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PSYCHO-ACOUSTICAL ERGONOMICS IN A LIGHT AIRCRAFT INTERIOR

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Abstract:

Noise levels in light aircraft interiors, particularly during take-off and climb phases of flight, often exceed acceptable values. Communication between a pilot, copilot and an Air Traffic Control (ATC) staff, as well as among passengers, is severe disrupted in such noisy environments. Based on noise measurements in a typical representative of a light aircraft, its spectral content and corresponding noise levels, parameters relevant to speech intelligibility are calculated. Speech Interference Level (SIL), Articulation Index (AI) and maximum communication distances are determined for various flight phases and vocal efforts.

1. INTRODUCTION

High levels of noise considerably downgrade the quality of speech communication, confirming this setback as a serious flight safety issue, [1]. Communication between pilot, copilot and ATC staff is often downgraded by the masking effects of background noise, [1, 2]. Beside communication difficulties, high noise levels increase stress and anxiety levels that influence psychomotor performance and can increase numerous errors in tasks that require vigilance, concentration, calculations and timing judgments, [3]. Interior noise level depends a lot on the aircraft and its powerplant, i.e. engine and propeller, but on average, the values are 80 dBA and above, up to 110 dBA in case of some piston aircraft (e.g. Cessna 210). Prolonged exposure to the noise exceeding 85 dBA is related to hearing damage risk, [2]. For certain phases of flight (e.g. takeoff) most general aviation aircraft do not provide adequate acoustical ergonomics.

2. THE SOURCES OF AIRCRAFT INTERIOR NOISE

Aircraft noise contains the following main components: engine noise (with engine compartment elements such as pumps and alternator, and an exhaust system), propeller noise, airframe noise and structure borne noise (as a particular kind of airframe noise),

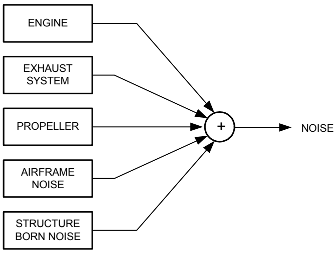

Figure 1: **A**ircraft noise sources

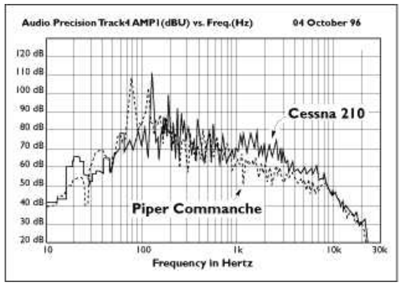

Figure 2: Noise spectrum (adopted from [6])

[4, 5]. Aircraft interior noise is combination of all mentioned components that, with various degrees, penetrate into the aircraft cabin as shown in Fig. 1. At low RPM interior noise is dominated by engine and exhaust noise. At higher RPM, due to propeller tip speed, the influence of propeller noise becomes considerable. In flight, aerodynamic noise becomes more significant as progressive speed rises. Noise spectrum of two common light aircraft is shown in Fig. 2, [6].

3. SPEECH COMMUNICATION UNDER NOISY CONDITIONS

Human speech has a fundamental frequency (pitch) in the range of 100-400 Hz (about 100 Hz for men and 200 Hz for women). Spectral peaks of the short term speech spectrum are called formants and are determined by the resonant characteristics of the vocal tract. Various vowel sounds and transitions among them are created by these formants. Normal conversation takes place in the frequency range from 500 to 3,000 Hz. Consonant sounds are impulsive and/or noisy, and occur in the frequency range of 2 kHz to about 9 kHz. Speech communication is often degraded by the masking effect of background noise and changes in vocal effort are necessary for various background noise levels. Auditory masking is intrusion of unwanted sounds that inevitably interfere with the speech signal. Masking effect is illustrated in spectral domain in Fig. 3-5. When the low-frequency noise is louder than the speech signal it effectively masks speech. At high sound pressure levels such noise effectively masks both vowels and consonants. High-frequency noise masks only the consonants, and its masking effectiveness decreases as the noise gets louder. Noise exposure levels in a light aircraft afford less than desired intelligibility (<95%). The effects of cabin noise to speech communication could be compensated to some extent by various vocal efforts and by reducing the distance between the talker and listener. Long term spectrum of speech under various vocal efforts is shown in Fig. 6, [7] and corresponding sound levels in Table 1.

