High Velocity Oxy-Fuel Thermal Spray technique for Durable Coating

2015 Crosscutting Technology Research Review Meeting

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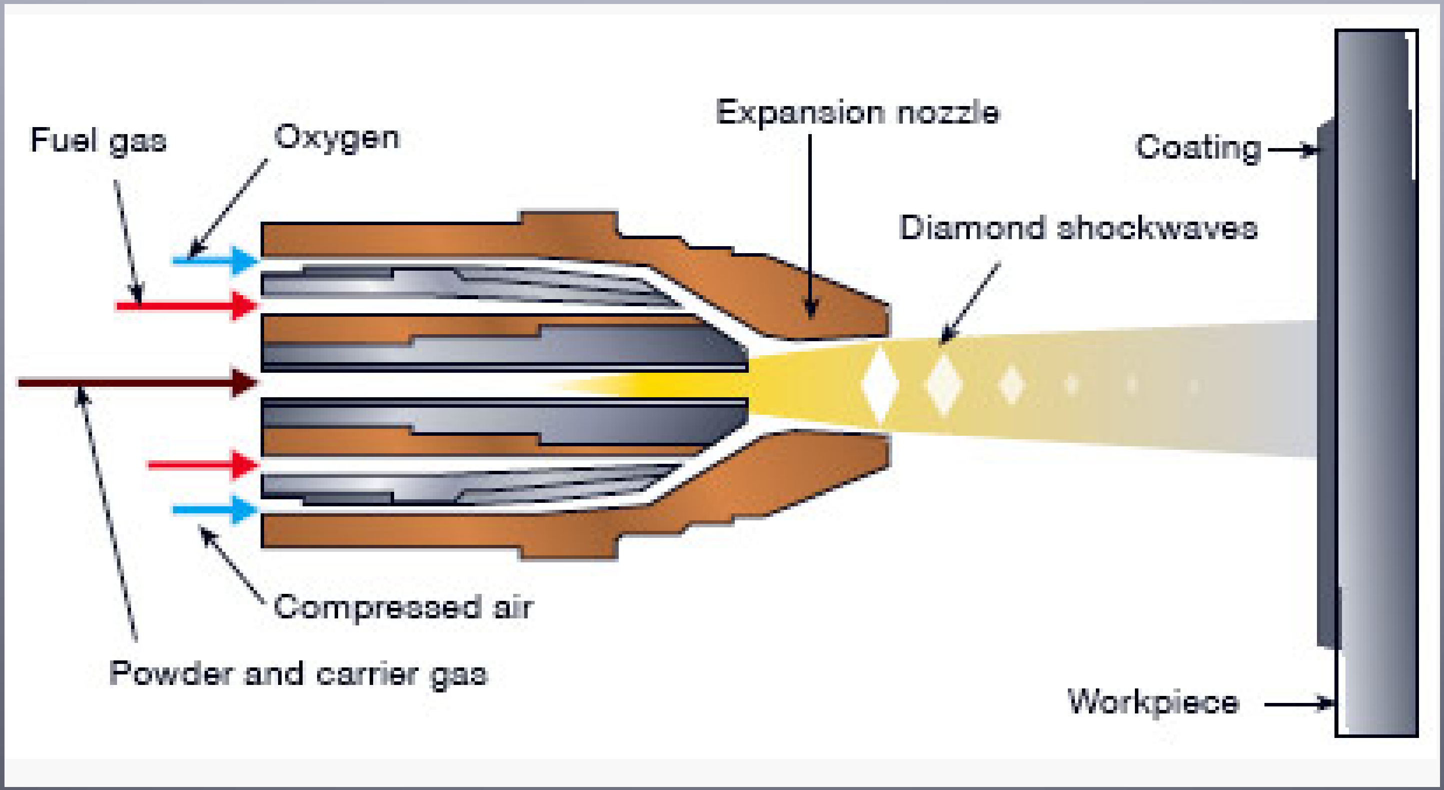
Introduction - HVOF



Source: thermalspray.com

Thermal Spraying Techniques

- Coating processes in which melted (or heated) materials are sprayed onto a surface

- Can provide thick coatings (20 micrometers to several mm)

- Available materials include metals, alloys, ceramics, plastics, composites

- Fed in powder form, heated to a molten or semi-molten state and accelerated towards substrates in the form of micrometer-size particles

Project Objectives

- To develop a modular HVOF Thermal Spray hardware to systematically study combustion chamber design, injector configurations, nozzle design, mixture ratio, gas flow rate, combustion chamber pressure, particle size, and position of substrate on the quality of Inconel and Fe-Al coatings.
  - LO_2/CH_4 Heritage Rocket Engine Technology
  - High-temperature tolerance, thermo-mechanical, thermo-chemical, and fracture toughness of the coatings
- Possibly Extend the operation to cryogenic and storable liquid fuel and oxidizers.

