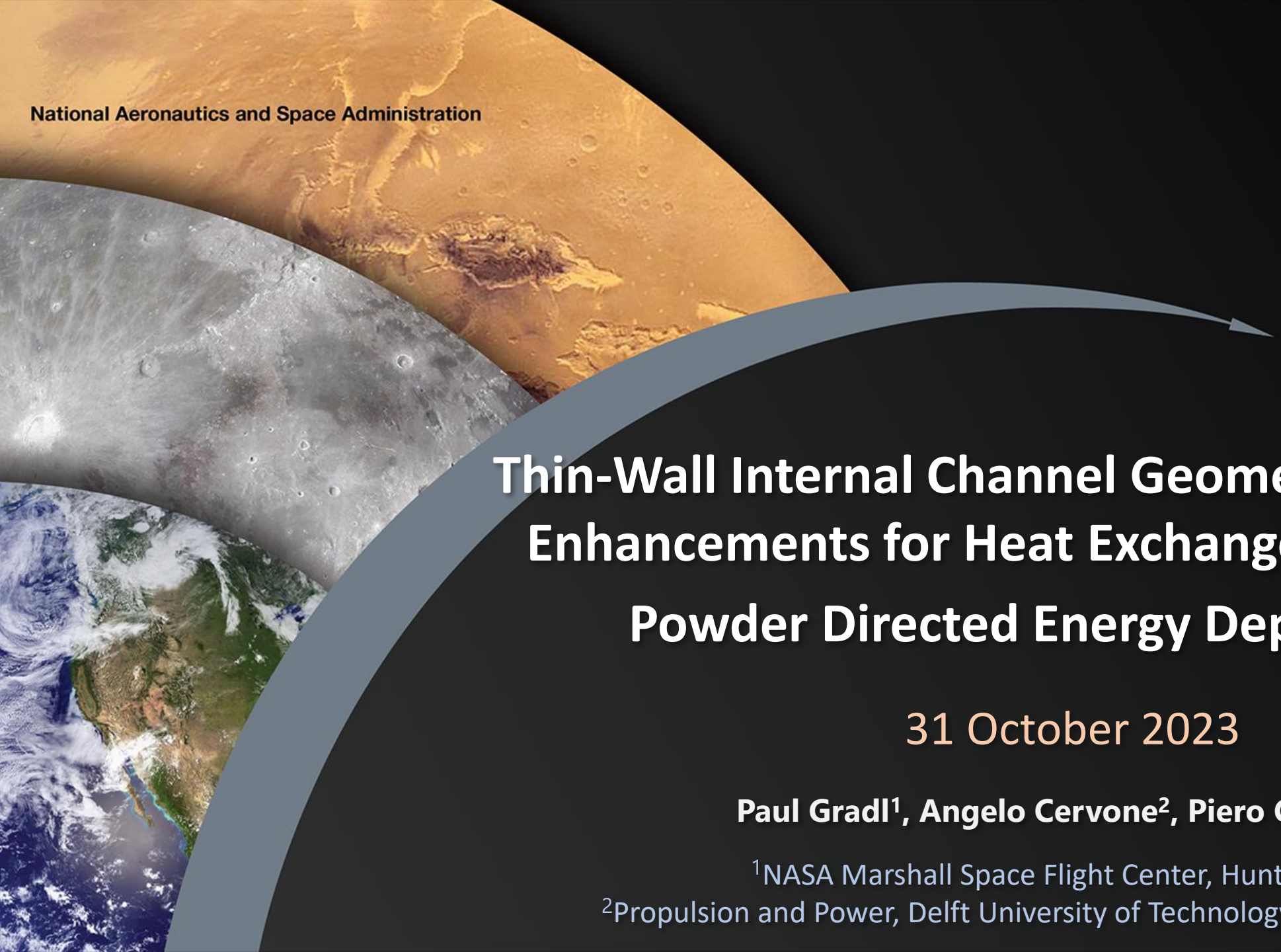

Thin-Wall Internal Channel Geometry and Surface Enhancements for Heat Exchangers using Laser Powder Directed Energy Deposition

31 October 2023

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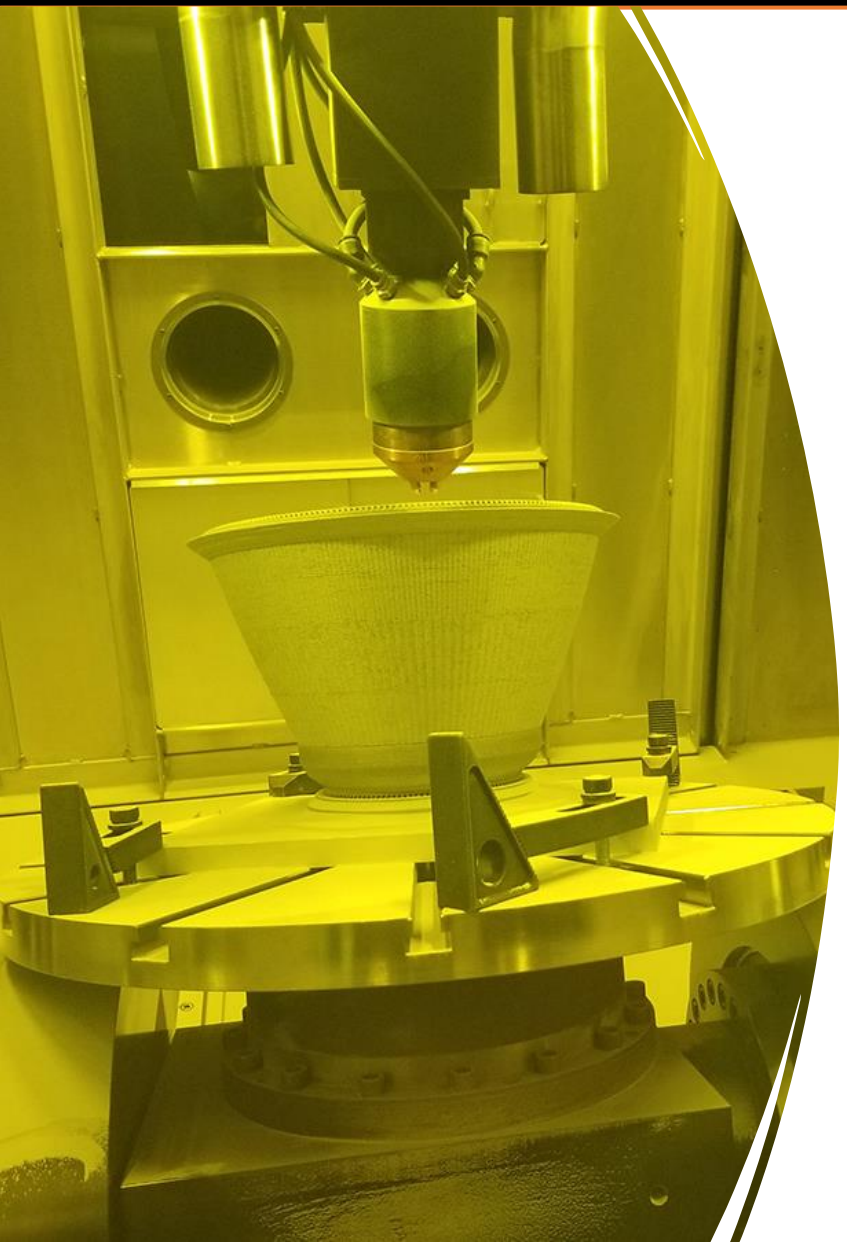
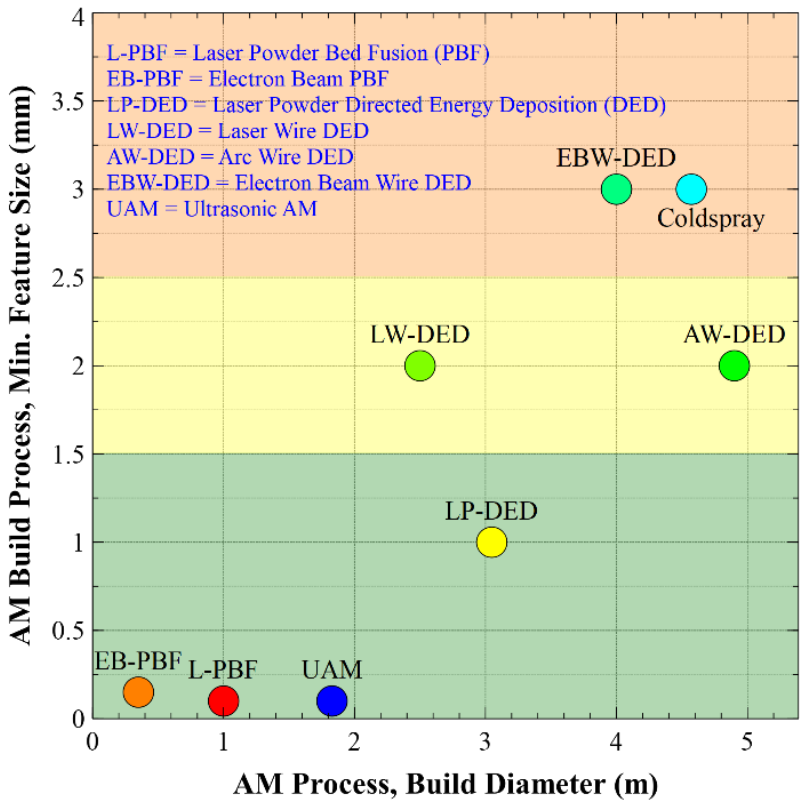
[2]Propulsion and Power, Delft University of Technology, Delft, Netherlands

Introduction



- LP-DED for heat exchangers
- Evaluation of thin-walls and features
- Channel characterization
- Surface enhancements
- Hot-fire and component testing
- Summary

