Oblique roll instability in inclined buoyancy layers

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Abstract

When an inclined plate is heated in a stably stratified fluid, a buoyancy-driven boundary-layer flow will be generated. According to previous studies, such a layer is mainly subjected to two instability mechanisms: the transverse traveling (TS) waves and the stationary longitudinal (SL) rolls. In present paper we identify a novel oblique roll (OR) instability. The oblique rolls are more unstable than SL rolls in fluids with Prandtl numbers P of the order unity or less for all angles of inclination χ with respect to the horizontal except those close to 0°. The OR mode has smaller critical Grashof numbers than the TS waves in some regions of the P–χ-parameter space. This feature is surprising because the transverse TS wave has been reported as the most unstable infinitesimal disturbances in boundary-layer flows. In comparison with TS waves, oblique rolls have a lower critical frequency, which coincides with the Brunt–Väisälä frequency of internal waves when the surface temperature is fixed and the tilt angle is large. Another important feature of the OR mode is that its amplitude decreases less rapidly with distance from the plate than the amplitudes of SL rolls and TS waves. As a result, OR mode disturbances penetrate into the stably stratified region for nearly three times the thickness of the boundary layer. Further investigation reveals that in low Prandtl number fluids with a uniform-heat-flux boundary the preference for onset of oblique rolls instead of TS waves is even stronger than in the case of a fixed temperature at the plate.

Keywords: Boundary layer; Thermal convection; Shear instability; TS wave; Longitudinal roll; Oblique roll