POWERING MODEL VEHICLES WITH VALVELESS PULSEJET ENGINES

 by Larry Cottrill 03 June 2008

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In this paper, I won't talk about how to design and build an engine - there are plenty of discussions on the www.pulse-jets.com forums (and several other places) where these issues are discussed in detail. Instead, I'll concentrate on describing (for aspiring jet modelers) how to actually use such an engine to power a model vehicle (R/C or U-control plane, dragster or speedboat).

There are many, many potential problems here - so many, in fact, that the average model builder might find the situation quite daunting. On the other hand, I hope you are the kind of individual who will let nothing stop you - go for it! At a MINIMUM, here are some of the design problems you will have to face to get the job done:

- Engine size limitations:
I started out trying to develop what are considered "tiny" pulsejet engines, and have yet to be really successful at getting either reliable operation or good performance. My old DynaJet (a valved engine that I bought back in the 1960s) is about 21 inches (over 500mm) long and exactly 2.5 inches (approximately 64 mm) maximum diameter and weighs ONE POUND (half a KG)!. All of the few very small commercial pulsejets I've ever seen photos of are almost that same length, even if they are less than an inch (25mm) in diameter and very light in weight! So, at the present state of the art, the "smallness" of usable pulsejet engines is limited - there are a lot of technical reasons for this, but I won't burden you with the details here.

- High heat output:
Radiated heat is probably the single most difficult problem in pulsejet powered model vehicles. Many models have caught fire in the few moments between starting the engine and launching the model. By their very nature, pulsejets run literally red hot from the primary combustion zone near the front all the way back to the exit nozzle (I need to modify this statement a little - once they're moving and getting plenty of airflow around them, the red hot zone is more limited, but is still a potential problem). Fuel spillage is especially hazardous in or around pulsejet powered models. You MUST provide (a) some sort of 'heat shield' (sheet aluminum is ideal) between the engine body and the vehicle structure, and (b) really good airflow to and around the engine itself once the vehicle is in motion. Also, you need to "get moving" right away after startup, and avoid "static running" (full power without forward motion) as much as possible.

- Interruptions in fuel flow (esp. liquid fueling):
A pulsejet of any type MUST have absolutely smooth fuel delivery - in the case of liquid fuel, it will stop immediately if a significant bubble comes up the fuel line. In a pulsejet, there is simply no "flywheel" action to carry the operation of the engine through even a split-second fuel interruption. For a vehicle that runs on ground or water, this makes it VERY difficult to design and build fuel systems. Many things have been tried - for model planes, I like to 'fill' the fuel tank with nylon scrubber material (by this, I mean the 'kitchen scrubber' kind) to baffle the slosh of the fuel. Of course, this means you have to make the tank larger for the amount of fuel you want to carry. Probably the best option, technically, would be a 'bladder' or 'balloon' tank, carefully purged of air when refilled. But, most rubber balloon materials (basically latex) don't last long when exposed to the kinds of fuel needed (white gasoline, ether, etc.) so they need frequent replacement. They will last longer with most alcohols, which are also reasonable fuels (note that unlike typical "model airplane fuel", there should be no oil of any kind mixed into pulsejet fuels!).

- Problems with carbureted liquid fueling:
I have always used liquid fuels in model aircraft I've designed and built for valved pulsejets, and these engines use simple carburetion for fueling (no pumps, etc.), making this the simplest, most straightforward pulsejet fueling method by far. Unfortunately, carburetion in valveless designs is somewhat more complex. I know of only one historical example (found in an old magazine article) of a model actually flown with a valveless engine liquid fueled via its intake suction alone. At this writing (summer 2008), serious experimentation on valveless engine carburetion is being undertaken. For various technical reasons, throttling is more difficult than with a pressure-driven system. In my opinion, in the case of models where fine throttling control is unnecessary (e.g. U-control scale, sport or speed flying) carbureted liquid fueling will have no peer, once properly developed. The advantages are obvious:
- Extreme simplicity and maintainability
- Very low weight of the entire fuel system
- Minimum system bulk for the amount of fuel carried
- Wide variety of available cheap fuels

Of course, there are disadvantages as well. Liquid fuels are not necessarily the safest option in crash situations (a lot depends on specific circumstances, of course). Carbureted liquid systems are the most vulnerable to engine failure due to the fuel bubble problem discussed above. Pressure changes due to G forces in maneuvering can cause significant engine power variations. Like everything else in vehicle design, all this has to be weighed in terms of what you’re trying to accomplish.

