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Annual Scientific Report

Mechanisms of Exhaust Pollutants and Plume Formation in Continuous Combustion

G. S. Samuelsen
Principal Investigator

AFOSR 78-3586
Directorate of Aerospace Sciences
Department of the Air Force
Air Force Office of Scientific Research (AFSC)
Bolling Air Force Base
Washington, D. S. 20332

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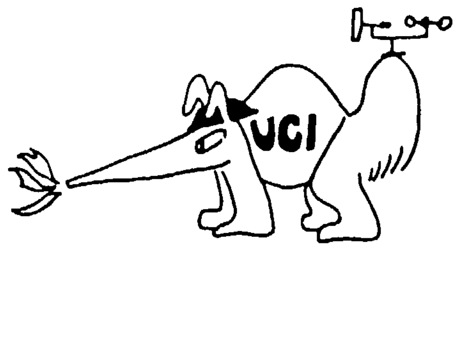
UCI COMBUSTION LABORATORY

Mechanical Engineering
University of California
Irvine 92717



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During this period, emphasis has been placed on the construction, evaluation, and operation of a two-color laser anemometry (LA) system. The significance of such a system is the capability to measure simultaneously two components of velocity and hence the Reynolds stress, and thereby facilitate the evaluation and development of numerical and closure models, and promote the understanding of the basic physics that control gaseous pollutant and particulate formation. A bragg cell has been incorporated into the LA system and successfully employed to measure velocity and turbulence intensity in the recirculation regions

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of both the opposed jet and centerbody configurations. Seeding methods have been developed to (1) ensure an equal density of seeds in both the main flow and jet, and (2) allow measurements under reacting conditions. The numerical code has been modified for the centerbody configuration, and successfully employed to model the present experiment. Detailed velocity and turbulence intensity measurements have also been acquired in a water analog of the opposed jet configuration, and are scheduled for the centerbody configuration. Application of the numerical code to this case was initiated during the present reporting period for both the opposed jet and centerbody configuration, and the results are being checked with the experimental data as they become available. Hi speed photography has been employed in both the combustor and hydrodynamic facilities to study the swirl and non-swirl performance of the centerbody configuration, and to optimize the design. Techniques have been developed (dyes in the hydrodynamic system and smoke in the combustor) to visually record the penetration and dynamics of the fuel jet. The NO probe experiments have addressed the effect of potentially resistant materials, and a refined experiment for the introduction of water and low concentrations of hydrocarbons typical of turbine emission has been completed. Data provide guidelines for the materials and temperature limits to employ in the measurement of NO_x.
In addition to meeting the immediate objectives of the subject AFOSR program, the flowfield data are provided to other AFOSR contractors concerned with the use and evaluation of flow models, and are used to assist AFAPL staff in evaluating and understanding centerbody performance. Futhermore, the AFESC/RDVC has contracted with the UCI Combustion Laboratory to fabricate a centerbody combustor facility for the conduct of fuels testing at Tyndall AFB, and an EPA contractor has successfully utilized the opposed jet to resolve problems attendant to catalytic combustor conditioning and preheat. Finally, in an AFESC/RDVC program, the centerbody has been employed to quantify the perturbation on local soot morphology and soot density produced by a physical extrative probe in comparative measurements with a nonintrusive optical probe.

MECHANISMS OF EXHAUST POLLUTANTS AND PLUME
FORMATION IN CONTINUOUS COMBUSTION

(AFOSR 78-3586)

ANNUAL SCIENTIFIC REPORT

G. S. SAMUELSEN

UCI-ARTR-81-03

Table of Contents

Summary of Progress		1
1.0 Introduction		2
2.0 Approach		2
3.0 Progress and Status		6
4.0 Interaction with Air Force Programs		6
Table I	Program Progress and Status	7
Table II	Facility Progress and Status	8
Table III	Publication Progress and Status	9
Table IV	List of Personnel	12

MECHANISMS OF EXHAUST POLLUTANTS AND PLUME FORMATION IN CONTINUOUS COMBUSTION

(AFOSR 78-3586)

