Gravity currents in a stratified ambient fluid

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1. Introduction

Despite their conceptual simplicity, gravity currents have proven a significant intellectual challenge. Much of our knowledge has been accumulated over the last fifty years from simple laboratory experiments. The majority of these experiments have been carried out in an ambient fluid that is initially homogeneous and quiescent. The dominant impact of the ambient fluid is the drag associated with accelerating it out of the way of the current, Benjamin (1968).

In the natural environment the atmosphere and oceans are seldom at rest, and often exhibit background stratifications that are dynamically important because they support internal gravity waves. In general, the ambient fluid has three key characteristics: mean flow (often sheared), turbulence and stratification. The impact of each of these characteristics has been studied separately. There have, however, been few attempts to combine them.

The principal aim of this work is to use an advancement of the experimental setup of Odell & Kovaszany (1971) and Koop (1981) (who developed a flume where a stratified flow could be driven by a set of horizontal intermeshed disks) to determine and quantify the interaction between a gravity current and a stratified ambient fluid that has either a uniform or sheared cross-flow velocity profile.

Specific objectives include establishing the role played by the stratification in reducing the propagation speed of the gravity current, quantifying the production of internal waves and how these affect the current both upstream and downstream of the front, and determining the amount of mixing between the current and ambient fluid. The aims have been achieved primarily through laboratory experiments, the study also includes an element of analytical and numerical modelling to provide descriptions and parameterisations at a variety of levels, and to aid the interpretation of the experimental measurements.

2. Experimental procedure

A series of experiments are undertaken where a constant flux release from a point or line source is used to create the gravity current in a flume that is capable of maintaining a uniform or sheared cross-flow with a stratified background density profile. In these experiments the gravity current and the internal wave field it generates in the ambient fluid are observed using synthetic schlieren, Dalziel, Hughes & Sutherland (2000). A dye attenuation technique, Cenedese & Dalziel (1998), is also used to examine mixing in the head of the gravity current.

3. Results

The figures discussed below are a sample of a wider range of results that will be discussed

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in the talk. Figure 1 (a)–(d) show processed width integrated experimental results where a gravity current is injected into the ambient fluid at the position indicated by the ‘↓’ in figure 1 (a), the stratified ambient fluid is travelling from left to right.

![Images](a) (b) (c) (d)

Figure 1. Synthetic schlieren results showing the $x$ and the $y$ gradients of the density field for (a)–(b) the transient stage as the internal waves establish themselves ($t \approx 10s$), (c)–(d) a time average over thirty seconds showing the steady state internal wave field for a uniform cross-flow.

### 3.1. Transient internal waves

Figures 1 (a) and (b) show a typical single time frame of the $x$ and $y$ gradients of the density field respectively. The results are acquired approximately ten seconds after a constant flux point source is initiated. In both figures the upper sections of the synthetic schlieren results are relatively noisy; this is due to large density gradients induced by mixing between the gravity current and the stratified ambient cross-flow. Further examination of these results shows a coherent internal wave field beneath the head of the gravity current. The wavelength of the internal waves is approximately $\lambda_T = 65$ mm with typical crest angles $\sigma_T = 45^\circ$ to the vertical. The transient wave field shows waves propagating upstream of the head of the gravity current.

### 3.2. The stationary internal wave field

The $x$ and $y$ gradients of the stationary internal wave field are displayed in figures 1 (c) and (d). Unlike the transient internal wave fields the filled contour plots of the gradients of the density field are time averages obtain by calculating the mean density gradient over 720 frames ($30s$). The results clearly display a stationary internal wave field generated only by
the interaction of the gravity current and the stratified cross-flow. The results differ from the transient internal wave field in several ways: firstly, although the internal waves closest to the gravity current have remained approximately the same wavelength $\lambda_T = \lambda_S$ they have changed their orientation and make an angle of approximately $\sigma_T = 35^\circ$ with respect to the vertical axis, secondly, the transient internal waves that exist upstream of the gravity current are not present in the stationary wave field. Time averaging removes the local distortions to the density field around the point source.

The internal wave field in figure 1 (c) and (d) appears to be similar in form to results, Chashechkin (1989), for stratified flow around a solid circular object. This suggests that the dynamics of the gravity current do not play a major role in the generation/destruction of the coherent structures in the internal wave field.

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References