inter.noise 2000
The 29th International Congress and Exhibition on Noise Control Engineering
27-30 August 2000, Nice, FRANCE

I-INCE Classification: 7.6

MASS LOADING EFFECTS ON THE PARAMETERS OF A STATISTICAL ENERGY ANALYSIS EXPERIMENTAL MODEL

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Keywords:
STATISTICAL ENERGY ANALYSIS, MASS LOADING, HIGH FREQUENCY, EXPERIMENTAL TECHNIQUES

ABSTRACT
The effects of the added mass of instrumentation on a structure in the high frequency range, where high modal density and overlap occur, were investigated. The study was carried out to identify the possible errors introduced in a experimental statistical energy analysis (SEA) model built using frequency response functions (FRFs). It was performed using different instrumentation to acquire sets of measurements, each of which would be devoted to one particular measurement error. The results obtained by postprocessing the measurements showed that the coupling loss factors (CLFs) of the experimental SEA model were never affected by the measurement errors, whereas the other parameters could be affected by the type of measuring instrumentation selected.

1 - INTRODUCTION
The effects of the mass loading of instrumentation are described in the literature [1-3], but the analysis is limited to the low frequency range, where low modal density and overlap occur. The aim of this work, which examines the high frequency range, was to verify the possibility of correcting the experimentally derived FRFs and to assess the effects of the measurement errors on the parameters of an experimental SEA model.

2 - CORRECTION FORMULAS
The use of improper instrumentation to perform FRF measurements can introduce various kinds of errors. In this work, we used an experimental setup consisting mainly of a shaker, connected to the structure by means of a pushrod and an impedance head. The output was measured by accelerometers. In the experimental setup, the instrumentation could affect the results because of the additional mass introduced by the impedance head and/or by the accelerometers.
Assuming that the value of the additional mass is known, we can develop a formulation which connects it and the biased measurements to the exact measurements. In the case of a driving-point FRF, only the impedance head error is important. The FRF can be expressed as

$$H_{ii}^{c} = \frac{H_{ii}^{m}}{(1 - m_h \cdot H_{ii}^{m})} \tag{1}$$

where H is the FRF (acceleration/force). The subscripts indicate the input and output points; m_h is the additional mass introduced by the impedance head, the superscript m indicates a biased measure, and c indicates a correct measurement. Thus, we can readily correct a driving-point FRF using the apparent mass of the impedance head−which is also the value of the additional mass structure−and the biased measure. Interestingly, the additional mass is not simply the impedance head mass, but it is the

mass that can be determined for an FRF with no structure attached to the impedance head. Thus, the additional mass depends also on how the sensor was constructed.
In the case of an error in the output point, both effects (impedance head and accelerometers) may be present. The correction formula is

$$H_{oi}^{c} = \frac{H_{oi}^{m}}{(1 - m_h \cdot H_{ii}^{m}) \cdot (1 - m_a \cdot H_{oo}^{m})} \tag{2}$$

where m_a is the additional mass introduced by the accelerometers, H_{oi} is the driving point between a generic output point and the input, and H_{oo}^{m} is the driving-point FRF measured in the output point biased with a mass m_a. It is impossible to measure H_{oo}^{m} unless the impedance head used for measurements introduces an error equal to that of the accelerometer. Besides obtaining the correct measurements, we would also have to perform as many driving-point measurements as there are output points. Hence, it is impossible to correct for accelerometer errors.
Practical experience showed that the errors for the additional instrumentation mass become increasingly important at high frequencies, where inertia can make even a small mass produce considerably distorted results. Since the error is dependent upon both the frequency and mass−thereby making it virtually impossible to know the unaffected frequency range beforehand−we wanted to determine the effects of the error for an SEA experimental model.

3 - EFFECTS OF ADDED MASS ON THE SEA MODEL

The test structure consisted of three plates linked by a bolted T-joint (Figure 1). The right and center plates were 2 mm thick; the left plate was 3 mm thick. All the plates were damped to meet SEA applicability requirements. The reference measurements were made with an impedance head having an additional mass of 2.2 g and accelerometers whose total mass was 0.65 g. Measurements were performed up to the 8 000 Hz one-third octave band. A check of the FRF shapes confirmed that the measurements could be used to build the SEA reference model, since there was no error introduced by the instrumentation. Two additional sets of measurements were made to separately determine the effects of the impedance head and the accelerometers. In the first, a mass of 12 g was added between the impedance head and the structure, with the accelerometers having the same mass (0.65 g). In the second, the impedance head was directly connected to the structure, and accelerometers with a total mass of 11 g were used.
The data were processed to extract the SEA model parameters, i.e., equivalent mass, modal density, and the coupling loss factors. Figures 2 to 7 show the exact values for the parameter and the biased model. As visible in Figure 2, the bias produced by an impedance head did not affect the estimation of its equivalent mass. The same result was found for the coupling loss factors (Figure 3), which normally constitute the experimental model's foremost parameter. The error was considerable in the case of modal density (Figure 4):