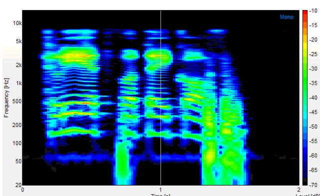

Figure 3: Clean speech

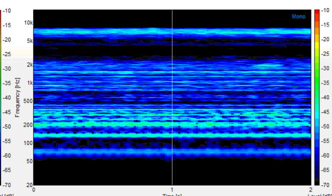

Figure 4: Cabin noise

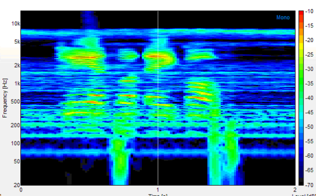

Figure 5: Speech + noise

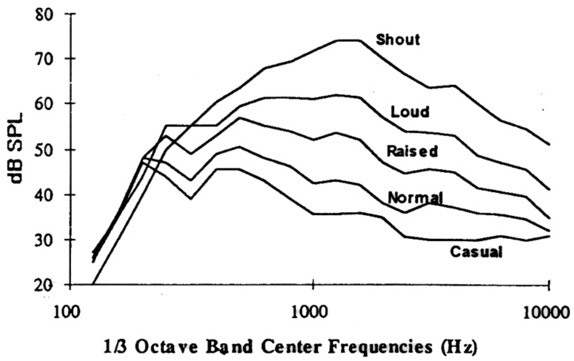

Figure 6: Long term spectra of voice under various vocal efforts (adopted from [7])

Table 1: Speech levels at various vocal efforts dBA

Voice	Average level dB/dBA
Casual	52.0/42.0
Normal	57.0/47.0 (private speech)
Raised	64.0/57.0
Loud	73.0/62.0
Shout	85.0/72.0

4. THE MEASURES OF SPEECH INTELIGIBILITY

Several noise metrics have evolved for assessing the influence of noise on speech, [2].

4.1 Speech Interference Level (SIL)

Speech Interference Level is defined as the arithmetic average of the sound pressure levels at 500, 1000, 2000 and 4000 Hz octave bands, [1, 2].

$$SIL = \frac{L_{p500} + L_{p1000} + L_{p2000} + L_{p4000}}{4} \qquad \textbf{(1)}$$

A-weighted sound level L_{pa} correlate well with SIL for most sounds associated with aviation, [2]. Acceptable results of SIL values may be derived from A-weighted noise levels by using the following expression, [1]:

$$SIL = L_{pA} - 10 \qquad \textbf{(2)}$$

4.3 Articulation Index (AI)

Articulation Index is the value, between zero and 1.0, which describes the masking of speech by background noise; this value is found by evaluating the signal to noise ratio in specific frequency bands, [2]. A quantitative measure of speech intelligibility is the percentage of speech items correctly perceived and recorded.

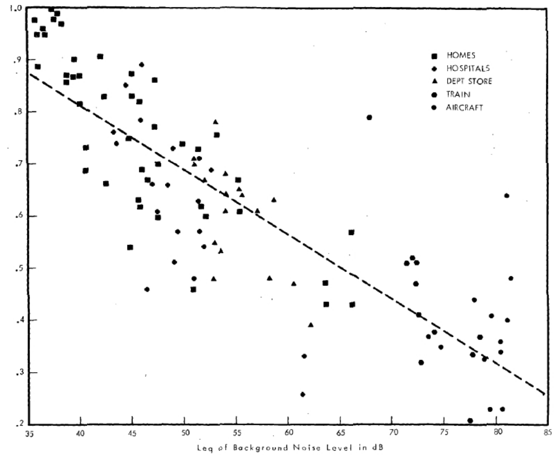

Figure 7: AI for conversations in various environments (adopted from [8])

An AI of 100% means that all speech can be understood, 0% means that no speech can be understood. An AI < 0,05 is representative of very poor speech intelligibility, and an AI > 0.80 represents good speech intelligibility. Articulation Index can be calculated from the 1/3 octave band levels between 200 Hz and 6300 Hz centre frequencies, [9]. It can also be approximately determined from graph shown in Fig. 7. Speech intelligibility should not be confused with speech quality, since speech intelligibility is related to the amount of speech items that are recognized correctly while speech quality is related to the quality of a reproduced speech signal with respect to the amount of audible distortions.

5. THE EXPERIMENT

Measurements were performed in Cessna 172N, a four-passenger, single piston-engine propeller driven aircraft. Noise signals were recorded with 40 kHz sampling frequency in 16-bit resolution, mono, using the ECM800 Behringer microphone, M-AUDIO Exterior Sound Card C400 and laptop computer. Noise levels were measured using Nor140 Norsonic Sound Analyzer. A-level weighting is used for measurements due to high correlation with people's subjective judgment of the loudness, [2]. Measurement position was between the front seats at the head level, according to ISO 5129:2001 standard.

