inter.noise 2000
The 29th International Congress and Exhibition on Noise Control Engineering
27-30 August 2000, Nice, FRANCE

I-INCE Classification: 0.0

DIMENSIONS OF COMBINED ACOUSTIC AND VIBRATION PERCEPTION IN AIRCRAFTS DERIVED BY FACTOR ANALYSIS OF SEMANTIC DIFFERENTIAL DATA

J. Quehl*, A. Schick*, V. Mellert, B. Schulte-Fortkamp**, H. Remmers*****

* University of Oldenburg, Department of Psychology, Institute for Research into Man-Environment-Relations, D-26111, Oldenburg, Germany

** University of Oldenburg, Department of Physics and Acoustics, D-26111, Oldenburg, Germany

*** Institute for Technical and Applied Acoustics (ITAP) GmbH, University of Oldenburg, D-26111, Oldenburg, Germany

Tel.: +49 441 798 5515 / Email: quehl@psychologie.uni-oldenburg.de

Keywords:
SOUND, PERCEPTION, VIBRATION, SEMANTIC DIFFERENTIAL

ABSTRACT
An aircraft simulation test was carried out in a mock-up (laboratory equipment) with a sample of 117 subjects. Seven cruising conditions of two aircraft types (4 jet and 3 propeller airplanes) were evaluated using semantic differential (abb. SD) with 15 adjective pairs and the standardized scales of the German "Eigenschaftswörterliste" (abb. EWL) of Janke & Debus (1981) (multidimensional mood scale). Using the SD three psychological dimensions were isolated by factor analysis describing the combined acoustic and vibration perception in aircraft. The most important dimension explaining one third of the variance was a comfort factor related to specific sound characteristics such as loudness or roughness and particular vibration attributes. The second dimension was associated with time features of the flight situations and further vibration qualities. The third factor was confined to the perception of tonality.

1 - INTRODUCTION
How many dimensions do we require to show the great variety of hearing experiences? What is the form, what is the structure of the characteristics according to which hearing experiences can be classified? It is a fundamental concern of scientific hearing research to reduce the variety of hearing impressions to a few psychological dimensions with maximal discriminating power (Schick 1994, 1996, 1998). Since Bismarck's (1974) factorial investigation into the verbal attributes of timbre SD procedures (Osgood et al., 1957, Osgood 1976) and factor analysis have been used in psychoacoustical research to derive a limited number of independent dimensions describing hearing sensations in terms of verbal attributes.
A survey of the literature of the last 20 years has shown that little is known about the basic dimensions characterizing the perception of combined acoustic and vibration configurations in aircraft. With the aid of SD and factor analysis, in the present investigation by evaluating typical aircraft flight situations those psychological dimensions were extracted which can be described in terms of verbal properties (Quehl et al., 2000). The aim is to improve the comfort of aircraft passengers by the modification of those psychoacoustic and vibration parameters that physically correspond to the dimensions distinguishing combined acoustic and vibration perceptions in aircraft (Quehl et al., 1999). "Comfort" is used as defined by Pineau (1982, p. 271) who characterizes the concept as "everything contributing to the well-being and convenience of the material aspects of life; thus it constitutes an improvement of living conditions in inhabited space".
Accordingly comfort and well-being are closely related because the subjective comfort sensation of a person can contribute to his or her individual well-being. "Well-being" is here applied in the sense of a subjective mood defined as a momentary, real state including internal experiences and subjective

sensations of a person (e.g., positive emotions, moods and physical sensations) (Abele & Becker, 1991, Janke & Debus, 1981).

2 - METHODS

Reviewing the recent psychoacoustical and the relevant psychological literature, it became obvious that an adequate methodological instrument for the evaluation of acoustic and vibration experiences in aircraft does not currently exist. Based on laboratory and field pretests a verbal space oriented instrument was developed (Quehl et al., 2000) consisting of a concept-specific SD which covers 15 adjective pairs for aircraft interior sound and vibration, comfort and well-being as well as psychoacoustic descriptors for loudness, roughness, sharpness, tonality and fluctuation strength, according to Zwicker (1999) (see figure 1). Furthermore, four subscales of the German EWL of Janke & Debus (1981) (multidimensional mood scale) constituting "well-being" and "fear" have been integrated. The EWL can be used to measure mood changes depending on interventions such as environmental conditions. The hypothesis is that emotional changes of the subjects (Ss) in the laboratory setting may influence the evaluation of combined acoustic and vibration stimulus configurations (Höge, 1984).

