Sharpe Eye Engineering
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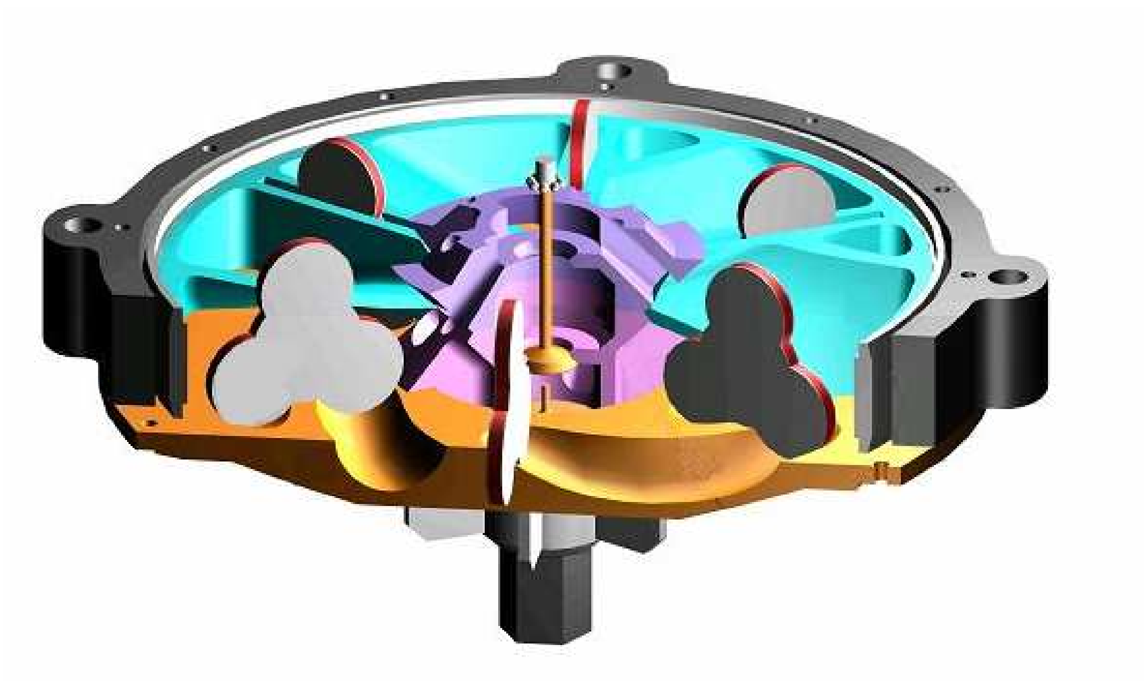
Ducted Blade Rotary Technology
Feasibility Study & Analysis
February 2010



By Peter Sharpe
BEng Aerospace Engineering Design, Kingston University, London

Chief Engineer & Technical Editor, Sharpe Eye Engineering

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Abstract

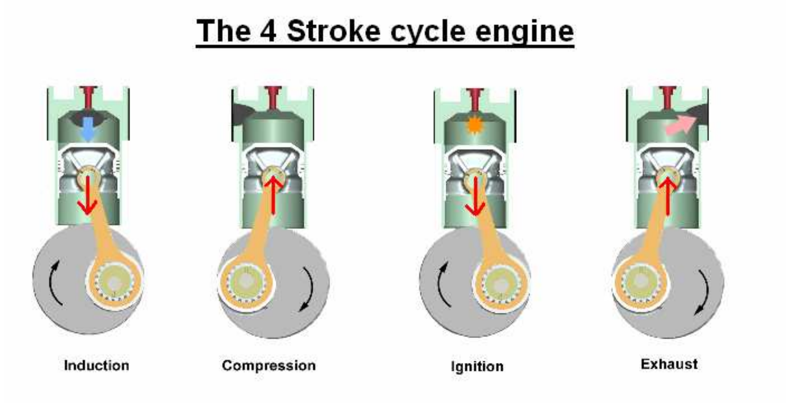
The Ducted Blade Rotary Technology engine is an innovative new approach to internal combustion engine design. By orientating six rotating 3-lobed plates about a central axis with each plate completing two full helical turns per rotation as they pass through 12 separate chambers, it is possible to achieve a rotary engine which completes six Otto cycles with every rotation, with six induction strokes, six compression strokes, six power strokes and six exhaust strokes.

A hypothetical DBR-tech based engine has the potential to be an extremely compact, lightweight and vibration free powerplant, the likes of which could potentially outperform a conventional reciprocating engine or a Wankel rotary engine in both fuel economy and high-end performance.

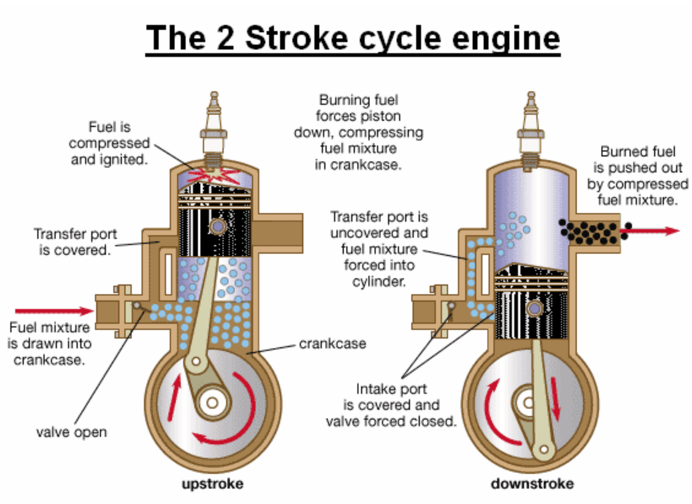
Introduction

A Brief History of Internal Combustion Technology Development

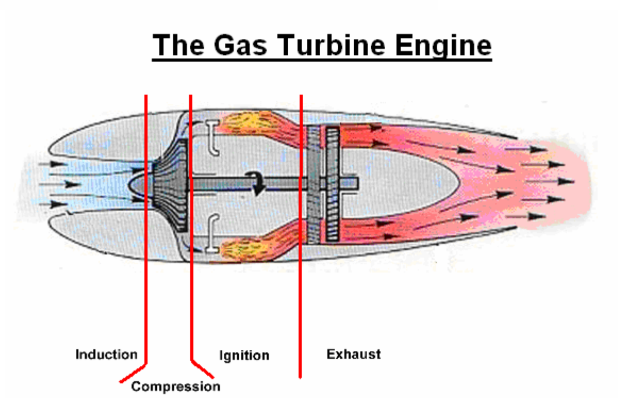
Since its inception in 1861 when first patented by Alphonse Beau de Rochas and later developed by Nicolaus Otto, the 'Otto cycle' internal combustion piston engine has been the mainstay portable automotive power source for the world's vehicles on land, sea and in the air.



Derived from the same mechanism which drove steam engines; a reciprocal piston driving a crankshaft, the fundamental design used to achieve the 4 cycles – suction, compression, power and exhaust, has not changed in nearly 150 years.



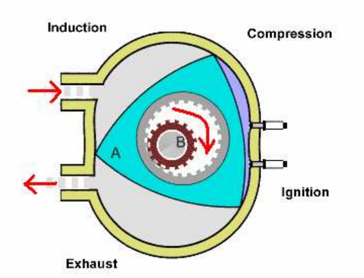
Internal combustion advancement has come in fits and starts, in 1881 Dugald Clerk's development of the Clerk cycle engine consolidated 4 cycles to 2, simplifying its operation into what eventually became a new compact, super-portable breed of engines now commonly used in mopeds and lightweight powered equipment such as leaf blowers and chainsaws as well as being used for large heavy-duty diesel powerplants in locomotives and generators.

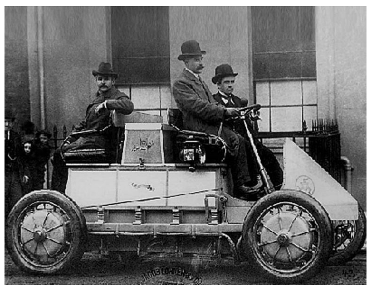


In the 1930's Frank Whittle and Hans Von Ohain debuted their respective piston-less gas turbine 'jet' engines, creating a high-thrust Powerplant ideal for modern aircraft applications. Later Gyorgy Jendrassik designed the first CS-1 turbo-prop engine in 1938, an evolution of the gas turbine jet engine which is now popular in regional aircraft, helicopter & maritime applications.

In 1954 Felix Wankel designed a piston-less rotary engine, with an eccentric rounded triangular 'trochoid' rotor spinning within an oval crankcase, the development of which is ongoing. The Wankel rotary engine most notably powers recent & current production Mazda vehicles such as the RX-8 and closely mimics the performance of conventional reciprocal piston engines while being more compact and lightweight.

The Wankel Rotary Engine





In 1901, Ferdinand Porsche created the first gas-electric 'hybrid' automobile concept; named the 'Mixte' because it 'mixed' internal combustion & electric power by powering a generator with an internal combustion engine, then driving four electric motors with the electric power produced by the generator - one at each wheel hub. Pictured left.

The Hybrid

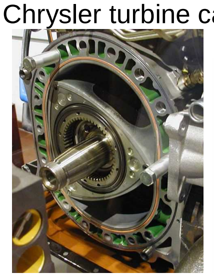
More recently the hybrid concept has been revived & popularized in the form of the Toyota Prius and Honda Insight vehicles among various others, commonly touted to be some of the most fuel efficient cars currently available.

Consider though that pictured left, the hybrid below is fundamentally no more advanced than the hybrid pictured above, built 109 years earlier - the underlying principle in each concept is the same.

Room for Improvement

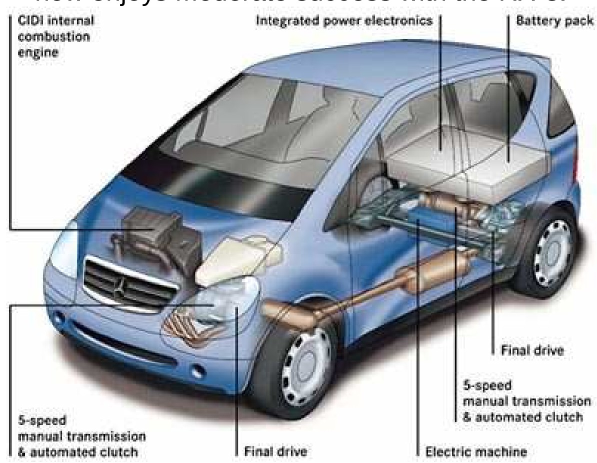
Though innovative, turbines, wankels and hybrids are not the pinnacle of internal combustion engine development, especially where automobile technology is concerned.

