Blast Compression Valveless Pulsejet Engine

(A Layman's Concept)

Note

This is an amended version of the paper that was originally published on the Internet in October 2000, on Kenneth Moller's site devoted to small jet engines (http://www.pulse-jets.com).

As the sub-title says, this is not a scientific or engineering paper. It is intended for general readership, more specifically for people already interested in pulsejets. I found it difficult to predict the level of knowledge of the audience with any precision. My own knowledge represents an accumulation of over 30 years of tidbits read or heard here and there, on top of high-school level of familiarity with physics.

The reader should be at least vaguely familiar with the principle of functioning of the pulsejet engine. Explanations given in the text are based on the general knowledge a tinkerer or any other person interested in pulsejets will almost certainly have. For the readers completely unfamiliar with the pulsejet engine, my suggestion would be to try Bruce Simpson's website (http://aardvark.co.nz/pjet/howtheywork.shtml), which offers an excellent description of the basics.

To some readers, I will often be stating the obvious, or putting certain things in oversimplified terms. I can only ask them to bear with me. Restating the conventional sometimes helps explain the unusual.

Elusive Promise

During World War II and for some time afterwards, the pulsejet engine looked hugely promising. The principle was familiar from the pre-war years, but its use in the German V-1 "buzz-bomb" underscored its potential dramatically. Before the war was properly over, scores of researchers and developers descended on the alluringly simple concept to analyze it and see what could be done with it. Soon, many of them were on the trail of significant improvements.

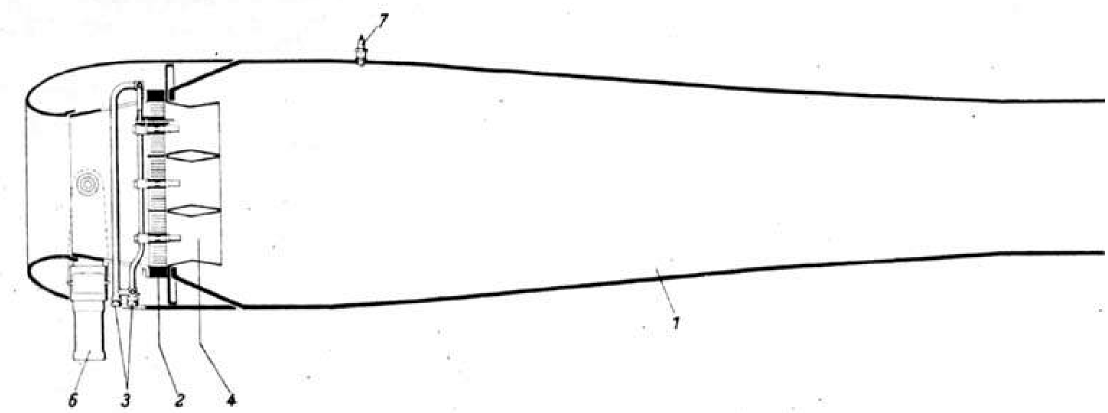

Fig. 1 – Diagram of the Argus engine of the Fiesseler (V-1) flying bomb

However, during the 1950s, most researchers gradually abandoned their efforts and turned to other things. Partly, the reason was disappointment. Even the improved pulsejets were comparatively inefficient, horribly noisy and depended on fragile and short-lived valves.

Also, there was little they were really good for. For a while, it looked like they would power small helicopters (but never made the grade), there was some use on powered flying drones, and a modified version of the German Argus tube was briefly commissioned to power a missile for the US military. By the mid-1960s, very few people still considered the pulsejet as an aircraft powerplant. The noisy tube was perceived as a blind alley and relegated to the role of model aircraft engine and, perhaps surprisingly, combustor for central heating systems.

The reason I am looking at the pulsejet now is the change of circumstances. Sometime in the early 1980s, ultralight fun flying started getting increasingly popular due to the availability of good, simple and affordable flying platforms – hang gliders and paragliders. When provided with motor power, these machines offered unprecedented freedom of flight to anyone interested.

By their nature, however, all the engines currently used in ultralight flying are heavy and cumbersome, even in their simplest form. They also require much ancillary equipment, like reductors, prop shafts, propellers etc. etc. Having all that gear mounted on a light foot-launched hang glider defeats the original purpose. In this light, the simple, cheap and lightweight pulsejet engine starts making a lot of sense. It is perhaps time to blow the dust off the concept.

Facing the Drawbacks

Of course, one must not be blind to its obvious shortcomings. A noisy and inefficient engine of dubious reliability and short working life does not sound like a good recipe for fun in the air. A modern pulsejet must be a step closer to the turbojet in efficiency, longevity and reliability to have any hope of success. The issue of noise must also be addressed.

After much thought and inspection of various past designs, I decided that tinkering with small improvements would not do much. Namely, the pulsejet engine has certain inherent traits one can do very little about. They have endeared it to builders of flying models and other amateur enthusiasts but worked against most other practical uses. This is as true today as it was in the 1950s.

One of them is the use of reed (or flap) valves, which limits reliability and longevity and causes the peculiarly painful quality of the pulsejet noise. Another is the reliance on resonance, which limits combustion efficiency. The third is the low energy-mass transfer ratio, which limits thrust directly. Let us review them briefly first.

