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Design Considerations to Reduce Mass
of Engine Internals

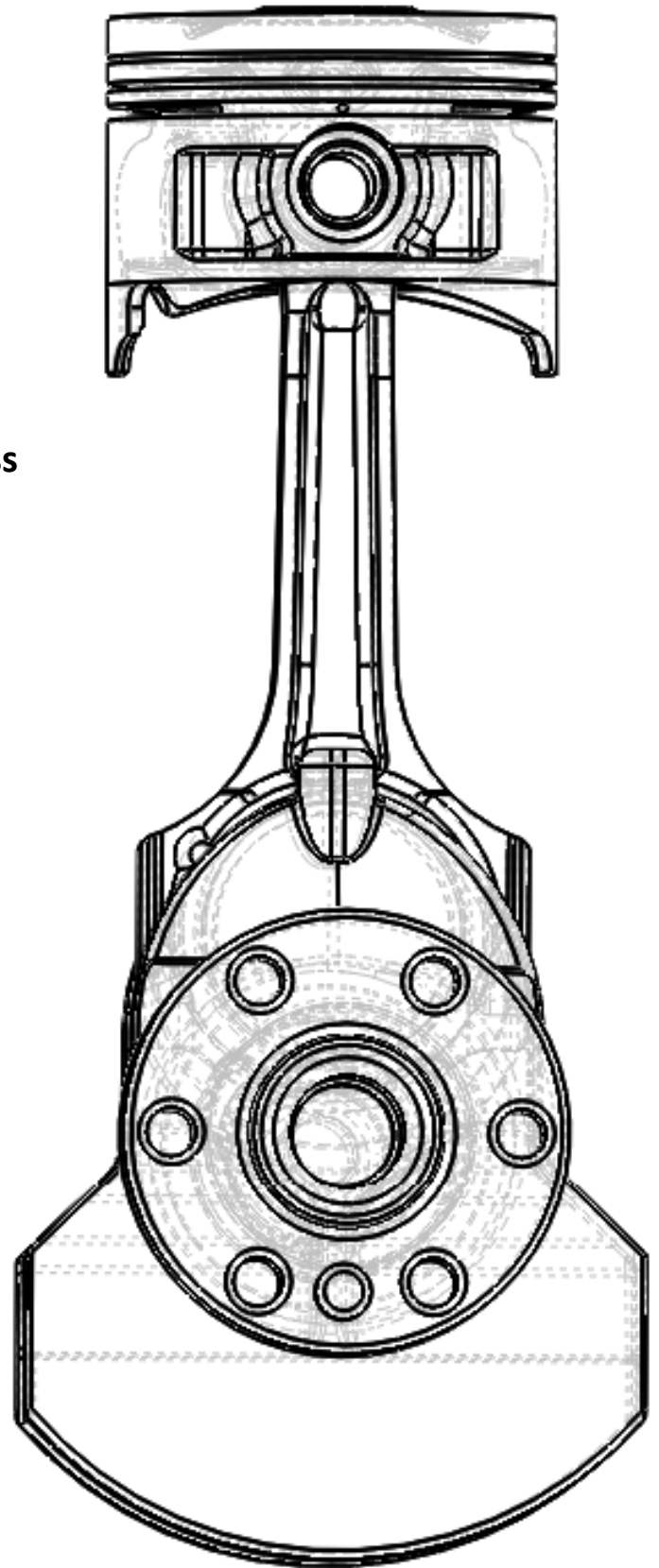
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DECLARATION OF AUTHENTICITY

This Thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.

Signed: R Evans

Date: 30/04/2019

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My sincere gratitude goes to my supervisor & Lecturer Malcolm McDonald who has been a great help through my final year. Not only has he been able to provide high quality lectures but has also shown a real interest in the project work and has encouraged good thoughts, praise & much needed motivation throughout the year. I would also like to extend my gratitude to my Wife who has shown a great deal of support and encouragement throughout my 4 years in Higher education. Lastly my thanks to all the other members of staff who have helped along the way.

