Fluid Dynamics Research, Vol. 29 (4) (2001) pp. 227-250

PII: S0169-5983(01)00025-9

Numerical study of stably stratified flows over a two-dimensional hill in a channel of finite depth ¤

Takanori Uchida * takanori@riam.kyushu-u.ac.jp and Yuji Ohya

Research Institute for Applied Mechanics, Kyushu University, 6-1 Kasuga-koen, Kasuga-city, Fukuoka 816-8580, Japan

Received 20 December 2000; received in revised form 25 April 2001; accepted 30 June 2001

Abstract

Stably stratified flows over a two-dimensional hill in a channel of finite depth are investigated numerically at a Reynolds number of 2000, which is based on the uniform upstream velocity *U* and the hill height *h*. As a first step, we assume a free-slip condition on the ground, both upstream and downstream of the hill, and impose a no-slip condition only on the hill surface. Such a configuration corresponds to that of the previous towing tank experiments and numerical studies. For strong stratification ($1<K=NH/\pi U\leqslant 2$), the present numerical results confirmed that the flow around the hill is intrinsically unsteady, which is manifested very clearly as periodic oscillations in the drag coefficient C_d on the hill, and emphasize the following features, where *N* is the buoyancy frequency and *H* is the channel depth. For $1.1\leqslant K\leqslant 1.7$, columnar disturbances with mode n=1 are dominant so that the flow around the hill shows a persistent periodic unsteadiness. This flow unsteadiness is mainly due to the periodic shedding of upstream advancing columnar disturbances with mode n=1 with a clockwise circulation. For $1.8\leqslant K\leqslant 2$, as columnar disturbances with mode n=2 become dominant, the flow around the hill rapidly reaches an almost steady state. In addition, through the calculations with the blockage ratio H/h=6,10 and corresponding Re=20,100 and 2000, it is found that the normalized periods of C_d oscillations have a strong dependence on both the H/h and Re. As a next step, to investigate the flow around the hill under real atmospheric situations, we have performed calculations under imposition of a no-slip condition on the ground, particularly focusing on the effect of stable stratifications on the unsteady separated-reattached flow behind the hill. The flow around the hill exhibits different behavior over the whole range $0\leqslant K\leqslant 2$, corresponding to the difference in the boundary condition on the ground. For $0\leqslant K\leqslant 0.9$, the vortex shedding from the separation bubble behind the hill occurs. For K=1 and 1.1, the vortex shedding is strongly suppressed so that the flow around the hill rapidly reaches an almost steady state. Under strong stratification ($1<K\leqslant 2$), although lee waves are excited downstream of the hill, the vortex shedding clearly exists. For $1.2\leqslant K\leqslant 1.5$, the flow field with a vortex shedding shows an approximately steady state, corresponding to the stationary lee wave. It is much more likely that there is no significant change in the approaching flow just ahead of the hill, because the change in the columnar disturbances with mode n=1 is very small. Only when $1.6\leqslant K\leqslant 2$ does the flow around the hill become unsteady. However, the rate of the periodic change in the separation bubble is very small. These flow mechanisms for $1.6\leqslant K\leqslant 2$ are almost the same as those discussed in the prior numerical results.

Keywords: Direct numerical simulation; Finite-difference method; Stably stratified flows; Finite depth; Two-dimensional hill; Unsteady flow; Columnar disturbance; Separated-reattached flow

*Corresponding author. Fax: +81-92-583-7779

¤This is an English version translated from two Japanese papers published in Nagare (1998) 17(1) 45-56, and (1999) 18(5) 308-320.

[Full text] (PDF 836.6 Kb)