INFLUENCE OF NOISE AND VIBRATION ON THE PERCEPTION OF THE AMBIENCE INSIDE THE CABIN.

V. Mellert, I. Baumann, N. Freese, R. Weber
Oldenburg University, Inst. f. Physics
26111 Oldenburg
Germany

OVERVIEW

Noise and vibration affect flight attendants and pilots at their workplace in the cabin besides numerous other physical environmental parameters, e.g. air quality, draft, temperature distribution, glare, etc. Additionally, the physiological setting and psychological attitude modulate the influence of the ambience on perception. The relations between environmental parameters at the work place, the psychophysiological response, and the performance is investigated in the EU-project HEACE ("Health Effects in Aircraft Cabin Environment", www.heace.org). Studies are conducted in simulators and mock-ups as well as in real long-haul flights. Environmental measurements are performed with the help of the project partners EADS-CRC (Germany), Building Research Establishment BRE (UK), itap GmbH and Paragon Ltd. Physiological and medical data are recorded by the Medical University Vienna. Questionnaires are designed with support of BRE. A comprehensive data analysis is performed with BRE, CIRA, University of Patras and Medical University Vienna. The sound level is one important parameter besides measures of air quality which exert negative impact on subjective feeling and have significant bias on the crew's performance, in particular when effective during long-haul flights.

1. TEST DESIGN

Variation of environmental conditions in real flight is obviously limited, and experimental set-ups in an airplane have to follow rigid boundary conditions by taking safety issues into account. It is therefore useful to conduct additionally experiments in a simulator facility which provides a sufficient natural ambience with the help of virtual reality and an appropriate mock-up environment in hardware. Experiments in HEACE are carried out in both, simulators and during real flights. Details of the experimental set-ups are reported in [1, 2] and therefore only recalled shortly in this paper.

The test design comprises an elaborate questionnaire and the registration of numerous physiological and health parameters.

Simulator tests are carried out in two facilities: The emergency trainer of Austrian Airlines in Vienna and in the ACE test facility of BRE in Watford [3]. The environmental condition is adjusted in a full three-step variation of the three parameters "sound and vibration" (vibration signal derived from the acoustic input), "humidity", and "temperature". 22 pilots and 86 flight attendants serving 544 (test) passengers participated in the simulator tests.

The questionnaire addresses some 120 items from following areas

- health and well-being (30 items)
- environmental conditions (45 items)
- demand for control over environment (8 items)
- effect of the environment (18 items)
- relative comfort contribution (18 items)
- ability to work (8 items)
- alertness and mood (9 items).

The questionnaires are designed by the partners from Oldenburg University, Medical University Vienna and BRE.

Flight experiments are conducted with support of Austrian Airlines in 6 long-haul flights of 8 and 12 hour duration with participation of 132 flight attendants and 30 pilots: Vienna-Delhi-Vienna (8 h duration) and Vienna-Tokyo-Vienna (12 h duration) in Airbus A330 and A340. The environmental data are registered as "naturally" offered; the data from the cabin crew is recorded with the same tools and by the same means as used in the simulator experiments.

Environmental data are measured in cockpit, galleys, cabin, and crew-rest compartments at various locations. The experiments and data acquisition are carried out with the partners of Oldenburg University, Medical University Vienna, EADS-CRC, itap GmbH and Paragon Ltd.

Following environmental parameters are measured:

- sound and vibration (time history and level)
- temperature
- humidity
- draft
- air quality (CO_2, CO, VOCs, number of germs).

Practically coherent in the same time, the following physiological parameters are measured in parallel [4, 5]

- heart rate and -variability
- blood pressure
- oxygen saturation
- salivary cortisol
- skin conductance

while questionnaires are filled in by the crew members. This is scheduled after service (three-times during Tokyo flight and two-times during Delhi flight).

The data base covers finally a matrix of some hundred test persons, each with numerous perceptive indicators and physiological and health parameters under various environmental conditions.

2. DISTRIBUTION OF SOUND AND VIBRATION

An example for the environmental condition with respect to sound pressure level is given in Fig. 1, which notes the A- and B-levels at different locations of the planes. A difference between A- and B-weighted level indicates additional low-frequency contributions (most pronounced in the first economy compartment in the middle of the fuselage near the wings). Both planes have about the same noise level in cabin and cockpit during the flight tests except for the aft of the A330, where the level is slightly increased (due to the two louder engines).

Fig. 2 gives the dB(A) level from the cockpit location to the aft, averaged over all flights and distinguished between the two types of aircraft (A330 and A340). A continuous increase with location is observed. Fig. 3 indicates in particular an increase of low-frequency components starting at the "economy 1"-location. The vibration levels of acceleration are measured at about the same locations and depicted in Fig. 4.

