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NOISE EXPOSURE DURING AMBULANCE FLIGHTS AND REPATRIATION OPERATIONS

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Abstract
Objectives: Although ambulance flights are routine work and thousands of employees work in repatriation organizations, there is no data on noise exposure which may be used for preventive advice. We investigated the noise exposure of crews working in ambulance flight organizations for international patient repatriation to get the data for specific guidelines concerning noise protection. **Material and Methods:** Noise levels inside Learjet 35A, the aircraft type which is most often used for repatriation operations, were collected from locations where flight crews typically spend their time. A sound level meter class 1 meeting the DIN IEC 651 requirements was used for noise measurements, but several factors during the real flight situations caused a measurement error of ~3%. Therefore, the results fulfill the specifications for class 2. The data was collected during several real repatriation operations and was combined with the flight data (hours per day) regarding the personnel to evaluate the occupationally encountered equivalent noise level according to DIN 45645-2. **Results and Conclusions:** The measured noise levels were safely just below the 85 dB(A) threshold and should not induce permanent threshold shifts, provided that additional high noise exposure by non-occupational or private activities was avoided. As the levels of the noise produced by the engines outside the cabin are significantly above the 85 dB(A) threshold, the doors of the aircraft must be kept closed while the engines are running, and any activity performed outside the aircraft — or with the doors opened while the engines are running — must be done with adequate noise protection. The new EU noise directive (2003/10/EG) states that protective equipment must be made available to the aircrew to protect their hearing, though its use is not mandatory.

Key words:
Ambulance flights, Aviation, Noise prevention, Occupational medicine, Occupational noise

INTRODUCTION

The risk of permanent hearing damage due to noise exposure has been known since Plinius reported in 50 B.C. that people living near the rapids of the river Nile showed hearing impairment [1]. Ignored for a long time, occupational noise exposure was eventually identified in the 1930s as being responsible for the hearing loss of pilots who experienced the hearing loss corresponding to the hours they had flown [2]. However, there were no similar systematic investigations carried out on flight personnel working in air rescue organizations, except for our previous paper about noise exposure during alpine helicopter rescue operations [3].

METHODS

Noise levels were measured at typical points inside an ambulance version of Learjet 35A (twin engine Allied-Signal TFE73122B Turbofan, each engine had a 15.6 kN

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Photo 1. Learjet 35A with AlliedSignal TFE73122B Turbofan engines as used for measurements (reproduced with permission from German Air Rescue Ltd.).

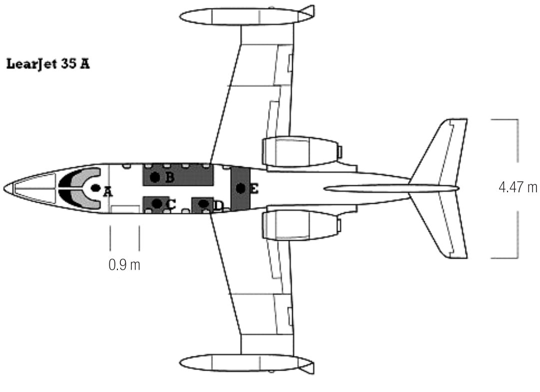


Fig. 1. Positions of the microphones inside Learjet 35A: (A) pilots; (B) patient; (C–E) physician or nurse.

propulsive force; Photo 1) as indicated in Figure 1. The flight personnel determined these chosen points as representing the usual positions held by the crew and the patient during a repatriation operation. The inside surface of the cabin was constructed as a Helmholtz resonator. Significant differences in the noise exposure were expected as the back seats were located between the two engines ("E" in Figure 1).

