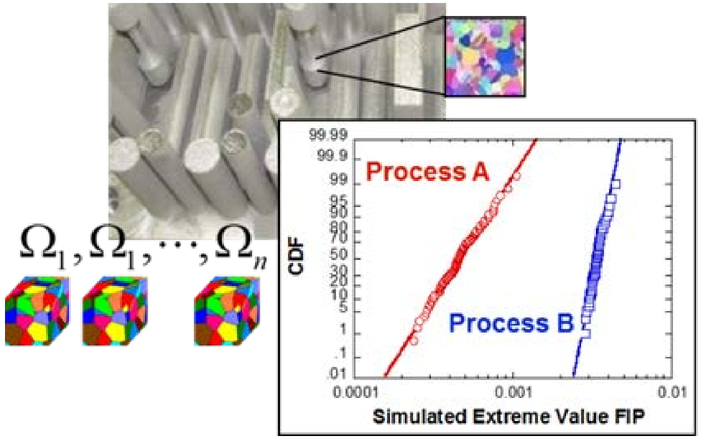
SOUTHWEST RESEARCH INSTITUTE®

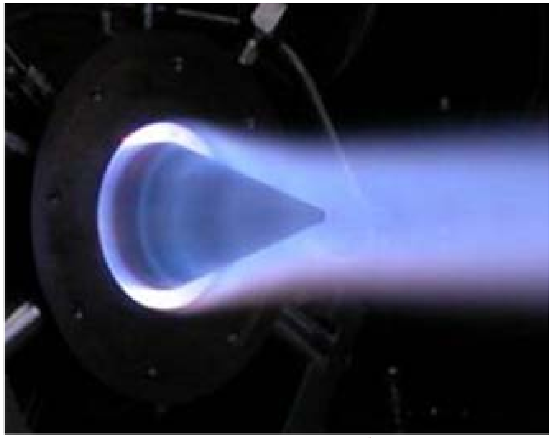
Digital Twin Model for Advanced Manufacture of a Rotating Detonation Engine Injector

This project will utilize a digital twin material model (DTMM) for the optimum application of advanced manufacturing (AM) techniques to advance the state-of-the-art in rotating detonation engine (RDE) injector design

DTMM



RDE



Shane Coogan
Senior Research Engineer

September 22, 2020

SwRI®

Georgia Tech

AEROJET ROCKETDYNE

©SOUTHWEST RESEARCH INSTITUTE

The 1st project objective is to demonstrate a low-loss RDE injector

*Focus of previous work by AR, SwRI, and others under an earlier NETL program

- RDE injector pressure losses must be reduced to field a commercially viable power generation system
- This project is using AM as an enabling technology to build an operable injector with reduced losses

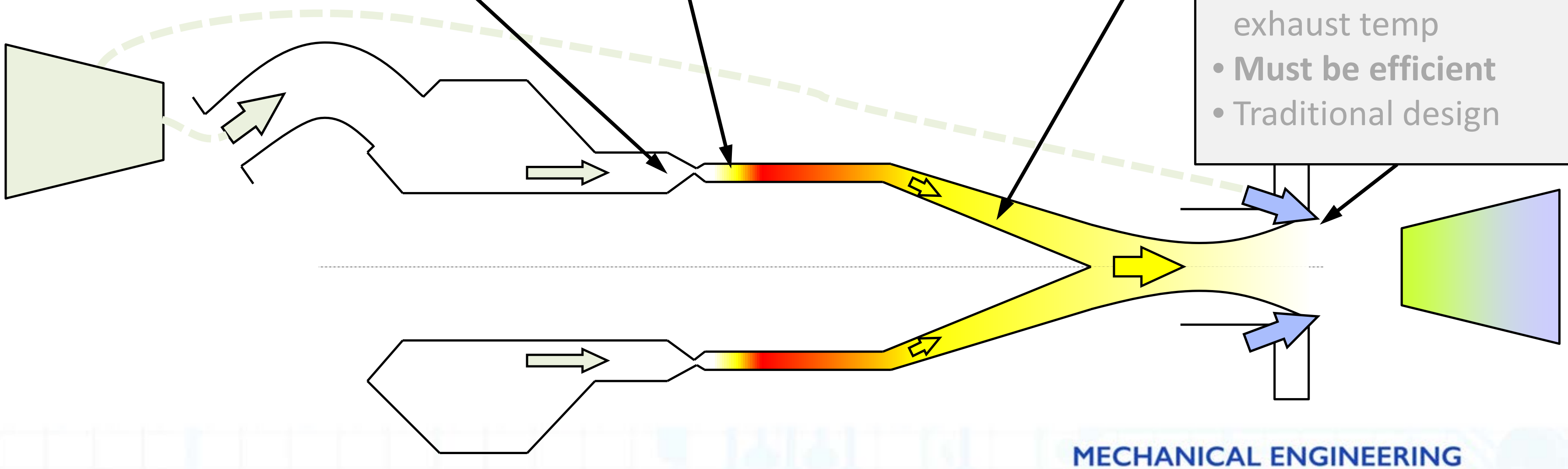
Sources of Significant Pressure Loss

ISOLATOR/INJECTOR
- Reduce upstream pressure fluctuations
- Various devices shown to be effective
- Prior program demonstrated <20% Pt loss, and peak oscillation