Valves

The reed valve array produces aerodynamic drag. A lot of valve area provides relatively little effective intake area. Instead of smooth passages, the valve gear offers various edges and projections to the air stream, producing terrible turbulence. You want some turbulence to help the atomization of fuel and mixing with air, but not too much and certainly not in the wrong place.

Working life is an even bigger problem. Valves on V-1 engines lasted for about 30 minutes of continuous use. After that, the entire contraption was supposed to drop on England, so the short working life did not cause much concern in the German camp. In peacetime, however, you really want your engine to last a bit longer. Postwar development improved the design in many ways and stretched its working life from minutes into hours, but the fundamental problem remained.

Namely, the valves in a pulsejet are supposed to satisfy conflicting demands. To open and close wide and quickly (in the interest of efficiency), they have to be as light as possible. Because they have to endure great mechanical stress (bending and high-speed slamming open and shut) and do it in a high-temperature environment, they have to be very, very tough. If something has to be light, yet exposed to great abuse, it either spells short life or exotic technology. The former is impractical and the latter is expensive.

> **Note**: Working tirelessly in New Zealand, Bruce Simpson appears to have produced a valve-equipped engine -- called the X-jet -- that does not abuse its valves nearly as much as conventional pulsejet. See it at http://aardvark.co.nz. At the time of writing, valves on his prototypes were into several dozen hours of operation with no damage visible. The secret appears to be in shielding the valves from direct blast.

Resonance

The subject of resonance in pulsejets is somewhat controversial.

Paul Schmidt, whom many see as the inventor of the pulsejet as we know it, considered his machine purely as an acoustic resonance engine. All stages of its working cycle – scavenging, intake, compression and ignition – are performed by standing waves created by the explosion of the fuel/air mixture. The behavior of the standing waves is determined by the geometry, the mechanical and acoustical properties of the engine parts. It works best when they are all in tune, so to speak. Rather aptly, the tuning of a conventional pulsejet has been compared to the tuning of a church organ.

It even looks like a part of an organ (Fig. 2). A pulsejet is little more than a straight tube cut to the required dimensions, with a few small flaps and a fuel jet at one end. The tube must be of a certain length and certain diameter to work best with the given valve gear. Conversely, the characteristics of the valve mechanism (size, bending properties, natural frequency etc.) have to relate to the natural frequency of the tube in a proper way. Preferably, the valve frequency should be much higher than the tube frequency. The requirements are not difficult to achieve and the result is an engine that is simple and elegant in mechanical terms.

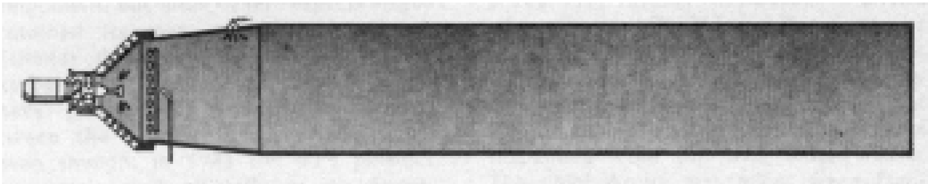

Fig. 2 – A typical Schmidt-type pulsejet engine

There are several problems with it, however. One of them is efficiency. In this mechanism, the standing wave is not harnessed very effectively. The high-pressure peak of the explosion cannot be put to work very well, because it has very little mass to propel. At the same time, the low-pressure trough is expected to do too many different things – suck fresh air in, slow down the hot exhaust gas, stop it and suck a part of it back for ignition etc.

It means that the high end of the energy is wasted and the low end overburdened -- the opposite of what one would really want.

In fact, the working cycle of the resonant pulsejet is misapplied for propulsion purposes. Jet propulsion is achieved by thrust, which is really a byproduct here, incidental to the process. It is easy to design a pulsejet that will happily potter away producing no thrust to speak of. Indeed, the greatest commercial success achieved with the principle has been its use for fruit, vegetable and slurry drying equipment in food processing industry and for central heating burner units – see Fig. 3. In both applications, thrust is best avoided altogether.

Another problem is throttling. If the engine is resonating in its natural frequency, it will be impossible to move it out of that frequency without considerable energy loss. So, the only way to throttle the engine up and down is to vary the amplitude of the oscillation -- the size of the individual bangs. Just about the only simple way to do this is to vary the amount of fuel fed to the engine. This implies some kind of intermittent, metered fuel injection, which detracts from the basic simplicity of the pulsejet.

