



RCV Engine

Technical Analysis and Real World Benefits

IMechE Conference

Internal Combustion Engines: Improving Performance, Fuel Economy and Emissions

29 November 2011

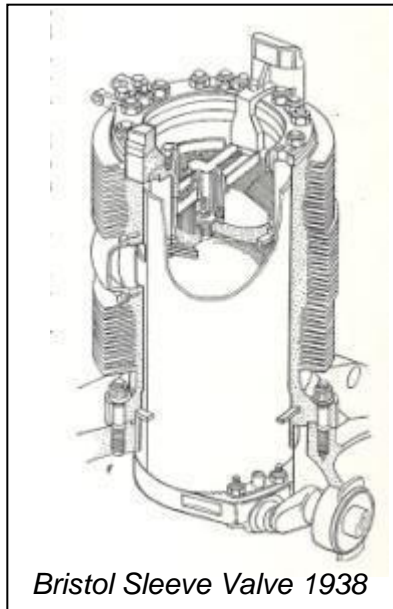
K T Lawes and Dr B R Mason

The RCV engine – Technical analysis and real world benefits

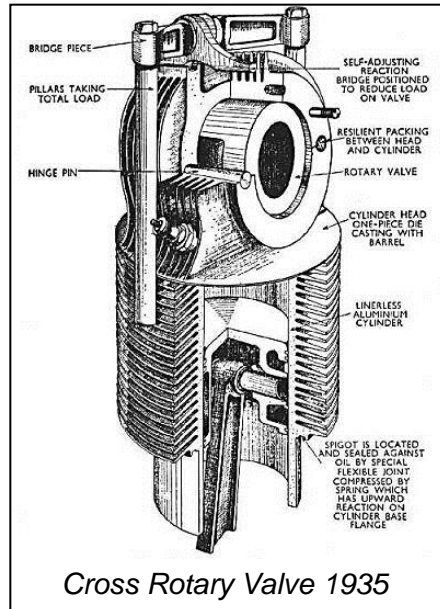


- Introduction
 - Rotary Valve Engines
 - Functional requirements
 - Small engine applications
- RCV technology
 - RCV concept
 - Valve sealing
 - Valve layouts
- RCV Applications
 - SP series model aircraft engine
 - HRCV 35 utility engine
 - VRCV70 heavy fuel UAV engine

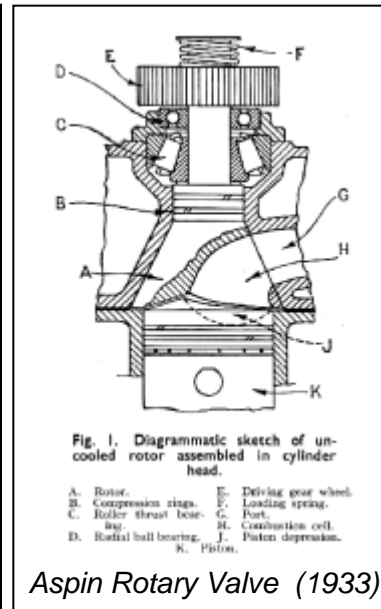
Sleeve and Rotary Valve Engines



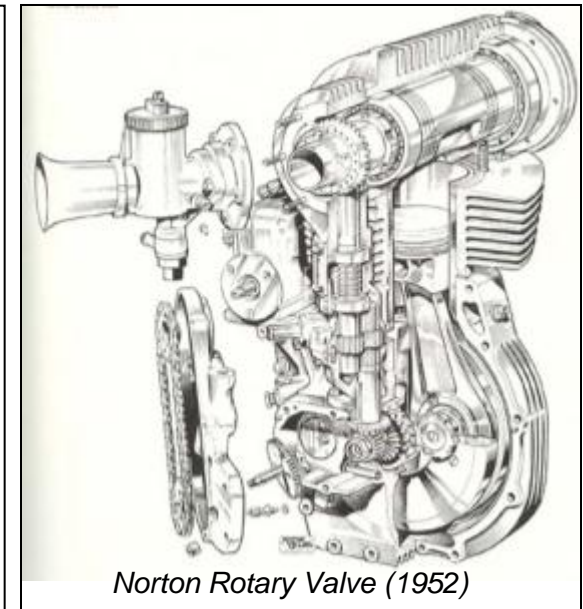
Bristol Sleeve Valve 1938



Cross Rotary Valve 1935



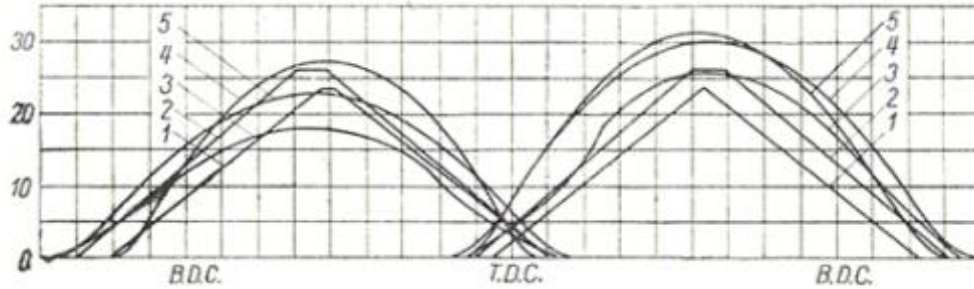
Aspin Rotary Valve (1933)



Norton Rotary Valve (1952)

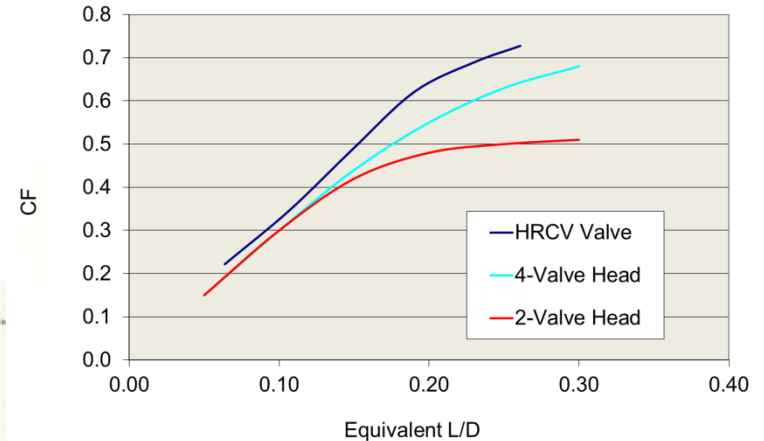
- Sleeve and rotary valve engines have been developed since the 1920's
- Early poppet valve engines were sensitive to detonation and unreliable at the time sleeve/rotary valves offered a solution
- Sleeve valves were successfully used in aircraft engines using specialist materials and precision components.
- Motorcycle and automotive examples with lower cost rotary valve concepts had limited success, offering marginal benefits.

