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CONTROL FOR FLAT PLATE SKIN-FRICTION DRAG WITH COMPLIANT COATINGS (PREDICTIONS AND EXPERIMENT)

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Experimental verification of drag reduction capabilities of compliant viscoelastic coatings is a long-standing actual problem. In the presentation, based on detail determination of the properties of coatings under test, the flow velocity range is predicted, where an optimal interaction of the coatings with water flow is expected. The prediction is performed using a semi-empirical model, which exhibit quite promising results in preliminary tests. Some results on turbulent boundary layer in a water tunnel and comparison of the experimentally estimated skin friction modifications with the predictions are given.

The experiments were conducted in a water tunnel of Pusan National University. Test section of the facility is 2 m long and consists of three identical sections with area 600×200 mm^2. The central part of the bottom of the downstream section has a rectangular orifice of 100×50 mm^2 area for inserts. The upper surface of the insert can be either flat and polished or made in the form of a mould for compliant coating. The gap between the internal wall of the orifice and the sidewall of the rectangular inset as well as the relative level of their test surfaces were carefully controlled with accurately better than 5 μm. The rectangular insert is equipped with a strain-gauge system for measuring the skin friction. Silicone rubbers polymerized with the help of a catalyst at room temperature and pressure were used to produce the coatings (Table 1).

Table 1: List of coatings

Material	Production firm	Thickness, mm
RTV3133	Xiameter	2, 4, 6, 8, 10, 12
S2	Dow Corning	7

The viscoelastic properties of these materials were carefully measured by the method described in detail in [1, 2]. Then, the dynamic compliance was computed. The computation is based on results of [3, 4], where the normal and longitudinal components of deformation of the surface coating affected by a pressure wave were considered.

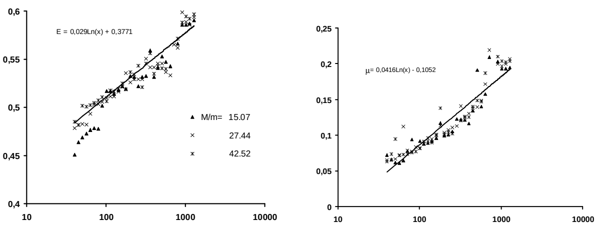
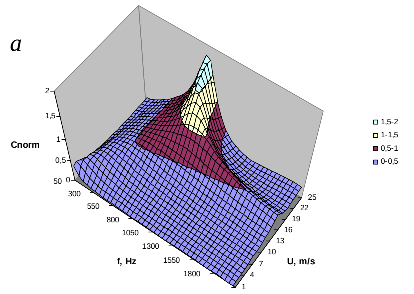


Figure 1: Modulus of elasticity and loss factor for RTV-3133.



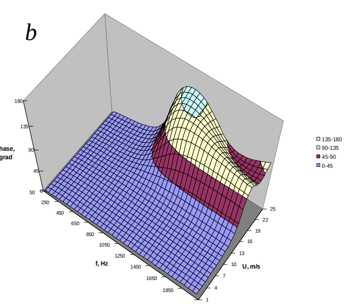


Figure 2: Dependencies of the normal component of compliance (*a*) and the phase lag between pressure and displacement (*b*) of the coating from RTV-3133 with H = 8 mm.

In the ranges of both the flow velocities, approximately corresponding the velocity range of the water tunnel, and the measured frequencies of viscoelastic properties there is a maximum of C_n, which moves towards lower frequencies with increasing thickness of the coating. For example, when H = 4 mm, the frequency corresponding to the maximum of C_n is f_m

= 1250 Hz; when H = 6 mm frequency f_m =1100 Hz; when H = 8 mm f_m = 800 Hz (see fig. 2*a*); when H = 12 mm, f_m =550 Hz. The flow velocity corresponding to the edge of the compliance peak depends on the viscoelastic material properties and is independent of the thickness of the coating. For instance, the flow velocity at which $C_n > 1$, is equal to 16─17 m/s and $C_n > 2$ is equal to 20─24 m/c. At U = 16─17 m/s, the normal compliance has a crest elongated in the direction of high frequencies. In the right corner of fig. 2*a* (i.e. at low disturbance frequencies and low flow velocities) is the second compliance crest. Unlike the high-frequency crest, the phase shift on the crest is virtually absent.

