EXPERIMENTAL INVESTIGATION OF THE INFLUENCE OF CURVATURE ON TRANSITION TO TURBULENCE IN A PIPE

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Abstract Transition to turbulence in curved pipes is different from transition in straight pipes, as the onset of turbulence is delayed to higher Reynolds numbers. Moreover, the transition scenario is considerably modified by curvature: a sequence of bifurcations instead of a sudden, direct transition to turbulence is found.
We investigate the transition to turbulence in curved pipe flow experimentally with particular attention to the detection of travelling waves and coherent structures. To that end a novel experiment was set up that realizes a constant flow rate in a toroidal pipe. The flow is driven by a sphere that is moved from outside the closed toroidal cavity using a magnet. Three ratios of tube to coiling diameter are investigated: 0.1, 0.049 and 0.025.
Laser Doppler Velocimetry and a high-speed stereoscopic Particle Image Velocimetry (S-PIV) system have been used to investigate and capture the appearance and development of the transitional flow. Using S-PIV we were able to reconstruct all three components of the velocity vectors in the measurement plane covering the entire cross-section of the tube.
For a Reynolds number below a first critical Reynolds number Re_{c1}, which depends on the curvature ratio, we find a steady laminar flow. Above Re_{c1} we find a supercritical instability of the steady basic flow to a flow which is periodically modulated in the streamwise (toroidal) direction. Investigations of the instantaneous flow field, power spectra and bifurcation diagrams at the first instability are presented.

EXPERIMENTAL SETUP AND METHODS

Figure 1 provides a sketch of the driving mechanism and the main parts of the experimental setup. Two highly transparent and polished plexiglas disks into each of which a concentric notch of half-circular cross section has been machined were flush mounted such that they form a toroidal cavity. The toroidal cavity is filled with the working fluid and a steel sphere. The sphere is actuated by a magnet which is mounted on a rotating arm. To achieve a constant, precisely adjustable flow rate in the torus the boom is rotated by an electric gear motor, thereby moving the sphere and, hence, the flow (motor not shown in fig. 1).
Based on the measured revolution times of the rotating boom and the temperature in the torus, the bulk velocity in axial direction U and the kinematic viscosity ν the Reynolds number $Re=Ud/\nu$ of the flow can be calculated. The setup provides the possibility to investigate the flow in the torus for adjustable Reynolds numbers ranging from 1000 to 15.000 with an accuracy of +/-2%. Three different curvature ratios of the tube (d) to the coiling diameter (D) were investigated: d/D= 0.1, 0.049 and 0.025.
For investigations with Laser Doppler Velocimetry (LDV), a 2D-LDV system (Dantec Dynamics, Argon-ion-laser Model 5500A, 750 mW, class IV) was used to measure velocity time-series of the streamwise velocity component at selected points.
A high-speed stereo PIV system has been used to measure the three components of the velocity vectors over a cross section perpendicular to the flow as a function of time. The data enable the analysis of the dynamics of the transitional flow. The PIV system consisted of a pulsed Quantronix Darwin Duo laser (diode pumped Nd:YLF laser, wavelength 527nm, 60mJ total energy) and two Phantom high-speed cameras with a full resolution of 2400x1900px.

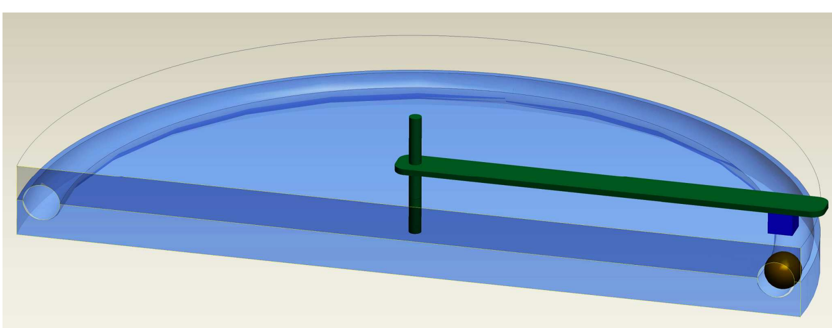

Figure 1. Sketch of the experimental setup used to realize a constant flow rate in a torus: two disks of perspex into each of which a concentric notch of half-circular cross sections has been machined, and a rotating boom driving a sphere by means of a magnet. The sphere hence drives the flow.

