REPORT ON ACTIVITIES DURING TENURE OF AIR POLLUTION FELLOWSHIP FROM THE ENVIRONMENTAL PROTECTION AGENCY UNDER THE CLEAN AIR ACT (P.L. 88-206)

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Introduction

The activities described herein were accomplished while under support from an Air Pollution Fellowship from the Environmental Protection Agency and regular salary provided by the Civil Engineering Department, Colorado State University, for staff on sabbatical leave. Work was accomplished during the period 6 September 1972 through 22 August 1973 while in residence in the Aeronautics Department of the Imperial College of Science and Technology, London, U.K. Attendance of lecture courses, seminars, and short courses, research, presentation of seminars, and visits to various universities and laboratories constitute the four main types of activities contributing to the program for which the fellowship was requested. Each type of activity is described separately in the following sections.

Objectives of the proposed program of study and research under the fellowship were the following:

1) Strengthen research on basic problems of turbulence and fluid dynamics encountered in the fields of geophysics, micrometeorology, and meteorology.
2) Increase capability for teaching courses in geophysics and industrial fluid mechanics.
3) Become acquainted with the organization of graduate programs and research related to industrial fluid mechanics in European universities.

These objectives were all examined during the period provided by this academic leave. Studying and working in the association of learned scientists such as Professors Bradshaw, Bearman, Owen, Spalding, Launder, and Scorer at Imperial College who have extended experience in the fields of turbulence, wind tunnel technique , industrial aerodynamics and atmospheric dispersion provided a creative design experience for the applicant. The United Kingdom also represents a depository of knowledge and scientific effort on problems of industrial aerodynamics and atmospheric dispersion which precedes work in the United States. The academic leave did provide opportunities to visit at the National Physical Laboratory, Teddington; University of Cambridge, Cambridge; and various facilities run by the Central Electric Boards. The examination of atmospheric flows in the laboratory is and international effort; however, effort in the United States is limited to only a few institutes including CSU.

It was extremely beneficial to expand knowledge of methods and techniques used outside my own institution.

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Research Program

Three research areas were examined in detail:

1. Flow and Dispersion in the Presence of Urban Heat Islands or Large Thermal Plumes:

On the smaller mososcale the vagrancies of sea-land breezes, the effects of inversion on pollution in cities, or the flow over a heated island or a city represent examples of two and three dimensional interaction of a thermal boundary with the lower atmospheric shear flow. Specifically, the interaction of a metropolitan area as a heat source of finite extent on wind patterns and the potential penetration of heat plumes through inversion layers resulting in fumigation are relevant research topics.

Sabersky (1970) in his recent review "Heat Transfer Research in the 70's" emphasized the consensus that the application of heat transfer methodology to urban or agricultural heating appears fruitful. In their review titled "Meteorological Effects of the Heat and Moisture Produced by Man", Hanna and Swisher (1971) concluded that "there is clearly a need for numerical models and observations of air flow over mesoscale areas where surface momentum, heat and moisture fluxes vary". They suggested such studies will contribute to estimation of moisture losses from ponds and reservoirs, impact of space heating, and air conditioning over urban areas.

In a recent report (Yamada and Meroney, 1972) some simple nonhomogeneous boundary two-dimensional and a single disturbance was placed perpendicular to the flow field. The results obtained both by numerical and wind tunnel experiments agree closely. They reproduced the primary characteristics of the urban heat island and the heated island phenomena.

During the academic leave the computer program for simple heat island flows was completely rewritten. An alternating direction implicit method was used to solve the equations of change for mass, vorticity, and energy. All boundary conditions were incorporated implicitly into the integration procedure rather than being updated at alternate time steps. The finite difference algorithms were solved by successive sweeps of a tri-diagonal matrix algorithm. A "high-lateral-flux modification" as used by Professor Spalding's research group was incorporated into the numerical procedure to assure numerical stability.

In addition attention was given the question of appropriate simulation procedures for laboratory representation of heat-maintain flow problems. It was concluded that the appropriate simulation parameters must be Reynolds, Grashoff, Bulk Richardson, and Dimensionless Mountain Height numbers. However the crictical gross parameters may be recombined as two primary parameters

$$\text{Gamma} = \frac{2(\text{Bulk Richardson No.})}{(\text{Reynolds No.})(\text{Prandtl No.})} \times \left(\frac{\text{Island Length}}{\text{Inversion Depth}}\right)$$

and

$$\text{Mountain Scale} = \frac{(\text{Temperature Excess Island})}{(\text{Change in Temperature Over Inversion})} \frac{(\text{Inversion Depth})}{(\text{Island Length})}$$

These parameters appear compatible with recent linear analytical calculation parameters proposed by Olfe and Lee (1971).

