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CORRELATION BETWEEN SIL AND SII IN A LIGHT AIRCRAFT CABIN DURING FLIGHT

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Abstract

Several reports confirm that high levels of interior noise in small GA aircraft considerably downgrade the quality of speech communication, confirming this setback as a serious flight safety issue. In order to quantify the levels of interaction between cockpit speech and noise, numerous octave-band noise measurements in Cessna 172R cabin have been conducted during various flight conditions, from which Speech Interference Level (SIL) and Speech Intelligibility Index (SII) were derived. The subsequent comparison of the results was made and presented in this paper. Although based on different grounds, these two methods have shown acceptable degree of correlation under given conditions.

1. INTRODUCTION

Aircraft noise is a common side-effect of aerodynamic flow over the fuselage, a strong powerplant operation, and, especially in large aircraft, onboard systems performance (pressurization, APU etc.). Transferred through the fuselage, interior (aka cabin- or cockpit-) noise levels may be so high that they provoke serious discomfort and fatigue of crew and passengers, and interfere with speech communication between the crew and/or ATC which can lead to the general deterioration of the aircraft safety [1].

The procedures used to reduce and control interior noise unfortunately boost the aircraft weight, decrease the cabin space and deteriorate flight performances. Consequently, the noise level and frequency spectrum are important parameters in the aircraft design and operation. The cabin noise abatement involves permanent seek for the best possible compromise between the acceptable noise level and the overall aircraft performance.

The interfering effect of aircraft interior noise on speech communication is particularly high in helicopters and in small G/A propeller-driven aircraft, both piston and turbo engine. The powerplant operation in small aircraft with non-pressurized cabin often produces interior noise levels even up to 100 dBA, with dominant frequency components in the lower part of the audible spectrum. Due to long wavelengths it is very difficult to accomplish acceptable noise reduction in the fuselage structure that contains numerous “sound bridges” such as weakly sealed doors and windows, allowing uninterrupted noise transmission into the cabin.

According to the *masking theory*, the most successful masking of speech is achieved by the masking sound in the frequency range of 300 Hz to 500 Hz, in which the cabin noise components are unfortunately dominant. Moreover, the masking of the entire speech range is possible due to *spreading effect*, which means that the cabin noise is very efficient speech masker [2].

Unfortunately, the achievements in the cabin noise reduction are quite limited. Although there are recommendations regarding acceptable levels of cabin noise for certain types of aircraft, the standardization has not been carried out yet, since it is generally believed that the typical levels of cabin noise under usual exposure do not endanger health. The communication problems are therefore commonly resolved on a “case by case” basis, with more or less success.

2. SIL AND SII AS NOISE VS. SPEECH DESCRIPTORS IN AIRCRAFT CABIN

The Speech Interference Level (SIL) represents basically, as well as the Articulation Index (AI), level of masking the speech by surrounding noise, and therefore, as a method simpler and faster than AI, it is commonly used *in situ* for assessing the influence of noise on speech communication, i.e. for estimating the presence of frequencies of significant “weight” in surrounding noise that interferes with speech.

The SIL method was introduced by Beranek [3] studying the characteristics of aircraft cabin noise, estimating, after having experimented with numerous narrow spectral bands, that for a satisfactory analysis in the majority of conditions three bands are sufficient, determined according to the “old” octave bands of 600-1200 Hz, 1200-2400 Hz and 2400-4800 Hz range, whose arithmetic mean of audio levels give feasible results. Based on the Fletcher-Munson loudness curves, Beranek shortly afterwards introduced one more band of 300-600 Hz range, noticing the important participation of this part of spectrum under conditions of higher noise levels.

Webster [4] expanded Beranek’s research by introducing the *preferred* octave of center frequencies 500Hz, 1000Hz and 2000Hz within the total range of 350 Hz to 2830 Hz. Thus, new SIL method becomes known as *Three-band Preferred-octave Speech Interference Level* (PSIL), or just PSIL, and the new values of speech interference level are calculated by the expression:

$$\mathrm{PSIL} = \frac{L_{p500} + L_{p1000} + L_{p2000}}{3} \qquad [\mathrm{dB}] \tag{1}$$

By further adding one more octave with the center frequency of 4 kHz the expression (1) is modified into

$$\mathrm{SIL} = \frac{L_{p500} + L_{p1000} + L_{p2000} + L_{p4000}}{4} \qquad [\mathrm{dB}] \tag{2}$$

The method becomes standard (ANSI S3.14-1977, R-1986; ISO TR3352 1974 i ISO 9921-1 1996) under the name *Four-band Preferred-octave Speech Interference Level*, ANSI-SIL, or simply SIL. The average values for SIL are by about 1 dB higher than the Beranek’s SIL values, and about 2.5-3 dB lower than PSIL.

