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

- 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

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

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

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)
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.

- 383 Hz
- 160 Hz
- 53 Hz
The material model is developed from statistical analysis of sample build microstructures and property tests.

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

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

Two orientations

Two scales
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)

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.
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](image1.png)

![Build 9 microstructure](image2.png)
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
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.

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