Proc. Estonian Acad. Sci. Phys. Math., 1990. 39, N 3, 290—295
https://doi.org/10.3176/phys.math.1990.3.14

УДК 532.621

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INVESTIGATION OF THE VELOCITY DISTRIBUTION AND SHEAR STRESSES IN DECELERATED PIPE FLOW

(Presented by H. Aben)

One of the most interesting problems in modern hydrodynamics concerns unsteady flow characteristics. From the engineering aspect the behaviour of the skin friction coefficient during the unsteadiness is one of the most important questions. The steady flow has been quite thoroughly examined and various formulas and graphs are available for determining the value of the skin friction coefficient. As unsteady flows have generally been less investigated, there is very little information available on that issue. Knowledge about decelerated flows is especially poor. Even contradicting results have been presented in numerous theoretical and experiment-based reports [1–6].

In the hydrodynamics laboratory of the Tallinn Technical University problems concerning unsteady accelerated flows have been studied for more than 20 years. The present paper summarizes the results of experimental investigations of decelerated flows carried out in recent years.

The experimental set-up used in those investigations is described in [3]. Two different hydraulically smooth pipe diameters (34 and 60 mm) were used in order to examine the flow. The experimental program was enlarged, as described in [3]. The applied set-up differs from the commonly used ones by the location of the motor-driven valve in the beginning of the pipe's working section.

During the experiments the following physical characteristics of the unsteady flow were measured:

(i) shear stress on the wall τ_{0N} using flush-mounted CTA hot-film sensors;

(ii) instantaneous cross-sectional mean velocity V;

(iii) pressure drop $p_1 - p_2$ between two cross-sections of the pipe;

(vi) using a LDA system two components of the local velocity in 17 points over a radius of the pipe.

A total of 17 different decelerations were investigated.

Reports [1–3] based on the variation of the shear stress on the wall present the skin friction coefficient behaviour which varies qualitatively at different pipe diameters. It is essential to mention here that the formerly used unsteady flow parameters dependent on dV/dt were not sufficient to characterize completely the time dependency of the above-mentioned coefficient.

In Figs. 1 and 2 the axial velocity distributions u, with corresponding mean velocity and shear stresses variation depending on the different time moments are presented for two different pipe diameters. In the starting period of the deceleration there is no distinct difference in velocity distributions determining the shear stresses. Both runs are realized by the same initial pressure ($p=98100$ N/m^2) in the upstream head tank and the same deceleration period. This means that there are different initial velocities, Reynolds numbers and decelerations in the test section

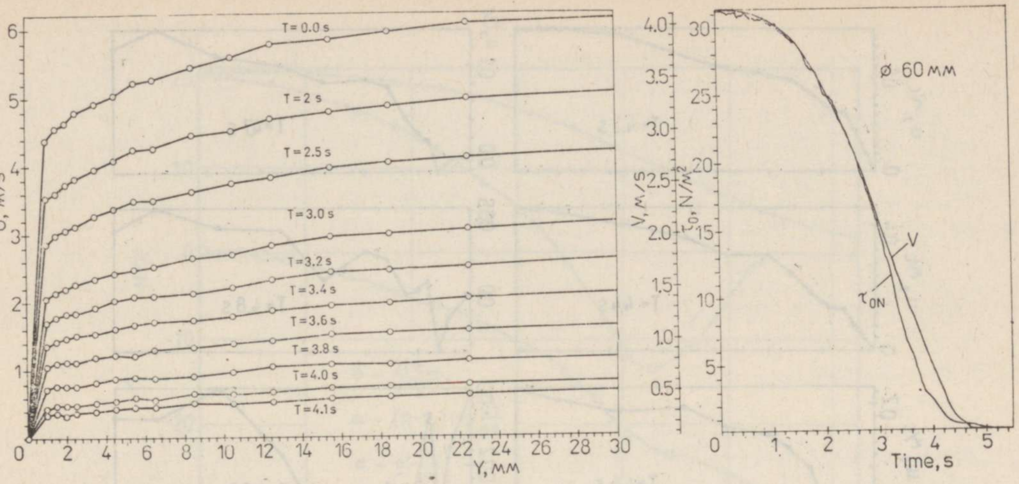

Fig. 1. Instantaneous axial velocity distributions at different time moments, mean velocities and wall shear stresses realizations of the decelerated flow. Pipe diameter 60 mm.

