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SOURCES AND LEVELS OF NOISE UNDER MOTORCYCLISTS' HELMETS

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1 INTRODUCTION

Noise levels at the ear under a motorcyclist's helmet increase rapidly as speed increases. At high speeds, above about 60 or 70 kilometres per hour (35 - 45 mph), the aerodynamic noise caused by the airflow around the motorcycle and rider exceeds the noise generated by the motorcycle itself. Noise exposures for many working riders such as police motorcyclists are likely to exceed the First and Second Action Levels specified in the Noise At Work Regulations 1989 [1]. An interim solution, adopted by some police forces, is to provide earplugs for motorcyclists. This is far from ideal. In the longer term it is desirable to reduce noise levels at the ear by improving the aerodynamic and acoustic design of motorcycles and helmets. This paper briefly reports noise measurements in a wind tunnel and on the road to quantify noise levels and identify noise sources and paths.

2 WIND TUNNEL MEASUREMENTS

Noise levels and spectra were measured using calibrated miniature microphones (Knowles Electronics BT 1759) at the ears of a motorcycle rider, a police driving instructor, in the 2.1 m x 1.7 m (7 ft x 5 ft) Subsonic Wind Tunnel at the University of Southampton. Preliminary measurements showed the background noise levels in the tunnel to be sufficiently low not to affect the tests. Two motorcycles were used, a BMW K 100 and a BMW K 1100 LT. In each case measurements were made with several helmets, up to 27 samples of 13 different types or prototypes. Each helmet was allocated a number for identification. Airspeeds were 22, 27 and 32 m/s (approximately 50, 60 and 70 mph) measured in the undisturbed flow upstream. Helmets were tested as supplied and with various treatments or modifications in an attempt to identify where and how the noise was generated, to identify transmission paths of the noise from the source to the ear, and to reduce the noise at the ear. Measurements on the K 100 motorcycle were made without a windscreen and with three screens of different heights. Measurements on the K 1100 LT were made with its electrically-adjustable windscreen at various heights.

The various modifications to helmets included: ● fitting draught excluder to seal the top edge or all around the visor, ● using insulating tape to seal the visor to the helmet and fair the visor into the helmet, ● placing strips of draught excluder across the top of the helmet to modify the airflow, ● changing the shape of the helmet with plastic or card attachments at the front or back, ● isolating the visor from the shell by replacing hinges with foam spacer and tape, ● attaching an extra visor in front of the normal visor to keep the airflow off the normal visor, ● sealing the gap around the riders neck, and, ● with the help of a manufacturer, modifying the internal materials in contact with the helmet shell, close to the ears, at the forehead and around the chin bar. Time did not permit all modifications to be tried with all helmets. All measurements reported here were made with closed visors.

Airflow and turbulence were mapped at the rider's position using a pitot tube and a hot-wire anemometer. Flow visualization techniques included smoke and wool tufts.

3 MEASUREMENTS ON THE ROAD

Levels and spectra were measured from Digital Audio Tape recordings of noise at the ears of the motorcycle rider at speeds of up to 120 mph as registered by the certified speedometer. Recordings were made on a road with the same rider and motorcycles as in the wind tunnel. Only roadworthy helmets without modifications were worn.

4. RESULTS AND DISCUSSION

Noise levels in the wind tunnel were similar at the two ears for any condition, typically within one to two decibels. When tests were repeated on different occasions the test-retest repeatability was also of the order of 1 to 2 dB.

The air velocity around the rider was higher than the reference or nominal velocity measured upstream because of the blockage presented by the motorcycle and rider in the wind tunnel. The free-stream velocities at the longitudinal station of the rider were increased to 116% of the nominal with the K 100 motorcycle and standard windscreen, to 124% on the K 1100 LT motorcycle with the windscreen lowered, and to 131% with the windscreen raised.

4.1 Noise levels measured with the K 100 motorcycle in the wind tunnel

Noise levels for the helmets, tested as supplied, increased as a function of speed at a similar rate for each helmet. At 22 m/s nominal airspeed the noise levels at the ear ranged from 90 to 99 dB(A) and at 32 m/s from 97 to 104 dB(A) and were similar whether no windscreen or the standard windscreen was fitted. Whether a helmet's air ventilation slots were open or closed had little or no effect on the noise levels at the ear.