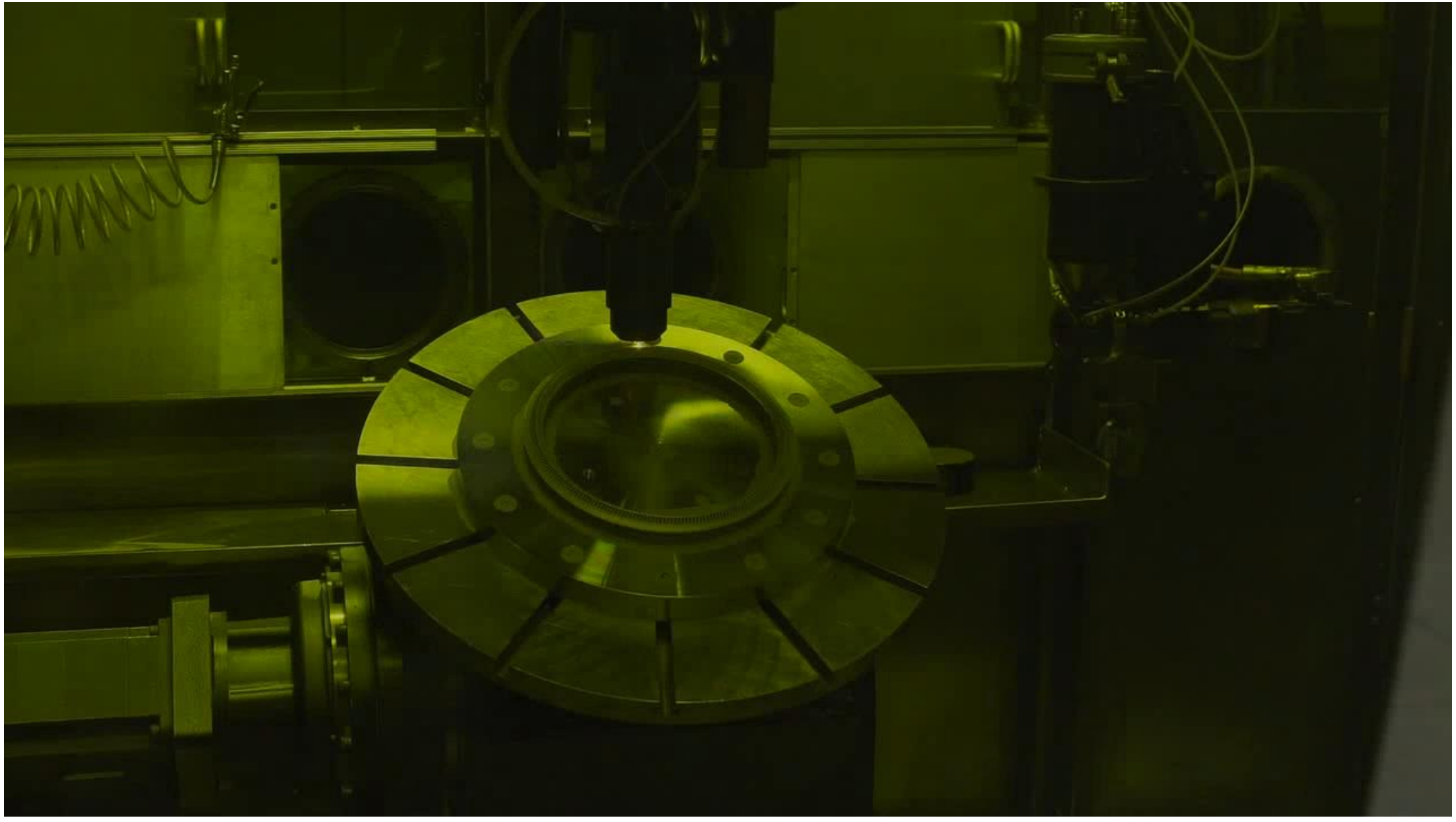
Laser Powder Directed Energy Deposition (LP-DED)



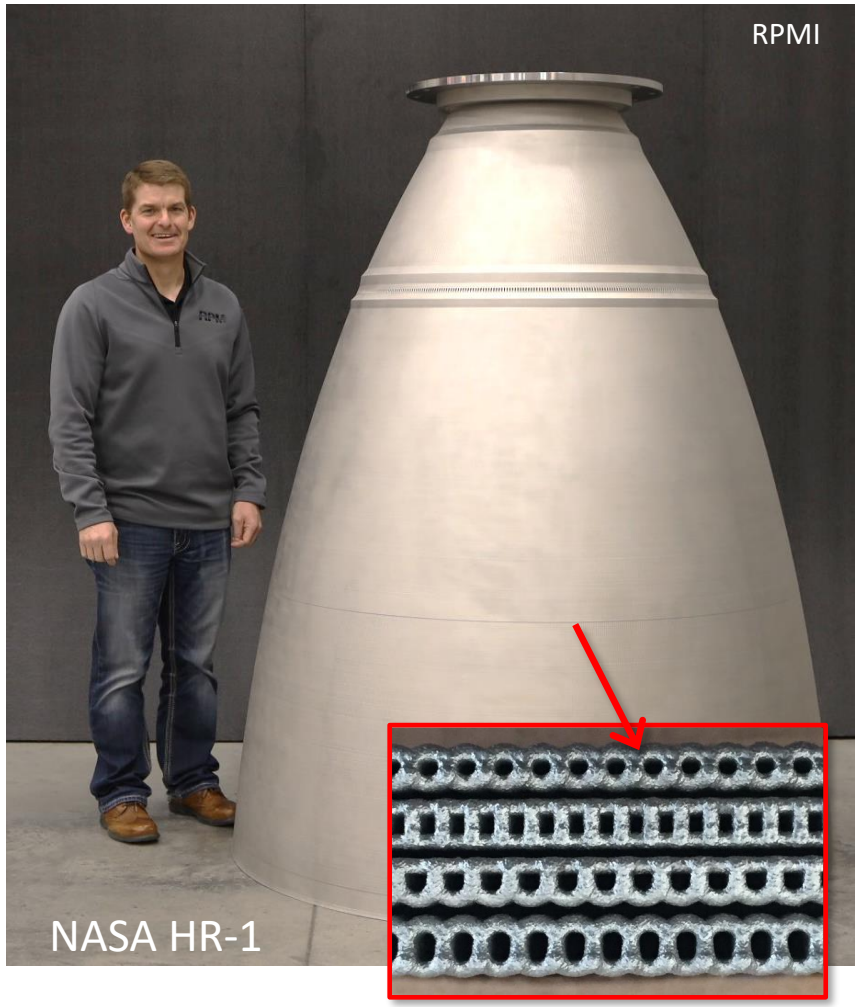
AM process selection balances design requirements, process limitations, and programmatic considerations.

Gradl, P., Cervone, A., Colonna, P., 2022. Integral Channel Nozzles and Heat Exchangers using Additive Manufacturing Directed Energy Deposition NASA HR-1 Alloy. 73rd International Astronautical Congress. Paris, France, IAC-22,C4,2,x73690.

Example of LP-DED with small features



LP-DED Large Scale Nozzle Development



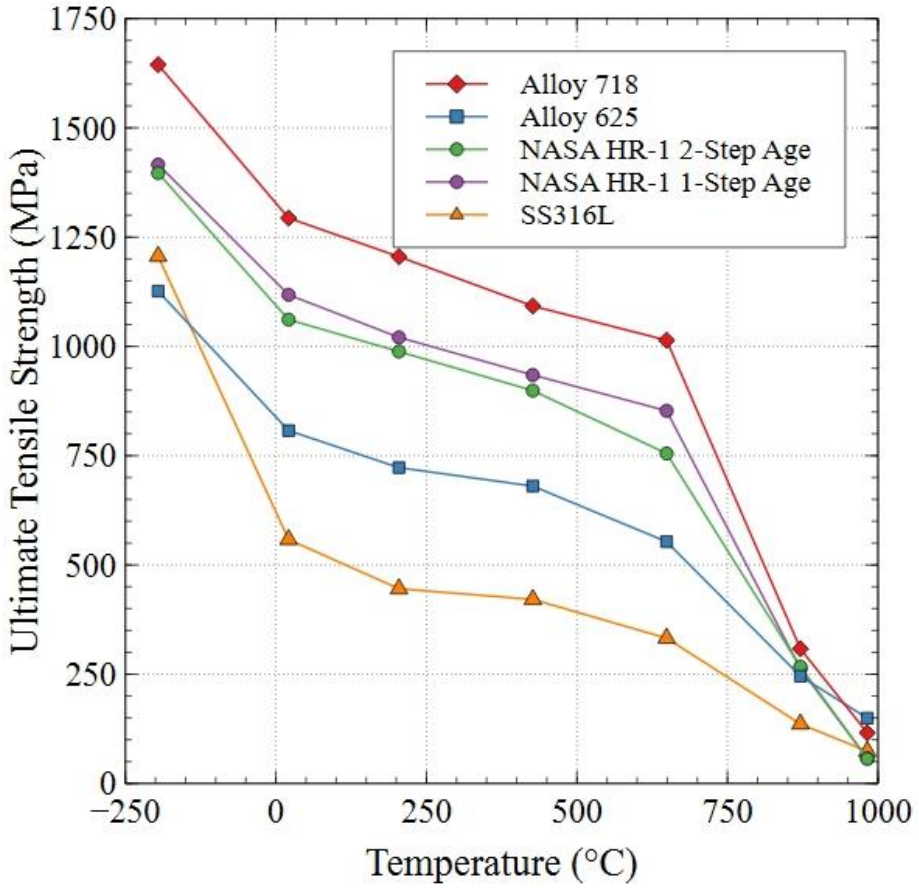
60” (1.52 m) diameter and 70” (1.78 m) height with integral channels
90 day deposition

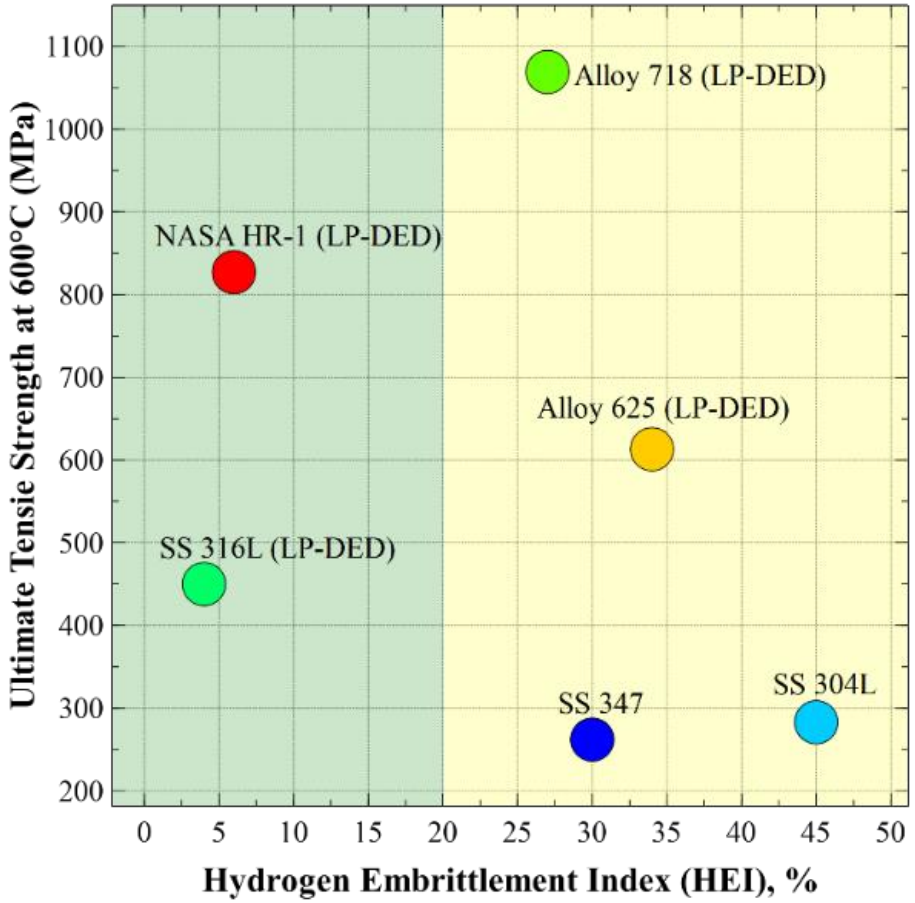
95” (2.41 m) dia and 111” (2.82 m) height
Near Net Shape Forging Replacement

Reference: P.R. Gradl, T.W. Teasley, C.S. Protz, C. Katsarelis, P. Chen, Process Development and Hot-fire Testing of Additively Manufactured NASA HR-1 for Liquid Rocket Engine Applications, in: AIAA Propuls. Energy 2021, 2021: pp. 1–23. https://doi.org/10.2514/6.2021-3236.

