Noise or Music? Tony Foale sounds the depths in this exhaustive study and discovers the problems are manifold. Silence please

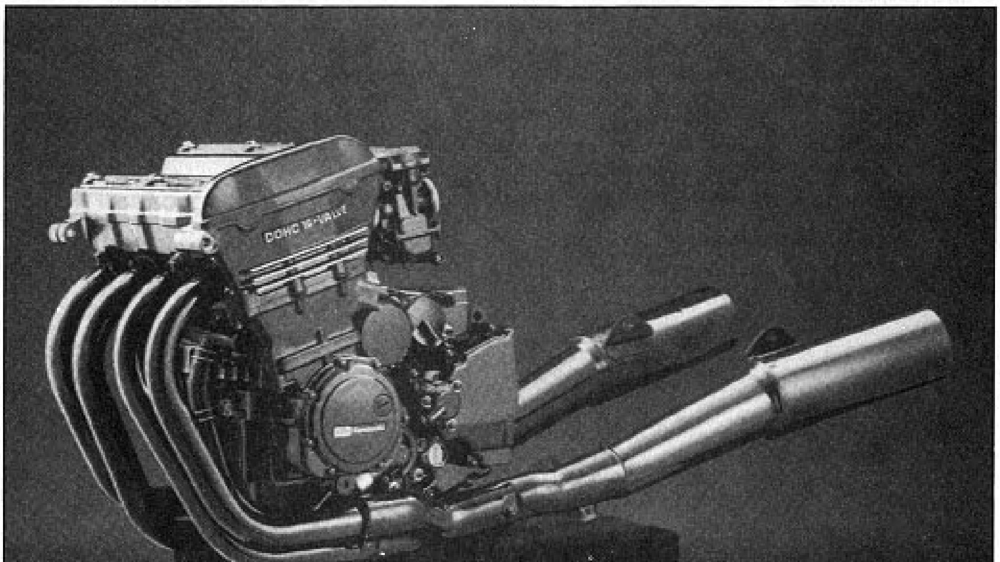
The appreciation of noise is a very personal thing; to some the sound of Mozart is sheer ecstasy and yet for others it needs Geldof to produce the same feeling. To most motorcyclists the exhaust note of a finely honed engine can be pure magic. The yowl of a vintage Scott, the bark of a Manx Norton, the wail of a three cylinder MV, or even the ring-ding-clatter-bang of a TZ can all be guaranteed to get the adrenalin pumping in the veins of the true enthusiast. But it is this very music that is the single biggest cause of the general public's alienation toward bikes. Music haters they may be, but we have to live with the fact that in order to continue to enjoy our machines, noise emissions will have to be continually reduced. We have no choice in this matter, the legislators have seen to that, and legal limits are being always toughened up.

Legal limits do not concern themselves with the source of the noise, e.g. exhaust or induction roar, but refer only to the total disturbance. Traditionally the exhaust has been the main problem on a bike, and even with today's quiet machines it is still this aspect; which offend the public most. But the authority's noise meters make no such distinction, and as silencers become ever more efficient, other sources of noise assume greater significance.

Intake noise is potentially the biggest problem and its reduction has led to the present voluminous air box fed through smallish tapered intake tubes. The silencing effect is due to the same principle as the exhaust expansion chamber, as we shall see later.

As you can imagine, the actual noise in the combustion chamber itself is very loud indeed. Something like ten million times the threshold of pain. So it is hardly surprising that some of this noise escapes directly through the cylinder walls. It is this noise and general internal mechanical clatter that is being reduced by the increasing use of water cooling, and the now common adoption of enclosing fairings.

Noise limits are now becoming so tight that the sound of the chain going around is important. Sound measurements typicaly show a 1dB. greater level on the chain side of the machine than on the other. Little wonder then that shaft drive is becoming more common, although of course there are additional reasons for this. To meet current and proposed noise regulations, all manufacturers must therefore design the bike as a whole entity, the days when a quiet bike simply meant a quiet exhaust are gone forever.



