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Experimental Characterization of Surface Roughness and Geometric Evaluations of Thin-Wall Laser Powder Directed Energy Deposition

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Presenter Biography

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Paul Gradl

Paul Gradl is a Senior Propulsion Engineer at the NASA Marshall Space Flight Center (MSFC) in Huntsville, Alabama, United States. Mr. Gradl serves as Principal Investigator and leads several projects for additive manufacturing of liquid rocket engine combustion devices and supports a variety of development and flight programs over the last 17 years. He authored and co-authored over 60 journal articles and conference papers; holds four patents in additive; and regularly teaches courses in additive manufacturing. Gradl is the recipient of numerous NASA and industry awards including two NASA Exceptional Achievement Medals, NASA Exceptional Service Medal, NASA Research and Technology, and a NASA Space Flight Honoree to name a few. Mr. Gradl is an Associate Fellow of American Institute of Aeronautics and Astronautics (AIAA), serves on several committees across industry and chairs various sessions at leading conferences on additive manufacturing, and a PhD candidate at Delft University of Technology. Mr. Gradl is currently authoring a textbook on metal additive manufacturing for propulsion. Gradl was named one of “The Most Influential Personalities of Additive Manufacturing in 2020” by 3Dnatives.

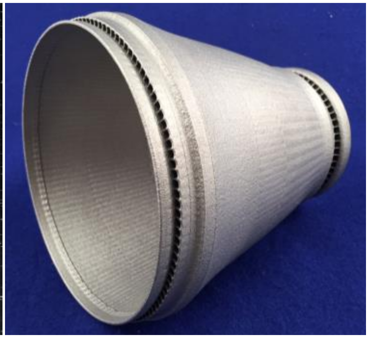
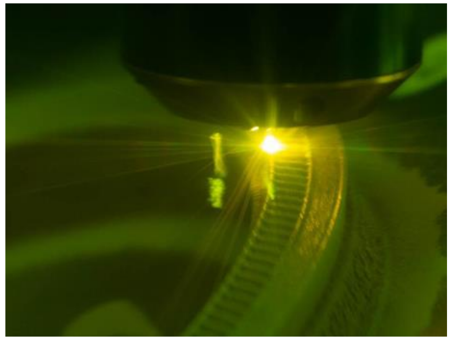
Background of Application

- NASA and commercial space have been adopting additive manufacturing (AM) to replace and augment traditional manufacturing techniques.
- One of the primary uses of AM is for complex heat exchanger components (e.g. combustion chambers, nozzles) for industry and aerospace applications.
- AM allows for cost and schedule reductions in addition to minimizing parts.
- Most of the process development and research advancements have been on the Laser Powder Bed Fusion Process (L-PBF).

Motivation and Research Need

- L-PBF provides fine feature resolution (~0.2 mm) needed for heat exchanger components but is limited in build diameter to < ~600 mm diameter.
- AM processes such as directed energy deposition (DED) offer build sizes > 1 m in diameter, but generally lack the fine feature resolution.
- The Laser Powder DED (LP-DED) process has been demonstrated as a potential option to build large scale nozzles with integral channels in walls at 1 mm.
- There is a gap in research associated with LP-DED fine features, limitations of features, and surface roughness characterization for the LP-DED process.
- The focus of this research is on surface roughness, which can impact fluid flow pressure drop and fatigue life.



Objective of this Presentation

- Introduce the concepts of using the LP-DED process for thin-wall (~1 mm) fine features, while maintaining the ability to build large scale components (>1 m).
- Provide an overview of experiments conducted to determine generic feature geometry and limitations for heat exchangers.
- Discuss average surface roughness (Sa) as it relates to the LP-DED process.
- Provide experimental results from the LP-DED process to reduce surface roughness as it relates to thin-wall features.