$$n(f) = 4 \cdot m \cdot G(f) \tag{3}$$

where $G(f)$ is the conductance (real part of the mobility) for a driving-point FRF and m is the subsystem's equivalent mass. While the mass is correctly estimated, the conductance is biased: the measured value is underestimated because of the additional mass. It should be noted that an exact value for the equivalent mass in a SEA model does not necessarily mean that the measurements are correct, since the equivalent mass is derived through processing of the measurements−which, in the case illustrated, compensated for the errors. Thus, the modal density error is directly proportional to the measured conductance error.
In the case of the accelerometer-induced error, the results show that the equivalent mass was significantly overestimated. Also, the thinner the plate was, the more evident the error exhibited, since the thinner plates have an higher mobility and therefore are more sensitive to the presence of an additional mass (Figure 5). In addition, the coupling loss factors were not affected by the bias (Figure 6). The modal density had an error proportional to that of the equivalent mass (Figure 7). In this case, the conductance was measured correctly, since there was no additional mass under the impedance head. Thus, the only variable affecting the modal density estimation was the equivalent mass.

4 - CONCLUSIONS

It has been shown that a bias in experimental measurements can be corrected using analytical formulations only when the error has been introduced by the additional mass of the impedance head. Because it was impossible to correct the error in all situations, the investigation was focused on the effects of

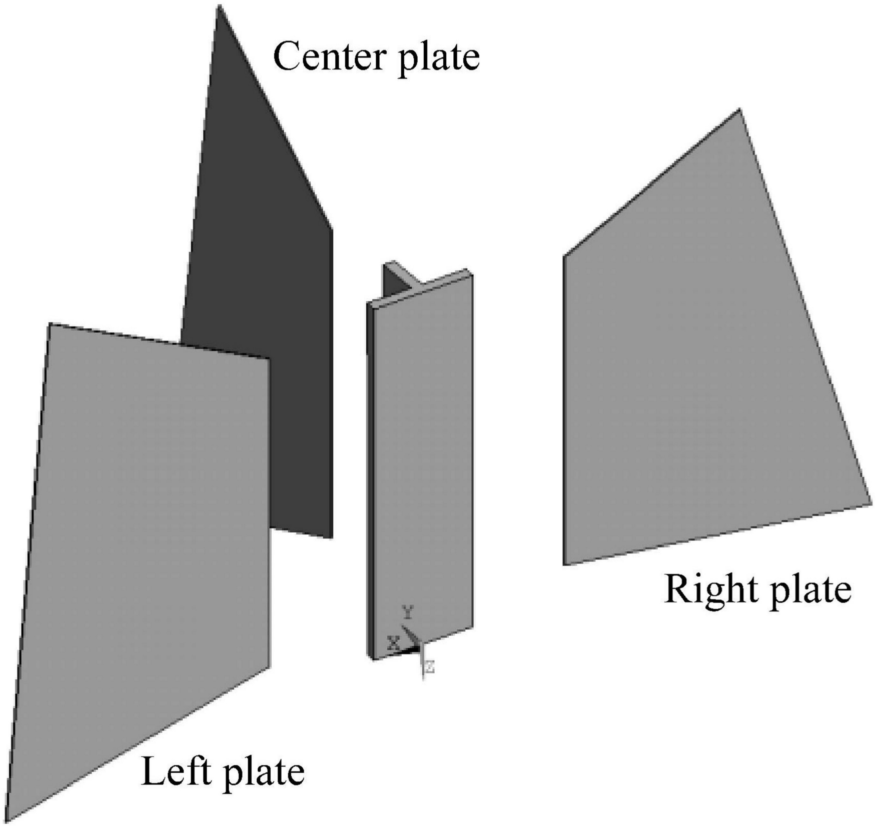

Figure 1: Structure used for experimental measurements.

the error in estimating the parameters of an experimental SEA model. Using several sets of measurements, it was demonstrated that the coupling loss factors were always determined correctly, even when the measurements were biased. In the case of an impedance head error, the equivalent mass was also correct, even though the modal density was wrong. In the case of accelerometer-generated errors, both the equivalent mass and the modal density were wrong. Thus, if the main objective of an experimental SEA model is to determine the coupling loss factors, the measurements can be carried out on any kind of instrumentation.

