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RAIL VEHICLE NOISE

BY

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and AUTHOR'S CLOSURE

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ASME-AIEE-EIC Joint Railway Conference Paper No. 62-EIC-RR1

RAIL VEHICLE NOISE

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THERE WAS a time when noise from rail vehicles — especially subway trains — was always placed at the top of the list of unpleasant noises. In recent years the picture has changed somewhat. On the one hand even more noisome noises such as jet aircraft have become commonplace; and on the other, there has been a substantial effort to reduce rail vehicle noise. The worst offenders have been retired and what is more the whole category of street cars has been largely replaced by buses or underground systems. The general attitude about underground systems has changed too. The earliest ones were purely utilitarian, and they looked it and sounded like it; today the customer expects to be transported not only rapidly but in reasonable comfort. The main thread of this discussion will therefore be rapid transit problems, although there will be an occasional reference to a comparable problem in railroad systems.

What constitutes a noise depends on your point of view. A passenger on a rapid transit system has a vested interest in it — he wants to be transported somewhere rapidly — and he will tolerate a certain amount of noise in the accomplishing of this. The dweller in an adjacent apartment, on the other hand, has no such interest, and will not appreciate hearing trains passing through his bedroom or living room. Measures for the control of noise also depend on whether you consider occupants of subway trains or of adjacent buildings. Hence it will be necessary to distinguish between the two viewpoints when discussing noise control problems.

CRITERIA

It has been suggested that the subway passenger tolerates a reasonable amount of noise. It would be more precise to say that he prefers a certain optimum amount of noise. Certainly the level must be kept below the range of discomfort or pain. Somewhat below this is the level at which speech communication becomes possible. The passenger will wish to be able to talk to his nearest neighbours, say at a range of two to four feet, in a raised voice if necessary. This marks the upper limit of the optimum range. The lower limit is determined by the fact that he does not ordinarily wish to talk or listen to all the rest of his fellow travellers. One can express rather precisely the noise requirements that will permit conversation, perhaps in a raised voice, at two to four feet but make communication increasingly difficult beyond that range.

Speech intelligibility depends mainly on the middle frequencies (about 500 to 2000 cycles/sec). This is also the range of maximum sensitivity of the ear, and hence the region that matters most in determining the subjective impression of loudness of a complex sound. The two factors, loudness and speech communication, are both found to govern the acceptability of noises and the well-known noise criteria, or NC curves, which take both factors into account are useful in classifying complex noises. Fig. 1 shows the application of these criteria to the subway noise problem. A suitable objective is the range NC-55 to NC-65; the NCA-65 contour is equivalent to NC-65 from the viewpoint of speech intelligibility, but is less acceptable from the viewpoint of loudness. A further requirement in applying these criteria is that the noise have a continuous frequency characteristic with no discrete frequencies, which have a more disturbing effect than can be judged simply by their intensity. Such noises as the whine of a motor-generator or the clatter of a compressor are in this category. The lower limit of the optimum range is actually below NC-55, perhaps NC-50 or NC-45; this is an appropriate objective for railroad coaches which travel at high speeds for long periods. But in a subway system maximum speed is reached only for a minute or so at a time between stations, and at every stop there is a shuffle of incoming and outgoing passengers that raises the level to about NC-55 in any case.

Also shown in Fig. 1 are two noise spectra for the Toronto Transportation Commission subway, corresponding to operations with open and closed windows. These measurements were taken at normal speed and on a curve, and represent about the maximum that occurs. It will be noted that the closed-window condition meets the objective fairly well, but the open-window condition is somewhat high.

For comparison Fig. 2 shows similar spectra for the interiors of other vehicles. The top curve is for commercial passenger aircraft. This is said to be "accepted" by passengers, but not, I might say, without some grumbling. As a result the newer aeroplanes, especially the jets, are a little quieter.