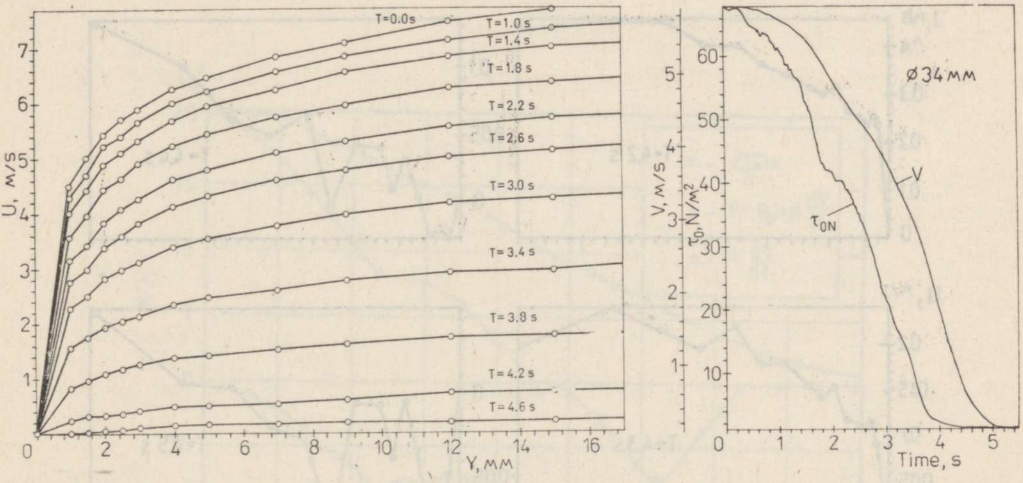

Fig. 2. Instantaneous axial velocity distributions at different time moments, mean velocities and wall shear stresses realizations of the decelerated flow. Pipe diameter 34 mm.

of the pipe. It is clearly visible in Fig. 3, where the velocity distributions for the final stage of deceleration in pipe $d=0.034$ m are presented. At a definite time moment $t=4.6$ s the velocity gradient on the wall is zero and this is also reflected in the value of the shear stress τ_{0N} at the same moment (Fig. 1).

The velocity distributions in the pipe with the diameter $d=0.06$ m (Fig. 4) show that, contrary to the situation described above, there is no similar influence of the deceleration on the fluid layers near the wall.

The presented results lead to the assumption that, regardless of the different inertia forces, the skin friction coefficient is among other factors affected also by the pipe diameter.

