Hybrid FEM/SEA model of an aircraft fuselage section

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Introduction

This paper deals with the SEA- and hybrid model generation derived from a detailed finite element model of a fuselage structure using the software VAOne [1]. First, starting from a modal analysis a check of the dynamic behaviour of the selected subsystem configuration is performed. Based on these results and using the energy flow method (EFM) as SEA post-processing is applied. All criteria that are required for the evaluation of each subsystem configuration can be derived, i.e. the modal density and the coupling behaviour between the subsystems. Based on this calculation the appropriate frequency range and subsystem configuration is selected.

The second part deals with a hybrid model of this configuration using a structural FE-model coupled to SEA cavities. One focus of both approached was the feasibility of these methods using models of realistic size and the commercial software VAOne.

EFM / EIC modelling

The energy flow method (EFM) or energy influence coefficient (EIC) method was introduced by Mace in [2]. The first step in EFM processing is to select subsystems out of the FE model from experience or visual inspection of overall mode shapes. The outcome of this selection is shown in Figure 1.

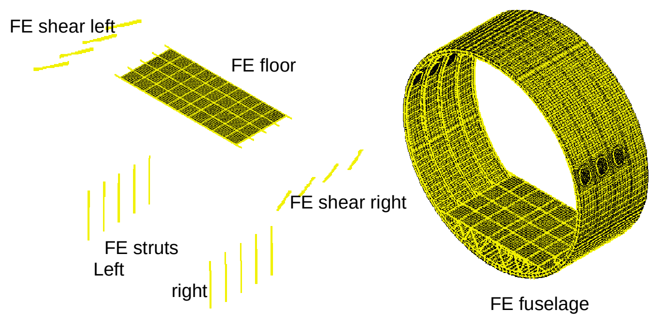

Figure 1: Selected subsystems for EFM simulation

Modes in band

Figure 2 shows that the fuselage is appropriate for SEA from 100 to 400 Hz if we consider ten modes in band as sufficient. The same is valid for the floor above 250 Hz. This means that structural SEA may give reasonable results above 250 Hz if a four bay fuselage is considered and coupling between those subsystems is not too strong. All other subsystems from Figure 1 are considered as inactive and therefore only act as coupling element in the further calculations.

Some parts of the model provide local modes due to low stiffness. To avoid those modes some modifications were done in order to remove the local effects. Thus, a new model is selected including two additional frame bays and some corrections in order to avoid the local modes.

The selected subsystem configuration for this new model will be similar to the first model and is shown in Figure 3. Again, all systems having a low modal density will be inactive, i.e. the structure serves only as coupling element and not as resonant subsystem.

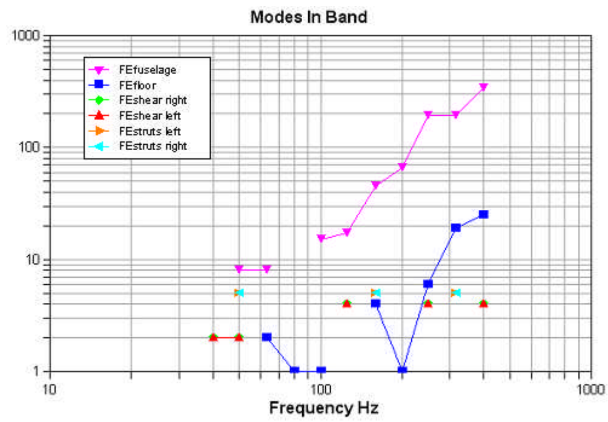

Figure 2: Modes in band for the systems from Figure 1

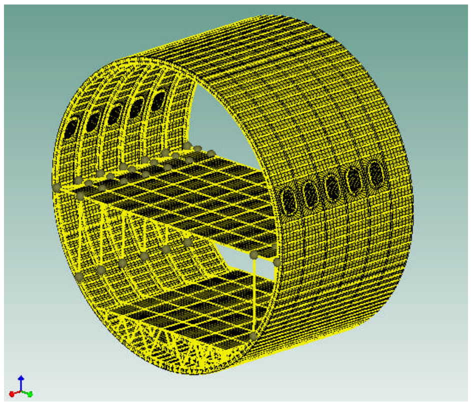

Figure 3: Extended and modified FE model

Results for modified and extended model

The new modes in band situation is shown in Figure 4 and remains in general the same as the one presented in Figure 2. The fuselage has enough modes for statistical simulation, but the floor modal density remains low in comparison. The upper frequency limit is now 250 Hz due to computational limitations of the extended, new model.