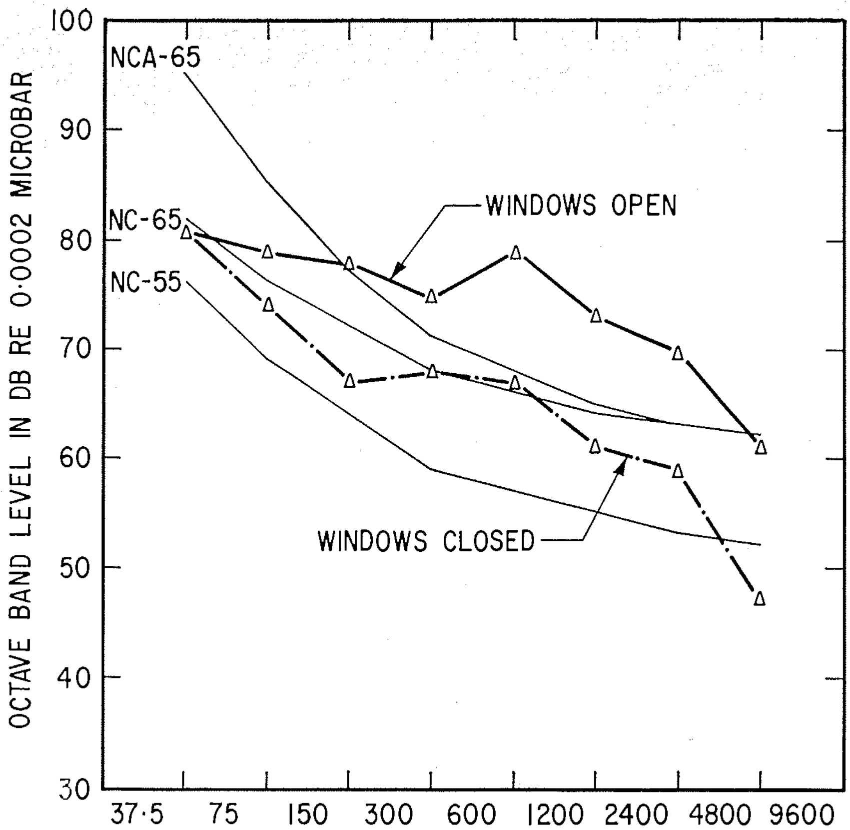

Fig. 1. Recommended criteria for noise inside subway trains.

Also shown are curves for an old streetcar and for the PCC streetcar developed in the U.S. during the thirties. The curve for modern railroad coaches shows that their designers have done a good noise reduction job. This is for a mid-coach position; there would be more low frequency noise toward the ends, over the wheels.

It is more difficult to establish an acceptable level for noise transmitted to adjacent buildings. A conservative objective is to keep intruding noise below the ambient level in each frequency band and thus imperceptible. The ambient level is a highly fluctuating thing and it will usually suffice to reduce subway noise to the same order as other frequently occurring noises.

If a subway line is built below a busy thoroughfare the chances are that it will not add significantly to the total noise produced by traffic. If it traverses a quiet neighbourhood, and especially if it passes under houses, apartment buildings, or special buildings such as theatres or concert halls, there will be a lower ambient level to contend with and a more critical group of listeners.

In dwellings the ambient level will be quite low during the night, and this is the condition to be designed for. The peak ambient level will probably still depend on street traffic, although in winter time it might be determined by internal noises such as that from an oil burning furnace or in the case of a theatre by the ventilating system. An example of the importance of ambient noise is the Royal Festival Hall in Britain. The noise of the subway line beneath it is quite discernible in the empty hall. Fortunately it is no longer noticeable when the ventilation system is on and an audience is present.

Noise Sources and Control

Turning now to the sources of rail vehicle noise, we shall first deal briefly with half a dozen minor ones, leaving to the last the major problem of noise produced by the contact of metal wheels on rails. A frequent problem is brake noise, which in a well-designed system is an unpitched hissing sound, but which in some circumstances becomes a chattering or intense squealing sound. Chattering usually results from play in the brake-block mountings. A high-pitched squeal usually is caused by the excitation of a resonance in the wheels. In both cases the excitation is caused by the friction properties of the brake system. Usually the coefficient of friction increases as the

