Human discomfort in aircraft cabins: effect of noise level and vibration magnitude

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ABSTRACT

In recent years, the air transport industry has made significant advancement in technology in context to fuel consumption, maintenance and performance. The most promising developments in terms of fuel efficiency and therefore minimisation of emissions is in future turboprop aircraft (i.e. those generating thrust from a propeller). The main drawback with propeller aircraft is that they tend to have noisier cabins, and there is an increased level of discomfort from vibration due to the tonality that is present. Human comfort perception is a key factor for aircraft manufacturers in the design of airframes and aircraft interiors; the aim of this research study is focused towards building a comfort model for aircraft to enable designers and engineers to optimise the passengers travelling experience. In this paper the authors demonstrate a laboratory experimental study in order to determine the relative importance of noise and vibration for the turboprop aircraft cabin. The results showed that with the increase in noise levels and vibration magnitudes the overall human discomfort also increased, indicating a cross- modal interaction.

KEYWORDS

Human comfort, Vibration discomfort, Noise

Introduction

The aviation industry is stepping towards innovative technologies to improve the human comfort in context to the discomfort to both the crew and passengers from noise and vibration inside the aircraft cabin. Future aircraft will be designed differently to make them more sustainable. They will be lighter and many more will be propeller driven to enable battery power and reduce environmental emissions (Babikian et al., 2002 and Schafer et al., 2019). Changes in design will mean that the noise and vibration experienced by passengers in the aircraft will be different to that experience in current aircraft.

Turboprop (propeller passenger aircraft) are more fuel efficient than jets but generate more noise and vibration inside the cabin resulting in discomfort amongst both crew members and passengers (Vink & Brauer, 2011). Optimisation of aircraft cabin noise levels and vibration magnitudes is essential to enhance the comfort of the passengers. The comfort perception of passengers in air vehicle environments should be taken into consideration during the aircraft cabin design, not only for wellbeing but also because a willingness to use similar aircraft again for travelling is influenced by the human comfort (Bellmann et al.,2004).

The aim of the present investigation was to map how individual comfort perception varies with different combinations of noise and vibration. Furthermore, we aim to build an overall comfort model in a vibro-acoustic environment for the aircraft passengers in order to enhance the travelling experience for the passengers.

Methods

18 volunteers (12 male, 6 female; 19-52 years) participated in a laboratory experiment at Nottingham Trent University, UK. Each volunteer was exposed to each combination of pairs of 10-15s stimuli comprising synthesized noise and vibration representative of those experienced in a turboprop. They were seated on a prototype aircraft seat which was mounted on a shaker platform (Figure 1). Noise was presented at each of 72, 78, 84 and 90 dB(A); vibration was presented at each of 0.50, 0.67, 0.83, 1.00 m/s^2 r.m.s. (r.s.s. bandlimited) comprising a multi-tonal signal. The order of stimuli was randomized. Participants were required to rate their perceived discomfort from noise, perceived discomfort from vibration, and their overall discomfort. Both noise and vibration ratings were based on the scale developed from ISO 2631-1 (Figure 2(a)), the overall discomfort was assessed using the Borg CR-100 scale (Figure 2(b)). They were also required to select whether they would choose to reduce the noise or the vibration to improve comfort. The study was approved by the NTU Research Ethics Committee.

Fig. 1. Aircraft seat mounted on a vibration simulator. The centre seat was used in the study. The image also shows amplifiers and positioning of loudspeakers.

2(a)

1	Not uncomfortable
2	A little uncomfortable
3	Fairly uncomfortable
4	Uncomfortable
5	Very uncomfortable
6	Extremely uncomfortable

1	Not uncomfortable
2	A little uncomfortable
3	Fairly uncomfortable
4	Uncomfortable
5	Very uncomfortable
6	Extremely uncomfortable

2(b)

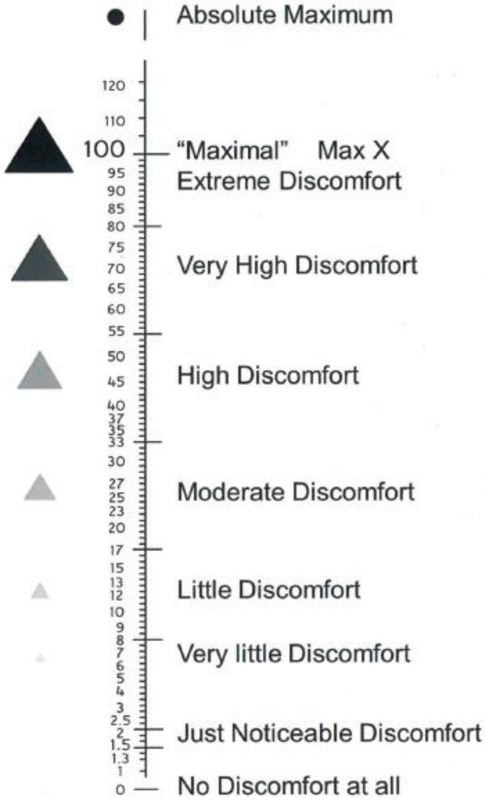

Fig.2. Subjective response scales. (a) Noise ratings and Vibration ratings based on scale from ISO 2631-1. (Sammonds et al., 2017 and Mansfield, N.J. 2004) (b) Borg CR100 scale for overcall discomfort ratings. Adapted from (Borg. E, 2002).

