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Force Balance in Rapidly Rotating Dynamos

David W. Hughes
School of Mathematics, University of Leeds, UK

One of the long-standing and fundamental problems in geophysical and planetary magnetohydrodynamics (MHD) is determining the nature of the force balance in dynamos in rapidly rotating bodies, such as the Earth. In particular, is it possible to reach a balance between buoyancy, Coriolis and Lorentz forces, thereby neglecting inertia and viscous forces? On theoretical grounds, it is believed that such a balance must exist in rapidly rotating bodies, but computing such dynamos has proved to be extremely difficult. Here we consider plane layer dynamos driven by rapidly rotating convection. We choose to neglect inertia from the outset, but retain the viscous terms.

The neglect of inertia is not only physically justifiable, but allows a useful decomposition of the momentum equation into its thermal and magnetic components. As such it is possible to provide a new approach to considering the force balance that ensues. We consider both weak field dynamos (in which the change from purely hydrodynamic convection is small) and strong field dynamos (in which the change from the hydrodynamic state is marked) and analyse which forces are important in each of these cases. The key result is that in our strong field dynamos, although viscosity can indeed be neglected in determining the thermal velocity component, crucially, for the magnetic velocity component, this is never the case.