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RESEARCH OF AEROPHYSICS INSTITUTE FOR STRATEGIC TECHNOLOGY

Martin H. Bloom

Polytechnic Institute of Brooklyn

Prepared for:

Army Research Office
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SEMI-ANNUAL TECHNICAL SUMMARY OF
RESEARCH OF AEROPHYSICS INSTITUTE
FOR STRATEGIC TECHNOLOGY

for the period ending 28 February 1973

Sponsored by

ADVANCED RESEARCH PROJECTS AGENCY
ARPA Order No. 1442, Amendment 2
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PIBAL
Report 73-A

for
U.S. Army Research Office
Contract No. DAHCO4-69-C-0077

POLYTECHNIC INSTITUTE OF BROOKLYN

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Submitted by: Martin H. Bloom
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Director of Gas Dynamics
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13. ABSTRACT

This report contains a description of the technical problem areas and accomplishments achieved during the reporting period. In addition, a complete list of publications, presentations, lectures, etc. is included and the personnel associated with the program are listed. The research projects are in the general subject areas of fluid and plasma dynamics. The work described was carried out under an ARPA contract, Order No. 1442, Amendment 2.

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ABSTRACT

This report contains a description of the technical problem areas and accomplishments achieved during the reporting period. In addition, a complete list of publications, presentations, lectures, etc. is included and the personnel associated with this program are listed. The research projects are in the general subject areas of fluid and plasma dynamics. The work described was carried out under an ARPA contract, Order No. 1442, Amendment 2.

I. INTRODUCTION

The Polytechnic Institute of Brooklyn is conducting an interdisciplinary program involving both theoretical and experimental studies in the areas of aerodynamics, plasma dynamics, and turbulence. In particular, those aspects are dealt with which are directly applicable to the immediate and long range interests of the ARPA Strategic Technology Office. Laboratory simulations, experimental devices and comparison of results with observed flight behavior are under consideration. Generation of new ideas and the review and evaluation of research performed by others in the professional community is also a significant part of the research effort.

In addition to the research studies briefly summarized in the following section, the investigators are engaged in ARPA committees and discussions and normally participate in the various workshops and meetings pertinent to the overall program.

II. RESEARCH PROJECTS

In this section, the various technical aspects of the individual research projects are discussed. In addition to a description of the task, the investigators, including faculty and students, and the current effort and major accomplishments to date are described. The various research areas are listed here for reference:

A. Flow Diagnostic Development

B. Electron Beam Diagnostics of Turbulent Plasmas

C. Entrainment, Vortex Structures and Turbulence

D. Laser Brightness Experiment

E. Multiphase Flow Diagnostics

A. Flow Diagnostic Development

Investigator: Professor S. Lederman

Technical Program and Accomplishments:

As indicated in the previous progress report, the emphasis in our research effort in flow diagnostic developments has been shifted from electrostatic probes, electron beams[1] and microwaves[2,3] to the field of spectroscopy and in general laser diagnostic techniques. Several aspects of these techniques are under investigation in our laboratory. These are concentration measurements of specific components of gas mixtures by means of the Raman effect, concentration measurements by means of the resonant Raman effect; temperature measurements by means of the vibrational Stokes to Anti-Stokes intensities; temperature measurements by means of rotational intensities, Stokes to Anti-Stokes, Stokes to Stokes and Anti-Stokes to Anti-Stokes; and velocity measurements by means of a Laser Doppler velocity meter. In another aspect of this work the problem of interference of aluminum oxides with the diagnostics of an exhaust of rockets by means of the Raman scattering techniques was examined. For that purpose a special apparatus was constructed. It was possible to inject into the viewing volume of known specie concentration a known amount of powdered aluminum oxide, and measure the effect of the latter on the scattered intensity of the incident radiation due to the known concentration of a given specie. The results of this work were reported in PIBAL Report No. 72-39.[4] In the course of the resonant Raman effect investigation, after some encouraging preliminary work conducted with iodine vapor and a ruby laser, an attempt was made to use a tunable dye laser for a series of relevant gases. Our efforts in this direction were, however, unsuccessful due to the very narrow range of laser tunability and a disproportional drop in power output of the laser at shorter wavelength. Due to this development our attention has been shifted towards the use of a dye laser pumped with a pulsed nitrogen laser. At the moment we are in the process of maximizing the power output and calibrating the nitrogen laser. Simultaneously, a special chamber with the proper input and output ports, proper pumping and pressurizing, as well as heating facilities, has been constructed. With the above, a systematic investigation of the resonant Raman effect on a series of relevant gases should be possible to perform.

