Dynamics of a tilted cylinder wake in a stratified fluid

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ABSTRACT

Despite the large amount of research devoted to bluff body wakes [1], very few studies have focused on stratified wakes despite their obvious applications to geophysical flows. Moreover, most of these studies have studied the turbulent regime in the wake of a sphere or an ellipsoid [2,3], due to its naval applications for submarine wakes. These bluff bodies have a finite height, which leads to a quasi-2D flow at late stages, and which may be very different from a vertical cylinder wake where the height is infinite. It is thus surprising to see that there has never been any paper on the dynamics of a vertical or tilted cylinder wake in a stratified fluid, although this dynamics is very well known and extremely rich for a homogeneous fluid. The goal of this study is to analyse experimentally, numerically and theoretically how a linear density stratification modifies this dynamics.

The first part focuses on the transition from a recirculation bubble to a von Karman vortex street which appears at a critical Reynolds number of 50 in a homogeneous fluid [4]. This bifurcation remains supercritical for a stratified wake, but the critical Reynolds number strongly varies with the stratification if the cylinder is tilted with respect to the vertical: it can increase by a factor almost three for moderate stratifications. This stabilisation of the flow allows a reduction of the vertical velocity created by the tilted vortices, consistent with the effect of the stratification. However, for strong stratifications, a second unstable mode appears, which still contains alternate vortices but with no vertical velocity although the axes of the vortices are tilted with respect to the vertical. This mode leads to a regular 2D cylinder wake in each horizontal plane, such that the critical Reynolds number is close to its value in a homogeneous fluid.

In a second part, we study the internal waves generated by the cylinder. They create a strong axial velocity, which oscillates at the Brunt-Väisälä frequency with an amplitude proportional to the density gradient for weak stratifications. The structure and amplitude of these Lee waves can be predicted qualitatively and quantitatively using the Lighthill theory.

Finally, preliminary results will be presented on the 3D instabilities of the cylinder wake. For a vertical cylinder, the well known mode A [5] can be nicely visualised by shadowgraph. However, for large tilt angles, the shadowgraph visualisations reveal a different instability composed of thin dark lines which undulate at a very specific wavelength. These structures are similar to the Kelvin-Helmholtz billows which have been observed recently [6] in the critical layer of a tilted stratified vortex.

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