TUNED PIPES

The tuned pipe has "come of age," says Kevin Lindsey, designer of E.D. Powerpipes, who reveals their secrets of operation and design

IN the late '40's the brilliant design engineers of MZ in East Germany invented most of the important features of the modern two-stroke, the tuned exhaust system being just one of these. Modellers were slow to catch on to the advantages; I must have been one of the first users (Bill Wisniewski of K&B Engines being the real first) in late '65. So many applications of pipes are seen in the model world that the 'pipe' has, at last, "come-of-age."

The tuned-length exhaust pipe 'looks' very simple though the working details are so complex a book could be written on the subject, and even then a lot of the details would be uncertain or subject to debate. By a combination of basic theory, practical experience and common sense the details can be condensed to a fairly simple story that explains the principles quite well. I don't mind if the very technically minded take me to task over some of the generalisations in this article; I can correspond privately with them; I'll try to keep this article readable.

This article is not intended to teach the individual how to become a pipe designer, the intention is to shed some light on pipes to assist in using them. I'm not suggesting that modellers make their own pipes; pipes are like safety pins — easy for a factory to make, not easy to make on a one-a-year basis.

The modern pipes can, as well as increasing power over a wide rev-band, reduce noise and, surprisingly, improve throttling. I hope to show how far these qualities can be refined, thus how wide the applications of pipes could be. Up to now I've taken most interest in aircraft, some in boats, but very little in cars. In future my interests may be spread more evenly over the three areas.

I won't try to describe all commercial pipes in detail; it would be presumptious to talk about other people's design philosophies; rather I'll concentrate on my own E.D. Power Pipes; I think my comments will be adequately relevant to 'pipes' in general.

As my own interest in pipes is somewhat academic in a future article; Clive Weller and Mike Smith will be describing their *practical* experiences in R/C Aerobatics and Pylon Racing.

Power and Noise

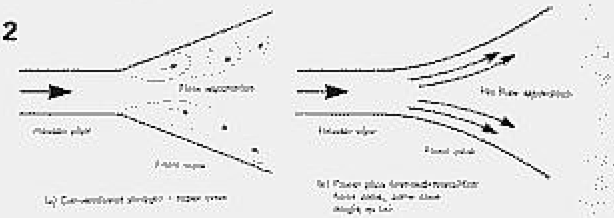
The first pipes came to the model world as the first rumblings were heard from the noise and environment conscious. A happy coincidence to my mind; I love power but I'm not very keen on noise. The possibility of combining power gain with noise reduction in one device was a challenge. On early pipes, noise reduction was of secondary importance; for environmental reasons, it's now of much higher importance. It would be confusing to mix discussion of power gain and noise reduction, so I'll talk about power first, then noise.

Pipes for Power (and Flexibility)

The first pipes seen on the flying field were so 'peaky' they were practically on-off switches; lots of power gain but very narrow useful rev-bands. Things have come a long way in 12 years. Let's look at pipe workings to see how things have improved.

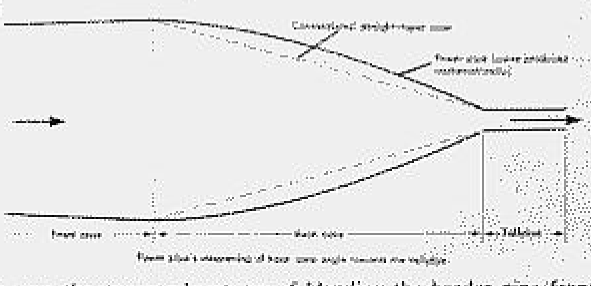
As the angle of the front extractor cone increases, the potential power gain goes up and up. The upper limit is when airflow separation occurs then the power gain drops off quickly; half a degree too much can make all the difference between good improvement, and none at all. Rather than play safe and keep this angle down, we can blend the transition between the reservoir header pipe and the front cone to cut down the chance of flow separation. I do this on the Power Pipe and get away with angles bigger than found on most pipes.

