R/C Pattern by dean pappas

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Well hello again. To be sure, we've said this time and time again, but repetition takes nothing away from the truth of it: when it comes to aerobatics, a good power-to-weight ratio with predictable controllability is the holy grail. All this happens against the backdrop of the noise limit rules in Pattern. Pattern is the first aeromodelling event, both domestically and worldwide, to put meaningful noise limiting rules on itself. For quite a few years, it was the only one. Then the FAI Precision Scale folks toughened up their rules and the Scale Aerobatics (IMAC) folks started studying the issue in a serious way maybe a decade later.

Back when the noise rules first happened in the early eighties, the dominant powerplant was the piped 60 two-stroke. The 10 cc displacement rules in both AMA and FAI simply assumed that two-strokes ruled! How different things are now ...

Still, if you are running a two-stroke engine, just about the best weapon for noise abatement *and* good horsepower is the tuned exhaust system. Why? The long version of the answer is ... well, long and rather involved. But the short version is this: the tuned expansion chamber uses the energy in the exhaust that would normally create noise and uses a portion of it to create a torque boost at the tuned rpm. Also, the tuning effect produces a noise filter. Just as the length of a trombone affects the note that it produces, the tuned pipe filter attenuates (reduces) and absorbs the noise energy at frequencies that correspond to the higher harmonics of the running rpm, while passing the fundamental through.

For example 12,000 rpm works out to 200 cycles per second or just a little more than a full octave below concert "A". The result is that the remaining noise has a more mellow tone. Muffled two-stroke engines always sound raspier than their piped counterparts. This is even true with the best mufflers that have added baffles.

For this reason, tuned pipe use has always offered the promise of more horsepower and a less offensive sound. These are valuable characteristics, not just for Aerobatics but for Sport as well. The problem is that the difficulties in getting a piped setup to work properly rendered them as little more than curiosities for most. The reasons for this are few but important. Let's explore them.

To begin with, even if you have all the right components for the job, pipe tuning requires an "ear" and an understanding of the process. Knowing what an overly long or an overly short tuning length sounds and behaves like takes time. Unfortunately, the instructions that were often given did not help to de-mystify the process., and many of us using pipes in the competitive arena didn't do a very good job of explaining, either!

Secondly, the promise of more horsepower tends to lead people astray. The useful setup for both Aerobatics and for Sport is not one that produces the *most* horsepower, just *more* horsepower. For a while, pipe manufacturers were selling pre-tuned setups that were designed for the most horsepower, because after all, peak horsepower sells! Almost by definition, these are the setups with the poorest handling characteristics, or table manners. You don't give children their first horseback ride on a thoroughbred!

The available hardware that came to market, like the pipes themselves, were often placed on the market based on which ones gave the highest horsepower boost. Even if you had the knack for tuning them, the handling characteristics were bound to be less than ideal.

Only in the twilight of the tuned pipe equipped two-stroke's hegemony in Pattern did the emphasis turn toward tractability throughout the full range of rpm and load. It was Turnaround that did it: instead of needing maximum speed and momentum for running maneuver entries, Pattern now emphasized uphill grunt and downhill brakes. Pipe designs changed from simple double-cone designs optimized for peak power at a narrow band of rpm (the power-band) to shapes with more forgiving characteristics. Unfortunately these shapes did not reach the non-competition market!

First let's very quickly run through the "Reader's Digest" version of tuned pipe theory. If you would like the long version, let me suggest Gordon Jennings' Two Stroke Tuner's Handbook. The book has been out of print, probably for decades now, but it can be found online in PDF form at: http://edj. net/2stroke/jennings/.

I have had some success looking for used copies of the book through some of the larger book stores, too. The "gospel according to Jennings" is an enjoyable read and it has enough theory to satisfy just about anyone's need to understand the subject in depth. First, let's very briefly look at how a pipe works. The header pipe actually helps scavenge the exhaust out of the cylinder. All it has to do is to be the right length. This is because two things happen when a simple piece of pipe is hooked up to the exhaust of the engine. When the exhaust port opens, the hot exhaust gasses will expand as they dump out of the cylinder. If these gasses are allowed to expand completely, very suddenly, then a very intense but very short suction pulse is created.

This does help pull fresh mixture from the crankcase into the cylinder, but not very well. If that expansion is stretched-out in time then this scavenging will be much more effective. How much more effective will it be? Car tuners and Drag Racers have always known that the right length header pipes make more horsepower ... and more noise!