Summary of Progress

1 March 1980 to 28 February 1981

During this period, emphasis has been placed on the construction, evaluation, and operation of a two-color laser anemometry (LA) system. The significance of such a system is the capability to measure simultaneously two components of velocity and hence the Reynolds stress, and thereby facilitate the evaluation and development of numerical and closure models, and promote the understanding of the basic physics that control gaseous pollutant and particulate formation. A bragg cell has been incorporated into the LA system and successfully employed to measure velocity and turbulence intensity in the recirculation regions of both the opposed jet and centerbody configurations. Seeding methods have been developed to (1) ensure an equal density of seeds in both the main flow and jet, and (2) allow measurements under reacting conditions. The numerical code has been modified for the centerbody configuration, and successfully employed to model the present experiment.

Detailed velocity and turbulence intensity measurements have also been acquired in a water analog of the opposed jet configuration, and are scheduled for the centerbody configuration. Application of the numerical code to this case was initiated during the present reporting period for both the opposed jet and centerbody configurations, and the results are being checked with the experimental data as they become available.

Hi-speed photography has been employed in both the combustor and hydrodynamic facilities to study the swirl and non-swirl performance of the centerbody configuration, and to optimize the design. Techniques have been developed (dyes in the hydrodynamic system and smoke in the combustor) to visually record the penetration and dynamics of the fuel jet.

The NO probe experiments have addressed the effect of potentially resistant materials, and a refined experiment for the introduction of water and low concentrations of hydrocarbons typical of turbine emission has been completed. Data provide guidelines for the materials and temperature limits to employ in the measurement of NO_x.

In addition to meeting the immediate objectives of the subject AFOSR program, the flowfield data are provided to other AFOSR contractors concerned with the use and evaluation of flow models, and are used to assist AFAPL staff in evaluating and understanding centerbody performance. Furthermore, the AFESC/RDVC has contracted with the UCI Combustion Laboratory to fabricate a centerbody combustor facility for the conduct of fuels testing at Tyndall AFB, and an EPA contractor has successfully utilized the opposed jet to resolve problems attendant to catalytic combustor conditioning and preheat. Finally, in an AFESC/RDVC program, the centerbody has been employed to quantify the perturbation on local soot morphology and soot density produced by a physical extractive probe in comparative measurements with a nonintrusive optical probe.

MECHANISMS OF EXHAUST POLLUTANTS AND PLUME FORMATION IN CONTINUOUS COMBUSTION

(AFOSR 78-3586)

1.0 Introduction

The AFOSR program conducted at the UCI Combustion Laboratory is directed to modeling and exploring mechanisms associated with pollutant production in continuous combustion. The objectives of the study are:

- To develop and verify numerical methods and associated models of turbulence and kinetics as applied to recirculating turbulent reacting flowfields characteristic of turbine combustion via a judicious coupling of numerical methods to experiment. Such information is pertinent to establishing a method that can be readily adapted to the flow geometry of gas turbine, dump, and ramjet combustors.
- To develop an understanding of pollutant formation in continuous combustion stabilized by recirculation. Such information is pertinent to reducing environmental impact and controlling plume signature.
- To initiate and/or conduct suppplemental studies pertinent to pollutant formation, combustion stability, and use of alternative fuels in turbine, dump, and ramjet combustors.

2.0 Approach

The AFOSR UCI Combustion Laboratory program includes both experimental and analytical studies in a task organization of three elements:

- Element A: Model Development and Evaluation

  The evaluation and refinement of numerical procedures by a judicious comparison of numerically predicted profiles of velocity, turbulence energy, temperature, tracer concentration, and mass fractions of hydrocarbons, nitric oxide, nitrogen dioxide, carbon monoxide, oxygen and carbon dioxide to experimentally determine profiles.

- Element B: Mechanisms of Pollutant/Plume Formation

  The conduct of parametric studies to identify the relative contribution of the chemical reactions, transport processes, and system parameters to pollutant formation.

