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# ASSESSMENT METHODOLOGY OF INTERIOR AIRCRAFT NOISE INFLUENCE ON PILOT PERFORMANCE AND TEMPORARY THRESHOLD SHIFT

***ABSTRACT***

*Previous studies have shown that the impact of interior aircraft noise on pilot performance was not unambiguous, neither there was any unanimous methodology used for measuring it. Furthermore, the cumulative character of noise was never taken into account. This research proposes a methodology that aims to determine the impact of accumulated general aviation aircraft interior noise on pilot performance in laboratory conditions. The assessment of the aircraft interior noise influence on Temporary Threshold Shift is integrated as well, enabling extended research of all aspects of the physiological noise impact on pilots. Methodology defines measurable noise and pilot performance parameters in general aviation, equipment requirements, necessary laboratory conditions and subject selection criteria. The analysis of the deviation from the specified flight parameters along with Temporary Threshold Shift values at different accumulated noise doses is carried out. Data is analyzed using descriptive statistics, visualization methods and linear mixed effects models with False Discovery Rate as the method for correction for multiple testing which allows the determination of the potential population effect.*

***KEY WORDS***

*aircraft interior noise; pilot performance; physiological noise effects; temporary threshold shift; regression analysis; mixed models;*

## 1. INTRODUCTION

Every day's flight tasks performed by pilots require concentration, analytical illation, precise movements, continuous performance, and long-term attention. Such tasks are particularly expressed in the process of flight training since automatic flight control systems on the general aviation aircraft during basic flight training are not in use. The effectiveness of the pilot in performing tasks significantly affects flight efficiency and safety. At the same time, pilot performance is affected by the environmental factors in the cockpit with noise being the most significant one.

Human factors in aviation were gradually developed and institutionalized by the end of the 1970s. They denote a term that describes various pilot performance aspects interacting with environmental factors in the aircraft cockpit, while pilot performance means aircraft guidance along with navigation and communication management. The error, which is defined as the action - or lack of action - and which leads pilots to deviate from the institutional or the pilot's intentions or expectations, is important performance viewpoint in aviation. The quality of pilot work has certain significance, not only as the effectiveness, but also as for outcomes such as efficiency and flight safety [1]. McFadden in [2] elaborates on the causes of pilot errors and safety threats in aviation, but does not include the impact of all the working environment factors in the aircraft cockpit. These factors are humidity, temperature, pressure, vibration, and, above all, the noise. Noise impact on pilots requires a sufficient level of noise etiology knowledge in order to reduce the potential negative impact on the efficiency and flight safety through adequate noise reduction procedures. This requirement is more pronounced in cases with a high degree of interaction between the pilot and the aircraft which is particularly distinctive in general aviation aircraft during basic flight training where there is no auto-pilot system in use. Research conducted on the Croatian national carrier pilots showed that flight safety was at least once disturbed by noise in 27.8% and 38.5% of turbofan and turboprop aircraft pilots, respectively [3]. The results were achieved by polling without putting the emphasis on actual effect of noise on pilot performance.

The effects of exposure to noise can be physiological and psychological. The physiological effects can be auditory or non-auditory (extra-auditory or psychogenic). Typical auditory physiological effect of noise is Temporary Threshold Shift (TTS), a temporary increase in the threshold of hearing that occurs when someone is exposed to a high level of noise in an individually determined time period. The processes of threshold increase speed and the recovery speed are the functions of intensity and duration of the noise. Accumulation of fatigue, if the noise exposure is prolonged and/or repeated without leaving enough time for recovery (e.g. at daily eight-hour exposure to noise greater than 80 dBA for a few years, which generally corresponds to the daily working conditions of pilots), leads to Permanent Threshold Shift (PTS). The latest research conducted on Chinese military pilots, of different ages and the number of flight hours, showed significant hearing loss in 3-8 kHz frequency range [4]. These losses are higher in pilots with a greater number of hours flown. Ivković et al. [3] confirmed those results surveying Croatian national carrier pilots showing comparable hearing loss/flight hour correlation.

Non-auditory physiological effects of noise may occur at noise levels lower than those needed for auditory effects to happen, and include a variety of subjective symptoms such as lethargy, anxiety, headaches, dizziness, nausea, fatigue or irritability. Due to increased exertion and energy consumption, several outcomes are possible: loss of concentration, increased reaction time, decrease the sharpness of perception and judgment, working memory shortage and distortion of coordination, which all impair pilot performance directly impacting the efficiency and safety of flight.

The effect of noise on human performance is not unique. Sometimes the noise has no effect, while in some cases it may have even a positive outcome. In accordance with the Yerkes – Dodson's law of optimal level of arousal, the noise can have a positive impact on human performance to a certain cut-off point, beyond which the adverse effect of noise occurs. A cut-off point depends mostly on the complexity of the task and the noise dose that a person accumulates [5].