Comparison of Valve Open Area as % of Bore Area



Comparison of rotary- and sleeve-valve gear with poppet-valve gear.
Rate of port openings given as percentage of piston crown area
1 — Aspin 250 cm³, bore/stroke 67/70 mm; 2 — Cross 250 cm³, 62/82 mm;
3 — Napier Sabre, 127/120.6 mm; 4 — Mercedes Benz, four-valve, 66/70 mm;
5 — Mercedes Benz, two-valve, hemispherical cylinder head, 55/52.5 mm

Comparison of Flow Coefficient 56Ø Bore



- A perceived advantage with rotary valves is of increased valve area although this is limited by design considerations and offers no real advantage over the poppet valve taking into consideration valve opening rate
 - Open area can be larger but this reduces compression ratio
 - Opening rate is controlled by port height and valve diameter
- Advantages compared to a poppet valve system come from
 - Significantly improved flow performance
 - No valve springs and associated dynamic issues
 - No maintenance requirements – clearances to adjust
 - No valve to piston clearance issues giving high speed potential

Adoption of a New Engine Technology



- The Technology Concept has to
 - Consider cost of production
 - Achieve threshold performance
 - Be reliability and robust
 - Have no detrimental attributes

.....work.

- It has to offer real Product Benefits in one or more attributes
 - Power / Weight / Cost
 - Fuel type
 - NVH

.....to enable a better product.

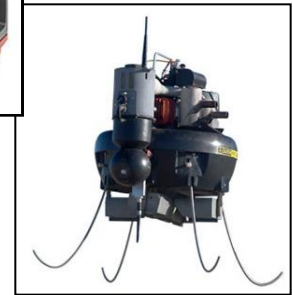
- Be available at the right time
 - When a there is a change in requirements or regulations

.....to be incorporated in product development cycles.

New Technology Demands for Small Engines



- Products using Small Engines have typically used air-cooled 2 strokes
 - Low cost and powerful
 - But with high HC emissions and fuel consumption
- New Technology Demands
 - Motorcycles
 - Noise and exhaust emissions regulations
 - Military generator sets and UAV applications
 - Heavy fuel operation – JP8
 - Hand-held garden tools
 - Exhaust emissions regulations

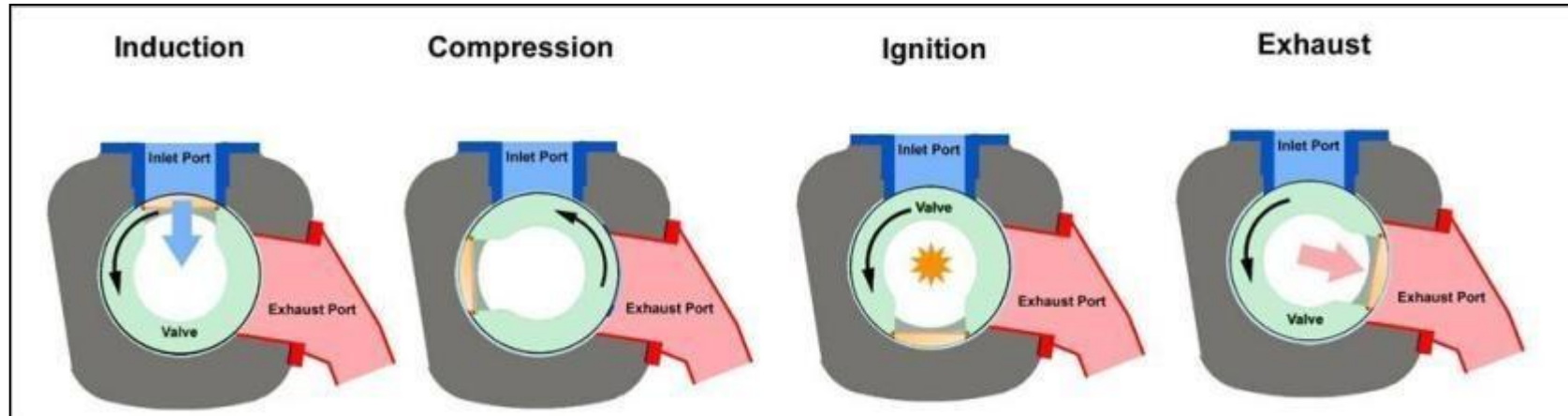


The RCV engine – Technical analysis and real world benefits



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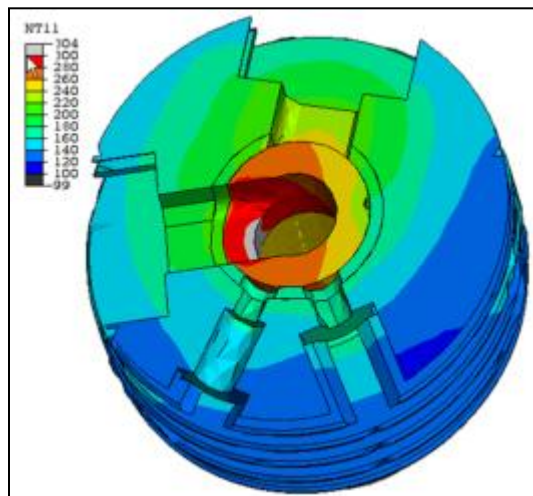
RCV 4-stroke cycle



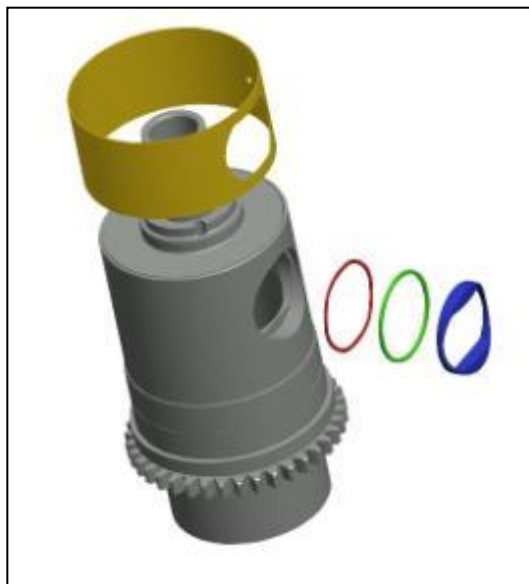
- The RCV concept is based on a 4-stroke cycle using a cylindrical rotating valve to control the gas exchange process
- Unique features of RCV concept are:
 - Engines can be smaller and more compact compared to standard 4-strokes
 - Simple construction with fewer components
 - Low fuel consumption and emissions (CO₂) compared to 2-strokes
 - Multi-fuel capability; methanol, gasoline, kerosene and even diesel
 - High performance operation on kerosene (100hp/litre)
 - No reciprocating valve train – high speed operation possible