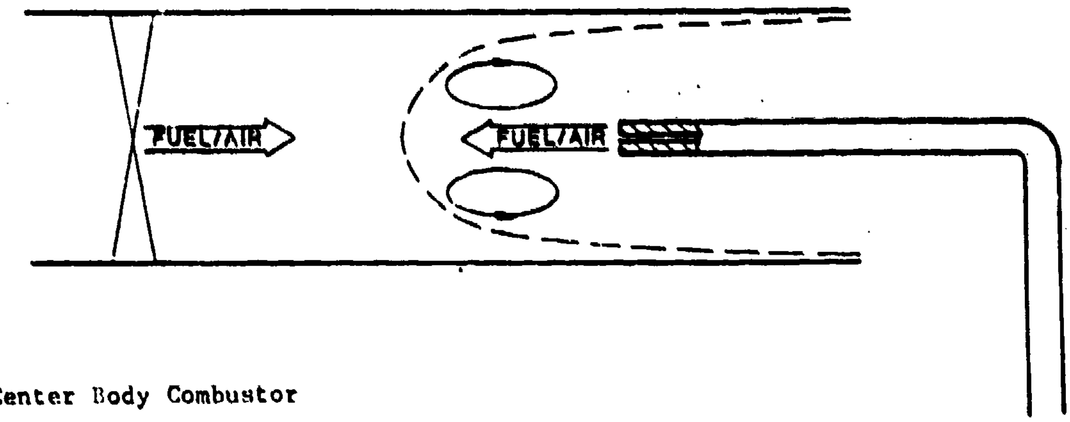
- <u>Element C: Supplemental Studies</u>

  The initiation and conduct of studies that support the investigation of combustion stability, pollutant formation, and numerical methods, and address specialized questions current to practical backmixed combustion systems.

<u>Combustion Systems.</u> Two combustor systems--premixed and non-premixed--are employed in the UCI program. Schematics of both systems are presented in Figure 1. The combustors operate at atmospheric pressure with preheat capability to 350°C (expandable to 600°C). The premixed system shown in Figure 1a, is an opposed-recting-jet combustor (OJC). The centerbody combustor (CBC), shown in Figure 1b, operates in both the premixed and non-premixed modes. In the nonpremixed mode, the CBC represents more conventional turbine combustor configurations and provides a foundation for exploring the effects of mixing two dissimilar streams on pollutant formation and numerical prediction. In the premixed mode, the CBC represents configurations considered for premixed-prevaporized combustors and provides a foundation for exploring lean-stabilized combustion.

<u>Laser Anemometer System (LA).</u> The laser anemometer (LA) is evolving into a 2-component system. A schematic is shown in Figure 2. The system components shown in solid boundaries are acquired and in place. The components shown in italics comprise instrumentation scheduled for acquisition. The LA system is based on a 200-mW Argon-Ion laser. Two bragg cells are employed for frequency shift and two Macrodyne Processors for signal processing. A PDP 11/23 computer is used for data acquisition. A UCI designed and built interface has been incorporated to time label each event and thereby provide a measurement of the Reynolds stresses. Seeding is provided by specially designed pressure controlled nebulizers that generate uniform seeding in both the main and jet flows with either polystyrene or aluminum particles.

