CURVE FITTING PROCEDURES FOR HIGH SPEED TRAINS MEASURED NOISE LEVELS

MMA 9202 *MARS 1992*

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1 - INTRODUCTION

The evolution, with respect to speed V, of the pass-by noise level L of a moving vehicle can usually be described by a two parameters law :

$$L = \alpha + \beta \log\left(\frac{V}{V_{ref}}\right) \qquad (1)$$

This implies that a unique type of source is predominant in the measured speed range.

The noise of high speed trains are known to result from at least two types of sources :

- a rolling noise which predominates at low speeds
- an aerodynamic noise which predominates at high speeds.

Each noise component follows a speed law as given by Eq. (1) but not their combination ie not the total noise.

The classical linear regression technique, which is commonly used to estimate the α and β coefficients of Eq. 1 from measured data cannot be applied when two noise components contribute to the measured levels.

In this report, we present various approaches which can be applied depending on the speed range used for the measurements.

2 - ONE SINGLE TYPE OF NOISE SOURCE

The pass-by noise levels L_m are usually described, with respect to speed V, by a two parameters curve :

$$L_m(V) = \alpha + \beta \log\left(\frac{V}{V_{ref}}\right) \quad (2.1)$$

where V_{ref} is a reference speed (arbitrary).

The α and β parameters (α depends on the choice of V_{ref}) can be determined from measured values $L_m(V_i)$ with a classical regression analysis : one considers

$$\Psi(\alpha,\beta) = \frac{1}{N}\sum_{i=1}^{N}[\alpha + \beta X_i - Y_i]^2 \quad (2.2)$$

$$X_i = \log\left(\frac{V_i}{V_{ref}}\right)$$

$$Y_i = L_m(V_i)$$

N = number of measurements

$\psi(\alpha, \beta)$ is an evaluation of the quadratic difference between the model (Eq. 2.1) and the measurements.

α and β are selected so that $\psi(\alpha, \beta)$ is minimum ie

$$\frac{\partial \Psi}{\partial \alpha} = 0 \qquad \frac{\partial \Psi}{\partial \beta} = 0 \quad (2.3)$$

which yields a simple set of two linear equations for the two unknowns α and β.

This regression is well suited for noise radiated by a unique type of source e.g. for rolling noise or for aerodynamic noise, whose speed dependence is known to correspond to Eq. 2.1 [cf. final report § 1.1].

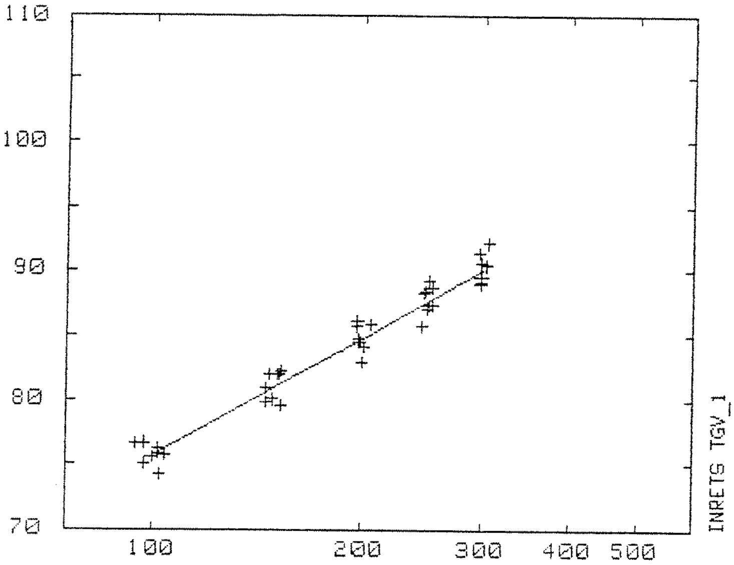
Simulation 1

**** The noise is supposed to be due to one source :***

$$L_T = 90 + 30 \log\left(\frac{V}{300}\right) \quad (2.4)$$

**** Measured values are simulated for various speeds*** *(cf. Fig. 2.1)*

- nominal speeds		*: 100 to 300 km/h, every 50 km/h*
- number of measurements for each speed		*: 8*
- standard deviation :	*on speed*	*: 3 km/h*
	on noise levels	*: 1 dB*



Simulation 1 - One source
Single regression on the whole speed range
FIGURE 2.1

** The estimated values, obtained from the regression analysis, are :*

α		β	
Exact	*Estimated*	*Exact*	*Estimated*
90	$90 \pm 0{,}5$	30	30 ± 2

Single source case
Estimation of α and β from simulated measurements (Fig. 2.1)

$$L_T = \alpha + \beta \log\left(\frac{V}{300}\right)$$

3 - TWO TYPES OF NOISE SOURCES

When two types of noise sources radiate, e.g. rolling noise **and** aerodynamic noise, the total noise L_T is given by :

$$L_T = 10 \log [10^{L_r/10} + 10^{L_a/10}] \qquad (3.1)$$

$$L_r = \alpha_r + \beta_r \log\left(\frac{V}{V_{ref}}\right) \qquad \text{rolling noise}$$

$$L_a = \alpha_a + \beta_a \log\left(\frac{V}{V_{ref}}\right) \qquad \text{aerodynamic noise}$$

which can also be written :

$$\breve{p}_T^2 = A_r\left(\frac{V}{V_{ref}}\right)^{B_r} + A_a\left(\frac{V}{V_{ref}}\right)^{B_a} \qquad (3.2)$$

$$A = 10^{\alpha/10}$$

$$B = \beta / 10$$

If one considers the (quadratic) difference between the model and the experiments ie.

$$\Psi(A_r, B_r, A_a, B_a) = \frac{1}{N}\sum_{i=1}^{N}[A_r x_i^{B_r} + A_a x_i^{B_a} - y_i]^2 \qquad (3.3)$$

$$x_i = \frac{V}{V_{ref}}$$

$$y_i = 10^{L_m(V_i)/10}$$

Stating that this difference be minimum ie solving for

$$\frac{\partial \Psi}{\partial A_r} = 0, \quad \frac{\partial \Psi}{\partial B_r} = 0, \quad \frac{\partial \Psi}{\partial A_a} = 0, \quad \frac{\partial \Psi}{\partial B_a} = 0 \qquad (3.4)$$

does not yield a set of linear equations in A_r, B_r, A_a, B_a. The solution is not as simple as in the single type of noise source case (§ 2).

Various approaches can be considered depending on what is aimed at :

- one can wish to evaluate the contribution of each type of source in the overall noise level. This implies that the a's and b's parameters of Eq. 3.1 be found,

- one can wish to merely describe numerically the total noise level evolution $L_T(V)$ in which case a two or three parameters regression curve might be adequate.

