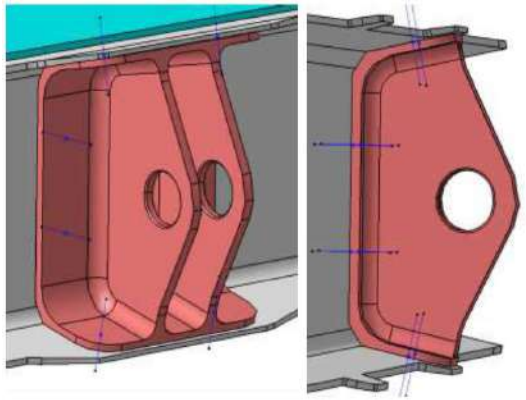
Introduction to AM in EWIRA

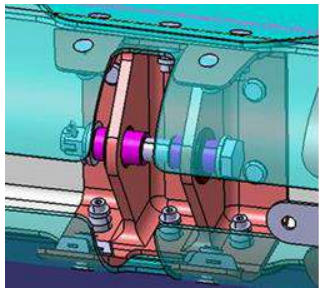
Aileron bracket

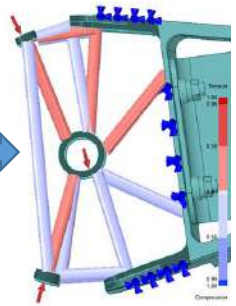


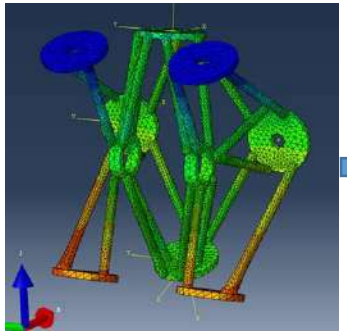


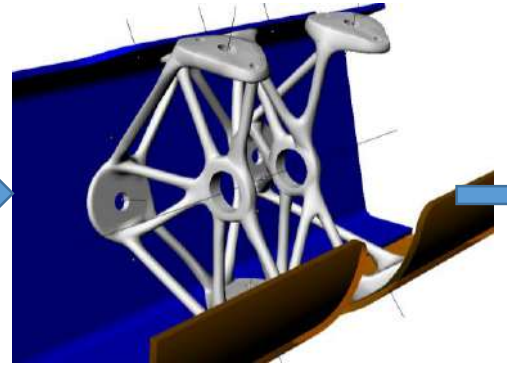












AIRBUS DEFENCE & SPACE

Material Qualification

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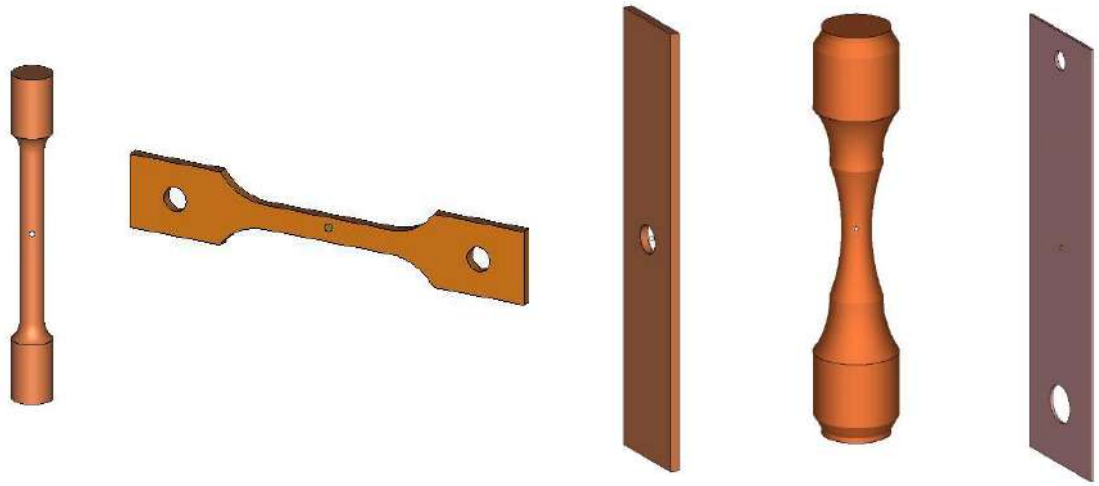
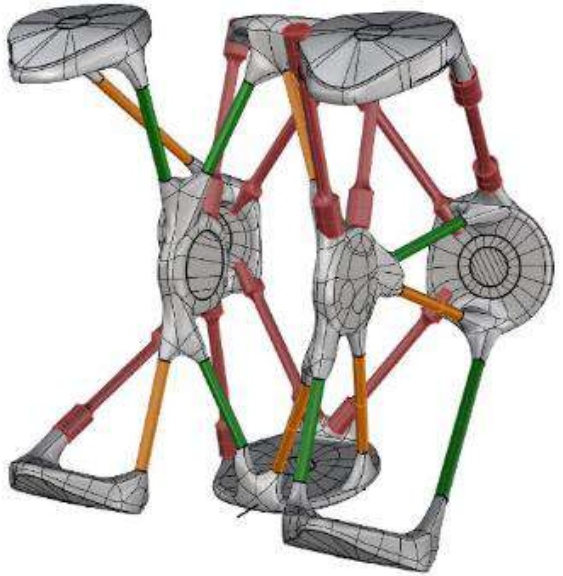
Material Qualification