Rotary Valve Challenges

RCV Plain Valve

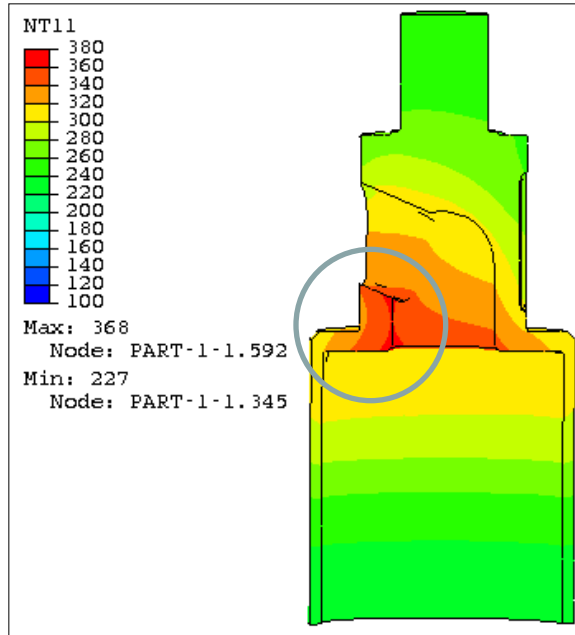


RCV Active Valve



- Principal challenges
 - Valve sealing and durability
 - Thermal stability and deposit control with JP8
 - Low cost drive system design
- Plain tolerance controlled valves
 - Allow simple construction
 - Size limited due to valve grip
- Active valves
 - Increase cost and complexity
 - Allow larger diameter valve use
 - Work with cylinder pressure

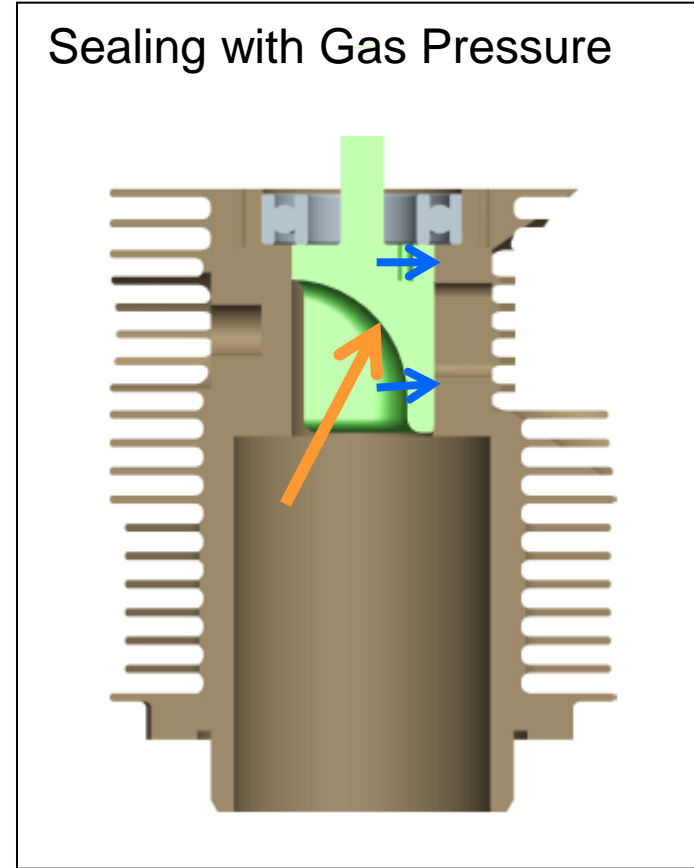
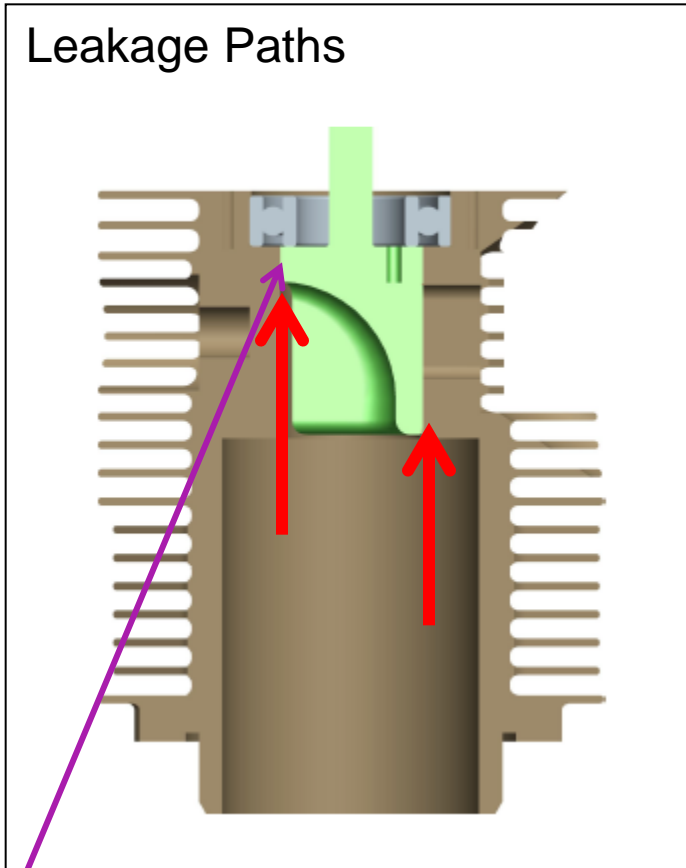
FEA of Rotating Cylinder Valve