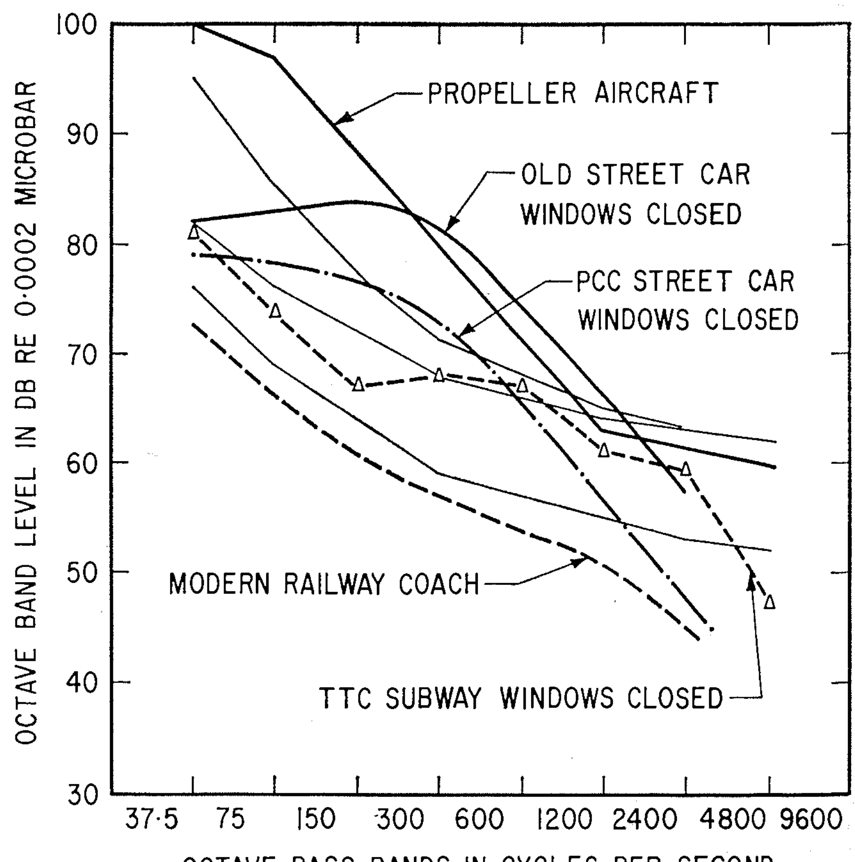

Fig. 2. Typical noise levels inside public vehicles.

relative velocity of the sliding surfaces decreases; if this variation is too rapid the brakes tend to grab and then release, in what is known as a stick-slip process. By a suitable choice of brake material it can usually be avoided. Torontonians may recall the intense brake squeal characteristics of the original subway cars here. This was reduced by using a different type of cast-iron brakeshoe and eventually disposed of completely by using a lining similar to automobile brake lining.

One can enumerate smaller but frequently troublesome noise sources. On some of the older vehicles there used to be a substantial contribution from a primitive spur gear drive, but this is not characteristic of vehicles built in the last 30 years. Nevertheless, even fairly modern vehicles are equipped with noisy air compressors, fans and motor generators. The cures for these problems are simple and well known and will not be dwelt upon here.

Let us now return to the principal noise-producing mechanism: the contact between rolling metal wheels and rails. Noise results from the series of impacts developed because of small irregularities on wheels and rails. Obviously one of the first steps in controlling the noise is good maintenance, the elimination of such major irregularities as flat wheels and corrugated tracks. Open rail joints used to be a problem, now usually disposed of by welding.

Apart from providing smooth-running surfaces the other means of limiting noise at the source is to reduce the weight of the unsprung elements associated with the wheel rim: the intensity of impact and noise is closely related to this weight. In this respect the PCC car design, used extensively for streetcars in North America — and also I believe in the Chicago subway — represents the ideal: the only unsprung weight is the wheel rim connected to the hub by layers of rubber. The motors are separately suspended so as not to add to the axle weight. The main suspension consists of rubber springs introduced between axle and bolster.

A more drastic approach is to use a rubber-tired vehicle as has been done experimentally on one line of the Paris Métro. This has some obvious practical difficulties: metal bogie wheels may still be necessary for guiding the vehicle in a narrow tunnel and for power connections. Hence, if one were not careful, the rail noise problem might still be present.

