Road traffic noise prediction model “ASJ RTN-Model 2013” proposed by the Acoustical Society of Japan – Part 2: Study on sound emission of road vehicles

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ABSTRACT

The Acoustical Society of Japan (ASJ) has published a new revised version of road traffic noise prediction method “ASJ RTN-Model 2013”, in which the calculation formulas for the A-weighted sound power level of each type of road vehicle are specified. The sound power level is given simply as a function of the running speed in consideration of practicality and convenience. The several calculation formulas in this model had been developed using the measured data in 1991–1998. Since 2009, the Research Committee in ASJ has been accumulating new data about noise emission of road vehicles. In this study, the A-weighted sound power levels measured during the 1990’s were compared with those in recent years. In addition, during the last decade, hybrid and electric vehicles are becoming popular and the number of production is rapidly increasing. The noise reduction effect of these low-emission vehicles was examined. As a result, it has been found that there are not any remarkable differences between the sound power levels measured in the 1990's and those in recent years, and the noise reduction effect of low-emission vehicles could be applied to the noise prediction in the vicinity of signalized intersections or expressway tollgates.

Keywords: Sound power level, vehicle noise regulation, hybrid vehicles
I-INCE Classification of Subjects Number(s): 13.2

1. INTRODUCTION

In ASJ RTN-Model 2013, the calculation formulas for the sound power level of road vehicles have been developed based on a large amount of pass-by noise measurements performed at roadsides of expressway and general roads (1-3). The sound power level depends not only on the difference of the vehicle type but also on the running condition, pavement type and so on. The basic calculation formula for the sound power level is given as a function of the running speed, and the influences of other factors are considered in the correction terms. The most measurement data used for determining the formulas had been performed on dense asphalt pavements in 1991–1998 (2, 3). Since 2009, in order to improve the model more accurately, the Research Committee has been accumulating new data about noise emission of road vehicles. In this paper, the differences between the A-weighted sound power levels measured in the 1990's and those in recent years were examined. In addition, the examples of the investigation on the noise reduction effect of hybrid vehicles are presented.

2. OUTLINE OF VEHICLE NOISE SITUATION IN JAPAN

2.1 Number of Registered Road Vehicles

Figure 1 shows the number of the registered road vehicles until fiscal 2011 in Japan. The other

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vehicles in the figure indicate the sum of motorcycles, buses and special-purpose vehicles. The total number of road vehicles had increased steadily since record-keeping started, but it stagnated at about 78 million cars during the last decades. Meanwhile, the number of trucks had decreased gradually from 1990, and it was about 15 million cars in 2011. At the end of fiscal 2011, the rates of the registered passenger cars and trucks in all vehicles were 77 % and 19%, respectively.

On the other hand, the average service life of road vehicles has been increasing, as shown in Figure 2. In recent years, the average service life of vehicles in Japan are over 12 years for passenger cars and 13 years for trucks.

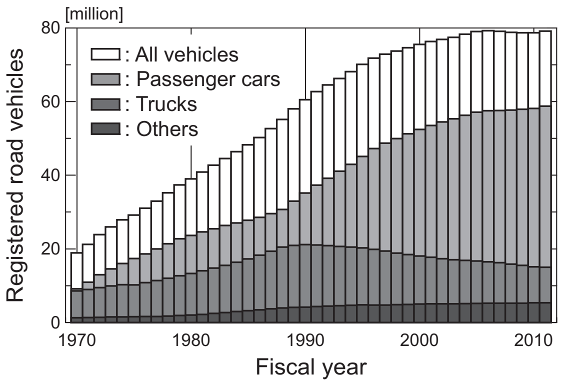


Figure 1 – Number of registered road vehicles in Japan (passenger cars, trucks and others)

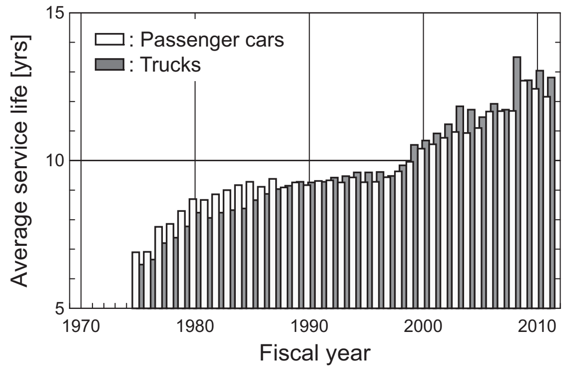


Figure 2 – Average service life of road vehicles in Japan (passenger cars and trucks)

