



## Water-cooled Pivotal Piston

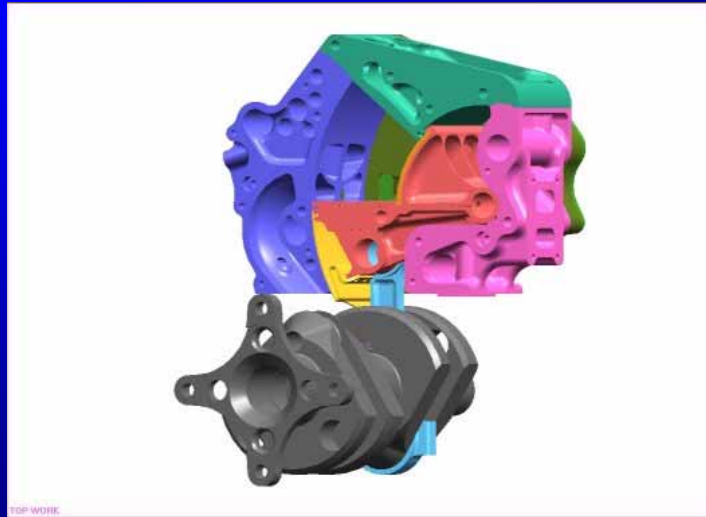
A key technology to deliver high power density with significant advantages for operating on hydrogen fuel.

Hello

Today we will explore the key differences of the water-cooled pivotal piston engine and how these differences affect its suitability to meet power needs in a hydrogen age.

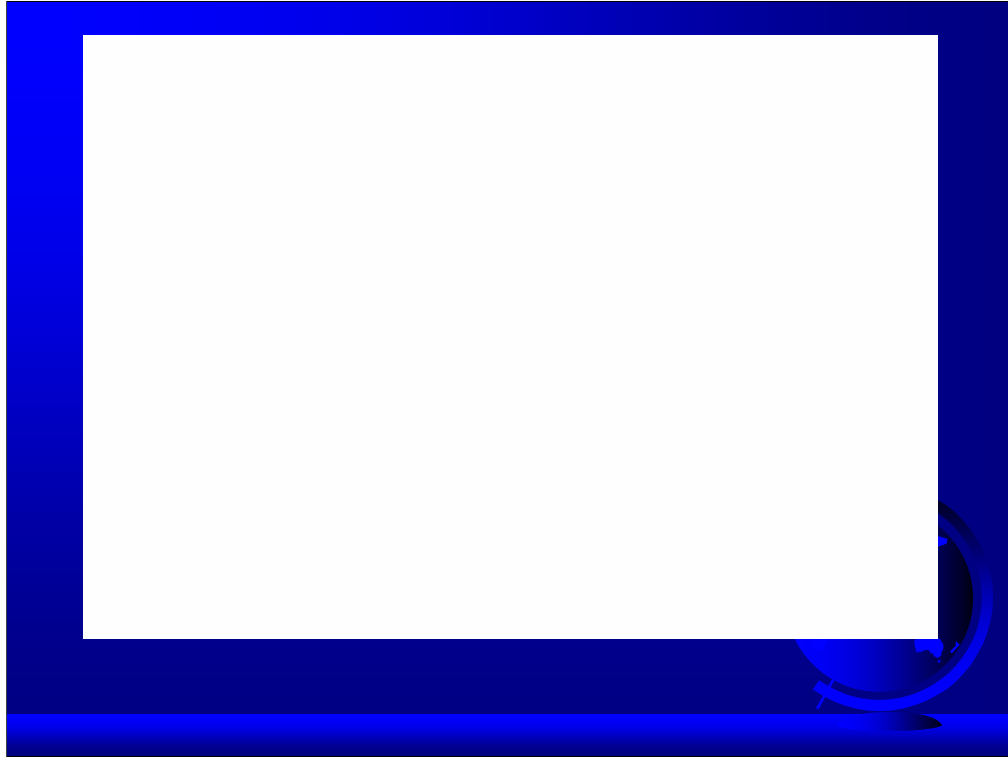
However this technology does present advantages which are also applicable to gasoline, diesel and CNG, so the Pivotal engine could operate switching seamlessly between hydrogen/gasoline.

