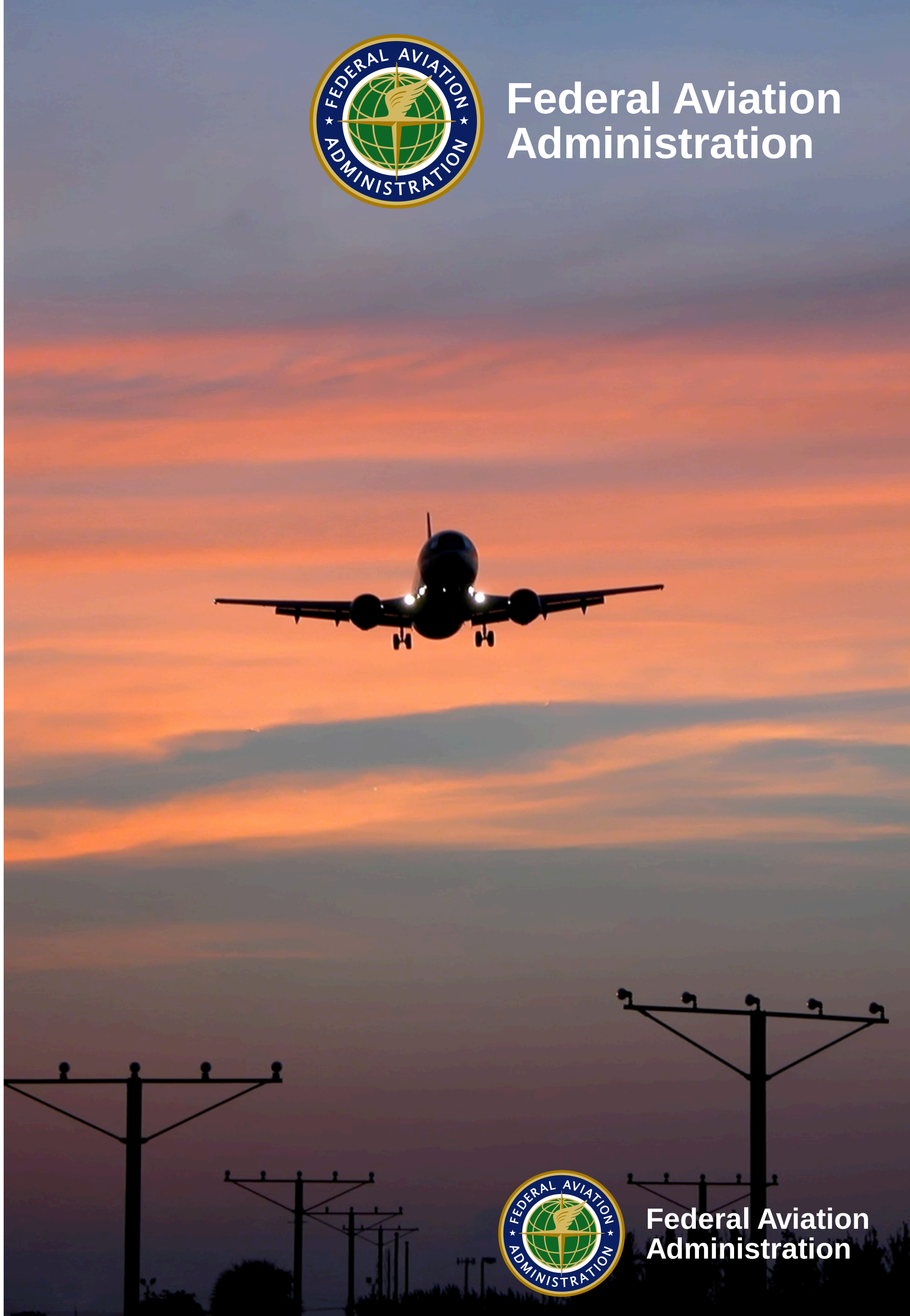
FAA Status on Additive Manufacturing

Presented to: 2016 EASA Additive Manufacturing Workshop

By: Robert Grant

Date: September 28, 2016



Outline

- Recent FAA Activities involving AM
- FAA Internal Memo, "Engineering Considerations for Powder Bed Fusion Additively Manufactured Parts"