2.2 Vehicle Noise Emission Limits

In order to control noise emission of road vehicles, vehicle noise regulation is legislated in each country, but the test methods and limit values are not unified internationally (4, 5). In Japan, the permissible limits for acceleration running noise, steady running noise and exhaust proximity noise are stipulated and the measurement methods for these noises are specified, respectively. Figure 3 shows the process of noise emission limits under the acceleration and steady running conditions in Japan.

In case of acceleration running noise, the limit values have been tightened stepwise. The noise reduction from the 1990's until the present time is almost 2dB for all vehicle categories. The limits for steady running noise have been changed only once in 1998 for passenger cars and in 2001 for heavy trucks, respectively. The noise reduction under the steady running condition is 2dB due to the change of this regulation. However, considering that the average service life of vehicles is over 12 years, as shown in Figure 2, some noncompliance vehicles with the latest noise limit would be still running on roads at the present time.

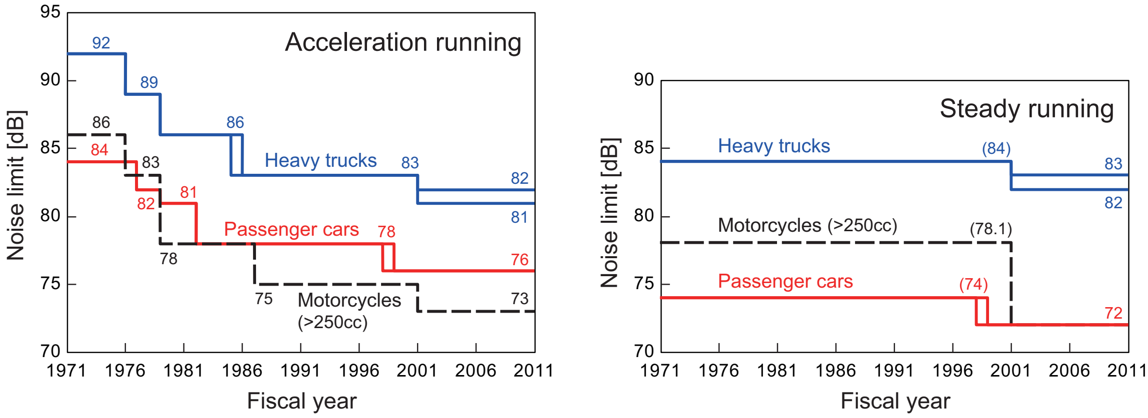


Figure 3 – Vehicle noise emission limits for acceleration and steady running noise in Japan.

3. CALUCULATION METHOD OF SOUND POWER LEVEL

3.1 Classification of Road Vehicles

In ASJ RTN-Model 2013, road vehicles are basically classified into four or two categories similarly to in the previous model, ASJ RTN-Model 2008 (1). The four-category classification places importance on noise radiation characteristics. The noise generated from motorcycles can be also considered separately. Table 1 shows the classification of road vehicles and motorcycles defined in ASJ RTN-Model. This classification almost corresponds to that of road vehicle noise regulations in Japan which is based on vehicle weight and engine output. The two-category classification, which is light and heavy vehicles, takes practicality into account. In the prediction of road traffic noise, not only sound power level of each vehicle but also the percentage of each type of vehicle comprising the traffic volume is an important factor. Thus, the percentage of heavy vehicles (medium- and large-sized vehicles) in the two-category classification is widely used.

Table 1 – Vehicle classification defined in ASJ RTN-Model.

