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THE USE OF FINITE ELEMENT METHODS IN SEA APPLICATIONS

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1. INTRODUCTION

A programme of work is underway to develop a general Statistical Energy Analysis (SEA) program to predict aircraft internal noise. As part of this work a general SEA program has been developed applicable to beam structures and is reported in ref(1).

The SEA program is based on impedance methods, as described by K.Heron (2), which assumes that each element is rigidly connected to its neighbour at the beam junction.

This assumption is not always true, for example where several beams meet at a beam junction the cleating arrangement may favour a particular load path, such that one of the beams is weakly coupled to the joint. Using the general SEA method to model such a beam junction would not represent the true structure and give rise to inaccurate predicted noise levels.

The objective of this work was to investigate the use of finite element methods (FEM) to augment the SEA model and enable complex beam junctions to be taken into account. It is argued that the use of FE models is valid, in that the beam junction has a low modal density within the frequency range of interest. (eg. 250 Hz to 8000 Hz)

6. REFERENCES

[1] A.W.Rossall,P.C.Wood,'SEA of a Cabin Box Structure by Progressive Stages - Phase I Beams', RP755, May 1989.

[2] K.Heron,'SEA based on Impedance methods',Private Communication, RAE - WHL 1988.

[3] P.Bremner,K.Heron,J.M.O'Keffe,'A Finite Element Solution for the Prediction of Transmission Loss and Radiation Efficiency of Panels' , Industrial Vibration Modelling, Proceedings of Polymodel9, May 21,1986.

7. ACKNOWLEDGEMENTS

The author wishes to thank Dr.K.Heron (MOD Farnborough) for his helpful comments and encouragement in this work.

2. STATISTICAL ENERGY ANALYSIS

SEA is a technique for noise and vibration analysis in complex systems. Essentially the method analyses the vibrational energy flow around the structure, in terms of the energy storage capacity of its various sub-systems, their internal dissipations and system-to-system transfers. The calculations are normally conducted in a number of separate frequency bands, over which the mean response is calculated.

The term 'statistical' is used in the sense that the main aim is to predict the mean response over a frequency band. If the input vibrational power is known, the theory provides estimates of the 'energy' in each sub-system, and hence their vibrational amplitudes.

The general theory is outlined in ref(1), and shows how a set of transmission coefficients (TC's) can be obtained by considering the power flow at a beam junction. Energy travels toward the beam junction carried by a wave type, which then migrates into the other beams connected to the junction, travelling in possible different wave types. Some of the wave energy may also be reflected at the beam junction, again travelling in possible different wave types. The TC's are calculated by considering the ratio of the energy of the incoming wave, to the energy in the outgoing wave types and by conservation of energy the sum of the ratios must equal unity.

Essentially the TC's describe how wave energy is transported around the beam network, and represent the major calculation in the SEA program.

3. FINITE ELEMENT IMPEDANCE DATA

The finite element model is constructed such that the beam ends link into a rigid body element which defines the beam contact area. The independent grid point of the rigid body is located at the centroid of the beam cross-section.

A direct frequency response analysis was used to obtain the beam junction impedance data.

The number of elements and mesh density was related to the wave length of the travelling waves and was usually fixed by the bending wave velocity. In practise the cost of running such models was negligible, and the mesh density chosen usually was well within the wave length tolerance. The error associated with mesh refinement is discussed further in ref(3).

4. DISCUSSION AND RESULTS

Several models have been investigated, increasing in complexity, from the simple case of two rectangular beams in-line, to the complete picture frame structure studied in ref(1).

4.1 Two Rectangular Beams In-line

As would be expected for two in-line rectangular beams the input power is transferred to the second beam without any energy loss occurring at the beam junction. In other words there is no reflected energy at the beam junction, and there is no interaction between the wave types. The resulting TC matrix is shown in table(1) and it can be seen that the wave types migrate through the beam junction perfectly. (ie. L1 = L2, etc.)

This result is predicted by the general SEA program given in ref(1). The simplicity of this example provides a good test for the FE/SEA method and enables the accuracy of this technique to be assessed.

Arbitrary beam dimensions of 0.01 * 0.01m were chosen and the corresponding FE model is shown in figure(1). Note that the beam end locations on the FE model are connected to a rigid body which connects the whole end face of the model.

