

SOUND RADIATION FROM ORTHOTROPIC RECTANGULAR PLATES

Part II: Validation by comparison with numerical and experimental results

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THE PREPARATION OF THIS DATA ITEM

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1. NOTATION

		<i>Units</i>	
		<i>SI</i>	<i>British</i>
a	length of plate in x -direction	m	in
b	length of plate in y -direction	m	in
D_x	bending stiffness in x -direction	N m	lbf in
D_y	bending stiffness in y -direction	N m	lbf in
D_{xy}	torsional stiffness of plate about x - and y -axes	N m	lbf in
E	Young's modulus for material of plate	Pa	lbf/in ²
E_x	Young's modulus in x -direction	Pa	lbf/in ²
E_y	Young's modulus in y -direction	Pa	lbf/in ²
E_1, E_{11}	Young's modulus for lamina in 1-direction	Pa	lbf/in ²
E_2, E_{22}	Young's modulus for lamina in 2-direction	Pa	lbf/in ²
f_c	critical frequency of wave coincidence	Hz	Hz
f_{c1}	critical frequency of wave coincidence (lower value)	Hz	Hz
f_{c2}	critical frequency of wave coincidence (upper value)	Hz	Hz
G_{xy}	shear modulus in xy -plane of plate	Pa	lbf/in ²
G_{12}	shear modulus in plane of lamina	Pa	lbf/in ²
h	thickness of plate	m	in
I	second moment of area	m ⁴	in ⁴
k	acoustic wavenumber	m ⁻¹	in ⁻¹
$\mathbf{k}_{mn}$	wavenumber vector = $[m\pi/a, n\pi/b]$	m ⁻¹	in ⁻¹
m	modal number in x -direction		
n	modal number in y -direction		
s	spacing between ribs or corrugations	m	in

x, y, z	coordinates of plate		
γ	dimensionless frequency parameter		
ν	Poisson's ratio for isotropic plate		
ν_{xy}	Poisson's ratio for load in x -direction, contraction in y -direction		
ν_{yx}	Poisson's ratio for load in y -direction, contraction in x -direction		
ν_{12}	Poisson's ratio for lamina		
ρ	density of plate	kg/m ³	*
σ	radiation efficiency of plate		
$\bar{\sigma}, \bar{\sigma}$	average radiation efficiencies of plate		
1, 2, 3	principal material coordinates of plate		

* In the British units for the system to be coherent the mass in lb must be divided by the constant 386.4.

2. INTRODUCTION

ESDU Item No. 02009 (Derivation 11) is concerned with the sound radiation from orthotropic, rectangular plates. The subject of radiation efficiency of orthotropic plates has not been discussed widely in the technical literature. In particular there are few experimental results which can be used to validate the estimates of sound radiation efficiency made by the method in Item No. 02009.

The purpose of this Item is to carry out a validation of Item No. 02009 by:

- (1) considering existing experimental data on sound radiation efficiencies of isotropic and orthotropic plates,
- (2) estimating numerically sound radiation efficiencies of orthotropic plates.

The validation presented refers in general to three aspects.

- (a) Application of the asymptotic model of Leppington *et al.* (Derivation 9) to the estimation of modal sound radiation efficiencies.
- (b) Consideration of the averaged radiation efficiencies of isotropic plates.
- (c) Determination of the averaged radiation efficiencies of orthotropic plates.

Since a verification of the asymptotic model was carried out by Leppington *et al.* (Derivation 9) for relatively high modes, numerical calculations were performed for this Item for the lower modes using the asymptotic approach, as well as direct calculation from Rayleigh's integral (Sections 3 and 8). Modal sound radiation efficiencies for resonant modes were estimated by direct calculation of Rayleigh's integral (Section 8) and independently using an FE/FFT numerical method (Section 6). The method of averaging sound radiation efficiency for isotropic and orthotropic plates, proposed in Item No. 02009, has been compared with the

averaging of sound radiation efficiencies of individual resonant modes and with experimental results. An additional purpose was to assess the lower frequency limit of applicability of the asymptotic model.

