Reply

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7 July 1984 and 26 February 1985

Dr. Chock raises a number of points in his comment regarding our interpretation of the Long Island Expressway data, and questions the existence of significant amounts of traffic-induced turbulent energy at frequencies greater than 0.5 Hz. Before discussing the points Dr. Chock has raised, we will outline the facts supporting our hypothesis that signficant amounts of traffic-induced turbulent energy at frequencies above 0.5 Hz are found in highway experiments. First, physical reasoning and fluid modeling experiments suggest that the dominant turbulent eddy size in the wake of an obstacle should scale to the dimension of the obstacle. Hence, one would expect the length scale of the eddies in the wake of automobiles to be in the range of 1.0 to 2.0 m. The velocity spectra from the wind tunnel experiments of Eskridge and Thompson (1982) showed (see their Fig. C-1) that the maximum energy was in wavelengths near 1.0 m. Turbulent energy at this wavelength near a highway with cross-road wind speeds greater than 1.0 m s^{-1} will appear in the velocity spectra at frequencies greater than 0.5 Hz (see discussion p. 1440 of Eskridge and Rao, 1983). Gill anemometers, as used in the General Motors experiment (Cadle *et al.*, 1976), are not capable of resolving turbulent eddies of this size. Second, Chock's (1980) Figs. 6 and 8 show that the turbulent energy is increasing up to 0.5 Hz downwind of the roadway! Some of the energy above 0.5 Hz has been aliased and appears below 0.5 Hz in these figures. However, the anemometers have measured very little of the energy in the frequencies above 0.5 Hz because the instrument response is too slow. The effect of a low sampling rate on the velocity variance is shown in Fig. 2.2 of Pasquill and Smith (1983). Third, regarding Dr. Chock's comments on the Long Island data and our interpretation of it, we note that according to the theoretical predictions and observations of surface layer turbulence (Kaimal *et al.*, 1972), the high frequency part of the spectra under different atmospheric conditions should nearly coincide under proper nondimensionalization. The augmentation of spectral energy at high frequencies due to the presence of traffic-induced turbulence (f greater than 1.0) is evident in the normalized spectra presented in Fig. 2 of Rao *et al.* (1979). From Fig. 4d of Rao *et al.* it is evident that there is a significant amount of energy in the dimensional frequency range greater than 0.5 Hz. Comparison of Figs. 4d and 2b reveals that this portion of the velocity variance is due to the traffic generated eddies. We feel that while Dr. Chock has raised some interesting points, the preponderance of evidence and physics supports our contention that there is significant turbulent energy in the short wavelengths (i.e., at frequencies above 0.5 Hz). The Gill anemometers are not capable of a sufficiently fast response to measure these high frequency velocity fluctuations.

We now address Dr. Chock's specific comments. In paragraph 5, Dr. Chock states "ER indicated that aliasing underestimated the total turbulence energy." The sentence on pg. 1440 of Eskridge and Rao was poorly worded and has led Dr. Chock to misinterpret what we intended to say. The underestimation of the spectrum is due not to aliasing but to the anemometer's inability to sample at a sufficiently high rate, as Dr. Chock states in his comments.

The statement made by Dr. Chock that ". . . eddies due to traffic had large amplitudes so that the frequency response of the anemometers was high," is at odds with our understanding of instrument response and the analysis given in Section 2.1 of Pasquill and Smith (1983) regarding the amount of the variance measured per the sampling rate. We do agree with Dr. Chock that sampling more than once per second with the Gill UVW anemometers used in the General Motors experiment would not have produced valid data.

Regarding the 29 s wave, we note that Dr. Chock (1980) states "substantial energy is stored at 0.034 Hz which corresponds to the 29 s interval of car pack passage. Its harmonics at 0.069 and 0.103 Hz are also visible." A turbulent eddy is not characterized by a narrow spike in the spectrum at a frequency or wave number. A narrow spike in the spectrum creates slowly damped oscillations in the correlation. A correlation

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with this characteristic is typical of wave-like disturbances but not turbulent eddies.

The decay of the 29 s wave is predicted by wake theory and in Table 3 of Eskridge and Rao. When the analyzed wake passing is compared to the model values, it is seen that the agreement is quite good. The 29 s wave owes its existence to the repeated passage of vehicle packs past the instruments at 29 s intervals throughout the experiment. Thus, every 29 s the high frequency content of the record is enhanced due to vehicle wake passage. This repetitious or switching frequency is an artifact introduced into the sensors at 29 s intervals. Since it is only a modulation of the turbulence "carrier" signal, it is not turbulent itself. However, it will die out with the traffic wakes by which it is carried.

The wake-passing effect is an artifact in real world data. It cannot be separated out in real world conditions since there will not be a repetitious frequency as in the General Motors experiment. Because of the very design of the General Motors experiment, it is possible to distinguish this artifact and reveal the velocity fields and eddy diffusion coefficients that are truly representative of the traffic-induced turbulence. The uniqueness of the General Motors experiment allowed us to separate the wake-passing effect from the real turbulence.

The purpose of the laminar wake example in Eskridge and Rao was to logically show how the velocity data can indicate turbulence when none is present. The wake-passing effect arises because the measurements are Eulerian rather than Lagrangian, as they should be in turbulence measurements. Clearly, a turbulent wake will have a velocity deficit, which will lead to a wake-passing effect just as in the laminar wake example we gave. This enhancement of the velocity variance is not diffusive! Molecular diffusion takes place in the laminar wake, as Dr. Chock notes, but for the time scale of atmospheric problems its magnitude is vanishingly small and molecular diffusion can be ignored.

In summary, the facts support our contention that significant amounts of vehicle-induced turbulent energy were not measured in the General Motors experiment; second, a significant amount of the measured velocity variance was due to the wake-passing effect; and finally, the 29 s wave is nondiffusive and is explained by the vehicle wake theory.

We wish to note that Eskridge and Rao (1983) contains an error. The text on p. 1441, line 10 reads "However, as Fig. 11 and Fig. 7 show, . . ."; it should read "However, Table 3 shows . . .".

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