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PRACTICAL DEVELOPMENT PROBLEMS IN ACHIEVING 74dB(A) FOR CARS

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1. INTRODUCTION

The requirement to achieve a drive-by level of 74 dB(A) for passenger cars from October 1995 is another step in the reduction of traffic noise by the legislators. In the past reductions in drive-by levels have been comparatively easy, however, meeting the impending legislation presents a major challenge to the automotive manufacturers and suppliers.

The current ECE homologation level of 77 dB(A) and Swiss level of 75 dB(A) combined with improving interior noise refinement have resulted in considerable advances in the design of vehicle exhaust and intake systems over the last 15 years. As a result of this, many production vehicles have roughly equal drive-by noise contributions from the following sources:

(i) Intake
(ii) Exhaust
(iii) Powertrain radiation
(iv) Tyres

This dictates that the development effort required to achieve the new targets must be distributed across the range of vehicle components. Furthermore this effort must be carefully targeted to achieve satisfactory results without excessive component or development costs.

This paper summarises the recent advances in drive-by noise testing and development made by Lotus Engineering at its Hethel site and their implications for the motor industry.

2. UNDERSTANDING THE PROBLEM

Over the years much work has been done to understand and reduce vehicle noise. Prediction and analysis techniques are being developed which provide the tools for the NVH engineer. When planning a new model it is, of course, essential to set target levels and ensure that components are designed to meet them. This allows sufficient packaging space to be allocated at the design stage.

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The vehicle manufacturers increasingly rely on the expertise of the sub-system suppliers to develop components to agreed targets. These systems are often highly complex in their own right and require specialist knowledge. For example exhaust system suppliers have, and are continuing to develop, a detailed understanding of their products. Since the demands on all components to meet 74 dB(A) are extremely stringent, accurate targets are very important in order to minimise development costs. If targets are set too low a high degree of development effort may be expended to no practical gain. On the other hand if they are set too high redevelopment may subsequently be necessary.

Detailed noise source ranking of prototype vehicles can be used to fine tune the targets for vehicle subsystems.

3. DRIVE-BY NOISE SOURCE RANKING TEST

The classic method of identifying sources has been to mask the sources and calculate their contribution to the total. In order to achieve 74 dB(A) the sources are likely to be of a similar level, therefore careful attention to detail is necessary. In practical terms this means that the masking of each source must aim to achieve at least 10 dB reduction with no acoustic leaks. As a diagnostic tool it is also necessary to understand masking effects in the frequency domain. For instance when lagging an exhaust system the high frequencies can readily be attenuated with fibrous material such as Rockwool or ceramic fibre. If low frequency attenuation is also required then lead wrapping is necessary, however in reality exhaust system radiation is dominated by high frequencies, therefore lead is not always used.

Intake and exhaust gas noise is attenuated by the use of additional silencers. These are designed to work across a broad frequency spectrum. They are tested with near field measurements so that the attenuation is known for each vehicle installation. The engine is encapsulated with the remaining volume packed with absorption material.

In the past noise source ranking based on sound level meter readings has been adequate. It is now important to obtain accurate noise data versus vehicle position in the test zone. The method used at Lotus allows frequency domain data from both sides of the vehicle to be taken at predetermined points together with speed, RPM and throttle opening position. This requires radar, telemetry and a computer controlled real time analyser as shown in Figure 1.
This equipment allows plots of noise versus vehicle position in the test zone to be derived as shown in Figure 2. Data is sampled during every 0.25 metres of the vehicle's travel. Associated with each data point is a 1/3, 1/12 or 1/24th octave spectrum. The entry speed and throttle actuation readings allow the accuracy of every test to be interpreted interactively and repeats to be carried out if necessary.