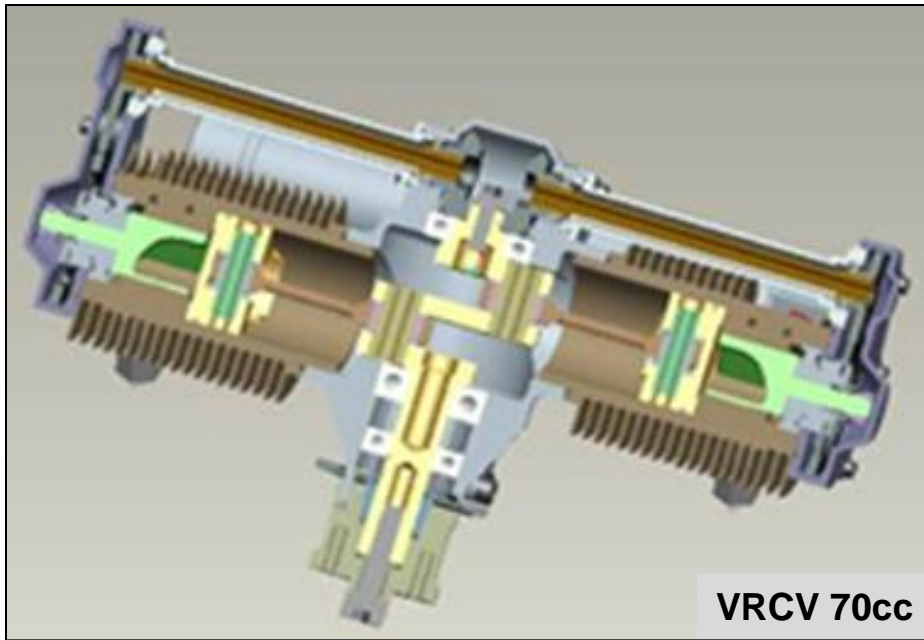
Cutaway Valve



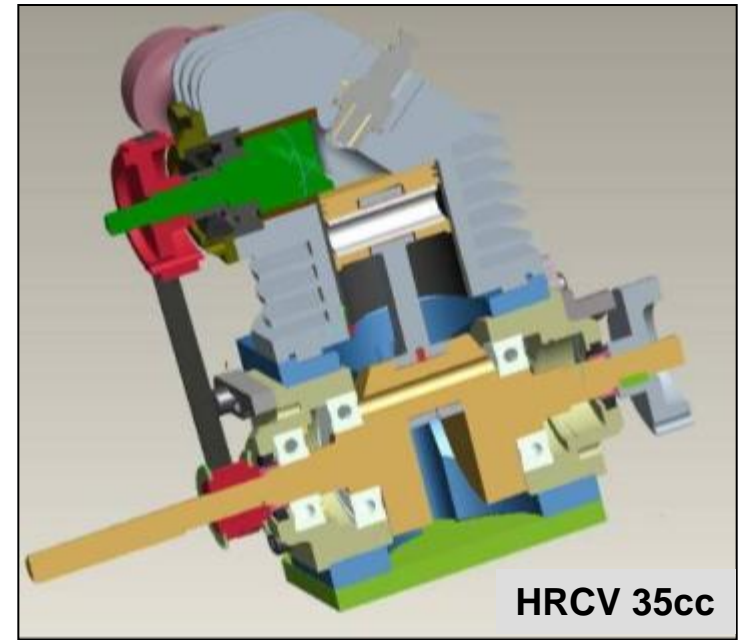
- Developments to improve cooling performance lead to several changes to the original “Rotating Cylinder Valve” concept
 - Non-rotating cylinder allowing conventional piston/cylinder cooling.
 - Use of a Nicosil coated Aluminium housing with steel expansion control rings - controls the operating clearance.
 - Removal of the lower rim of the valve to eliminate material exposed to hot gasses and with poor conduction paths – reduces valve distortion
- Sealing is achieved as the valve is allowed to float radially
 - Semi active valve seals inlet and exhaust ports with combustion pressure
- With engines upto 35cc the valve is now a fit and forget component.



Leakage limited by clearance control using an expansion control ring



- VRCV - Vertical rotating valve
- Developed for UAV's
- Power upto 75 kW/litre
- Requires complex valve drive system



- HRCV - Horizontal rotating valve
- Developed for handheld power tools
- Power upto 55 kW/litre
- Simple low cost valve drive system

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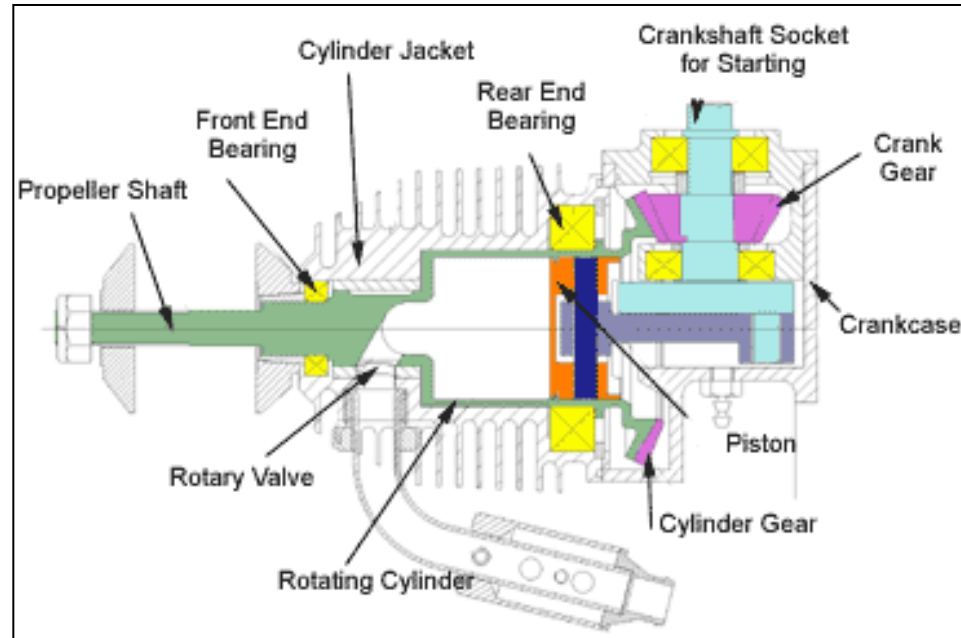


RCV SP Rotating Cylinder Valve Engine

RCV – SP Rotating Cylinder Valve Engine



RCV SP Model Aircraft Engine



- Engine based on a rotating cylinder geared at $\frac{1}{2}$ crankshaft speed
 - Can incorporate the output drive
 - Incorporates a rotary valve
 - Rotating cylinder is the valve drive system

SP Series Model Aircraft Engine



- The SP is a unique engine providing modellers with a number of benefits
 - Compact layout
 - 2:1 gearing on the propeller drive permits larger propellers in scale with the aircraft
 - Access to the crank for starting behind the propeller
- RCV SP and CD model aircraft engines have been in production for more than 12 years with 15,000 engines sold worldwide





HRCV 35 Handheld Power Tool Engine



- Hand-held power tools are subject to exhaust emissions regulations this has resulted in stratified charge 2-strokes and 4-strokes to be developed.
- The new 4-strokes are heavy and have limited over-speed potential – the maximum rpm has to be limited to avoid engine failure. Products with these engines are not as good as the original 2-strokes.
- The stratified charge 2-stroke engines present a marginal emissions solution. Depending on the engine may require a catalyst for emissions compliance – a fire risk for chainsaws.

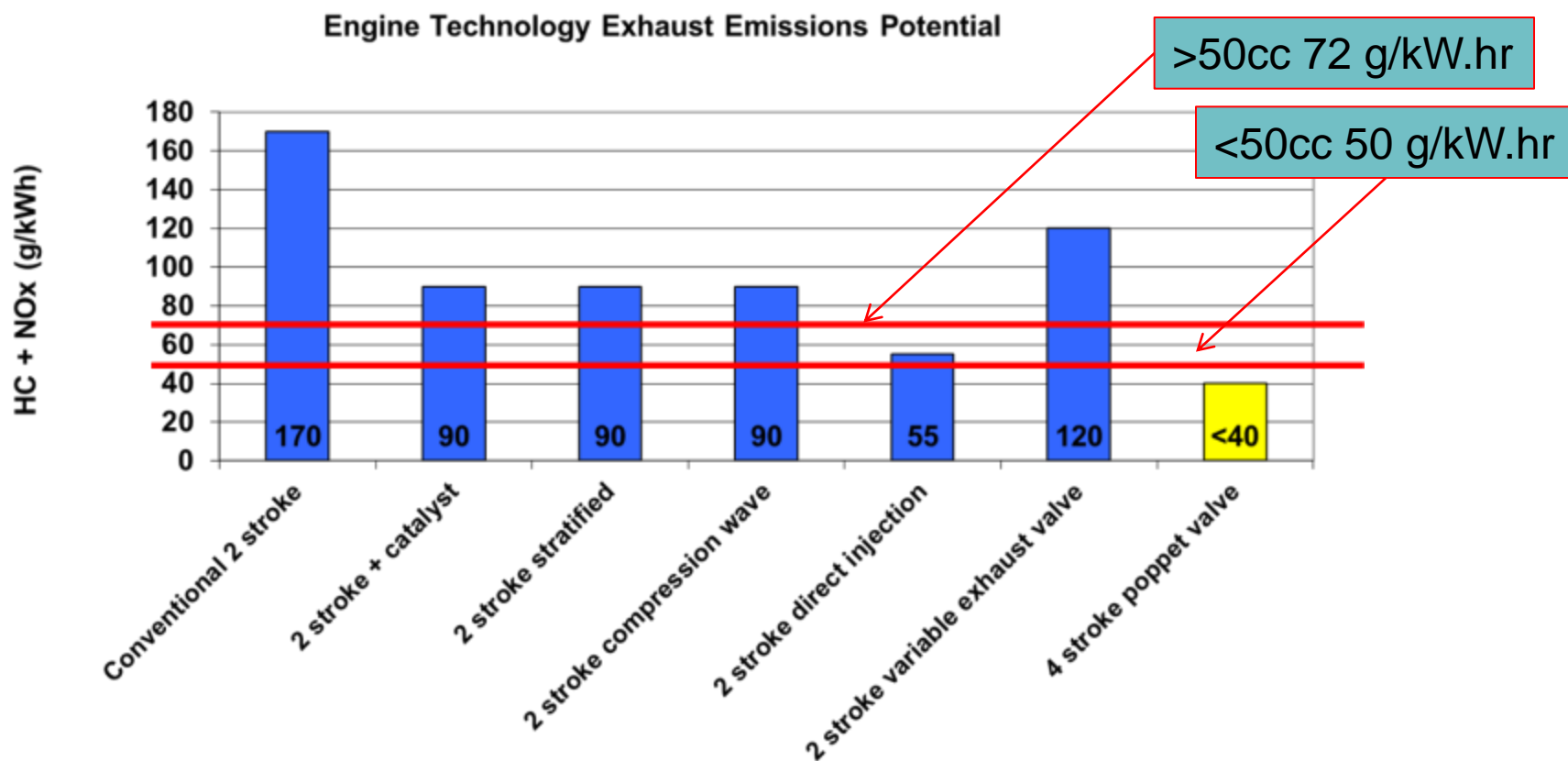
Comparison of Technology to EU2 and EPA2 Limits

