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# Analysis of Aerodynamic Noise in High Speed Trains

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**Abstract**

Controlling the exterior and interior noise emission has become an important issue in the research and development of high speed trains. As the operating speed of the train increases, the noise emission characteristics are expected to deviate from that of the existing trains due to several changes in the basic train layout. For train speed in excess of 350 km/h in particular, the aerodynamic noise component starts to exceed the structure-borne noise component, and even an incremental speed increase is accompanied by a rapid elevation in the noise level. The present study presents an engineering approach for predicting the aerodynamic noise level at the design stage for high speed trains. The experimental noise measurements from test run of Korean high speed train under development are presented as a partial validation of the proposed approach. While the overall aerodynamic noise can be cast in a single power law relationship against the train speed, different parts of the train show power law relationships unique to each component.

***Keywords*** **:** *Aerodynamic noise, Dynamic components, High-speed train, Noise emission characteristics*

## 1. Introduction

At train operation speeds in excess of 350km/hr, the noise generated rapidly increases as the train speed is increased. This trend is accompanied by the predominance of aerodynamic noise over structure-borne noise. To help in the design of low-noise Korean high speed train, the present work focuses on elucidating the speed dependence of aerodynamic noise for train speeds in excess of 300 km/hr. The speed dependence can be conveniently expressed via power law relationships with power law coefficients serving as indicators of sensitivity. Data on aerodynamic noise for various train systems operating worldwide today are presented via appropriate power law coefficients. The aerodynamic sound level measurements for Korean high-speed trains are presented, and power law coefficients are determined for each test case.

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## 2. Speed Dependence of Aerodynamic Noise

An important consideration in any aerodynamic noise investigation is determining which theoretical relationship to apply to the problem at hand. Generally, the dependence of aerodynamic sound pressure level on train speed can be predicted by the following power law relationship.

$$\text{Sound Pressure Level (dB)} \propto 10\log(\text{train speed}^{\alpha})$$

### 2.1 Criterion for $6^{th}$ power law relationship

Perhaps the most widely employed of the analytical expressions on aerodynamic sound pressure level in high speed trains predicts that the sound pressure level increases in proportion to the 6th power of the train speed ($\alpha$=6). Aerodynamic noise occurs due to vortex shedding at the boundary layer on the exterior surface of the train as well as the presence of a mixing shear zone. In contrast to structure-borne noise arising from wheel/rail interactions, aerodynamic noise can be accurately predicted if the material characteristics and surface profile of the train exterior are known. In the case of magnetically levitated trains in which the structure-borne noise due to wheel/rail interactions can be safely neglected, a fairly accurate correlation between analytically predicted and experimentally mea-

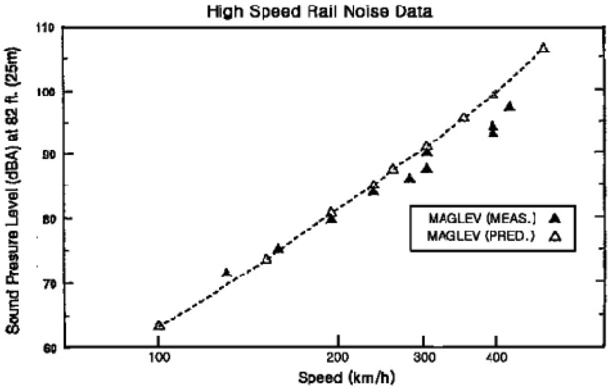


**Fig. 1** Comparison of measured and theoretically predicted values in MAGLEV (at 25 m distance)

sured values has been obtained. The main finding along this line of investigation has been the 6th power law relationship between aerodynamic noise and train speed. Fig. 1 compares the theoretically predicted and experimentally measured values of the German magnetic levitation train called MAGLEV. Both sound pressure levels are found to be well described by the 6th power law relationship.