Both types will be considered and illustrated with simulated measurement results.

Simulation of the measurement results

**** The total noise will be supposed to be due to two sources :***

– *rolling noise* $$L_r = 90 + 30 \log\left(\frac{V}{300}\right) \quad (3.5)$$

– *aerodynamic noise* $$L_a = 90 + 80 \log\left(\frac{V}{300}\right) \quad (3.6)$$

The total noise is $$L_T = 10 \log [10^{L_r/10} + 10^{L_a/10}] \quad (3.7)$$

the transition speed for which $L_a = L_r$ *is* $V_t = 300$ *km/h.*

**** Measured results will be simulated as follows :***

- *number of measurements for a given speed : 8*
- *standard deviation on speed : 3 km/h*
- *standard deviation on levels : 1 dB.*

4 - LOW AND HIGH SPEED DOMAINS SEPARATION

A "physical" approach can be followed if measurements are available in "sufficiently high" and "sufficiently low" speed domains. If indeed one can consider

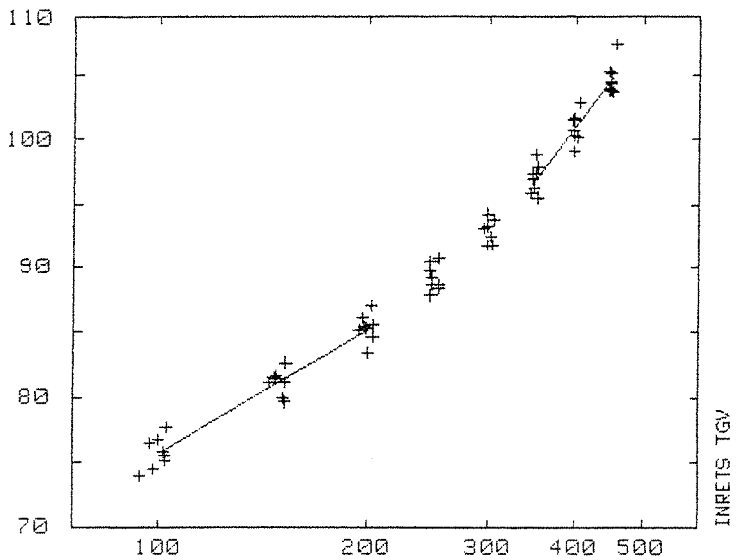
– a low speed domain where $L_r >> L_a$ —> $L_T \approx L_r = \alpha_r + \beta_r \log\left(\frac{V}{V_{ref}}\right)$

– a high speed domain where $L_r << L_a$ —> $L_T \approx L_a = \alpha_a + \beta_a \log\left(\frac{V}{V_{ref}}\right)$.

Then, in each domain, the α and β coefficients can be estimated using the classical regression.

Simulation 2 (Fig. 4.1)

- *rolling noise estimation domain* $100 < V < 200$ *km/h*
- *aerodynamic noise estimation domain* $350 < V < 500$ *km/h*



Simulation 2 - Two sources (Eq. 3.5 to 3.7)

Linear regression in low and high speed domains

FIGURE 4.1

*** Results of the estimation**

	α		β	
	Exact	*Estimated*	*Exact*	*Estimated*
Rolling noise	*90*	*90.7 ±1.2*	*30*	*31.6 ±3.6*
Aerodynamic noise	*90*	*92.1 ±1.4*	*80*	*71.4 ±11.2*

Estimation of α and β from simulated measurements (Fig. 4.1) using linear regressions in low and high speed domains

*** Transition speed** *exact 300 km/h*
estimated 270 km/h

*** Noise levels at various speeds***

Speed (km/h)	100		300		500	
	Exact	Estimated	Exact	Estimated	Exact	Estimated
Rolling noise	75.6	75.6	90	90.7	96.6	97.7
Aerodynamic noise	51.8	58.0	90	92.1	107.7	107.9
Total noise	75.7	75.6	93	94.4	108.0	108.3

Two sources simulation - Cf. Fig. 4.1
Noise levels estimated from linear regressions in low and high speed domains

*** Influence of a rolling noise reduction of 5 dB on the total noise level***

- *transition speed exact 238 km/h*
  estimated 207 km/h

- *noise levels at various speeds*

Speed (km/h)	100		300		500	
	Exact	Estimated	Exact	Estimated	Exact	Estimated
Reduced rolling noise	70.6	70.6	85	85.7	91.6	92.7
Aerodynamic noise	51.8	58.0	90	92.1	107.7	107.9
Total noise	70.7	70.8	91.1	92.9	107.8	108.0

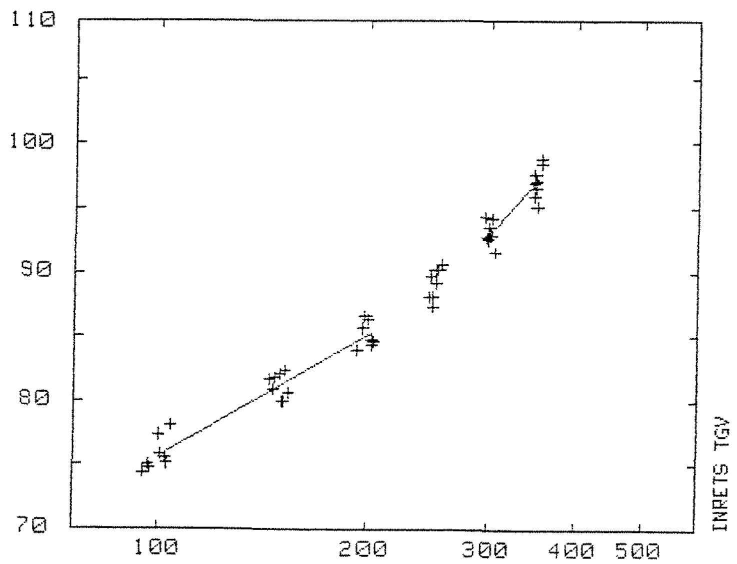
Two sources simulation - Cf. Fig. 4.1
Noise levels after a reduction of 5 dB on the rolling noise

Simulation 2 Bis (Fig. 4.2)

Same as simulation 2 except that the measured results are available up to 350 km/h only

- *rolling noise estimation domain* : $100 < V < 200$ km/h
- *aerodynamic noise estimation domain* : $300 < V < 350$ km/h

Remark *: The aerodynamic noise estimation domain contains the transition speed (300 km/h).*



Simulation 2 Bis - Two sources (Eq. 3.5 to 3.7)
Linear regressions in low and high speed domains
FIGURE 4.2

*** Results of the estimation***

	α		β	
	Exact	Estimated	Exact	Estimated
Rolling noise	90	90.7 ± 1.2	30	31.6 ± 3.6
Aerodynamic noise	90	93 ± 0.7	80	63.3 ± 16