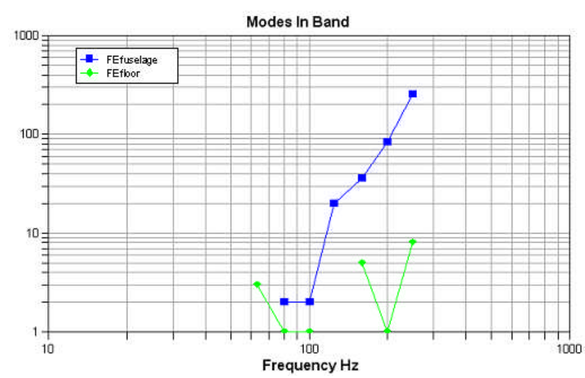

Figure 4: Modes in band for modified model

If the system loss factors are supposed to be about 2% the coupling loss factors, as shown in Figure 5, are low enough to fulfil the golden rules of SEA.

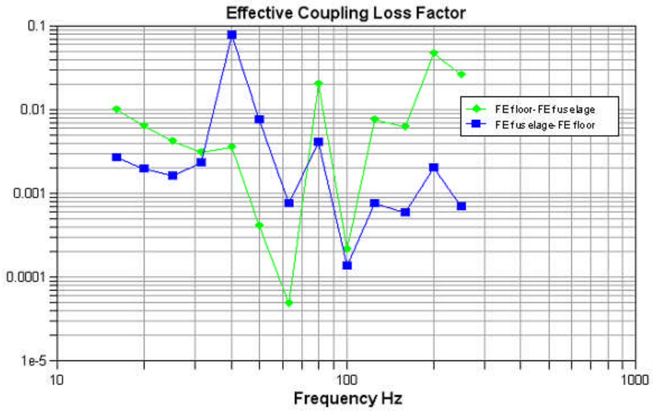

Figure 5: CLF between floor and fuselage

One further check is the reciprocity condition for the CLFs. In Figure 6 one can see that the reciprocity is fulfilled for the chosen subsystem selection. For comparison the results for the first as well as the modified model are given. One can see some minor improvement in reciprocity in the 80 and 100 Hz band.

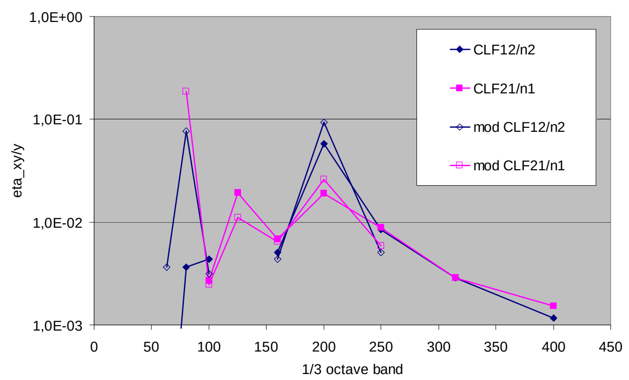

Figure 6: Reciprocity check between first and modified model

Conclusions from EFM

The EFM processing shows that the SEA method is possible but might not be appropriate for simulation in this frequency range. In addition, pre-stressing due to pressurization is not considered and will further reduce the modal density.

Another drawback might be that the EFM method does not include FE models of the fluid. For further improvement, especially the understanding of the coupled phenomena, the inclusion of a full structure-fluid model into the EFM might be useful.

However, structural SEA modelling in that frequency range remains cumbersome. As a consequence the hybrid approach described in [3] and [4] will suit better to this task. Thus, a hybrid model is created that consists of a full FEM model for the structure and SEA systems describing the interior cavities.

Hybrid model

A straightforward approach is used for the hybrid subsystem definition. The structure is modelled as FE and the cavities as SEA subsystem (Figure 7). All coupling and excitation is defined via the faces as shown in Figure 8. They also allow for partial coupling of subsystems. There is no face concept in the SEA approach of VAOne which will further increase the low frequency limit of SEA.

