# INTERACTION OF ACOUSTIC WAVES
# GENERATED BY COUPLED PLATE

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July 1990

Progress Report
Grant Number NAG-1-1077

Submitted to
NASA Langley Research Center
Hampton, Virginia 23665

# Foreword

This report describes the work performed during the period January 1990 to July 1990, under Research Grant Number NAG-1-1077, entitled, "Mobility Power Flow Analysis of Flexible Plate Structure Enclosing an Acoustic Cavity". This is the first progress report under this research grant. Two new students, both studying for a Ph.D with specialization in Structural Acoustics have been working on this project. One addressing the acoustics structure interaction while the other considering the experimental set up and later on will include the structural analysis part of the problem.

The author would like to acknowledge the help from the graduate students who are participating in this research work, the Department of Ocean Engineering and most important the financial support from the Structural Acoustics Division of the NASA Langley Research Center.

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# Abstract

When two substructures are coupled, the acoustic field generated by the motion of each of the substructures will interact with the motion of the other substructure. This would be the case of a structure enclosing an acoustic cavity. In this report, a technique to model the interaction of the generated sound fields from the two components of a coupled structure, and the influence of this interaction on the vibration of the structural components is presented. Using a mobility power flow approach, each element of the substructure is treated independently both when developing the structural response and when determining the acoustic field generated by this component. The presence of the other substructural components is introduced by assuming these components to be rigid baffles. In this report, the excitation of one of the substructures is assumed to be by an incident acoustic wave which is dependent of the motion of the substructure. The sound field generated by the motion of the substructure is included in the solution of the response.

# 1. INTRODUCTION

If a structure is in contact with an acoustic medium, the motion of the structure will generate acoustic waves. These acoustic waves will interact with the motion of the structure, resulting in the classical fluid structure interaction problem. Work has in the past been done [1,2,3] on the interaction of single plate like structures in contact with an adjacent acoustic medium, where different boundary conditions, including the surface of the structure being surrounded by a rigid baffle [1,2] or for free edges [3] are considered.

For coupled structural surfaces surrounded by an acoustic medium, the acoustic waves generated by the motion of one of the substructure surfaces will interact with the motion of the other substructures. That is, in this case, coupling between the substructural elements of the structure is both structural and acoustical.

To investigate this problem of the acoustic interaction between coupled structures, the acoustic field on the inside surface between two coupled plates joined in an L-shaped configuration is considered. The reason for selecting the inside surface is that this can be considered to be the first two components in dealing with the influence of an acoustic cavity. For a rectangular cavity, the analysis would be extended to deal with the six couple plates instead of two, however the concept remains the same. A second reason for considering the inside surface is that on the outside, where the two plates come together, a sharp edge is created. The influence of this sharp edge on the acoustic field especially its diffraction characteristics, can be difficult to model. In any event, the outside field would be outside the scope of modeling the acoustic field in the cavity.

The approach that will be used to deal with this problem is based on the Mobility Power Flow (MPF) [4,5] method. The structure is divided into two components and each component, both for its structural and acoustical response, will be dealt with independently of the other component. However, to introduce the influence of the second component, this is replaced by a rigid baffle. That is, due to the presence of the second component, and its influence on the acoustic field, the effective surface area of the first component is twice the actual surface area, and the motion of the surface of this component is symmetrical about the edge bounded by the rigid baffle which is in a plane perpendicular to this surface. The baffle acts as a reflecting, zero velocity, surface. Using the MPF approach, the equations for the response of the substructures will be developed. A complete solution is sought for both substructures by considering compatibility of motion and forces at the junction, including the modification of the acoustic field when both surfaces are considered, same as in the case of the structural response of the plates [5].