Estimation of α and β from simulated measurements (Fig. 4.2)
Using linear regressions in low and high speed domains

*** Transition speed** *exact* 300 km/h

estimated 254 km/h

** Noise levels at various speeds*

Speed (km/h)	*100*		*300*		*500*	
	Exact	*Estimated*	*Exact*	*Estimated*	*Exact*	*Estimated*
Rolling noise	*75.6*	*75.6*	*90*	*90.7*	*96.6*	*97.7*
Aerodynamic noise	*51.8*	*62.7*	*90*	*93*	*107.7*	*107.0*
Total noise	*75.7*	*75.8*	*93*	*95.0*	*108.0*	*107.5*

Two sources simulation - Cf. Fig. 4.2
Noise levels estimated from linear regressions in low and high speed domains

**** Influence of a rolling noise reduction of 5 dB on the total noise level***

- *transition speed* *exact* *238 km/h*
  estimated *176 km/h*

- *noise levels at various speeds.*

Speed (km/h)	*100*		*300*		*500*	
	Exact	*Estimated*	*Exact*	*Estimated*	*Exact*	*Estimated*
Rolling noise	*70.6*	*70.6*	*85*	*85.7*	*91.6*	*92.7*
Aerodynamic noise	*51.8*	*62.7*	*90*	*93*	*107.7*	*107.0*
Total noise	*70.7*	*71.2*	*91.1*	*93.7*	*107.8*	*107.2*

Two sources simulation - Cf. Fig. 4.2
Noise levels after a reduction of 5 dB on the rolling noise

COMMENTS

The major problem is here to cover a speed range sufficiently wide and sufficiently high to evaluate correctly the aerodynamic noise contribution.
This representation appears to yield a "poor" estimation of noise levels in the intermediate range (estimations at the transition speed, 300 km/h, are up to 3 dB too high).
The transition speed is underestimated.

5 - ROLLING NOISE EXTRACTION

An improvement of the preceeding method can be expected by "extracting" the rolling noise contribution from the total noise.

- The rolling noise is estimated, as above, from the low speed domain results :

$$\hat{L}_r(V) = \hat{\alpha}_r + \hat{\beta}_r \log\left(\frac{V}{V_{ref}}\right) \qquad (5.1)$$

- it is then extracted, **in the higher speed range domain**, from the measured total noise to yield an estimation of the "measured" aerodynamic noise

$$\hat{L}_a(V_i) = 10 \log [\, 10^{L_m(V_i)/10} - 10^{\hat{L}_r(V_i)/10} \,] \qquad (5.2)$$

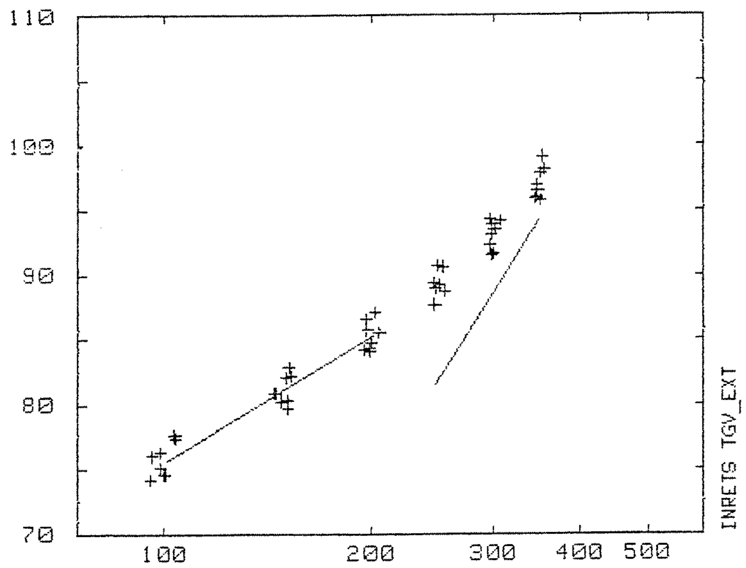
This is possible only if the measured level $L_m(V_i)$ is higher than the estimated rolling noise $L_a(V_i)$ ie if

$$L_m(V_i) > L_r(V_i) \qquad (5.3)$$

Simulation 3 (Fig. 3.1)

- *Rolling noise estimation domain :* *100 < V < 200 km/h*

- *Aerodynamic noise estimation domain* *250 < V < 350 km/h*



Simulation 3 - Two sources (Eq. 3.5 to 3.7)
Rolling noise extraction between 250 and 350 km/h
FIGURE 5.1

**** Results of the estimation***

	α		β	
	Exact	Estimated	Exact	Estimated
Rolling noise	90	90.8 ± 1.2	30	31.8 ± 3.6
Aerodynamic noise	90	88.6 ± 1.6	80	86.4 ± 28

Estimation of α and β from simulated measurements (Fig. 5.1) using Eq. 5.2 for aerodynamic noise estimation (rolling noise extraction)

**** Transition speed***	*exact*	*300 km/h*
	estimated	*329 km/h*

**** Noise levels at various speeds***

Speed (km/h)	100		300		500	
	Exact	Estimated	Exact	Estimated	Exact	Estimated
Rolling noise	75.6	75.6	90	90.8	96.6	97.8
Aerodynamic noise	51.8	47.3	90	88.6	107.7	107.7
Total noise	75.7	75.6	93	92.8	108	108.1

Two sources simulation - Cf. Fig. 5.1
Aerodynamic noise levels estimated using the rolling noise extraction technique

**** Influence of a rolling noise reduction of 5 dB on the total noise level***

- Transition speed exact 238 km/h

estimated 266 km/h

- Noise levels at various speeds

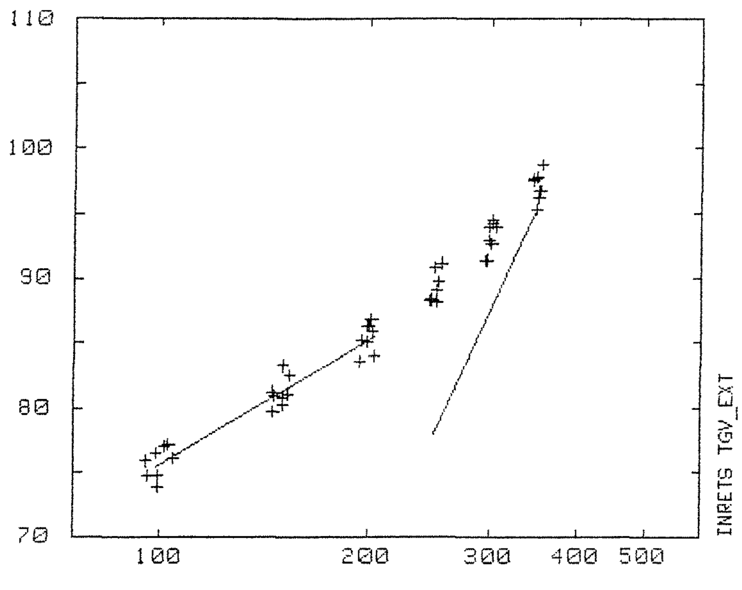
Speed (km/h)	*100*		*300*		*500*	
	Exact	*Estimated*	*Exact*	*Estimated*	*Exact*	*Estimated*
Reduced rolling noise	*70.6*	*70.6*	*85*	*85.8*	*91.6*	*92.8*
Aerodyna-mic noise	*51.8*	*47.3*	*90*	*88.6*	*107.7*	*107.7*
Total noise	*70.7*	*70.6*	*91.1*	*90.4*	*107.8*	*107.9*

