Reply to "Comments on 'Harmonic and transient scattering from *time* varying obstacles' " [J. Acoust. Soc. Am. 76, 1527–1534 (1984)]

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The present reply to the above comments by Piquette and Van Buren [J. Acoust. Soc. Am. 79, 179–180 (1986)] examines the legitimacy of the Doppler method for analysis of wave problems involving moving boundaries. Inasmuch as different results are predicted by Piquette and Van Buren, the ultimate test will have to be the experiment.

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The Doppler effect of frequency shifts due to motion of sources and scatterers dates back to 1842.[1,2] Since then, it has been successfully applied to all branches of physics, including acoustics, where it serves as an efficient tool for remote-sensing moving objects and boundaries, in biomedical and industrial applications. As mentioned by Toman,[2] the application of the principle to systems of material media, such as acoustics, has been questioned by Petzval. This argument has been resolved by Mach (see references in Toman[2]), who showed that Doppler's principle applied to any case where sources (or scatterers) and observers move relative to each other. There is no doubt that this effect exists in acoustical systems. In its simplest form, the Doppler effect is analyzed by transformation of coordinates. However, this is only applicable to constant uniform velocity. A more general method (yielding the same results as the coordinate transformation method for the simple cases) is to solve directly the boundary value problem for the time-dependent conditions.[3–5] The vibrating boundary is only one of the problems solved in this way. The electromagnetic problem[6] has its own difficulties,[1,7] but certainly for vacuum electrodynamics, the problem of the moving boundaries displacing the surrounding medium does not exist. In acoustics, this problem exists for impermeable objects. In principle, we can visualize objects whose surface is perforated, such that motion will not displace the surrounding fluid, but if the mesh size is much smaller than wavelength, the surface will act as a scatterer. This is a very restricted case, but it serves to prove a point—the only effect on scattering, in such a case, will be due to time-dependent boundary conditions, i.e., the Doppler effects discussed in the subject paper. A much more realistic model of this kind is given by a semi-infinite string with a roller at the end.[5,8] Here, too, the string "medium" can "flow" through the rollers, and the time-dependent boundary conditions will produce Doppler effects.

In the analysis in the subject paper, the effect of the motion of the displaced fluid is simply ignored. To date, invariably all the Doppler-effect analyses in acoustics ignore this factor, and the experimental results seem to be well within the range of expected results. In this sense, the Doppler-effect analysis should be perceived as an approximation. In any case, only solutions of the linear wave equation are considered.

Piquette and Van Buren, above, and Rogers[9] before them, maintain that the problem *must* be solved by considering the nonlinearities of the medium. They predict results that supposedly are decisive for determining which theory is right and which one is wrong. Unfortunately,[10,11] they also maintain that a decisive experiment is not feasible, at this time. If this is true, then we have a deadlock.

It is therefore worthwhile to examine a few points that might help to resolve the problem. First, it must be noted that in order to generate new spectral components, we do not need a nonlinear medium (i.e., a medium for which the wave fields are solutions of nonlinear differential equations). This is apparent in the electromagnetic Doppler effect, in which everything is linear, and a time-dependent boundary condition exists. Mathematically, new frequencies can be generated in a system governed by a linear differential equation with time-dependent parameters, e.g., in the Floquet theory.[12,13] On the other hand, from the point of view of the system theorist, the process which changes the frequency of the scattered wave due to a Doppler effect constitutes, by definition, a nonlinear operation. It is a very peculiar operator, because if we inject into the system two frequencies f_1, f_2, the Doppler effect will produce, say, f_1', f_2', but there will be no interaction between f_1 and f_2, or f_1' and f_2'. The nonlinear theory of Piquette and Van Buren would suggest that such an interaction does exist. Could this point the way toward a solution of the conflict? Finally, if the Doppler effect is, in a restricted sense, a nonlinear operation, could it be that the two theories are alternative descriptions of the same physical situation? Obviously Piquette and Van Buren do not believe that this could be the case.

Can the experiment be improved? On the grounds of theoretical considerations one could visualize a source scatterer, such that the Ω (low-frequency) field radiation pattern has zeroes in certain directions. If the receiver is situated in such a "shadow zone" in the farfield, and is operated well within the linear part of its dynamic range, then amplitudes associated with ω, $\omega \pm \Omega$ can be measured and separated. That should contribute to resolving the present conflict.

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[2]K. Toman, "Christian Doppler and the Doppler effect," Eos 65, 1193–1194 (1984).
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[9]P. H. Rogers, "Comments on 'Scattering by time varying obstacles,'" J. Sound Vib. 28, 746–768 (1973).
[10]J. C. Piquette and A. L. Van Buren, "Nonlinear scattering of acoustic waves by vibrating surfaces," J. Acoust. Soc. Am. 76, 880–889 (1984).
[11]Piquette and Van Buren also discovered, as reported in Ref. 11, that sum and difference frequency waves arising from scattering from a vibrating surface in an acoustic medium cannot be accurately measured using presently available acoustic sensors. This is due to nonlinearities which are inherent in the acoustically sensitive material used to fabricate such sensors. It should be noted, however, that this limitation is far less severe than that associated with uncertainties in the state of motion of the sensor relative to the fluid. This latter effect alone would preclude successful measurement of the effect predicted by Censor in the acoustic case.
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High-energy impulsive noise assessment

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In 1977 and again in 1981, the National Research Council (NRC) concluded that the C-weighted Day–Night Level was the best available measure with which to assess community response to high-energy impulse noise. Rattles in homes were the major adverse factor indicated by sonic boom and blast noise studies and cited by the NRC reports. Studies, since 1981, by the U. S. Army further support the NRC conclusions. Despite this wide consensus, there remain advocates for using only the A-weighting for measuring noise in the community—including that from high-energy impulses. This letter covers issues not considered in the NRC reports and provides additional rationale for the use of C-weighting, based on measurability and mitigation implications. This letter shows that impulsive noise is commonly hidden in other neighborhood sources when using A-weighting, but only rarely hidden when using C-weighting. There is a 10-dB improvement in signal to noise when using C-weighting. Also, A-weighting can mislead the public since it implies large benefits (up to 15 dB) for mitigation techniques such as barriers or forests. Low-frequency impulse energy, which rattles houses, is not attenuated by barriers or forests. Thus no large benefit is gained. C-weighting predicts the correct answer—only a few decibels of attenuation.

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INTRODUCTION

A. Background

In 1977, the National Research Council examined the issue of assessing impulse noise as part of a study dealing with the preparation of environmental impact statements (noise).[1] In 1981, Working Group 84 of the National Research Council specifically reviewed the 1977 NRC report, and other more recent research findings, in order to develop its 1981 report dealing with the "assessment of community response to high-energy impulsive sound." This 1981 report recommended the continued use of the C-weighted Sound Exposure Level (CSEL) as the descriptor for high-energy impulsive sounds, but revised the functional relationship between the C-weighted Day–Night Level (CDNL) and the community response expressed in terms of percent highly annoyed.[2]

The 1977 NRC report recognized that high-energy impulsive sounds, such as sonic boom, artillery fire, and quarry blasting, can "engender annoyance beyond that associated with a simple audibility of the impulses by inducing house vibrations, startle affects, or other responses, and thus should be treated differently from more common sounds such as those produced from transportation noise sources."