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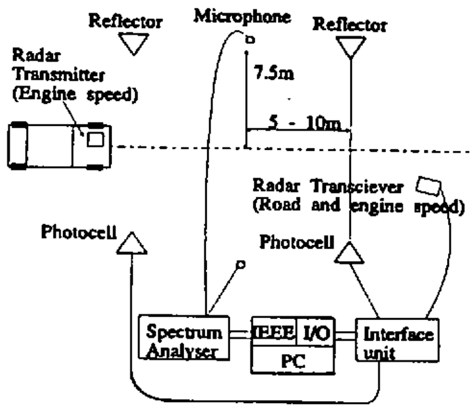

Figure 1: Noise drive-by test layout

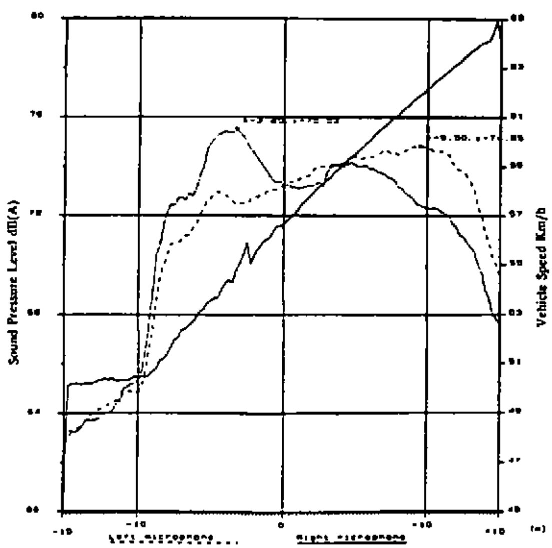

Figure 2: Plot of noise versus vehicle position

An additional transmitter is used as required to transmit other useful vehicle data during the test. For example with turbo charged engines such as the Esprit, plots of boost pressure versus position in the zone can be obtained. This is useful since boost lag characteristics have a very strong influence on the 2nd gear drive-by noise levels.

A series of tests are carried out starting with all potential sources masked. Each source is then unmasked in turn starting with those likely to be lowest in the ranking. Each source is tested in at least two conditions to allow cross checks for experimental error.

Tyre noise is estimated by measuring levels with the vehicle coasting through the zone with the engine off. The test is repeated at several speeds so that a linear graph of tyre noise versus speed can be plotted (Figure 3). In order to gain a better understanding of the relationship between speed and position and tyre noise, data from a series of tests was replotted as a contour plot. Figure 4 shows this data with the 2nd and 3rd gear speeds versus distance overlaid. It confirms the linear relationship between noise and vehicle speed, but shows that at any given position noise is insensitive to small speed changes. This technique gives an estimate only since tyre noise under torque is higher than during coast.

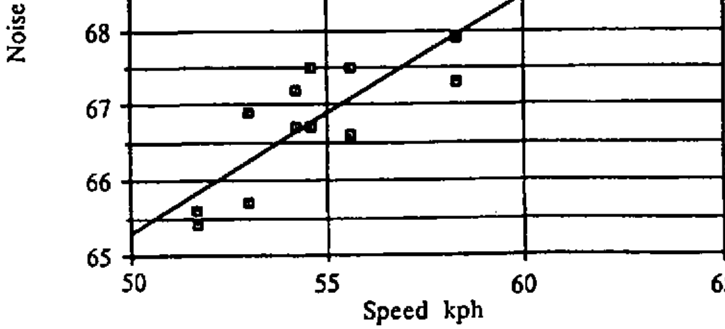

Figure 3: Plot of tyre noise versus speed

Data from the system is post processed in the office to allow the basic results to be plotted. In addition noise levels and spectra can be subtracted from each other to allow the absolute contribution of each component to be predicted. The accuracy of the predictions are checked by summing and comparing with the measured overall level.