All microphones were capacitor microphones (Type 4135; Brüel and Kjaer). This type shows an extraordinary linearity in the range of 20–2000 Hz and the signal is fairly linear between 2 kHz and 20 kHz. From previous investigations in the area of aviation and military noise (shooting) we knew that this one gives the most reliable data of all the microphones available at that time. This may be a consequence of its construction which guarantees that it can be used in strong magnetic fields (e.g. near a big engine). The signal was digitally stored according to DIN IEC 651 [4] by the integrating-averaging sound level meter Norsonic 110 Sound and Vibration Analyzer (Norsonic AS, Tranby, Norway). The system was switched onto the 'fast' mode and recorded in dB(A) [4]. The system was calibrated according to DIN IEC 651 [4] using a sound calibrator type 4230 (Brüel and Kjaer, series No. 1511608) at 94 dB and 1000 Hz. This system design corresponds to class 1 DIN IEC 651 [4].

The data acquisition inside the aircraft was performed during constant straight flight. According to DIN ISO 5129 (a specification which was specifically designed for noise measurements inside aircrafts), at each point of measurement the microphone was held directly (0.1 m) beside the ear of a person working or sitting at the positions as indicated in Figure 1 [5]. To estimate the influence of flight maneuvers on the noise level, additional measurements were performed during no-load running, rolling, take-off and landing. All measurements were performed during real repatriation operations.

At least three independent measures of the noise levels (dB) during different flights were recorded at every position for a minimum period of one minute. This is more than the number of recordings recommended in DIN/ISO 5129 [5], but we preferred a conservative setting. To calculate the equivalent noise level, the average of these levels was used if their difference was < 5%. The equivalent noise level (Leq_{8h}) was calculated using the equation given by DIN 45645-2 for an 8-hour period [6]. This DIN gives the formula

$$L_r = L_{aeqT} + K_l + K_T + 10\lg\frac{T}{T_t}\ dB \qquad (1)$$

to calculate the noise rating level. With abandonment of the factors for tonality and pulse, which are specific German recommendations (abolished at a later date), data evaluation is compatible with this coming from other countries and the formula is simplified to

$$L_r = L_{aeqT} + 10\lg\frac{T}{T_t}\ dB \qquad (2)$$

We chose such solution in order to ensure the possibility of a comparison with international literature. Both formulas should be used for noise levels which are almost constant during a work shift. If there are phases with significantly higher or lower noise levels during a shift, as it is for aviation personnel with no exposure when planning the flight and a higher or lower exposure during the flight itself, the shifts should be classified into sections of similar noise levels. These sections should be calculated based on the relevant:

$$L_r = 10\lg\left[\frac{1}{T}\sum_{i=1}^{n} T_i \times 10^{0.1\times L_i}\right] dB \qquad (3)$$

With a normal working shift of 8 hours (480 min) as a standard working day this formula changes to:

$$L_r = 10\lg\left[\frac{1}{480}\sum_{i=1}^{n} T_i \times 10^{0.1\times L_i}\right] dB \qquad (4)$$

To get an idea about the noise characteristics other than noise levels, a noise frequency analysis was performed with the use of 1/3-octave bands according to DIN EN 61620, and data acquisition was set to "fast" to optimize the measurement of short periods of high sound levels.

For the sake of statistics, the Wilcoxon Signed-Ranks Test was used to check whether there are differences in the sound levels among several points of measurement and $P < 0.05$ was defined as significant. At least 10 independent recordings were taken at each location. The error of measurement was calculated as the standard deviation in % of the mean value as recommended in [4].

RESULTS

All noise levels are presented as average ± standard deviation. For details see Table 1. Since the measurements follow Gaussian distribution, we gave not only the range (in dB), but also the standard deviation (in dB) and the standard deviation (in %) of the mean values (i.e. the variability coefficient) to get a better idea of how precise the measurements were. Although the devices for data acquisition fulfilled class 1 of DIN IEC 651, the measurement error of the data obtained in real situations of repatriation operations equaled ~3%, and therefore, the results should be considered as according to class 2 [4].