The acceleration levels in Fig. 4 are averaged values in the frequency bands 16-80 Hz, 100-160 Hz, 200-250 Hz and weighted according to ISO 2631-1. The level values in Fig. 4 are numerically reduced by 20 dB in order to provide numbers of same magnitude as sound pressure levels, with the objective to construct a balanced input vector for a neural network analysis (acceleration level of 140 dB equals about 1 g – the reference in Fig. 4 is 120 dB). Measurements and input vector are provided by itap GmbH and EADS-CRC [6, 7]. The vibration level is lowest in the front part with a slight increase in the first galley.

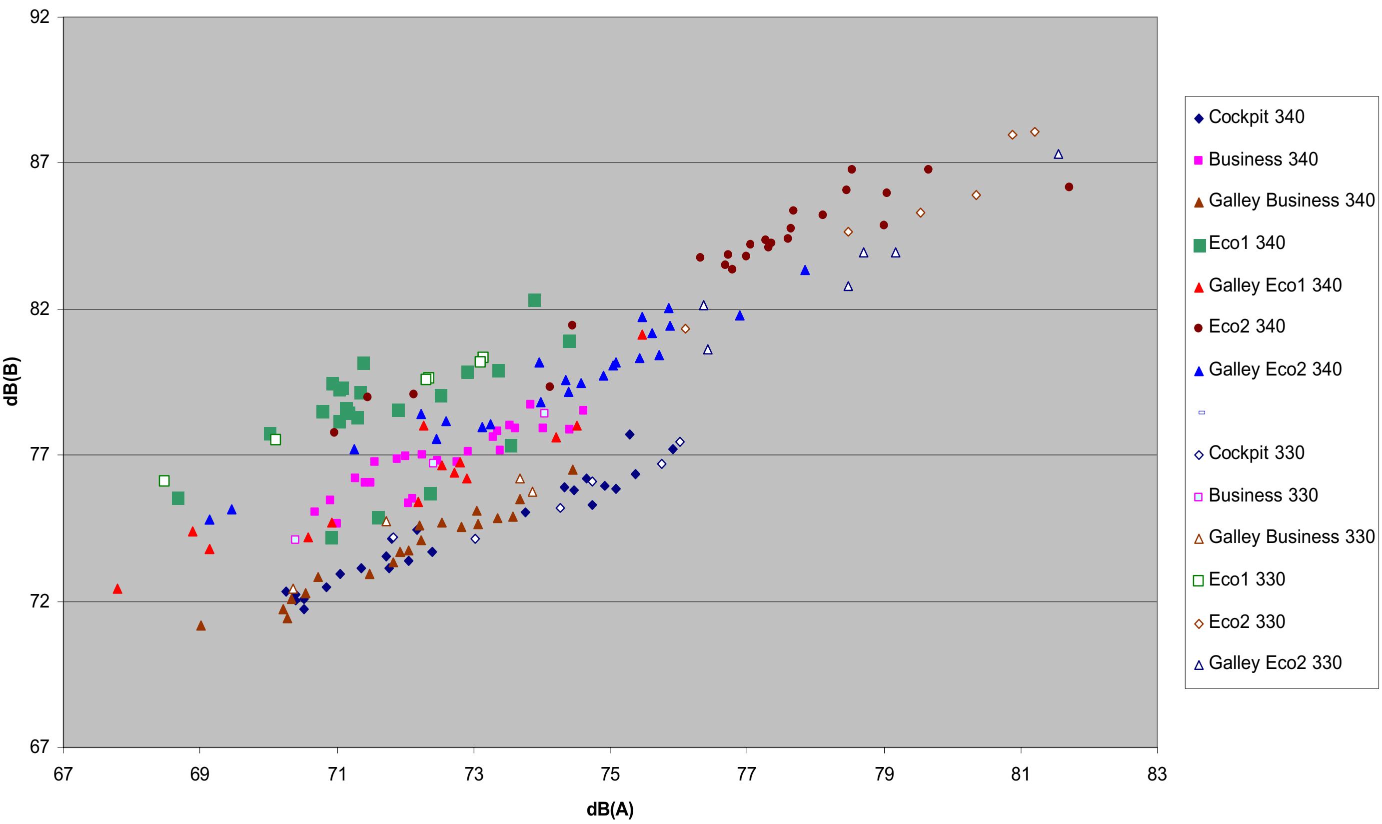

FIG 1. Distribution of A- vs. B-weighted sound level in cockpit and cabin for A340 (filled symbols) and A330 (open symbols) during periods of filling in the respective questionnaire (location given in table). dB(B)>dB(A) indicates low-frequency contribution to interior noise level.