Fig. 2



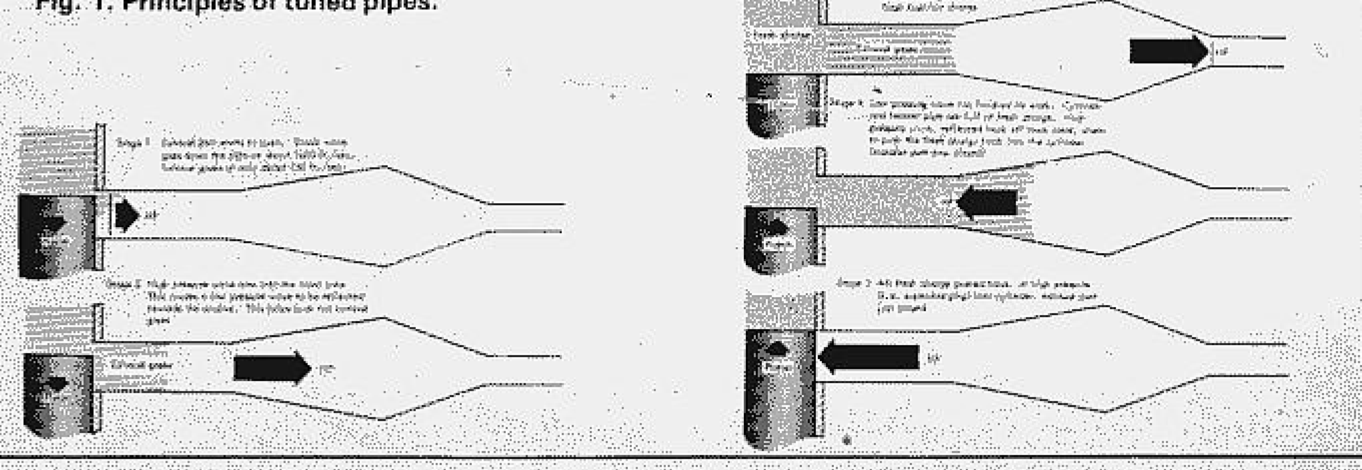
As the angle of the supercharger back cone decreases, more of the supercharging high pressure wave is smoothly directed out of the tailpipe, thus resulting in less power and more noise. What I do is to make the back cone a mathematical shape (the calculations are too involved to explain here) in order to achieve maximum supercharging without the pipe becoming too 'peaky.'

Fig. 3



We've seen the *power* advantages of blending the header pipe/front cone transition and steepening the back cone angle; now we have to talk about the usable rev band. If you rigidly define the three main areas of the pipe you rigidly define the conditions it will work at, that is, you rigidly define the optimum revs. This is acceptable on a racing motor bike with 24 gears but not for the way we operate engines. If we now blend the three areas, we less rigidly define the optimum conditions, i.e. we have a wider rev-band. This doesn't result in an overall reduction of maximum power increase because, in this shape blending a couple of principles which increase power are incorporated. So the overall power gain is much the same as a 'conventional' straight-coned pipe, but the rev band is much wider. This improved rev-band is not to be disregarded even for narrow rev-band operation — how many of us accurately know the revs we run our motors at? There's no point in optimising a peaky pipe/engine combination on the bench at 20,000 if we could be 2,000 out in the in-air revs. So we're talking about *realisable* power.

Fig. 1. Principles of tuned pipes.



Pipe Length

A simple formula will get you close to optimum pipe length.

Tuned Length =

$$\frac{\text{Pressure pulse velocity}}{2} \times \frac{\text{Exhaust port timing}}{360^\circ} \cdot \frac{1}{\text{rpm}}$$

or even simpler:

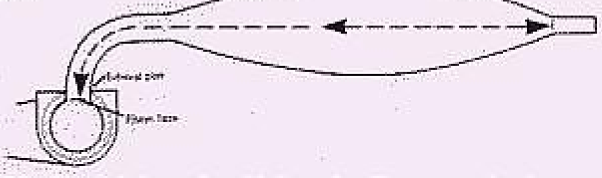
$$\frac{\text{Exhaust port timing} \times 1650}{\text{rpm}} \quad \text{(inches)}$$

or:

$$\frac{\text{Exhaust port timing} \times 41900}{\text{rpm}} \quad \text{(millimetres)}$$

This length is measured from the edge of piston to the back cone/tail pipe transition down the centreline of the exhaust manifold and pipe.

Fig. 4



With a blended-shape pipe, this formula will get you quite close enough under most circumstances; with a 'peaky' pipe you'll have to regard it as a starting point.

If the pipe is hung outside the model in the cold breeze, the pipe cools, the pressure pulse velocity drops slightly and the tuned length reduces slightly. Conversely, with an inside-fuselage assembly, the tuned length increases slightly. These are pretty small effects, however, no cause for undue concern.

In-air Rev Pick-up

It is fairly easy to measure engine revs on the ground (though some commercial rev meters are depressingly inaccurate). It is not easy to measure revs in the air, so how is it possible to set a pipe for in-air revs? The following generalisation will get fairly close. In-air pickup with a coarse-pitch prop is more than with a fine-pitch prop. With six inches pitch the pick-up will be around ten per cent, rising to about 15% for a nine inch pitch. So a six inch pitch prop giving 12,000 on the ground will increase to about 13,200 in the air, a nine inch pitch will increase to nearer 14,000.