Overview of the LP-DED Process

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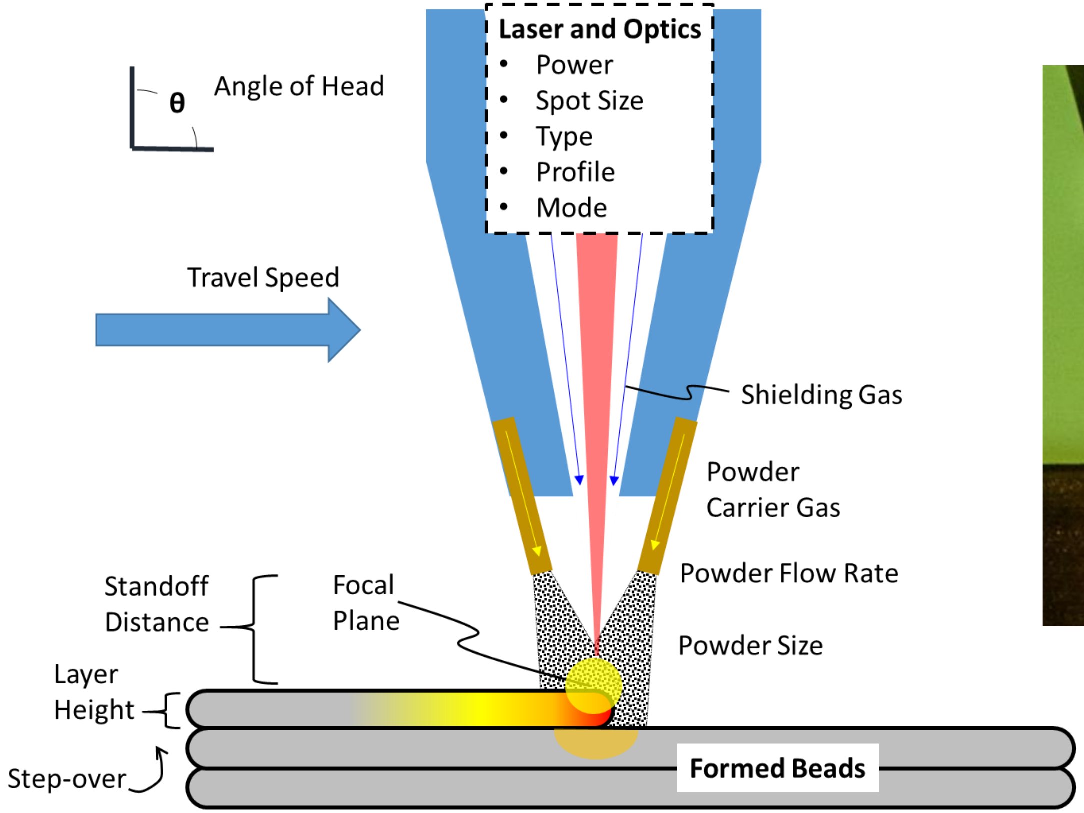
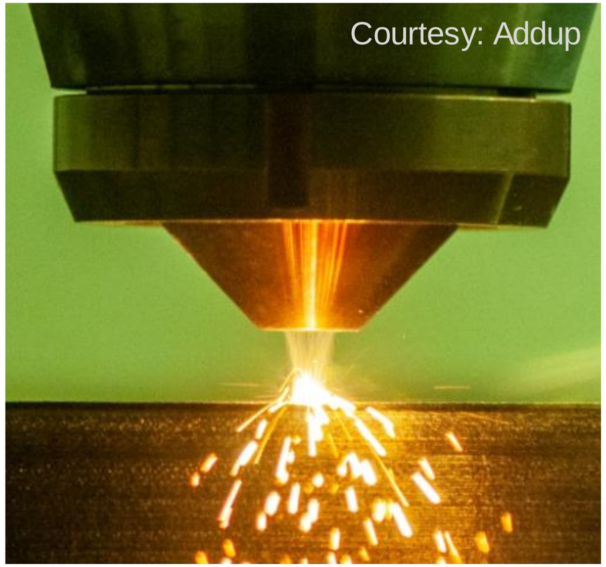
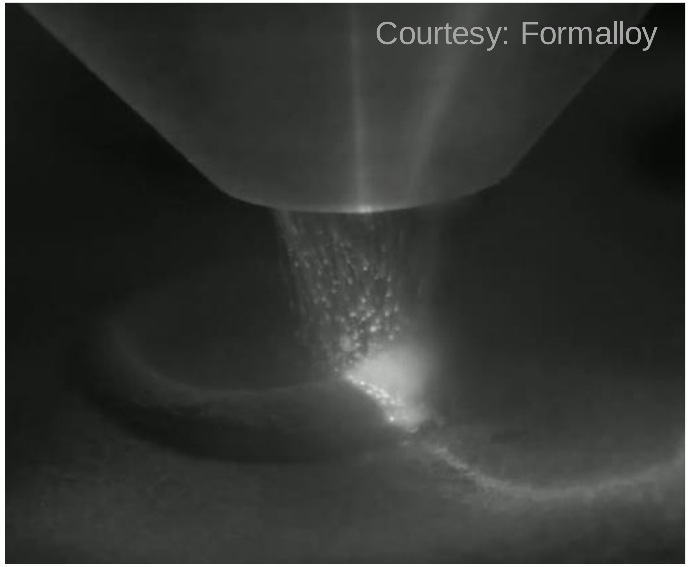
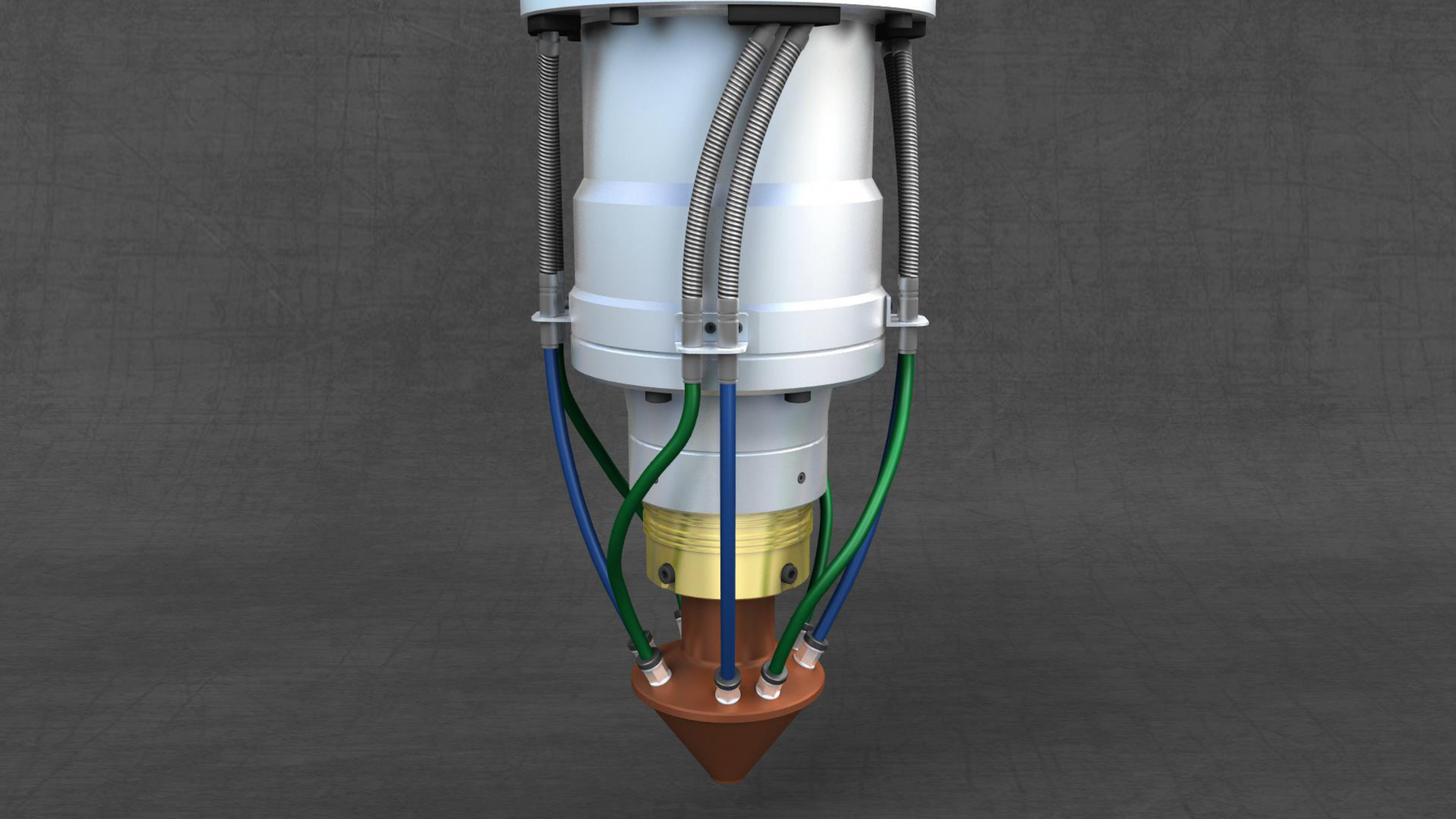
LP-DED process blows powder into a melt pool created by a laser based and can build freeform components based on a defined toolpath