Recent FAA Activities in AM

- AMNT (Additive Manufacturing National Team) chartered by FAA management (Oct 2015).
  - Includes representatives of four Directorates, Flight Standards, Tech Center, MIDO, Chief Scientists, and HQ
  - Development of agency's AM Roadmap
- AM added to each Directorates' Significant Project List
- AM Issue Papers (TAD, EPD complete)
- Benchmarking of Type Design Holders and AM machine manufacturer's in progress

Recent FAA Activities in AM, 'cont'

- We are working with other government agencies, standards organizations, academia, and industry including:
  - SAE, ASTM
  - AIA
  - America Makes
- FAA / USAF co-host annual AM Workshop
  - 2nd workshop held August 30 – Sept 1
- Development of an AM Manufacturing Job Aid is in progress for use by FAA ASI's
- FAA Internal Memorandum AIR100-16-130-GM18, "Engineering Considerations for Powder Bed Fusion Additively Manufactured Parts", was issued July 7, 2016. (AM Engineering Memorandum)

FAA AM Engineering Memorandum

- Was developed by AMNT Engineering Team for internal FAA use only.
- Is not FAA policy.
- Is limited to the AM technology of Powder Bed Fusion.
- Is a good starting point for a discussion with an applicant wanting to certify an additively manufactured part.

Federal Aviation Administration

Memorandum

Date:	July 7, 2016
To:	See Distribution List
From:	Richard E. Jennings, Acting Manager, Design, Manufacturing, & Airworthiness Division, AIR-100
Prepared by:	Robert Grant, Electrical and Mechanical Equipment Section, AIR-133
Supported by:	Mark Freisthler (ANM-115), Michael Gorelik (AIR-100), Mark James (ACE-111), and Tim Mouzakis (ANE-111)
Subject:	Engineering Considerations for Powder Bed Fusion Additively Manufactured Parts
Memo No.:	AIR100-16-130-GM18

Background

The introduction of Additive Manufacturing (AM) in commercial aviation part production presents a unique certification challenge to the ACO engineer. The term AM does not describe one manufacturing method, but a wide range of methods, each with its own set of concerns and requirements. The engineering considerations in Appendix 1 are a good starting point for a certification discussion with an applicant that may be documented in an Issue Paper (IP). The ACO engineer may tailor their questions depending on the proposed AM process (e.g., laser or electron beam energy source), the part failure consequence, and the applicable governing regulations.

Appendix 1 addresses the Powder Bed Fusion (PBF) AM process. This memorandum will be updated to include other AM technologies and additional information on the PBF process.

Requested Actions

In evaluating a certification project involving AM, the ACO engineer should discuss the engineering considerations listed in Appendix 1 with the applicant. Each directorate has AM on their respective significant project list; therefore, the certification office must contact the cognizant accountable directorate AM focal point by email to discuss whether a method of compliance IP is necessary.

FAA AM Engineering Memorandum, ‘cont’

Memorandum Outline

1. Definitions
2. General Description
3. Component Design
4. Powder Feedstock
5. Powder Bed Fusion Process
   - 5.1 Process Controls
   - 5.2 Powder Blending
   - 5.3 Powder Recycling
   - 5.4 Energy Source Performance
6. Post Build Consideratons
   - 6.1 General

FAA AM Engineering Memorandum, ‘cont’

Memorandum Outline, ‘cont’

6.2 Powder Removal

6.3 Build Plate and Support Structure Removal

7. Inspection Methods

8. Other Considerations

8.1 Part Models, Build Assemblies, and Associated Electronic Data

8.2 Part Process Control

8.3 Build Interruptions

8.4 Contamination and FOD

8.5 Traceability

9. Process Validation

10. Material Design Values Development

Component Design Considerations

Metal Powder Bed Fusion methods have unique design considerations that the FAA engineer should be aware of:

Support Structures

- Support structures are used to transfer heat away from the part as new layers are added and also to help hold the part's shape as it forms.
- Supports prevent the part from warping during rapid melting and cooling process.
- Support removal process can be intensive.