## Pivotal Piston at BDC.



The Pivotal engine has exhaust ports and the transfer porting in the exhaust block with only transfer porting in the side plate.

Also visible is the piston skirt which is used only to seal off the exhaust port as the piston descends compressing the primary charge in the crankcase.



The piston is fully controlled by being located at two points, the pivot and the piston pin. There is no piston tipping or rocking.

The air flow is as per a conventional crankcase induction two-stroke engine with the fuel trapped in the chamber with a direct injection system.

The piston skirt is pushed to the outer surface by the primary compression and seals off the exhaust port at TDC.

The load is applied to the crankshaft in a direct path with minimal load on the pivot bearings.

## Cutaway of The Pivotal Piston



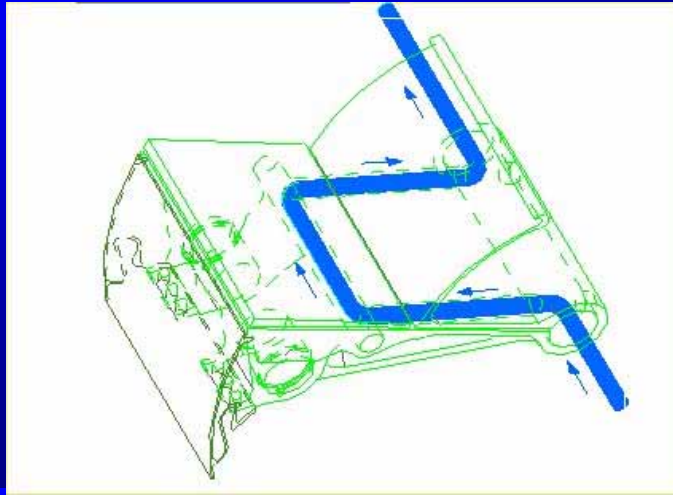
On the left is a conventional two-stroke piston exhibiting severe damage from piston over-heating and detonation.

On the right a cut-away of the pivotal piston showing the water-cooling circuit.

Coolant enters at the pivot centre, out to the piston crown area, and back out the other side of the pivot shaft.

The panel below indicates the contact area between water and piston , dissipating heat from the piston through 360o of the engine cycle.

## The Pivotal Piston is Directly and Independently Water-cooled.

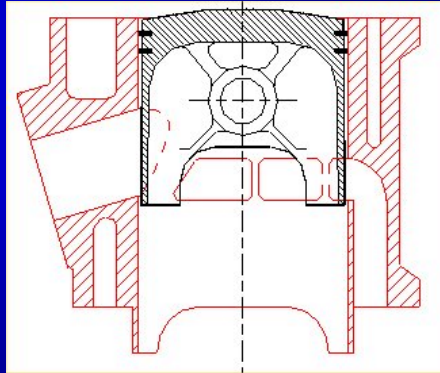


The water gallery can be designed to dissipate heat at whatever rate is required and alter the piston crown temperature in a moment.

It is the independence of the piston cooling that provides the opportunity to operate the engine at a higher, more thermally efficient temperature bringing full control over the combustion environment.

## The conventional sliding piston in a two-stroke engine.

- ☞ The conventional piston is reliant on heat dissipation via the compression rings and piston skirt. This demands that the engine is always cooler than the piston to promote heat flow away from the piston.



In a conventional piston, heat is absorbed by the piston crown and dissipated via the piston rings and skirt where they contact the water-cooled cylinder.

Due to the exhaust port, transfer ports and passages the contact of the piston skirt onto effective cooling surface is limited.

It relies on the cylinder wall to restrain the piston and limit rotation around the piston pin.

## What is wrong with the sliding piston in a two/stroke engine?

- ☞ The conventional sliding piston never fits - it is too loose when cold or too tight hot.
- ☞ It has a poor heat dissipation rate and relies on the engine being run in an overcooled state to avoid overheating the piston.
- ☞ The piston rocks and catches in the exhaust port and unseats the compression ring.
- ☞ It requires lubrication - resulting in oil being lost out of the exhaust port.