Source; SAE 2000-01-0896

Low Emission Technologies for High-Performance Handheld Outdoor products

Limits introduced from 2005 to 2008. Top handle hedge trimmers and chainsaws do not meet this legislation and are exempt in EU until August 2013. The EPA has the ABT Program “Averaging, Banking and Trading” that allows a similar get out for chainsaws.

Although the 4-stroke is capable of meeting EU2 and EPA2 limits, the poppet valve 4-stroke is unsuitable for handheld applications due to: weight, low power, and high engine speed capability.



Requirements for Hand-held Utility Engines



Feature	Requirement	Consideration
Fuel	Gasoline	Variable amounts of Ethanol in fuel
Power	1 to 3 kW (>30 kW/litre)	Capable of high rpm (>13000 rpm)
Weight	Minimise	Close to basic 2-stroke
Starting	-20° to 40° C	Easy rope start with minimum pulls
BSFC	Not yet considered	Better than a basic 2-stroke
Emissions	EU2	Catalyst creates a hazard
Production	High volume low cost	Cost/quality
Cooling	Air	Minimum weight
Other	Multi-position operation	Lubrication system

HRCV 35 Handheld Engine



Proof of Concept



In-Product Prototype



Demonstrator



- HRCV35 prototype 35cc engine has been installed in a Honda GX35 line trimmer
- Lubrication is by 50:1 oil in fuel mix with blow-by lubrication of the crank-train
- Current piston results in a compression ratio of 6.5:1
- Pull starting is very easy – the rotary valve mechanically mixing the fuel/air mixture giving an instant start
- Inlet and exhaust ports are straight so feasible for die casting
- The RCV engine features a unique balancer for low vibration
- The engine concept and features are protected by patents – copying is a significant industry problem

Comparative Performance

- In critical performance parameters power, exhaust emissions and fuel consumption the RCV demonstrator is better than other similar sized handheld engines
- High rpm potential, is as good as a 2-stroke but with half the fuel consumption
- Back to back emissions testing against a Stihl 31cc 4-stroke shows better NOx and HC emissions indicating EU2 capability
- Performance simulation at 9.5:1 compression ratio indicates similar fuel consumption to the Stihl engine with increase in specific power to 55 kW/litre

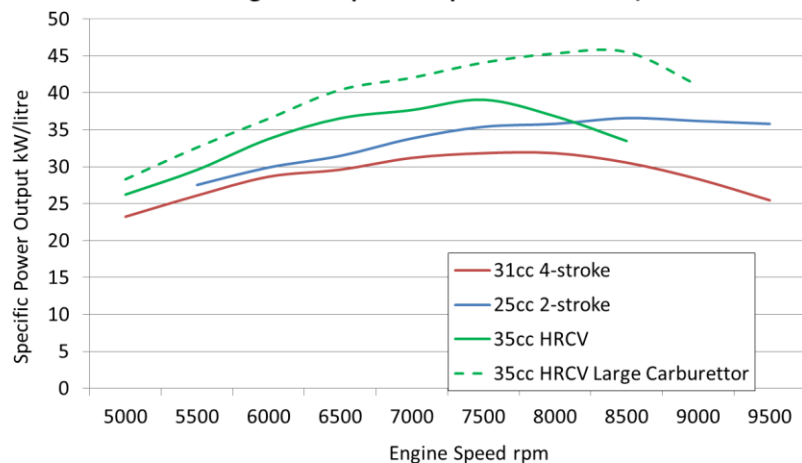
Performance Comparison

Engine	RCV 35cc	Stihl 31cc 4Mix	Honda GX35	Stihl 36cc 4Mix	Stihl 38cc Strat 2-T
Power kW	1.7	1.2	1.2	1.4	1.7
Sp.power kW/L	48.6	38.7	34.3	38.9	44.7
Max speed rpm	>12000	<9500	<8500	<9500	>12000

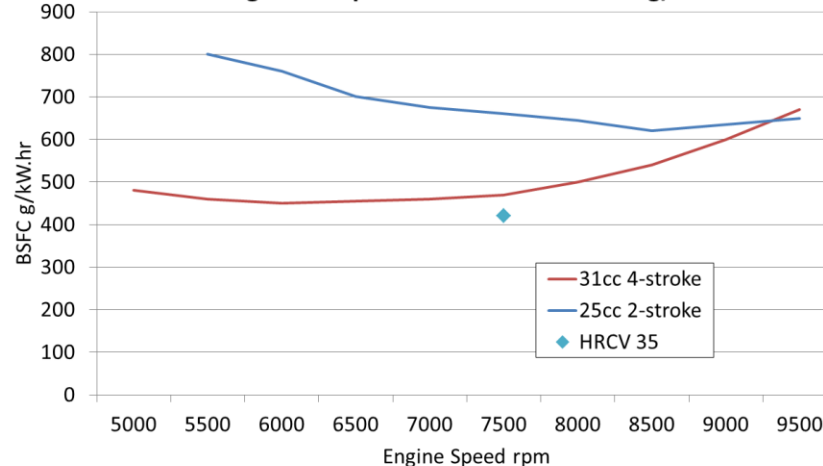
Emissions Comparison

Engine	RCV HRCV 35cc	Stihl 31cc 4Mix	Typical 26cc 2 stroke
Power kW	1.7	1.2	0.8
HC at WOT ppm	250-350	300-450	(3000)
NOx at WOT ppm	200-700	600-1200	(100)
HC at idle ppm	250-350	400-600	
WOT fuel consumption g/kWhr	390-440	360-380	700