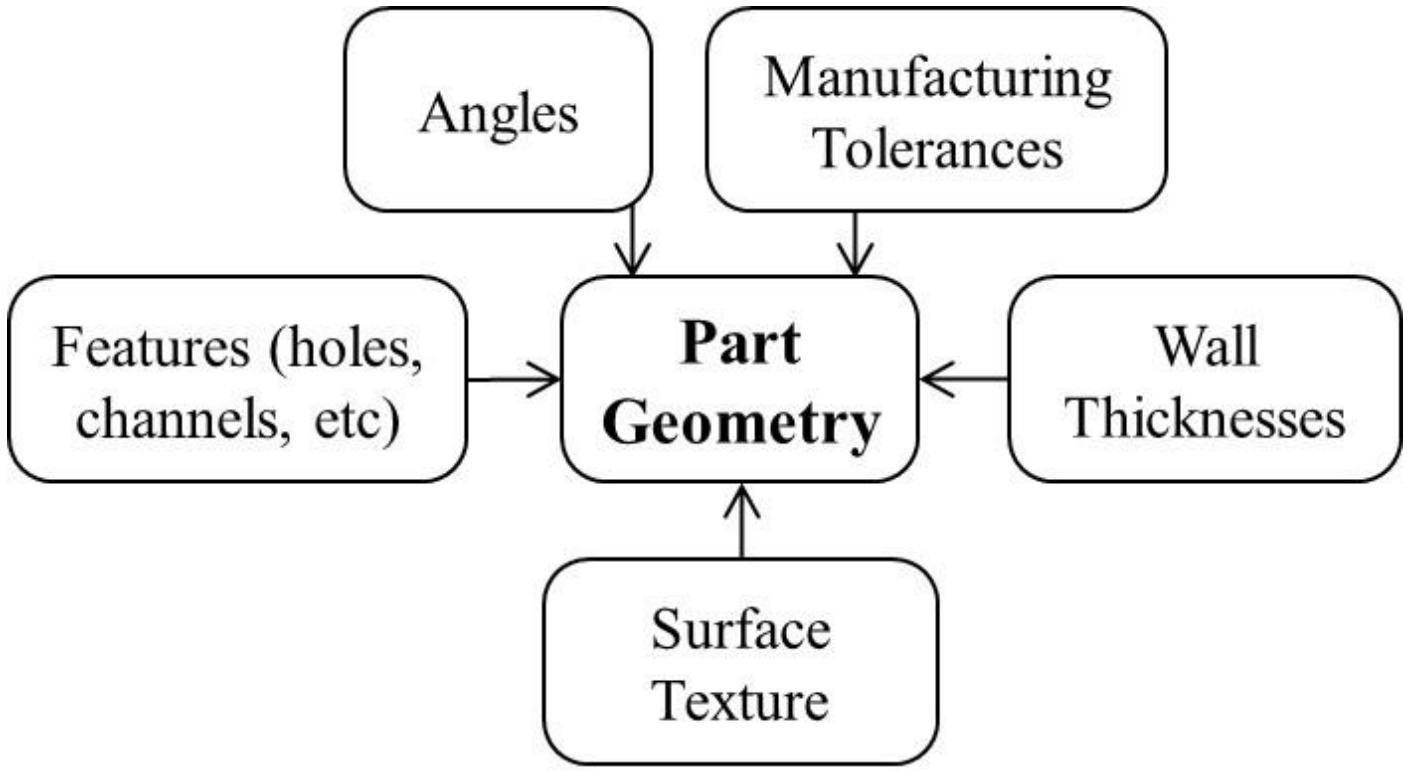
NASA HR-1 for high pressure hydrogen applications

NASA HR-1 (Fe-Ni-Cr) is a high strength super alloy developed for high pressure hydrogen environments (ie. HR = Hydrogen Resistant)

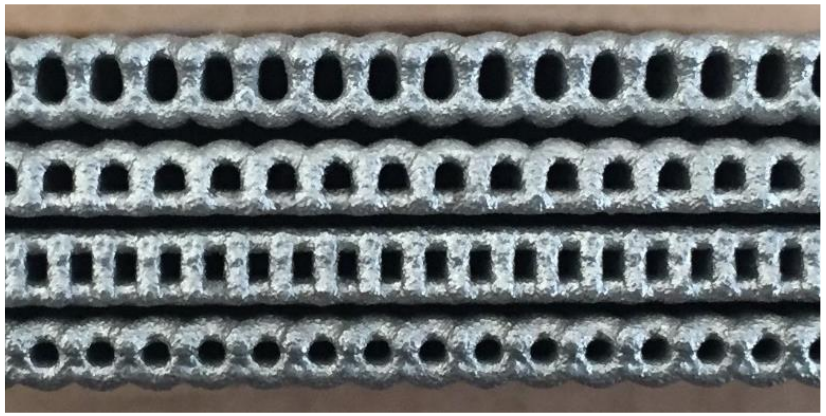




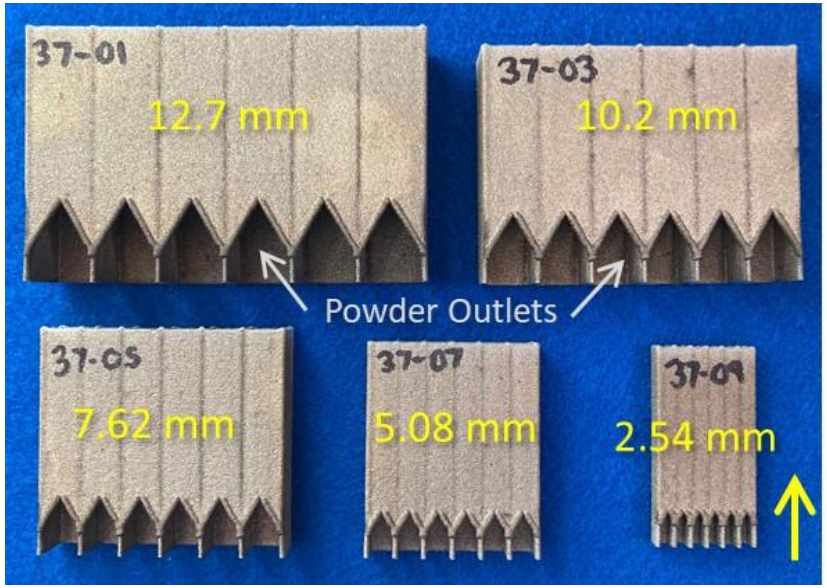
Factors that impact geometry built using LP-DED



