Chapter 7. Building a larger capacity or high RPM bottom end

There are 2 basic ways to modify the engine bottom end to get more power.

1. Increase the capacity of the engine through greater bore and stroke.
2. Increase the maximum RPM the engine can run at.

For a road car increasing the maximum RPM is of limited use as high RPM's are rarely used on the road and increasing power at high RPMs generally reduces mid-range torque and drivability to some extent. However more torque / power can also be generated at the same capacity and RPM through camshaft and related cylinder head modifications that improve the breathing, and this will be discussed in other chapters.

For a race car there are generally class capacity limits that affect how much the capacity can be increased via bore or stroke modifications but often don't restrict internal engine modifications to increase RPM limits. Bottom end RPM increase does require matching the desired maximum RPM the bottom end is capable of, to the RPM the cylinder head and camshafts will work at.

Increasing capacity of the Ford "Kent" block

Bore Increase.

The standard Lotus bore of 82.55 mm is already an increase on the original design bore for the block casting of 81.0 mm. The outside diameter of the bore castings appears to vary in practice between 88 mm and 92 mm for all Kent blocks based on the many bore wall ultrasonic thickness measurements I have done with no systematic difference between the early 116E blocks and the last 701M blocks and L blocks and non L blocks or the block T number. The bore casting is also normally not centred on the bore with the centre line of the casting being offset from the centre line of the bore and crank by up to 2 mm.

The minimum reliable bore wall thickness is approximately 2.5 mm / 0.10 inch and 3.0 mm / 0.12 inch is desirable especially in a more highly stressed modified engine.

Thus the maximum bores that can be possibly achieved are as follows based on a 3.0 mm bore wall thickness with the reboring offset as needed to centre the bore in the casting.

88 mm casting O/D 82.0 mm bore.

90 mm casting O/D 84.0 mm bore.

92 mm casting O/D 86.0 mm bore.

In practice it is not always possible to centre the reboring in the casting fully, especially if it has been rebored already. Approximately 90% of all bore castings are in the 89 mm to 91 mm diameter range and possible to bore to 83.5 mm with offset boring. 5% may go to 85.0 mm and 5% will not go to 83.5 mm. There is also an oil passage between cylinder 2 and 3 and boring beyond 83.5 mm can break through into this passage depending on the block casting and machining tolerances. As the bore gets bigger the amount of metal holding the centre main journal to the block decreases and the block can crack through to the water jackets from the bearing, dumping the coolant into the sump, older blocks with significant corrosion at the bottom of the water jacket are most likely to suffer from this.

The largest bore I have seen attempted in a standard block casting was 87mm in a block with 92+ mm O/D on the bore casting which is very very rare. The bore casting O/D was so oversize that the cylinders were partially siamesed where the sand had fallen away as it was so thin between the bores. Unfortunately the 87mm bores appear to have not been offset and the wall thickness in places was only 1.5 mm where in others it was over 3 mm. The oil passage between cylinders 2 and 3 had also been broken into and it had been sleeved to retain oil. The block had clearly been used for a very short period and was probably removed due to the bores being out of round due to their extreme thinness in places and the rings not seating. The block could possibly be sleeved back to standard bore but custom sleeves would need to be made as the standard sleeves are less than 87mm O/D and the lack of roundness may prevent the sleeves from seating properly.

If you really want to go to a big 85mm to 90mm bore block then alloy blocks of 1600 block height designed for the 2 litre BDG are available from Burtons and others. Cosworth originally made Iron blocks for the 2 litre BDG engines with similar siamesed bores by cutting out the bore casting and furnace brazing in a new set of bores and top deck. Gathercole Race Engines in the UK appear to be casting 90 mm bore Iron blocks as well as Alloy blocks. The cost of these blocks is high and significant modifications are required if you don't want to run a dry sump engine oil pump as they lack the normal block oil passage that runs across the block between cylinders 2 and 3.

Burton Alloy Block

Stroke Increase.

The standard Lotus stroke was the same as the 1500cc Fords at 72.75 mm.