HRCV Engine Comparison Specific Power kW/litre

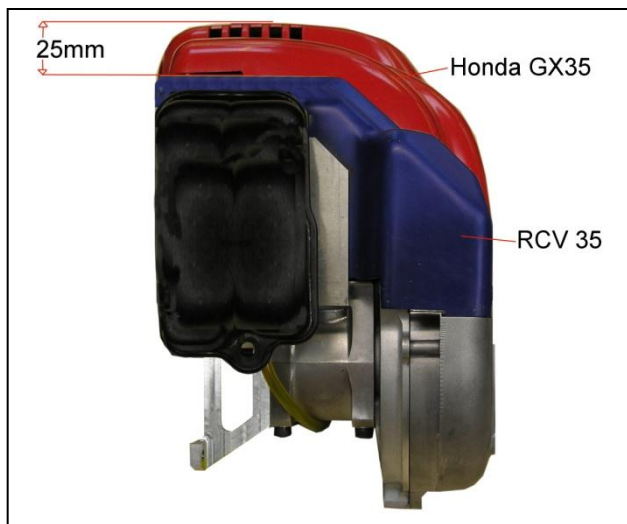


F&G Engine Comparison of Full Load BSFC g/kW.hr

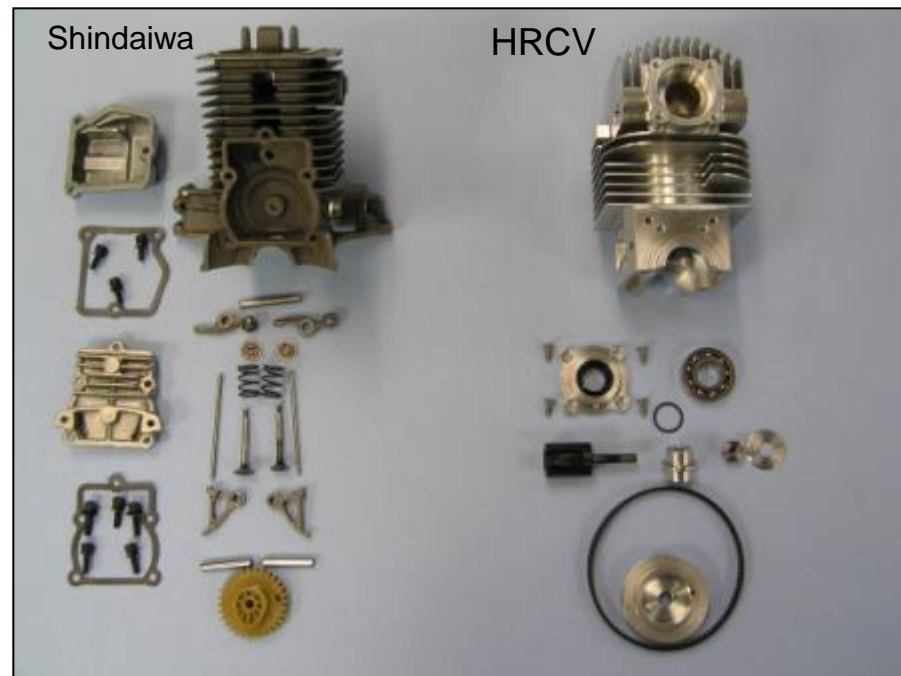


- The HRCV 35 has been evaluated with using carburettors sourced from existing production engines – these are diaphragm type which are activated with cylinder pressure fluctuations
- The “35cc HRCV” build uses a 4-stroke carburettor, which is undersized for the engine. The “35cc HRCV Large Carburettor” build is with a 2 stroke carburettor not well calibrated for transient operation – but shows the potential of the engine
- The 35cc HRCV has 2-stroke levels of performance with 4-stroke levels of fuel consumption

Comparisons

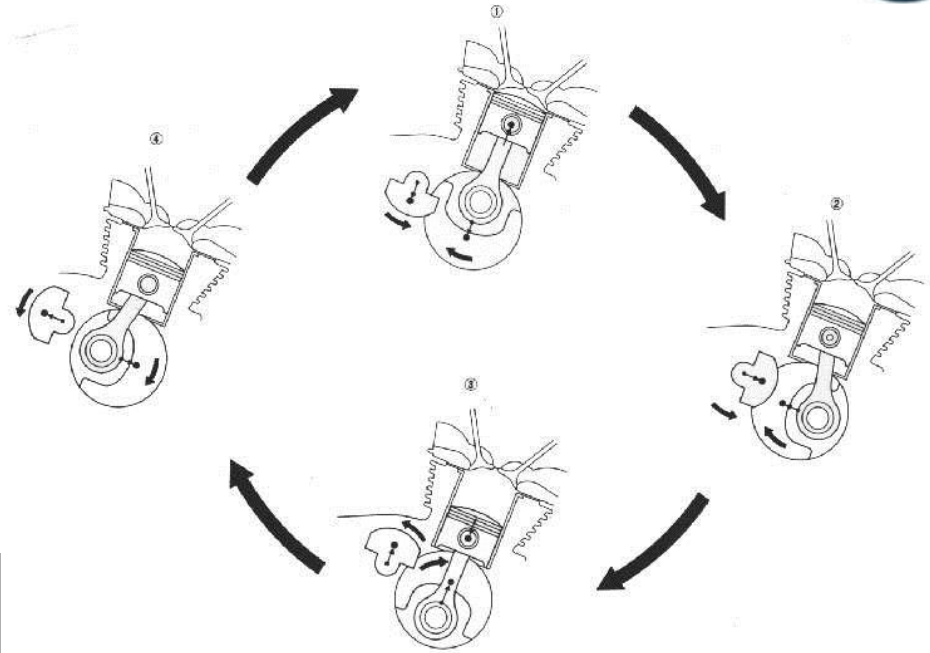
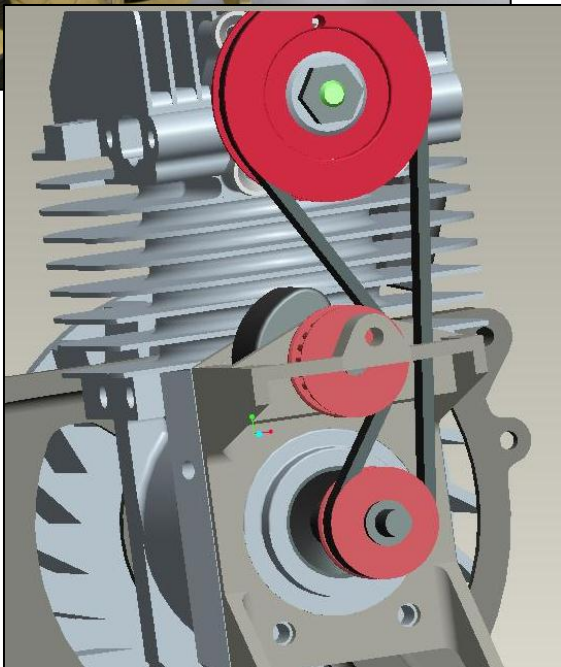
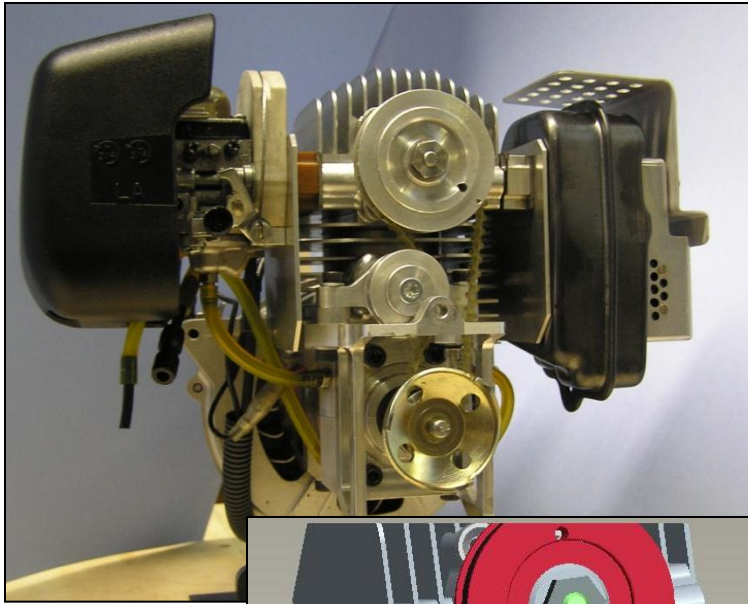


