OPTIMIZATION STUDY AND PANEL PARAMETER STUDY FOR NOISE RADIATION REDUCTION OF AN AIRCRAFT PANEL EXCITED BY TURBULENT FLOW

Steven A.J. Sonnenberg † and Joana Rocha ‡
Department of Mechanical and Aerospace Engineering, Carleton University, Ottawa, Ontario.

1 Introduction

The noise and vibration in an aircraft cabin, during cruise conditions, is primarily caused by the external turbulent boundary layer (TBL) [1]. The TBL causes the fuselage panels on the aircraft to vibrate, which radiate sound energy in the form of noise in the cabin. Therefore, it is of great interest to determine which aircraft panel parameter(s) is/are most effective in decreasing the amount of radiated sound power, and how to optimize these parameters to reduce the noise in the aircraft cabin.

One approach to calculate the radiated sound power (RSP) of vibrating structures is to use a modal analysis, as done by Roy and Lapi [2]. This approach is necessary when analyzing obscure shapes, but requires great computational power and time, making it difficult to iterate the calculations for optimization routines. Therefore, when looking at simple shapes, like that of a flat panel, analytical computational methods become a better choice. The analytical expressions for RSP can be derived for a given aircraft panel, in terms of the displacement power spectral density (PSD) [1, 3, 4]. The acceleration PSD is calculated from the displacement PSD, which is proportional to the RSP [4]. The analytical models developed were modified to account for other panel and enclosure combinations [5, 6]. Berry also showed that the same type of analytical analysis was possible for panels with arbitrary boundary conditions [7].

An analytical model that calculates the acceleration PSD was created in Matlab. A sensitivity study was performed on the panel parameters to determine the percent change in acceleration PSD, versus the percent change in seven different panel parameters. An analytical method to optimize an aircraft panel is presented in this paper for reducing the acceleration PSD of the panel caused by the TBL.

2 Methodology

To calculate the acceleration PSD of an aircraft panel, a few assumptions must be made; the panel is assumed to be flat, simply supported and not under tension. The panel is also assumed to not be fixed to an enclosure and with a TBL caused from a single constant freestream velocity. The displacement PSD at a single point (taken to be the centre of the panel in all calculations for this study) can be calculated for a given frequency, using the displacement PSD matrix as follows [1]:

$$S_{WW}(x_1, y_1, x_2, y_2, \omega) = \sum_{m_{x_1}, m_{x_2}=1}^{M_x^2} \sum_{m_{y_1}, m_{y_2}=1}^{M_y^2} \alpha_{m_{x_1}}(x_1) * \alpha_{m_{x_2}}(x_2) * \beta_{m_{y_1}}(y_1) * \beta_{m_{y_2}}(y_2) * S_{ww}(\omega)_{m_1, m_2} \quad (1)$$

Where $\alpha_{m_x} = \sqrt{\frac{2}{a}} \sin\left(\frac{m_x \pi x}{a}\right)$ and $\beta_{m_y} = \sqrt{\frac{2}{b}} \sin\left(\frac{m_y \pi y}{b}\right)$ are spatial functions that define the variation in vibration for a simply supported plate and Where (m_x, m_y) is the plate mode and $M = Mx = My$ is the total number of plate modes considered [1]. The velocity PSD (S_{VV}) and the acceleration PSD (S_{AA}) at a single point on the panel are as follows [4]:

$$S_{VV} = \omega^2 * S_{WW} \quad (2)$$
$$S_{AA} = \omega^4 * S_{WW} \quad (3)$$

A complete description/derivation of the equations used for this study can be found in Rocha's earlier work [1, 3].

3 Results

A sensitivity study was performed on seven panel parameters, to determine which parameter is most effective at reducing the acceleration PSD in select octave bands. The parameters were varied individually, and the changes in the acceleration PSD in each of the octave bands were analyzed. To run a full, in depth sensitivity study, all the frequencies in the human hearing range would need to be analyzed, but as the frequency increases, the analysis takes exponentially longer to run, therefore only four lower frequency octave bands have been analyzed. The octave bands are from 89.1-178 Hz, 178-355 Hz, 355-708 Hz and 708-1410 Hz. The sensitivity study was run for the following parameters: thickness, material density, panel width and length, elastic modulus, Poisson's ratio and damping ratio. Figure 1 contains a sensitivity study for a single octave band.