Classification		Characteristic
Passenger cars	Light vehicles	Vehicles used exclusively for carrying passengers, with capacity of 10 or fewer passengers
Small-sized vehicles		Vehicles with engine displacement exceeding 0.050 liter and with overall length of 4.7m or less
Medium-sized vehicles	Heavy vehicles	Vehicles with overall length exceeding 4.7m excluding large-sized vehicles (most vehicles in this category have 2 axles) Medium-sized buses with capacity from 11 to 29 passengers
Large-sized vehicles		Vehicles with gross vehicle weight of over 8 t or maximum authorized payload of over 5 t (most vehicles in this category have 3 or more axles) Large-sized buses with capacity of 30 or more passengers
Motorcycles		Motorcycles and mopeds

3.2 Sound Power Level of Road Vehicles

The sound power level of road vehicles generally varies not only with the difference of vehicle type, but also with the vehicle running speed, engine rotational speed and engine load (6). However, in this model, the sound power level for each type of vehicle is given simply as a function of the running speed, in consideration of practicality and convenience. The A-weighted sound power level L_{WA} of a road vehicle is given by

$$L_{\mathrm{WA}} = a + b\,\mathrm{lg}V + C \tag{1}$$

$$C = \Delta L_{\mathrm{surf}} + \Delta L_{\mathrm{grad}} + \Delta L_{\mathrm{dir}} + \Delta L_{\mathrm{etc}} \tag{2}$$

where V is the vehicle running speed [km/h], a and b are regression coefficients, and C is the correction term for the change in the noise generated due to a drainage asphalt pavement ΔL_{suf} [dB], road gradient ΔL_{grad} [dB], sound radiation directivity ΔL_{dir} [dB] and other factors ΔL_{etc} [dB].

In this model, the values of coefficients a and b are provided separately for sections under several vehicle running conditions, which are defined as follows.

(a) Steady traffic flow section: This is a section of expressway or general road sufficiently distant from signalized intersections, where vehicles can be driven in top-gear position or equivalent. The vehicle running speed V is in the range from 40 to 140 km/h.

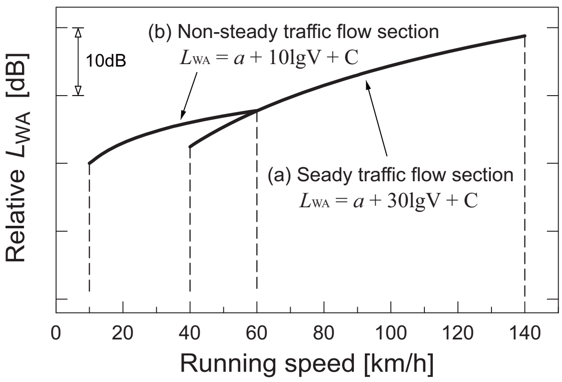
(b) Non-steady traffic flow section: This is a general road including signalized intersections, where vehicles frequently accelerate and decelerate. The vehicle running speed V is in the range from 10 to 60 km/h.

(c) Acceleration section : The running condition in this section is defined as a transitional state from the stopping condition at an expressway tollgate to the steady running condition in the main lane. The vehicle running speed V is in the range from 1 to 80 km/h. Acceleration at speeds exceeding 80 km/h is treated as the steady running condition. Also, a constant power level is applied at speeds of less than 1 km/h.

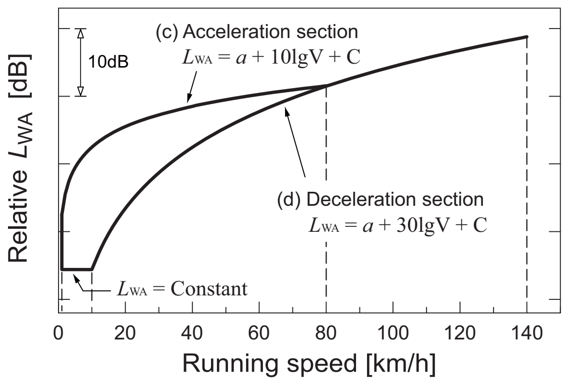
(d) Deceleration section: The running condition in this section is defined as the transitional state from the steady running condition in the main lane to the stopping condition at the tollgate. The vehicle running speed V is in the range from 10 to 140 km/h. A constant power level is applied at speeds of less than 10 km/h.

A schematic illustration of the A-weighted sound power level L_{WA} in individual sections on a dense asphalt pavement is shown in Figure 4. The examples of the coefficients a, b for four-category classification in the sections of steady and non-steady traffic flow are given in Table 2. The coefficient a for each type of vehicle was determined based on a large amount of pass-by noise measurements performed at roadsides of expressways and general roads. For the determination of the coefficient b which represents the running speed dependence of the generated noise, the pass-by noise measurements have been performed on test tracks and several general roads using each type of vehicle. As results of those studies (3, 6), it has been revealed that the value of coefficient b can be given by 30 for steady traffic flow section, and 10 for non-steady traffic flow section, respectively.

