Wall, D. P.; **Nagata, M.**

Exact coherent states in channel flow. (English) Zbl 1381.76093

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Summary: Three spatially extended travelling wave exact coherent states, together with one spanwise-localised state, are presented for channel flow. Two of the extended flows are derived by homotopy from solutions to the problem of channel flow subject to a spanwise rotation investigated by *D. P. Wall* and *M. Nagata* [J. Fluid Mech. 727, 533–581 (2013; Zbl 1291.76342)]. Both these flows are asymmetric with respect to the channel centreplane, and feature streaky structures in streamwise velocity flanked by staggered vortical structures. One of these flows features two streak/vortex systems per spanwise wavelength, while the other features one such system. The former substantially reduces the value of the lowest Reynolds number at which channel flow solutions ,other than the basic flow, are known to exist down to 665. The third flow has, in contrast, half-turn rotational symmetry about a streamwise axis through a point on the channel centreplane, and is found to be the flow from which one of the asymmetric flows bifurcates in a symmetry-breaking bifurcation. This flow is found to exist on an isolated bifurcation branch, whose upper and lower branches both lie on the boundary basin separating initial conditions that lead to turbulent events, and those that directly decay back to laminar flow. The structure of this flow, in which the disturbance to the basic flow is concentrated in a core region in a spanwise period, allowed the derivation of a corresponding spanwise-localised flow, which is also discussed.

MSC:

76F06 Transition to turbulence
76Exx Hydrodynamic stability
76F20 Dynamical systems approach to turbulence

Keywords:

instability; nonlinear dynamical systems; transition to turbulence

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References:

[1] Abe, M.2009 Nonlinear solutions in plane MHD Poiseuille flow. Masters thesis, Kyoto University, Kyoto, Japan.

[2] Avila, M.; Mellibovsky, F.; Roland, N.; Hof, B., Streamwise-localized solutions at the onset of turbulence in pipe flow, Phys. Rev. Lett., 110, (2013)

[3] Byrd, R. H.; Lu, P.; Nocedal, J.; Zhu, C., A limited memory algorithm for bound constrained optimization, SIAM J. Sci. Comput., 16, 1190-1208, (1995) · Zbl 0836.65080

[4] Davies, S. J.; White, C. M., An experimental study of the flow of water pipes of rectangular section, Proc. R. Soc. Lond. A, 119, 92-107, (1928) · Zbl 54.0924.01

[5] Deguchi, K.; Nagata, M., Travelling hairpin shaped fluid vortices in plane Couette flow, Phys. Rev. E, 82, (2010)

[6] Drazin, P. G.; Reid, W. H., Hydrodynamic Stability, (1981), Cambridge University Press

[7] Ehrenstein, U.; Koch, W., Three-dimensional wavelike equilibrium states in plane Poiseuille flow, J. Fluid Mech., 228, 111-148, (1991) · Zbl 0724.76036

[8] Faisst, H.; Eckhardt, B., Traveling waves in pipe flow, Phys. Rev. Lett., 91, (2003)

[9] Gibson, J. F.2013 Channelflow: a spectral Navier-Stokes simulator in $\text{C}++$. \textit{Tech. Rep.} University of New Hampshire.

[10] Gibson, J. F.; Brand, E., Spanwise-localized solutions of planar shear flows, J. Fluid Mech., 745, 25-61, (2014)

[11] Gibson, J. F.; Halcrow, J.; Cvitanovic, P., Equilibrium and travelling-wave solutions of plane Couette flow, J. Fluid Mech., 638, 243-266, (2009) · Zbl 1183.76688

[12] Hamilton, J. M.; Kim, J.; Waleffe, F., Regeneration mechanisms of near-wall turbulence structures, J. Fluid Mech., 287, 317-348, (1995) · Zbl 0867.76032

[13] Hof, B.; Van Doorne, C. W. H.; Westerweel, J.; Nieuwstadt, F. T. M.; Faisst, H.; Eckhardt, B.; Wedin, H.; Kerswell, R. R.; Waleffe, F., Experimental observation of nonlinear traveling waves in turbulent pipe flow, Science, 305, 5690, 1594-1598, (2004)

[14] Itano, T.; Generalis, S. C., Hairpin vortex solution in planar Couette flow: a tapestry of knotted vortices, Phys. Rev. Lett., 102, (2009)

