EVALUATION OF ACOUSTIC RISKS IN AIRCRAFT USING THE RISK MATRIX

MICHAELA BALAZIKOVA, MARIANNA TOMASKOVA, MARTINA DULEBOVA

Technical University of Kosice, Faculty of Mechanical Engineering, Department of Safety and Quality, Slovak Republic

DOI: 10.17973/MMSJ.2017_11_201713

e- mail: michaela.balazikova@tuke.sk

Noise is one of the elementary and the most annoyance harmful civilizing factor in the present time. Possibilities of reduction noise load and protection against it are problematic. Air transport is currently involved to noise exposure significantly and effects on health are not only on flying personnel, passengers but also on people living around airports. Noise as the spreading of acoustic energy has also a negative non-auditory impact, particularly on neuropsychic and cardiovascular system and on sense-motoric functions, disturbance the performance and efficiency of human activities, increasing the number of accidents. The aim of the article is to assess the effects of non-auditory noise, based on the proposed method - the matrix of acoustic risks, for flying personnel.

KEYWORDS

noise, risk assessment, aviation, auditory noise effects, non-auditory noise effects

1 INTRODUCTION

Air transport is one of the most commonly used mode of transportation and hence passenger comfort is highly desirable. Aircraft interior noise is important, especially in long-term flights, concerning the health, comfort, and psychological wellness of both passengers and flight crew. Noise levels, which changes according to different motions of aircraft, can be defined as the noise during takeoff and landing and during level flight (cruise). There are also non-aircraft-originating noise sources in the cabin. These can be classified into those caused by passenger activities such as conversations and luggage-related rearrangements as well as those caused by flight-crew such as flight attendant-related speaking activities, announcements from pilot and flight attendants, mechanical noises during food/beverage services and flight security demonstrations, and other announcement signals.

Health, performance, safe operation are key issues for flight and cabin crew as well as for passengers. [Mellert 2004] The environment is loaded with unwanted noise, which is most produced by aircraft engine components.

The impact of noise on humans, notably in terms of upper decibel scale or long-term exposure in the bottom of the decibel scale, leads to loading of the organism and to a lasting change in health, which is undesirable in terms of full-area.

The possibility of non-auditory health effects in connection with occupational exposure to high level sound is supposed by some researchers, but is still debated. [Jensen 2009]

Non-auditory effects of noise can be defined as all those effects on health and well-being which are caused by exposure to noise, with the exclusion of effects on the hearing organ and the effects which are due to the masking of auditory information [Babisch 2011].

Noise research has been focusing on cardiovascular health outcomes because cardiovascular diseases have a high prevalence in the general population. [Babisch 2014] Noise-induced cardiovascular effects may therefore be relevant for public health and provide a strong argument for noise abatement policies within the global context of adverse health effects due to community noise, including annoyance and sleep disturbance. [Babisch 2015]

For acoustic risk assessment questions (even at low noise levels, or sound) and subsequent reduction of noise must be given much more attention, if we want to preserve human health against civilization diseases. [Balazikova 2012]

2 IDENTIFICATION OF THE THREAT IN THE AIRCRAFT

Undesirable sound waves in an environment are defined as noise. The importance of noise pollution increases every day, due to its human-related hazards in modern world. Noise have both physiologically and psychologically negative effects on human health such as influencing temporary hearing losses like elevation of noise hearing threshold and continuous hearing losses like acoustic trauma. [Karpuzcu 1999]

These problems can be influenced by both exposure time and/or level of noise. There are several effects of noise on human psychology such as fatigue, nervousness, stress, insomnia, decrease of concentration and labor yield, and changes in both memory and social behaviors. [Ingle 2005]

Although personal and public differences exist, it is generally accepted that sleeping and other activities are seriously disturbed and humans become irritated from noise, when sound level is above 65 dB(A). [Karabiber 1999]

Sources of noise in aircraft

There are many different sources in and around an airport that produce noise. Noise is produced by aircraft equipment powerplants, transmission systems, jet efflux, propellers, rotors, hydraulic and electrical actuators, cabin conditioning and pressurization systems, cockpit advisory and alert systems, communications equipment, etc. [FAA 2016]

Cabin sound levels vary greatly between different types of aircraft. So when we talk about quiet cabins, we have to keep in mind that there are significant variations based on size, engine type, and use of the airplane.

