

DEVELOPMENT OF A MODEL FOR PREDICTING
TRAIN PASS-BY NOISE PROFILES

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1. INTRODUCTION

Transportation represents the most significant community noise producer today. The three transportation sources - traffic, aircraft and trains - place considerable areas of land in a deteriorated noise environment and hence necessitate careful land use assessment to avoid inefficient or unsuitable development. In the major cities of Canada land is often at a premium, making efficient land use even more necessary.

Considerable effort has been brought to bear on prediction methods for aircraft and traffic noise. For aircraft noise in particular, sophisticated and detailed prediction methods exist (1). Traffic noise models have also been derived and are in general use (2,3,4). Although some work has been performed in the area of train noise prediction (5,6,7) it is not as considerable as that for aircraft or traffic.

The work which has been done is also made less applicable in Canada by several factors. Many models predict only the wheel-rail noise and have no prediction for locomotives. Many are concerned mainly with welded track and give widely varying corrections for the jointed rail in use in Canada and very few are concerned with prediction of the entire pass-by profile of the train.

Derivation of the complete pass-by is necessary for two reasons. First, noise control measures such as set-back, berms and double-glazing give different attenuations for the locomotive and wheel-rail noise because of differing source type, height and spectral content. To accurately predict the usefulness of noise control measures, the locomotive and wheel-rail signatures must be predicted separately. Secondly, for short trains (such as self propelled passenger trains or turbo-trains) the rise and decay of the noise profile as the train approaches and recedes can add significantly to the total noise exposure of the pass-by.

To fulfill these needs a semi-empirical train noise pass-by profile model was developed. The locomotive and wheel-rail noises were first considered theoretically as point and line sources respectively. Practical measurements in the field supplied the necessary level information of locomotive and wheel-rail noise for insertion into the theoretical model.

2. THEORY

The model of a passing train was taken to be as shown in Fig. 1. The observer track distance was taken as d . The train head - taken as being the locomotive, or first locomotive if several - passes the observer at time $t=0$ with velocity V . The locomotives are considered point sources located at the mid point of each and hence separated by one locomotive length. The rest of the train, the wheel-rail noise, is considered as a line source of length λ . Before the theory can be developed, consideration must be given to the directional characteristics of these sources. Peters (8) considered this problem and found the assumption of dipole radiation gave the best prediction of the rise and decay portions of the pass-by profile. Dipole radiation was assumed for both the locomotive and wheel-rail noise.

2.1 Locomotive Noise

The sound pressure, $P_L(t)$ due to a locomotive of sound power W_L at the observer is given by

$$P_L^2(t) = \frac{W_L \rho c}{2\pi} \cdot \frac{\cos^n \theta}{y^2}$$

where ρc = the characteristic acoustic impedance of air
 y is the locomotive observer distance
 and θ is as shown in Fig. 2.

The term $\cos^n \theta$ describes the directivity pattern of the radiation as described by Meakawa (9) for a dipole source. It was found from the practical measurements described in section 3 of this paper that $n=1$ gave the best agreement with measured pass-by profiles giving

$$P_L^2(t) = \frac{W_L \rho c}{2\pi} \cdot \frac{\cos \theta}{y^2} \quad (1)$$

$$\text{or } P_L^2(t) = \frac{W_L \rho c}{2\pi} \cdot \frac{d}{\{d^2 + (vt)^2\}^{3/2}} \quad (2)$$

Practical measurements were taken of train pass-bys at a distance of 50 feet to give the maximum locomotive sound pressure P_L . For these measurements

$$P_L^2 = \frac{W_L \rho c}{2\pi} \cdot \frac{1}{50^2} \quad (4)$$

$$\text{Thus } P_L^2(t) = P_L^2 \cdot \left(\frac{50}{d}\right)^2 \cdot \frac{1}{\{1 + (\frac{vt}{d})^2\}^{3/2}} \quad (5)$$

Or, finally converting to dBA levels.

$$L_L(t) = L_L + 20 \log_{10} \frac{50}{d} - 15 \log_{10} \left\{ 1 + \left(\frac{vt}{d} \right)^2 \right\} \quad (6)$$

Where $L_L(t)$ is the dBA level due to the locomotive at time t and L_L is the maximum dBA level measured at a distance of 50 feet.