PIPES OF PEACE

There are probably few things about sound that cause greater confusion than its method and units of measurement: mysterious things called "dB.s" or decibels (decibel being one tenth of a bel). The human ear is a very discerning sound analyser, but it does not respond to the degree of noise in a linear proportional way, rather it perceives sound level on a logarithmic scale. This means quite simply that, the louder the noise the greater must be any change in that sound before our ears detect a change.

To illustrate: Assume that we were subject to a noise of a set level. Now if we added more noise of a level equal to the first, the sound would have been doubled and we would easily be able to detect the change. But if the starting sound level was ten times higher, then the previous amount of added noise would only represent a 10% increase in level and would probably go unnoticed. For our ears to perceive the same apparent increase the sound level would need to be doubled again, i.e. the change in level would need to be ten times the value of the change at the lower starting level. This is the reason for using the decibel unit for measurement, because regardless of the base sound level a similar change in dB.s will be interpreted by our ear as a similar change in sound level.

To put this into figures: a 3 dB. increase in sound is equivalent to a doubling of the noise level, regardless of whether we have gone from 3 dB. to 6 dB. or 100 dB. to 103 dB. Consider by way of contrast a normal linear scale of measurement, say MPH. for example:- A change from 3mph to 6mph represents a doubling of the speed as on the dB. scale, but 100mph to 103mph is only 3% increase, whereas 100dB to 103dB is a 100% change.

I apologise not, for labouring this point because in order to appreciate quoted noise figures an understanding of the scale of measurement is vital, e.g. if the authorities proposed a reduction in noise level from the present 86dB to 83dB it does not sound too onerous, on a linear scale it would only be 3.5% change. But of course on the logarithmic dB. scale it really means halving the noise output, obviously no easy task in one go. So have a little sympathy for the manufacturers when faced with such seemingly innocuous requirements.

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Let's look at the current European method of doing the noise test. A 20 metre long test strip is laid out on a flat, dry, hard surface with no obstacle within a 50 metre radius. The measuring instrument is placed 7.5 metres away from the centre of the test run, to one side. The machine to be tested enters the test area at a given speed and is then given full throttle acceleration along the 20 metre strip.

The pre-1980 EEC regulations (1983 in the UK) for 500cc and larger machines, specified an entry speed of 31mph with the machine in third gear, (second gear for bikes with less than five speeds). Under these conditions the measured sound level should have been under 86dB. The current regulations keep the same noise limit but the method of testing is changed; 2nd, not 3rd gear must be used, and instead of 31mph the entry speed must be that which corresponds with an engine RPM figure equal to half that at which maximum BHP is developed. Under these conditions the engine is working much harder than in the earlier test, and so, even though the noise limit is unchanged the test is a much harder one. Depending on the size and type of machine it is effectively 4-6dB tougher. Remember that 3dB represents a 2 to 1 change and so 6dB means 4 to 1. So despite an innocent looking change in the test procedure, the powers that be have in reality imposed much more stringent requirements.

New regulations were due to be in use by about now, but the usual committee wranglings have delayed proceedings and the likely date is now 1988/89. The new limit will be between 80 and 83db., probably 82dB. but using yet another method.

Before looking in more detail at exhaust silencing methods let's reflect on the nature of sound itself.

Sound, in air, is basically a series of small vibrations of the air molecules (small particles). As the molecules vibrate they bump into adjacent ones and pass the motion on. It is in this way that the noise traverses the space between the source and our ears. The rapidity of movement through the air is, not surprisingly, known as "The Speed of Sound" and is determined by barometric pressure and temperature.

Two other important sound parameters are frequency and intensity. Frequency is the rate at which the air molecules make a complete vibration, normally expressed as cycles per second (Hertz or Hz. in modern parlance). Intensity describes the magnitude of the vibration or loudness of the noise and is measured in dB. as previously discussed.

Now, as the sound reaches our ear it causes the ear drum to vibrate in sympathy and thus send appropriate messages to the brain. At high sound frequencies, say 12-15 KHz. and above (KHz. means 1000Hz.), depending on age and condition, the ear drum is unable to respond fast enough and these sounds will be undetected.

