AD/A-001 817

RESEARCH IN RADIATION PHYSICS AND AERODYNAMICS

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Prepared for:

Army Research Office - Durham
Advanced Research Projects Agency

31 March 1974

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SEMI-ANNUAL TECHNICAL STATUS REPORT

October 1, 1973 - March 31, 1974

Sponsored by
Advanced Research Projects Agency
ARPA Order No. 570

Name of Contractor:	The Regents of the University of California Institute for Pure and Applied Physical Sciences
Effective Date of Contract:	July 1, 1972
Contract Number:	DAHC04-72-C-0037 U. S. Army Research Office
Principal Investigator and Phone Number:	S. C. Lin (714) 453-2000, ext. 1664
Short Title of Work:	Research in Radiation Physics and Aerodynamics
Contract Expiration Date:	June 30, 1974
Amount of Contract:	$1,145,000

TABLE OF CONTENTS

I. INTRODUCTION AND SUMMARY

The current ARPA/IPAPS program as defined in UCSD Continuation Proposal 5559, as revised March 13, 1973, and in the U. S. Army Research Office-Durham Contract DAHC04-72-C-0037 dated June 22, 1973, called for the performance of experimental and theoretical research in selected areas of radiation physics and fluid mechanics. The program shall emphasize technologies and activities which bear directly on the areas of current and long range interest to the ARPA Strategic Technology Office. The research shall be conducted in six research areas and shall include but not be limited to:

a. Laser Physics. Experiments shall be conducted to investigate (a) population phenomena which may look promising for efficient laser generation in the visible as well as in the infrared region and (b) laser-saturation or coherence effects for the NOCl molecule. Included in this area of investigation are the following three specific tasks:

1. Non-linear phenomena in bound-free transitions induced by lasers;
2. Upward laser frequency conversion in gaseous media;
3. Kinetics in electron-beam-seeded gas lasers.

b. Optics and Atmospheric Propagation. Conduct an analysis of existing turbulence data relevant to atmospheric and underwater optical propagation. Conduct an experimental investigation of optical image decorrelation by turbulence utilizing a turbulent field generated behind a strongly-heated grid in the IPAPS open-circuit wind tunnel. An experiment shall be conducted to determine the effects on atmospheric refractive index of temperature and humidity fluctuations over land. Specific tasks shall include:

1. Scalar mixing and turbulent shear flow;
2. Optical image de-correlation by turbulence;
3. Optical propagation over land.

c. High Temperature Entrainment and Metal Oxide Emissivity. Continue the high temperature air bubble entrainment experiment with new emphasis placed on the improvement of discharge symmetry and uniformity so that the effects of initial conditions on the rate of entrainment and turbulent mixing can be assessed. Continue measurements of f-numbers for electronic and vibrational-rotation bands of metal oxides. Specific tasks shall include:

1. High temperature entrainment;
2. Shock tube measurements of metal oxide f-numbers.

d. Plume Physics and Radiation. Experimentally investigate chemical reactions in crossed atomic and molecular beams which are relevant to the problem of visible and infrared radiation from high-altitude rocket plumes. Continue experimental measurements of f-numbers for metal oxides. Specific tasks shall include:

1. Chemical reactions in crossed molecular beams;
2. Shock tube measurements of metal oxide f-numbers.

e. Stratified Flow and Ocean Physics. Conduct a laboratory experimental investigation of turbulence-stratified flow interaction related to wake collapse phenomenon and subsequent generation of internal waves. These experiments are to be conducted in the IPAPS 12-layer continuous-flow water channel. Experimentally investigate the generation and propagation of large-amplitude, high-frequency stress wave trains in water. Using the IPAPS 100-watt argon ion laser, conduct an experimental investigation of the propagation and scattering of intense visible laser beams in water. Theoretically analyze the propagation of 45-75 Hz ELF waves in atmospheres below the ionosphere. Specific tasks shall include:

1. Turbulence in stratified flow;
2. Laser-induced stress wave propagation in solids and liquids;
3. Propagation and scattering of intense visible laser beams in water;
4. Propagation of ELF waves below the ionosphere.

f. Ionospheric Physics and Plasma Interactions. Continue theoretical analysis of ionospheric heating and nonlinear electromagnetic-wave-plasma interactions. Emphasis is to be placed upon analysis of saturation spectra and parametric excitation of Bernstein modes. Specific tasks shall include:

1. Theory of ionospheric heating;
2. Non-linear interaction between electromagnetic waves and plasmas.

II. HIGHLIGHTS OF RECENT ACCOMPLISHMENTS

Our major effort during the past eighteen months has been in the continuing reorientation and redirection of the overall program in response to the new ARPA/STO research priorities as expressed in the September 28, 1972 Institutional Research Review Briefing, and as communicated from time to time by cognizant ARPA/STO Program Managers to the Principal Investigator thereafter. In view of the projected changes in ARPA/STO research interests over the next several years and the long lead time required to construct certain experimental apparatus, we found it desirable to start phasing in some of the new research topics considerably ahead of schedule while phasing out some of the research topics in an orderly manner so as to cause a minimum of trauma to the ongoing research of the affected students and faculty members. As a result of these efforts and close cooperation among IPAPS participants and affected UCSD academic departments, the reorientation process has been relatively smooth and essentially completed by the Fall Quarter of 1973. Unfortunately, just at that time, the Institute (IPAPS) was informed by ARPA/STO that research funding for the follow-on year (July 1974-June 1975) would be further decreased by more than a factor of two. This created a serious morale problem not only among the participating faculty members and students, but also the machinists, laboratory technicians, computer programmers, and other affected University personnel upon whom much of progress for the planned research program depended.