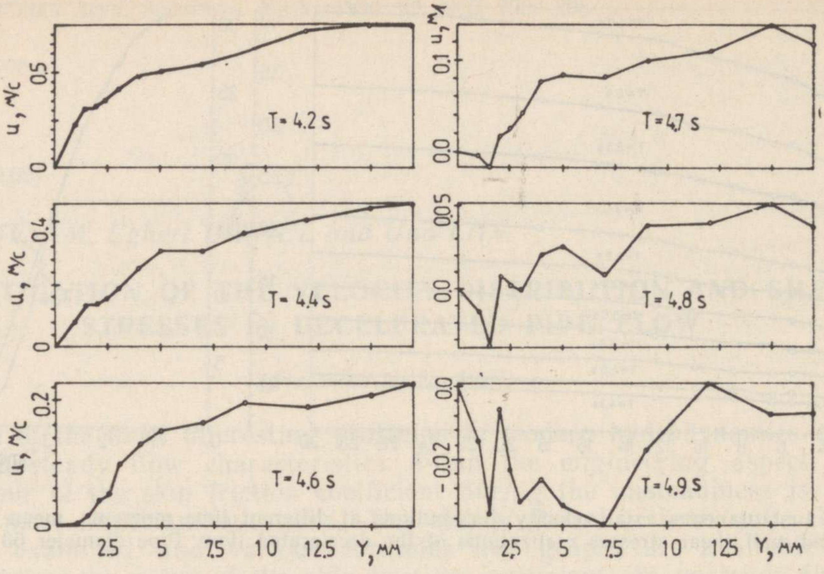

Fig. 3. Axial velocity distributions during the final stage of deceleration. Pipe diameter 34 mm.

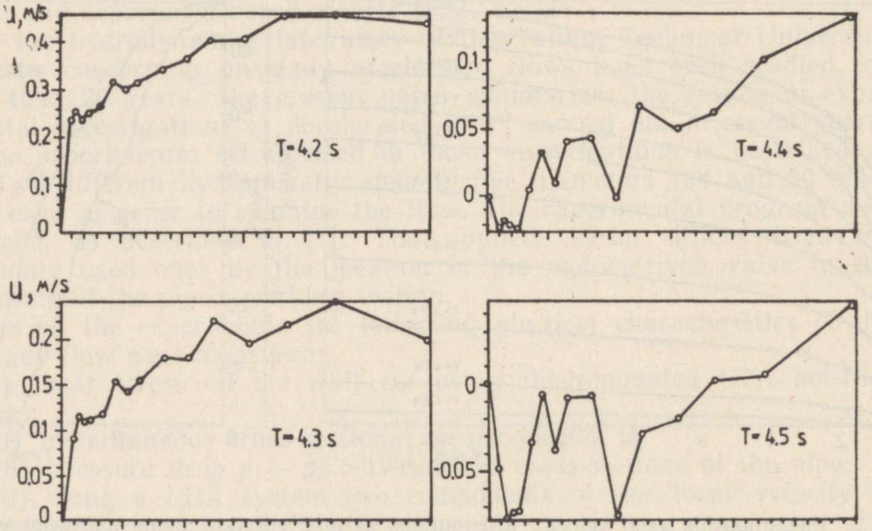

Fig. 4. Axial velocity distributions during the final stage of deceleration. Pipe diameter 60 mm.

During the experiments all three terms of the one-dimensional momentum equation for an unsteady flow were measured. This equation of motion in an unsteady incompressible flow is expressed as follows:

$$\frac{2L\tau_{0N}}{r} = (p_1 - p_2) - \varrho L \frac{dv}{dt}, \qquad (1)$$

where L — pipe length; τ_{0N} — shear stress on the wall; r — radius of the pipe; p — pressure in the observed cross-section of the pipe; V — instantaneous mean velocity.

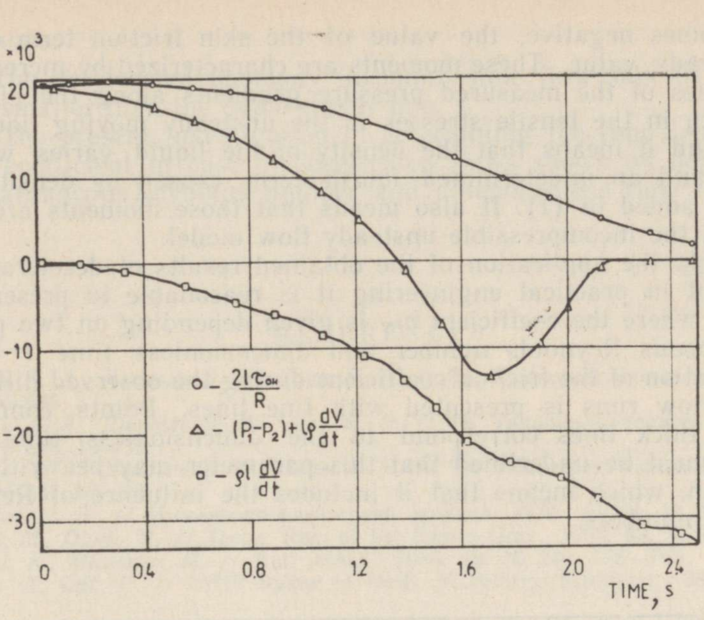

Fig. 5.. Time dependence of measured terms in the momentum equation. Deceleration period 5 sec, pipe diameter 60 mm.