1. Definition of Statistical Data Analysis methods in relation to requirements
2. Definition of a Materials Test Plan
   - Design of test coupons to meet functional and structural requirements
   - Creation of test matrices to specify coupon testing rationale (quantity/type/location/orientation/etc.)
   - Test Definition
3. Design of a Qualification Test Programme
   - Material testing to generate Material Test Data
   - Test data analysis to generate Material Allowables
   - Material Allowables analysis to create Design Allowables





Challenges for Qualification in AM

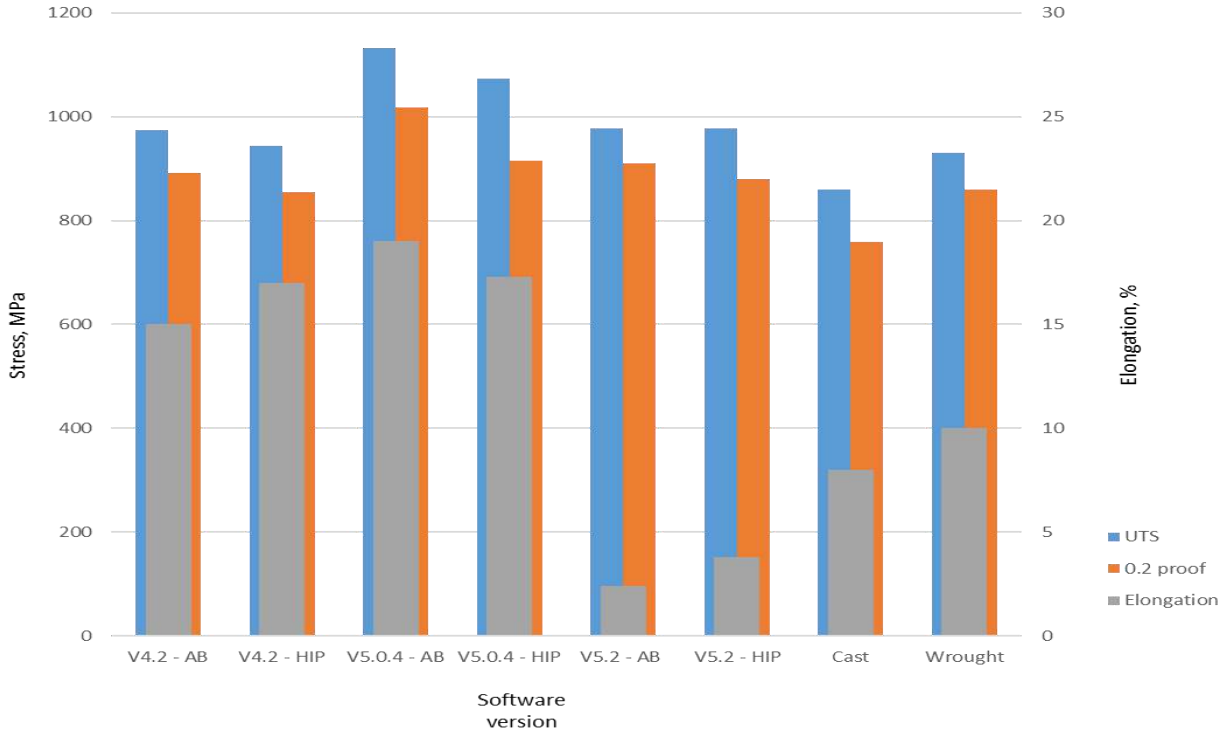
Throughout this material qualification programme we encountered a number of challenges, which resulted in the failure to qualify the part for test flight:

1. Lack of repeatability and reproducibility of the EB-PBF process
2. Sensitivity of the EB-PBF process to design changes
3. Manufacture of conventional/standardised test coupons
4. Setting of tolerances based on conventional manufacturing
5. Surface finishing the component provided the most significant challenge

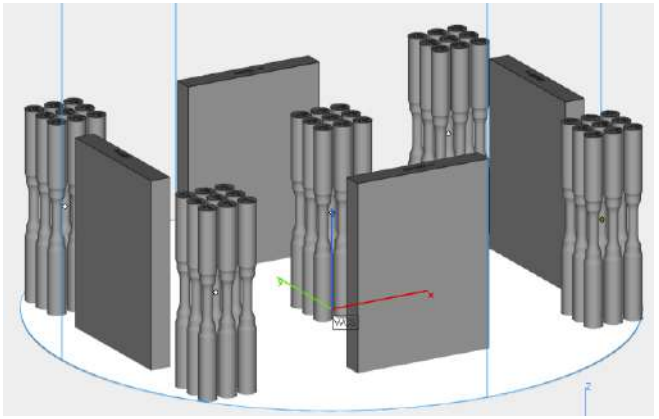
Challenges for Qualification in AM

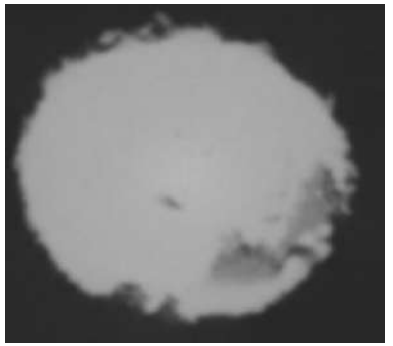
Sensitivity of the AM process

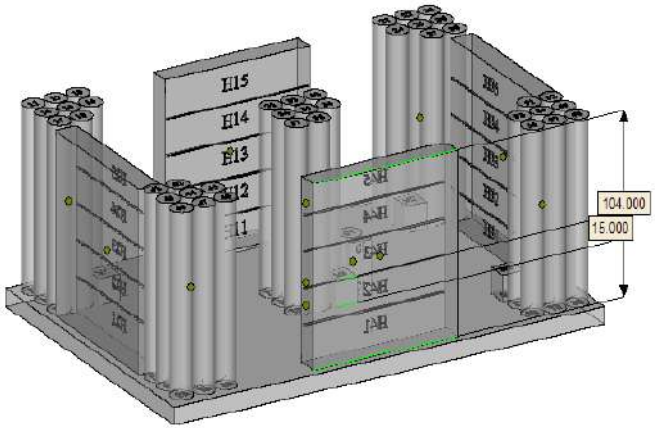
Sensitivity to process change



Sensitivity to geometry



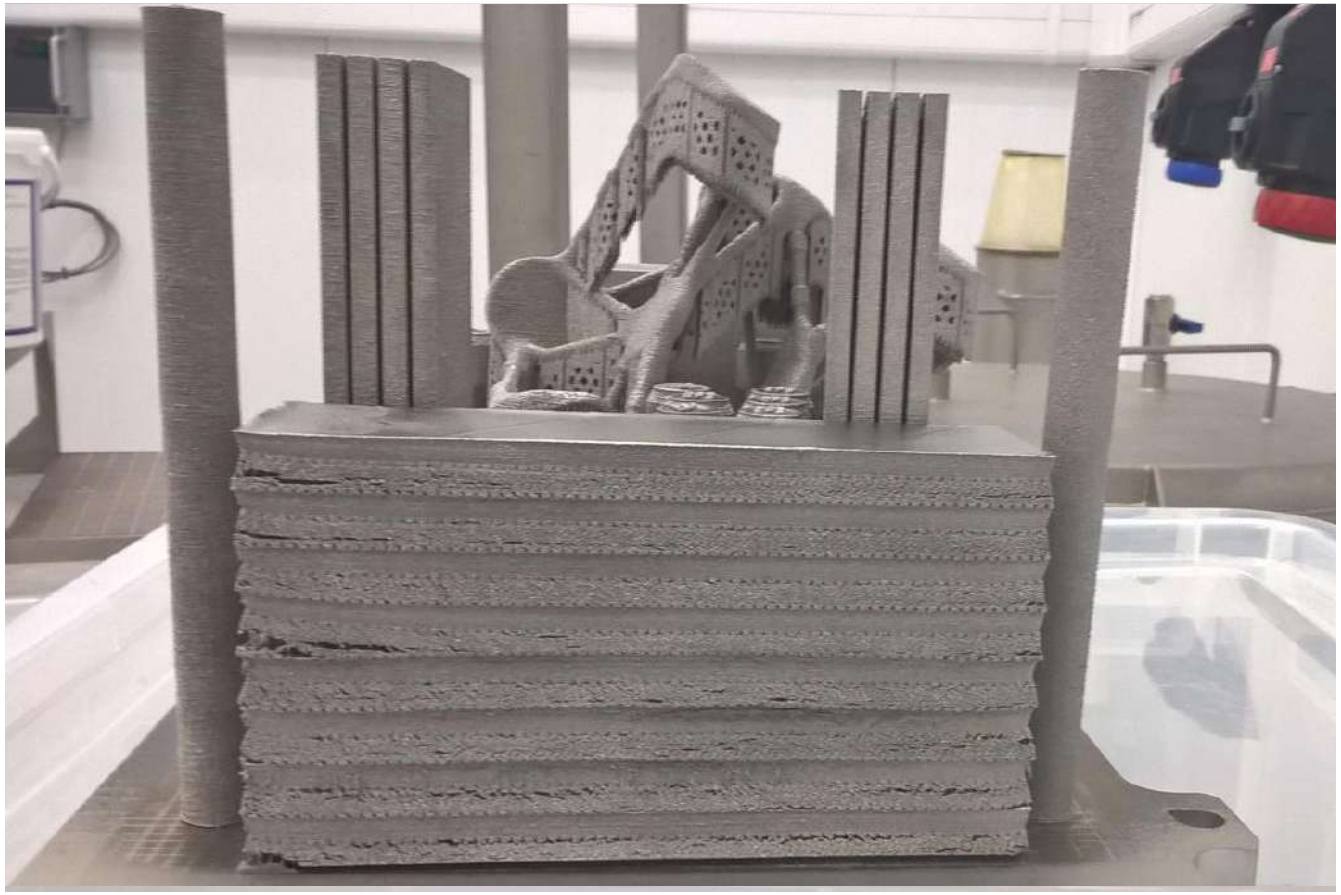




Challenges for Qualification in AM

Test Coupon Design

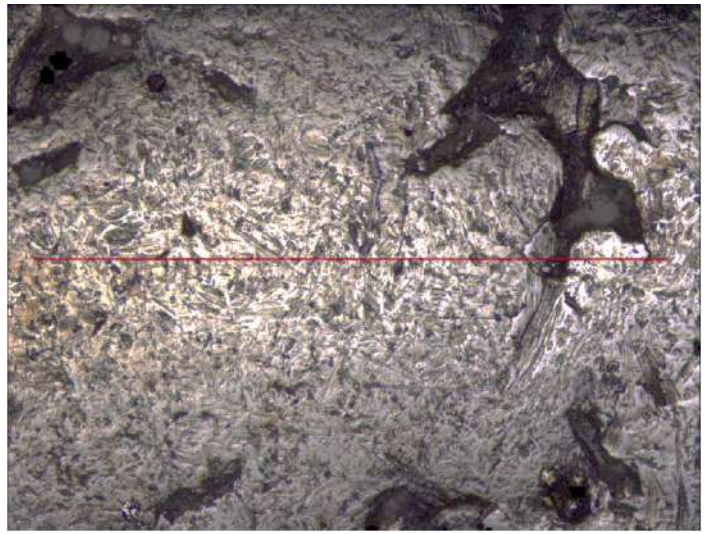
- Over the course of the project over 40 aileron hinge brackets were successfully built.
- However, multiple challenges occurred with the manufacture of some test coupons.
- Orientations with large melt areas showed the largest amount of difficulty.
- Challenge is due to thermal consistency and level of heat input.
- Therefore we should ask a question, surrounding the validity of doing such tests, as it is clear that these components undergo very different thermal cycles that the component does.
- Extraction of test pieces would provide benefits but in lean AM components may not be possible.
- Innovation is required here to improve the applicability of the material qualification process.