Student Team

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Project plan

Year 1

Design analysis
Hardware development

Year 2

Parameter testing
Initial Coating

Year 3

Coating optimization characterization

Completed

Completed

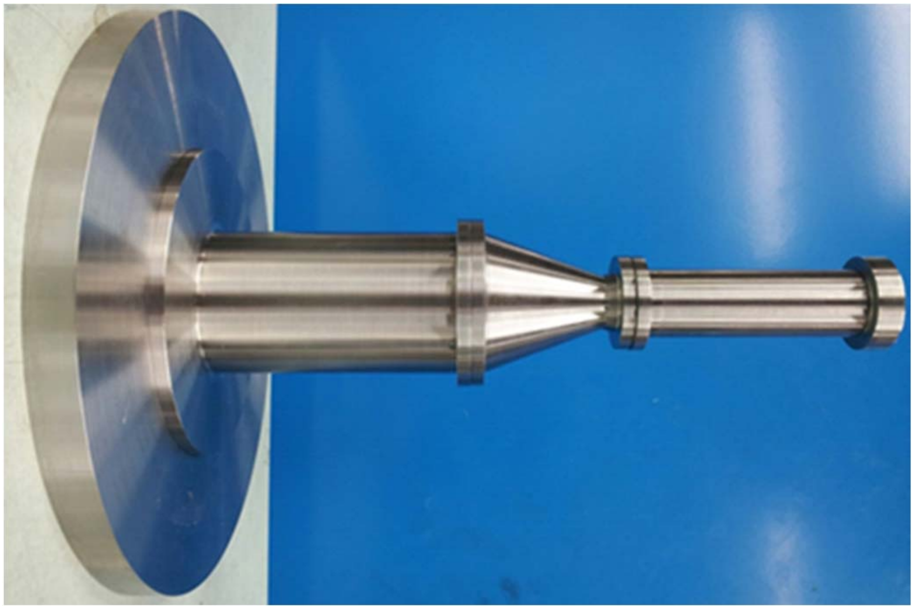
Ongoing

Requirement Overview

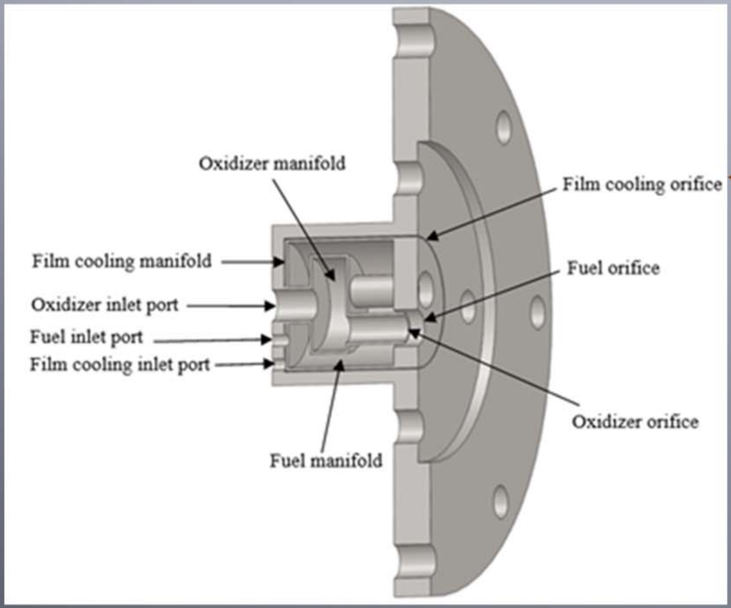
- Deep throttle capability (4:1)
- Maximum exit Mach number: **1.4**
- Exit temperature: 2000-3000 K