RCV HRCV35 Demonstrator and Honda GX35 showing that the RCV has a lower height and is more compact.



RCV HRCV35 Demonstrator and Shindaiwa 4-Stroke showing that the RCV has less parts.

Balancer for Low Vibration Version



- The HRCV can include a single axis balancer to reduce vibration
- Vibration is a big issue for professional products
- The system uses a double sided tooth belt to achieve a counter rotating drive
- The system is included in the HRCV Engine features patent

RCV's Competitive Position – Hand-held Utility Engines



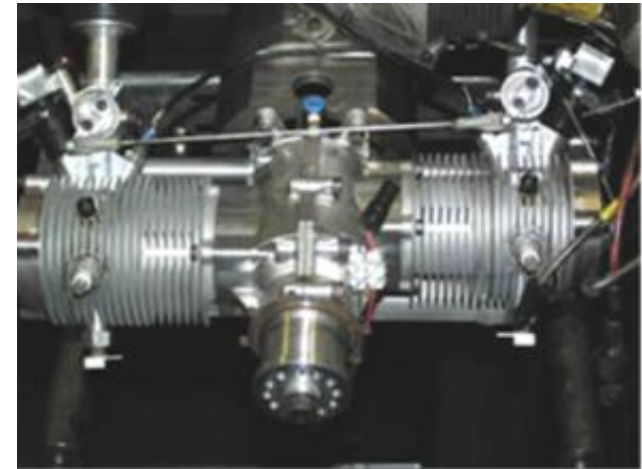
- A standard 2-stroke can not meet emissions regulations
- Stratified charge 2-strokes require a catalyst for emissions compliance
- A direct injection 2-stroke can meet regulations but with a cost and weight penalty
- The poppet valve mini 4-stroke does not have the high rpm potential
- Considering a number of attributes the HRCV engine shows potential

ENGINE TECHNOLOGY	High rpm	Specific Power	Weight	Fuel Consumption	No Catalyst	Emissions	Starting
2 stroke – with Catalyst	✓	✓	✓	X	✓	X	✓
2 stroke – stratified charge	✓	✓	✓	✓	✓	X	✓
2 stroke – stratified charge with catalyst	✓	✓	✓	✓	X	✓	✓
2 stroke – direct injection	✓	✓	X	✓	✓	✓	?
4 stroke - poppet valve	X	X	X	✓	✓	✓	X
4 stroke – HRCV	✓	✓	✓	✓	✓	✓	✓



VRCV 70 Unmanned Air Vehicle Engine

- The U.S. Department of Defence (DOD) has set out a single fuel policy – to use the kerosene based heavy fuel JP8 for improved logistics and reduced hazard (gasoline storage)
- Current small gasoline engines do not operate on heavy fuel due to issues with difficult starting, detonation and carbonisation.
- The RCV combustion system has been developed over several years and works consistently well on JP8 heavy fuel – the engine can also operate on both diesel and gasoline – providing a unique capability

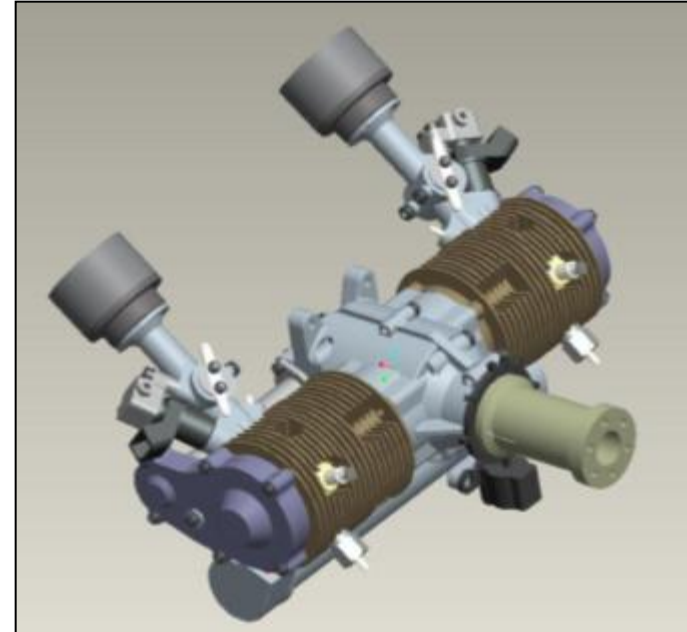
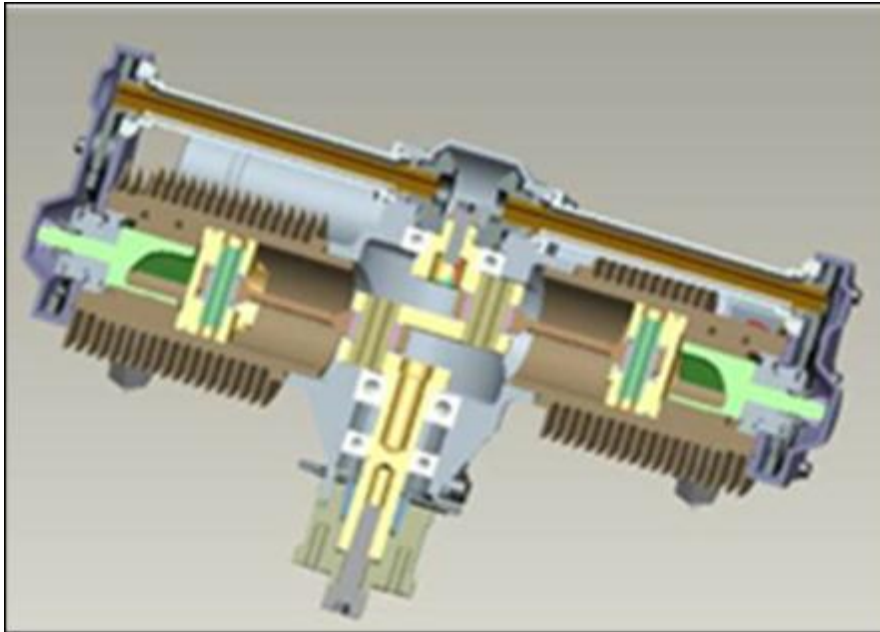


