Noise Annoyance Produced by Commercial Vehicles Transit on Rumble Strips

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Abstract. This paper reports on research examining the extent of noise annoyance affecting residents within the vicinity of installation of two types of transverse rumble strips (TRS), namely Middle Overlapped (MO) and Multilayer Overlapping (MLO). In order to assess the noise annoyance in the area, measurements were taken at 7.5m from centre of road with TRS installation using single vehicle test to determine the extent of changes of sound level indices and sound spectrum. Two light and two medium weight commercial vehicles were used. Indicators L_{Aeq}, L_{AFmax}, L_{AImax}, L_{AIeq}, and L_{ASmax} were used to determine impulsivity that led to noise annoyance. The results showed that, at 30 km/h, all commercial vehicles considered in this study that transited on MO produced impulsive noise, while only light commercial vehicles caused noise annoyance when they transited on MLO. The research also analysed the extent of low-frequency noise and found a significant low-frequency component, which indicated that noise annoyance might arise from the hitting of MO and MLO by the commercial vehicles. For night-time related annoyance, it was suggested that an additional weighting factor could be added to the average A-weighted value during night-time.

1 Introduction

Rumble strips can be defined as a set of yellow bars painted on the pavement with a specific thickness to alert road users through their colour, sound, and physical vibrations. TRS have a specific sectional profile and they are laid perpendicular to the vehicle's flow. In Malaysia, there are three common types of TRS profiles: Multilayer Overlapping (MLO), Rumbler Raised (RR), and Middle Overlapped (MO) [1, 2]. TRS are used to inform road users that there is a change in the road environment that requires drivers to be more cautious. They are placed at a critical point before reaching a junction, roundabout,

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toll plaza, road hump, and pedestrian crossing. These are the alternatives used to reduce accident rate as they give drivers a warning to slow down.

TRS are mostly utilised as traffic calming measures implemented in the vicinity of schools, business areas, and neighbourhoods [2, 3]. Thus, one of the prime issues caused by the existence of TRS is noise annoyance. Night-time noise that causes sleep disturbance is the major source of concern, therefore, some TRS have to be replaced by other traffic calming devices due to the complaints by nearby residents. TRS' physical properties such as profile, thickness, number, and spacing between bar are selected without any proper references to standards or guidelines [4], and purely on the basis of the local traffic engineers' experience. Apart from that, vehicle speed on the road will also affect the level of noise during transit on the TRS. Furthermore, it was found that, as the vehicle speed increased the pass-by noise levels caused by the TRS also increased [1,5]. In addition to that, the vehicle's type and weight also influenced the noise level. Haron et al (2016) found that a 980 kg compact car caused a significant increase in pass-by noise level when it traversed the TRS and generated a significant impulsive sound that made it more annoying than a continuous noise [1]. According to An et al. [5] in general, the increase in noise was greater at 100 km/h than at 40 km/h and lower for a sedan than a truck.

Previous research suggested that the typical evaluations of noise annoyance based on the A-weighted equivalent level by the regulatory authorities were inadequate and can lead to incorrect decisions [6]. Annoyance caused by sound in the low-frequency region (20 Hz up to 100 Hz) cannot be assessed using the A-weighting but rather with the consideration of the C-weighting [7]. Moreover, it was suggested that low-frequency components may increase the adverse effects considerably, pose more detrimental impacts to public health, and become more annoying as claimed by individuals [8, 9]. Acoustically, noise annoyance is the result of interference with daily activities, feelings, thoughts, sleep, or rest, and may be accompanied by negative emotional responses, such as irritability, distress, exhaustion, a wish to escape the noise and other stress-related symptoms [10].

The current study investigated noise annoyance that arisen due to TRS installation by commercial vehicles with a particular emphasis on low frequency noise content. It focused on commercial vehicles because their percentage on the road is currently about 12% [11] and represented 10% of the total sales of vehicles in Malaysia as of March 2017. Furthermore, in traffic noise prediction, commercial vehicles are denoted as light, medium, and heavy vehicles. Therefore, the objectives of this research are to (1) determine the change in sound level indices associated with the installation of two TRS profiles, and (2) analyse noise annoyance objectively through sound level changes and low-frequency content.

