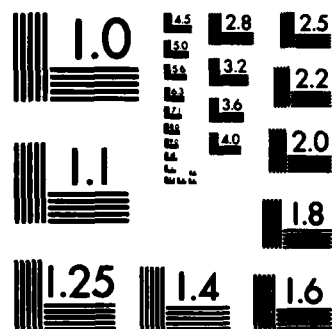


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TURBULENT MIXING AND COMBUSTION OF MULTI-PHASE
REACTING FLOWS IN RAMJET AND DUCTED ROCKET ENVIRONMENT

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Experiments with gaseous fuels to establish the base for the multi-phase fuel tests were completed for the axisymmetric-coaxial flow fields. Radial and axial profiles of pressure, velocity, species concentration and temperature were determined. Agreement between measured values (velocity and temperature) and computer predictions was, in general, reasonably good. Experiments to determine axial and radial temperature profiles with boron particle-laden fuels were started.		<table border="1"> <tr> <td colspan="2">Accession For</td> </tr> <tr> <td>NTIS GRA&I</td> <td><input checked="" type="checkbox"/></td> </tr> <tr> <td>DTIC TAB</td> <td><input type="checkbox"/></td> </tr> <tr> <td>Unannounced</td> <td><input type="checkbox"/></td> </tr> <tr> <td colspan="2">Justification</td> </tr> <tr> <td colspan="2">By</td> </tr> <tr> <td colspan="2">Distribution/</td> </tr> <tr> <td colspan="2">Availability Codes</td> </tr> <tr> <td>Dist</td> <td>Avail and/or Special</td> </tr> <tr> <td>A</td> <td></td> </tr> </table>		Accession For		NTIS GRA&I	<input checked="" type="checkbox"/>	DTIC TAB	<input type="checkbox"/>	Unannounced	<input type="checkbox"/>	Justification		By		Distribution/		Availability Codes		Dist	Avail and/or Special	A	
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Research Objectives

Turbulent mixing and combustion of multi-phase flows are relevant to problems in many airbreathing propulsion systems, such as the gas-generator ramjet (ducted rocket) with solid boron propellants and the slurry fuel ramjet. The ability to deal with the complex flow field in these systems requires detailed experimental and analytical knowledge of a number of coupled physical and chemical processes, including turbulent mixing, recirculating flow, and gaseous/particulate fuel ignition/combustion.

In recent years, considerable progress has been made towards development of analytical models to deal with the multitude of coupled mechanisms. However, evaluation of the models has been hampered by the lack of detailed experimental flow-field information. The objective of this program is to obtain a comprehensive data base that would specifically aid evaluation and further refinement of analytical techniques developed by Sciences Applications, Inc. (SAI) (Drs. Edelman and Harsha) under AFOSR funding. Because of the complexity of the phenomena to be studied, a systematic step-by-step approach will be taken for both the fuel characteristics (gaseous fuels, boron-laden gaseous fuels, liquid fuels, and slurry fuels) and the flow field (axisymmetric-coaxial, axisymmetric with dump, axisymmetric non-coaxial, and three-dimensional).

Combustion tests will be made under realistic operational ramjet conditions to determine axial and radial profiles of temperature, pressure, species concentration, velocity, turbulence intensity, and particle/droplet size using intrusive probes and optical diagnostic methods (laser doppler velocimeter (LDV)).

Presently, the study is related to gas-generator ramjets. Specific objectives for the reporting period were: (1) to perform detailed flow measurements with gaseous fuels in an axisymmetric-coaxial flow field without dump to establish the base for the multi-phase fuel tests; (2) to compare experimental data with theoretical predictions by SAI, and (3) to initiate tests with boron-laden gaseous fuels in an axisymmetric-coaxial flow field without dump.

Status of Research Effort

Experiments with gaseous fuels to establish the base for the boron fuel tests were completed. Agreement between measured values for velocity (pitot probes and LDV) and temperature (thermocouples) and computed values by SAI was, in general, reasonably good. Further refinements to the mixing and kinetic models are being pursued at SAI to improve the level of agreement indicated by Figures 1 (temperature) and 2 (velocity).