RDE COMBUSTOR*
- Air/NG detonation difficult due to large cell size (300mm @ STP)
- Requires large combustor
- Injection, mixing significant

DIFFUSER*
- Primary focus of Phase I, II program
- Reduce downstream pressure fluctuations
- Minimal total pressure loss

BYPASS MIXER
- May be req'd to lower exhaust temp
- **Must be efficient**
- Traditional design



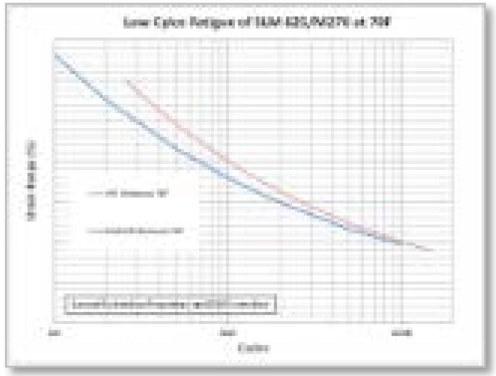
©SOUTHWEST RESEARCH INSTITUTE

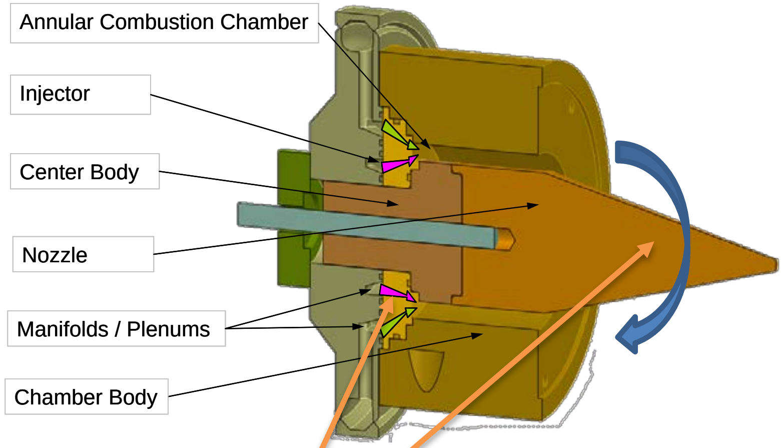
The 2nd project objective is to develop a material model that predicts fatigue performance of the AM injector