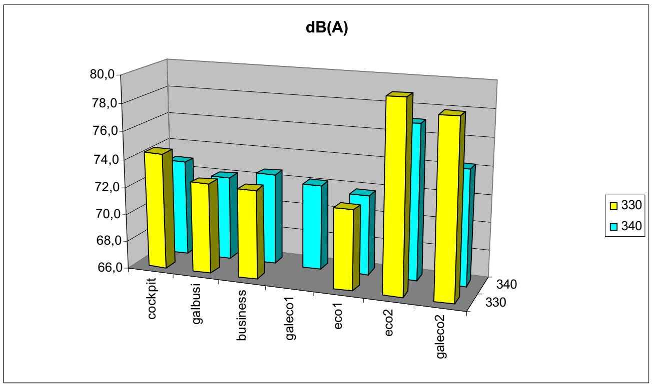

FIG 2. dB(A)-levels in cockpit and cabin along aircrafts A330 and A340 from front to aft at respective location during long-haul flights (average in time over flight duration)

The distribution of all unweighted noise levels in the galleys (Fig. 5) clearly exhibits a two-fold distribution, while this information is lost by A-weighting (Fig. 6). This is just another point of view of Fig. 1. Obviously there is a change in noise spectrum due to low-frequency components in the different work places. In particular, there is a pronounced difference of the average levels in the business class galley compared to the economy galleys (Fig. 7).

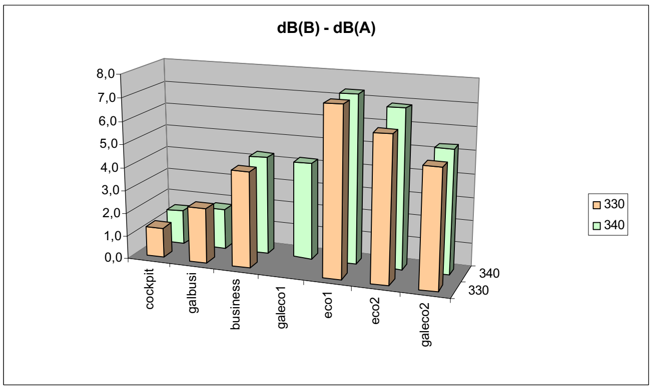

FIG 3. Increase of dB(B) level over dB(A) level along aircrafts A330 and A340 (derived from Fig. 2).

The given distribution of vibro-acoustic levels facilitates a certain variability of environmental input to the crew. But the "overall" analysis neither takes into account that the noise levels vary with time nor that the members of the crew do not change their work place during flight within all areas of the plane thus being not subject to the different environmental conditions. Analysis of the work place (recorded in the questionnaire) reveals that the flight attendants (except for the purser) stay practically in one of the three segments "business", "economy 1" or "economy 2" (including the respective galleys). Location "economy 1" is addressed in the analysis in chapt. 5.

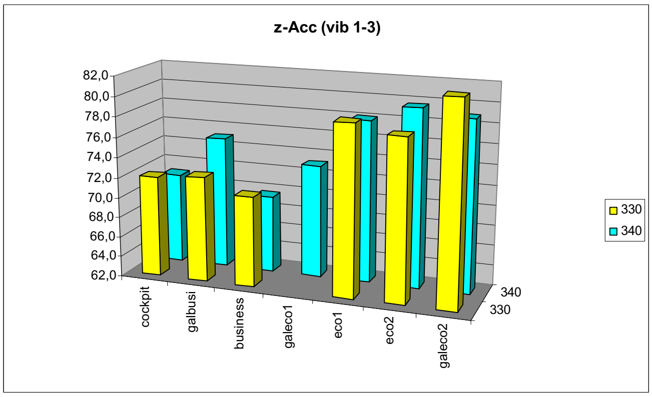

FIG 4. Weighted vibration levels [dB] at same location as in Fig. 2. The ordinate scale is shifted by 20 dB to adjust the numbers for training of an artificial neural net (details see text).

3. TIME DEPENDENCY

The flights are divided into 2 or 3 phases according to the service by the crew. A detailed analysis of the data according to the flight phase reveals significant dependencies on time of certain subjective symptoms and of health parameters. Environmental conditions change also with time. It is observed that e.g. the levels of sound and vibration lower with flight duration, presumably due to the reduction of weight, which results from the reduced engine power.