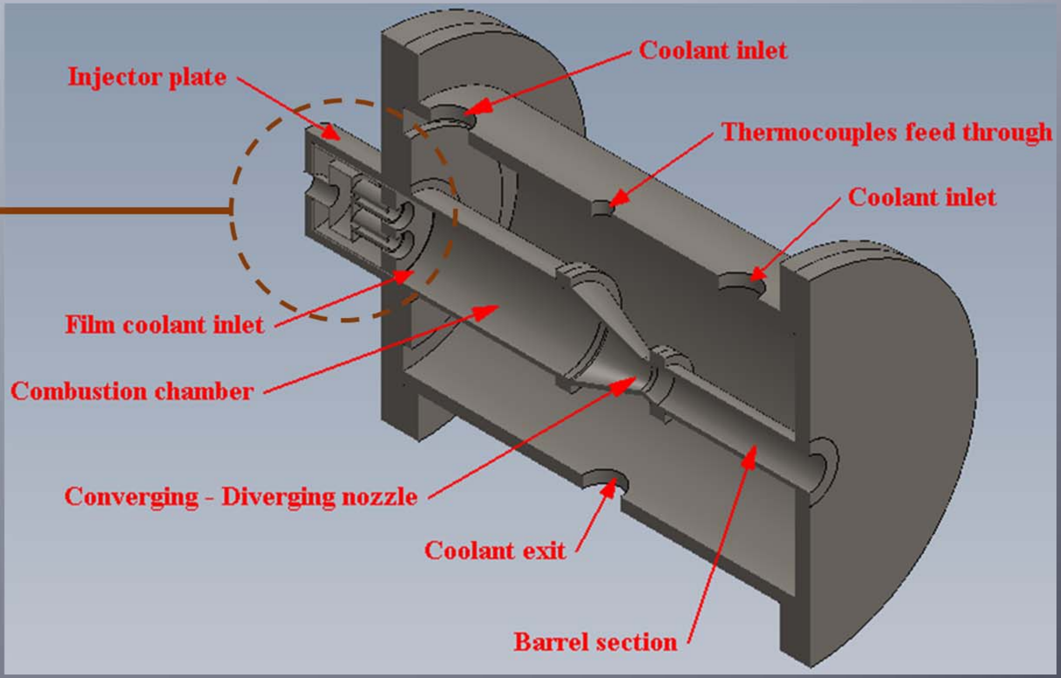
Requirement Overview

- **Five Modular** Sections:
- Injection system
- Combustion chamber section
- Converging-Diverging Nozzle
- Barrel section
- Cooling jacket



