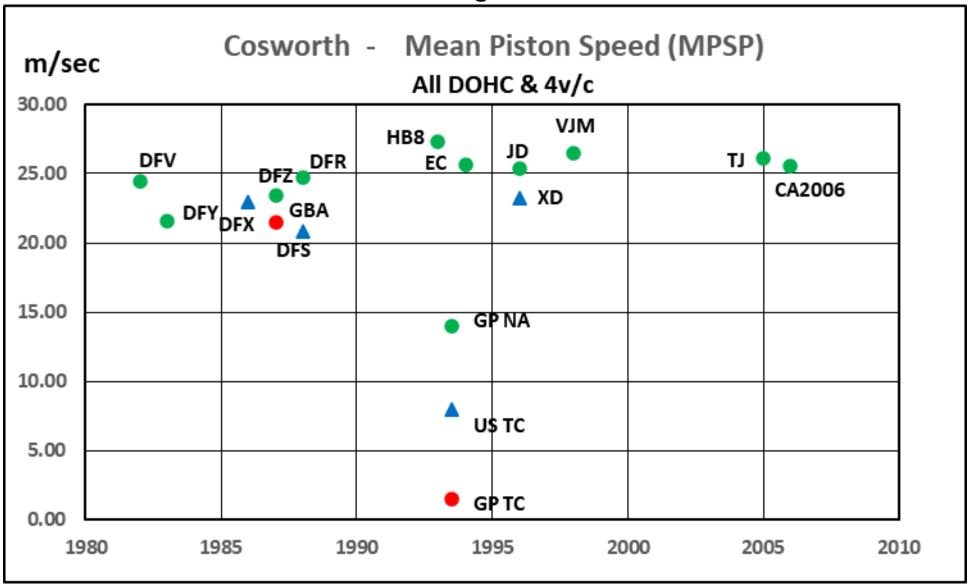
Note 143 COSWORTH Bore/Stroke ratios, 1967 – 2006

Figures for the Bore (B), Stroke (S) and Peak-power RPM (NP) of the Cosworth racing engines made between 1982 (when the 1967 DFV as developed last powered the Drivers' Champion) and the 2006 CA (the last Grand Prix unit before the FIA imposed RPM limits) have been used as further illustrations of the Mechanical Speed Limits for 4-stroke piston engines described in Note 13.

Where a series of similar engines was involved, only the fully-developed rating is plotted on Fig. 1. The engines for the various US open-wheeled formulae are taken up to 1996, after which RPM limits were imposed there. F2, Tasman, Sports-Racing engines and Formula 3000 units (RPM limited) are not considered (but data are given in Appendix A on P.5). Data is not available for the V10 engines built between 1999 and 2002 (i.e., CK, VK and LK, aka CR series).

Mean Piston Speed at Peak Power (MPSP)

Fig. 1



Data are given in Appendix A on P.5.

The theory behind MPSP is given in Part 1 of Note 13. Note 13 Part 1 Sub-note A addition and Note 13 Part 2 describe the limit set by piston-ring flutter and how this was overcome.

The engines in Fig. 1 were all made with pistons of Al-alloy RR58 processed in various ways and therefore it is not surprising that the value of MPSP was fairly constant over 25 years. The average was just over 24 m/s, the "outliers" being the 1993 HB8 at 27.3 and the 1988 DFS at 20.8. The 1994 EC was tried in development with Mg-alloy but did not have sufficient life. Cosworth never made pistons with the 62% Aluminium-38% Beryllium alloy used by Ilmor in 1998 – 2000 before it was banned by the FIA on cost and toxicity grounds.