At the frequency of the compliance maximum, the phase lag between the coating displacement and pressure is equal approximately to 90°. As the frequency grows, the phase reaches its maximum, which similarly to C_n has a crest in the direction of high frequencies (see fig. 2, b).

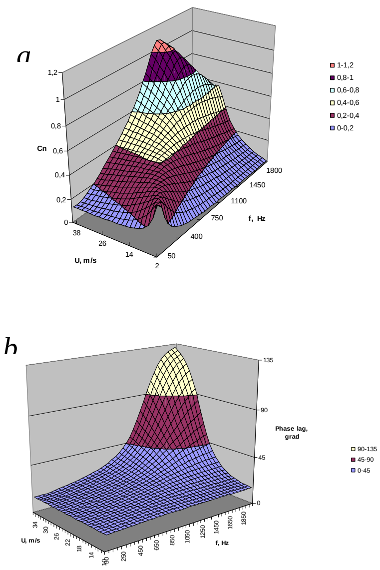


Figure 3: Dependencies of the normal component of compliance (*a*) and the phase lag between pressure and displacement (*b*) of the coating from material S2

Coating of S2 material has the maximum of normal compliance at flow velocity $U > 35$ m/s that far exceeds the tunnel operation speeds. The phase value on the plateau (see Figure 3*b*) is rather large ($\theta \approx 15°$) compared to Figure 2*b* that is explained by the high loss factor of S2 ($\mu \approx 0.25$).

The primary results of drag measurements of a rigid insert and a series of the compliant coatings of different thicknesses produced of RTV-3133 material are shown in Fig. 4. The 4 mm and 12 mm thick coatings have an increased drag compared to the rigid wall. The 6 mm and 10 mm thick coatings show the drag reduction of quite similar value, while maximum effect is reached at 8 mm thickness. The changes of the drag in respect to velocity are monotonous without a dedicated maximum as it might be expected from the computation. The location of the crest of the compliance maximum at high frequencies near U =16─17 m/s which are the maximum possible speeds of the tunnel can be a reason for its absence. At U < 10 m/s, the compliance crest moves to small frequencies and velocities (right side of fig. 2*a*) become apparently important for the drag modification. The magnitude of this crest is about the same as the high-frequency crest at U=16-17m/s. The friction drags are compared in fig. 5 for the 7 mm S2 coating and the rigid wall. As the velocity grows, a small drag reduction is observed with S2, which can be attributed to the effect of the low-frequency crest of the compliance (fig. 3*a*) and large phase shift (fig. 3*b*).

Hence, the water tunnel results are in line with the predictions of the coating properties based on the measurements of viscoelastic properties of the material and the corresponding calculations of the dynamic compliance of the coatings.

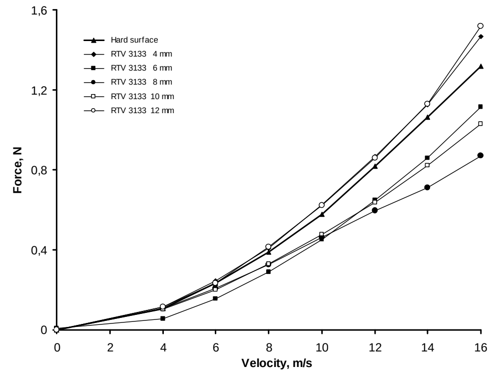


Figure 4: Drag force of coatings from material RTV 3133.

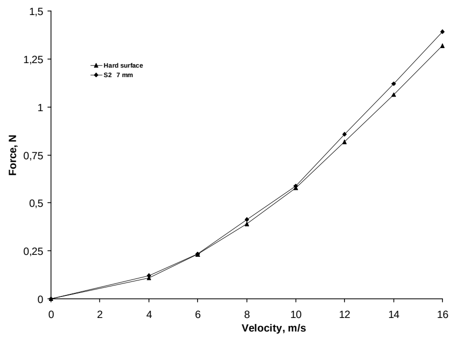


Figure 5: Drag force of coatings from material S2.

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