which were just mentioned as contributing to the spread of observed data. On the other hand, the errors probable or possible in the experimental measurements, or in determining the inertial head drop term, would not alter the stated conclusions.

In the case of the uniform diameter conduit, the magnitude of the boundary resistance during accelerated flow is very nearly the same as for the equivalent steady motion. Nevertheless, in Fig. 7 there is a definite indication that K_u/K_s is greater than unity. Thus the case of resistance due to boundary-layer shear stresses is affected differently by unsteadiness than resistance associated with the turbulence generation and diffusion accompanying separation and jet formation. For these data, Schonfeld's theory is used as a guide, and a straight line having a small positive slope is drawn through the plotted points. The relation in Table 4 shows K_s to be a function of Reynolds number while the relations derived from Schonfeld's theory (Equations [15–17]) predict c_2 and K_u also to be dependent on R. The variation in c_2 is small, however. Using Equations [17] and [18] over the range of Reynolds number investigated, c_2 varies only between 0.010 and 0.015. Hence a single straight line with a slope indicating a constant c_2 = 0.010 was arbitrarily chosen to represent test data qualitatively.

For decelerated flow the boundary resistance of the uniform tube is less than for steady flow. In this case, however, there is a clear indication of effects not predicted by Schonfeld's results. As shown, these data can be represented by a family of lines, essentially parallel, one for each deceleration. At any particular velocity, the proportion of boundary resistance to over-all potential drop is different, decreasing with increasing deceleration. All of these runs were started from the same steady-state velocity, but included different initial impulse periods. From the parallel displacement of the lines for different decelerations, it appears that the flow conditions of the subsequent established phase depend on the previous flow history.

These observations for the uniform tube are consistent with the view that under acceleration the central portion of the stream moves somewhat bodily while the velocity profile steepens, giving higher shear. For deceleration, the reverse seems to hold. In either event, it appears that unsteadiness does not result in marked changes from equivalent steady-state flows.

In the case of the orifices, however, it appears that the imposition of a transient results in flows having quite different velocity and turbulence characteristics. This was indicated not only by the relative magnitude of K_u and K_s, but also by what was first thought to be an anomalous experimental result. For decelerated flow through the smaller orifices, it was observed that as the unsteady run proceeded the magnitude of the potential drop changed from less than the equivalent steady-state drop (as required to establish the deceleration) to more; i.e., K_a/K_s became greater than 1.0 as the test run proceeded. This observation was repeated on many runs and cannot be attributed to measurement errors. For acceleration through the 0.3 orifice, there was some indication that a corresponding change to $K_a/K_s < 1.0$ occurred late in the run. However, experimental errors conceivably could account for the shift in this case. Such results could only mean that as the unsteady flow proceeded the internal structure of the velocity and the turbulence distribution changed to the point that it was no longer comparable to any steady-state flow condition.

Such effects as mentioned in the preceding paragraph clearly indicate that the particular state from which an unsteady run was initiated would affect the subsequent flow history. In fact, more generally it means that any particular unsteady state is dependent on the previous flow history, as seemed to be indicated by the deceleration tests with the uniform tube.

Summary

In summary, it is concluded that the imposition of an unsteady transient produces different effects for the two basic types of flow investigated, as follows:

1 For cases of surface resistance caused by boundary shear stresses.

(a) With acceleration the resistance is slightly but not appreciably greater than for the equivalent steady state.

(b) With deceleration the resistance is appreciably less than for the equivalent steady state.

(c) With either acceleration or deceleration, it appears that the internal flow structure is not markedly different from that for steady states.

2 For cases of form-type resistance associated with the high shear and generation and diffusion of turbulence accompanying jet formation.

(a) With acceleration the resistance is appreciably less than for the equivalent steady state.

(b) With deceleration the resistance is appreciably more than for the equivalent steady state.

(c) For intense jet action as obtained with small orifice-to-tube-diameter ratios, it appears that unsteadiness produces an internal flow structure that is no longer comparable to any steady-state condition.

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Discussion

F. S. Weinig.[7] The writer would appreciate having stated the nondimensional quantities which control the unsteady flow in addition to the equations derived in the paper, especially since the nonlinear effects play a role in the range of the tests.

Authors' Closure

In reply to Dr. Weinig's suggestion, the authors appreciate that there are other approaches to the analysis of unsteady flow effects. The procedure chosen in this instant seemed especially appropriate to the evaluation of effects on resistance and was used for these experiments in preference to the formulation of nondimensional parameters by dimensional analysis methods.

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