It has perhaps been implied that the rail, which forms the other half

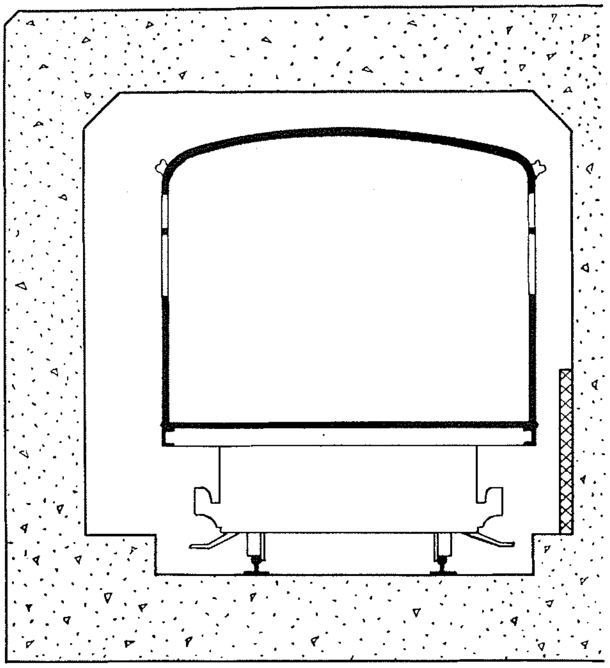

Fig. 3. Application of absorption treatment to subway tunnel.

of the noise-producing mechanism, is a rigid unyielding surface. This is roughly true if it is clamped solidly to a concrete base, but if it is resiliently supported then it also becomes a mass-spring system. If the vehicle has solid wheels rigidly attached to an axle, the rail, in fact, becomes the smallest mass in the system, and its mounting becomes critically important in determining the noise level in the tunnel. It is also important, of course, for determining the transmission of vibration to the underlying structure and to adjacent buildings. The two most important steps in reducing rail noise are to reduce the unsprung portion of the vehicle to a minimum, and to introduce the maximum amount of resilience in the rail mounting. Both measures are important for control of noise in the tunnel and vibrations transmitted to adjacent property.

Apart from modifications to the source, the other approach to noise control is to dispose of the sound before it reaches the passenger. Rail noise is radiated as air-borne sound from the point of contact of rail and wheel. This sound may be transmitted through the floor and walls of the vehicle and through the windows, especially if they are open. Some of the sound is also transmitted directly through the car structure.

In railway coach design air-borne sound is not important — chiefly because the windows are sealed. Structure-borne sound is the major problem, and in the best designs the interior walls and floor — especially the floor — are of double construction, with a resilient link between the inner layers and the main frame.

In the enclosed space of a subway tunnel the air-borne sound is of major importance, although enough low frequency sound is still transmitted via the floor to make a double floor desirable. Air-borne sound can be kept out by making the walls and windows double and keeping the windows closed. Open windows are a serious enough drawback to make an alternative ventilating system desirable. Perhaps, instead of open windows, separate openings could be provided with built-in sound-attenuating sections. The most elegant solution, of course, would be air-conditioning, as in railroad coaches.

Finally, we may consider what can be done with sound absorption treatment in the tunnel. The geometry of a tunnel with a train present is shown in Fig. 3. Peripheral space around the car can be treated as if it were a flat duct, with noise originating at the bottom and getting into the car chiefly through the windows, part way up the side. Lining one side of this duct, especially at the bottom corner, is an effective way of reducing the sound arriving at the window.

The quantitative effects of some of these measures are illustrated in the next few figures. Fig. 4 shows the reduction gained by adding a double floor — this is actually for a bus, for which "before" and "after" data were available, but similar reductions have been achieved for railway coaches.

Fig. 5 shows the value of absorption treatment in a subway tunnel. The first treatment was on one side only and covered only about four feet in height. The new proposal entails treatment of a six-foot strip on each side. Note again the desirability of keeping windows closed.

