Deformation of a viscoelastic wall layer in turbulent flows

H. O. G. Benschop*, A. J. Greidanus*, R. Delfos*,
J. Westerweel* and W.-P. Breugem*

Flows over compliant wall coatings have been much studied since experiments of Kramer[1] in the early 1960s indicated the possibility of turbulent drag reduction[2]. Here we present a one-way coupling approach for the deformation of a *linear viscoelastic* wall layer in turbulent flows[3]. The turbulent surface stress fluctuations are represented by a sum of travelling waves of which the amplitudes are determined from the point spectra of the wall shear stress and wall pressure of the corresponding flow over a rigid (undeformable) wall. Given the surface stress spectra, the deformation of the viscoelastic layer is analytically computed from first principles as in Chase[4]. The layer is characterized by 5 parameters: the mass density, the layer thickness, the stiffness, the viscoelasticity and the compressibility.

First, we have performed an in-depth parameter study in which we systematically varied the viscoelastic layer properties for the case of fully-developed turbulent plane channel flow at a friction Reynolds number $Re_\tau = 720$. The required stress spectra were obtained from a Direct Numerical Simulation of Hu et al.[5]. For each frequency the turbulent convection velocity was determined from a semi-empirical model of Del Álamo and Jiménez[6]. We studied the effect of the viscoelastic layer parameters on the root-mean-square (rms) of the horizontal and vertical surface displacements as well as the corresponding point spectra. Also, we were able to derive analytical relations for the short- and long-wave limit, corresponding to, respectively, very thick and very thin coatings.

Second, we have compared our model with high-speed Background Oriented Schlieren (BOS) data from Delfos et al.[7] and Greidanus et al.[8] for turbulent boundary-layer flow over a plane viscoelastic layer. The surface normal stress (pressure) spectrum was obtained from the model proposed by Goody[9]. Our model captures the observed increase in the normalized rms of the vertical surface displacement (normalised with the viscous wall unit) with the friction Reynolds number, except for a constant scaling factor. Furthermore, the rms appears to scale linearly with the rms of the surface pressure divided by the magnitude of the shear modulus. Finally, our model captures the normalised point spectra of the measured vertical surface displacement fluctuations reasonably well.

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*Delft University of Technology, Laboratory for Aero and Hydrodynamics, Leeghwaterstraat 21, 2628 CA Delft, The Netherlands. E-mail: w.p.breugem@tudelft.nl

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