Machine Parameters | **Material Properties** | **Part Performance**

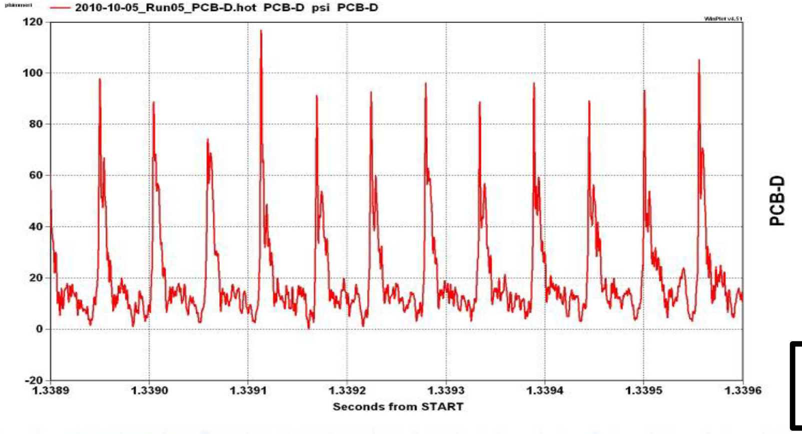
Modeling here…

…reduces iteration here





Dynamic pressure environment of an RDE
~5 kHz pressure oscillations

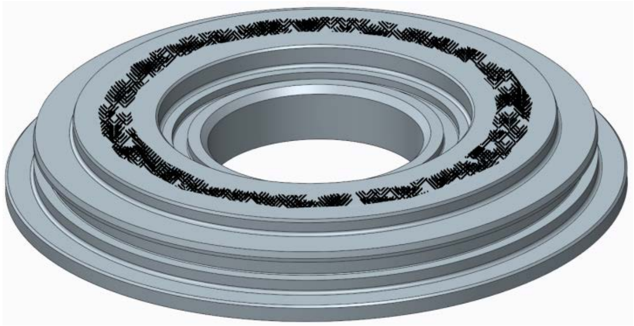


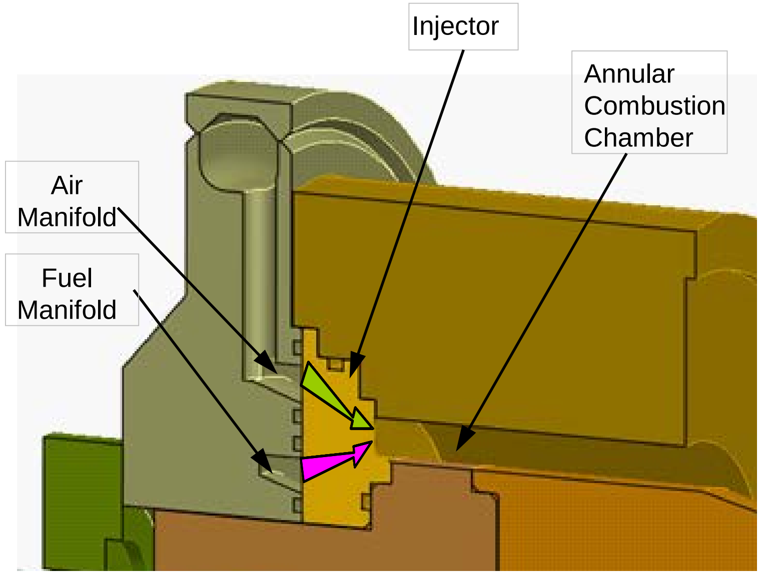
Pressure oscillations create a high frequency wobbling motion that transmits loads to the injector

The injector is potentially subject to high cycle fatigue, particularly in the context of a commercial power generation application

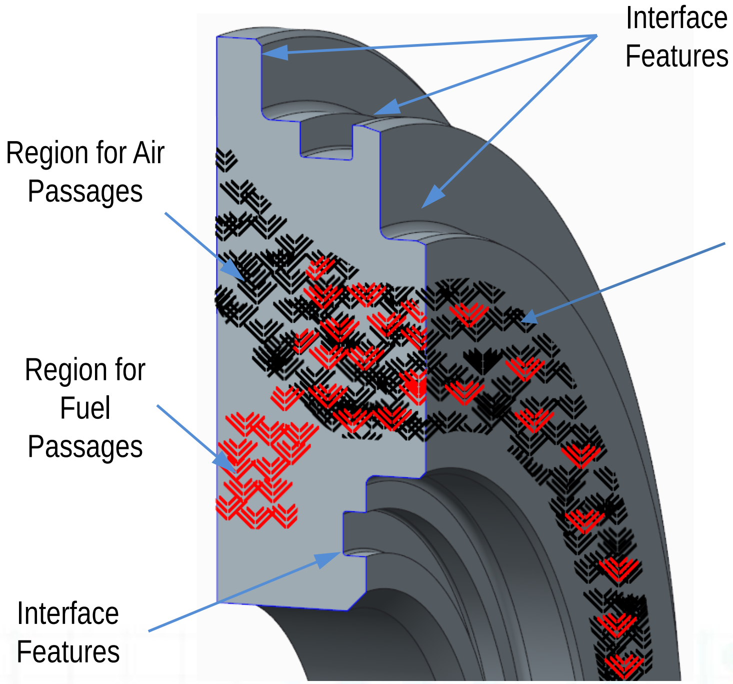
AM process settings must be selected to maximize injector fatigue strength

Two injectors have been designed to address the project objectives





- Injector #1
  - Opens the oxidizer flow path
  - Low pressure losses
  - Will be fired a few times to assess operability and pressure losses (project objective #1)
- Injector #2
  - Constricts the oxidizer flow path
  - Has more pressure losses
  - Lower risk of operability issues
  - Will be repeatedly fired to develop high cycle fatigue for comparison to model predictions (project objective #2)