Challenges for Qualification in AM

Tolerances and criteria

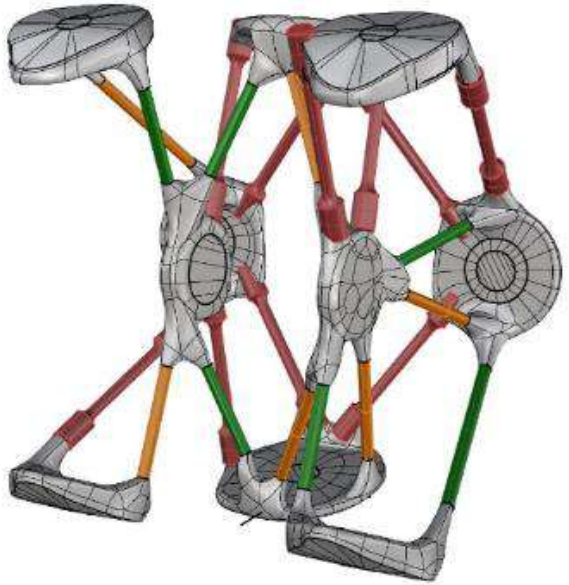
Three key criteria were set for our component based on adoption of the conventional manufacturing process, which posed major challenges to manufacture:



1. Surface finish requirement of 3.2 µm Ra across the entire component surface
   - Stream finishing was not able to achieve this level of surface finish across the entire component.
   - It is unknown that this level of finish will give the required performance under the current conditions and load.
   - Ra is not a sufficient measure to understand an AM surface texture.

2. Defect limit of spherical defects or inclusions no greater than 200 µm
   - This was not linked to a known level of material properties, nor exact fatigue life calculation in the AM component and therefore may have been overly conservative or overly risky.

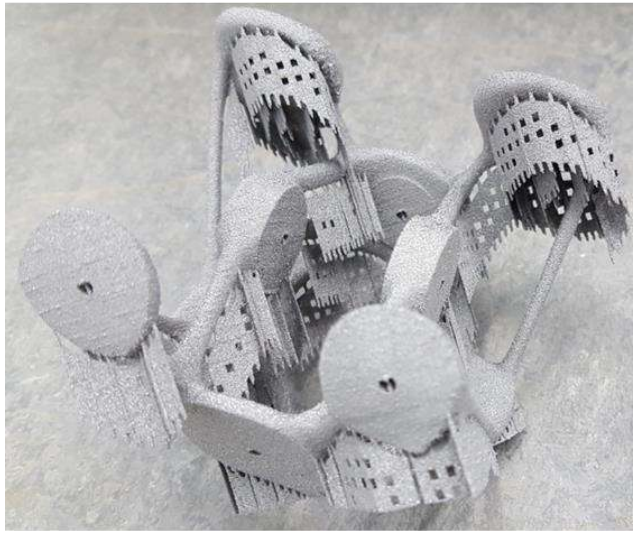
3. Test coupon sizes
   - Standard test piece sizes for various tests require significant material bulk
   - Correlation of bulk material testing to fine featured components must be questioned.
   - Our substantiation test bracket (shown right) with test piece extraction was going to utilised to challenge/validate this point but all are non-valid test geometries.



Challenges for Qualification in AM

Surface finishing

- Multiple surface finishing methods were utilised but the most suitable was demonstrated as stream finishing.
- Significant challenges were observed in achieving an acceptable surface finish, with the 3.2 µm Ra requirement not met.
- A further challenge to the manufacture of the component was prediction of material removal. The stream finishing process removed a significant amount of material but this was challenging to predict and therefore pre-distort during building.
- The design was optimised to allow for improved media flow during finishing, however, the benefits were limited.
- Unknown what effect the compressive residual stresses post finishing have on the fatigue properties and therefore what effect this could have in loosening the surface finish requirement.
- All this uncertainty erodes the confidence in the component, the business case and poses further challenges for qualification and therefore necessitates further testing programmes.