Acceptable results of SIL values my be also derived from A-weighted noise levels using the expression

$$\text{SIL} = L_{pA} - 10 \qquad [\text{dB}] \tag{3}$$

The influence of surrounding noise on the quality of speech communication is estimated by comparison the obtained SIL value with the values in the reference Table 1. which shows maximum distance of the speaking parties at which the intelligibility of communication at normal (A) and raised voice (B) is still satisfactory for different SIL values. Table 2. shows maximum acceptable SIL values for some examples of confined spaces.

Table 1. Maximum distance of speaking partners for satisfactory intelligibility in dependence of the SIL value

SIL [dB]	**A [m]**	**B [m]**
35	7,5	15
40	4,2	8,4
45	2,3	4,6
50	1,3	2,6
55	0,75	1,5
60	0,42	0,85
65	0,25	0,5
70	0,13	0,26

Table 2. Examples of maximum acceptable SIL values

CONFINED SPACE	**MAX. ACCEPTABLE SIL [dB]**
CLASSROOMS	30
CONFERENCE HALLS	35
OFFICES	45
TELEPHONE BOOTHS	60
AIRCRAFT CABINS	55-70

The Speech Intelligibility Index (SII) method has been derived from Articulation Index (AI) method, and, especially, Speech Transmission Index (STI) method, and presented with ANSI S3.5-1997 standard which allows four measuring procedures, each with a different number and bandwidths, and, consequently, different accuracy. Ordered from the most to the least precise one, they are the following: 1. critical band (21 bands); 2. 1/3 octave-band (18 bands); 3. equally contributing critical band (17 bands); 4. octave-band (6 bands).

All four procedures use adequate weight factors I_i of single bands N in the intelligibility evaluation, whose sum is:

$$\sum_{i=1}^{N} I_i = 1 \tag{4}$$

and then the Speech Intelligibility Index SII is

$$\text{SII} = \sum_{i=1}^{N} A_i I_i \tag{5}$$

where A_i is band audibility.

The SII value can range from 0 (complete lack of intelligibility) through >0.45, considered as minimum acceptable and >0.75 to maximum 1, considered as excellent intelligibility. The SII method also correlates well with the statistical tests and is characterized by wide measuring spectrum (150 Hz to 8,5 kHz), algorithms which include echo, noise and distortion effects into the Modulation Transfer Function (MTF) and, especially when using critical bands procedure, a resolution much higher than the resolutions of all other known methods of measuring intelligibility, which makes it the most reliable and the most precise objective method.

However, under certain conditions the SII method can yield erroneous results. In purely acoustical transmission, the delayed reflection and echo and the masking sounds below 100 Hz greatly influence the accuracy of results, whereas in electro-acoustic transmission systems the influence of non-linear effects is also significant. Besides, as with the RASTI method, the compressors and limiters, influencing the modulation index, give lower SII values.

3. THE EXPERIMENT

3.1 Measurement layout

Although the debate is still going on about the most appropriate method of measuring cabin noise, due to the simplicity the most commonly used is the A-weighted SPL method. Since there are still no adequate standards, the empirical values of acceptable noise levels are used in everyday's practice. Thus, e.g. the levels of up to 70 dBA are considered as good for the acoustic conditions in the cabin, whereas the levels above 90 dBA are definitely unacceptable. In the majority of today's commercial aircraft the level of cabin noise is generally lower than 80 dBA, and the speech communication is mainly undisturbed. However, in smaller propeller piston engine aircraft the levels are still considerably higher.

The object of investigation was the training aircraft type *Cessna* 172R operated by Croatian Aviation Training Centre at the Faculty of Transport and Traffic Sciences in Zagreb, Croatia. The cabin noise has been measured during all successive phases of flight, and the obtained results have been used for SIL and SII calculation. The noise was measured by means of Brüel & Kjær 2231 Sound Level Meter with appropriate octave filters. During the measuring procedures, the applicable recommendations from [5, 6] were used. Measurements of the cabin noise were performed by locating the audiometer between the front seats within the cabin space at the head-level, as presented in Figure 1.

Figure 1. The location of the measuring equipment, port view

A-weighted and octave-band cabin noise measurements were performed in all phases of flight, including ground checks and maneuvering i.e. taxiing, before take-off check, take-off run, takeoff, climb, cruising at various altitudes, descent and approach.