The conventional two-stroke piston is either too loose and slapping when cold or too tight and seizing when hot.

The heat dissipation of a sliding piston is poor and so high performance engines are generally run in an over-cooled state in order to save the piston from thermal damage.

The piston tends to rock around the piston pin which is the major cause of cold engine damage. This rocking also unseats the compression rings.

It must be lubricated and much of this oil is scrapped off into the exhaust port and into the environment as unburned hydrocarbons.

## The Pivotal Piston Advantage

- ☞ Sound mechanical control with the piston movement guided by the pivot bearing.
- ☞ No piston thrust on the chamber wall, so no cold engine damage to piston or cylinder.
- ☞ No piston rocking to unseat compression seals (piston rings).
- ☞ The straight seals pass over the open ports without protruding into port openings.
- ☞ No piston lubrication required (oil delivered to the compression seals only).



The pivotal piston is fully restrained by the pivot bearing so that it is not thrust against the chamber wall.

It does not require lubrication other than for the compression seals.

Because it is located at the pivot point it cannot rock around the piston pin axis.

Also because the compression seals are straight beams with separate pre-loading springs they do not protrude into the port openings.

## The 'Independently Water-cooled' Pivotal Piston Advantage

- ☞ The independent control of the piston temperature is essential to maintaining a uniform combustion chamber surface temperature.
- ☞ With full and independent control of piston and head temperatures engine damage from pre-ignition or detonation can be avoided.
- ☞ The engine can sustain high load operation.

The ability to control piston temperature independently from engine temperature is a major breakthrough in the management of the combustion process.

This is further enhanced when applied in a two-stroke engine where the head, piston and to a small degree, the chamber wall, make up the boundary surface of the combustion chamber.

A thermally smooth or uniform combustion chamber surface dramatically extends the potential to operate an engine on a high hydrogen/air ratio.

## How to Utilize these Advantages.

- ☞ With the piston thermally and mechanically controlled the high power density of a two/stroke engine can now be employed to full advantage.
- ☞ With the ability to control the temperature of all combustion chamber surfaces, combustion efficiency can be optimized.
- ☞ These advantages culminate in a reduction in engine and vehicle mass.



The transition to hydrogen fuel will accentuate the need for high power density, both in the fuel storage system and to reduce the total mass of the vehicle to be moved.

High power density will reduce the operating cost of the vehicle and extend the range between refueling.

Low mass is a prime objective and one which will ultimately deliver convenient and sustainable, independent transportation in the coming hydrogen age.

- ☞ With full control over the combustion environment the pivotal engine can operate with less stable or higher temperature fuels.
- ☞ Oiling can be accurately metered specifically to the bearings and compression seals, reducing oil usage to less than 10% of a conventional two-stroke engine.
- ☞ By utilizing high speed direct fuel injection a very low level of HC emissions can be achieved when operating on gasoline.



With full thermal control of the combustion chamber and a lubrication requirement down to a level similar to a four-stroke engine, it becomes clear that a high efficiency, low emission, two-stroke engine can become a viable automotive power unit.

Recognizing-- that direct to chamber fuel delivery system will be essential whether it is hydrogen, CNG, gasoline or diesel.

## The Water-cooled Pivotal Piston is Central to Meeting all of These Objectives in a Single Engine.

- ☞ Full thermal control
- ☞ Light weight
- ☞ Compact size
- ☞ High power
- ☞ Low emissions
- ☞ fuel economy
- ☞ Longevity
- ☞ Low operating cost
- ☞ Low manufacturing cost



The development of the pivotal piston concept was driven by the belief that it was possible to capture the light weight, high power, compact size, and low manufacturing cost of a two/stroke engine and still achieve the low emissions, good fuel economy and longevity which are recognized four/stroke engine advantages.

By developing a completely new design for the two-stroke engine the potential to meet or exceed the best of both has become evident.