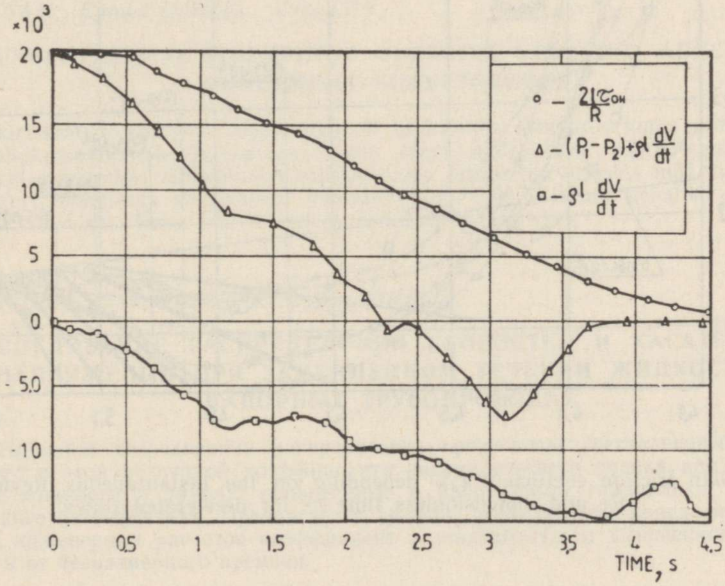

Fig. 6. Time dependence of the measured terms in the momentum equation. Deceleration period 8 sec, pipe diameter 60 mm.

It is remarkable that the terms of this equation have never before been measured simultaneously, but according to reports [4–6] the friction losses have been determined using either the difference in the right hand terms in (1), or a similar energy equation.

For two runs in a $d = 0.06$ m inside diameter pipe with the deceleration periods 3.0 and 5.0 s, respectively, the time dependency of all the three terms containing (1) are presented in Figs. 5 and 6. It is important to point out that at the moments 1.15 and 2.12 s, when the right side of

(1) becomes negative, the value of the skin friction term exceeds the quasi-steady value. These moments are characterized by increasing negative values of the measured pressure gradients along the pipe, leading to growth in the tensile stresses in the unsteady moving liquid. On the other hand it means that the density of the liquid varies within large ranges, and an undetermined fourth term caused by density variation must be added in (1). It also means that those moments are the boundaries of the incompressible unsteady flow model.

To help the application of the obtained results of decelerated friction coefficient in practical engineering it is reasonable to present a graph (Fig. 7) where the coefficient c_{fN} is given depending on two parameters: instantaneous Reynolds number and dimensionless time $t^+=\nu t/r^2$ [7]. The variation of the friction coefficient during the observed different decelerated flow runs is presented with fine lines. Points connected with straight thick lines correspond to the dimensionless time $t^+=\mathrm{const}$. Here it must be underlined that this parameter may be written as $t^+=1/\mathrm{ReSh}$, which means that it includes the influence of Reynolds and Strouhal numbers.