Various channel geometries using LP-DED

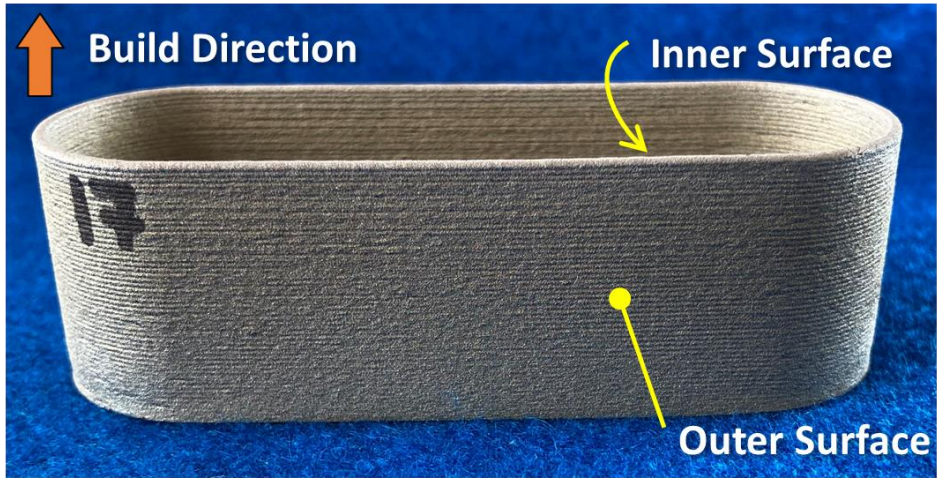


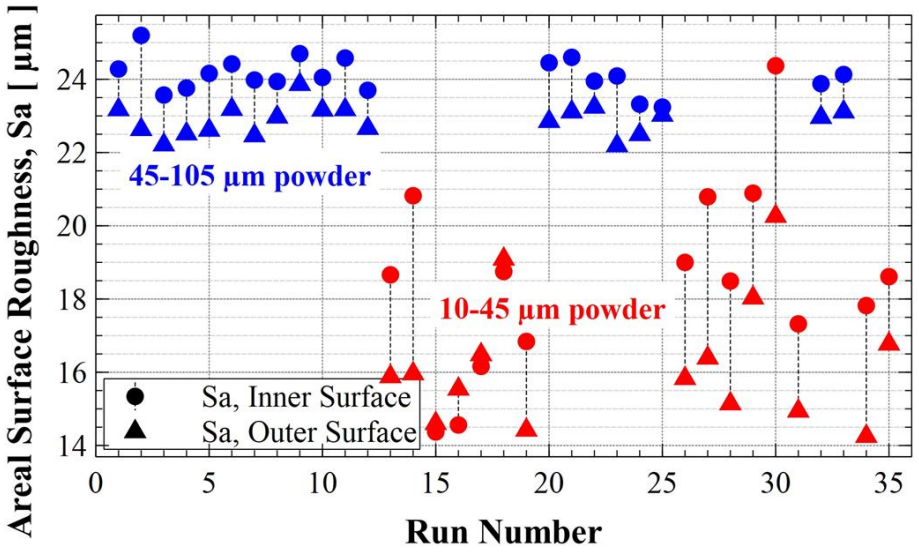
Various channel sizes LP-DED

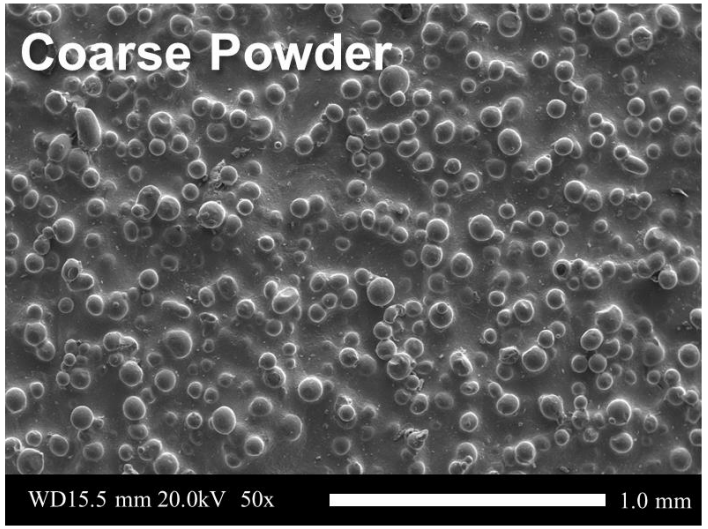


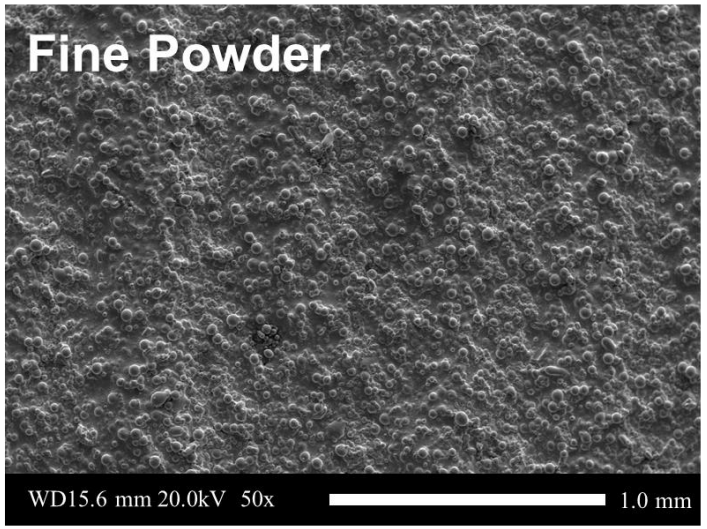
AM process limitations consider several aspects that constitute the as-built geometry (ie. no processing) for heat exchanger applications.

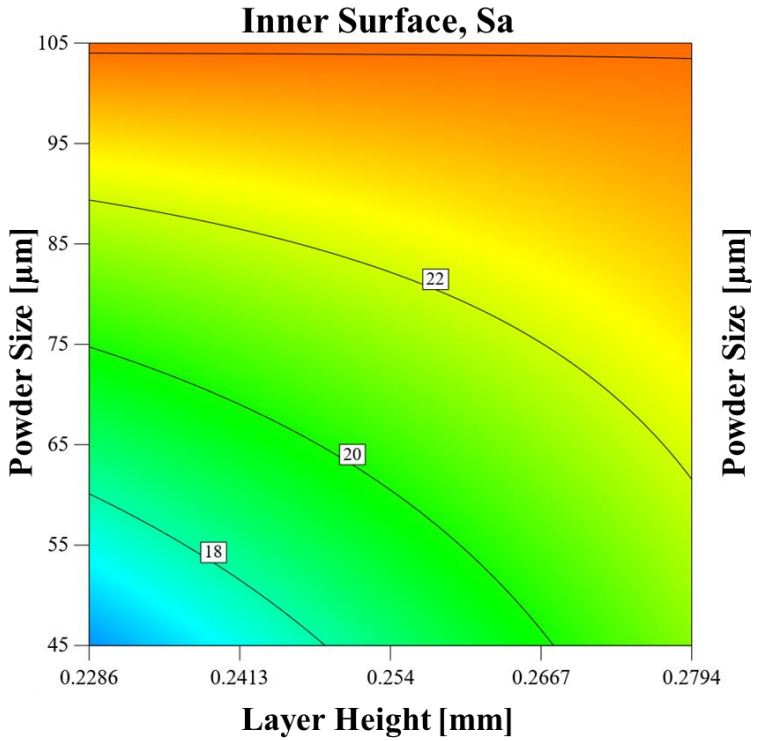
Initial Study to Optimize Parameters







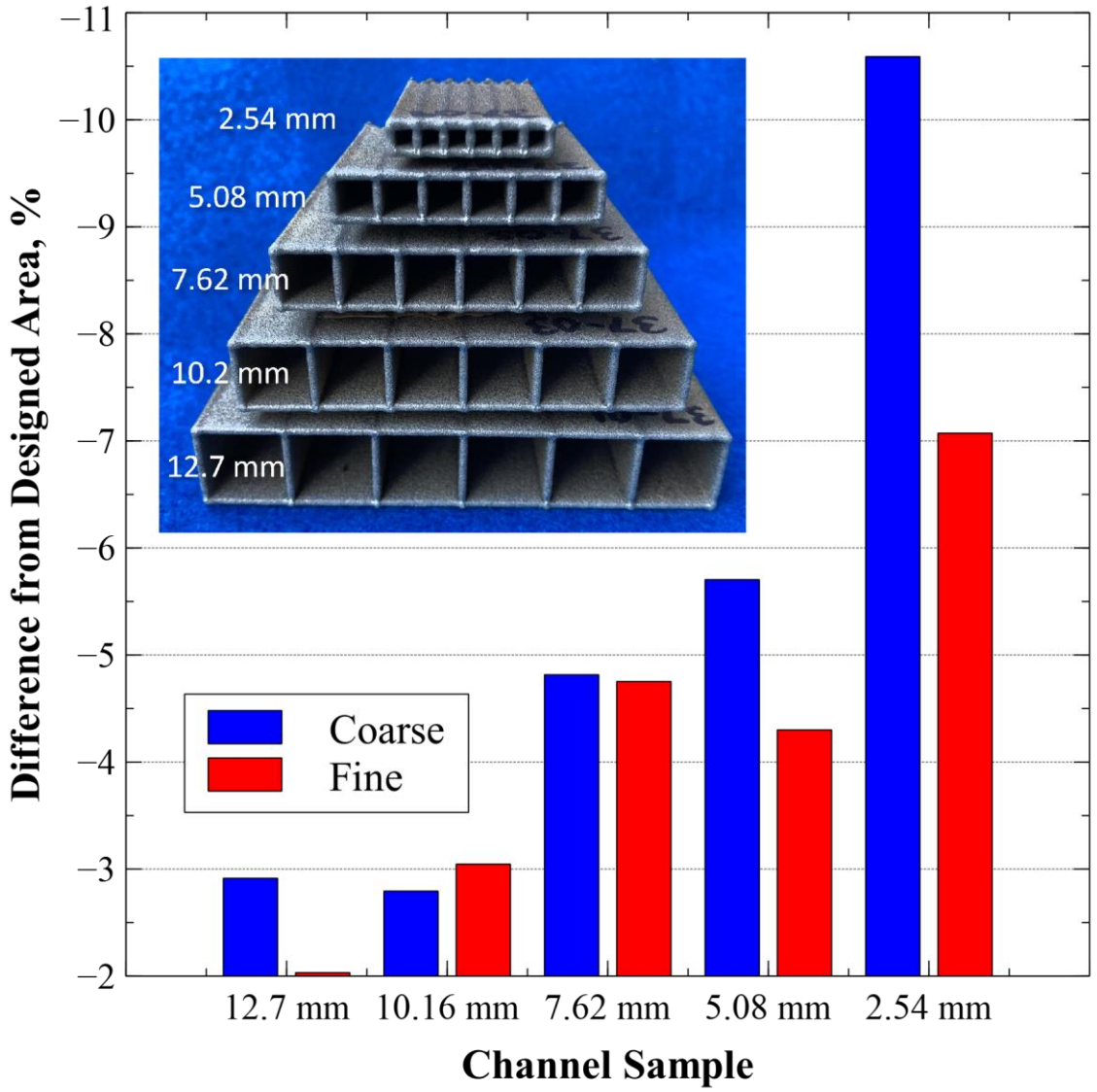




Gradl, P.R., Cervone, A., Gill, E., 2022. Surface texture characterization for thin-wall NASA HR-1 Fe – Ni – Cr alloy using laser powder directed energy deposition (LP-DED). Advances in Industrial and Manufacturing Engineering 4, 100084. https://doi.org/10.1016/j.aime.2022.100084

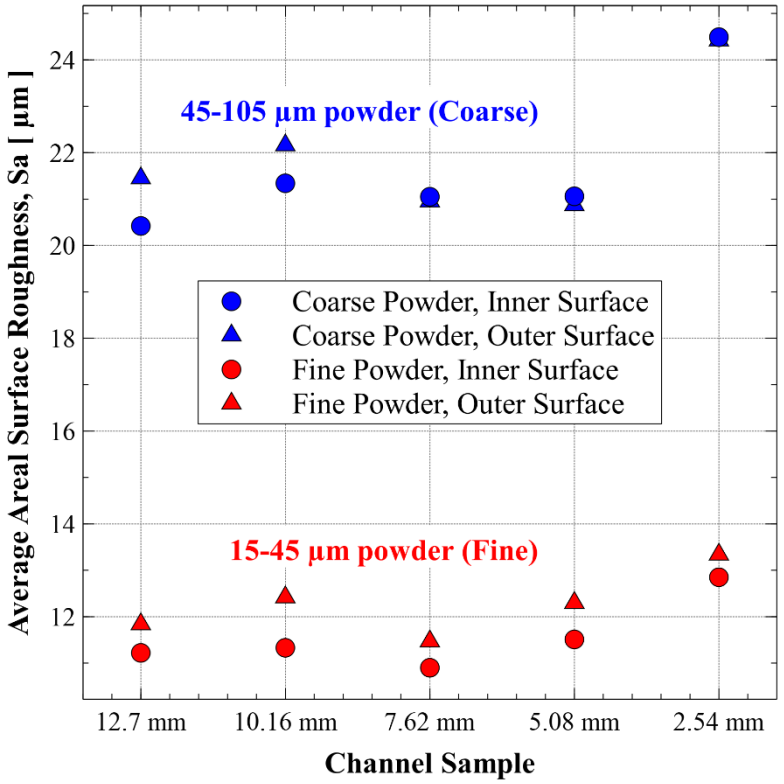
LP-DED Channel Geometry

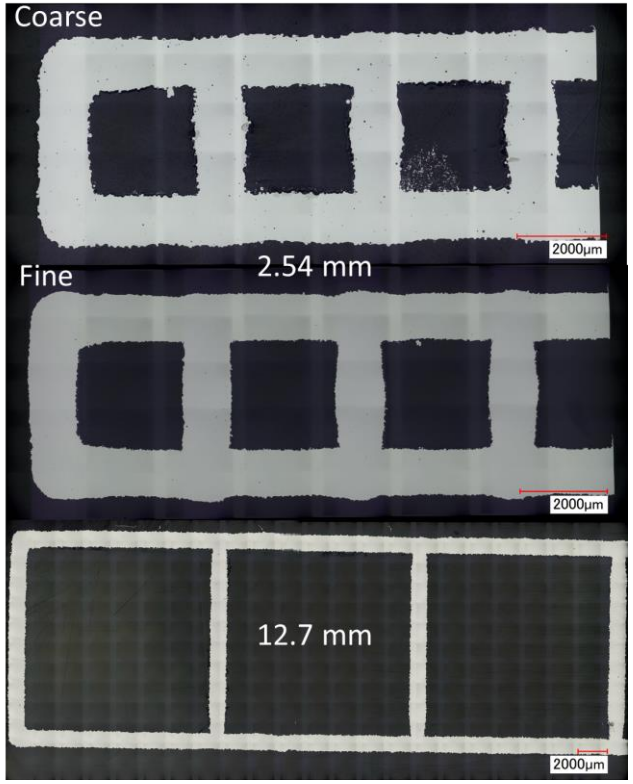
- Various channels built on an RPMI 557 machine targeting 1 mm wall thickness.
- Channels built with fine (10 – 45 µm) and coarse (45 – 105 µm) powder sizes.
- Successfully deposited channels down to 2.54 mm; smaller channels resulted in increased powder packing (ie. clogged channels).
- All channel samples are smaller cross-sectional than as-designed areas due to powder adherence and melt pool irregularities.