On a commercial airliner, the cabin is usually kept at a (barely) comfortable 65 – 80 dB(A), allowing conversation with the person next to you, but not much more than that. OSHA requires that workers use some form of personal protection equipment when exposed to sound levels in excess of 85 dB(A), so airlines have to make sure that their flight attendants are not exposed to noise above that threshold for extended periods of time. But there is not much of an incentive for additional cabin soundproofing.

Table 1 presents various sources of noise with sound level in dB, for illustration there are also sources from aviation – jet transport, small single plane, single rotor helicopter and jet engine (proximity).

Noise sources	Level dB(A)
Whispered Voice	20-30
Urban home, Average office	40-60
Average Male Conversation	60-65
Noisy Office, Low Traffic Street	60-80
Jet Transports (Cabin)	60-88
Small Single Plane (Cockpit)	70-90
Public Address (PA) Systems	90-100
Busy City Street	80-100
Single Rotor Helicopter (Cockpit)	80-102
Power Lawn Mower, Chain Saw	100-110
Snowmobile, Thunder	110-120
Rock Concert	115-120
Jet Engine (Proximity)	130-160

Table 1. Noise sources with sound level in dB (A) [FAA 2016]

Noise can also be caused by the aerodynamic interaction between ambient air (boundary layer) and the surface of the aircraft fuselage, wings, control surfaces, and landing gear. These auditory inputs allow pilots to assess and monitor the operational status of their aircraft. All pilots know the sounds of a normal-functioning aircraft. On the other hand, unexpected sounds or the lack of them may alert pilots to possible malfunctions, failures, or hazards. Every pilot has experienced a cockpit or cabin environment that was so loud that it was necessary to shout to be heard. These sounds not only make the work environment more stressful but can, over time, cause permanent hearing impairment. However, it is also important to remember that individual exposure to noise is a common occurrence away from the aviation working environment—at home or work, on the road, and in public areas. The effects of pre-flight exposure to noise can adversely affect pilot in-flight performance. [Zaporozhets 2011]

One of the main sources of noise is wind. So during the design phase of modern aircraft, computational tools model the aerodynamics of the aeroplane to highlight areas of high airflow that are likely to increase cabin noise. [Moskvitch 2014]

Sources of noise in aircraft are aircraft powerplant, turbulent air flow circumfluent the plane, radiocorrespondence, air conditioning, supersonic bang. [Dosel 1999]

Aircraft:

- The source of noise in the jet aircraft is engine intake port and outlet nozzle. Noise of intake port is in the vicinity of the intensity 90-100 dB(A). Noise of outlet nozzle has broadband character and radiates into the conically expanding area of the outflow of gas. The noise reaching up to 140 dB(A).
- Noise source in propeller aircraft are engines and propellers. The noise generated by the propeller has a relatively narrow frequency spectrum predominantly in a lower frequency. Is affected by the engine mode, the number of revolutions of the propeller and the number of their leaves. The mean intensity value is 110 dB(A).
- Maximum noise emissions is in the axis of the airplane

Turbulent air flow circumfluent plane:

- The noise is caused by air turbulence between the layers of air circumfluent the plane.
- This is the noise in a wide frequency range.
- With increasing speed is also growing especially high frequency component. The intensity and character of the noise level is influenced by the aerodynamic design of fuselage and the bearing surfaces of aircraft, altitude and airspeed and flight path profiles.

Radiocorrespondence:

- Is a wideband noise with impulsive character with a maximum in the range 500 to 4000 Hz.
- Frequency characteristics, intensity and frequency acoustic pulses depends on the depth and strength of voice, speed of call, density of radiocorrespondence, volume of listening and so on.
- The maximum intensity value can reach up to 110 dB(A).