ABSTRACT

This report is the basis of an idea started initially by comparing two engines from different eras in engine design and technology, moving onto the aim of reducing internal mass of one engine by using the internals from another. With the use of CAD to produce dimensionally correct parts of the engines it was then possible to show if the intended parts would be able to fit, if not what could be done to make them if. Also stress calculations could be done to show if the components were safe to use.

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NOMENCLATURE

DOHC – Double overhead camshaft

4A-GE – Engine code for the Toyota 1.6l naturally aspirated engine

7A-FE – Engine code for the Toyota 1.8l naturally aspirated engine

EcoBoost – Fords 1.6l turbo engine

Hybrid – the new engine comprising of the Ford & Toyota components

TDC – Top dead centre

BDC – Bottom dead centre

FEM or FEA – Finite Element Methods/Analysis

F_{Gas} – Gas Force

P – Pressure

M_{Piston} – Piston Mass

M_{Rec} – Reciprocating Mass

M_{Rot} – Rotating Mass

σ_{max} – Maximum Stress

σ_{min} – Minimum Stress

INTRODUCTION

The Internal combustion engine has been powering vehicles for well over a century and Engine design has evolved through the years with engineers striving for efficiency, performance and reliability so a balance usually has to be made. However, the engineer will favour reliability over efficiency and performance of the average road car engine as an unreliable engine will not be favoured by the car purchaser. So, with this thought in mind engine designers over engineer engine components to a certain degree to ensure longevity and will apply what is known as a Factor of Safety. Through the use of basic calculations, the engineer can assess the critical points within the component be it a connecting rod or a crankshaft. Over engineering has slowly decreased with time due to the assistance of modern computer methods of CAD and finite element analysis and with the advancement of such software, engine manufacturers can produce a lighter and more compact engine. An engine which can be made lighter becomes more efficient overall as there is less mass to move it. Therefore, requires less energy to do so. With the aid of CAD software, engine designers can manipulate designs with ease and use a virtual space to create detailed and complex assemblies which can also be tested by the means of Finite Element Methods, (FEM).

This report will focus on the comparison of two engine s from different eras, each engine differs in how it acquires its power delivery, one is naturally aspirated and requires high revs to make its peak power, the other is forced induction and has a tame max Rpm to employ efficiency. Comparisons of mass will be taken into account and considered further. The authors aim is to concentrate on the reduction of internal mass within one engine and go a step further and attempt to retro fit engine components not intended for the engine originally. It is thought that if the lighter internal components of one engine can be proved adequate to use in the other then a process shall begin on how to consider fitment and with the use of CAD the initial stages can be visualised in a virtual space before any unnecessary modifying takes place and conclude if the whole process is viable or just an idea which could be deemed too much work for little gain.

1 REASON FOR PROJECT

The authors decision for the project was influenced by an engine of interest, a Toyota 1600cc DOHC 16v known as the 4A-GE which resides in their self-built Locost. Wishing to develop the engine further they chose to use it to compare with a modern offering from Ford, the 1.6l Ecoboost. The authors intentions were to analyse the engine internals of both engines to see how they differ with the idea to improve the 4A-GE to best suit its application this would also give the author an insight into engine design and the structural aspect of an engine. A range of calculations were completed.

The author wanted to model the engine internals of both engines to allow the use of motion sim and FEA of components, upon modelling of the crankshafts the author noticed the dimensions of the cranks were very similar however, the Ford components being a lot lighter and so thought to change the project direction slightly by trying to implement the Ford crankshaft and connecting rods into the 4A-GE with the aim of reducing rotating mass of the bottom end of engine while trying to retain as much of the engines performance as possible. This led to comparing the both cranks and conrods with the aim to prove the Ecoboost a viable option in terms of structural strength by means of hand calculations and FEA of the components.



Figure 1-1 The engine of interest, the 4A-GE.