Requirements for Small UAV Engines

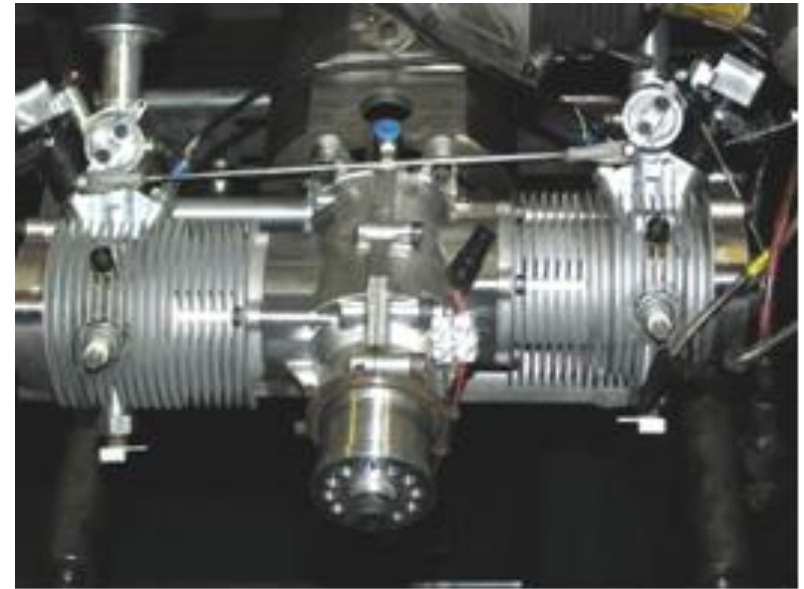
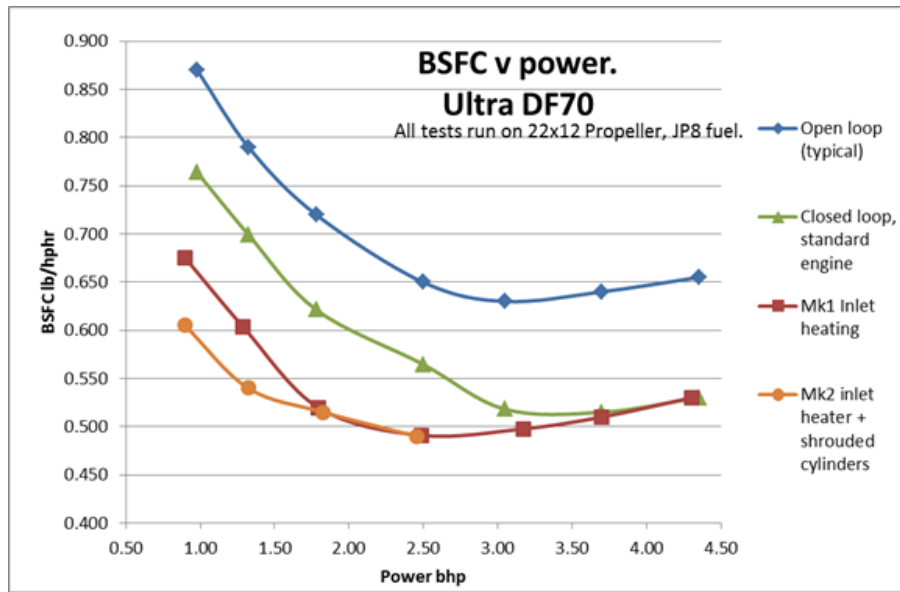


Feature	Requirement	Consideration
Fuel	JP5, JP8	JP8 has variable octane rating
Power	2 to 5 kW	Typical for mini UAV
Weight	1 hp/lb (0.34 kW/kg)	Maximum take off weight with fuel
Starting	-20° to 40° C	Start in <45 seconds
BSFC	<0.5 lb/hp.hr (309 g/kW.hr)	Effects take off weight and range
Emissions	None	
Production	Low Volume	Aerospace manufacturing standards
Cooling	Air	Minimum weight and altitude operation
Other	Altitude 10,000ft	Altitude fuelling compensation required

VRCV 70 UAV Engine



- VRCV 70 heavy fuel engine developed for UAV applications
- Twin cylinder fuel injected engine with heaters used for cold starting
- The vertical rotary valves are driven by a gear drive system
- The engine produces 4.1kW on JP8 and weighs 2.7Kg (0.94 hp/lb)
- CAE used to optimise cooling and engine weight
- The engine has been successfully flight tested in fixed wing, vertical take off fan and helicopter UAVs



- Initial development objectives for 1 hp/lb power to weight for a vertical take off ducted fan UAV – current engine achieves 0.94 hp/lb with ECU, fuel and exhaust systems
- Testing n-Heptane to assess low octane tolerance – as with other rotary valve engines – the combustion system tolerates low octane fuels
- Fuel efficient engine build for ultra endurance fixed wing UAVs achieves <0.5lb/hp.hr with closed loop fuelling control, exhaust heated inlets and controlled cylinder temperatures
- The engine also runs on Diesel fuel although with a 5-10% power penalty – specific diesel development is now in progress

RCV's Competitive Position - UAV 4 kW Heavy Fuel Engines



- Existing 2-stroke and 4-stroke engines derived from hobby or handheld applications do not operate on JP8 without modification
- Other 2-strokes have to use bulky fuelling systems resulting in unfavorable power to weight for a 2 to 4 kW engine and/or are sensitive to fuel octane rating
- The small Wankel engine has unfavorable fuel consumption and has detonation sensitive combustion system
- Considering a number of attributes the VRCV engine offers significant potential

ENGINE TECHNOLOGY	Specific Power Output	Power to Weight	Fuel Consumption	Gasoline	Kerosene (JP8)
2 stroke – derived from hobby or garden tool engine	✓	✓	X	✓	X
4 stroke – derived from garden tool engine	X	X	✓	✓	X
2 stroke diesel	X	X	✓	X	✓
2 stroke with controlled auto ignition	✓	✓	✓	✓	✓
2 stroke with direct fuel injection	✓	X	✓	✓	✓
4 stroke with rotary valve (RCV)	✓	✓	✓	✓	✓
Rotary Wankel	✓	✓	X	✓	✓



- RCV have evolved a simple yet effective rotary valve that has been successfully implemented on engine applications up to 35cc/cylinder
- The SP model aircraft engine provides model aircraft builders a compact engine with geared propeller drive allowing in scale propellers
- The HRCV 35 engine demonstrates significant potential for handheld power tools with high power and compact dimensions together with an over-speed capability that mini 4-strokes do not have
- The VRCV 70 heavy fuel engine for UAVs has excellent power to weight, competitive fuel consumption and a multi-fuel capability