In developing this approach, it is not important what type of excitation is considered since it is the presence of the scattered acoustic field which is of importance here. In this report, acoustic excitation will be considered. The analysis will be formulated following the procedure outlined in [1]. That is the excitation from the incident acoustic field can be represented by two components, one equal to twice the incident pressure amplitude and this is independent of the structure surface, this is the part that can be replaced by mechanical load without any modification of the analysis. The second component will be the scattered pressure component, and this will be present irrespective whether the excitation is by an incident acoustic wave or a directly applied mechanical load. The excitation will be considered to be on the outside surface, and the plate being excited is located in an infinite baffle. This is to avoid the edge effects mentioned previously.

## 2. APPROACH

The structure to be considered in the analysis is shown in Figure (1). The plate on which the excitation from the incident acoustic waves is considered is surrounded by a rigid baffle. On the opposite side of the excitation, in the cavity between the two plates, acoustic waves are generated due to the response of the two plates (Figure 2). The problem of determining this acoustic field is solved by considering the L-shaped plate to be decomposed into two subsystems. The solution to the response functions for obtaining the global response can be obtained from consideration of the three set-ups as shown in Figure (3).

One set-up consists of a simply supported plate surrounded by a baffle and with an acoustic wave incidence on the plate surface on one side, and with a second baffle perpendicular to the plate located along one of the plate edges, the edge that forms the junction with the second plate, (Figure 3(a)).

The second set-up is similar to the first set-up but instead of the incident acoustic wave excitation, the excitation is by an edge moment (Figure 3(b)). The third set-up is similar to the second set-up except for the orientation of the baffles. (Figure 3(c)). It will be assumed that the plates' structural characteristics are identical, same size, thickness and damping. With the introduction of the baffles, some of the expressions developed in [4], which deals with a similar problem but excludes the interactions of the acoustic waves generated by the two elements of the L-shaped plate structure, will be modified. The baffles can be treated as reflecting surfaces and hence the three set-ups discussed in the previous paragraph will be equivalent to the three set-ups shown in Figure (4), with one condition. An incident acoustic wave on a rigid surface is reflected without any change in phase. Therefore, the amplitude of the motion of the image plate surface is the same as that for the real plate surface. If the origin is placed at the location of the baffle, and if W represents the displacement, and y is the coordinate perpendicular to the baffle, then

$$W(-y) = W(y) \qquad 1.$$

where $W(-y)$ represents the displacement of the image plate and $W(y)$ represents the displacement of the real plate. This will modify the evaluation of the scattered pressure component on the side of the plate opposite the excitation side, (in the case of the source plate). This scattered pressure component was neglected in reference [4]. Similarly for the case of the edge moment excitation. For the second set up for the scattered pressure on the side of the baffle, the same conditions as in the first set up applies. There is reflection of the scattered pressure due to the presence of the baffle. For the third set-up, the arrangement is symmetrical, and therefore the same scattered pressure applies on both sides of the plate. An additional condition that is being assumed for this third set up is that the plate is surrounded by a rigid baffle. This is not necessary, free boundary conditions or other boundary conditions can be assumed [3]. However, since the objective of the development of the solution is as an initial step to solve the acoustic cavity problem, there is no benefit to consider any other boundary conditions but with a baffle all around.

## 3. FORMATION OF THE SOLUTION

### 3.1 System in Figure (4(a))

The response of this system with all four edges simply supported and with an acoustic wave obliquely incident on one side of the plate can be obtained from a solution to the wave equation of motion describing the response of the plate. The excitation pressure can be defined as:

$$p(x,y,t) = 2\, p_i\, (x,y,t) + p_{s1}(x,y,z_+,t) + p_{s2}\, (x,y,z_-,t) \qquad 2.$$

where $p_i$ is the incident pressure, including both the external acoustic field and the pressure created by the second plate, $p_{s1}$ is the scattered pressure component acting on the z+ side and $p_{s2}$ the scattered pressure component acting on the z- side, (figure 4(a) for coordinate system). The solution to the wave equation can proceed in the same way as in reference [4].

