Internal hydraulic jumps: Interactions between entraining shear layers and altered conjugate states

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Despite their widespread occurrence and considerable interest in their role in vertical mixing, relatively little is known about the nature and structure of internal hydraulic jumps. While there have been many analytical and numerical studies of internal hydraulic jumps, experimental verification is lacking. Here we present the results of laboratory experiments that shed light on the nature of internal hydraulic jumps and provide data to test the predictions of analytical and numerical models.

Many internal hydraulic jumps occur in flows that are barotropically forced, either by tides, or by large-scale pressure gradients in the atmosphere. To model barotropically driven flows in the laboratory it is necessary to install a horizontal contraction at the downstream end of the test section. Wood (1968) has shown that this configuration yields an upstream velocity profile that is uniform with depth for layered flows, when a virtual control exists in the contraction. We investigate two-layer flows where the contraction imposes internally subcritical uniform flow upstream of the contraction. Inserting a smooth, two-dimensional sill into this flow generates an internally supercritical flow on the lee of the sill.

The flow now has two distinct features. The first, is the supercritical entraining and density altering flow; and the second, is the internal hydraulic jump which connects this altered supercritical flow to the uniform downstream conjugate state. The location of the jump is determined by the conjugate state, which is in turn governed by the width of the downstream contraction.

Upstream of the jump the lower layer is flowing faster than the upper layer and a train of Kelvin-Helmholtz billows form on the interface. Upper layer fluid is entrained into these billows, which are subsequently advected into the lower portion of the jump. These billows are broken down by the turbulence of the jump, and the entrained upper layer fluid is mixed with lower layer fluid. Downstream of the jump the upper layer remains homogeneous, the density step at the interface is weakened, the upper portion of the lower layer is linearly stratified, and the lower portion of the lower layer retains its original density. This altered density profile is the downstream conjugate state of the jump.

Since the position of the jump is determined by the width of the downstream contraction and the altered downstream density profile; when the contraction is narrowed the jump moves upstream and "drowns" part of the train of billows, reducing the amount of entrainment. Thus, while the jump is ultimately responsible for mixing fluid from the upper layer into the lower layer, it is the position of the jump relative to the upstream train of billows that determines the amount of entrainment, and therefore the amount of mixing. These two distinct features of the flow observed in our experiments are crucial to the understanding of internal hydraulic jumps.

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