Our ears are also insensitive to low frequency noise, say below about 50Hz. Any sounds with a frequency outside our range of hearing can obviously not annoy the public at large, and the authorities allow for this in the noise testing procedure by (broadly speaking) filtering out these frequencies from the sound level measurement. This is known as measuring on the 'A' scale, which also allows for the fact that people generally are less annoyed by the lower frequencies, even within their hearing capabilties. On this 'A' scale, frequencies below 1KHz. are discounted as follows: 3dB. at 500Hz., −6dB at 250 Hz., and −9dB., at 125 Hz. and so on.

An absolutely vital point to grasp, particularly when considering the workings of exhaust silencers, is that sound is the transmission of a vibration through the air, it is not the bulk movement of the air itself. In the context of silencers, this means that the transmission of acoustic (sound) waves through the exhaust system is separate from the flow of the actual exhaust gases. This effect can be likened to the waves on the surface of a pond, caused by throwing a pebble in. Surface waves on the water radiate outwards from the disturbance but there is not a flow of water away from this zone.

It would be easy to assume that the exhaust noise would consist of a single frequency, or note, determined solely by the engine RPM. e.g. 6000RPM. is the same as 100 cycles per second, but if the engine were a single cylinder four-stroke then there would be only one bang every second revolution or at a rate of 50 per second. A four cylinder engine at this RPM would have four times this frequency, or 200Hz. But this will not give an even note of only 200 Hz sound, because the exhaust consists of a series of sharp pulses rather than a smoothly varying pressure. For fairly complex mathematical reasons, a sharp pulse produces sound at a number of other frequencies (called harmonics) in addition to sound at the engine determined frequency (called the FUNDAMENTAL). In effect we have smaller high frequency sound waves on top of the main noise. Waves on waves. There are other reasons that cause the sound to consist of even more frequencies and a return to the "waves on water" analogy can provide a visual demonstration of this. If you watch a small stream flowing, then at any obstacle, such as a twig or narrowing of the banks, even a change of depth, you will notice waves developing. A similar thing happens in an exhaust system, if the pipe section changes or the gas hits a baffle plate or is forced to go through holes then more frequencies are produced.

This all results in an exhaust noise which consists of a whole range of frequencies all at different magnitudes. This is known as the sound spectrum. In practice, all this means that the silencer design is complicated. If there were only the fundamental to silence, then even a four cylinder four stroke at 12000 RPM would produce a high note of 400 Hz and as we can't hear much below 50 or 100Hz anyway, the range of frequencies that would need silencing would be, say, between 100 and 400 Hz. But in reality the spectrum extends up to around 8000 Hz. The higher frequencies are more annoying to the human ear and so are very important factors in silencer design. Fortunately though, these higher notes start off with lower intensities and are easier to quieten down, anyway.