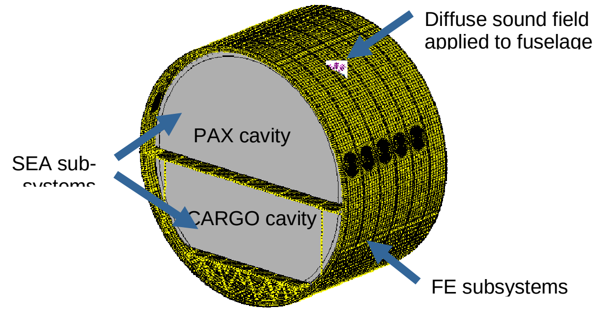

Figure 7: Hybrid model of fuselage section and cavities

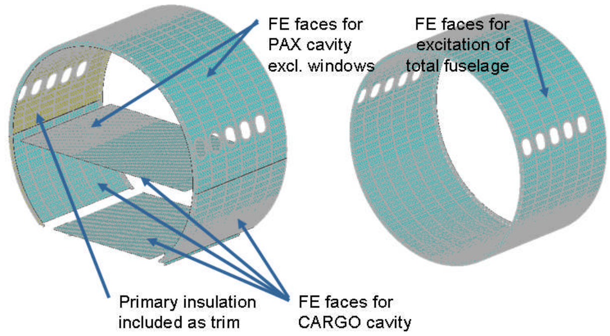

Figure 8: Faces for coupling and cavity definition

As shown in Figure 8 the faces allow for coupling to both the interior cavities (only partially) and the exterior excitation via a diffuse sound field (the total external fuselage). All coupling is defined by the diffused sound field reciprocity based on the modal radiation impedance [4]. This radiation impedance assumes free field conditions leading to certain limitations in accuracy. However, if the internal cavities are assumed to be appropriate for SEA this free radiation assumption should be correct.

In addition, the software allows for the consideration of local treatment. Here, the mode shapes are coupled to the fluid using the transfer impedance of the treatment.

Configurations

In order to understand the effects of different configurations we calculated four configurations:

1. Green (no insulation) and 1% structural damping
2. Fuselage with primary insulation, 1% structural damping
3. ρc termination at end caps of cavities, fuselage with primary insulation, 1% structural damping
4. Fuselage with primary insulation, 2% structural damping

The ρc termination was used to check the influence on the interior absorption.

Results

In Figure 9 all results are shown in comparison to flight test data. In general, the green configuration shows the highest levels. However, at some frequencies the pressure level is even higher with the insulation. One must keep in mind that the only noise treatment is the primary insulation consisting of a two inch layer of light glass wool. Furthermore, the aim of these investigations was to show the principle function of the hybrid approach with models of this order of magnitude.

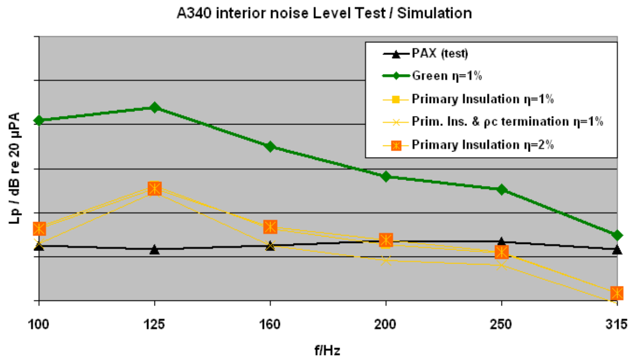

Figure 9: Interior sound level due to external excitation

Conclusions and outlook

The results prove that hybrid modelling of large scale fuselage structures is feasible. However, the calculation time remains high and the simulation is only possible for low frequencies due to the very high mode count of the fuselage. Thus, in the frequency range valid for SEA one should still think about SEA modelling using the information derived from the EFM analysis.

A further step is the comparison with high frequency FEM results in the overlap region. Finally, the inclusion of real lining, trim, and seats shall allow for realistic interior noise simulation. However, this will still be a real challenge due to the high amount of hybrid couplings.

References

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[3] P.J. Shorter, R.S. Langley: Vibro-acoustic analysis of complex systems, JSV (2005) 288, pp. 669-699

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