Air conditioning:

- Low frequency sound, that are long-term exposure to passengers and aircrew.
- Its characteristics and intensity depends on the design of the air conditioning system, the engine running, size of pressurized cabin and can reach significant values up to 100 dB(A). [Dosel 1999]

3 IMPLEMENTATION OF AUDITORY AND NON-AUDITORY EFFECTS OF NOISE INTO THE RISK ASSESSMENT PROCESS

Science-based risk assessment can be defined as a systematic process of evaluation and interpretation of factual information about a system. The information serves for the identification of hazard (noise, in this case), effects (of auditory and non-auditory nature) resulting from the given hazard, and it is possible to qualify or quantify the level of risk and subsequently judge its acceptability.
The method is part of the safety and health of workers at work, where the concept of risk is the likelihood of occurrence of a negative phenomenon and its result. [Balazikova 2012]

A Risk matrix is a matrix that is used during risk assessment to define the level of risk by considering the category of probability or likelihood against the category of consequence severity. This is a simple mechanism to increase visibility of risks and assist management decision making.
A risk is the amount of harm that can be expected to occur during a given time period due to specific harm event (e.g., an accident). Statistically, the level of risk can be calculated as the product of the probability that harm occurs (e.g., that an accident happens) multiplied by the severity of that harm (i.e., the average amount of harm or more conservatively the maximum credible amount of harm). In practice, the risk matrix is a useful approach where either the probability nor harm severity can not be estimated with accuracy and precision.

Possibilities of determining the integrated value of acceptable risk [Balazikova 2012]:

- acceptability of vibro-acoustic environment can be assessed as tolerability of adverse conditions caused by simultaneous noise and mechanical vibration in the working environment;
- vibro-acoustic acceptability of the environment can be assessed by the criterion of subjective feeling of disturbance, interference with human activity or efficiency, occupational health and safety or their arbitrary combination;
- another option is the application of the following equation:

$$R = P \times C \qquad R = f\,(R_1 \ldots\ldots\ldots R_n) \tag{1}$$

$$R = R_{aud.} + R_{non-aud.} \tag{2}$$

$$R = [(P \times C_{aud.}) + (P \times C_{non-aud.})]f \tag{3}$$

$$R_{acoust.} = \left[\begin{pmatrix} P_1\,C_{1aud.} & \cdots & P_1\,C_{3aud.} \\ \vdots & \ddots & \vdots \\ P_6\,C_{1aud.} & \cdots & P_6\,C_{3aud.} \end{pmatrix} + \begin{pmatrix} P_1\,C_{1non-aud.} & \cdots & P_1\,C_{3non-aud.} \\ \vdots & \ddots & \vdots \\ P_6\,C_{1non-aud.} & \cdots & P_6\,C_{3non-aud.} \end{pmatrix}\right] f \tag{4}$$

$$f = (t_{ex.}/t_{8hrs.}), \qquad C_{non-auditory} = \sum c_i \tag{5}$$

where:

R – acoustic risk,
$R_{aud.}$ – acoustic risk with auditory effects,
$R_{non-aud.}$ – acoustic risk with non-auditory effects,
P – probability of a person's exposure to noise,
C - the consequence,
$C_{aud.}$ – the consequence of the acoustic load on human auditory organs,
$C_{non-aud.}$ – the consequence of the acoustic load on human: non-auditory effects that are difficult to identify, C_i e.g. cardiovascular, neurological and gastric effects, etc.
f – exposure load coefficient,
$t_{8hrs.}$ – 8-hour working day = 480 min.,
$t_{ex.}$ – noise exposure time in minutes.

Partial risks are defined according to risk matrices as shown in the following tables. Table 2 presents the Acoustic Risk Matrix with auditory effects and Table 3 Acoustic Risk Matrix with non-auditory effects, including gastric changes, cardiovascular, neurological and other consequences.

