Frequency Response of Fluid Lines With Turbulent Flow

F. T. BROWN. This paper presents an interesting physical view. The results, however, can be deduced by a much simpler method and are nearly subsumed in authors' reference [6]. Further, application of the results beyond a specific boundary of frequency and Reynolds number will give false answers.

The results, as seen in Fig. 4, comprise a straight line sloped upward, common to all Reynolds numbers, one horizontal straight line for each Reynolds number, and rather sudden but smooth transitions between the lines.

The sloped straight line corresponds to the situation in which the dynamic boundary layer is so thin it lies within the effective laminar layer next to the wall. It is no surprise, then, that this result corresponds to Lember's of 1950 (reference [5]) for laminar flow, as pointed out in reference [6].

The horizontal lines ($\Phi = 1$) correspond to the nearly mythical situation of asymptotically large frequency with a constant I-R-C model in which the resistance, $R$, is found from friction factor data:

$$R = \frac{1}{\frac{d}{dV}} \left( \frac{1}{2} \rho V \right)$$

For the resistance to correspond to laminar-like perturbations, the friction factor $f$ within the above derivative varies inversely to $V$:

$$f = K(\sqrt{Re})/\sqrt{V}$$

Therefore, since $K$ is treated as a constant in the differentiation,

$$R = \frac{pK}{2} = \frac{pV}{2d} = \frac{f \sqrt{Re}}{2d}$$

The attenuation factor at high frequency is well known to be

$$\alpha = \frac{R}{2pc}$$

giving the answer of the present paper:

$$\alpha = \frac{f \sqrt{Re}}{4 cd^2}$$

The break frequencies are at the intersections of the horizontal lines and the sloped line.

Reference [6] also predicts, however, that the horizontal lines apply only to an almost vanishingly narrow frequency band. The predicted values of $\alpha$, unlike here, shift upward for frequencies just a little below those of the experiment, and drop off again (ultimately to zero) for much lower frequencies. Experimental results to be published in this Journal shortly corroborate this prediction, except that the upward shifts include two extremely sharp absorption bands and two sharp bands of exceedingly low attenuation, which are believed to be related to a non-random mechanism of turbulence production. The reader is cautioned, therefore, not to use the results of the present paper for frequencies any lower than those given by the experimental data (also taken from reference [6]).

Authors' Closure

The authors are somewhat puzzled by Brown's remark that their results "are nearly subsumed" in his earlier paper [6]. We found that paper to be unduly complex, offering neither the physical insight nor the sufficiently simple result to be of practical value to the engineer. The rather simple and straightforward approach we employ was described in one of our earlier papers (7) and was applied to the calculation of transmission viscous losses during single wave propagation in a tube containing a turbulent flow. Comparison with experimental data was very good. These results, along with what we considered to be the unnecessarily complicated approach taken by Brown [6], motivated us to apply our technique to the frequency response problem, as we had indicated [7] could be done. When our theoretical results agreed closely with the experimental data published by Brown [6], we concluded that the single laminar boundary layer model is adequate over a wide range of frequencies and further provides a theoretically sound and simple computation of the attenuation factor.

We must also dispute Brown's contention that the results could have been obtained by a much simpler method. There is no need to speculate about the "dynamic boundary" lying within the "effective laminar layer" next to the wall in order to explain high frequency results. As our results show, the main dynamic viscous effects occur in a single boundary layer whose thickness is determined by the Reynolds number for the flow, not the frequency.

We agree that a constant I-R-C model is nearly mythical, and for that reason have not used it and would be suspicious of any results obtained from the application of such a model. To seriously suggest that a constant I-R-C model will produce a result in which any confidence can be placed raises the question of why Brown went to so much trouble and complexity in his earlier [6] analytical treatment of this problem.

At low frequencies the dissipation factor is one as shown in Fig. 3. This means that dynamic effects are negligible and the attenuation factor can be deduced from steady state considerations as we pointed out in the paper. As any theoretically sound model should, our model predicts this result. However, to imply that our results can be obtained by looking at these two extreme situations is ludicrous. This reasoning could be extended to all efforts to describe transient viscous effects and would inspire little confidence in the results.

The results presented in our paper agree with experimental data over a relatively large frequency range and would be expected to apply to many engineering problems. This essentially means that the single laminar boundary layer can adequately describe transient viscous effects in this frequency range. However, Brown suggests that other phenomena such as turbulence production may affect the results at lower frequencies. We do not presently have access to the data which Brown refers to but we do agree with him that our results should not be applied for frequencies higher than those for which data were presented.

In summary, we have presented a simple straightforward analysis which produces results which compare as well with experimental data as those of a far more complicated and involved approach. We have now shown that results from our model agree very well with experimental data for single wave attenuation and for sinusoidally varying flows, for which we have identified a single dissipation factor which completely determines the attenuation. Brown's comments are inconsistent with the approach he himself has taken to this problem.