Turbines for instance are ideal for aircraft applications & large ships where consistent high-power output is demanded, but for stop-go use in a car turbines have proven to be too fuel-thirsty, noisy and too slow to spool up/shut down, as evidenced in the case of the failed Chrysler turbine car, pictured right.



Wankel rotary engines have the advantage of being more compact and lightweight than a reciprocating piston engine and operate in largely the same way, but historically they have been shown to be oil-thirsty high-wear engines which are less economical than a piston and have not gained popular acceptance in the automotive industry except with Mazda which now enjoys moderate success with the RX-8.

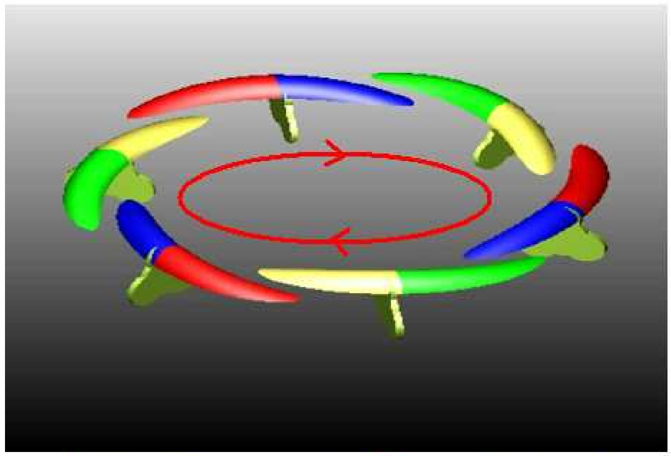
Lastly, hybrid technology promises to be the ultimate in fuel economy, pairing electric drive and internal combustion power to bridge the gap between the pure internal combustion and pure electric powered vehicles, each of which have pros and cons. But hybrid technology has its own drawbacks; heavy electric components and battery power storage increase a hybrids' curb weight meaning that while it has superior efficiency at urban speeds the economy of a hybrid suffers during a highway cruise & during any period of high-acceleration due to its heavy components and associated power losses. Pictured right is an example schematic of a hybrid-powered Mercedes A-class.



The UK motoring television show 'Top Gear' publicized the weakness of a typical hybrid with a somewhat biased test whereby a Toyota Prius was fueled with 1 gallon of gasoline alongside a BMW M3, also fuelled with only 1 gallon of gasoline. The Prius was driven at high speed around a track with the BMW following at the same speed, just keeping up with the Prius – after a period of time had elapsed, the Prius eventually rolls to a halt having run out of fuel, while the pure internal combustion powered BMW is able to continue with fuel remaining.
Though clearly unfair, the test highlighted the weakness of the compromised engineering in a hybrid when it comes to high-end performance, demonstrating that to achieve efficient low speed fuel economy modern hybrids have sacrificed high-end power and their high-speed fuel economy suffers because of that.

Ducted Blade Rotary Technology

The subject of this paper; the Ducted Blade Rotary Technology engine which is being developed by Atlas Motor Works has the potential to eclipse all other internal combustion automotive engines. By utilizing six tri-lobed plates rotating on a disc in a sweeping helical motion through twelve helical swept chambers assisted by stop-start technology, the DBR-Tech engine may be able to produce superior fuel economy *and* very high power output per unit weight.



Intake Compression Power Exhaust

When running, at any one point there are six suction, compression, power & exhaust strokes occurring at two different stages simultaneously. The 6 tri-lobed drive plates follow each other through each chamber as they rotate, one chamber above and another overlapping below, repeating the 4 strokes over and over again, making for a constant uninterrupted supply of power as opposed to, for example, a typical four-cylinder 4-stroke engine where only one piston is producing power at any one time. There is also minimal vibration in a DBR engine as opposed to the jarring stop-start motion of a reciprocal piston.
The DBR-tech engine may also lend itself well to potential power-adding methods such as turbo/supercharging and octane boosting methods such as water/ethanol injection or even nitrous oxide injection, so despite a compact size it *could* have high power output equivalent to that of a large displacement V-8 engine in a much smaller package.

The basis for the stop-start technology planned for the DBR-tech engine is that when running the fuel could be cut off to switch it from being a 4-stroke internal combustion turbine to a 2 stroke air compressor instantly – by compressing air into an accumulator the pneumatic energy is stored to be re-used. This could be achieved by cutting off fuel to some chambers while others continue to produce power, then an accumulator valve would briefly open to accept the newly compressed air. Alternately, an 'engine braking' mode could scavenge compressed air from the engine, turning the vehicle's momentum into stored enthalpy for re-use when the vehicle is to move off again. But this is just one potential stop-start technology system design; others are discussed later in this paper.

Regardless of the exact method of how it's achieved, be it pneumatic, hydraulic, electric or kinetic, stop-start technology will allow the DBR-tech engine to be able to come to a complete halt rather than idling to save fuel, then when throttle is applied to move off again initial inertia can be overcome without using fuel, instantly re-starting the engine on demand, allowing instantaneous application of full power if necessary.

These technologies and their advantages/disadvantages and design challenges will be explored further in this paper; the DBR-tech engine will be compared to existing engine technologies and evaluated as an overall design concept.

Analysis of DBR-Technology

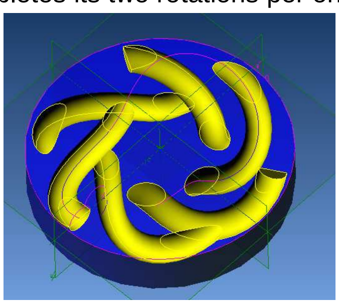
Displacement

To determine potential power output of the DBR-tech engine the helical gas chamber volumes must be calculated, this can be computed electronically with CAD software but it is also important in our analysis to devise a mathematical method of calculating the volume without a computer.

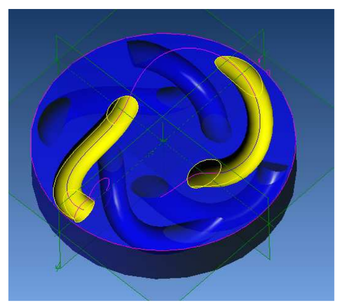
Though the example design has 12 separate helical gas chambers - 6 above and 6 below, it might *appear* at first that because induction/compression stages sequentially take place in one chamber and combustion/exhaust in another that only the volume of the 6 combustion chambers 'count' when comparing displacement volume with a reciprocal piston engine where all four cycles take place within the same volume.
But in the DBR-tech engine because the induction/compression chambers work in parallel with the combustion/exhaust chamber, processing gasses simultaneously, all 12 chambers are considered 'working displacement' when comparing with a standard reciprocal engine.

The helical sweep of the drive plates through the gas chambers in the DBR-tech engine creates a complex eccentric parabolic concave curved lens shape which is not as easy to calculate volume for as the cylinders in a reciprocal piston engine.
To avoid using un-necessarily complicated calculus to compute the chamber volume we can make some simple assumptions;

1. The sweeping helical path of the drive plate lobe through the chamber utilizes the same volume as if the 'helix' were uncoiled like straightening a spring – think of a slinky. Illustrated below left is a semi-transparent image showing the rotational path of the three drive plate lobes – the transparency makes them appear to overlap more than they actually do. The illustration on the right shows the 'cut' that a single lobe makes as it completes its two rotations per orbit.



All 3 Lobe paths in one half of the engine.



2 sweeps of 1 lobe in one half of the engine.

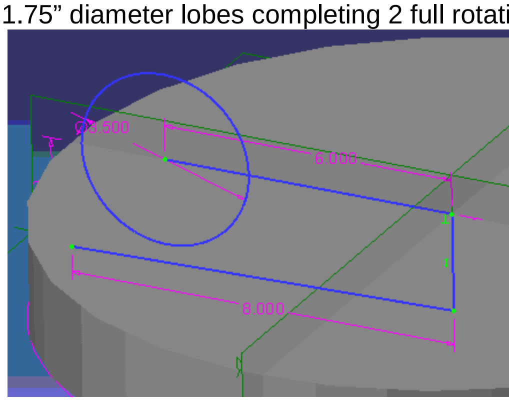
The formula for spiral length is; $L^2 = ((\pi x D)xN)^2 + (PxN)^2$, using the principle that an uncoiled spring forms the hypotenuse of a right angled triangle; this formula uses Pythagoras' theorem where multiplying pitch x rotations forms the height of the triangle and circumference x rotations forms its base.

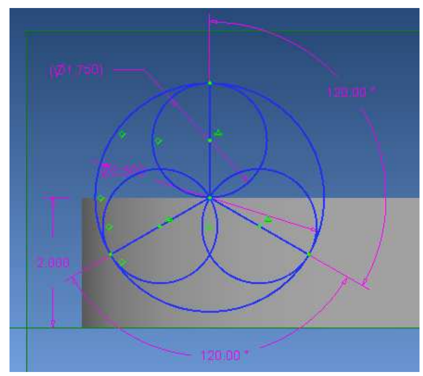
L = Length of straightened coil
D = Diameter of coil
N = number of turns
P = pitch, Pitch = $(\pi \times D)/2$

2. The 'straightened' sweep of a single drive plate lobe through a chamber forms at least the shape of a 'toric section' volume like cutting off the edge off of a donut. The depth at its center would be at least the same as the radius of the lobe. Illustrated below, if the sweep of a single lobe could be viewed in profile in a straight line it would look a bit like the graphic below, with the overlap of the top and bottom chambers clearly visible.

   Because we know the drive plate lobes will travel through these semi-circular paths as they sweep between each half of the engine alternately we can infer that the volume of those chambers is equivalent to half of a tube the same length as the total spiral.

3. The final assumptions to be made are on the target dimensions of the engine from which to derive our hypothetical chamber size. Atlas Motor Works state that a 'spare tire' sized engine could displace 525 cubic inches or 8.6 liters, for the purposes of this analysis a 'spare tire' is assumed to be 16 inches in diameter. Internally, that can leave room for a 3.5" diameter drive plate rotating on a 6" radius from the center of the engine with three 1.75" diameter lobes completing 2 full rotations per orbit.