2 Methodology

2.1 Measurement of sound level indices and frequency spectrum

The study focused on the change of sound level indices, impulsivity, and low-frequency content due to the transition of vehicles on the two types of TRS. Two road stretches in the state of Johor installed with MO (located at Skudai, width = 600 mm) and MLO (located at Kangkar Pulai, width = 400mm) were selected, with pavement and thermoplastic TRS profile were in good condition and have the same thickness (3 mm). Profile of both TRS is shown in Figure 1. The commercial vehicles adopted for the tests were 2 light vehicles (LV) (Toyota Hilux, with gross vehicle mass (GVW = 2780 kg), 1 HiAce van (GVW=2600 kg), and 2 medium vehicles (MV) namely a one ton lorry (GVW = 5000 kg) and a 40 seater bus (GVM = 7700 kg).

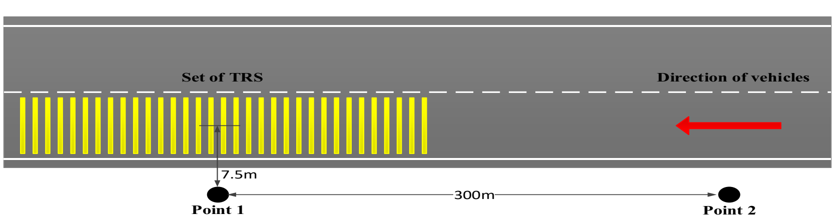
Measurements were carried out at mid-night to avoid disturbance from other noise sources. Also, wind speed and air temperature were below 5m/s and 5^0c to 40^0c, respectively for data validity [13]. The sound levels were measured using control pass-by (CPB) method in which microphones was placed at a defined distance from the vehicle path at the side of the roadway (Fig. 1). For measurement of noise level due to TS installation, sound level meter Pulsar Type 1 was placed at Point 1 at 7.5 m from the centre of the vehicle lane at a height of 1.2 m above the pavement [12]. Measurement for determination of sound level indices and frequency spectrum in this study were carried out separately. The noise indices recorded were L_{Aeq} , L_{AFmax}, L_{ASmax}, L_{AImax} and L_{AIeqT}. The L_{Aeq} is the constant noise level that expends the same amount of energy as a fluctuating level over the same time period [12]. L_{AFmax} is fast response maximum with the equivalent A-weighted sound pressure level while L_{AImax} is maximum A-weighted impulse response. Meanwhile, LAIeqT is the A-weighted impulse sound pressure levels averaged over the same time interval and L_{ASmax} is slow response maximum with the equivalent A-weighted sound pressure level. For determination of sound level indices and frequency spectrum, each vehicle was run using speed 30 km/h and 50 km/h as these speeds are the speed limit imposed on roadway at critical point and in each speed test were repeated 3 times. Vice versa point 2 was used to record the noise level when vehicles were run without TRS with the whole activities were repeated.

i) MO profile ii) MLO profile

(a) Rumble strips profiles

i) Hilux (2780 kg) ii)Hiace (2600kg) iii)Lorry (5000 kg) iv)Bus (7700 kg)

(b) Test vehicles types



(c) Experimental set up

Fig. 1. Profiles of TRS, test vehicles and measurement layout.

2.2 Change in sound levels indices

The change of noise level, L_{Aeq} can be directly obtained from the disparities of values between the tests (with and without TRS). A 3-dB change in noise level is considered just discernible; a 5-dB change is clearly discernible; and a 10-dB change louder or softer is perceived as a doubling or halving of volume, respectively [17]. Further, in this study, the significance of impulsivity was determined using several criteria involving recorded noise indices as suggested in previous research. In order to objectify the annoyance, the difference in noise indices was compared with the reference value. If any of these reference values is exceeded, it is assumed that the annoyance/complaint is objectively attributable to the TRS source. The reference values of the guideline are shown in Table 1.

Table 1. Impulsive characteristic determination.

Different in noise indices	L_{AFmax}-L_{AImax}	L_{AFmax} -L_{Aeq}	L_{AIeqT} -L_{Aeq}	L_{AImax}-L_{ASmax}
References limit (dB (A))	2	10	2	6