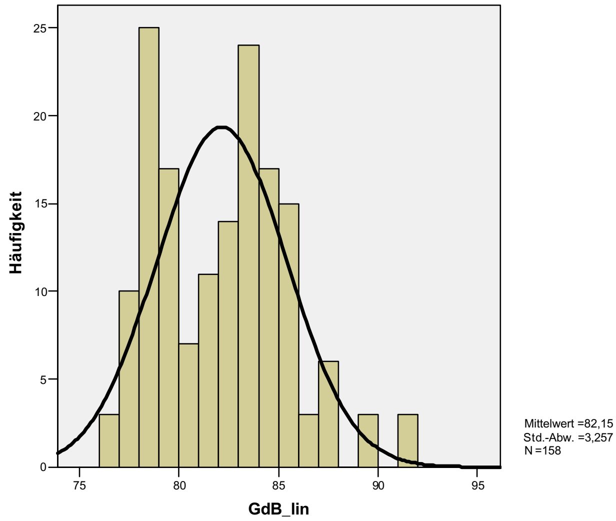

FIG 5. Average distribution of linear noise level in all galleys during whole flight.

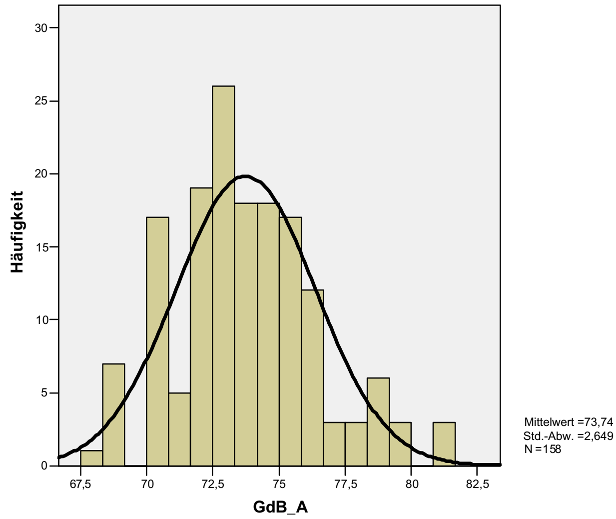

FIG 6. Same as Fig. 5 but with A-weighted levels

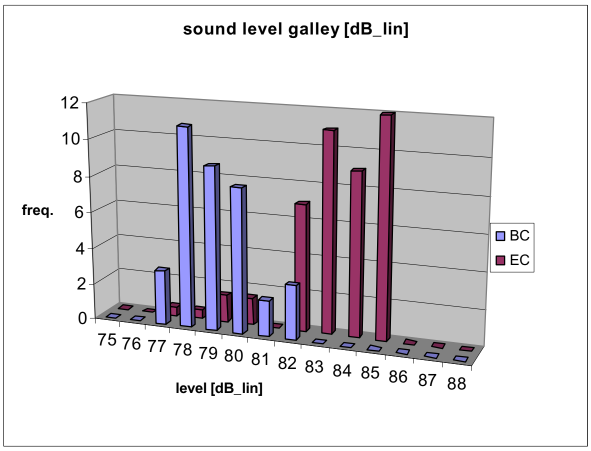

FIG 7. Level distribution in business class galley compared to distribution in economy class levels. The histogram illustrates a detail from Fig. 1.

The example of the symptom #24 (Question: “At this moment, to what extent are you experiencing swollen or heavy legs/feet?” Scale: 1= not at all, 7=very severely) illustrates the increase of this symptom with time (Fig. 8 and 9)

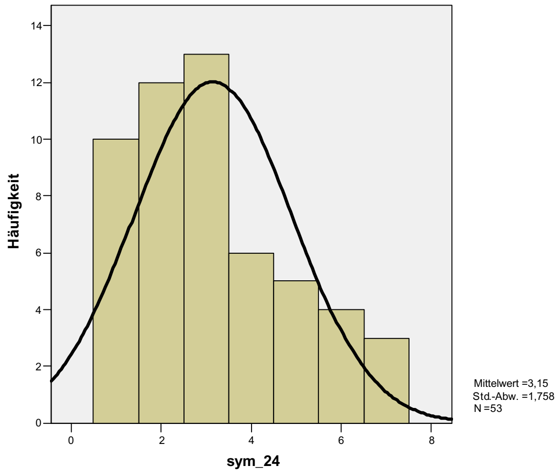

FIG 8. Distribution of perception of symptom #24 by flight attendants in first phase of flight.