Figure 1-2 Authors Locost powered by the 4A-GE (Evans, 2019)

2 LITERATURE REVIEW

As the authors original aim has taken a different approach, their intentions of implementing the Ford crank and conrods into another engine to lower rotational mass is an idea which must be carefully considered and thought out thoroughly. The idea is not one that is popular and so little information is known on whether it is even possible as the components were designed to operate in their original engine which differs to the intended engine, so for this project to be possible there must be some research into the design aspects and requirements for the ICE components. When initially designing an engine, the designers must consider bore & stroke sizes, and this will then dictate certain areas of the engines design (Manning, 2012). The engines discussed in the report are both classed as 1.6l with the EcoBoost having a cubic capacity of 1596cc and the 4A-GE 1587cc. however, both differ in design to attain this displacement as the bore, stroke and crank radius all differ on both engines. The Engines

2.1.1 Toyota 4A-GE

This engine although over 30 years old has a good reputation within the Japanese tuning fraternity as well as motorsport and has had significant development through its time. It has been used within the Formula Atlantic race series powering many open wheeled single seater cars with a performance figure of approx. 250 hp and able to rev to 10,000 RPM. In standard form according to an SAE paper the earliest version of the 4A-GE had a power output of 91kw (122hp) @6600 RPM and a torque figure of 142Nm @5200 RPM. (Kimbara, et al., 1984)

2.1.2 Ford EcoBoost

Ford's recent attempt to produce a modern efficient engine with the ability to achieve a great power output if necessary has been a popular success. It can achieve a high-power output at such low RPM thanks to its turbo. A company called Pumaspeed.co.uk specialize in tuning of the EcoBoost and offer an engine package that will boost performance to approx. 400bhp. According to their website they retain the original crank and re-balance to account for new pistons & conrods along with a new lightened flywheel enabling the EcoBoost to rev to a maximum of 8500 RPM (pumaspeed.co.uk, 2019) see appendix for info. This proves the crank is capable of a higher RPM with new pistons & rods. However, the author intends to retain the original conrods with a possibility of using a lighter piston.

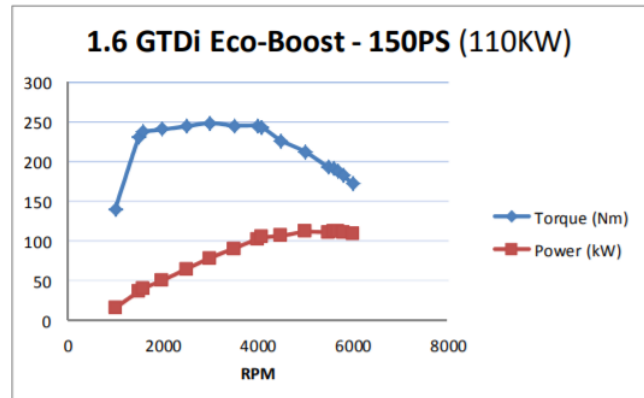


Figure 2-1 Power & Torque curve of EcoBoost (Ford-Uk, 2017)

2.1.3 The 7A-FE

Through product knowledge of the Toyota brand the author was aware that Toyota produced a 1.8l variant for its larger models the Celica & Avensis range which used an altered version of the 4A block. It used a larger crank radius along with longer rods with the bore remaining the same 81mm. This allowed it to be classed as an 1800cc. It is an option to use with the hybrid internals as it has a taller block allowing for the use of the Ford EcoBoost crank. Research on the net shows that the 7A-FE has been used in conjunction with the 4A-GE cylinder head. As it shares a lot in common the cylinder head fits the 7A-FE making an easy option for a larger

2.2 CRANKSHAFT CONSIDERATIONS

The crankshaft is the main component which is responsible for converting reciprocating motion into rotation with the aid of the connecting rods and pistons. The gas forces created by combustion exert a force acting on the piston, this force is then transferred to the conrod which acts upon the crank pin enabling rotation in the system. This system is known as the drivetrain (Manning, 2012). During its operation the drivetrain endures forces from combustion and inertia forces from the reciprocating movements. The combustion force results in a compression force and inertia in a tensile force which puts great stress on the drivetrain components and need to be contained by a structure strong enough to withstand the imposed loads. (Manning, 2012). The crank will suffer bending and torsional stress due to these loadings and so a suitable strength crank needs to be designed with

3 METHODOLOGY

3.1 ENGINE COMPARISON

The project initially started by comparing the Ecoboost & 4A-GE. Both engines are classed as 1.6l, however their means of achieving this displacement differs in the engine component dimensions.