a) Opposed Jet Combustor



b) Center Body Combustor

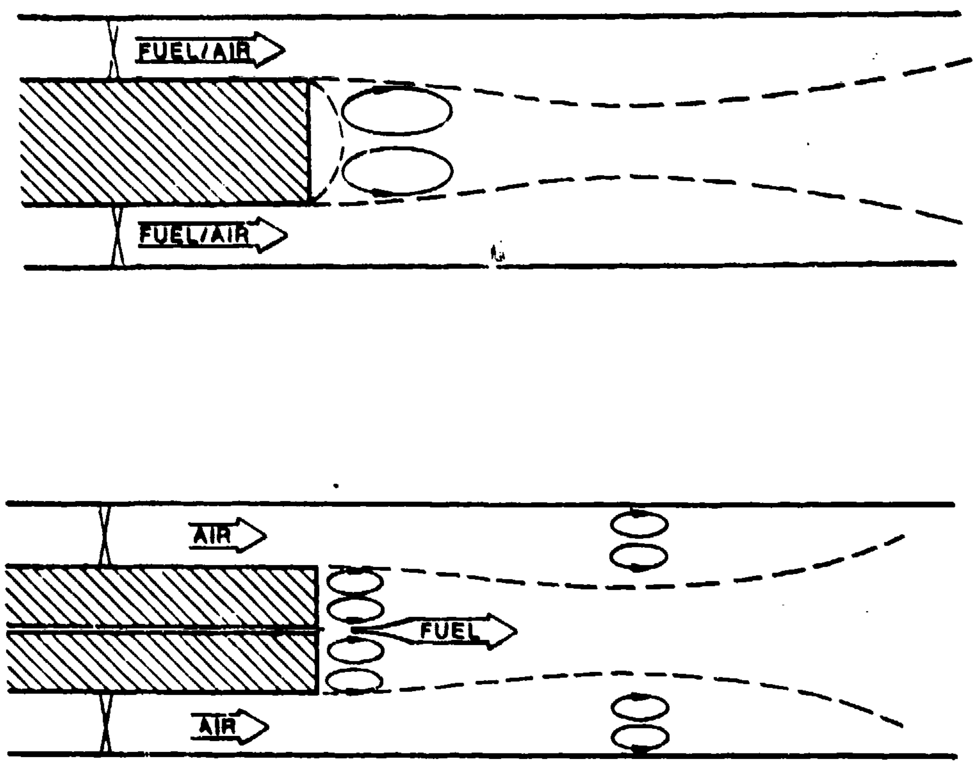


FIGURE 1 UCI Combustion Facility

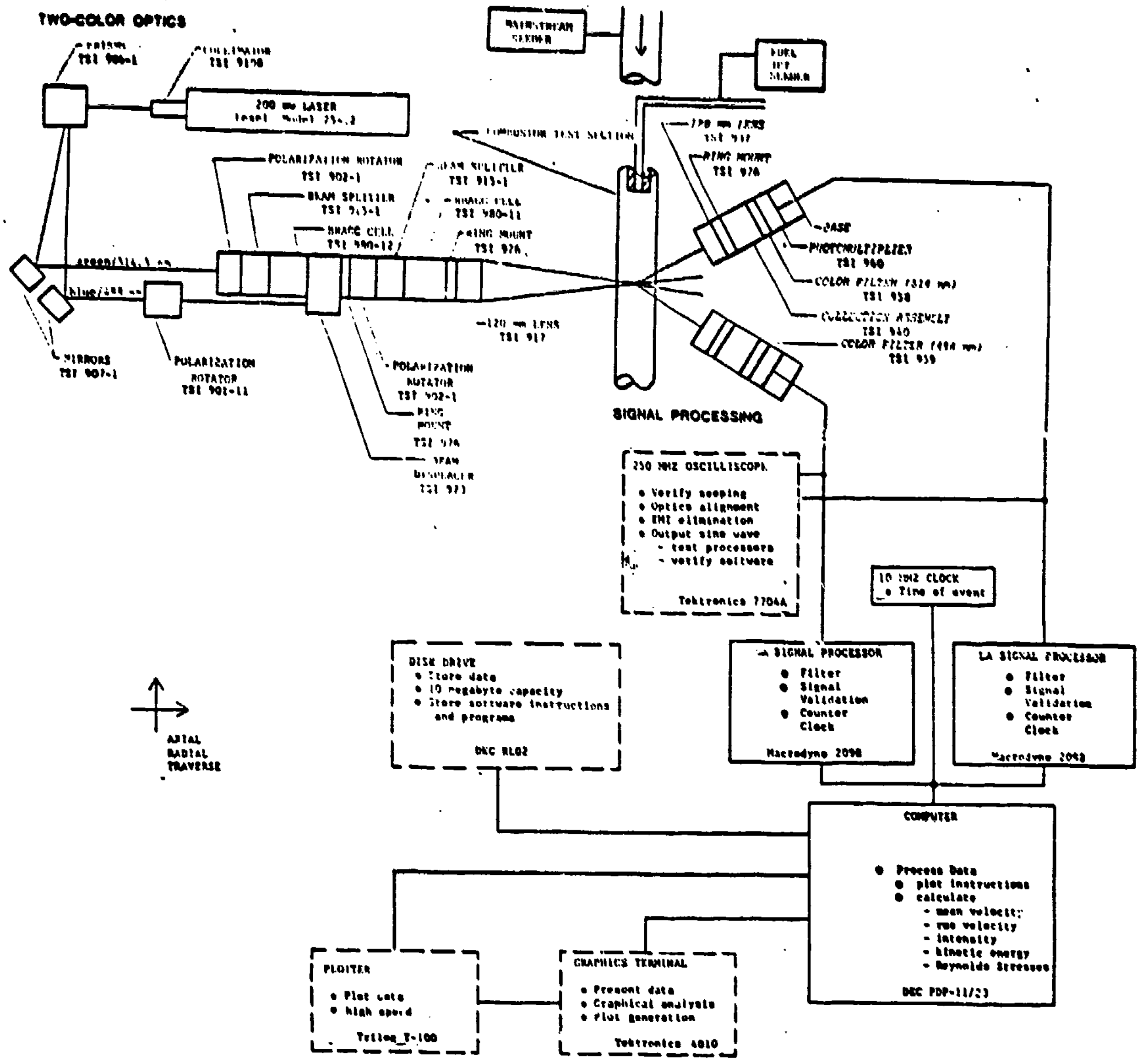


Figure 2. Two-Color Laser Anemometer System

3.0 Progress and Status

The progress and status of the program and the experimental facility is outlined in Tables I and II. The progress and status of the publications is summarized in Table III. A list of personnel is presented in Table IV.

4.0 Interaction with Air Force Programs

The interaction with Air Force programs is active at three levels: Air Force Engineering and Services Center, Air Force Aeropropulsion Laboratory, and AFOSR Contractors.

Air Force Engineering and Services Center. The UCI Combustion Laboratory is the prime contractor for an Air Force Engineering and Services Center (AFESC/RDVC) program directed to understanding and controlling the soot formation associated with the use of alternative and synthetic fuels in complex flows. Laser diagnostics are employed to measure in-situ the soot particle size and soot concentration at varius locations within a reacting, complex flow. The goal is to identify the mechanics of soot formation and burnout in flows governed by aerodynamics as well as by chemistry. The AFOSR work is assisting in understanding and optimizing the combustor geometries and basic aerodynamics employed.

In an independent study, the AFESC/RDVC has supported, through the AFOSR, studies that address the sampling of nitric oxides in combustion products. These studies have encompassed as well the conduct of surveys to document the data available regarding turbine emission of individual hydocarbon species and concentration.

Recently, the AFESC/RDVC contracted with the UCI Combustion Laboratory to construct and deliver to Tyndall AFB a replicate of the laboratory centerbody combustor and support system that has evolved largely under support from the AFOSR. This system is scheduled for a variety of in-house studies studies at Tyndall.

TABLE I

Program Progress and Status

(28 February 1981)

Element A: Model Development and Evaluation

Isothermal Flow. *Emphasis has been directed to acquisition of velocity data in the highly intense recirculation zone. This has been successful through (1) the use of a bragg cell secured under an NSF grant and (2) uniform seeding of the jet, as well as the main flow. Acquisition of detailed flowfield velocity data is in progress.*

A hydrodynamic facility has been built, tested, and utilized to water model the OJC and CBC configurations and, thereby, provide aid to flow visualization and modeling studies. A complete set of OJC data has been obtained.

