Center for Modeling of Turbulence and Transition
Research Briefs - 1990

N92-23349

Experiments and Modeling

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1. Motivation and Objectives

The usual approach in establishing the correctness and accuracy of turbulence models is to numerically solve the modeled differential equations and then compare the results with the experiment. However, in the case of a discrepancy, this procedure does not pinpoint where in the model the drawback lies. It is also possible that the model overcompensates one physical phenomenon and undercompensates the other so that the net result is a good agreement between the two. Therefore a more desirable approach is to directly compare the individual terms in the equations with their models. To achieve this objective primarily physical experiments have been used to carry out the second moment budgets. These can then be used to analyze and assess various models and closure assumptions and seek improvements/modifications where models prove deficient.

2. Work Accomplished

2.1 Evaluation and Development of Turbulence Models for Pressure Correlations.

A direct comparison between the pressure strain and pressure temperature-gradient correlations and their closure models is carried out. The flows used include both physical and numerical experiments on homogeneous shear flows and physical experiments on buoyant plumes. Models considered include both the linear and the more elaborate non-linear ones. It is found that the non-linear models provide a much better agreement with these experiments than the linear ones. A new model for the slow part of the pressure temperature-gradient correlation is also derived using joint realizability concept.

2.2 On the Ratio of Mechanical to Thermal Time Scales in Turbulent Flows.

The ratio of these time scales is very often employed in the two equation turbulence models. The study of Béguier et al (1978) recommended this ratio to be around 2.0. The current analysis using the buoyant plume and homogeneous shear flow experiments shows that this value is about 3.0. It is shown that this departure from the commonly used value is a consequence of the local equilibrium assumption being not satisfied by these experiments.

2.3 Turbulent Buoyant Transport - A Comparative Study between Models and Experiments.

The more popular gradient diffusion type models for the turbulent transport (third moments) were found to underestimate the experiment by an order of magnitude. More complex models (André et al 1976, Lumley et al 1978), based on the simplification of exact transport equations of third moments, do a much better job in reproducing the third moments although the results are still less than satisfactory.

2.4 Experimental Balances of Second Moment Equations for a Buoyant Plume.

Despite large volume of work on second moment closure, there is very little experimental information available about the budgets of the second moments. Part of this reason stems from our inability, at present, to measure the pressure correlations. Experimental budgets for Reynolds stresses and heat fluxes have been carried out for a boundary free shear flow (round plume) and the pressure correlations are obtained as the closing terms in these budgets. These budgets show how different terms in the equations are distributed across the flow and can be used to analyze some of the modeling assumptions. For example they show that the assumption of local equilibrium is not justified for bulk of the flow field - an idea fundamental to the algebraic stress models.

2.5 X-wire Response in Turbulent Flows of High Intensity Turbulence and Low Mean Velocities.

This work is based on an experimental study, which was carried out at SUNY/Buffalo, of angular response of an x-wire, at low velocities (0.25m/s to 1m/s). It is found that the k-factor in the modified Cosine Law is strongly velocity dependent. The implications of this on multi component turbulence measurements are explored. Expressions are also derived for evaluating when the cross-flow errors begin to affect x-wire measurements.

2.6 Modeling of Turbomachinery Flows using the Average Passage Approach.

Turbomachineray flows are turbulent and unsteady and numerical calculation of a flow in a multistage machine, at present, is not possible. However, the effects of periodic unsteadiness can be accounted through the models for deterministic stresses which arise in the average passage equation set (Adamczyk 1985). Exact equations governing the transport of these stresses have been derived and a two equation model is being developed and tested at present. The model uses ideas from turbulence modeling such as the gradient diffusion type hypotheses. This work is being performed in collaboration with J. Adamczyk of the Lewis Research Academy, at the NASA Lewis Research center.

3. Future Plans

3.1 Study the effect of buoyancy on turbulence by computating flows using turbulence models. In addition to environmental flows, such a work also has industrial applications e.g. cooling of nuclear reactors and electronic components, and "geyser" formation in fuel tanks in microgravity.

3.2 Seek improvements in the models for turbulent transport. In general the transport is not too important in most of the turbulent flows but in some applications, e.g. geophysical flows, the modeling of the transport could be critical in the success of a computation.

3.3 Seek improvements in the existing two equation models by incorporating newer models for pressure correlations etc.

3.4 Assess the models for deterministic stresses in a multistage turbomachinery environment.

4. Publications

1. Pressure Correlations in the Reynolds Stress and Heat Flux Equations - A Comparison between Experiment and Models. A. Shabbir. *APS Bulletin*, Vol. 35, No. 10, Nov. 90, Abstract KC4.

2. Evaluation of Turbulence Models for Predicting Buoyant Flows. A. Shabbir and D.B. Taulbee. *J. Heat Transfer*, 1990, Vol 112, No 4, pp 945-951.

3. Experiments on Round Turbulent Buoyant Plumes. A. Shabbir and

W.K. George. Under review for publication in *J. Fluid Mechanics.*

4. Advances in Modeling Pressure Correlation Terms in the Second Moment Equations. T.-H. Shih and A. Shabbir. Presented at the *Symposium honoring J. Lumley's 60th birthday*, November 90, NASA Langley Research Center.

5. X-wire Response in Turbulent Flows of High Intensity Turbulence and Low Mean Velocities. A. Shabbir, P.D. Beuther, and W.K. George. Submitted to *Experimental Thermal and Fluid Science.*

5. References

Adamczyk, J. J. "Model Equation for Simulating Flows in Multistage Turbomachinery", ASME Paper No. 85-GT-226. (1985)

André J.C., G. De Moor, P. Lacarrére and R. du Vachat "Turbulence Approximation for Inhomogeneous Flows: Part I. The Clipping Approximation", *J. Atmos. Sci.*, Vol. **33**, pp. 476-481, (1976)

Béguier, C., I. Dekeyser and B. E. Launder "Ratio of Scalar and Velocity Dissipation Time Scales in Shear Flow Turbulence" ," *Phys. Fluids*, Vol. **21**, pp. 307-310 (1978).

Lumley, J. L., O. Zeman and J. Siess "The influence of Buoyancy on Turbulent Transport", *J. Fluid Mech.*, Vol. **84**, pp. 581-597 (1978).