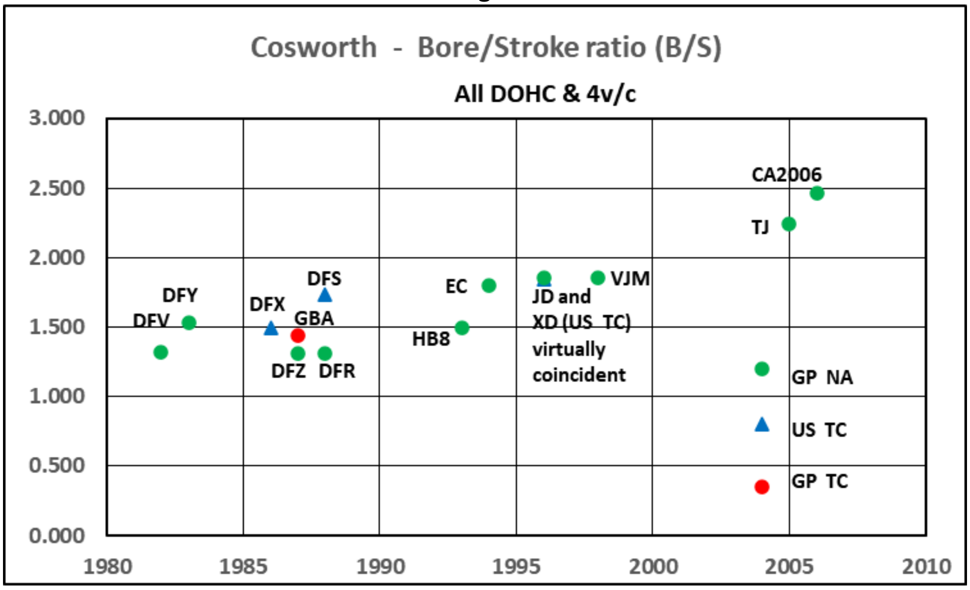
Bore/Stroke (B/S) ratio

In "The General Design of Racing Piston Engines" at P.3 it is shown that, when Brake Mean Effective Pressure (BMPP at Peak Power PP) is limited by rules on Fuel or any Pressure-Charging, at best practice regarding Volumetric, Combustion and Mechanical Efficiencies and when MPSP is near enough constant, then

Volume Specific Power (PP/V) is proportional to 1/S.

With Volume set by regulation and the Number of Cylinders chosen, this means raising B/S ratio to raise power. Fig. 2 on P.2 shows how Cosworth B/S ratios varied over 1982 to 2006. The Grand Prix engines rose from 1.32 (DFV) to 2.46 (CA), after which the FIA imposed restrictions. The US engines rose from 1.42 (DFX) to 1.85 (XD).

Fig.2

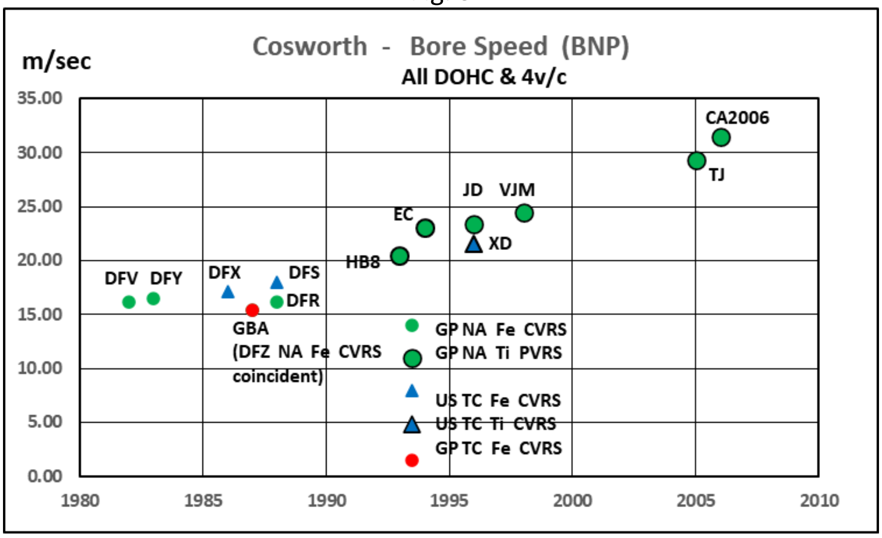


Bore Speed at Peak power (BNP) (Surrogate for Mean Valve Speed)