3 - AIRCRAFT SIMULATION TEST

An aircraft simulation test was carried out in a mock-up (laboratory equipment) with a sample of 117 Ss (37 female and 80 male, aged 19 to 61).

Seven typical cruising conditions of two aircraft types (three propeller and four jet airplanes) were presented twice in randomized orders in two test runs. The 17 seats in the mock-up were divided into four so-called vibro-acoustic clusters based on measurements of the spectra of both aircraft types. At least 20 Ss were subjected to the same sound and vibration field.

Each flight situation was evaluated using the SD in the native language of the Ss (German). The Ss' mood was measured by means of the EWL before the test took place, between the first and second test run, and at the end of the runs.

4 - RESULTS

4.1 - Inference statistics

The two-factor repeated measures analysis of variance revealed no significant evaluation differences within both aircraft types [propeller [$F(2,207.4) = .143$; $p = .865$; statistics according to Greenhouse Geisser (G.G.)] and jet [$F(2.9;300,0) = 1.964$; $p = .123$ (G.G.)]. Nevertheless, both types differed significantly in their judgment [$F(15,99) = 28,7$; $p < .000$]. T-tests for related data showed significant differences ($p < .003$) between the evaluation of the propeller and the jet on 13 of 15 qualities of the SD (see figure 1). The assessments in the four vibro-acoustic clusters did not vary significantly, in other words, the clusters did not systematically influence the evaluation of both aircraft types [propeller: $F(3,105) = .268$; $p = .848$ and jet: $F(3,105) = 1.992$; $p = .120$]. Therefore, the following analyses of the SD data were not carried out for each cluster. Rather, all 17 seats of the mock-up were considered in the analyses.

4.2 - Semantic profiles

The mean semantic profiles for each aircraft type averaged for three or four flight situations are shown in figure 1.

It was again found that the overall impression of the propeller airplane was different from the jet airplane. The mean evaluation of the propeller ranged from 2.2 to 5.3 with standard deviations between.81 and 1.33. The jet was assessed between 2.6 and 5.2 with standard deviations ranging from 0.90 to 1.47.

The propeller gave a more negative impression than the jet. It is rather perceived as "shaking", "uncomfortable", "low frequent", "unbearable", "threatening", "unacceptable", "not muffled", "vibrating", "loud", "sharp", "rough", "tonal" and "unsteady" than the jet. The differences amount up to 1.5 scale points, for instance for the attributes "comfortable", "bearable", "acceptable" and "loud". The evaluation of both aircraft types did not deviate with regard to the adjective pairs "monotonous vs. varied" and "regular vs. irregular".

4.3 - Factor analysis

With the aid of factor analysis, it was attempted to extract from the SD data independent psychological dimensions describing the combined acoustic and vibration perception in aircraft. Varimaxrotated principal component analysis was carried out for

- each aircraft type with three propeller and/or four jet cruising situations (see figure 2), and
- the mean evaluation of both aircraft types.

Applying the criterion of eigenvalues > 1 three interpretable factors were found explaining about two thirds of the total variance. Each factor explained at least 10 % of the variance. The factors were interpreted by means of the clusters of adjectives loaded at least >.50 on each.
The factor explaining one third of the variance was a comfort factor related to aircraft interior sound and vibration (see figure 2). Comfort seemed to be the counterpart of specific sound characteristics such as the perceived loudness or roughness as well as particular vibration attributes (e.g., "vibrating"). Adjectives coming from everyday life such as "comfortable", "bearable" and "acceptable" that cluster strongly described a similar semantic quality representing comfort in the perceptual space. The second dimension was associated with time characteristics of the flight situations like "monotonous" and "regular" and further vibration qualities like "unsteady" and "shaking". The third factor was confined to the perception of tonality.