The performance of pilots is crucial for flight safety [6]. Continuous high intensity noise impairs pilot performance in tasks that require concentration, learning, analytical judging, precise movements, continuous performance and long-term attention. Also, adversely affects the performance of simultaneous tasks [7]. Antunano [8] more specifically states that the tasks that require alertness, vigilance, concentration, calculation or timing may be significantly degraded by exposure to noise greater than 100 dBA. Measuring and analyzing interior noise levels of a small piston-prop aircraft in flight and on the apron, Ivošević et al. [9, 10, 11 and 12] have shown that at certain flight stages interior noise exceeds 100 dBA.

Study of the long-term interior noise impact on performance of the helicopter pilots has shown relatively low correlation, except for some cases of significant performance degradation [13]. However, the pilot performance was measured only at the lower levels of the procedure complexity, as a deviation from fixed heading and altitude in a flight simulator. A similar investigation of the helicopter crew, showed, however, significant performance degradation due to the impact of accumulated interior noise [14]. Performance was measured before and after the flight in the form of precise reaction to moving objects, the response to the frequency change of flickering lights and others. The influence of environmental factors in the aircraft cabin on the performance, contentment and health of the crew was investigated by the European project HEACE (Health Effects in Aircraft Cabin Environment) [15]. The survey was conducted in real conditions, taking into account all of the factors surrounding the aircraft in which the subjects of surveying subjectively spoke about the changes in observed indicators. The research results showed, among other things, significant noise impact on the expected performance of pilots. Similarly, research on the impact of 12 different samples of interior noise on the expected pilot performance showed positive expectations regarding changes in performance at low noise levels [1].

## 2. STARTING ASSUMPTIONS

Assumptions of research include defining measurable parameters and noise performance of pilots, the minimum requirements for measuring equipment and laboratory conditions in which research is carried out, along with the selection of participants.

### 2.1 Measureable noise and performance parameters

All preceding studies on impact of noise on the airline pilots take instantaneous sound pressure level as the relevant noise parameter. The noise level and sound pressure level is generally defined as the logarithmic ratio of sound pressure $p$ and the reference sound pressure level $p_0$ = 20 μPa.

As the noise has a cumulative character, in addition to the instantaneous noise level influence on humans, previously accumulated noise in an individually determined time of exposure should be taken into account as well. Therefore, since the pilot inside the cockpit is exposed to continuous noise which effect accumulates, a comparative analysis of pilot performance should be carried out taking into account the accumulated noise dose.

The accumulated noise dose was initially introduced in order to, according to different standards that depend on the legislation of a state or service, define the maximum recommended daily human exposure to noise in the workplace with the purpose of preventing permanent hearing threshold shift or Noise Induced

Hearing Loss - NIHL. Accumulated noise dose $D$ is given by:

$$D = \frac{100}{T_n}\sum_{i=1}^{N}(T_i)10^{[((L_i-L_c)/q)]} \tag{1}$$

where:

$D$ – dose expressed as acceptable daily dose percentage

$T_n$ – normalized time period (usually 8 hours),

$T_i$ – duration of $i$-th time period,

$L_i$ – equivalent sound pressure level in $i$-th time period,

$L_c$ – sound level criterion (usually 85 or 90 dBA),

$q$ – non-dimensional character which determines change in time; $q=n/\log 2$ , for $n$ dB law of change,

$N$ – number of intervals.

The maximum recommended daily noise dose that pilot is allowed to accumulate is defined according to OSHA where the noise level criterion is 90 dBA, with the law of change of 5 dB [16]. This means that during the eight-hour duty time pilot may be subjected to the equivalent interior noise of 90 dBA, corresponding to 100% of the recommended daily dosage. Any further increase in the equivalent noise by 5 dB results in halving the recommended exposure time. The maximum acceptable continuous noise to OSHA is 115 dBA for 15 min exposure period (*Table 1*).

Noise level and the accumulated noise dose comparison is shown in *Figure 1*. While observing the same flight parameter at the same time in two separate measurements at different levels of continuous noise, a difference in the dose- accumulated noise will increase linearly with time of noise exposure (left chart). In this way the comparison of performance of pilots in order to determine the influence of the internal noise of the aircraft is not completely reliable. Observing the same flight parameters at the same time in two separate measurements, with the same continuous noise levels, but with different starting noise exposure doses, the difference in accumulated noise dose during entire measured time is the same (chart at right). In this case the comparison is more consistent.

The pilot performance concerning the aircraft management can be measured by the average and/or maximum deviation from the standard flight parameters to be held at a given time. These parameters are e.g. heading, speed, altitude, rate of climb and descent, etc. Also, it is necessary to distinguish the terms like flight exercises, flight elements and the complexity of flying elements. The flight element includes maintaining at least one flight parameter in a particular phase or regime of flight. The regime includes level flight, climbing or descending. The complexity of the flight elements depends on the number of maintained flight parameters and the regime. Flight exercise scenario (may be also called flight procedure) is determined by the consecutive execution of predefined flight elements of the same or different levels of complexity.