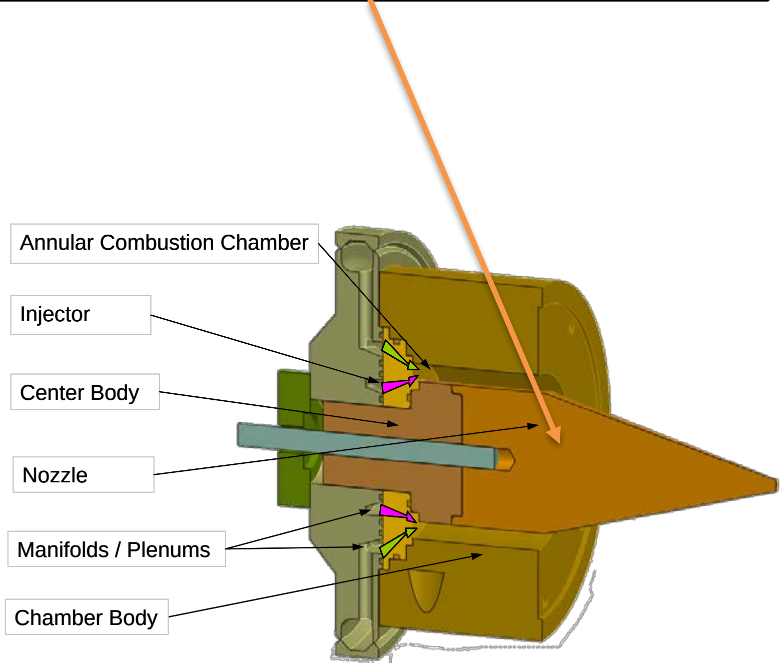


Location of aggressive mixing geometry that is enabled by additive manufacturing

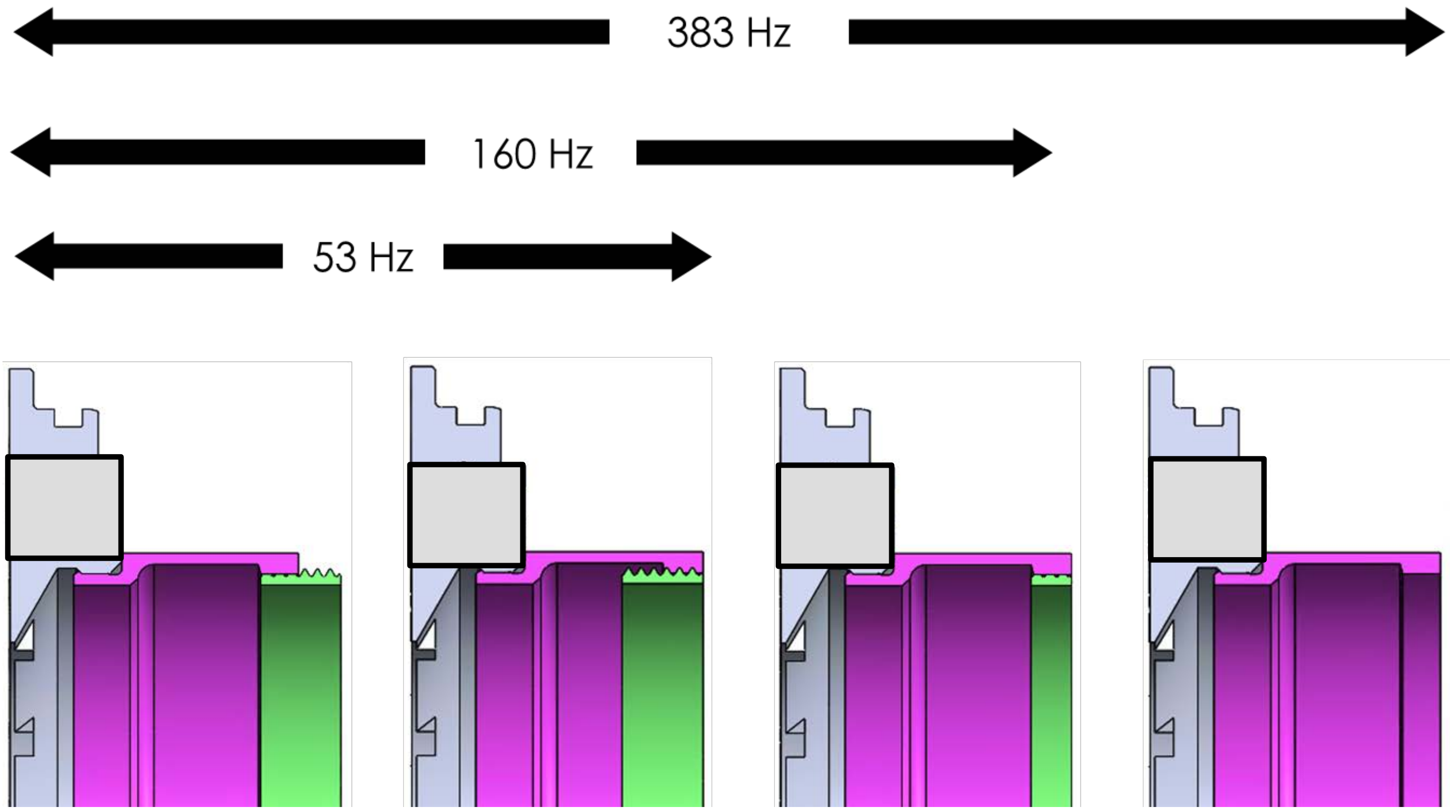
©SOUTHWEST RESEARCH INSTITUTE

A high cycle fatigue condition is designed into the RDE system to test material model predictions

Typical development hardware uses a massive center body that filters high frequency excitation



This project uses a lightweight center body with adjustment features to align the mechanical natural frequency with the RDE detonation frequency



©SOUTHWEST RESEARCH INSTITUTE

The material model is developed from statistical analysis of sample build microstructures and property tests

Processing

DofE Builds

Collect all processing history for each discretized digital volumes

SwRI, AR

Structure

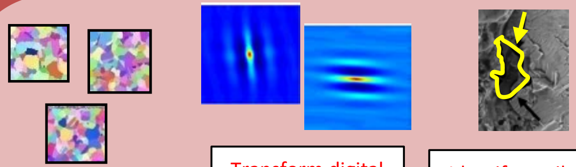


Image each built volume to resolve critical attributes of the structure

Transform digital images to a statistical quantification of the structure

Identify attributes controlling HCF from characterizing fracture surfaces

Compute low-dimensional description of microstructure

Establish the P-S relationship via regression

Establish the S-P relationship via regression

GT

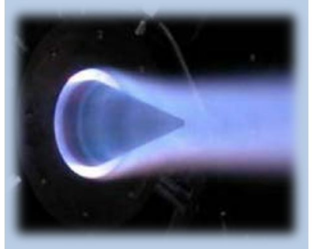
Properties

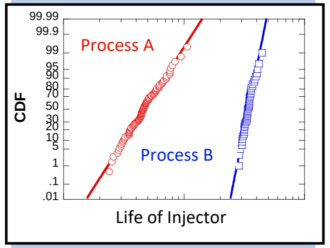
Conduct tensile tests in two orientations (build direction and transverse)