### 2.2 Criteria for 3rd to 8th power law relationships

In contrast to the 6th power law relationship found to closely describe aerodynamic noise in MAGLEV as a whole, the operators of the more conventional high speed trains have attempted to derive their own proportionality relationships between aerodynamic noise and train speed for different parts of the train. Table 1 summarizes the power law relationships for these trains. For TGV, the power law coefficients range from 3 to 7.5. For TGV-A, the range is between 2.9 and 5.2, while Shinkansen uses the value of 6 for the whole train. The power law relationships derived for different parts of TGV-A which served as the base model for Korean high speed train furnish particularly useful reference values.

**Table 1.** Power law coefficients for different train systems

| Noise type | Train system | | Proportionality ($\propto \upsilon^2$) |
|---|---|---|---|
| Aerodynamic Noise | TGV | Locomotive | 3 (up to 300 km/h) |
| | | | 7~7.5 (beyond 350 km/h) |
| | | Coach | 3 (up to 300 km/h) |
| | | | 6 (beyond 350 km/h) |
| | * TGV-A | | 4.3 |
| | ICE | | 6~8 |
| | TR70 (MAGLEV) | | 6 (fluid separation) |
| | | | 8~9 (turbulent boundary layer) |
| | Shinkansen | | 6 |

**Table 1.** Continued

| Noise source (TGV-A) | | α |
|---|---|---|
| Wheel | middle coach | 2.9 |
| | front locomotive | 3.2 |
| | rear locomotive | 3.0 |
| Pantograph(rear locomotive) | | 5.7 |
| Cooling fan | front locomotive | 4.7 |
| | rear locomotive | 4.6 |
| Front window (front locomotive) | | 5.1 |
| Between coaches | | 4.2 |
| Bogie | | 6.1 |
| Turbulent boundary layer(per square meter) | | 4.3 |

## 3. Brooks Equations and Overall Aerodynamic Noise

The theoretical relationship proposed in the present study is derived from the following equations due to Brooks, which shows that the aerodynamic sound pressure level is proportional to the 4th power (α=4) of the train speed.

Narrow Band:

$$p^2{}_{\omega}(f) = 8.7\times10^{-8}\rho^2\delta^* U_0{}^3[1+(\pi S)^2]^{-\frac{3}{2}} \tag{2}$$

Broad Band:

$$p^2(f) = \int_0^\infty p^2(f)df$$

$$= 8.7\times10^{-3}\rho^2\delta U_0^3\int_0^\infty[1+(\pi S)^2]^{-\frac{3}{2}}df \tag{3}$$

For calculating the bandwidth noise, the constant $8.7\times10^{-8}$ represents a value derived from data measured at 25 m distance from the center of the railroad track, ñ denotes the air density, δ* denotes the equivalent boundary thickness, and S denotes the Strouhal number.

For verifying the analytical expressions presented above, three types of power law relationships have been curve fitted with the four different noise levels using the proposed equation. Fig. 2 shows the three curves representing 4th, 4.4th, and 6th power law relationships. The aerodynamic

