A simplified model for predicting vibrations of airplane fuselage

J. Missaoui and L. Cheng
Department of Mechanical Engineering
Laval University Quebec, Canada, G1K 7P4

1. Introduction

Several previous investigations were performed to study and to understand the airplane cabin's structural and acoustical responses. The aircraft fuselage was mostly modelled as a cylindrical shell with and without stringers. In the real case, the cylindrical model does not always warranty a good prediction of the vibration level other than permitting a general understanding of mechanism of noise transmission. The addition of a floor to the cylindrical shell seems to be more realistic. In ref. [1], the free vibration of a cylindrical shell with a floor partition has been studied by including the effect of several parameters. More recently, in ref. [2], he natural frequencies of a simply supported stiffened cylindrical with a floor partition have been calculated. In this work, fuselage is treated as a cylindrical shell coupled to a floor. A general formulation is presented to study the structural influence of the cabin floor on the modal characteristics and the vibration level.

2. Analytical approach

The analytical formulation is based on the application of Hamilton's principle where the energies of the whole system shown in Figure 1 is minimized. The structural coupling between the floor and the cylindrical structure is investigated by introducing a set of uniform distributed artificial springs as dynamic element [3]. The coupled modal equations of motion are developped [4] using a physical modal basis with a *shear diaphragm* condition. The in-plane motion and the transversal bending of the floor are included to the model. Furthermore, the external dynamic loadings are considered to be a punctual forces directly applied on the external surface of the shell. Finally, an average quadratic radial velocity is used to characterize the vibration level of the coupled system.

3. Numerical results

The developed model is validated with available results in the literature. Moreover, a Finite Element Analysis using a commercial code is also performed. The agreement is good except for the fundamental mode reported in ref. [1] where the error increased with increasing the floor angle. The mode shapes are also examined and analysed showing three controlled regions in the modal behavior of the coupled structure. In Figure 2, a physical observation of the mode shapes shows that the lowest frequency corresponds to a mode which is basically dominated by a floor motion. The second mode is a strongly coupled one in which the the substructures vibrate with a comparable level. The third mode is a shell-controlled mode , in which one notice a slight deformation of the floor and a strong motion of the shell.
The effect of the in-plane motion of the floor on the combined system is also discussed. The analysis shows that at low frequency region, the in-plane motion has no effect on symmetric modes but a visible effect is observed for the antisymmetric modes. So, at least rigid motion of the floor in the horizontal direction must be considered in the simulation at this region. It is also pointed out that the longitudinal motion has no visible effect on the modal behavior of the combined system.
This section study the structural response under a point excitation, the procedure consists on comparing first the vibration levels of the shell with and without the floor, and second, the floor behavior compared to the shell when the system is structurally coupled. The vibration level is calculated by considering the radial quadratic velocity. It can be seen from figure 3 that the inclusion of the floor into the model does not basically change the general trend of the overall vibration level of shell. A detailed examination of the two curves shows that the floor has a visible effect on the shell response. More specifically, due to the coupling introduced by the floor, resonance peaks are shifted. Moreover, additional resonances dominated by the floor motion can be clearly identified. Figure 4 illustrates the vibration levels for both substructures. It can be seen that at low and mid-

dle frequency regions, a strong coupling between the shell and the floor exists. But at a high frequency region, the shell which is directly excited is more active than the floor. Combining the two figures, one can notice that from the dynamic analysis point of view, the single shell model seems to be sufficient to estimate the global vibration of an airplane fuselage. This justifies the common use of a single shell model in numerous papers. From the noise prediction point of view, due to the strong structural coupling at low and middle frequency regions, the floor could be considered as a sound radiator in noise prediction.

4. Conclusion

The fundamental structural influence of the cabin floor has been discussed using analytical approach. The structural coupling was found to be strong at low and frequency regions. However, from acoustical view point, the floor may change significantly the internal pressure level.

References

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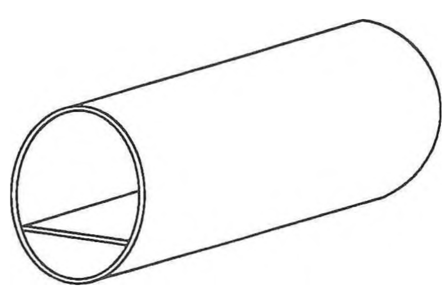

Figure 1: Cylindrical shell with a floor partition

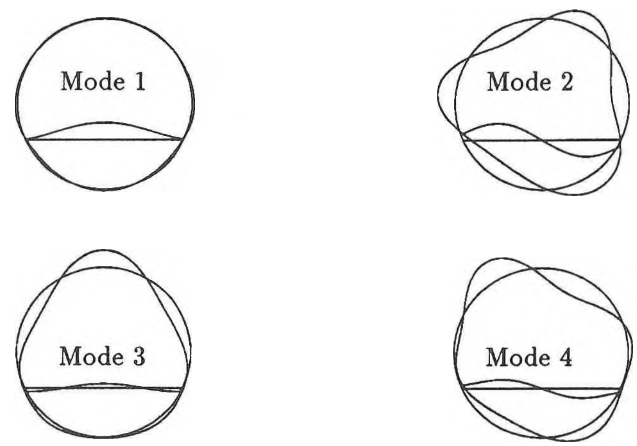

Figure 2: Mode shapes of the partitioned structure

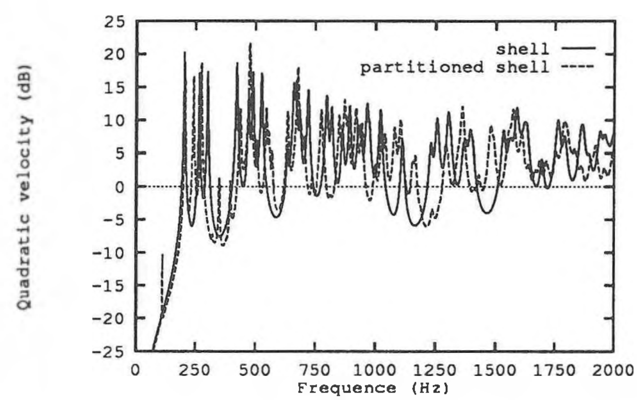

Figure 3: Vibration level of the cylindrical structure

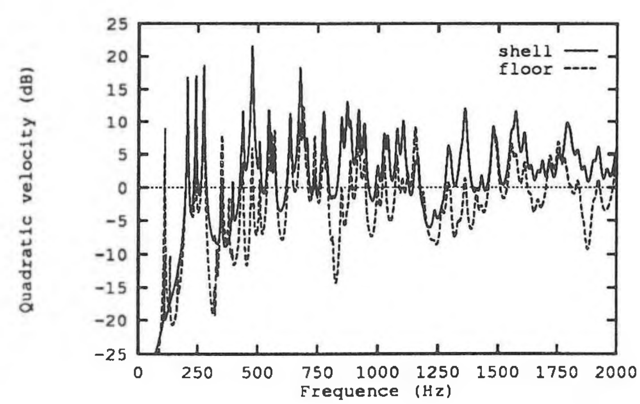

Figure 4: Vibration level of the combined structure