5 - FUTURE RESEARCH

In order to improve aircraft passengers' comfort it is intended to correlate physical measurements of the aircraft sound and vibration configurations with the factor scores of each flight situation on the relevant dimensions of combined sound and vibration perceptions. Afterwards, the aircraft engineer can optimize those psychoacoustic and vibration parameters that physically correspond to the psychological dimensions.
Most of these previous investigations regarding the influence of an exposure to aircraft interior sound and vibration took only the single effect of sound or vibration into account but not their combined impacts. Excepted are the field and laboratory investigations of the NASA carried out to develop a general model for the estimation of aircraft passengers' *discomfort* response to combined sound and vibration stimuli in aircraft (e.g., Stephens et al., 1990). It is intended to develop a model for the synergetic effects of aircraft interior sound and vibration. For this purpose, a laboratory study will be carried out by means of the *"sound and vibration reproduction system"* developed at Itap (Remmers et al., 1999). The sound and vibration level of one propeller and one jet cruising situation also presented in the aircraft simulation test described above will be systematically varied (3 ×3 design) and evaluated using SD and EWL.

ACKNOWLEDGEMENTS

The investigation is supported by the BRITE-EURAM project "IDEA PACI" (BE97-4056) and the Graduate College "Psychoacoustics".

REFERENCES

1. **Abele, A. and Becker, P.**, *Wohlbefinden. Theorie. Empirie. Diagnostik*, Weinheim: Juventa, 1991

2. **Bismarck, G. von**, Timbre of steady sounds: A factorial investigation of its verbal attributes, *Acustica*, Vol. 30, pp. 146-158, 1974

3. **Höge, H.**, *Emotionale Grundlagen ästhetischen Urteilens*, Europäische Hochschulschriften. Frankfurt am Main: Peter Lang, 1984

4. **Janke, W. and Debus, G.**, *Die Eigenschaftswörterliste: EWL; eine mehrdimensionale Methode zur Beschreibung des Befindens*, Göttingen: Hogrefe, 1981

5. **Osgood, C.E, Suci, G.J. and Tannenbaum, P.H.**, *The measurement of meaning*, Urbana: University Press of Illinois, 1957

6. **Osgood, C.E.**, *Focus on meaning*, The Hague: Mouton, 1976

7. **Pineau, C.**, The psychological meaning of comfort, *International Review of Applied Psychology*, Vol. 31, pp. 271-283, 1982

8. **Quehl, J., Schick, A., Mellert, V., Schulte-Fortkamp, B. and Remmers, H.**, Effects of helicopter and aircraft interior noise and vibration on passengers' comfort sensation and subjective well-being, *J. Acoust. Soc. Am.*, Vol. 105 (2), pp. 1084, 1999

9. **Quehl, J., Schick, A., Mellert, V., Schulte-Fortkamp, B. and Remmers, H.**, *Evaluation of combined aircraft interior sound and vibration effects on passengers' well-being and comfort sensation: the elaboration of a concept-specific methodologoical instrument*, Results of the 8th Oldenburg symposium on psychological acoustics. Oldenburg: bis, 2000

10. **Quehl, J., Schick, A., Mellert, V., Schulte-Fortkamp, B. and Remmers, H.**, Hauptdimensionen einer kombinierten Geräusch- und Vibrationswahrnehmung in Flugsituationen: Auswertungen zum semantischen Differential, In *Fortschritte der Akustik - DAGA 2000, Oldenburg (in print)*, 2000

11. **Remmers, H., Reckhardt, C. and Bellmann, M.**, A system of natural reproduction of sound and vibration, *J. Acoust. Soc. Am.*, Vol. 105 (2), 1999

12. **Schick, A.**, History and evaluation of sound and noise in cars, *Noise abstracts and reviews*, Vol. 1 (3), pp. 3-10, 1994

13. **Schick, A.**, Evaluation of sound and noise in passenger cars - History and survey of the japanese applied timbre research - Thoughts on the role of psychology in the field of vehicle acoustics, In *Faculty of Mechanical Engineering University of Ljublijana, Slovenia*, 1996

14. **Schick, A.**, Theories of meaning as bridges between psychology and engineering, In *Proceedings of the EURO-NOISE, München*, pp. 529-534, 1998