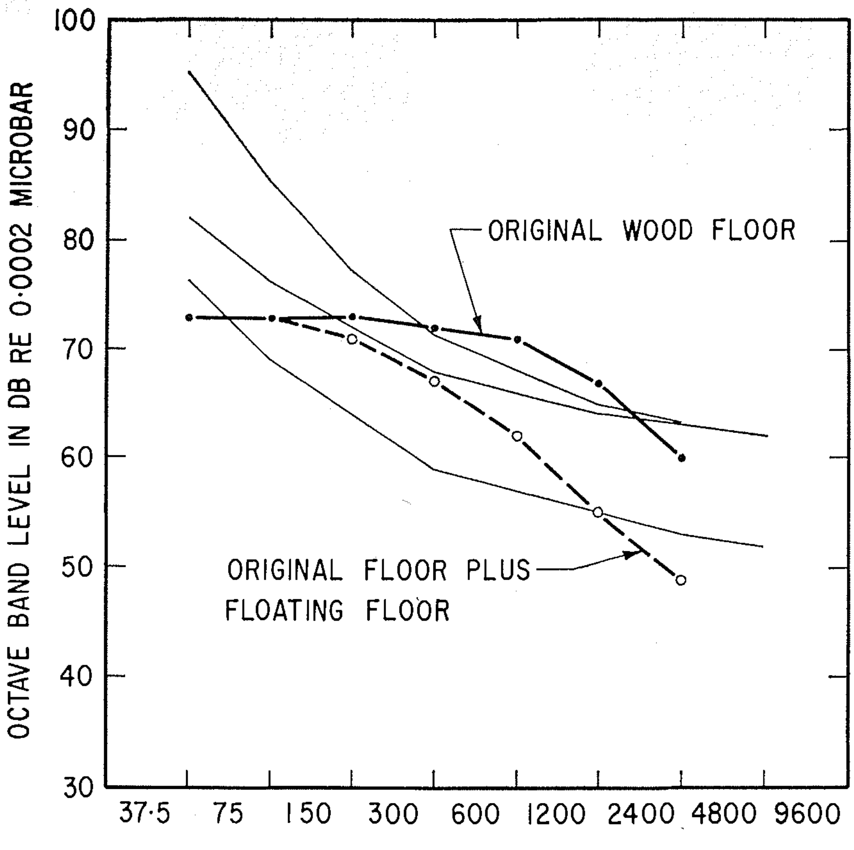

Fig. 4. Noise reduction due to addition of floating floor (in bus).

Two special problems remain to be discussed. First of these is noise in subway stations. Here the people on the platform are not protected by the car body, and here also the noise of an approaching train is augmented by brake noise. It is desirable to shield as much as possible the noise-producing areas from the station platform and to provide thorough absorption treatment of the station enclosure.

The second special problem is the increased noise and squeal that frequently occurs on curves. In part this is simply the result of the tendency of cars to bear to the outside of a curve until the flanges of the outer wheels rub on the rails. One could take care of this, perhaps, by increasing the elevation of the outer rail, but the matter is complicated by a more basic difficulty; since the inner and outer wheels are rigidly connected to a common axle there must be some slip to compensate for the difference in path length of inner and outer rails. The squeal that develops is similar to brake squeal. Again a wheel resonance vibration is induced by a stick-slip phenomenon. Possibly it could be eliminated by making the rails, for curves at any rate, from a slightly different material with different friction properties. A simple but inelegant solution is to spray the rails with water.

