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Readers' Forum

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Comment on "Experimental Study of a Normal Shock/Homogeneous Turbulence Interaction"

H. S. Ribner*
University of Toronto,
Downsview, Ontario M3H 5T6, Canada

THIS paper by Barre et al.[1] appears to be a careful, well-thought-out experimental investigation of shock–turbulence interaction at Mach 3. Among other things, measurements are made of the postshock and preshock mean square longitudinal components of turbulent velocity, $\langle u'^2\rangle$ and $\langle u_0'^2\rangle$, respectively, and their spectra. The authors point out that the measured amplification ratio $\langle u'^2\rangle/\langle u_0'^2\rangle$ is close to the theoretical value of about 1.5 predicted by Ribner's theory.[2,3] That work of some 40 plus years ago initiated the analytical study of shock–turbulence interaction.

However, the authors seem unaware of a much later paper that extends the predictions to changes in spectra.[4] Here, again, there seems to be agreement if Fig. 15 of their paper is reworked. Specifically, the postshock spectrum must be 1) reexpressed from postshock to preshock wave number and 2) multiplied by $\langle u'^2\rangle/\langle u_0'^2\rangle$ to remove the normalization. Step 1 requires division of the plotted wave number by the mean flow velocity ratio across the shock (because the product velocity times wave number preserves invariance of frequency in a shock-fixed frame). The ratio of velocities at $x_c = 0$ and 11 mm yields a value of 2.87; this corresponds to a shift of the postshock spectrum in Fig. 9 by 12.9 mm to the left. Step 2 requires multiplication of the ordinate by the cited amplification of 1.5; this is a shift of the spectrum upward by 4.4 mm.

When the two shifts are made, the postshock spectrum lies slightly above the preshock spectrum at all wave numbers above $k = 200\ \mathrm{m}^{-1}$. Except at the low end, this is essentially what is predicted by Ref. 4, Figs. 6 and 7. It is observed that $k = 200\ \mathrm{m}^{-1}$ corresponds to a wave length of 31.4 mm. Thus the 150-mm shock is only about five wavelengths across. Thus at this and smaller values of k the infinite shock assumption of the theory, in relation to the wavelengths of concern, is not met in the experimental scenario.

In these same respects, the experimental results of Barre et al.[1] are compatible with the direct numerical simulations (DNS) of shock–turbulence interaction of Lee et al.[5] In parallel with the DNS they made comparison calculations via Ribner's theory.[2–4] The latter was referred to as the linear interaction theory (LIA). Quoting from their abstract, "The predictions of the linear analysis compare favourably with simulation results for flows with [turbulence Mach number] $M_t < a(M_1^2 - 1)$ with $a \approx 0.1 \ldots$" The DNS computations were limited to the range $1.05 \leq M_1 \leq 1.20$, but the LIA calculations extended over $1.0 \leq M_1 \leq 10$.

Lee et al.'s recalculations[5] agree with my original LIA calculations[2,3] in predicting the measure of anisotropy downstream of the shock as $u'/v' = 0.87$ for $M_1 = 3$. This is almost the inverse of the measured anisotropy presented in Fig. 12: This shows $u'/v' =$ approximately 1.5. It is only at Mach numbers below 2 that the theory predicts u'/v' exceeding unity; moreover, the highest predicted value is only about 1.1 (at $M = 1.25$). In view of the earlier cited cases of agreement of theory and experiment, and the support of computational fluid dynamics computation (DNS) for the theory (LIA), this discrepancy remains a puzzle.

The LIA theory[2,3] as reconstituted in Ref. 5 is somewhat ambiguous, and details are lacking. The basic building blocks are oblique plane sinusoidal waves of vorticity (shear waves). These are single spectral components (in three dimensions) of an instantaneous snapshot of an arbitrary flow. The waves are considered to interact independently with the shock according to the analysis of Ref. 2; hence the designation linear interaction theory. Then the waves are superposed to represent turbulence upstream and downstream of the shock. The detailed statistical formalism for this was developed in Ref. 3 (and partly summarized in Ref. 4); it is from this that specific predictions of quantities like $\langle u'^2\rangle/\langle u_0'^2\rangle$ are worked out.

References

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[4]Ribner, H. S., "Spectra of Noise and Amplified Turbulence Emanating from Shock-Turbulence Interaction," *AIAA Journal*, Vol. 25, No. 3, 1987, pp. 436–442.

[5]Lee, S., Lele, S. K., and Moin, P., "Direct Numerical Simulation of Isotropic Turbulence Interacting with a Weak Shock Wave," *Journal of Fluid Mechanics*, Vol. 251, 1993, pp. 533–562.

F. W. Chambers
Associate Editor

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*Professor Emeritus, Institute for Aerospace Studies, 4925 Dufferin Street; also Distinguished Research Associate, NASA Langley Research Center, Hampton, VA 23681-0001. Fellow AIAA.