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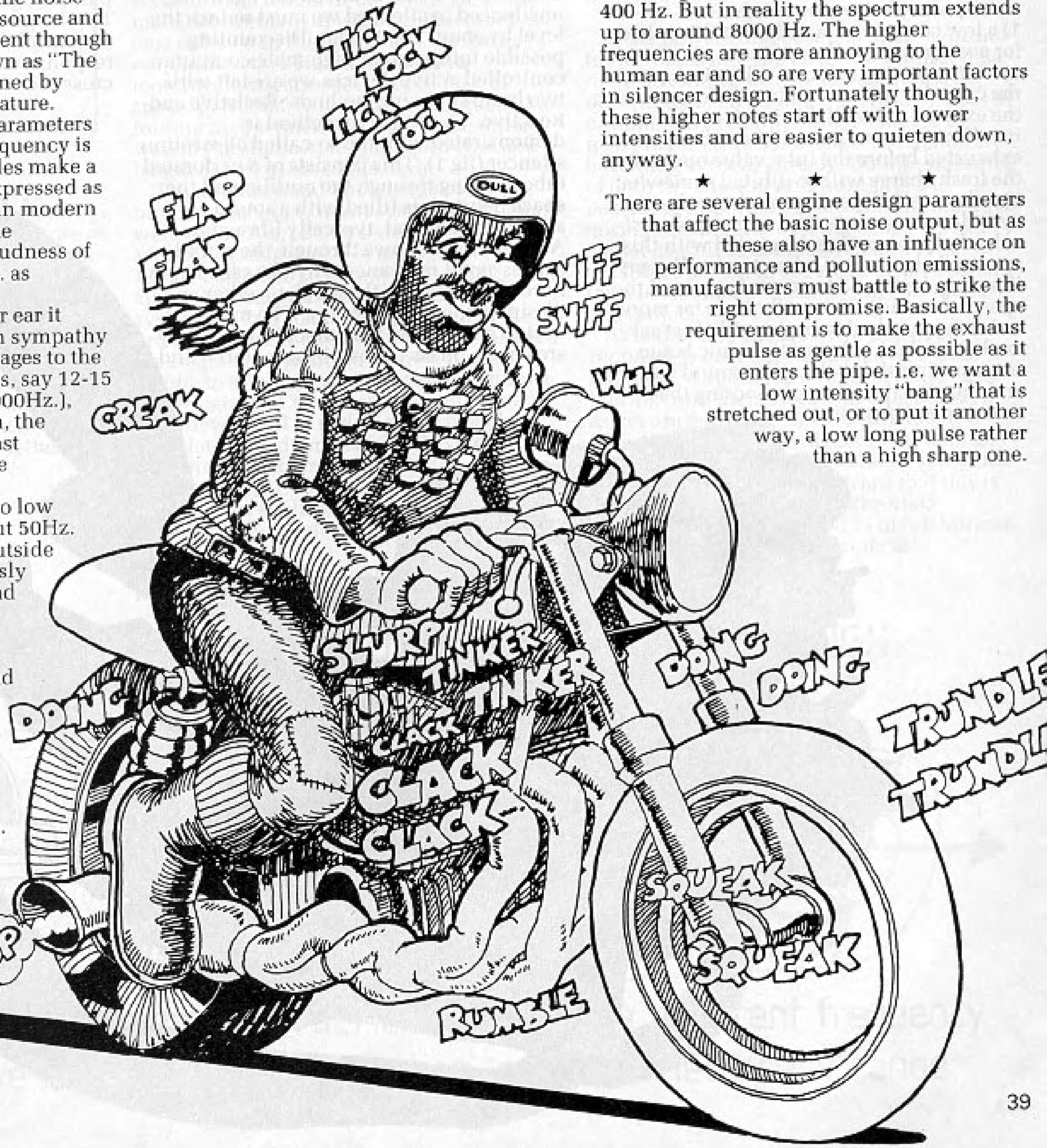
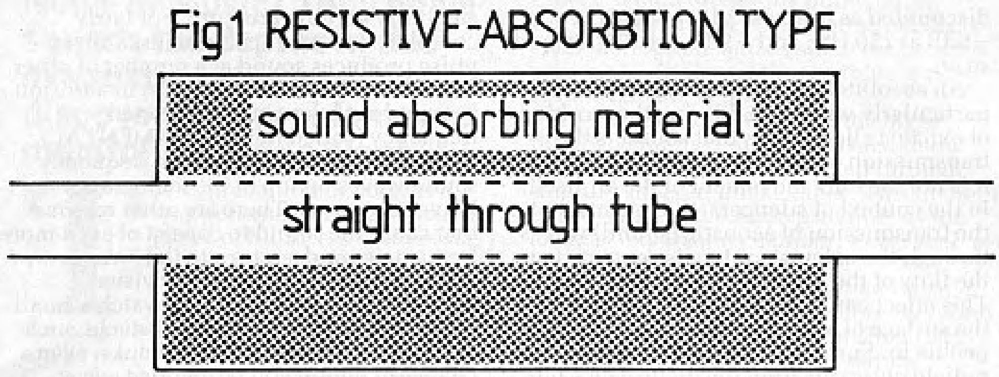
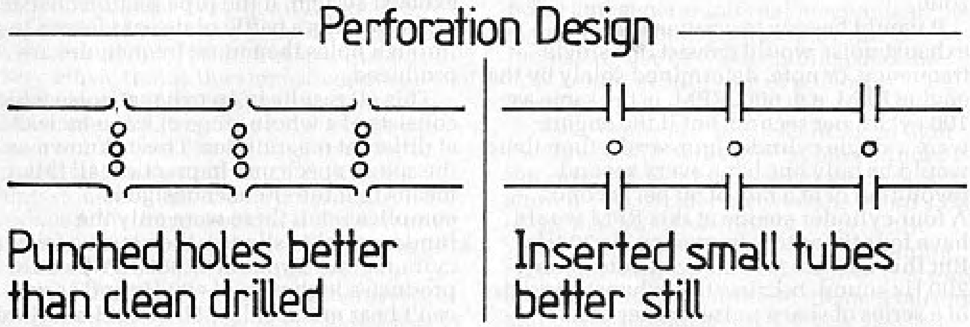
There are several engine design parameters that affect the basic noise output, but as these also have an influence on performance and pollution emissions, manufacturers must battle to strike the right compromise. Basically, the requirement is to make the exhaust pulse as gentle as possible as it enters the pipe. i.e. we want a low intensity "bang" that is stretched out, or to put it another way, a low long pulse rather than a high sharp one.







