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THE DEVELOPMENT OF A TEST PROCEDURE FOR THE MEASUREMENT OF LORRY TYRE NOISE

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1. INTRODUCTION

The noise emitted by road vehicles is subject to regulation in many countries. The test method currently used in the EEC is based upon the "full acceleration" test specified in the International Standard, ISO R362 (International Standards Organisation, 1964). Recently, a European Commission Working Group known as ERGA–Noise has considered further changes to the motor vehicle noise Directive and has made recommendations to the Commission that a separate test procedure for tyre noise should be introduced. These recommendations reflect the realisation that simply limiting the noise from the power unit alone will not greatly affect the noise emitted by vehicles operating at both moderate and high passing speeds. Under these conditions, the noise generated by the tyres is often the dominant noise source. The EC has accepted the proposals of the Working Group and has asked the Transport Research Laboratory in the United Kingdom to carry out a programme of research to develop a suitable test procedure for lorry tyres. This Paper reviews the options available for tyre noise testing and discusses the rationale behind the experimental methodology that was used in this study. The Paper briefly describes the measurements that were taken and the results obtained[1].

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[1] A full description of the study including the recommendations for a tyre noise test procedure are contained within the final Report to the European Commission, Directorate General for Internal Market and Industrial Affairs (DG3).

2. EXPERIMENTAL DESIGN CONSIDERATIONS

In order to determine a suitable test procedure for the regulatory control of lorry tyre noise, it is necessary to satisfy three basic requirements. These are that the method should be simple to perform, and should give **repeatable** and **reproducible** results and should be **representative** of tyre noise generated by vehicles in road traffic situations. Provided these conditions are fully met it is anticipated that effective tyre noise regulations could be introduced via European Community regulations.

In order to determine a suitable test procedure, several methods of tyre noise testing were considered.

2.1 Possible Test Procedures

The various methods of measuring the noise generated by tyre/road surface interaction can be broadly categorised into three groups:-

- coast-by method
- trailer method
- laboratory drum method

For the purpose of developing a suitable test procedure for lorry tyres, this study concentrated on comparing the relative suitability of the first two methods. The drum method was not included in view of the uncertainty associated with the reproducibility and representativity of the noise levels obtained with drums.

Briefly the **coast-by method** involves measuring the noise from tyres fitted to a test vehicle which is coasted past the measurement microphone with the engine switched off. This type of test offers the advantage of simplicity and representability, where the noise generated has a close correlation with that generated by moving vehicles in traffic. The main disadvantages are that there may be an influence from the type of vehicle used as noise may be generated by the prop-shaft bearings, drive axle differential, wheel hub bearings. In addition, the body of the vehicle may affect the propagation of noise In addition noise will be generated by the tyres mounted on the other axles.

The **trailer method** involves mounting a test tyre or tyres on a trailer which is towed behind a car or truck. Microphones are normally positioned close to the test tyre(s). This method offers high precision and reproducibility and measurements are relatively simple to carry out. The main disadvantages of the method are that measurements taken in close proximity to the tyres tend to emphasise the directional characteristics of the noise that is generated which may, therefore, not be representative of the noise propagating from actual traffic streams, and the fact that vehicle mounted microphones are affected by turbulence at the microphone diaphragm at speeds above about 70–80 km/h which effectively limit the range of tests that could be carried out.

Some of the problems with measuring the noise in the near field using a trailer can be overcome by taking measurements of noise from the trailer tyres using a trackside microphone position, eg 7.5m from the centre line of the test track, provided the influence of noise from the towing vehicle can be sufficiently eliminated from the measurements of noise from the trailer tyres. The ability to discriminate between the noise emitted by the test tyres and other sources including the towing vehicle can be achieved in theory by using a specially quietened towing vehicle and a long trailer boom to separate the towing vehicle from the test tyres mounted on the trailer (Sandberg and Ejsmont, 1992). The main advantage is that wind noise is not a problem for this type of measurement and so representative passing speeds can be tested, and the unwanted effects of directionality, which are present in close proximity, are largely eliminated.