2.2 Wheel-Rail Noise

The wheel-rail noise is considered to be a line source as shown in Fig. 3. The sound power at the observer due to a small element dx of the train is integrated over the length of the train (l) to give the total sound pressure $P_W(t)$. The wheel-rail noise is assumed to have sound power W_W per unit length, $P_W(t)$ being given by:

$$P_W^2(t) = \int_0^l \frac{W_W \rho c}{2\pi} \cdot \frac{\cos^n \theta}{y^2} \cdot dx \quad (7)$$

Again the $\cos^n \theta$ term describes the directivity pattern of the radiation. For the wheel-rail noise, practical measurements (described in section 3) indicated that $n=1$ also gives the best agreement with pass-by profiles giving

$$P_W^2(t) = \frac{W_W \rho c}{2\pi} \int_0^l \frac{\cos \theta}{y^2} dx \quad (8)$$

$$\text{or } P_W^2(t) = \frac{W_W \rho c}{2\pi} \int_0^l \frac{d}{\{d^2 + (vt-l+x)^2\}^{3/2}} \cdot dx \quad (9)$$

which when integrated gives

$$P_W^2(t) = \frac{W_W \rho c}{2\pi} \cdot \frac{l}{d} \left[\frac{vt}{\{d^2 + (vt)^2\}^{1/2}} - \frac{vt-l}{\{d^2 + (vt-l)^2\}^{1/2}} \right] \quad (10)$$

Practical measurements of train pass-by taken at a distance of 50 feet to give the average wheel-rail sound pressure P_W . For these measurements

$$vt = l/2, \quad d = 50 \text{ ft. and } l \ll d \text{ giving} \quad (11)$$

$$P_W^2 = \frac{W_W \rho c}{2\pi} \cdot \frac{l}{50} \cdot 2$$

$$\text{Thus } P_W^2(t) = \frac{1}{2} P_W^2 \cdot \frac{50}{d} \left[\frac{vt}{\{d^2 + (vt)^2\}^{1/2}} - \frac{vt-l}{\{d^2 + (vt-l)^2\}^{1/2}} \right] \quad (12)$$

$$L_w(t) = L_w + 10 \log \frac{50}{10 d} + 10 \log \left[\frac{vt}{d^2 + (vt)^2} - \frac{vt-l}{d^2 + (vt-l)^2} \right] - 3 \quad (13)$$

Inherent in equation 13 is the decrease in sound level with distance perpendicular to the track. When $d \ll \lambda$ & than the final term is negligible and the sound level decreases 3 dB per doubling of distance. There then follows a transition region after which the two terms together produce a sound level decrease of 6 dB per doubling distance.

3. PRACTICAL MEASUREMENTS

3.1 Instrumentation

Sound from the train pass-by was detected by a B & K 2209 Impulse Precision Sound Level Meter fitted with a $\frac{1}{2}$ inch Condenser Microphone. Amplified signals were fed to a Nagra Tape Recorder and recorded at 3 3/4 i.p.s. Recordings were made unweighted i.e. on "Linear" if wind conditions permitted or with "A" weighting if not.

The recorded signals were played back through the B & K 2209 and 'A' weighted if recorded unweighted. Unaveraged signals from the 2209 were passed to a B & K 2305 Level Recorder where the pass-by profiles were drawn out on paper tape. Averaging was performed by the Level Recorder with the equivalent of "Fast" set.

Train speeds were measured with a digital reading radar unit.

3.2 Measurement Details

Measurements were made at four locations in the Toronto area at a distance of 50 feet from new and old track operated by both Canadian National Railways and Canadian Pacific Railways. Pass-bys of some 40 trains (passenger, GO, turbo and freight trains) were recorded over a range of speeds from 10 to 70 miles per hour. As well as a sound recording and speed assessment for each pass-by other information such as type of train, type of locomotive and number of cars was noted.

4. MEASUREMENT RESULTS

From the paper trace of each train pass-by the maximum locomotive level and the average wheel-rail level was obtained. As the method of handling these two types of level was different they will be considered separately.

4.1 Locomotive Levels

The levels from each locomotive pass-by were plotted against speed as shown in Fig. 4. It was realized that a lower limit existed for the locomotive levels at low speed. Fortunately several of the GO train pass-bys included idling locomotives at the rear of the train. From the level of these locomotives and the plotted levels it was concluded that below 20 m.p.h. this lower limit level is in force. A linear regression analysis was then performed of level against the logarithm of speed for all constant speed locomotives travelling at more than 20 m.p.h. A correlation coefficient of 0.82 was obtained with a standard deviation of ± 2.4 dBA