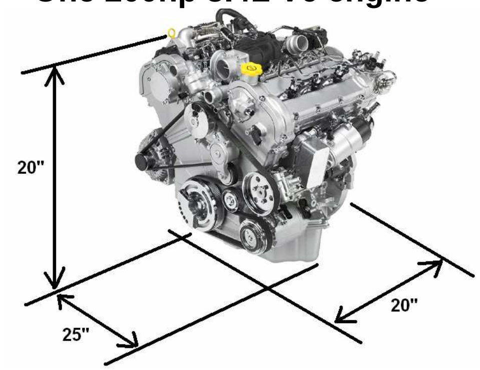


Total Displacement:
Using the aforementioned formulae (see appendices for detailed calculation) we can determine that our hypothetical 16" diameter engine has at least a displacement volume of 208.97 cubic inches or 3.42 liters, with 17.41 cubic inches/285cc of volume per chamber.

Based on our calculations, in our example a 'spare tire' sized DBR engine equates to at least a 3.4L displacement powerplant. An engine of 3.4L volume is equivalent in capacity to an average V6 which is a good deal bulkier! A typical 3.4L V6 engine usually makes power in the 160-210hp range; also consider that a *1.4L* Renesis Wankel engine makes *230hp* – if the DBRE behaves anything like a Wankel in scaling up power against displacement, 200hp from 3.4L of engine volume is a conservative estimate.

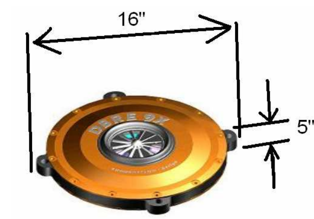
A hypothetical 200hp available from such a compact unit like the DBR-tech engine opens up a myriad of new design permutations, be they for snub nosed front-engine/front wheel drive runabouts, or sleek aerodynamic mid-engine/rear wheel drive supercars - car designers would be climbing over each other to get a chance to use such a high power density engine in their vehicle!

One 200hp 3.4L V6 engine =



Occupies 5.12 cubic feet of engine bay
Weighs 500lbs
= 39 hp/cubic foot
= 0.4 hp/lb

…One 200hp 3.4L DBRE.



Only needs 2.2 cubic feet
(2.92 cubic feet less space)

Theoretical weight of 215lbs (57% lighter)
= 90.9 hp/cubic foot
= 0.93 hp/lb

Compression Ratio

Control of the compression ratio in the DBR engine is extremely important for smooth & efficient operation and must be tuned to the particular characteristics of the fuel used and whether any power-adding turbo or super-charging pressure boost is used.

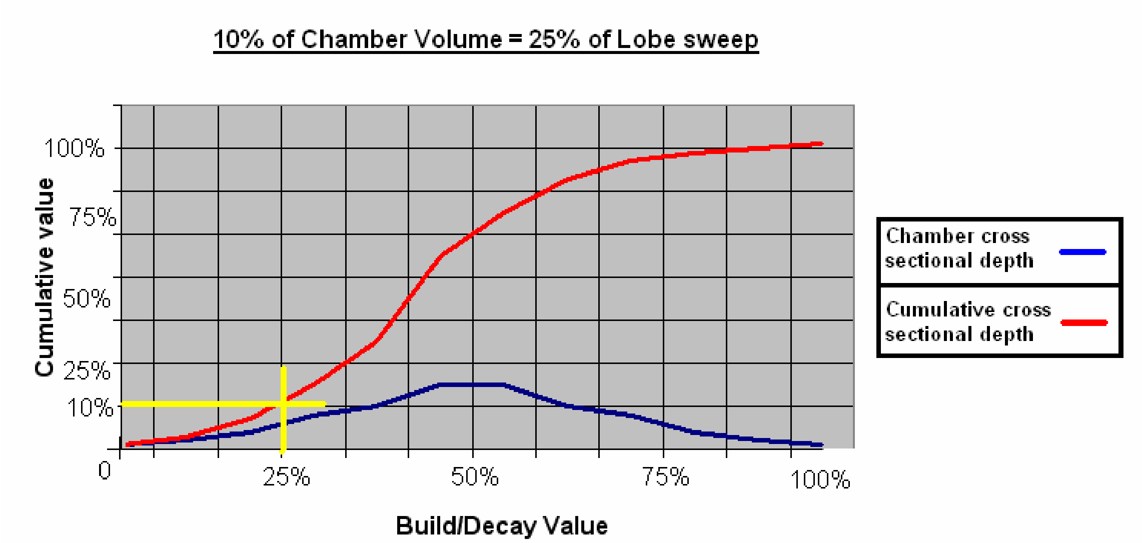
For example, a reciprocal diesel engine requires a higher compression ratio - between 14:1 and 20:1, than a reciprocal gasoline engine – 10:1, the implications of that for the DBR engine are that if it were to be powered with diesel fuel the drive plate lobe must be allowed to travel a greater length through the chamber before the compressed fuel/air mixture is transferred into the next chamber to be combusted.

Conversely if turbo or supercharging is used instead of normal aspiration the required compression ratio becomes lower – between 8:1 and 9.5:1 for gasoline, so the distance traveled through the induction/compression chamber before gas transfer happens becomes proportionally shorter.

Calculating the exact distance the drive plate needs to travel through a chamber is complicated by the fact that they are not uniform like a cylinder in a reciprocal engine, thus complicated mathematical formulae becomes necessary to precisely calculate the required drive plate travel.

However, as before when we calculated the total cubic volume of the engine with the 'helical half pipe' method, some simple assumptions can be made to negate the need for a math professor! Returning then to the 'straightened toric section' and its elliptical footprint, when we look at the longest outside edge of the ellipse we notice the radius start off small at the beginning, gradually increasing until reaching halfway, then gradually reducing again to a smaller radius.

If you take those radial values and plot them on a graph, then alongside sum up those values cumulatively and plot another curve it allows us to visualize the change in cross-sectional area. The simple graph below illustrates that, for 25% of the length of an ellipse we have an approximate 10% change in the cumulative value, so it's logical that for in one quarter-length of a chamber we have 10% of its total volume.



Thus, to achieve a 10:1 ratio for a normal gasoline combustion cycle, our drive plate will compress the 285cc chamber volume into a 28.5cc space in 75% of the length of its sweep – in other words at the ¾ sweep mark the fuel air mixture is sufficiently compressed and can be transferred at that volume into the combustion/exhaust chamber.

Up until now, the subject of porting and valve train has not been mentioned, that part of the engine design is not yet fully developed. But because the DBR engine design relies on induction/compression happening in one chamber and combustion/exhaust in another there *has* to be a way to move our compressed fuel air mixture from the chamber where it was breathed in and squashed into the chamber where it will explode and expel.

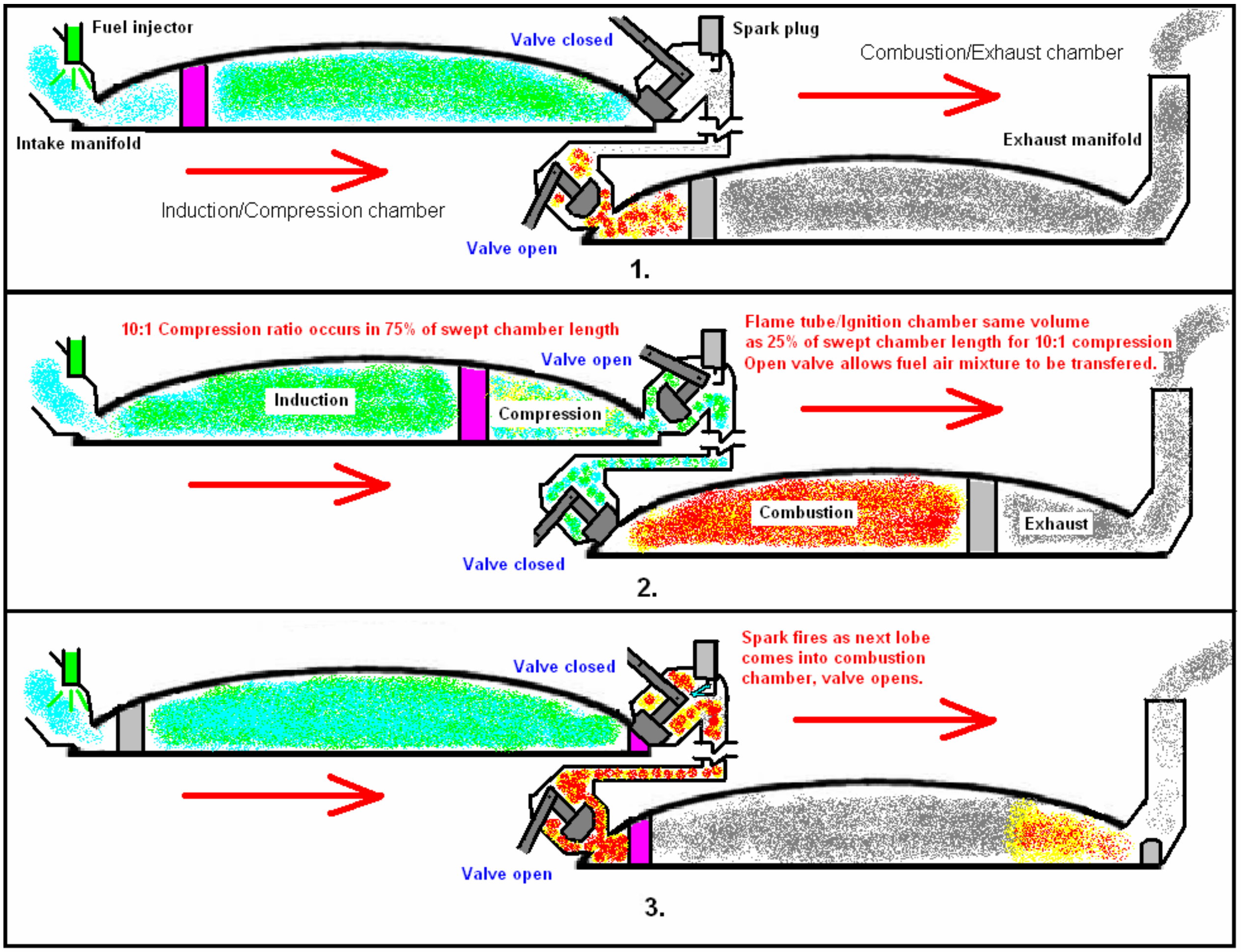
Atlas Motor Works' intention is to engineer a system of valve 'slots', and though that particular design is not described here, below is a potential alternative system which could use more traditional rocker-type valves.