From the experiment/theory comparison in Figure 1, it is evident that the model indicates near-stoichiometric combustion temperatures in the near field ($x/D = 0$), which was not experimentally observed. The differences in temperature level imply that improvements are required in the chemical-kinetic modeling of the combustion process, particularly with respect to the fuel-rich combustion process that occurs in the near field for this gas-generator simulation.

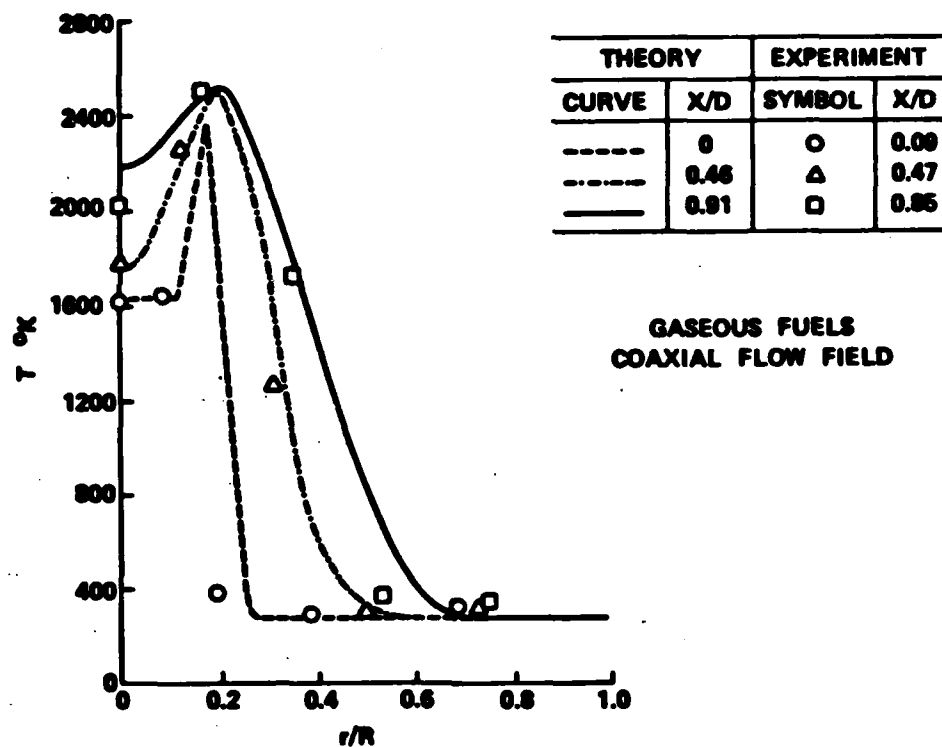


FIGURE 1. Comparison of Measured and Predicted Temperature Profiles.