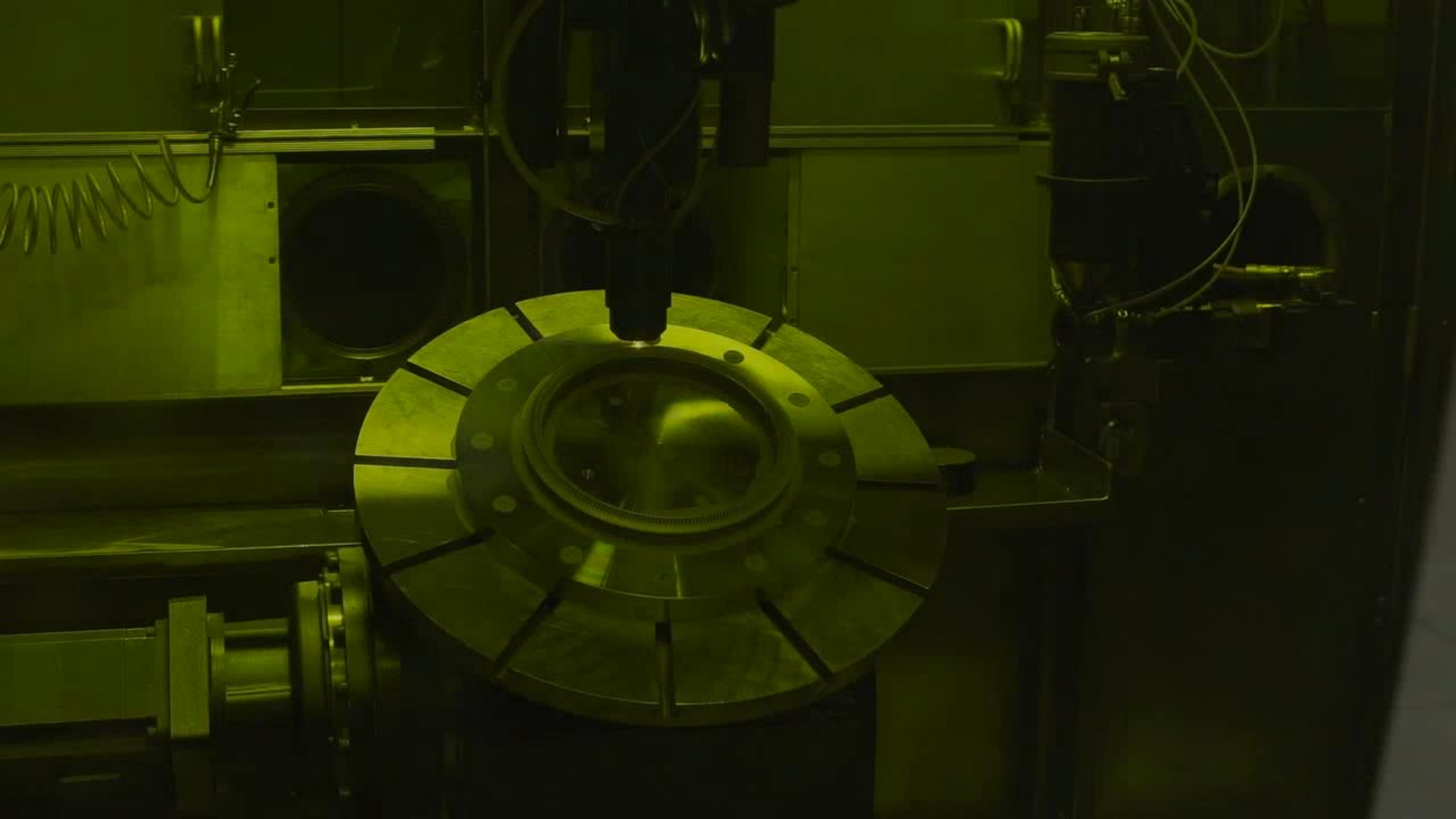


Gradl, Protz, Mireles, Garcia. Metal Additive Manufacturing for Propulsion Applications. AIAA book, in review.