3.2 The results of octave-band cabin noise measurements

The smallest changes in the octave-band cabin noise levels during certain phases of flight are noticed for the lowest measured octave band up to 1 kHz, which can be explained by the dominant share of low-frequency powerplant noise (engine/propeller) in the overall sound image (Table 3.).

Table 3. Levels of aircraft cabin noise in dB measured by octave-band method for different phases of flight

PHASE OF FLIGHT	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz
	[dB]	[dB]	[dB]	[dB]	[dB]	[dB]
TAXIING	79	75	68	48	46	43
BEFORE TAKE OFF CHECK	85	79,5	75	68	64	60
TAKE OFF RUN	85	82	77	68	63	68
TAKE OFF 500 ft	87	82	76	67	64	56
CLIMB 1000 ft	87	82	76	68,5	63	57
CLIMB 2000 ft	85	82	75	68	64,5	57
CRUISE 3000 ft	84,5	83	74	68	65	56
CRUISE 4000 ft	83	81,5	75	67	66	56
DESCENT 2000 ft	77	75	67	64	61	51
DESCENT 1000 ft	78	74	67	64,5	64	52
APPROACH 500 ft	75	70	63	58	53	48

3.3 SIL calculation

By measuring octave-band noise levels and using the expression (2) the results of SIL values have been obtained (Table 4. and Figure 2.) [8].

Table 4. SIL values for different phases of flight

PHASE OF FLIGHT	SIL [dB]
TAXIING	59
BEFORE TAKE OFF CHECK	71
TAKE OFF RUN	72,5
TAKE OFF 500 ft	72
CLIMB 1000 ft	72
CLIMB 2000 ft	72
CRUISE 3000 ft	72,5
CRUISE 4000 ft	72
DESCENT 2000 ft	67
DESCENT 1000 ft	67
APPROACH 500 ft	61

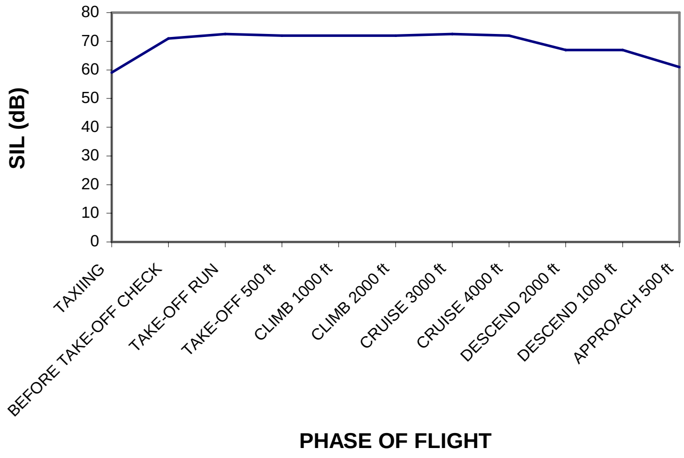

Figure 2. SIL values for different phases of flight

3.4 SII calculation

For the calculation of SII values the computer application *SII Calculation 1.0© for ANSI S3.5 – 1997 standardized method* was used, published as a *freeware* [7]. The application allows SII calculation for all SII procedures mentioned above, for four different levels of speech. The basic input parameters necessary for calculation are: speech level, noise band levels and the Band Importance Function (BIF), as well as some additional input parameters which are mainly used in the diagnostic audiometry. In order to obtain compatibility with SIL, the octave-band procedure was used. By entering the results of octave-band cabin noise measurements for various phases of flight into the application, the SII values were obtained and presented in Table 5. and Figure 3. [9].

Table 5. Octave-based SII values for different speech levels and phases of flight

PHASE OF FLIGHT	SII			
	Normal speech	Raised speech	Loud speech	Shouted speech
TAXIING	0,26	0,49	0,68	0,75
BEFORE T/O CHECK	0	0,08	0,3	0,53
TAKE OFF RUN	0	0,06	0,28	0,49
TAKE OFF 500 ft	0	0,07	0,3	0,52
CLIMB 1000 ft	0	0,07	0,29	0,52
CLIMB 2000 ft	0	0,07	0,29	0,52
CRUISE 3000 ft	0	0,07	0,29	0,52
CRUISE 4000 ft	0	0,07	0,3	0,52
DESCENT 2000 ft	0,02	0,23	0,46	0,68
DESCENT 1000 ft	0,02	0,21	0,44	0,66
APPROACH 500 ft	0,17	0,41	0,64	0,8