C aud. / P ($L_{AEX,8h}$)	None (no auditory effects)	Moderate (short-term tinnitus, inability to communicate)	Persisting (long-term)
P_1 (up to 40 dB)	5	5	10
P_2 (40 – 50 dB)	5	10	20
P_3 (50 – 65 dB)	10	15	25
P_4 (65 – 80 dB)	10	20	35
P_5 (80 – 85 dB)	15	25	40
P_6 (over 85 dB)	20	30	45

Table 2. Acoustic risk matrix: Auditory risks – $R_{aud.}$

C non-aud. / P ($L_{AEX,8h}$)	None (increased blood pressure, EEG changes, gastric changes - none)	Moderate (increased blood pressure, EEG changes, gastric changes - temporary)	Persisting (increased blood pressure, EEG changes, gastric changes - permanent)
P_1 (up to 40 dB)	3	6	16
P_2 (40 – 50 dB)	3	10	20
P_3 (50 – 65 dB)	6	10	20
P_4 (65 – 80 dB)	6	13	23
P_5 (80 – 85 dB)	10	16	26
P_6 (over 85 dB)	10	20	30

Table 3. Acoustic risk matrix: Non-auditory risks – $R_{non-aud.}$

In case of acoustic assessment of risk, the consequences are not only auditory but also non-auditory and the probability value includes subliminal levels of noise exposure. Non-auditory effects of noise are addressed mainly in the environment. The proposed method deals directly with the working environment, which results from the Directive No. 391/1989 /EU on Health and Safety.

Normalized level of noise exposure is the level determined from the equivalent level of sound A and the 8-hour working day according to the equation [Balazikova 2012]:

$$L_{AEX,8h} = L_{Aeq,T} + 10\,\log(T/T_n) \tag{6}$$

where:
T - the duration of the equivalent level of sound A during the work shift,
T_n - is the duration of the work shift – 8 hrs.

Legislative limit values:

Exposure limit values and exposure action values have been set e.g. by the Directive 2003/10/EC of the European Parliament and of the Council on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise); in order to protect workers' health, particularly auditory organs, from the risks arising from noise. The Directive lists the following values:

a) exposure limit values $L_{AEX,8h,L}$ = 87 dB(A) and L_{CPk} = 140 dB,
b) upper exposure action values $L_{AEX,8h,a}$ = 85 dB(A) and L_{CPk} = 137 dB,
c) lower exposure action values $_{LAEX,8h,a}$ = 80 dB(A) and L_{CPk} = 135 dB.

Acoustic risk values:
The resulting acoustic risk value can range from 1 to 75. The impact of such risk is graded with regard to the effects of noise and time exposure. In case of long-term effects, either auditory or non-auditory, and higher (calculated) impact risk value, the risk is unacceptable.

Calculation of acoustic risk by proposed method for aircrew:

Category P, in auditory and non-auditory effects, is above **73,2 dB(A)** - based on studies of measurement of noise exposure in aircraft cabin. [Jensen 2009] [Kurtulus 2006]
Category $C_{aud.}$ is selected on the basis of subjective feelings in category moderate due to persistent auditory problems, which after a stay in noiseless environment eventually disappears. Table 4 presents acoustic risk matrix for auditory risks $C_{aud.}$.

$C_{audit.}$ / P ($L_{AEX,8h}$)	None (no auditory effects)	Moderate (short-term tinnitus, inability to communicate)	Persisting (long-term)
P_1 (up to 40 dB)	5	5	10
P_2 (40 – 50 dB)	5	10	20
P_3 (50 – 65 dB)	10	15	25
P_4 (65 – 80 dB)	10	20	35
P_5 (80 – 85 dB)	15	25	40
P_6 (over 85 dB)	20	30	45

Table 4. Acoustic risk matrix: Auditory risks – C $_{aud.}$

Category $C_{non-aud.}$ is selected also on the basis of subjective feelings in category moderate due to persistent non- auditory problems. Table 5 presents the acoustic risk matrix for non-auditory risks $C_{non-aud.}$