2.3 Analysing the Low frequency noise for the annoyance

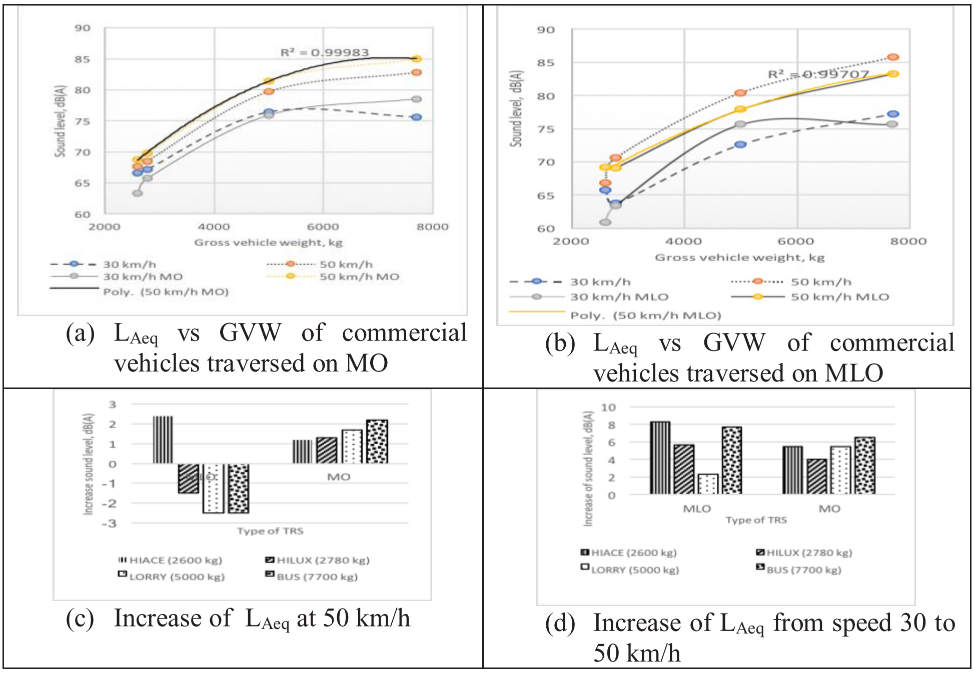
Data on frequency spectra were used to calculate dB(A) and dB(C). Furthermore, Kjellberg et al. [13] suggested that if the difference between A and C-weighted values exceeds 15dB then a low-frequency noise problem may exist. Then, Broner and Knight-Merz [14] method was considered in which they proposed simple criteria for the control of annoyance due to low-frequency noise. They suggested that if the noise level is fluctuating by 5dB(C), then a penalty of 5dB(C) should be added i.e., the criteria should be reduced. Consequently, an examination on the presence of a tone was carried out. Data on frequency spectra were used to identify the presence of a tone. The level in one 1/3rd octave band to the level in the two adjacent bands was compared according to ISO 1996-2 [15]. It was suggested that if the tone is 15 dB in the low-frequency one-third-octave band (25 Hz to 125 Hz), the annoyance might be due to low-frequency content. Then, a further procedure for the assessment of low frequency noise presented by Newman and McEwan [16] who referred a British Gas Corporation criterion for specifying noise control for gas turbines will be referred. The procedure involves a 60 dB limit in the 31.5 Hz octave band at the nearest dwelling. An additional weighting factor of 5 dB can be added to the average A-weighted if the limit is exceeded.

3 Results and discussions

3.1 Annoyance due to change in sound levels indices

The relationship between the L_{Aeq} produced with speed and MO and MLO is shown in Fig. 2 (a) and (b), respectively. The increasing trend in sound level with GVW was found to be in polynomial equation of second degree with very good relationship, where the GVW explained more than 90% of the variations. In general, both type of TRS generated higher sound level at higher speed (50 km/h) by maximum 8 dB(A) compared with speed 30 km/h only by 6 dB(A) when traversed by all tested commercial vehicles.

It can be seen that the MO, when transited by all types of commercial vehicle with speed of 50 km/h, produced increasing sound level from 1 to 2.2 dB(A) relative to the normal road, while at the lower speed, only the 40 seated bus (7700 kg) yielded sound level increment of 2.9 dB(A). On the other hand, the MLO seemed to absorb the sound level produced by the tyre and propulsion as the vehicle speed reached 50 km/h. The installation of MLO increased sound level at value of 2.4dB(A) only when the Hiace with GVW of 2600kg at 50 km/h traversed it and also from the one ton lorry with speed of 30 km/h and 3 dB(A) increase in sound level. Based on the increment of sound level, only the one ton lorry which travelled at 30km/h produced the increment of 3 dB(A). It is seen that the corresponding increase in sound level values for with and without do not exceed the 5 dB(A) [17], this indicates that there may not be a significant problem in the noise generated by both type TRS when vehicles transit on them.