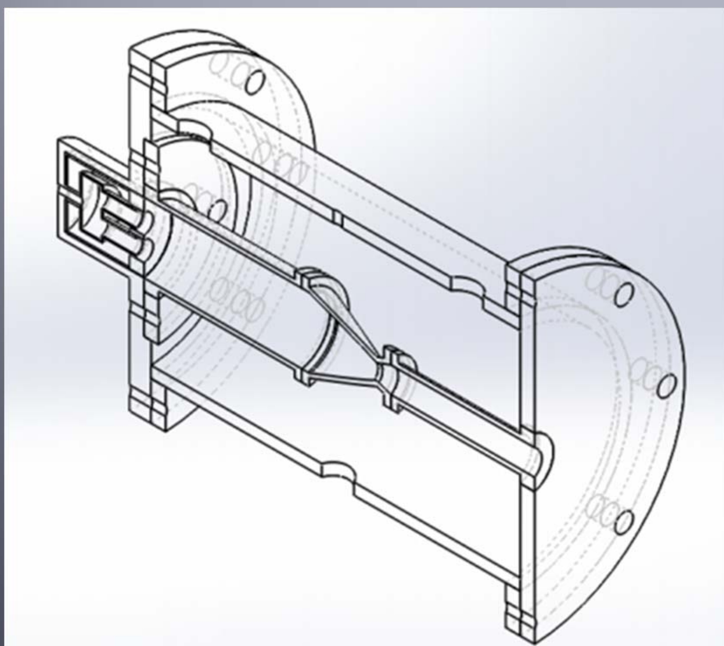
Technical Approach - Injector

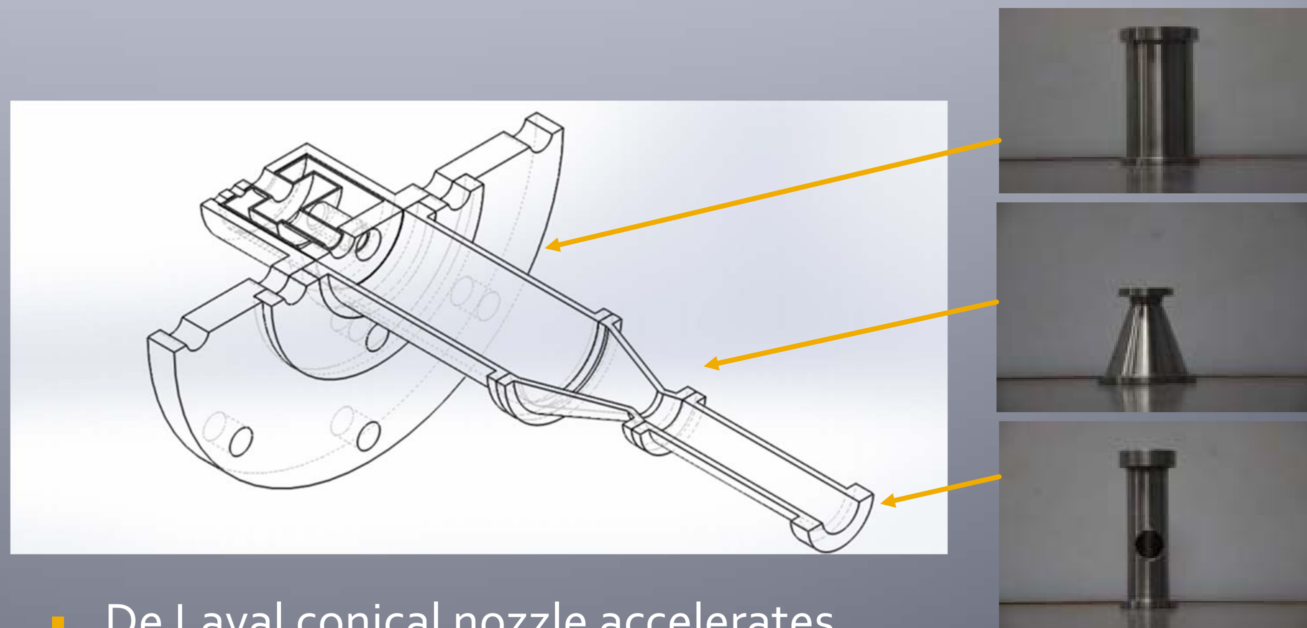




Shear coaxial injection configuration

Technical Approach –Nozzle

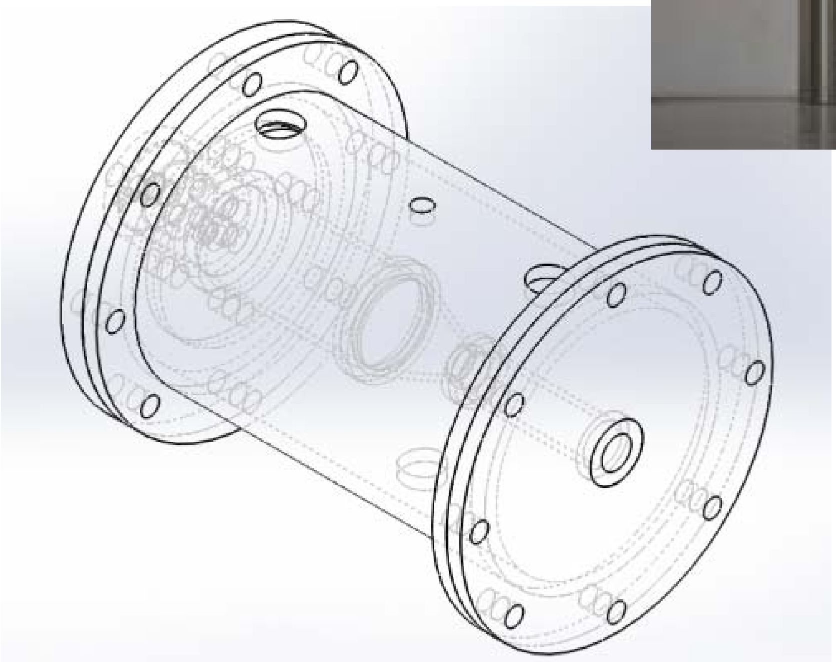




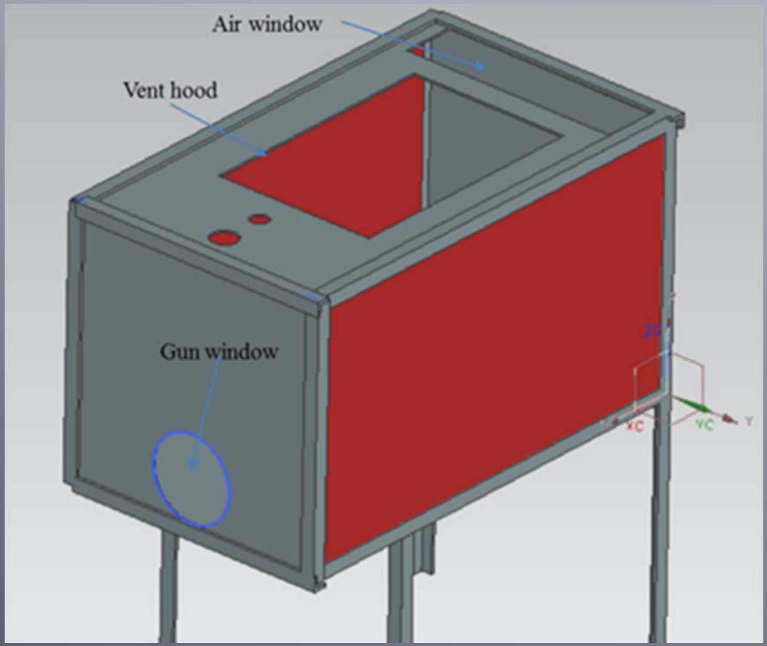
- De Laval conical nozzle accelerates gases to supersonic speeds
- Addition of barrel section allows for smooth particle integration into the flow

Technical Approach – Cooling Jacket

- Ethylene glycol combination fluid allows for effective heat removal
- Design allows coolant flows of up to 33 LPM
- Configuration acts as a heat sink when testing for short durations