15. **Stephens, G.D., Leatherwood, J.D. and Clevenson, S.A.**, The development of interior noise and vibration criteria, *Archives of Complex Environmental Studies*, Vol. 2, pp. 9-16, 1990

16. **Zwicker, E.**, *Psychoakustik*, Berlin: Springer, 1999

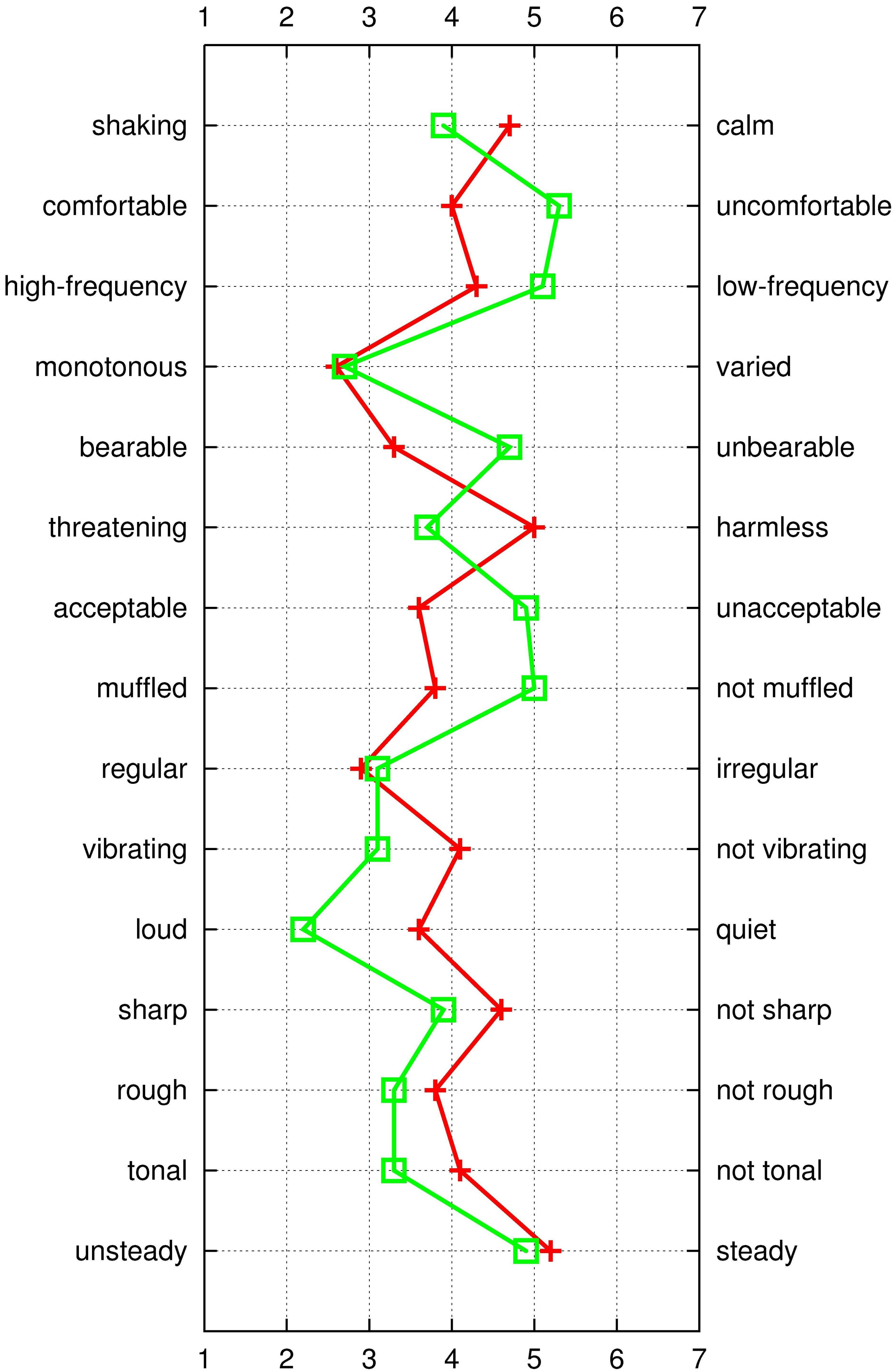

Figure 1: Mean semantic profiles for the aircraft types propeller (□) and jet (+).

