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Perceived discomfort for tri-axial helicopters vibrations

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Abstract

Vibrations are an important contributor to perceived discomfort in helicopters cabins. A test campaign was conducted in order to understand how discomfort varies for helicopter tri-axial excitations. Six experiments were conducted, which involved 30 participants. Subjects were seated on a six degree of freedom vibration table. They had to evaluate discomfort of several stimuli. The first three experiments investigated the influence of vibrations due to the blade passage frequency of the main rotor, to the tail boom modal behaviour and to a combination of these two sources. The impact of a phase shifted vibrations and of amplitude-modulated excitations were studied in a fourth and fifth experiments. Finally, the last experiment focused on real signals measured on several helicopters of Airbus fleet. Results showed that 1) vertical vibrations represent the major contributor to discomfort in helicopters; 2) for amplitude-modulated excitations, discomfort only depends on the amplitude of the modulation, not on the modulation frequency; 3) out of phase stimuli are perceived in the same way than phased stimuli; 4) helicopter frequency content above 30 Hz does not increase discomfort; 5) ISO2631-1 comfort index is a good predictor of discomfort evaluations.

Keywords: Perception, vibrations, helicopters

1 INTRODUCTION

Helicopter manufacturers are closely interested in ride comfort because it has become an important marketing argument. They need to have a full understanding of comfort parameters and to be able to estimate it from in-flight measurements, in order to offer a good product to their customers.

Ride comfort is partly governed by vibration-related comfort. The ISO2631-1 standard [1] makes it possible to evaluate the discomfort produced by any transportation means based on vibration measurements at the points of contact between the person and the machine. However, this standard has been the subject of studies that have shown that it does not accurately estimate discomfort from all types of sources, and deserves to be slightly adapted for each application [2].

This is why this study aims to verify the suitability of ISO2631-1 to helicopter vibrations. It will focus on raw signals measured in helicopters but also on signals reproducing the main characteristics of vibrations measured in helicopters . This paper will only present subjective evaluation of discomfort due to the excitation related to the blade passage frequency, which represents the highest excitation in the measured spectra.

2 METHODS

2.1 Participants

Thirty people participated in the experiment. This group consisted of 7 women and 23 men, aged between 22 and 55 (average=40, std=9.8 years). They were recruited from Airbus and were engineers in vibration or acoustics. Participants had to sign a waiver beforehand attesting to their good health (no recent fractures or surgery, no retinal problems...).

Before exposing participants to vibration, the RMS value of the weighted acceleration normalized to an 8-

hour reference period of all vibration signals in the session was computed using the ISO 2631-1 method. The obtained value was 0.12 m.s-2, which is below the 0.5 m.s-2 threshold value (for which a remedical action should be taken), and far below the daily exposure limit value of 1.15 m.s-2, as defined by the regulation [3].

2.2 Test equipments

The experiment used a vibration simulator (Airbus Cube in Toulouse). This bench is a six degrees-of-freedom simulator, but only translational vibrations were used in this study.

The test means allows a 50 mm displacement on X and Y axes, and a 100mm displacement on vertical axis. Nominal frequency bandwidth goes from 0 to 250 Hz for all axes.

On the top platform, whose dimensions are approximately 150 cm $\times$ 150 cm, a standard helicopter seat was fixed. Subjects participated in the experiment one by one.

The vibrations played by the Cube for each participant were recorded by three accelerometers. The first one was a conventional triaxial accelerometer fixed to the ground at the level of the seat legs. The other two were triaxial pad accelerometers attached to the seat and the backrest. The sampling frequency was 204 Hz and all signals submitted to each participant were recorded.

2.3 Stimuli

In order to understand the influence of different vibratory excitations on perceived discomfort, real signals and synthesized stimuli were played.

The real signals were derived from flight measurements performed in several helicopters of the Airbus fleet. Vibrations were measured at the floor during stabilized forward flight phases.

Eight signals from eight different helicopters were selected to be played to participants. In four of these signals the high frequency content (above 30 Hz) had a high level. A low-pass filtering was applied (cut-off frequency : 30 Hz) which created four modified signals. The objective was to know if comfort analysis can be limited to the low-frequency range or should include upper frequencies (mainly due to harmonics of the main rotor excitation). All together, 12 "real" signals were presented to the participants.

The synthesized stimuli aimed to represent typical vibrations of helicopters. Different sources of vibration have been studied but this paper will be limited to the main rotor blade passage.

The amplitudes of the measured vibrations vary from 0.05 to 0.5g and are generally higher on the vertical axis. The blade passage frequency varies according to the number of blades and the type of machine from 17 to 30 Hz.

In that case, the frequency was fixed to 17 Hz and the influence of level in the three directions was studied, using a full experimental design. Factors were the vibration level in each direction. Each factor had 3 levels, which lead to an overall number of 27 stimuli. In the vertical direction, levels were 0.1, 0.18 and 0.32 g. In the two horizontal directions, levels were 0.057, 0.1 and 0.18 g. In all cases, the increase between two levels was 5 dB.

