INFLUENCE OF THE STRATIFICATION ON THE TURBULENT CONVECTIVE FLOW IN A TILTED CHANNEL

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Averaging the small scales of a turbulent flow has the consequence to introduce new stresses, the Reynolds stresses, in the equations followed by the averaged velocity. For the closure of these equations, one has to relate these stresses to the properties of the averaged velocity field. For instance, a popular approximation for the shear stress is the so called Smagorinsky [1] one, which relates it to the transverse velocity gradient.

$$\sigma_{xy} = \langle v'_x v'_y \rangle = -\ell^2 \left| \frac{\partial V_y}{\partial x} \right| \frac{\partial V_y}{\partial x} \tag{1}$$

where the velocity field $\vec{v}$ is decomposed in smooth $\vec{V}$ and fluctuation $\vec{v}'$ parts.
In a stratified flow, characterized by a local Brunt-Väisälä frequency N, one can expect additional contributions to the Reynolds shear stress. In particular, the following expression has been proposed [2]:

$$\sigma_{xy} = \langle v'_x v'_y \rangle = -\ell^2 \left(\left(\frac{\partial V_y}{\partial x} \right)^2 - \epsilon N^2 \right)^{1/2} \frac{\partial V_y}{\partial x} \tag{2}$$

It expresses that the Reynolds shear stress can vanish, even if the mean velocity gradient is not zero, if the stratification is strong enough. Defining the Richardson number:

$$Ri = \frac{N^2}{(\frac{\partial V_y}{\partial x})^2} \tag{3}$$

ϵ can be seen as the inverse of the critical Ri number.
Here, we report systematic experiments with a model flow, a square heat pipe, allowing precise comparison with the consequences of such an expression. Our set-up is an inclined, square channel, connecting two chambers, one heated at the bottom, and the top one being cooled down. The fluid is deionized water. It results in a shear mean flow, whose profile is measured via PIV. It also results in a transverse temperature profile, the hot fluid flowing along the upper wall, and the cold fluid along the lower one. The temperature gradient, and thus the corresponding Brunt-Väisälä frequency N, can easily be deduced from the measurement of the Reynolds shear stress profile. We observe (see figure 1) that, when the inclination angle ψ increases, the velocity gradient profile flattens, which cannot be explained with the simple Smagorinsky expression for the stress (1), but is compatible with the modified one (2).

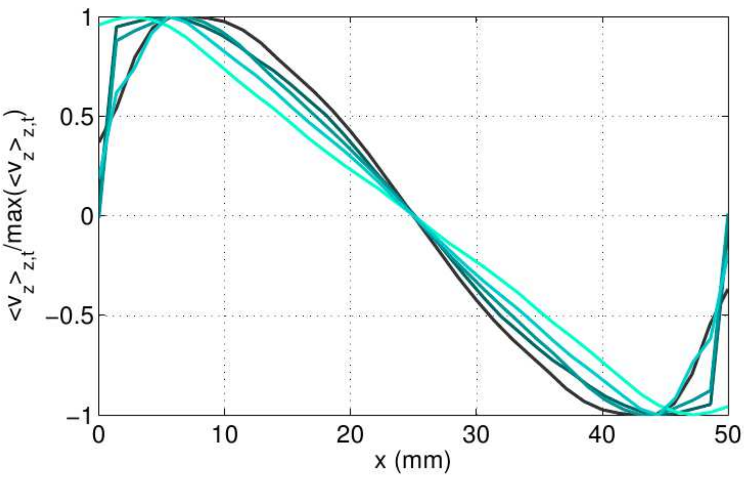

Figure 1. The velocity profile, normalized to its maximum, for channel inclination angles of $0°$, $2°$, $5°$, $10°$ and $20°$.

References

[1] Smagorinsky J., "General circulation experiments with the primitive equations" Mon. Weather Rev. **91**, 99 (1963).
[2] Eidson T. M., "Numerical simulation of the turbulent Rayleigh-Bénard problem using subgrid modeling", J. Fluid Mech. **158**, 245 (1985).