Having established a way of getting pipe length near optimum (if you want to); measure the static revs of your (intended) flying prop. Use the pickup percentage to work out your in-air revs then put a faster prop on, capable of statically giving your intended in-air revs. Optimise pipe length; swap back to your flying prop and off you go. Mike Smith will explain in a future article how he does this for his very successful FAI Pylon Racer.

It can be deduced from the foregoing that the other advantage of a non-peaky blended-shape pipe. Let me explain by example. Back in '66 when operating a high revving C/L Speed MVVS 2.5 on a very peaky pipe: the pipe was well 'off' at ground revs, 'on' in the air. But the rev loss on the ground contrasted with the pipe gain in the air, plus prop in-air pick-up produced a rev difference of 6,000; nearly 30 per cent. This made it very difficult to operate. If the rev band of the pipe spans in-air and on-ground operation, life is so much easier.

Pipe Proportion

The length of the back cone is related to the exhaust port timing; the length of the front cone is related mainly to the transfer port timing whilst the length of the header pipe depends mainly on the exhaust timing. As the exhaust port timing goes up, then the lengths of the back cone and header pipe increase at the expense of the front cone. This means, for instance, that if you try to change the operating revs of a pipe drastically by increasing or decreasing the manifold header pipe, you go off optimum proportions. Again a good reason for function blending so that this is not too critical. How far can you go with non-critical operation? Let's look at a couple of examples from my files; one pipe is the present Size 2, Mk.II E.D. Quiet Pipe, the other was an experimental predecessor where the shape blending wasn't as good.

So on the better, new pipe, set for peaking at 14,000, we were obtaining a power rise over a rev band of about 6,500 rpm.

Pipe 'Come-in'

You will notice both pipes cross the line and give a power loss below 10-11,000 rpm. Some pipes swap violently from power loss to power gain at a certain rpm. This is 'come-in' and not a particularly welcome feature, certainly not on a model where flexible operation is needed, e.g. R/C Aerobatics. This 'come-in' rpm can be calculated from exhaust timing and transfer timing and pipe proportions, but rather than tell you how to calculate it, I prefer to smooth it out with a blended pipe so that we hardly notice it. The fact that at lower revs the pipe reduces power is not necessarily bad; this reduced power is stabilised by the pipe so a smoother, greater power ratio results; useful for R/C throttling.

One last point about 'come-in.' Some people think because they hear the pipe 'come-in' they're on peak power. Not true! It *only* means it's swapped from power loss to power gain. The calculable 'come-in' rpm can be thousands below the calculable 'peak' rpm.

Tailpipe Size and 'Strangling'

If the tailpipe is too small, the engine is 'strangled,' that is, it overheats and power drops. As the tailpipe diameter is increased the engine stops overheating; if you open it up too much, power starts dropping because more and more of the useful supercharging pressure pulse goes out of the back. As the tailpipe diameter increases, this extra pressure pulse emission means more noise, so there is an optimum for best power increase with no engine overheating and good noise reduction, which is given by the following (generalised) formula. If you can't be bothered with mathematics, it translates as ¼" on a 12,000 to 14,000 rpm '60.

Tailpipe bore =

$$\frac{\text{Engine capacity (in cc)} \times \text{rpm}}{912{,}000} \quad \text{(inches)}$$

This is satisfactory for normal, shortish tailpipes, say one to two inches. However if you want to duct out the exhaust gases with an extension tube, increase the bore of the extending tube, by approximately 50 per cent to be on the safe side.

Exhaust Timing

C/L Speed men use timings up to 185° or more. Racing motor bikes go to about 200°. Up to recently, 135° was common with R/C motors, you may notice this has crept up to 150°-165°. Why does this help? Without a pipe, it doesn't. With a pipe, it does because power gain is dependent on available supercharging time, which is about equal to exhaust timing minus transfer timing. A little more exactly, look at my (admittedly theoretical graph.