2. Turbulence Models for Stratified Shear Flow

Investigators have proposed a number of models to represent the effect of stratification on turbulent transport in the atmosphere. Delage and Taylor (1970), and Olfe (1971), Derickson (1972). Hadeen and Friend (1972), Estoque and Brumralkar (1971), Pandolfo (1971), and Nappo (1972) all utilized stability corrections based on the assumption of the existence of eddy viscosity and eddy diffusivity. Unfortunately such models are incapable of physically behaving as the measurements in the presence of strong stable or unstable stratification suggest (Tennekes and Lumley, 1972; or Scorer, 1960). Recently C. du P. Donaldson (1972), Lumley (1972), and Daly (1972) have proposed closures of the equation of turbulent motion which include equations for all Reynold's stresses and heat fluxes. Unfortunately even for a one-dimensional model Donaldson then found it necessary to solve simultaneously ten partial differential equations and one algebraic relation. Other theories suggested an even higher total.

Utilizing the Donaldson clear-air turbulence exercise as a test case I have succeeded in representing the important characteristics of the flow by solving only four partial differential equations in addition to the mean equations of change. The newly suggested model required additional equations for total turbulent kinetic energy k, total turbulent temperature fluctuations, k_T, eddy dissipation, ε, and thermal eddy dissipation, ε_T. These may be related to the various fluxes through use of the Prandtl-Kolmogorov eddy viscosity assumption, or if necessary the use of separate algebraic stress model relations.

This work represents an extension of the ideas regularly utilized by Dr. Spalding and Launder in their now routine modeling of industrial transport problems.

3. Effects of Streamline curvature on Turbulent Boundary Layers:

The presence of longitudinal rolls imbedded in the atmospheric surface layer may explain anomalies often found in measured heat, mass and momentum fluxes. Over the last few years my students and I have examined a number of laboratory situations where longitudinal rolls occur (Meroney and Kahawita, 1973, 1972) (Rayt, 1972). An analogy may be made between the effects of gravity on thermally stratified flows and the behavior realized in the presence of centrifugal or Coriolis forces. As part of an existing research program on the effects of extra rates of stain on turbulent flows by Mr. P. Bradshaw, Reader, Imperial College of Science and Technology I examined the effect on a turbulent boundary layer of a gradual curvature ($\delta/R \simeq .01$). These represent the first measurements since Schmidbauers in 1936 capable of testing current corrections for curvature typical of aerfoils and turbomachinery without the complications of compressibility.

A complete set of measurements including mean velocity, static pressures, wall skin friction, longitudinal turbulent intensity, and shear flow were obtained. Results compare well with calculations produced by programs developed by Bradshaw.

The results of this research are currently being prepared into a series of reports and papers for publication.

During the fellowship year, the following joint and single author papers resulting from my research program at Colorado State University were submitted for publication.

Reports

Yang, B. T. and R. N. Meroney, ON DIFFUSION FROM AN INSTANTANEOUS POINT SOURCE IN A NEUTRALLY STRATIFIED TURBULENT BOUNDARY LAYER WITH A LASER LIGHT SCATTERING PROBE, Project THEMIS Technical Report No. 20, October 1972, CER72-73BTY-RN17.

Kahawita, R. A. and R. N. Meroney, THE STABILITY OF PARALLEL, QUASI PARALLEL AND STATIONARY FLOWS, Project THEMIS, Technical Report No. 24, September 1973, CER73-74RAK-RNM12.

Meroney, R. N., Peterka, J. A. and Hoot, T., WIND TUNNEL SITE ANALYSIS OF DOW CHEMICAL FACILITY AT ROCKY FLATS, COLORADO, PART II, March 1973, CER72-73RNM-JAP-TGH16, 81 p.

Meroney, R. N., Hoot, T. G., and Peterka, J. A., WIND TUNNEL TESTS OF NEGATIVELY BUOYANT PLUMES, October 1973, CER73-74TGH-RNM-JAP13.

Meroney, R. N., and E. J. Plate, WIND TUNNELS AND FIELD INVESTIGATIONS OF SHAPES FOR BALLOON SHELTERS, NCAR Technical Note TN/EDD-82. February, 1973.