A previous study showed that for single frequency vertical vibrations discomfort depends on the vibratory velocity. Hence, by choosing a low frequency vibration, higher frequencies discomfort can be inferred. Amplitude levels varying in 5dB increment allowed to have a significant variation in discomfort (differential threshold = 1.5 dB [4]) and to cover a wide range of amplitudes with only three levels.

All signals (real and synthesized ones) had a duration of 5 second. They were presented one after the other with a 5-second pause between two stimuli.

2.4 Procedure

Participants assessed the discomfort produced by vibration by direct scaling. They had to give a numerical value corresponding to their discomfort, using a continuous scale numbered 0 to 50, labelled from "no vibration" to "extremely uncomfortable". Between these extremes, five semantic labels helped participants to give their answer : "5 - a little uncomfortable", "15 - fairly uncomfortable", "25 - medium", "35 - uncomfortable" and "45 - very uncomfortable". This scale is based on the one provided in the ISO16832 standard [6] for loudness evaluation. Participants gave their evaluations aloud, during the 5-second pause between two signals, and the experimenter stored them in a computer.

Sample signals were played to participants at the beginning of each experiment. This allowed them to become familiar with the stimuli and the discomfort rating method. Sample signals were taken from the stimuli sets of the experiments. They were chosen to represent the full range of stimuli for each experiment.

The experiments were presented in a semi random order to the participants. Within each experiment, the signals were played in a random order. Unfortunately, due to practical limitation of the bench and to time, only two random draws for all 30 participants were made.

2.5 Analysis methods

Repeated measures variance analyses (ANOVA) were used to process the data.

For visualization, perceived discomfort ratings given by participants are normalized. This is done for each assessment, by removing the average of all ratings of the participant, and adding the average of all ratings of all participants.

3 RESULTS

Six participants had to be removed from the dataset due to a malfunction of the vibrating bench during an day of testing.

The average of the participants' normalized evaluations of the real helicopter signals varies from 16 to 29 points of discomfort. This corresponds to discomfort between the "a little uncomfortable" and "uncomfortable" labels. In comparison, the average of the ISO2631-1 comfort indexes computed from vibrations measurements on the participants varies from 0.2 to 0.7 m.s^{-2}, i.e. from "no uncomfortable" to "uncomfortable" depending on the standard. All discomfort evaluations given by the participants are therefore included in the discomfort estimates proposed by the standard.

Figure 1 shows the details of the averages of the normalized evaluations for each signal as a function of the associated values of ISO2631-1 comfort index. It shows that the perceptive evaluations and comfort indexes of the standard follow an increasing law and are well correlated (corr=0.93).

Figure 1 shows that there is little difference between perceived discomfort assessments of unfiltered signals (circles) and filtered signals (triangle). The effect of frequency content filtering greater than 30 Hz for these signals is studied with a repeated measurement ANOVA. Two factors are introduced: the filtering or not of high frequencies (two levels), and the type of machine (four levels according to the four helicopters). The results of the ANOVA show that only the type of machine significantly impacts discomfort (p=6.5e -16).

For stimuli representing the blade passage frequency, the normalized averages of discomfort assessments range from 23 to 40 discomfort points. This means that participants found these stimuli "a little uncomfortable" to "uncomfortable". The associated comfort index of ISO2631-1 range from 0.4 to 1.6 m.s^{-2}, i.e. from "slightly

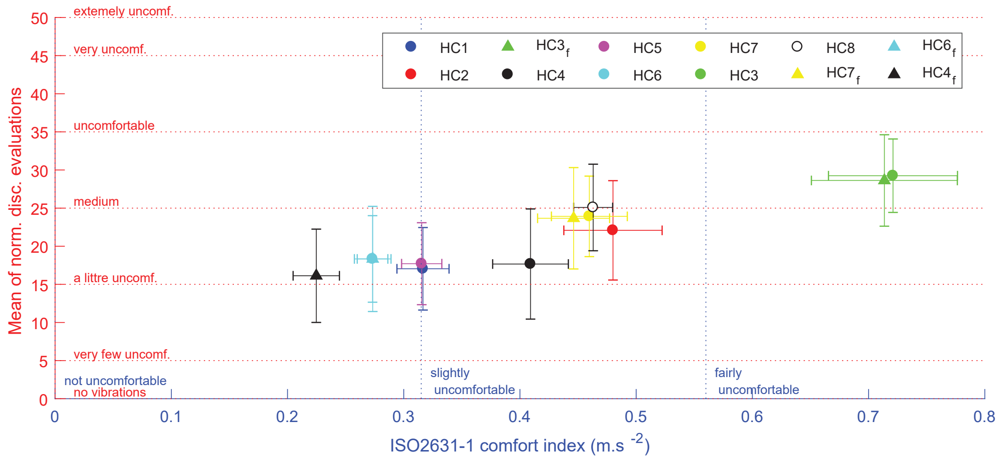


Figure 1. Standardized discomfort ratings compared to ISO2631-1 comfort indexes of "real" signals. The helicopters (HC) from which the signals are derived are distinguished by different coloured markers. Triangular markers indicate signals whose frequency content has been filtered beyond 30Hz.

uncomfortable" to "very uncomfortable", which means that the standard overestimates discomfort a little for these stimuli.