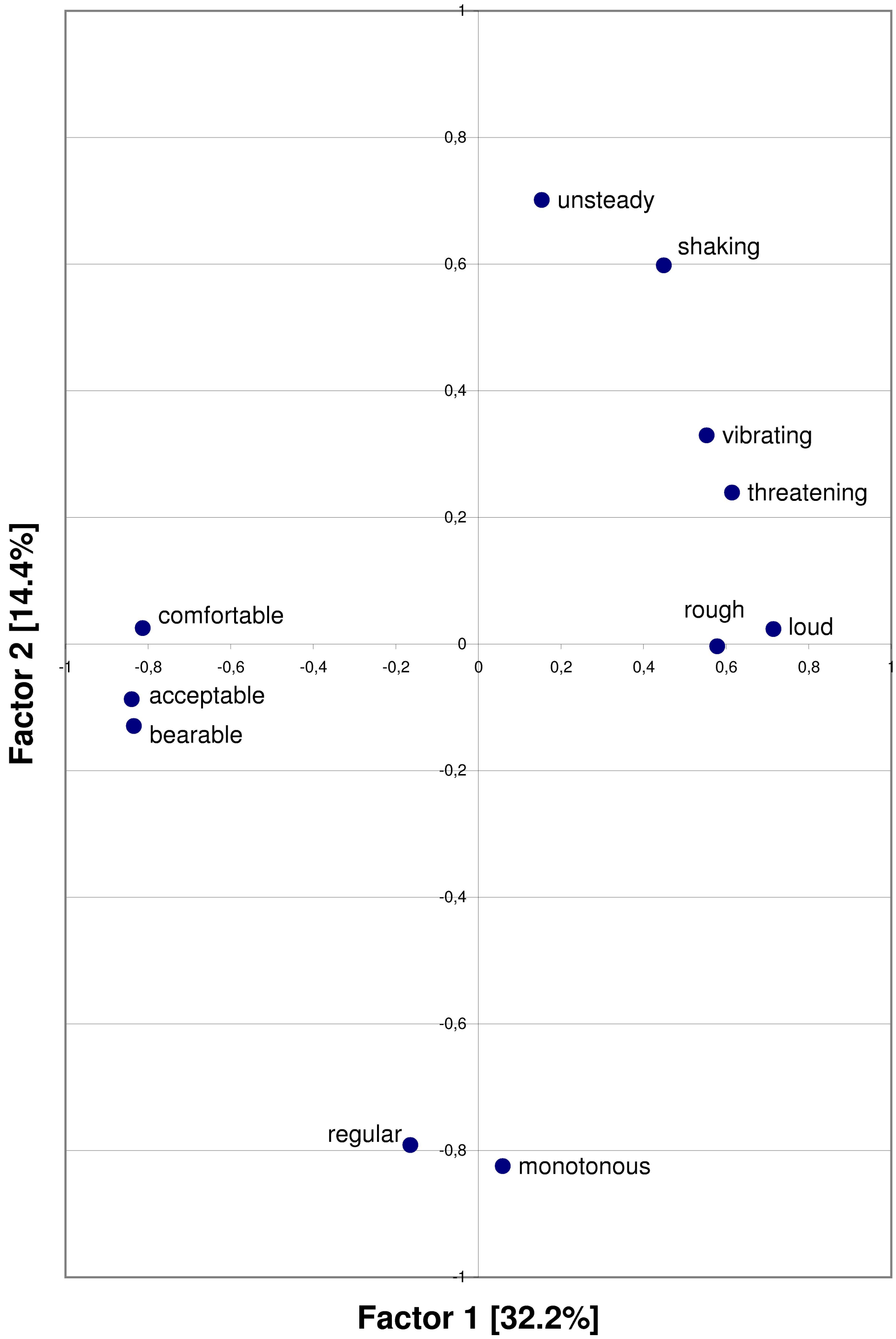

Figure 2: Factor analysis for the aircraft type propeller with three flight situations.