## What are the Characteristics of Hydrogen Fuel?

high power density- by weight

low power density- by volume

fast combustion burn rate

high combustion temperatures

low ignition energy requirement

good ignition at low fuel/air ratio

high octane rating

no evaporative cooling

no lubricating qualities

To establish a criteria which will guide the design of a hydrogen ICE demands that the very different characteristics of hydrogen are studied. This will lead to the development of a new and different mechanical design.

The characteristics of hydrogen fuel and how they effect the criteria for engine design are dealt with further in our paper –

Titled:

Discussion on the Potential of the Water-cooled Pivotal Piston H<sub>2</sub>ICE to Extend Power Density and Total Vehicle Efficiency.

This paper is available on [www.pivotalengine.com](http://www.pivotalengine.com)

A look inside the Pivotal Piston  
Engine as it runs through a cycle.



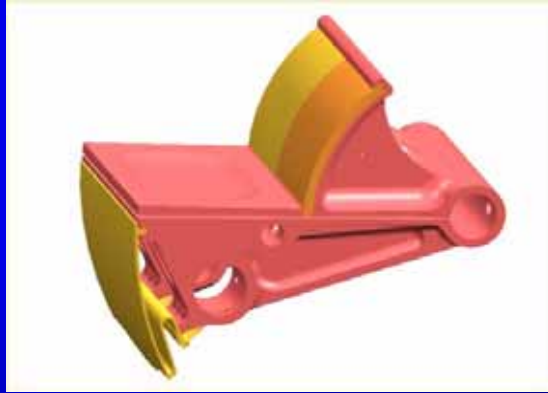
The air flow through the current pivotal engine is much the same as a conventional two-stroke engine.

## The Components that make up a Single Module.



The Pivotal design is very modular with each chamber module being made up from a small number of simple components.

## Pivotal Piston



- ☞ The piston body retains the arc seals and the exhaust control skirt.
- ☞ The compression seals are linked at the corners to ensure minimal gas leakage.



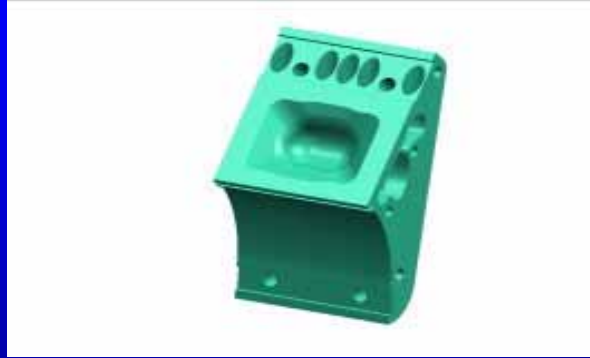
The groove for the compression seals is visible here. These seals are preloaded by a wave type spring and the side compression seals link into the front seal at the corners.

The arc seal is in two components, which have a stepped joint at the centre. There is a spring behind them which preloads these seals out to the side plates.

The piston skirt is attached to the piston at the bottom and floats free at the top.

Hopefully the piston being passed around will come to you soon if it hasn't already.

## Thermally Smooth Head



The head is free of poppet valves and therefore offers absolute freedom in combustion chamber geometry and placement of injectors and plugs.

This shows the thermally smooth combustion chamber surface in the head.

Sparkplug positions are not indicated here but for hydrogen fuel it would utilize twin surface gap plugs.

The groove in the head is the head seal. This seals to the piston arc seal surface.

The two round holes are for bolts and the four elliptical holes are part of the water-cooling circuit.

There is a head being passed around which will make these features clear.

## Side Plate (inner surface)



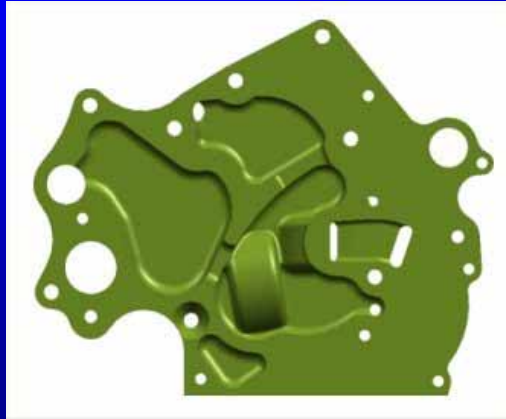
- ☞ Houses additional transfer ports
- ☞ Coated with hard wear surface



This view of the side plate inner surface shows the thermal spray, wear surface coating and the side transfer ports.

