Powder Bed Fusion: Part Porosity Sources

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INTRODUCTION

- ***Boeing** is interested in **additive manufacturing** with laser powder bed fusion (LPBF) for aerospace applications*
- *LPBF works by selectively fusing metal powder to form solid layers; powder then swept over to form more layers for a 3D part*
- *EOS M290 LPBF system under study*
- *Advs. of LPBF: **lower density & lighter weight, less wasted material, complex geometry capability***
- *Current reliability issues in LPBF: **local part porosity, material defects, mechanical properties***
- *Argon gas (shielding gas to prevent oxidation) is used in manuf. process and is believed to be a main factor in reliability*
- *Project goal is to analyze and correlate Ar gas flow (process pressure setting) changes on test coupon material quality with gas dynamics in the chamber*
- *Seeking process pressure setting that produce the **most reliable quality** of LPBF metal parts to use in prototyping, low-vol. prod.*

PROBLEM STATEMENT

How can changing process pressure settings & gas flow improve LPBF metal quality (porosity)?

CORE FUNCTIONS & APPROACH

Mockup Chamber
- 1:1 scale mockup of M290
- Fabricate in the ME machine shop & assemble

CFD Validation
- Computational fluid dynamics
- Analyze gas flow inside chamber

Literature Review
- Gas flow effects on porosity

Past Data Analysis
- Local effect on porosity, mechanical properties

Test Parameters

Test Builds
- DOE: Test at 0.6 and 0.8 mbar diff pressure

Sample Analysis
- Porosity
- Mechanical properties

Conclusions
- Tie together
- Gas flow & validation
- Build analysis + results

1:1 scale mockup chamber fabrication paralleled with design of experiment (DOE) based on design & logistical constraints, Boeing computational fluid dynamics (CFD), literature research, UW Round Robin data, and collaboration with Boeing & LPBF Interruption capstone builds

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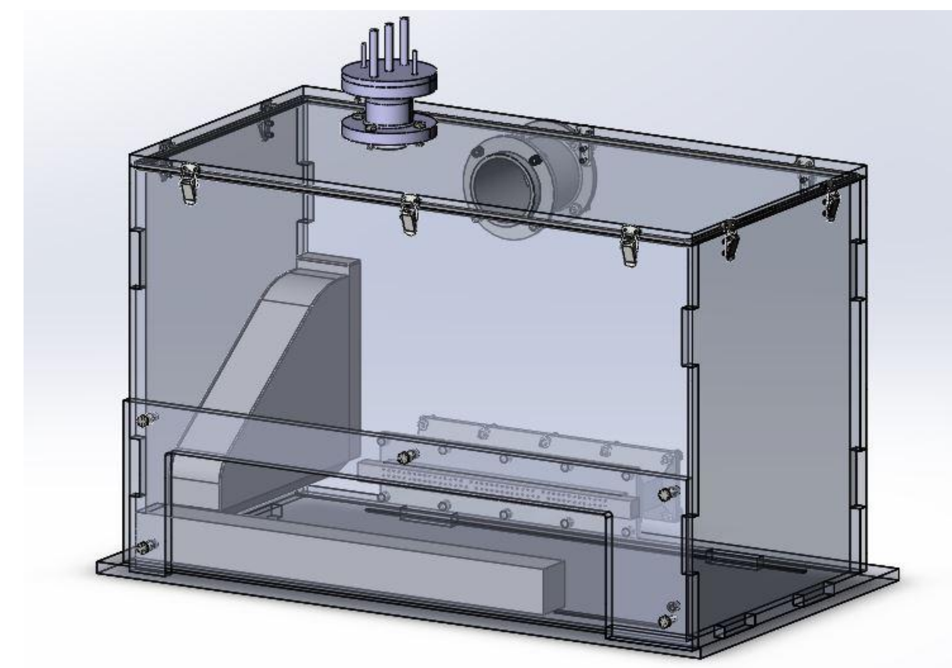
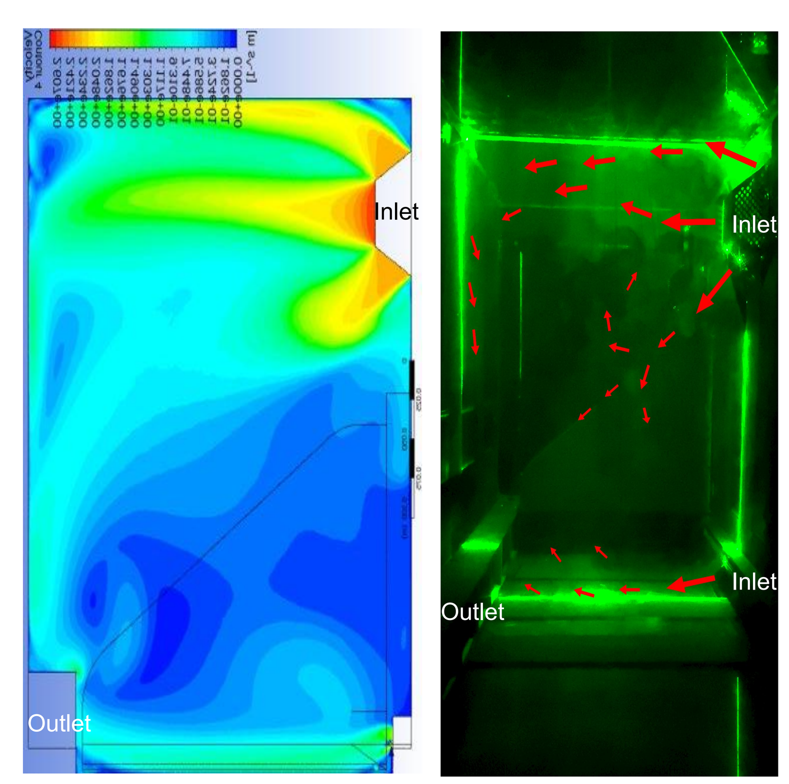
MOCKUP DESIGN AND DEVELOPMENT