Determine HCF behavior under reference condition in two orientations (build direction and transverse)

GT, SwRI

Performance





Injector Builds

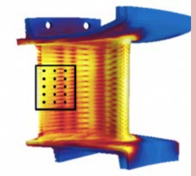
Collect all processing history and loading from FEA for each discretized digital volumes

AR, SwRI

Predict the low-dimensional descriptor of microstructure of each discretized volume

GT

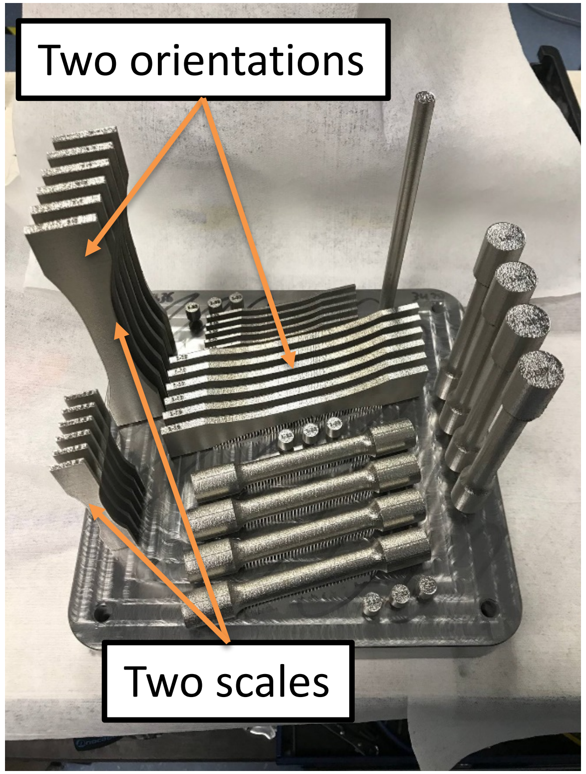
Impose macroscopic stress and thermal FEA of injector to each discretized volume in the digital twin to predict properties and state of each volume



Prognose performance of each volume in the digital twin; validate predictions of microstructure and properties

GT, SwRI

1 of 11 sample builds manufactured to create data for the material model

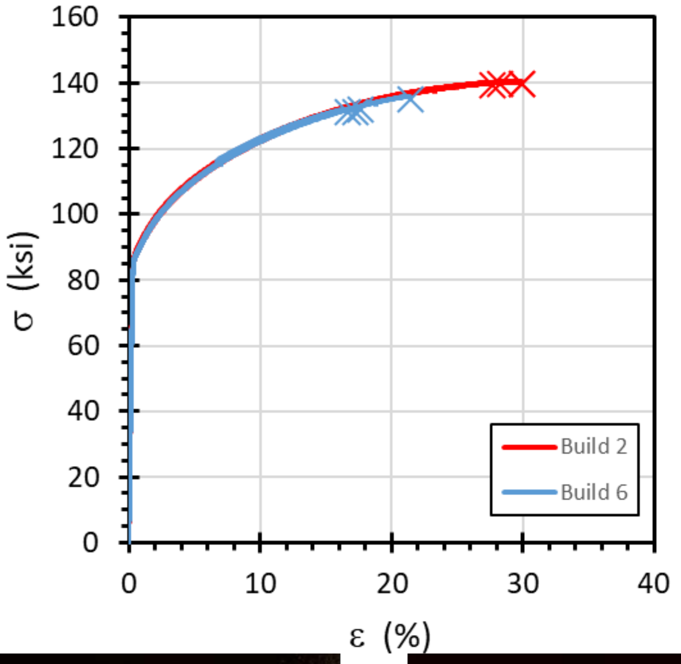


Sample build variables include AM machine type, scan speed, hatch spacing, and post-build annealing

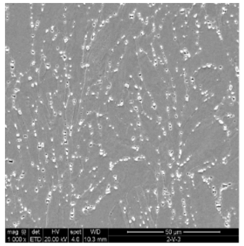
©SOUTHWEST RESEARCH INSTITUTE

Untracked process variations are found to be a limiting factor in the modeling of AM materials

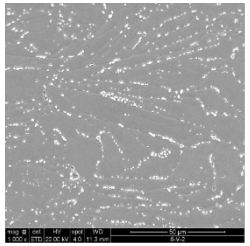
Identical builds exhibit notably different ductility (Built on same machine according to the same settings, but on different days)