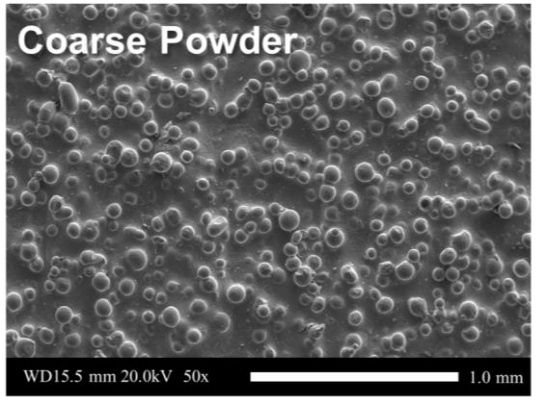


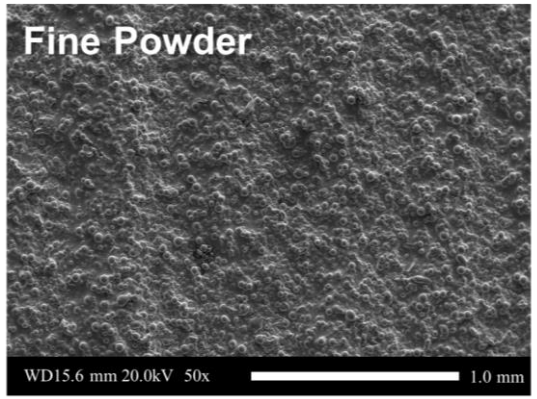
Surface Texture of LP-DED Process

- Surface texture is a critical aspect of design due to impacts to heat transfer, friction factors resulting in pressure losses, and fatigue life.
- Areal surface roughness (Sa) is higher in coarse powder samples compared to coarse powder.
- There are minor differences in channel samples between internal and outside surfaces.



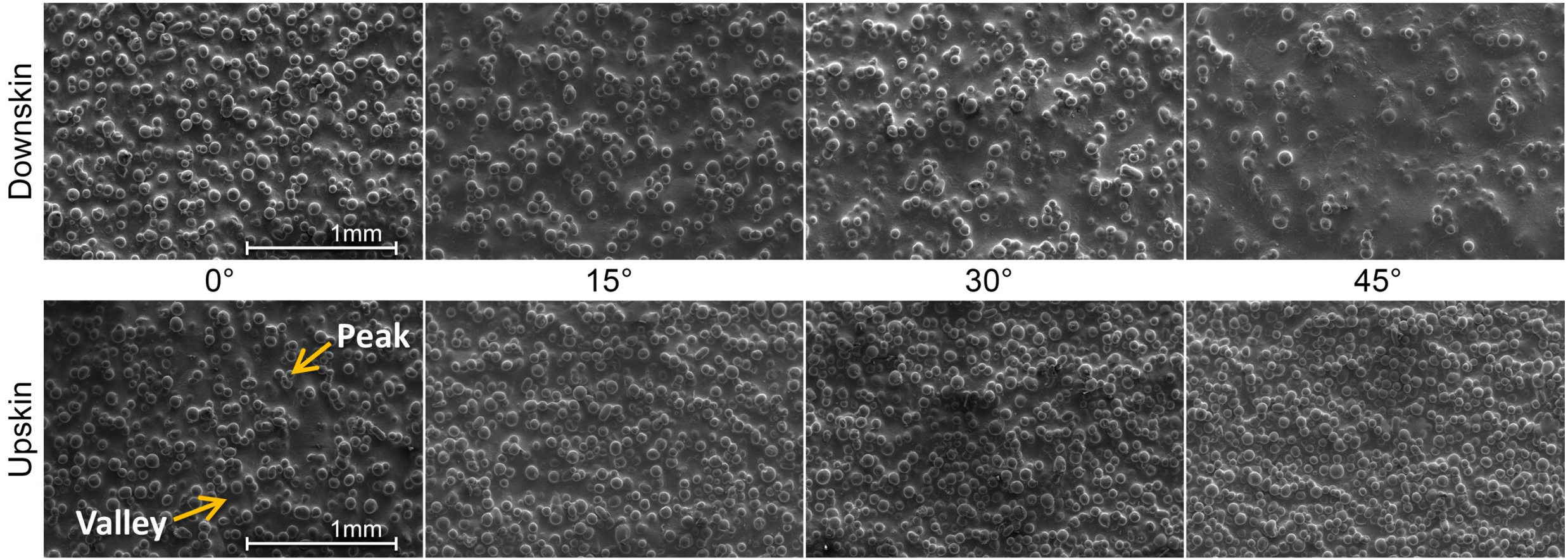






Geometric Build Limitations – Angles

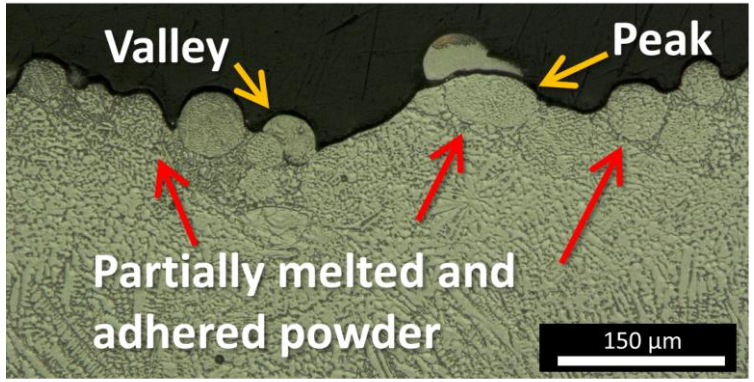
- Coarse Powder (45 – 105 µm)
- 350W Power

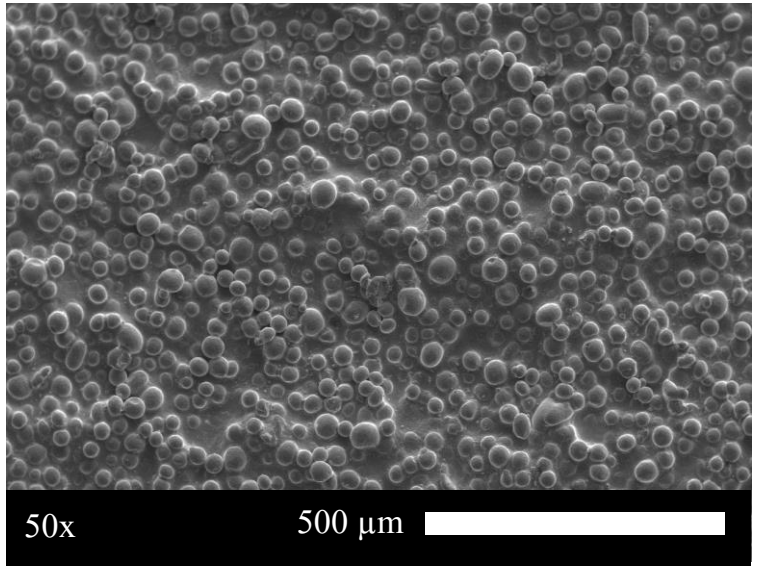


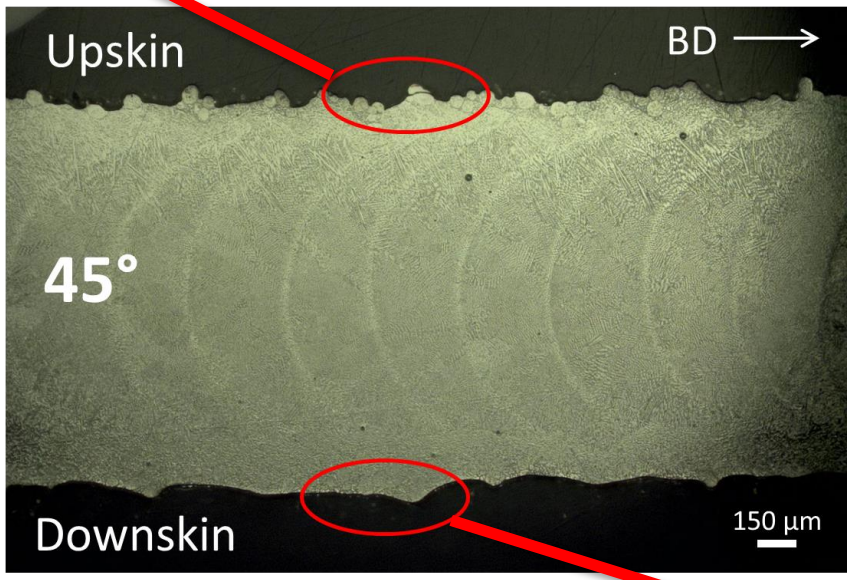
Gradl, P., Cervone, A., Colonna, P., 2023. Influence of build angles on thin-wall geometry and surface texture in laser powder directed energy deposition. Materials & Design 234, 112352. https://doi.org/10.1016/j.matdes.2023.112352

Geometric Build Limitations – Surface Orientation

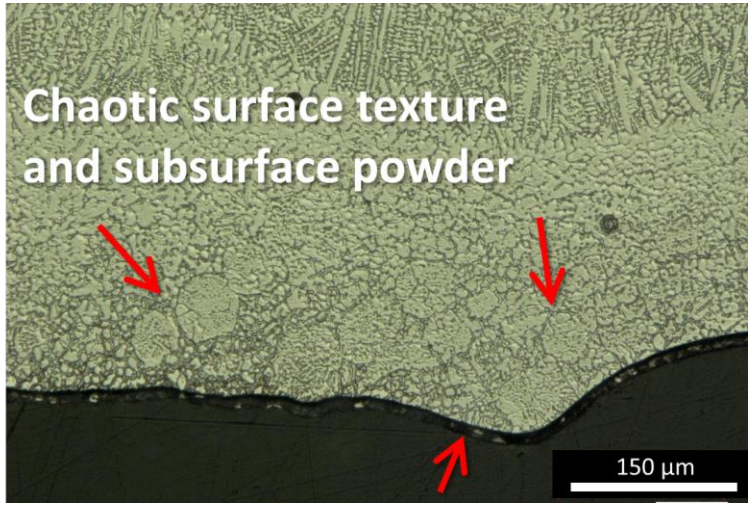
Upskin (Exterior)