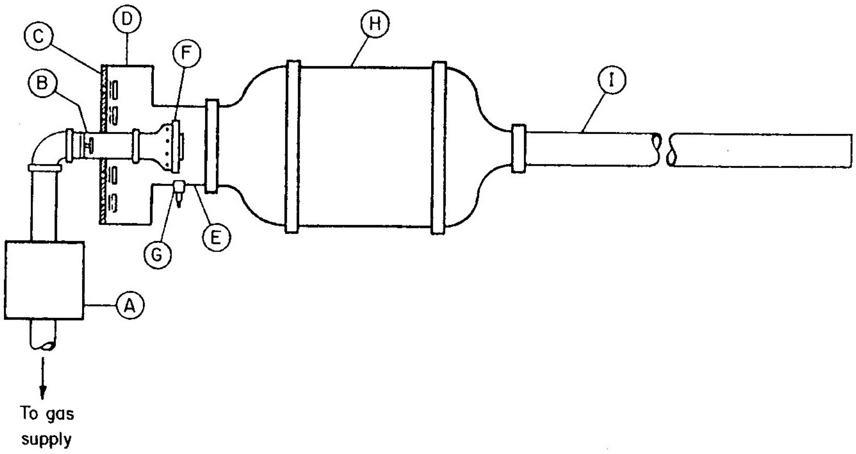

Fig. 3 – A simplified diagram of a Lennox Pulse burner for central heating

Why did I say the subject was controversial? Because there are indications that resonance may, but need not, be the governing mechanism in pulsejets. Some people think that resonance in those pulsejets that do resonate at their acoustical frequency is a lucky coincidence, helping the engine work well. In other pulsejets, the frequency of the working cycle is simply different from that of the tube. The engine is actually working against the effort of the tube to resonate at its natural frequency, at the cost of a considerable waste of energy. (If the two frequencies are not close to each other to start with, the further apart they are, the better.)

This is an insufficiently explored field. While I do feel that standing waves do not offer an adequate mechanism for engine aspiration, further research may yield better ways to exploit their formation or to avoid it.

<u>Energy-Mass Transfer Ratio</u>

A well-known textbook on jet engines says succinctly: "*Basically, a jet engine is a machine whose purpose is to increase the momentum of the air stream passing through it*." Air passes through the engine, where energy is added to it in the form of heat. The process imparts speed to the stream, and the resulting momentum manifests itself as thrust.

The problem with pulsejets is immediately obvious: Air stream <u>does not</u> pass through them. A small amount is sucked into the combustion chamber and used for combustion and a slightly larger amount is sucked back into the exhaust tube between explosions. That is all. There is very little propulsion mass for the energy to act on. Because of that, only a small part of the considerable thermal energy liberated by the process of combustion can be converted to kinetic energy (thrust). The energy-mass transfer ratio is very low.

Fig. 4 – An early version of the Lockwood-designed engine with add-on thrust augmenter cones clearly visible after each exhaust

This was best shown by the experiments performed by Ray Lockwood with his so-called resojet during the (ultimately abandoned) development in Fairchild and Hiller aircraft companies in the 1950s and 60s. Addition of a thrust augmenter (a device that uses the stream of hot exhaust gas to suck additional fresh air into the exhaust jet gas stream) noticeably increased the thrust of his engine (Fig. 4).

Curiously, previous experiments with thrust augmenters showed little or no improvement. My conviction is that the reason was simple – those experiments were performed either with compressed air (notably by NACA) or with turbojet engines. Both could only offer the mechanical part of augmentation. Even the turbojet exhaust gas had little extra energy to give that had not already been utilized for propulsion. Tacking augmenters onto its exhaust pipe did nothing. In contrast, the super-hot exhaust of the Lockwood resojet cried out for additional propulsion mass to heat up and accelerate.

A New Departure

Even though the three problems outlined above appear to be inherent in the concept, somehow the promise does seem to be in there somewhere. I found it hard to reject an idea of such simplicity and elegance. Instead, I have tried to see what could be done to improve things. Over a number of years, I have gradually come up with some answers. At one point, they clicked together into a new concept.

When I started thinking of improvements, I tried to start from the basics.

Efficiency of all internal combustion engines depends on the mean effective pressure in the working cycle. To keep it high, a designer should aim to pump as much fuel/air mixture as possible into the engine, compress it as highly as practical and have it burn at the highest feasible temperature. Jet engines also have to achieve a good energy-mass transfer rate. That means that the thermal energy generated by combustion should be made to accelerate as great a mass of ambient air as possible to the highest possible speed.

Pulsejets score well only on the temperature side. On the other three counts, their performance is pitiful.

Looking at the three weak areas, I decided that pumping more mixture into the combustion chamber would be difficult without an ancillary device -- a supercharger of some kind. As I wanted the engine to remain as simple as possible, I left that approach alone. That left the compression and the energy-mass transfer rate.

So far, pulsejets have not had notable pre-compression. In fact, some researchers have taken the absence of pre-compression to be one of the basic features of pulsejets. What little pre-compression is achieved is passive -- due only to the inertia of fresh air rushing into the combustion chamber. The compression ratio does not exceed 1.2:1, meaning that the pressure before ignition is barely 20 percent above atmospheric. In turbojets, it is up to 30 times atmospheric and in piston engines, it is 10-20 times atmospheric.

My concept introduces a rather complex "active" mechanism, using the force of one exploding charge of the fuel/air mixture to compress the next charge. It is a strong force and the process should raise the compression ratio closer to the range associated with piston engines.

To improve the energy-mass transfer rate, my engine would use a completely different breathing mechanism, which would allow it to ingest a large amount of ambient air. Both the available heat and the kinetic energy of the expanding gas would be harnessed to work on a much greater propulsion mass than normally available in the conventional pulsejets.