The pivot bearing is located in the side plate here.

## Side Plate (outer surface)



- ☞ Water cooling passages.
- ☞ Retains pivot bearing.



This is the outer surface of the side plate with the water-cooling gallery.

The water flow is from the ‘water in’ hole down across to various outlet positions where it flows through the head and exhaust block before exiting at the ‘water out’ position.

## Exhaust Block



- ↳ Houses exhaust port and transfer ports.
- ↳ Water cooled.
- ↳ Coated on the arced surface with same thermal coating wear surface as the side plates.

The exhaust block component shows the extent of the water-cooling.

The arced surface is thermally coated to provide a wear surface for the compression seals.

It is keyed at the top to locate into the head component.

## Modular Assembly

- ☞ Fast introduction of new products.
  - reduced parts inventories
  - reduced development time and cost
  - reduced tooling costs



This is a four chamber engine built up from components of an earlier twin chamber test engine.

This demonstrates modular flexibility to construct various engine layouts.

## Modular Manufacturing

- ☞ Common components will be assembled into multi chamber engines of varying configurations to fit the engine to the vehicle.
- ☞ This flexibility extends the options on engine placement within the vehicle enabling further savings for increased passenger space, payload or fuel capacity.



The high degree of modularity makes it possible to utilize developed modules and systems in a wide range of engine sizes and configurations.

Small components assemble into modules which can then feed down to a broad range of engines.

Reducing the manufactured cost of each power unit.

## Niche Applications for Water-cooled Pivotal Piston Engines

- ☞ Recreation vehicles - motorcycles, snowmobiles, jetskis, outboard engines, light aircraft, UAVs and emergency or portable power generation.
- ☞ High power density is very important in these markets and there is increasing pressure to reduce emissions in recreation products and to improve both reliability and longevity.



In considering the most suitable application for commercializing the pivotal engine we took into account the maturity of the engine industry.

This made it clear that we needed to focus on high value, low volume and where power density and sustained high load operation were in demand.

This steered us toward recreation vehicle applications. Light aircraft and UAVs demand high power density and snowmobiles need to reduce HC emissions without losing responsiveness.

## Potential Products

- ☞ Sports motorcycles from Italy, low emission scooters in Europe, China and India.
- ☞ JP8 fueled military power units for UAVs, landing craft and power generation.
- ☞ Utility vehicles, super cars and hybrid systems.
- ☞ Diesel truck engines, marine CNG engines.
- ☞ Home heat/power cogeneration systems.
- ☞ The pivotal hydrogen IC engine.



The range of potential applications for lighter and smaller power units is vast and we anticipate that pivotal engine technology will continue to be introduced into new markets.

## The Automotive Potential.

Achieving low fuel consumption and minimal emissions in mobility applications starts with choosing a high power density engine.

All technological advances which reduce parasitic friction, improve combustion efficiency and exhaust after-treatment are further extended by a reduction in the total mass to be moved.

