Flow Simulations of The Dynamics of a Perturbed Solid-Body Rotation Flow

SHIXIAO WANG, Auckland University, CHUNJUAN FENG, Northwestern Polytechnical University, FENG LIU, University of California, Irvine, ZVI RUSAK, Rensselaer Polytechnic Institute — DNS is conducted to study the 3-D flow dynamics of a base solid-body rotation flow with a uniform axial velocity in a finite-length pipe. The simulation results describe the neutral stability line in response to either axisymmetric or 3-dimensional perturbations in a diagram of Reynolds number ($Re$, based on inlet axial velocity and pipe radius) versus the incoming flow swirl ratio ($\omega$). This line is in good agreement with the neutral stability line recently predicted by the linear stability theory of Wang et al. (2016). The Wang & Rusak (1996) axisymmetric instability mechanism and evolution to an axisymmetric breakdown state is recovered in the simulations at certain operational conditions in terms of $Re$ and $\omega$. However, at other operational conditions there exists a dominant, 3-dimensional spiral type of instability mode that agrees with the linear stability theory of Wang et al. (2016). The growth of this mode leads to a spiral type of flow roll-up that subsequently nonlinearly saturates on a rotating spiral type of vortex breakdown. The computed time history of the velocity components at a certain point in the flow is used to describe 3-dimensional phase portraits of the flow global dynamics and its long-term behavior.