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Extended Abstract

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Extended Abstract

The identification of metallic effluent materials in a rocket engine exhaust plume indicates the health of the engine. Since 1989, emission spectroscopy of the plume of the Space Shuttle Main Engine (SSME) has been used for ground testing at NASA's Stennis Space Center (SSC). This technique allows the identification and quantification of alloys from the metallic elements observed in the plume. With the prospect of hydrocarbon-fueled rocket engines, such as Rocket Propellant 1 (RP-1) or methane (CH₄) fueled engines being considered for use in future space flight systems, the contributions of intermediate or final combustion products resulting from the hydrocarbon fuels are of great interest. The effect of several diatomic molecular radicals, such as Carbon Dioxide, Carbon Monoxide, Molecular Carbon, Methylene Radical, Cyanide or Cyano Radical, and Nitric Oxide, needs to be identified and the effects of their band systems on the spectral region from 300 nm to 850 nm determined.

Hydrocarbon-fueled rocket engines will play a prominent role in future space exploration programs. Although hydrogen fuel provides for higher engine performance, hydrocarbon fuels are denser, safer to handle, and less costly. For hydrocarbon-fueled engines using RP-1 or CH₄, the plume is different from a hydrogen fueled engine due to the presence of several other species, such as CO₂, C₂, CO, CH, CN, and NO, in the exhaust plume, in addition to the standard H₂O and OH. These species occur as intermediate or final combustion products or as a result of mixing of the hot plume with the atmosphere.

Exhaust plume emission spectroscopy has emerged as a comprehensive non-intrusive sensing technology which can be applied to a wide variety of engine performance conditions with a high degree of sensitivity and specificity. Stennis Space Center researchers have been in the forefront of advancing experimental techniques and developing theoretical approaches in order to bring

this technology to a more mature stage.

In order to extend the capabilities of Plume Diagnostics to the hydrocarbon-fueled engine arena, an understanding of the plume contributions of these species was necessary. The capabilities of the SSC rocket plume spectroscopy simulation code (RPSSC) was extended by incorporating the latest and most accurate molecular and spectroscopic parameters for C₂, CO, CH, CN, and NO. All the relevant bands for these five molecules were included in the program. A testing program utilizing a gaseous methane/gaseous oxygen fueled thruster was implemented, to identify intermediate combustion product radicals in a hydrocarbon fueled rocket engine exhaust plume. It was necessary to determine if the spectral bands associated with the species identified have any effect on the wavelength regions monitored for the metallic effluents associated with engine health monitoring.

The identification of the spectral bands attributed to CO₂, C₂, CO, CH, CN, OH, and NO in the plume and how the contributions of the selected species intensity profiles changed the monitored spectrum due to the change in the fuel-to-oxidizer (O/F) ratio was investigated, Fig 1. The line-of-sight and field-of-view was also varied to determine the optimum configuration for the spectral data acquisition system, Fig. 2.

In order to help determine the optimal LOS through the plume for the spectral systems, a Computational Fluid Dynamics simulation was run. The model was run on SSC's Beowulf Computation Cluster using CRUNCH CFD[®] software from Combustion Research and Flow Technology, Inc. The CRUNCH CFD[®] code package is a multi-element (*i.e.* tetrahedral, prismatic, pyramid, and hexahedral cells), unstructured flow solver for viscous, real gas systems for all flow regimes as well as multi-phase fluids. Its major features allow for generalized thermochemistry specifications, permits dynamic grid motion, and implementation of a coupled two-equation turbulence model. Fig. 3 shows the results as expressed as the temperature profile of the exhaust plume. The line-of-sight of the spectral instrumentation is denoted by the black angled line bisecting the plume. Mass fraction concentrations of the species of interest were extracted from the model results, Fig 4.

The input conditions for the CFD model were calculated using the Chemical Equilibrium with Applications (CEA) code developed at NASA's Glenn Research Center. CEA is a program which calculates chemical equilibrium product concentrations from any set of reactants and determines thermodynamic and transport properties for the product mixture. Built-in applications include calculation of theoretical rocket performance, Chapman-Jouguet detonation parameters, shock tube parameters, and combustion properties.

In order to study the plume reactants produced under typical rocket engine operating conditions, a unique experimental setup is required to generate a suitable exhaust plume. To meet these needs, the Methane Thruster Testbed Program was instituted. The test article, operating parameters and measurement instrumentation will be discussed.