$C_{non-aud.}$ / P ($L_{AEX,8h}$)	None (increased blood pressure, EEG changes, gastric changes - none)	Moderate (increased blood pressure, EEG changes, gastric changes - temporary)	Persisting (increased blood pressure, EEG changes, gastric changes - permanent)
P_1 (up to 40 dB)	3	6	16
P_2 (40 – 50 dB)	3	10	20
P_3 (50 – 65 dB)	6	10	20
P_4 (65 – 80 dB)	6	13	23
P_5 (80 – 85 dB)	10	16	26
P_6 (over 85 dB)	10	20	30

Table 5. Acoustic risk matrix: Non-auditory risks – $C_{non-aud.}$

Category $C_{non-audi.}$ is selected in category persisting, because of:

R – acoustic risk for aircrew:

$$\mathbf{R = [R_{aud.} + R_{non-aud}]}\ f$$

$$R = [R_{aud.} + R_{non-aud.}]\ t_{ex.} / t_{8hrs}$$

$$R = [(35) + (23)]\ 360/480 = \mathbf{43,5}$$

4 CONCLUSION

In this acoustic risk assessment using proposed methodology in the context of experimental measurements is acoustic risk **43, 5** - which is a **significant risk**. It means that in the long term can this noise exposure have negative non-auditory impact on staff, so it is important to repeat the acoustic risk assessment in periodical intervals.
The noise during a typical plane journey can vary significantly. Take-off and landing are the loudest moments, when noise levels inside the cabin can reach 105 decibels (dB). At cruising altitudes, noise drops to around 85 dB (A), based on studies of measurements of noise. [Moskvitch 2014]
Aircraft manufacturers and airlines recognise the issue, and try to reduce the noise inside cabins. But it's far from straightforward, because some noise reduction techniques – such as adding thick insulation to the cabin walls – can add weight, which increases fuel consumption.
There are various noise-reduction technologies now emerging. Adding vibration-absorbing materials can dissipate energy in the fuselage. Airbus is even trying to quieten the air conditioning, by designing the contours of the cabin so that it doesn't interfere with the air flow, allowing it to circulate freely. [Moskvitch 2014]
The article presented the proposed methods to assess the acoustic risk, which combines non-auditory effects of noise and auditory effects that are specified legislatively in Directive. 10/2003/EED. This Directive lays down the requirements for occupational health and safety of employees in relation to noise exposure in the workplace and preventing risks and threats that arise or may arise in relation to noise exposure, especially preventing damage of hearing. This government regulation does not include non-auditory effects of noise, therefore, a method of acoustic risk assessment, which includes these noise effects, was created. The proposed method enables monitoring effects and sub threshold values noise. This means that even non-excess of normalized noise exposure may pose an increased risk of non-auditory effects of noise. To minimize this risk, it is necessary to deal with this issue and propose appropriate measures.

ACKNOWLEDGMENTS:
This contribution is the result of the project VEGA no. 1/0150/15 Development of methods of implementation and verification of integrated safety systems, machine, machinery, systems and industrial technologies

This contribution is the result of the project implementation "Center for Research of control of technical, environmental a human risks for permanent development of productions and products in mechanical engineering" (ITMS 26220120060), supported by the Research & Development Operational Program funded by the ERDF.

REFERENCES

Book:

[Babisch 2011] Babisch, W. Cardiovascular Effects of Noise, Federal Environmental Agency, Berlin. Encyklopedia of Environmental Health, 2011, p. 532-42. ISBN 978-0-444-52272-6.

[Dimino 2015] Dimino, I., Aliabadi, F. Active control of aircraft cabin noise. London: Imperial College Press, 2015, 279 p. ISBN 978-1-78326-657-9.

[Zaporozhets 2011] Zaporozhets, O., Tokarev, V., Attenborough, K. Aircraft noise propagation, exposure & reduction: assessment, prediciton and control. New York: Spon Press, 2011. ISBN 978-0-20388-882-7.