- Difficulties (and possibilities) of liquid fuel injection:
For experimental purposes, fuel injected vapor fuel designs have some advantages, but the complexities (and potential hazards) of such systems may not be considered acceptable (see the next subtopic). Liquid fuels can be injected under pressure within the engine intake pipe if a finely atomized spray can be achieved. However, there are some difficulties. Injection of liquid fuel requires a regulated pressure source such as a pump (which needs a battery in the vehicle, naturally) or a pressure tank and regulator (and if you're doing all that, you might as well just use vapor fuel like propane instead). One advantage to pump-driven liquid fuel injection is that it is fairly easy to control the pump output, providing a suitable mechanism for engine throttling. Another is that maneuvering G forces won’t alter engine thrust. On the downside, atomizing injection nozzles for liquid fuel necessarily have very small ports, and careful filtering of the fuel is essential to prevent clogging by impurities. Also note that in any pressurized system, connections, hoses, etc. have to be maintained in perfect condition (and checked frequently) to guarantee safe operation.

At this writing, the best developed system I’ve seen for throttleable liquid fuel injection to a valveless pulsejet is the one developed by my friend James Irvine of Irvine Aeropulse Labs, headquartered in Australia. His system design, while much more complex than simple carburetion, gives a high degree of engine control and (with modern battery technology) is very lightweight and compact. It is specifically designed for R/C vehicles. One definite advantage to James’ system is that throttling is via direct voltage control of the pump, without the need for a servo! You can email James at **irvineaeropulse@optusnet.com.au** to ask for his 12-page photo illustrated report describing this system, or visit **http://irvineaeropulse.co.nr** to see his TIG-welded injection nozzles, fuel filters and other offerings for valveless pulsejet users.

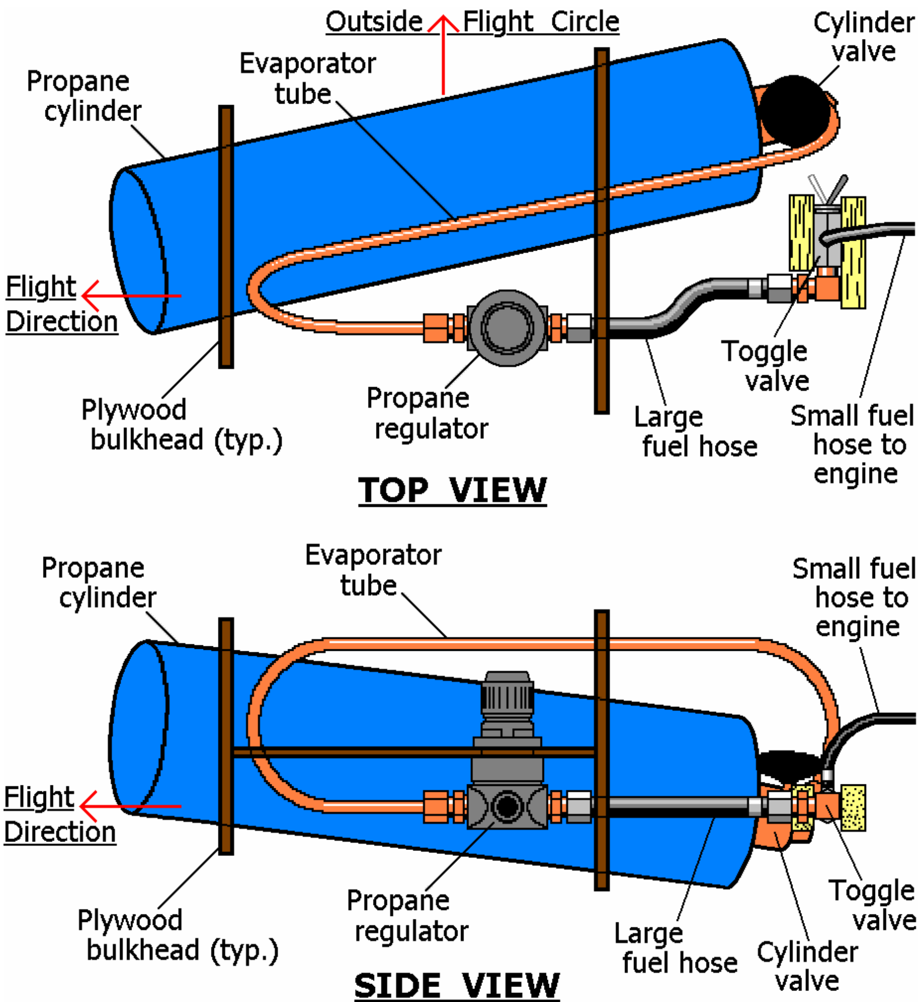
- Regulating fuel pressure and flow in vapor fueling:

NOTE: Don't expect to fly a model aircraft fueled with pressurized vapor (such as propane) at an AMA sanctioned meet (USA) – this is disallowed specifically by the current rules. You will probably find similar restrictions in most other countries. This is mainly due to the known dangers presented by pressurized systems in crashes. It is crucial to know and strictly observe all necessary precautions in designing, building, testing and using pressurized vapor fuel systems.

When we use vapor (pressurized gas, such as propane) for fuel, vapor pressure itself is the only driving force for fuel flow to the engine. Unfortunately, this apparent simplicity is offset by the fact that the cylinder vapor pressure of such gases is highly variable, and in general will decline significantly (and RAPIDLY) as the gas is consumed. This is because the gas is actually stored in the cylinder as liquid, which boils (even at ordinary outdoor temperature) to provide the vapor needed – this rapid evaporation chills the cylinder contents, immediately lowering the vapor pressure. Dropping pressure means decreasing fuel flow, and hence, decreasing engine power. A pressure regulator can be used to stabilize delivery pressure, but only until the pressure in the cylinder finally reaches a value too low for the regulator to handle (after that, the engine will rapidly lose power and ultimately quit running).

Most regulators made for propane cooking equipment are either too low in maximum pressure or too restrictive for the high flow volume that pulsejets demand. Most compressed air regulators will work for propane, but are set up for too high an adjustable range, which makes settings "touchy", i.e. difficult to set "just right". Most of these regulators are also too bulky and heavy. There is now a miniature lightweight air regulator that is adequate to run small pulsejets – the **ARO Model 86045**, with a 0-50 PSIG adjustable range and a supply pressure limit of 250 PSIG (this is adequate for propane under normal summertime conditions, but NOT at elevated temperatures). The regulator is less than 3 inches (75mm) in height, and weighs just a few ounces. Nice features are a self-locking (spring loaded) adjustment knob and a threaded mounting ring (optional). You can order one directly at this Web page: **http://www.regulatorstore.com/prodinfo.asp?number=86045**

Of course, the regulator by itself does nothing to prevent the cylinder from chilling. This process can be slowed, however (for longer duration fuel delivery) by moving most of the evaporation outside the cylinder into a copper evaporator tube. Basically, the fuel is still in liquid form leaving the cylinder valve, but then evaporates (due to the pressure drop at the valve). Thus, major cooling is taken up in the evaporator tube, leaving the main liquid mass unaffected. The cylinder valve needs to be kept low (and to the outside of the flight circle, in the case of U-control) so that liquid will always be delivered to the evaporator section. The setup would be arranged something like this (the valve functions will be explained in the next subtopic):



- Interrupting fuel flow when you NEED to (yes, it CAN happen):
Regardless of the fuel and fuel delivery system used, you MUST be able to immediately force your engine to stop, by completely shutting off fuel flow, under any of several emergency conditions:
- Vehicle crash
- Emergency during starting or launching
- Loss of engine power
- Other "in flight" emergency

The most dependable way to get crash fuel shutoff is with an inertial “crash valve”. This can be any good quality miniature valve that can be shut off by a sliding weight that “flies forward” when your vehicle comes to a sudden stop. A toggle valve is ideal for this purpose, because the protruding toggle gives the flying weight a nice size target, with all the leverage needed to assure a positive shutoff. This type of valve is “all or nothing”, it’s either wide open or completely closed, and that’s exactly what we want. The weight should run in a short tunnel or track to guide it to the toggle; it can be held back against normal inertial forces by a replaceable “shear pin” of stick balsa.