Reviewed Papers prepared,

Chaudhry, F. H., and Meroney, R. N., A LABORATORY STUDY OF DIFFUSION IN STABLY STRATIFIED FLOW, FDDL. Colorado State University, Published in Atmospheric Environment, Vol. 7, pp. 443-454, 1973, CEP70-71FHC-RNM, CEP70-71FHC-RNM63.

Meroney, R. N., and Anyiwo, J., EFFECTIVE VISCOSITY MODEL FOR TURBULENT WALL BOUNDARY LAYERS, Aeronautical Quarterly, Vol. 24, May 1973, pp. 92-102.

Anyiwo, J. C., and Meroney, R. N., A FORCE FIELD THEORY, PART I - LAMINAR FLOW INSTABILITY, in AIAA Journal, Vol. II, No. 1, January 1973, CEP70-71JC-RNM43.

Yamada, T., and Meroney, R. N., A WIND TUNNEL FACILITY FOR SIMULATING MOUNTAIN AND HEAT ISLAND GRAVITY WAVES, (Accepted for Publication in J. of Boundary Layer Meteorology 1973) CEP 71-72TY-RNM-45.

Meroney, R. N., and Anyiwo, J. C., A FORCE FIELD THEORY, PART II - LAMINAR-TO-TURBULENT FLOW TRANSITION, CEP71-72JCA-RNM53. (Accepted AIAA J. 1973).

Yang, B. T., and R. N. Meroney, CONSTRUCTION OF A LAGRANGIAN SIMILARITY DISTRIBUTION FUNCTION FOR A NON-STATIONARY ATMOSPHERIC DIFFUSION PROCESS, Preprint Volume of the Third Conference on Probability and Statistics in Atmospheric Science, 19-22 June 1973, Boulder, Colorado, CEP72-73BTY-RNM73.

Kahawita, R. A., and Meroney, R. N., VORTEX MODE OF INSTABILITY IN NATURAL CONVECTION FLOW ALONG INCLINED PLATES, (Accepted for publication IJHMT, 1973).

Kahawita, R. A., and Meroney, R. N., LONGITUDINAL VORTEX INSTABILITIES IN LAMINAR BOUNDARY LAYERS OF CURVED HEATED SURFACES, Submitted to Physics of Fluids, June 10, 1973.

Veenhuizen, S. D., and Meroney, R. N., SECONDARY FLOW IN THE ENTRANCE REGION BOUNDARY LAYERS OF AN EXPANDING SQUARE DUCT, Presented at Winter Annual ASME Meeting, New York, N.Y., November 1972, Paper 72-WA/FE-34, To appear in Transactions of ASME.

Meroney, R. N., and Chaudhry, F. H., COMMENT ON THE DISPERSION OF MATTER IN NEUTRAL AND STABLY STRATIFIED ATMOSPHERIC SURFACE LAYERS, by K. Atesman, (To appear in IJHMT, 1973).

Meroney, R. N., WHERE WE ARE: International Air Pollution - Great Britain J. of APCA, Vol. 23, No. 7, pp. 574-576, 1973.

Yang, B. T., and Meroney, R. N., A PORTABLE LASER LIGHT SCATTERING PROBE FOR CONCENTRATION MEASUREMENTS, Submitted to Review of Scientific Instruments, March 1973.

Kahawita, R., and Meroney, R. N., THE INFLUENCE OF HEATING ON THE STABILITY OF LAMINAR BOUNDARY LAYERS ALONG CONCAVE HEATED WALLS, Submitted to Canadian Journal of Mechanical Engineering Fall, 1973.

Lecture Courses Attended:

Seminars were held periodically by the Aeronautics, Meteorology, and Mathematics Departments of Imperial College of Science and Technology. These lectures were attended when the guest speakers were speaking in an area of interest.

I also was invited to attend a short course on "Turbulence Models and their Experimental Verification" presented by Drs. Spalding, Launder, and Whitelaw, April 2-4, 1973.

I continued to actively advise graduate students at CSU during the 1972-73 year: Correspondence and review of draft and final dissertations were made with

Dr. B. T. Yang
Dr. R. Kahawita
Mr. T. Hoot
Dr. Ken Barnett

Lectures and Seminars Presented, University and Government Laboratories Visited

Seminars on my experience in wind engineering, urban heat island modeling, and mountain wave modeling were presented a number of times during the year. Besides speaking to and visiting with various departments at the Imperial College of Science and Technology, London, brief visits were made to the following laboratories, research establishments and universities. (A star indicates a seminar was presented).