Paper in a journal:

[Babisch 2015] Babisch, W. The cardiovascular effects of noise on man. In: The Journal of the Acoustic Society of Amerika, 2015, vol. 137, issue 4, 2278 (2015); http://dx.doi.org/10.1121/1.4920311.

[Babish 2014] Basner, M, Babisch, W, Davis, A. et al. Auditory and non-auditory effects of noise on health. In: Lancet. 2014, 383 (9925), 1325-1332. http://doi.org/10.1016/S0140-6736 (13)61613-X.

[Balazikova 2012] Balazikova, M., Sinay, J. Implementation of auditory and non-auditory effects of noise in the risk assessment process in mechanical engineering. In: Procedia Engineering, 2012, no. 48, p. 621-628. ISSN 1877-7058.

[Deshaies 2015] Deshaies, P., et al. Noise as an explanatory factor in work-related fatality reports. In: Noise Health, 2015, vol. 17, p. 294-299.

[Dosel 1999] Dosel, P. Hluk. In: L+K, 1999, vol.16, 17, ISSN 0024-1156.

[FAA 2016] Federal Aviaton Administration (FAA): Hearing and noise in aviation. In: Aeromedical Safety Brochures [online] [cit. 3-3-2017]. <https://www.faa.gov/pilots/safety/pilotsafetybrochures/media/hearing.pdf>.

[Ingle 2005] Ingle, S. T., Pachpande, B. G, Wagh, N. D., Attarde, S. B. (2005) Noise exposure and hearing loss among the traffic policemen working at busy streets of Jalgaon urban centre. Transportation Research Part D 10, 69-75.

[Jensen 2009] Jensen A, Lund, S. P., Lucke, T.H., Clausen, O.V., Vendsen, J. T. Non-auditory health effects among air force crew chiefs exposed to high level sound. In: Noise Health, 2009, vol. 11, no. 44, p.176-81.

[Karpuzcu 1999] Karpuczu, M. and Esin, T. (1999) Noise control in building element design, City Administration Human and Environment Problems'99 Symposium, pp.301-311. Istanbul, Turkey.

[Karabirer 1999] Karabiber, Z. Environmental noise control requirements according to building type and examples from Istanbul, City Administration Human and Environment Problems '99 Symposium, pp.321-331. Istanbul, Turkey.

[Kurtulus 2006] Kurtulus, H. O., Nemlioglu, S. In: In-Cabin noise levels during commercial aircraft flights. In: Canadian Acoustics, 2006, vol. 34, no. 4.

[Mellert 2004] Mellert, V., Baumann, I., Freese, N., Weber, R. Investigation of noise and vibration impact on aircraft crew, studied in an aircraft simulator, In: The 33rd International Congress and Exposition on Noise Control Engineering - Inter noise, 2004. Place: Prague, Czech republic, august 22-25. p. 1-8.

[Moskvitch 2014] Moskvitch, K. How to cut noise in the plane cabin. In: BBC Future, 2014. [online] [cit.3-3-2017]. Available from <http://www.bbc.com/future/story/20140226-tricks-for-a-peaceful-flight>.

[Taoyuan City Government 2016] Aircraft Noise Control Fund and Feedback Consultation Guidance System. Facts about Aircraft Noise. [online] [cit.3-3-2017]. Available from <http://aviation.tydep.gov.tw/english/main/5about%20Aircraft%20Noise/5-1facts.html>.

CONTACTS:

doc. Ing. Michaela Balazikova, PhD.
doc. Ing. Marianna Tomaskova PhD.
Ing. Martina Dulebova
Technical University of Kosice
Faculty of Mechanical Engineering
Department of Safety and Quality
Letna 9, 042 00 Kosice, Slovakia
e-mails:michaela.balazikova@tuke.sk, marianna.tomaskova@tuke.sk, martina.dulebova@tuke.sk
www.tuke.sk