As far as specie concentration and temperature measurements are concerned, a number of experiments have been performed in a stationary system in our laboratory, proving to our satisfaction the basic principles and techniques. At present, an effort is being made to obtain simultaneously the concentration temperature and velocity of a flow field on an instantaneous basis at a point, as well as a mean value of the data at a given point in space. To this end a system consisting of a pulsed laser, a c.w. laser, spectroscopes, data acquisition and processing equipment, as well as an on-line computer is being utilized. Some preliminary results utilizing this system have been reported in Ref. 5. The temperature measurement capabilities should be greatly increased with the acquisition of a Spex 1402 double monochromator. This instrument is scheduled for delivery shortly. With this instrument the temperature measurement utilizing the rotational Raman spectrum will be possible.

References:

1. Lederman, S. and Avidor, J.M.: Slightly Ionized Low Density Hypersonic Flow About a Sharp Plate and Its Diagnostics. Paper to be presented at the AIAA 6th Fluid & Plasma Dynamics Conference, Palm Springs, California, July 1973.
2. Lederman, S. and Dawson, E.F.: Pulsed Microwave Breakdown in Gases With a Low Degree of Preionization. J. Appl. Phys. (to be published).
3. Lederman, S. and Dawson, E.F.: Effect of Microwave Radiation on a Shock-Produced Electron Precursor. PIBAL Report No. 71-13, May 1971.
4. Lederman, S.: Raman Scattering Diagnostics in the Present of Al_2O_3. PIBAL Report No. 72-39, December 1972.
5. Lederman, S. and Bornstein, J.: Specie Concentration and Temperature Measurements in Flow Fields. PIBAL Report No. 72-30, October 1972.

B. Electron Beam Diagnostics of Turbulent Plasmas

Investigators: Professors R.G.E. Hutter and H. Farber

Technical Program and Accomplishments:

It is the purpose of this program to demonstrate the feasibility of using an electron beam as a diagnostic tool for the detection of turbulent fluctuations in an ionized medium.

During the period covered by this report, the data obtained during the previous period and described in the preceding report were analyzed. It was found possible to explain all observations quantitatively. The causes for the seemingly non-repeatability of the experiments on different days were found and the theory was able to described the effects.

The theory commonly employed, to describe amplification characteristics of beam-plasma systems, was extended to include "initial conditions" and "inhomogeneities" of plasmas.

A paper describing the experimental results and theoretical explanations has been written and is being submitted for publication.[1]

Reference:

1. Hutter, R.G.E.: Beam-Plasma Experiments. Submitted for publication in the J. Appl. Phys.

C. Entrainment, Vortex Structures and Turbulence

Investigator: Professor P.M. Sforza

Technical Program and Accomplishments:

Density variations and their effect upon turbulent mixing processes are important features of undersea flow fields. Our laboratory experiments on the wake behind a heated circular cylinder, whose axis is aligned with the free stream direction, indicate that the effect of small upstream disturbances influence the initial conditions for the wake. This experience was described to the participants in the ARPA-APL joint workshop held at IDA, April 2-4, 1973. The experimental facility is in the process of being altered to provide particularly accurate control of the upstream flow field. Such flow-induced three-dimensionalities can influence those that are density-induced and thereby significantly later the far field wake and, perhaps, the wake collapse distance.

Studies of basic vortex phenomena connected with entrainment processes peculiar to turbulent flows are continuing. Understanding the entrainment mechanism related to vortex "gulping" of ambient fluid can lead to control of this process, thereby providing a means to alter the initial conditions for a jet, wake, or fireball-type flow field.