Visits

National Society for Clean Air Office, Brighton (Secretary & President Representatives of Control Agencies H. M. Alkali Inspectorate CEGB)	Oct. 4, 1972
Associated Portland Cement Manufacturers Ltd., Shorehorn Works, Sussex	Oct. 4, 1972
Health Physiology Division United Kingdom Atomic Energy Authority Research Established at Harvell (Dr. Stewart, & Dr. W.S. Clough) (Dr. Pearson, Dr. Clark)	Oct. 5, 1972
Didcot Power Station, Berkshire CEGB (Mr. A. J. Clarke Group Head Environmental Studies CEGB Sudbury House 15 Newgate Street London EC1).	Oct. 5, 1972
Association pour la Prevention de la Pollutin Atmospherique Main Offices (Mr. J. R. Delondre - Director) (Mr. M. J. Syrota - Chief Engineer of Mines)	Oct. 9, 1972
Laboratoire Central de la Prefécture de Police, Paris, France (Professor Paul Chavin - Director)	Oct. 9, 1972

	Laboratoire d'Hygiene de la Ville de Paris, France	Oct. 10, 1973
	Laboratoire de Pollution Atmospherique d'Electricite de France, Saint Dans, France (M. Edouard, Chef de la Pension Environment)	Oct. 10, 1973
	Union Technique de l'Automobile, du Montaraple et du Cycle, 157-159, rue Lecourbe, Paris 15e-France	Oct. 10, 1972
	Verein Deutsches Ingenieure Kommissen Reinhaltung der Luft Dusseldorf, Federal Republic of Germany (Dupl.-Ing. Norbert Endell, Secretary General of International Union of Air Pollution Prevention Associations)	Oct. 13, 1972
	Londesonstalt fur Immisions-und Bodennutzungschutz, Essen, Narthrhine Westphalia, Federal Republic of Germany	Oct. 13, 1972
	Bayer Chemical Plant, Leverkusen Federal Republic of Germany (Dr. Wolfrom Breuer) (Dr. Meyer)	Oct. 16, 1972
	Research Institute for Public Health Engineering, TNO, - Netherlands Organization for Applied Scientific Research (SICOM officials) (Ir. L.J. Brasser - Head Air Pollution Dir)	Oct. 18, 1973
	Shell Refinery & Chemical Works, Rotterdam	Oct. 18, 1973
	Rynmond Authority, Schredam, The Netherlands (Dr. L.A. Clarenburg - President of Strichting International Contactargoan Milienbescherming (SICOM))	
	Aeronautics Group National Physical Laboratory Teddington, Middlesex, UK	Nov. 7, 1972
*	(Dr. J. Wells)	
	Warren Springs Laboratory Department of Trade & Industry Stevenage, Hertfordshire, UK	Dec. 4, 1972
*	(Dr. D. Hall, & Dr. J. Barrett)	

Fluid Dynamics Section — Dec. 12, 1972
Central Electric Research Laboratories
Leatherhead, Surrey
* (Dr. D.J.W. Richards - Head of Section)

Industrial Aerodynamics Department — Jan. 10, 1973
University of Bristol, Bristol
* (Mr. T.V. Lawson
Dr. N. Cook)

Department of Aeronautics — Jan. 25, 1973
Queen Mary College
University of London, London
* (Prof. A. D. Young)

37th Industrial Fluid Mechanics — March 7, 1973
Meeting, NPL., UK
* Gave paper. (Wind Tunnel Modeling of External
Flows: Possibility and Effects of Scalar Distortion)

Science Research Council - Turbo Machinery Laboratory — March 15, 1973
Cambridge, Cambridgeshire, UK
(Dr. J. Hunt)

Engineering Department — March 16, 1973
Cambridge University, Cambridge
(Dr. L.C. Squire - Lecturer)

Department of Geophysics — June 1, 1973
University of Reading
Reading, UK
* (Mr. Simpson)

Marshwood Engineering Laboratory — July 10, 1973
Central Electric Generating Board
Southhampton, UK
(Drs. Nick Jackson,
* Dr. Tom Casto)

Comments

The foregoing activities and the stimulation and cooperation of many members of the Imperial College faculty -- particularly Mr. P. Bradshaw, Professor D. B. Spalding, Dr. B. E. Launder, Professor R. Scorer, and all of the Aeronautics Department staff -- made the fellowship year satisfying and fruitful. Much of the success of this year is due to Dr. J.E. Cermak and Dr. J.A. Peterka who made leave of absence possible by assuming the duties I left behind.