Impact of Sound and Vibration on Work Load of Cabin and Flight Crew

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Impact of sound and vibration, climate and air quality, duration of flight, and from other environmental parameters on the work load of cabin and flight crew were investigated in the EU-project HEACE as well as psychological and physiological factors (partners see www.heace.org). Results are reported on the part which sound and vibration contributes to comfort and performance of the crew.

1 Introduction

The investigation of health effects in aircraft cabin environment was the objective of the EU project HEACE (www.heace.org). The aim of the research was to develop a model which relates the environmental impact at the workplace of pilots and flight attendants inside the aircraft to health parameters, to subjective comfort, to performance, in order to derive recommendations for an improved design of the interior of cabin and cockpit.

The investigation was carried out with partners from BRE (Building Research Establishment, UK), Medical University Vienna, EADS-CRC (Germany), CIRA (Italy), University of Patras, LFME (Greece), itap GmbH (Germany) and Paragon Ltd (Greece). A test design was developed for simulator experiments in the emergency trainer of Austrian in Vienna and in the ACE test facility of BRE in Watford. The design comprised a long questionnaire to be used before, during and after the test period, a full three-step variation of the environmental parameters sound (and vibration), humidity and temperature, as well as extensive monitoring of environmental parameters. Additionally, numerous physiological and health indices were registered. 22 pilots and 86 flight attendants serving 544 (simulated) passengers participated in the simulator tests. These experiments were complimented by 6 real long-haul flights, in which altogether 132 flight attendants and 30 pilots participated.

2 Experiments in Simulator

2.1 Pre-tests

In order to develop and validate a questionnaire, pre-tests were performed in the emergency trainer of Austrian (Fig. 1). The design of the questionnaires was facilitated by the experience of BRE (flight tests in previous investigations), Oldenburg University (previous investigations on car noise) and Medical University Vienna (competence in environmental health). Crew personnel was interviewed, key-words selected, pairs of adjectives (antonyms) constructed, appropriate scales defined, duration of filling-in the answers estimated, and finally a layout for electronically transmission of the paper sheets designed.

Figure 1: Flight attendants from Austrian serving test persons acting as passengers in an emergency trainer

Additionally, the measurement devices for physical environmental parameters (time series of sound, temperature, humidity etc.) and for mobile recording of physiological data of the flight and cabin crew were tested (Fig. 2).

Figure 2: “Wired” pilot with recording of physiological parameters (EKG, blood pressure etc.) during pre-test.
A typical example of a part of the questionnaire related to perceived noise is shown in Fig. 3. A scale of 7 steps is used in this case. Other questions were combined with bipolar and 5-step scales.

**Noise in the cabin**

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Figure 3: Example for questionnaire, related to perceived noise.

In summary for tests during (real or simulated) flight: 30 items were asked related to health and well-being, 45 items related to the (perceived) environmental condition, 8 items asking for active control over the environment, 18 items asking for the impact of the environmental conditions, 18 items related to the contribution to comfort, 8 items asked for the ability to work, and 9 items related to alertness and mood.

### 2.2 Main tests

Main tests were carried out in the simulator facility of BRE [1, 2], which has the important property to establish a defined climate inside the fuselage, even down to about 10% humidity in order to simulate the condition of a long-haul flight, but has the disadvantage not to provide motion.

Due to restriction in time a $3 \times 3 \times 3$ test design was chosen with 3 levels each in sound, in temperature and in noise. The vibration signals were derived from the sound, hence both were coupled. The sound signal originated from a real flight (passenger jet). Due to the relaxation time of a stable condition in temperature and humidity the experimental design could not be randomized but followed the scheme depicted in Fig. 4. Each condition simulated a flight of about 1 h duration. The (acoustic) transition between the adjacent conditions was adjusted so smooth that it was not noticeable, not even for supervisors of the test. Questionnaires were filled in by the crew at the end of each condition. Corresponding environmental, medical and physiological data were recorded the same time. The environmental parameters were adjusted as follows:

- temperature: 21-22, 24-25, 27-28 °C
- relative humidity: 5-10, 15-20, 25-30 %
- sound level: 70, 73, 76 dB(A)

Of course, the real parameters within cockpit, cabin and galley deviated from the given values. The statistical analysis referred to the 3-step aggregation of the environmental condition.

![Diagram of experimental design](image)

Figure 4: Scheme of experimental design for 3 h simulated flight. Temperature and humidity kept constant, while sound and vibration level changes.

### 2.3 Results

Statistical analysis of the questionnaires reveals that about 52 variables from altogether 146 questions contribute by variance to the perception of the crew. A PCA on the 52 variables yields a 2-dimensional space of perception. Questions dealing with annoyance and disturbance due to noise and vibration relate to one dimension with significant correlation with perceived levels of noise (e.g. “perceived volume of noise in cabin”). Questions dealing with air quality and feeling temperature and related comfort make up the second dimension. The results is not surprising since the only independent variables in the experimental design have been noise level and air quality (temperature and humidity combined).