It must be noted that simple beam theory assumes plane sections remain plane. However, only the ends of the FE model remain plane, where the beam ends are located, the central portion of the model is not constrained in this manner and is fully elastic. Hence there is an incompatibility between the beam theory employed by the SEA program and the fully elastic solution provided by the FE method.

This incompatibility gives rise to small off diagonal terms in the TC matrices which represent migrating travelling waves. From table(2) it can be seen that these terms are negligible in comparison with the leading diagonal terms indicating the accuracy of the method.

4.2 Two Rectangular Beams in-line and offset

Having shown that the method works for two in-line beams, an added complexity is to offset the beams, such that a longitudinal wave in beam 1, induces bending waves in beam 2., etc.

Figure(2) shows the FE model used in the analysis and the position of the two offset beams. The dimensions of the beam are 0.01 * 0.01m, with an offset of 0.01m, and an overlap length of 0.005m.

The FE/SEA and SEA results for 250Hz and 8000Hz are given in table(3) for comparison. It can be seen that for 250Hz the TC matrices are almost identical, and at 8000Hz the comparison yields no significant differences.

4.3 Picture Frame Structure.

The 'picture frame' was the first real structure analysed and both measured and predicted results for a range of drive points, are given in ref(1).

The 'picture frame' is a simple welded rectangular structure made up from symmetric 'L' shaped beams, 4.75mm thick by 50mm external dimension, and measuring 1.22m by 1.524m overall. Figure(3) shows a sketch of the complete structure.

The finite element model of the beam junction is shown in figure(4) and it will be observed that the SEA beam ends are attached at the centriod of the beam cross-section via a rigid body element.

The TC matrices derived using the general SEA program and the modified FE/SEA program are presented in table(4). Again the discrepancy at 250Hz is minor, indicating that the junction is behaving like a rigid body. At 8000Hz the discrepancies between the two methods are more pronounced, however the general levels remain similar. Note that the FE/SEA method predicts all wave types will interact to some degree.

Having obtained the modified TC data for the picture frame junction it was a relatively simple task to predict the response of the whole structure. The results of ref(1) are reproduced here, and overlayed are the results obtained using the FE/SEA program. See figure(5), which shows typical measured and predicted results for drive points 2 and 3. As expected, the use of a more detailed model at the beam junction provides better estimates for the structural response.

5. CONCLUSIONS

The general conclusion is that the technique works, and has been successfully used to improve the general SEA method in the case of the 'picture frame' structure.

The technique is generally applicable to beam junctions which are complex, and cannot be considered to be rigid.

The method can be implemented with little effort and requires a further sub-routine in the standard SEA program to manipulate the FE mobility data.

FINITE ELEMENT METHODS IN SEA APPLICATIONS

Table(1) Transmission Coefficients generated by the general SEA program for Two Beams In-line.

TAU-L	Zero				Symmetric
TAU-T					
TAU-BY					
TAU-BZ					
TAU-L	1.0000				Zero
TAU-T		1.0000			
TAU-BY			1.0000		
TAU-BZ				1.0000	

Table(2) Transmission Coefficients generated by the FE/SEA program for Two Beams In-line. Model 07

	250 (Hz)				8000 (Hz)			
TAU-L								
TAU-T						0.0017		
TAU-BY			0.0021				0.0558	
TAU-BZ				0.0021				0.0558
TAU-L	1.0000				1.0000			
TAU-T		1.0000				0.9983		
TAU-BY			0.9979				0.9442	
TAU-BZ				0.9979				0.9442

Block dimensions - 5 * 10 * 10 (mm)

