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Inertial oscillations in a confined vortex subjected to background rotation

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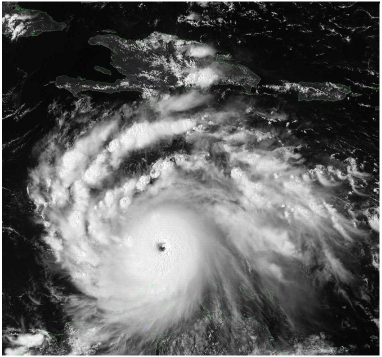
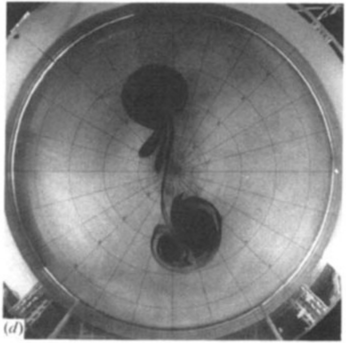
Waves and instabilities in geophysical and astrophysical flows
25-31 May 2009, Porquerolles, France

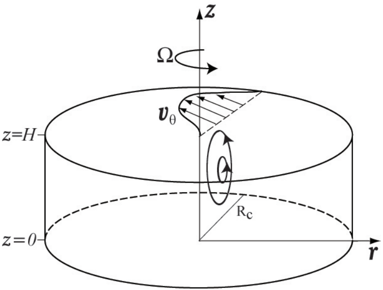
Motivation





Kloosterziel and van Heijst (1991)

The problem



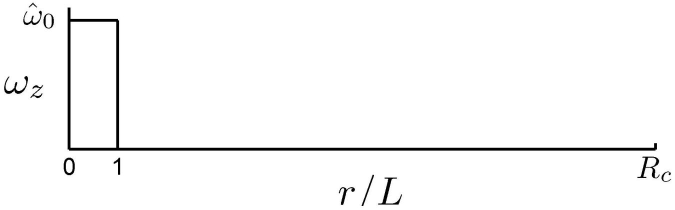
Stress-free boundaries

$$\mathrm{Ro} = \frac{\hat{\omega}_0}{2\Omega}, \quad \mathrm{Re} = \frac{\hat{\omega}_0 L^2}{\nu}, \quad \delta = H/L, \qquad \mathrm{R_c} = R_c/L$$

Characterize the axisymmetric inertial waves sustained by a confined monopolar vortex subjected to background rotation

The primary motion

A "frozen" Rankine vortex



with a small perturbation

Method

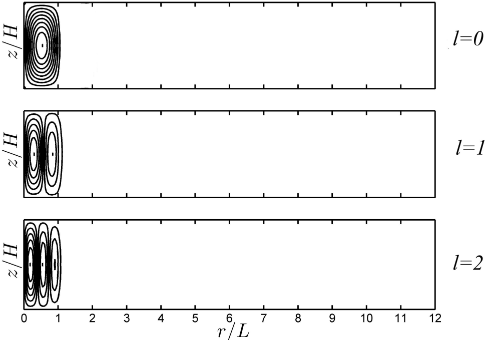
- Inviscid Navier–Stokes equations
- Linearize around the basic primary motion

↓

- Eigenvalue problem for the secondary flow which has been solved analytically
- Harmonic time dependence $\sim e^{i\xi t}$
- Two wave numbers: k (vertical) and l (horizontal)

No rotation (Kelvin 1880)

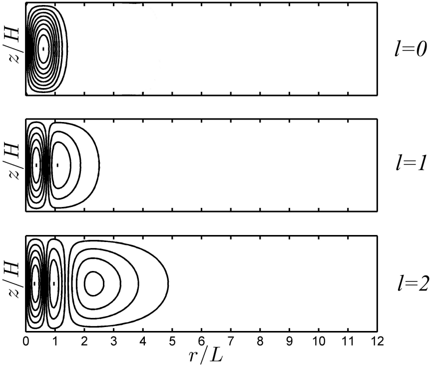
Ro=∞, $Re = \infty$,$\delta = 0.25$, $k = 0$