## 2.2 Measuring equipment requirements

In order to successfully realize the research on the impact of aircraft interior noise on the pilot performance, to set the minimum requirements for measuring equipment is needed, as well as the necessary technical specifications of each part of equipment. It is necessary to ensure:

- Aircraft in which interior noise will be recorded during flight;
- Sound level meter (SLM) or measurement set for recording the samples of aircraft interior noise in flight;
- Audiometer for assessing the audiogram of subjects in the preliminary phase and after each cycle of performance measurement
- P.A. system for recorded interior noise playback;

*Table 1 – Comparison of the permitted sound pressure level and duration of daily exposure according to OSHA*

| Sound Pressure Level [dBA] | 90 | 92 | 95 | 100 | 105 | 110 | 115 |
|---|---|---|---|---|---|---|---|
| Daily exposure [h] | 8 | 6 | 4 | 2 | 1 | 0.5 | 0.25 |

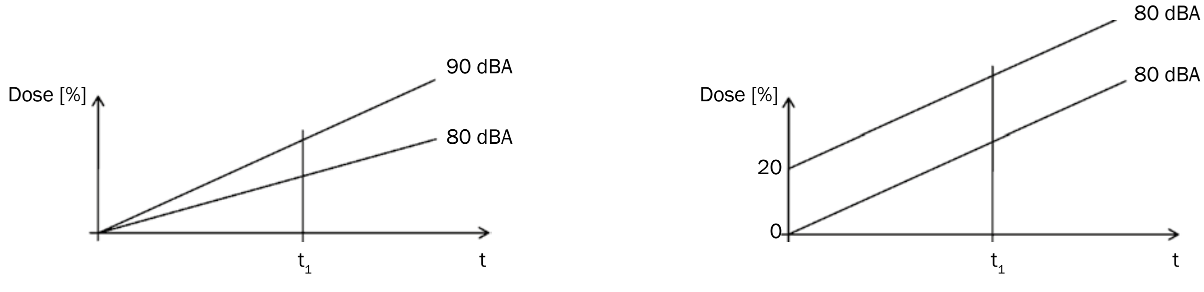


*Figure 1 –Noise level and noise exposure dose comparison*

- Noise dosimeter for measuring the noise dose accumulated by subjects prior to each cycle of performance measurement;
- Multifunction instrument with microclimatic probe for supervising the four main climatic factors in the research room;
- Flight Simulation Training Device – FSTD, i.e. flight simulator, in which the pilot performance of subjects will be measured.

*Aircraft*

The most common criteria for the general classification of aircraft are the powerplant features, runway length requirement, the size or capacity and purpose. According to powerplant features, aircraft are divided into piston and jet powered. According to size and capacity, aircraft are basically divided into three categories, small (up to 30 seats), medium (30 - 100 seats) and large (more than 100 seats). If the aircraft interior noise is defined as a synergy of airborne and structure borne noise generated by exterior and interior sources, then the most significant contribution to the levels of individual noise spectrum components are provided by exterior sources, i.e. powerplant and aerodynamic flow, which among other things, depend on the fuselage structure and the aircraft size. Therefore, typical interior noise spectra can be defined considering powerplant and size, i.e. according to aircraft classification.

*Sound level meter or measurement set*

The basic requirement for SLM or measurement set that will record samples of aircraft interior noise in flight is a high degree of accuracy and the ability to record or store the sound samples in one of the uncompressed digital formats, like WAVE, for example. That way the interior noise samples can be post-processed without loss of quality. In addition, for a more detailed interior noise analysis, the possibility of measuring distinctive noise assessing parameters is necessary.

*Audiometer*

The audiometer is a diagnostic instrument that measures human hearing threshold within the audible frequency range. In addition to a high degree of accuracy, the basic requirements required for an audiometer are the maximum change in sound intensity step of 5 dB and the minimum set of basic test tones as follows: 500 Hz, 1 kHz, 2 kHz, 4 kHz and 8 kHz. For a more detailed analysis, additional test tones are needed in the lower and higher audio band, typically 250 Hz and 12.5 kHz. Furthermore, in order to analyze the extent of hearing loss caused by noise, which is characterized by a typical "4 kHz notch" within the audiogram, it is necessary to have the possibility of a more detailed insight into the auditory characteristic around that frequency. Usually this is accomplished by the test tones at 3 kHz and 6 kHz.

