Progress Report
for
Contract Project DE-FG03-87-ER13757

FLUID DYNAMICS OF DOUBLE DIFFUSIVE SYSTEMS

1 MAY, 1988

PRINCIPAL INVESTIGATOR

J.R. Koseff
School of Engineering
Terman Engineering Center
Stanford University
Stanford, CA 94305.

Received by ECR

NOV 12 1991

PROJECT SUMMARY

A study of mixing processes in doubly diffusive systems is being conducted. Continuous gradients of two diffusing components (heat and salinity in our case) are being used as initial conditions, and forcing is introduced by lateral heating, surface shear and sloping boundaries. The goals of the proposed work include: (1) quantification of the effects of finite amplitude disturbances on stable, double diffusive systems, particularly with respect to lateral heating, (2) development of an improved understanding of the physical phenomena present in wind-driven shear flows in double diffusive stratified environments, (3) increasing our knowledge-base on turbulent flow in stratified environments and how to represent it, and (4) formulation of a numerical code for such flows. The work is being carried out in a new experimental facility which is located in the Stanford Environmental Fluid Mechanics Laboratory, and on laboratory minicomputers and CRAY computers.

In particular we are focusing on the following key issues:

- (i) The formation and propagation of double diffusive intrusions away from a heated wall and the effects of lateral heating on the double diffusive system;
- (ii) The interaction between the double diffusively influenced fluxes and the turbulence induced fluxes;
- (iii) The formation of gravitational intrusions; and
- (iv) The influence of double diffusive gradients on mixed layer deepening.

PROJECT GOALS FOR FIRST YEAR

The goals of the project for the first year (Aug. 1 1987 to Jul. 31 1988) were as follows:

a. Physical experiments

- (i) Construct experimental facility
- (ii) Modify and fabricate instrument racks

MASTER

JRK

- (iii) Develop sampling and calibration software
- (iv) Develop stratification techniques
- (v) Conduct flow visualization studies
- (vi) Qualify wind tunnel over a range of wind speeds

b. Numerical experiments

- (i) Adapt REMIXCS to handle turbulent flows
- (ii) Investigate approaches for specifying wind field
- (iii) Perform calculations for low wind speeds

PROGRESS TO MAY 1 1988

A great deal of progress has been made in the first 7 months of this project, particularly in the experimental aspects. With the exception of item (vi), all the tasks have already been completed and we are now conducting quantitative experiments. This was largely the result of a decision to commence construction of a new stand-alone experimental facility. Originally it had been envisioned that an existing wind-wave flume would be extensively modified for our purposes. However this turned out to be impractical. A brief description and a photograph of the new facility are provided in Appendix A.

We have also modified our original concept for the instrument racks. We have now constructed two, independent, high resolution profiling instruments. (It is planned to construct two additional instruments during the second year of funding.) The instruments are easily placed at a number of sampling ports at the top of the experimental facility. A description of the profiling system and an example of its capabilities are provided in Appendix B. Flow visualization studies have also been proceeding (see Appendix B). Using injections of fluorescein and rhodamine we have been able to produce striking images of the intrusions. Shadowgraph methods have also been used. These were particularly useful for our early experiments into perfecting the construction of a linear stratification. A start has also been made in using thymol-blue and rheoscopic liquid as an indicator of vertical shear in the intrusions.

Prior to commencing the experiments a number of calibrations were performed. These included the Seabird conductivity test cell, the rapid response conductivity sensors and thermistors, and the heating lights. Tests of heat loss from the facility were also conducted. Because the wind tunnel has only recently been constructed, no experiments have been conducted with wind. The qualifying of the wind tunnel is expected to be completed before August 1988.

There has been less progress on the numerical side, although work is proceeding. Since the original proposal was completed, there has been a substantial amount of work done on the REMIXCS code in general. It is now a vastly different (and superior) code from its early versions, and now goes by the acronym SEAFLOS. The SEAFLOS code will now be the basis of the numerical work we will be undertaking. We have implemented the solution of a salinity equation in SEAFLOS, and have also commenced working on a test numerical solution of the "simplest" double diffusion problem, viz., the heating of a stable salinity gradient from below. We believe that this problem can be satisfactorily solved using the existing code. Doing so will enable us to compare our numerical result with existing experimental data, and so check the accuracy of the code.

PLANNED PROGRESS TO AUGUST 1, 1988

We are currently conducting a series of quantitative experiments aimed at comparing the nature of intrusions produced in the presence of just a single stratifying component with those produced in the presence of twin gradients of temperature and salinity. These should be well advanced by August. We are also planning to qualify the wind tunnel. Numerically, we are planning on completing the simulation of the test problem, and on progressing further with the development of an adaptive grid code for this problem.

