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POLLUTION	FLAMES	X-RAY	SENSORS	
RADICALS	LASERS	FILTERING	TOMOGRAPHY	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This program explores the potential of absorption techniques for low ppm, real time 3-dimensional combustion diagnostics. In the current phase of activity, a laser beam has been transformed into a sheet of light and made to converge on a 126-element array, with electronics suitable for repeatable 1.5 KHz scanning and data processing. Available memory modules (4K) allow for 34 successive slicings of a passing target within 20 milliseconds. In this manner, a detailed projection of three-dimensional flow field concentrations is available. An axisymmetrical flow (tobacco smoke rings) has been measured and a tomographic procedure

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was applied to these data. Better ranges of absorption are being considered and multiangular experiments (non-symmetrical cases) will follow. The construction of a portable tomographic unit is also in progress. It was upgraded to non-steady flow capabilities by coupling a CAMAC digitizer with a MINC minicomputer. The source and sensor part of the experiment have been completed. Data processing and flow controls will follow. A theoretical review of flow instabilities is underway. Existing qualitative work suggests three-dimensional patterns for which this tomographic approach is ideally suited.

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MULTIANGULAR SCANNING ABSORPTION

TECHNIQUES FOR

THREE DIMENSIONAL

COMBUSTION DIAGNOSTICS

AFOSR-77-3439

[illegible]

Annual Technical Report

prepared for:

AFOSR, Bolling AFB

Attn: Dr. L. H. Caveny

September 1, 1980 - August 30, 1981

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MATTHEW J. KE[illegible]
Chief, Technical Information Division

RESEARCH OBJECTIVES

The objective of this research is to demonstrate in the laboratory the feasibility of low ppm, real time, three-dimensional mapping of flames by tomographic methods. If it meets with success, it will be superior in a number of cases to the other diagnostics methods presently used or proposed. It has been used successfully in the medical field (X-ray "CAT" Scanners"). Similar computer algorithms can be used for combustion gases in the optical frequency range. The objective is to measure low levels of radicals and pollutants (100 ppm and less) and to complete a three-dimensional map of such concentrations in a time shorter than the combustion characteristic time (50 microseconds). In this fashion, it will be possible to observe the growth and decay of turbulent eddies, rather than to have to rely on time-averaged concepts such as intermittency or correlations (pdf).

Low ppm absorption measurements are possible with current laser-sensor combinations; their sensitivity is markedly better than what is obtainable with scattering methods, even after the necessary computer inversion. Although particulates are the easiest to detect with almost any laser, there exists ultraviolet and infrared lasers which can detect nearly all combustion constiuents. Thus the whole range of combustion events could be monitored.

The real time potential of the method depends on one's ability to design near-simultaneous illumination of the target area (i.e. within 50 microseconds). Several concepts have been presented, using mirrors, beamsplitters, etc. There exists also beamscanners, silicon arrays (UV and visible) and photodectors (IR) which have the required time response, including data storage.

This technique, which has been first tested experimentally in the steady non-reacting mode (methane-argon jet), has been applied to other configurations (twin jets, diffusion flame). It is now being expanded to particulates (visible light) and molecular tracers (Na, K). Such experiments fall in the visible range: it allows for greater experimental convenience and lower cost, especially when considering high speed measurements.

Such a system has been completed, where a laser sheet is directed at an absorbing flow in short 50 μsec bursts, i.e., less than any relevant physical process in the flow. The intensity of the emerging sheet, diminished in proportion to the concentration of the absorbing species, can be measured at 126 positions within 600 microseconds (silicon arrays). These readings can be repeated and stored 34 times at a 1.5 KHz rate. This allows the mapping in three dimensions of the concentrations of a passing symmetrical object (e.g., initial eddies of a circular jet). When the system will have been completely tested, a multiangular configuration will be designed.

Once this three-dimensional real-time capability has been established in visible light, the infra-red and ultra violet range will be used, with a view to understanding combustion processes, especially those involving the short-lived intermediate products.

STATUS OF RESEARCH EFFORT

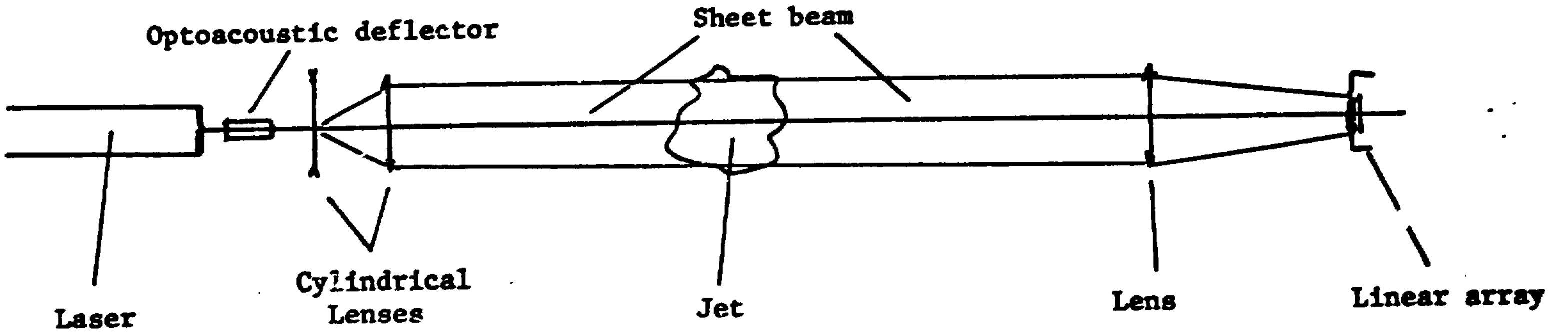
September 1, 1980 - August 30, 1981

During the period September 1, 1980 - August 30, 1981, progress has been made in the following areas:

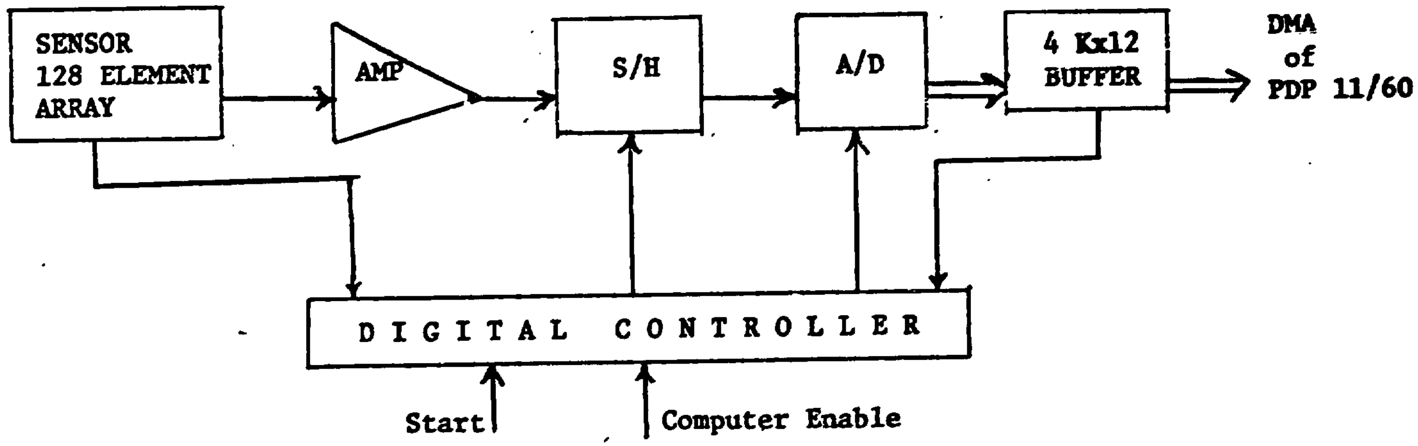
1. Development of 1.5 KHz diagnostics

The single beam axisymmetrical target experiment was discussed in detail in last year's proposal. Since then, a system has been installed at NBS by Dr. Santoro and Dr. Emmerman, as sketched in Fig. 1. Considerable time was expanded in trying to develop the proper software to match the PDP-11/60 in use at NBS. In the early part of this period the purely optical part of the system (top half of Fig. 1) was tested by having the laser beam shine its Gaussian shaped intensity distribution on the linear array. An oscilloscope was rolled in and good measurements were made. Later on, the data processing (lower half of Fig. 2) was built and programmed.

A choice had to be made earlier, as to the scanning mode which could be adopted (Fig. 2). One could have a fixed sheet of light, flashed at rapid intervals, so that an absorbing flow structure passing through this plane would be sliced many times in succession. The reconstruction of these parallel slices, separated by a distance corresponding to the product (velocity x time interval), is a quasi-instantaneous 3-D map of the structure. This method is the one currently developed at NBS. Another method would have been to shine an expanded laser beam of square cross section into a rectangular matrix array made of 100 x 100 sensors.



a) Optical layout



b) Data processing

Fig. 1 - Real time tomography of an axisymmetrical jet

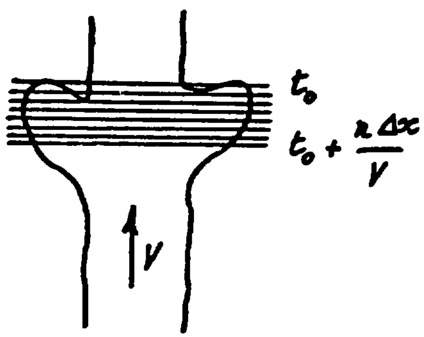


Fig. 2a - Linear Array Slicing

Relative motion of the fixed laser sheet with respect to the moving flow structure

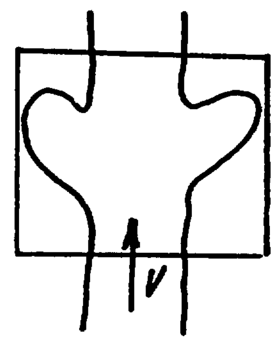


Fig. 2b - Rectangular Array Matrix

Instantaneous (50 μsec) data collection for the whole structure

This approach would give a truly instantaneous 3-D picture of a passing flow structure, but with some limitation in light power and sensor dynamic range. This method will be tried in the portable unit being developed at GW.