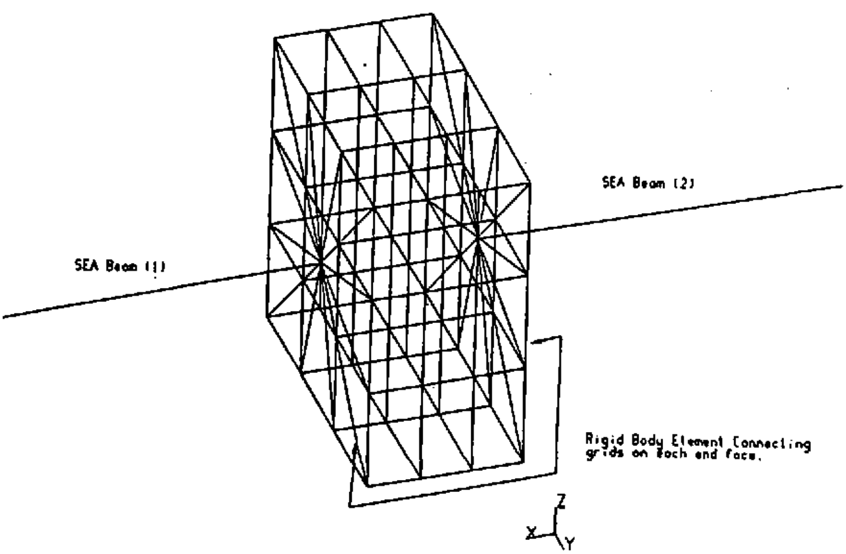

Figure (1) Model 07 - Two Beams In-line.

Table(3) Transmission Coefficients generated by the general SEA program for Two Beams In-line Offset

ISO 1/3 rd. Octave Centre Frequency 250 (Hz)

	SEA program				FE/SEA program			
TAU-L	0.0035			0.0409	0.0039			0.0409
TAU-T		0.0028	0.0371			0.0036	0.0364	
TAU-BY		0.0371	0.0020			0.0364	0.0075	
TAU-BZ	0.0409			0.0024	0.0409			0.0135
TAU-L	0.9147			0.0409	0.9144			0.0409
TAU-T		0.9230	0.0371			0.9222	0.0378	
TAU-BY		0.0371	0.9238			0.0378	0.9184	
TAU-BZ	0.0409			0.9158	0.0409			0.9048

ISO 1/3 rd. Octave Centre Frequency 8000 (Hz)

	SEA program				FE/SEA program			
TAU-L	0.0601			0.1558	0.1073			0.1450
TAU-T		0.0507	0.1463			0.1650	0.1090	
TAU-BY		0.1463	0.0391			0.1090	0.1885	
TAU-BZ	0.1558			0.0432	0.1450			0.2558
TAU-L	0.6284			0.1558	0.6022			0.1454
TAU-T		0.6568	0.1463			0.5835	0.1425	
TAU-BY		0.1463	0.6683			0.1425	0.5601	
TAU-BZ	0.1558			0.6452	0.1454			0.4538

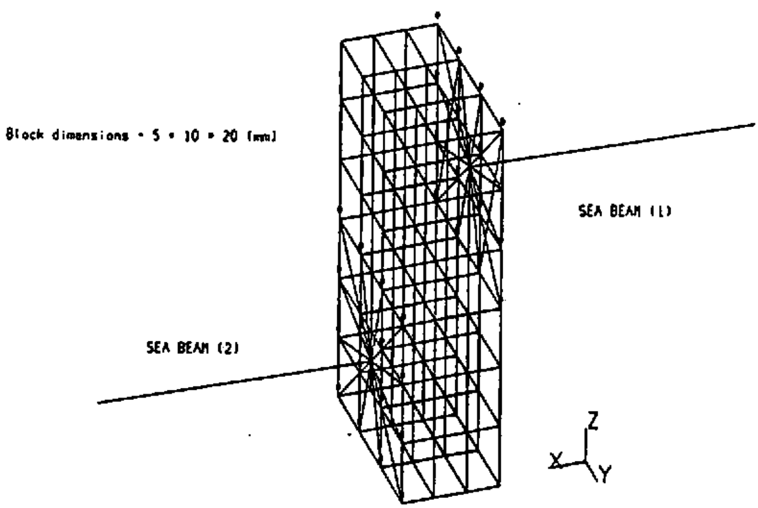

Figure (2) Model 10 - Two Beams In-line and Offset.

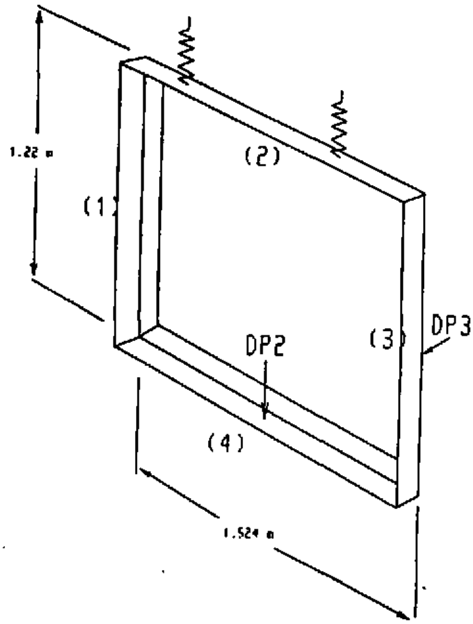

Figure (3) Sketch of Picture Frame Structure.