For the other calculation formulas for the sound power level in acceleration and deceleration sections or the correction term such as the noise reduction effect of a drainage asphalt pavement, please refer to the model (1).



Steady and non-steady traffic flow sections



Acceleration and deceleration sections

Figure 4 – A-weighted sound power level in individual sections.

Table 2 – Examples of coefficients a and b for steady and non-steady traffic flow sections.

Four-category classification	Steady traffic flow section (40 km/h ≤ V ≤ 140 km/h)		Non-steady traffic flow section (10 km/h ≤ V ≤ 60 km/h)	
	a	b	a	b
Passenger cars	46.4		82.0	
Small-sized vehicles	47.6		83.2	
Medium-sized vehicles	51.5	30	87.1	10
Large-sized vehicles	54.4		90.0	
Motorcycles	49.6		85.2	

4. MEASURMENT RESULTS OF SOUND POWER LEVEL IN RECENT YEARS

The several calculation formulas for the A-weighted sound power level in ASJ RTN-Model 2013 had been developed using the measured data in 1991–1998. Since 2009, in order to improve the model more accurately, the Research Committee has been accumulating new data about noise emission of road vehicles.

In this section, the difference between the sound power levels L_{WA} measured during the 1990's and those in recent years was examined. Figure 5 shows the relationship between the running speed and the sound power level for each type of vehicle in ASJ RTN-Model 2013. In this figure, the formula indicates the regression expression under the steady running condition, as given in Table 2. The symbols (n, r, s) represent the number of data, the correlation coefficient and standard error, respectively. Also, the A-weighted sound power levels calculated from data measured during 2009–2011 are shown in Figure 6. The dashed line indicates the formula specified in ASJ RTN-Model 2013.