In spite of the above mentioned crises, solid progress has been made during the past six months on many of the assigned research tasks. Worth special mention are those research topics in laser physics, optical propagation through turbulence, and stratified flow/turbulence interactions which involved initiation of new experiments and/or extensive development of new laboratory facilities as a result of the 1973 Institute's research reorientation program. For example, in the optical propagation through turbulence problem, we have recently obtained some spatial and temporal correlation functions for an incoherent point source modulated by a nearly homogeneous, isotropic, refractive index turbulence under carefully controlled laboratory conditions. Our preliminary results indicate that there exists a very strong dependence of the speckle image correlation time on the absolute intensity of the refractive index fluctuation at a fixed turbulence velocity. We also observed a continuous decrease of the image correlation time with increasing sampling frequency for a fixed refractive index fluctuation field. At the highest usable sampling frequency (about 4,000 times per second), the observed image correlation time is found to be about an order of magnitude shorter than the characteristic correlation time of the turbulence field itself. These results may have important implications on the life-time of isoplanatic patches, reciprocity, and performance of certain image improvement techniques which take advantage of the richer spectral contents of short-time exposures. (Please see Section III-b-2 below).

III. REPORT OF PROGRESS IN BRIEF

a. Laser Physics

Task #1. Non-Linear Phenomena in Bound-Free Transitions Induced by Lasers

INVESTIGATORS: S. S. Penner and student

SUBJECT DESCRIPTION: Experimental study of anomalous near-ultraviolet laser propagation through molecular gases Cl_2 and NOCl

PROGRESS IN BRIEF: Non-linear transmission of the doubled ruby frequency through NOCl at moderate pressures has been observed to be qualitatively simiiar to earlier results obtained on Cl_2. Studies concerning the absorption behavior of this bound-free system at much higher pressures (when no measurable transmission should occur) are inconclusive. ARPA support for this research is scheduled to be terminated as of June 30, 1974.

POSSIBLE APPLICATIONS: High-power laser propagation; chemical lasers

PUBLICATIONS:

1. R. C. Sepucha and S. S. Penner, "Observations of Anomalous Transparency in Bound-Free Transitions in Cl_2," Phys. Rev. Letters 28, pp. 395-397 (1972).
2. R. C. Sepucha and S. S. Penner, "Transmission of 3471 Å Laser Radiation through Cl_2 and Cl_2-Inert Gas Mixtures," JQSRT 13, pp. 635-662 (1973).
3. J. Bernard and S. S. Penner, "Transmission of 3471 A Laser Radiation through NOCl and NOCl-Inert-Gas Mixtures," in preparation.

Task #2. Upward Laser Frequency Conversion in Gaseous Media

INVESTIGATORS: S. C. Lin and student

SUBJECT DESCRIPTION: Theoretical and experimental study of transient vibrational/rotational population in polyatomic gases, such as BCl_3 and SF_6, during resonant absorption of high-intensity infrared radiation.

PROGRESS IN BRIEF: Professor S. C. Lin and graduate student J. Morris are continuing on their investigation of transient vibrational/rotational population in polyatomic gases, such as BCl_3 and SF_6, during resonant absorption of high-intensity infrared radiation. The objective is to search for the existence of population inversions between the upper levels of the absorbing vibrational/rotational modes and the lower levels of the non-absorbing vibrational/rotational modes that can be utilized for upward frequency conversion of high-power infrared lasers.

The theoretical part of this investigation using thirteen (13) coupled kinetic and radiative rate equations is completed. For the case of BCl_3, it is found that conversion of pulsed CO_2 laser energy from $\lambda \sim 10.6\ \mu$ to $\lambda \sim 6.0\ \mu$ using the $2\nu_3 \rightarrow 1\nu_4$ transitions with energy conversion efficiency of about 15 percent should be possible under certain conditions. In the experimental part of this investigation, J. H. Morris has just completed the construction of a double-discharge TEA-type pulsed CO_2 laser capable of delivering a few joules of energy in a time scale of the order of 100 nsec. The laser is also provided with an infrared grating for wavelength selection and with a beam spreader for distributing the laser energy uniformly over a 30-cm long infrared absorption cell. Preliminary experiments are in progress for checking out our preliminary theoretical findings. This investigation is scheduled to be terminated as of June 30, 1974 due to lack of funding support, however.

POSSIBLE APPLICATIONS: High-power lasers in the near-infrared and visible regions; tunable infrared lasers.

PUBLICATIONS:

1. J. H. Morris, "Upward Laser Frequency Conversion in Gaseous Media," Ph.D. Dissertation, University of California, San Diego. (In preparation.)

Task #3. Kinetics in Electron-Beam-Seeded Gas Lasers

INVESTIGATORS: S. C. Lin, C. P. Wang, and students.

SUBJECT DESCRIPTION: Theoretical and experimental study of excitation and population inversion in electron-beam-seeded gas lasers.

PROGRESS IN BRIEF: This is a relatively new research topic initiated about 18 months ago by Professor S. C. Lin and Dr. C. P. Wang in response to expressed ARPA interest in high-power laser technology, nonlinear laser propagation, laser-induced breakdown and laser energy coupling.[1]

Construction of the major experimental apparatus based on our own first-generation hot-cathode electron beam design was essentially complete at the time of writing of the last Semi-Annual Technical Status Report (for period April 1, 1973-September 30, 1973). A brief description of the design parameters for this electron beam, as well as a photograph of its initial assembly, was given in that Report.