The analysis was then modified to determine the optimal panel parameters that resulted in the smallest average acceleration PSD over the octave band. The optimization analysis implemented in this study, is an add-on to Matlab. It uses an interior point algorithm for a nonlinear equation, which is a method of constrained minimization that solves a sequence of approximate minimization problems. The analysis is used to optimize each of the seven parameters individually and concurrently. Since the general trend of the sensitivity studies predicts that the minimum acceleration PSD is reached when both the thickness and the density are maximized to the upper constraint, optimizing these parameters individually simply results in the upper constraint. Therefore, it is of more interest to determine if there is a correlation between the

† Steven.Sonnenberg@carleton.ca
‡ Joana.Rocha@carleton.ca

octave band and the panel length. Figure 2 shows the optimal panel length at the center frequency of different octave bands and compares these values to the calculated flexural wavelength, convective wavelength and acoustic wavelength at the same frequencies.

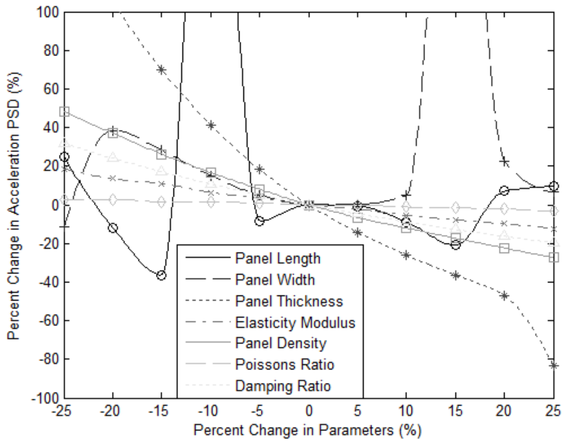

Figure 1: Percent change in acceleration PSD versus percent change in panel parameter for octave 355-708 Hz with limited Y-axis extents.

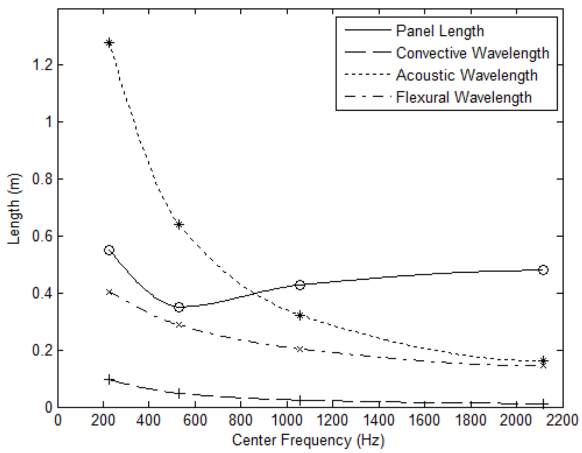

Figure 2: Optimal panel length at the center frequency of different octave bands compared to the calculated flexural wavelength, convective wavelength and acoustic wavelength.

4 Discussion

As shown in Figure 1, both the panel width and length have fluctuating values. These fluctuations are believed to occur because the panel width and length are main components of calculating $S_{tbl}(\omega)$. The variables are located within sinusoidal functions, with the change in these parameters being non-linear. For this reason, these parameters cannot be defined by a simple trend, and therefore, are not the most sensitive at reducing the overall acceleration PSD.

It was found that the two parameters that are the most effective for reducing the average acceleration PSD within the different octave bands are panel thickness and panel density as these two parameters have the steepest slopes. As the thickness is increased, the higher frequency noise is reduced which is what can be expected. However it has less effect on the lower frequency (longer wavelength) signals. Even though the panel density has more gradual slopes in comparison to the panel thickness, the trend is more consistent across all of the analyzed octave bands. Therefore, it is likely that panel density is the most sensitive at reducing the overall noise across the human hearing range, whereas thickness may be the most sensitive at reducing the noise at certain octave bands.

It was assumed that the optimal panel length would follow the same exponential decay as the flexural wavelength, convective wavelength and acoustic wavelength, however, Figure 2 does not support this hypothesis. The optimization routine currently finds local minimums in the constrained space rather than the global minimum. The next step in this research will to be to modify the optimization routine to find the global minimums and determine the true trend of the panel length.

5 Conclusion

An optimization study is presented, with the objective to reduce the acceleration PSD of a panel excited by a TBL. It is shown that panel thickness and panel density are the most consistent, and effective parameters at reducing the acceleration PSD at different octave bands in the human hearing range.

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