The term that changes is the term $W(\beta)$ which forms part of the expression for the scattered pressure. The term is the spatial transform of the response of the plate in the direction perpendicular to the edge which will be connected to the second plate. For the present case, this term has two components, since the scattered pressure is considered on both sides of the plate. However, the two components are not identical since a reflecting baffle perpendicular to the plan of the plate is located on the one side opposite the excitation. Thus (refer to equation (A.23) in [4]).

$$\frac{1}{D_p}\int_o^b p_s(\xi)\,\sin\,(k_2\xi)\,d\xi = \frac{j}{2\pi^2 a}\left[\frac{m\pi}{a}\right]^2 \frac{W^2\rho_o}{D_p}\int_{-\infty}^{\infty} I(\beta)\,W(\beta)\,S(\beta)\,d\beta \tag{3.}$$

where

$$p_s\,(y) = p_{s1}(y) - p_{s2}(y) \tag{4.}$$

$$W(\beta) = W_1(\beta) + W_2(\beta) \tag{5.}$$

$$W_1(\beta) = \int_o^b W(y)\,e^{j\beta y}\,dy \tag{6.}$$

$$W_2(\beta) = 2\int_o^b W(y)\,\cos\,(\beta y)\,dy \tag{7.}$$

where b is the length of the plate along the direction which is perpendicular to the edge which will form the junction with the coupled plate.

### 3.2 System in Figure (4(b)

In this case, the plate is subjected to the same form of excitation as the system in Figure (4(a)) with the additional excitation by an edge moment. An incident pressure on the inside surface of the plate is considered to 'account' for the acoustic field generated by the other plate when coupled. This pressure will be independent of the response of this plate. For the scattered pressure components, these are identical to those given by Equations

(4) and (7). The solution for the rest of the system is identical, from this point on to that given in reference [4].

### 3.3 System in Figure (4(c))

In this case, the excitation on the system are from an edge moment, and on one side from an external acoustic pressure representing the acoustic field generated by the other plate when coupled. The scattered pressure components on both sides of the plate are identical because of the symmetry in the location of the baffles. For this system, the expressions for $W(\beta)$ for both sides of the plate would be given by Equation (7).

Having described the excitation and the expressions for the scattered pressure the solution follows as in reference [4].

### 3.4 All Systems

For all the subsystems considered in the previous subsections an incident pressure that will represent the acoustic field generated by the other substructures is considered. This incident pressure will be independent of the response of the system, but since it will influence the vibration of the plate, it will contribute to the scattered pressure. this contribution can be independently considered.

An expression for this incident pressure can be obtained after solving for the scattered pressure components from the other substructures. The scattered pressure is obtained from continuity of particle velocity at the surface of the substructure. The value of this scattered pressure component can be evaluated at any other arbitrary point in space. Therefore, the expression for the incident pressure on one substructure due to the scattered pressure from the second substructure can be obtained by evaluating the scattered pressure from the second substructure on the surface of the first substructure and treat this as a incident acoustic wave. The response of the first substructure to this incident pressure can be treated as described in subsections 3.1, 3.2 and 3.3 or alternatively treat this as a completely independent form of excitation.

## 4. CONCLUSION

Presented in this paper is a MPF analysis of the interaction of the acoustic waves generated by two coupled plate substructures. The analysis can be extended to other coupled plate substructures to enclose an acoustic space between six coupled plates. The analysis builds on work that was done previously on the use of MPF to deal with acoustic excitation of a structure including the scattered pressure component generated by the motion of the structure. In the previous work, it was assumed that no interaction takes place between the coupled structural components apart from that due to the structural coupling.

It would be expected that the influence of the acoustic interaction is not so significant when dealing with interactions through an open acoustic space. However, as the acoustic medium is enclosed by more components of the structure, standing waves can be set up within the acoustic medium which would make up for a very strong acoustic field, and which can interact strongly with the response of elements of the structure. A complete solution for the enclosed acoustic cavity is being formulated.