*P.A. system*

The system comprising an amplifier and a loudspeaker, which is used to playback the recorded aircraft noise, should meet following basic requirements: Hi-Fi sound reproduction with at least 95 dBA SPL at subject's standpoint. That way, necessary noise dose accumulation prior to pilot performance measurement will be possible to achieve. The loudspeaker has to be a full-range loudspeaker, being able to reproduce very low frequency components of noise which are relevant for the noise annoyance, especially for small aircraft in general aviation.

*Noise dosimeter*

In addition to a high degree of accuracy, the basic requirement for noise dosimeter is the ability to choose different noise level criteria with different levels of changes. In addition, the measuring ranges of measurable levels and noise dose should minimally include the value of certain research methodology, i.e. 50% of the noise dose to 95 dBA noise level.

*Multifunction instrument with microclimatic probe*

Multifunction instrument with microclimatic probe should have a high degree of accuracy and resolution within the measuring range, which covers the required values of monitored ambient parameters: temperature, relative humidity and air movement in the rooms in which research is carried out.

*Flight Simulation Training Device*

Four types of Flight Simulation Training Devices - FSTDs can be potentially used for pilot performance measurements:
- Full Flight Simulator - FFS;
- Flight Training Device - FTD;
- Flight and Navigation Procedures Trainer – FNPT, and
- Basic Instrument Training Device - BITD.

The basic requirement for FSTD is the unlimited repetition possibility of flying elements according to the test flight scenario. Since the exercise is performed under instrument flight rules (IFR), FSTD must be able to control basic visual parameters (visibility, cloud parameters: base, top and density, nighttime/daytime scenery). For later analysis, FSTD should have the ability to track and store the average and maximum deviation from supervised flight parameters to be maintained, at any given time. It should be fully functional and have a valid FSTD certificate in accordance with [17].

### 2.3 Essential laboratory conditions

Essential laboratory conditions define the minimum requirements for the space in which research is carried out and the physical conditions of research work premises. For successful execution of the research, following spaces are necessary: anechoic or semi-anechoic chamber where the audiometric measurements are conducted; "accumulation room" in which the subjects are exposed to noise in order to accumulate initial noise dose; and, finally, the FSTD room in which the pilot performance measurements are carried out. The physical conditions of research work premises are defined by air temperature, surrounding surface temperature, relative humidity and air movement. Since the four climatic factors define the subjective feeling of thermal comfort which must not be disturbed during the execution of the entire research, the following ambient recommendations are:

– Air temperature should be between 20 and 21°C in winter and between 20 and 24°C in summer;
– Temperature of surrounding objects and surfaces should be equal to air temperature or differ not more than 3°C;
– Relative humidity should not be lower than 30% in wintertime due to possibility of respiratory tract dehydration, while in summertime the relative humidity naturally spans between 40-60%, which is considered comfortable;
– Air movement at head and lap levels should not exceed 0.2 m/s.

In addition to the aforementioned recommendations, for the subjective sense of comfort and optimum task performance in research work areas, it is necessary to keep the average illuminance between 400 and 850 lx.

### 2.4 Criteria of subject selection

Prospective subjects - research participants must have flight training completed under a training program at one of the approved organizations for aircraft pilot training (Approved Training Organization - ATO), and should have a national pilot license or Part- FCL (Flight Crew License) permit issued in accordance with applicable EU regulations, which is recognized in all Member States. The selection criteria for participants are determined by the area of research interest i.e. age of pilots, years of service and number of hours flown. Those criteria can be also combined. For example, aircraft pilot training organizations have predominant young pilots without years of service and with little number of hours flown. So the research would be more limited for such organization. Larger organizations, for instance airline companies, can split their pilots in additional groups according to predefined categories in order to carry out much more specified research.

## 3. RESEARCH METHODOLOGY

Given the goal set and the starting research hypotheses, it is necessary to conduct a comparative analysis of pilot performance at different noise doses which are determined by the level and time of exposure. Due to technical and operational limitations of using actual aircraft during the research, pilot performance is measured in a certified FSTD under controlled laboratory conditions using the real, previously recorded in-situ, aircraft interior noise as a background sound within. Research methodology is divided into two parts: laboratory experiment and data analysis. The laboratory part of the research is divided into two phases: a preliminary phase and performance measurement phase. Research methodology is shown in *Figure 2*.