The simplest increase is to the use the 77.62 mm stroke crank from the Ford 1600 engines. This longer stroke can be built in the Ford 1500 block height used by Lotus or the taller 1600 Ford block height with appropriate rods and pistons. Some machining of the 1500 block for rod clearance at the base of the bores may be required depending on the rods used.

Longer stroke custom cranks can be purchased to build engines based on the taller 1600 block with strokes up to 86.0 mm which when combined with a 90mm bore produces a capacity of 2.2 litres.

As the stroke is increased it is also desirable to increase the rod length to maintain the stroke to rod length ratio. The table below shows the range of common options for blocks crack stroke and rod length. There are more options still if going for custom longer stroke cranks and other BD rod options but these need detailed consideration of all the issues involved. The biggest challenge as the stroke is increased and rod length increased is the piston compression height starts to get smaller and fitting in the ring pack becomes difficult. Compression heights down to about 30mm can be done with custom forged pistons but below that the oil ring starts to interfere with the wrist pin bore. Some of the long rod, long stroke, short block combinations in the table below are not practical due to that.

It's possible to fit a standard Lotus Twincam piston into a 1600 block using standard 1600 rods by decking the block by about 5mm. This has been done successfully but it weakens the top of the block deck and it's better to use custom deck height pistons rather than decking the block these days due to the relatively low cost of custom forged pistons from companies like CP or JE in the USA.

The table below gives a calculated piston compression height and is based on the piston deck being level with the block top and the block being the nominal standard height listed. If the block has been machined. I personally like the piston deck to be around 0.5mm / 0.020 in below the block top. You want to double check and measure all other components before ordering custom compression height pistons.

	1600 block & 1600 crank		1500 Block &1600 crank		1500 Block & 1500 crank	
Standard Twin Cam Rod	**inch**	**mm**	**inch**	**mm**	**inch**	**mm**
block height	8.227	208.60	7.791	197.90	7.791	197.90
stroke	3.056	77.62	3.056	77.62	2.864	72.75
Twin Cam Rod	4.800	121.92	4.800	121.92	4.800	121.92
Calc Piston compression height	1.899	48.24	1.463	37.17	1.559	39.61
Rod/ Stroke	1.571	1.571	1.571	1.571	1.676	1.676
Cosworth Length Twin Cam Rod						
block height	8.227	208.60	7.791	197.90	7.791	197.90
stroke	3.056	77.62	3.056	77.62	2.864	72.75
Twin Cam Cosworth Rod	4.823	122.50	4.823	122.50	4.823	122.50
Calc Piston compression height	1.876	47.65	1.440	36.59	1.536	39.02
Rod/ Stroke	1.578	1.578	1.578	1.578	1.684	1.684
Standard 1600 Rod						
block height	8.227	208.60	7.791	197.90	7.791	197.90
stroke	3.056	77.62	3.056	77.62	2.864	72.75
std 1600 rod	4.930	125.22	4.930	125.22	4.930	125.22
Calc Piston compression height	1.769	44.93	1.333	33.87	1.429	36.30
Rod/ Stroke	1.613	1.613	1.613	1.613	1.721	1.721
BDx rod						
block height	8.227	208.60	7.791	197.90	7.791	197.90
stroke	3.056	77.62	3.056	77.62	2.864	72.75
BDx rod	5.230	132.84	5.230	132.84	5.230	132.84
Calc Piston compression height	1.469	37.31	1.033	26.25	1.129	28.68
Rod/ Stroke	1.711	1.711	1.711	1.711	1.826	1.826
Long BDx rod						
block height	8.227	208.60	7.791	197.90	7.791	197.90
stroke	3.056	77.62	3.056	77.62	2.864	72.75
Long BDx rod	5.480	139.19	5.480	139.19	5.480	139.19
Calc Piston compression height	1.219	30.96	0.783	19.90	0.879	22.33
Rod/ Stroke	1.793	1.793	1.793	1.793	1.913	1.913