This is easier to accomplish with a low power output, but who wants that? From a noise point of view, we need:
1) a low compression ratio, but this is bad for economy as well as power.
2) a late opening exhaust valve timing to let the cylinder pressure reduce before opening the exhaust valve. If this is left too late then insufficient waste gas will have been exhausted before the inlet valve opens and the fresh charge will be diluted somewhat.
3) a slow valve opening to release the cylinder pressure gently; a small exhaust valve helps also. Care is needed with this approach, because if taken too far, the gas flow may be forced to go sonic (exceed the speed of sound). This will create far more noise than we had to begin with. Just ask anybody who has heard the sonic boom from an aircraft breaking the sound barier, and imagine the effect of shooting that down an exhaust pipe.

But after all this is done we are still left with maybe 30 dB to knock off, i.e. from unsilenced to silenced we must reduce the level by about 1000 times. Discounting possible future super high-tech, computer controlled active devices we are left with two basic silencing methods: Resistive and Reactive. The resistive method is demonstrated with the so-called absorption silencer (fig 1). This consists of a perforated tube running through the muffler and the space between is filled with a sound absorbing material, typically fibre-glass. As the exhaust flows through, the sound causes small movements to take place in the fibre-glass strands, these rub together and dissipate the sound energy. The main design parameters that affect its efficiency are length, mass of absorbing material and size, number and type of perforations. Punched holes being preferable to clean drilled. The best feature of this design is good flow, i.e. there is minimum restriction to the existing exhaust gas. For this reason it is universal wear for racing use, but it is difficult to meet current noise standards within the space available on a motor bike.

The packing material is also liable to get completely blown out and so silencing performance deteriorates with use. A characteristic frowned on by the authorities. This design is best at attenuating the higher frequencies, and the lower ones left are what give this type its distinctive "sporty" note.

The reactive silencer is, in its most elementary form just a large box or expansion chamber. (Fig 2). The gas contained in the chamber acts to cushion the pulsating flow, in a similar fashion to that of a suspension spring on the bike cushioning the rider from the wheel movements. In other words the gas in the chamber acts as a gas spring to soften the effect of the incoming pressure pulses. But, just as an undamped or under-damped suspension will perform badly at some speeds, so does the expansion chamber not work at certain frequencies Fig.3 shows an idealized plot of how the attenuation varies with different frequencies. Some notes just pass straight through un-attenuated. The length of the chamber tends to control the frequency response and the cross sectional

