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AN EXPERIMENT ON TURBULENCE IN DENSITY STRATIFIED FLUIDS

by

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SUMMARY

A turbulent heat transfer experimental programme was conducted on an asymetrically heated (top surface) 30m x 0.6m x 0.1m rectangular duct to investigate the effects of density stratification on mean and turbulent flow parameters.

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Turbulence in atmospheric or oceanographic situations is normally density inhomogeneous; these inhomogeneities being brought about by temperature, salinity, moisture content or a similar scalar quantity. The most common and possibly most interesting situation, though also the one which has attracted least attention, is when the density gradient is a stabilizing one i.e. the density decreases in the opposite direction to the fluid body force.

This paper is a report on a laboratory turbulent heat transfer experimental programme in which the density inhomogeneities were controlled so as to have considerable dynamical effect on the mean and turbulent flow parameters.

Nicholl (1), Arya (2), Cermak and Chuang (3), have considered stablizing buoyancy effects on turbulent boundary layers while Webster (4) considered a flow in which temperature and velocity gradients were constant. All four references, but particularly (1), (2) and (3) observed suppression of turbulence with a comparatively small buoyancy parameter.

The Richardson flux number

$$R_f = \frac{g\beta \, \overline{u_3\Theta}}{\overline{u_1u_3} \, \frac{\partial \bar{U}_1}{\partial x_3}}$$

is a local parameter comparing turbulent energy removal via buoyancy forces with turbulent energy production by the velocity field. Specification of this parameter throughout the flow field is essential when considering the effect of density inhomogeneities on the field. Specification of R_f, *a priori*, for boundary layer flow is difficult. However for fully developed internal or free surface flows,

$$R_f = \frac{\varepsilon_m^*}{L} . f$$

where ε_m^* is a momentum transport coefficient dimensionalized to a length

$$L = \frac{\rho \, C_p \, u_*^3}{k \, g \, \beta q_o} = \text{Monim Obukhov length}$$

and f is a known function of position

R_f is large in regions of the flow in which the heat flux and shear stress profiles are dissimilar (with heat flux being finite and shear stress $\simeq$ o). This was achieved experimentally with an asymetrically heated internal flow.

The upper surface of a rectangular duct (30m x 0.6m x 0.1m) was electrically heated over 20m of its length; the first 8m of the duct being an entry length and the final 2m an exit length.

A cross hot-wire anemometer probe and an adjacent single probe were combined on line with an analogue computer to produce signals proportional to two turbulent velocities (u_1, u_3) and the turbulent temperature Θ. These were multiplied in pairs to form instantaneous signals of the turbulent shear stress $u_1 u_3$, vertical turbulent heat flux $u_3\Theta$ and longitudinal turbulent heat flux $u_1\Theta$. The reduction in heat transfer coefficient (non dimensionalized to a Nusselt number Nu, with density stratification will be shown on a Nu = f (R_e, S) where S is a suitable parameter denoting density stratification).

Density stratification effects on $\overline{u_1^2}$, $\overline{u_3^2}$, $\overline{\Theta^2}$, $\overline{u_1\Theta}$, $\overline{u_3\Theta}$, $\overline{u_1u_3}$ will be shown together with effects on the spectral distribution of these parameters for low flow Reynolds numbers (of the order of 20,000 based on hydraulic diamter and mean velocity) and surface heat fluxes from 0 - 10^3 watts/m^2

(1) NICHOLL - Some Dynamical effects of heat on a turbulent boundary layer. Journal of Fluid Mechanics (1970) Vol 40 pt.2 pp361-384.

(2) ARYA - Structure of stably stratified turbulent boundary layer. Ph.D. Colorado State University (1968).

(3) CERMAK & CHUANG. - Vertical-velocity fluctuations in thermally stratified shear flows. (1965) Colarado State University, Fluid Mechanics Programme - Technical Report CER 65 JEC-HC 48.

(4) WEBSTER - An experimental study of turbulence in a density stratified shear flow. Journal of Fluid Mechanics (1964) Vol. 19 pp221 -.