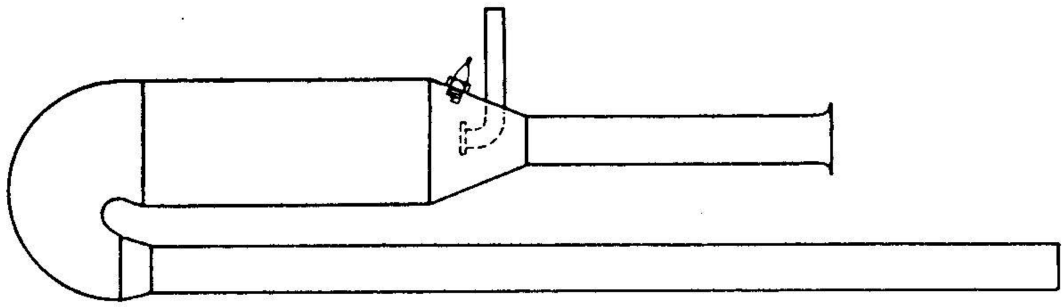

Fig. 5 – SNECMA Ecrevisse

Additionally, the design proposed here boldly aims to go the valveless way. For reasons left unexplained in the reference texts I was able to find, valveless pulsejets never really caught on among the model builders. For amateur developers, they may have been too tricky to adjust properly. What little evidence I do have suggests that they are much more sensitive to proper geometry of parts than the reed valve types.

Whatever the case, the engine described in this paper has no moving parts. If nothing else, it should help reliability. There is nothing to break, seize or bend. The proof of soundness of this approach I found in the fact that the two engines that so nearly made it on the market – the Ecrevisse, produced by the French SNECMA (Fig. 5), and the almost identical Lockwood resojet in the US – were valveless.

Engine Layout

On the way to the new concept of pulsejet, I plumbed the modest depths of my imagination to the full, but also tried to see what smart people had done before. The result thus owes its features to several different past designs (not all of them in the field of jet propulsion) but combines them in the way that has not been tried before to the best of my knowledge.

(“Before” may be a wrong word. It has not been tried at all. At the moment of writing -- summer of 2001 -- not a single truly successful prototype of this engine has been built. While considering it, please remember that this is still just a paper engine.)

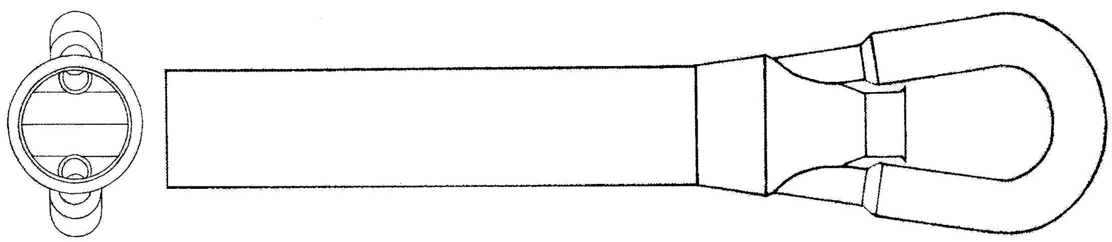

Fig. 6 – Possible layout of the proposed engine

The envisaged engine (Fig. 6) has three main components – the curved combustor tube, the straight central tube and the fuel supply system.

Combustor

It is a tube that consists of two straight sections connected by a curved section to make a teardrop shape (Fig. 7). Each straight side of the teardrop serves as a combustion chamber.

Each “chamber” ends in an abruptly tapered constriction and has a narrower tubular nozzle projecting into the central tube of the engine. The curved part connecting the two combustion chambers serves only to allow the pressure pulses to travel freely from one chamber to the other.

This is not the first time a pulsejet has had two combustion zones in a single tube. In 1906, a Frenchman, Robert Esnault-Pelterie, patented a pulsejet in which one chamber fired against the other (Fig. 8). His machine had a valve at either end of a straight tube. Explosions alternated between the ends. Hot gas was ejected from the center point between the two chambers into an exhaust branch set at the right angle to the main tube. The machine was not an engine in itself, but a gas generator for a gas turbine.

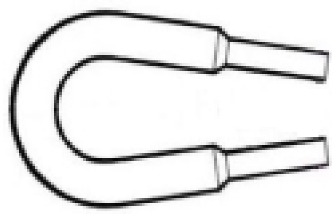

Fig. 7 -- Combustor tube

My design is different in being valveless, having a curved tube instead of straight, and in ejecting hot gas from the ends of the common tube, rather than from the middle, but the basic principle of interaction of two combustion chambers in one tube is the same.

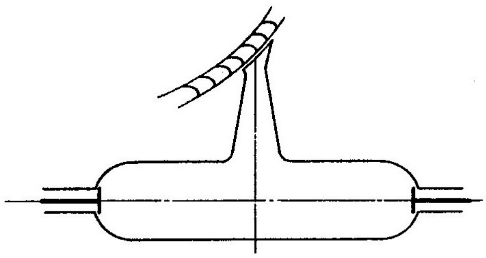

Fig. 8 – Layout of the Esnault-Pelterie engine
(The curved structure visible on the top is the perimeter of a turbine wheel)

Central Tube

For easier explanation, the simplified cross-sectional drawing in Fig. 9 shows the central tube divided into five stations. Each station has a different and separate function.

Station (1) is the intake port. All fresh air enters the engine here. As can be seen from the drawing, the tube offers unimpeded passage of fresh air from the intake port all the way to the end of the exhaust.

Through the next three stations, the tube is divided into two passages by the central deflector. This is a simple structure of two wedges connected at the blunt end, with the sharp ends pointing towards the intake and the exhaust, respectively. The passages to either side of the deflector are D-shaped (or crescent-shaped) in cross-section. This is best seen in the view into the exhaust tube, on the left of Fig. 6.