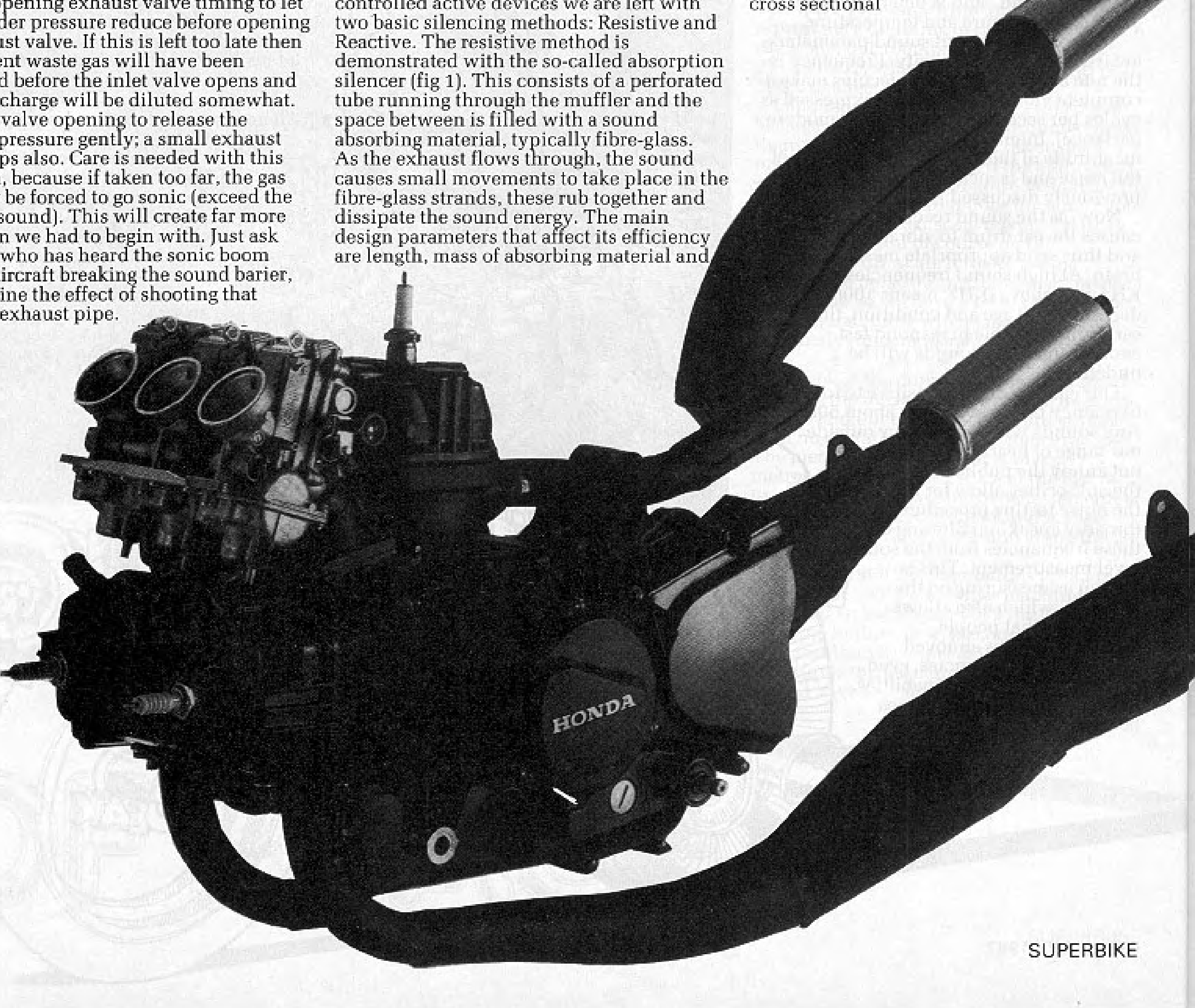
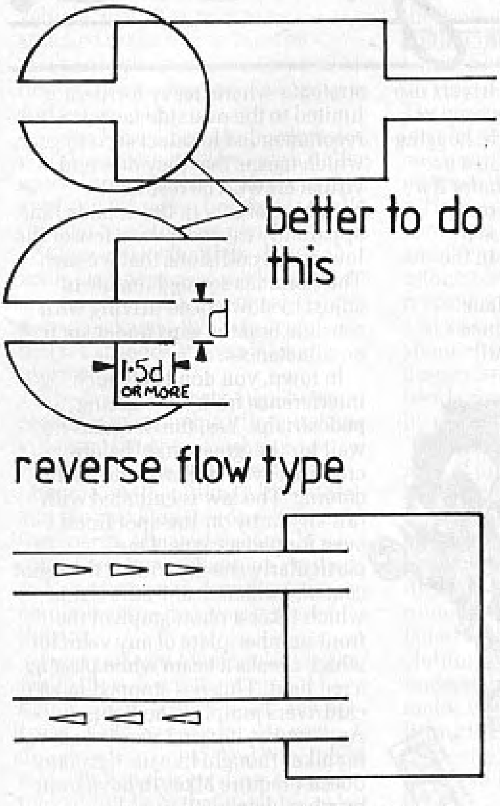