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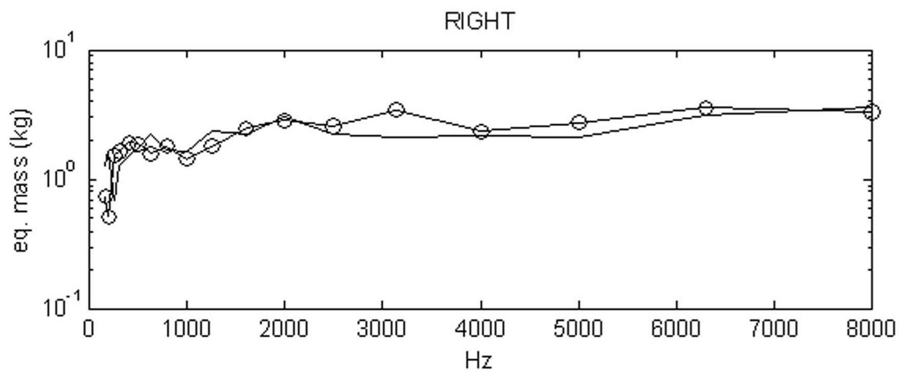

Figure 2: Equivalent mass for impedance head error (straight line − reference; dotted line − biased model).

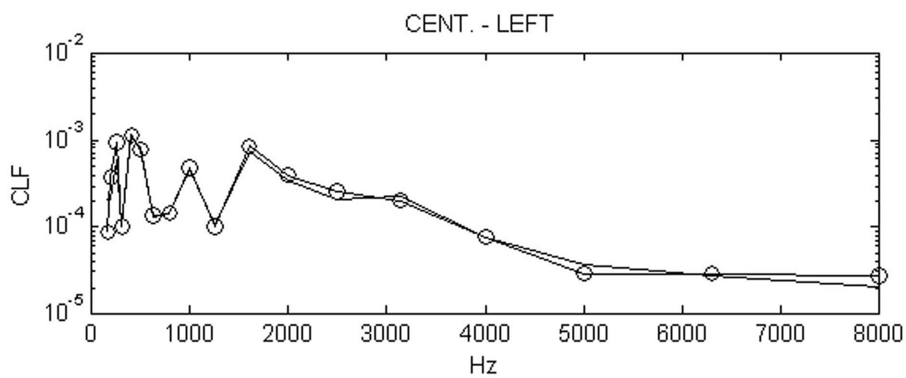

Figure 3: Coupling loss factor center to left plate for impedance head error (straight line − reference; dotted line − biased model).

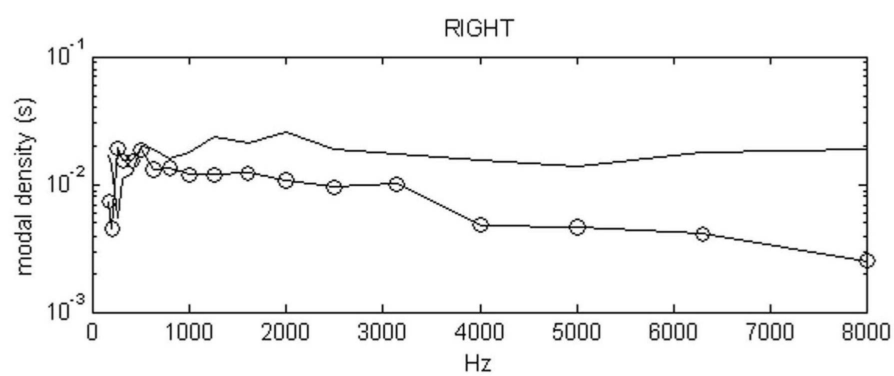

Figure 4: Modal density for impedance head error (straight line − reference; dotted line − biased model).

