CRITICAL POINTS AND BACK FLOW EVENTS IN THE SKIN FRICTION FIELD OF TOROIDAL PIPE FLOWS

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In incompressible wall bounded flow, the skin friction field and surface vorticity field are associated with turbulence transport mechanism. At the wall, the topology of critical points in the skin friction field (and surface vorticity field) is determined by the no-slip tensor (see [2]) and rare backflow streamwise velocity events have previously been reported in canonical wall-bounded turbulent flows [1, 2, 3]. These studies were performed using direct numerical simulations (DNS) of turbulent channel and boundary layer flows with imposed (artificial) periodic boundary conditions in the streamwise and spanwise directions, allowing the topology of the skin friction field and surface vorticity field to be studied by mapping the no-slip wall into a toroidal surface. In this paper, the topology of the skin friction and surface vorticity field is extended to the DNS of a real toroidal pipe when the flow is naturally periodic and the skin friction field varies with azimuthal distance from the innermost radius as highlighted by the axial velocity field shown in figure 1(a). The toroidal pipe data that will be analysed is taken from Noorani and Schlatter [4]. The toroidal pipe has mean friction Reynolds number, $Re_\tau \approx 470$ and the non-dimensional curvatures $\kappa = 0.1$ & 0.3, where $\kappa = R_a/R_c$, R_a is defined the radius of the cross section of the pipe and R_c is the radius of curvature at the pipe centreline.

(a)

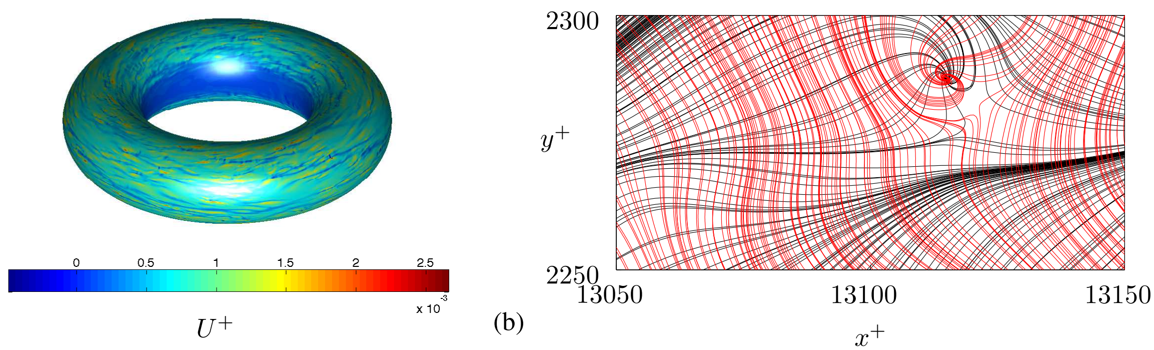

Figure 1. For $\kappa = 0.3$, (a) Instantaneous axial velocity at wall-normal location $y^+ = 0.01$ indicative of the local shear stress.. Blue contour indicates low velocity and red is high velocity. (b) A pair of critical points in the skin friction field showing a node and saddle. Red lines are surface vorticity lines and black lines are skin friction lines. Axial and azimuthal directions are given as x^+ & y^+.

At the innermost position of the torus, the flow field exhibits signs of relaminarisation. This shows that the toroidal pipe probably has transitional to fully developed turbulence occuring as the azimuthal position varies from the innermost to outermost radius of the torus. Here we will investigate, as a function of the position, the existence of critical points as shown in figure 1(b) and rare backflow events in the toroidal pipe and particularly characterise these critical points and the conditional averaged flow field where these critical points occur. A probability density function (PDF) of the density of critical points and backflow events as a function of azimuthal distance will be discussed. The identification of backflow events is relatively straightforward by locating negative axial velocities. The identification of the critical points will be performed using the methodology outlined in [1, 2]. As secondary motion exists in bent pipes, further investigation will be focused on the dynamics and the effects of the secondary motion on critical points.

References

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