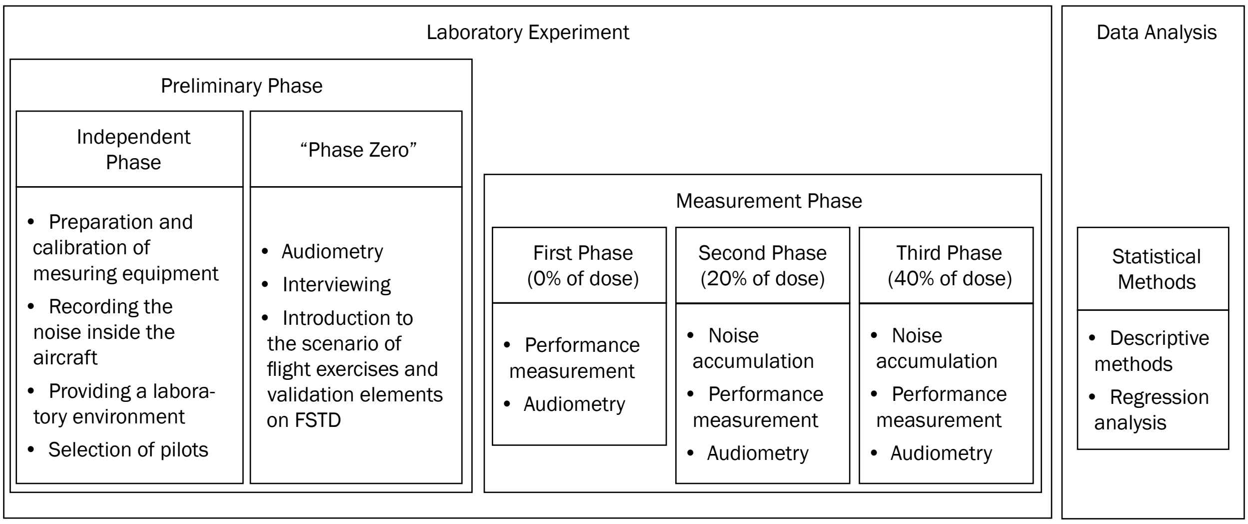


*Figure 2 –Research methodology*

## 3.1 Preliminary phase

The preliminary phase of the research is composed of independent phase and "phase zero" research. Independent (out-of-loop) phase includes the preparation and calibration of measuring equipment, recording the noise inside the aircraft, providing a laboratory environment and selection of pilots. "Phase zero" research involves working with each selected subject prior to performance measurement phase and includes audiometry, interviewing and introduction to the scenario of flight exercises and validation elements on FSTD. Interior noise recording is done by SLM in the aircraft cockpit, during straight and level flight, with powerplant set for optimum cruising regime regarding the type of aircraft. SLM position should be between the pilot and co-pilot seats at head level, according to ISO 5129.

The physical conditions of research work premises must be supervised and kept steady and the same for all subjects in order to rule out the influence of climatic comfort factors on pilot performance.

The selection of pilots is performed in accordance with the selection criteria preserving the requirements of minimum statistical sample. After the initial recruitment, additional selection is done according to audiometric results, since the selected subjects should have healthy hearing according to predetermined criteria.

The interviewing is executed at "phase zero" of research, and at the beginning of the first day of work with the subjects. The aim is to collect the basic personal information including date of birth, the total number of flight hours and the years of pilot service.

Audiometry of the subjects is executed by pure sine tones with no opposite ear masking, and the criteria used for selection is the zero degree of hearing impairment, according to WHO, for both ears. The degree of hearing loss is determined by the average hearing threshold for the better ear at typical octave frequency, according to the formula:

$$\overline{hl}_{WHO} = \frac{hl_{500} + hl_{1000} + hl_{2000} + hl_{4000}}{4} \quad (2)$$

where:

$\overline{hl}_{WHO}$ – average hearing threshold in dB,

$hl_{500}$ – hearing threshold at 500 Hz in dB,

$hl_{1000}$ – hearing threshold at 1,000 Hz in dB,

$hl_{2000}$ – hearing threshold at 2,000 Hz, in dB,

$hl_{4000}$ – hearing threshold at 4,000 Hz in dB.

Given the amount of the average threshold calculated by *Equation 2*, the degree of hearing impairment is classified in five grades according to *Table 2*.

Following the preliminary phase, subjects need to come across the exercise scenario and flight validation elements that are evaluated in the research. Flight exercise is performed in laboratory conditions on the FSTD, and the goal is to correctly perform 18 consecutive complex elements while observing flight instruments readout, as seen in *Figure 3* and as explained later in section 3.2.2.

After getting acquainted with flight scenario in the preliminary phase, all subjects undergo entire flight exercise three times consecutively, in order to avoid the impact of different personal adjustment time to FSTD on the results.

## 3.2 The measurement

Measurement phase is made up of several cycles characterized by different initial noise dose accumulated by subjects. Subjects have performed an identical flight exercise in three cycles under simulated interior noise: 1) with no initial accumulated noise dose, 2) with 20% and 3) with 40% of the initial accumulated aircraft noise dose. Using larger initial dose is not justified since in practice abovementioned daily dose values during flight duty are, as a rule of thumb, seldom exceeded. Each study cycle consists of a uniform process that involves preliminary noise accumulation to the initial dose, performance measurement and audiometry. Before each performance measurements, subjects fill in the questionnaire to determine whether they meet minimum requirements of psychophysical readiness in order to prevent the impact of lack of mental and physical readiness on the results obtained.