A characteristics solution for one-dimensional, two-dimensional, or spherical blasts originating from finite volume containers has been obtained. Calculations for conditions relevant to fireball blast conditions have been performed. It is expected that this type of capability will provide the inviscid flow field conditions for application to studies of the turbulent mixing of the fireball with its surroundings.

D. Laser Brightness Experiment

Investigators: Dr. W.T. Walter and Prof. J.T. LaTourrette

Technical Program and Accomplishments:

The utility of high-power lasers will depend on their output brightness, or on how closely their operation approaches diffraction-limited performance. Several types of high-power lasers require rapid and intimate mixing of two or more components to produce the excitation reaction. Output beam quality can be affected by: (1) index of refraction gradients, (2) turbulence produced by the mixing, and (3) the resulting high gain (4dB/cm), output in the green portion of the visible spectrum (510 6nm) and can be operated in a static or non-flowing configuration. A copper vapor laser is being used as a model for the infrared gas-dynamic and chemical lasers to uncouple and separately investigate the effects of high gain and turbulence in the more tractable visible spectral region.

During initial experiments in which a transverse flow was introduced within the optical cavity of a copper vapor laser, very little change was observed in the near-field output beam pattern of the laser. This result is not conclusive, since the turbulence-produced distortion of the laser output waveform might be difficult to distinguish within the non-coherent multimode output of the laser. The optical cavity was a plane-parallel Fabry-Perot whose output beam divergence was much greater than the diffraction-limit because of the high gain available in the active medium. An effect of the disturbance caused by the introduced flow should be easier to detect if the spatial coherence of the laser were improved. The number of transverse modes oscillating can be reduced to a single one by reducing the effective diameter to 2mm. However, such a transverse distance is too small to conveniently introduce a controlled transverse flow distribution. Replacement of the Fabry-Perot cavity by a "high-loss" resonator with a large effective magnification factor is relatively insensitive to distortions. The sensitivity to distortion can be increased by decreasing the magnification. These experiments will be carried out during the next reporting period.

The copper vapor laser has the potential for development as an efficient, high-power laser[1]. One problem in this development has been the management of the heat required to vaporize the copper. The initially-developed electrically-heated systems[2] produced 40kw peak power and an electrical conversion efficiency of 1.2% (not including heater power). A self-heated copper vapor laser system has recently been reported[3] with a peak power of 200kw, an average power of 15w and an overall electrical efficiency of 1%. One disadvantage of these electrically heated systems is a relatively long warm-up time (several hours). Several other systems with faster startup times have been tested or suggested. These include exploding wire[4], arc heater[5], and electron beam heating[6]. All of these systems also involve electrical heating but with considerably less efficiency so that their overall electrical efficiency is less than 10^{-4}.

Chemical generation of the copper vapor has the double advantage of a rapid startup time while at the same time preserving the high electrical efficiency of the copper vapor laser. The theoretical limiting efficiency of the pulsed copper vapor laser is 38% while 10% may represent a practically-attainable goal[2].

Exothermic reactions between metal oxides and reducing agents have been used to produce molten metals usually for welding applications. The usual Thermit reaction employs powdered aluminum to reduce iron oxide. Many other metallic oxides can be reduced by aluminum with the release of a considerable amount of heat; for example,

$$3Cu_2O + 2Al \rightarrow 6Cu + Al_2O_3 + 260.3K\ cal.$$

We propose to use this reaction to demonstrate a chemically generated copper vapor laser. Initial experiments indicate that this reaction can generate molten copper at a temperature of 1600°C in a few minutes.

There is a need for better light sources near the maximum of the water transmission band (460-490nm). Atomic chromium has the potential of pulsed laser action at 494 or 497nm similar to the laser action we discovered and are developing at 510.6nm in copper vapor. We have furnaces capable of producing the 1550°C required to generate the 0.1 Torr of chromium vapor necessary for an adequate test. In fact, our copper vapor laser has been operated as high as 1650°C where the chromium vapor pressure is 0.5 Torr.