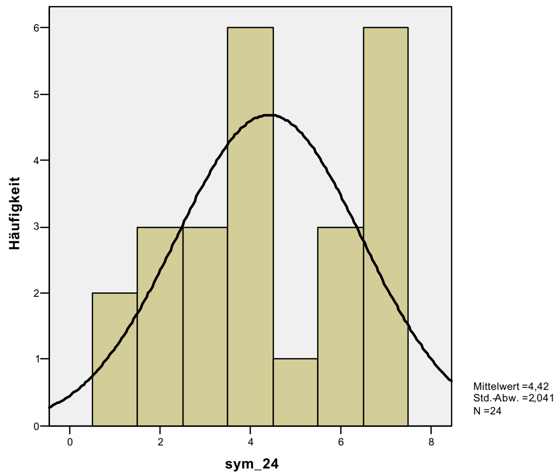

FIG 9. Distribution of perception of symptom #24 by flight attendants in last phase of flight.

Fig. 8 and Fig. 9 demonstrate additionally a problem for the data analysis if the number of cases in distributions becomes small, though in this example the difference is not only obvious but also statistically significant.

Analysis of variance (ANOVA), principal component analysis (PCA) and correlation analysis is employed to identify relevant environmental and intrinsic parameters which contribute to a certain output of a crew member, e.g. a medical or psychological index or symptom. If the analysis is carried out for all subjects in all flights, i.e. in all conditions, some general results are derived [1, 2]. Parameters with insufficient variation are identified, and a PCA reveals the space of perception of all subjective data, indicates those items which cluster, and gives an estimate, which perceptions are correlated with independent variables, e.g. with a certain environmental condition. The PCA displays clear clusters of similar perception, which can be arranged in 11 dimensions related to

- subjective noise-effects (e.g. distraction or annoyance due to noise)
- symptoms (like headache, dizziness, etc.), except those related to dry air or muscle pain
- effects from vibration and motion
- perception of temperature and parameters of local climate (e.g. cold feet)
- motivation, concentration
- perception of air quality
- request to change certain environmental conditions
- communication (incl. intelligibility)
- perceived draft and overall comfort
- symptoms related to dry air
- symptoms related to muscle/ joint pain.

But a correlation of these factors with environmental conditions fails due to the inhomogeneous conditions in (work-) space and (flight-) time.

The change of the environmental condition and of the subjective and physiological state of the subjects prohibits the successful data analysis of all data in one scheme. Further differentiation is therefore carried out by selection of homogeneous subgroups of the subject and by taking the time dependency into account.

4. GENERAL RESULTS

As reported in [1, 2] it is possible to derive general relations between the measured average environment and the average human response. Medical University Vienna calculated representative indices for health, performance, physiological and psychological load [9, 10]. Together with appropriate (partly pre-processed) input vectors from physical parameters [6, 7] partners from University of Patras and from CIRA developed artificial neural networks [11, 12], which provide the above mentioned indices as output with an error below about ½ step-size of the subjective scales (i.e. about ±7% absolute error). The disadvantage of the neural network is of course the lack of insight into relations and mutual interactions between the different input and output parameters. A sensitivity analysis is not yet performed.

5. ECONOMY 1

A PCA is carried out for all flight attendants working in the area “economy 1” (cf. Fig. 2: eco1 and galeco1). The symptoms

- #5: “dry nose”
- #7: “dry/ irritated throat”
- #9: “dry skin/ lips”
- #16: “difficulty in concentrating or remembering”
- #24: “swollen or heavy legs/ feet”
- #25: “muscle/ joint pain in back”

are included in the analysis since these changed significantly with time (flight phase). Additionally, the subjective ratings

- “How would you rate the mental demand placed on you since ... ?”
- “How would you rate the physical demand placed on you since ... ?”
- “How high is you ability to concentrate?”

together with ratings about the perception of noise and vibration are included in the PCA. The time (as "phase") and the direction of flight (from or back home) are used as independent variables.