TRL have therefore conducted measurements of the noise generated by a range of test tyres fitted to a specially constructed trailer towed behind a quietened vehicle and with the tyres fitted to a standard rigid truck. In both cases measurements were taken with microphones at 7.5m and in close proximity to the test tyres.

3. EQUIPMENT, FACILITIES AND TYRE SELECTION

3.1 Vehicles

Two vehicles were used for the TRL study. The TRL Quiet Heavy Vehicle (QHV), which acted as the towing vehicle for the tyre trailer, and a standard production Renault Dodge flatbed truck.

The TRL Quiet Heavy Vehicle (QHV) is a quietened 38 tonne tractor and was the first of its type to have the noise level reduced to 80 dB(A) measured according to the ISO drive-by test. Its quietened Rolls Royce Eagle engine develops 258 kW and is capable of operating at the current maximum carrying capacity of 38 tonnes.

A standard production flat bed rigid truck was chosen because it was relatively easy to adjust the loading on the test tyres by modifying the static load placed on the bed of the vehicle. The vehicle chosen was powered by a turbo-charged diesel engine developing 119 kW maximum power and was plated for a maximum carrying capacity of 16 tonnes.

3.2 Tyre trailer

A lorry tyre trailer was designed specifically for this study. The trailer consisted of a single axle assembly supported by air suspension units to ensure quiet running. The axle was attached to the towing vehicle by a beam having a minimum cross section consistent with strength to reduce air resistance and hence aerodynamic noise. The distance between the vehicle rear axle and the trailer axle was approximately 10m. This distance was determined by preliminary calculation of the likely contribution of the noise from the towing vehicle and the need to ensure that the whole rig would remain stable under high speed driving conditions. A loading tray was positioned over the trailer axle to allow the addition of static concrete weights to vary the loading applied to the test tyres. Figure 1 shows the tyre trailer connected to the QHV.

3.3 Tyres

Eight types of tyre of identical dimensions (315/80 R 22.5) were identified for testing and were chosen taking into account the views of the manufacturers, the market share of each tyre and the range of possibilities that might be offered for type approval. The selection comprised of a set of slick tyres (for baseline measurements), three sets of drive axle tyres, three sets of steer axle tyres and a set of off-highway tyre. Figure 2 shows examples of the tyres used.

3.4 Test track

As tyre noise levels are dependent upon the road surface, two different track surfaces were chosen for study from the range of surfaces available on the TRL test track facility. The surfaces chosen were a coarse textured hot rolled asphalt surface (HRA) made with a maximum aggregate size of 20 mm designed specifically for high speed motorway traffic conditions and conforming to the specification given in BS 594 (British Standards Institute, 1985), and a smooth fine rolled asphalt material (FRA) made with a maximum aggregate size of 10 mm. This material is not suited for high speed road applications but would be suitable for lightly trafficked residential streets and car parks. The materials specification conforms to BS 1690 (British Standards Institute, 1962).

4. EXPERIMENTAL METHODOLOGY

Initially noise measurements were taken using the QHV tractor coasting over both test surfaces. This was done to establish some baseline noise levels for the vehicle which could then be used to isolate and determine the noise from the test tyres mounted on the tyre trailer. Throughout these tests the QHV was fitted with specially manufactured slick tyres made to normal tread thicknesses. These were fitted to both the steer and drive axles (single configuration). Following the baseline measurements the tyre trailer was attached to the QHV tractor and a similar series of coast-by tests were carried out using the full range of tyres selected for this study. Noise measurements were also taken with the same test tyres mounted on the drive axle of the flat bed truck . In all cases slick tyres were fitted to the steer axle of the truck.

Prior to testing, loads were applied to the test tyres mounted on the trailer or on the flat bed truck using concrete blocks. The loads were chosen according to whether the tyres were designed for drive axle or steer axle applications and were taken to be representative of the maximum loading likely to be encountered in practice. Table 1 lists the loadings applied to the test tyres in each case. The Table also includes the tyre pressures used for each tyre tested. The tyre inflation pressures were set according to the manufacturers recommendations and were held at these values during the course of the testing. Tests were conducted with the tyre trailer and QHV on both the test surfaces. The tyres mounted on the flat bed truck were tested on the rough surface only.