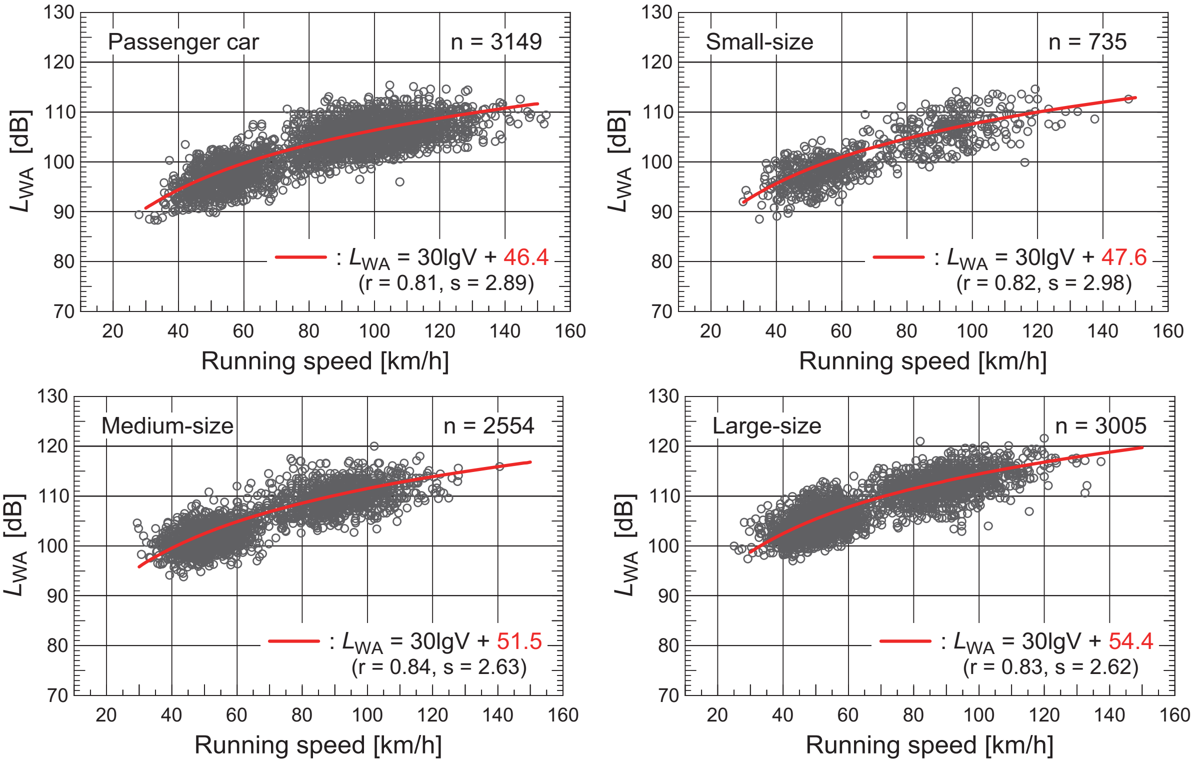


Figure 5 – Relationship between running speed and sound power level in ASJ RTN-Model 2013.
(steady traffic flow section, — : formula determined using measured data in 1991–1998)

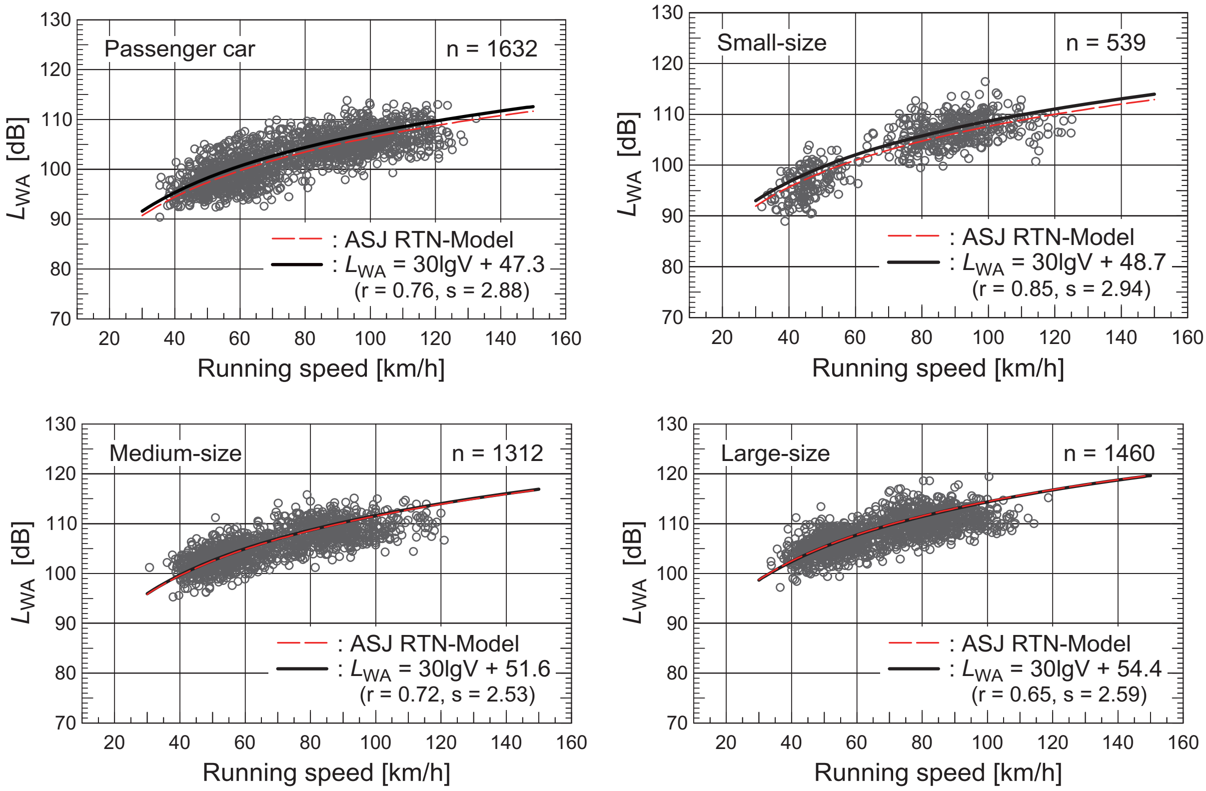


Figure 6 – Relationship between running speed and sound power level in recent years.
(steady traffic flow section, — : formula determined using measured data in 2009–2011)

The sound power levels L_{WA} for passenger cars and small-sized vehicles tend to be almost 1.0 dB larger in recent years, although the number of the measured data since 2009 was lower than that in the 1990's. On the other hand, for large- and medium-sized vehicles, the sound power level of them are almost the same. As a whole, the noise reduction effect due to the vehicle noise regulation cannot be recognized, as mentioned in Section 2.