For the engine comparison the author needed to disassemble the 4A-GE engine down to a bare block to gain all the necessary dimensions. The dimensions for the Ecoboost were taken from a selection of components readily available from the Universities engine shop.

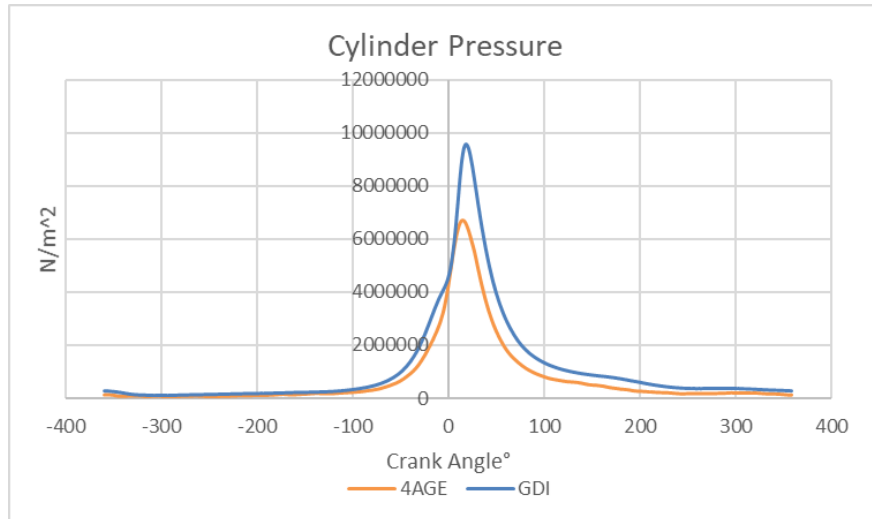
Although both are classed as 1.6l in capacity the engines can be considered different as they are from different periods of engine technology, approx. 30 years apart with the 4A-GE being a standard naturally aspirated 1.6l with an over square ratio of 1.05:1 and with a max Rpm of approx. 7800

Table 1 Engine Data for the Ecoboost & 4A-GE showing differences in component sizes.

Engine Data	EcoBoost	4A-GE	
Engine Disp/Cyl	0.000399	0.000397	M ³
Engine Disp total	0.001596	0.001587	M ³
Head Gasket Vol	0.00000392	0.00000412	M ³
Combustion Chamber Vol	0.00003600	0.00003600	M ³
Con-rod Length (L)	0.1340	0.1220	M
Cylinder Bore	0.0790	0.0810	M
Piston Stroke	0.0814	0.0770	M
Ratio of Bore/stroke	0.9705	1.0519	
Crank Radius (R)	1.0000	0.0385	M
Engine Speed	6000	7800	RPM
Angular velocity (ω)	628	817	Rads/s

To compare the both engines the author created an excel model requiring data from the both engines, this included all dimensions and masses along with combustion pressure data which, fortunately was available from Malcolm McDonald, courtesy of FORD to enable accurate calculations of the Ecoboost however, no pressure data was available for the 4A-GE so it was decided to use pressure data for a 1.6l N/A Ford engine which when discussed with Malcolm McDonald was thought to be adequate for the necessary calculations to compare both engines. As can be seen from Graph 1 the pressures differ massively due to the Ecoboost being pressure charged by means of a turbo where the 4A-GE is naturally aspirated. This difference will produce very different result from the comparisons and will most likely show differences in design factors of the components. It must also be noted that the data supplied was only available up to 6000 RPM. So, to allow the calculations to continue up to 7800 RPM the author used the data range from 6000 RPM repeatedly.