Initial Experiment to Understand LP-DED Roughness

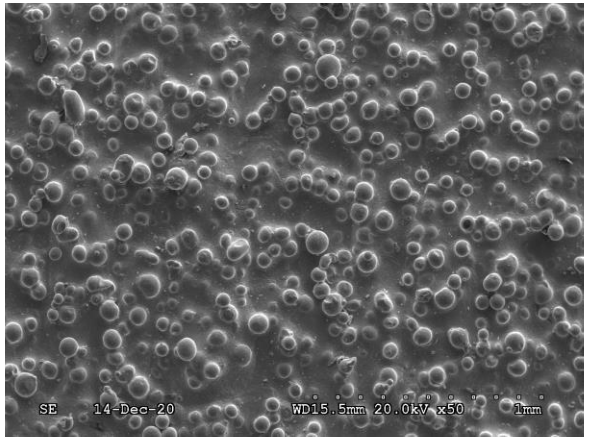
- Completed a Design of Experiments (DOE) to determine contributing build parameters and factors for surface roughness
- Alloy used was NASA HR-1 (Fe-Ni hydrogen resistance alloy)
- Geometry used was a “racetrack” ~75 mm length and ~30 mm height
- Varied all parameters in a 35-run split-DOE (coarse and fine powder)

Down selected Parameters	Values
Laser Power	Low, Standard, High
Flow rate of powder	Low, Standard, High
Travel speed (feed rate)	Low, Standard, High
Layer height	Low, Standard, High
Powder Size	Fine (15-45 µm) ; Coarse (45-105 µm)

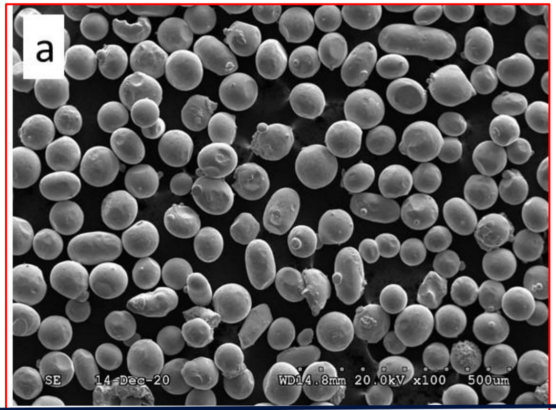
Initial Experiment to Understand LP-DED Roughness

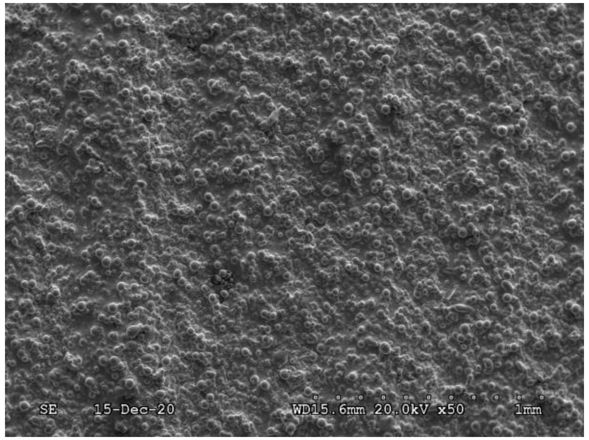
External of Sample

Sample of Powder

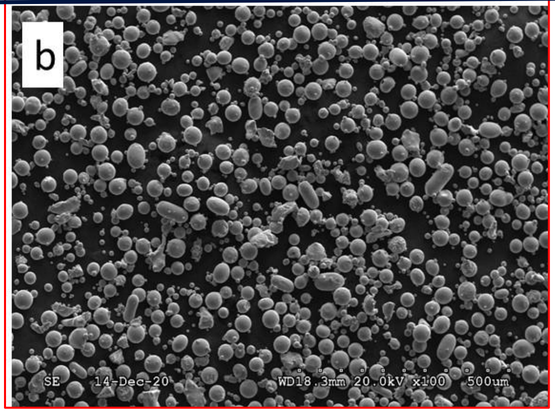


Coarse Powder (45-105 µm)





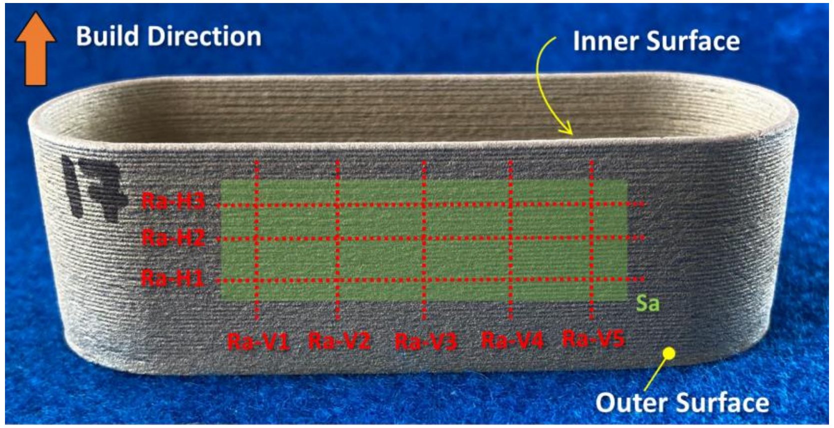
Fine Powder (15-45 µm)