*Noise accumulation*

The accumulation of the initial noise dose takes place in the so-called "accumulation room", where the subjects are exposed to aircraft interior noise (previously recorded in situ) while wearing personal dosimeter. The accumulation of noise is executed by the levels appropriate for equivalent levels of aircraft interior noise whose influence is the focus of research. The criteria used for this is 90 dBA noise level with 5 dB step changes. In order to cancel out the cumulative character of noise, it is necessary to provide time period of at least 24 hours between each measurement cycle. Performance measurement should be done immediately after noise accumulation process since the

*Table 2 – WHO hearing impairment classification*

| $\overline{hl}_{WHO}(dB)$ | ≤ 25 | 26 - 40 | 41 - 60 | 61 - 80 | ≥ 81 |
|---|---|---|---|---|---|
| Hearing impairment grade | 0 | 1 | 2 | 3 | 4 |

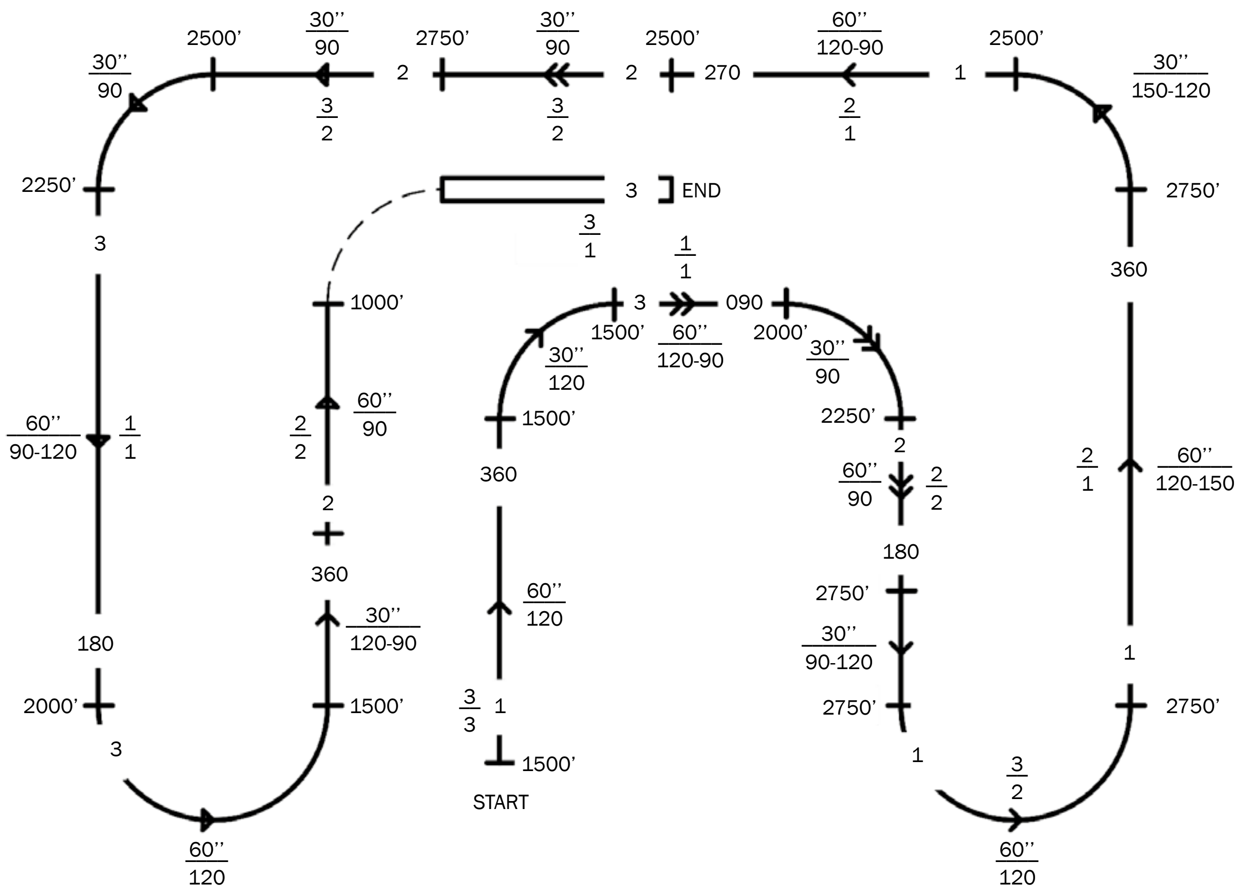


*Figure 3 – Graphical outline of the flight exercise scenario, the number of maintained and supervised flight parameters and flight complexity*

subjects need to be constantly exposed to aircraft cabin noise during the measurement.