In order to raise Bore/Stroke ratio for engines which had steel Coil-spring Valve Return Systems (CVRS), which set a limit to the Mean Valve Speed, as discussed in Note 13 Part 3, it was necessary to adopt new valve materials or another way of returning the valves. The first design method of raising RPM at given CVRS limit, by shortening Inlet Valve Lift (IVL) via adopting 4 valves per cylinder (4 v/c) was already a basic part of Cosworth design since 1966 (the *earliest* method, of using Double Overhead Camshafts (DOHC), to reduce the mass controlled by the spring, had, of course, been standard practice for most designers since Ernest Henri's 1912 Peugeot). The second method was to use Ti-alloy to lighten all valves and this was applied to the HB series in 1989. The third method was to change to the Pneumatic Valve Return System (PVRS) invented by J-P Boudy for Renault in 1984, and this was incorporated in the HB in late 1992 (see 3rd Naturally-Aspirated Era (3NA) Part 1 at P.17). All subsequent Cosworth Grand Prix engines used this valve operating system. With experience and development, which must have involved higher valve-cylinder pressures, ever higher BNP – surrogate for Mean Valve Speed - could be achieved, as shown on Fig.3 below and B/S raised as shown on Fig. 2 above for ever-higher power.

(For full details of valve gear development see Note 15.)

Fig. 3



Mean Valve Speed at Peak power (MVSP)

Where Inlet-valve Open Duration (IOD),and Inlet Valve maximum Lift (IVL) (both on-off cam) are known, Mean Valve Speed (MVSP) is defined as:-

$$MVSP = \frac{\text{IVL mm x NP RPM}}{\text{83.333 x IOD crank degrees}} \text{ m/sec}$$ (Line 97 in Appendix 1)

The "valving" details are known for the DFV and the CA but not for other Cosworth engines in the charts. It is reasonable to assume that the DFV non-dimensional numbers apply to them also:-

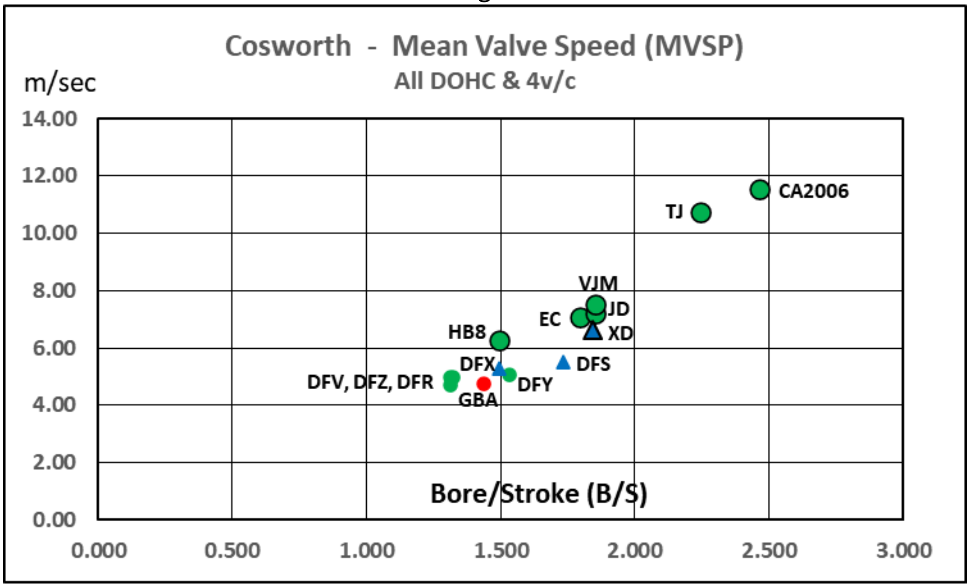
IOD = 320 degrees; IVL/(Inlet Valve Diameter, IVD) = 0.339;

Inlet Valve Area (IVA)/Piston Area (PA) = 0.324.

With these assumptions, MVSP/BNP = 0.307.

This relation has been used to provide Fig. 4. (the CA uses its slightly larger valving numbers and the TJ assumes the same).

Fig.4



US engines

Having begun in the US with CVRS in the DFX Turbo-Charged engine, their regulatory authorities decided that the later PVRS was too complex/costly for their formulae, so it is not permitted. By accepting Ti-alloy valves, however, (a valve material actually pioneered in the States for NASCAR engines originally) the level of CVRS in the XD of 1996 did reach that of the earliest PVRS, as can be seen. Some details of how CVRS levels are achieved in the XD can be found in the website "http://lolachampcars.com", particularly in "XD Refresh".