As we have anticipated, subsequent shake-down testing of this apparatus has revealed numerous weak spots in our first-generation design. These included inadequate high-vacuum pumping provisions, inadequate radii of curvature for electrodes and other internal structures, and inadequate insulations, which led to prematured high-voltage breakdowns; inadequate heat-shielding for the aluminum foil window which led to prematured breakage; faults in the remote optical triggering circuits which led to unreliable electron beam current control, etc.. During the past six months, most of the above mentioned design deficiencies have been corrected. At the time of writing of this Semi-Annual Technical Status Report, we have been able to hold the hot-cathode electron gun close to the designed accelerating voltage (100 kV) for a prolonged period of time without prematured breakdown, and are presently awaiting the arrival of a titanium getter pump previously on order for further improvement of the background vacuum level.

Barring unforeseen delays in components (such as the getter pump) delivery schedule, we anticipate that electron-beam-seeding experiments can begin very shortly. The next step would be the addition of the secondary discharge chamber (sustainer) and the cavity mirrors so as to complete the electron-beam-stabilized electrical discharge laser system. Our present research plan calls for some initial calibration of the completed system performance using some well-studied infrared laser mixtures, such as $CO_2 : N_2$, or $CO_2 : N_2 : He$, before moving onto new mixtures and/or new experiments.

POSSIBLE APPLICATIONS: High-power laser technology; nonlinear laser propagation; laser-induced breakdown and interactions.

PUBLICATIONS: None

References:

1. E. T. Gerry, "Update and Review of STO Programs-Lasers," ARPA/STO Institutional Research Review Briefing, Washington, D.C., 28 September 1972.

b. Optics and Atmospheric Propagation

Task #1. Scalar Mixing and Turbulent Shear Flow

INVESTIGATORS: C. A. Friehe, J. C. LaRue and C. H. Gibson

SUBJECT DESCRIPTION: Atmospheric measurements relating to refractive index fluctuations and optical propagation through the atmosphere

PROGRESS IN BRIEF: Temperature and humidity fluctuation data were obtained during two atmospheric boundary layer field experiments: one over the open ocean 100 miles off the coast of Mexico from the Research Platform FLIP, and the other at the shoreline of the Salton Sea, Imperial County, California. The fluctuating temperature field was measured with 0.000025 inch diameter platinum wire and a 0.0025 inch thermistor bead, respectively. Humidity fluctuations were measured with ERC Lyman-alpha humidiometers, which were calibrated at the Naval Undersea Center, San Diego, in a Cambridge Systems Hygrometric facility. The data were recorded on analog FM tape recorders, reproduced in the laboratory, digitized using 12 or 14 bit analog-to-digital converters, and then analyzed on CDC 3600 and IBM 1130 computers. Two and one-half hours of the open ocean data and 20 minutes of the Salton Sea data were used for the calculations of the variances and power spectra.

The variances of $n' \times 10^6$ calculated from the measured temperature and humidity variances and covariances are presented in the following table:

Exp.	$1.00 \langle \theta^2 \rangle$	$0.113 \langle \theta q \rangle$	$3.21 \times 10^{-3} \langle q \rangle^2$	$\langle (n' \times 10^6)^2 \rangle$
Open Ocean	5.48×10^{-3}	$+1.17 \times 10^{-3}$	0.11×10^{-3}	6.8×10^{-3}
Salton Sea	31.7×10^{-3}	-34.9×10^{-3}	16.2×10^{-3}	13.0×10^{-3}

For the open ocean data, where the temperature-humidity covariance was positive, the inclusion of the humidity terms increased the refractive index variance by 24% over that which is obtained by considering only the temperature term. For the Salton Sea data, where the temperature-humidity covariance was negative, inclusion of the humidity terms decreased the refractive index variance by 59% from that obtained from only the temperature term.

The temperature power spectrum for the open ocean data does not exhibit the Kolmogorov inertial subrange form, $\phi_\theta(f) \sim f^{-5/3}$. Since $\phi_\theta(f)$ contributes significantly to $\phi_n' 10^6(f)$ at all frequencies, $\phi_n' 10^6(f)$ also does not exhibit an inertial subrange form, as is often assumed. For the Salton Sea data, the large negative values of $Co_{\theta q}(f)$ at low frequencies cause the shape of $\phi_n' 10^6(f)$ to be quite different from that which would be inferred from only $\phi_\theta(f)$.

These results will be presented at the forthcoming Topical Meeting on Optical Propagation through Turbulence sponsored by the Optical Society of America in Boulder, Colorado, July 9-11, 1974.[4]

POSSIBLE APPLICATIONS: Laser propagation; geodesy; telescope images; radio frequency propagation.

PUBLICATIONS: (Full or partial support from ARPA/IPAPS acknowledged):

1. C. A. Friehe, C. H. Gibson and G. Dreyer, "Effects of Temperature and Humidity on Density and Refractive Index Fluctuations Over the Open Ocean," presented at the Optical Society Meeting, 17-20 October 1972.

2. C. A. Friehe and J. C. LaRue, "Effect of Humidity and Temperature on Optical Refractive Index Fluctuations," presented at the Optical Society Meeting, 9-12 October 1973.