Two sources simulation - Cf. Fig. 5.1

Noise levels after a reduction of 5 dB on the rolling noise

It appears that the extraction technique can improve the estimations when compared to the preceeding low and high speed domains separation method (§ 4).

However, care must be taken when differences between $L_m(V_i)$ and $L_r(V_i)$ get close to zero : the estimated value $L_a(V_i)$ from Eq. 5.2 can become abnormally small, and this affects the regression results. Cf. example Fig. 5.2 where the estimated value is $\beta_a = 120$!



The aerodynamic noise is estimated using Eq. 5.2 in the domain 250-350 km/h

At 250 km/h some $\hat{L}_a(V_i)$ values are small enough to affect the regression

FIGURE 5.2

This technique should therefore be used at "sufficiently high" speeds when the total noise is sufficiently higher than the estimated rolling noise. In our case it would be seem that an appropriate domain would be :

speed range $V \geq 300$ km /h (transition speed)

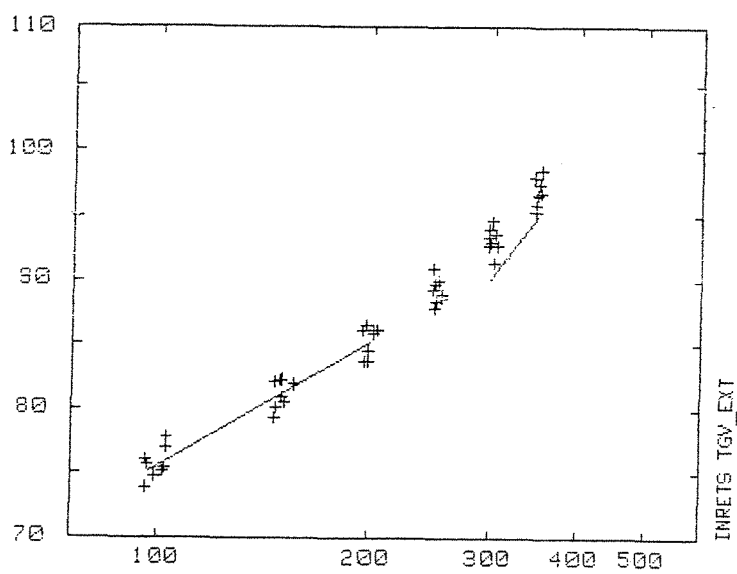
with condition $L_m(V_i) > \hat{L}_r(V_i) + 2$ dB

Cf. example Fig. 5.3

Simulation 4 - Fig. 5.3

- *Rolling noise estimation domain* $100 < V < 200$ *km/h*
- *Aerodynamic noise estimation domain* $300 < V < 350$ *km/h*

Condition used : $L_m(V_i) > \hat{L}_r(V_i) + 2$ dB



Simulation 4 - Two sources (Eq. 3.5 to 3.7)
Rolling noise extraction between 300 and 350 km/h
FIGURE 5.3

**** Results of the estimation***

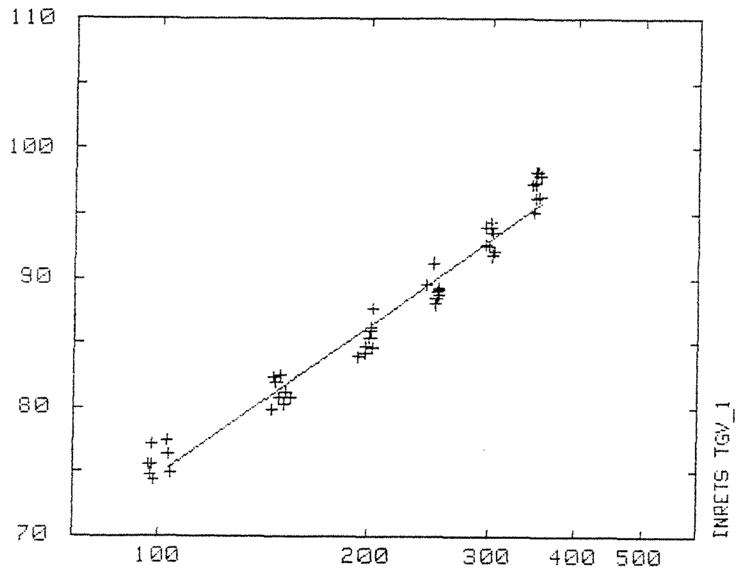
	α		β	
	Exact	*Estimated*	*Exact*	*Estimated*
Rolling noise	*90*	*90.7 ± 1.2*	*30*	*31.7 ± 3.6*
Aerodynamic noise	*90*	*90.2 ± 1.6*	*80*	*70.3 ± 30.8*

Estimation of α and β from simulated measurements (Fig. 5.3)
using Eq. 5.2 for aerodynamic noise estimation (rolling noise extraction)
To be compared to simulation 2 Bis

6 - SINGLE LINEAR REGRESSION

When the speed range does not extend far above the transition speed it is not obvious to distinguish the presence of two sources in the measured results. On Fig. 6.1 for instance, where results are given up to 350 km/h ie barely above the transition speed (300 km/h) a single linear regression could seem adequate.

Simulation 5



Simulation 5 - Two sources (Eq. 3.5 to 3.7)
Single regression between 100 and 350 km/h
FIGURE 6.1

α		β	
Exact	*Estimated*	*Exact*	*Estimated*
-	93 ±0.6	-	38.4 ±2.2

Estimation of α and β from simulated measurements (Fig. 6.1)
using a single linear regression (§ 2)

The single regression procedure assumes that there is a unique type of source. No information can therefore be obtained on a transition speed.

** Noise levels at various speeds*

Speed (km/h)	100		300		500	
	Exact	Estim.	Exact	Estim.	Exact	Estim.
Total noise	75.7	74.6	93.0	93.0	108.0	101.5

Two sources simulation (Fig. 6.1)

Noise levels estimated from a single linear regression analysis

Within the measured speed range, the noise levels are quite well estimated.