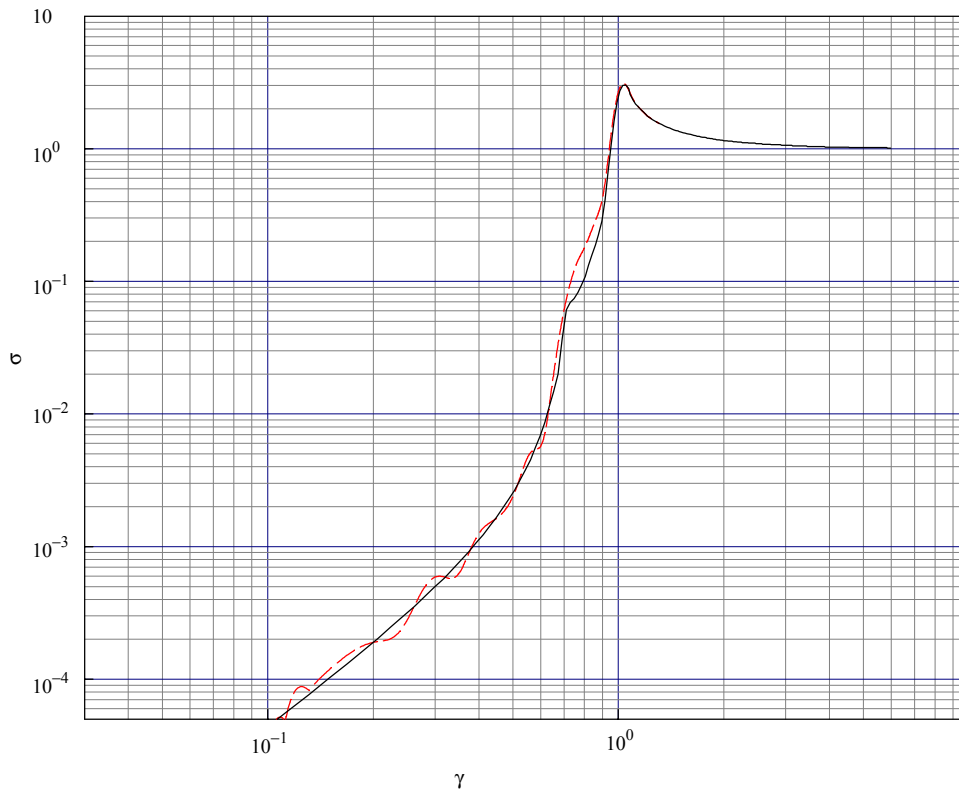
3. MODAL SOUND RADIATION EFFICIENCY FOR SIMPLY-SUPPORTED PLATES

The prediction of radiation efficiencies of single modes is based on an asymptotic method (Derivation 9) which also allows the estimation of averaged modes for isotropic plates. As the asymptotic models are valid for large values of ka and kb , where k is the acoustic wave number and a and b are the lengths of the plate edges, the method can be applied to models based on Statistical Energy Analysis. There are several articles in which the radiation efficiencies of simply-supported, baffled rectangular plates have been estimated for a given single mode. However, none was concerned with asymptotic approximations of radiation efficiency for high values of ka and kb . Wallace (Derivation 6) estimated the radiation efficiency of a simply-supported, baffled rectangular panel for a given mode by direct integration of Rayleigh's integral (Derivation 1).