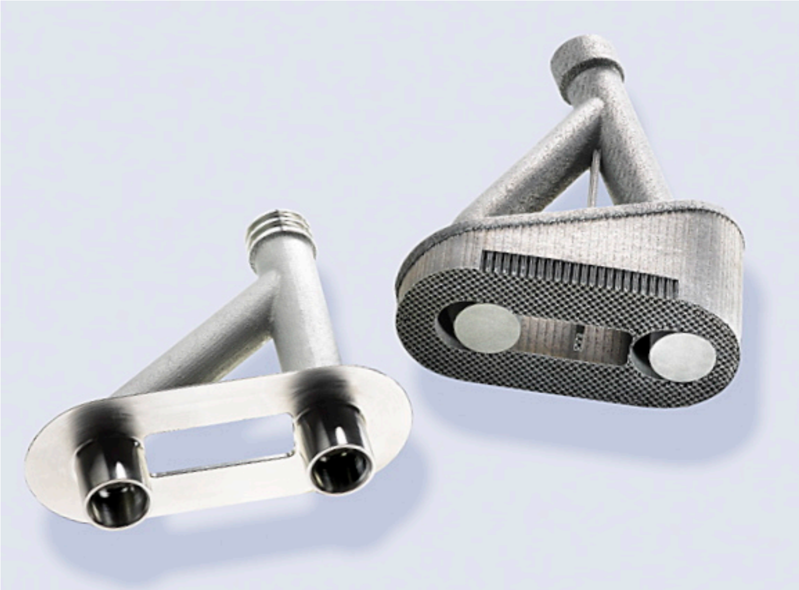


Photo courtesy of Proto Labs

Component Design Considerations, ‘cont’

Surface Roughness

- Varies based on material, build parameters, and part orientation.
- Can be improved by post processing, but all areas may not be accessible.

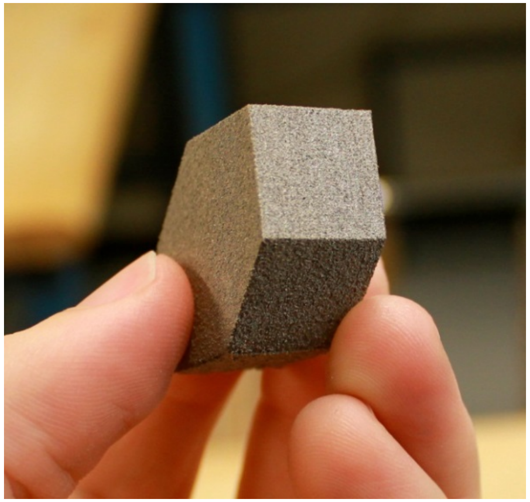


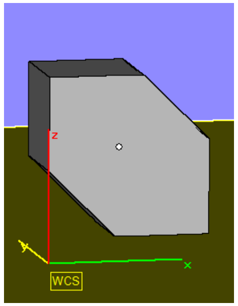
Photo courtesy of Proto Labs

Component Design Considerations, 'cont'

Surface Roughness, 'cont'

Parts have received our standard finish: bead blasting and shot peening

Machine	Material	Vertical Sidewall (Ra)	Angled Upfacing Surface (45°) (Ra)	Upfacing Surface (Ra)	Angled Downfacing Surface (45°) (Ra)
Concept Laser M2 (250 mm)	*Stainless Steel (316L)*	*195*	*225*	*395*	*565*
	Titanium (Ti64 ELI)	*215*	*250*	*305*	*335*
	Aluminum (AlSi10Mg)	*250*	*295*	*415*	*435*
	Inconel 718	*350*	*405*	*610*	*960*



Data and photo courtesy of Proto Labs

Component Design Considerations, ‘cont’

Internal Features

- A significant benefit of the PBF process is the ability to create complex internal features
- Accessibility for powder removal should be taken into consideration
- If an internal feature requires supports, but allows no access, the supports will remain inside.
- The orientation of holes, overhangs, self supporting angles and bridge dimensions must all be taken into consideration when designing areas that may be hard to access.

Courtesy of Proto Labs

Component Design Considerations, ‘cont’

Example Questions

- How is the component oriented on the build platform?
- What considerations led to this orientation?
- How is the component supported (support structure)?
- Does the component have features that overhang or have internal unsupported features?
- What are the unique considerations for these unsupported features?

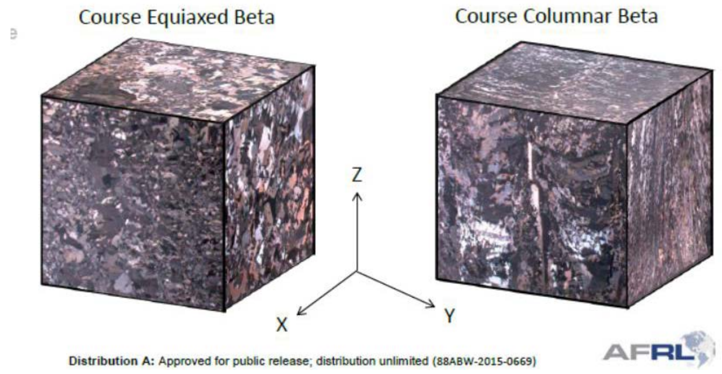
Powder Feedstock Considerations

- Control of the powder feedstock is essential to a quality fusion process.