As expected, an extrapolation of the estimation in the high speed domain (500 km/h for instance) does not yield satisfactory results.

No physical insight is obtained concerning the possible different types of sources : the only interpretation would be here that rolling noise is predominant in the measured speed range.

A 5 dB reduction in the rolling noise would be estimated to give the following results :

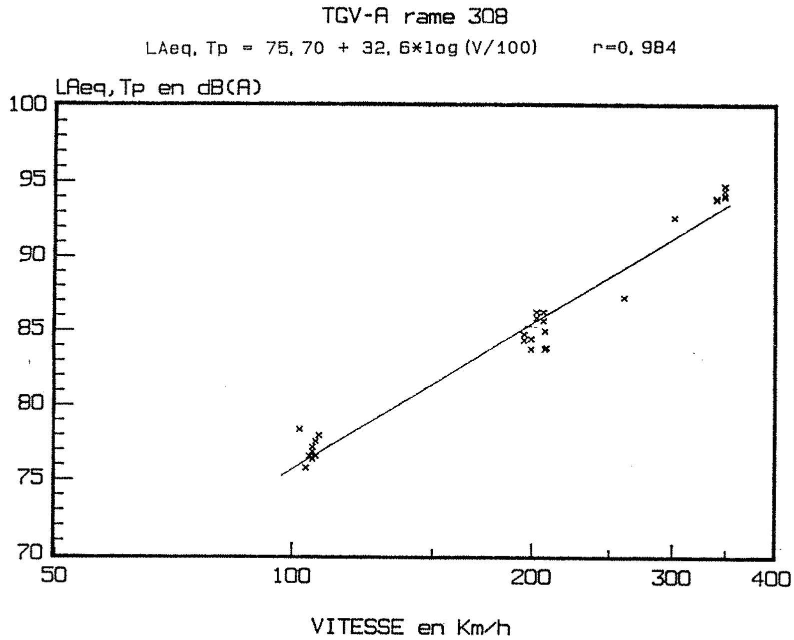
Speed (km/h)	100		300		500	
	Exact	Estim.	Exact	Estim.	Exact	Estim.
Reduced noise	70.7	69.6	91.1	88.0	107.8	96.5

Two sources simulation - Fig. 6.1

Noise levels after a 5 dB reduction on the rolling noise

Actual measurements

Results obtained with the TGV-A (Fig. 6.2) could quite well correspond to this situation.



Noise levels measured with the TGV-A (from SNCF)

FIGURE 6.2

7 - QUADRATIC REGRESSION

The presence of two sources induces a curvature in the noise level evolution curve. It is noticeable on Fig. 6.1. A quadratic regression can be used to improve the numerical estimations within the speed range of the measurements. The levels are described by the following expression :

$$L_m(V) = \alpha + \beta \log\left(\frac{V}{V_{ref}}\right) + \gamma \log^2\left(\frac{V}{V_{ref}}\right) \qquad (7.1)$$

The α, β and γ parameters are determined from measured values by minimizing the expression :

$$\Psi(\alpha,\beta,\gamma) = \frac{1}{N}\sum_{i=1}^{N}[\alpha + \beta X_i + \gamma X_i^2 - Y_i]^2 \qquad (7.2)$$

$$X_i = \log\left(\frac{V_i}{V_{ref}}\right)$$

$$Y_i = L_m(V_i)$$

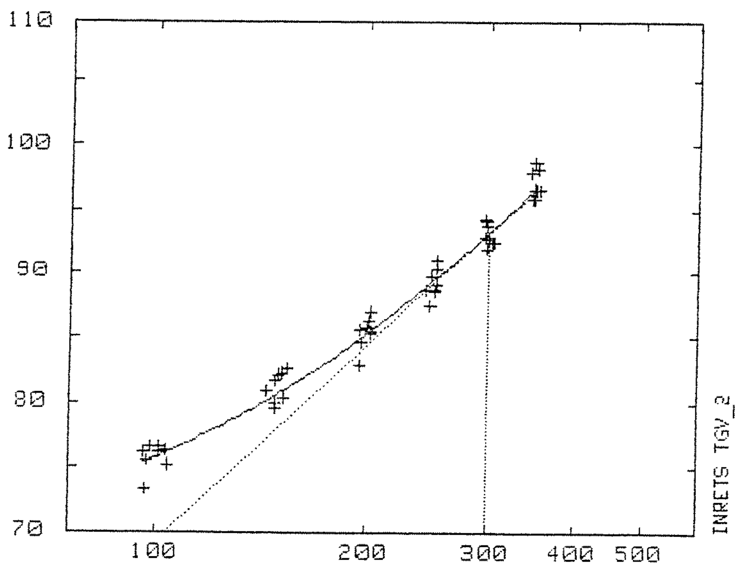
N = number of measurements

The minimizing conditions are :

$$\frac{\partial \Psi}{\partial \alpha} = 0 \qquad \frac{\partial \Psi}{\partial \beta} = 0 \qquad \frac{\partial \Psi}{\partial \gamma} = 0 \qquad (7.3)$$

which yields a simple set of three linear equations for the three unknowns, α, β, γ.

Simulation 6 - The reference speed (Eq. 7.1) is taken to be V_{ref} = 300 km/h



Simulation 6 - Two sources (Eq. 3.5 to 3.7)

Quadratic regression between 100 and 350 km/h

FIGURE 7.1

	α		β		γ	
	Exact	*Estim.*	*Exact*	*Estim.*	*Exact*	*Estim.*
Total noise	-	93.3	-	50.6	-	29.6

Estimation of α, β, γ from simulated measurements (Fig. 7.1)
using a quadratic regression analysis (Eq. 7.1)

*** No information can be obtained on the transition speed***

*** Noise levels at various speeds***

Speed (km/h)	100		300		500	
	Exact	*Estim.*	*Exact*	*Estim.*	*Exact*	*Estim.*
Reduced noise	75.7	75.8	93.0	93.3	108.0	105.9

Two sources simulation - Fig. 7.1
Noise levels estimated
from a single quadratic regression analysis

- Within the measured speed range, the noise levels are very well estimated, better than with the single linear regression,

- Extrapolations of the results at high speeds (500 km/h for instance) remain hasardous.

Here again, no physical insight is obtained concerning the types of sources. An estimation of the impact of a 5 dB reduction on the rolling noise would not be much better than the one made in the single linear regression case (§ 6).

8 - PROBLEMS FROM HAVING FEW MEASUREMENTS IN A REDUCED SPEED RANGE

From what was presented up till now, a distinction must be made between :

- the problem of a numerical estimation of measured results in the measured speed range,

- the problem of evaluating the contribution of the various types of sources in the overall noise level.