4.1 Measurement method

Measurements of coasting noise were taken at different passing speeds. In order to facilitate the measurement of both the position and speed of the vehicles the track surfaces were marked out with reflective tape. The strips were placed at one metre intervals along the centre line of the track and alongside one edge of the test surface. Infra-red transmitter/receiver units were fitted to the QHV tractor and flat bed truck and were arranged so that the light beam emitted from the transmitter was reflected from the strips and detected by the sensor as the vehicle was driven through the site. The marker strips and sensor unit were positioned for each vehicle so that the initial trigger occurred at the point when the leading edge of the contact patch of the test tyres mounted on either the trailer or the flat bed truck would pass over the start position of the test site.

The sensor unit was designed to produce a trigger pulse each time a reflection was detected. The trigger pulses generated by the sensor were relayed to a data logger located in the cab of the vehicle which stored the pulses as a function of time on disc for later analysis of position and speed. The sensors on the vehicles were also synchronised with a second infra-red transmitter/receiver unit positioned alongside the test track. This unit also detected the point at which the test tyres pass over the start line during a test and was triggered by focusing the beam on a reflective panel located on the side of the vehicle.

Noise measurements were taken at a microphone located 7.5 metres from the centre line of the test surfaces. In all cases vehicles were coasted past the microphone at various speeds within the range 60 -90 km/h. During each coast-by test, the signal from the trackside microphone was relayed to a 1/3rd octave band frequency analyses which was programmed to record and store a complete 1/3rd octave band spectra every 2 milliseconds. The instrument was capable of storing a maximum of 1000 individual spectra during each pass-by test giving a total interval of 2 seconds during which data was collected. The instrument was triggered using the trackside infra-red sensor so that data collection only commenced at the point when the tyre mounted on the trailer would have passed over the start position at the entrance to the test strip. This information together with overall dB(A) levels were stored on disc for later analysis.

Noise measurements were also taken in close proximity to one of the test tyres. Previous work had recommended that close proximity measurements should be taken using a microphone located 0.4m outside the undeflected tyre sidewall and 0.1m above the road surface with the microphone pointing towards the tyre sidewall at an angle of 135^0 to the direction of travel (Economic Commission for Europe, 1986). For this study two microphones were employed, one located at the 135^0 position, as recommended by the ECE, and a further microphone located at 90^0 to the direction of travel. The second microphone located at 90^0 to the direction of travel was intended to be used to enable a fuller description of the directionality characteristics of each tyre to be made. However, both microphones were located at 15 cm above the track surface and not at 10 cm as recommended by the ECE. This was found to be necessary to avoid the risk of grounding the microphones during normal driving.

During the measurements, the signals from the close proximity microphones were relayed to a high quality dual channel tape recorder located in the cab of the vehicle. Recordings were triggered using the commentary track on the tape recorder to ensure that the data was recorded on the test surface only.

Prior to every test session the air temperature and track surface temperature were taken and wind speed and direction was monitored during the course of the experiments. Before commencing the tests the vehicles were driven for approximately 20 minutes to ensure that the engine components and tyres were at normal operating temperatures for the prevailing conditions.

A plan of one of the test sites shown in Figure 3. The Figure indicates the vehicle position strips, the microphone positions and equipment layout. Figure 4 shows details of the close proximity microphone positions used.

5. ANALYSIS AND RESULTS

5.1 Data analysis procedure

The analysis of the coast-by data initially involved the synchronisation of the coast-by noise recordings taken at the 7.5m microphone and the vehicle position and speed recordings taken using the data logger located in the cab of the vehicles. This was achieved by transferring the vehicle position data stored for each test to a PC. Under the control of appropriate software, the time between each position pulse was determined and the speed of the vehicle at each position along the test track was calculated. The data at the trackside microphone was also transferred to a PC and the 1/3rd octave spectra corresponding to each trigger pulse was determined by synchronising the two records. In this way, for each test, the speed and noise levels in both third octave and overall dB(A) terms were determined for each position along the test strip. At each of the track surface marker positions, the noise levels at each of the speeds tested were regressed against the logarithm of speed and the resulting regression line was then used to determine the coast-by noise time history at any given speed. The same technique was used to determine time histories for the QHV tractor alone, for the QHV and tyre trailer combination and for the flat bed truck.