Analysis of variance showed that the three factors, as well as the majority of their interactions were significant. Only the interaction between X and Y axes was not significant.

According to the values of the partial eta squared η_p^2, the effect of the amplitude variation on Z is the strongest one ($\eta_p^2 = 0.83$). The effects of amplitude variations on X and Y ($\eta_p^2 = 0.5$ and $\eta_p^2 = 0.36$ respectively) follow. Finally, factors interactions have a weaker effect force ($\eta_p^2 = 0.065$ for $Y-Z$, $\eta_p^2 = 0.062$ for $X-Z$ and $\eta_p^2 = 0.058$ for $X-Y-Z$).

These results are shown in Figure 2a which presents the simple effects of the three factors. These same simple effects are shown in Figure 2b for the comfort indexes of ISO2631-1. This figure shows that the variations in the indexes are similar to the variations in perceived discomfort.

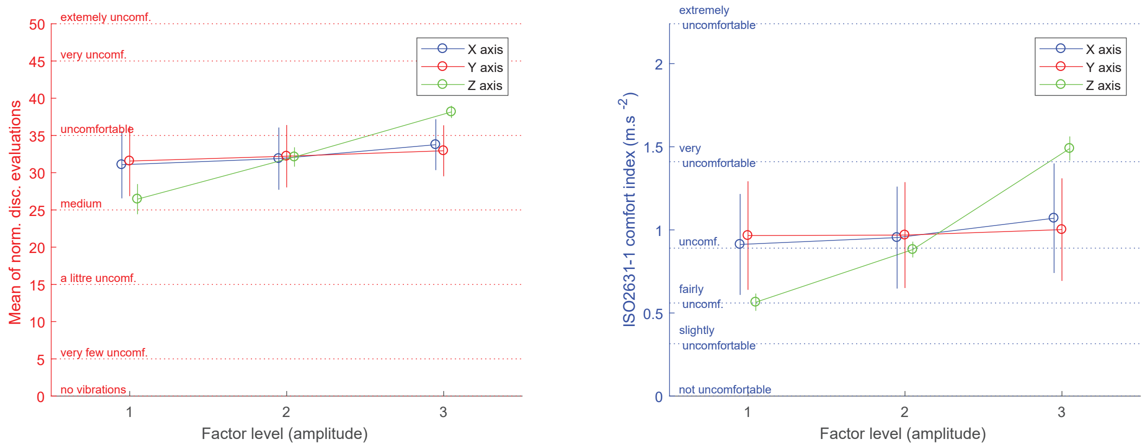
4 DISCUSSION

These results show that the index as computed by the ISO2631-1 standard provides a good estimation of perceived discomfort, whether for signals measured in flight or synthesized stimuli.

This index is already used at Airbus, but does not always correspond to the feeling of the flying crew. This raises the question of the difference in the perception of discomfort in flight and in laboratory conditions, because passengers are submitted to many other stimuli in the real situation.

The results also show that the vibratory frequency content greater than 30 Hz does not influence the perception of discomfort. Differences between perceptive evaluations and ISO indexes may then appear and shows an overestimation of discomfort by the standard (see black signals figure 1).

The results of the experiment on stimuli simulating vibrations related to the blade passage frequency tend to show that the vertical axis has the greatest impact on perceived discomfort. These results are consistent with ISO2631-1, which penalizes vertical vibrations more than lateral and horizontal vibrations.



(a) Perceptive evaluations

(b) ISO2631-1 comfort index

Figure 2. Simple effects of amplitude variations on each vibration axis

Overall, the comfort indexes of the standard provide a good approximation of helicopter vibratory discomfort. However, the semantic labels can be slightly adjusted to better match the feelings given by the participants.

5 CONCLUSION

This test campaign provided a better understanding of the discomfort associated with helicopter vibrations. The ISO2631-1 standard provides a good estimation of discomfort, both for signals from measurements and synthesized signals. The measured effects of the variation in the amplitude of the vibrations according to the axes X, Y and Z are in accordance with the recommendations of the standard, which is that vibrations on the vertical axis have the greatest impact on discomfort. The standard comfort index could be slightly improved to best suit the specificities of helicopters, by adjusting semantic labels for example. It should be noted, however, that this standard does not take into account the effect of beating that can occur for two sinusoidal vibration sources of close frequency. This phenomenon will be further tested.

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