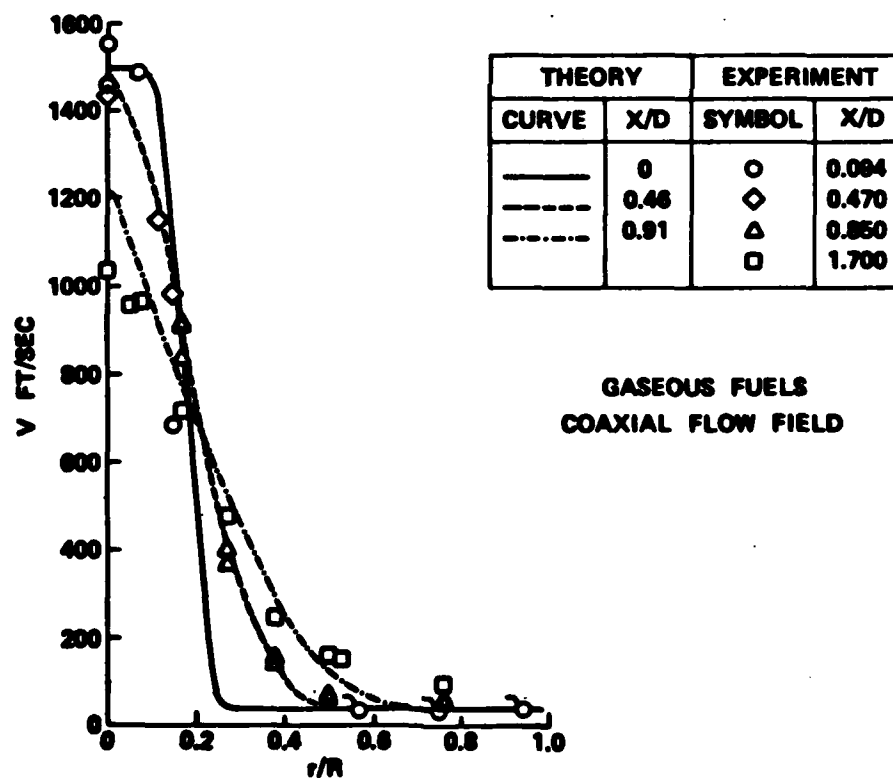


FIGURE 2. Comparison of Measured and Predicted Velocity Profiles.

Additional data indicate the presence of oxygen along the flow centerline downstream of the gas-generator nozzle exit. The presence of oxygen in this region is not indicated by analytical model results that utilize an equilibrium gas-generator nozzle exit assumption to provide initial conditions for the computations. However, computations begun using measured initial oxygen concentrations do reproduce the experimental observations, thus, suggesting that finite rate kinetics effects in the gas-generator may play a role in the observed phenomena. Also, turbulence-chemistry interactions, which involve the modification of basic chemical reaction rates by the fluctuations in temperature and species mass fraction in a turbulent flow, along with intermittency phenomena, may contribute to the presence of oxygen along the flow centerline downstream of the nozzle exit. The importance of the intermittency phenomena is underlined by the fact that the oxygen concentration at the centerline increased with increasing mixing length.

Current AFOSR-sponsored work at SAI includes the extension of chemical-kinetic modeling techniques to the analysis of highly fuel-rich combustion phenomena, as well as the investigation of the phenomena involved in the turbulence-chemistry interaction problem. This work is expected to help provide explanations of the observations made in this test series.

Prior to the detailed flow measurements with gaseous fuels, preliminary tests were performed to further optimize air flow uniformity and select baseline operational conditions. In particular, the latter task required extensive testing because auto-ignition of the hot gas-generator reaction products in the airstream was difficult to achieve under simple flow conditions (no recirculating flow), yet realistic operation ramjet conditions (low gas-generator combustion temperature and low ramjet combustor pressure). The requirement to maintain a simple flow field was crucial to make a meaningful experiment/theory comparison possible.

Tests with boron-laden, gaseous fuels were started. In these tests, the submicron boron powder was mixed with gaseous gas-generator reaction product before injection into the ramjet combustor. Extensive testing was necessary to establish baseline conditions for the detailed flow measurements. In the preliminary tests, the limits of auto-ignition of the fuel-rich, boron-laden plume in the coaxial airstream were determined in a plexiglas-walled ramjet combustor, primarily as a function of gas-generator combustion temperature and ramjet combustor pressure. In these preliminary tests, combustion pressure oscillations were observed. These oscillations at about 50 Hz originated in the boron particle feed system and resulted in oscillating boron particle mass flow and, therefore, oscillating ramjet combustor pressure. The peak-to-peak pressure amplitude was about 20% of the mean pressure value. The oscillations, which were identified as the Helmholtz mode of the boron container, were minimized by a suppression device in the neck of the boron container.

Detailed flow measurements were started to determine axial temperature profiles with tungsten rhenium thermocouples.

Personal Responsibilities

The work is carried out in the Engineering Sciences Division (Dr. Ronald L. Derr). Drs. Myung-Jae Lee and Klaus C. Schadow are co-principal investigators.

Interactions

The abstract of the paper "Fuel-Rich Plume Combustion," by M. J. Lee and K. C. Schadow, was submitted to the 20th JANNAF Combustion Meeting to be held at the Naval Postgraduate School, Monterey, Calif., October 17-21, 1983.

Discussions were held with Dr. Ephraim Gutmark, University of Southern California, to apply their elliptic jet research results to the ducted rocket environment. It is expected that with elliptic jets, instead of the present circular jets issuing from the gas generator, the mixing rate with the air can be significantly increased. Preliminary tests are scheduled towards the end of FY 83.

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