In the world of aviation, turboprop engines often utilize reverse-flow combustion chambers, in a turboprop core air is thrown from a centrifugal compressor and then does a complete 180 degree turn where fuel is injected and combusted, then the burning gasses reverse again to pass over the turbine blades. A similar principle could work for the DBR tech engine, except because we are relying on a 4 stroke cycle we require some kind of valve-porting at the end of the compression chamber and at the beginning of the combustion chamber. The induction and exhaust ports however need no valves since the drive plates act like pressure gates, meaning the intake/exhaust ports can remain open at all times.
The simplified diagram overleaf illustrates a potential system whereby a 'flame tube' or 'ignition manifold' connects the overlapping compression and combustion chambers.

In box 1 the pink drive plate is compressing a fuel air mixture, the valve at the end of the chamber is closed.

In box 2 the pink drive plate has reached the ¾ / 75% travel mark, compressing the 285cc volume of gas into 28.5 cubic centimeters of space. At this point the first valve opens allowing the compressed mixture into the 'flame tube' which must be no greater than 28.5cc in volume.

In box 3 the pink drive plate has reached the end of its stroke and the lobe is rotating out of the compression chamber while the next lobe rotates into the beginning of the combustion chamber – at this point the compression valve closes, the combustion valve opens and a spark ignites the mixture.



Stop-start Technology

Of the burgeoning advances in engine technology today, one that is rapidly becoming more commonplace is stop-start technology. The capability to seamlessly bring your engine to a halt for brief periods when the car is stationary and have it immediately restart on demand with no input from the driver except for using the brake and then the throttle gives untold fuel savings in heavy urban traffic situations.

Pneumatic Stop-start

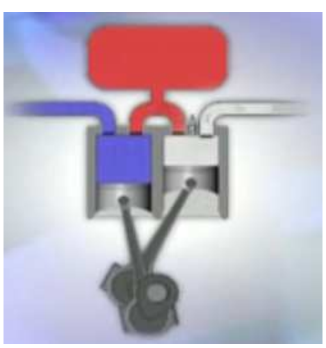
Atlas Motor Works' intention is to implement pneumatic stop-start technology in conjunction with the DBR engine, the basis being that it could capture pneumatic energy by switching from 'engine mode' to 'compressor mode' when decelerating, converting the kinetic energy of a vehicles' movement into stored pressure enthalpy in an accumulator/pressure vessel, however this system would likely incur some thermal losses from the process of compressing the air.
Upon the vehicle becoming stationary, the DBR engine would come to a halt and then use the stored pneumatic power to immediately restart it on demand to move away again.

The principle of storing pneumatic power for re-use is sound and is evidenced in the common use of pneumatic air tools & pneumatic brakes. Yet another example is in aircraft applications where emergency pneumatic storage bottles are commonly used as hydraulic backup systems, but when it comes to automotive applications pneumatic power seems to have not yet found its feet.

In France, the Motor Development International company has produced a range of prototype pure pneumatic powered cars, pictured right, which are powered by stored pressurized air in onboard composite tanks. Their development is now being actively pursued by Tata Motors in India.

Commonly touted as 'emission free', these vehicles rely on an external pneumatic power source to 'refuel' them – generally an electric powered compressor, so in actuality the vehicles' emissions come from the power station smoke stacks rather than the cars' tailpipe.

Also, initially they have been shown to have limited range and there are safety concerns over the integrity of the onboard pressure vessels in a crash. Nonetheless, the MDI air-powered cars *do prove* that pneumatic storage is a valid automotive power source, if not necessarily an *exclusive* power source.



Another engine system under development which demonstrates the pneumatic stop-start principle envisaged by Atlas Motor Works is the Scuderi split-cycle pneumatic hybrid engine, illustrated in the diagram to the left.

Very similar in cycle operation to the proposed design of the DBR engine, the Scuderi instead uses paired conventional reciprocating pistons to achieve the same result, with one piston exclusively compressing and the other producing power.

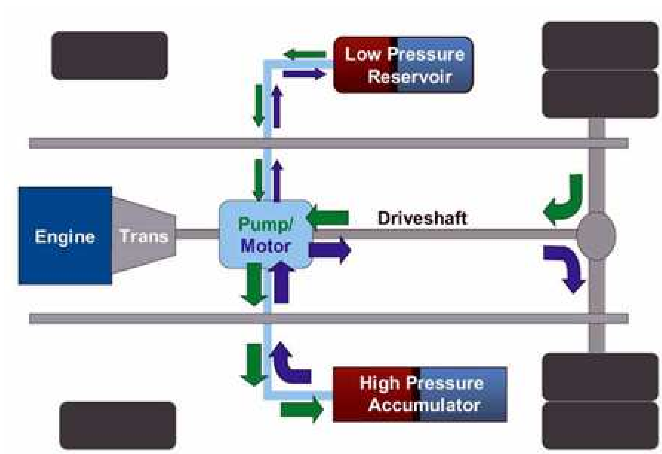
Though potentially a strong competitor to the DBR engine in efficiency with a similar pneumatic hybrid approach, the patented ducted blade rotary technology still gives intrinsic weight and volume advantages over the Scuderi design on top of pumping efficiency/inertial loss advantages, meaning a DBR powered vehicle could still be both lighter and more aerodynamic than a competing Scuderi-engined car.

Additionally, the fact that the DBR engine has 12 chambers operating simultaneously in constant balance means that with a momentary blast of compressed air the DBR engine would instantly re-start with maximum power immediately available upon the drivers whim.

Hydraulic Stop-start

Operating along similar lines to the pneumatic stop-start principle, new 'hydraulic hybrid' technology is rapidly gaining momentum amongst mpg-hunting automotive engineers.
It is now being trialed on UPS delivery trucks and Eaton who have partnered with Ford are even planning to implement its use on garbage trucks too.

Commonly explained by techno-journalists as a means of 'storing hydraulic energy', hydraulic hybrids are actually just another form of *pneumatic* hybrid.
The reason is that the term 'hydraulic' itself refers to fluid mechanical energy transmission – hydraulic systems are great at conveying energy but they do not and can not actually store it, the defining aspect being that hydraulic 'fluid' – usually some kind of oil, is incompressible.
Most of the techno-journalists reporting on the new hydraulic hybrid technology at least correctly identify the 'accumulator' as being the component which actually stores the energy, but most fail to explain *how*.



A hydraulic accumulator is very much like an air/oil shock absorber in a suspension system, essentially a compression spring. The accumulator is a cylinder containing a piston in which oil flows in from one side and a gas is compressed on the other – the mechanical energy is stored by the *gas* as *pneumatic energy,* not by the fluid.

The hydraulic oil is pushed into the pressurized accumulator by a hydraulic pump driven by the motion of the vehicle; the work done by compression of the gas in the accumulator creates the regenerative braking effect. The stored energy exerts a force on the hydraulic fluid which can in turn reverse the action of the pump, acting as a hydraulic motor to start the vehicle moving once again upon demand.

This system is sound and very efficient; the incompressibility of the fluid reduces heat loss except from the accumulator itself, meaning that for stop-start operation a hydraulic hybrid system can rival both electric and pure-pneumatic hybrid systems.
The applicability of this technology for the DBR-tech engine is the same as for any other vehicle, such a system could work in conjunction with a DBR Powerplant but would not be dependant on it in any way. The unique implication for ducted blade rotary technology is that an independent DBR-based hydraulic pump could be used in just such a system – the principle of a DBR-tech based hydraulic pump is explained later in this paper.

Electric Stop-start

The Toyota Prius electric hybrid system is by far the most popularized form of stop-start technology currently in use. As aforementioned earlier in this report, the gas-electric hybrid concept began with Ferdinand Porches' 'Mixte' car in 1901, the only crucial difference between that 109 year old concept and the modern Prius being the large Nickel Metal-Hydride battery located under the back seats which stores regenerated power captured during braking.

In theory, the electric stop start capability of the Prius makes for very efficient city driving with the engine only kicking in at higher speeds as more power is demanded, but in practice an average impatient motorist can easily nullify this advantage every time they gun the throttle at traffic lights, forcing the engine to take over every time any harsh acceleration is demanded.

Generally though, electric stop-start systems for hybrid and 'mild-hybrid' vehicles have gained widespread acceptance in the automotive industry, so it would be short sighted to overlook the potential of integrating such a system with the DBR engine.

With the compact low-profile disc like shape of the DBR engine it would actually lend itself very well to coupling with an ancillary electric motor/generator, perhaps mounted right on top of the engine sharing a common drive shaft.

There would be a weight penalty by adding a motor/generator unit plus a large enough battery, there would also be added complexity in combining the two systems. The one intrinsic advantage to such a combination being that power dependant ancillary systems like heating/air conditioning could continue to operate with the engine stationary due to the larger electric power supply available.

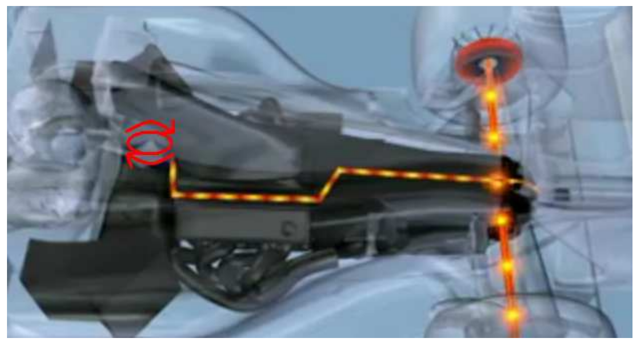
If popularity alone is proof of the viability of a concept, then electric stop-start technology is clearly feasible as evidenced by the sheer number of new cars on the market with it installed. While none of the above pictured models are true hybrids, they use the 'mild-hybrid' technology to negate the frequent periods of zero-mpg engine operation while stopped.
In some cases however in a 'mild hybrid' when using power-dependant ancillary systems like the air conditioning the engine is never allowed to stop running.

KERS Stop-start

In the 2009 Formula 1 racing season manufacturers were encouraged to develop and implement regenerative braking systems to add competitiveness to the sport.
The idea was that an onboard energy storage system could capture braking energy to be released by the driver at the push of a button, the one rule being that it could only be used for 6 seconds per lap.