Station (2) is the "cold" diffuser. Being a cone, its cross-sectional area gradually increases, which slows down the incoming fresh air and raises its pressure. Tubular nozzles of the combustor -- visible in station (2) – take up the center of each passage, but fresh air can pass around them.

Hot exhaust gas produced in the combustor blasts from those nozzles into station (3), which functions as a gas ejector. Here, pulses of hot gas hit the passing fresh air and push it towards the exhaust.

Station (4) is the "hot" diffuser, which mixes fresh air and hot exhaust gases. Here, the interface between the hot gas and cold air disappears; the air is mixed with gas, heated and accelerated further. The diffuser is conical in shape and the cross-section of its passages gradually increases, allowing the mixture of hot exhaust gas and heated air to expand in an orderly fashion.

Station (5) is the exhaust tube. Alternating blasts of gas from the two converging passages are entrained here to blow in the same direction. Each blast also generates suction from the opposed side in Station (4).

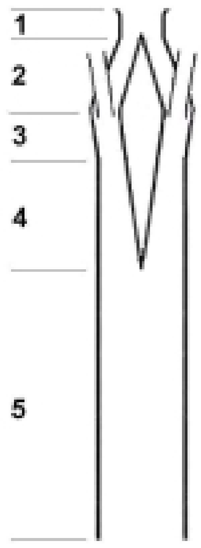

Fig. 9 – Central tube

While the ejector principle first came to my attention in an old German design of an outboard pulsejet boat engine, in which the hot exhaust gas pushed water to create propulsion, it should also work with air as the propulsion medium. After all, that is essentially what turbojets and fanjets do. They ingest a great quantity of air (much more than they need for combustion) and push it to great speed to provide thrust. Fanjets have a particularly great proportion of "driven" to "consumed" air. The majority of air does not even enter the hot core engine, but is propelled around it.

My engine also aims to push a lot of air to produce thrust, but uses pressure pulses instead of fan blades.

Fuel Feed

The fuel supply system consists of a gas flow regulator from which two tubular struts lead into the mouths of combustor nozzles. Each strut has a gas jet at the end.

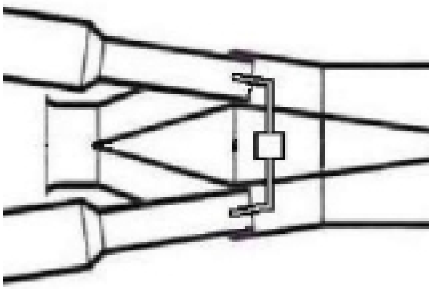

Fig. 10 The fuel supply

Fuel flow is constant. In theory, it would be better for propane to squirt into the combustion chamber on demand, but the mechanism to do that would add to the complexity. I want the engine to be as simple as possible and free of all the ancillary systems I can get rid of. Should someone offer a really simple intermittent injection system, I will be glad to use it.

The Schmidt-Argus tube and the Lockwood valveless engine both worked rather well with continuous injection and I would choose to stick to it too, confident that in practice, the gains that might come with intermittent supply would be annulled by the added cost, weight and complexity.

The Working Cycle

Alternating Combustion

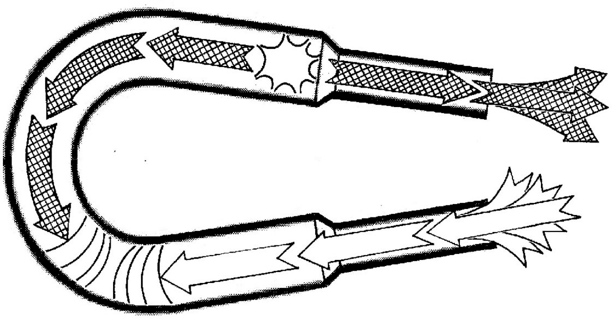

Fig. 11 – Expansion in the upper combustion chamber and intake in the lower

Each straight part of the teardrop-shaped combustor tube can be considered as a separate combustion chamber. When the fuel/air mixture within the chamber ignites and explodes, hot gas (represented by the darkly hatched arrows in Fig. 11) is driven in two directions. As shown in the upper part of the diagram, one part of the hot gas blows through the nozzle (and into the central tube). The other part goes through the curved section towards the other combustion chamber.

The process in the other chamber (lower part of Fig. 11) is out of phase with the first. At the moment when the expansion starts in the upper chamber, it is already over in the lower one.

As in the conventional pulsejet, by the end of expansion the pressure in the chamber drops below atmospheric. Low pressure sucks fresh air in (white arrows in the diagram). There is a plentiful supply of air right in front of the mouth of the combustor nozzle -- the entire flow of fresh air passes by on its way towards the exhaust tube. As the air enters the lower chamber through the nozzle, it mixes with propane that is coming out of the fuel feed strut (not shown on this diagram). The mixture fills the combustion chamber.

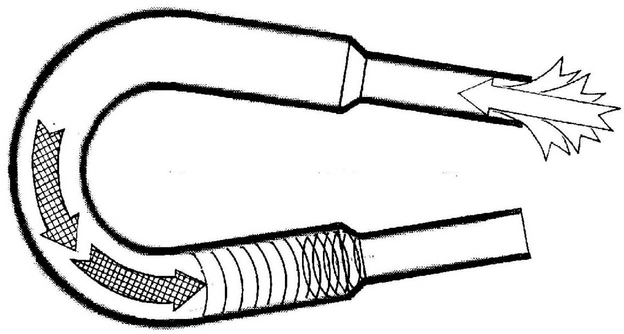

Fig. 12 – Compression in the lower combustion chamber and intake in the upper

So, at this moment, as shown on Fig. 11, there are two pressure fronts traveling fast towards each other. A cold pressure front of fuel/air mixture is moving inwards from the mouth of the lower chamber, while a hot pressure front of burning gas is moving towards it from the upper chamber. The two fronts slam into each other.