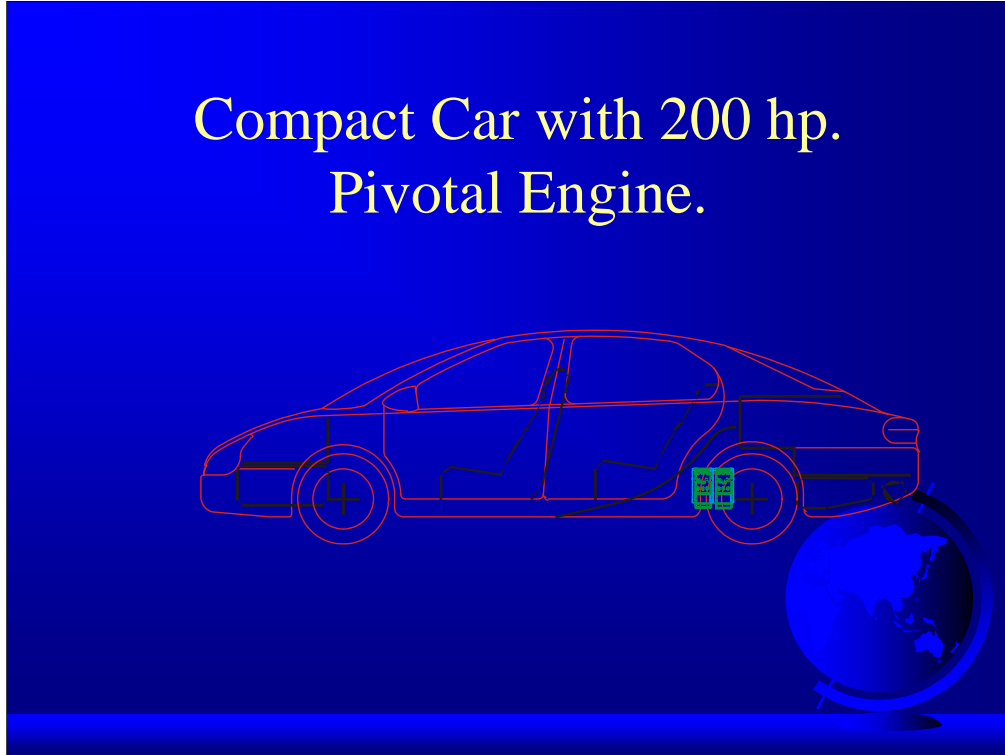


The unique features of the pivotal piston engine bring the high power density of the two-stroke back into automotive engine potential.

Major OEMs of the automotive industry are looking ahead to changing times and are uncertain of what the ubiquitous power unit in future vehicles might be.

With fuel cell technology still some distance from volume marketability the ideal hydrogen IC engine may still be the catalyst to herald in the hydrogen age.

## Compact Car with 200 hp. Pivotal Engine.



This depiction of an opposed four chamber pivotal engine in a compact car gives a good indication of how compact size can influence the position of the engine.

However we like to dream of the 240 hp four driving the front wheels and a 360 hp six at the rear.

Of course either engine could be used, front or back until unless there was a need for four wheel drive or 600hp.

## The Flow-on Effect of High Power Density

- ☞ The weight and size of the powertrain will influence many other vehicle design criteria.
- ☞ Components from engine bay to subframe suspension, wheels and brakes are designed to house or restrain this mass.
- ☞ Reducing the mass of a vehicle reduces the total cost over the life-cycle, from manufacture right through to the eventual recycling of the materials.



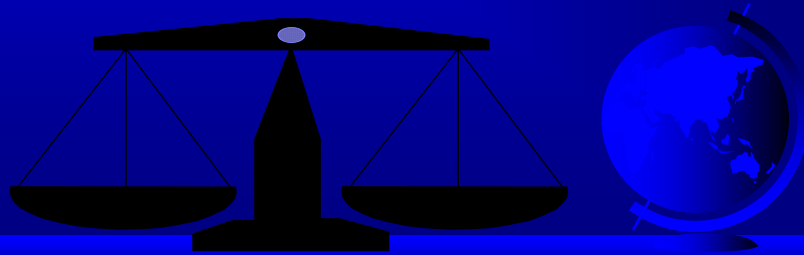
Power density is important for anything that moves.

Formula One teams know that if 10kg can be taken off the engine then 10kg more can be removed from the chassis wheels and brakes.

Size and weight of the engine dictates much in vehicle design and has a significant impact on the total cost effectiveness of a vehicle, from manufacture to operation and service and finally on to the eventual recycling of materials.