Unfortunately what was intended to become the new ‘push to pass’ button for aggressive overtaking became a defensive ‘push not to be passed’ button, ultimately discouraging competition and subsequently has been dropped for the 2010 F1 season, but in the course of their development the different racing teams came up with their own individual methods to recover and re-use braking energy.

Some teams like Ferrari utilized the Prius-like battery storage method for their cars, others like McLaren and Williams took a different approach. With the added weight of generators & batteries in a very high-performance orientated motor sport like formula 1 the electric hybrid system was recognized as more of a compromise than an advantage.



McLaren and William’s solution was to use a kinetic energy recovery, or ‘flybrid’ system as illustrated above, whereby electric or mechanical power spins up a lightweight flywheel which continues to rotate until needed, either for a sudden burst of acceleration when racing, or to restart a stationary engine when pulling away from traffic lights in an ordinary car.

One such KERS system design spawned the formation of a company itself named ‘Flybrid’. In its own F1 design the flywheel was accelerated to an extremely high 64,000rpm, such high speed rotation generates thermodynamic losses from friction with the air, so in the Flybrid company design the flywheel was encased in a hermetically sealed vacuum chamber with an integral clutch to transfer the stored kinetic energy to the transmission. The chamber was also designed to contain flying debris in the event of flywheel disintegration.

So now with the 2010 F1 season rules changed to discontinue competitive use of KERS systems, where does its future lie? McLaren’s engine supplier Mercedes has publicly stated that there is no road-car application for the McLaren KERS system, meanwhile Williams is pursuing non-competitive road car development for its own KERS system and reportedly Jaguar and Land Rover are already developing their own mild-hybrid concepts with the KERS technology.

Crucially then, a KERS Flybrid-type system becomes an obvious potential choice for pairing with the DBR-tech engine. Because the 12 gas chambers in the DBR engine are balanced and arranged in a radial pattern, unlike a conventional engine which relies on the momentum of a flywheel to keep its pistons reciprocating at idle power the DBR tech engine *is a flywheel itself* and thus could easily stop and start quickly when taking advantage of a coupled KERS flywheel.

Power Adding

With the DBR engine already very powerful for its size, the opportunity to use power-adding forced aspiration shouldn't necessarily be viewed as a chance the max out its performance but rather to *minimize its weight and volume for a given power output*, giving the car designer more options with respect to engine placement, aerodynamic body sculpting and additional storage.

If a 16" diameter DBR engine can make 200hp or more, it's feasible that a tiny supercharged 10" diameter engine would still have ample power for a small family car and yet be almost small enough to even mount under the floorboards – this opens up a myriad of possibilities; the space in the now-vacant engine bay becomes storage, or maybe a 3rd or 4th row of seats can be added.

Another application of forced aspiration could be to use increased boost pressure to *allow a reduced compression ratio for the efficient use of diesel fuel*. Turbochargers are already commonly used on diesel engines both large and small for that purpose; the DBR engine could use them to the same effect.

Turbo charging

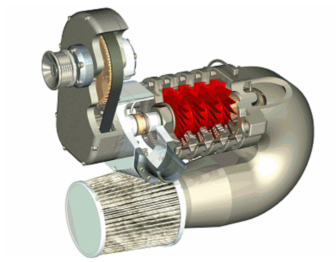
Forced aspiration achieved by driving a centrifugal compressor with an exhaust gas driven turbine, aka Turbo charging is a well understood science. The additional 'boost pressure' created by a turbo can give a piston engine a kick of power in the high RPM range or increased economy during a high-speed cruise.

The DBR engine is no different, it too could benefit from exhaust derived boost pressure – normal turbo systems *would* be compatible with it, in fact one advantage of the DBR engine might be an ability to change compression ratio on the fly by controlling the timing of the compression valve since turbo boost pressure necessitates lower compression ratios of 8:1 – 9.5:1.

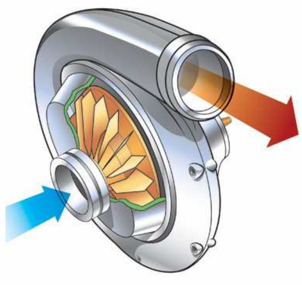
Supercharging

The inherent disadvantage with a Turbocharger is of course 'Turbo-lag', which is just the time it takes for the increase in exhaust flow to spool up the turbine and generate boost pressure. This problem is absent in a Supercharger, despite some initial parasitic power loss due to being mechanically driven by the engine itself, the overall thermodynamic enthalpy added to the system by a supercharger results in a net gain in power.

The development of superchargers over the years has resulted in multiple configurations, all with the same purpose – to compress air and deliver it to the engine to increase horsepower. It's also worth noting that the development of axial and centrifugal superchargers in the 1930's are what ultimately led to the development of the first *jet turbines*; Whittle's first design favoring the centrifugal compressor and Ohain's the axial.



Axial



Centrifugal

Roots

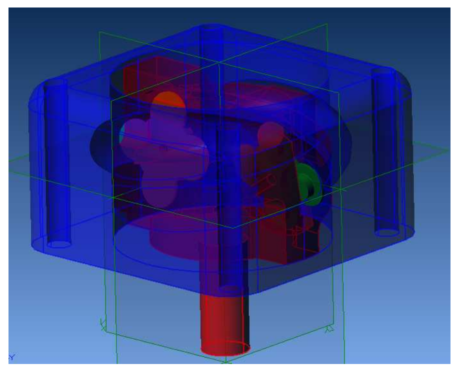
Ultimately any of the conventional supercharger designs could be integrated with a DBR engine, either an axial, centrifugal or roots type supercharger could be driven via an ancillary gearbox or pulley system. Typically the axial and roots type superchargers tend to occupy the most room, leaving the compact centrifugal design the ideal choice for use with a DBR engine where compact size is considered a primary goal and advantage.

A centrifugal supercharger could even be 'stacked' on top of a DBR disc-shaped engine block, perhaps driven directly with the engine's driveshaft, or via a planetary gear overdrive to achieve the high RPM required for effective centrifugal compression. This would be a similar configuration to the way a propeller is driven via a turboprop engine, except a turboprop driven propeller is reduction geared.

There is one more option not yet mentioned which is that ducted blade rotary technology *itself* can be effectively applied in an air compressor / supercharger role.
There are two options to consider; either the chambers within the DBR engine unit itself could be dedicated to pre-charging air, or a separate DBR compressor unit driven by the main engine could feed it with compressed air instead.

Using chambers within the DBR engine itself could result in very high boost pressures and increased heat soak but hypothetically that could help to overcome any compression losses due to slack tolerances within the engine, possibly helping to make it easier to manufacture.

Conversely, using a separate DBR unit dedicated solely to being a supercharger would allow more power strokes to be completed per engine cycle in the block itself, but a separate DBR compressor unit would entail added weight & complexity.



Above, Atlas Motor Works' 'popov' pump design, capable of working as a stand-alone air compressor or even as a supercharger.

Comparisons/Trade-off

In comparison of some of the aspects of different powerplants we consider average automotive type engines – though there are specially developed engines which may lie outside these general criteria, the purpose of the table below is to show where the DBR engine's strengths and weaknesses may lie.

Also included in the comparison, though it may seem outlandish, is the gas turbine engine because of its use in the Chrysler and Rover turbine cars. Those vehicles when originally designed were intended to be everyday vehicles but failed due to their unfavorable characteristics, so they represent a good 'bottom line'.

We also consider the pure electric motor as used in the new pure-electric type Tesla Roadster sports cars which represent a good 'top of the line' as far as a green technology target is considered.

Engine type	**Useful Typ. RPM range (idle-max)**	**Typical Automotive power output**	**Torque**	**Throttle response**	**Overall Design Complexity**
Reciprocal piston	750-7000	Low-Medium	Medium	Medium	Medium
Wankel rotary	900-9000	Medium-High	Low	Medium	Medium
Gas turbine	13000-26000	Very High	Very High	Slow	High
Ducted blade rotary	0-2000	Low-High	High	Medium	Medium
Electric motor	0-14000	Low-Medium	High	Instant	Low

Engine type	**Longevity/Time to wear out**	**Fuel Burn**	**Size**	**Weight**	**Vibration**
Reciprocal piston	Medium	Medium	Medium	Medium	Medium
Wankel rotary	Low	Medium-High	Small-Medium	Light-Medium	Low-Medium
Gas turbine	Medium	Very High	Large	Heavy	High
Ducted blade rotary	Medium	Low-Medium	Small	Light	Low
Electric motor	High	Low	Small	Medium-Heavy (Including battery of equivalent range)	Low

Overall, we see the DBR engine is expected to excel in power output, size, weight and vibration but may suffer in overall design complexity due to the valve train, ignition, cooling and oil system design and it may also potentially suffer from wear/longevity problems as the early Wankel engines did. These topics are discussed further in the 'Design Considerations' section next.

Points of Note:

RPM Range

When considering RPM, a useful power band is more important than just a very high number. High performance racing engines developed for Formula 1 can rev to over 16,000rpm, but conversely the main fan of a GE90 jet engine spins at only 750rpm with its blade tips going supersonic. In this category we ignore those extreme numbers because they are not a fair or relevant comparison.

A typical reciprocal engine duty cycle is idle at 750 and max power at 6-7000rpm, an equivalent Wankel idles higher at 900 and can spin up to 9000rpm due to being better balanced.
A gas turbine requires an rpm range so high it would need extreme reduction gearing to be useful and then would lose any efficiency in doing so. An electric motor can develop maximum torque from 0rpm all the way to redline 14,000rpm or even higher, a limitation dictated only by the transmission and available battery power.

At first glance then the DBR engine would seem to offer potentially high RPM numbers; in the first draft of this report it was *erroneously* assumed that because the DBR engine bears similarities to high-revving Wankel and Turbine engines, and also because its flywheel-like design will have very good dynamic rotary balance it will be a very high revving engine.
In fact the DBR technology's inventor, Steve Johnson, pointed out that the rotary drive plate speed will be equivalent to piston speed in a reciprocal piston engine because of dependence on the rate of expansion of the combusted gasses.
In the appendices of this report is a short calculation of the maximum RPM of our hypothetical 16" diameter DBR engine based on known typical piston speeds in reciprocal piston engines, showing that the theoretical maximum RPM of our 16" diameter DBR engine is approximately 1400-2000rpm. This number would increase for a smaller diameter engine and vice versa.