3. C. A. Friehe, "Generation of Temperature Fluctuations by Static Pressure Fluctuations in the Atmospheric Boundary Layer," in progress. Presented at the Annual Meeting of Division of Fluid Dynamics, American Physical Society, 19-21 November 1973, and again at the Eighth Annual Congress of the Canadian Meteorological Society, Toronto, Canada, May 29-31, 1974.

4. C. A. Friehe and J. C. LaRue, "Dependence of Optical Refractive Index on Humidity and Temperature. To be presented at the OSA Optical Propagation through Turbulence Meeting, Boulder, Colorado, July 9-11, 1974.

Task #2. Optical Image De-Correlation by Turbulence

INVESTIGATORS: S. C. Lin and Samuel Lin

SUBJECT DESCRIPTION: Experimental study of optical image decorrelation by refractive index fluctuations due to strong temperature mixing in nearly homogeneous, isotropic turbulence.

PROGRESS IN BRIEF: We are studying the space-time variation of the speckle image of an incoherent point source (an arc-lamp-illuminated pinhole) modulated by a nearly homogeneous, isotropic, refractive index turbulence generated in a strongly-heated air turbulence tunnel.[1,2] The experimental setup was described in the last Semi-Annual Technical Status Report (for period April 1, 1973-September, 1973). Some samples of consecutive frame movie pictures of the turbulence-modulated speckle pattern taken at two different framing rates were also shown.

By doing one-dimensional scanning of the speckle image intensity using a photodensitometer (Applied Research Laboratories, Model 22,000 Spectroline Scanner) and subsequent statistical processing of many such scanned images, we have obtained various spatial and temporal correlation functions of the speckle pattern as well as the power spectrum for the one-dimensional speckle image intensity fluctuations in spite of a very severe poor-quality-window problem.* The most significant results we find so far from these preliminary statistical data are: (1) the apparent sensitivity of the temporal correlation to the intensity of the refractive index fluctuation at a fixed turbulence velocity (i.e., the higher the value of C_n^2, the shorter the speckle image correlation time); (2) the continuous decrease of the speckle image correlation time with decreasing film exposure time (which is inversely proportional to the camera framing rate) for a fixed turbulence velocity and at a fixed value of C_n^2. Thus, even at a relative slow wind tunnel flow speed of 11 meters/sec and at a modest value of $C_n^2 \simeq 7 \times 10^{-13} \text{cm}^{-2/3}$, the speckle image correlation time observed at the highest usable camera framing rate (about 4,000 frames/sec, which is governed by the minimum film exposure required to produce a readable speckle image) is found to be about an order of magnitude shorter than the correlation times of the turbulent temperature and velocity fields

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*Please see Quarterly Management Report, July 1, 1974.

themselves that generated the refractive index fluctuations. These results may have important implications on the questions of iso-planatic patch life-time, reciprocity failure, as well as the question of optimum exposure time for certain image improvement techniques which take advantage of the richer spectral contents in short-time exposures.[3-5]

The above mentioned preliminary results will be presented at the forthcoming Topical Meeting on Optical Propagation through Turbulence sponsored by the Optical Society of America in Boulder, Colorado, July 9-11, 1974.[6] This research is continuing.

POSSIBLE APPLICATIONS: Optical and laser propagation; high temperature entrainment; plume physics; reentry physics; chemical laser

REFERENCES AND PUBLICATIONS:

1. Shih-Chun Lin and Shao-Chi Lin, Phys. Fluids, 16, 1587 (1973).

2. Shih-Chun Lin, T. T. Yeh and Shao-Chi Lin, "Temperature-Velocity Correlation in Strongly-Heated Grid Turbulence" (to be published).

3. Labeyrie, A., "Attainment of Diffraction Limited Resolution in Large Telescopes by Fourier Analyzing Speckle Patterns in Star Images," Astron. and Astrophys. 6, pp. 85-87 (1970).

4. Korff, D., Dryden, G., and Miller, M. G., "Information Retrieval from Atmospheric Induced Speckle Patterns," Optics Communications, 5, No. 3, pp. 187-192 (1972).

5. Gezari, D. Y., Labeyrie, A., and Stachnik, R. V., "Speckle Interferometry: Diffraction-Limited Measurements of Nine Stars with the 200-Inch Telescopes," The Astrophysical Journal, 173, pp. L1-L5 (1972).

6. Shih-Chun Lin and Shao-Chi Lin, "Rate of Speckle Image De-Correlation by Homogeneous Isotropic Turbulence." To be presented at the OSA Optical Propagation through Turbulence Meeting, Boulder, Colorado, July 9-11, 1974.

Task #3. Optical Propagation Over Land

INVESTIGATORS: C. A. Friehe and J. C. LaRue

SUBJECT DESCRIPTION: Field experiment in Minnesota relating to temperature and humidity fluctuations in the atmosphere which affects optical propagation over land.

PROGRESS IN BRIEF: In 1973, we performed an experiment at the Air Force Cambridge Research Laboratories meteorological site in Minnesota. The purpose was to obtain the appropriate measurements of temperature and humidity fluctuations from which statistical information of the refractive index field could be determined. Data analysis is almost complete and preliminary results indicate that the humidity fluctuations caused about a 10% increase in refractive index variance due to the contribution from the positive temperature-humidity correlation for the particular run selected for analysis. Further work is in progress to analyze data from the other runs, both by ourselves and by AFCRL.