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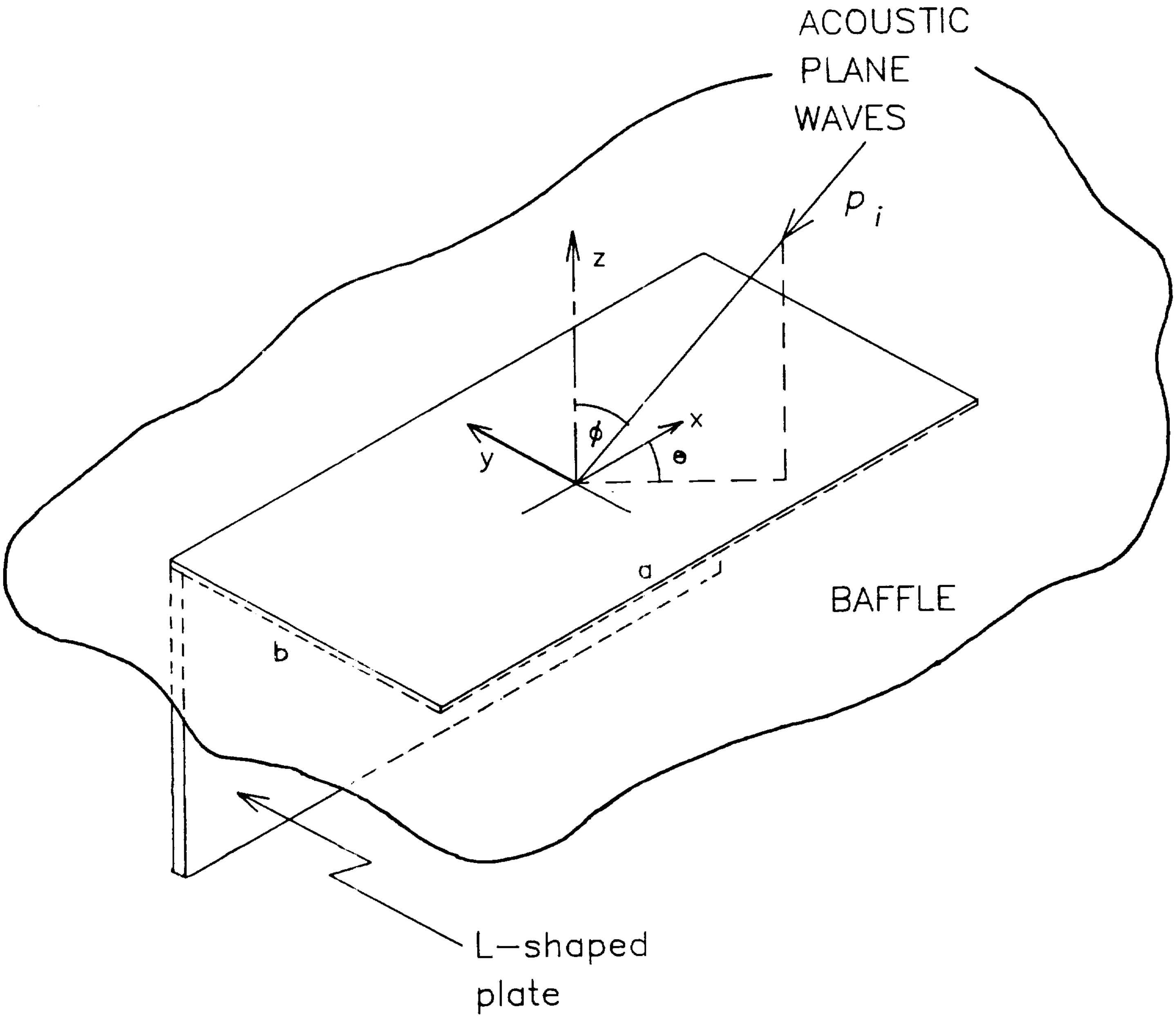

Figure 1. Coupled plates configuration and axes.