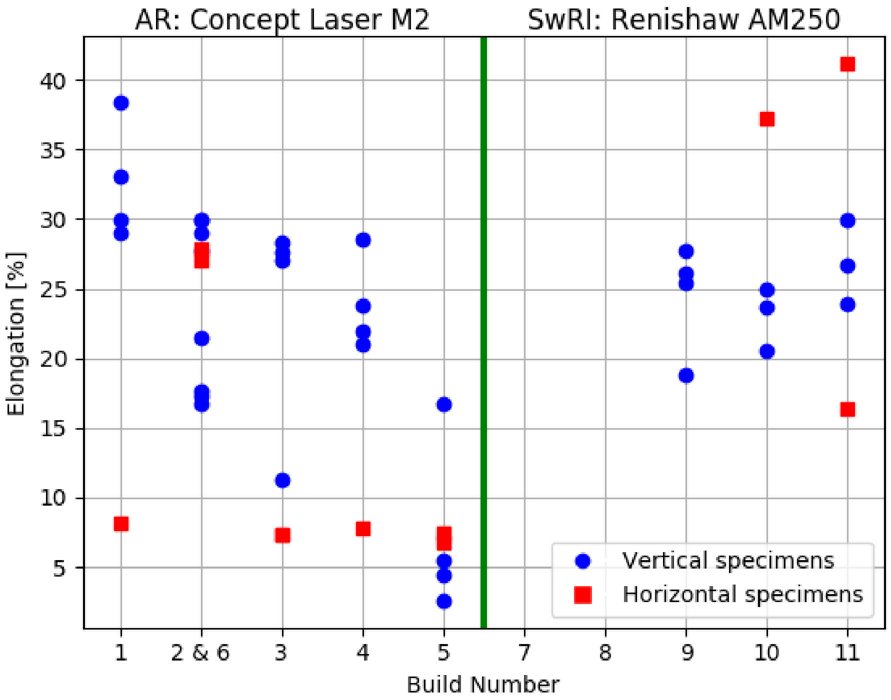
Build 2 microstructure

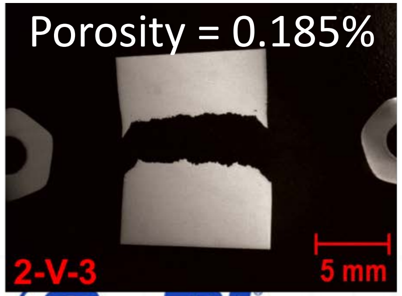


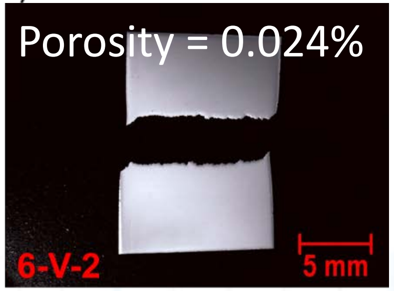
Build 6 microstructure



Significant property variations also exist in specimens within a single build





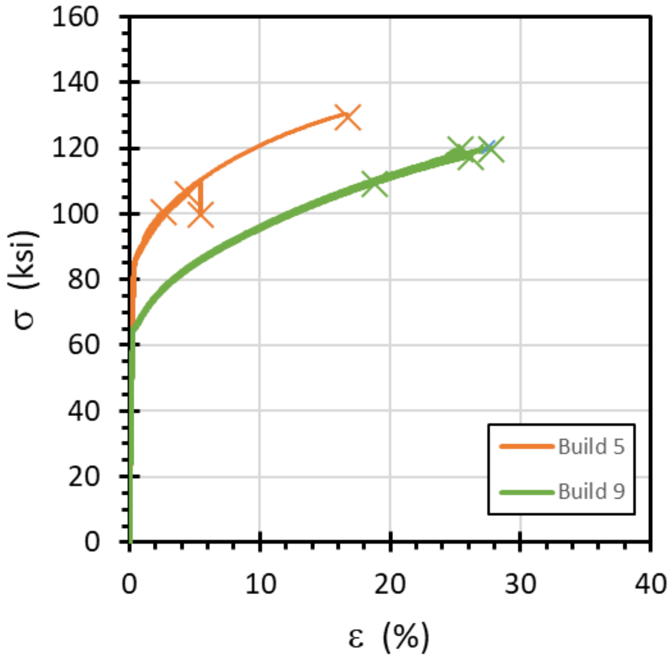


Property difference occurs despite the builds having identical microstructures and similar porosities (the lower ductility build actually has less porosity). Difference may be related to small differences in the prevalence of surface defects.

©SOUTHWEST RESEARCH INSTITUTE

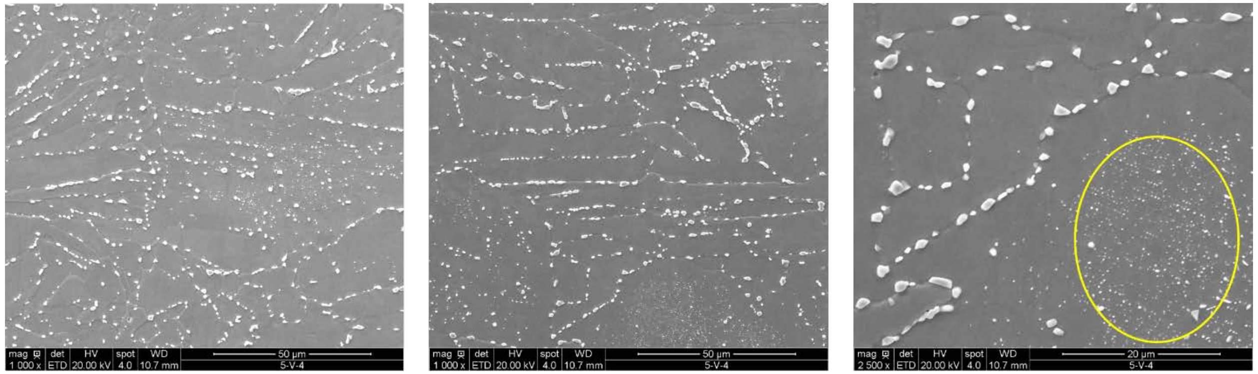
Parts from additive manufacturing machines of different makes and models are notably different even when the same settings are used