POSSIBLE APPLICATIONS: Laser propagation; geodesy; telescope images; radio frequency propagation

PUBLICATIONS: (Please see list under Task #1 in this sub-section by the same investigators.)

c. High Temperature Entrainment and Metal Oxide Emissivity

Task #1. High Temperature Entrainment

INVESTIGATORS: S. C. Lin, L. Tsang, and C. P. Wang

SUBJECT DESCRIPTION: Temperature field structure in strongly-heated buoyant thermals

PROGRESS IN BRIEF: We are continuously making important progress on the study of laboratory-generated buoyant thermals. During the past six months, we have studied the effects of initial formation geometry on the evolution and temperature field structure of strongly heated buoyant thermals (or "fireballs") by comparing the observational results obtained from thermal bubbles generated by a vertically-symmetric electrical discharge with those obtained previously from a horizontal discharge.[1] It is found that for a given initial thermal energy deposition, the rise velocity of the vertically generated bubble is significantly slower than that of the horizontally generated bubbles due to the absence of an initial upward magnetic impulse on the former. Also, on account of the high degree of initial symmetry with respect to the gravitational vector, the vertically generated bubble is observed to evolve consistently into a vortex-ring-like structure at relatively early times. This is in sharp contrast to the irregular nature of the early time evolution of the horizontally generated bubbles. However, at later times after the entrainment process has fully developed and the buoyant thermal has arisen to a height equal to a few times the initial bubble diameter, the temperature field structure and statistical properties of the turbulent thermals generated by the two different initial formation geometries are found to be nearly indistinguishable.

This research will be terminated as of June 30, 1974 due to the lack of continuing ARPA funding support.

POSSIBLE APPLICATIONS: Ivy Owl; fireball chemistry; shock-bubble interactions; tropospheric turbulence related to laser propagation and air travel.

PUBLICATIONS:

1. S. C. Lin, L. Tsang, and C. P. Wang, "Temperature Field Structure in Strongly Heated Buoyant Thermals," Phys. Fluids 15, pp. 2118-2128 (1972).

2. C. P. Wang, "Motion of a Turbulent Buoyant Thermal in a Calm Stably-Stratified Atmosphere," 16, pp. 744-749 (1973).

3. L. Tsang, C. P. Wang and S. C. Lin, "Initial Formation Geometry and Evolution of Temperature Field in Buoyant Thermals" (to be published).

Task #2. Shock Tube Measurements of Metal Oxides f-Numbers

INVESTIGATORS: S. S. Penner, K. G. P. Sulzmann and students

SUBJECT DESCRIPTION: Shock-tube measurements of absolute intensities of AlO vibration-rotation bands and of selected Fe-lines

PROGRESS IN BRIEF: We have obtained preliminary data for the f-number of the fundamental band system of AlO. The present reduction of our measurements leads to the value $f \simeq 5 \times 10^{-5} \pm 80\%$. During the remainder of the contract period, we will conduct a careful data analysis which should yield an f-number estimate within $\pm 20\%$.

ARPA support for this research is scheduled to be terminated as of June 30, 1974.

POSSIBLE APPLICATIONS: Ivy Owl; plume physics

PUBLICATIONS:

1. H. Fissan and K. G. P. Sulzmann, "Absorption Coefficient for the Infrared Vibration-Rotation Spectrum of FeO," JQSRT 12, pp. 979-874 (1972).

2. A. G. Gilbert and K. G. P. Sulzmann, "The Vapor Pressure of Iron Pentacarbonyl," submitted to J. Electrochem. Soc. (1973).

3. A.G. Gilbert, K. G. P. Sulzmann and S. S. Penner, "Measurements of gf-Values for FeI Lines," in press in JQSRT (1974).

4. K. G. P. Sulzmann, "Relative Spectral Absorption Coefficients for the Fundamental Vibration-Rotation Bands of AlO," JQSRT 13, pp. 931-935 (1973).

5. K. G. P. Sulzmann, "Non-LTE Spectral Absorption Coefficients for Vibration-Rotation Bands of Diatomic Molecules," submitted to JQSRT (1973).

d. Plume Physics and Radiation

Task #1. Chemical Reactions in Crossed Molecular Beams

INVESTIGATORS: D. R. Miller and students

SUBJECT DESCRIPTION: Studies of free-jet expansions of binary gas mixtures and their application to chemical kinetic studies of endothermic reactions; crossed molecular beam experiments.

PROGRESS IN BRIEF: We have completed our studies of N_2 mixture expansions and we have developed a simple model to predict the velocity and internal state distribution in these expansions.

Our anomalous results for lower energy electron scattering from atomic oxygen[1] have been qualitatively substantiated by the recent theoretical calculations of Dr. Lowell Thomas, IBM, California. We have designed and analyzed a hexapole magnetic field assembly to improve the purity of our atomic oxygen beam so that we can improve our data on oxygen. We wish to also extend these low energy electron scattering measurements to atomic fluorine where there is interest in the data for laser systems.

We have constructed a high energy H_2O source (1 eV), utilizing mixtures of H_2O with He, for our crossed beam studies of $O + H_2O \rightarrow OH + OH$. We have also examined the possibility of detecting OH beams by utilizing the selective associative ionization reaction $OH + Ba \rightarrow BaOH^+ + e$; the sensitivity calculations appear quite promising and would give us a unique method of identification of OH radicals.