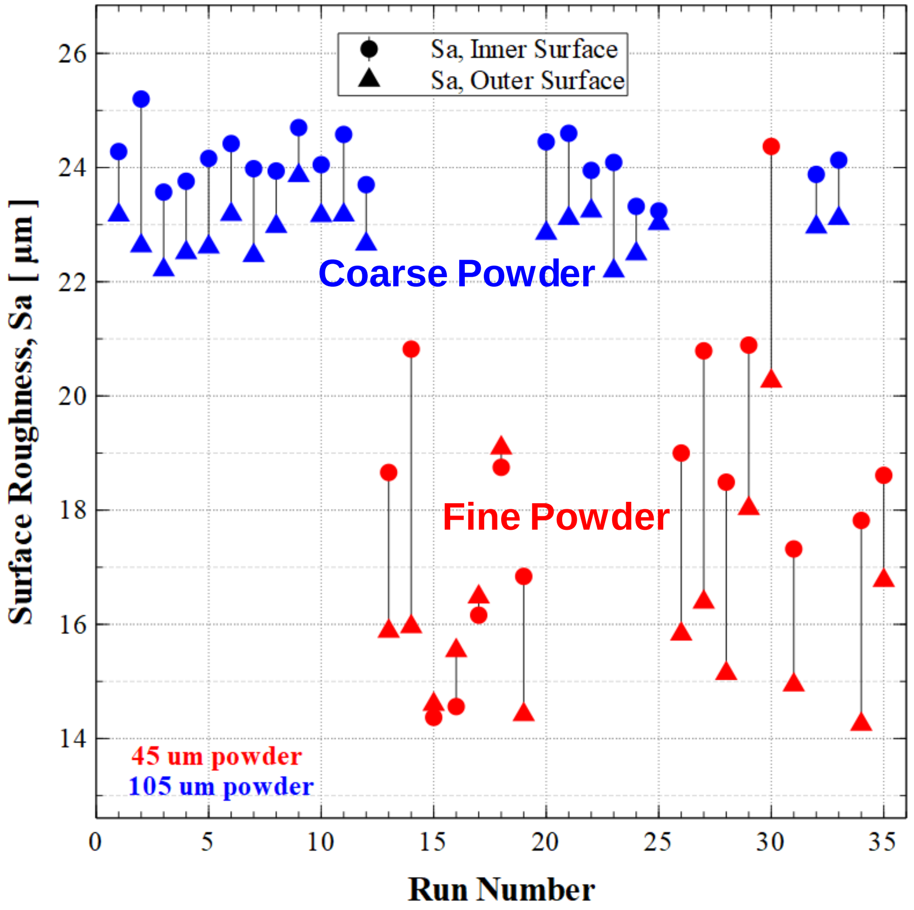


With LP-DED process the excess powder not melted can adhere to the sidewalls and increases the surface roughness

Initial Experiment to Understand LP-DED Roughness

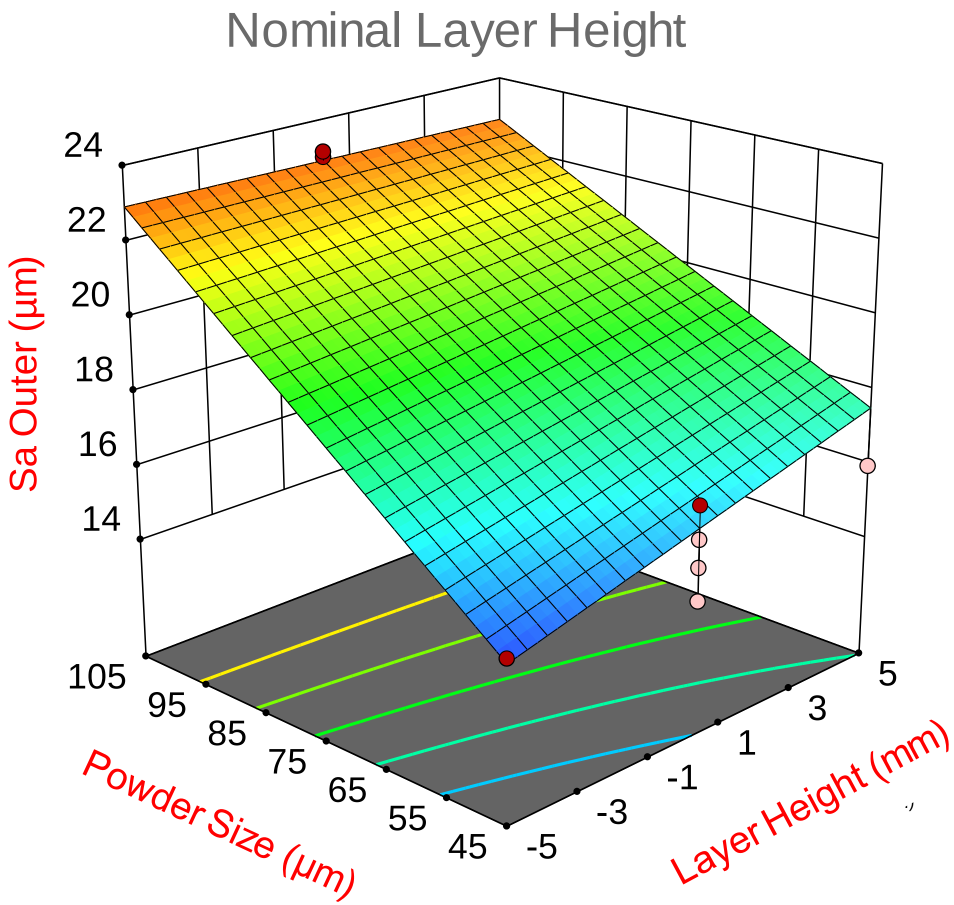
- Measured average surface roughness (Sa) using Keyence VR-5200 at 80x magnification
- Outer surface measured, samples sectioned and then measured inner surface
- No filtering used for initial measurements
- Sa evaluated as one of the primary responses in experiment
- Differences observed in internal and external surfaces
- Repeatability measured at ±0.7µm, consistent with instrument error





