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RESEARCH OF AEROPHYSICS INSTITUTE FOR STRATEGIC TECHNOLOGY

Martin H. Bloom

Polytechnic Institute of Brooklyn

Prepared for:

Army Research Office-Durham
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March 1972

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

for the period ending 31 August 1972

Sponsored by

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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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PIBAL
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for
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Submitted by: Martin H. Bloom
Principal Investigator
Director of Gas Dynamics Research
Dean of Engineering

POLYTECHNIC INSTITUTE OF BROOKLYN

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ADDENDUM to the
SEMI-ANNUAL TECHNICAL SUMMARY OF
RESEARCH OF AEROPHYSICS INSTITUTE
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POLYTECHNIC INSTITUTE OF BROOKLYN

Department of Aerospace Engineering
and Applied Mechanics

ADDENDUM

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

for the period ending 31 August 1972

PIBAL Report No. 72-B

II. RESEARCH PROJECTS

A. Flow Diagnostic Development

Investigator: Professor S. Lederman

Defense Significance:

The significance of the research conducted in the field of diagnostics is applicable directly in several ways to the field of defense. The ability to measure concentration of species and temperature of the exhausts of rockets and jet engines without interfering probes in the field and laboratory can contribute to a better understanding of the processes involved as they are relevant to observables and design. The ability to diagnose remotely the plumes of high altitude rockets is of significant aid in recognition, decision-making on the countermeasures, and intelligence. Likewise the remote observation and diagnosis of explosions is of clear importance. Finally, the remote Raman sensing can provide a significant aid in detection of hidden enemy supply concentrations in or near a battlefield.

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

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

Defense Significance:

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

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brightness of any gas laser ($3x10^{11}W/cm^2$-ster)[1], 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 5106Å which is near the maximum of the water transmission band. The development of this laser for use with gated viewing systems could significantly increase the present limited optical ranges under water.

E. <u>Multiphase Flow Diagnostics</u>

<u>Investigators</u>: Professor R.J. Cresci and Mr. E.J. Kawecki

<u>Defense Significance</u>:

This sutdy 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.

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

F. High Altitude Plume Gas-Dynamics

A. Flow Diagnostic Development

Investigator: Professor S. Lederman

Technical Program and Accomplishments:

Since the shift in emphasis in our research effort on flow field diagnostics from electrostatic probes and electron beam techniques to the Raman scattering techniques, as reported in our progress report covering the period ending in February 1972, progress has been made concerning several aspects of this effort. As reported in the last summary of our research effort, the problem of the Resonance Raman Effect was under preliminary investigation. After some encouraging results obtained in iodine vapor (I_2) utilizing a ruby laser, it was decided to expand this investigation with this effect using other gases and vapors. Since the Ruby laser radiation wavelength was unsuitable for this work, a tunable dye laser was assembled in our laboratory utilizing the design and most major components of Synergetics Corp. This laser is now in operation and in conjunction with a specially designed heatable chamber should enable us to perform a systematic investigation of the Resonance Raman Effect on a series of relevant gases.

In the context of this work on Raman diagnostic techniques, the problem of interference of oxides of aluminum found in exhausts of rockets appears to be of importance. To find this effect, if any, and the degree of interference on specie concentration measurements at the exhaust of rockets utilizing the Raman effect, an apparatus capable of injecting a known amount of aluminum oxides into a known concentration of species was constructed and is now being calibrated. This will permit the evaluation of the effects of the presence of any particulate in a flow field.

In another aspect of our work, the reflected shock of a shock tube was used to generate a hot burst of gas of limited duration into a still atmosphere in an attempt to gain an insight into the entrainment of the constituents of the ambient atmosphere into the processed slug of hot gas. The results of this investigation are given in Ref. 1.

The completion of the work on precursors and microwave discharges resulted in two papers[2-3].

As a result of some of the work concerned with the Raman diagnostic techniques, a paper dealing with the determination of some of the molecular invariants[4] has been prepared.

References:

1. Lederman, S., Dawson, E.F. and Khosla, P.K.: Creation of Spherical Shock Wave in the Atmosphere by Using a Shock Tube. (In preparation).