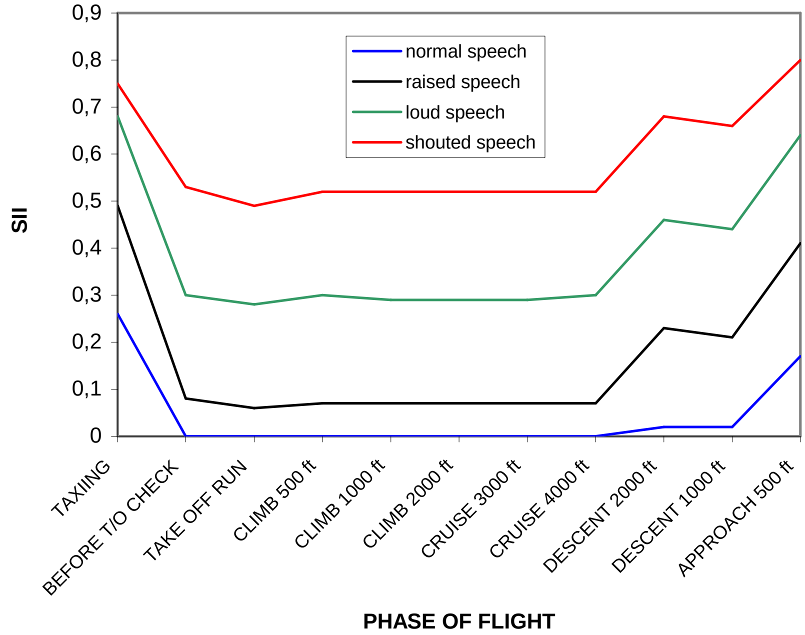

Figure 3. Octave-based SII values for different speech levels and phases of flight

The SII values are expectedly low for the phases of flight which require high engine power set, and increase only in the phases of taxiing on the ground, descent and approach. Since SII>0,75 is required for excellent communication while >0,45 for the minimum acceptable, reliable communication in the cockpit is possible in all the phases of flight only by shouting, whereas loud speech can be used to communicate reliably only in the initial and final phases of flight.

3.5 Correlation between SIL and SII

Although SIL, as a measure of noise interfering with speech, and SII, as a measure of speech intelligibility are indices of different origins, almost linear correlation for two different speech levels was found by using the results of octave-band noise measurements, which can be seen in Figure 4.

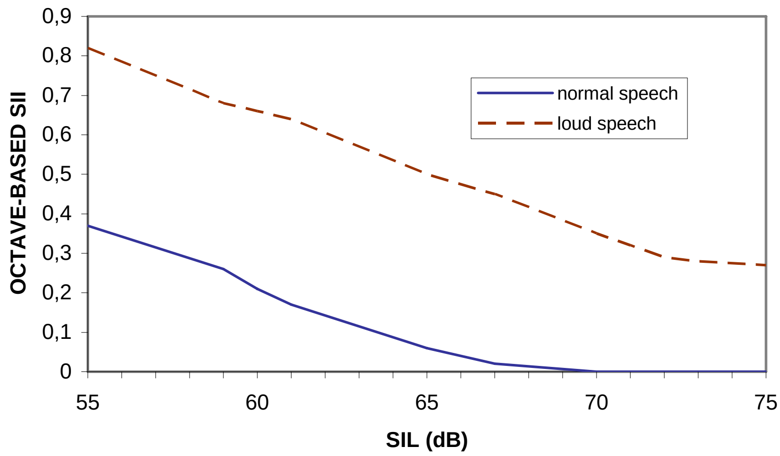

Figure 4. Correlation between SIL and octave-based SII values for normal and loud speech

4. CONCLUSIONS

The cabin noise characteristics reflect directly on the quality of speech communication in the cockpit, the influence of which are being especially significant for the flight phases which require high engine power set. The octave-band levels of cabin noise are generally most pronounced in static and in near-static conditions (before take-off check and the take-off run phase, respectively), where the power is set to maximum and the progressive speeds are nil or low, due to increase in loading noise of the propeller. Comparing the recommended SIL values for the aircraft cabin, it may be concluded that direct communication between the crew at the normal level of speech is practically impossible in any of the phases of flight. During the "quieter" phases of flight, communication is possible to some extent by speaking in raised if not even loud levels, whereas shouting is almost the only possible way during the "loud" phases of flight. As expected, SII values behave accordingly, i.e. in general reversely follow overall noise levels within aircraft cabin. When put together i.e. cross-correlated in order to obtain their numerical interdependence, SIL and SII have shown almost linear correlation for certain cabin noise conditions and speech levels.

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