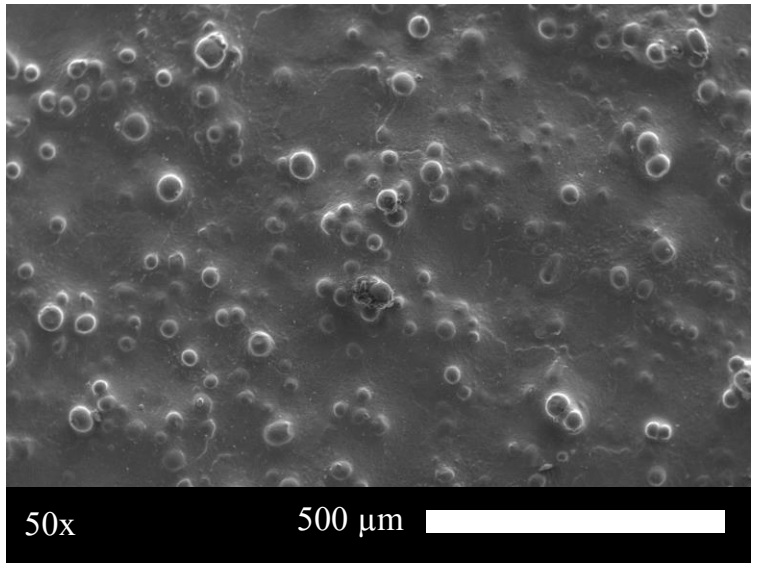






Upskin (Internal)





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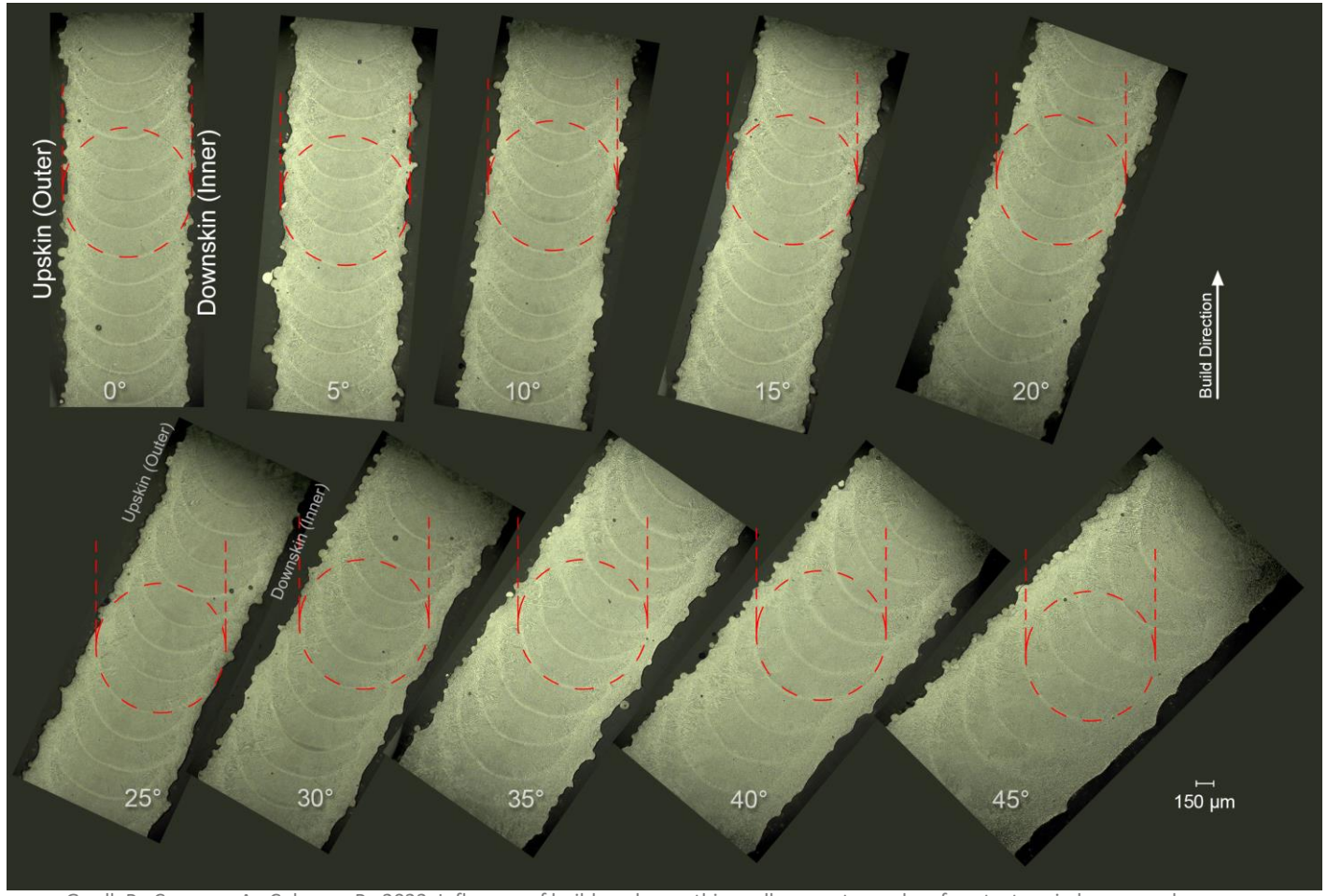
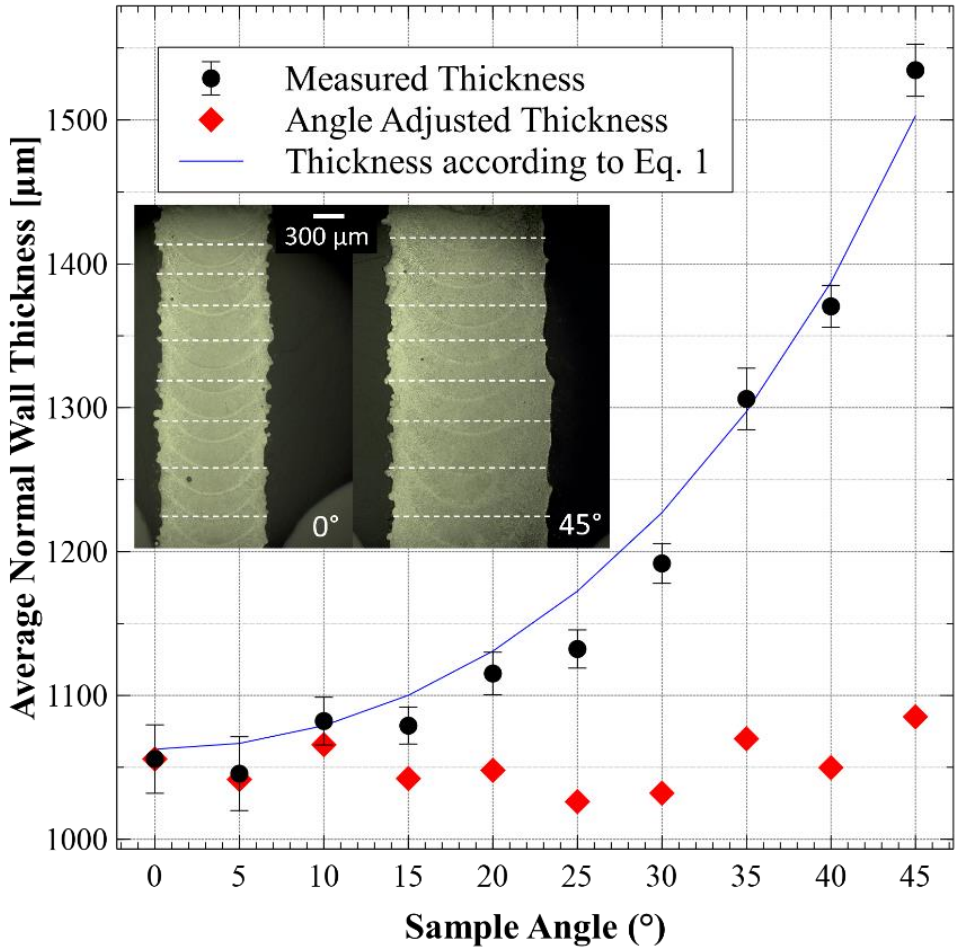
Geometric Build Limitations – Wall Thickness

Material droop on downskin and excess deposition on upskin caused increases in thickness with increased angle