Notes

Design 1500 block height tolerance was 197.74 to 198.10 mm so used 197.90 mm in table
block machining over the years means many blocks are less than this now
I don’t have design dimensions for the 1600 block
But based on a few unmachined blocks I have measured it appears to be in tolerance of
208.3 to 208.9 mm so used 208.6 mm in the table
Ford Motor sport quote the new 1600 blocks as standard at 8.200 inch / 208.28
which is the bottom end of the range I have measured
They also quote the 1500 height Lotus block at 7.800 inch / 198.12 mm
which is the top end of the design tolerance range

Capacity outcomes

The bore and stroke options give a large range of capacity outcomes. I have listed what's possible using what can be bored from standard blocks and 1500 / 1600 crank strokes which are the most common modifications. The 85mm bore in a standard Ford block while possible needs careful ultrasonic checking of bore wall thickness and offset boring and even then, only around 5% of blocks are suitable to achieve the desirable 3mm minimum wall thickness. Iron or Alloy blocks with 90 mm bores and custom cranks to 84mm or 86 mm strokes are available to get capacities up to 2.2l but costs are very high.

Twin Cam Capacity Table (CC)

Stroke mm	**Bore mm**				
	82.55	**83.50**	**85.00**	**90.00**	
72.75	1557	1594	1651	1851	Standard 1500 stroke
77.62	1662	1700	1762	1975	Standard 1600 stroke
80.00	1713	1752	1816	2036	Custom billet stroke
84.00	1798	1840	1907	2138	Custom billet stroke
86.00	1841	1884	1952	2188	Custom billet stroke
	Std Lotus bore	Possible overbore of standard block		Custom alloy or iron block	

<u>Increasing Bottom End RPM Limits</u>

The standard bottom end of a twin cam engine had a mechanical rev limiter in the distributor rotor arm. This was not very accurate but was nominally set at 6500 rpm in early engines and 6750 rpm in the later Sprint engines. The standard Lotus Twincam assembly of cast crank, 125E rods and cast pistons, in good condition is good for occasional use to 7000 rpm in a road engine but can quickly fail above that, generally due to crank failure. Many standard cast iron cranks also have cracks present by now, so they may not be good for even that, so a used crank either 1500 (72.75mm stroke) or 1600 (77.62mm stroke) needs to be crack tested before use. New 77.62mm stroke cast cranks intended for use in Formula Ford are available from SCAT but these have the same recommended RPM limit.

If looking to go only a little over 7000 rpm to say 7500 rpm in a road engine then the crank needs to be replaced and round bearings caps replaced if present. However standard Ford 125E rods (with ARP bolts) can be used. The standard cast pistons would be good for road use with limited bursts to 7500 rpm but they are only available in limited sizes and most modified engine builds even for road use will require use of forged pistons that match the required compression height, intruder height, bore, and valve cut outs.

Bottom end modifications for increased RPM use in the 7500 to 9000 RPM range involves replacement of the pistons, rods and crank and main bearing caps for items light enough and strong enough to be suitable for this higher RPM use.

Cranks

There are a number of manufacturers of high quality machined billet steel cranks such as Arrow or Farndon in the UK that are good for 9000rpm. With modern CNC machine tools these are much more affordable than they used to be. Four bolt / four counterweight / rope seal cranks are available for FIA compliant race engines. Much lower cost and potentially lower quality versions from China are also being sold. Cranks are also available custom in a large variety of strokes in addition to the standard Ford strokes as this is now much easy also with CNC machining.

For an inline 4 cylinder engine, cranks can come in a four counterweight design or eight. The original Ford cranks used four counterweights and replacement machine billet steel cranks typically use eight. An eight counterweight design in general should generate less crank flexing at high revs and be a little smoother at 8000rpm but this will also depend on its design details and balance.

The billet steel cranks typically come with a 12 bolt fixing for the flywheel and these flywheels are available from the suppliers of the cranks. The cranks can come with a narrower crank big end journal of 23.7 mm as used by Cosworth in the BDx engines or the standard wider Ford crank journals of 26.7 mm and thus the Rods used need to suit the journal width. Many steel cranks are designed for the BDx series of engines which requires a longer crank nose than a Twincam so you need to check the crank can be supplied with the Twincam crank nose design.