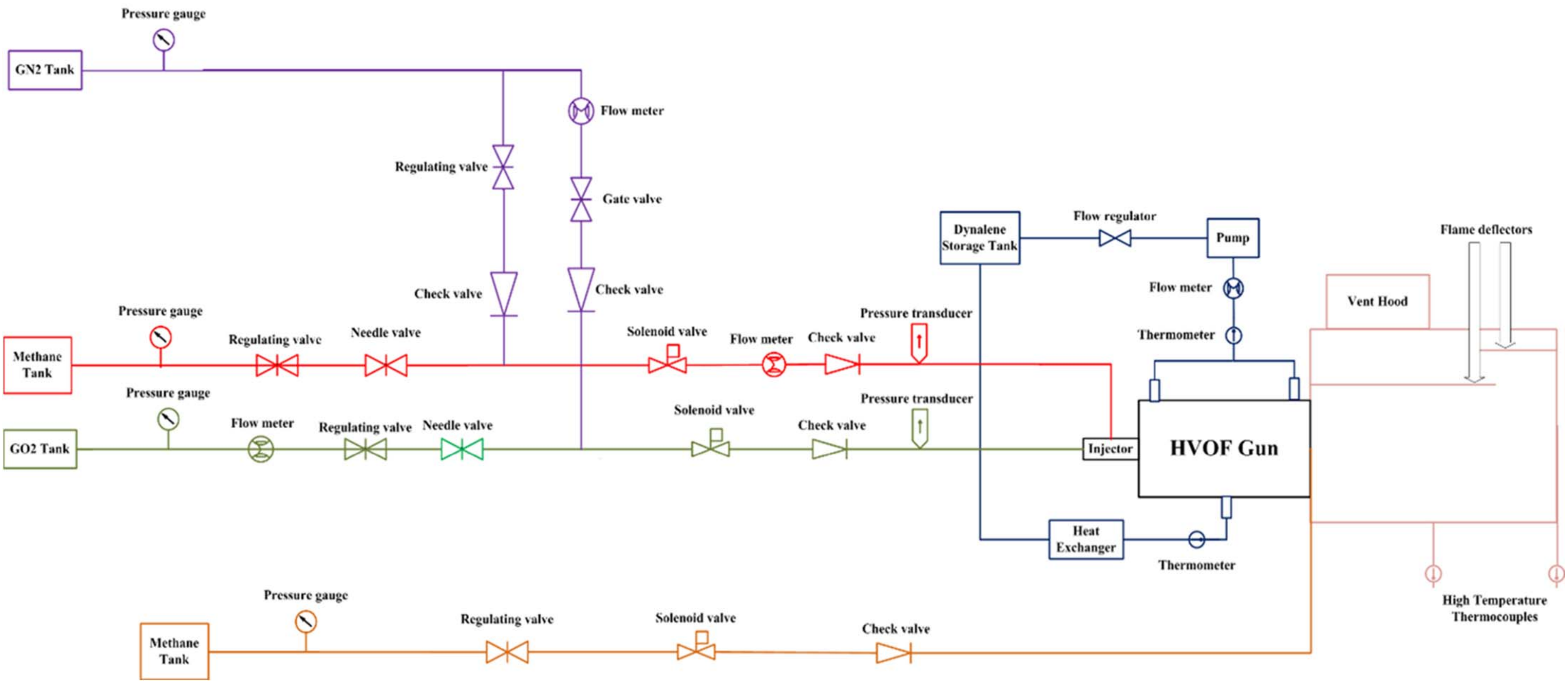
Technical Approach - Products



Vent enclosure ensures proper disposal of products/particles

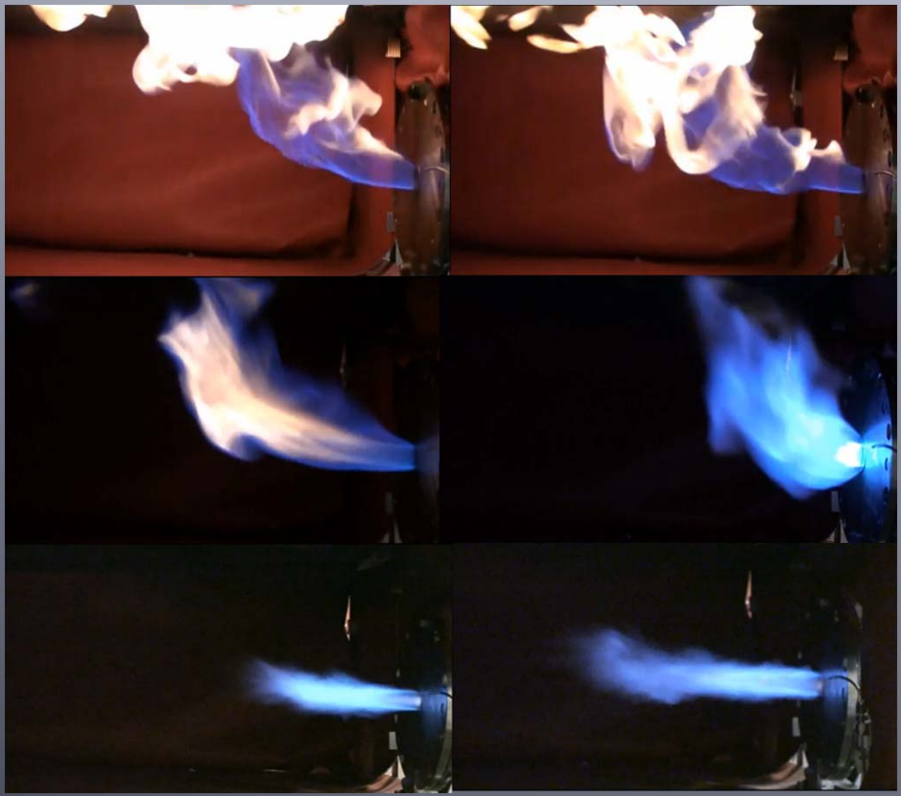
Fire blankets are placed around setup exhaust for added protection

System Layout



System Layout

Operational Optimization



- Low output velocities presented stable flame in all ignition configurations
- High velocity approach required additional experimentation
- Outside torch ignition yielded instabilities
- Spark ignition configuration was optimized to avoid hard starts