Fig. 5

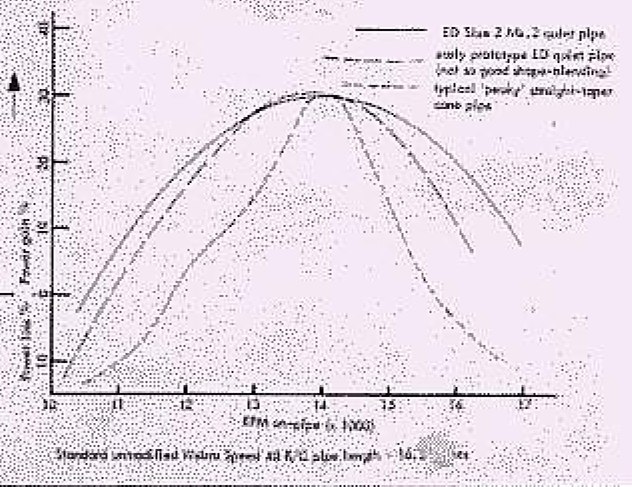
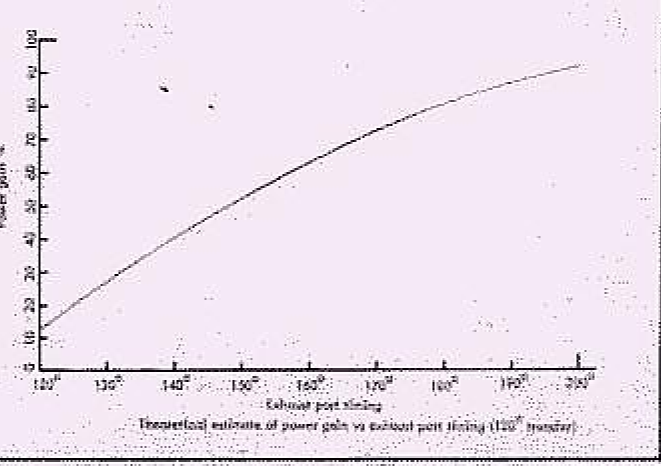


Fig. 6



The gain does start flattening off as we get near 200° but certainly it seems to make sense to go up to at least 180°. As I'll explain in a minute, though, working up to this slowly is a good idea. At the bottom end, it is interesting to note that if the exhaust and transfer timings are *equal* you still get a power gain. This is because of the separation of the ports which gives an effective lead of the exhaust port of about 8°. Look at the power gains I'm suggesting are possible up the top end — nearly 100 per cent. I'm serious! We've shown that if you just chop a 140° exhaust up to 160°-170° and re-optimise the pipe, the extra power fits the graph quite well.

As the exhaust timing and power go up, the pipe more and more dominates the engine; the pipe more or less tells the engine where it is going to produce peak power. Let's go off peak power; let's lower the revs, not altering pipe length, etc. Instead of first extracting the exhaust gases, then pumping the header-pipe's store of fresh fuel/air into the cylinder, the supercharging pressure pulse gets back too soon and ultimately pumps back just exhaust gases, resulting in a lot less power but also a lot lower fuel consumption. Looking at this the other way, as the revs come up (start up — warming up — picking up in the air) the fuel required increases. This need increases rather rapidly and may not be too obvious with moderatly timed engines where R/C carburetter versatility can cope, but could be with 160° to 180° timings. C/L speedmen solved the problem with a CFS (centrifugal fuel switch). As the model goes round faster, the increasing centrifugal force opens up the fuel supply more.

As a 'pipe' 'comes-in' higher pressure can be tapped from the pipe or manifold to pressurise the fuel tank and therefore more fuel to the carb and should be sufficient for engines of moderate exhaust timings, but I can't tell you whether this approach will be adequate with 180° + R/C motors; I don't have any experience; so for now all I can advise is that you don't go too far in modifying your motor, I'm not sure I should advise you to modify it at all, since 150° to 165° engines are now on the market, and engines can suffer "nasties" from grinders and files.

This need of the pipe for more fuel as it 'comes-in' doesn't mean engines are extra thirsty on pipes. If anything, the thermal efficiency of an engine on a pipe is a bit better but reflect that to fly ten per cent faster you need 21 per cent more power, so with unaltered thermal efficiency you would be using up fuel 21 per cent faster; with the extra (pipe) power. You must expect to use up fuel a bit faster, but probably not as much as indicated above, due to the improved efficiency.

Transfer Timing

Leave alone! The present timings of 120° to 130° are fine.

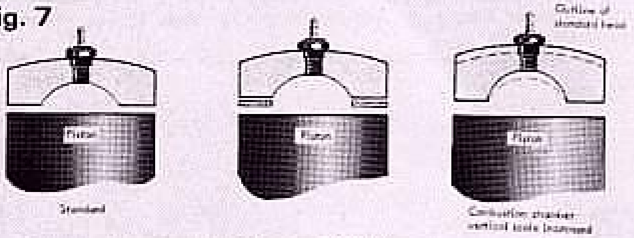
Manifolds, etc.