An Air Force group has expressed an interest in using organometallic compounds to generate metal vapors at low temperatures (0-400°C). The presence of the organic fragments, however, may inhibit laser action in the metallic vapor. Therefore, we propose as the most direct first step, an examination of chromium-rare gas mixtures for laser action.

References:

1. Walter, W.T., Solimene, N., Piltch, M. and Gould, G.: Efficient Pulsed Gas Discharge Lasers. IEEE Journal of Quantum Electronics, QE-2, 474 (1966).
2. Walter, W.T.: Metal Vapor Lasers. IEE Journal of Quantum Electronics, QE-4, 355 (1968) and 40-kw Pulsed Copper Vapor Laser. Bulletin of the American Physical Society, 12, 90 (1967).
3. Isaev, A.A., Kazaryan, M.A. and Petrash, G.G.: Effective Pulsed Copper-Vapor Laser with High Average Generation Power. JETP Letters, 16, 27 (1972).

4. Asmus, J.F. and Moncur, N.K.: Pulse Broadening in a MHD Copper Vapor Laser. Applied Physics Letters, 13, 384 (1968).

5. Russell, G.R., Nerheim, N.M. and Pivirotto, T.J.: Supersonic Electric-Discharge Copper Vapor Laser. Applied Physics Letters, 21, 565 (1972).

6. Baksht, R.B., Bychkov, Yu.I, and Mesyats, G.A.: Possible Utilization of a Vapor, Formed by the Action of a High-Power Electron Beam on a Target, as an Active Medium for Stimulated Emission of Light. Soviet Journal of Quantum Electronics, 2, 272 (1972).

E. Multiphase Flow Diagnostics

Investigators: Professor R.J. Cresci and Mr. E.J. Kawecki

Technical Program and Accomplishments:

This research is concerned with the application of the Raman scattering technique to multiphase flow diagnostics in a supersonic stream. The objective is to measure the specie mass concentrations and resolve the fraction of each specie in the liquid and gaseous phases.

The first phase of this work is to demonstrate, in a controlled static test chamber, that the technique can distinguish liquid from gaseous phases and accurately measure concentrations of each.

The experimental apparatus has been constructed, optically aligned and calibrated. The desired droplet distributions, ranging from fine to large particle fogs, have been repeatably achieved by a controlled adiabatic expansion of saturated air within the chamber. Visualization and qualitative classification of the fog was by mie scattering of a Helium-Neon laser beam. The predicted Raman shifts for water were verified with the pulsed Ruby laser.

Work is now proceeding towards measuring the liquid water content of droplets using Raman scattering.

III. SUMMARY OF RESEARCH PUBLICATIONS

A. Published Articles

P.M. Sforza and R.N. Valentine, "Unsteady Flow Within a Circular Cavity". "Recent Research on Unsteady Boundary Layers, Vol. 2. Proceedings of the International Union of Theoretical and Applied Mechanics Symposium on Unsteady Boundary Layers, Laval University Press, Canada, 1972. (PIBAL Report No. 72-34)

An exact solution to the time dependent Stokes' momentum equations in stream function form is used to solve for the flow inside an infinite circular cylinder. The flow is started by applying an impulsive motion to the cylinder wall. The applied velocity may be any function of angular location. The solution is split into two parts: a steady state stream function $\phi(r,\theta)$ to which is added an artificial transient distribution $\alpha(r,\theta,t)$. Various aspects of this solution, obtained in series form, are discussed.

G. Moretti and M. Pandolfi, "Entropy Layers".* Computers and Fluids, Vol. 1, pp. 19-35, January 1973. (PIBAL Report No. 71-33)

The entropy layer on a blunt-nosed cone is analyzed, in view of the difficulties it produces in numerical computations. A rule is given to determine at what distance from the nose the entropy layer layer is a given fraction of the shock layer, for a given free stream Mach number.