Increase in Volume Specific Peak Power, 1967 – 2006

The increase in Naturally-Aspirated Volume Specific Power over the 40 years 1967 to 2006 was as follows:-_

Year	Type	Con.fig. & B/S	PP HP/V Litres	
1967	DFV	90V8 1.323	405/2.987 = 135.6	Datum
1982	DFV	90V8 1.323	515/2.987 = 172.4	+27%
1994	EC	75V8 1.796	730/3.499 = 208.6	+54%
2006	CA	90V8 2.465	755/2.399 = 314.7	+132%

The improvement in Power/Weight ratio was:_

1967 DFV 405/162 Kg = 2.50 HP/Kg; 2006 CA 755/(95 by rule) = 7.95 HP/Kg x3.18

An illustration of the CA valve gear cf. the DFV is shown on P.4.

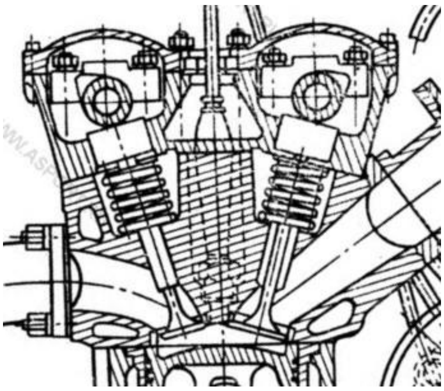
2006 Cosworth CA PVRS valve gear

racecarengineering.com

90V8 98 mm/39.75 = 1.465 2,399 cc.
DOHC. 4 v/c.
The Valve Included Angle (VIA) is 20 degrees (the 4-cylinder banks are at 45 degrees to the vertical).

Note the hollowed-out cams to save weight and the finger-followers. It can be assumed that these, and the caps over the valve stems, were given Diamond-Like Coating (DLC) (see Note 103).
Further details of the type CA engine are given in Appendix 1 at SO25 and in Note 108.

1967 Cosworth DFV CVRS valve gear



carthrottle.com

90V8 3.373''/2.55'' [85.6742 mm/64.77]= 1.323 2,987 cc
DOHC. 4v/c.
VIA = 32 degrees.
Woods-type piston tappets above valves.
Inlet ports angled, in conjunction with 54 degrees downdraft, to give "Barrel Turbulence" (aka "Tumble Swirl") – Keith Duckworth's secret weapon!
(The drawing, probably deliberately, does not truly represent the non-orthogonality of the inlet port. KD kept his secret for some years! Nor does it show the true 160 degrees (320 crank) opening duration of the cams)

"The Unique Cosworth Story", Appendix 1, Notes 75, 75B, 84, 85, 88 and in CORRECTIONS & ADDITIONS at PP 18, 30,and 40 and also in CORRECTIONS & ADDITIONS: PART 2 at P.3.

Volume-Specific Powers (PP/V) for other engine makes

The PP/V figure of 314.7 HP/Litre for the 2006 Cosworth CA is the existing record for a Naturally-Aspirated 4-stroke petrol-burning engine which raced. However, it was closely preceded by a BMW engine with a similar PP/V which never raced:-

Year	Type	Con.fig. & B/S	PP HP/V Litres
2005	P85	90V10 98 mm/39.75 2.465	937/2.998 = 312.5 HP/L

Details of the P85 are given in Appendix 1 at SO27 and Note 112.
Having been designed for 800 km life, instead of the late-imposed 1600km and not having to conform to a minimum weight limit, the P85 had a record PP/W ratio of 937 HP/82 kg = 11.43.

Forty years earlier Honda had achieved a local 4-stroke PP/V record in a motor-cycle engine by using extreme miniaturisation:-

1965.5   RC149   IL5 35.5 mm/25.1 1.414   32.7/124.2 cc = 263.2 HP/L

Details of the RC149 are given in Appendix 1 at SO18 and "Significant Other".

During the '60s 2-stroke motor-cycle engines had come to the fore as designers learned how to increase BMPP, starting with the smaller classes (see "Grand Prix Motorcycle Engine Development, 1949 – 2008"). The all-time record PP/V was achieved by a miniature Suzuki, as follows:-

1968   RP68   V3 28 mm/26.5 1.057   19.8/48.95 cc = 404.5 HP/L!

This was an experimental engine which was not raced (ref. DASO1247 p.206).

In the 500 cc premier motorcycle class by the '90s, Honda came well up towards that peak:-

1997   NSR500   112V4 54 mm/54.5 0.991   182/499.3 cc = 364.5 HP/L

Details of the NSR500 are given in Appendix 4 and the above-referenced GP m/c engine review.