6. THE RESULTS

Noise measurements were performed on a one-hour route flight. Flight phases and their corresponding noise levels are shown in Table 2. Speech intelligibility measures are determined for each flight phase and presented in Table 3, with duplicated flight phases being omitted in the table. An articulation index of 0.3 was identified as adequate for acceptable communication, [5], which is, in this case, found equivalent to SIL 72, or 82 dBA.

Table 2: Flight phases and corresponding noise levels

Phase	Noise level dBA (+/- 0.5dBA)
taxiing	78.9
hold	80.2
taxiing	81.3
take off run	93.9
take off	91.1
climb	88.9
cruise	83.1
descend	74.0
landing	76.0
roll off	79.3
taxiing	78.7

Table 3: Speech intelligibility metrics

Flight phase	SIL	AI
taxiing	68.9	0.33
hold	70.2	0.32
take off run	83.9	0,15
take off	81.1	0.17
climb	78.9	0.17
cruise	73.1	0.28
descend	64.0	0.38
landing	66.0	0.36
roll off	68.7	0.34

The distance between the talker and listener (i.e. communication distance) is important when the conversation takes place. Speech levels are reduced typically by 6 dB for each distance doubling between the talker and listener, [10]. Distance for various values of SIL is shown in Fig. 8, and values for various flight phases (extracted from the graph) in Table 4.

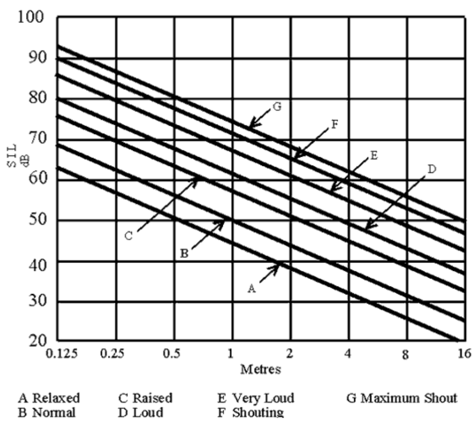

Figure 8: Communication distance for various values of SIL (adopted from [10])

Table 4: Communication distance for normal and loud voice

Flight phase	normal	loud
taxing	0.13	0,48
holding	-	0.42
take off run	-	-
take off	-	0.13
climb	-	0.17
cruise	-	0.33
descend	0.23	0.90
landing	0.19	0.70
roll off	0.12	0.47

7. CONCLUSION

Cabin noise in a light aircraft significantly interferes with speech intelligibility, particularly during high power settings, e.g. take-off and climb phase of a flight. At such noise levels, communication between pilot, copilot and ATC staff should be performed using communication headphones, preferably of noise canceling type. Despite the fact that an articulation index of 0.3 was identified as adequate for acceptable communication, the background noise level of less than 70 dBA should be a goal for speech communication in airplane (as in modern cars, for instance). Additional soundproofing may be required to achieve such sound levels, and may enable more comfortable travel, at least during cruise phase of a flight. It would also provide further noise reduction essential for hearing protection of pilots and passengers

REFERENCES

[1] Bucak, T., Bazijanac, E. & Juričić, B: Correlation Between SIL and SII in a Light Aircraft Cabin During Flight, *Proc. ICSV14*, Cairns, Australia, 2007

[2] Newman J. S. & Beattie K. R., *Aviation Noise Effects*, Report No. FAA-EE-85-2, US DoT FAA, March 1985

[3] Sharp L. F., Swiney J. F., Dansby M. R., Hyatt S. C. & Schimmel D. E.: *Behavioral and physiological correlates of varying noise environments*, EPA-600/1-77-038, Environment Protection Agency, June 1977

[4] Miljković D., Maletić M. & Obad M.: Comparative Investigation Of Aircraft Interior Noise Properties, *Proc. AAAA 2007*, Graz, 2007

[5] Miljković D., Ivošević J. & Bucak T.: Two vs. Three Blade Propeller - Cockpit Noise Comparison, *Proc. AAAA 2012*, Petrčane, 2012

[6] Airplane Issues, ANR 101 - A Tutorial on Active Noise Reduction, *Available from* http://www.lightspeedaviation.com/content/lightspeedaviation/CustomPages/ANR-101-A-Tutorial-on-Active-Noise-Reduction/Section-3-Airplane-Issues.htm *Accessed:* 2013-05-10

[7] Tobin, H.: *Practical Hearing Aid Selection and Fitting*, DIANE Publishing, 1997

[8] Pearsons K., Bennett Ricarda L. & Fidell S.: *Speech levels in various noise environments*, EPA-600/1-77-025, Environment Protection Agency, May 1997

[9] Articulation Index, *Available from* http://www.diracdelta.co.uk/science/source/a/r/articulation%20index/source.html *Accessed:* 2013-05-10

[10] Transportation Safety Board of Canada (TSB), Railway Investigation Report R98V0148