*Performance measurement*

Measuring the performance of all subjects should take place at the same time of day in order to balance the impact of internal circadian biorhythms on the results. Before each measurement, by means of survey method (questionnaire), subjects personally evaluate their current psycho-physical readiness (Temporally Psychophysical Readiness - TPR). Survey questions about TPR and associated weight factors are shown in *Table 3*.

After subjective evaluation by filling out the questionnaire, TPR for each subject is calculated according to the formula:

$$TPR = 1.75 + \sum_{i=1}^{10} o_i p_i \qquad (3)$$

where:

*TPR* – non-dimensional number designating psycho-physical readiness,

$o_i$ - value of the i-th question of the subject (1-5),

$p_i$ - weighting factor of the i-th question

According to *Equation 3*, the minimum value of TPR is 1 which corresponds to good mental and physical fitness, while the maximum value is 7.6, corresponding to poor mental and physical readiness. The methodology of the research is determined by the condition TPR ≤ 5.0 as a necessary condition of psychophysical readiness of subjects for each performance measurement cycle. In case of non-compliance with minimum requirement, the subject will have to reschedule the measurement cycle.

After establishment of subject's psychophysical readiness, flight exercise is performed. This paper is focusing on general aviation because there would be quite different flying tasks in commercial aviation according to different aircraft performance.

The first flight element involves maintaining one-minute straight and level flight (360° heading, 120 kn airspeed and 1,500 ft altitude). The second element involves maintaining 120kn airspeed and 1,500 ft altitude in a standard right turn until intercepting 090° heading. The third element is one-minute maintaining 090° heading while climbing to 2,000 ft

*Table 3 – Subjects' psycho-physical readiness questionnaire with weighting factors*

| No. | Question | Weighting factor |
|---|---|---|
| 1 | Are you sleepy? (1- not at all; 5- very) | 0.2 |
| 2 | Do you feel tired? (1- not at all; 5- very) | 0.1 |
| 3 | Do you feel sick? (1- not at all; 5- very) | 0.3 |
| 4 | Are you taking any medication in the last few days? (1- not at all; 2- food supplements; 3- against inflammation; 4- against allergy; 5- sedative) | 0.1 |
| 5 | Amount of alcohol taken in last two hours? (1- not at all; 5- substantial) | 0.3 |
| 6 | What kind of beverage did you take in last two hours? (1-non-energy drink; 2-coke or green tea; 3-energy drink; 4-coffee; 5-combination of the above) | -0.2 |
| 7 | Are you hungry and/or thirsty? Do you need to go to toilet, etc? (1- not at all; 5- very) | 0.05 |
| 8 | Are you upset, irritated, depressed, anxious or thoughtful? Are you presently disturbed? (1- not at all; 5- very) | 0.1 |
| 9 | Are you anxious or afraid of being tested for any reason? (1 - not at all; 5 - very) | 0.1 |
| 10 | Are you feeling competitive for this testing? (1- not at all; 5- very) | -0.2 |

altitude and reducing the airspeed to 90 knots and so on. The last, i.e. eighteenth element is to maintain aircraft attitude and 100kn airspeed during an instrument approach to landing. Twelve out of these eighteen flight elements are evaluated in this research, as follows:

- Maintaining speed in straight and level flight;
- Maintaining heading in climb to a given altitude while reducing airspeed to a given value;
- Maintaining heading and airspeed while climbing to a given altitude;
- Maintaining airspeed and altitude in a standard turn;
- Maintaining straight and level flight while accelerating to a given airspeed;
- Maintaining straight and level flight while decelerating to a given airspeed;
- Maintaining airspeed and rate of climb in climbing;
- Maintaining airspeed and rate of descent in descending;
- Maintaining heading in descending to a given altitude and accelerating to a given airspeed;
- Maintaining airspeed while changing altitude in a standard turn;
- Maintaining heading and airspeed while descending to a given altitude;
- Maintaining attitude and airspeed during ILS approach.

Due to diverse number of flight parameters to be maintained and regimes flown, the complexity and performance of individual flight elements are different. In this study, in which 21 pilots and/or flight instructors with more than 1,000 hours of flight duty have participated, the validation complexity of flight elements has been established. *Figure 3* shows total number of maintained flight parameters within the validation elements (numerator of a fraction), the number of supervised flight parameters (the denominator of a fraction), as well as the complexity of the validated flight elements (1 - low level of complexity, 2 - medium level of complexity, 3 - high level of complexity). Particular results of this actual study, however, will be summarized and published in a near future.

In order to measure the performance of pilots, it is necessary to ensure continuous monitoring of flight element execution in a given time in order to determine the average and maximum deviation from the predefined values.