2. Dawson, E.F. and Lederman, S.: Effect of Microwave Radiation on a Shock Produced Electron Precursor. To be published in The Physics of Fluids.

3. Dawson, E.F. and Lederman, S.: Pulsed Microwave Breakdown in Gases With a Low Degree of Preionization. To be published in the Journal of Applied Physics.

4. Lederman, S. and Kawecki, E.J.: Determination of Molecular Invariants α' and γ'. PIBAL Report No. 72-26, August 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.[1]

During the period covered by this report the apparatus, previously described, has been instrumented for semi-automatic operation. The discharge characteristic as well as the amplified and/or noise signals can be recorded automatically as a function of the plasma density or discharge current.

A total number of 157 recording sheets with multiple traces of various characteristics were obtained. Preliminary conclusions are:

a) The thermionically heated mercury arc discharge is not a quiescent plasma, as might be assumed on the basis of previously published studies. Strong microwave signals are present in certain operating regimes of the discharge.

b) The amplification characteristics of the beam-plasma system are strongly dependent on the volt-amp characteristic of the discharge, on the magnetic field and on the beam velocity. Comparison with pertinent theory is present undertaken, on the basis of the dispersion relation, which has been derived.

c) Repeatability of experiments during the period of one day is very good; it is poor from day-to-day.

Reference:

1. Eichler, R., Hutter, R.G.E. and Levi, E.: Interaction Between an Electron Beam and a Turbulent Plasma. J. Appl. Phys., 43, 7, July 1972.

C. En rainment, Vortex Structures and Turbulence

Investigator: Professor P.M. Sforza

Technical Program and Accomplishments:

With regard to fireballs, an analytic investigation is in progress on the flow field due to the expansion of a spherical mass of high-pressure, high-temperature (but not necessarily uniform) gas into an unbounded gas ambient. The flow is calculated by means of the method of characteristics. A computer program has been written for this problem and the individual subroutines are currently being tested. Solutions will provide information relevant particularly to the initial phases of fireball development.

With regard to undersea effects, the low-speed wake of a heated axisymmetric body with axis coincident with the free stream direction is currently being studied analytically and experimentally. This flow field has many features in common with that of a submarine vessel. In particular, the density variations induced by heating the body give rise to a "flattening" of the wake cross-section. This is an effect which is additional to the stratification flattening and warrants evaluation as well. At the present time, the body and its heating device are mounted in a low-speed wind tunnel and the flow in the test section is being calibrated, after which testing will start.

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 of the excited medium. As described in the previous semi-annual report coveromg the period ending February 29, 1972, we are using a visible, high-gain copper-vapor laser 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.

A flow generator has been modified to introduce a barded pattern of flowing gases transverse to the laser beam and within the optical cavity of a copper vapor laser. The flow generator, which is described in the previous semi-annual report, consists of a manifold of seven small tubes placed horizontally one above another inside of a larger tub. Separate flows in the smaller tubes and in the surrounding larger tube are adjusted to give sharp boundaries between the flows. An improved smoke generator has been assembled and connected in series with the flow in the smaller tubes to provide a visual indication of the boundary between the separate streams.

Initial experiments have been carried out using air + smoke versus air only. The resulting striped or "Venetian-blind" pattern was introduced in the high reflectance end of a plane-parallel Fabry-Perot cavity. Very little change was observed in the near-field output beam pattern of the copper vapor laser.

It is not yet clear whether distinguishable changes will be observed in the far field pattern or whether so many modes are involved in the output that although the modal make-up of the output beam changes, the integrated output intensity does not change substantially. In this case we shall proceed to reduce the number of transverse modes by employing a high-loss optical resonator. Preliminary results with a high-loss cavity produced nearly diffraction-limited output from a copper vapor laser as well as the highest peak brightness (3 x 10^{11} W/cm^2-ster) of any gas laser[1]. An improved high-loss resonator has been assembled and will be tested during the next reporting period.