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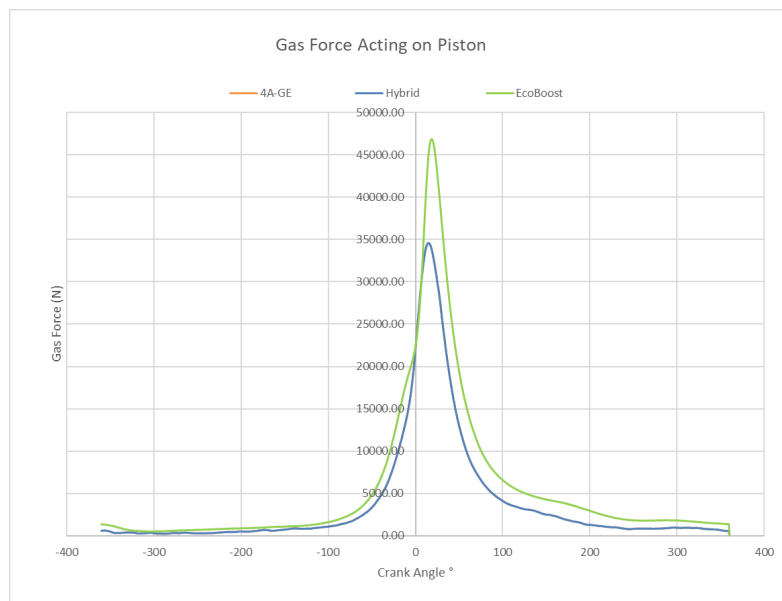
Graph 1 Cylinder Pressure Data from Malcolm McDonald, courtesy of FORD used & entered into Excel. Notice the difference due to the EcoBoost being Turbo charged.

From the cylinder pressure data, it could be possible to calculate the gas force acting on the piston using the simple formula for pressure rearranged for force;

$$Force = pressure * area$$

$$F_{Gas} = P * \frac{\pi d^2}{4} \quad (1)$$

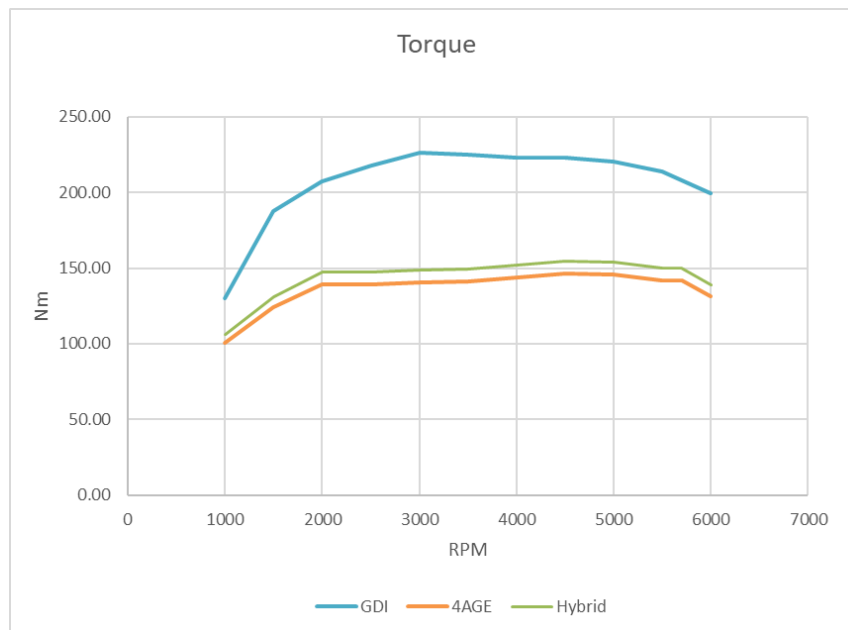
Using Excel, the gas force was calculated and plotted against crank angle to give a graph to show the max gas force at crank angle. (see Graph 2). The graph shows the EcoBoost to have a large difference of gas force acting on the piston and is down to the forced induction of the turbo. With this in mind it is safe to assume the components will be suitable in compression loading for the authors intension as the gas force from the 4A-GE only reaches a maximum of below 35000N.



Graph 2 Gas force acting on piston from Excel calculations

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Using the data from each engine the torque produced by the engine was calculated, as can be seen in graph 3 due to the longer crank radius the hybrid engine has increased in torque.