The secondary motion

Regime I: $\hat{\omega}_0 + 2\Omega > \xi \geq 2\Omega$

Ro=0.1, Re=∞,$\delta = 0.25$, $k = 0$

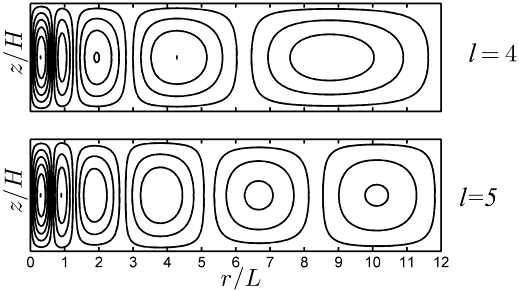


Confined only if $\xi > \frac{(k+1)\pi}{\delta}\sqrt{2\Omega\hat{\omega}_0}$

The secondary motion

Regime II: $2\Omega > \xi > 0$

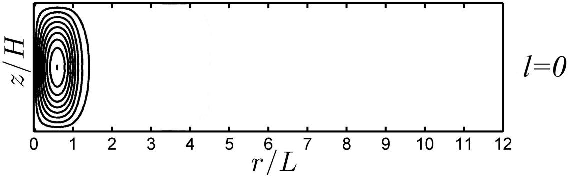
Ro=0.1, Re=∞,$\delta = 0.25$, $k = 1$



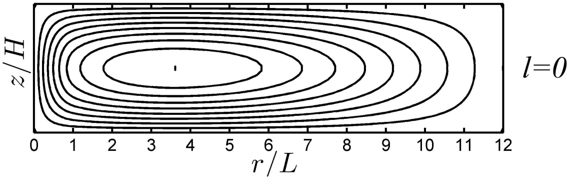
The second regime only exists if the vortex is confined.
(Not for $\psi \rightarrow 0$ for $r \rightarrow \infty$)

The dependence on the aspect ratio δ

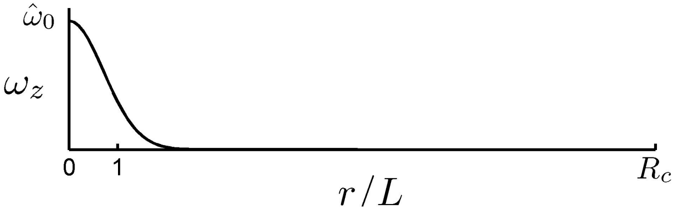
- Regime I: Ro=0.1, $\mathrm{Re} = \infty$, $\delta = 0.25$, $k = 0$



- Regime II: Ro=0.1, $\mathrm{Re} = \infty$, $\delta = 1$, $k = 0$



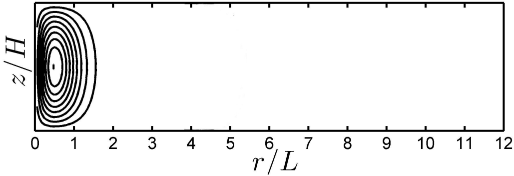
The Lamb-Oseen vortex



The secondary motion

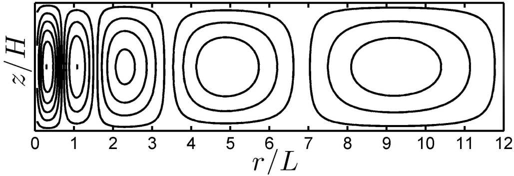
Ro=0.1, Re=∞, $\delta = 0.25$, $k = 0$

- Regime I:



l=0

- Regime II:



l=4

The effect of viscosity

Ro=0.1, Re=250, $\delta = 0.25$, $k = 0$, $l = 0$

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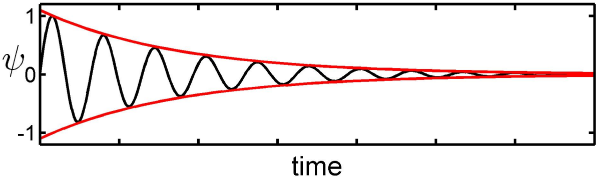

$$\sim \exp\left(-\frac{\nu\pi^2(k+1)^2}{H^2}t\right)$$

The effects of a no-slip bottom

Ro=0.1, Re=2500, $\delta = 0.5$

.

The oscillations are superimposed to a secondary motion as long as the boundary layer is small.

Summary

- Due to confinement and rotation there are two regimes:
  - $\hat{\omega}_0 + 2\Omega > \xi \geq 2\Omega$
  - $2\Omega > \xi > 0$
- Viscosity damps the amplitude and decreases the frequency of the oscillations.
- The results for the Rankine vortex and the Lamb vortex are similar.
- Inertial oscillations exist when a no-slip bottom is present as long as the boundary layer is small compared to H.