Evaluation of vibration perception in passenger cabin

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1. Introduction

The comfort or discomfort caused by interior sound and vibration in a passenger cabin is an important property which became more and more important for the acceptability of transport facilities over the last years, especially in automotive and aircraft industry. In this study, vibro-acoustic multi-channel recordings are measured in different types of passenger cabins in different vehicles and aircrafts. It would be very advantageous knowing the properties of noise and vibration signals that are fundamental for quality assessments. This study focuses just on vibration perception. On the basis of representative spectra typical vibration characteristics of different types of exposure in cabins are discussed, like relevant frequency and magnitude selectivity aspects. Furthermore, new and reliable possibilities to evaluate and to describe vibration perception in passenger cabins are pointed out. The discussion refers to experiences and results from previous studies from automotive and aircraft industry, as well as basic experiments [3] which take into account sinusoidal (deterministic) and stochastic broadband stimuli excitation. The benefit is to improve the objective description of subjective (dis-) comfort caused by vibrations.

2. Vibration recordings in passenger cabins

2.1 Measurement equipment

Some vibration recordings were made in different types of passenger aircrafts and helicopters during scheduled and test flights, as well as in idle running cars (middle class cars). Two difficulties for conducting recordings in aircrafts exist: the space for recording devices is very limited and passengers should not be disturbed. The other and more important aspect is that most of the used electronic devices in aircrafts have to fulfill special requirements (after RTCA DO-160 Sect.21 Cat. M and IEC 61672-1 class 2). It is just briefly noted that the most standard measurement equipments do not fulfill these requirements. In this study one triaxial accelerometer and partly ear channel microphones in combination with a laptop partial are used for recordings during in-flight. Moreover, vibro-acoustic multi-channel recordings with up to 80 channels (pressure microphones and triaxial accelerometers) are carried out during two test-flights in an A320-232 and in idle running cars. The measurement positions of vibration are at seat rail, on the floor or man-machine interface (e.g., the seat).

2.2 Representative vibration spectra

Figure 1 shows typical averaged spectra in three directions (x-, y- and z- axes) of vibrations in a DASH 8-300 during cruise condition (10.000 feet). The vibration spectra exhibit a typical peak valley structure which can be interpreted in terms of propeller blade orders (dominant order around 16 Hz). However, there are a lot of accelerations above 100 Hz which result from air flow turbulences at the outer

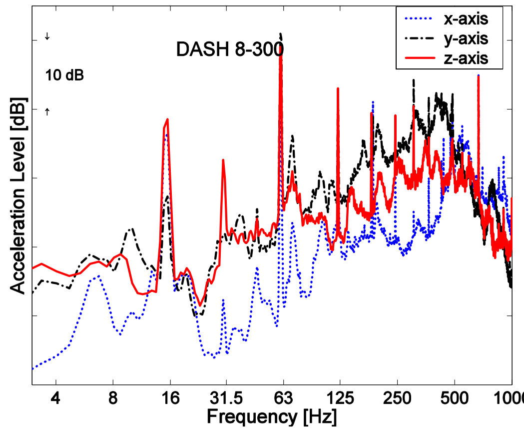

Figure 1: Typical averaged vibration spectra of a DASH 8-300 during cruise condition in all three (x-, y- and z-) directions. The vibrations were measured at the seat rail of seat F in row 12.

surface and the wings of the aircraft. These components depend significantly on measurement position in aircraft. In Figure 2 typical spectra from different types of aircrafts are diagrammed in vertical (z-) axis. This figure shows two main differences between propeller and turbine actuated aircrafts: (i) typical spectra of the turbine actuated aircrafts show only one peak at the first rotor order of the turbine. This narrow band peak dominates the lower frequency range and is constant during the whole flight - typically around 80 Hz. (ii) Furthermore, the acceleration in vertical direction is considerable lower at frequencies below 100 Hz. In comparison to the spectra from different types of aircrafts representative spectra of a passenger vehicle (middle class car in idle running) and a helicopter (with maximum indicated air speed – 140 knots) are illustrated in Figure 2, as well. These spectra show an overview of typical vibrations humans are exposed to in different transport facilities. The spectra are just figured in a frequency range from 3 to 200 Hz since this is the relevant one for vibration comfort. Again, the peak valley structure can be interpreted in terms of rotor blade orders (helicopter) and motor orders (vehicle).

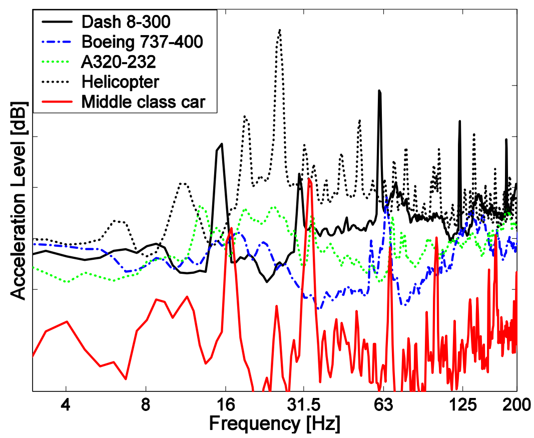

Figure 2: An overview of vibration exposure in passenger cabin for different transport facilities (aircraft, helicopter and vehicle).