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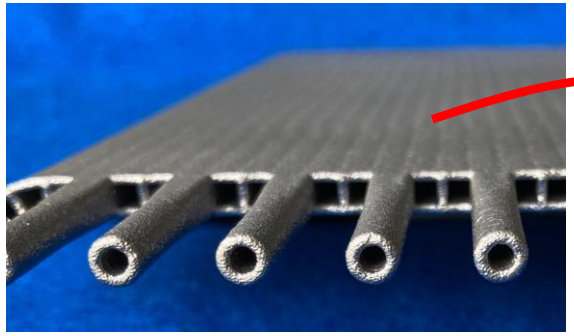
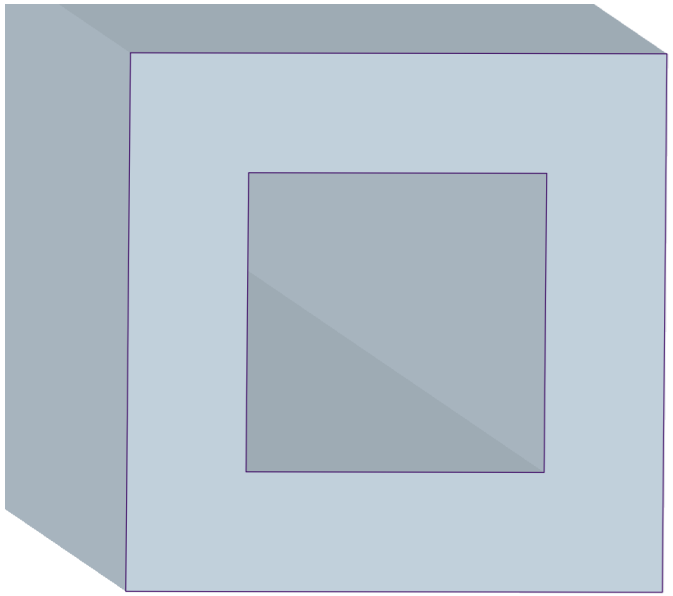
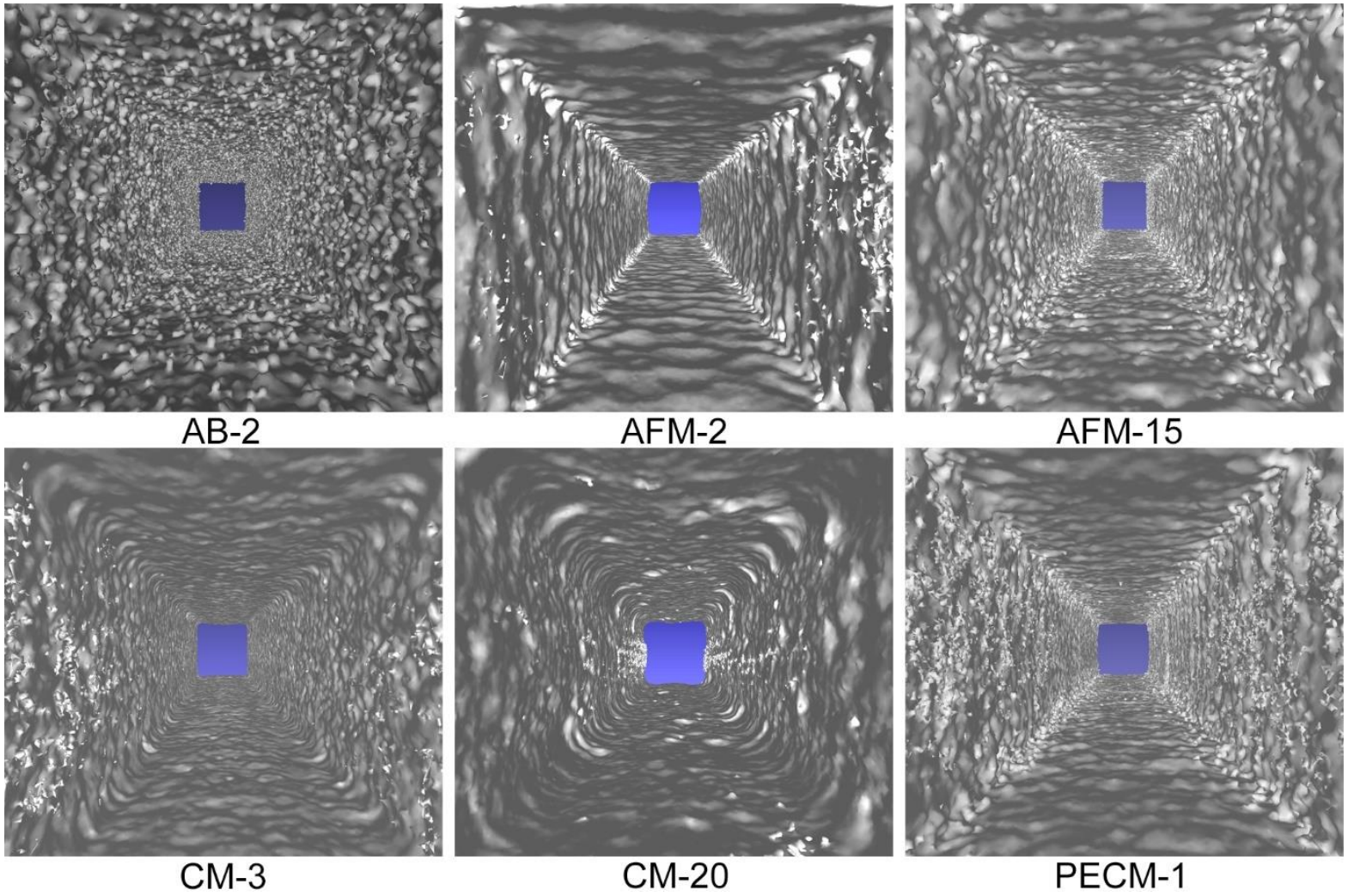
Development of Surface Enhancements (Polishing)





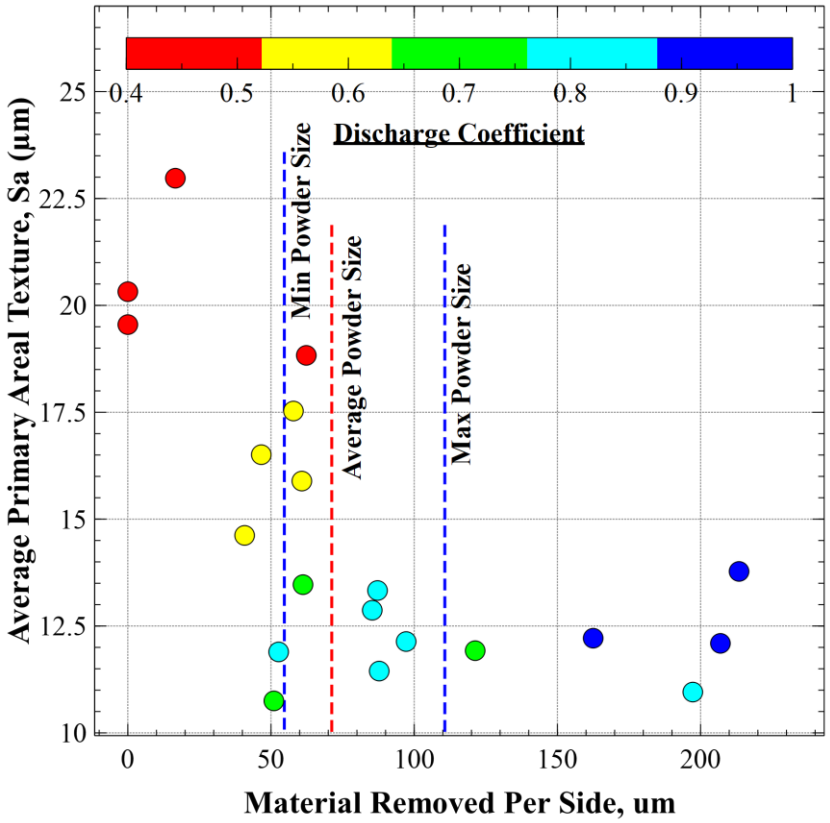
The Design Intent

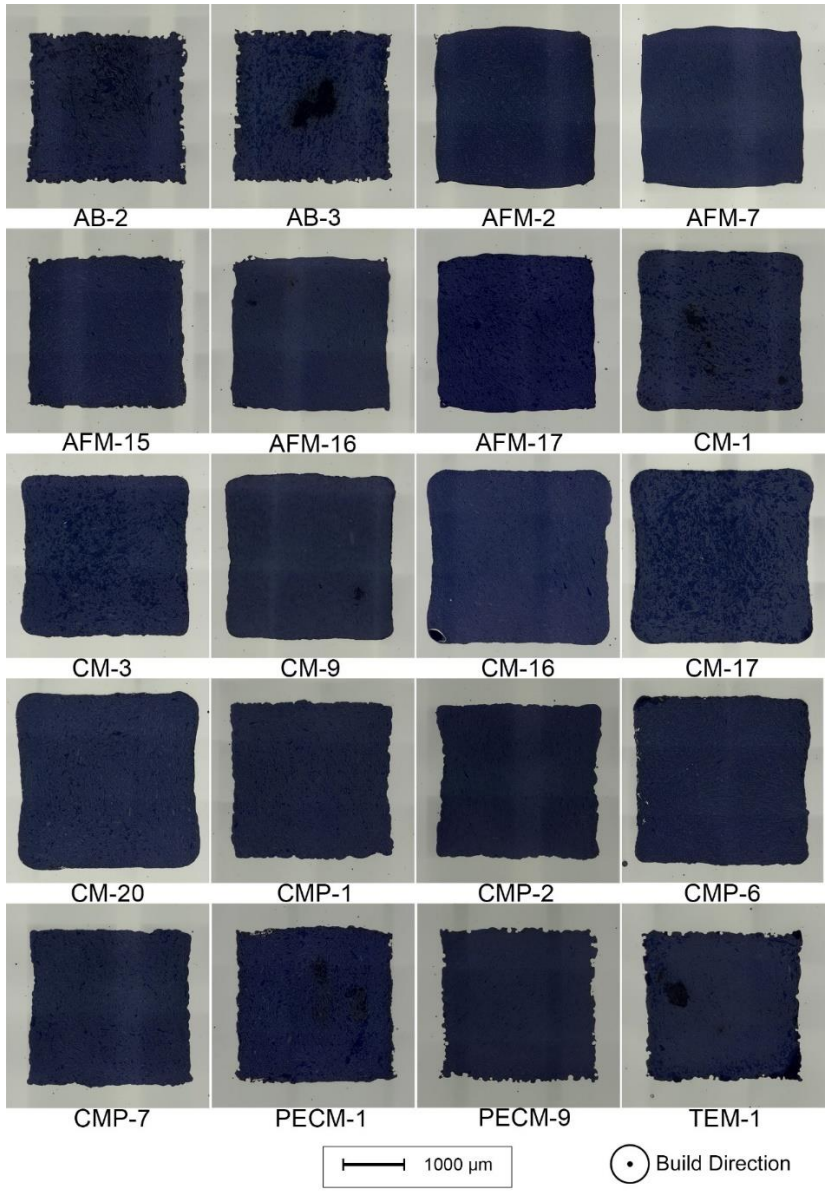


Reality

Surface Enhancements and Impact on Flow

- Surface enhancements had a significant impact on discharge coefficient (Cd)
- A minimum of the average powder particle size (70 µm) must be removed to reduce texture