As it was felt that the locomotive level was also a function of the loading of the locomotive, the errors between each locomotive level and the regression line were plotted against the number of cars per locomotive in the train as shown in Fig. 5. A regression analysis was performed on these results, a correlation coefficient of 0.59 (significant at the 1% level) and a standard deviation of 2.6 dBA was obtained. The regression line plus and minus one standard deviation is shown in Fig. 5. At zero loading the regression line gave a correction of -3 dBA. The regression line of locomotive level against speed was lowered by 3 dBA to give an unloaded regression line. This is shown with plus and minus one standard deviation on Fig. 4. The results of the locomotive level analysis can be summarized as follows:

for idling, coasting or decelerating locomotives

$$L_L = 83.6(\pm 2.4) \text{ dBA} \quad (14)$$

for constant speed locomotives at less than 20 m.p.h.

$$L_L = 83.6 (\pm 2.4) + 0.15 N (\pm 2.6) \quad (15)$$

where N is the number of cars per locomotive

for constant speed locomotives at greater than 20 m.p.h.

$$L_L = 94.8 + 23.5 \log \frac{V}{60} (\pm 2.4) + 0.15N (\pm 2.6) \quad (16)$$

Also plotted on Fig. 4 are some points for accelerating or up-grade locomotives. It was judged that 3 dBA should be added to the above levels for locomotives which are either accelerating or going up-grade.

Fig. 6 shows a comparison of equation (15) and (16) with data from another source (10). In the cases where locomotives from ref. (10) were loaded, a loading correction was applied. Fair agreement is shown.

4.2 Wheel Rail Levels

Analysis of the wheel rail levels was more straight forward than the locomotive levels, a single regression analysis was performed of level against the logarithm of the speed. A correlation coefficient of 0.82 was obtained with a standard deviation of 3.5 dBA. The individual points along with the regression line and the plus and minus one standard deviation lines are shown in Fig. 7. The results for the wheel rail noise is as follows:

$$L_W = 87.8 + 25.7 \log_{10} \left(\frac{V}{60} \right) (\pm 3.5) \text{ dBA} \quad (17)$$

Fig. 8 shows a comparison of equation (17) with data from other sources (5,6,11,12). Again reasonable agreement is obtained.

4.3 Prediction of the number of locomotive per train

As it is not always known how many locomotives will be pulling a certain train some method of predicting this is required. Fig. 9 shows a plot of the number of locomotives pulling a train against the total number of cars. From these results it was thought that the approximation shown on Fig. 9 gave a reasonable prediction of the number of locomotives, as follows:

0 to 35 cars	1 locomotive
35 to 70 cars	2 locomotives
70 to 105 cars	3 locomotives
105 to 140 cars	4 locomotives

etc.

5. CONCLUSIONS

A semi-empirical train pass-by noise profile model has been developed which is able to predict locomotive levels, wheel rail levels, level rise and fall as the train approaches and recedes and level decrease with distance. It is felt that the level decrease with distance as predicted could be a weak point in the

method as practical measurements were only taken at a single distance relative to the track. It has been noted (5) that divergencies can occur from the classical 3 dB and 6 dB per double distance decrements. This is probably due more to varying ground cover rather than model errors but is a problem which requires further investigation.

ACKNOWLEDGEMENTS

The author would like to thank those members of the Noise Pollution Control Section who provided valuable assistance to this project. The work of Jorgen Madsen, a summer student from Denmark is also gratefully acknowledged.

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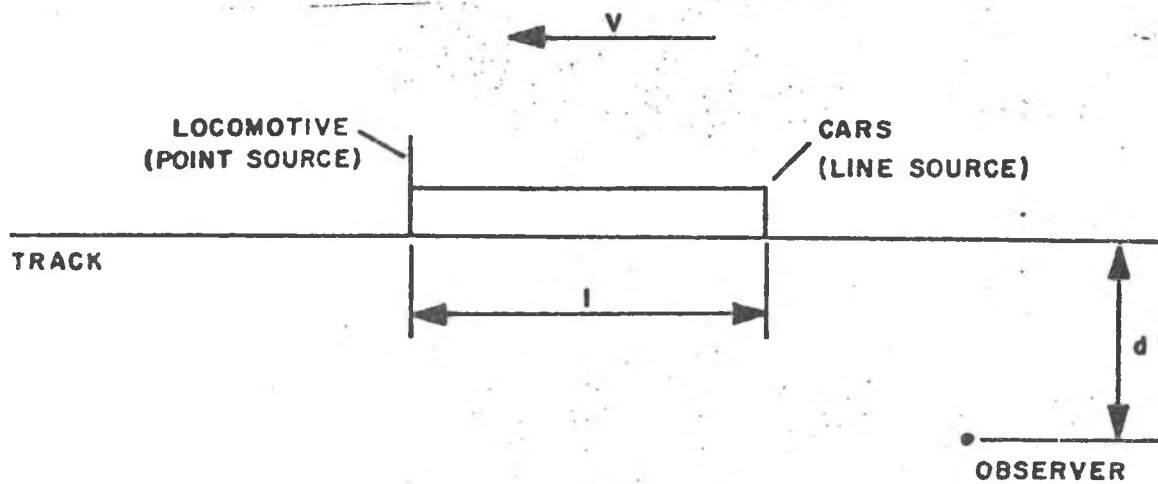