EN19 four counterweight steel crank from QED that’s legal for FIA racing engines

EN40 eight counterweight steel crank

An option that was popular as a low cost high RPM crank was to modify the Datsun L16 or L18 crank. These cranks are a very strong steel forging and used the same cylinder spacing and thus bearing centres as the Ford cranks. Datsun appear to have copied many elements of the Ford block when designing the L16 / L18 engine series. The cranks can be machined down to drop into a 1500 or 1600 block to build a 9000rpm engine. The L16 crank can be modified for the 72.75 mm Ford stroke and the L18 crank for the 77.62mm Ford stroke. The L16 crank used 4 counterweights and the L18 crank came in four and eight counterweight versions.

I have used the L16 crank in my competition Twincam engines for 30 years without problems. The thrust bearing spacing ends up slightly wider than standard and oversize thrust bearings are required. The big end journals also end up 10 thou undersize to machine the correct 72.75 mm stroke. On the older 120E blocks a small amount of grinding on the block may be required to clear non-critical casting details with the counterweights (I have not fitted one to a later 701M block).

These cranks are now getting hard to find and the cost of modifying them is getting much closer to the cost of a new billet steel crank, especially the low cost Chinese versions. The Datsun design also used 5 bolts for retaining the flywheel, thus a custom flywheel to match is required.

The following article provides more detail on the Datsun crank modification.

https://rsmotorsport.com.au/files/TC_Datsun_Crank.pdf

Two of the modified Datsun L16 cranks I use in my competition engines. The crank in the front is darker as it has been nitrided. The rear crank was not nitrided. Neither crank has shown any significant wear despite many racing kilometres.

Rods

Lighter weight and higher strength rods can be purchased from companies such as Carrillo in the USA in the various Ford or Cosworth lengths. These rods are “H” section rods and are significantly lighter than the standard Ford 125E “I” section rods.

e.g.

Standard Ford 125E rods are 650 g compared to the equivalent Carrillo rods at 519g including the rod bolts.

Maxpeeding.com also can supply H section rods from China at a substantially lower cost and they have been used successfully in race engines however they are significantly heavier at 564 g than an equivalent Carrillo rod and the shot peening is coarser and corner radius detailing is definitely inferior.

Arrow in the UK supply “I” section rods for FIA compliant racing Twincam engine builds

Rod bolts are the most highly stressed component in an engine, and using high quality bolts and tightening them using a stretch gauge is critical when building a modified engine. I normally use the original bolts supplied by Carrillo with their rods or use ARP 2000 bolts when rebuilding engines. I normally do not reuse rod bolts and when replacing bolts in rods you also need to ensure the bolt is identical in under head length and thread length to match what the rod was designed for. People like Burtons sell ARP bolts for “steel” rods which are 1.5 inches long and while they may fit, the length may not be totally correct for the particular rod you are using. E.g. Carrillo rods use 1.6 inch long bolts which has the threaded section of the bolt not crossing the rod big end join.

Pistons

Forged pistons from JE or CP in the USA or Accralite in the UK are available at reasonable cost in both standard and custom bore and compression height sizes to suit modified engine builds. Forged pistons are both lighter and stronger than the original Lotus cast pistons and are required if building engine to run regularly over 7000 rpm. The intruder height needs to be specified or later machined down to obtain the desired compression ratio in combination with all the other elements such as displacement, head chamber capacity and head gasket thickness used in a modified engine.

CP pistons from the Lotus7.com web site on the left with quoted weight 344 g. The JE pistons I have used are 318 g and standard cast pistons are around 380 g. Modern forged pistons also use thinner and lighter rings which bed in quicker and don't wear the piston ring lands as fast due to their lighter weight.

Accralite forged piston from Burtons

Main bearing caps

The round style cast bearing caps used in Twincams up to about 1967 are not suitable for a high revving or long stroke engine. Stronger round style steel caps are now available from people like QED or TTR for building FIA compliant engines which require use of the early round style.

QED Round style steel main bearing cap with square steel cap behind it.