In the gas-surface interaction area, we are still in the process of calibrating our instrumentation for measurement on internal and translational energy accommodation of polyatomic gases at metal surfaces. We have been slowed by the need to satisfy safety requirements for handling fluorine, F_2, and in the manufacture of a satisfactory high pressure iridium beam source to dissociate F_2 to F.

ARPA support for this research will be terminated as of June 30, 1974.

POSSIBLE APPLICATIONS: Plume physics; chemical laser, Ivy Owl.

PUBLICATIONS:

1. R. Dehmel, M. Fineman and D. R. Miller, "Ratios of Forward-to-Back Scattering of Low Energy Electrons by Neutral Gases," Phys. Rev. A9, 1564 (1974).

Task #2. <u>Shock Tube Measurements of Metal Oxides f-Numbers</u>

INVESTIGATORS: S. S. Penner, K. G. P. Sulzmann and students

SUBJECT DESCRIPTION: Shock-tube measurements of AlO vibration-rotation bands and of selected Fe-lines

PROGRESS IN BRIEF: (Please see sub-section III-c-2 by the same investigators.)

POSSIBLE APPLICATIONS: Ivy Owl; plume physics

PUBLICATIONS: (Please see list in sub-section III-c-2 by the same investigators.)

e. Stratified Flow and Ocean Physics

Task #1. Turbulence in Stratified Flows

INVESTIGATORS: K. Helland, J. Park, D. Stillinger, and C. W. Van Atta

SUBJECT DESCRIPTION: Experimental and theoretical study of turbulence in strongly-stratified flows

PROGRESS IN BRIEF: The stratified continuous flow water tunnel is currently being developed to permit long test times with various density and velocity profiles. A brief description of this new experimental facility, together with a photograph showing its initial assembly, was given in the last Semi-Annual Technical Status Report (for period April 1, 1973-September 30, 1973). A number of experiments are planned once the operational objectives have been met. In particular, experiments such as the flow of a stratified fluid through a grid will be studied to compare the experimental techniques with results from several studies of grids towed through stationary stratified fluids. Other highly interesting flows are the turbulent wakes behind cylinders, spheres, and in particular the momentumless wake.

Before experiments begin, the tunnel must be tested for background turbulence levels, uniformity of velocity and density profiles. Calibration techniques for velocity and density will be examined and tested. In particular cross checks on the calibration methods is desirable such as velocity calibration by both hydrogen bubble techniques and manometry, and density calibration by hygrometry and index of refraction.

The construction of the tunnel is essentially complete and the process of testing has begun since the time of writing of the last progress report. Early indications are that the tunnel will meet design objectives with at most minor modifications to the existing structure. However, a sharp cutback in the number of available support personnel such as machine shop and electronic technicians at the University is expected to slow some stages of the experimental program. This is due to a general reduction in the overhead recovery from extramurally funded research contracts which ordinarily permits stable employment of support personnel by severa unrelated investigators. This problem is going to worsen next year as the funding level for ARPA Institutional Research support continues to deteriorate.

On the technical side, no serious technical problems have appeared so far. There are some indications of motor-induced vibrations which must be reduced by the measurement support systems. Two problems are expected to be encountered shortly. One, previous investigators have experienced contamination problems in the hot-film and conductivity probe measurement systems. More filtering methods than presently employed may be required. Two, some difficulty is expected in the development of experimental procedures for maintaining prescribed density profiles for long (2 to 3 hours) times necessary for high quality statistical measurements in a turbulent flow field.

In regard to general instrumentation for this new research facility, it may be desirable to develop sophisticated quasi-visualization techniques which would permit reduction of video tape data on the computer. Such techniques could provide powerful analysis techniques by combining the high quantitative accuracies of traditional hot-film and conductivity probe techniques with the immensely useful, qualitative visualization techniques such as tracers and hydrogen bubbles.

In the area of high Reynolds number turbulence related to atmospheric and ocean physics, Ken Helland has just completed his doctoral dissertation on "Energy Transfer in High Reynolds Number Turbulence." This is an extensive experimental and theoretical study of the fundamental dynamics of the cascade of energy from large scales to smaller scales in turbulent flows. We hope to pursue this work to even larger Reynolds number in geophysical turbulent flows in the coming years.

A second paper by Van Atta and Yeh is nearing completion on "Internal Intermittency in Turbulent Flows at High Reynolds Number," based on further extensive calculations of internal intermittency of the small scale turbulence in the atmospheric boundary layer. This work ties up many loose ends and questions raised by comparison of our previous studies with those recently published by Kholmyansky and Novikov. This work will continue in some new directions this year, suggested by our recent results and discussions with others regarding the importance of internal intermittency to optical and other electromagnetic wave propagation. In this area, Joel Park now has sufficient data for a definitive study of the temperature-velocity dissipation rate correlation which we have contemplated for some time. The data were obtained from the Naval Undersea Research Tower off Mission Beach.

Van Atta has also been working on Higher-Order Turbulent Spectra, both experimentally and theoretically. This work complements our earlier work on higher-order correlations and structure functions. It is hoped that this work will be well advanced by this fall, so that an invited paper can be given on the subject at the 5th Australasian Conference on Hydraulics and Fluid Mechanics, if travel funds are available.

POSSIBLE APPLICATIONS: Undersea technology; oceanography; air-sea interactions.