Results and Discussion

Participants were each exposed to 16 combinations of noise and vibration and gave 4 responses to each combination. Kolmogorov-Smirnov tests confirmed that parametric statistics could be used for data analysis ($p<0.0001$ for all 64 data sets).

Ratings of noise discomfort increased with noise level for each vibration magnitude (Figure 3). Two-way analysis of variance (ANOVA) showed a significant main effect of noise ($p<0.0001$) but no effect of vibration ($p=0.88$) and no interaction ($p=0.99$). Post-hoc t-tests confirmed a change in noise ratings at 72 dB and 90 dB for each of the vibration magnitudes ($p<0.0001$). There was no change in ratings of noise with vibration presented at 0.5 m/s^2 and 1.0 m/s^2 ($p=0.38$, 0.72, 1.00, 1.00) showing that there was no cross-modal effect observed.

Ratings of vibration discomfort increased with vibration magnitude for each noise level (Figure 4). Two-way analysis of variance (ANOVA) showed a main effect of vibration ($p<0.0001$) but no effect of noise ($p=0.76$) and no interaction ($p=0.98$). Post-hoc t-tests confirmed a change in vibration ratings at 0.5 m/s^2 and 1.0 m/s^2 for each of the noise levels ($p<0.0001$). There was no difference in ratings of vibration with noise presented at 72 dB and 90 dB ($p=0.83$, 1.00, 0.86, 0.17) showing that there was no cross-modal effect observed.

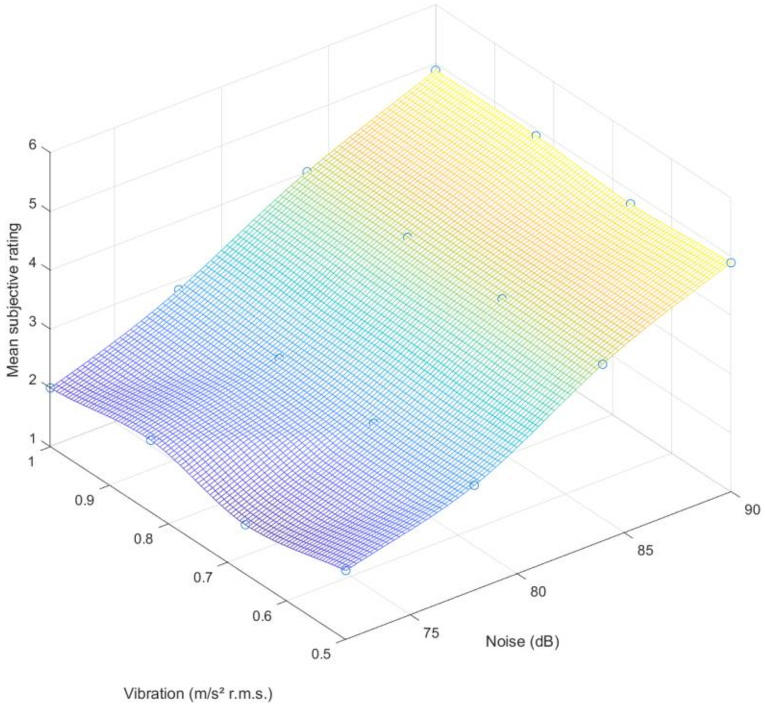

Fig.3. Mean subjective ratings of noise for all combinations of noise and vibration with cubic interpolated surface superimposed.