In the "slicing" option used at NBS, the following characteristic times are available:

(a) the optoacoustic deflector (20 KHz) provides 50 μsec flashes which illuminates the target with only 1/10 mm blur on a 2m/sec jet.

(b) the 128 element array can be shifted at 1.5 KHz as the absorbing jet structure flows by. At 2m/sec the structure can be chopped every 1.3 mm: thus, a one centimeter long jet structure can be displayed as a set of 7 layered concentration maps.

(c) the 4K memory can store the output of 34 consecutive slices of 128 readings each. Thus a continuous viewing time of 34/1.5 ≈ 20 milliseconds is available. At 2m/sec, a 4 cm long jet section can be displayed.

With the expected improvement in shift rates, better resolution of faster jets will become possible.

2. Coherent Structure Analysis

As the practicality of laser tomography gets nearer, the question of what specifically to measure is becoming increasingly more relevantt. The proposal reviewed the current state of affairs in coherent structures: since then, the time of the principal investigator has been mostly spent on structuring the available literature on the subject. It is remarkable that in spite of the abundance of publications on the subject, very few theoretical results seem to come close to a basis for reliable predictions, even for the well-known Tollmien-Schlichting waves. Current knowledge of multidimensional instabilities (c.f. Chigier, Roshko) is mostly qualitative. An accurate mapping of the early phases of jet mixing would provide a quantitative basis for the onset of coherent structure, especially in their role as flame front carriers.

Also, a research project led by Dr. Foa, at GW University, is focused on the rate of entrainment of adjoining fluid layers for propulsion purposes. Clearly the two projects complement each other since the exchange of mass and that of momentum are different aspects of the same mixing phenomena.

3. The portable tomographic unit

The recent availability of a MINC computer at the GW laboratory has allowed us to propose the assembly of a portable real time diagnostics system.

Progress has been made towards our first goal which was to establish a steady flow point measurement capability. The assembly and calibration of the optical system was carried out. The design of the flow mixing controls is under way. The data processing unit -- with its KHz conversion capability -- was delayed by a breakdown of the MINC computer, and by the late arrival of some parts. This part, however, will be completed in the current phase of our grant and real time measurements will be effected in the GW laboratory.

LIST OF PUBLICATIONS

1. "Optical Tomography for Flow Field Diagnostics" R.J. Santoro, P.J. Emmerman, R. Goulard, and H.G. Semerjian, in Laser Probes for Combustion Chemistry, (D. R. Crosley, ed.), ACS Symposium Series, Vol. 134, American Chemical Society, Washington, D. C., 1980.

2. "Optical Tomography for Flow Field Diagnostics," R. J. Santoro, H. G. Semerjian, P. J. Emmerman, and R. Goulard, International Journal of Heat and Mass Transfer, Vol. 24, No. 7, pp. 1139-1150, 1980.

3. "Optical Tomography for Flow Field and Combustion Diagnostics," R.J. Santoro, et al., Eastern Section of the Combustion Institute, 12-19 November 1980, Princeton University, NJ.

4. "Non-Dimensional Parameters in Radiation Gas Dynamics" AIAA Paper 81-1191. To appear in Aeronautics and Astronautics Series, 1982.

5. "Optical Tomography for Diagnostics in Combusting Flows" H. G. Semerjian et al. ASME Symposium on Fluid Mechanics of Combustion Systems, Boulder, Colorado, June 1981.

LIST OF PERSONNEL

Robert Goulard, Professor	3 man-months
Philip H. Emmerman, Research Associate	3 man-months
Masood Noori, Graduate Research Assistant	3 man-months

Part 1 of the experimental work reported above was performed at the National Bureau of Standards with their own support. Drs. Semerjian and Santoro are the main investigators.

INTERACTION

1. The papers listed in the list of publications were given at the corresponding professional meetings. Lively discussions were experienced on each occasion. Attendance at other meetings and contractor's reviews have also generated active discussions regarding this new technique.

2. An increasing amount of interest is being generated by this research. Similar efforts have been initiated, in particular the AFOSR advance diagnostics laboratory at Stanford (Byer). Other groups have already started an effort in combustion related tomography [General Motors (Bara), Princeton (Santavicca), Stanford (Hesselink)]. Interest in X-ray Tomography for solid rocket propellant testing seems to be continuing at AFRPC. The National Bureau of Standards has singled out their own involvement in this application as one of their innovative programs.

SPECIFIC APPLICATIONS OF THE RESEARCH

Three-dimensional absorption diagnostics by multi-angular scanning have been demonstrated with complete success in such commercial applications as medical X-Ray tomography and materials testing. An important new step would consist of making this technique applicable to dynamic situations, where real time histories of non-steady phenomena would be recorded. Heart and lung motion, liquid boiling, plasma dynamics, cloud evolution, combustion fluidized beds are examples which come to mind. Especially promising is the three-dimensional time history of coherent structures in transitional jet mixing.