Methane Thruster Test Program

The Methane Thruster Test Program (MTTP) testbed incorporates a 50 lb thrust Gaseous Oxygen/Gaseous Methane (GOX/GCH₄) thruster. The thruster originally designed for use with LOX/RP-1 propellants has been successfully used with methane. The thruster's chamber is radiatively cooled with a water-cooled nozzle. It is designed for flexibility and can operate at conditions exceeding those required for the study. The rocket chamber makes use of a modular design allowing the combustion chamber length to be modified as needs dictate. The chamber sections are held together by use of four threaded rods tightened onto flanges, creating a press-type configuration. The thruster design specifications are summarized in Table 1.

Table 1. MTTP Thruster Specifications

<i>Chamber</i>	
Construction	Cylindrical, oxygen-free copper
Length	8.7"
Inner Diameter	2"
Thickness	1.25"
<i>Injector</i>	
Construction	Stainless steel coaxial injector
Fuel Inlet Area	0.167 in ²
Oxidizer Inlet Area	0.073 in ²
<i>Nozzle</i>	
Construction	Conical, oxygen-free copper
Contraction Ratio	20.2, 30° half-angle
Expansion Ratio	4.66, 15° half-angle

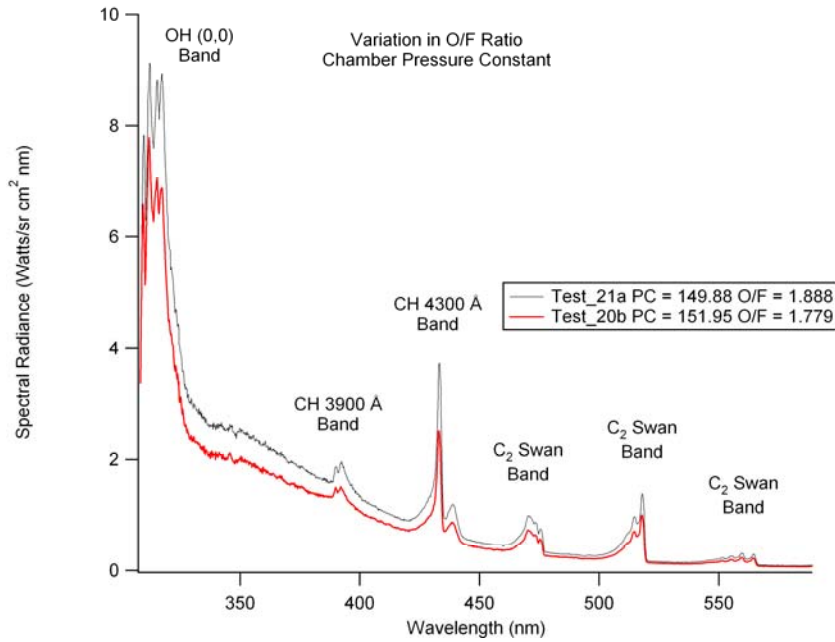


Figure 1. Variation in O/F Ratio, Chamber Pressure Constant

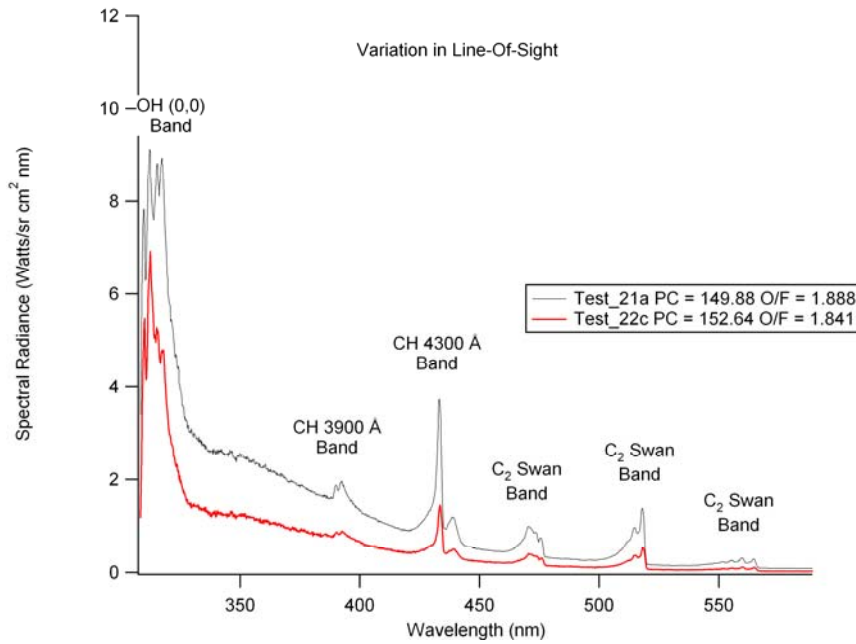


Figure 2. Variation in Optical System Line-of-Sight

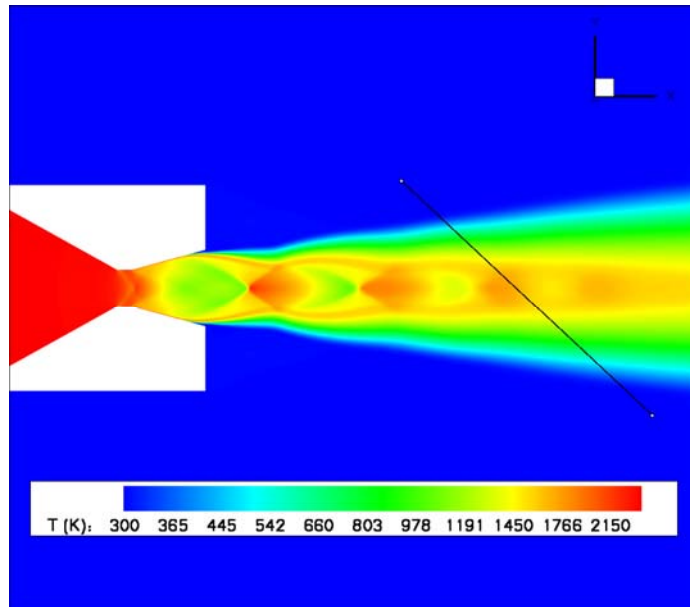


Figure 3. CFD results showing temperature profile of GOX/CH4 exhaust plume. Black line bisecting plume is LOS of spectral instrumentation.

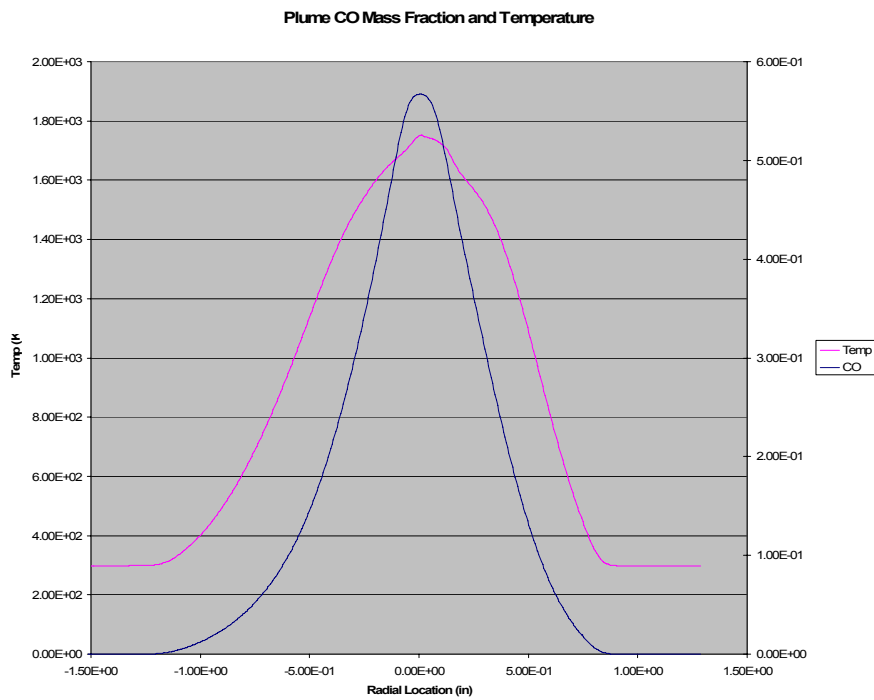


Figure 4. Plume CO Mass Fractions and Temperature Extracted from Plume CFD Results