Mockup Chamber

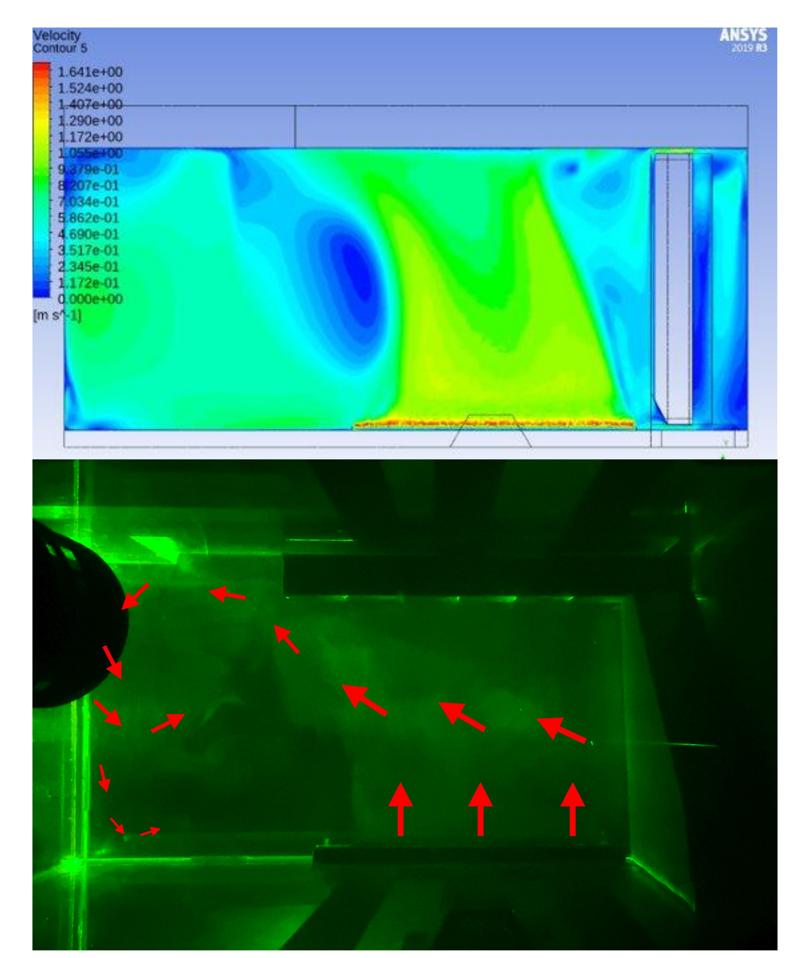


Design & Manufacturing Steps
- Designed a CAD model of the chamber
- Applied DFMA to improve design concepts for producibility, ease of assembly
- Developed manufacturing process: timeline, bills of materials, drawing files and required tools and machines
- Manufactured components of the chamber at machine shop using waterjet, CNC mill, 3D printer, vertical bandsaw, drill press, etc
- Assembled the chamber, conducted leak test to ensure airtight and resolve technical issues

Gas Flow Validation



Boeing CFD model from right side (left); Zone 0 gas flow analysis (right)

