# Metal 3D Printing of Low-NOx Fuel Injectors with Integrated Temperature Sensors

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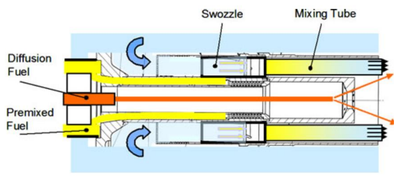
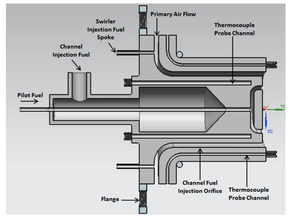
## Introduction

### Objective:

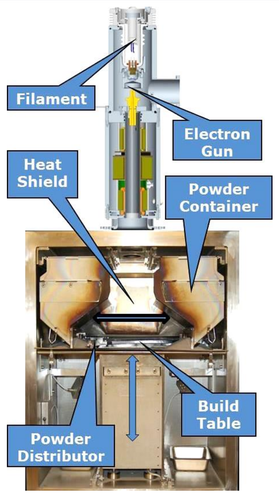
- To utilize additive manufacturing for the fabrication of seamless low-NOx fuel injectors with integrated temperature measurement capabilities.



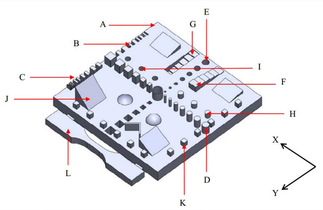




## Methodology & Materials

### Electron Beam Melting:




### Process characterization:



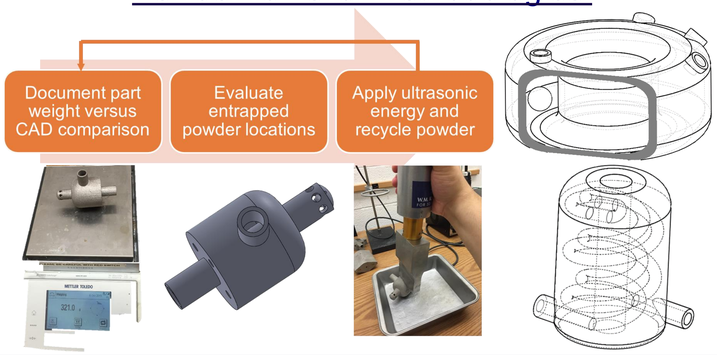

| Letter | Feature | Factor Tested |
|---|---|---|
| A | Square base | Dimensional accuracy |
| B | Lateral ridges (+) | |
| C | Lateral ridges (-) | |
| D | Descending cylinders (-) | |
| E | Descending cylinders (+) | |
| F | Staircase (-) | |
| G | Staircase (+) | |
| H | Cylinders (-) | |
| I | Cylinders (+) | |
| J | Ramps | Surface roughness |
| K | Rectangular prisms | Linear displacement error |
| L | Tensile bar | Ultimate tensile strength |

### Powder removal methodologies:

Document part weight versus CAD comparison

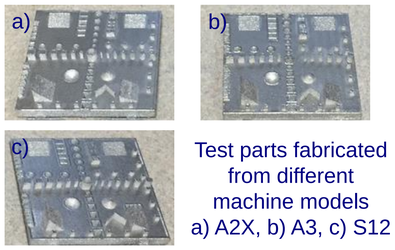
Evaluate entrapped powder locations

Apply ultrasonic energy and recycle powder



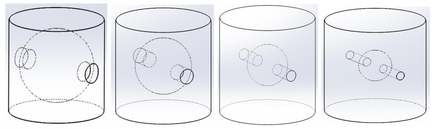
## Results

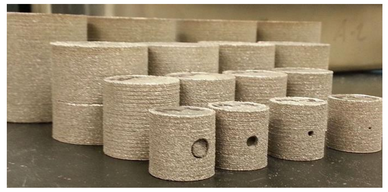
### EBM part fabrication:




Test parts fabricated from different machine models a) A2X, b) A3, c) S12

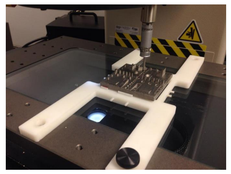
Test parts fabricated for powder removal demonstration, each containing different sized output channels (1mm - 6mm)

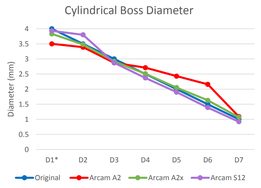


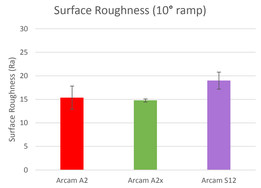


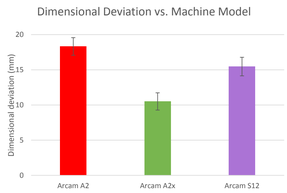
### Process Characterization:

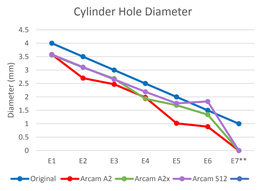
Measurement setup

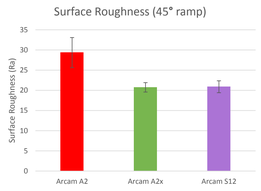




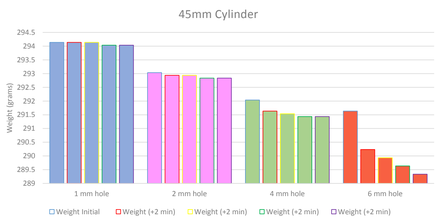



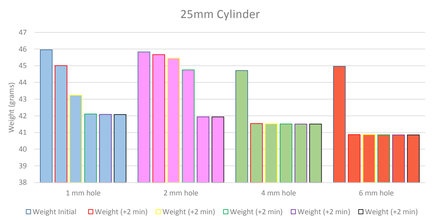



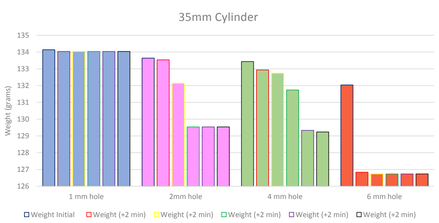



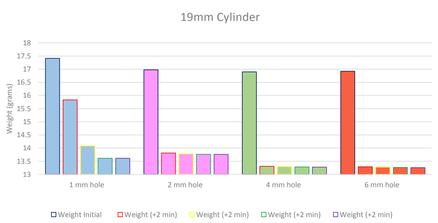




### Powder removal demonstration:




## Takeaways:

Process characterization:

- Features smaller than 2.5 mm become deformed and the fabricated part measured larger than the intended geometry.
- Features larger than 2.5 mm are very close to the intended geometry.
- Walls tend to be thicker than the intended geometry, which may be due to surface roughness due to powder size.

Powder removal:

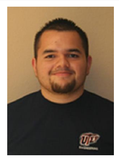
- Powder removal did not progress after 10 minutes of removing powder using the machine's powder removal station.
- Ultrasonic powder removal method is currently under further evaluation.

## Future Work

- Evaluate other powder removal methods including process parameter variations.
- Begin the re-design and fabrication of a Low-NOx fuel injector given design constraints.

| | Year 1 | | | | Year 2 | | | | Year 3 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 |
| **Task 1: Development of design methodologies for EBM** | | | | | | | | | | | | |
| Fabrication of test parts for technology evaluation | | | | | | | | | | | | |
| Evaluation of test parts | | | | | | | | | | | | |
| Re-design for AM of Low-NOx fuel injector | | | | | | | | | | | | |
| Alternative designs for sensor integration | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| **Task 2: Development of powder removal techniques** | | | | | | | | | | | | |
| Powder removal for internal channels | | | | | | | | | | | | |
| Powder removal for internal cavities | | | | | | | | | | | | |
| Process parameter modifications for optimal powder sintering | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| **Task 3: Testing of EBM-fabricated fuel injectors** | | | | | | | | | | | | |
| Functionality assessment of EBM-fabricated fuel injector | | | | | | | | | | | | |

## Student Involvement



## Acknowledgements

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