results or Bradshaw and Wong's [7]). In practice the layer's upstream history would not much effect flow around "isolated" elements for spacings greater than $P/_K = 20$, which is near the limit of this data.

The results presented confirm that the principles of Reynolds number similarity (Townsend [8] 1956) applies to rough wall flow for a wide range of geometries. However the results shown in Fig. 6 seem at odds with this result in that the turbulent motions that produced similarity of u'/U_s in Fig. 2 did not apparently produce similarity in the eddy viscosity profiles.

Another area of concern is the very large uncertainty bands on some of these results, up to 50 percent of reading in the case of the data presented in Fig. 3. In view of this uncertainty it is not appropriate to quote formulas for curve fits to this data to three significant places as has been done in conclusion 2 and elsewhere in the text. It is noted that these curve fits apply to both pipes which vary in diameter by a factor of 2. However the important lateral parameter that is varying is K/D and here there is only a difference of 30 percent which is quite insufficient to produce differences in the results greater than the scatter in the data. Perry et al. used differences of 800 percent in their boundary layer flows to support their conclusions.

There is room for further careful measurements in this field of research.

Additional References

5 Perry, A. E., Schofield, W. H., and Joubert, P. N., "Rough Wall Turbulent Boundary Layers," *Journal of Fluid Mechanics*, Vol. 37, 1969, pp. 383–413.

6 Tillman, W., "Investigations of Some Particularities of Turbulent Boundary Layers on Plates," British Rep. and Transl. CGD-497, MAP-VG 34-T.

7 Bradshaw, P., and Wong, F. V. F., "The Reattachment *and* Relaxation of a Turbulent Shear Layer," *Journal of Fluid Mechanics*, Vol. 52, pp. 113–135.

8 Townsend, A. A., *The Structure of Turbulent Shear Flow*, Cambridge University Press, 1956.

Authors' Closure

Response to E. Logan

Professor Logan points out many interesting comparisons between his work and ours. We are pleased that results from both studies are in agreement for comparable experimental configurations.

Response to W. H. Schofield

We agree with Dr. Schofield that given the uncertainty of the data, it is not appropriate, "to quote formulae for curved fits to this data to three significant places." We also agree that further careful measurements are need in this field.

Radial and Axial Variations in Transient Pressure Waves Transmitted Through Liquid Transmission Lines[1]

A. H. Weidermann.[2] The development of numerical methods for solutions of the Navier-Stokes equation are always useful and of interest. However, the subject title is not well served by the authors approach nor by their formulation of two relevant problems. Viscosity enters the selected flow problems in two basic ways. First, viscosity influences the transient flow field through the conservation equations and it is this characteristic which is being addressed in the paper; secondly, viscosity, for the low Reynolds number flows, establishes the flow velocity gradients in the (initial) flow field (i.e., the Poiseuille flow). In the former, the influence of viscosity is to introduce a spacial and temporal smearing effect on the flow and, perhaps, generate some additional wave systems. In the latter, viscosity introduces an energy and momentum gradient which under an appropriate stimuli will be redistributed within the flow field.

The authors selection of a finite duration (i.e., an essentially linear ramp) build-up to some step stimuli also introduces a spatial and temporal smearing effect on the transient flow field, and it is impossible, or at least difficult, to seperate the two contributions. I believe that a much more appropriate problem formulation for the waterhammer problem would have been one where the valve closes instantaneously. Additionally, the omission of viscosity in one such calculation would serve as an excellent reference problem (a two-dimension wave equation solution). The sudden stoppage of the flow at the valve location will (through momentum considerations) result in the momentary establishment of a pressure profice at this location which is proportional to the (initial) radial velocity profile; the peak pressure at the midpoint will be $2P_0$. Clearly, this early pressure distribution, together with the upstream flow gradients, will generate a radial wave system, and, of course, drive a pressure wave upstream into the fluid column. The major features of the transient flow, as shown in Fig. 1 of the paper, would certainly be present in such a reference solution. It appears, from the tabular data, that the viscosity effect is extremely small, and in some instances is of the order of the numerical uncertainties generated by the numerical methodology. I hope that the authors will have the opportunity, in the near future, to present the results of such an idealized reference solution such that we can all better understand and appreciate the proper contribution that viscosity plays in these two basic problems. Finally, in any engineering problem, the apparent minor role that viscosity plays in the transient flow will generally be masked by other system uncertainties and problem idealizations, for example, the elastic response of the containment system (i.e., pipe response).

Authors' Closure

We appreciate Dr. Wiedermann's interest in our paper; his view of the problem is somewhat different than ours. The essential point of our work is that the no-slip boundary condition can be satisfied exactly only by a simultaneous solution of both the axial and radial components of the Navier-Stokes equations. A two-dimensional non-viscous solution is not possible because the order of Euler's equations is not high enough; they cannot satisfy the no-slip condition

[1] By A. K. Mitra and W. T. Rouleau published in the March 1985 issue of the Journal of Fluids Engineering, Vol. 107, pp. 105–111.

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as well as the condition of zero normal velocity at a solid boundary. Thus, for inviscid flow the initial axial velocity profile will necessarily be flat and valve closure would then establish a flat pressure profile. This brings us back to classical one-dimensional water hammer.

Our choice of cubic and fourth order leading and trailing profiles is physically more realistic than jump discontinuities; it offers, in addition, the computational advantages provided by smooth functions. But we were very conservative with our smoothing: The dimensionless valve closing time we chose was of order unity, which corresponds to the order of a microsecond for the case considered in the paper. This is commensurate with experimentally attainable "instantaneous" closure, as well as being short enough to permit direct comparison with analytical solutions for instantaneous closure. In our work, the initial wave front travels only a relatively short distance before the valve is completely closed or before the pulse reaches its plateau. The agreement with Reference [5] has already been noted. Figure 1(*a*) shows that the peak centerline pressure is approximately 1.83, which compares favorably with the momentary value of 2 suggested by Dr. Wiedermann for his idealized case. From Fig. 4 it is evident that our pulse is essentially rectangular.