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Three-dimensional extensions to Jeffery-Hamel flow

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Abstract

We consider two viscous flows, both of which are in a class of three-dimensional flow states that are closely related to the classical Jeffery-Hamel solutions. In the first configuration, we consider a flow between two planes, intersecting at an angle α, and driven by a line-source-like solution in the neighbourhood of the apex of intersection (just as in classical, two-dimensional, Jeffery-Hamel flow). However, in addition we allow for a flow in the direction of the line of intersection of the planes (in order to capture the broader class of three-dimensional solutions). In this flow, two solution scenarios are possible; the first of these originates as a bifurcation from Jeffery-Hamel flow, whilst the second scenario describes a radial velocity of the classical Jeffery-Hamel form (also with a zero azimuthal velocity component), but with an axial velocity determined from the radial flow. Both of these solutions are exact within the Navier-Stokes framework. In the second configuration, we consider the high Reynolds number, three-dimensional flow in a diverging channel, with (generally) non-straight walls close to a plane of symmetry, and driven by a pressure gradient. Similarity solutions are found, and a connection with Jeffery-Hamel flows is established for the particular case of a flow through straight (but non-parallel) channel walls, and again, additional three-dimensional solutions are found. One member of this general class (corresponding to the flow through a straight-walled channel, driven by linearly increasing pressure in both the axial and cross-channel directions), leads to a further family of exact Navier-Stokes solutions.

Keywords: Jeffery-Hamel; Exact Navier-Stokes solutions; Three-dimensional boundary layers

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