(a) L_{Aeq} vs GVW of commercial vehicles traversed on MO

(b) L_{Aeq} vs GVW of commercial vehicles traversed on MLO

(c) Increase of L_{Aeq} at 50 km/h

(d) Increase of L_{Aeq} from speed 30 to 50 km/h

Fig. 2. Changes in sound level.

3.1.1 Impulsive characteristics

Fig. 3 shows the comparison of impulsive chrateristics with reference limits. According to (LAIeqT -LAeq), it was found out that all vehicles do not poses impulsive noise (Figure 3c). However, by considering (LAFmax – LAImax), (LAFmax – LAeq) and (LAImax-LASmax), it was founded that the MO produced significant impulsive noise when both LV and MV transited at speed of 30 km/h. The significant impulsivity was obtained when GVW>5000 kg produced (LAFmax – LAImax) and (LAImax-LASmax) values greater than 10 (Fig. 3a) and 6 dB (Fig. 3d), respectively, while GVW< 5000 kg yielded (LAFmax-LAeq) value greater than 10 (Fig. 3b). For MLO, only LV produced significant impulsive noise when it traversed at speed of 30 km/h and this can be identified through (LAFmax – LAeq) value which exceeded 10 dB when GVW<4000 kg. Thus, MO and MLO will cause impulsive characteristics if the LV such as Hiace and Hilux transit on them at a lower speed. From the standpoint of annoyance, if the activity occurs at night-time the effect would be considerably more detrimental than day-time exposure.

3.2 Annoyance due to Low frequency noise

3.2.1 dB(C)-dB(A)

TRS profile also affects the frequency spectrum composition of the noise emitted in low, medium, and high frequencies. Fig. 4 shows sound level spectrum, A-weighted, and C-weighted sound level generated by a bus that travelled on MO and without MO. The

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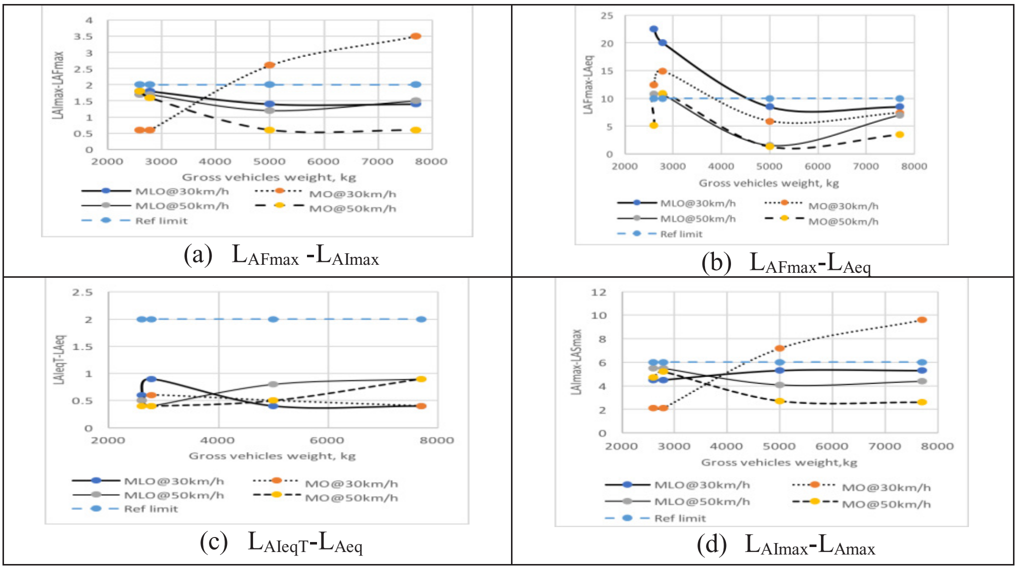
average increase in sound level in low frequency fluctuated compared to the higher frequency. Overall, the increase of total dB(A) and total dB(C) from that of without MO were, 1.18 dB(A) and 1.39 dB(C), respectively. The results of the dB(C)-dB(A) values with and without TRS at different speeds highlighted that the corresponding values did not exceed the 15dB threshold as suggested by Kjellberg et al [13]. As mentioned previously, this situation indicated that there may not be a significant low-frequency problem in the noise generated by both types of TRS when the vehicles traversed them.