Noise levels were similar to those measured elsewhere where data were available for the same motorcycle and helmet combinations [2]. The spectra were similar in form to those reported in the literature, eg [3]. A-weighting the spectrum illustrated that the frequency region around 300 to 400 Hz contributed most to the overall A-weighted level frequencies below about 100 Hz contributed little. It was difficult if not impossible to relate noise levels and spectra to constructional features of the helmet since each helmet differed from any other in many different ways each of which may have had some significance under some conditions.

Four helmets were selected for more detailed examination. The noise levels for these were measured with different windscreen heights from no windscreen through to the highest windscreen, which was approximately level with the rider's eye-line. An important fact emerged. Helmet 21 was the quietest of the four when the windscreen was removed, but the same helmet was the noisiest with the highest windscreen. In fact Helmet 21 steadily progressed from quietest to noisiest as the windscreen height was increased, regardless of the air speed. This can be seen clearly in Figure 1 where noise levels are plotted against windscreen height for the middle air speed of 27 m/s. The same pattern occurred at the other two airspeeds.

The noise levels under the four helmets vary with windscreen height in different ways. The noise level from Helmet 21 generally increases as the windscreen height increases. Helmet 18 shows a tendency for noise levels to reduce with windscreen height. With Helmet 9 the noise level appears to increase then decrease again as windscreen height increases, whereas Helmet 20 shows noise levels which change little or, if anything, decrease then increase.

An important conclusion is that the wind noise measured under a helmet depends upon both the helmet and the motorcycle. The position of the rider's head in relation to the airflow over the motorcycle is clearly an important factor. Similar findings have been noted elsewhere [3]. This is discussed further in Section 4.4 below. It follows from this that a single number sound level rating for a helmet, as sometimes published for consumer guides [eg, 4] should be treated with caution when comparing, choosing or specifying a helmet.

4.2 Effects of modifications to helmets with the K 100 motorcycle

The most comprehensive range of modifications were made to Helmet 21. When the windscreen was removed from the motorcycle, fitting draught excluder to seal the gap between the visor and the helmet had little or no effect. However a collar fashioned out of a strip of polyurethane foam and used to seal around the neck reduced the noise levels. The reduction was greater with a thicker foam collar. A plastic extension to the front base of the helmet showed little noise reduction. However, when the extension was sealed to the rider's leathers with fabric tape, noise levels were reduced and were similar to those obtained with the thick foam collar. The greatest noise reduction obtained was approximately 5 dB and this was obtained at each speed.

Neither the thick foam collar nor the plastic extension sealed to the rider's leathers is a practicable means of noise control: both severely restrict head movements and would not be safe. These modifications do however show that with a low or no windscreen on the motorcycle much of the noise at the ear enters at the base of the helmet around the neck or results from airflow into or over the gap at the base of the helmet. For motorcycles with a low windscreen attention should be directed towards improving the fit of the helmet around the neck. Attention to sealing the visor has little or no effect.

With the standard height windscreen the noise in the helmet is generated or transmitted differently. With this windscreen the foam collar around the rider's neck was not effective in reducing noise, but tape around the visor or draught excluder between the visor and helmet was effective at the two higher speeds giving reductions of between 4 and 7 dB. When the standard windscreen is fitted the noise at the ear seems to be generated at the visor or is transmitted through or around the visor. The tape and draught excluder can have various effects they can modify local airflow, they can seal gaps through which sound leaks or they can damp vibration or ringing in the visor. The gap between the rider's neck is no longer the dominant path for noise and attention to this area has little effect.

Although measurements on the other helmets were less comprehensive the measurements where available are consistent with the effects noted above.

4.3 Effect of riding position

The effect of head position on the noise at the ear was explored. With the standard height windscreen the noise level at the ear was near its maximum value in the normal or natural riding position. With the rider sitting very upright so his head was higher than normal the noise level was reduced (by 4-5 dB), and with the rider leaning forward to bring his head into the lee of the windscreen the noise level was also reduced (by 8-9 dB).

The rider confirmed that he and many of his colleagues favour the standard height windscreen. This is high enough to keep the force of the wind off the body but low enough for the rider to look over the top. A higher windscreen might reduce noise at the ear, but would require the rider to look through rather than over the optically poor windscreen. A lower than standard windscreen would expose the rider more to the force of the airflow. Neither would be acceptable.