- The powder shape and particle size distribution affect how uniformly and consistency the powder can be spread in the powder bed.
- Factors such as chemistry, particle size distribution, cleanliness, and powder flow characteristics are expected to be defined in a powder specification.

PBF Process Considerations

- The fundamental goal of the fusion process is to consolidate the powder without the presence of fusion-related defects.
- The fusion process parameters are specified to achieve the desired material density, geometric detail, microstructure, surface texture, etc. of the as-built structure.
- The process must be properly controlled to produce stable and reproducible dimensions, properties, and quality.



PBF Process Considerations, ‘cont’

Process Control example questions:

- What process elements, including parameters, are defined as significant elements and are frozen and require requalification if changed?
- How is the performance of the energy source and associated control systems evaluated?
- How is the performance of the PBF machine with respect to surface texture and detail rendering documented?
- If in-situ monitoring is performed how is the monitored data used (e.g., active control, post build quality evaluation, or for information only)?

PBF Process Considerations, 'cont'

Powder Recycling

- It is expected that PBF process specifications will allow the use of recycled powder.
- Examples of recycle limits:
  - Number of times that the same used powder can be used in a build operation.
  - Number of machine operation hours

Example questions:

- What factor limited the re-use of the powder?
- What requirements does the recycled powder have to meet?
- How is the recycling status tracked and identified for each machine and/or build?

Post Build Considerations

- The post build operations, including the sequence of operations must be clearly stated.
- The post build sequence of operations may affect the final part microstructure, material characteristics, residual stress, and dimensional control.
- It is expected that parts manufactured using PBF will require thermal processing operations to evolve the as-built microstructure into a final form providing proper and predictable material performance.

Post Processing Considerations, 'cont'

Example questions:

- What is the post build sequence of operations?
- How is the part removed from the build plate?
- How is the support structure removed from the part?
- Is a stress relief thermal cycle used?
- Is the part HIPed?
- What heat treatment cycle(s), if any, are aimed at improving the material microstructure?

Inspection Method Considerations

- The physics of the layered AM process does not tend to produce defects with significant height in the build direction.
- Planar defects, such as aligned or chained porosity or cracks tend to form along the build plane.
- The as-built surfaces can be rough and mask the presence of typically unallowable surface defects.
- AM parts may require the use of multiple NDI techniques to achieve full coverage.
- A combination of radiography, dye penetrant, eddy current, or ultrasonic techniques may be used on a single part.

Inspection Method Considerations, 'cont'

Example questions:

- What NDI methods are used on the as-built part?
- What NDI methods are used on the final part?
- What flaw type, if any, is each NDI method intending to detect?
- How is micro-sectioning of parts and microstructural evaluation of designated locations used in the production inspection program?

Other Considerations

Part Models, Build Assemblies, and Associated Electronic Data

- The number of electronic files required to execute the AM process can be large.
- This includes part CAD files, test geometry files, support structure definition, part build file, STL files, slice files, parameter files, and execution scripts.

Example questions:

- Describe the configuration control, traceability, and security of these electronic files.
- What witness specimens are included in the build file?

Other Considerations, ‘cont’

Contamination and Foreign Object Debris (FOD)

- A plan to address the control of contamination and FOD during all operations associated with the PBF process is necessary
- Airflow in the build chamber is important to prevent the by-products of the fusion process from falling into the powder bed.

Traceability

- A list of records associated with each part produced may be necessary.
- Records such as powder heat, powder condition, machine S/N, and build number may need to be retained for each part produced.

Process Validation Considerations

- Process Validation is the methodology used to verify that a component manufactured to a specific process, process sequence, and drawing requirements meets design intent.
- Requirements may include part cutups, metallurgical examinations, chemistry, mechanical properties, and review of manufacturing sequence sheets.
- Aspects of variability to be considered include, but are not limited to feedstock variability, machine variability, and variability within the build volume.
- When a robust process that is determined to meet design intent is established, the process is frozen.
- All changes to significant process elements in a frozen process specification must undergo re-qualification.