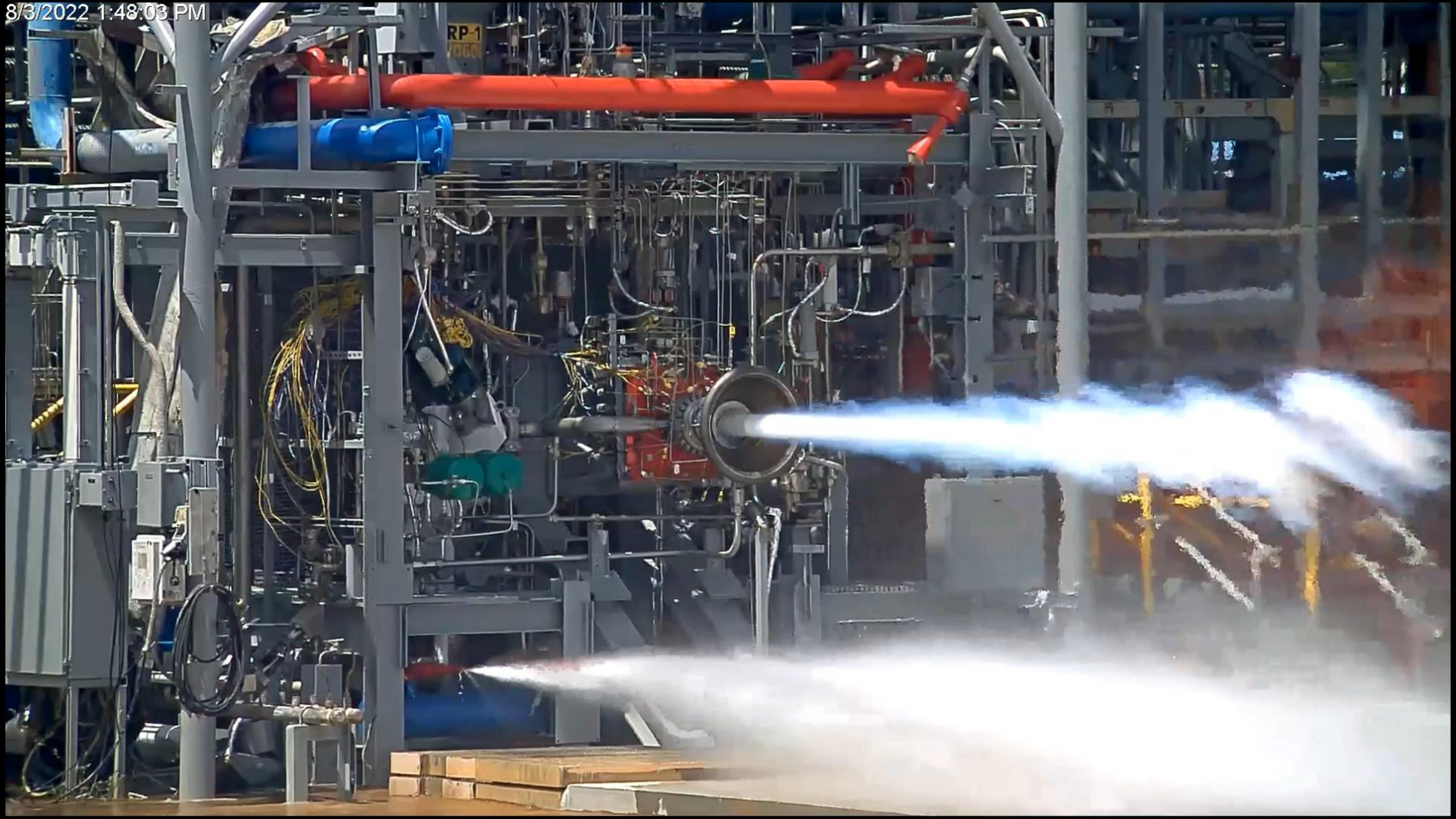
Hot-fire Testing Summary of LP-DED Nozzles

- Tested nozzles from 2K to 35K-lbf thrust class.
- All major propellants tested (LOX/H2, LOX/CH4, LOX/RP-1).
- Accumulated over 16,289 sec and 488 starts on various nozzles.
- Single nozzle accumulated 207 starts and 6,756 seconds.
- Nozzles all tested successfully and met performance expectations.


2,000 lbf LOX/GH2


7,000 lbf LOX/GH2


35,000 lbf LOX/LH2


8/3/2022 1:48:03 PM
RP-1

Summary and Future Work

- LP-DED process demonstrated small channels with repeatable geometry and ability to deposit thin-walls for channel wall nozzles up to 60”+ (1.5 m) diameter.
- Manufacturing demonstration components and samples completed to understand the LP-DED process capabilities.
- Various geometric limitations for channel sizes, angles, and surface texture were evaluated and characterized.
- Improvements being evaluated for internal channels including surface enhancements (polishing) and characterization of with the ability to tune the surface texture.
- Hot-fire testing accumulated 16,289 sec and 488 starts.
- Future experiments and analysis will evaluate flow testing with various types of polishing processes.

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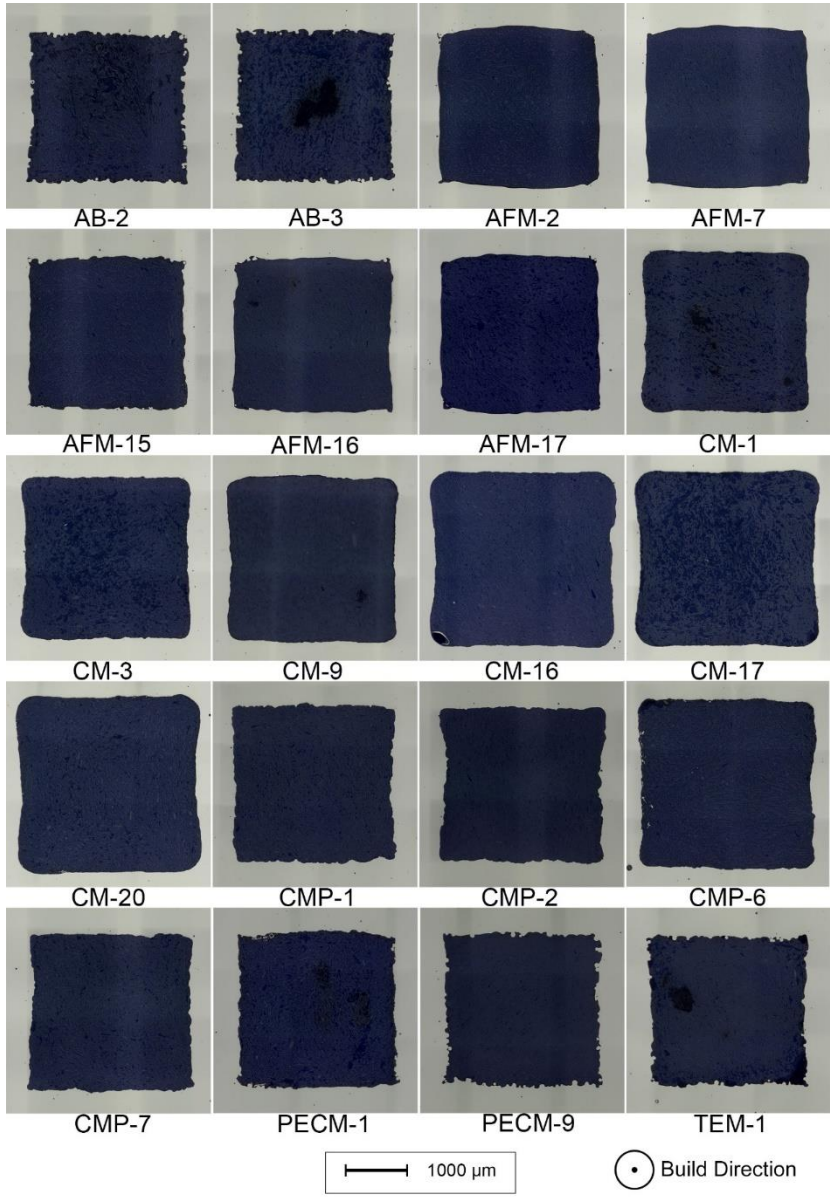
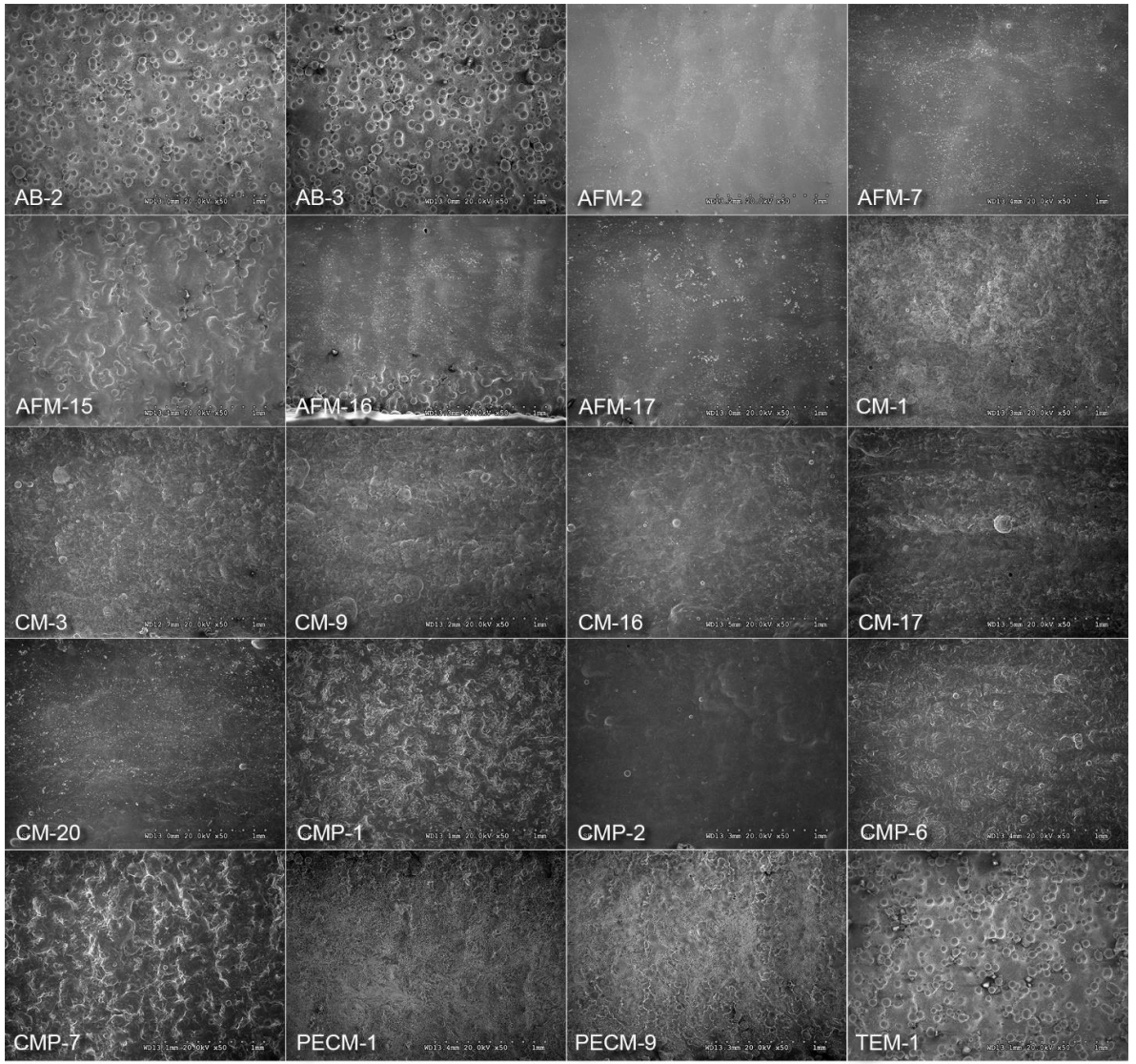
Photo: NASA/Ben Smegelsky

Surface modification of internal channels





Acknowledgements

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Matt Medders
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Johnny Heflin
Mike Shadoan
Keegan Jackson
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