4 .4 Flow visualization and measurement with the BMW K 100 motorcycle
When a hot-wire anemometer and pilot-static rube were traversed from the ceiling of the wind tunnel down to the motorcycle saddle a characteristic airflow pattern was found. As the measurement position was lowered from the ceiling the mean flow velocity indicated by both the pitot-static tube and the anemometer remained steady until it suddenly fell as the wake of the fairing and windscreen was encountered. The rms velocity fluctuation about the mean value recorded by the hot wire provides a measure of the unsteadiness of the flow, and this showed that there was a narrow region of highly turbulent flow at the edge of the windscreen's wake. An example is shown in Figure 2. The highly turbulent flow at the edge of the wake is clearly visible. The height of the turbulent zone is dependent upon the windscreen height.

The airflow measurements are consistent with the noise measurements and the types of helmet modifications which reduce the noise at the ear. With no windscreen or a low windscreen the turbulent zone at the edge of the wake hits the rider's shoulders and neck and improving the sealing of the helmet to the neck reduces noise levels at the ears, whereas treatments to the visor have little effect. With higher windscreens the turbulent wake from the windscreen hits the top of the visor and helmet and treatments to the visor sealing or mounting reduce noise at the ears but treatments to the neck area have little effect.

4.5 Helmet aerodynamics
Modifying the boundary layer airflow over the helmet surface by applying strips of draught excluder made no significant changes to the noise levels or spectrum at the ear, but often reduced the drag experienced by the rider. Airflow over the helmet and separation from the helmet did not appear to be major sources of noise turbulent flow from the motorcycle windscreen impinging on the helmet dominated.

4.6 Noise measurements on the K 1100 LT motorcycle in the wind tunnel
As with the K 100 motorcycle, although the rank ordering of the helmets in terms of the noise levels hardly varies with speed, it does vary according to the windscreen height. There was no universal pattern. With some helmets the noise reduced as windscreen height increased, but with some helmets the noise remained similar or varied up and down.

Helmet modifications which improved the seal at the rider's neck were not effective with the K 1100 LT motorcycle whereas treatments to the visor, such as sealing it and isolating it from its hinges could be effective, and resulted in a 7 - 9 dB reduction in noise under one of the helmets. Airflow measurements showed that the turbulent zone coincided with the chinbar or bottom of the visor when the electric windscreen was fully lowered, too high for modifications to the base of a helmet to be effective.

The opportunity arose during the tests on the K 1100 LT to compare the effects of different internal helmet linings and paddings in identical outer helmet shells and of damping materials placed m contact with the inside of the shell in the chinbar, ear region or forehead region. Noise levels were virtually identical with each helmet variant despite the considerable internal differences among helmets. The one exception was that damping material placed in the forehead region appeared to reduce noise levels by 6 to 7 dB but only when the windscreen was fully raised or nearly so.

4.7 Noise under helmets measured on the open road
Noise levels measured under a limited number of helmets with each motorcycle driven on a road ranged from 78 - 90 dB(A) at 13 m/s (30 mph, 48 km/h) to 114 - 116 dB(A) at 54 m/s (120 mph, 193 km/h) and depended upon the helmet road speed, and motorcycle and windscreen. The average rate of increase in noise levels during the road trials was 15.5 dB per doubling of speed, for speeds above approximately

25 m/s (*55* mph). The noise levels measured on the road were similar to those in the wind tunnel when the air velocity in the wind tunnel was corrected to allow for the blockage caused by the motorcycle and rider.

The A-weighted noise levels recorded on the open road are plotted for one helmet as a representative example in Figure 3. On the BMW K 1100 LT motorcycle noise levels at the ear during road trials were lower with the windscreen fully raised than with the windscreen down. Noise levels on the K 100 motorcycle with the standard windscreen were similar to or higher than those on the K 1100 LT with the windscreen down, depending upon the helmet worn. It is important however to note that raising the windscreen on the K 1100 LT is not a viable means of reducing noise at the ear – raising the windscreen at high speeds severely degrades the handling of the motorcycle and increases drag and vibration. The windscreen would not normally be raised at high speed.