A linear or quadratic regression analysis can be well suited for solving the first problem (§ 1, 6, 7).

An analysis of the results in partial domains (in the case where different types of sources are assumed to contribute to the total noise) is necessary for the second problem (§ 3, 4, 5).

A difficulty arises when few data are available in a restricted speed range. In Fig. 6.2 for instance which corresponds to actual measured values, sets of data are available at 100, 200, 350 km/h (nominal speeds). Single values are given at 260 and 300 km/h.

We shall use these results to illustrate the various difficulties encountered when attempting to apply the techniques presented up till now (§ 3, 4, 5).

Illustrations will be made using simulated measurement results.

TGV-A Simulation

The TGV-A data which will be presented will be simulated values, computed so that one gets, when compared to actual values (Fig. 6.1) :

- the same number of measurements per speed

- the same average speeds

- the same average noise levels

- the same standard deviations.

- The ***rolling noise*** can be estimated, by a simple regression, from results at 100 and 200 km/h (Fig. 7.1);

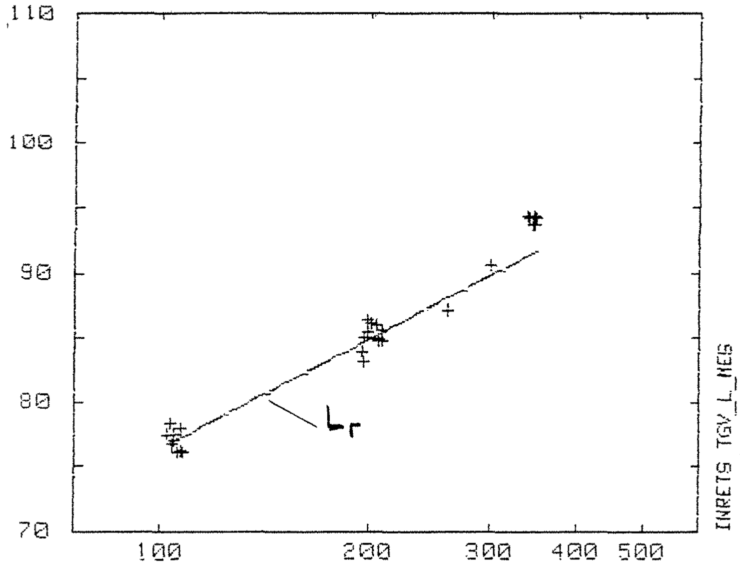
	α estimated	β estimated
rolling noise	89.7 ± 1.1	28.2 ± 3.3

Simulated TGV-A measurements

Simple linear regression between 100 and 200 km/h - Cf. Fig. 7.1

Though the estimation uses data at 100 and 200 km/h only, on can see Fig. 7.1 that the results at 260 and 300 km/h could very well be said to correspond to rolling noise.

The values at 350 km/h are however clearly higher than the rolling noise and could correspond to an aerodynamic noise contribution.



L_r : rolling noise estimation
from measurements at 100 and 200 km/h
Simulated TGV-A measurements
FIGURE 7.1

- The aerodynamic noise is, in particular case, quite difficult to estimate.

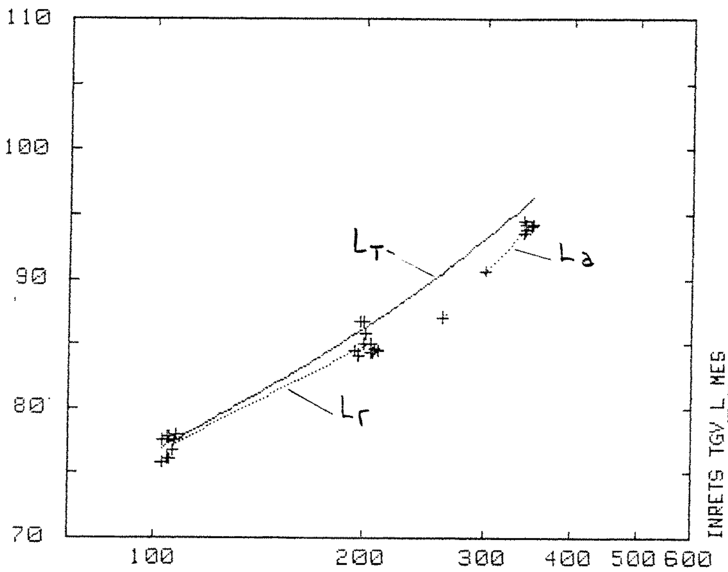
*** Aerodynamic noise estimation using the linear regression in the high speed domain (§ 4)**

The method is hardly applicable : only two sets of data are available for the estimation (300 and 350 km/h) and the level at 300 km/h can hardly be said to correspond to aerodynamic noise.

The results would be the following (cf. Fig. 7.2).

	α estimated	β estimated
aerodynamic noise	90.5 ± 0.5	57.1 ± 8.9

Simulated TGV-A measurements
Simple linear regression between 300 and 350 km/h - Cf. Fig. 7.2



L_a : aerodynamic noise estimated
using a simple linear regression between 300 and 350 km/h
L_T : estimated total noise

Simulated TGV-A measurements

FIGURE 7.2

The estimated transition speed is V_{trans} = 282 km/h.

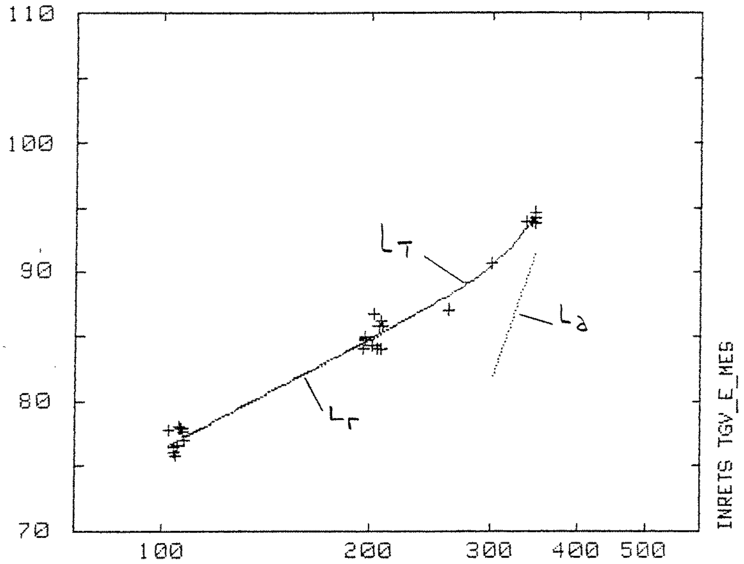
As could be expected (cf. § 4 simulation 2 Bis) the aerodynamic noise is overestimated : the total noise estimated values are higher than the "measured" values at high speeds. The transition speed is probably underestimated.