RESULTS

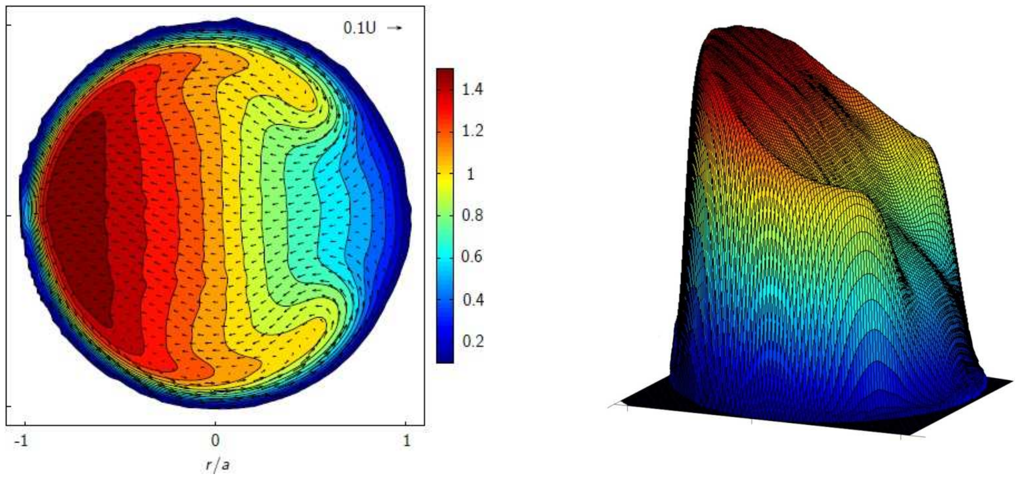

Figure 2. Steady and axisymmetric basic flow for Re=3600. Left: Mean streamwise velocity (color contours) and in-plane velocity (vector field), both normalized with the bulk velocity U. The maximum velocity arises near the out wall (on the left). Right: Three-dimensional view of the characteristic streamwise velocity profile.

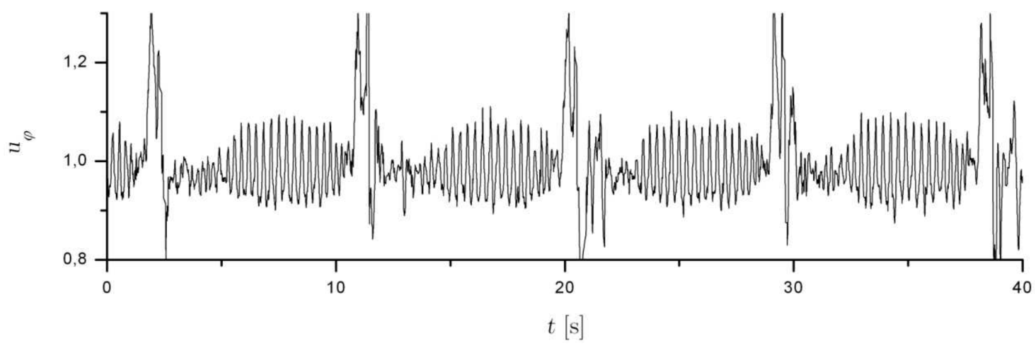

Figure 3. Typical time trace of the streamwise velocity for four full revolutions of the sphere in the periodic regime for Re>Re_{c1} measured by LDV. The streamwise velocity is periodically modulated between successive passings of the sphere in the vicinity of which the oscillations are interrupted.

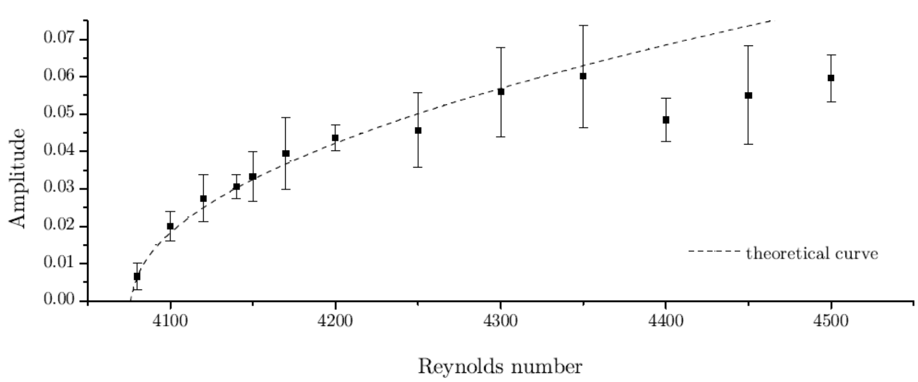

Figure 4. Amplitude of the dominant frequency as a function of Re for d/D = 0.049. The dashed line is a square root fit to the data. Error bars represent the maximum deviation of the measured values for single revolutions.