This same valve can be used in case of starting / launching emergencies by equipping the toggle with a music wire “pullrod” extending out through the side or top of the model where the launcher can grab and pull it quickly in an emergency. In my opinion, the best setup features a bellcrank so the wire would be pulled rearward, with a loop in the wire that the launcher keeps one finger in while holding the model for launch; if no emergency arises after the engine is started, he slips his finger out of the loop just as his hands release the model.

Toggle valves are also available in “momentary, normally closed” designs – in this case, the toggle is spring loaded, and it takes over a pound (1/2 Kg) or so to hold the toggle over so the valve stays open. This is perfect for power loss shutoff. If the engine loses power during the run for some reason, and if fuel is still allowed to flow, the engine can easily “flame out” with a huge volume of billowing flame. We can shut things down before this can happen by using the engine thrust itself to hold the valve open against the spring-loaded toggle. To do this, our engine mount is made as a sliding rail that moves freely forward in a track or channel. After the engine starts, the rail applies its thrust to the toggle; before starting, the toggle has to be held in the open position by some other means, so fuel will flow to the engine. This could be via a metal pin that the starter removes once the engine is running.

Once your vehicle is moving at speed and you’re getting adequate cooling around the engine, it’s extremely unlikely that a fire or other fuel-related emergency will occur; however, you can add an extra level of safety by providing some way of activating the crash valve independently. On an R/C model, this would require another servo; on a U-control model, this could be done with a “third wire” going out to the control handle, but pulled only when the pilot observes an unsafe condition at the model.

All these valves, along with the bellcrank and pullrod setups, etc., need to be anchored solidly into your model, just like your landing gear, control system, etc. Don’t glue them in, though – anchor them in hardwood or plywood mounts with screws and washers, so they can be removed for repair or replacement.

- Engine mounting complexities:
Because you have to insulate the vehicle body from the engine heat, mounting can be difficult. Your mounting, besides supporting the weight and inertial "maneuvering forces" of the engine, needs to be a good heat radiator, without conducting much heat to the mount points on the vehicle. Remember also that since these engines are long, you need to provide support not just for weight and thrust, but also for the rotational "thrashing" forces as you maneuver. This can just be some lightweight metal bracing out near the tail end of the engine.

- Throttleability issues:
Pulsejets can be VERY limited in their ability to be throttled, although we have seen reasonable throttleability in vapor-injected (as opposed to liquid-fueled) engines. Our propane-fueled valveless jobs are throttleable over a fairly wide range – BUT, I can assure you, the bottom end is nothing approaching the low output of a piston mill at 'idle'. What this means is that your "slowing down" is going to be mostly a matter of good braking and traction (for a land vehicle) or waiting for drag to take over (in air or on water), rather than the "engine braking" you might be used to. So be warned - stopping a jet vehicle will NOT be instantaneous!

- Poor thrust/weight ratio:
Traditionally, valveless pulsejets have been reputed to have poor thrust/weight ratios - the notable exception being the Lockwood-Hiller design in its best configurations. The L-H would be a fine engine for a car or boat, although it's rather bulky, especially in terms of overall cross-section (probably not as critical as it might be in an airplane). At this writing (summer 2008), we are just beginning to realize small, relatively compact valveless pulsejet designs that have low enough bulk and weight to use as practical flight engines. Another issue is achieving practical, simple methods of liquid fueling without a large weight penalty for the vehicle. Only a few practical miniature valveless designs are commercially available now, but a greater variety can be expected in the near future.