In the collision, the mixture is compressed. As the hot front is stronger, it drives the mixture back towards the nozzle. Here is where the sharp conical constriction comes in. The relatively tight funnel does not allow a massive flow rate. In addition, the 90-degree taper of the constriction acts as a wave reflector. Thus, most of the mixture driven into the end of the chamber will not be able to escape and will be compressed further (Fig. 12).

Meanwhile, the heat transfer from the hot gas to cold will ignite the mixture. It will explode, and the cycle will be repeated in the opposite direction (see Fig. 13). The new explosion also drives hot gas in two directions. A part blows into the central tube, while the rest travels as a hot pressure front back to the first chamber to compress and ignite the mixture that has formed there in the meantime.

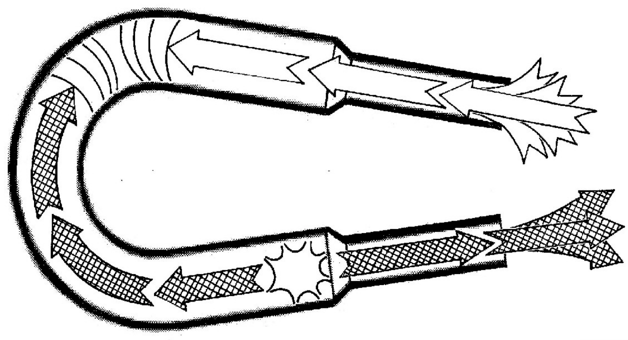

Fig. 13 – Expansion in the lower combustion chamber and intake in the upper

Explosions thus alternate between the ends of the tube. While the engine works, there will be a column of hot gas constantly shuttling back and forth through the curved part of the combustor. It will play the role of the piston in the reciprocating engines and of the turbine and compressor in the turbojet. Experiments have shown that for a brief period the interface between the hot and cold gas fronts indeed behaves like a piston. Gas pressure rises in front of the "piston" and falls behind it. In Esnault-Pelterie's combustor, pressure at one end of the short tube would drop far enough for the vacuum to open a heavy spring-loaded valve and suck air in, even though it was rising quite steeply at the other end at the same time.

Ignition

As with most pulsejets, spark or some other form of outside ignition is only needed at startup. After that, ignition of the fuel/air mixture is achieved by heat transfer from hot gas (the hot front that compresses the mixture).

This kind of ignition is more reliable than that produced by spark because it encompasses a large part of the mixture (the entire interface between the fronts), not just the miniature bubble near the spark plug electrodes. The excellent ignition properties will allow the use of lean fuel/air mixture, meaning that a relatively small amount of fuel will propel a relatively big quantity of air through the engine.

Provision of mutual ignition between the two combustion chambers means that this engine does not need to suck hot gas back from the exhaust tube. That peculiar process – common to all conventional pulsejets -- must rob them of a considerable amount of power. With that power loss eliminated, the potential energy of the vacuum created by expansion of hot gas is used solely for production of the fresh fuel/air mixture.

Multi-Stage Compression

In the intake part of the cycle, fresh air drawn by the post-explosion vacuum rushes into the combustion chamber through the tubular nozzle. It mixes with propane coming from the fuel jet. The nozzle, in fact, functions as a kind of Bunsen tube, preparing the even fuel/air mixture.

The tapered transition between the nozzle and the chamber acts as a divergent diffuser. The mixture slows down as it expands in the diffuser and its pressure rises even before the active compression starts. This is the first stage in the process that should (I hope) produce a compression ratio unheard-of in a pulsejet.

Propagation of the mixture inward is slowed, but it still travels at some speed up the combustor tube, forming a cold pressure front. At the same time, the hot pressure front of burning gas is traveling towards it from the other chamber. The two fronts will slam into each other. (The place of collision will be determined mostly by the combustor geometry.) When the strong hot front hits the weaker cold front, the progress of fuel/air mixture inward is stopped. The kinetic energy of the mixture is converted into pressure in the hammer effect. This is the second increment of the pressure increase.

Next, the stopped and compressed column of the fuel/air mixture is accelerated backwards. At the same time, pressure transfer from hot gas to the cold fuel/air mixture takes place, giving the third increase in pressure.

Traveling back towards the exit of the combustor tube, the compressed column of mixture comes to the convergent taper. Such a sudden conical constriction presents a very effective obstacle to a fast-moving column of gas. It will practically stop it dead, almost as if it hit a flat wall. This will produce the fourth stage of compression – by another hammer effect (see Fig. 12).

The effect is obvious even on the everyday level. Whoever has tried to pour water (or any other liquid) through a funnel knows that it can pass only a certain amount in a given time. Pour too much and the funnel will fill with water. Squirt it in too fast and the water will splash back into your face. Simple.