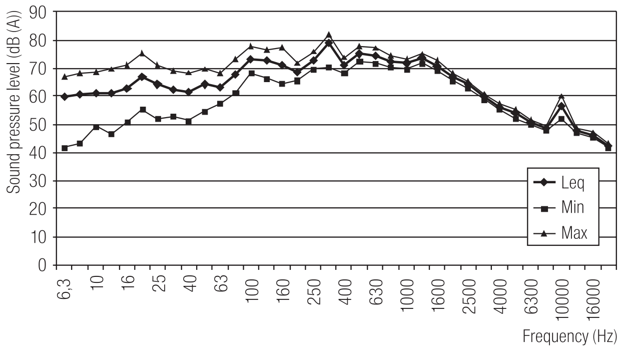
The pilots were exposed to 82.6 dB(A) (±1.0) during constant flight ("A" in Figure 1). Respective measurements recorded during maneuvers were close to those recorded during constant flight: 80.9 dB(A) during take-off, 83.1 dB(A) during approach, and 74.1 dB(A) during rolling. As these maneuvers produced similar noise levels and took little time in comparison to the total flying time, the level of the constant flight was used to calculate the equivalent noise level. The noise level at the position of the patient ("B" in Figure 1) was 80.8 dB(A) (±2.5) during constant flight. During take-off the level was 80.2 dB(A), during approach 78.5 dB(A), and during rolling 78.2 dB(A).

At position (C) (Figure 1), noise levels during constant flight equaled 80.8 dB(A) (±0.5) and during take-off 79.7 dB(A). At position (D) (Figure 1), the personnel was exposed to 80.7 dB(A) during constant flight, 82.3 dB(A) during take-off, 80.2 dB(A) during approach, 77.7 dB(A) while

Table 1. Noise levels at different positions and the number of measurements*

Position**	N	Mean Leq (dB)	Minimal Leq measured (dB)	Maximal Leq measured (dB)	Sx	Sx%
A (Pilot)	18	82.6	80.5	83.6	1.0	1.2
B (Patient)	19	80.8	77.0	83.8	2.5	3.0
C (Medical Personnel)	12	80.0	80.0	81.3	0.5	0.7
D (Medical Personnel)	28	80.7	75.8	83.4	2.0	2.5
E (Back Seat)	21	82.2	78.6	85.5	1.9	2.3

* The data acquisition was performed during 6 different repatriation operations.
** See Figure 1.
N — number of measurements at the respective location; Leq — equivalent noise level.
Sx — standard deviation; Sx% — standard deviation in % of mean value.



Leq — equivalent noise level (average of the measurements).
Min — minimal noise level of all measurements.
Max — maximal noise level of all measurements.

Fig. 2. Typical 1/3 octave band frequency spectrum of noise inside Learjet 35A (measurement point: position "C" in Figure 1).

the aircraft was rolling, and 75.4 dB(A) with the engine at no-load while running. At position (D) (Figure 1), the mean noise level was 82.2 dB(A) (±2.0) during constant flight. At take-off, the level equaled 88.4 dB(A), during approach 86.6 dB(A), and while rolling 82.2 dB(A). A typical terz analysis of the noise is shown in Figure 2. The collective engine noise produced by several components resulted in chassis sound within the range below 1000 Hz and the engine noise with a peak at 10 kHz (Figure 2).

On 207 of a total of 660 days there was a repatriation operation, which meant noise exposure for the personnel. The average flying time, and therefore the average occupational noise exposure per day, was 424.4 min (±167.1, range: 104–875 min, Table 2). As a result of the work shifts, every member of the rescue service had an operation on every third day on average.

Table 2. Duration of noise exposure per operation day

Duration of exposure (min)	Exposure days (%)	Days (n)
1–100	0	0
101–200	1.9	4
201–300	29.5	61
301–400	11.6	24
401–500	32.4	67
501–600	4.3	9
601–700	10.6	22
701–800	8.2	17
801–900	1.4	3
901–1 000	0	0

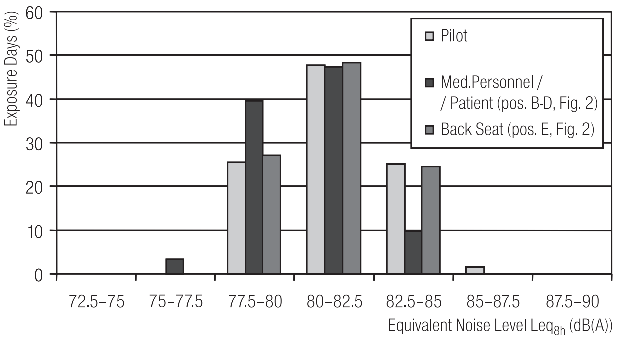


Fig. 3. Equivalent noise exposure (Leq_{8h}) of the crews.