A closer analysis of variance (ANOVA) shows a significant difference between the two subsets in the experimental design (see Fig. 4). With increasing level with time during the 3-hour-flight a significant impact of the dB-level with error less than (number in brackets) is observed on

- noise in cabin with respect to
  - level of distraction (< 3 %)
  - level of annoyance (1 %)
  - overall (dis)satisfaction (< 1 %)
- perception of vibration (< 2 %) and movement (< 1 %)
- perceived symptoms (< 1 %) on
  - lethargy, tiredness
  - difficulty in concentration/ remembering
But for the second subset, namely decreasing level with time, no significant relation with previous items is observed. Only the perceived volume of noise in the cabin is with 2% error related to the dB-level. This result proves that the time of work significantly impacts the perception of the environmental condition (with respect to noise and vibration) including numerous symptoms, and might have severe consequences for the ability to work and perform safety-relevant tasks. On the other hand, the possibly positive effect of a reduction of noise (in this case with about 6 dB overall) is compensated by the increasing task load during the 3-hour flight in the simulator experiment.

3 Flight Experiments

3 flights Vienna – Delhi – Vienna of 8 h duration and 3 flights Vienna – Tokyo – Vienna of 12 h duration were investigated with support of Austrian. Environmental parameters were measured in cockpit, galley, cabin and crew-rest compartment. Mobile physiological recordings and questionnaires were used for the crew as validated in the simulator experiments.

3.1 Experiments and tests

Questionnaires were filled in before and after flight and during flight according to the work tasks of the flight attendants serving the passengers, and of the pilots according to their workflow. Following environmental parameters were measured continuously at numerous points in the fuselage:
- sound and vibration (time history and level)
- temperature
- humidity
- draft (at certain work places)
- air quality (CO, CO₂, VOC, germs).

Following physiological and medical parameters were recorded in-situ from the crew:
- heart-rate and variability
- blood pressure
- oxygen saturation
- salivary cortisol
- skin conductance

All measurements were arranged in a huge data base including time stamp, history of work (e.g. crew rest, shift work), work place etc., and serve as input for a statistical analysis and for the construction of a human response model. The analysis of the data is still ongoing, only part of the statistical analysis is reported in this paper.

3.2 Results

The development of a human response model follows two approaches. The main (independent) input variables have to be defined (and measured, e.g. [3]) and the most important output variables - in general dependant, but partly modulating the input – must be identified. Both sets of variable can either be combined by an appropriate statistical analysis or by an artificial neural network. The latter approach proved to be successfully, and was recently reported [5, 6]. Numerous medical indices have been derived from the measurements so far [4], and serve as target values for the human response model.

Within this paper only the impact of sound and vibration on other intermediate and output parameters is discussed for flight attendants. A PCA of all questionnaires and all flight attendants without taking the time of work into account yields three components accounting for 20.5 %, 8.5 % and 6.5% of the total variance. Rotation gives well identification of at least 5 factors, which contribute to the perception of the cabin crew. These are related to questions due to:
- annoyance and distraction due to noise
- the same due to vibration and motion
- feeling of temperature in various contexts
- various symptoms
- tiredness, sleepiness, concentration, motivation

![Figure 5a: Space of perception – plane of first dimensions (symbols see text).](image-url)
Fig. 5 gives a view of the space of perception for the plane of factor 1 and 2 (Fig. 5a), and for the plane of factor 2 and 3 (Fig. 5b). Similar colored symbols indicate related perceptions: Brown symbols refer to annoyance and distraction due to noise, magenta refer to vibration and motion issues. The two red ones are answers to lighting, the two green ones to aspects of comfort. The group of yellow symbols refer to feelings and perceptions of temperature, obviously defining dimension 3.

While a clear clustering of akin perceptions is observed the correlation with environmental parameters is poor, though still significant. The yellow square represents the dB(B) value, which is at most correlated within the space of perception. The blue symbol indicate the correlation with different measures of temperature. The one green gives the correlation with the CO\textsubscript{2} content.

In summary: The subjective impressions are well clustered for all flight attendants and define a clear space of perception while the correlation with environmental parameters is less convincing, though still significant.

Since strong effects from the phase of the workflow was observed in the simulator experiments, the three phases of serving passengers are analyzed separately (12 h flight). The PCA gives contributions of clustered questions distributed into 8 dimensions, in the first dimensions similar to the list above, but more differentiated with respect to related impressions. Analyzing the importance of environmental parameters (measured by the magnitude of correlation in the multidimensional space of perception), an interesting development from phase 1 to phase 3 can be observed.

Sound level and temperature are of similar importance during the whole flight. While in the beginning of the flight the pressure is ranked most important, relative humidity becomes the parameter at the end, which is highest correlated with subjective impressions.

4 Summary

The investigation of comfort, health, performance etc. during real flight is only possible within rigid limits. Therefore it is necessary to establish test beds with simulators which allow excellent virtual reality. Questionnaires and measurement devices have been developed and validated in simulator experiments and in a series of long-haul flights. Extensive measurements have been made in simulator facilities and real flights. Strong effects of the phase of workflow (time of work) on the performance of the crew were observed. The main environmental impacts are identified, but the correlation with the subjective impressions is not high. Components of a human response model have been derived. The model has a high-dimensional input and a multidimensional output vector. Input-output relations can be modeled by an artificial neural network, but structural relations between identifiable environmental parameters are not yet derived.

References

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