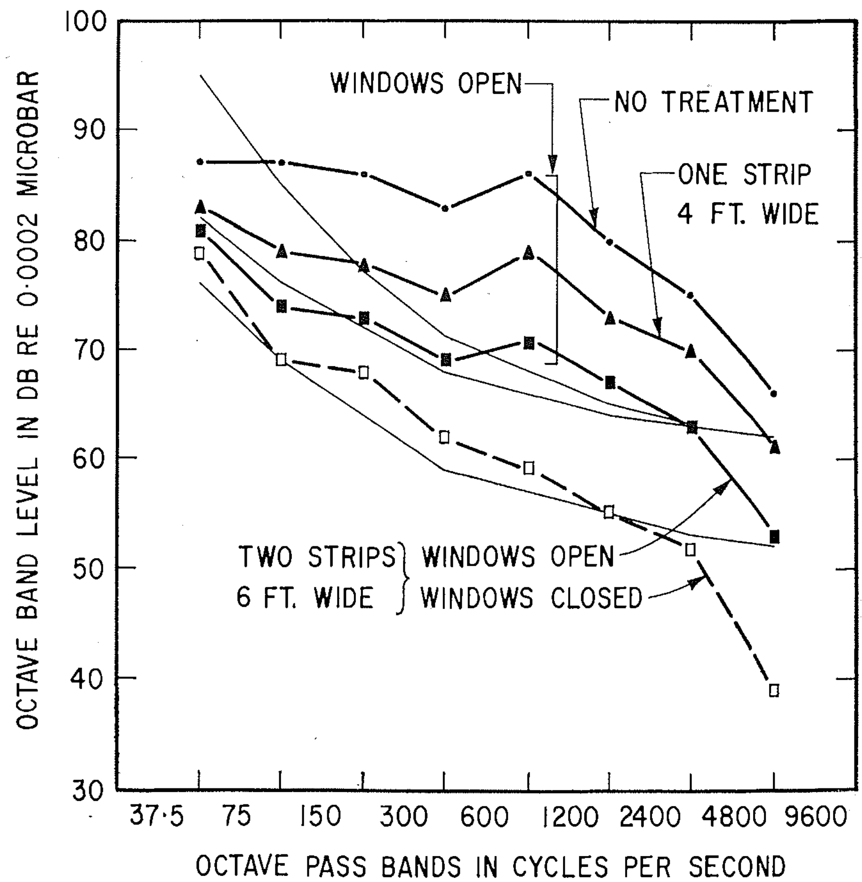

Fig. 5. Effect of tunnel absorption treatment on noise inside subway trains.

In this presentation I have tried to comment on the major sources of rail vehicle noise, and to indicate how much can be done by various methods of noise reduction. It may be seen that when some of these noise reduction techniques are applied a subway train compares favourably with other types of public travel, and in fact meets the objective of providing a noise level low enough for comfortable conversation with one's nearest fellow passenger. The remaining problem, of course, is to determine how far it is profitable to go in the effort to make the customer comfortable. With this problem in mind I have been as quantitative as possible about the engineering aspects. My only comment about the economic aspect is that noise control measures are most economical when incorporated in the initial design.

Noise in adjacent buildings is not as clear-cut a problem; but when the ambient noise level in the region is low it becomes critically important to provide a resilient support for the track and/or to provide a resilient layer in the vehicle wheels.

Acknowledgment

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Discussion

RAIL VEHICLE NOISE

T. D. Northwood

Head, Building Physics Section, Division of Building Research, National Research Council, Ottawa

The Engineering Journal, January, 1963 page 30

Discussion by A. T. Edwards, Hydro-Electric Power Commission of Ontario

Discussion by Ian J. Billington, Dilworth, Secord, Meagher and Associates, Toronto

It has been my pleasure to have been associated with Dr. Northwood on a number of co-operative studies during the past few years. Among these is included the development of a rail supporting system for suppressing ground-transmitted noise and thus I much appreciate this opportunity of discussing his paper on railroad noise.

I very much like Dr. Northwood's concept of optimum noise. In these times when there is a growing awareness, by the general public, of noise, we are apt to believe that the lowest possible noise level for any environment is the ideal objective. Recently I had the experience of an office noise problem where the ambient level is actually so low that it is possible to hear a pin drop, say 50 ft. away. This has resulted from two factors. The first is that the building is air-conditioned and thus is impervious to outside noise and the second is that the ventilating equipment is exceptionally quiet. Actually in this office there would be very much less disturbance from other workers sharing the same space if the ambient level had been 10 decibels higher but it has been difficult to get the rather unusual idea of raising the noise level accepted. Dr. Northwood's criterion of an ambient level in which it is possible to converse easily at 3 or 4 ft. but not be understood at greater distances seems very logical and should be quite satisfactory for rapid transit cars. In this connection, for the benefit of those who are not conversant with acoustical terminology, I would suggest that perhaps it would be worth-while, if there is time for Dr. Northwood to quickly define for you such terms as, decibel, loudness, NC and NCA. I wonder also whether NC 65 is not somewhat too high as I have found it difficult to converse in noise levels with a speech interference level of 60-65 decibels.