While a 1400-2000rpm redline may seem low, the result is a very compact low-RPM high-torque engine, resulting in favorable gearing/transmission connotations for a typical car.
Usually in a standard transmission car gears 1-3 are all reduction gears, compensating for the necessarily high RPM operating speed of a piston engine, gear 4 is 1:1 and 5 is 'overdrive' for highway cruising.

It's clear then that with a DBR powerplant reduction gearing can be eliminated altogether, with only overdrive ratios required to reach the necessary speeds, this could make a continuously variable transmission system (CVT) ideal for integration with a DBR engine.

Typical Automotive Power output

If we consider the power output of a conventional reciprocal piston engine to be 'low-medium' varying with size, a Wankel is considered medium-high because it produces more horsepower per unit of displacement. A gas turbine engine power output is very high, again not considered to be practical in an automotive application, but a DBR engine power output could range from low-high varying with size depending on the power requirements of the vehicle, its power density being potentially more compact than both a piston or Wankel engine.
An electric motor power output is considered to be low-medium based of the limitations of the power delivery of its battery – though vehicles like are Tesla are undoubtedly fast, they only achieve this only by building as light a chassis as possible, as hydrocarbon fuels store 10 to 20 times more energy than batteries of equivalent size and weight.

Design Considerations

Friction & Lubrication

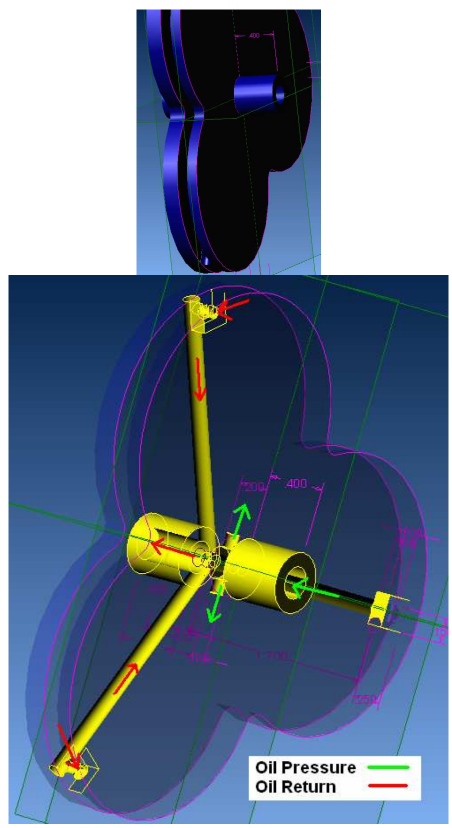
Of the different DBR-Tech engine design aspects, probably the most important element to consider for its success is engine *friction & lubrication*. In order to maintain the drive plate rim seal as it rotates through the chambers the tolerances in the DBR engine will need to be tight, that fact alone is not a huge problem, but the fact that those tolerances will need to remain tight throughout the life of the engine does present a challenge.

Atlas Motor Works have expressed interest in an oil-free design, achieving low enough internal friction coefficients with careful material selection such as ceramic-lined chambers paired with composite drive plates for instance. While an oil free engine design is possible using the right materials, it would not be the cheapest option and no existing engine manufacturer has yet achieved it.

One possibility is to add lubricant to the fuel as in a 2-stroke engine where oil is pre-mixed before hand – this was also the case with early Wankel engines. In a 2 stroke engine the oil is burnt and expelled with the exhaust gasses meaning oil has to be re-fuelled occasionally along with the gasoline itself, but pre-mixing oil has emissions implications – 2 strokes always have a distinctive smokey exhaust smell which is instantly recognizable because it contains burnt oil.
While 2-stroke smog is generally accepted when emitted by a small capacity engine as used on a moped or rickshaw type vehicle, plus lawnmowers/chainsaws etc, it would be considered 'dirty' to power an ordinary car with pre-mix fuel.

Another possibility is leaded gasoline – lead of course is no longer accepted as a general automotive fuel additive but is still allowed in aviation fuel, so for the possibility of using a DBR engine as a light aircraft powerplant leaded fuel would help alleviate some lubrication problems, but not solve them entirely.

Summarily then, an inexpensive automotive DBR engine designed for longevity and standard emissions *would need an oil system.*
Such an oil system could be relatively simple with only the two main crankshaft bearings and the 6 drive plates to consider. To be able to lubricate the chamber walls one possible solution might be to make the drive plate into an 'oil sandwich' as pictured right.

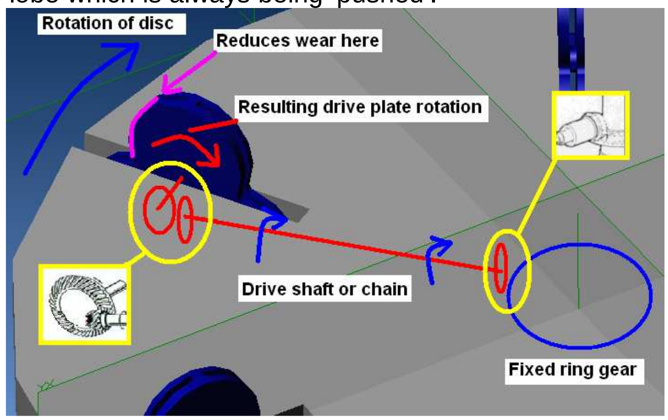


By using a pocket drilled part way through the bearing shaft of the drive plate as an oil channel, a pump or the centrifugal force of the rotation of the engine could supply pressurized oil into a thin gap between two mated drive plates via small pilot holes in the drive plate shaft. Pressure would then fill the gap with oil, lubricating the chambers continuously as it sweeps through, returning to the sump via 'scoop holes' at the tip of each lobe sandwich. Channels within the drive plate itself would give oil a return path back to a return shaft – pressurized by the rotation of the drive plate and assisted by an oil scavenging suction pump. This is one method by which an iron walled chamber DBR engine could be lubricated to achieve low-wear operation.

Drive Plate Gearing

The Archimedes screw-like helical path through which the drive plates travel will consistently load one side of each lobe, meaning that even with an effective means of dry or liquid lubrication wear will primarily occur on the side of the lobe which is always being 'pushed'.

One way to alleviate this condition would be to incorporate a hub and spoke gearing system so that the drive plates are driven around as the disc of the engine rotates, reducing or eliminating side loading on each lobe, increasing the life of each drive plate and lengthening the period of time it takes for a drive plate to wear to the point of losing compression.



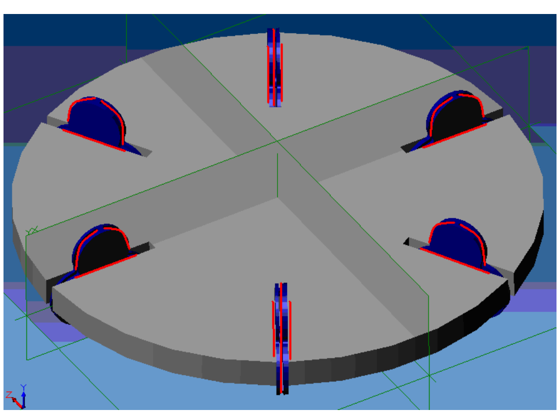
Above, a simplified diagram of how a hub and spoke gearing system might work. (Not a final design!)

While this system would decrease the wear on the drive plates and extend their service life, any drive shaft, gear, chain or belt transmission components would incur wear themselves and increase the overall design complexity of the engine. Only experimentation and reliability testing can determine whether such a system might really be needed.

Sealing & Compression

Due to the unusual shape and motion of the drive plates in the DBR engine, it's not known exactly how well they may be able to seal and thus give effective compression.
This is one advantage of a conventional reciprocal engine whereby a simple circular piston ring creates the seal to allow compression within the cylinder, conversely in a Wankel rotary engine the compression seal is created by a single edge of the trochoid rotor plus side seals in contact with the casing.

In the DBR engine a constant seal needs to be maintained between the drive plate's lobes and the chamber walls, between the face of each lobe and the disc rotor and between the edge of each chamber and the disc rotor. Considering that both these kinds of seals have been effectively utilized in piston and Wankel rotary engines we can be fairly certain it would be straightforward to achieve this in the DBR engine as well.



Custom designed piston rings or finger seals could be designed to seat in a grove on the 3-leaf clover shape of the DBR drive plates, and linear seals of a similar design could be utilized in a small gap between the rotor-disc and drive plate face on both sides. Effective ring/seal design may also be the best way to achieve low friction, reducing wear and potentially opening up design tolerances to make the engine easier to manufacture.

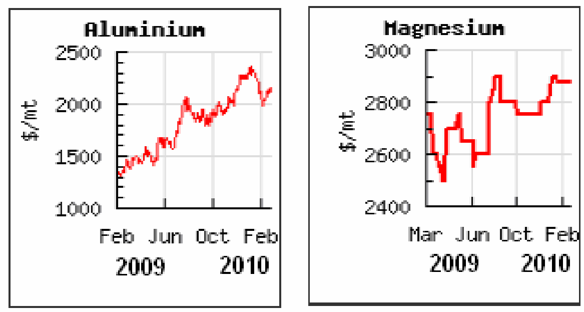
Illustrated left, the edges highlighted in red would be the locations of such seals.

<u>Materials</u>

The selection of the right materials in the DBR engine design is crucial to its success as material choice directly affects weight, life cycle and manufacturability. For the engine block itself, the obvious choices of iron/steel, aluminum and magnesium present themselves with steel generally losing out due to weight and difficulty in machining, and magnesium losing to aluminum over cost per unit volume.

Magnesium can however reap cost savings in casting; a casting die can take more casting 'shots' from magnesium than aluminum, but aside from the engine block what other material considerations are there? We know wear intensive bearing elements of the disc shaft will need to be made from steel as a general rule, as will any geared power transmission components.

But the real question is how to manufacture the drive plate and chamber walls – a hypothetical 'oil free' engine might use some exotic combination of a ceramic chamber wall with a Kevlar/Asbestos composite drive plate, but the manufacturing methods and material costs involved could be prohibitive.



Magnesium is lighter than Aluminum making it preferable where light weight is valued; it is more expensive to buy but less expensive to cast.