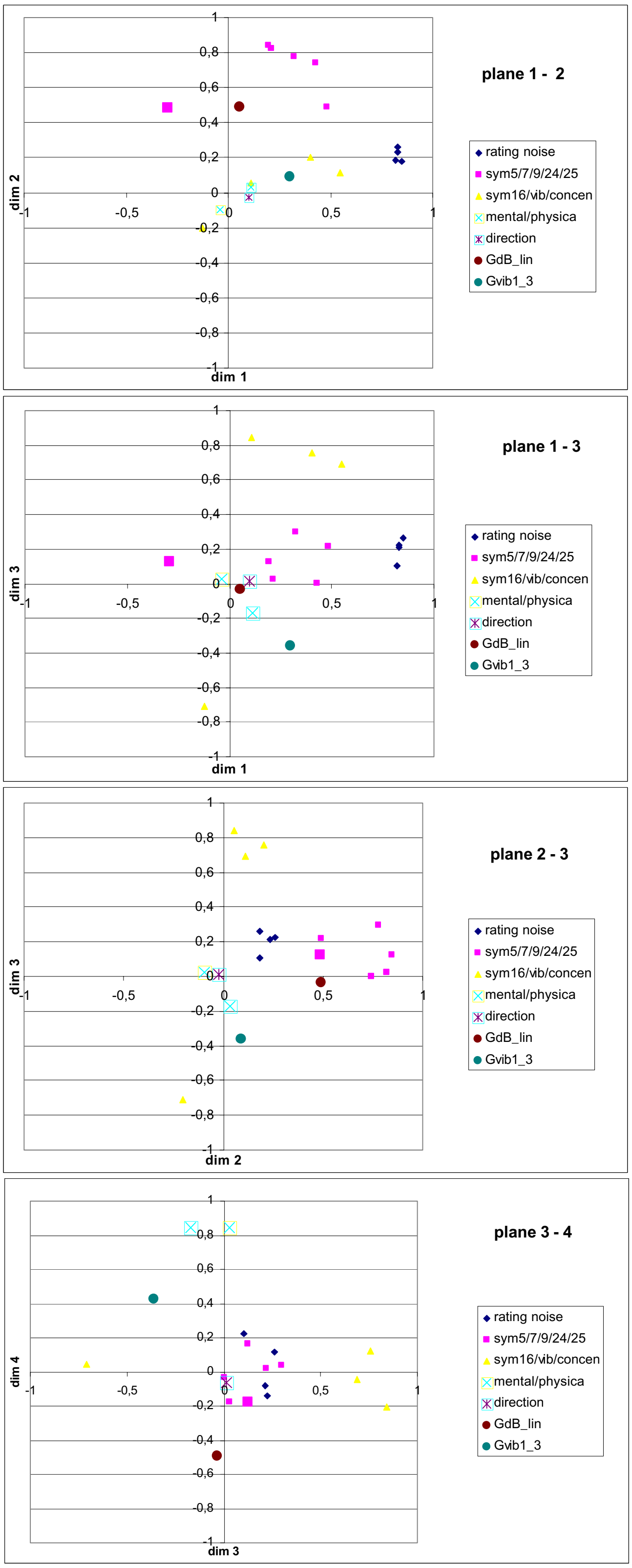

FIG 10. Views into the space of perception of flight attendants in „economy 2". Discussion and legend: See text.

The PCA yields five significant dimensions of the space of perception, more or less attributed to

- noise ratings
- symptoms #5, 7, 9, 24, 25
- symptom #16, concentration, rating of vibration
- mental/ physical demand
- direction

Obviously none of the parameters in this PCA is related to the direction of flight, whereas in the overall analysis it was previously revealed that the ability to concentrate was significantly degraded by about 14%, averaged over all flights, when travelling "home" (error < 0.1%) [1].

Some planes of the space of perception in the group of flight attendants working in "economy 2" are depicted in Fig. 10.

The first dimension (dim 1) is clearly defined by the subjective ratings of noise. The second (dim 2) is given by the symptoms related to the dry air, but these have also some contribution to dim 1. The third dimension is related to the ability to concentrate and to perception of vibration, but the two ratings of vibration have significant components (correlation) with the "noise" factor (dim 1). The "concentration" (dim 3) is clearly negatively correlated with symptom #16 and the perception of vibration, due to the different (opposite) scaling.

The time (phase) is well correlated with the symptoms (highlighted by an enlarged square symbol in Fig. 10), indicating that the selected symptoms do not only vary with dim 1 (perception of noise) but also with time.

Additionally, two significant environmental parameters are notified in Fig. 10 (enlarged round symbols): The levels of sound (unweighted) and of vibration (weighted). The two parameters are arranged according to the correlation with the respective factor. The parameters contribute to every dimension. The overall length in the 5-dimensional space is 0.70 (sound level) and 0.84 (vibration level), respectively, and therefore indicates a highly significant correlation.

In contrast to the "overall" analysis presented in [1, 2] it is possible to relate the identified perceptive space of the PCA to environmental impacts, if a subgroup of subjects is selected, who works under homogenous conditions. The PCA is a first step to develop a comprehensive model of perception, which takes all relevant environmental parameters into account. In order to reveal relations between environmental and perceptive, medical, performance etc. parameters it is necessary to conduct experiments under well defined conditions of the ambiance. This is only possible in a simulator, though the artificial condition of a simulator experiment hinders a simple transfer of results to the real-flight condition.

