Comment on "Development of panel loudspeaker system: Design, evaluation and enhancement" [J. Acoust Soc. Am. 106, 2751–2761 (2001)] (L)

Frank Fahy[a)]
University of Southampton, Southampton SO17 1BJ, United Kingdom

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This letter concerns the paper ''Development of panel loudspeaker system: Design, evaluation and enhancement'' [M. R. Bai and T. Huang, J. Acoust. Soc. Am. **109**, 2751–2761 (2001)]. It is suggested that the radiation field generated by the near vibration field induced by a point force acting on the plate has been neglected. It is pointed out that its relative contribution is crucially dependent upon the mechanical loss factor of the panel, for which no data are presented. The conclusion that the radiated power per unit mean square force is independent of frequency neglects the radiation efficiency factor. Other perceived shortcomings of the paper are noted. [DOI: 10.1121/1.1526495]

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In a recent paper by Bai and Huang, the authors state that ''The 'coupled' electrical-mechanical-acoustical system should be solved simultaneously. For the present, this is somewhat impractical from the engineering standpoint.'' I am surprised by this statement, since the computational tools for solving fully coupled vibroacoustic problems involving flat, baffled panels coupled to semi-infinite fluid volumes has been commercially available for a number of years. When the calculation has to cover the full audio-frequency range, this is, admittedly, a large computational problem, but it would have been useful to readers to learn the reasons for the authors' contention of impracticability.

It is stated that ''Resonance of flexural motion is encouraged such that the panel vibrates as randomly as possible.'' I feel that clarification of this statement is necessary, since the vibration field of a linear elastic structure excited by a single point force is everywhere fully coherent, irrespective of the time history of the force. Perhaps the authors mean that the spatial correlation of the field, evaluated in frequency bands sufficiently large to encompass the resonant response of a number of modes, tends to that of an ideal, two-dimensional diffuse field. It should also be pointed out that, contrary to the implication at the end of Sec. II, the evanescent components of panel vibration associated with other than simply supported boundaries do contribute to panel radiation since they contain supersonic wave number components.

It is surprising that the discussion of radiation is confined to the reverberant component of the vibration field and that no explicit mention is made of the radiation associated with the near vibration field generated by a point force acting on a plate. Interestingly, at frequencies well below the critical frequency (10 214 Hz for the experimental DML), the far field so generated is omni-directional and the associated sound power per unit mean square force is independent of frequency and plate stiffness and inversely dependent on the square of the panel mass per unit area. The contribution of this source of sound, relative to that of the reverberant vibration field in the plate, increases with the plate loss factor. Control of the panel mechanical loss factor is vital, because the proportion of input power radiated by the reverberant component of panel vibration is crucially dependent upon the ratio of mechanical to radiation loss factor. Unfortunately, the paper informs us of neither the value of panel loss factor employed in the calculations nor that of the experimental plate.

The authors admit that a more rigorous analysis of the problem demands that the frequency dependence of the driving point impedance of a reverberant panel should be taken into account. However, it is likely that the assumption of a frequency-independent, real impedance is reasonable, on two grounds. First, the average of the driving point impedance of a finite plate over a frequency band containing a number of resonance frequencies equals that of the infinite plate. Second, the effects of the back emf in the coil, which reduces the current from a constant voltage amplifier at plate resonances, together with its inertial impedance, which may become comparable with that of the plate at resonances, tend to smooth out the effect of resonant peaks in plate admittance.

The statement below Eq. (23), that either small bending stiffness *or* small mass per unit area should be selected for small panels, is rather puzzling. It would have been useful to point out at this stage that the asymptotic density of flexural modes is proportional to the inverse of the expression for *fo* given by Eq. (23), which is another reason for keeping *fo* as small as possible.

As a matter of good scientific practice, the value of the ratio of bending stiffness to mass per unit area should not be quoted to five significant figures. We are not told how the material properties of the polyurethane panel were estimated (and we should be), but even the most highly refined experimental estimates cannot produce such precision.

It is stated in Sec. II that the radiated power per unit force should be ''constant'' (presumably meaning ''independent of frequency''), because the point impedance is independent of frequency, and so therefore is the driving point

[a)]Electronic mail: frank.fahy@care4free.net

velocity. Even if the space-averaged mean square reverberant field velocity were consequently independent of frequency (which is the case only for frequency-independent loss factor), the sound power is proportional to the product of the space-average mean square velocity and the radiation efficiency, and the latter is certainly not independent of frequency below the critical frequency.

The results presented in Fig. 12 are somewhat worrisome. The DML radiation spectrum in Fig. 12(a) shows a ''peak'' at just below 20 kHz, which is higher than substantial portions of the curve *within* the stated bandwidth of excitation (0–16 kHz). Is this an indication of nonlinearity of response? In Fig. 12(b), the experimental curves for both forms of loudspeaker exhibit a sharp minimum at about 530 Hz. Is this an artifact of the test conditions—interference from a floor reflection perhaps? If so, the claim to have minimized the effect of room response cannot be upheld. The authors make no comment about the broad radiation peak in the vicinity of 9 kHz, but the proximity of the estimated critical frequency is surely significant.

The paper contains a number of mathematical errors. The factor 2*Pi is missing from the denominator of Eq. (9) and the leading sign should not be negative. The exponents in both Eqs. (9) and (10) lack a negative sign [the authors use $+j$ in the time exponent in Eq. (3)]. The panel mobility quoted in Table I has the units inverted.

Irrespective of the foregoing comments, I suggest that the claim made in the abstract that ''Panel speakers are investigated...'' is too sweeping, since only one particular form of DML was studied. The enigmatic conclusion that ''To further improve the efficiency of panel speakers, planar radiators without resort to the mechanism of flexural waves should be sought in future'' appears to conflict with the authors' comments that the generation of many flexural modes produces the beneficial effects of suppression of beaming through ''diffuse'' radiation. Elaboration of this intriguing proposal is eagerly awaited.

[1] M. R. Bai and T. Huang, ''Development of panel loudspeaker system: Design, evaluation and enhancement,'' J. Acoust. Soc. Am. **109**, 2751–2761 (2001).