Appendix A

COSWORTH B/S ratios, 1967 - 2006								
All DOHC 4/v/c								
Year	1967	1969	1967	1982	1967.2	1975	1986	1981
Type	FVA	FVA	DFV	DFV	DFW	DFX	DFX	DFL
Capacity L NA/TC	1.6 NA	1.6 NA	3 NA	3 NA	2.5 NA	2.65 TC	2.65 TC	3.9 NA
Configuration	IL4	IL4	90V8	90V8	90V8	90V8	90V8	90V8
No. Cylinders (CN)	4	4	8	8	8	8	8	8
Valve Gear	CVRS	CVRS	CVRS	CVRS	CVRS	CVRS	CVRS	CVRS
Valve Material	Fe alloy	Fe alloy	Fe alloy	Fe alloy	Fe alloy	Fe alloy	Fe alloy	Fe alloy
Bore (B) mm	85.725	85.725	85.6742	85.6742	85.6742	85.6742	85.6742	90
Stroke (S) mm	69.14	69.14	64.77	64.77	54	57.3024	57.3024	77.7
B/S	1.240	1.240	1.323	1.323	1.587	1.495	1.495	1.158
V cc	1596.2	1596.2	2987.1	2987.1	2490.4	2642.7	2642.7	3954.4
NP RPM	9000	9750	9000	11300	9750	9500	12000	9250
MPSP m/s	20.74	22.47	19.43	24.40	17.55	18.15	22.92	23.96
BNP m/s	12.86	13.93	12.85	16.14	13.92	13.57	17.13	13.88
MVSP =0.307 x BNP	3.95	4.28	3.95	4.95	4.27	4.16	5.26	4.26

Year	1981	1983	1987	1987	1988	1988	1989	1992
Type	DFL	DFY	DFZ	GBA	DFR	DFS	HB2	HB5
Capacity L NA/TC	3.3 NA	3 NA/22.5	3.5 NA	1.5 TC	3.5 NA	2.65 TC	3.5 NA	3.5 NA
Configuration	90V8	90V8	90V8	120V6	90V8	90V8	90V8	90V8
No. Cylinders (CN)	8	8	8	6	8	8	8	8
Valve Gear	CVRS	CVRS	CVRS	CVRS	CVRS	CVRS	CVRS	CVRS
Valve Material	Fe alloy	Fe alloy	Fe alloy	Fe alloy	Fe alloy	Fe alloy	Ti alloy	Ti alloy
Bore (B) mm	90	90	90	77	90	90	94	94
Stroke (S) mm	64.8	58.8	68.65	53.6	68.65	52	63	63
B/S	1.389	1.531	1.311	1.437	1.311	1.731	1.492	1.492
V cc	3297.9	2992.6	3493.9	1497.6	3493.9	2646.5	3497.6	3497.6
NP RPM	9000	11000	10250	12000	10800	12000	11500	12800
MPSP m/s	19.44	21.56	23.46	21.44	24.71	20.80	24.15	26.88
BNP m/s	13.50	16.50	15.38	15.40	16.20	18.00	18.02	20.05
MVSP =0.307 x BNP	4.14	5.07	4.72	4.73	4.97	5.53	5.53	6.16