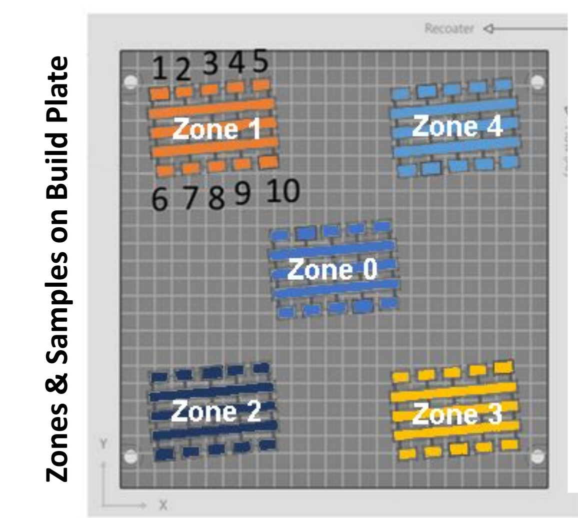


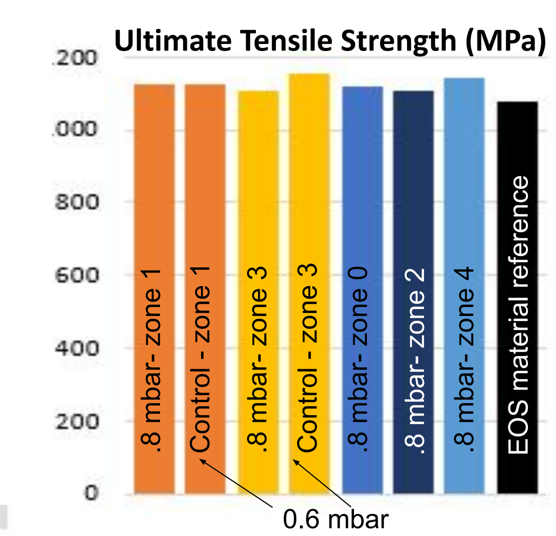
Boeing CFD top-down model (top); lower horizontal plane gas flow analysis (bottom)

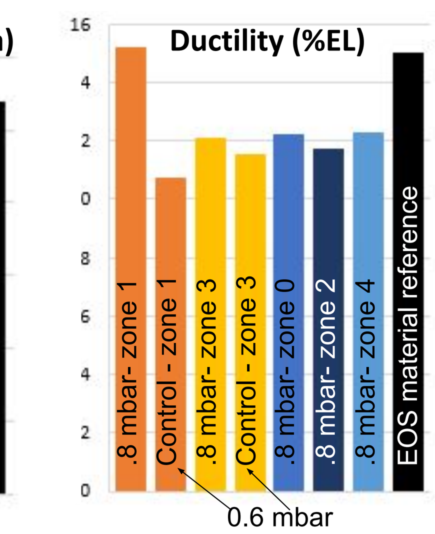
Gas Flow Results
- Mockup validation setup a viable method of visualizing M290 gas flow
- All three vertical planes and horizontal planes **largely matched that of the Boeing CFD model**
- Slight discrepancies in size of dead zones located in the center and bottom of the vertical planes
- Unable to quantitatively correlate the models due to equipment issues

COUPON RESULTS/VALIDATION

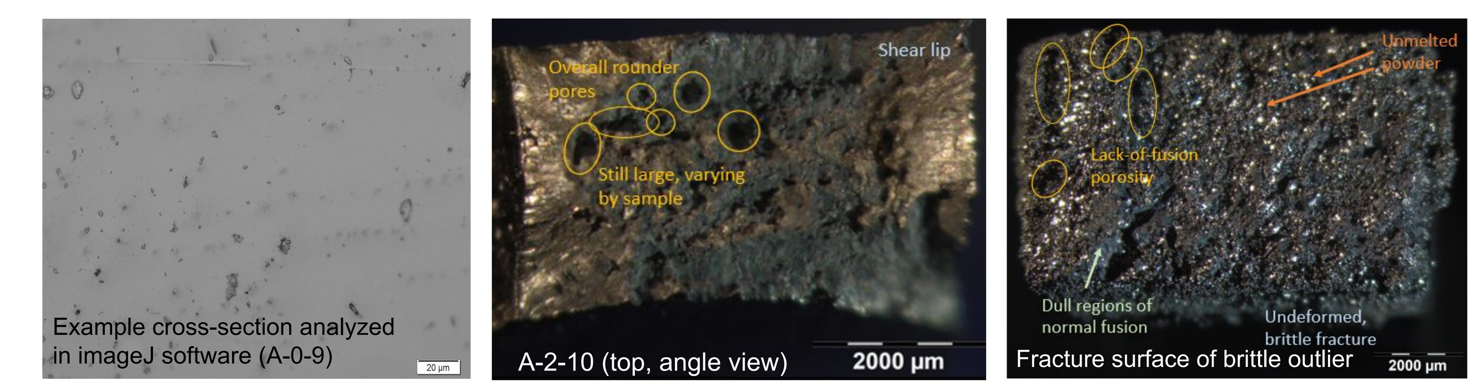
- **0.8 mbar** differential pressure test build **& 0.6 mbar** control







- Tensile results met strength specification but had varying ductility, and two outliers failed in grip section rather than gauge section (see fracture surfaces)



- MicroCT porosity analysis plan was designed and then **adapted to microscopy due to equipment failure**
- ImageJ cross-section analysis provided **quantitative porosity results**
- Fractures surfaces showed another perspective + **causes of outlier failures**

Coupon Analysis Results
- Differences between zones or pressures in mechanical properties, fracture surface appearance, and porosity were **statistically insignificant**.
- Instead, **variations within and between samples** appeared consistently across metrics.

CONCLUSION & FUTURE WORK

- CFD model validated, completing product of multi-year Boeing effort
- Porosity, fracture and tensile properties analyzed for 0.6 and 0.8 mbar
- Experiment can identify relationships between pressure, flow, and mechanical properties

Next Steps: Particle image velocimetry (PIV), additional builds at higher and lower pressure, micro-CT porosity analysis

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Mechanical Engineering Capstone Exposition
June 2nd 2022, Husky Union Building, University of Washington, Seattle