FIG 1

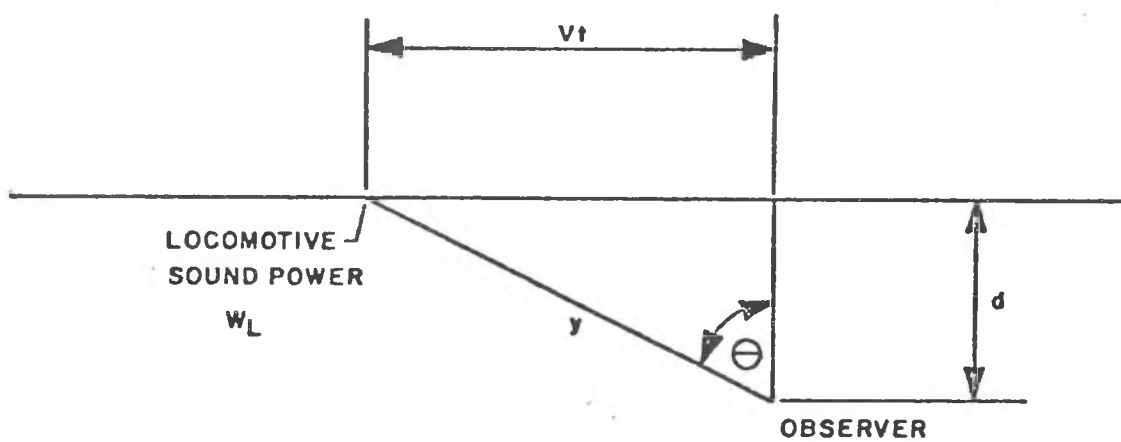


FIG 2

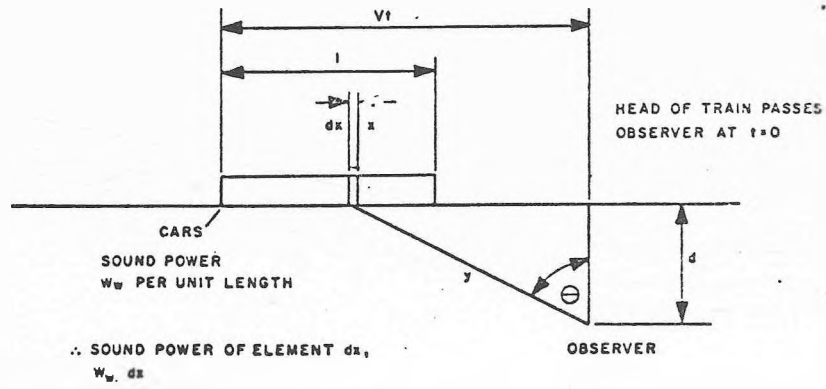
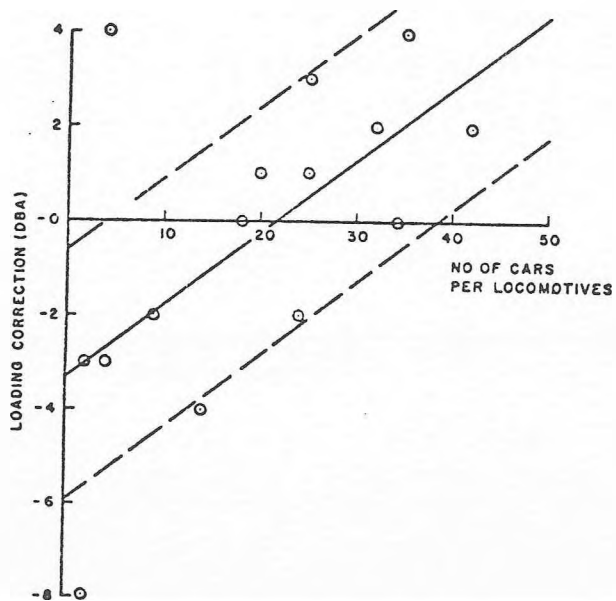
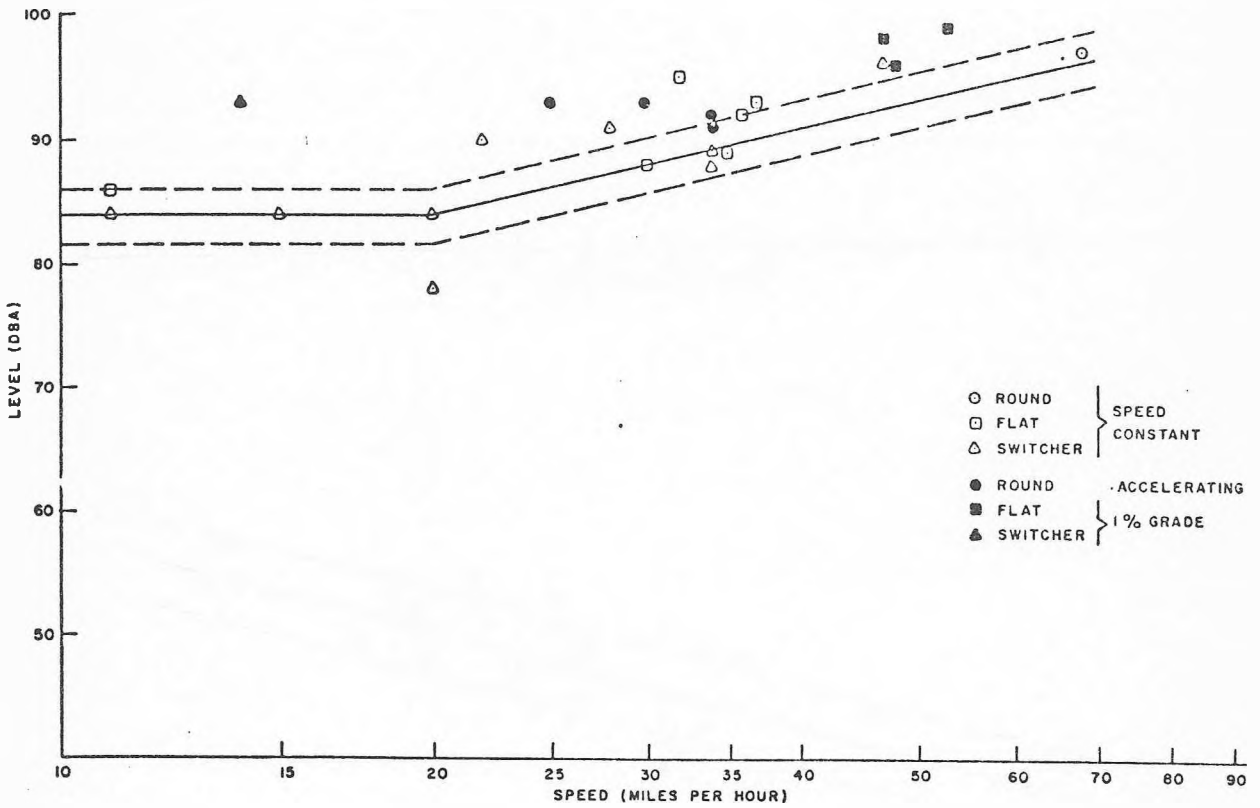