In addition, the sound power levels were divided into three groups in consideration of the running speed dependence, and the differences in the sound power level L_{WA} between them in each speed range were investigated. Figure 7 shows the mean and standard deviation of L_{WA} for each type of vehicle in the running speed range of 40–60 km/h, 60–100 km/h and 100–140 km/h. The open and filled circles (○, ●) in the figure indicate the mean levels L_{WA} in ASJ RTN-Model 2013 and those measured since 2009, respectively. The symbol (*) indicates a significant difference among them at the $p < 0.05$ level.

Regarding passenger cars, it can be seen that the sound power levels L_{WA} in recent years are larger than those in the 1990's regardless of the running speed range, and the difference in the sound power levels L_{WA} between them is statistically significant ($p < 0.05$). For small-sized vehicles, there are no statistically significant difference between both L_{WA} except for the range of 60–100 km/h. For medium- and large-sized vehicles, the sound power levels L_{WA} in the range of 60–100 km/h are lower in recent years, but L_{WA} in the range of 40–60 km/h are larger. Thus, it can be said that the sound power levels measured in recent years are not necessarily lower than those specified in ASJ RTN-Model.

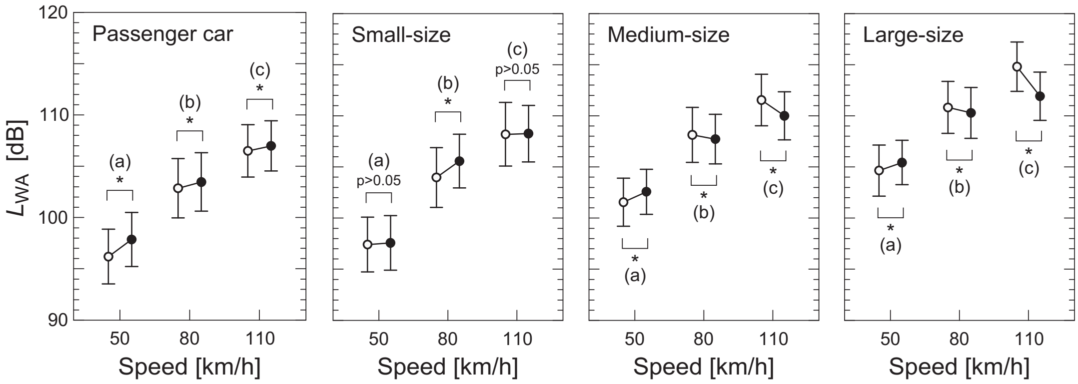


Figure 7 – Comparison of mean and standard deviation of sound power level measured in 1991–1998 and 2009–2011. (○: ASJ RTN-Model, ●: L_{WA} measured in recent years, (a, b, c): L_{WA} calculated from data in the running speed range of 40–60, 60–100 and 100–140 km/h, respectively)

As a result, no remarkable differences between the sound power level measured in the 1990's and those in recent years could be realized. Therefore, the Research Committee decided not to revise the calculation formulas for the sound power level, but to intend conducting the pass-by measurements continuously for accumulating the noise emission data of road vehicles in consideration of the changes in the noise level by the difference of vehicle gross weight, tire size and so on in the future.

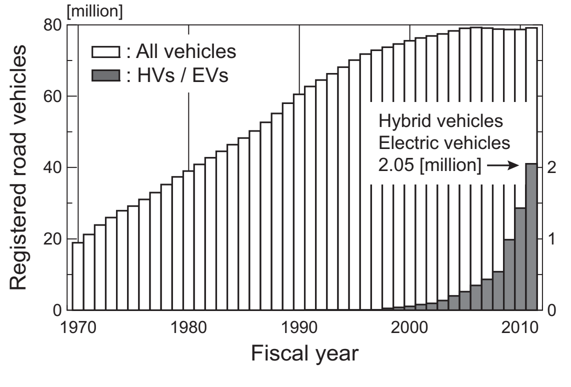


Figure 8 – Number of registered hybrid and electric vehicles in Japan.