3. Methods to improve objective description of subjective (dis-) comfort

Objective signal parameters – determined from vibration recordings like the measured data in chapter 2 – are desirable which describe and are able to predict subjective assessments of vibration. The aim is to show possible analysis methods to improve the objective description of the subjective (dis-) comfort caused by vibrations. Additionally, a proposal for psychophysically motivated vibration parameters is discussed on the basis of results from a study in automotive industry which deals with seat vibrations and with results from basic research [1].

From the vibration recordings in cars objective spectral signal parameters for seat vibrations were calculated and correlated with subjective ratings thereafter, Figure 3. Existing standards and industrial guidelines [e.g., 2, 3] served as a calculation basis for these parameters. The subjective ratings were determined by professional testers from automotive industry. The findings point out that spectrally unweighted but band limited vibration signal parameters correlate significantly higher with subjective assessments than spectrally weighted parameters. These findings are standing in contradiction to assumption of existing standards. Additionally, the vibrations, which were measured at comfort relevant interfaces between the vibrating seat and the subject obtain the highest correlation coefficients with subjective (dis-) comfort ratings (some clues are also found in [4]).

One possible reason for these findings is that there are legitimate disbeliefs in the correctness of the used spectral weighting functions (W_d and W_k for horizontal or vertical excitation) which based on standard perception thresholds [3]. Because literature data show considerable differences to standard perception thresholds (e.g., summarized in [1]). For example, measured perception thresholds and equal-vibration level contours measured on a rigid and semi rigid seat are shown in Figure 4 in comparison to standard data. It is just briefly noted that the new draft the ISO/FDIS 2631-2 [5] do not specify any standard perception thresholds und propose just one weighting function W_m for a combined horizontal and vertical excitation. However, the standard weighting functions are independent of the exposure level.

Nevertheless, on the basis of the illustrated data in Figure 4 vibration signals measured in passenger vehicles were spectrally weighted (depending on acceleration level). Therefore, psychophysically motivated parameters were calculated. These parameters correlate higher with subjective ratings and are consequently better suited to describe subjective comfort than the used other parameters.

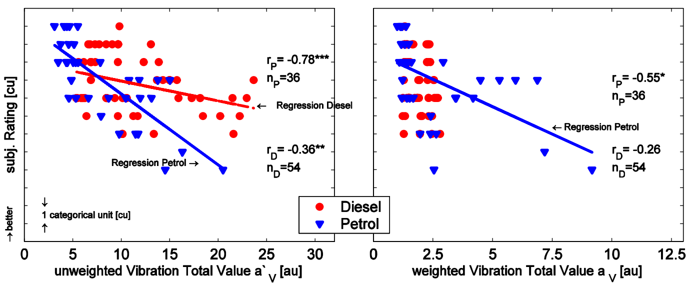

Figure 4: Relation between spectrally unweighted (left) and weighted (right) vibration total values a'_V, a_V of the driver seat and subjective ratings. (Adapted from [1])

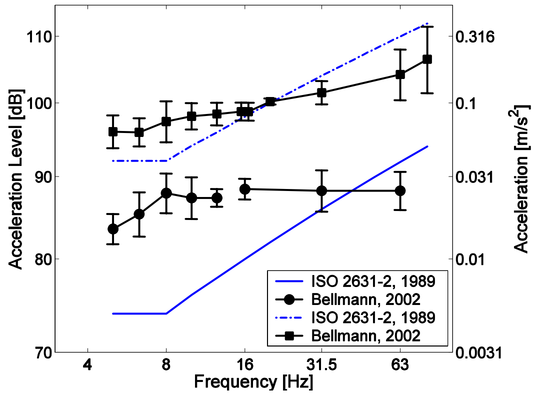

Figure 5: Measured perception threshold and equal-vibration level contours in comparison to standard data. (Adapted from [1])

4. Discussion and conclusion

- An overview about vibration exposure in passenger cabins is given, Figure 1 and 2.
- Psychophysically motivated spectrally weighting functions which depend on vibration excitation level are needed for a better suited objective description of the subjective vibration comfort.
- These resultant weighting functions should take into account knowledge about basic experiments on the perception of vibration (e.g., perception threshold and equal-vibration level contours, Figure 4).
- Additionally, spectrally band limited parameters around prominent vibration components are sufficient to describe subjective comfort, Figure 3.
- However, the vibration signals should be measured at the man-machine interfaces between the vibrating part of the machine (e.g., the seat) and the human body. But new and better suited vibration sensors are needed.
- In this study just frequency (spectral) depending parameters are used but comfort cannot be explained directly by spectral features of the monitored vibrations alone. Therefore, it is not precluded that also parameters which depend on time and duration are needed for a full description of the subjective (dis-) comfort caused by vibrations. Therefore, combined parameters, which include a combination of frequency and time/duration depending properties, should be investigated to obtain a full description of subjective (dis-) comfort in passenger cabin.

5. References

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[3] ISO 2631-2 Part 2 (**1989**) „Evaluation of human exposure to whole-body vibration - Part 2: Continuous and shock-induced vibration in buildings (1 to 80 Hz)“

[4] Mansfield, N.J. (**2001**) “Localized vibration at the automotive seat-person interface”, presented at: *Internoise 2001*, The Hague, Netherlands

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