Test Conditions

- CH_4+O_2 mixture
- Oxidizer to fuel ratio = 3.5
- Distance to substrate = 50-150 mm
- Test Duration = 2-5 seconds
- Inconel 718, FeAl particles tested
- Exit Temperatures = 2980 K – 3020 K
- Exit Velocities = 938-1400 m/s

Premixed flame in supersonic conditions

Coatings

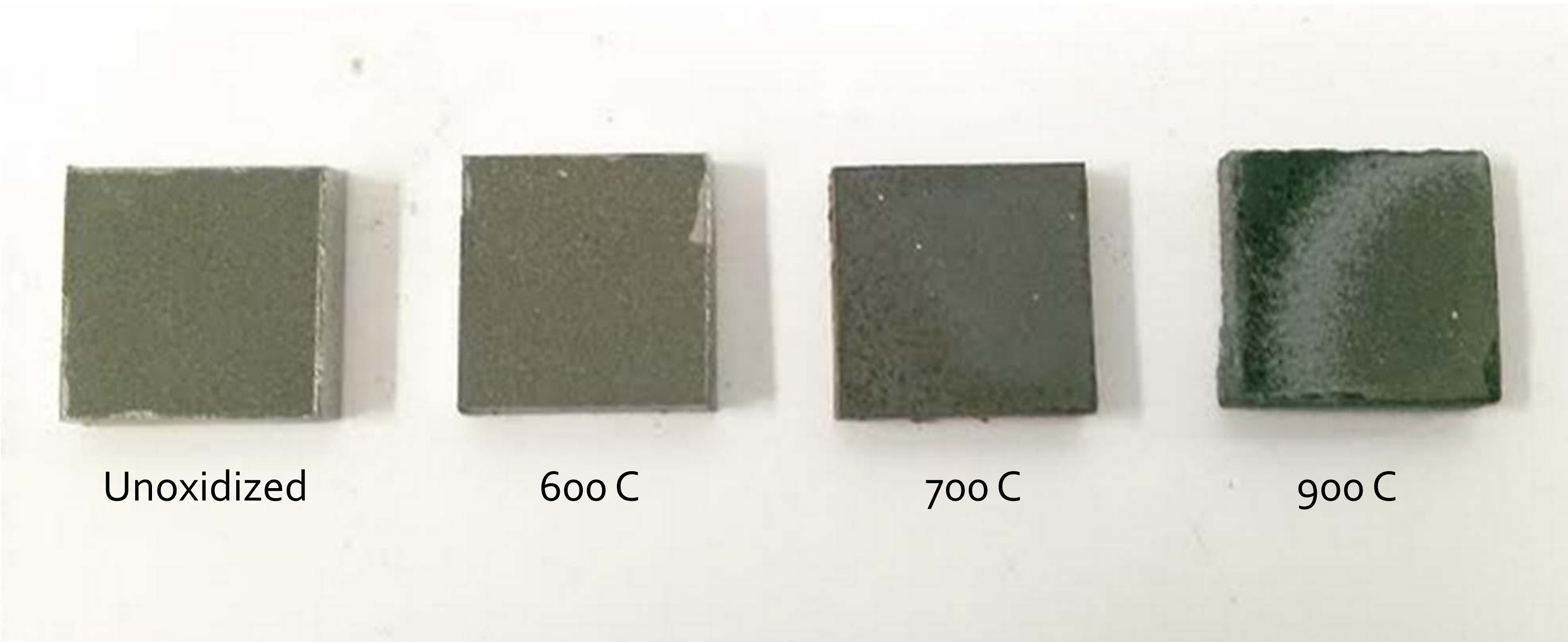
Substrate positioning/holding in experimental setup