Table 3 – Types of commercially available hybrid and electric vehicles in Japan.

Classification		2012	2013
Hybrid vehicles	Passenger cars	28	47
	Trucks	6	6
	Buses	3	3
Electric vehicles	Passenger cars	11	11
	Trucks	2	3
	Buses	5	4
Total number		55	74

5. EXAMPLES OF NOISE MESURMENTS FOR LOW-EMISSION VEHICLES

Hybrid and electric vehicles are becoming popular and the number of production is rapidly increasing in Japan, as in many other countries (7, 8). Figure 8 shows the number of the registered total road vehicles and these low-emission vehicles until fiscal 2011 in Japan. The number of hybrid and electric vehicles was about 2.03 million cars and 0.02 million cars, respectively. While the rate of the registered these vehicles was about 3 % in all vehicles, the different types of the commercially available hybrid vehicles for passenger cars are rapidly increasing as shown in Table 3. It can be predicted that the rate of the market share of these low-emission vehicles in conventional passenger cars will be growth in the future.

The propulsion noise of hybrid and electric vehicles are lower than gasoline engine vehicles, particularly at low speeds (4, 7-10). The examples of comparison between the noise generated from hybrid vehicles and that from gasoline engine vehicles are described as follows. Figure 9 shows the measurement result of the running noise of a hybrid and two types of gasoline engine vehicles, performed by the Japan Automobile Research Institute (9). These values represent the maximum A-weighted sound pressure levels $L_{A,Fmax}$ measured at a distance of 2 m from the center of the lane. During idling, the difference in the noise level $L_{A,Fmax}$ for both vehicles is more than 15dB. In the speed range below 15 km/h, the noise reduction effect of the hybrid vehicle can be expected to be more than 5 dB.

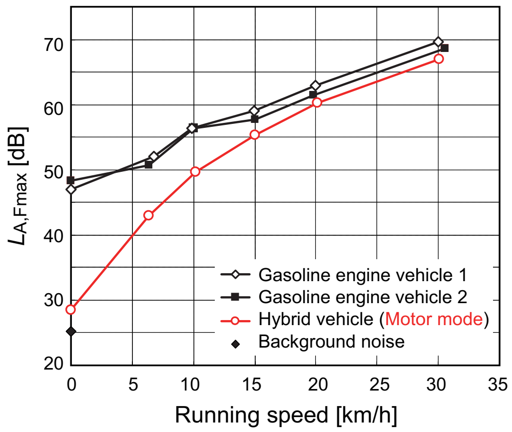
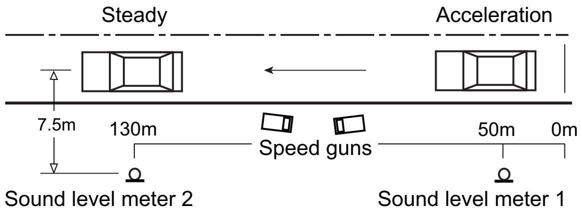


Figure 9 – Comparison of sound pressure level between hybrid and gasoline engine vehicles.

In addition, to compare the A-weighted sound power level L_{WA} of hybrid and gasoline engine vehicles, the noise measurement was carried out on a dense asphalt pavement, as shown in Figure 10. The receiving points were set at distances of 50 m and 130 m from the starting line, respectively, to measure the noise levels under the steady and acceleration running conditions. These points at a height of 1.2 m were placed at a distance of 7.5 m from the center of the lane. The vehicles with the same engine type and displacement were used in this measurement. The weight and tire size of these vehicles were also almost the same.



	HV	GEV
Engine	Straight-4 gasoline engine	
Displacement	1.5 lit.	
Vehicle weight	1.25 t	1.35 t
Tire size	185 / 65 R15	185 / 55 R15

Figure 10 – Receiving point arrangement for vehicle noise emission measurement.