*** Aerodynamic noise estimation using the rolling noise extraction method (§ 5)**

Similarly to the preceeding method, two sets of data only can be used : 300 and 350 km/h.

	α estimated	β estimated
aerodynamic noise	81.7 ± 3.8	153 ± 68

Simulated TGV-A measurements
Rolling noise extraction between 300 and 350 km/h - Cf. Fig. 7.3



L_a : aerodynamic noise estimated
from measurements at 300 and 350 km/h
using the rolling noise extraction method
L_T : estimated total noise

Simulated TGV-A measurements

FIGURE 7.3

The estimated transition speed is V_{trans} = 348 km/h.

The slope β_a of the aerodynamic noise is conditionned by the single data at 300 km/h, whose value happens to be very close to the estimated rolling noise at that speed. Useless to say that its estimation is less than reliable (Cf. Fig. 5.2).

Remark : The total noise estimation L_T is quite well estimated in the measured speed range.

9 - A MIXED METHOD

In § 3, a theoretical expression for the total noise due to the radiation of two sources was presented (Eq. 3.1). A quadratic difference expression between this expression and measured values was given :

$$\Psi(A_r, B_r, A_a, B_a) = \frac{1}{N}\sum_{i=1}^{N}[A_r x_i^{B_r} + A_a x_i^{B_a} - y_i]^2 \qquad (3.3)$$

$$x_i = \frac{V}{V_{ref}}$$

$$y_i = 10^{L_m(V_i)/10}$$

The problem was, at that stage, that the minimization of ψ with respect to the A's and B's coefficients did not yield a set of linear equations with respect to these coefficients.

The proposed mixed method consists in the following :

-- estimate the rolling noise as was done up till now, ie with a linear regression in the low speed domain :

$$\hat{L}_r(V) = \hat{\alpha}_r + \hat{\beta}_r \log\left(\frac{V}{V_{ref}}\right) \qquad (5.1)$$

-- incorporate this estimation in the quadratic difference Eq. 3.3, with :

$$\hat{A}_r = 10^{\hat{\alpha}_r/10}$$

$$\hat{B}_r = \hat{\beta}_r / 10$$

-- and look for the A_a and B_a values which minimize this difference which we write :

$$\Psi(A_a, B_a) = \frac{1}{N}\sum_{i=1}^{N}\left[A_a x_i^{B_a} - (y_i - \hat{A}_r x_i^{\hat{B}_r})\right]^2 \qquad (9.1)$$

We use a partly analytical, partly numerical method (mixed method).

For an assumed B_{a_0} value we evaluate analytically the A_{a_0} value which minimizes Eq. 9.1

$$\left.\frac{\partial \Psi}{\partial A_a}\right|_{B_a = B_{ao}} = 0 \qquad \text{the solution is} \quad A_a = A_{ao}$$

then use this A_{a_0} estimation to compute, numerically a B_{a_1} value which minimizes Eq. 9.1 ; this allows for a new estimation A_{a_1} and so on.

Three simulations are presented to illustrate the performances of the method :

- *Simulation 7*

Data are assumed to be available in a large speed range (100-450 km/h) similar to simulation 2. The estimations come out very close to the exact values.

- *Simulation 7 Bis*

The speed range is lowered (100-350 km/h), similar to simulations 2 Bis and 3. The estimations remain quite correct, better than the previous methods.

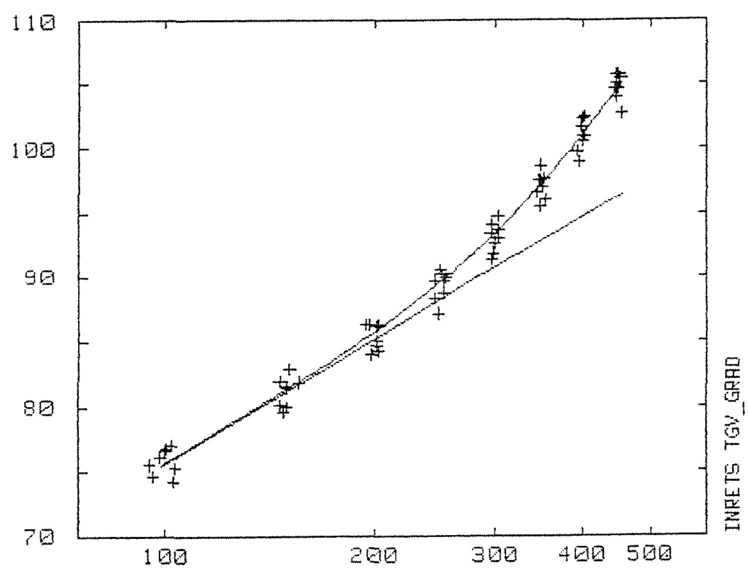
- Simulation 7 ter

A delicate situation : the speed range does not extend above the transition speed. The aerodynamic noise contribution **in the measured speed range** remains remarkably well estimated.

Simulation 7 100 < V < 450 km/h - Fig. 9.1

- The rolling noise is estimated using a simple linear regression with data values between 100 and 200 km/h.

- The aerodynamic noise is then estimated using data in the whole speed range.



Simulation 7 - Two sources (Eq. 3.5 to 3.7)
Speed range from 100 to 450 km/h
Mixed method
FIGURE 9.1

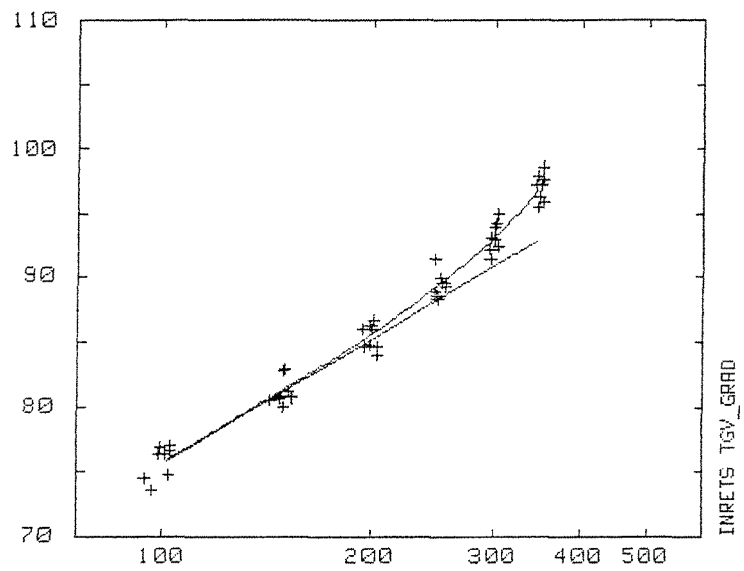
**** Results of the estimation***

	α		β	
	Exact	*Estimated*	*Exact*	*Estimated*
Rolling noise	*90*	*90.7 ± 1.2*	*30*	*31.5 ± 3.6*
Aerodynamic noise	*90*	*90.1*	*80*	*78.8*

Estimation of α and β from simulated measurements (Fig. 9.1) using the mixed method

* Transition speed	exact	300 km/h
	estimated	309 km/h

Simulation 7 Bis 100 < V < 300 km/h - Fig. 9.2



Simulation 7 Bis - Two sources (Eq. 3.5 to 3.7)
Speed range from 100 to 350 km/h
Mixed method
FIGURE 9.2

*** Results of the estimation**

Same as simulation 7 for the rolling noise.