I have seen some information on experiments performed at the Rensselaer Polytechnic Institute in the 1950s with constrictions in tubular wave engines, which confirm that it works well with fast moving gases, too. The Rensselaer people clearly detected the hammer effect under the circumstances I expect to see in the proposed engine. (They called it "quasi hammer", as it is generated by wave fronts rather than solid obstacles and thus differs in certain details, but the practical result is the same.)

I have described the compression stages as discrete events, but in practice they overlap each other to some extent. At the same time, heat exchange also takes place. The process of combustion coincides with the last four stages of compression.

This gives rise to the fifth stage. The fact that the burning mixture "stops" at the end of the combustor tube -- hemmed in between the hot front coming from the other chamber and the hammer wave front -- means that its expansion is briefly postponed. For a moment, combustion continues within constant volume. The increasing quantity of hot gas produced by combustion will transfer pressure to the unburned part of the mixture. The effect is fleeting and encompasses an ever-decreasing amount of unburned fuel, but there is no doubt that yet another pressure increment will be added. This is a well-known effect and gives an additional measure of efficiency to piston engines.

Ideally, it is only at this moment that the hot gas expands from the combustion zone in an explosion-like event.

Let us recapitulate. First the pressure of incoming fresh air rises in the intake diffuser. Next, the pressure of the fuel/air mixture rises as the mixture enters the combustion chamber, because it is slowed in the divergent taper. After that, the hot pressure front slams into it at full speed. The compressed mixture is pushed towards the mouth of the chamber, picking up pressure from the hot front. It hits the constriction and is stopped in its tracks by the hammer, which produces another steep pressure increment. Finally the pressure rises still further because combustion produces a great quantity of gas that cannot expand immediately.

I have no idea how high a compression ratio can be achieved by the half-dozen pressure increments. I have not seen any data on the compression achieved by Esnault-Pelterie's engine, which would provide some kind of a benchmark. What is certain is that it will be far greater than the paltry 1.2:1 ratio achieved by the standing wave in a Schmidt-type tube.

I will be pleased with anything over 5:1. That is the beginning of the range achieved by conventional piston engines. Offhand, looking at the geometry of the combustor and the forces involved, I have a feeling that this (and more) should be readily achievable. However, I cannot back the conviction with numbers.

There is a problem here that the designers of jet engines are not normally concerned with. In turbojets and fanjets, combustion takes place at constant pressure, so that the engine parts can be built lightly. With the use of shocks to raise compression, and with combustion taking place at least partly at constant volume, we are treading on the piston engine ground. The explosions taking place in the combustion chamber may turn out to be strong enough to require a heavier build and different materials than those usually deemed necessary by builders of pulsejets.

Pumping Air

The bent combustor tube can be considered as an engine in itself. It will perform well on its own -- indeed, better than most conventional reed valve pulsejets because of the much higher compression ratio. Jets of hot gas will blow from the combustor nozzles into the central tube in the alternating sequence and provide propulsion (thrust) by shooting out of the back end of the engine at considerable speed.

That, however, is only half the story. Hot gas will also perform other useful work if asked to. As I pointed out earlier, it does so in most jet engines. In a turbojet, it drives a turbine that powers an air compressor. In a fanjet, an additional turbine drives a big ducted fan that provides a strong flow of ambient air to aid propulsion. My engine uses blasts of hot gas to propel fresh air directly, without the mediation of turbine, compressor or fan wheels.

As each pressure pulse of the burning gas blows from a combustor nozzle into the central tube, it propels air mechanically in three different ways. First, it hits fresh air in the ejector passage between the cold and the hot diffuser -- station (3) in Fig. 9 -- and pushes it forward, with the hot/cold interface again acting as a piston. Readers familiar with the Comprex supercharger, which uses the same effect, know that it works well.

Second, the flow of hot gas between the nozzle and the hot diffuser creates low pressure in the ejector and pulls air in from the cold diffuser. Third, the flow of the mixture of hot gas and fresh air from one side of the hot diffuser into the exhaust tube -- from station (4) into station (5) -- creates low pressure in the other side.

[Note: What I call the hot diffuser here is conventionally called "thrust augmenter". I have decided on a different term because thrust augmenters are normally add-ons, tacked onto some pulsejets to boost performance (Fig. 4). In my engine, the thrust augmenter is an integral part of the engine. Without it, the engine comes closer to conventional pulsejets and makes much less sense.]

At any point in the process, one side of the engine provides power and the other ingests fresh air. The roles alternate in quick succession. As a result, unlike the conventional pulsejet engines, both the intake of fresh air and the exhaust of hot gas will be even, rather than pulsating. It should be smooth enough to drive even an axial turbine if necessary.

Utilizing Excess Heat

As I have stressed before, conventional pulsejets produce more heat than they are able to convert into thrust. They operate with a relatively small amount of propulsion mass -- just the gaseous products of combustion and the small amount of air that can enter the exhaust tube from behind between the pulses. This is in great contrast to all other jet engines.

One of the main reasons turbojets and fanjets ingest much more fresh air than they need for combustion is to lower the working temperature to a practical level. The parts inside the engine have to endure great mechanical stress and do it at a very high temperature. There are limits to what even the best and fanciest materials will take, so that the working temperature must not be too high.

The big bonus, however, is that extra air adds mass to the exhaust gas. The additional mass of air is heated and accelerated and increases the thrust appreciably, while keeping the moving parts cool enough. There are no moving parts to keep cool in my engine, but there is the same opportunity to convert excess heat into kinetic energy.