The equivalent noise exposure Leq_{8h}, as calculated from the retrospective observational data of flight frequency and duration, indicated that on most exposure days the pilots experienced noise of 80–82.5 dB(A) (47.8% of exposure days, Figure 3). This exposure was nearly identical to the one experienced at the so-called "Rang 1" that corresponded to positions "B" and "C" in Figure 1 (patient/ physician). On 1.5% of all exposure days, the pilots experienced an increased Leq_{8h} exposure of 85–87.5 dB(A) (Figure 3). At the back seat position ("Rang 3", "E" in Figure 1) the distribution pattern of Leq_{8h} was similar.

Nevertheless, there were significant differences between the positions tested with the highest Leq_{8h} for the pilots (81.8 dB(A)), and those lower by about 2 dB(A) for the medical personnel at position "C" (80.0 dB(A), Figure 1) and the patient ($p < 0.001$). The back seat position has Leq_{8h} of 81.4 dB(A), which was also lower than the one experienced by the pilots, but higher than the ones for the patient and medical personnel (both $P < 0.001$).

DISCUSSION

Compared to flight crews from alpine helicopter rescue organizations [3], ambulance flight crews were exposed to significantly lower noise levels during routine flight operations when the cabin doors were closed, even though the flights were of a significantly longer duration.

There is an international consensus that noise exposure > 85 dB(A) equivalent noise level (Leq_{8h}) is a potential risk factor for hearing loss. Such noise exposure causes aural and extra-aural effects that can be temporary or permanent depending on the sound level and the exposure duration. In contrast to rescue helicopters, the noise level inside Learjet 35A was lower and should not cause additional risk by disturbed internal flight communication. However, our data showed that constant noise levels were maintained just below the 85 dB(A) "threshold" and communication by radio or intercom could further increase this noise exposure by +3–6 dB(A) [1,7,8]. On the other hand, active noise systems reduce the sound level in airplanes by about 10 to 20 dB(A) [9], but unfortunately most companies do not provide them for the crews.

Our data shows that the crews of Learjet 35A — although exposed to noise just under the threshold for acceptable occupational noise exposure during work — should not be at risk of hearing damage. The working shifts system with an average of one operation every third day ensures enough time for the ears to recover and there were only a few days when the 85 dB(A)-"threshold" was exceeded. Nevertheless, there are some points that should be taken into account when considering the potential hearing damage and ear protection discussed, and that is hypobaric hypoxia and non-occupational (private) noise.

There is a limited number of comparable studies, because most of them were performed in military aircrafts which are much noisier than ordinary ones. They have more powerful engines — often located near the aircrafts personnel (e.g. jets, fighters) — and less noise reduction equipment built into their construction in order to minimize weight and optimize their operational range and maximum flight levels. Since 1930s it has been well known that there is a relation between hearing loss of pilots and the number of hours flown [2]. This was confirmed in some more recent investigations and the number of flown hours is accepted as an independent risk factor in addition to others like age and non-occupational noise [10–14]. Studies focusing on civil aircrafts are rare. Lindgren has published certain data provided by SAS (Scandinavian Airlines) which showed normal hearing of the personnel [15], but the measurements were taken inside modern widebody aircrafts with the state-of-the-art chassis reduction equipment. The size of these aircrafts with the engines far away from the passengers and crew makes the principal difference to Learjet 35A and similar aircrafts, which leads to noise exposure reduction concerning any person on board. The same group reported in another paper, that tinnitus is relatively common among commercial pilots, but obviously it is caused by non-occupational noise and not related to the number of flown hours [16]. In contrast to commercial airliners and their personnel, there is no data regarding flight instructors or pilots of small — mostly private — aircrafts, although there are noise levels above 90 dB(A) reported [8]. To our knowledge, our study is the only one which focuses on the crews of ambulance jets. Our data suggests, that these crews are exposed to higher noise levels than the personnel of commercial airlines in widebody aircrafts, but to lower levels than flight instructors or pilots of small aircrafts, fighters, and helicopters.