FIG 3



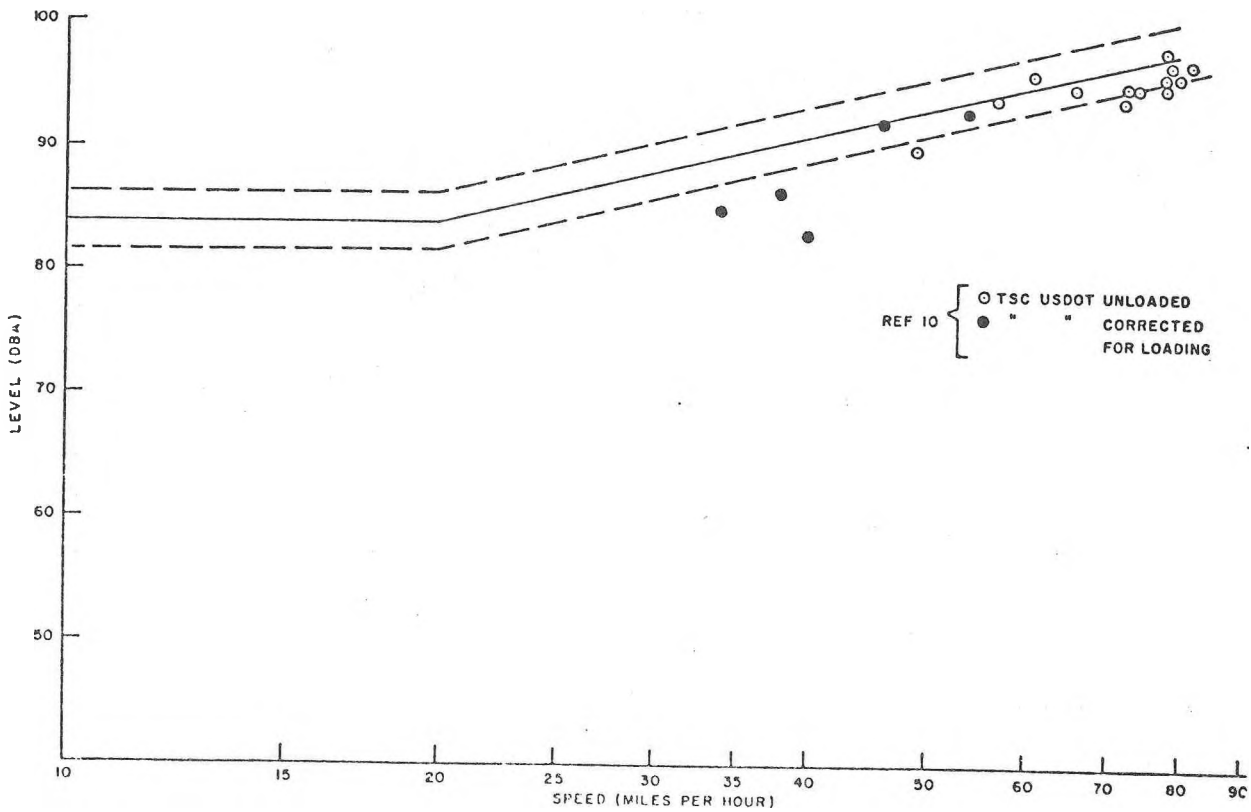
