Turbulent flows in tubes: a possibility of flow stabilization by multilayer coatings

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Abstract:

The flow over the surfaces, inside the tubes of the technical and biomedical devices and inside large blood vessels often creates turbulent boundary layers, which can lead to significant loss in efficiency. For instance, the turbulent drag is responsible for a large part of the drag experienced by aircrafts, ships and underwater vehicles. Reducing turbulent sound production, which is the main noise source inside the vehicle, is of a great interest for manufactures. In water and wind tunnels the methods of delaying laminar to turbulence transition, skin-friction drag reduction in the turbulent flows, quelling vibrations, and suppressing the flow-induced noise are promising for different applications. Blood flow is aorta and large arteries is characterized by high Reynolds numbers Re=1000-5800, so the turbulence flow developed at the peak flow speeds can produce large oscillations of the wall shear rate, that was found a source of the wall damage, degeneration and plaque formation leading to stenosis and atherosclerosis [1]. Healthy blood vessel walls can remodel themselves according to the wall shear stress and hydrostatic pressure providing the flow stabilization at varied conditions. The layered coatings can be used for reduction of the skin-friction drag in turbulent wall-bounded flows. The compliant coatings are attractive due to their potential to inhibit/foster the dynamic instabilities that characterize both transitional and turbulent boundary layer flows, and in turn to modify the mass, heat and momentum fluxes and change the drag and the acoustic properties [2].

In this paper stability of the developed turbulent flow in the multilayer tube composed of anisotropic viscoelastic layers with different thickness, density, shear modules, Poisson ratios and viscosities is studied. The temporal and spatial amplification rates and Eigen modes for the no displacement (fastened wall) and no stress (free wall) boundary conditions at the outer surface of the tube are computed. It was shown at least two unstable modes exist for different Re numbers. Thus, the absolute instability, flow-limitation phenomena and self-excited oscillations may be observed at those conditions. It was shown in some cases the flow stabilization may be achieved by a proper choice of the material parameters of the layers depending on the boundary conditions and flow regimes. The results differ from the previously obtained for the Poiseuille flow that can be stabilized by increasing stability of the most unstable mode and thus cancelling the absolute instability [3]. In that way the turbulent flow may be stabilized by decreasing the instability of one or two of the absolutely unstable modes.

References

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