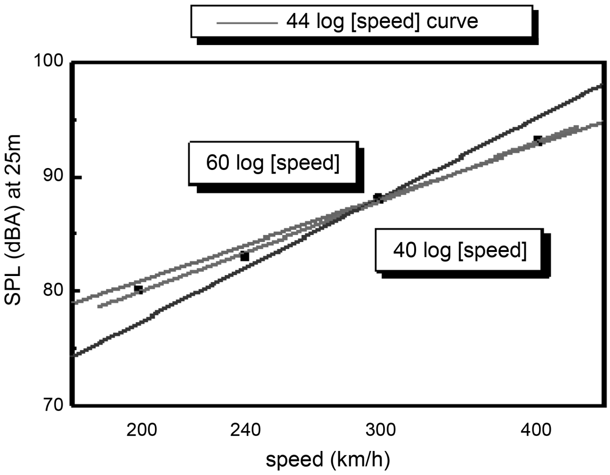


**Fig. 2** Variation of aerodynamic noise vs. train speed

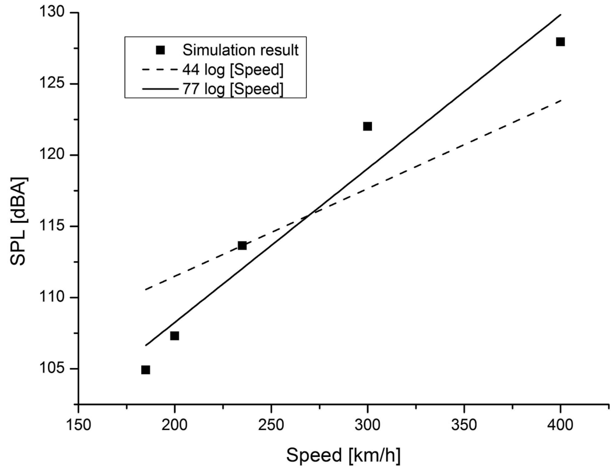


**Fig. 3** Inter-coach space noise vs. train speed

sound pressure levels for the existing Korean high speed train with the maximum operating speed of 300 km/hr are plotted and show the best fit with the curve representing the 4.4th power law ($\alpha$=4.4). The data were obtained by taking measurements at 25 m distance from the center of the railroad track. The comparison of the measured values with Table 1 hints that 4.4th power law relationship between aerodynamic noise and train speed could be due to a combined effect of the aerodynamic noise characteristics of different parts of train which obey distinct power law relationships.

## 4. Noise Characteristics of Train Dynamic Components

Different parts of the train that contribute to the overall aerodynamic sound pressure level may show varying dependence on the train speed. The two dynamic components of the train that are known to contribute significantly are inter-coach space and pantograph. The sound pressure levels for these key dynamic components are measured during a test run at the speed range of 170 km/h to 400 km/h for the proposed next generation Korean high speed train. Fig. 3 shows that the measured sound pressure values at the inter-coach space show the best fit with the curve representing the 7.7th power law. In contrast, the sound pressure measurements at the pantograph have relatively gradual increase with the train speed, showing the best fit with the curve representing the 3.7th power law. The results confirm the early hypothesis that different parts of the train may have distinct power law coefficients. The power law coefficient of 4.4 obtained in Section 3 can thus be regarded as a weighted average value.

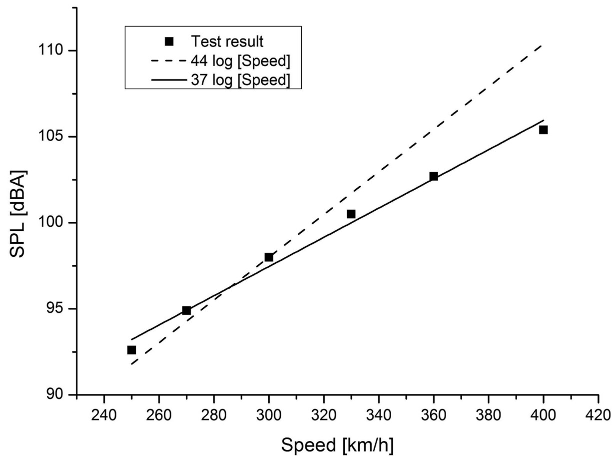


**Fig. 4** Pantograph noise vs. train speed

## 5. Conclusion

The measurement of the train aerodynamic sound pressure at 25 m distance from the center of the track reveals that the functional relationship based on the 4.4th power law provides the best fit. In other words, the overall aerodynamic noise in the current Korean high speed train varies in proportion to the 4.4th power of the train speed. To more closely examine this issue, sound pressure at the inter-coach space and pantograph are measured. The inter-coach space aerodynamic noise is found to vary to the 7.7th power, while the pantograph aerodynamic noise is found to vary to the 3.7th power. The results indicate that different parts of the train may have varying aerodynamic noise characteristics and suggest that a single power law coefficient for train represents at best a weighted average of different speed dependences. A sharp dependence of the aerodynamic sound on train speed is quite troublesome from the community noise point of view, and warrants appropriate remedy.

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