A simple and very efficient way of computing flows with strong entropy layer effects is given. It is essentially based on the insertion of a line representing a locus of rapid changes in entropy derivatives, and on forbidding certain differentiations across such a line

*This work is partially sponsored by the Office of Naval Research under Contract No. N00014-67-A-0438-0009, Project No. NR 061-135.

Edward F. Dawson and S. Lederman, "Effect of Microwave Radiation on a Shock-Produced Electron Precursor". The Physics of Fluids, Volume 16, No. 2, February 1973. (PIBAL Report No. 71-13)

Results of experiments in which a small pressure driven shock tube was used to produce a shocks in argon and air above Mach 10 are presented. This was strong enough to produce low level precursor ionization ahead of the shock. At the same time, the shock tube was used as a waveguide for pulsed X-band microwave radiation with a peak power of a few kilowatts. This further ionized the gas in the precursor region, resulting in an ionization wave which propagated very rapidly toward the microwave source. The velocity of this wave was measured as a function of the microwave power and an interpretation and comparison with other data is given.

B. Presentations at Technical Meetings

S. Lederman and E.J. Kawecki are authors of a paper entitled "Determination of Molecular Invariants α' and γ'", which was presented at the 38th Meeting of the Supersonic Tunnel Association, held in San Diego, Calif., September 11-12, 1972.

W. T. Walter presented an invited paper entitled "Copper Vapor Lasers" at the JSEP Topical Conference on High Power and Tunable Lasers, held at the University of Southern California in Los Angeles, January 31, 1973.

C. P.I.B. Reports, Dissertations and Books

S. Lederman. "Raman Scattering Diagnostics in the Presence of Al_2O_3", PIBAL Report No. 72-39, December 1972.

S. Lederman, E.F. Dawson, and P.K. Khosla, "Creation of Spherical Shock Wave in the Atmosphere by Using a Shock Tube", PIBAL Report No. 72-38, December 1972.

P.K. Khosla, "Interaction of Spherical Source Flow and Axisymmetric Free Jet with a Rarefied Background", PIBAL Report No. 72-25, May 1972.

IV. ARPA-RELATED ACTIVITIES, LECTURES AND CONSULTANTS

A. ARPA-Related Activities

Martin H. Bloom, Dean of Engineering, is a member of the Plume Physics Panel of DARPA/IDA. He is an Army consultant on the Safeguard program. He serves as Editor of the new International Journal of Computers and Fluids, which deals with computational fluid dynamics. He was the chief organizer of the Symposium on Application of Computers to Fluid Dynamic Analysis and Design, held in January 1973. He is a member of the Educational Affairs Committee of the American Institute of Aeronautics and Astronautics. He has been chosen an Outstanding Educator of America for 1973, an award of nation recognition based on exceptional service, achievements and leadership in the field of education, and is features in the national awards volume of Outstanding Educators of America.

Participation at meetings relevant to the program:

Martin H. Bloom attended the Second Conference on Applications of Chemistry to Nuclear Weapons Effects, sponsored by the Defense Nuclear Agency at the IDA, Washington, D.C., September 12-14, 1972.

Samuel Lederman, Robert J. Cresci, Martin H. Bloom and Enrico Levi attended the ARPA/STO Institutional Research Review Briefing, held at ARPA, September 28, 1972.

Enrico Levi attended the Industry Application Society Meeting, held in Philadelphia, Pa., October 10, 1972.

J.T. LaTourrette and W.T. Walter were invited to participate in a colloquium on New Laser Concepts which was held at Key Largo, Florida, November 8-10, 1972.

P.M. Sforza was an invited discusser at the Fluids Engineering Session of the 93rd ASME Winter Annual Meeting, held in New York City, November 29, 1972.

S. Lederman gave presentations on "Raman Scattering Diagnostics in the Presence of Al_2O_3" and "Development of a Laboratory Program for Laser Raman Scattering of Flames and Rocket Exhausts", at the Review and Planning of ARPA Program on Rocket-Plume Diagnostics held at IDA, December 14, 1972.

B. <u>Lectures</u>

S. Lederman gave a seminar on "The Application of the Raman Effect to Flow Field Diagnostics" at the Naval Ordnance Laboratory, Silver Spring, Md., December 13, 1972.