*Audiometry*

Upon completion of each cycle, subjects undergo the audiometry in order to further investigate the effect of different noise doses to a temporary threshold shift. Audiometry is executed on both ears immediately after the performance measurement, where the total accumulated noise dose is the sum of initial noise dose acquired in the accumulation room and the dose gained within the FSTD cabin during performance measurement.

## 3.3 Data analysis

Data analysis includes the analysis of all the results of research, i.e. the noise impact on the pilot performance and temporary threshold shift, as well as the results of the interviewing. The research results are issued individually or collectively, but with no identifiers that can be linked to individual subjects. In measuring performance, discretization of maintained parameters is completed with minimum rate of $f_s = 1/3$ Hz, which means that one sample of measured parameter is taken every three seconds. Thus, during one-minute of flight element execution, 20 discrete values are supervised. Due to transition from one to another flight element, it is necessary to discard two adjoining samples of each maintained parameter and use the remaining values to determine the average and maximum deviation according to:

$$\Delta p = \frac{\sum_{i=1}^{16} |v_1 - v_0|}{16} \quad (4)$$

$$\Delta m = \max | v_i - v_0 | , i \in [1,2,\ldots,16] \quad 5)$$

where:

$\Delta p$ – average deviation of flight parameter in a given time,

$\Delta m$ – maximum deviation of flight parameter in a given time,

$v_i$ – instantaneous value of $i$-th maintained flight parameter sample,

$v_0$ – predefined value of the maintained flight parameter.

The values of average and maximum deviation calculated by using Equations 4 and 5 for each subject and each performance measurement cycle are usually put out in a graphical layout. While analyzing the data, in addition to standard descriptive statistical methods, it is necessary to use a regression analysis to determine the possible functional dependency of performance changes or temporary threshold shift due to noise exposure dose. Also, a mixed linear regression model with adjustment for multiple testing using False Discovery Rate (FDR) method is mandatory [18]. In that case, the associated $P$-value of less than 0.05 should be considered significant.

## 4. CONCLUSION

The paper suggests a methodology developed for determining aircraft interior noise impact on the flight performance of pilots. The need for introduction a new methodology is derived from the results of previous studies which have shown that the relevant impact is not unique, nor is the methodology to measure the impact itself. Suggested methodology represents a significant divergence from previous researches that do not take into account the cumulative character of noise. The necessity of considering the accumulated noise dose as a relevant parameter is justified by the very nature of noise effects on humans, as well as by being closer to the actual noise conditions in the aircraft cockpit the pilots are exposed within. New methodology enables not only a comparative analysis of the impact of different types of aviation noise on pilot performance, but, in addition to population effect, can also provide insight to individual effects of noise. The latter may be used for aviation medicine purposes, by means of tracking the changes in noise impact on pilots during their active duty – flight hours and/or years of service. Also, it can be of interest to various aviation-related organizations such as flight training schools, scientific institutes or airlines. As the pilot performance is also affected by the other working environment factors, the methodology could be extended with other input variables in future research, with the aim of assessing the overall impact. However, the full effect of external factors cannot be entirely reached in the laboratory conditions since the stress generally builds up during the actual flight i.e. in real environment.

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### *METODOLOGIJA ODREĐIVANJA UTJECAJA UNUTARNJE BUKE ZRAKOPLOVA NA PERFORMANSE I PRIVREMENI POMAK PRAGA ČUJNOSTI PILOTA*

### *SAŽETAK*

*Dosadašnjim istraživanjima pokazano je da utjecaj unutarnje buke zrakoplova na performanse pilota nije jednoznačan, niti postoji jedinstvena metodologija kojom se mjeri. Nadalje, nije se dosad uzimao u obzir ni akumulirajući karakter buke. Ovo je istraživanje usmjereno na određivanje utjecaja akumulirane unutarnje buke aviona Općeg zrakoplovstva na performanse pilota u laboratorijskim uvjetima. U metodologiju je integrirano određivanje utjecaja unutarnje buke na privremeni pomak praga čujnosti pilota, čime je omogućeno prošireno istraživanje svih aspekata fizioloških utjecaja buke na pilote. Metodologijom su definirani mjerljivi parametri buke i performansi pilota, zahtjevi za mjernom opremom, nužni laboratorijski uvjeti te kriterij odabira ispitanika. Analiza odstupanja od održavanih letačkih veličina te privremenih pomaka praga čujnosti pri različitim dozama akumulirane buke izvršava se deskriptivnim statističkim metodama te mješovitim linearnim regresijskim modelom uz prilagodbu za višestruka testiranja korištenjem False Discovery Rate metode, što omogućuje određivanje možebitnog populacijskog efekta.*

### *KLJUČNE RIJEČI*

*unutarnja buka zrakoplova; performanse pilota; fiziološki utjecaj buke; privremeni pomak praga čujnosti; regresijska analiza; mješoviti modeli;*

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