Fe Al samples generated at a distance of 100 mm

Mach 1.2

Mach 1

Coatings

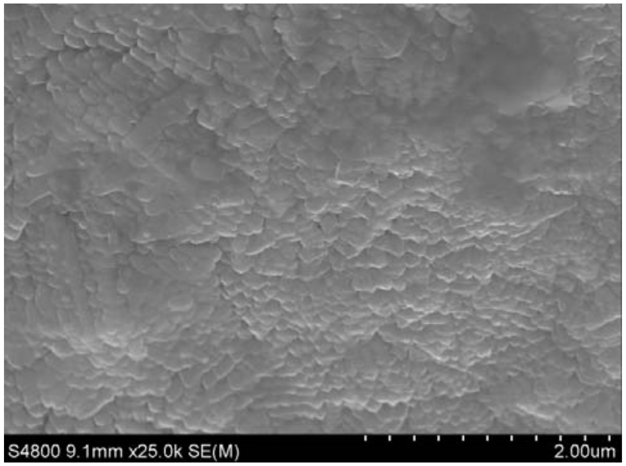


Coatings

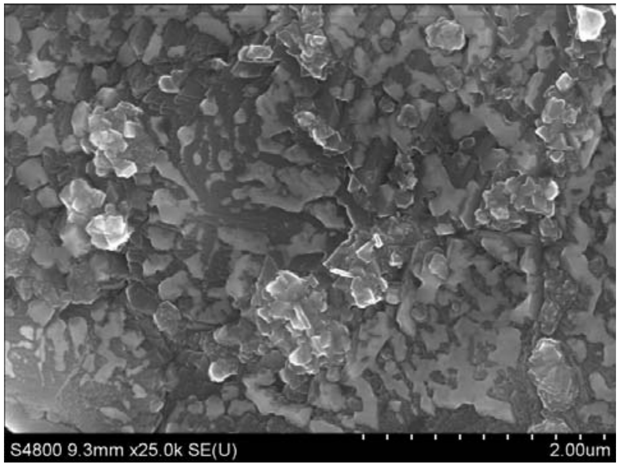
- **Operational Parameters**
  - **Studied**
  - Exit velocity
  - Distance to substrate
  - Coating material
  - **To be studied**
  - Propellant composition
  - O/F ratio

- **Testing Methods**
  - **Exposure -** Furnace thermal treatment, high pressure combustion
  - **Imaging** – Scanning Electron Microscopy
  - **Composition** – X-Ray Diffraction
  - **Mechanical Testing** – Nanoindentation

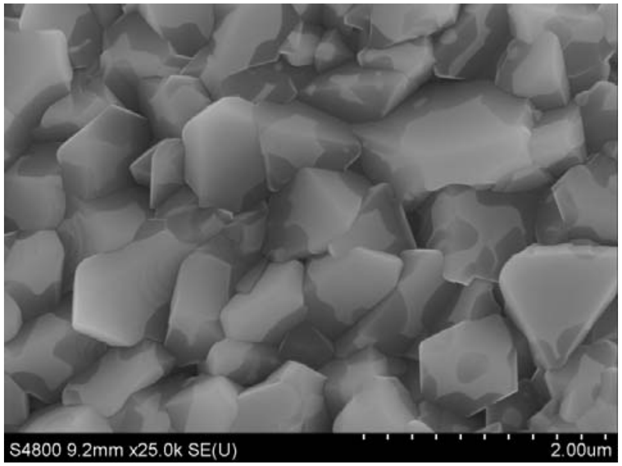
SEM imaging (Inconel 718, 100 mm to substrate)