Builds 5 and 9 use equivalent settings
Build 5: AR's Concept M2
Build 9: SwRI's Renishaw 250

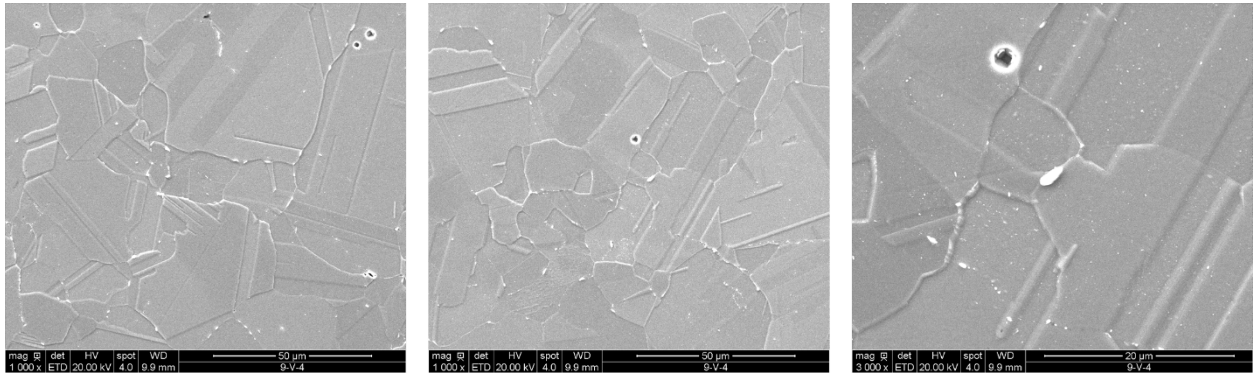


The two AM machines generate completely different microstructures

Build 5 microstructure



Build 9 microstructure

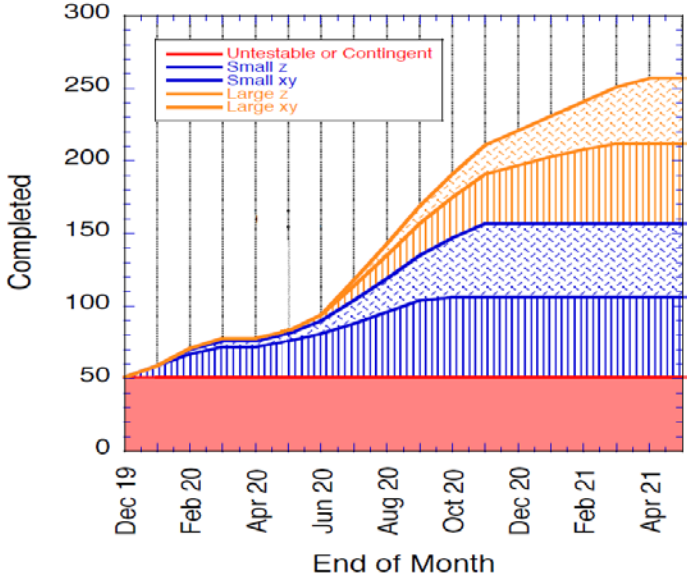


©SOUTHWEST RESEARCH INSTITUTE

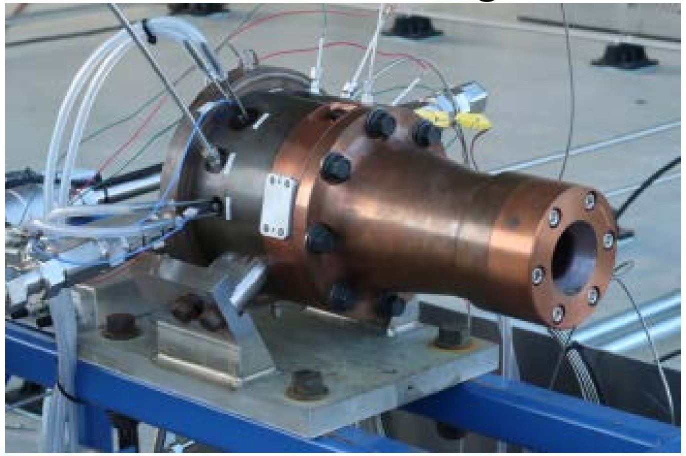
The project is on track for a September 2021 completion

