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This Week's Citation Classic

Greenspan H P & Howard L N. On a time-dependent motion of a rotating fluid.
J. Fluid Mech. **17**:385-404, 1963.
[Mathematics Dept., Massachusetts Institute of Technology, Cambridge, MA]

We consider the manner in which a state of rigid rotation of a contained viscous fluid is established. It is found that the motion consists of three distinct phases, namely, the development of the Ekman layer, inviscid spin-up of the fluid, and the decay of residual oscillations. [The *SCI®* indicates that this paper has been cited over 135 times since 1963.]

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"This paper originated in an industrial problem concerning unwanted oscillations within a liquid gyroscope. It soon became apparent, however, that an adequate quantitative description could not be given even for the seemingly elementary rotating fluid motion in which a stirred cup of tea settles to rest. Lunchtime experimentation provided some insight into the dynamics involved; the obvious gathering of tea leaves at the bottom center of the cup was certain evidence of a secondary circulation of some importance (a fact already noted by others), but rough estimates of the appropriate time scales were off by an order of magnitude. An idealized problem was then formulated which retained the essential physics but replaced the real geometry by a far simpler configuration of parallel infinite planes in order to facilitate theoretical analysis. The question was also rephrased to advantage: 'How is a slight change in the rotation rate of the container communicated to the enclosed fluid?' It was this restricted, but very complex problem for which we gave the complete solution (that is still exceptional in this regard). The understanding attained about all phases of the 'spin-up' process allowed for a simple, accurate, physical interpretation of events, which in turn became the basis of approximations for dealing quite generally with rotating fluid motions.

"This paper complemented concurrent theoretical advances in oceanography and meteorology. The effect of viscosity on swirling flows is basically the same whether the object of study is the dissipation of a hurricane over land, or the coming to rest of stirred tea. Rotating fluid motions —those in technology or of the earth's atmosphere, oceans, and interior—were made a little more comprehensible by our work and this probably accounts for the many citations to it.[1]

"The study of rotating fluids continued to occupy my attention for several years. A special fascination for the subject was engendered by the ease with which important and extraordinary phenomena could be observed in the very simplest of experiments, many of which I did myself. The research culminated in my monograph, *The Theory of Rotating Fluids,*[2] recently reprinted in paperback.

"Although I have since migrated to other areas of fluid dynamics, I return sometimes to attack that core of hard intriguing problems on rotation that remain unsolved. I expect to continue to do so; I expect also that they will remain unsolved."

1. **Benton E R & Clark A, Jr.** Spin-up. *Annu. Rev. Fluid Mech.* **6**:257-80, 1974.
2. **Greenspan H P.** *The theory of rotating fluids.* London: Cambridge University Press, 1968. 327 p.