(a) L_{AFmax} -L_{AImax} (b) L_{AFmax}-L_{Aeq} (c) L_{AIeqT}-L_{Aeq} (d) L_{AImax}-L_{Amax}

Fig. 3. Examination of impulsive characteristic.

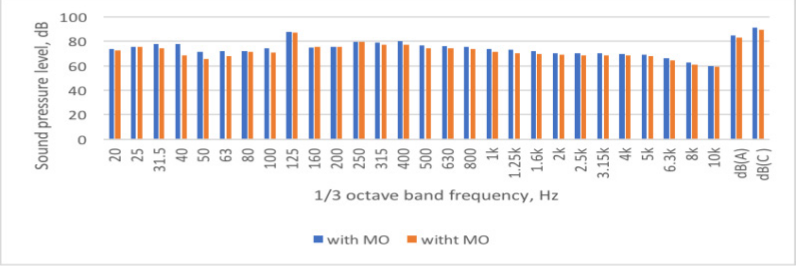


Fig. 4. Frequency spectra in dB, dB(A) and dB(C) when 40 set bus traverse on TRS at speed 50 km/h.

3.2.2 Fluctuation of dB(C)

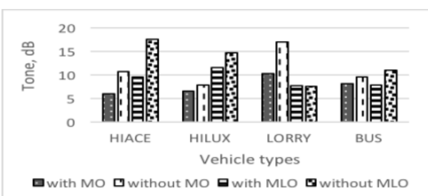
Table 2 shows the fluctuation of dB(C) between with and without TRS and speeds of 30 km/h and 50 km/h. The noise level fluctuation was higher than 5 dB(C) when a lorry traversed the MLO, which indicated the presence of a low-frequency noise. Thus, a spectrum analysis was conducted to assess the extent of noise in the lower frequency bands, namely in the region between 20 Hz to 125 Hz.

3.2.3 Tonal examination in 20 Hz to 125 Hz

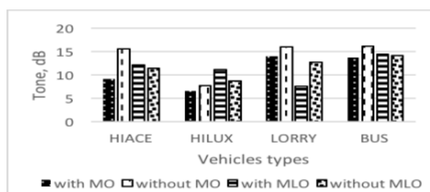
The investigation showed that there were no significant tones that can be identified using the methodology outlined in ISO 1996-2 when LV and MV, investigated in this study, traversed the TRS. Fig.5 shows the difference of level or tone produced between 20 Hz to 125 Hz when vehicles transit and do not transit the TRS. In general, the tone produced by the vehicles that transited on the TRS appeared to be reduced. The installation of MO reduced the annoyance from the Hiace, lorry, and bus travelling at speed of 50 km/h. Moreover, at 30 km/h, the MLO and and MO reduced the significant tone generated by the Hiace and lorry, respectively. Thus, it can be said that noise generated by the TRS produced a broadband source with a clear low-frequency content.

Table 2. Fluctuation of dB(C) with and without TRS.

Vehicles type	30 km/h		50 km/h	
	MO dB(C)	MLO dB(C)	MO dB(C)	MLO dB(C)
HiAce	0.72	-6.98	4.98	-15.04
Hilux	0.92	-4.32	3.67	-14.5
Lorry	-2.59	0.09	-5.49	5.59
Bus	0.93	-6.36	1.39	-3.95



(a) speed 30 km/h

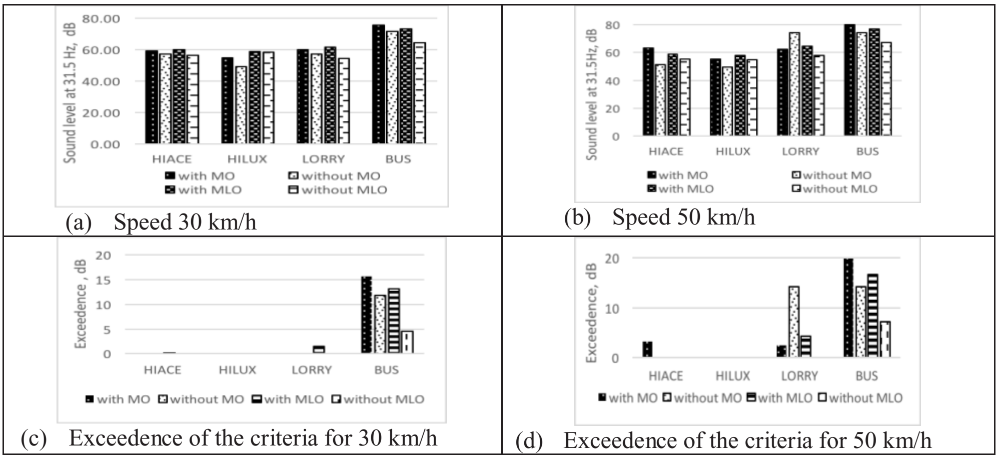


(b) speed 50 km/h

Fig. 5. Examination of tone existing between 25 to 125 Hz when vehicles traverse on TRS.

