INCOMPRESSIBLE AND COMPRESSIBLE SWIRLING FLOWS IN DIVERGING/CONTRACTING LONG PIPES

by

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ABSTRACT

The equilibrium states of inviscid, axisymmetric swirling flows in finite-length straight, diverging and contracting pipes and at incompressible and subsonic compressible speeds is studied. A mathematical model is formulated to describe the swirling flow steady state behavior. With the assumption of a fully developed flow at the pipe outlet, that is applicable for sufficiently long pipes, the flow equations are reduced to a nonlinear ordinary differential equation for the solution of the flow stream function in both incompressible and compressible flows with centerline and wall conditions. The problem gives rise to the existence of 5 types of solutions including the base flow states, decelerated flow states, accelerated flow states, vortex breakdown states, and wall separation states. A numerical strategy for the search of the solutions is developed. The computational results provide the bifurcation diagrams of solutions in terms of various inflow profiles such as solid-body rotation and the Burgers vortex, incoming flow swirl ratio, pipe divergence or contraction, and flow inlet Mach number. Critical swirls for the bifurcation of the various types of solutions are identified and branches of solutions are established. Together with existing stability studies, results shed light on the complex dynamics of swirling flows in pipes and the transition to vortex breakdown states. It is also found that pipe divergence promotes vortex breakdown to lower levels of swirl while pipe contraction delays the appearance of vortex breakdown to higher levels of swirl. Compressibility delays the onset of breakdown to higher levels of swirl. Yet, geometry effects are determined to be more dominating than compressibility effects, when compared one with the other. Results can be applied towards the improved design of vortex flows over slender wings at high angles of attack, apparatuses where swirling flows or vortices dominate, and combustion systems assisted by swirl and vortex breakdown.