Analysis of the close proximity microphone measurements taken on both the tyre trailer and flat bed truck involved re-playing the recordings to a frequency analyzer. The analyzer was set up to determine an overall level in dB(A) and the level was averaged over a one second period selected from each recording to correspond with the period when the test tyres passed over the test surface. This data was then loaded on a PC and using the average speed calculated from the position data, all the runs were regressed.

5.2 Results

Measurements taken with the QHV and tyre trailer

Figure 5 shows three coast-by characteristics obtained from measurements taken at the 7.5m position alongside the HRA surface. The values have been normalised to a passing speed of 80 km/h. The Figure shows the coast-by characteristic for the QHV alone, fitted with slick tyres, as well as the total noise obtained at each marker position for the QHV/trailer combination. In this case the tyres fitted to the trailer were a set of steer axle tyres (Tyre A). The coast-by characteristic obtained for the test tyres was obtained by subtracting, at each marker position, the noise recorded for the QHV alone from the total noise emitted by the QHV/trailer combination. It can be seen in this example that the peak noise level from the test tyres is indicated to occur at approximately 15m beyond the start position whereas the peak from the characteristic obtained for the total noise generated by the QHV/trailer combination occurred at approximately 5m from the start position.

Using the above procedure, the peak noise level in dB(A) has been determined for each tyre mounted on the tyre trailer running on both surfaces. The results obtained for speeds of 70, 80 and 90 km/h are given in Table 2. It should be noted that data for tyre F coasting on the FRA surface was not collected.

This data shows that the tyre noise levels recorded on the FRA surface were generally lower than on the HRA surface apart from tyre E which was noisier on the FRA surface at all speeds and tyre G which was noisier at 90 km/h. It can also be seen that the increase in noise with increasing speed differs according to the tyre and road surface combination studied.

Close proximity microphones

The results of the measurements taken at the close proximity microphones mounted on the tyre trailer are given for coasting speeds of 70, 80 and 90km/h in Table 2 Included in the Table are the data obtained from both the 135^0 and 90^0 microphones and the mean of the two values for each test condition.

The most striking feature about this data is the distinct difference between the ranges of noise registered at the 135^0 microphone for the test tyres coasting over the FRA surface and the HRA surface. For example, at a coasting speed of 80 km/h the close proximity noise levels at the 135^0 microphone gave a range of 7.7 dB(A) for the FRA surface whereas the corresponding range for tyres coasting over the HRA surface was only 1.9 dB(A). It is also evident from the data that the location of the close proximity microphone can also affect both the overall magnitude of noise generated by different tyres as well as the rank order of noise. These results clearly illustrate the influence of directionality of noise radiated by the test tyres on the noise measured at the close proximity microphones.

Flat bed truck

The peak noise levels determined from the measurements taken at the 7.5 metre microphone and the average noise levels determined from the measurements taken using the close proximity microphones are listed in Table 3. It can be seen that there are significant differences in the rank ordering of the noise from the test tyres according to the measurement position adopted. For example, the noisiest tyre was found to be tyre E when measured at the 7.5m microphone position but was only rated 5th noisiest when measured in close proximity at the 135^0 microphone position.

Comparison of noise from tyres mounted on the tyre trailer and flat bed truck

As part of the process of evaluating the relative merits of the different options available for measuring and testing the noise generated by truck tyres, it is useful to compare the results obtained by the different methods. A convenient approach is to compare the rank ordering of the noise levels measured according to each test.

Table 4 gives the rank order of noise levels from the results obtained with the tyre trailer and the flat bed truck coasting on the HRA surface at a speed of 80 km/h. The convention adopted in ranking the noise levels was to assign a ranking of 1 to the noisiest tyre with 7 denoting the quietest. Included in the Table are the values obtained for both close proximity microphones together with rankings for the mean values. The final column of the Table gives a total rank order score which was obtained by summing the scores for each tyre across the different methods of testing. The column of rank order scores which has been highlighted in the Table is the peak coast-by noise levels obtained for the trailer mounted tyres alone.