Tooling Amortization Magnesium vs. Aluminium

	Magnesium	Aluminium
Cost of Tool	$75,000.00	$75,000.00
Est.Tool Life	500,000 shots	150,000 shots
Cost per shot	$.15	$.50

Machining of the swept-path chambers will likely be the most expensive stage of manufacturing in the DBR engine, in comparison surface finishing them from a press-forged mold could be cheaper in very high volumes but forging incurs high initial tooling cost. In either case their machining requires more precision than just honing a cylinder bore in a reciprocal piston or Wankel rotary engine. Because of this potentially high manufacturing cost we do not want the chamber walls of the DBR engine to wear easily, the drive plate lobes whether lubricated or not need to be the consumable component so they will be machined from a softer alloy than the chamber walls are cast with, perhaps to be replaced as part of scheduled maintenance?

The easiest solution then is to mimic typical piston engine design where a steel 'sleeve' is inserted within a cast aluminum casing – in the case of the DBR it would more of a steel 'half-shell' than a sleeve which could be fastened in place either by press-fitting studs into the aluminum casing or by using fasteners. Once affixed to the casing the individual steel half-shells could be honed into their helical swept volume by CNC machining.

The drive plate would be required to maintain a constant tight fit with tight manufacturing tolerances to achieve maximum compression; additionally it is also required to be softer than the steel chamber walls so it can be the sacrificial wear component in the design, allowing occasional engine drive plate replacement instead of needing to replace the entire engine casing at regular intervals!

With these requirements, the ideal material choice for the drive plate becomes that of a 'hypereutectic alloy piston'. An example of a hypereutectic alloy is one that utilizes aluminum with silicon content higher than what is soluble in it at typical piston engine operating temperature, the effect this has is a lower coefficient of thermal expansion, allowing tighter tolerances to be held. Thus, hypothetically an aluminum hypereutectic alloy would also be the ideal material choice for the drive plates in the DBR engine.

Cooling

As with any internal combustion engine, a DBR powerplant will be just as susceptible to the laws of thermodynamics that govern any exothermic chemical gas reaction where some energy must always be lost as heat. While the increase in pressure created by internal combustion creates the mechanical energy used to drive our vehicle, the excess thermal energy must be removed to avoid damage to the engine.
There are two fundamental methods of doing this; air cooling and liquid cooling. Either method would be compatible with the DBR engine.

Air cooling the DBR engine could be easily achieved by driving a fan straight from the crank shaft, while there are various ways of achieving this it is actually illustrated in Atlas Motor Works' own concept graphics.

Air cooling this way is an acceptable means of removing unwanted heat and has been used on various vehicles including most motor cycles, also traditionally the flat 4 cylinder engines used on early Porches and VW beetles were always air cooled, but when stuck in traffic on a hot day an air cooled engine could overheat due to lack of airflow. They were not the only air-cooled engined cars with that potential problem.

Above, Atlas Motor Works envisage the DBR engine with what looks like an engine driven cooling fan, but if it is air cooled the DBR engine design will require the addition of cooling fins like those on a typical motorcycle engine pictured below.

Another application of air-cooling which does *not* suffer from the airflow problem as easily is in light aircraft applications, where even at idle power the propeller can produce enough airflow to keep the engine cool.

A DBR engine cooled by fan airflow is feasible and it is the less complicated of the two options however the casting of the engine block would be affected as cooling fins would have to be incorporated into the design – the addition of stop-start technology would also help alleviate idle overheating problems historically associated with air cooling.
Liquid cooling is much more common in automotive applications; by using a fan-assisted liquid coolant radiator coupled with a water pump, thermostat and some simple electronics an engine is allowed to maintain a homeostatic thermal condition in all phases of operation. It would be fairly easy to implement a 'water blanket' cooling design with the DBR engine but it would incur a weight penalty because of the aforementioned ancillary components such as the radiator, water pump etc.

The primary advantage of a liquid cooled engine is being able to remain cool at idle on a hot day, as well as being able to hold tighter tolerances due to reduced thermal expansion.
Even with the use of a stop-start system liquid cooling can prove extremely beneficial if the engine is required to drive ancillary systems that must continue running when stationary such as the air conditioning.

For simplicity, a prototype DBR engine might be air cooled at first then perhaps later versions might incorporate a liquid coolant system to be able to cope with the heavy mechanical system demands of a modern car.

Other DBR-Tech applications

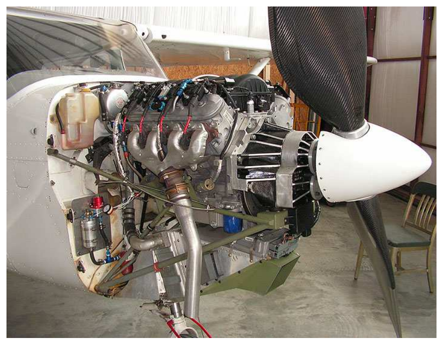
DBR-Tech Engine as an Aircraft Powerplant

With its inherent small size, low weight & low vibration advantages a DBR engine would seem to be an ideal choice as a light aircraft powerplant. Aircraft designers wrestle with engine choices to try to maximize power for minimum weight penalty and a hypothetical DBR engine will apparently exceed current aircraft piston engine designs in both aspects.

While the era of large radial piston engined airliners has long since been superseded by the jet and the turboprop, small 'general aviation' aircraft continue to depend on piston power.
Small two to six seat fixed wing aircraft and also many two to four seat helicopters predominantly depend on either Lycoming or Continental flat 4 and 6 cylinder engines in the 150-300hp range.

The basic design of both Lycoming and Continental engines is essentially a copy of the early air cooled VW/Porsche 'boxer' flat 4 cylinder engines first used in the VW Beetle and Porsche sports cars, in fact VW beetle engines to this day are still converted for use in aircraft, and the Mooney aircraft company once even offered a Porsche automotive engine as a powerplant option for their aircraft. To a lesser extent, Rotax, a company whose origins are in snowmobile engines, are also now a mainstay engine supplier for light aircraft, producing a smaller higher RPM liquid cooled flat 4 cylinder engine which is now extremely popular in 'light sport' category aircraft.

In the world of experimental hobby-built aircraft, designer/builders who are usually also the owners and pilots themselves have a lot of freedom in their engine selection and often use automotive engine conversions to power their aircraft. Aside from the aforementioned VW & Porsche engines, Suzuki 4 cylinder engines are popular, as are the Subaru boxer flat 4 cylinder engines.
Even GM's Chevy LS1 V8 has been used – definitely not the smallest or the lightest of powerplants.



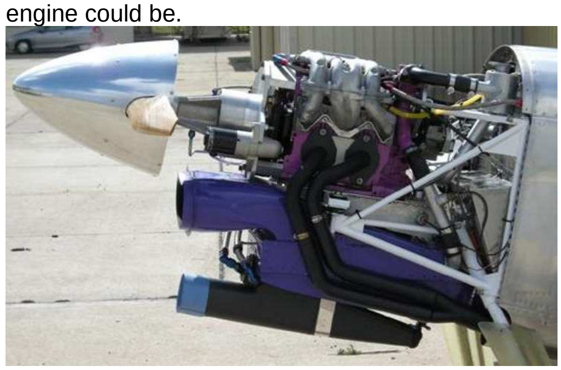
Above, this experimental configuration Cessna 172 has been re-engined with a 400hp Corvette LS1 V8 engine driving a large composite propeller.
While certainly powerful it is not as light as an equivalent power DBR engine could be.

However the noted exception in the experimental aircraft homebuilding scene is the 13B series of Mazda Wankel rotary engines, in particular the Renesis unit used in the RX-8 sports car.

Despite their slightly higher fuel consumption than equivalent power reciprocal piston engines, many homebuilders are favoring the Mazda rotary engines because they are compact and light weight in comparison to engines of similar power output.

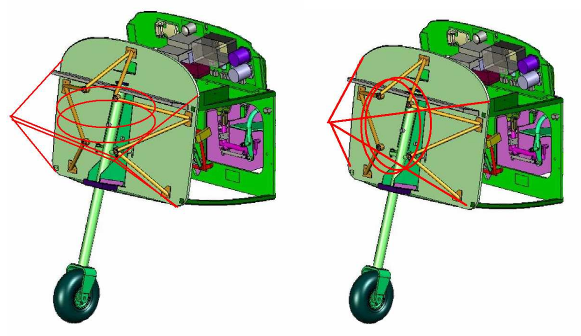
With experimental aircraft homebuilders leaning toward lightweight powerful engines like the Mazda rotaries it's possible that if the DBR engine could outperform them it will most certainly excel in the small aircraft field.
The experimental aircraft market is also a promising niche and proving ground for the DBR technology because experimental aircraft are not subject to emissions regulations as a car would be and they are not required to be FAA certified as a mainstream aircraft powerplant is.

Below, this experimental Vans RV-4 kit plane has been built with a Mazda 13B Wankel rotary engine as its powerplant, capitalizing on its relatively high power-to-weight ratio – but not as high as the DBR engine could be.



The final point to mention on this topic is that the low profile disc-like shape of the DBR design offers multiple options for low-drag engine placement on an aircraft.

In a standard front engine tractor-type configuration the engine could either be mounted almost right up against the firewall with a long crankshaft to the propeller encased in a sleek cone-shaped cowling, or the engine could be mounted perpendicular to the propeller, driving it via a 90 degree gearbox, encased in an aerodynamic cheese-wedge shaped cowl.
The only disadvantage to such an installation might be that ballast would have to be added to the nose to offset the light weight DBR engine!

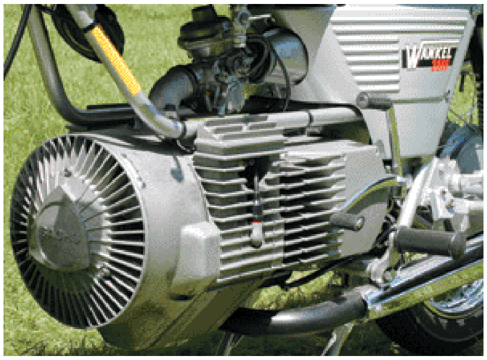


But in all seriousness, if a DBR engine prototype is successful it potentially has the makings of a very successful aircraft powerplant, so if a working DBR engine prototype were to be rejected by the automotive industry as the Wankel was initially, it too could potentially find a home in aviation.

Motorcycle/ATV etc. (Small displacement)

Just as easily as powering a car or light aircraft, a DBR engine could also power motorcycles, scooters, atvs, or other similarly sized vehicles.
Of course, there are a myriad of different piston engine configurations for such vehicles in both four and two stroke variants and their prevalence is primarily due to low cost of manufacture.
In a well equipped, well staffed manufacturing plant it's very easy to produce thousands of small capacity engines per day, be they two or four stroke in single or multiple cylinder designs.