6. SIMULATOR TESTS

Pre-tests are carried out in the emergency trainer of Austrian Airlines in Vienna. This simulator has the advantage to provide quite good natural ambience with respect to noise, vibration and motion, but lacks of stable conditions for temperature and humidity. Main simulator tests are carried out in the ACE at Watford, which allows for an excellent stabilization of climatic conditions (except pressure), even at very low humidity [8], but has the disadvantage not to provide motion, which lowers considerably the impression of a natural ambience.

The simulator experiments are carried out by BRE, Medical University Vienna, itap GmbH and Oldenburg University.

Simulator flights could only take place with duration of three to four hours daily due to limitations of the facility. A full 3 × 3 × 3 factorial test design is chosen: 3 levels of noise (and vibration, which was derived from the sound signal), 3 levels of temperature, and 3 levels of humidity. The lowest noise level is determined by the background noise of the air conditioning (Table 1). Because the whole set-up (including test persons) has a considerable relaxation time with respect to the target levels of the climate-parameters (in particular for the humidity), the test design is chosen such that during a simulated 3-hour-flight temperature and humidity are kept constant, whereas noise is adjusted to the given three levels (with a smooth transition which is not noticeable, not even for the supervisors of the experiment).

In short summary, a simulator flight starts with boarding, public welcome address, "start" procedure, one hour "flight" at a given noise level, catering, one hour "flight" at next noise level, catering, one hour "flight" at third noise level, landing procedure. The climatic conditions are kept constant during this session.

Questionnaires are filled in by the passengers and by the crew after each service. The service of the crew includes the distribution of additional questionnaires to passengers.

A PCA exhibits a two-dimensional space of perception, as could be expected from the test design (i.e. variation of the two independent variables noise and climate). One factor represents all items related to "noise". This result is in agreement with the observation of the flight tests. In contrast to the flight measurement, the dB-level relates well to this subjective factor. The second factor includes all items related to the air quality and subjective views related to temperature conditions.

The test design was such that during a Case I of the simulated flight the noise level increased (step 1, 2, 3) and during Case II the level decreased (step 3, 2, 1) monotonously.

temperature [°C]	21 – 22	24 – 25	27 – 28
relative humidity [%]	5 – 10	15 – 20	25 – 30
Sound level step #	step 1	step 2	step 3
sound level [dB(A)]	70	74	78

TAB 1. Test design in ACE simulator with parameter ranges as observed in the cabin. The target values for sound were not realised at each passenger seat, the levels range in about 70-76, 73-78.5, 75-80.5 dB(A)

ANOVA reveals significant dependencies on perceived noise and vibration and on several symptoms for Case I, in particular, the noise level has significant impact on (error in brackets):

- level of distraction (3 %)
- level of annoyance (1 %)
- overall satisfaction (< 1 %)
- perception of vibration (< 2 %) and movement (< 1 %)
- symptoms (< 1%)
  - lethargy/ tiredness
  - difficulty in concentration/ remembering
  - swollen or heavy legs/ feet
  - headache

But the noise level has **no** significant impact on any of the previous items for Case II, except for the "perceived volume of noise in the cabin".

An obvious interpretation of this observation is that symptoms in general increase with time, as already identified in the real flight measurements, but consciousness is lowered if the noise level is decreased. If the noise level increases, the crew members become aware of the change of symptoms (Fig. 11).

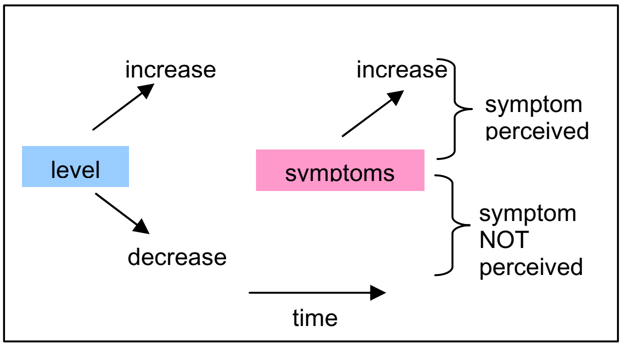

FIG 11. Scheme to illustrate the trade-off between reported symptoms and change of noise level. Symptoms increase with time, but become aware only if noise level increases as well. Symptoms do not become aware with decreasing noise level

The same scheme illustrates that it is not directly possible to decompose the psycho-physiological impact exerted by different environmental physical parameters, if these change with time. The rather high noise level in the workplace "economy 2" could have significant impact on e.g. the performance of work, but if the level decreases with time, the degradation of performance with time would be compensated. A differentiated analysis is in progress.