Heated Flow. *The modeling code includes the production, transport, and dissipation of the fluctuating component of temperature. The code has been applied to the case where the OJC jet was preferentially heated in a nonreacting condition and spatial measurement of temperature and temperature fluctuation compared to experimental measurement. Complementary studies in the CBC configuration have been initiated.*

Hot Flow. *Emphasis has been directed to acquisition of velocity data for the case of reacting flow. Seeding techniques for the introduction of alumina particles have been successfully developed and introduced. Preliminary tests are in progress. The modeling code has been modified to incorporate the CBC configuration. A complementary grant from the National Science Foundation provides support for (1) the acquisition of carbon monoxide fueled operation and (2) modeling the reacting flow case.*

Element B: Mechanisms of Pollutant/Plume Formation

The detailed flowfield measurements made above for the hot flow conditions are being systematically evaluated to identify the pollutant formation behavior as a function of recirculation zone size, recirculation zone intensity, local stoichiometry, and local mixing. High speed motion pictures have been made of the reacting OJC and CBC to aid in the flow visualization.

Element C: Supplemental Studies

NO Probe. *The study conducted during the present grant period has been directed to the inclusion of H_2O in the experiment, and the fabrication of a refined experiment, designed to provide more uniform control of temperature and simulate, as well, hot probe tip temperature. An assessment of probe history, sample pressure, residence time, and hydrocarbon species and concentrations representative of gas turbine exhausts is in progress. Exploratory tests of these effects have been completed and tests in the refined experiment have been initiated.*

Soot Formation and Burnout. *Installation of the liquid fuel supply and injection system is in progress. A contract from AFESC/RDVC provides for an indepth study of soot formation in a joint venture with Spectron Development Laboratories. The AFOSR program will address the detailed measurements of temperature, species, concentration, velocity, and turbulence intensity in the CBC configuration.*

TABLE II

Facility Progress and Status

(28 February 1981)

Swirl. *Swirl is an integral factor in promoting flame stabilization in practical, continuous combustion devices. The numerical methods must be tested for the case of swirl, as well as nonswirl, if successful simulations of practical devices are to be achieved. Tests of the swirl are in progress. Included is an assessment of swirl angle, swirl location, and swirl blade design.*

Liquid Fuel. *A liquid fuel system has been designed for use in two modes: prevaporized, and liquid fuel injection. The system is presently being installed into the present combustor system and will be tested during the present grant period.*

LA System. *A bragg cell has been added to remove flow direction ambiguity. Optics for a two-color system have been received. In addition, a 200mW Argon-ion laser has been acquired to provide (1) a higher power source and (2) the capability for two-color work. The two-color substantially expands the capability of the LA system by allowing simultaneous measurements of two velocity components, thereby providing direct measurement of the Reynolds stress. AFOSR funding contributed to the laser acquisition. The remaining funds were obtained from the National Science Foundation and University sources. The system has been installed and is presently being employed on the combustor in a single component mode. Two components awaits the integration of the expanded data acquisition system. This integration is in progress and will be completed during the presented grant period.*

TABLE III

Publication Progress and Status

(28 February 1981)

ELEMENT[a]	Title	Publications	STATUS: In Preparation	Submitted	Accepted	Published
A	Elghobashi, S.E., G.S. Samuelsen J.E. Wuerer, and J.C. LaRue (1979). Prediction and Measurement of Mass, Heat, and Momentum Transport in a Nonreacting Turbulent Flow of a Jet in an Opposing Stream	Proceedings, Second Symposium on Turbulent Stream Flows			X	X
	Elghobashi, S.E., G.S. Samuelsen J.E. Wuerer, and J.C. LaRue (1981). Prediction and Measurement of Mass, Heat, and Momentum Transport in a Nonreacting Turbulent Flow of a Jet in an Opposing Stream	Journal of Fluids Engineering, 103, 127		X	X	X
	Acoumanis, D.C. (1980). Water Analog of the Opposed-Jet Combustor: Velocity Field Measurements and Flow Visualization	UCI Combustion Laboratory Report UCI-ARTR-80-5				X
	Samuelsen, G.S., R.E. Peck, J.E. Wuerer, and R.B. Brum (1981). Predictive Modeling of Momentum and Mass Transport in Turbulent Flow with Backmixing	Journal of Fluids Engineering	X			
B	McDannel, M.D., P.R. Peterson, and G.S. Samuelsen (1980). Emission Behavior of Aerodynamically Stabilized, Lean Premixed Combustion	Combustion Science and Technology	X	X		
	McDannel, M.D. (1979). An Experimental Study of Pollutant Formation in Premixed Propane-Air Fired, Recirculating Flow Combustion	UCI Combustion Laboratory Report UCI-ARTR-79-1			X	
C	Samuelsen, G.S., and R.C. Benson (1979). Chemical Transformation of Nitrogen Oxides While Sampling Combustion Products, in Grosjean D. (ed.), Nitrogenous Air Pollutants: Chemical and Biological Implications	Ann Arbor Science, Inc.		X	X	X