PUBLICATIONS:

1. C. W. Van Atta and T. T. Yeh, "The Structure of Internal Intermittency in Turbulent Flows at Large Reynolds Number: Experiments on Scale Similarity," J. Fluid Mech. 59, pp. 537-559 (1973).

2. K. N. Helland and C. W. Van Atta, "Higher-Order Moments of Artificial Turbulence as a Response Test of Constant-Current and Constant-Temperature Anemometry, (submitted to Phys. of Fluids).

3. C. W. Van Atta and M. Z. Kholmyansky, "Experimental Investigations of Turbulent Cascade Coefficients" (in preparation).

4. C. W. Van Atta, "Influence of Fluctuations in Local Dissipation Rates on Some Statistical Properties of Turbulent Scalar Fields," Izvestia Acad. Sci. USSR, Atmos. and Oceanic Physics (to appear in 1974).

5. C. W. Van Atta and T. T. Yeh, "The Structure of Internal Intermittency in Turbulent Flows at Large Reynolds Number. II. Further Experiments and Comparisons with Scale-Similarity Theory (in preparation).

6. K. N. Helland, Energy Transfer in High Reynolds Number Turbulence, Ph.D. Thesis, April 1974.

Task #2. Laser-Induced Stress Wave Propagation in Solids and Liquids

INVESTIGATORS: A. T. Ellis and M. P. Felix

SUBJECT DESCRIPTION: Experimental study and utilization of laser-induced stress wave propagation in solids and liquids

PROGRESS IN BRIEF: We have succeeded in generating nearly sinusoidal stress wave trains of 20-30 cycle duration in water. The amplitudes of these trains have approached 40 atmospheres of excess pressure (peak-to-peak), and the frequencies have been between 1 and 25 MHz. We are presently ensonifying inanimate objects with these laser-generated sound wave trains and we are probing the resulting sound field with visible laser light using a Bragg diffraction technique. This technique is one method of acoustic imaging; acoustical holography is another. We intend to use both schemes to demonstrate the usefulness of laser generated sound waves for acoustical imaging.

ARPA support for this research is scheduled to be terminated as of June 30, 1974.

POSSIBLE APPLICATIONS: Laser-induced material damage; high-power sonar generation and propagation; acoustic holography and imaging

PUBLICATIONS:

1. M. P. Felix and A. T. Ellis, "Laser-Induced Liquid Breakdown - A Step-by-Step Account," Applied Physics Letters 19, 484 (1971).

2. M. P. Felix and A. T. Ellis, "Stress Pulse Propagation in Solids - A Closer Look at Dispersion," Applied Physics Letters 21, Dec. 1, (1972).

3. M. P. Felix, "Short Duration Stress Pulse Propagation in Solids and Liquids," Ph.D. Thesis, University of California, San Diego, February, 1973.

Task #3. Propagation and Scattering of Intense Visible Laser Beams in Water

INVESTIGATORS: S. C. Lin, C. P. Wang, and students

SUBJECT DESCRIPTION: Experimental investigation of the propagation and scattering of intense visible laser beams in water, using the IPAPS 100-watt argon ion laser

PROGRESS IN BRIEF: Propagation and scattering of high power laser through water are relevant to a number of new underwater technology problems, such as doppler velocimetry,[1-3] remote chemical analysis, and remote thermometry. To practice on the latter, we have recently attempted the detection of Raman scattering from liquid water using the IPAPS 100-watt argon ion laser operating in the continuous wave (CW) mode, a specially constructed scattering tank, and a 0.5 meter Spex double-grating monochromator, but found excessive photo-detector noise. In order to suppress such detector noise (i.e., to enhance the signal/noise ratio), we found it desirable to use a gated pulse detection system.[4] Accordingly, we have concentrated our effort during the past six months in converting our 100-watt CW argon ion laser into a very high repetition rate pulsed system of approximately the same (i.e., within a factor of two or three) averaged power. Our approach is to use a "cavity dumped" system in which the stored laser field energy within a three-mirror cavity[5] is repeatedly released by a high frequency acousto-optics modulation of our own design. In parallel with this ion laser conversion effort, we are also constructing a high power pulsed nitrogen laser using a modified Blumlein circuit of our own design and with an anticipated output much greater than that used in Ref. 4 for pumping of tunable visible dye lasers operating in the blue-green.

At the time of writing of this progress report, stability analysis and testing of the three-mirror cavity is essentially completed,[5] and we are awaiting the delivery of the modulator crystal and associated electronic drive. Construction of the high power pulsed nitrogen laser is also nearly completed. However, in view of the fact that ARPA support for this research project will be terminated as of June 30, 1974, it does not appear likely that this work can be carried to fruition.

POSSIBLE APPLICATIONS: Underwater technology; remote sensing and thermometry

PUBLICATIONS:

1. C. P. Wang, "Instantaneous Turbulence Velocity Measurement by Laser Doppler Velocimeter," Appl. Phys. Letters 20, 339 (1972).

2. C. P. Wang, "A Unified Analysis on Laser Doppler Velocimeter," J. Phys. E: Scientific Instruments 5, 763 (1972).

3. C. P. Wang, "Measurement of Turbulence by Optical Mixing Spectroscopy," Proceedings of the Laser Doppler Velocimeter Workshop, Purdue University, March 9-10, 1972 (to be published).

4. J. I. Levatter, R. L. Sandstrom and S. C. Lin, "Raman Cross Sections Measured by Short-Pulse Laser Scattering and Photon Counting, Journal of Applied Physics 44, 3273 (1973).