The Table shows quite clearly that there are differences in the ranking produced by the different methods. Perhaps the most obvious example can be seen by examining the results obtained for tyre E which is a drive axle tyre. This tyre was found to be the noisiest tyre tested in most cases apart from the measurements taken in close proximity at the 135^0 microphone position where it was found to be 4th or 5th noisiest depending upon whether the results were obtained from tyres mounted on the trailer or on the flat bed truck respectively. Another important observation to note from Table 4 is the very close agreement in the rank order of the results obtained at 7.5m for the trailer mounted tyres (highlighted) and the ranking produced from the results obtained at 7.5m for the tyres mounted on the flat bed truck. For this comparison the ranking for the noisiest four tyres was identical and there was also agreement over the quietest tyre. Although the 5th and 6th noisiest tyres were transposed in the different rankings, it should be noted that the coast-by noise levels for these two tyres, obtained using the trailer method, were almost

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identical.

6. DISCUSSION AND CONCLUSIONS

Using a specially designed tyre trailer, the noise levels generated by a representative range of truck tyres have been obtained and these levels have been compared with the results of measurements taken in close proximity to the test tyres. In addition measurements of coast-by noise have been taken with the tyres mounted on a flat bed truck and these levels have also been compared with the measurements at 7.5m obtained using the tyre trailer.

This comparison has enabled the merits of different methods of measuring tyre noise to be assessed. For example, it has been confirmed that differences in the rank ordering of noise from different tyres can occur depending upon the method of measurement adopted. This was found to be particularly noticeable for measurements taken in close proximity where different rank orders were produced depending largely upon the position of the close proximity microphone(s). This result illustrates the importance of directionality of the noise generated by tyres. For example, it is clearly possible for a tyre to be rated as a quiet tyre when measurements are taken close to the tyre but rated significantly noisier when measurements are taken at the trackside position and vice-versa. A further potential problem associated with close proximity measurements is the influence, particularly at low frequencies, of wind noise induced by turbulence generated by the microphone body and associated framework.

An important result to emerge from the comparison of the different methods of testing is the close agreement obtained between the rank order of tyre trailer noise levels measured at the trackside microphone and the noise levels taken using the flat bed truck again at the trackside microphone position. This is potentially a very useful result since it is clearly not feasible to consider the use of the tyre trailer as a means of establishing a simple test procedure for lorry tyre noise as both the measurement and analysis procedures needed are far too complex for routine testing purposes. An alternative method is therefore required which ideally would give the same rank ordering of tyre noise as that obtained using the trailer method but would require minimal instrumentation and would be a simple test to perform.

It would appear that these requirements could be met by mounting the test tyres on a conventional truck which is then coasted at a specified speed past a microphone located at the trackside. Such a procedure would appear, in principle, to be simple to carry out and would be representative of tyre noise generated by vehicles in traffic provided the test speed, track surface and other details were correctly defined.

This approach has several advantages over other possible methods. Firstly, since the measurements are taken at, say 7.5m, from the test tyres, the problems of directionality and wind turbulence which are associated with close proximity vehicle mounted microphones are eliminated. Secondly, since the tests would be performed with the tyres mounted on a vehicle running on a real road surface, the test levels obtained would be representative of tyre noise generated in practical situations. Finally, the test procedure itself would be simple to carry out and would require relatively simple instrumentation in order to determine the test noise levels.

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Figure 1: Lorry tyre noise trailer connected to the QHV

tyre			
code	type	combined axle load (tonnes)	tyre pressure (bar)
A	steer	8	7.8
B	steer	8	7.8
C	steer	8	7.8
D	drive	5¾	7.2
E	drive	5¾	7.2
F	drive	5¾	7.2
G	off-highway	5¾	7.2