A tuned expansion chamber, or pipe, is much more interesting than a mere header. The header now opens up into a cone, which produces a greater expansion of the exhaust gasses, and maintains that expansion for longer than that created by a header pipe that simply dumps to atmosphere. The length of the header and expanding cone is "tuned" to correspond with the portion of the crankshaft cycle that starts with the initial opening of the exhaust, and continues through the opening of the intake or bypass ports. Quite a bit of fresh intake mixture is pulled from the crankcase, through both the bypass and exhaust ports and part of the way down the pipe. What comes next is the neat part.

The expanding cone ends with a reflecting cone or baffle(s) that reverse the whole expansion process. Now, a reflected high pressure wave pushes that fresh mixture in the pipe, back into the cylinder. If the lengths of all the pieces are right, then this fresh mixture is compressed in the cylinder in the time between the closing of the bypass ports and the closing of the exhaust port, as the piston rises some 150 to 180 degrees after the exhaust first opened.

Tuning for maximum boost means that the expanding and then compressing pressure waves finish their job, just as the exhaust port closes. This is free supercharging: packing more fresh fuel/air mixture into the cylinder, and producing more torque at the rpm where this all happens.

The amount of effective compression boost is a function of the engine's timing and the shapes and lengths of the header pipe and expansion chamber, or pipe. At this point, you can easily imagine, I would think, that there is an optimum length, angle, or diameter for each and every part of the header and pipe. This perfect combination will produce maximum power at the chosen rpm. If you are truly interested, read Chapter 4 of Jennings ... the third reading usually suffices! As with most things in Life, for every upside, there is a downside ...

At something like half the tuned rpm, the pipe works exactly wrong. The effective compression is reduced, which tends to make the engine behave under-compressed, cold, and often rich. This is the cause of the rich mid-range "bog" that is the bane of tuned pipe users. The better at extracting maximum boost that a header/pipe combination is, the better it will be at producing this annoying anti-resonance.

Now is when sensible compromise comes in. Changes to pipe geometry can create boost that is not as strong, but that works well over a wide rpm range. We'll discuss those changes just a bit later. Wide boost bands mean that the system can typically be set for lower rpm, or longer (think of the trombone) while still providing good boost at typical in-air rpm. This means that the anti-resonance moves down in rpm too, hopefully to rpm so low that they correspond to very tiny carburetor openings. At this point, the tiny opening dominates the engine's breathing characteristics, and the unhappy effects of the anti-resonance are greatly diminished.

So the first thing we do is to find friendly shaped pipes. If you are still interested in getting close to maximum boost, then you need a pipe that could be termed a long-chamber design. These usually have a long constant diameter section between the expanding cone and the converging cone or baffle. How long? If the straight part is about as long as the expanding cone, or longer, then what you have is a long-chamber pipe. Don't be fooled by the outside shape; use a small flashlight and a long stick to find the reflecting cone or baffle.

The "canister" mufflers usually sold for Giant Scale and Scale Aerobatics use are even friendlier, and as a result, they offer a little less boost. They are available in a range of sizes, even for 40s and 60s though it may take a bit of effort to find them! Most of these have at least one baffled muffler chamber, and as a result are nice and quiet.

Header pipes are not terribly fussy, but they generally come in two flavors: skinny for the engine size and those with larger diameters. For example, the larger diameter headers for 120 sized two-strokes were around ⅞ inch inside diameter and were most useful in setups that maximized engine rpm. Lower rpm, high torque setups used headers that were closer to ⅝ inch in diameter. That's nearly a 2:1 difference in cross-sectional area. When it comes to reducing peakiness, the larger diameter headers are what is called for.

Once you have identified the exhaust components, it's time to set the tuning length. This is where we contradict the instructions that came with all those tuned pipes that were sold twenty and thirty years ago. Those instructions said to test the engine on the ground with the system components assembled at full length, and to measure the peak rpm achieved. Then the system would be shortened by something like ¼ inch and the ground test repeated. Like the instructions on the shampoo bottle: lather, rinse, repeat until the rpm no longer gets higher or drops with the last shortening. Then back off one step. The procedure is straightforward, and it uses a tachometer: it is quantitative, so it must be right!