Competing designs such as the Wankel rotary engine have never really gained a foothold in the small-displacement engine market and not for want of trying.
The first motorcycle with a Wankel rotary engine was the Hercules W2000, its power was constrained to 30hp by a restrictive patent license; it ran very hot and often over-revved, either damaging or destroying its internals in the process.
Now it is just a curiosity consigned to motorcycle history, but there have been a few others since.



Above, the 30hp Wankel rotary engine of the Hercules W2000 was less than successful but dared to be different.

Despite a less than ideal start, the introduction of the Wankel engine to the motorcycle world did prove that there was an alternative to pistons! But likewise, an introduction of the DBR engine to the small-displacement world may also be met with similar skepticism.

Again, the one intrinsic advantage the DBR engine will have over its rivals is light weight and compact size – in *a very compact* package a DBR engine could be an ideal powerplant for a high gas mileage scooter/moped. In the current climate of spiking oil prices light motorcycle and scooter sales have been soaring and this could be a potential entry market for a small low horsepower DBR-Tech based motor.

Generator

In the introduction to this paper we mention Ferdinand Porsche's 'Mixte' hybrid, an early hybrid vehicle which propelled itself with the electricity generated by its onboard engine.
This was the first hybrid electric vehicle, but the basis of generating electricity with a piston engine was in use long before that and has been ever since.

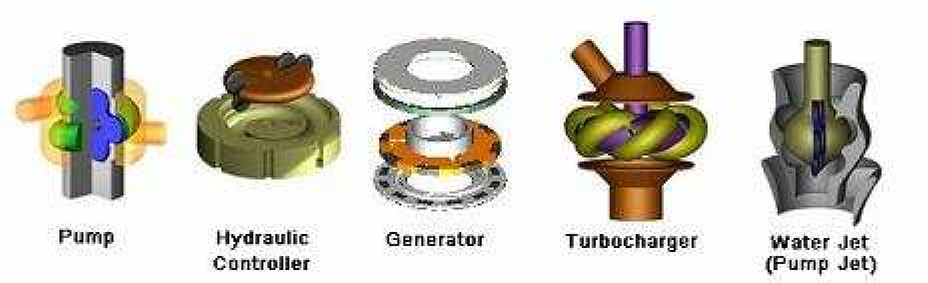
With the DBR engine promising to be an ideal Powerplant for automobiles it may just as easily spin up a generator as a transmission. Generators of course vary hugely in size, from tiny portable units to giant industrial fixtures.

The DBR engine is scaleable – it could readily power a tiny portable generator running on pre-mix two stroke fuel or an enormous industrial generator running on diesel.

With DBR technology, tiny portable generators may become even tinier and more portable, while large fixed generators may occupy less floor space, or just produce more power!

Compressor/Pump/ Impeller

As aforementioned on page 13 and page 17, the basis of DBR technology that is helical rotation of a drive plate about an axis has the potential to be utilized for much more than just an alternative to the piston engine, it would also serve well as a hydraulic or pneumatic pump and other such devices; Atlas Motor Works recognize this and envisage the following possibilities…



The compressive pneumatic capabilities of DBR technology would make for a great stand-alone compressor, but could also double as a supercharger or even a simple horn blower.
The DBR technology also has potential applications with incompressible fluids as well, possibly as an oil pump, an impeller for a jet-ski (or water jet as pictured), or to some degree a hydraulic pump as well.

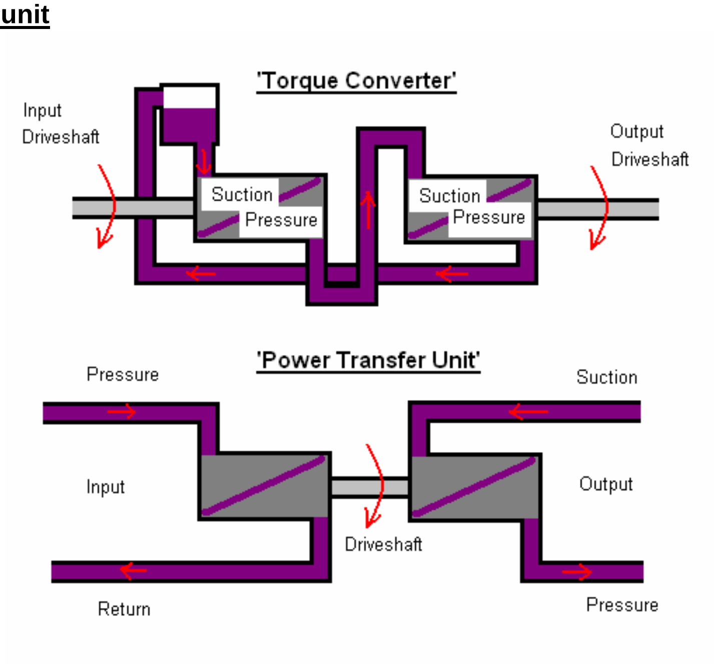
As a simple fixed-output hydraulic pump, DBR technology is ideal; likely to be very efficient with low heat build up in comparison to a typical reciprocal piston based hydraulic pump, however there does not yet seem to be any obvious way to make a DBR-based hydraulic pump into a true fixed RPM variable-displacement unit akin to a variable displacement swash-plate, or 'self idling' type radial pump as used on aircraft systems.

Complex hydraulic systems as used on industrial construction equipment and aircraft usually require variable displacement hydraulic pumps whereby different volumes of fluid can be displaced for the same RPM – unfortunately there does not at first glance seem to be any way to achieve this with a ducted blade rotary hydraulic pump.

Torque converter/Power Transfer unit

Elaborating on the hydraulic principle, two applications which might seem to be suitable for a DBR hydraulic pump are as a 'torque converter' as used in an automatic transmission to hydraulically transfer mechanical power and also as a power transfer unit or PTU as used on an aircraft to mechanically transfer hydraulic power to provide hydraulic system redundancy.

Both of these applications also draw parallels with the 'hydraulic hybrid' concept discussed earlier in this paper. The simple diagrams to the left illustrate the basic principle where a hydraulic DBR pump/motor could be used.



Conclusion

To summarize the viability, feasibility & technical soundness of the ducted blade rotary engine concept, we can review some of the basic design characteristics which have been covered in this paper.

- A DBR engine will be very powerful for its size.
- A DBR engine will be compact and lightweight for its power.
- The DBR engine will be compatible with nearly any form of stop-start technology.
- The DBR engine will require development of new custom valve train, lubrication systems and compression sealing components.
- The DBR engine can be either air or liquid cooled.
- The DBR engine can use existing materials, but will require new unique CNC manufacturing programs to be created for its production.
- There are numerous other applications for DBR technology aside from just the engine.

What this amounts to is a stack of potential design benefits, with relatively few potential problems aside from needing additional detail design, research and testing to be carried out.
What's left to overcome then is the fondness and familiarity that many associate with the traditional piston engine. It's foreseeable that even if a 500hp DBR engine is set on display next to a 500hp V8 engine it will be viewed as inferior just because of its more diminutive stature and also because at first, many simply won't understand how it works.
A big V8 looks robust & powerful, in comparison the DBR engine design might appear to be a wolf in sheep's clothing, many might not believe its potential.
The same might happen when comparing with a Wankel rotary engine to the DBR technology, the helical rotary motion of the drive plates may at first be difficult to grasp for some.

But this wouldn't be the first time that an apparently diminutive inferior design has failed to be taken seriously at first, to use an appropriate analogy we can rewind to a 165 year old story of the HMS Alecto and the HMS Rattler.
In the 1800's the industrial revolution was in full swing; steam power was becoming popular and eventually superseded the traditional sails as a means of propelling ships.
Initially, steam powered ships used paddle wheels as their mode of propulsion and looked to be an effective method of impulse – giant thrashing paddle wheels must have *looked* powerful.
But in 1839 the SS Archimedes became the first steam powered ship to utilize the Archimedes screw underwater propeller, the arrival of which probably sparked arguments as to which was the most efficient means of propelling a boat.
Eventually, the British Navy set up a challenge in April of 1845 to find out just which was the most effective method. The HMS Alecto was paddle-wheel driven while the HMS Rattler utilized the new-fangled Archimedes screw propeller.
Each ship was of equal power and weight and in two head-to-head races the propeller driven Rattler won both times. Ultimately, a tug of war publicity stunt was arranged, in which the propeller driven Rattler was initially pulled backwards by the Alecto while it built up steam.
After 5 minutes, the Rattler eventually reached full power, slowing the Alecto first to a halt, then towing it backwards at 2.5 knots, proving its superior design.

Ultimately the result of that competition was the demise of sea-going paddle boats and the universal adoption of the underwater Archimedes screw propeller, the moral of the story being that given the chance to prove it self with enough publicity, regardless of diminutive proportions, the most effective design prevails. All that's needed for *the DBR engine* then is a chance to prove itself.

Appendices

Chamber volume calculation:

Spiral length:

Using $L^2 = ((лxD)xN)^2 + (PxN)^2$
Where L = length of coil
D = diameter of coil — D = 3.5
N = number of turns — N = 2
P = pitch — P = 9.424 = ((лxD)/2) = ((лx6) /2)

$\sqrt{(((л x3.5)x2)^2 + (9.424x2)^2)} = 28.96"$

Finding one half surface area of 1 lobe:

Using $2лxR^2 = A$

Where R = Lobe radius — R = 1.75 / 2 = 0.875
A = Area

$2 x л x 0.875^2 = 4.81"$

$4.81/2 = 2.4"^2$

Finding volume of 1 semi-circular ‘tube’ :

Using A x L = V
Where A = Area — A = 2.4
L = Spiral length — L = 28.96
V = Volume

2.4 x 28.96 = 69.656

3 Lobes = 3 ‘tubes’

$69.656 X 3 = 208.97"^3$

$1 liter = 61.024"^3$

208.97 / 61.024 = 3.42 liter

Finding the volume of the 12 individual chambers:

208.97 / 12 = 17.41 cubic

3.4 / 12 = 0.285 x 1000 = 285cc

Theoretical Maximum RPM calculation:

Based on real world typical max piston speed of reciprocal engines:
Stock Motor - 3,500 fpm
Drag Racing Motor - 5,000 fpm

& using spiral length of 28.96”
= 2.41ft

3500/2.41= 1452.3rpm
5000/2.41= 2074.7rpm