Fig2 REACTIVE TYPE EXPANSION CHAMBER



area controls the degree of attenuation. For best results the cross section should have, at least, four times the area of the incoming pipe. If we connect two or more of these chambers, each of different length, in series it is possible to use one to attenuate those frequencies that pass straight through another, and so build up a system that works well over a wide range of frequencies. This can easily be seen on many cars, which may have three silencers connected together. Less obvious on a motor-cycle perhaps, but this system is the basis of most modern designs, with the different chambers contained within the one silencer casing. This highlights one big problem with bikes — lack of space.

Theoretical calculations show that 20-30dB attenuation might be expected from a single simple chamber, but the space limitations on a bike mean that closer to 2dB is the practical value. Although there are various measures that can be taken to improve on this. Whenever sound meets a change in section or a baffle plate etc, some of the noise gets reflected back from whence it came. If the reflected wave is out of phase with the incident wave then they will partially cancel each other and reduce the sound level.

Along the length of the silencer (if long enough) there will also be areas where the two waves reinforce each other and increase the noise magnitude.

For a steady engine speed these areas in the silencer where the sound is partially cancelled or increased remain stationary and this gives what is known as a standing wave. The trick is to place the cancellation point at the chamber outlet.

Fig 2. shows some design features that emphasise this effect. If the incoming pipe is extended into the chamber by more than about 1.5 times its diameter, this helps with the establishment of the standing waves, as also does the design shown with flow reversal. The length of the chamber is the main determinant of which frequencies are best reduced in this manner. This further emphasises that big problem for the motorcycle silencer designer — lack of space, particularly length. Techniques like folding up the internals, within the outer wall of the silencer, to gain more effective length are all tricks of the trade.

To gain first hand knowledge of the problems facing exhaust system designers I went to see Alan Baker — the gaffer of Motad International. For a long, long time Alan's outfit has stood out from other after-market manufacturers with their systematic and scientific approach to the problem. Over the years they have analysed the frequency spectrum of most types of engine to establish which notes to optimise the design for. Computer programs have been developed to use this information to calculate pipe diameters, baffle spacing etc, etc. The vast experience built up has given them an intuitive feel for the requirements which often enables time saving short cuts to be taken in the development of a new system.

It has been found possible to standardize on one basic design concept for most engines; only the detail baffle spacing, tube sizes etc, need changing to suit various models. This enables many silencer components to be common on several models, which helps toward lower costs.

Fig. 4 shows the basic layout used. The first section uses a perforated pipe as in an absorption device, but at this point the sound intensity is still very high and the outer casing uses double skinning to lower the vibration in the outer wall and to reduce the direct sound radiation from that surface. The following chambers have differing lengths and volumes, adjusted for each type of engine to give the desired frequency response. Techniques mentioned earlier are used, e.g. note how the internal pipes protrude through the baffles, to assist the formation of the standing waves.

