

Instability Characteristics of the Flow Through the Gibraltar Straits

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ABSTRACT

In this paper we investigate the hydrodynamic stability of the flow through the Gibraltar Straits using a simple model with rectilinear variation of the velocity, and piecewise constant variation of density. The equations of motion are linearized around this flow, and the absolute/convective character of the instability is determined. The parameters of the model are fitted using field measurements. It is shown that the presence of flow reversal is a necessary, but not sufficient, condition for the occurrence of absolute instability. For the flow through the Gibraltar Straits, stability analysis of field measurements shows that absolute instability develops in the flow over the Camarinal Sill, from 5 to 7 h after high water (when Atlantic water starts flowing eastward). The resulting internal waves are short, of the order of 350 m. Their periods vary throughout this time, from 10 min in the beginning to 48 min toward the end. The instability waves thus have an initially fast phase, and subsequently slow down, until they are eventually dissipated after the elimination of absolute instability conditions in the Straits. By computing the shapes of the eigenfunctions it is shown that the instability waves disturb mostly the upper layer of the ocean, and, to a lesser extent, the transition layer between the two counterflowing streams.

INTRODUCTION

Internal waves in the ocean are one of the major factors influencing the biological synthesis in the ocean and have attracted considerable attention in recent years (Garret and Munk, 1979). Internal waves can be generated from a multitude of causes (see Phillips, 1977, and Garret and Munk, 1979, for comprehensive reviews). One important source of internal waves is hydrodynamic instabilities, developing in strongly sheared flows with stratification. The idea can be traced back to the work of G.I. Taylor (1931), and later to the work of Holmboe (1962) and Hazel (1972). As these studies demonstrate, stratified shear flows in an unbounded fluid become unstable at a different wavenumber range than homogeneous flows same velocity shear. The band of unstable wavenumbers is centered around a value determined by the Richardson number of the flow. Thus, although stratification reduces the range of unstable wavenumbers, it has the important effect of shifting this range, by destabilizing waves that are stable in a homogeneous fluid. The above conclusions have been confirmed and further elaborated experimentally by Koop and Browand (1979).

The purpose of this paper is to study the instability of stratified shear flows through the Straits, where flow reversal occurs. The important difference with the aforementioned studies is that flow in the Straits is bounded by the bottom of the ocean from below and the free surface from above; both factors influence the instability process. The presence of the free surface complicates things, as it is a dynamic boundary and, depending on the value of the Froude number of the instability waves, can behave like a rigid wall, or like a completely compliant boundary. In the first case the free surface tends to suppress the shear flow instability, whereas in the second case it participates in the instability process (Triantafyllou and Dimas, 1989). A second important difference with the aforementioned studies is that we consider the instability in relation with the distinction between absolute and convective instabilities (see Bers, 1983, for a rigorous discussion of absolute and

convective instabilities). This has attracted a lot of interest recently in connection with the spontaneous appearance of unsteadiness in shear flows. In this paper, a relatively simple model of the stratified shear flow through the Straits is developed, which approximates the velocity profile with a polygonal form, and the density profile with a piecewise constant variation. The model can readily be fitted using data field measurements.

Application of the absolute/convective instability concepts has been motivated by recent work on self-excited oscillations in the wake of bluff objects: When a bluff object is immersed in a uniform stream, after the Reynolds number exceeds some critical value, the flow in the wake behind the object becomes unsteady, producing two series of vortices of opposite rotation (the Karman vortex street). The phenomenon is self-excited, in the sense that no external excitation is required to trigger the formation of the vortex street; any background noise is sufficient to accomplish this. It has recently been established (Triantafyllou et al., 1986, 1987; Karniadakis and Triantafyllou, 1989) that the vortex street is caused by an absolute instability of the flow in the wake (in a frame of reference fixed in the object), which amplifies the background noise into the vortex street. The frequency and wavelength of the vortex street, as well as the threshold Reynolds number for its appearance, can be determined using linear instability theory, whereas the amplitude of the flow oscillation is determined by nonlinear effects. Similarly, for the problem considered in the present paper, we can anticipate that, if at some point of the tidal cycle the flow becomes absolutely unstable in a frame of reference fixed in the boundaries of the Straits, self-excited internal waves will appear. The frequency and wavenumber of these waves will be determined by the instability of the flow, and their generation will last for as long as the instability remains absolute. The waves themselves will naturally last much longer, until they are dissipated by viscous and turbulent diffusion.

The best-known case where flow reversal is observed is, perhaps, that of the Gibraltar Straits. The flow through the Gibraltar Straits is characterized by a variety of complex hydrodynamic phenomena and plays the key role in all exchanges between the Mediterranean and the Atlantic. A great volume of literature exists documenting and interpreting the various hydrodynamic phenomena (Lacombe and Richez, 1982; Lacombe and Richez, 1984;

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