3.2.4 Examination of sound level in 31.5 Hz

Fig. 6 shows the logarithmic addition of the 25Hz, 31.5 Hz, and 40Hz third octave band levels comparison with the 31.5Hz octave band criterion of 60dB as set by British Gas Corporation [16]. It can be seen that total sound levels with the TRS was higher than that of without TRS and also the criteria were exceeded even though the MV transited and did not transit the TRS. The bus produced the highest sound levels when passing the road with MO at speeds of 30 and 50 km/h and exceeded by 15.7 dB and 19.9 dB, respectively. This indicated that a low-frequency noise was likely to be added to the overall night-time sleep disturbance and annoyance level at nearby residents. The results showed that the low-frequency noise was significant when the MV traversed the MO and MO, an additional weighting factor of 5 dB can be added to the average A-weighted value during night-time.



(a) Speed 30 km/h
(b) Speed 50 km/h
(c) Exceedence of the criteria for 30 km/h
(d) Exceedence of the criteria for 50 km/h

Fig. 6. Examination on sound level at 31.5 Hz.

4 Conclusions

The current study investigated noise annoyance that arised due to the MO and MLO installations as they were traversed by commercial vehicles. The following conclusions were obtained:

- Both types of TRS produced higher sound level at higher speed (50 km/h) compared to the lower speed (30 km/h) when traversed by all commercial vehicles.
- Annoyance did not arise due to the increase of sound level as it was below the limit of 5dB.
- Annoyance occurred when all commercial vehicles considered in this study transited the MO with speed of 30 km/h and only light commercial vehicles with the same speed of 30 km/h traversed the MLO.
- Annoyance also arised due to low frequency noise that resulted when light (Hiace) and medium weight commercial vehicles (bus and lorry) traversed both MO and MLO.
- MO reduced annoyance from Hiace, lorry, and bus that travelled at 50 km/h.

References

1. Z. Haron, M.H. Othman, M. H., K. Yahya, K., M.R. Hainin, K. Ambak, & N. Darus*, MATEC Web of Conferences.*(2017)
2. M. H. Othman, Z. Haron, M.R. Hainin, K. Yahya, H. Yaacob, M. E. Sanik: Jurnal Teknologi. **73** (2015)
3. M.M. Abd Manan, P.W.H, Alvin, Malaysian institute of Road Malaysian Research (2009)
4. Manual fasiliti keselamatan jalan, Cawangan Kejuruteraan Jalan dan Geoteknik, Jabatan Kerja Raya Malaysia (2014).
5. D. S. An, S.A. Kwon, J. Lee, Y.C. Suh, ASCE, J. Perf. Faci. ASCE (2016)
6. E. Murphy, E.A. King, Environment International **63** (2014)
7. K. Persson, M. Bjorkman, J Sound Vibration **127** (1988)
8. B. Berglund, T. Lindvall, D. Schwela, K.T. Goh, WHO (1999)
9. G.H. Leventhall, DEFRA (2003)

10. M.E. Beutel, C. Jünger, E.M. Klein, P.W.K Lackner, M. Blettner, H. Binder, M. Michal, J. Wiltink, E. Brähler, T. Münzel, https://doi.org/10.1371/journal.pone.0155357(2016)
11. http://www.maa.org.my/info_summary.htm, (assessed March 2017)
12. ISO (1997a). ISO 11819-1:2001
13. Kjellberg, M. Tesarz, K. Holmberg, U. *Landstrom (Environment International*) **23** (1997)
14. N. Broner, S. Knight-Merz, *Acoustics Australia* **39** (2011)
15. ISO 1996-2 (2007) ISO 1996-2:2007
16. J.R. Newman, K.I. McEwan K. I, Journal of Engineering for Power **102** (1980)
17. J.L. Darbyshire, J.D. Young, *Critical Care* **17** (2013)