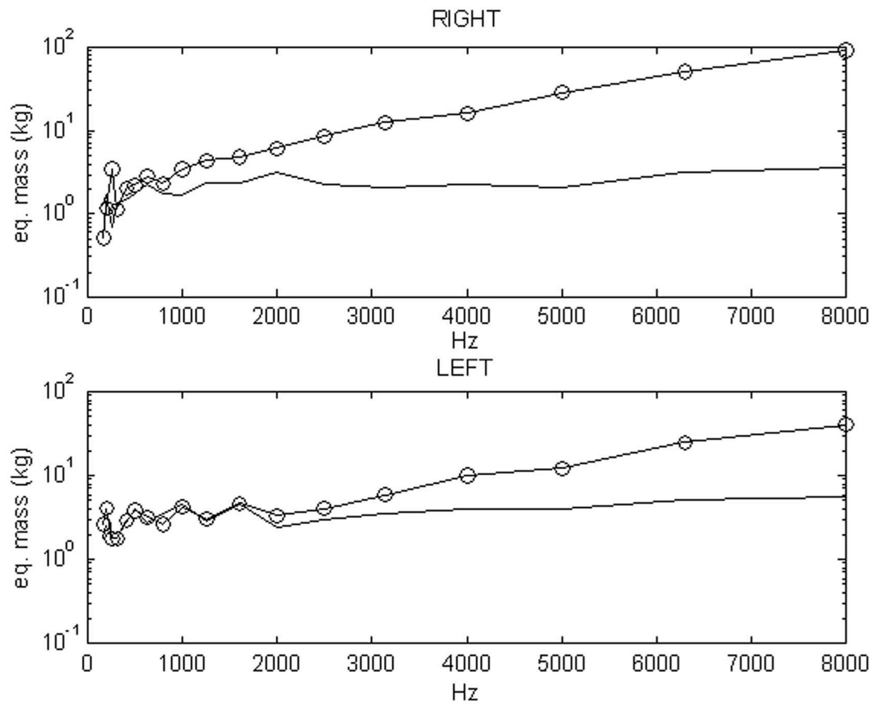

Figure 5: Equivalent mass for accelerometer error of right and left plate (straight line − reference; dotted line − biased model).

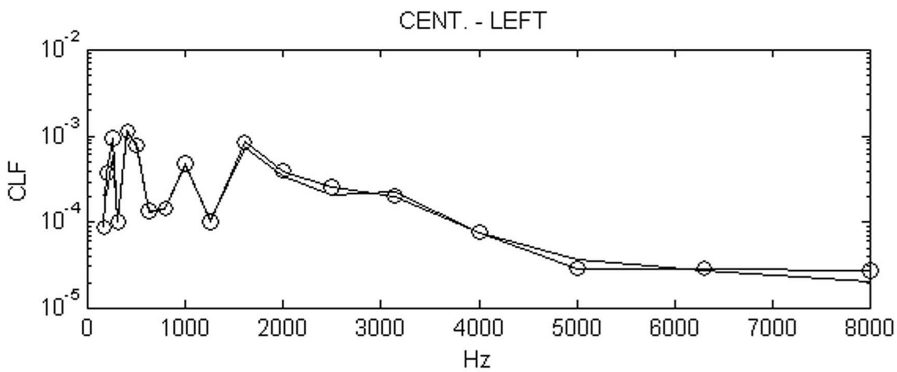

Figure 6: Coupling loss factor center to left plate for accelerometer error (straight line − reference; dotted line − biased model).

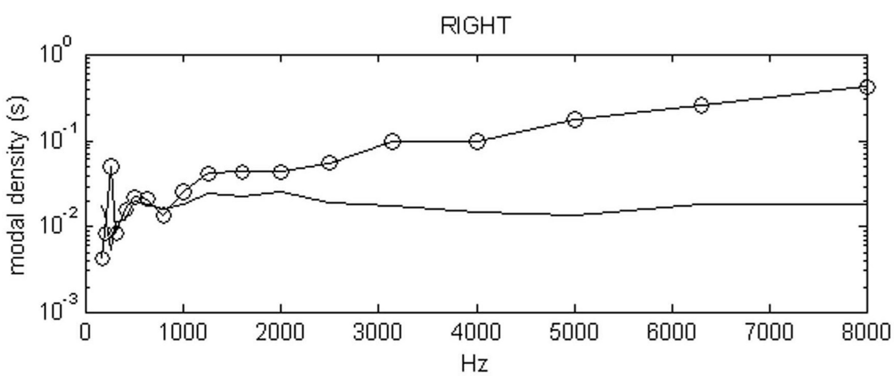

Figure 7: Modal density for accelerometer error (straight line − reference; dotted line − biased model).