Table 1: Tyre loads and pressures

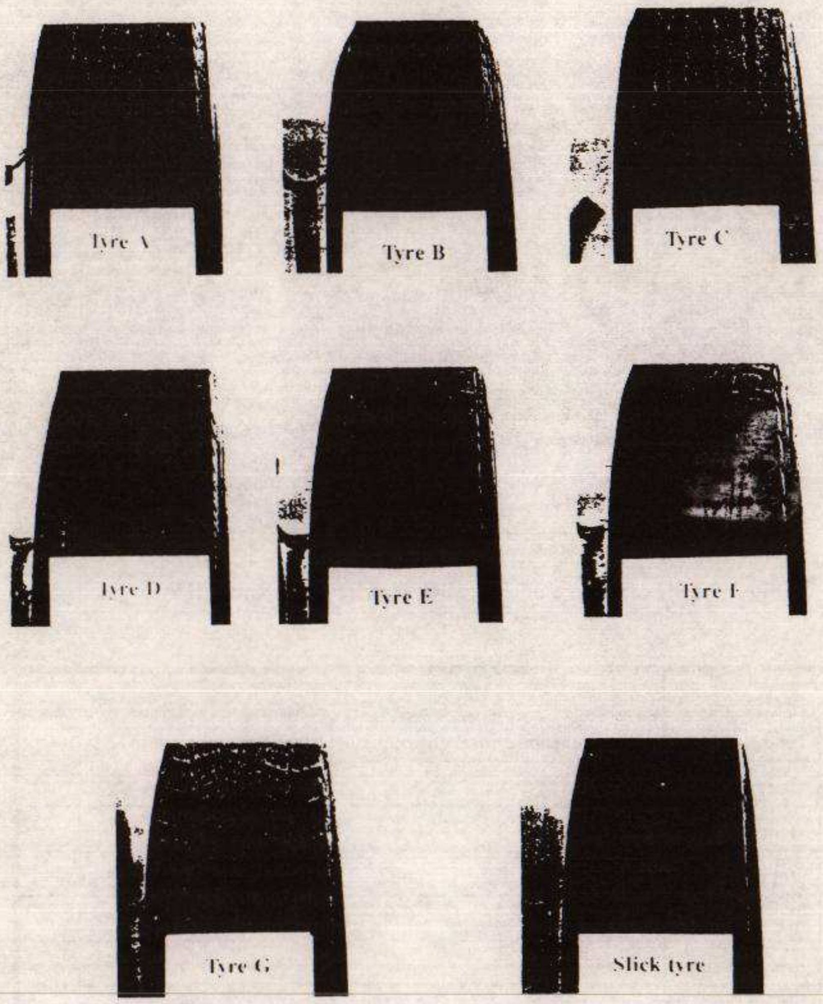


Figure 2: Detail of tyres used in the study