UNOXIDIZED

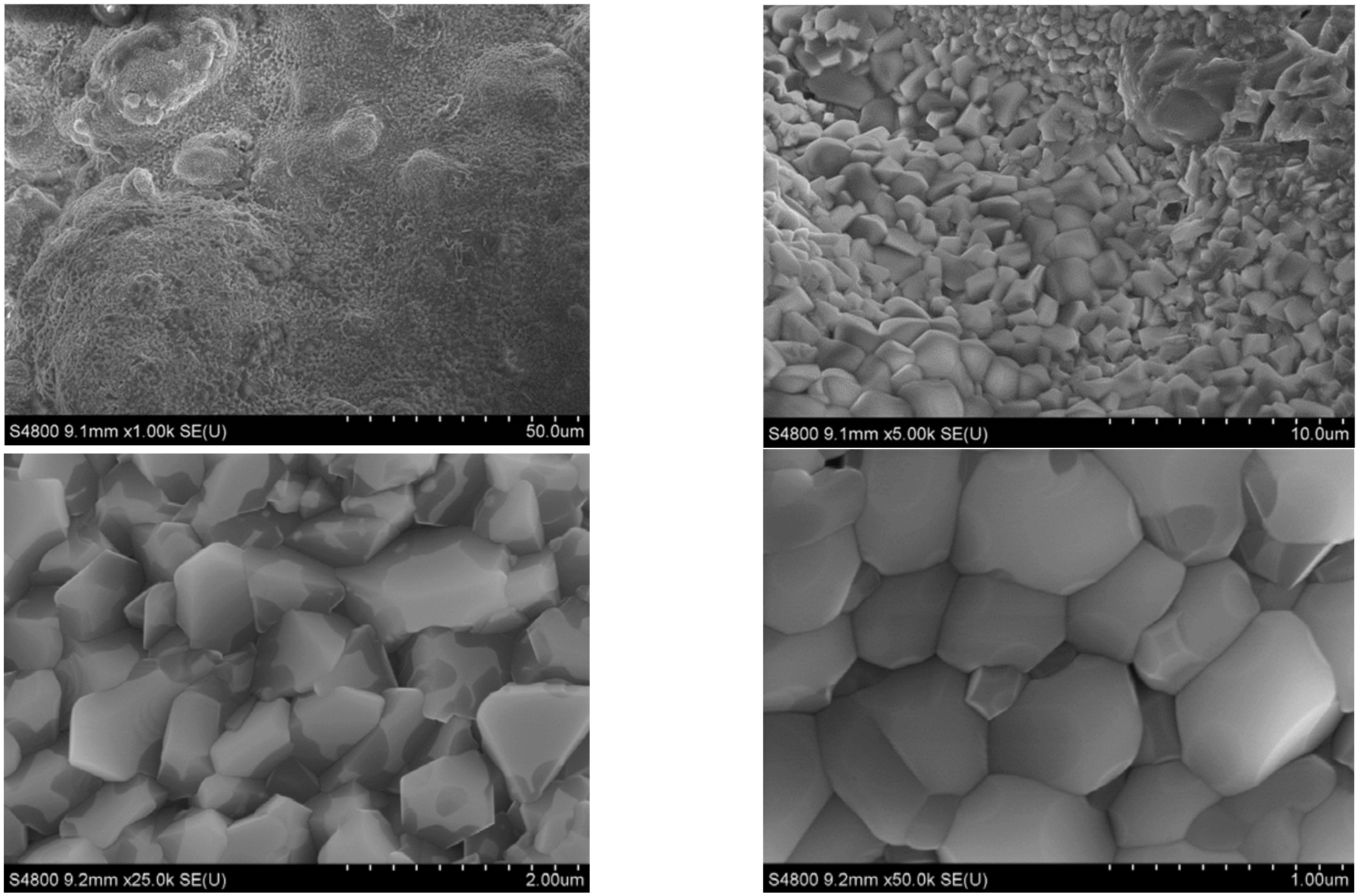


600 C

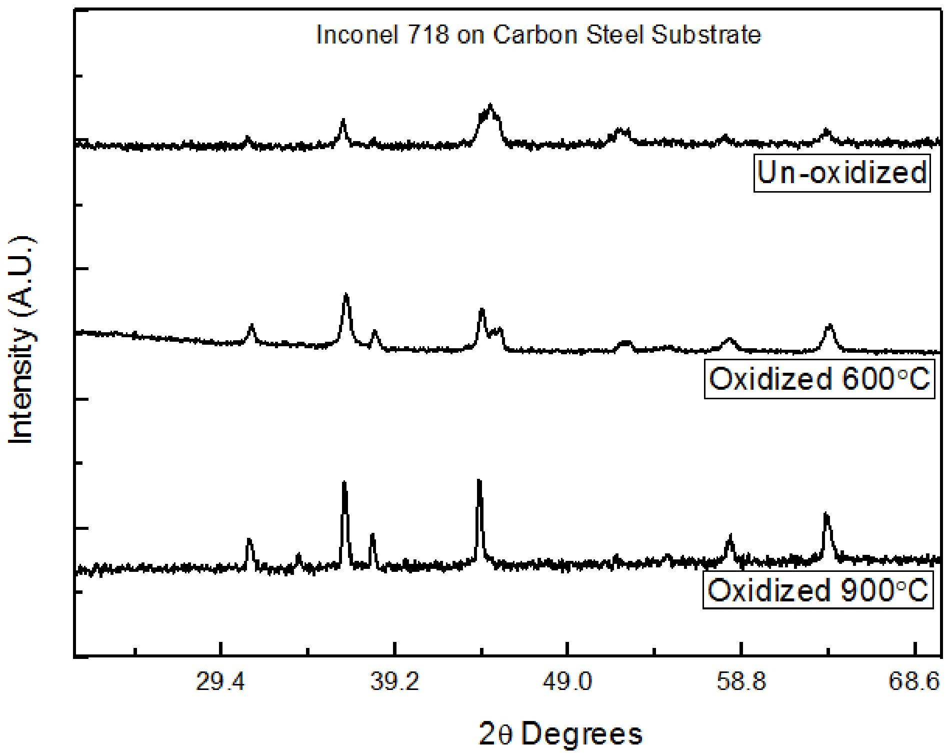


900 C

SEM imaging (900 C)



SEM/XRD Analysis Results



- High crystallization shown at increased oxidation states where amorphous structure is shown as initial
- Grain growth at high temperatures implies evaporation and restructuring of coating components
- Nanoindentation preliminary testing shows decrease in hardness, Young's modulus in oxidized samples
- Additional analysis will be performed to compare operational parameters, coating materials

Year 3 plan

- Sample testing completion
- Test matrix refinement and testing
- Development of liquid-fuelled system

Publications

- Luisa A. Cabrera, Diaaeldin Mohamed, Norman Love and Ahsan Choudhuri, " High Velocity Oxy-Fuel Thermal Spraying Techniques: A review," 3rd Southwest Energy Science and Engineering Symposium, April 27, 2013, El Paso, Texas, USA.
- Diaaeldin Mohamed, Luisa A. Cabrera, Norman Love and Ahsan Choudhuri, " High Velocity Oxy-Fuel Thermal Spray Gun Design," AIAA SciTech 2014, Jan 13-17, 2014, Maryland, USA
- Diaaeldin Mohamed, Luisa A. Cabrera, Norman Love and Ahsan Choudhuri, " An Experimental Study Using Particle Image Velocimetry to Characterize Flows in High Velocity Oxy-Fuel Thermal Sprays," AIAA Propulsion and Energy Forum 2014, July 28-30, 2014, Cleveland, OH, USA
- Diaaeldin Mohamed, Luisa A. Cabrera, Ana Rios, Norman .Love, Ahsan Choudhuri, "Flow Characterization of Liquid Fueled High Velocity Oxy-Fuel Thermal Sprays", 5th Southwest Energy Science and Engineering Symposium, April 4, 2015, El Paso, Texas, USA.

Thank You

Questions?