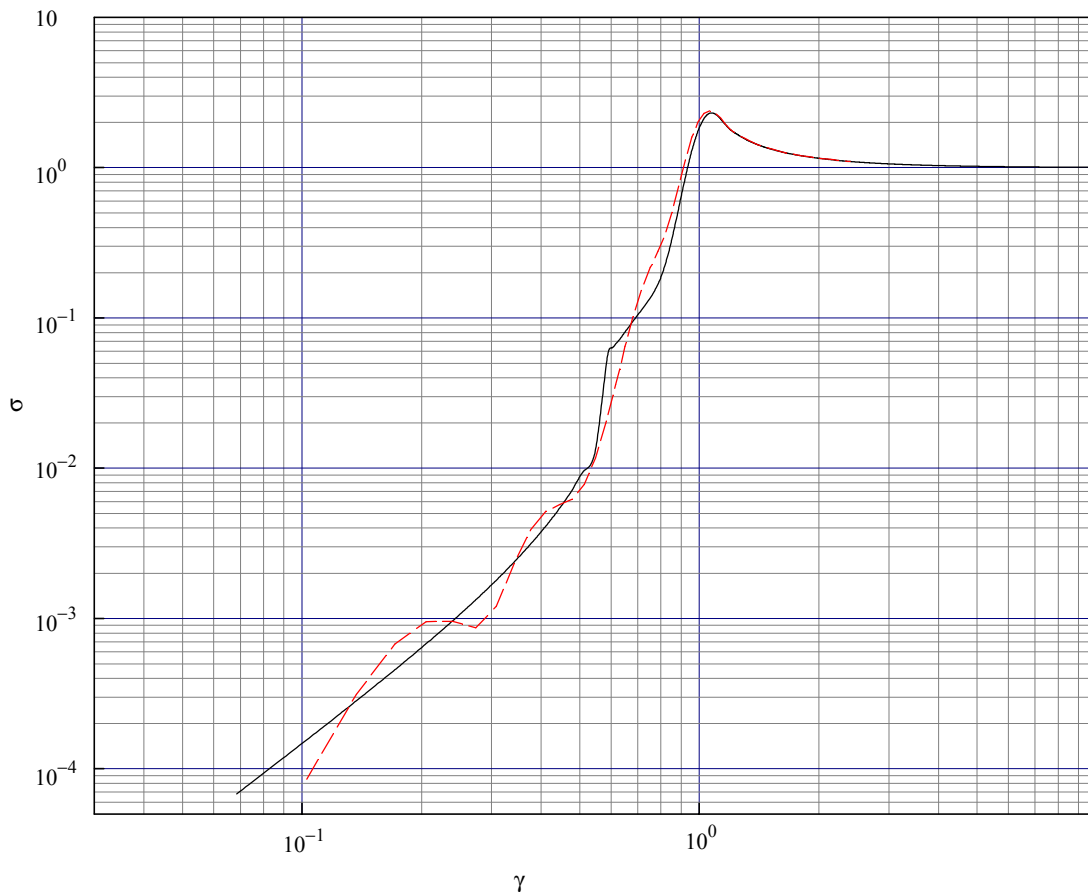
Wallace has provided results for square plates for modal numbers, m and n , which are relatively small (m and n less than or equal to 12). Gomperts (Reference 15) and Chang and Leehey (Reference 16) have carried out similar estimations of the modal radiation efficiencies and have reported that their results agree with those of Wallace. In the case of Gomperts some of the modes calculated are the same as those investigated by Wallace and hence it can be checked directly that the results are the same. Direct calculation of the modal radiation efficiencies was also performed for this Item and the agreement with the results of Wallace was confirmed. Thus, it is reasonable to assume that the results of Wallace are well-established and correct.

Leppington *et al.* have validated their asymptotic method for modal sound radiation efficiency by comparing numerical results from a transformed version of Rayleigh's integral with asymptotic values for the case of one mode ($m = 22, n = 14$) and three aspect ratios of the plate: 0.5, 1.5 and 3. The data published by Wallace (Derivation 6) and by Leppington *et al.* (Derivation 9) do not allow a direct comparison of the modal radiation efficiencies, as the modal numbers selected for the estimates are not the same. The results of Wallace are given for modes with low modal numbers, whereas the good agreement of Leppington *et al.* between the asymptotic and numerical results is expected to occur at higher modal numbers.

In order to check whether modal sound radiation efficiency obtained by the asymptotic method is in agreement with the results from the direct numerical calculation of Rayleigh's integral two modes (11, 11) and (6, 6) were considered for a square plate of dimensions 1 m $\times$ 1 m. It can be seen from Sketches 3.1 and 3.2 that the asymptotic results are in agreement with the results directly calculated from Rayleigh's integral, although the fine detail of the modal radiation efficiency, obtained numerically from Rayleigh's integral, is not reproduced by the asymptotic method. Sketch 3.1 is presented as additional evidence that the asymptotic theory is an adequate representation of the modal radiation efficiency. The same conclusion can be drawn from Sketch 3.2, where results obtained by the asymptotic and exact methods are shown for mode (6, 6).



Sketch 3.1 Comparison of the radiation efficiencies of a simply-supported, baffled rectangular plate, $m = 11$, $n = 11$, $b/a = 1$. — method of Item No. 02009 (asymptotic method); --- from Rayleigh's integral