Process Validation Considerations, ‘cont’

Example questions:

- What procedure ensures that significant process elements in the frozen specification are not inadvertantly changed?
- What changes result in a requalification to a frozen process specification?
- What is the procedure for evaluating and approving changes to a frozen process specification?

Material Design Values Development Considerations

- Material strength and design values used for AM components that require structural analysis must account for variability due to the material and production methods.
- The physics of the layered AM process may produce anisotropic material properties.
- In general, the variability of the material in the final component is accounted for by testing of specimens extracted from actual components.
- If specimens can not be extracted from actual components, purpose built witness specimens may be used.
  - However, this will require that the witness specimen material properties are shown to be representative of the actual part.

Material Design Values Development Considerations, 'cont'

Example questions:

- Were the material design values determined using test specimens produced in accordance with frozen material, process, and part specifications?
- What sources of variation were evaluated during the material design value test program?
- Did the material design value test program encompass sufficient lots of material and production builds to capture the variability of the final production material?
- What are the key types of material anomalies that may result in material property debits?
- How were the effect of anomalies established and reflected in the material design values?

Contact Information

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Questions?

Information Slides

FAA Regulations

§ 2X.603 Materials.

The suitability and durability of materials used for parts, failure of which could adversely affect safety, must:

- Be established on the basis of experience or tests
- Meet approved specifications that ensure their having the strength and other properties assumed in the design data; and
- Take into account the effects of environmental conditions, such as temperature and humidity, expected in service.

FAA Regulations, ‘cont’

§ 2X.605 Fabrication methods.

- The methods of fabrication used must produce a consistently sound structure.
- If a fabrication process requires close control to reach this objective, the process must be performed according to an approved process specification
- Each new aircraft fabrication method must be substantiated by a test program.

Publically available AM material and process specifications have not been used in FAA approved metallic AM parts.

✓ Company-developed proprietary specifications

FAA Regulations, ‘cont’

§ 2X.613 Material strength properties and design values.

- Material strength properties must be based on enough tests of materials meeting specifications to establish design values on a statistical basis.
- Design values must be chosen to minimize the probability of structural failure due to material variability. Design values must assure material strength with the following probability:
  - Single load paths, where failure would result in loss of structural integrity of the component , 99% probability with 95% confidence
  - Redundant load path, 90% probability with 95% confidence statistics

FAA Regulations, 'cont'

§ 29.619 Special Factors

(a) The special factors presecribed in 29.621 through 29.625 apply to each part of the structure whose strength is -

(1) Uncertain; or

(2) Likely to deteriorate in service before normal replacement; or

(3) Subject to appreciable variability due to –

(i) Uncertainties in manufacturing processes; or

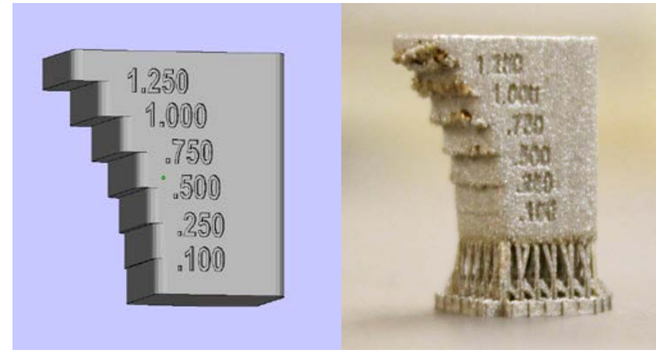
(ii) Uncertainties in inspection methods.