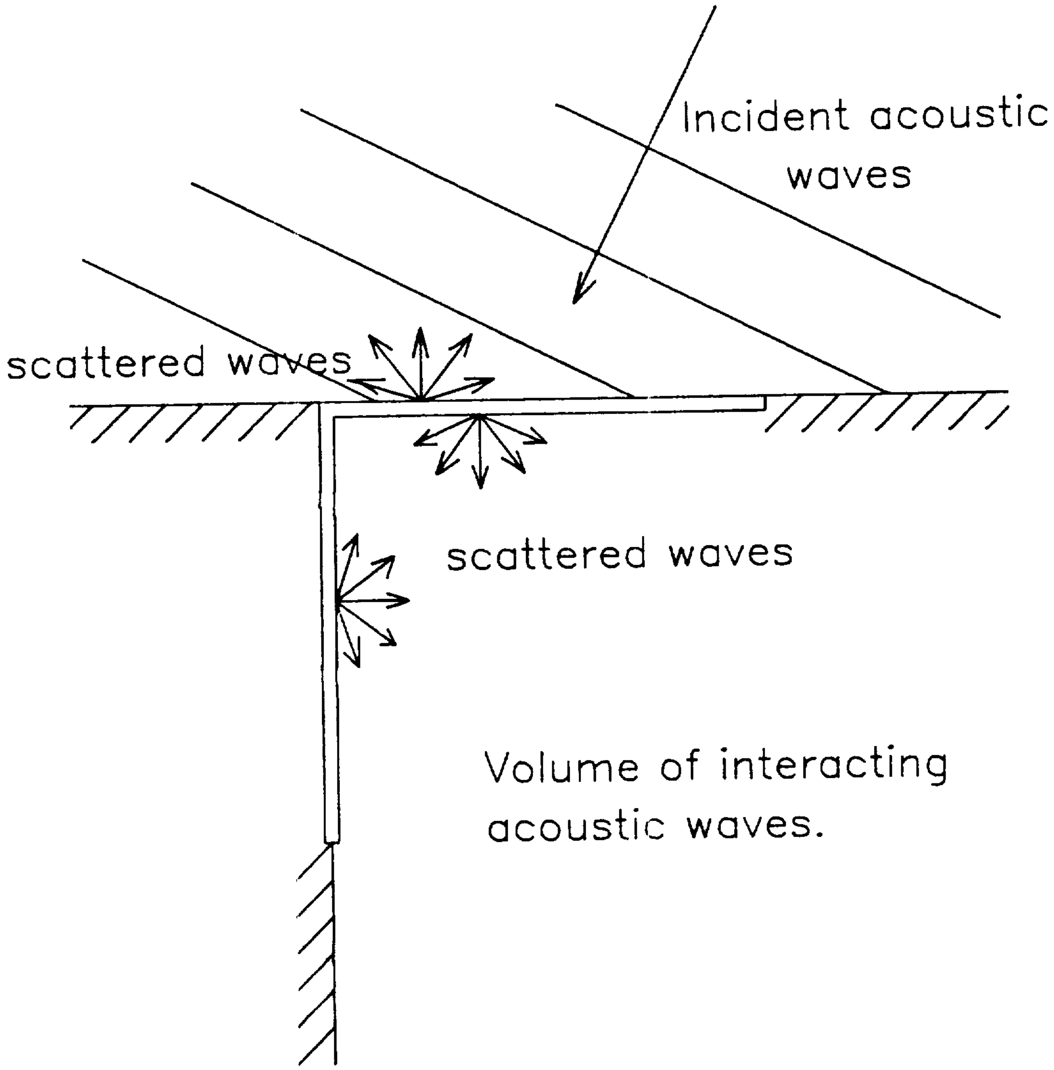

Figure 2. Side view model of L–shaped plate.