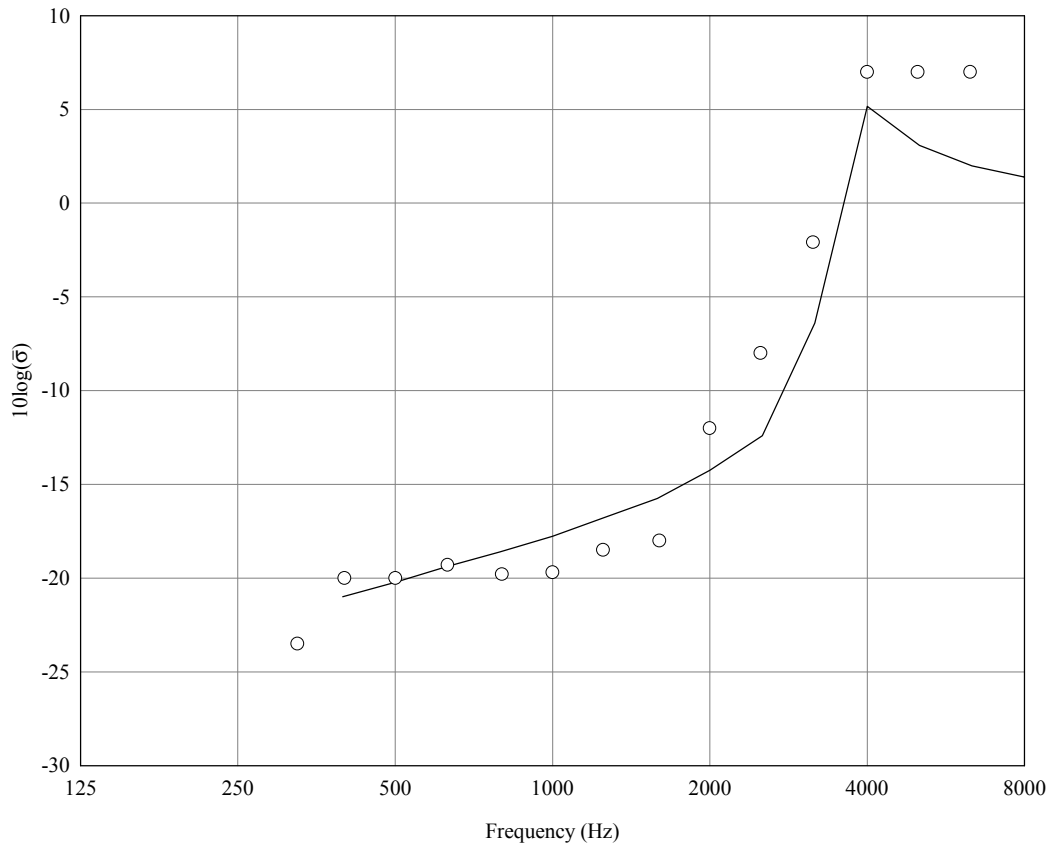


Sketch 3.2 Comparison of the radiation efficiencies of a simply-supported, baffled rectangular plate, $m = 6$, $n = 6$, $b/a = 1$: — method of Item No. 02009 (asymptotic method); ---- from Rayleigh's integral

4. COMPARISON BETWEEN AVERAGED RADIATION EFFICIENCIES IN ONE-THIRD OCTAVE BANDS AND EXPERIMENTAL RESULTS FOR ISOTROPIC PANELS

Experimental results are available for the radiation efficiency of rectangular, isotropic panels (Westphal (Reference 12), Crocker and Price (Derivation 5), von Venzke *et al.* (Derivation 7), McAdam (Reference 14) and Heron (Derivation 8)). These results, which are mostly averaged in one-third octave bands, may be compared with the results of the averaging method introduced in Section 7 of Item No. 02009.

Crocker and Price have produced results for an aluminium alloy plate, 1.97 m long, 1.55 m wide and 3.18 mm thick. Their experimental results, shown in Sketch 4.1, are for a simply-supported plate, mechanically excited, which radiates sound into a reverberation chamber. The experimental results (circles) are compared with the radiation efficiency estimated in one-third octave bands by the method of Item No. 02009. In their article Crocker and Price compare their results with results estimated from the corrected formulae of Maidanik (Derivation 4) for isotropic plates. For the special case of isotropic plates Maidanik's formulae lead to results which are similar to those of Item No. 02009, apart from in the region of coincidence. Crocker and Price reported that their results 'appear to agree well with the theory'.



Sketch 4.1 Comparison of results in one-third octave bands for an isotropic, rectangular plate: o experimental results of Crocker and Price; — estimated by the method of Item No. 02009

Crocker and Price also measured the radiation efficiency indirectly from measurements where the panel was fixed in an opening between two reverberation chambers. In this case the boundary conditions are more similar to those of a clamped plate.

Von Venzke *et al.* tested an aluminium alloy plate, length 3.4 m, width 2.7 m and thickness 4 mm. Their plate was clamped in a frame between two reverberation chambers and excited by a point force. A comparison of the experimental results and the results estimated using method presented in Item No. 02009 is shown in Sketch 4.2.