Reference:

1. Chimenti, R. and Walter, W.T.: Coherence Properties of the Pulsed Copper Vapor Laser. Bulletin American Physical Society, 16, p. 41, 1971.

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. Water was selected as the test working fluid because its spectroscopic properties are well-known and its phase properties lend themselves to straightforward experimental techniques.

The experimental apparatus now being constructed consists of a cross-shaped scattering chamber within which the desired vapor liquid distributions are created by vaporizing, then subsequently condensing the water. When required, additional liquid water is supplied by spray heads.

The illuminating light source is a 100 megawatt pulsed ruby laser. The raman scattered light is monitored perpendicular to the incident beam along the other axis of the cross. The particular Raman wavelengths of interest are selected by a single pass spectrometer in conjunction with stop fitters.

F. High Altitude Plume Gas-Dynamics

Investigators: Professor S.G. Rubin, Dr. P.K. Khosla, and Mr. J. Kelly

Technical Program and Accomplishments:

An evaluation of the flow field associated with a retro-plume interaction has been initiated. The basic flow configuration has previously been established in experiments and simple analysis and it is our intent to carry out a combined theoretical and experimental program so that the flow properties, including pressure and temperature levels, can be determined for a wide range of stream and jet conditions.

The aim of the theoretical analysis is to present results that are easily obtainable without the need of complex computer programs which may not be readily obtainable or easy to duplicate. It is recognized that time-dependent programs do exist and may be capable of calculating the retro-plume flow field in reasonable computer times so that our aim is an engineering approach that can provide the desired information (1) in an analytic form so that specific effects can be evaluated systematically; (2) can be used by other investigators who do not have access to, or cannot deal with the intricacies of a time-dependent program; and (3) may be useful as an analytic solution in the further evaluation of viscous and far field effects. Typical results for the bow shock region have already been completed. The details of the analysis are not presented here, but are typical of thin shock layer theories on blunt bodies, and consider different expansions for the shock layer, contact surface layer and inner jet flow. The triple point interaction is to be included in the final analysis.

A simple experimental program is planned to establish the validity of the analysis. Flow field visualization and certain pressure measurements, in particular in the dead air recirculation or core region, will be included as they provide a simple and definitive means of comparison. More sophisticated measurements are under consideration and will be considered if deemed desirable.

In the non-continuum regime, an analysis has been made of the rearward-facing jet which emerges from the continuum regime in the near-field and proceeds through the transition region to the rarefied regime. The approach here is analytic and obviates several assumptions made in related kinetic studies of such jets. It permits extension to more comples conditions involving retroplumes and three-dimensional configurations.

III. SUMMARY OF RESEARCH PUBLICATIONS

A. Published Articles

J. Avidor and S. Lederman, "Flow Field Diagnostics in Rarefied Slightly Ionized Hypersonic Flow". Israel Journal of Technology, Vol. 10, No. 1-2, pp. 113-121, March 1972. Proceedings of the XIV Israel Annual Conference on Aviation and Astronautics, Weizmann Science Press of Israel, 1972. (PIBAL Report No. 71-18)

In this investigation two independent diagnostic techniques, the electrostatic probe and the electron density probe, were utilized in order to determine the relation between the ionized and neutral specie concentrations in a flow field. The wake of a 10° half angle cone in a hypersonic shock tunnel was utilized for that purpose. The resulting experimental data lead to the conclusions that the ionized specie concentration can only be related to the neutral density concentration in a frozen chemistry flow field and in regions where diffusion is nonexistent or negligible.

D.J. Palumbo and E.L. Rubin, "Solution of the Two-Dimensional, Unsteady, Compressible Navier-Stokes Equations using a Second-Order Accurate Numerical Scheme"*. Journal of Computational Physics, Vol. 9, No. 3, pp. 466-495, June 1972.

