Phase II Project Summary

Research Objective

Radiation cooled thrust chambers and nozzle extensions of liquid rocket engines require a high emissivity, approaching near black body, in order to properly dissipate thermal energy from the component. One specific example is the nozzle extension of the J-2X engine. The J-2X is an upper stage engine that operates in a severe environment. The internal surface of the nozzle extension contains the hydrogen-oxygen combustion gases, which are expanded through the nozzle at extremely high velocities. Wall temperatures of the nozzle extension approach 2100 degrees Fahrenheit. The internal surfaces of the nozzle extension must have an emittance approaching 85% in order to dissipate some of the heat through the plume. The outer surface of the nozzle extension, which is exposed to the vacuum of space, will dissipate a majority of the energy, thus also requires an emittance approaching 85%. The objective of the Phase II research was to identify/develop a highly emissive coating suitable for the J-2X nozzle extension. Following coating selection, emissivity and performance optimization, a secondary objective was to demonstrate application of coating to a full-scale sized component.

Research Performed

In response to the coating requirements identified by NASA, Plasma Processes developed a highly emissive coating that exceeds the operational requirements of the J-2X NE. The coating was formulated by blending commercially available powders. Powder chemistry was precisely tailored to optimize the emissive properties. The coating is applied via thermal spray technology using an inert gas shroud. The emissive properties and durability of the coating were successfully demonstrated in relative environments at Marshall Space Flight Center, Thermophysical Research Laboratory at Purdue University, and Plasma Processes. Unlike industrial-based high emissivity coatings, Plasma Processes' coating does not require post-deposition treatments such as elevated temperature curing. Furthermore, Plasma Processes demonstrated the ability to scale the coating deposition process by applying the coating to the internal and external surfaces of a mock full-scale J-2X nozzle extension.

Research Results

The developed emissivity coating provides unique features that meet the operational requirements of the nozzle extension on the J-2X engine. The main features that were demonstrated are high emittance at high temperatures and durability under severe flow and pressure environments. The unique features of the coating are detailed as follows:

- The coating has demonstrated high emittance approaching 80% or better at broad wavelengths within the infrared spectrum. It has shown to have an extremely stable emittance of 87% at lower wavelengths within the IR spectrum, where energy dissipation is critical at elevated temperatures. This was demonstrated during evaluations at Marshall Space Flight Center (MSFC) [via a Laboratory Portable Infrared Reflectometer (LPIR)], Thermophysical Research Laboratory at Purdue University, and Plasma Processes [via Pyrofiber® Lab Automatic Emissivity Measurement System (AEMS)].
- Rapid heating of coating (approximately 65 degrees Fahrenheit per second) to 2000 degrees Fahrenheit. This was demonstrated at Plasma Processes via resistance heating in vacuum.

- Stable at continuous elevated temperatures. The coating showed no signs of spalling during continuous 10 minute holds at 2000 degrees Fahrenheit. This was demonstrated at Plasma Processes via resistance heating in vacuum.
- Good performance of the coating under high strains of the base material with minimal to no spalling noted. This was demonstrated in the Marshall Space Flight Center's Hot Gas Facility. The coating was exposed to a gaseous hydrogen/missile grade air combustor at high velocities. Due to rapid heating of the base metal, the material would expand causing strain of the coating. The coating performed well, exhibiting little to no spallation under extreme strained conditions.
- The coating features high durability to withstand erosion under high velocity, elevated temperature conditions. This attribute was demonstrated in the Marshall Space Flight Center (MSFC) Hot Gas Facility. The coating was exposed to a gaseous hydrogen/missile grade air combustor at velocities approaching Mach 4. The coating was run under these conditions for a total of 2915 seconds and experienced little coating loss. This was also demonstrated in the highly turbulent flow environment of the J-2X Gas Generator turbine exhaust duct at MSFC.
- The coating has shown good durability within the hydrogen and hydrogen-rich steam environment. This has been demonstrated in the Marshall Space Flight Center (MSFC) Hot Gas Facility. The coating was exposed to a gaseous hydrogen/missile grade air combustor at high velocities. This was also demonstrated in the exhaust products of the J-2X Gas Generator turbine exhaust duct at MSFC.
- The coating has demonstrated negligible coating loss and acceptable emissivity degradation after multiple thermal cycling from room temperature to elevated temperatures in relevant nozzle extension environments. This has been demonstrated in the Marshall Space Flight Center (MSFC) Hot Gas Facility where the coating was exposed to a gaseous hydrogen/missile grade air combustor at high velocities. Additionally, thermal cycling was conducted at high vacuum conditions at Thermophysical Research Laboratory at Purdue University and Plasma Processes.
- The main constituents of the formulated coating are widely employed as surface coating materials to improve wear, erosion, cavitation, fretting and corrosion resistance in a variety of applications.
- The coating requires no pre- or post-depositing processing steps, such as elevated temperature pre-oxidation treatments and curing cycles. Considering elevated temperature can degrade the base metal properties and cause distortion, the lack of such requirements is a very unique feature of the coating developed by Plasma Processes.