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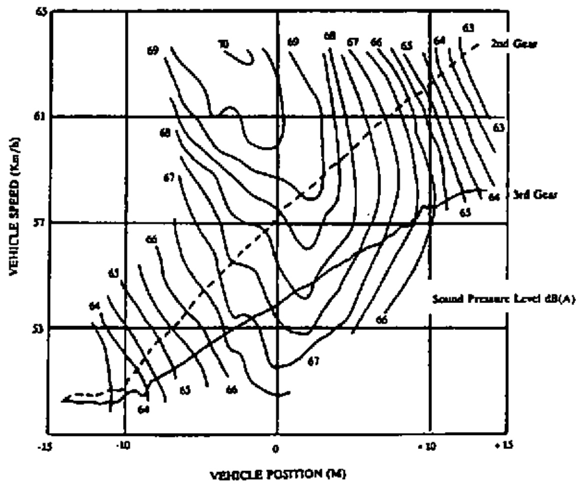

Figure 4: Tyre noise (coast) test results

4. DRIVE-BY NOISE SOURCE RANKING RESULTS

Drive-by noise source ranking of vehicles with clear exhaust and/or intake dominance is comparatively straight forward. Figure 5 shows the ranking obtained from a high performance sports car when tested to SAE J1207. This shows clear dominance of intake noise at the beginning of the test zone which changes to exhaust dominance at the end. Significant reductions in the overall noise can only be obtained by reducing both intake and exhaust levels.

Figure 6a and 6b show more typical results for a sporting saloon car tested to ECE 51. These show that in second gear the significance of individual vehicle components depends heavily on the position of the vehicle in the zone and is also different on each side of the vehicle. Intake noise is the dominant source in the early part of the test but is most significant on the right hand side of the vehicle. In the middle of the test zone the engine noise becomes dominant, towards the end exhaust outlet noise becomes significant, particularly on the left hand side. These results show that to reduce the overall drive-by level significant reductions in base engine noise must be made, together with improvements in intake and exhaust.

The situation in 3rd gear is somewhat different (figures 6c and 6d) in that the relative significance of tyre noise has increased. These figures suggest that reductions in both base power unit and tyre noise are required to significantly improve the overall level.

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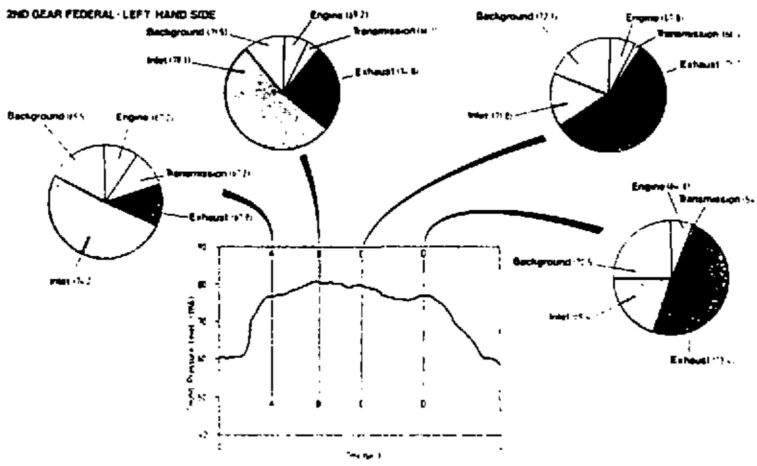

Figure 5: Noise source ranking

Having determined the overall ranking of components the spectral information becomes important. For example figure 7 shows that the spectral content of the intake system is dominated by 630 Hz. This information can be correlated with the results of near field and bench tests to gain a complete understanding of the intake system.