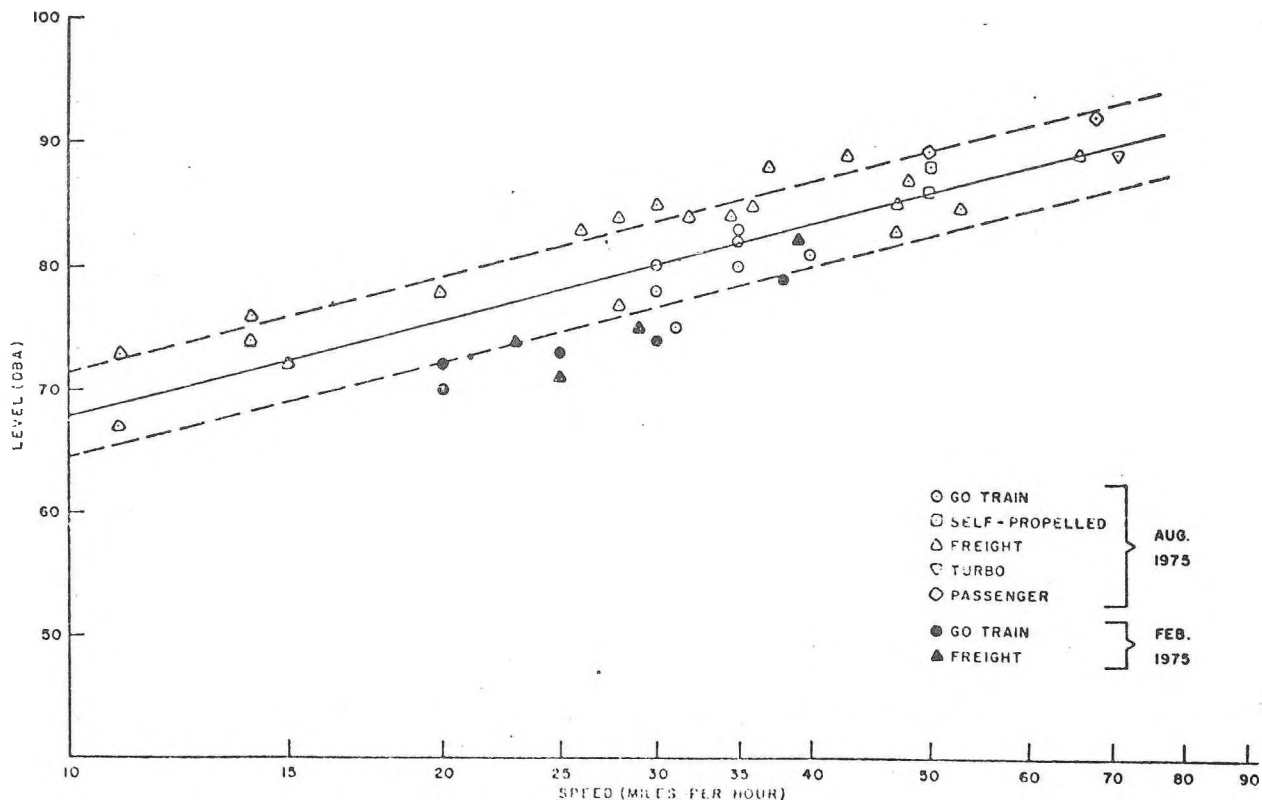
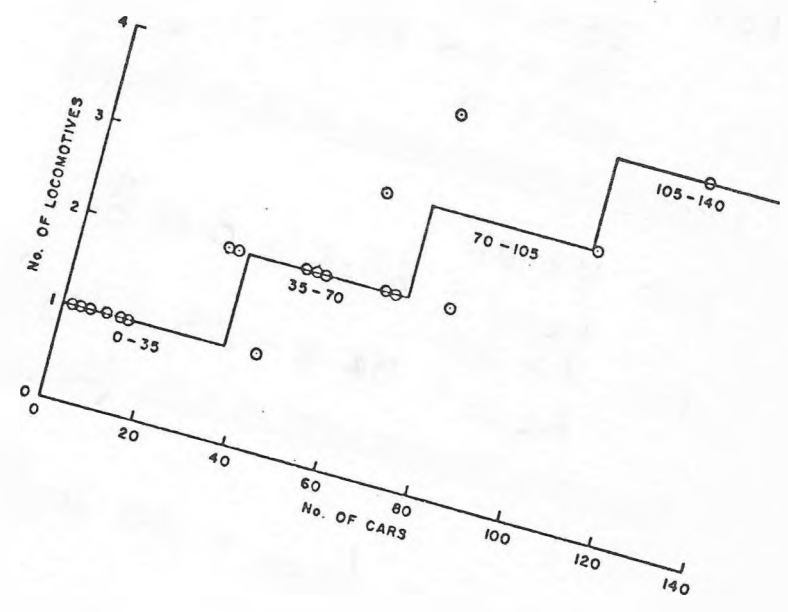