Our research indicates significant differences in the noise levels at typical places inside the aircraft with the back seat showing the highest noise level. Although significant, these differences are relatively small and remain close to the range of measurement uncertainties. Nonetheless, some control measures performed after evaluation of the study showed reproducibility of these differences. This may be a simple consequence of the geometry of the aircraft with the back seat directly between the engines and the pilot sitting in front of an intercostal panel which partially separates the cockpit from the cabin. Resonance effects or echoes may also contribute to the differences in the noise levels. For occupational medicine and safety these differences are negligible because of two reasons: (i) they are minimal, and (ii) the place of the highest exposure (position "E" in Figure 1) is normally not used by the crew, but by the companions of the patient (if any).

Since the auditory hair cells get their oxygen by diffusion, the hypobaric hypoxia present in the cabin of an aircraft during a flight — which typically provides an equivalent pressure of about 2000 to 2300 m — may increase the risk of hearing loss due to noise. The additional risk of hypoxia may contribute to a reduced cochlear capillary perfusion and result in the decrease of perilymphatic oxygen partial pressure induced by the noise [17,18]. Both these effects last for several hours even after the termination of the causal noise exposure [18]. Hypoxia is an independent risk factor for hearing threshold shifts, as an exposure to 5% oxygen induces such a reversible shift [19] that is less pronounced in acclimatized animals [20]. Humans show similar reactions at about 4500 m a.s.l. [21]. Animal studies on noise and hypobaric hypoxia indicate a link between these conditions and possible hearing damage. It is suggested that there is an active secretion of ATP into the perilymphe of the *stria vascularis* during noise exposure [22]. This active secretion may lead to "energetic exhaustion" and result in a threshold shift [22]. Such effect may be more pronounced as a result of hypoxia, though research on humans in this area is scant.

Like all other investigators, we have assumed that the time between flights is "quiet" and deprived of any risk of hearing loss, but this is not realistic. As demonstrated by Matschke et al., the general public are intermittently exposed to high noise levels during non-occupational pursuits — i.e. concerts, portable stereo use, nagging bosses, teachers and spouses, those learning to play musical instruments (with poor results), wannabe rockstars, singing in showers, etc. [23,24]. All these effects show individual differences.

As the interior design of an aircraft and the proximity of the engines in relation to the cabin space are the key contributory variables to the noise levels experienced during flight, it is not possible to directly apply the findings obtained from this study to a standard equipped airliner or jet. For the same reasons our data from several helicopter types cannot be used to evaluate the risk of hearing loss for crews of ambulance flights. A special problem is, that some crew members join non-governmental rescue organizations at weekends and are exposed to high levels of helicopter noise there. It was not possible to quantify this exposure within the study presented here.

The European Union (EU) regulations on occupational noise exposure have recently been changed [25]. These regulations state that at work the personal use of protective hearing equipment is not mandatory, but that such equipment must be made available to the workers. Air rescue companies must provide such equipment because the EU regulation for lower exposure action value was exceeded. For crews on repatriation flights, these devices should reduce the noise level by at least 10 dB(A).

In summary, if this study realistically considers all the other variables that can contribute to hearing loss — the combination of the known noise exposure at or near the limits that are not supposed to do harm, hypobaric hypoxic cabin conditions during the flight and the additional noise exposure between the flight operations — the "offensive" use of ear protection during work is recommended. Flight personnel should also be advised to be careful about the possible impact of additional 'non-occupational' or 'private' noise exposure, because their occupational exposure is already near the tolerable limit.

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