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Wake Flows in Coastal Oceans: An Experimental Study of Topographic Effects

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Abstract

We consider the effects of coastal topography on the wake of an idealised headland model in a laboratory flume. Under a range of Reynolds numbers relevant to coastal oceans, we find that coherent eddies interact strongly with the headland shear layer and wake, affecting the width of the shear layer and the length of the wake. A preliminary investigation of turbulence statistics indicates that topography upstream of a headland can lead to a wider shear layer, a headland wake that extends further downstream, and enhanced horizontal diffusion out of the wake relative to the case with unperturbed oncoming flow.

Introduction

Flow around coastal topography usually involves strong wakes with vigorous recirculation after separation from the coastline. These wake flows and their associated eddies trap suspended particles, bring nutrients up from deeper waters and influence the deposition of sediments. Characterising them is important to waste disposal, the positioning of sewer outlets, the location of fisheries and recreational pursuits.

Field studies and numerical work indicate that disturbances upstream of islands or headlands can trigger instabilities in the wake. Only certain topographical features appear to produce large-scale eddies despite typically strong currents [1, 4, 7].

Figure 1 shows the flow pattern past Bass Point, a coastal headland 100 km south of Sydney (adapted from [4]). When a longshore current passes the headland, flow typically separates from the coastline. This separated flow has a very strong shear layer which injects strong vorticity into the lee of the headland. This can cause a large-scale eddy to form, as seen in figure 1. In some cases, a string of vortices may also be generated [6].

The most important dimensionless quantity for studying the transition to turbulence is the Reynolds number [2]:

$$Re = \frac{uL}{\nu}, \tag{1}$$

where u and L are characteristic velocity and length scales of the flow and ν is the kinematic viscosity of the fluid.

In oceanic flows it is more meaningful to evaluate the horizontal Reynolds number, Re_x, using the horizontal eddy diffusivity ν_x, a quantity characterising horizontal turbulent diffusion. The typical eddy diffusivity in coastal regions such as Bass Point is $\nu_x \sim 1\ \mathrm{m^2 s^{-1}}$, with length scale $L \sim 10^3$ m and flow speed $u \sim 1\ \mathrm{ms^{-1}}$, giving $Re_x \sim 1000$ [6]. The range of Reynolds numbers used in the laboratory experiments discussed here, based on the headland length scale, straddles this regime of interest.

In this paper we investigate the effects of incident disturbances on instability in the wake of a semi-cylindrical headland and seek an explanation in terms of the interaction between the mean flow and eddy field. We use ultrasonic Doppler velocimetry to characterise the flow in a laboratory flume, reporting on the velocity field, turbulence statistics and wake structure, comparing cases with and without an incident disturbance. Our measurements show that wake behaviour is modified, sometimes strongly, by incident disturbances.

Figure 1: This computer model of flow past Bass Point (35° S), a 4-km wide headland near Sydney, shows attached eddies and a vortex street in the headland wake (adapted from [4]).

Experimental Details

Apparatus

Experiments were conducted in a Perspex flume 3-m long, 0.4-m high and 0.75-m wide (figure 2). A semi-cylindrical vertical headland of radius $L = 49.27$ mm was fixed to the side wall of the flume, extending through the depth of the flow. A cylindrical 'island' of diameter $d = 12.6$ mm placed 114 mm upstream of the headland perturbs the oncoming flow.

The flume was filled with salt water to a depth $h = 56$ mm or 107 mm. The flow was seeded with neutrally buoyant Griltex copolyamide particles of 60 per cent 50-μm and 40 per cent 80-μm diameter to reflect ultrasound for velocimetry purposes. Pumps continuously recirculated fluid through the flume.

A number of flow-calming measures were employed. At the inlet end of the flume, fluid exited pump hoses through an array of small holes in lengths of horizontal PVC pipe. The pipes extended across the full flume width. The flow then passed over a weir before entering two polycarbonate honeycombs in series—each 750-mm wide, 127-mm high and 50.8-mm long with 3.2-mm circular cells—the second of which was wrapped with wire mesh. At the outlet end of the flume, the flow again passed over a weir and through honeycomb before entering the pumps through hoses and returning to the inlet end. In between was a 2.4-m working section in which the incident disturbance and headland model were positioned.