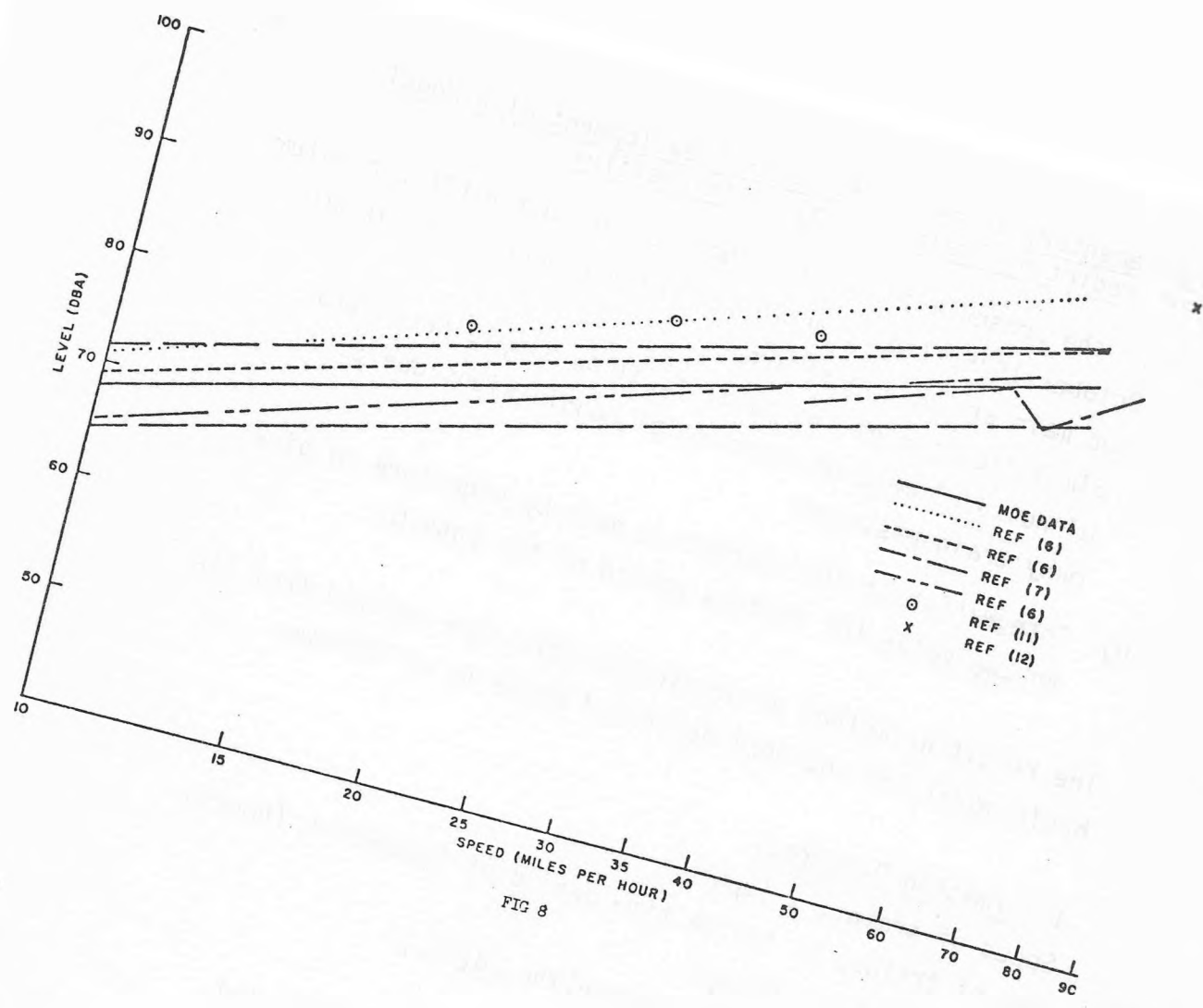