The Navier-Stokes equations are solved using a second-order accurate numerical technique. The supersonic flow ahead of a two-dimensional rectangular body is calculated as well as the laminar near wake. The fluid is assumed to be viscous and heat conducting with coefficients that depend on the temperature. A heuristic derivation of the difference

*This work is partially sponsored by the Office of Naval Research under Contract Nonr 839(34), Project No. NR 061-135; and in part by the Army Research Office, Office of Research and Development, under Grant No. DAHC19-70-G-0018, Project No. 2T065101M-710.

equations from the integral form of the conservation laws is presented as is a linearized stability analysis. The factors that go into the optimal choice of the time, length increment ratio are analyzed. Finally, the use of schemes of this type for the solution of problems where there are several different characteristic lengths is discussed. Results for the shocked region ahead and the wake region behind the body are presented.

R. Eichler, R. Hutter and E. Levi, "Interaction Between an Electron Beam and a Turbulent Plasma". Journal of Applied Physics, Vol. 43, No. 7, July 1972.

The growth of beam-current density fluctuations along an electron stream passing through a turbulent plasma slab is discussed.

G. Moretti, "A Critical Analysis of Numerical Techniques: The Piston-Driven Inviscid Flow". AGARD Lecture Series No. 48 on Numerical Methods in Fluid Dynamics, ed. by J.J. Smolderen, AGARD-LS-48, May 1972. (PIBAL Report No. 69-25)

This paper consists of two parts. In the first, a critical analysis of well-known procedures for the computation of one-dimensional shocked flows is made, in order to show the inconveniences of computing finite differences across a discontinuity and to prove that the use of the equations of motion in conservation form does not make the results any more accurate. In the second, a technique is developed to treat one-dimensional inviscid problems and it is applied to the problem of an accelerating piston. Practical and safe ways to predict the formation of a shock and to follow it up in its evolution are given.

B. Presentations at Technical Meetings

J. Avidor and S. Lederman are authors of a paper entitled "Flow Field Diagnostics in Rarefied Slightly Ionized Hypersonic Flow", which was presented at the XIV Annual Conference on Aviation and Astronautics, held in Tel-Aviv and Haifa, Israel, March 1972.

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

J. Starkenberg, "An Analysis of the Stability of Thin Liquid Films in Hypersonic Environments", PIBAL Report No. 72-11, April 1972.

E.F. Dawson and S. Lederman, "Pulsed Microwave Breakdown in Gases With a Low Degree of Preionization", PIBAL Report No. 72-14, April 1972.

S. Lederman and E.J. Kawecki, "Determination of Molecular Invariants α' and γ'", PIBAL Report No. 72-26, August 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 is the chief organizer of the forthcoming Symposium on Application of Computers to Fluid Dynamic Analysis and Design to be held January 1973. He is a member of the Educational Affairs Committee of the American Institute of Aeronautics and Astronautics.

Participation at meetings relevant to the program:

Martin H. Bloom was invited to participate in the ARPA-IVY-OWL Contractors' Meeting held at AVCO-Everett Research Laboratories, Everett, Mass., March 20-22, 1972.

Samuel Lederman attended a Design Review Meeting of a Raman Remote Measuring Device held at AVCO-Everett Research Laboratories, Everett, Mass., April 25, 1972.

Martin H. Bloom and Stanley G. Rubin visited Bell Laboratories, Whippany, New Jersey on June 27, 1972 to confer with a group concerning effects of explosions on vehicles. The Meeting was chaired by M. Stevens of Bell Laboratories.

Pasquale M. Sforza participated in the Langley Working Conference on Computation of Turbulent Free Shear Flows, held in Hampton, Va., July 20-21, 1972.

B. Lectures

March 1972

Dr. R. Korkegi Aerospace Research Laboratories, USAF	Aspects of Three-Dimensional High Speed Flow Separation

April 1972

Dr. J. Houbolt Aeronautical Research Associates of Princeton	Some New Concepts in Oscillatory Lifting Surface Theory

May 1972

Prof. S. Davis The Johns Hopkins University	Hydrodynamic Instability of Oscillatory Viscous Flows
Mr. B. Mangla Polytechnic Institute of Brooklyn	Self-Focusing and Stimulated Scattering

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
Stanley G. Rubin	Associate Professor
Pasquale M. Sforza	Associate Professor
Nicholas Truncellito	NSF Fellow
William T. Walter	Research Scientist