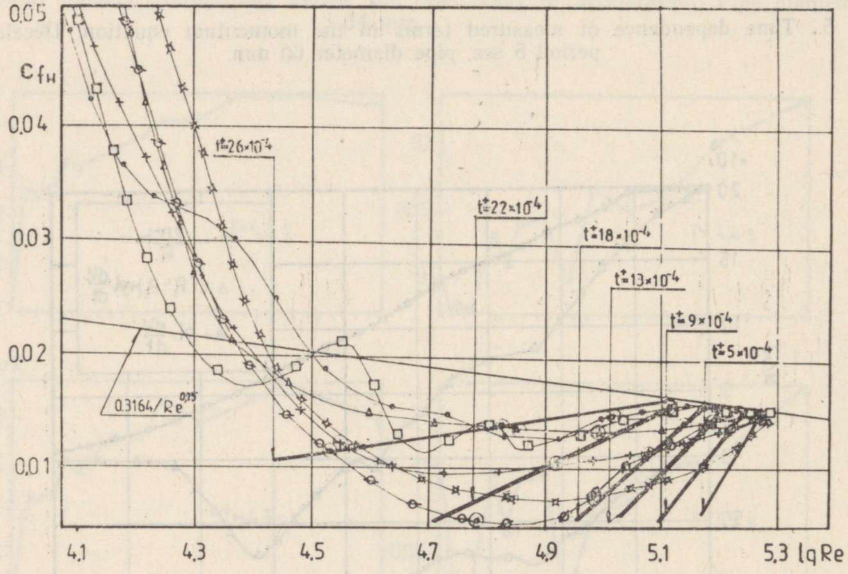

Fig. 7. Skin friction coefficient c_{fN} depending on the instantaneous Reynolds number Re and dimensionless time t^+ for decelerated flows.

When determining the time-dependent friction coefficient c_{fN}, the instantaneous mean velocity must be determined according to the valve closuring law, and it is necessary to compute the dimensionless time that has passed since the start of regulating the valve closure and also the corresponding instantaneous Reynolds number. According to these two parameters it is easy to find the time-dependent skin friction coefficient value on the vertical axes. In case the initial Reynolds number differs from the presented one, it is necessary to transfer the point $t^+=0$ along the smooth pipe line to the required Re_0. The smooth pipe law $\lambda=0.3164/\mathrm{Re}^{0.25}$ is the boundary for determining the skin friction coefficient in case of decelerated flow using the incompressible model.

Conclusions:

(i) The decelerated unsteady incompressible flow skin friction coefficient is smaller than the quasi-steady one.

(ii) The present investigation of determining the time-dependent skin friction coefficient in case of decelerated flows shows its dependence on the instantaneous Reynolds number and dimensionless time t^+.

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Received
Feb. 13, 1990

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KIIRUSEJAOTUSE JA NIHKEPINGE UURIMINE VEDELIKU AEGLUSTUVAL VOOLAMISEL SURVETORUDES

On kirjeldatud Tallinna Tehnikaülikooli hüdraulika laboratooriumis uuritud vedeliku kiiruse pikikomponentide ja sellega seoses oleva hüdraulilise hõõrdeteguri muutumist aeglustuval voolamisel silindrilistes survetorudes. Inseneriarvutustes määrava tähtsusega hõõrdeteguri leidmiseks aeglustuval voolamisel on töös esitatud graafik, milles otsitav on sõltuv hetkelisest Reynoldsi arvust ja dimensioonitust ajast.

Алар АЙТСАМ, Эгхерт ДАНИЕЛЬ, Уно ЛИЙВ

ИССЛЕДОВАНИЕ РАСПРЕДЕЛЕНИЯ СКОРОСТЕЙ И КАСАТЕЛЬНЫХ НАПРЯЖЕНИЙ ПРИ ЗАМЕДЛЕННОМ ТЕЧЕНИИ ЖИДКОСТИ В НАПОРНЫХ ТРУБОПРОВОДАХ

Описываются исследования распределения продольной составляющей скорости и связанного с этой величиной коэффициента гидравлического трения при замедленных течениях жидкости в трубах, проведенные в лаборатории гидравлики Таллиннского технического университета. Предлагается график, позволяющий определить этот важный для инженерных расчетов коэффициент в зависимости от мгновенного числа Рейнольдса и от безразмерного времени.