I have little further comment to make on the noise within the rail car other than to remark on the rather surprising effectiveness of the treatment of the tunnel walls. Is this result predictable? Would Dr. Northwood also comment on the desirability or otherwise of acoustically treating the internal surfaces of the car and of providing vibration damping on the outer shell of the car to reduce the effects of structurally-borne vibration and induced vibration generated by aerodynamic effects resulting from the movement of the train through the air.

I would like to discuss in more detail the problem of ground-transmitted vibration. The noise that is generated in buildings close to subways may travel by both the air-borne and ground-borne paths. In general the air-borne noise does not appear to be a problem with exception of the rail squeal, already referred to by Dr. Northwood. The ground-borne noise, however, can be significant and troublesome. We have measured in a few buildings adjacent to the Yonge Street subway an increase in noise level of 20 decibels when a train passes, and this is a justifiable cause for complaint by the residents. Dr. Northwood has pointed out that this source of noise is dependent on the maintenance of the rolling-stock. Our observations indicate this is associated with the mechanical braking system used on the present TTC cars and is due to irregularities in the wheel surfaces. This is produced in two ways:— occasionally, in the open-cut section in wet conditions, the mechanical brakes can lock a wheel and thus cause it to slide along the rail. This can generate flats, ½ in. to 3 in. in length, across the periphery of the wheel. A more frequent cause of irregularity is due to non-uniform pressure of the brake shoe against the tread of the wheel. The non-uniformity of the pressure arises from the holes in the composition lining which facilitate the riveting of it to the shoe. Along the line of the rivet holes excessive temperatures develop which cause the surface of the wheel tread to melt. The molten metal is carried off and deposited on other parts of the wheel. The deposited metal often builds up in the form of a ridge of the order ⅛ in. high.

Recently we have measured, in the Yonge Street subway, a 20-decibel improvement in the transmitted noise as compared to that generated by the rolling stock a year ago. This apparently is a reflection of improved maintenance and of the fact that the TTC now has six trains fitted with regenerative braking which should greatly reduce the possibility of producing out of roundness of wheels.

The ground transmitted noise can be substantially reduced by mounting the rails on elastic members. The following table shows the performance of various types of rail pads which have been evaluated in controlled tests on the Yonge Street subway.

Type of Pad	Reduction in Transmitted Noise, decibels
Steel	0 (reference)
Lead-Asbestos pad	1
Neoprene Pads	
½ in. 68 Durometer (tightly clamped)	14
½ in. 68 Durometer (unclamped)	17
½ in. 45 Durometer (tightly clamped)	21
½ in. 45 Durometer (unclamped)	24
1 in. 45 Durometer (unclamped)	24

This result shows that the lead-asbestos, as would be predicted, is virtually useless in reducing ground-transmitted vibration. Neoprene pads are very effective although it did appear, with the condition of the rolling stock a year ago, that it would be impractical to get sufficient reduction by the use of neoprene pads.

Finally, I would like to draw on our experience with an analogous problem to make a more general comment regarding ground-borne vibration. Our organization has been concerned with the transmission of vibrations from substation power transformers through the ground to adjacent buildings. Early attempts to solve the problem followed the usual simple procedure of choosing mounting elements whose stiffness, in combination with the transformer mass, would indicate a suitable resonance frequency well below the disturbing frequency. Design charts for this purpose are available from any manufacturer of vibration-isolating devices or materials. But the elastic properties of the mountings so chosen were very like those of the underlying soil, and the mountings therefore made no significant change.

The point to be noted here is the necessity of considering the whole transmission path. To be effective a vibration-isolating pad or mounting must introduce a substantial discontinuity between the disturbing body and the adjacent structure or medium. If the adjacent material is soil, or even concrete or rock, the use of relatively stiff materials such as layers of cork, lead or asbestos board may not be very helpful.

At the outset I should like to compliment Dr. Northwood on his most interesting and informative paper. To the laymen, the field of acoustics and even its special vocabulary are apt to be confusing; a situation which stems largely from the difficulty of measuring and describing noise phenomena in a meaningful manner. Dr. Northwood has managed to cover a rather complex acoustic problem in a clearly understandable manner while employing a minimum of acoustic terminology. In this respect I was intrigued by his criteria for the desirable noise level in a subway car.