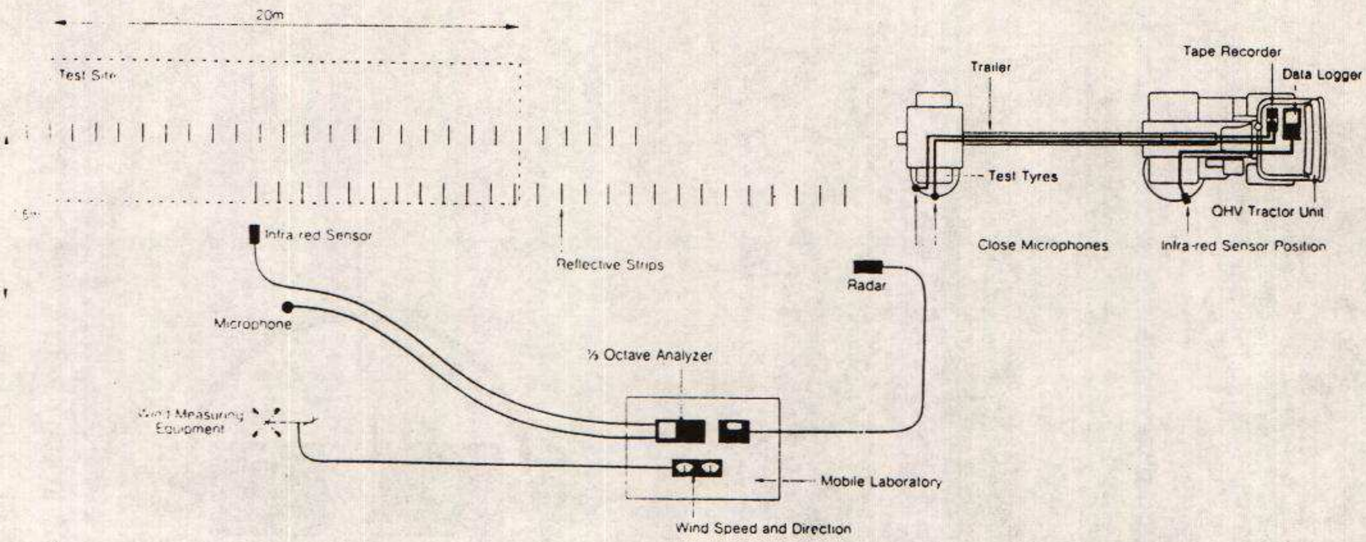
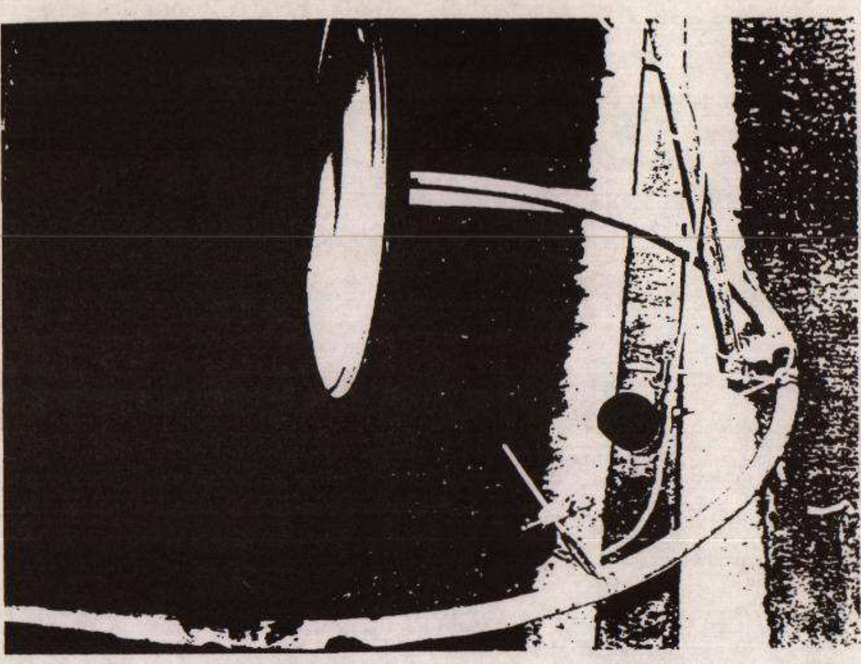
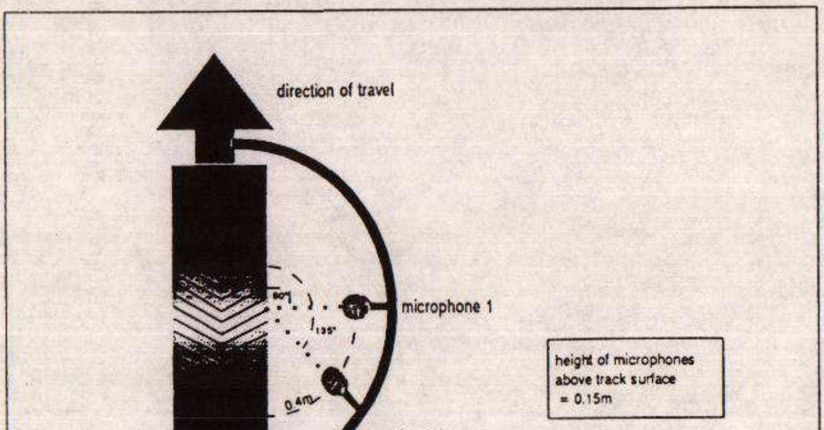


