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6. AUTHOR(S)
Karl R. Helfrich

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Woods Hole Oceanographic Institution
Mail Stop #21
Woods Hole, Massachusetts 02543

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9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of Naval Research
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This grant has supported study in the general area of time-dependent rotating hydraulics and nonlinear waves. Two recent projects have been completed. The first is a study of the fully nonlinear dam break problem in a rotating channel. One focus of this work has been to study of the characteristics and dynamics of the shocks and bores. The second project is an extension of Long's classic problem of upstream influence and establishment of hydraulically control to flow in rotating channels.

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Time-Dependent Stratified Flow Over Topography: Waves and Rotating Hydraulics

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Karl Helfrich
Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543

This grant has supported study in the general area of time-dependent rotating hydraulics and nonlinear waves. Two recent projects have been completed. The first is a study of the fully nonlinear dam break problem in a rotating channel. One focus of this work has been to study of the characteristics and dynamics of the shocks and bores. The second project is an extension of Long's classic problem of upstream influence and establishment of hydraulically control to flow in rotating channels.

Nonlinear Rossby adjustment in a channel:

The Rossby adjustment problem for a homogeneous fluid in a channel is solved for large values of the initial depth discontinuity. We begin by analyzing the classical dam break problem in which the depth on one side of the discontinuity is zero. An approximate solution for this case can be constructed by assuming semigeostrophic dynamics and using the method of characteristics. This theory is supplemented by numerical solutions to the full shallow water equations. The development of the flow and the final, equilibrium volume transport are governed by the ratio of the Rossby radius of deformation to the channel width, the only nondimensional parameter. After the dam is destroyed the rotating fluid spills down the dry section of the channel forming a rarefying intrusion which, for northern hemisphere rotation, is banked against the right-hand wall (facing downstream). As the channel width is increased the speed of the leading edge (along the right-hand wall) exceeds the intrusion speed for the nonrotating case, reaching the limiting value of 3.80 times the linear Kelvin wave speed in the upstream basin. On the left side of the channel fluid separates from the sidewall at a point whose speed decreases to zero as the channel width approaches infinity. Numerical computations of the evolving flow show good agreement with the semigeostrophic theory for widths less than about a deformation radius. For larger widths cross channel accelerations, absent in the semigeostrophic approximation, reduce the agreement. The final equilibrium transport down the channel is determined from the semigeostrophic theory and found to depart from the nonrotating result for channels widths greater than about one deformation radius. Rotation limits the transport to a constant maximum value for channel widths greater than about four deformation radii.

The case in which the initial fluid depth downstream of the dam is nonzero is then examined numerically. The leading rarefying intrusion is now replaced by a Kelvin shock, or bore, whose speed is substantially less than the zero depth intrusion speed. The shock is either straight across the channel or attached only to the right-hand wall depending on the channel width and the additional parameter, the initial depth difference. The shock speeds and amplitudes on the right-hand wall, for fixed downstream depth, increase above the nonrotating values with increasing channel width. However, rotation reduces the speed of a shock of given amplitude below the nonrotating case. We also find evidence of resonant generation of Poincare waves by the bore. Shock characteristics are compared to theories of rotating shocks and qualitative agreement is found except for the change in potential vorticity across the shock, which is very sensitive to the model dissipation. Behind the leading shock the flow evolves in much the same way as described by linear theory except for the generation of strongly nonlinear transverse oscillations and rapid advection down the right-hand channel wall of fluid originally upstream of the dam. Final steady state transports decrease from the zero upstream depth case as the initial depth difference is decreased.

Long's problem in a rotating channel:

To gain insight into the hydraulics of rotating channel flow, Long's problem, in which an topographic feature is introduced into a uniformly flowing stream, is extended to single layer flow in a rotating channel. Using the semigeostrophic approximation and the assumption of uniform potential vorticity a theory is derived which gives the critical obstacle height above which upstream influence and hydraulic control at the topographic crest is achieved. This height is a function of an appropriately defined initial flow Froude number, the channel width relative to the appropriate deformation radius and a parameter specifying how the initial volume flux is partitioned between side-wall boundary layers (which in all cases discussed is fixed for no flux in the right-hand (facing downstream) boundary layer). The temporal development of the flow is investigated through numerical solutions of the two-dimensional single-layer shallow water equations. These solutions reveal numerous interesting features such as upstream propagating shocks and separated rarefying intrusions, downstream hydraulic jumps (in both flow depth and width), flow separation and recirculation regions. The semigeostrophic prediction of the critical obstacle height is accurate for relatively narrow channels, but the departure between the theory and the numerical results increases as the channel width increases. Significantly, we find that contact with the left-hand wall is crucial to most of the interesting and important features. For example, no cases are found of hydraulic control of flows which are separated at the sill, despite the fact that such states have been predicted in previous steady semigeostrophic theories.

Publications:

Helfrich, K. R., A. C. Kuo and L. J. Pratt. Nonlinear Rossby adjustment in a channel. J. Fluid Mech., in press.

Pratt, L. J., K. R. Helfrich and E. Chassignet. Long's problem in a rotating channel. J. Fluid Mech., submitted.