[15] Itano, T.; Toh, S., The dynamics of bursting process in wall turbulence, J. Phys. Soc. Japan., 70, 703-716, (2001)

[16] Jimenez, J.; Moin, P., The minimal flow unit in near-wall turbulence, J. Fluid Mech., 225, 213-240, (1991) · Zbl 0721.76040

[17] Kawahara, G.; Uhlmann, M.; Van Veen, L., The significance of simple invariant solutions in turbulent flows, Annu. Rev. Fluid Mech., 44, 203-225, (2012) · Zbl 1352.76031

[18] Kerswell, R. R., Recent Progress in understanding the transition to turbulence in a pipe, Nonlinearity, 18, R17-R44, (2005) · Zbl 1084.76033

[19] Kreilos, T.; Eckhardt, B., Periodic orbits near onset of chaos in plane Couette flow, Chaos, 22, (2012)

[20] Nagata, M., Three-dimensional finite amplitude solutions in plane Couette flow, J. Fluid Mech., 217, 519-527, (1990)

[21] Nagata, M.; Deguchi, K., Mirror-symmetric exact coherent states in plane Poiseuille flow, J. Fluid Mech., 735, 1-11, (2013) · Zbl 1291.76133

[22] Nishioka, M.; Asai, M., Some observations of the subcritical transition in plane Poiseuille flow, J. Fluid Mech., 150, 441-450, (1985)

[23] Nishioka, M.; Iida, S.; Ichikawa, Y., An experimental investigation of the stability of plane Poiseuille flow, J. Fluid Mech., 72, 731-751, (1975)

[24] Patel, V. C.; Head, M. R., Some observations on skin friction and velocity profiles in fully developed pipe and channel flows, J. Fluid Mech., 38, 181-201, (1969)

[25] Pedley, T. J., On the instability of viscous flow in a rapidly rotating pipe, J. Fluid Mech., 35, 97-115, (1969) · Zbl 0159.58802

[26] Pringle, C. C. T.; Kerswell, R. R., Asymmetric, helical, and mirror-symmetric traveling waves in pipe flow, Phys. Rev. Lett., 99, (2007)

[27] Schmid, P. J.; Henningson, D. S., Stability and Transition in Shear Flows, (2001), Springer · Zbl 0966.76003

[28] Schneider, T. M.; Gibson, J. F.; Burke, J., Snakes and ladders: localized solutions of plane Couette flow, Phys. Rev. Lett., 104, (2010)

[29] Sengupta, T. K., Instabilities of Flows and Transition to Turbulence, (2012), CRC Press · Zbl 1253.76002

[30] Toh, S.; Itano, T., A periodic-like solution in channel flow, J. Fluid Mech., 481, 67-76, (2003) · Zbl 1034.76014

[31] Viswanath, D., Recurrent motions within plane Couette turbulence, J. Fluid Mech., 580, 339-358, (2007) · Zbl 1175.76074

[32] Waleffe, F., Hydrodynamic stability and turbulence: beyond transients to a self-sustaining process, Stud. Appl. Math., 95, 319-343, (1995) · Zbl 0838.76026

[33] Waleffe, F., On a self-sustaining process in shear flows, Phys. Fluids, 9, 883-900, (1997)

[34] Waleffe, F., Homotopy of exact coherent structures in plane shear flows, Phys. Fluids, 15, 1517-1534, (2003) · Zbl 1186.76556

[35] Wall, D. P.; Nagata, M., Nonlinear secondary flow through a rotating channel, J. Fluid Mech., 564, 25-55, (2006) · Zbl 1177.76123

[36] Wall, D. P.; Nagata, M., Three-dimensional exact coherent states in rotating channel flow, J. Fluid Mech., 727, 533-581, (2013) · Zbl 1291.76342

[37] Wedin, H.; Kerswell, R. R., Exact coherent structures in pipe flow: travelling wave solutions, J. Fluid Mech., 508, 333-371, (2004) · Zbl 1065.76072

[38] Zammert, S.; Eckhardt, B., Periodically bursting edge states in plane Poiseuille flow, Fluid Dyn. Res., 46, 4, (2014)

[39] Zammert, S.; Eckhardt, B., Streamwise and doubly-localised periodic orbits in plane Poiseuille flow, J. Fluid Mech., 761, 348-359, (2014)