The later square cast Ford caps used in the later Twincam 701M blocks (and some 681F blocks) 1500 blocks and Ford 711M 1600 blocks are good for modified engines to 9000rpm, alternatively steel caps can be purchased from people like Burtons and QED. Re-machining of the block and cap assembly with the new caps is required to re-establish the correct main bearing bore when the caps are replaced.

Ford square cast main caps as supplied with the new Ford Motorsport 711M blocks. Note the machining for the full circle thrust bearing on the centre cap on the right

Other Considerations in Bottom End Modifications

Flywheels

Lighter, low inertia flywheels help the engine accelerate quicker making it more responsive especially in track conditions.

The David Vizard book gives details of machining to lighten the standard cast iron flywheel though I would not recommend doing this due to an increased risk of failure at high RPMs. Lighter steel flywheels of various designs are available and much safer in high RPM engines.

Ultralight steel flywheel from TTR

Aluminium flywheel with steel insert wearing surface for clutch plate, weight is 3.6 Kg about half that of the standard cast iron flywheel. Note also the large, hardened steel 5 bolt hole "washer" for the crank bolts to stop them sinking into the aluminium. This is for the 5 bolt Datsun steel crank in my Elan.

Balancing

Using the lightest possible reciprocating components and balancing them well is essential in both a long stroke engine or a high RPM engine and a good idea even in a road engine of standard stroke.

Balancing of the rods (total and end weights) and pistons to match the weights of all four can be done with a cheap set of scales to within +/- 1 gm which is the accuracy needed. Dynamic balancing of the crank and the flywheel / pressure plate assembly separately and together needs specialist equipment. If a clutch pressure plate needs to be replaced, it can be rebalanced with the flywheel and then reinstalled on the crank in the original location (which should have had match marking done when it was balanced) without needing to remove the crank for rebalancing the whole assembly.

3 inch Front pulley

The standard 4 inch diameter cast iron pulley should be replaced with a 3 inch pulley to slow the water pump and alternator down if building an 8000+ RPM race engine. The rear flange on the cast iron pulley is very thin and often chipped so replacement with a 4 inch or 3 inch steel pulley is a good idea. I have never had the crank balanced with the front pulley as the diameter and weight is small and the steel pulley consistent in material weight and dimensions and is inherently balanced assuming no runout when mounted which can be easily checked with a dial gauge.

Standard 4 inch diameter cast iron pulley on the left. Lighter steel 4 inch pulley in the centre. 3 inch pulley on the right. With the smaller pulley the alternator and water pump are running at the equivalent speed of a 6000 rpm standard engine in an 8000 rpm race engine.

Tall block front covers / spacers/ drain tube/ chain and tensioner and bonnet clearance

If using a 711M 1600 block in a modified engine then a number of components need to be altered to suit the taller height of this block

The front timing chain cover and back plate needs to be taller and these taller covers are available from Burton and others. The alternative is to machine a spacer to match a standard height front cover to the taller block be it a standard or a decked 1600 block.

If using a spacer then longer bolts between the head and front cover will be required

The standard rubber vent / drain tube between the head and block also need to be lengthened via a machined spacer (see QED spacer on left) or replaced with a custom aluminium tube. Various designs of fixed adjustable alloy tubes have also been developed which can be found on the internet.

The standard timing chain is 120 links for the 1500 block. A 122 link timing chain is required if using a standard height 1600 block. 121 link timing chains can be purchased if using a decked 1600 block and thin spacer for which the 122 link chain is too long and the 120 link chain too short. The 121 link chain requires a special link to have an odd number of links in a chain.

Due to the change in geometry of the timing chain run versus the location of the tensioner sprocket a longer adjuster plunger or a longer tensioner sprocket quadrant is also required. What is best done depends on the details of how the other modifications to accommodate the tall block have been carried out.

The taller 1600 height 711m block can give bonnet clearance issues especially in a Plus 2 where the front of the cam cover (especially the Big Valve cover with the raised lettering on the front) is very close to the bonnet with the standard 1500 height block. The easiest solution is to slot the standard engine mount holes where it bolts to the chassis to drop the front of the engine down a little.