Experiment Results to Understand LP-DED Roughness

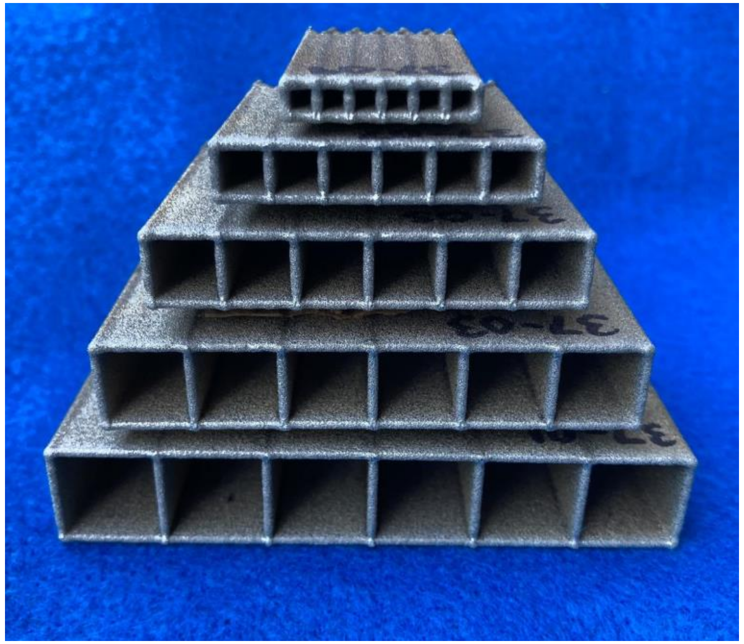
- Powder size was the primary contributing factor with layer height also having some contribution
- The interactions between powder and layer height were also significant; interaction between powder and travel speed also significant
- Fine powder is more sensitive to changes in the build parameters
- To minimize surface roughness, fine powder, and lower layer height can be used, but lower layer height increases the build time

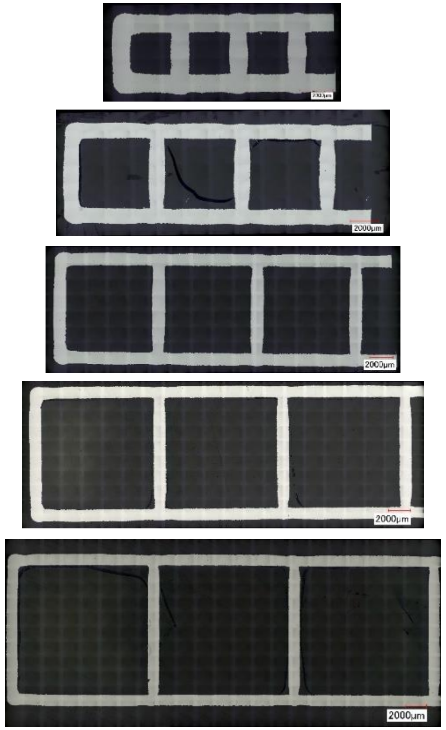


Fine Feature Channels

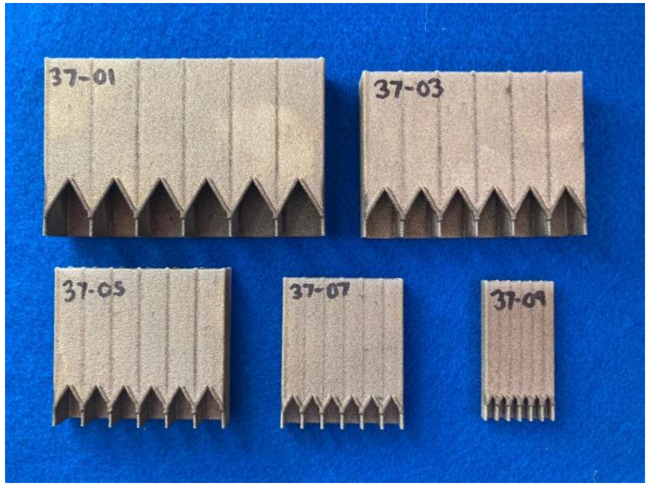
- Completed a series of fine feature builds with 1 mm wall thickness and different powder size distributions (15-45 µm ; 45-105 µm) using nominal parameters (350 W)
- Demonstrated the ability to successfully build integral channels to 2.54 mm with ease of powder removal