5. CONCLUSIONS

An important factor determining noise levels under a motorcyclist's helmet is the design of the motorcycle windscreen and its height and angle. The edge of the wake behind the windscreen is highly turbulent. This turbulence, acting on the helmet, appeared to be the dominant noise source. Airflow over the helmet surface and the flow separation from the helmet were not found to be major sources of noise in comparison.

With a low windscreen, or no windscreen, the turbulence was directed towards the base of the helmet and the rider's neck and shoulders. Improving the sealing between neck and helmet reduced the noise at the ear by 5 - 6 dB but changes to the visor had little or no effect.

Higher windscreens direct the turbulent flow towards the face and, depending upon screen height, hit the visor, the top of the visor or the helmet shell immediately above the visor. Modifications to the visor were effective in reducing noise at the ear but changes to the base of the helmet were not. Noise transmission through the visor, around the visor and through the visor hinges to the helmet shell appeared to be the main limiting factors. Effective noise reduction methods included using draught excluder to fill the gap between the top edge of the visor and the helmet, or replacing the visor hinges with small pads of foam then sealing around the visor. Noise reductions of typically 5-8 dB(A) were achieved by these means.

Internal padding and damping materials applied to the inside of the helmet shell were not effective, except in one particular case where damping in the forehead region appeared to reduce noise when the airflow could be directed sufficiently high.

Because the turbulent air hits different parts of the helmet and rider depending on the windscreen height the site of the noise generation and the transmission paths of noise to the ear vary. The strengths and weaknesses of different helmets are exposed by different motorcycles and at different windscreen heights. Rank ordering of helmets according to their noise level varies from motorcycle to motorcycle and from windscreen to windscreen. Any single number noise rating for a given helmet can therefore be misleading.

Many motorcyclists prefer the top of a windscreen to be a few centimetres below eye level. This windscreen height, which keeps airflow off the rider's body while allowing a good view of the road ahead, is poor in terms of noise levels at the ear. The turbulence is then directed towards the top of the visor. A rider seated on the K 100 in a normal posture looking just above the standard windscreen was at or near a position of maximum noise. Raising the head by a few centimetres reduced noise levels by 4-5 dB, or lowering the head into the lee of the windscreen reduced noise levels at the ear by 8-9 dB with some helmets.

Noise levels measured on the open road ranged from 78-90 dB(A) at 13 m/s (30 mph, 48 km/h) to 114-116 dB(A) at 54 m/s (120 mph, 193 km/h) depending upon the helmet, road speed, and motorcycle and windscreen. Noise levels increased by 15.5 dB per doubling of speed on average, for speeds above approximately 25 m/s (55 mph). The noise levels measured on the road were similar to those in the wind tunnel when the air velocity in the wind tunnel was corrected to allow for the blockage caused by the motorcycle and rider. The noise levels measured during road tests were also similar to those from other studies.

On the BMW K 1100 LT motorcycle noise levels at the ear during road trials were lower with the windscreen fully raised than with the windscreen down. However at high speeds a rider would be unlikely to raise the windscreen because both the handling of the motorcycle and the drag are adversely affected.

6 REFERENCES

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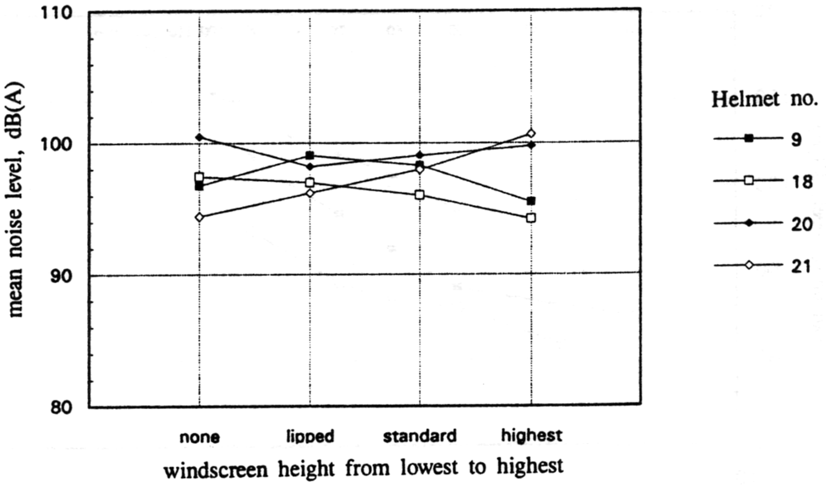

Figure 1 Variation of noise levels with windscreen height at 27 m/s nominal air speed.