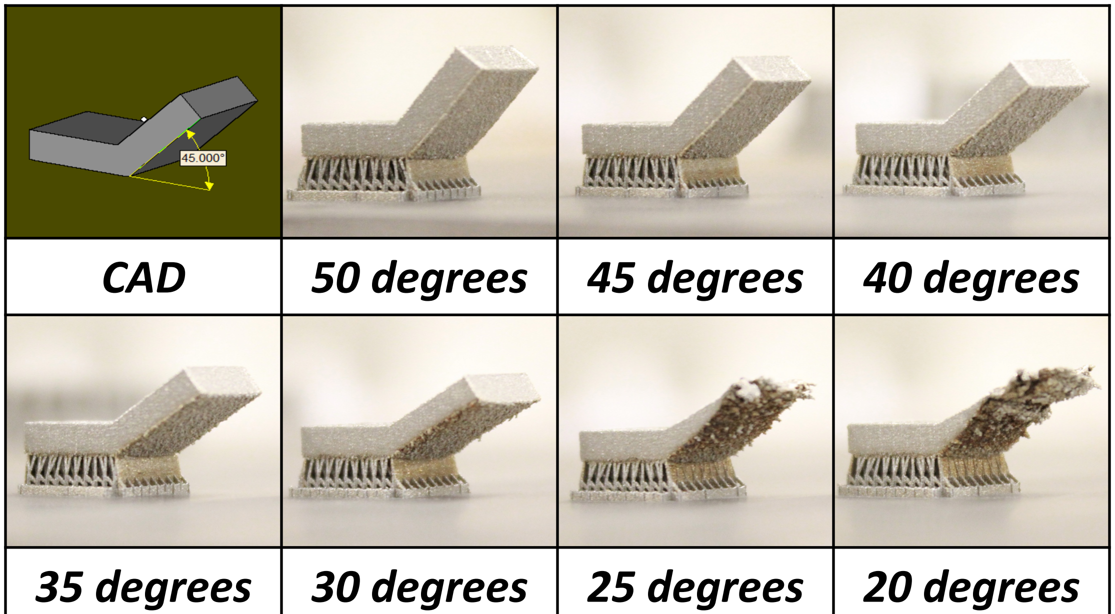
AM Research

- **Research to support policy, guidance and rulemaking**
  - Partner with AM Consortia
  - Methodology for developing special factors and design values
  - Effect of material reuse
  - Sensitivity study for threshold behavior of anomalies and assessment of NDI methodologies.
  - Development of F&DT framework for AM parts

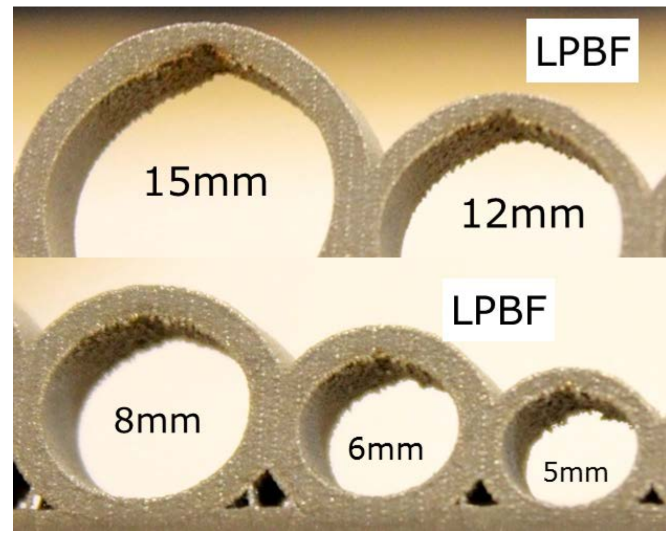
Component Design Considerations

- The orientation of these features to the build plate or the use of support structures can help mitigate the build issues shown here.





316L, 30 micron layers (LPBF)



Photo's courtesy of Proto Labs

America Makes

As the national accelerator for additive manufacturing (AM) and 3D printing (3DP), America Makes is the nation's leading and collaborative partner in AM and 3DP technology research, discovery, creation, and innovation. Structured as a public-private partnership with member organizations from industry, academia, government, non-government agencies, and workforce and economic development resources, we are working together to innovate and accelerate AM and 3DP to increase our nation's global manufacturing competitiveness by:

- Fostering a highly collaborative infrastructure for the open exchange of additive manufacturing information and research.
- Facilitating the development, evaluation, and deployment of efficient and flexible additive manufacturing technologies.
- Engaging with educational institutions and companies to supply education and training in additive manufacturing technologies to create an adaptive, leading workforce.
- Serving as a national Institute with regional and national impact on additive manufacturing capabilities.
- Linking and integrating U.S. companies with existing public, private, or not-for-profit industrial and economic development resources, and business incubators, with an emphasis on assisting small- and medium-sized enterprises and early-stage companies (start-ups).

Established in 2012 and based in Youngstown, Ohio, America Makes is the flagship Institute for the National Network for Manufacturing Innovation (NNMI) infrastructure of up to 45 Institutes to follow and is driven by the National Center for Defense Manufacturing and Machining (NCDMM).