- Injector design, manufacture, and test
  - Injector design is complete
  - Injector #1 is beginning manufacturing
  - Injector #2 will follow once the material model is complete
  - Hot-fire testing begins in Jan. 2021
- Material modeling
  - Tensile tests are completed
  - Small specimen fatigue tests are underway and will be completed by Nov. 2020
  - Model formulation is complete and is awaiting more data inputs – first version to be delivered in Nov. 2020
  - Material model will be updated at end of project based on subsequent large specimen data

Fatigue specimen testing schedule



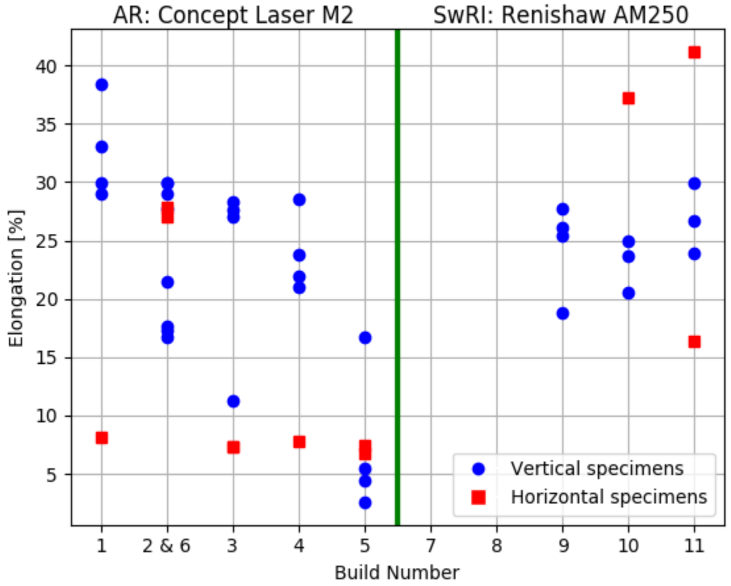
Hot-fire test rig



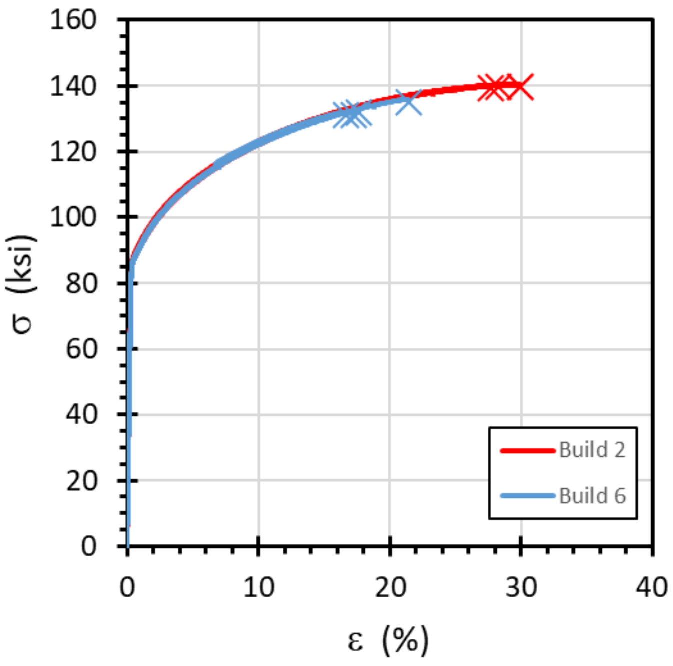
©SOUTHWEST RESEARCH INSTITUTE

There are several takeaways from the work completed to date

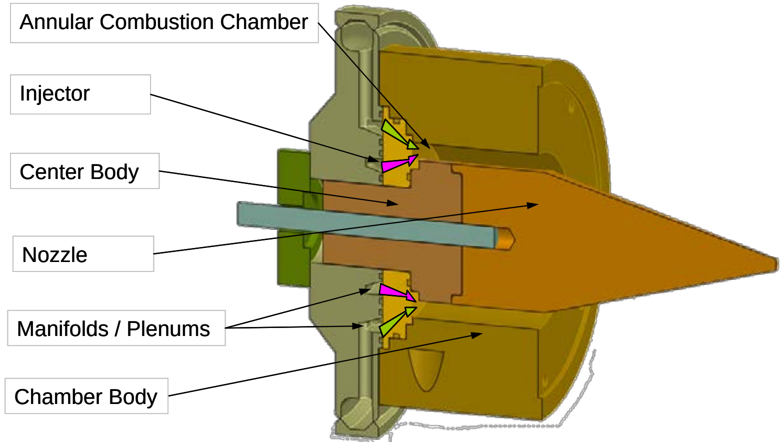
A large quantity of repeat builds are needed to accurately assess any AM build process



More specific in-situ measurements should be included in production processes to understand property differences between identical builds



Despite their inherent periodic operation, RDE's are not necessarily susceptible to fatigue due to center body filtering



Shane Coogan
Senior Research Engineer
shane.coogan@swri.org
210-522-2774

©SOUTHWEST RESEARCH INSTITUTE