- Starting equipment:
I have read many people saying you can light a pulsejet from the rear of the tailpipe, and in some cases I'm sure you can get away with this, but in general, spark plug ignition somewhere in the combustion zone probably provides more dependable results. I have experimented extensively with several commercial glow plugs with pulsejets and can tell you one thing they have in common: they don't work. Even using ethyl ether, I have never gotten a single bang out of one of my jets using glow plugs at their rated voltage. Spark plugs small enough for miniature pulsejet use have long been available and they work beautifully, after opening the spark gap way up. You must provide high voltage spark for starting (not needed after the engine is running) - I use a Model T Ford 'buzz box' type spark coil, but much more modern electronic solutions are available, of course. At any rate, a pulsejet starter is quite a rig to set up. For small engines, you need not only the spark source but also a supply of compressed air with steady (i.e. regulated) and easily adjustable delivery pressure, a 'push button' valve, etc., all of which means more complication and expense. For all my experimental work, I use the same portable pressure tank and spark coil rig I put together back in 1963 and it still does the job for all small engines.

- Poor fuel economy:
In pulsejets, you can forget about fuel economy at the speeds at which even a high-performance vehicle can be expected to operate. All pulsejets are "gas hogs" until you get up to a few hundred MPH. This is not usually a great concern to hobbyists, except that if you want to run for more than a minute or two, you're going to have to allow enough physical space in your vehicle design to house a BIG fuel tank, whether your fuel is liquid or pressurized gas. Naturally, the bigger it is, the heavier the tank and contained fuel will be.

- Vibration:
Pulsejets are vibration generators by their very nature, because of their multiple explosions-per-second operating mode. Make sure your radio gear is well cushioned against vibration (you'd probably be careful to do this, anyway). Back in the days of 'reed' radios (unless you're at least 50 years old, you probably don't even know what I'm talking about) there would have been a concern about the jet actuating a servo by acoustic resonance, but I can't imagine the modern stuff (especially FM, 'digital', etc.) having a problem like this. The point is, just make sure nothing critical in your model vehicle is vibration-sensitive at frequencies around a few hundred hertz (cycles/second).

Even in a simple U-control model, vibration can be a problem, because we depend on machine screws and nuts to hold some important things together – for example, our control systems! Threaded fasteners should have lockwashers or be secured with a drop of Loc-Tite(TM) compound when assembled; or in many cases, self-locking nuts (the ones with the little embedded nylon inserts) can be used, as long as they are well isolated from the engine heat. It's hard to imagine a worse model plane disaster than having a U-control jet model "come off the lines" and head for a crowd of spectators. It has been known to happen, even at big AMA-sanctioned events with their mandatory pre-flight safety checks!

- Fire safety issues:
Because of the very high operating temperature, the flame ejection (only two or three inches behind a small engine, but extremely hot and totally invisible in daylight) and the extremely volatile fuels used, safety is a big concern. Always keep a good fire extinguisher (Type A, B AND C) close at hand during starting, and always take it with you if you need to "chase down" a model that has stopped or crashed somewhere "downrange". You'll need to stay away from areas where your model might accidentally run off into dry grass, etc. Don't forget that a jet-powered R/C model can get out of radio range VERY quickly - the system should be rigged to immediately shut off fuel to the engine if this occurs. Remember - if anything can go wrong, it will - and with jet models, things can go wrong awfully fast, with the model VERY far out of reach!

Use good judgment as to WHERE and WHEN to operate a jet model. In recent years, the Southwestern US has been plagued with massive forest fires, many of which were caused by simple human carelessness. Before you head out with your pulsejet model, make sure you're not taking any chances with the dangers of a high flammability environment; always keep in mind that your model might end up in an unintended location, with the engine still running at full heat and power!

- Noise:
You may or may not be aware that pulsejets are the all-time loudest engines for their size and power ever devised by man. The reason, of course, is the multiple explosions (pulses) per second that create the thrust. This means that many areas you would normally use for electric or even piston-powered models will be definitely off limits for a pulsejet-powered model. It would be nice to be able to enjoy your hobby without arrest and prosecution, paying EPA fines (US), etc. So, always be sure you KNOW that you can legally and safely operate your model in the chosen location. And, ALWAYS provide top quality hearing protection for everyone involved in starting your engine and launching your model.

- Conclusion:
Now, if you think you can handle all that (and I'm sure other jet modelers can think of a few more things to consider!) then I say, **"Go for it!"**

Always operate your model SAFELY, and "go have a blast"!

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