5. C. P. Wang and R. L. Sandstrom, "Three-Mirror Stable Resonator for High-Power and Single-Mode Lasers (to be published).

Task #4. Propagation of ELF Waves Below the Ionosphere

INVESTIGATOR: H. G. Booker

SUBJECT DESCRIPTION: Theoretical investigation of extremely low frequency electromagnetic wave propagation between the earth's surface and the ionosphere.

PROGRESS IN BRIEF: Professor Booker's paper entitled "The ionosphere as the secondary conductor of a transformer at ELF" was published in the August/September 1973 issue of Radio Science.

Professor Booker is now devoting his attention to the propagation from the transmitter to the receiver of ELF waves between the earth and the ionosphere using an approximation to a full-wave treatment suitable when the free-space wavelength is large compared with the scale height in the lower ionosphere. His cooperation in this matter with the Groupe de Recherches Ionospheriques in Paris continues. Numerous bugs have been eliminated from the computer program being run in Paris, but some still remain. A draft paper covering the relevant theory has been prepared, but the paper cannot proceed further until the results of calculations are clearer. M. Lefeuvre in Paris is actively at work on these calculations at the present time and additional calculations are being made in La Jolla.

ARPA support for this research is scheduled to be terminated as of June 30, 1974.

POSSIBLE APPLICATIONS: Submarine communication; geophysics and ionospheric physics

PUBLICATIONS:

1. H. G. Booker, "The Ionosphere as the Secondary Conductor of a Transformer at ELF," August/September issue, Radio Science (1973).

f. Ionospheric Physics and Plasma Physics

Task #1. Theory of Ionospheric Heating

INVESTIGATORS: J. A. Fejer and students

SUBJECT DESCRIPTION: Theoretical studies of parametric instabilities related to the ionospheric heating experiment at Arecibo

PROGRESS IN BRIEF: Our current research program consists of the following:

(a) An investigation of the purely growing version of stimulated Brillouin scattering; this is really the same as what is termed by some as a focusing instability.

(b) An investigation of velocity diffusion by strong turbulent fields. In this case quasilinear theory is invalid and results are being obtained by computer modeling.

Results obtained so far indicate that mechanism (a) will explain artificial spread F and mechanism (b) will explain artificial airglow produced by ionospheric heating experiments. We hope to write up both results in the near future.

ARPA support for this research is scheduled to be terminated as of June 30, 1974.

POSSIBLE APPLICATIONS: Ionospheric heating experiment; laser interaction with plasmas

PUBLICATIONS:

1. J. A. Fejer and Y.-Y. Kuo, "Structure in the Non-linear Saturation Spectrum of Parametric Instabilities," submitted to Physics of Fluids, 1973.

Topic #3. <u>Nonlinear Interactions between Electromagnetic Waves and Plasmas</u>

INVESTIGATORS: G. J. Lewak and students

SUBJECT DESCRIPTION: Theoretical studies of nonlinear interactions between electromagnetic waves and plasmas. (Jointly sponsored by NASA and ARPA, with funding support in the approximate ratio of 60% NASA and 40% ARPA).

PROGRESS IN BRIEF: Professor G. J. Lewak and his students have nothing further to report.

ARPA support for this research is scheduled to be terminated as of June 30, 1974.

POSSIBLE APPLICATIONS: Ionospheric heating experiments; space probe experiments; laser interaction with plasmas

PUBLICATIONS:

1. G. J. Lewak and J. Ogunlana, "Nonlinear Interaction of Resonant Plasma Oscillations," J. Plasma Phys. 7, 207 (1972).

IV. PERSONNEL

Professor S. C. Lin became Principal Investigator on this contract as of February 1972. Personnel involved in the above research areas are listed below. Individuals listed as faculty members or as research scientists are members of the Institute for Pure and Applied Physical Sciences.

Bernard, Jay M.	Research Assistant
Booker, Henry G.	Professor of Applied Physics
Cragin, Bruce L.	Research Assistant
Ellis, Albert T.	Professor of Applied Mechanics
Erickson, Gary G.	Research Assistant
Fejer, Jules A.	Professor of Applied Physics
Felix, Michael P.	Assistant Research Engineer
Friis-Hansen, S. E.	Research Assistant
Gibson, Carl H.	Associate Professor of Aerospace Engineering
Heffington, Warren M.	Research Assistant
Helland, Kenneth N.	Research Assistant
Horne, James M.	Research Assistant
LaRue, John C.	Assistant Research Engineer
Lee, Hee-Jae	Research Assistant
Lewak, George J.	Associate Professor of Applied Physics
Lin, Samuel S.	Assistant Research Engineer
Lin, Shao-Chi	Professor of Engineering Physics
McConnell, Steven O.	Research Assistant

Miller, David R.	Associate Professor Engineering Physics
Morris, James H.	Research Assistant
Park, Joel T.	Research Assistant
Penner, S. S.	Professor of Engineering Physics
Poulsen, Peter	Research Assistant
Sotiropoulos, D.	Research Assistant
Stillinger, David C.	Research Assistant
Sulzmann, K. G. P.	Research Engineer
Tio, Tjaw K.	Research Assistant
Tsang, Leslie C. H.	Research Assistant
Van Atta, Charles W.	Associate Professor of Aerospace Engineering
Walters, Dolores A.	Research Assistant
Wang, Charles C. P.	Associate Research Engineer
Yeh, Tshy-Tyan	Assistant Research Engineer