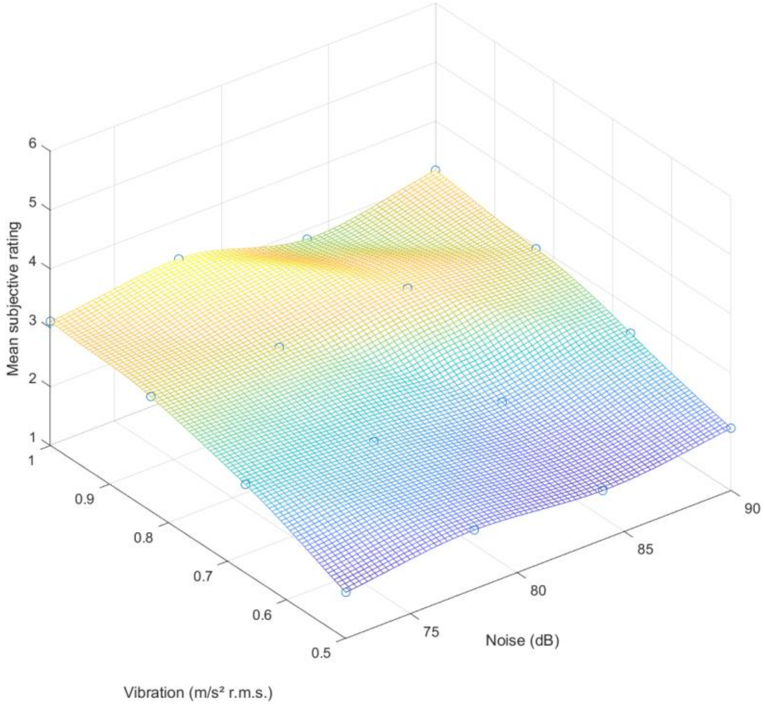

Fig.4. Mean subjective ratings of vibration for all combinations of noise and vibration with cubic interpolated surface superimposed.

Ratings of overall discomfort generally increased with both noise and vibration (Figure 5, Table 1). Whilst a two-way analysis of variance (ANOVA) showed a significant main effect of noise ($p<0.0001$) it did not reach significance for vibration ($p=0.23$) and no interaction ($p=0.99$). Post-hoc t-tests confirmed a significant change in overall ratings at 72 dB and 90 dB for each of the vibration magnitudes ($p<0.0001$). Overall ratings of discomfort significantly increased with vibration at 78 dB ($p<0.01$) but the trend did not reach significance at 72 dB ($p=0.04$), 84 dB ($p=0.02$), or 90 dB ($p=0.06$), despite systematic increases being apparent in mean data (Table 1).

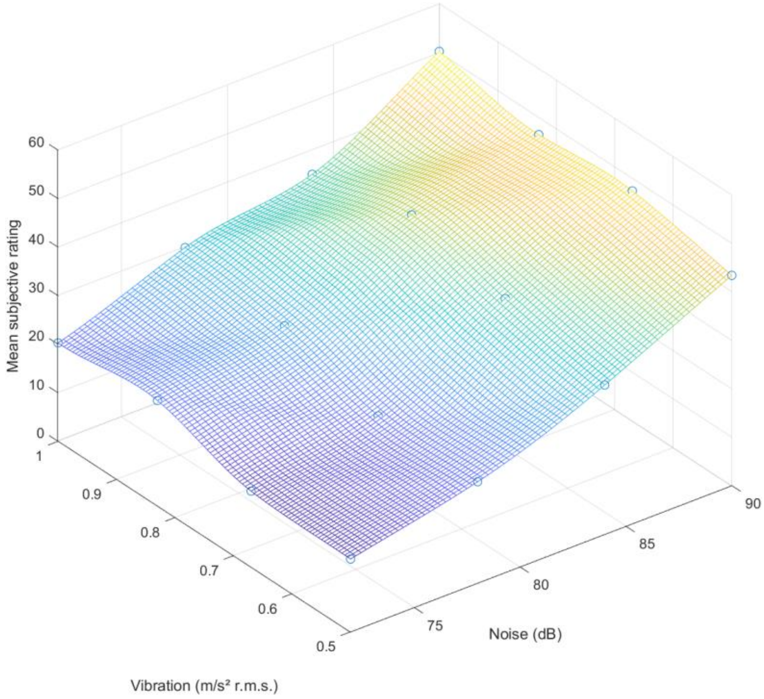

Fig.5. Mean subjective ratings of overall discomfort for all combinations of noise and vibration with cubic interpolated surface superimposed.

Table 1. Mean overall ratings of discomfort

	Vibration magnitude (m/s^2)			
Noise level (dB)	**0.50**	**0.67**	**0.83**	**1.00**
72	15.00	15.64	21.75	20.28
78	20.89	21.11	27.11	29.89
84	30.78	35.25	39.94	34.94
90	43.33	47.39	46.42	50.22

These data show that the overall perception of discomfort was a function of both the noise and the vibration. Therefore, both variables need to be accounted for when evaluating aircraft cabin environments. Whilst the changes in responses to noise were greater than those to vibration, it should be noted that the power scaling of the two stimuli were not matched.

Conclusions

The study investigated human discomfort in an aircraft cabin in context to different noise levels and vibration magnitudes. The discomfort score ratings of the participants increased with the increase in noise level and vibration magnitude respectively. The overall discomfort rating for the participants also showed rise at higher combinations of noise levels and vibration magnitude. For the ranges of noise and vibration investigated, there were clearer trends observed for noise responses than for vibration responses.

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