## An Automotive Comparison.

- |                            |                           |
|----------------------------|---------------------------|
| ☞ Toyota V6                | ☞ Pivotal opposed 4       |
| ☞ Three litre (183 cu. in) | ☞ Two litre (122 cu. in.) |
| ☞ Power - 220 hp.          | ☞ Power - 220 hp.         |
| ☞ Weight - 380 lb.         | ☞ Weight - 160 lb.        |
| ☞ Box size - 12 cu.ft.     | ☞ Box size - 6 cu. ft.    |



This broad comparison takes a well known automotive power unit of similar output to our current opposed four chamber engine and gives an indication of the magnitude of difference in size and weight.

In the progression to a fully developed automotive engine our pivotal engine may gain some weight. But it is at an early stage of optimization and we expect that the output and drivability will advance considerably as well.

## Prime Power Unit for Hybrid Systems.

- ☞ The IC engine is the heart of a hybrid system.
- ☞ This is an ideal application for the pivotal engine as compactness, fuel efficiency and quiet running are important.
- ☞ A wide range of fuels are envisaged for future hybrid systems - gasoline, diesel, natural gas and hydrogen.
- ☞ Hydrogen/electric, hydrogen/gasoline/electric or hydrogen/diesel/electric where compact design and the enhanced thermal control of the pivotal piston engine is of fundamental value.



Hydrogen ICE/electric hybrid systems will be utilized where ever a vehicle is predominantly used in city stop/start running.

A compact 'prime power unit' is an essential element in a hybrid system where space is at a premium.

## What Makes a Fuel Efficient Internal Combustion Engine ?

- ☞ Trapping the fuel inside the combustion chamber.
- ☞ Full and fast combustion.
- ☞ Minimal power loss through combustion quenching.
- ☞ Minimal friction and pumping losses.
- ☞ Compact and light weight power unit.



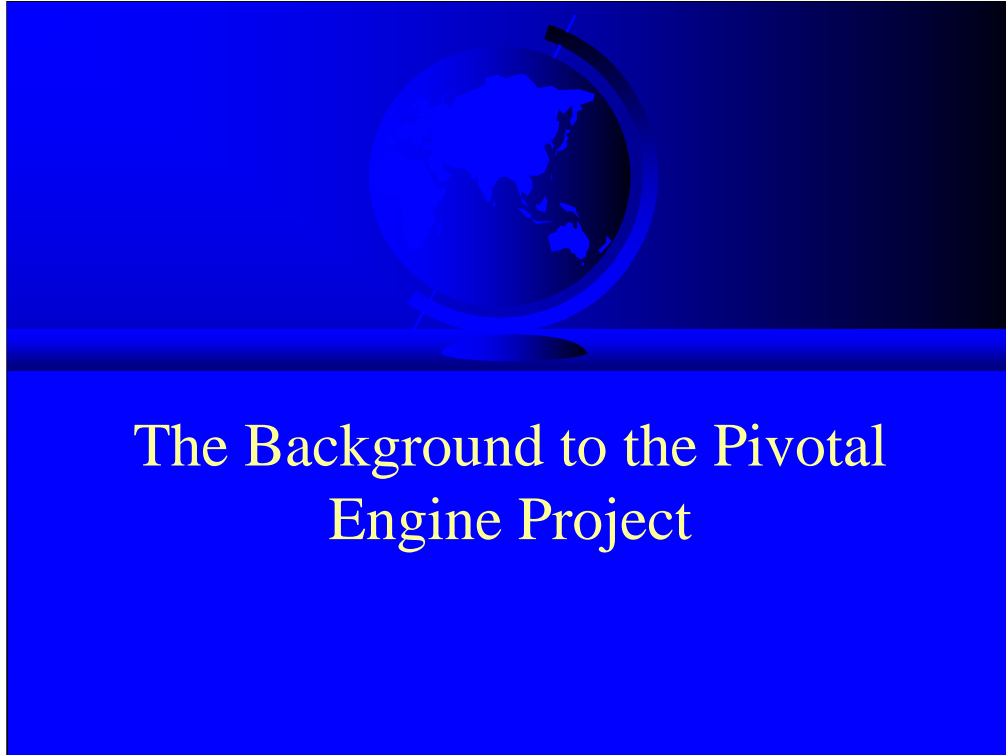
Whilst achieving high Break Specific Fuel Consumption from an internal combustion engine is complex, the objectives to be targeted for attention are relatively easy to identify.