2.54 mm
5.08 mm
7.62 mm
10.2 mm
12.7 mm

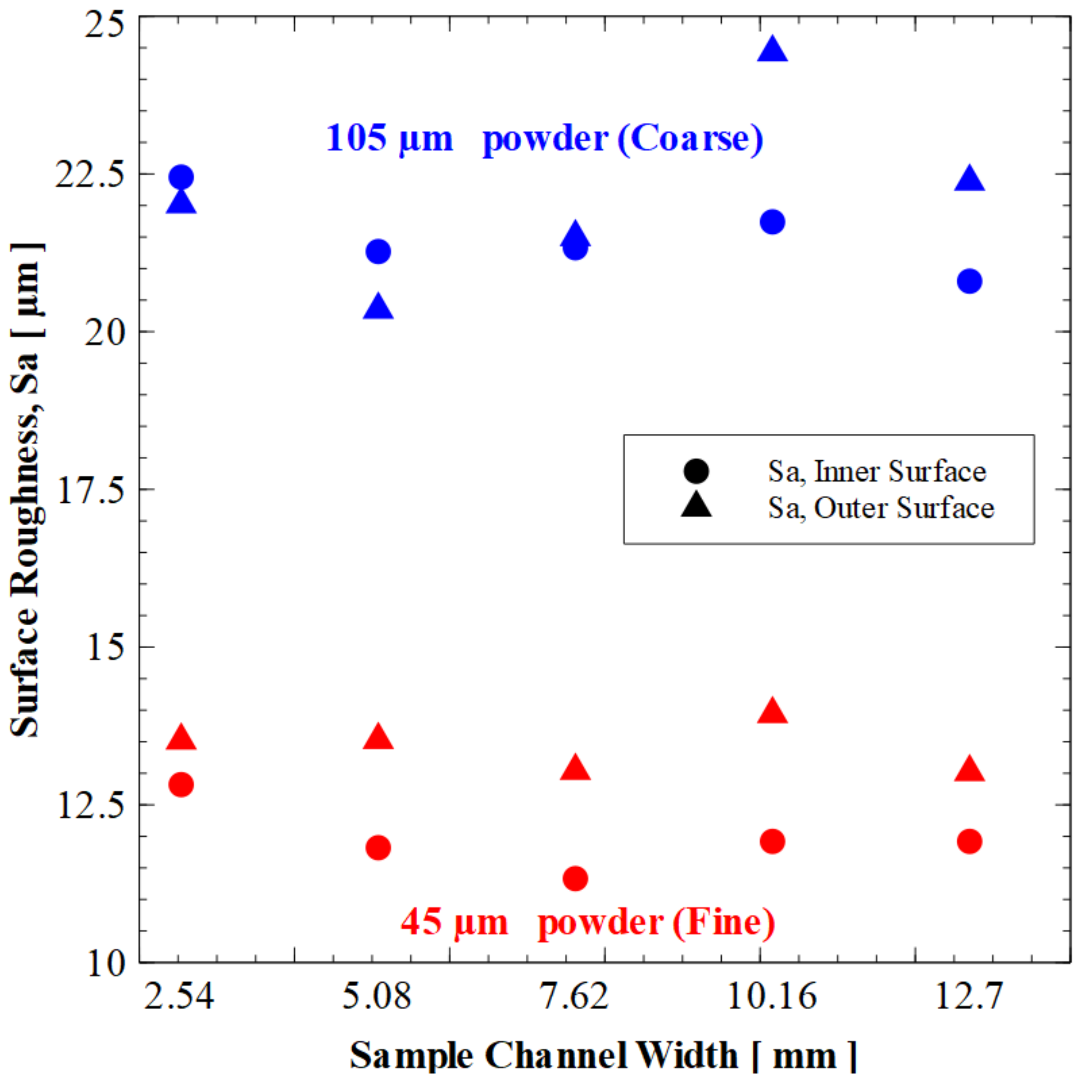




Fine powder shown



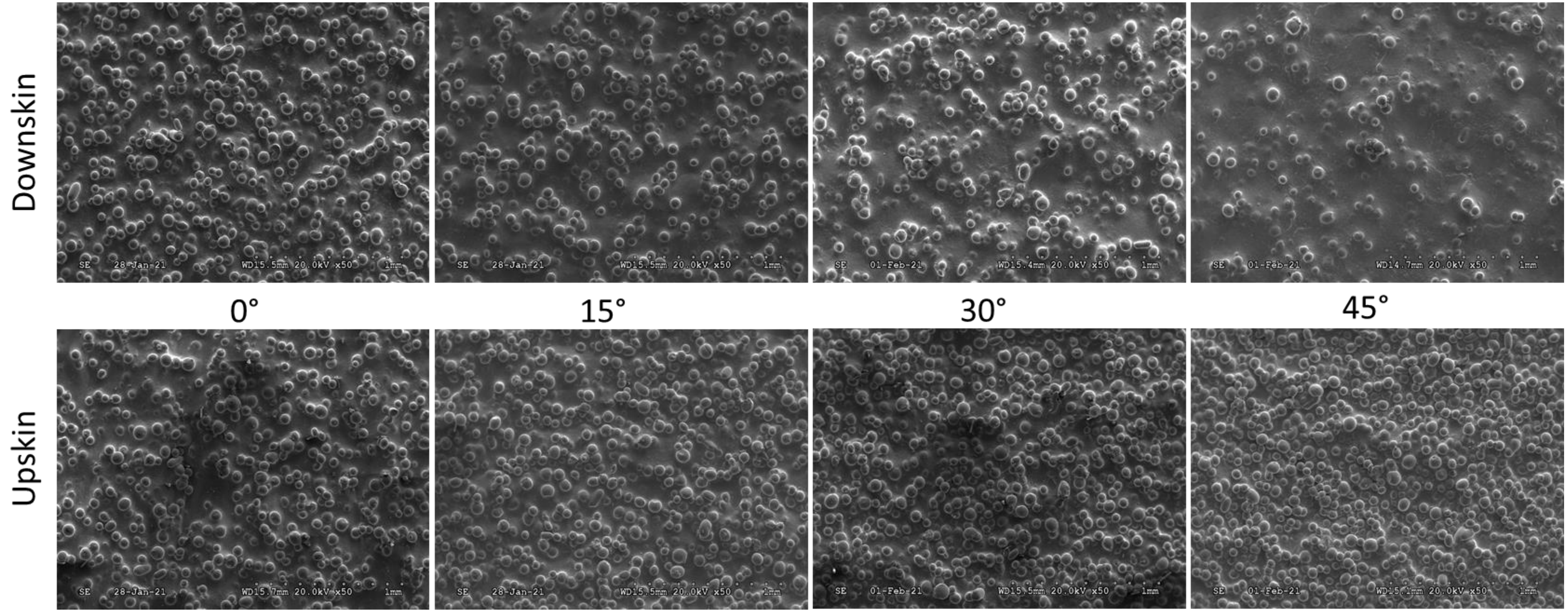
Results from Fine Feature Channels

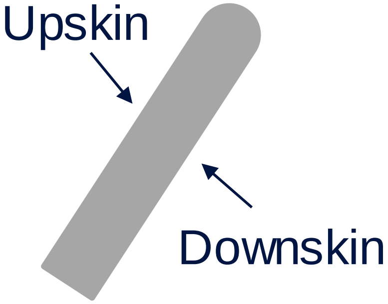


- Outer surface shows higher roughness; opposite of channels from racetrack experiment
- Primary difference is the enclosed racetrack and size compared to the powder exit at bottom of channel
- Fine powder tends to suspend more in the machine during build (outer surface) where inner surface is regularly purged – powder blown through with less opportunities for bonding
- High velocity flow on internal surface compared with low velocity on external surface during build

Variations in Build Angle

Angle relative to build direction





Surface Roughness of Various Build Angles

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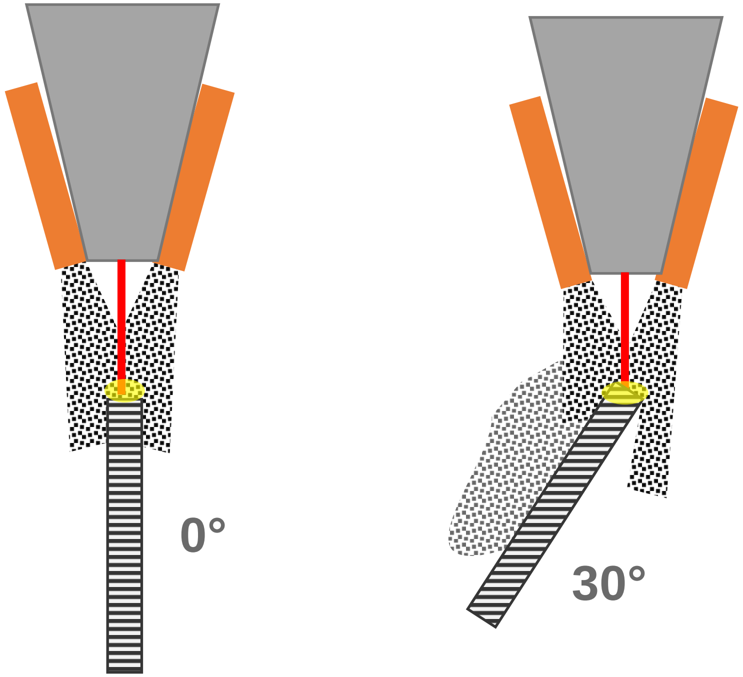
Angle relative to build direction

Angle relative to build direction



Conclusions

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- LP-DED has been demonstrated to build thin-wall (1 mm) fine feature channels (2.54 mm) used for heat exchangers
- The surface roughness from LP-DED is impacted by the powder size and layer height
- The coarse powder is less sensitive in roughness to varying build parameters
- Changes to the layer height will impact the overall build time (17-20%) with only minor impact (~5%) on surface roughness
- The geometry configuration will have an impact on the surface roughness including adjacent features and wall angle; can be a difference in roughness of internal and external features if powder removal not properly designed for
- The build angle limitation for thin-wall using 2.5D build is 30-35°
- The surface roughness for various build angles is higher for the upskin compared to the downskin (opposite of L-PBF)
- Results will be documented in a future journal article(s) to allow use for future designs
- Surface roughness remains an area of study for various metal AM processes

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Thank you.

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Acknowledgements

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Thank you to many of our colleagues and industry partners for inputs.

- NASA RAMPT Project
- John Fikes/NASA
- Lynn Machamer/NASA
- Chris Protz/NASA
- Sara Rengifo/NASA
- Darren Tinker/NASA
- Matt Marsh/NASA
- NASA Space Launch System (SLS) Liquid Engines Office (LEO)
- RPM Innovations (RPMI)
- Tyler Blumenthal/RPMI
- Covalent Metrology
- Steve Wofford/NASA
- BeAM/AddUp
- Formalloy