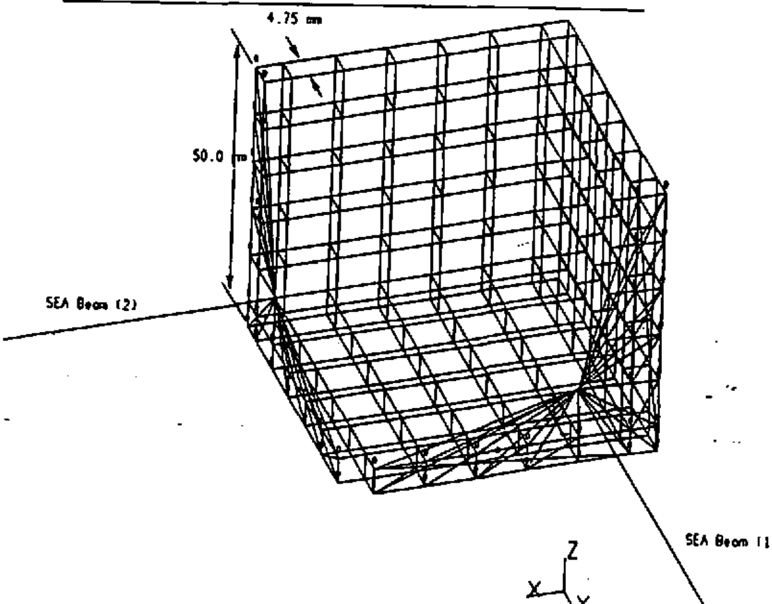

Figure (4) Model 03 - Picture Frame Junction.

Table(4) Transmission Coefficients generated by the general SEA program for the Picture Frame.

ISO 1/3 rd. Octave Centre Frequency 250 (Hz)

	SEA program				FE/SEA program			
TAU-L	0.8260		0.0063	0.0185	0.8230	0.0002	0.0087	0.0234
TAU-T		0.9647	0.0036	0.0039	0.0002	0.9531	0.0013	0.0058
TAU-BY	0.0063	0.0036	0.5768	0.0017	0.0087	0.0013	0.5612	0.0010
TAU-BZ	0.0185	0.0039	0.0017	0.3073	0.0234	0.0058	0.0010	0.2296
TAU-L	0.0014	0.0001	0.0765	0.0711	0.0021	0.0003	0.0752	0.0671
TAU-T	0.0001		0.0154	0.0123	0.0003	0.0068	0.0104	0.0221
TAU-BY	0.0765	0.0154	0.3155	0.0041	0.0752	0.0104	0.3415	0.0007
TAU-BZ	0.0711	0.0123	0.0041	0.5811	0.0671	0.0221	0.0007	0.6503

ISO 1/3 rd. Octave Centre Frequency 8000 (Hz)

	SEA program				FE/SEA program			
TAU-L	0.3594		0.0177	0.0522	0.6346	0.0158	0.0454	0.0721
TAU-T		0.8158	0.0188	0.0172	0.0158	0.7596	0.0041	0.0134
TAU-BY	0.0177	0.0188	0.3577	0.0090	0.0454	0.0041	0.5851	0.1011
TAU-BZ	0.0522	0.0172	0.0090	0.1702	0.0721	0.0134	0.1011	0.1825
TAU-L	0.0198	0.0015	0.2843	0.2651	0.0854	0.1035	0.0242	0.0190
TAU-T	0.0015	0.0007	0.0783	0.0677	0.1035	0.0506	0.0009	0.0522
TAU-BY	0.2843	0.0783	0.2195	0.0147	0.0242	0.0009	0.0457	0.1935
TAU-BZ	0.2651	0.0677	0.0147	0.4038	0.0190	0.0522	0.1935	0.3661

Figure (5). Comparisom of Measured + Predicted data