[a]A: Model Development and Evaluation
B: Mechanisms of Pollutant/Plume Formation
C: Supplemental Studies

Air Force Aero Propulsion Laboratory. Interaction is active and ongoing with Dr. Mel Roquemore regarding the evolution of the centerbody combustor configuration, and the measurement techniques and results associated with the centerbody combustor. Modeling of this configuration is also a topic of active interchange. A common test matrix has been developed by AFAPL and UCI with the goal of testing the scaling criteria for the centerbody configuration as well as providing a common base for the comparison of data.

In an independent effort, the AFAPL is providing some support through AFESC/RDVC to the soot formation and burnout study. The interest here is directed to the adequacy of the conventional techniques used to quantify the sooting tendency of both conventional and alternative/broad specification fuels. The contact is Mr. Chuck Martell.

AFOSR Contractors. The interaction with AFOSR contractors is continual and broad. Of the various examples, Five are especially noteworthy at this juncture.

(1) Exchange of information is occuring with Ray Edelman (SAI). SAI is a recipient of the progress reports on the AFESC/RDVC soot programs. With respect to the AFOSR studies, the status of the experimental and modeling studies is regularly conveyed to SAI. Most recently, the experimental data derived in two Master of Science studies have been forwarded by the provision of copies of the subject M.S. theses. These data are designed in part for application and tests of numerical codes. This exchange with SAI will allow the data to be used for this purpose by SAI. In addition, it will allow SAI to comment on the adequacy and extent of the data so that future efforts can be even more responsive to community requirements.

(2) Exchange of information is occurring with Marshall Lapp (GE) with respect to the need and potential for standardized combustor and flame configurations.

(3) Exchange of information is occurring with John Daily (U.C. Berkeley) with respect to laser anemometry (LA) techniques. UCI was provided with a schematic of an interface built at Berkeley which served as the basis for a 2-channel, UCI-designed interface for finger printing LA data with the time of occurrence. This has enabled the measurement of simultaneous events and, as a result, the measurement of Reynolds stress.

(4) Professor A. M. Mellor (Purdue) spent the Winter Quarter of 1980 in residence at UCI. This allowed for an active and beneficial interaction on the relationship of laboratory combustors to practical systems, diagnostics, and modeling.

(5) The interaction with the AFOSR programs at the University of Southern California has been regular. Examples during this past year include the provision to UCI of a high speed FASTAX framing camera (Mel Gerstein), the provision of modeling guidance by UCI to USC (Roy Choudhury) and the provision of information to USC (Roy Choudhury) regarding particulate measurement methods.

TABLE IV

List of Personnel

NAME	TITLE	DEGREE AWARDED	THESIS TITLE
G. S. Samuelsen	Associate Professor		
John T. Taylor	Staff Research Associate		
Craig P. Wood	Staff Research Associate		
Sherri Vakili	Staff Research Associate		
Dinos C. Acoumanis	M.S. Graduate Student	M.S. Degree March 1980	Water Analog of the Opposed Jet Combustor: Velocity Field Measurements and Flow Visualization
Roger Brum	Ph.D. Graduate Student		
Leanne Ikioka	M.S. Graduate Student		
Vince Roman	Undergraduate Student		
Marcos Jorge	Undergraduate Student		