The exhaust gas of a pulsejet is much hotter than in a turbojet. Many pulsejets glow yellow hot while in operation. Estimates and actual measurements put the temperatures between 1500^0C and 1800^0C for the core of the exhaust gas and about 1000^0C for the chamber walls. All that heat must be applied to a cooler fluid to be converted to kinetic energy. If the quantity of the cooler medium is too low, the energy-mass transfer rate (and thus thrust) will also be lower than necessary. Most of the heat will be transferred to the engine walls.

In addition, if the exhaust gas temperature is too high, it will create great turbulence behind the engine. What occurs is called (I think) “thermal shock”. I do not understand the mechanism very well, but apparently the heat transfer to the ambient air is not orderly because of the very high temperature gradient. It creates microscopic shockwaves going in all directions. In practice, this bursting of the flow generates increased drag.

Fanjets push a mantle of air around the core of hot exhaust gas, which keeps the gas stream better directed and allows the heat from the exhaust gas to be transferred first to the mantle (which is cooler than exhaust gas but hotter than ambient air) and then to the cold air, greatly reducing thermal shock.

To utilize the available heat properly, one should perhaps separate the intake of "oxidant" air (which goes into the combustion chamber) and "propellant" air (which goes into the hot diffuser) as completely as possible. The former is used in combustion and needs to be cold for better efficiency. It should be piped as directly as possible to the mouths of the combustion chamber nozzles. The latter, however, is only used as propulsion mass. The hotter it gets, the better. Heat makes it expand and imparts speed, which translates into thrust.

Pre-heating should be easy to do, as the combustor tube – the hottest part of the engine -- lies just ahead of the air intake. A simple shroud would probably do. However, such details are best addressed in the practical development of the prototype.

Problems

Noise Abatement

One of the biggest practical problems with pulsejets engines is their noise. The engine proposed here will hardly be quiet, either. However, the intensity of the noise should be diminished to some extent due to its internal diffusers.

The greater the temperature of the exhaust gas, the greater its speed. The greater the speed differential between the exhaust gas and the ambient air, the greater the noise. By providing a greater quantity of fresh air, mixing it with the hot exhaust and lowering the exhaust speed, the noise will be reduced. (This is the commonest method of noise abatement on jet engines.)

In addition, the noise may have a different quality. As Mike Kunz (a frequent contributor to Ken Moller's Pulsejet Forum on the Internet) has explained it to me, a part of the problem with pulsejet noise lies in the fact that the tube opens and closes through the working cycle. This changes its acoustic properties, as the tube constantly shuttles between ½ wavelength and ¼ wavelength resonance.

Because of that, it resonates in its natural frequency and both the even and the odd harmonics. The resulting sound is horrendous. My engine will only resonate at its natural frequency and the even harmonics. Not mellifluous, perhaps, but less grating on the ear.

Starting

This may well prove to be the greatest difficulty with the proposed concept. The proper functioning of the engine really depends on both sides doing their respective jobs at the same time, which will be very difficult to achieve at startup. At the moment, I do not see an obvious way to generate a strong hot blast from one side of the combustor and simultaneously make a cold front of fuel/air mixture move from the other side.

The first explosion in the first combustion chamber will be relatively weak, as the mixture will be at atmospheric pressure and will ignite without pre-compression. This weak blast, traveling towards the other combustion chamber will only be met by the stationary fuel-air mixture at atmospheric pressure. Under those circumstances, most of the mixture will be blown out of the combustor and into the exhaust tube. Only the last small portion (if any) will be accelerated to the speed great enough for the conical constriction to start being effective.

Alas, there is a distinct possibility that the engine could operate at a stable lower equilibrium, with the transfer tube producing ignition but not sufficient compression. It might just put-put away, never really building up to the necessary pressures. Another danger is for only the initial chamber to work, while the gas burns constantly and harmlessly in the other chamber. It would perform like a conventional (but badly designed) U-shaped valveless engine.

There are several tricks I can think of that would help. There are complex mechanisms that could be tried, but I have been hoping to devise something very simple and elegant that would not require ancillary equipment. If the entire engine consists of just a couple of bent and crimped empty tubes, it is somehow pointless to require complex machinery to start it. At the time of writing, I have no clear idea that I would care to publish.

The most effective-sounding idea that has surfaced so far -- proposed by Randal Graham, a Canadian pulsejet enthusiast -- is starting the engine at one end by firing a blank gun cartridge into the combustor. The resulting blast may well do the trick. The idea needs looking into.

Loss of Mixture Through Chamber Nozzle

A minor problem of similar provenance may occur during normal operation. Namely, my description treats the fuel/air mixture as a solid slug of gas. It is not. That means, among other things, that some of the mixture will start escaping from the combustion chamber into the fire tube as the hot front hits the mixture and pushes it backwards. The tapered nozzle will act as a barrier only above certain gas flow rate and will work best with the gas formed as a distinct pressure front. It will take some time for the front to form and to attain the speed at which the constriction will reflect it. Before that, the mixture will escape.

I hope that it will not matter much in practice. The pressure and speed build-up will be very quick and inertia will continue to push the fresh mixture forwards for some time even after the collision of the two fronts. Only a small part of the mixture is thus likely to escape. It will not be completely lost, either, but will burn up in the common exhaust tube and contribute to thrust.

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