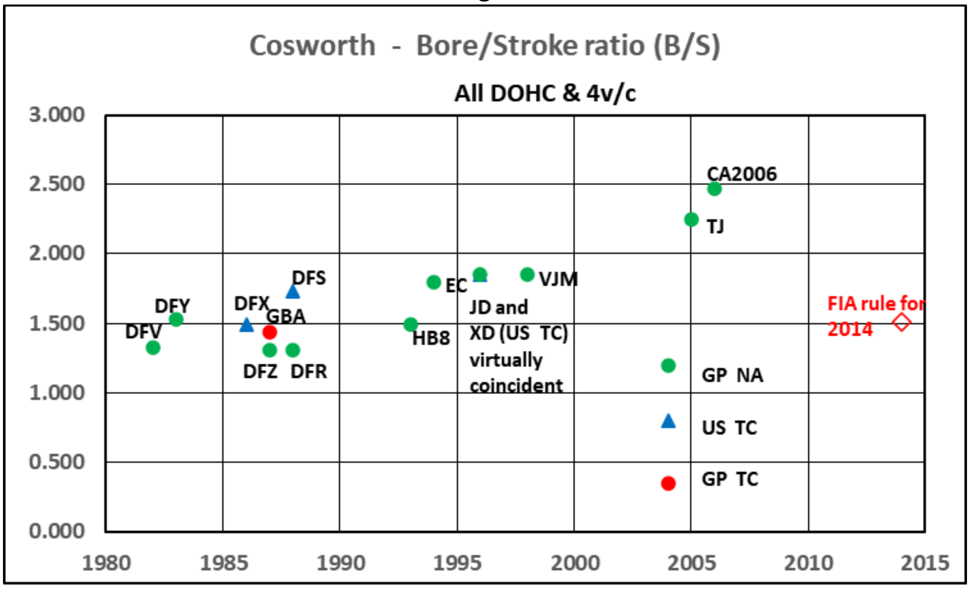
Year	1993	1993	1994	1996	1996	1998	2005	2006
Type	HB8	AC	EC	XD	JD	VJM	TJ	CA2006
Capacity L NA/TC	3.5 NA	3 NA	3.5 NA	2.65 TC	3 NA	3 NA	3 NA	2.4 NA
Configuration	90V8	90V8	75V8	80V8	72V10	72V10	90V10	90V8
No. Cylinders (CN)	8	8	8	8	10	10	10	8
Valve Gear	PVRS	CVRS	PVRS	CVRS	PVRS	PVRS	PVRS	PVRS
Valve Material	Ti alloy	Fe alloy	Ti alloy	Ti alloy?	Ti alloy	Ti alloy	Ti alloy	Ti alloy
Bore (B) mm	94	92	100	92	89	89	95	98
Stroke (S) mm	63	56.3	55.69	49.8	48.1	48.1	42.3	39.75
B/S	1.492	1.634	1.796	1.847	1.850	1.850	2.246	2.465
V cc	3497.6	2994.1	3499.1	2648.4	2992.4	2992.4	2998.3	2398.7
NP RPM	13000	9000	13800	14000	15800	16500	18500	19250
MPSP m/s	27.30	16.89	25.62	23.24	25.33	26.46	26.09	25.51
BNP m/s	20.37	13.80	23.00	21.47	23.44	24.48	29.29	31.44
MVSP =0.307 x BNP	6.25	4.24	7.06	6.59	7.20	7.51	10.76	11.55

P. S. Cosworth Grand Prix 2006 and after

In 2006 the Cosworth CA powered the Williams FW28, driven by Mark Webber and Nico Rosberg. Whatever the reason this combination did not flourish over the season. The team finished 8th in the Constructors' Championship. Williams then switched for 3 years to a Toyota engine because they were offered cheaper – possibly free – units by the world's largest car manufacturer (see Note 111 for details of their 2009 engine). Then Cosworth had no team to power through 2007 – 2009. With some kind of assistance from the FIA they returned in 2010 to power Williams again plus three new teams. The engine was re-developed for the 18,000 RPM limit and 2,000 km life. Once more the results were disappointing and remained so to the end of the 2.4 L formula in 2013.

The FIA in December 2010 issued a formula to come into effect in 2013 for a hybrid power plant whose core Internal Combustion Engine (ICE) was to be a Turbo-Charged IL4 of 1.6 Litres, with a Fuel Flow Rate restricted to a maximum of 100 kg of petrol/ethanol per hour at 10,500 RPM. Cosworth spent time and money on a suitable ICE design (coded HK) for 5 months. The FIA then abruptly changed the ICE configuration to 90V6 – at the behest of Ferrari (see CORRECTIONS & ADDITIONS at P.71). Introduction was put back to 2014. The Bore was mandated as 80 mm maximum, so at that figure the Stroke would be 53 mm, B/S = 1.509. Fig.5 shows how this related to previous Cosworth engines.

Fig.5



The firm did evaluate this revised hybrid and published their predictions in Race Engine Technology No. 72 of August 2013. They anticipated about 600 HP, plus an extra 161 HP for 33 seconds from a full brake-energy-recovery battery as allowed by the rules. Clearly they were hoping to spark interest from a sponsor but this did not happen. Cosworth Grand Prix engines therefore came to an end after 176 victories.