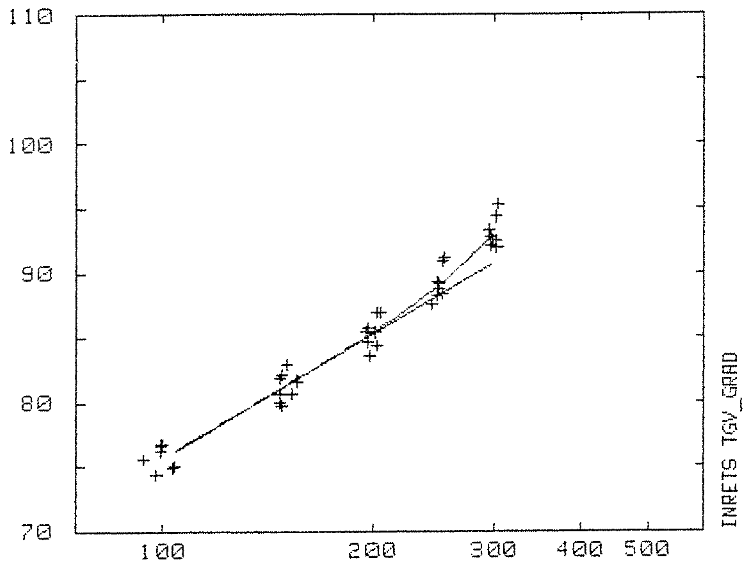
	α		β	
	Exact	*Estimated*	*Exact*	*Estimated*
Aerodynamic noise	*90*	*89.4*	*80*	*84.0*

Estimation of α and β from simulated measurements (Fig. 9.2) using the mixed method

* *Transition speed*	*exact*	*300 km/h*
	estimated	*318 km/h*

Simulation 7 ter   100 < V < 300 km/h - Fig. 9.3

The measurements are available up to the transition speed (300 km/h)



Simulation 7 ter - Two sources (Eq. 3.5 to 3.7)
Speed range from 100 to 300 km/h
Mixed method
FIGURE 9.3

***Results of the estimation**

Same as simulation 7 for the rolling noise.

	α		β	
	Exact	*Estimated*	*Exact*	*Estimated*
Aerodynamic noise	90	89.5	80	100.6

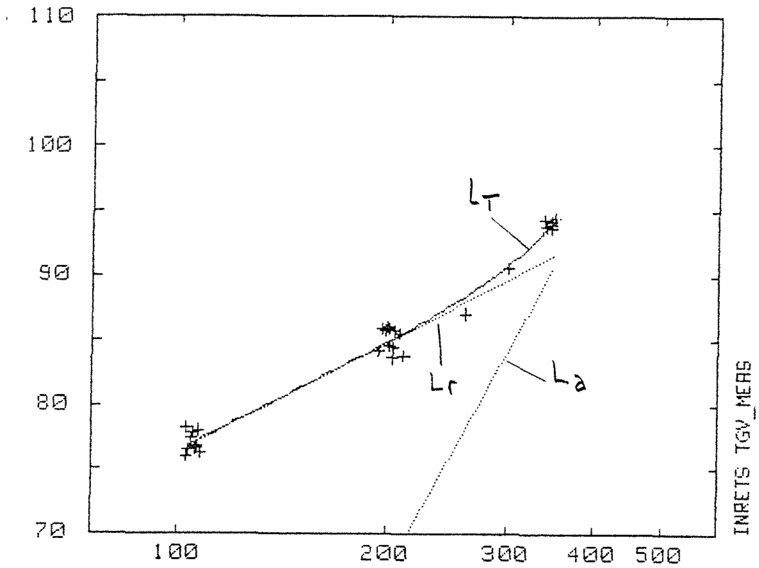
Estimation of α and β from simulated measurements (Fig. 9.3) using the mixed method

* *Transition speed*	*exact*	*300 km/h*
	estimated	*312 km/h*

10 - APPLICATION OF THE MIXED METHOD TO THE TGV-A RESULTS

The problem is presented § 8 where the rolling noise is estimated (cf. Fig. 7.1).

From those results, the aerodynamic noise is estimated in the whole speed range which yields the following.



Simulated TGV-A results

L_a ***aerodynamic noise estimation using the mixed method***

L_T ***estimated total noise***

FIGURE 10.1

	a	b
Aerodynamic noise	84.0	99.0

Estimated α and β
from one simulation of the TGV-A results (Fig. 10.1)
using the mixed method

Transition speed : estimated 360 km/h.

Remark : Several simulations of these TGV-A results have been made : we recall that the individual results are randomized but, from one simulation to the other, the number of measurements per speed, the average values and the standard devirations are fixed and the same.

Apart from the slope estimation (β), the estimations come out to be not too sensitive to the "errors" : there are found to lie within the following limits :

	α_a	β_a	$V_{transition}$ (km/h)
average standard deviation	84.5 0.7	92.8 11.9	361.9 3.3

Range of values obtained from several (35) simulations

Despite the restricted range of speeds for the measurements it is very plausible that :

- an aerodynamic noise brings a strong contribution to the total noise around 350 km/h. Its level is at that speed :

$$L_a(350) \cong 84.5 + 92.8 \log\left(\frac{350}{300}\right) = 90.7 \quad \text{dB}$$

while the rolling noise at that speed is :

$$L_r(350) \cong 89.7 + 28.2 \log\left(\frac{350}{300}\right) = 91.6 \quad \text{dB}$$

- the transition speed is close to 360 km/h.

11 - CONCLUSION

Pass-by noise levels of high speed trains can be described in terms of a rolling noise component which predominates at low speeds and an aerodynamic noise component which predominates at high speeds. At the transition speed, the two components have the same level.

Various methods have been considered to evaluate these components from pass-by noise measured noise levels.

The difficulty arises when the speed range used for the measurements extends barely above the transition speed. With an appropriate method, an acceptable estimation can be made.

The method has been applied to actual TGV-A measured results.