Alas, these are the instructions for producing maximum horsepower. The same ones that also produce poor table manners. Actually, the engine's throttle-ability will get even worse if the pipe is further shortened. That's not what we want.

Instead, we must use a system that starts with ground testing for throttle-ability and needle-valve friendliness. Then we move on to in-flight testing in order to find out whether we need to make a compromise to the adjustments made on the ground. It's not the kind of procedure that you would write out on a little slip of paper slipped into the plastic bag the pipe comes in.

The goal of the on-ground tests is to set the system *just* long enough that the needle-valve is easy to set, and so that the mid-range richness does not create a "bog" that prevents the engine throttling up reliably when the stick is slowly moved from idle to full. The slowly advanced throttle (maybe 5 seconds for the sweep) is an acid-test of sorts.

A correct initial length setting, even just in the ball-park, can save you a lot of testing, so if you have any data from someone else who tried a similar setup, go with that. If not, then use the rule of thumb: 200,000 / Desired rpm = Initial Length. Alternatively, if you have the exhaust system installed and it's not easy to change the length more than a little bit, then you will be searching for a propeller that turns at the rpm that corresponds to that length. Solving the same expression for rpm we get: rpm = 200,000 / System Length.

What is this system length, and how do you measure it? That's a fair enough question. The system length is the distance, "as the exhaust gas molecule flies" from the center of the combustion chamber, through the middle of the header pipe, through the expansion chamber to the baffle or the middle of the converging cone. As we said before, you may have to use a small flashlight and a long stick to find that first baffle.

Next, set the needle valve for a few hundred rpm rich of the peak, and carefully set the idle mixture so that the engine transitions cleanly and quickly from idle to full rpm when the throttle stick is "snapped" up to full. If this is not possible, then go no further: change the glow plug heat range and/or fuel until this works properly. If the chosen propeller does not allow the engine to turn at the desired rpm, then change prop size and load until this is true.

Now, for the needle-ability test. With the engine at full throttle and set, as we described, just a few hundred rpm on the rich side of peak, slowly ... very slowly ... open the needle until the engine starts to run blubbering rich. Now slowly work the needle back in to the original setting. Does the engine RPM respond smoothly? Is there a noticeable jump in rpm somewhere in the middle? Is there a giant and sudden jump?

The noticeable jump is acceptable, the sudden jump is an indicator that the pipe may be too short, and the complete lack of an rpm jump is a *likely* indicator that either the system is long or that there is no boost! Slowly richen the needle again, and look for where the big RPM drop occurs.

If the drop and the jump-up occur within an eighth of a turn of the needle valve of each other, then the system length is probably okay. If they are a quarter of a turn, or more, of the needle apart (you have to lean the needle a whole quarter turn to get the engine to jump back onto the pipe) then the system is probably too short.

With that information in hand, let's do the throttle-ability test. Set the high-end needle for just a few hundred rpm rich of the peak and now slowly work the throttle back and forth from idle to full. It should take about five seconds to go from one extreme to the other. If the engine throttles properly, go fly. If it stumbles rich on throttle up somewhere around half-stick then either the glow plug heat range is wrong, or the tuning length is too short. Provided the engine does not quit rich in the middle, you should be able to prove this by briefly pinching the fuel line while in that state. The engine will "clean-up" and go to full throttle nicely afterward. If you cannot notice any RPM jump at all near half throttle then take note of this as the exhaust may be set too long.

Provided your engine passes both tests (it's not a hard pass/fail, but more of a "feel") then it's time to fly. The test is a simple one: if the engine goes rich in prolonged full throttle straight and level flight, then the system is still a little long. Depending upon how objectionable you find this tendency, shorten the pipe and retest for throttle-ability and the in-air behavior.

If you are inclined to fly around at wide-open-throttle all the time, then you will almost certainly shorten the pipe until the richening tendency just disappears, or until you start to notice mid-range problems. That's where the compromise comes in! My flying buddy, Dave Lockhart (back before he changed over to electric), used to fly with a setup that would continue to accelerate in full-throttle level flight for two or three seconds and then start to go rich as the rpm unloaded past the upper end of the power-band. He didn't need full throttle except for vertical climbs, so the tendency never bothered him. Adjust the compromise to suit yourself, but long-chambered pipes and canister-type expansion chambers give you the wiggle-room you need.

Well, it's time to go for now. See you next month ... 'Till then, be careful and be kind.