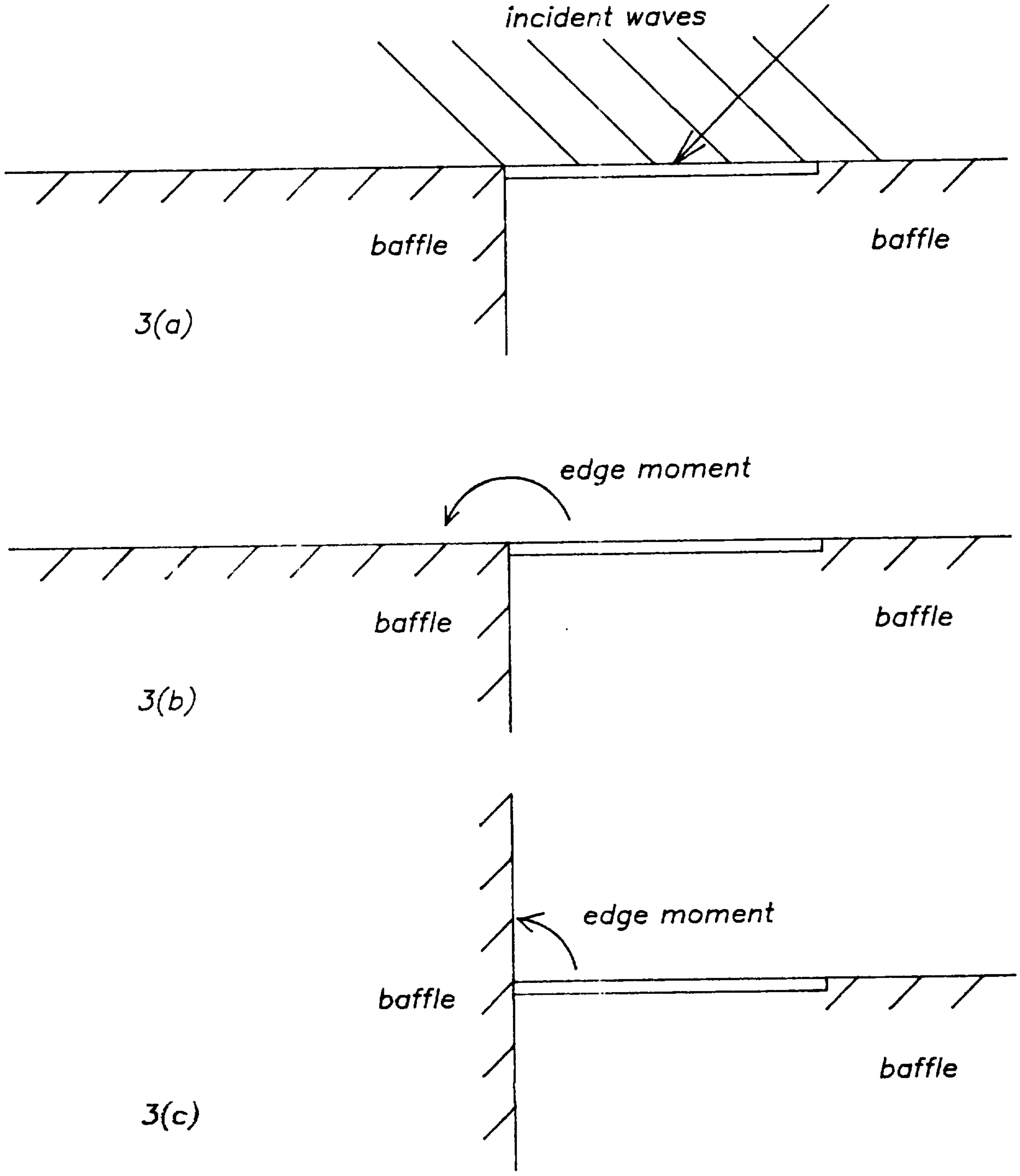

Figure 3. MPF subsystems models.