NEW DEVELOPMENTS

Partly as a result of the delay in completing the wind tunnel, we have not commenced work on the turbulence modeling or on the specification of the wind field (see items b(i) and (ii) of Project Goals section above). There seemed to be little point to developing the model independently of the measurements. However, our experience with the intrusions (see Appendix B) suggests that the high resolution required to satisfactorily represent the intrusion interfaces will make a conventional modeling approach very difficult. The number of grid points required to resolve the interfaces will rapidly exceed the available core even on a CRAY. For this reason we have commenced work on implementing an adaptive gridding procedure with SEAFLOS. Adaptive gridding allows the grid to be selectively refined only in those areas where high resolution is required. The Environmental Fluid Mechanics Laboratory at Stanford has been working on such methods for a number of years now, and so we are reasonably confident that the task can be satisfactorily accomplished. Although it will require extra time in these early stages, we believe the overall success of the numerical side depends on doing this.

PLANS FOR SECOND YEAR

In general we plan to follow the research program outlined in our original proposal. We shall, therefore, continue with both flow visualization and temperature and salinity measurements as well as development of our numerical facility. Our better than expected progress in the experiments in the first year may enable a greater range of physical experiments than initially envisioned. The exact nature of these experiments will become clearer as we progress with the analysis of our results to date.

BUDGET MODIFICATIONS

A budget for the second year of the project is attached. We have increased the salary for Dr. Geoffrey Schladow who is now a Research Associate at Stanford and who is responsible for the numerical work as well as some of the experimental work on this project. We are able to reduce the amount requested for the facility because of the School of Engineering's cost-sharing in constructing the facility. Finally, we decided to purchase a Seabird Conductivity Probe for our calibrations for \$2,200 and have scratched the Mettler Paar device from the budget.

APPENDIX A: The Experimental Facility

The double diffusion experimental facility consists of a 4.0m long, 0.8m high and 0.5m deep tank (see Figure 1). The walls are of composite construction: the inner pane being 6.25mm thick tempered float glass separated by a 6.25mm air gap from an outer plexiglas pane of similar thickness. The insulation afforded by this mode of construction allows us to conduct experiments with very large temperature gradients. One interior end wall of the tank is coated with a black, light absorbing film. On the outside of this wall a bank of lights with a total output of 1200W are used to produce a uniform field of diffuse light. By directing the light through the plexiglas and glass end wall, it is absorbed on the plastic film on the inside of the tank. In this manner a uniform heat flux is produced.

This experimental tank is directly connected to a wind tunnel. The water level when the tank is completely filled, forms the lower boundary of the wind layer. Air is drawn through the tunnel by an axial fan producing free-stream wind speeds up to 4m/s.

The stratification of the tank is accomplished using two 1300l water tanks. The "heavy" water is produced in one tank, and the "light" water is produced in the other. By pumping light water to the heavy water tank while vigorously stirring, and at the same time pumping the mixed water into the test tank, the test tank can be filled with progressively lighter water.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Figure 1 Double diffusion experimental facility. Black, heated sidewall is at the left of the test section. Variable speed fan at the wind tunnel outlet (top right) produces windspeeds of up to 4ms^{-1} . Contraction at wind tunnel inlet (top left) and mesh filters (not visible) remove large scale structures from air flow. Two profiling probes are visible above and to the left of the test section. The two stratifying tanks are behind the facility.

APPENDIX B: Some Experimental Results

The temperature and salinity profiles (see Figure 2) were measured as follows. An initially smooth salinity stratification was subjected to a lateral heat flux of 100 W/sq. m. A small dc motor drove an airfoil shaft containing the high resolution conductivity and temperature sensors down through the water column at a speed of 10 cm/s. Simultaneously, data from the sensors were fed to a Macintosh II workstation at a rate of 100 hz. The stepped conductivity profile in Fig. 2a was produced by intrusions propagating out from the heated wall as a result of a double diffusive instability. The "steps" are approximately 3 cm deep, while the interfaces between them are only 0.3 cm deep. The mean temperature stratification in Fig. 2b is a reflection of the ambient stratification in the laboratory, and has a negligible effect on this experiment. The small temperature inversions are associated with the intrusions.

Figure 2 Conductivity and temperature profiles during sidewall heating of a vertical salinity stratification.

END

**DATE
FILMED**

12/23/91