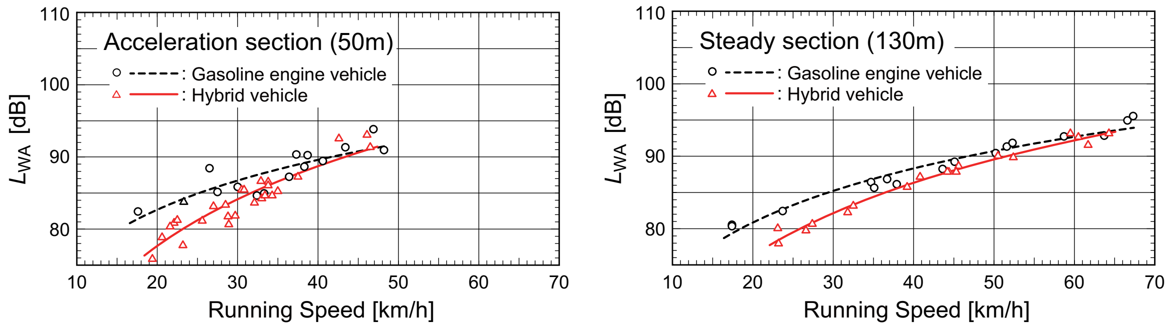


Figure 11 – Comparison of sound power level between hybrid and gasoline engine vehicles.

Figure 11 shows the comparison of the sound power levels L_{WA} for both vehicles under the acceleration and steady running conditions, respectively. It can be seen that the sound power levels of the hybrid vehicle in the acceleration section (50 m from the starting line) are almost 5dB lower than gasoline engine vehicle in the speed range of 20–30 km/h. However, during the steady running conditions at 50 km/h or more (130m from the starting line), there are not any significant difference in L_{WA} between hybrid and gasoline engine vehicles. It is found that the noise reduction effect of these low-emission vehicles can be expected in the vicinity of signalized intersections or expressway tollgates where are dominated by the propulsion noise of vehicles.

The Research Committee intends to gather the sound power levels of hybrid or electric vehicles and examine the calculation formula for the sound power level or the correction term about the noise reduction effect, in order to assess road traffic noise in the future environment.

6. CONCLUSIONS

The basic parts of the calculation formulas for the sound power level of road vehicles adopted in ASJ RTN-Model 2013 have been introduced. These formulas have not been revised from the previous model, because there are not any remarkable differences between the sound power levels measured in the 1990's and those in recent years. However, the Research Committee indents to conduct the pass-by noise measurements continuously for accumulating the sound power levels of the latest road vehicles and hybrid vehicles, considering the changes in noise level by the different types of vehicle gross weight, tire size, vehicle power source and so on.

REFERENCES

1. K. Yamamoto. Road traffic noise prediction model “ASJ RTN-Model 2008”: Report of the Research Committee on Road Traffic Noise. Acoustic Science and Technology, 2010; 31(1): 2-55.
2. S. Kono, et al. Road traffic noise prediction model “ASJ RTN-Model 2003” proposed by the Acoustical Society of Japan –Part 2: Calculation model of sound emission of road vehicles. Proc ICA 2004; Kyoto, Japan 2004.
3. Y. Oshino, et al. Road traffic noise prediction model “ASJ Model 1998” proposed by the Acoustical Society of Japan –Part 2: Calculation model of sound power levels of road vehicles. Proc INTER-NOISE 2000; Nice, France 2000.
4. H. Tachibana. General view of road traffic noise problem. Proc INTER-NOISE 2010; Lisbon, Portugal 2010.
5. U. Snadberg. Noise emissions of road vehicles: Effect of regulations. Final report 01-1 by the I-INCE WP-NERV, 2001.
6. Y. Oshino, et al. Prediction of road traffic noise taking account of transient running conditions of vehicles. Proc INTER-NOISE 93; Leuven, Belgium 1993.
7. J. Jabben, et al. Noise reduction by electric vehicles in the Netherlands. Proc INTER-NOISE 2012; New York City, USA 2012.
8. L. M. Iversen, et al. Noise from electric vehicles: 'state-of-the-art' literature survey. Proc INTER-NOISE 2013; Innsbruck, Austria 2013.
9. A study on approach warning systems for hybrid vehicle in motor mode, JASIC, Japan, 2009.
10. M. Pallars, et al. Noise emission levels for electric and hybrid vehicles – First results of the FOREVER project. Proc Transport Research Arena 2014; Paris, Italy 2014.