The best way to duct gases from the exhaust port to the header pipe is in a straight line; no corners, no changes of inside shape or cross-sectional area. So on aeroplane, a rear-exhaust engine is going to go faster than a side-exhaust engine where the exhaust gases and pressure pulse have to turn through 90°. For this and for noise and aerodynamic cleanliness reasons, rear-exhaust aircraft engines will almost certainly become very common. So far we've mainly had 'converted' C/L Speed and R/C Pylon Racing motors, but very soon we'll have good rear-exhaust R/C motors from top manufacturers. The *Super Tigre* X 60 R/C is only the start.

Engine Compression Ratio

Supercharged engines work better at slightly lower compression ratios. It doesn't make a dramatic difference but if you want to experiment, the first thing to try is just an extra gasket under the cylinder head. This is strictly the first step because it just increases the thickness of the squish band. Real optimising involves stretching the vertical scale of the head. I can't be more specific about all this; I haven't done enough work on this myself yet.

Fig. 7



Lowering compression ratio for optimum pipe operation

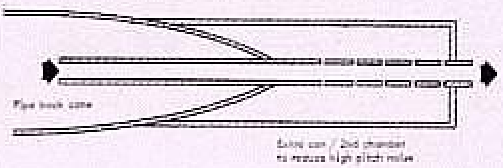
Pipes for Less Noise

A few years ago, I was very critical of the fact that most exhaust silencers were quite small diecast 'eggs.' From standard proven theory and practice, the size of an efficient silencer can be calculated; and the dimensions are quite frightening. An expansion chamber silencer for '60 at 12,000 rpm should be around 12in long and two inches diameter.

Gradually the size of commercial (non-pipe) silencers is increasing (an 'add-on' silencer makes the silencer effectively bigger).

To predict how one of these non-pipe type silencers will affect the engine power, you can regard the silencer as a mis-shapen pipe, and you conclude that a silencer without pipe features *can only lose some power*. Using this approach the other way; for silencing criteria, you can regard a pipe as a mis-shapen expansion chamber silencer. From this you come to the conclusion that the length and diameter are quite good but the shape is not ideal, noise-reduction-wise. The bigger the cone angles, the better. Pipe-size expansion chambers are good for reducing low-pitch noise; not so good for high pitches. For them we need a small expansion chamber — the can at the back of 'quiet-pipe' systems.

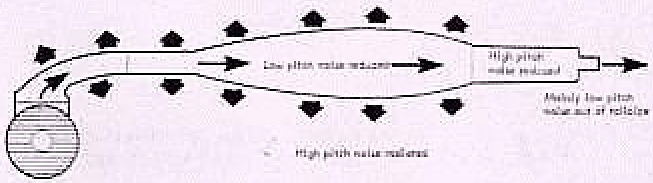
Fig. 8



Two-stroke motorbikes have been using this sort of pipe-silencer for years.

If we want to increase the quietening efficiency, we can sub-divide the back chamber with baffles, etc. each sub-chamber reducing certain pitch (frequency) bands. We can also extend the tailpipe back into the pipe back cone. These features are proven and used by many manufacturers. If you wave a dB meter at a quiet-pipe motor, you often find higher readings *alongside* the pipe than looking down the tailpipe. High-pitch noise goes through the side of the pipe and manifold.

Fig. 9



This can be reduced with accoustic foam 'lagging' and/or an enclosing in the fuselage.

A considerably more complicated approach than the little diecast eggs common a few years ago but it is the price we must pay for quietness-plus-power. What has to be remembered is that as power goes up, prop noise and engine noise are likely to go up, we have to try harder on the noise front than the not-so-power conscious.

So far I've talked about pipe/silencers which produce large power gains. Another approach would be to concentrate even harder on noise reduction and compromise power gain, that is, build some pipe principles into a near-optimum expansion chamber silencer to produce maybe a nominal power gain only. This looks like being one of my future projects.

Prop Noise

I know this is supposed to be an article on pipes but bear with me for a few moments. The usual trend with internal combustion engines is to increase power and operating rpm. Operating the prop faster means higher tip speeds which produce more prop noise and probably lower efficiency. Some of our competition '40's and '60's are producing prop tip speeds up to about Mach 0.9. We can't make airfoils well enough to get high efficiency at these rpms. So I'm making a plea for more pitch or blade area or more blades, not more rpm, with all this extra power. The resulting noise should be lower and the efficiency higher. With the power/weight ratios of modern motors, I don't think the lower initial acceleration of a higher pitch prop will be unacceptable when used with a wide rev band pipe designed to give power increases at more sensible revs such as I've tried to do with the Mk. II Power Pipes.

Below: Dave Brown of the U.S.A. used an *E.D. Mk II Quiet Pipe* on his *Phoenix 7* aerobatic model. Dave placed second at the 1977 R/C Aerobatics World Champs.