Figure 3: Plan of test site and equipment layout



(a) detail showing microphones and support framework



(b) schematic showing orientation of microphones

Figure 4: Close proximity microphones

tyre	surface	Peak noise levels at 7.5m			Close proximity noise levels								
		70 km/h	80 km/h	90 km/h	70 km/h			80 km/h			90 km/h		
					90°	135	mean	90°	135°	mean	90°	135°	mean
A	Hot rolled asphalt	76.5	78.1	79.6	93.8	97.0	95.4	95.4	99.2	97.3	96.8	101.1	98.9
B		75.6	77.6	79.6	90.2	95.4	92.8	92.3	97.7	95.0	94.1	99.7	96.9
C		75.0	75.9	77.3	90.9	95.3	93.1	93.3	98.0	95.7	95.4	100.4	98.0
D		76.4	77.5	78.9	96.5	97.7	97.1	97.3	99.2	98.3	98.1	100.5	99.3
E		77.9	80.3	82.4	96.6	96.6	96.6	98.7	98.7	98.7	100.5	100.6	100.5
F		76.4	78.5	81.1	95.4	95.7	95.5	98.0	98.2	98.1	100.4	100.5	100.4
G		77.2	79.3	81.5	95.7	98.3	97.0	96.9	99.6	98.2	97.9	100.7	99.3
A	Fine rolled asphalt	72.7	74.6	77.3	89.8	92.2	91.0	92.7	94.9	93.8	95.2	97.3	96.2
B		69.9	72.5	75.2	85.3	90.6	88.0	87.8	93.2	90.5	90.0	95.5	92.8
C		70.7	72.7	74.4	85.7	90.6	88.2	87.8	94.3	91.1	89.7	97.6	93.6
D		74.7	75.2	77.6	94.1	94.7	94.4	95.9	96.9	96.4	97.4	98.9	98.2
E		77.6	80.2	82.6	96.8	99.0	97.9	98.5	100.9	99.7	100.1	102.6	101.3
G		74.6	79.0	83.1	93.9	95.9	94.9	97.2	98.9	98.1	100.1	101.6	100.8

Table 2: Coast-by peak dB(A) levels obtained at 7.5m and in close proximity using the tyre trailer

tyre	surface	Peak noise levels at 7.5m			Close proximity noise levels								
		70 km/h	80 km/h	90 km/h	70 km/h			80 km/h			90 km/h		
					90°	135	mean	90°	135°	mean	90°	135°	mean
A	Hot rolled asphalt	78.9	80.5	82.0	93.9	97.8	95.9	95.7	99.8	97.7	97.3	101.5	99.4
B		78.7	80.4	82.1	95.4	97.4	96.4	97.4	99.4	98.4	99.1	101.2	100.2
C		77.9	79.6	81.4	95.0	96.2	95.6	96.2	98.1	97.1	97.1	99.7	98.4
D		78.5	80.4	82.3	94.9	98.9	96.9	96.3	100.5	98.4	97.5	102.0	99.7
E		79.9	81.3	83.1	98.4	96.9	97.6	100.5	98.9	99.7	102.3	100.6	101.4
F		78.5	80.6	82.8	95.0	95.7	95.3	97.3	98.0	97.6	99.3	100.0	99.7
G		79.3	81.1	82.8	96.8	98.4	97.6	98.9	100.6	99.7	100.7	102.5	101.6

Table 3: Coast-by peak dB(A) levels obtained at 7.5m and in close proximity using the flat bed truck

*ranking of maximum coast by levels at 80 km/h on HRA surface											
tyre		Tyre trailer measurements					Flat bed measurements				
		7.5m: total noise	7.5m: tyre noise	close prox: 90°	close prox: 135°	close prox: mean	7.5m	close prox: 90°	close prox: 135°	close prox: mean	total of ranking scores
A	steer	6	4	5	3	5	4	7	3	5	42
B	steer	5	5	7	7	7	6	3	4	3	47
C	steer	7	7	6	6	6	7	6	6	7	58
D	drive	4	6	3	2	2	5	5	2	4	33
E	drive	1	1	1	4	1	1	1	5	2	17
F	drive	3	3	2	5	4	3	4	7	6	37
G	off-highway	2	2	4	1	3	2	2	1	1	18

Table 4: Rank ordering of tyre noise obtained using different measurement methods
* 1 denotes noisiest tyre, 7 quietest