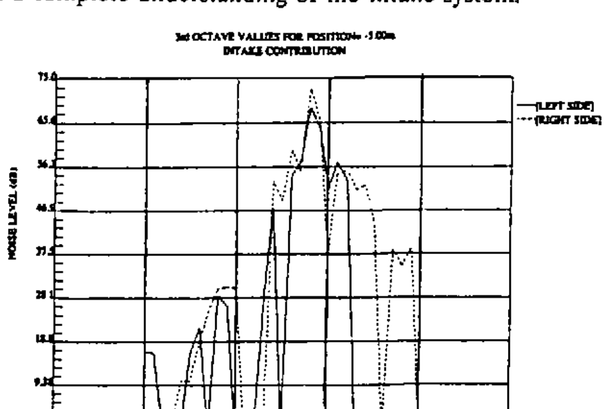

Figure 7: Plot of spectral information

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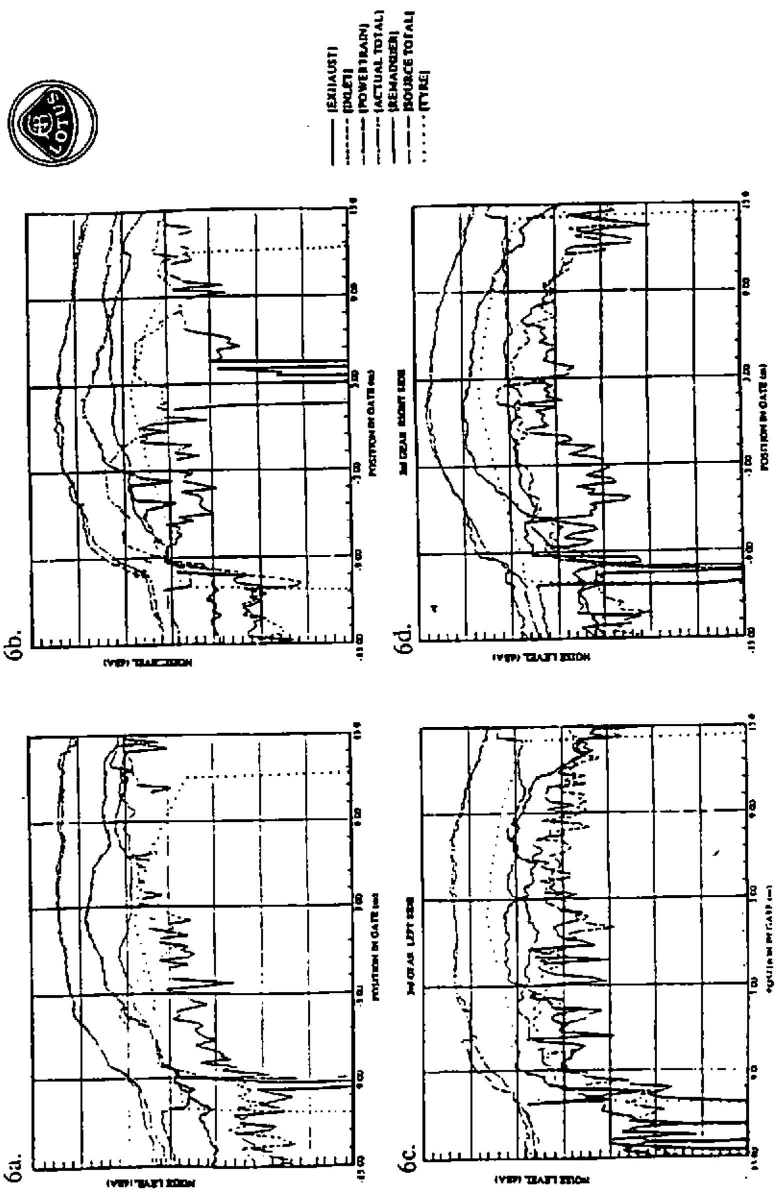

Figure 6: Drive pass noise source ranking

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Since predictions of the absolute noise levels for each sub-system have been derived from the experimental results it is possible to investigate the effect on the total vehicle noise of changes to subsystems. For example the effect of reducing engine noise by say 1 dB can be estimated by reducing the predicted engine noise level and summing to give a revised overall level.

The drive-by noise source ranking results allow a review of the targets for individual sub-systems with respect to their installed performance. If no single sub-system is dominant all similarly ranked sources must be tackled, they are then prioritised on the basis of factors such as practicality and cost. For example noise improvements obtained by partial engine encapsulation must be balanced against increasing vehicle mass, increased unit cost and increased development cost to obtain satisfactory engine cooling. This can be balanced against theoretically less effective alternatives such as intake or exhaust development.

