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Stewartson-layer instability in a wide-gap spherical Couette experiment: Rossby number dependence. (English) Zbl 1430.76178

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Summary: Instabilities of a viscous fluid between two fast but differentially rotating concentric spheres, the so-called spherical Couette flow, with a fixed radius ratio of $\eta = r_i/r_o = 1/3$ are studied, where r_i is the inner and r_o the outer radius of the spherical shell. Of particular interest is the difference between cases where the Rossby number $Ro = (\Omega_i - \Omega_o)/\Omega_o > 0$ and cases with $Ro < 0$, where Ω_i and Ω_o are the inner- and outer-sphere angular velocities. The basic state in both situations is an axisymmetric shear flow with a Stewartson layer situated on the tangent cylinder. The tangent cylinder is given by a cylinder that touches the equator of the inner sphere with an axis parallel to the axis of rotation. The experimental results presented fully confirm earlier numerical results obtained by *R. Hollerbach* [ibid. 492, 289-302 (2003; Zbl 1063.76558)] showing that for $Ro > 0$ a progression to higher azimuthal wavenumbers m can be seen as the rotation rate Ω_0 increases, but $Ro < 0$ gives $m = 1$ over a large range of rotation rates. It is further found that in the former case the modes have spiral structures radiating away from Stewartson layer towards the outer shell whereas for $Ro < 0$ the modes are trapped in the vicinity of the Stewartson layer. Further, the mean flow excited by inertial mode self-interaction and its correlation with the mode's amplitudes are investigated. The scaling of the critical Ro with Ekman number $E = \nu/(\Omega_o\, d^2)$, where ν is the kinematic viscosity and d the gap width, is well within the bounds that have been established in a number of experimental studies using cylindrical geometries and numerical studies using spherical cavities. However, the present work is the first that experimentally examines Stewartson-layer instabilities as a function of the sign of Ro for the true spherical-shell geometry.

MSC:

76E07 Rotation in hydrodynamic stability
76U05 General theory of rotating fluids
76E20 Stability and instability of geophysical and astrophysical flows

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References:

[1] ,; „ Instabilities of a barotropic shear layer in a rotating fluid: asymmetries with respect to sgn(Ro), Meteorol. Z., 15, 417-422, (2006)

[2] ,; „ Inertial waves identified in the Earth's fluid outer core, Nature, 325, 6103, 421-423, (1987)

[3] ,; ,; ,; „ Triadic resonances in the wide gap spherical Couette system, J. Fluid Mech., 843, 211-243, (2018)

[4] „ Shear flow instabilities in rotating systems, J. Fluid Mech., 33, 3, 577-589, (1968) · Zbl 0182.29102

[5] „ Steady fluid flow in a precessing spheroidal shell, J. Fluid Mech., 33, 4, 739-751, (1968) · Zbl 0177.55604

[6] ,; „ The existence of Taylor vortices and wide-gap instabilities in spherical Couette flow, Acta Mechanica, 111, 3-4, 125-140, (1995)

[7] ,; „ Data Analysis Methods in Physical Oceanography, (2001), Elsevier

[8] ,; „ Experiments on a barotropic rotating shear layer. Part 1. Instability and steady vortices, J. Fluid Mech., 383, 143-173, (1999) · Zbl 0941.76531

[9] „ The Theory of Rotating Fluids, (1968), Cambridge University Press · Zbl 0182.28103

[10] ,; „ Detached shear layers in a rotating fluid, J. Fluid Mech., 29, 1, 39, (1967)

[11] ,; ,; „ Experimental survey of linear and nonlinear inertial waves and wave instabilities in a spherical shell, J. Fluid Mech., 789, 589-616, (2016)

[12] ,; ,; „ Study of turbulence and interacting inertial modes in a differentially rotating spherical shell experiment, Phys. Rev. Fluids, 1, 4, (2016)

[13] „ Instabilities of the Stewartson layer. Part 1. The dependence on the sign of \textit{Ro}, J. Fluid Mech., 492, 289-302, (2003) · Zbl 1063.76558

[14] ,; ,; ,; „ Instabilities of the Stewartson layer. Part 2. Supercritical mode transitions, Theor. Comput. Fluid Dyn., 18, 197-204, (2004) · Zbl 1179.76034

[15] ,; ,; ,; „ Selection of inertial modes in spherical Couette flow, Phys. Rev. E, 81, (2010)

[16] ,; ,; ,; ,; „ Inertial waves driven by differential rotation in a planetary geometry, Geophys. Astrophys. Fluid Dyn., 101, 469-487, (2007)

[17] „ On the internal shear layers spawned by the critical regions in oscillatory Ekman boundary layers, J. Fluid Mech., 298, 311-325, (1995) · Zbl 0920.76090

[18] ,; ,; ,; „ Inertial waves in a spherical shell induced by librations of the inner sphere: experimental and numerical results, Fluid Dyn. Res., 45, (2013) · Zbl 1309.76008

[19] „ Flows driven by libration, precession, and tides in planetary cores, Phys. Rev. Fluids, 1, 6, (2016)

[20] ,; ,; „ Flows driven by libration, precession, and tides, Annu. Rev. Fluid Mech., 47, 1, 163-193, (2015)

[21] ,; ,; „ On the equatorial Ekman layer, J. Fluid Mech., 803, 395-435, (2016) · Zbl 1456.76040

[22] „ The almost-rigid rotation of viscous fluid between concentric spheres, J. Fluid Mech., 1, 5, 505-516, (1956) · Zbl 0072.20104

[23] „ Inertial modes in the liquid core of the Earth, Phys. Earth Planet. Inter., 91, 1-3, 41-46, (1995)

[24] ,; ,; ,; „ Excitation of inertial modes in an experimental spherical Couette flow, Phys. Rev. E, 86, 2, (2012)

[25] ,; „ Quasigeostrophic model of the instabilities of the Stewartson layer in flat and depth-varying containers, Phys. Fluids, 17, 10, (2005) · Zbl 1188.76138

[26] ,; „ Rossby-wave turbulence in a rapidly rotating sphere, Nonlinear Process. Geophys., 12, 6, 947-953, (2005)

[27] , 2007Planets and Moons, 1st edn. (ed. Schubert, G.), . Elsevier.

[28] „ On almost rigid rotations. Part 2, J. Fluid Mech., 26, 1, 131-144, (1966) · Zbl 0139.44102

[29] , 2004 An introduction to MatPIV v. 1.6.1. Preprint Series, Mechanics and Applied Mathematics, University of Oslo.

[30] , \& , 2004Quantitive imaging techniques and their application to wavy flows. In Advances in Coastal and Ocean Engineering, PIV and Water Waves (ed. Grue, J. \& Liu, P.L.-F.), pp. 1-49. World Scientific.

[31] , 2011 Inertial waves in a laboratory model of the Earth's core. PhD Thesis, University of Maryland, Maryland.

[32] ,; „ Instabilities of Shercliffe and Stewartson layers in spherical Couette flow, Phys. Rev. E, 78, (2008)

[33] „ Flow instabilities in the wide-gap spherical Couette system, J. Fluid Mech., 738, 184-221, (2014)

[34] ,; ,; ,; „ On inertial waves in a rotating fluid sphere, J. Fluid Mech., 437, 103-119, (2001) · Zbl 0981.76104

[35] ,; „ Theory and Modeling of Rotating Fluids, (2017), Cambridge University Press