Spin-down in a rapidly rotating cylinder container with mixed rigid and stress free boundary conditions

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Summary

Greenspan and Howard (J. Fluid Mech., 1963) studied the linear spin-down of a rapidly rotating viscous fluid at small Ekman number E inside a container with rigid boundaries, following an instantaneous small change in container angular velocity. Outside the Ekman layers, thickness $O(E^{1/2})$, the mainstream is in almost rigid rotation (geostrophic) but spins down rapidly due to Ekman suction. Additionally, there are thickening quasi-geostrophic and very weak ageostrophic $E^{1/3}$ shear layers adjacent to the cylindrical side-wall. Motivated by applications to isolated atmospheric structures (e.g., tropical cyclones, tornadoes) without side and top boundaries, we study numerically and asymptotically a variant with stress-free side-wall and top boundaries, which leads to unexpected consequences. The mainstream no longer rotates rigidly, while the ageostrophic $E^{1/3}$ shear layer, far from being passive, determines a spin-down rate dependent on $\ln E$. It is linked to an $E^{1/2} \times E^{1/2}$ corner region, where the rigid base and the stress-free side-wall meet; a singularity that limits asymptotic progress.