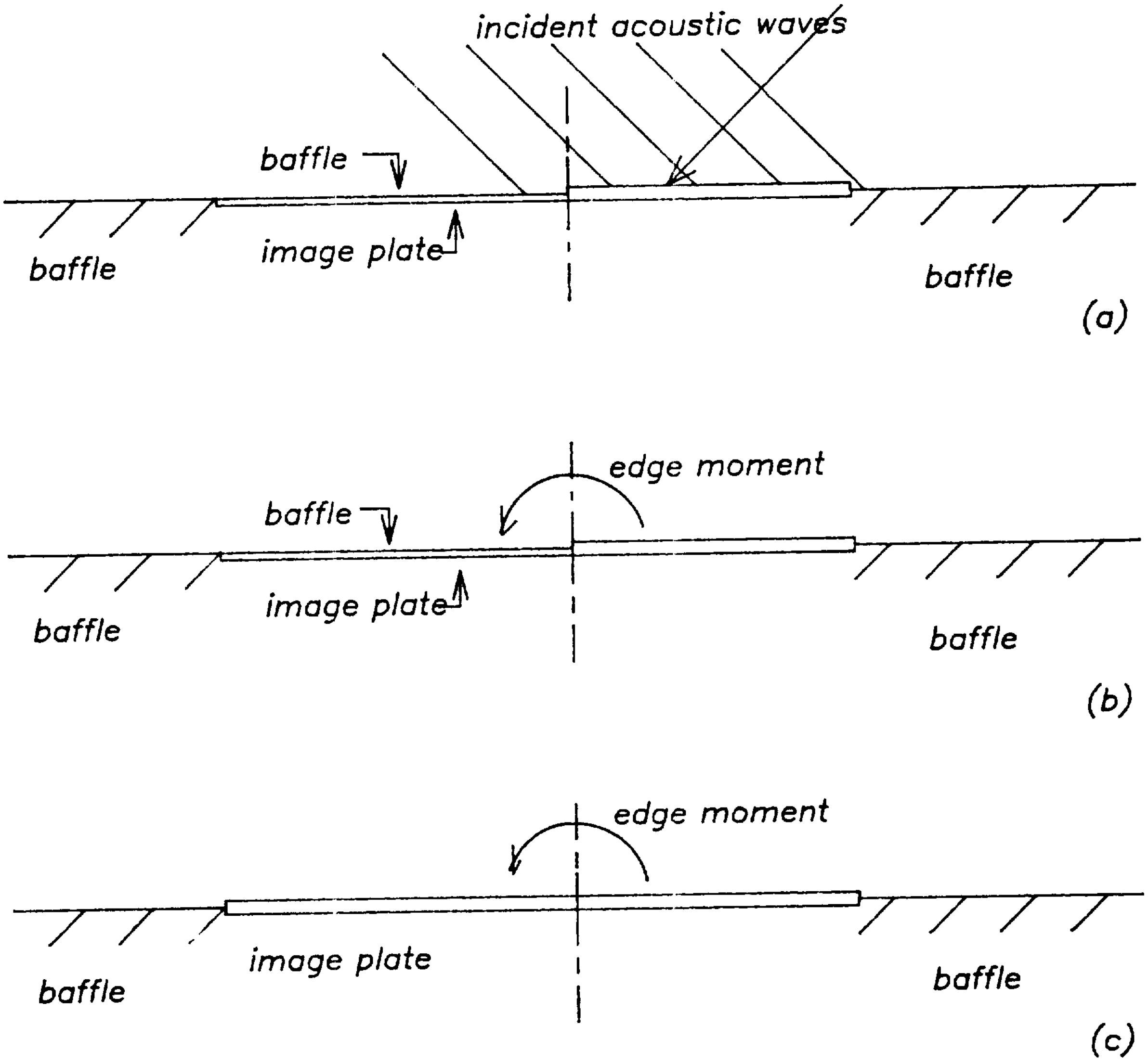

Figure 4. Equivalent models for the coupled plates.