Turbulent pipe flow response to wall changes targeting specific azimuthal modes

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We present an experimental study on the response of turbulent pipe flow at $Re_\tau = 3486$ to changes in pipe shape conceived to manipulate LSM and VLSM structure, particularly targeting the energetic modes described in Hellström & Smits (2014). Stereo PIV measurements were taken 5 pipe diameters downstream of 3D printed pipe inserts designed to target specific azimuthal Fourier mode numbers $m = 3$ and 15. Direct manipulation of the flow momentum (vortex generators) and secondary flows induced by Reynolds stresses (sinusoidally varying wall shape) are considered. The impact of the pipe inserts are seen in figure 1, showing the change in the streamwise velocity with respect to a smooth pipe.

The vortex generators substantially changed the mean flow, producing three distinct regions of momentum deficit equally spaced azimuthally. This resulted in a sharp increase in the energy at Fourier mode $m = 3$ and secondary energy peaks at $m \in \{3, 6, 9, 12\}$, which decayed in both energy and size with increasing mode numbers.

The Reynolds stress inducers had a smaller impact on the mean flow, but still created structures that corresponded to the modes that were specifically targeted, $m = 3$ and 15. Each produced corresponding increases in energy at the targeted modes, while also often reducing energy in the surrounding modes. This reveals a mechanism for suppressing a range of turbulent structures by targeting one predefined mode number. A cross-section insert that simultaneously targeted $m = 3$ and 15 showed that there is a non-linear interaction between the two induced modes, where the resulting structures contain similar energy levels to the directly induced modes.

REFERENCES

Figure 1. Baseline subtracted locally time-averaged streamwise velocity for the three Reynolds stress inducers targeting Fourier modes (a) $m = 3$, (b) $m = 15$, (c) $m = 3$ superimposed with $m = 15$; and the cross-section with (d) vortex generators.