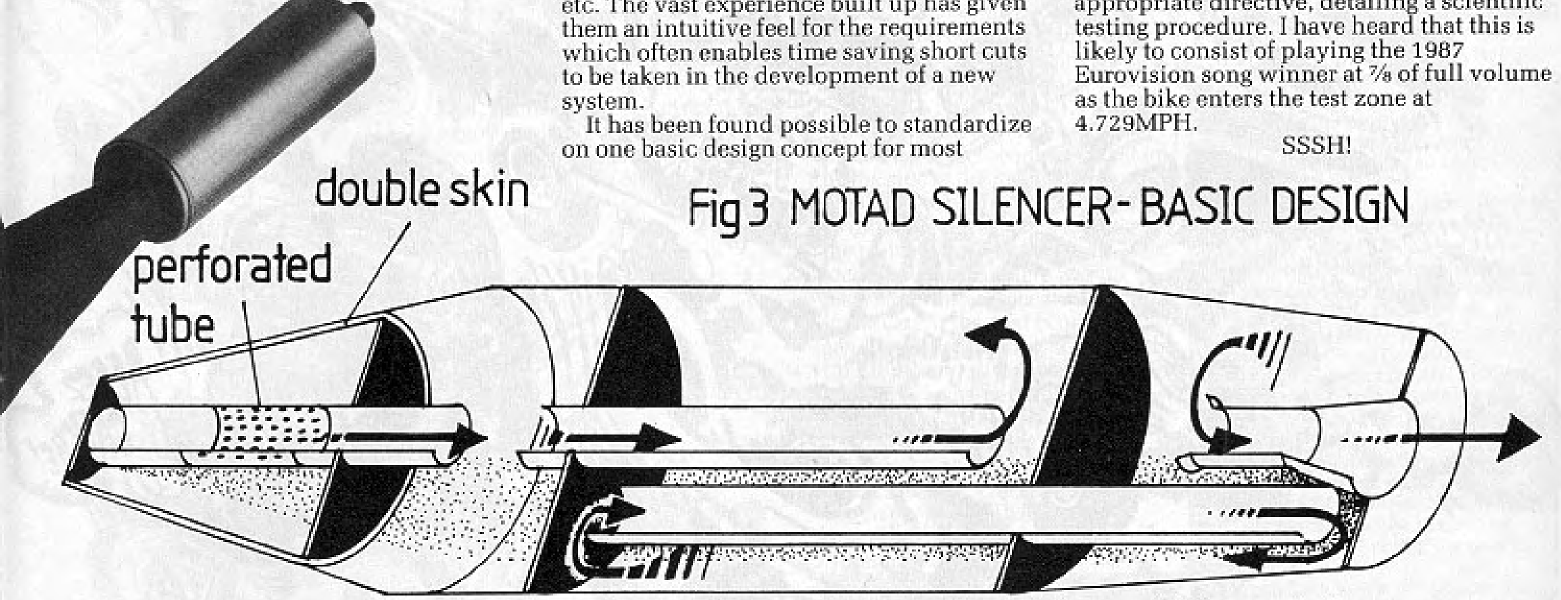
Motad, unlike some competitors have a policy of producing replacement exhausts that comply with the European standards, and require no changes to the carburation. The main parameter influencing carb settings is the degree of flow restriction in the system. This is checked on a special flow testing rig and compared to the original manufacturers exhaust. Apart from the noise level, to meet the regulations, the maximum BHP produced must be within 5% of the standard machine, and this power must also occur at an RPM figure within 5% of the original.

If the powers that be are to let us continue to ride bikes into the 90's and beyond, then there is nothing so certain that they will need to get even quieter than now. This will undoubtedly require design changes to many features. In some areas the trends are becoming evident already. Double skinning of both the silencer and front pipes is becoming important. Watercooling and full fairings are helpful to reduce mechanical clatter as well as combustion noise, but in the future expect to see steps to have some form of silencing on the cooling air intakes and outlets.

Whether Aspencade owners will be required to be totally enclosed in a glass bubble to contain the strains of Status Quo blaring from their megawatt tape decks, is as yet unresolved. But I am sure that the EEC commissioners will come up with an appropriate directive, detailing a scientific testing procedure. I have heard that this is likely to consist of playing the 1987 Eurovision song winner at ⅞ of full volume as the bike enters the test zone at 4.729MPH.

SSSH!

Fig3 MOTAD SILENCER- BASIC DESIGN



3 separate expansion chambers in series each with a different frequency response to give the required attenuation over the necessary range