7. CONCLUSIONS

The impact of environmental conditions like noise and vibration at the workplace of cabin- and flight crew on well-being, performance, and health is identified by measurements in long-haul flights and tests in simulator facilities. Various indices are developed to characterize the human response. A relationship between independent variables (characterizing the environment) and dependant variables (indicators of the human response) is well described by an ANN. Direct input-output dependencies of selected parameters reveal a complicated mutual interaction of numerous variables. Only if the experimental conditions are homogeneous in space and time it is possible to derive a quantitative interrelationship. The noise level exerts significant influence on various symptoms and health indices, in particular when the level increases with time of work.

The authors acknowledge the substantial support of the HEACE project by the European Commission, Proposal No.: GRD 1-2001-40118.

8. REFERENCES

[1] V. Mellert, I. Baumann, N. Freese, R. Weber (2007). Impact of sound and vibration on health, travel comfort and performance of flight attendants and pilots. Accepted in: Aerospace Science and Technology, EREA. 2007

[2] V. Mellert, I. Baumann, S. Buss, N. Freese, R. Kruse, R. Weber, M. Bellmann. Vibroacoustic impacts performance and well-being of cabin crew during long-haul flights (2007). In: Proc. 1st Inter. Workshop on aircraft System Technologies, 113-122. O. von Estorff (Ed.) Shaker, Aachen. 2007.

[3] http://projects.bre.co.uk/envdiv/aviation/test.html, ACE test rig of BRE.

[4] Trimmel, M., Goger, C., Vouk, E.M., Kritz, M., Klaus, A., & Groll-Knapp,E. (2005) Heart rate of pilots during long haul flights indicate low arousal states. Psychophysiology, 42, 2005.

[5] M. Trimmel, Chr. Goger, E. Groll-Knapp (2005): Umweltbedingungen und Belastungen für das fliegende Personal, Jahrstagung der Arbeitsgemeinschaft für Berufs- und Umweltdermatologie. Österreichische Gesellschaft für Arbeitsmedizin, Graz, 2005.

[6] M.A. Bellmann, A. Röder and H. Remmers (2005). Environmental Conditions for Cockpit and Cabin Crew Members during Long-Haul flights - from Experimental Results to a Representative Vibro-Acoustic Input Vector for ANN and Statistical Approaches. Proceedings 1st IC-EpsMsO, Athens, 6-9 July, 2005 (© IC-EpsMsO).

[7] M.A. Bellmann, H. Remmers, A. Röder (2007). Environmental conditions for cockpit and cabin crew members during long-haul flights. From experimental results to a representative vibro-acoustic input vector for ANN and statistical approaches. 33rd German Annual Conference on Acoustics in Stuttgart (DAGA 2007).

[8] Skinner C.J., Butler D.J.G., Seller J.P. (2005). Noise, Vibration and Air Conditioning - Reproduction of Environ¬mental Conditions in an Aircraft Cabin Simulator. Proceedings 1st IC-EpsMso Athens, 6-9 July, 2005 (© IC-EpsMsO).

[9] Trimmel, M., Groll-Knapp, E., Goger, C., Mellert, V., Baumann, I., Frese, N., Weber, R., Bellmann, M. & Remmers, H.(2005) Impact of environmental conditions on comfort, motivation, task load, physiological activity, health and performance in flight attendants. Proceedings of the UOEH: Comfort in the Workplace (2005), Kitakyushu (Japan)

[10] Trimmel, M., Goger, C., Groll-Knapp, E., Mellert, V., Baumann, I., Freese, N., Weber, R., Bellmann, M., Remmers, H., Grünewald, M., Faulhaber, P., Röder, A., Seller, J., Aizlewood, C., Emms, H., Hamilton, L., Tsahalis, D. (2005). Modeling the impact of environmental conditions on comfort, task load and motivation in the mock up and in real flights. Proceedings 1st IC-EpsMso Athens, 6-9 July, 2005 (© IC-EpsMsO).

[11] d'Ischia M., Brindisi A. (2005). Evaluation of Psycho-Physiological Response of Civil Aircraft Crewmembers. A Proposal for Modelling. Proceedings 1st IC-EpsMso Athens, 6-9 July, 2005 (© IC-EpsMsO).

[12] [7] Nokas G., Photeinos D., Tsokas K., Tsahalis D.,(2005). A Human Response Model for Aircraft Environ¬ment based on Neural Networks. Proceedings 1st IC-EpsMso Athens, 6-9 July, 2005 (© IC-EpsMsO).