- ☞ Fitted with direct fuel injection the water-cooled pivotal piston engine can meet all of these objectives within a single engine unit.
- ☞ The water-cooled pivotal piston technology is the key to simple ICE design and opens up new opportunities for maximizing combustion powered mobility.



A DI fuel delivery system will be an essential technology for a hydrogen engine. It will be required for good volumetric efficiency for maximum power and to deliver good fuel trapping for fuel efficiency.

Water-cooled pivotal piston technology opens new opportunities to optimize the internal combustion engine.



The development of the water-cooled pivotal piston technology has been progressing for ten years.

Early in the project we needed a way to demonstrate the technology.



We built a 400cc twin chamber engine so that we could show the potential to engine manufacturers.

After presenting this engine to some OEM companies we decided to focus development on a 500cc module.

We fitted a 400cc twin chamber engine into a motorcycle early in the project.

It performed surprisingly well, driving the motorcycle to 150 kph and running up to 11,500 rpm.

However this engine did not have internal piston water-cooling and was therefore limited in the potential to improve performance.

## One Litre Demonstration Twin.



This development lead to the building of this one litre twin chamber unit. This engine produced 100 hp at 6200 rpm.



This twin chamber engine is a development engine and one of the first engines to include internal piston water-cooling.

One hundred hp from a one litre twin was a celebrated milestone.

## The DI Engine.

- ☞ This 1100 cc twin chamber unit is fitted with Orbital direct to chamber fuel injection.
- ☞ It has not been fully calibrated but runs well using the Rotax engine ECU.



This engine was an exercise on direct fuel injection.

Although most of our development since then has been undertaken using crankcase injection we expect that almost all pivotal engine products will ultimately utilize a DI system.

## This Engine is being developed for the Experimental and Light Sport Plane markets.

### Targets

- ☛ Power 120 hp.
- ☛ Weight 120 lb.
- ☛ TBO 1000 hours
- ☛ BSFC 1/2 lb. per hp/hr.



We chose to focus product development toward high value niche market opportunities where high power density and sustained high load operation were paramount.

This Light Sport Plane engine project was initiated two years ago and has been under durability testing through 2004.

## Opposed Four Chamber 2.1 Litre Delivering 240hp Weighing 120 lb



The potential to further extend power density by building an opposed four chamber engine using the same components was hard to resist.

The engine we have on display at our booth is this 2.1 litre opposed four chamber engine.

This engine is fitted with an integrated starter / generator currently being developed by CE Niehoff of Chicago.

It adds to the compactness of the engine as well as adding some semi-hybrid features.



This engine can deliver 170 kW @ 6,500 rpm on gasoline. We calculate that if direct injected with hydrogen fuel at an equivalency ration of .6 the output would be 120 kW.

This represents 1.8 kW per kg of engine weight which is considerably better than the best of current gasoline automotive engines.


The Change to Hydrogen Fuel  
Demands that a Specifically Designed  
H2ICE is Developed to meet  
Independent Transportation  
Requirements.



A significant improvement in vehicle efficiency through the development of an advanced hydrogen IC engine design will impact on the numbers of H2ICE powered vehicles in the future.

The development of a suitable ICE design for hydrogen fuel is still to be undertaken and so the full potential to harness hydrogen combustion for mobility is as yet unknown.

Converting current four-stroke automotive engines to operate on hydrogen does not provide us with a bench mark upon which hydrogen IC engine potential can be measured.



‘Total Vehicle Efficiency’ is What  
Will Drive The Selection of Future  
Power Units.

The IC engine that offers high power density with low mechanical complexity and good thermal efficiency with minimal emissions will win the hydrogen race.

The Hydrogen Internal Combustion Engine has a long way to go. But on the bright side it could be relatively cheap to explore and the outcome better than currently envisaged.

It is our hope that we will be back at this conference in 2007 with a hydrogen powered car that is truly exciting to drive.

We are keen to talk to any organization or OEM that would like to work alongside us in this endeavour.