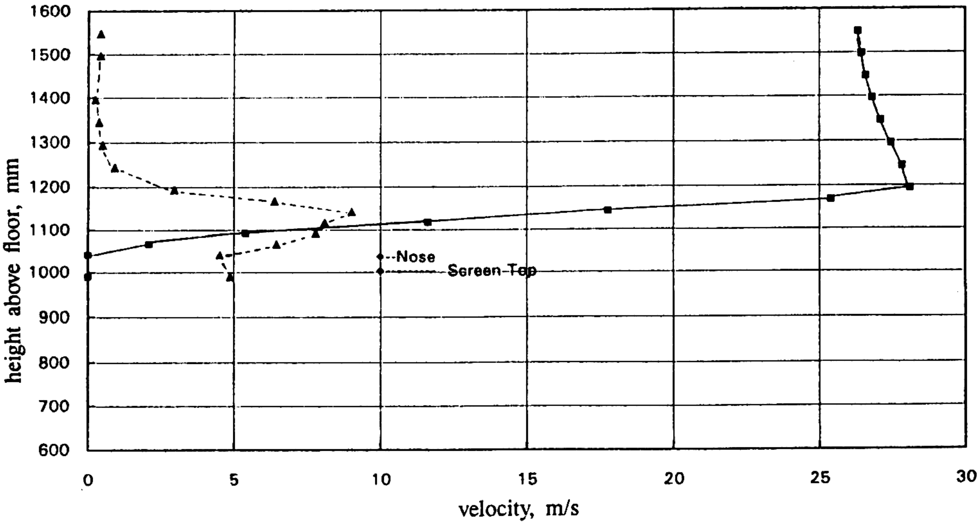

Figure 2 Results of pilot static tube and hot wire anemometer traverses on the K 100 motorcycle with standard windscreen.
Squares show the mean velocity parallel to the tunnel length. Triangles show the rms velocity fluctuations x 2. The heights of the windscreen and rider s nose are also shown.

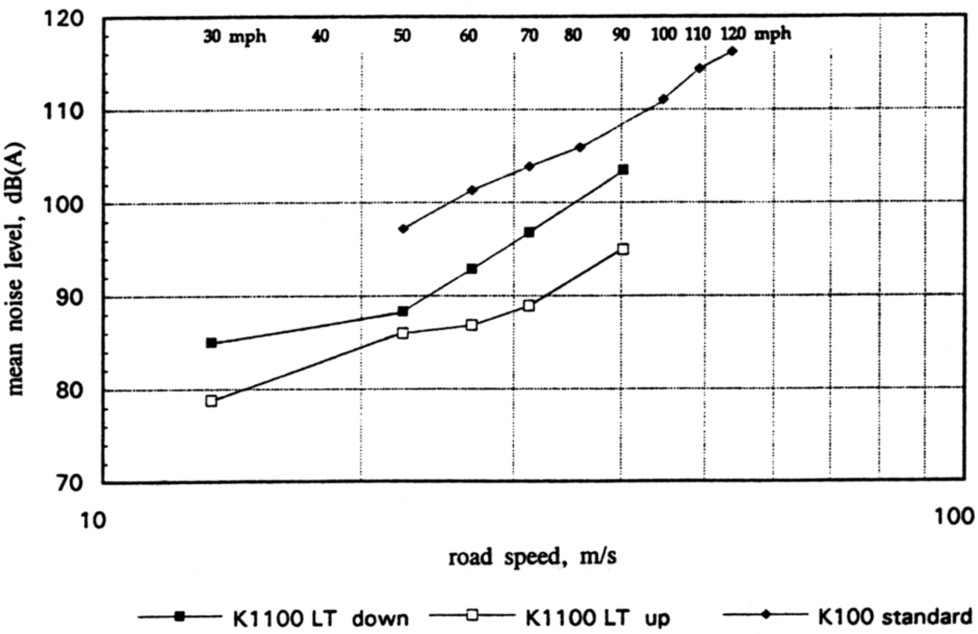

Figure 3 Noise levels measured under Helmet 21 during road trials on the K 1100 LT motorcycle with windscreen down and up, and on the K 100 motorcycle with standard windscreen height.