Conclusions

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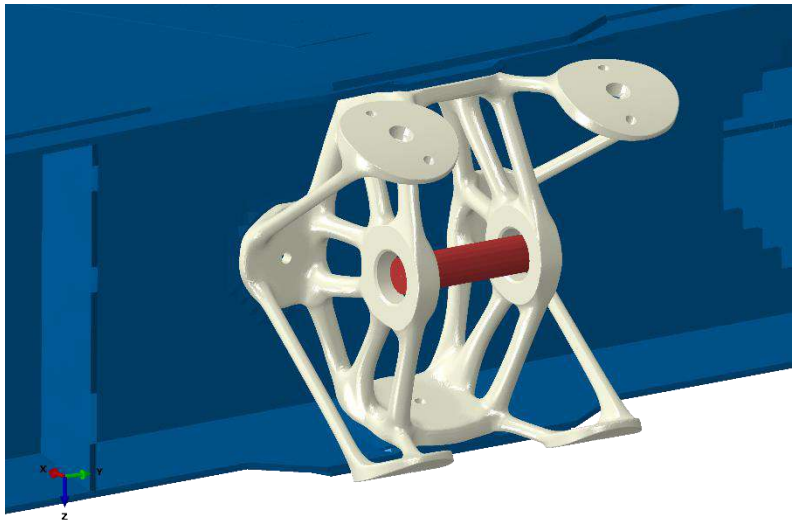
- The redesign of an aileron hinge bracket for EB-PBF provided benefits in weight reduction (15.9%) and waste material saving (90%).
- Qualification for a research permit for flight was not possible due to a number of challenges during the manufacturing process.
- A sensitivity of the AM process to small geometry changes was observed, whereby, reducing cross sections gave very different consolidation to plain geometry.
- Test coupon design is key in ensuring success of a material qualification test programme and we question the validity of using standard coupons sizes for lean AM structures.
- We must work backwards from what the entire manufacturing process is capable of, rather than dictating tolerances from conventionally manufactured products (defect, surface finish or geometry).
- Large challenges were faced with achieving the surface finish requirement but also with accounting for material removed through surface finishing, resulting in weight penalties.
- Challenges for qualification of AM components in critical aerospace applications will be time consuming, costly and therefore will have limited uptake and realisation of the benefits that AM can offer.



Success Stories

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- Multiple examples of AM components qualified for flight with varying levels of criticality.
- GE additive have demonstrated the capability to qualify components for flight. With two high profile examples:
  - Leap engine fuel nozzle
  - Titanium Aluminide low pressure turbine blades for the GE9X engine.
- Rolls-Royce utilised EB-PBF for manufacture of the front bearing housing at the time the largest aero engine structure to undertake a test flight.
- Additionally many AM machine manufacturers are more focused on development of machines for qualification scenarios.
  - Multiple machines (e.g. Arcam and Velo 3D) now offer various beam calibration methods prior to build to improve consistency and accuracy.

Reference: https://www.ge.com/additive/stories/additive-at-scale-avio-aero

Reference: https://www.ge.com/additive/stories/new-manufacturing-milestone-30000-additive-fuel-nozzles

Reference: https://www.theengineer.co.uk/rolls-royce-breaks-additive-record-with-printed-trent-xwb-bearing/

The Future?

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- In order to enable AM to be fully utilised across a full range of components and throughout the levels of the supply chain the qualification journey must be made easier.
- We should heavily utilise what has already been done (standards etc.) and prevent rework but only where the applicability is useful - standard test coupon geometries for fracture toughness?
- Improved standardisation of the AM processes to improve data consistency and correlation.
- Validation and adoption of small (<10 mm) testing techniques for AM, which could help gain more relevant data and reduce the number of builds for a qualification test programme.
  - For example small punch testing and electro-thermal mechanical testing.
- Finally, in order to improve the uptake of AM components in critical aerospace (and other industrial) applications it is expected that a more heavily computational approach is necessary, achieving a reduction in material qualification test programme size and allowing the reuse of data from previous test programmes.

Thank you for your attention

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