For the benefit of those who may not be familiar with the "noise criterion" curves shown in several of Dr. Northwood's figures, the following comments may be of interest. These curves are based on the degree to which a background noise will interfere with speech communication. The "NC" numbers attached to these curves represent the average sound level in that portion of the frequency spectrum which is most important from the point of view of speech intelligibility. For background noise approximating any particular NC curve it is possible to specify quite precisely how the ease of voice communication will vary with distance. It is also possible to use these curves as criteria for noise control in rooms and enclosures of various kinds. For example the NC-55 curve is considered to be the maximum permissible level for secretarial offices with typing. The sleeping areas of a dwelling should have a level below NC-25.

As a matter of interest I have compared some of Dr. Northwood's graphs with measurements which we have taken under various conditions. Some readings which we obtained of the ambient noise level on a street in downtown Montreal, but without moving vehicles near the microphone, correspond almost exactly with the NC-55 curve mentioned above. Another set of readings, taken in an enclosed railway station in the absence of moving trains, compared more closely with Dr. Northwood's curve for a modern railway coach and would correspond approximately to NC-45. The U.S. Air Force "Handbook of Acoustic Noise Control" also presents some data relevant to the present discussion — sound levels for a moving subway train at 20 ft. distance from the microphone. This is found to lie close to the NC-75 curve. It would be of interest to know how this compares with the TTC Yonge St. line.

The application of absorption treatment to the walls of the subway tunnel is a novel concept. I should like to know the source of the experimental data presented on this method. There are economic aspects to this problem — whether to treat the tunnel or the cars to obtain a specified noise reduction inside the train. I would also be interested to know whether treatment of the tunnel has any beneficial effects with respect to noise transmission to adjacent buildings. It appears that there is considerable room for further study in this area.

I suspect that many readers may wish to pursue this subject in greater depth. In this connection I should like to ask Dr. Northwood if he could suggest any references which might be a suitable starting point for further study.

Author's Reply

I thank Mr. A. T. Edwards and Dr. I. J. Billington for their illuminating discussions, which help to fill in a few areas where my paper was unduly brief. Perhaps the major omission was documentation; I append a list of references that elaborate on the various topics sketched in the paper. Reference 2, in particular, is a thorough review of the whole subject. The experimental data on subway noise are extracted from our studies on the Toronto system.

Both discussors have amplified usefully my discussion of the Noise Criteria (NC) Curves; these are discussed in further detail in Reference 1. Perhaps it might be added that although the NC curves are used in many applications they were developed specifically for office communication problems. The oppressively quiet office described by Mr. Edwards probably corresponds to about NC-30; a noise spectrum corresponding to NC-40 or 45 would provide some protection from other people's noise without interfering with normal short-range conversation. Regarding Mr. Edwards' doubt as to the suitability of NC-65 for subway trains, I would emphasize that this was proposed as an upper limit for the highly fluctuating sound characteristic of subway service. Communication, albeit in a raised voice, is still possible at 3 ft., but I agree that NC-65 would be too high for sustained noise.

Both discussors express surprise at the use of the absorption treatment in the tunnel and query the alternative of treating the interiors of the cars themselves. Other things being equal, the latter course would obviously be cheaper, since all the treatment would be concentrated near the noisy locations. Things are not equal, however. The tunnel may be regarded as a peripheral duct (around the train), with absorption treatment applied at the right-angle bends near the source. Absorption treatment in this ideal position may be expected to yield an attenuation of 10 to 15 db immediately opposite the wheels, and somewhat more in the space between wheels. To achieve an equivalent effect simply by treatment inside the car would require a thirty-fold increase in interior absorption, which is impossible.

The measures mentioned by Mr. Edwards for improving the sound insulation of the car body are useful and important. In a noise problem of this severity it is necessary to take all reasonable control measures to achieve an adequate over-all reduction. Aerodynamic noise, about which he inquires, is of negligible importance, compared to rail noise.

The tunnel absorption treatment is not relevant to the problem of noise transmission to adjacent buildings since air-borne sound is disposed of by the intervening layers of concrete and soil. Ground- or structure-borne vibration is the major source of trouble beyond the confines of the subway system. I cannot usefully add to Mr. Edwards' comments in this regard, which I commend to Dr. Billington.

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