W. T. Walter gave a seminar on "Copper Vapor Lasers" at the Naval Electronics Laboratory Center, San Diego, California, January 30, 1973.

Lectures at P.I.B.:

<u>September 1972</u>

Professor G.L. Mellor Princeton University	Turbulence Equations of General Ocean Circulation

<u>October 1972</u>

Dr. R.E. Wilson Naval Ordnance Laboratories	Problems Associated With Gas Dynamic Lasers

<u>November 1972</u>

Professor R.J. Cresci Polytechnic Institute of Brooklyn	Fire Safety in High Rise Buildings

<u>December 1972</u>

Professor J.A. Owczarek Lehigh University	Secondary Flows in Planar Nozzles

<u>February 1973</u>

Professor F.M. White University of Rhode Island	A Review of Simple Procedures for Calculating Turbulent Boundary Layers

V. PERSONNEL ASSOCIATED WITH THE RESEARCH PROGRAM

Martin H. Bloom	Principal Investigator Director of Gas Dynamics Research Dean of Engineering
Robert J. Cresci	Professor
Herman Farber	Associate Professor
Rudolf G.E. Hutter	Professor
Edwin J. Kawecki	Research Assistant
James T. LaTourrette	Professor
Samuel Lederman	Professor
Enrico Levi	Professor
Pasquale M. Sforza	Associate Professor
William T. Walter	Research Scientist

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POLYTECHNIC INSTITUTE OF BROOKLYN

Department of Aerospace Engineering
and Applied Mechanics

ADDENDUM

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II. RESEARCH PROJECTS

A. Flow Diagnostic Development

Investigator: Professor S. Lederman

Defense Significance:

The importance of this diagnostic technique can be best appreciated by the mere fact that it is possible to determine instantaneously and simultaneously the composition and temperature of a complex flow field remotely. This permits a better understanding of the phenomena occurring in the exhausts of rockets and in internal combustors. It also permits the remote determination of the composition of plumes and exposions. A very significant property of this diagnostic system is the ability to distinguish between the ionized and neutral state of the same specie, which may aid in the remote determination of a given field.

B. Electron Beam Diagnostics of Turbulent Plasmas

Investigators: Professors R.G.E. Hutter and H. Farber

Defense Significance:

Many forms of plasmas have military significance. The project aims to supply a diagnostic tool for plasmas, both in the field (e.g., high altitude effects), in devices (e.g., plasma stimulated lasers), and in the laboratory.

C. Entrainment, Vortex Structures and Turbulence

Investigator: Professor P. M. Sforza

Defense Significance:

The problems discussed briefly above have direct bearing on the Ivy-Owl and UW programs.

D. Laser Brightness Experiment

Ultimately it is the brightness (watts-cw^{-2}-steradian^{-1}) that will determine the usefulness of high power lasers such as gas dynamic and chemical for ballistic missile and other defense needs. By using a visible, high-gain copper vapor laser as a model for the infrared gas dynamic and chemical lasers, we hope to uncouple and separately investigate the effects of high-gain and turbulence on output brightness in the more tractable visible spectral region. In addition, since the copper vapor laser has produced the highest brightness of any gas laser (3×10^{11} W/cm^2-ster), further development and investigation of its potentiality is clearly indicated.

The maximum transmission of light through water occurs in the green portion of the visible spectrum. At present there is a deficiency of efficient, high-power light sources in the green. The output of the pulsed copper vapor laser is at 510.6nm which is near the maximum of the water transmission band. The development of this laser and other possibilities in chromium at 494 or 497nm or in bismuth at 472.2nm for use with gated viewing systems could significantly increase the present limited optical ranges under water.

E. Multiphase Flow Diagnostics

Investigators: Professor R.J. Cresci and Mr. E.J. Kawecki

Defense Significance:

This study is significant in the diagnosis of flows both in and around rocket nozzles (in the plumes produced by the expansion) and in multiphase flows in general. Further information on formation of water droplets or ice crystals can also be obtained.