FIG. 6





Supplementary Notes to the Paper "Development of a Model
For Predicting Train Pass-by Noise Profiles"

Since the presentation of the above paper to the CAA Symposium in October 1975, I have performed further work on the model in two main areas. These are:

- a) Simplification of the model to allow simple prediction of noise climate on residential subdivisions due to many train pass-bys.
- b) Integration of the locomotive pass-by signature to give an L_{eq} value for the time period of the pass-by.

The resulting method of prediction which has evolved from the basic model and the work described above is as follows:

Information Required:

Speed of trains, V (mph)

No. of trains, N , in the time period of interest H (hours)

No. of cars per train, n

Distance from the track centreline, d (ft.)

Estimation of the Number of locomotives per train (e)

for	$0 < n < 35$,	$e = 1$
	$35 < n < 70$,	$e = 2$
	$70 < n < 105$,	$e = 3$
	$105 < n$,	$e = 4$

Locomotive Maximum Level at 50 ft. ($L_{L,50}$)

for $V < 20$

$$L_{L,50} = 83.6 + 0.15 \frac{n}{e} \quad (\text{dBA})$$

for $V > 20$

$$L_{L,50} = 94.8 + 23.5 \log \frac{V}{60} + 0.15 \frac{n}{e} \quad (\text{dBA})$$

Locomotive Maximum Level at d ft. ($L_{L,d}$)

$$L_{L,d} = L_{L,50} + 20 \log \left(\frac{50}{d} \right) \quad (\text{dBA})$$

Locomotive L_{eq} at d ft. ($L_{EQ,L}$)

$$L_{EQ,L} = L_{L,d} + 10 \log \left(\frac{d}{55} \right) + 3 \quad (\text{dBA})$$

(L_{eq} , L turns out to be higher than expected as the time of the pass-by will be taken as the time for which the locomotive is in front of the observer. 55 ft. is a representative length for a locomotive.

Locomotive Time (T_L)

$$T_L = e.N. \frac{55}{V} \cdot \frac{15}{22} \quad (\text{seconds})$$

Wheel/Rail Level at 50 ft. ($L_{W,50}$)

$$L_{W,50} = 87.8 + 25.7 \log \frac{V}{60} \quad (\text{dBA})$$

Wheel/Rail L_{eq} at d ft. ($L_{EQ,W}$)

$$L_{EQ,W} = L_{W,50} + 10 \log \frac{50}{d} - 5 \log \left\{ 1 + 4 \left(\frac{d}{57n} \right)^2 \right\}$$

(the final term will be negligible if $d < \frac{1}{4} \cdot 57n$)

Wheel/Rail Time (T_W)

$$T_W = n.N. \frac{57}{V} \cdot \frac{15}{22} \quad (\text{seconds})$$

(57 ft. is a representative length of each car)

Total L_{eq} over time period H hours

$$L_{EQ} = 10 \log \frac{1}{H \cdot 3600} \left\{ 10^{0.1 L_{EQ,L} \cdot T_L} + 10^{0.1 L_{EQ,W} \cdot T_W} \right\}$$

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