5. VEHICLE DEVELOPMENT

A range of techniques can be applied to test and develop vehicle subsystems, these are examined in turn.

INTAKE AND EXHAUST

Intake systems are becoming increasingly sophisticated. Large volume remote air cleaners provide the broad band attenuation while Helmholtz resonators and quarter wave tubes are added to control specific frequencies.

Exhaust systems have evolved over the past 15 years to incorporate the following features:

- (i) Increased system volume
- (ii) The use of pressed shells to improve packaging efficiency
- (iii) Balanced use of reactive and passive elements

The detailed design of these systems benefits from the latest modelling software and for a more detailed account of these reference should be made to the accompanying paper 'Intake and Exhaust modelling' by M. F. Harrison of Lotus Engineering.

ENGINE NOISE

Historically base engine noise treatments have been applied to automotive diesel engines where engine noise dominates other sources. Design changes and palliative treatment of engines at source provides a very weight efficient means of reducing noise, but does add some complexity.

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The advances in intake and exhaust design have increased the relative significance of engine noise in passenger cars. The trend towards higher specific output, 16 valve, fast burn engines means that more engine noise control techniques will have to be adopted. This can draw on the experience already obtained with diesel engines.

The first step in reducing engine noise at source is to carry out a noise ranking exercise in a semi-anechoic chamber. A typical engine noise ranking might show that the oil pan and inlet manifold are targets for reduction. Treating these by well documented techniques such as isolation or close coupled shields has a significant effect on overall engine noise. This will give improvements in drive-by level corresponding to the relative engine dominance.

The current trend in engine development is towards more efficient engines with increased torque at low speed and a faster burn rate to meet the emission levels has a profound influence on engine noise. A recent test carried out on an experimental engine showed that a change in length of the intake runners could increase combustion noise by 5 dB. To achieve aggressive engine targets the trade offs between performance and noise are becoming important and careful management of the priorities will be required to produce the best balance. The long term implications of this are unclear at the present time.

An alternative to base engine treatment is enclosure. This is successfully used on some diesel engined vehicles. Complete enclosure of a front wheel drive car is not usually practical as allowance has to be made for the flow of cooling air through the radiator, packaging considerations preventing a separate air passage. We are therefore left with partial enclosure which takes the form of an undershield with gaps at the side for suspension, steering and driveshafts and at the rear for cooling. The shield can be lined with absorption to further reduce the noise. A larger radiator may be needed with additional development and validation work for cooling.

TYRES

Tyre noise represents a major challenge, solutions to which depend heavily on the expertise of the tyre manufacturers. Reductions in overall 3rd gear noise levels may be obtained by selecting quiet tyres from the range already available. In the future it is anticipated that further reductions in tyre noise will be obtained.

The table overleaf shows the results of a tyre comparison test on a mid range car. The highest level was 3.5dB(A) above the quietest tyre with a choice of 5 tyres within a spread of 1 dB above the reference level.

	Tyre noise dB(A) + Ref
Tyre A	+3.5
Tyre B	+3.0
Tyre C	+2.2
Tyre D	+1.9
Tyre E	+1.8
Tyre F	+1.7
Tyre G	+1.6
Tyre H	+0.9
Tyre I	+0.8
Tyre J	+0.6
Tyre K	+0.3
Tyre L	Ref

Ultimately a separate tyre noise homologation procedure may be introduced if legislated levels drop below 74dB(A). This has the advantage that the vehicle drive-by test still addresses the issue of powertrain noise in towns while the tyre noise test could address the separate problem of high speed traffic noise which is dominated by tyres.

7. CONCLUSIONS

Reductions in the permitted noise levels from cars are forcing detailed analysis of complete vehicle levels relative to position in the drive-by test zone. Noise source ranking of modern cars often shows roughly equal dominance of subsystems. In this case targets for subsystem noise levels must be chosen to minimise development and piece costs.

8. ACKNOWLEDGEMENTS

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