Graph 3 Torque figures from engine data

3.2 MASS COMPARISON

For the Excel model and mass comparisons all the components needed to be weighed and entered. The masses were also used to validate all of the Solidworks models.

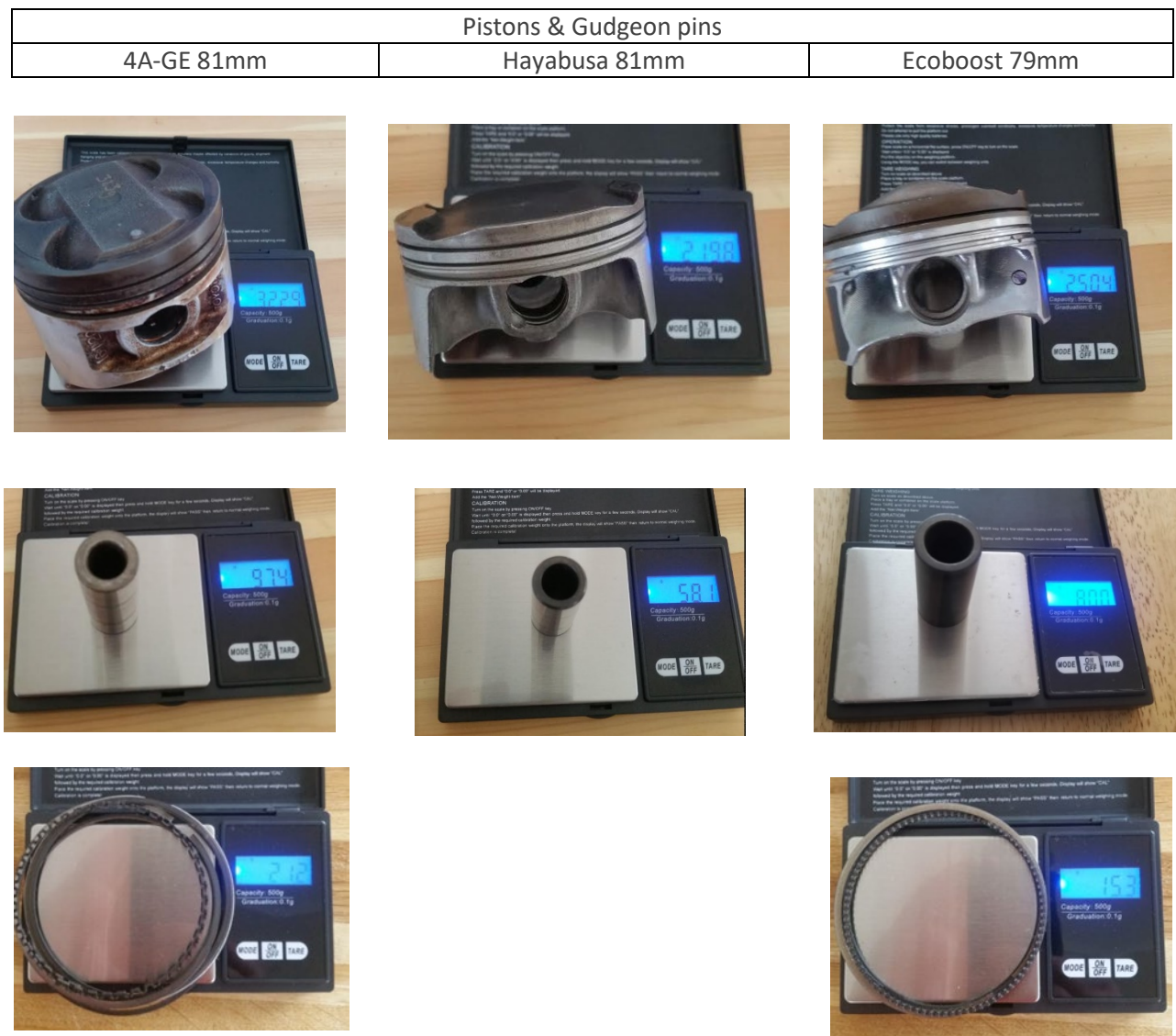


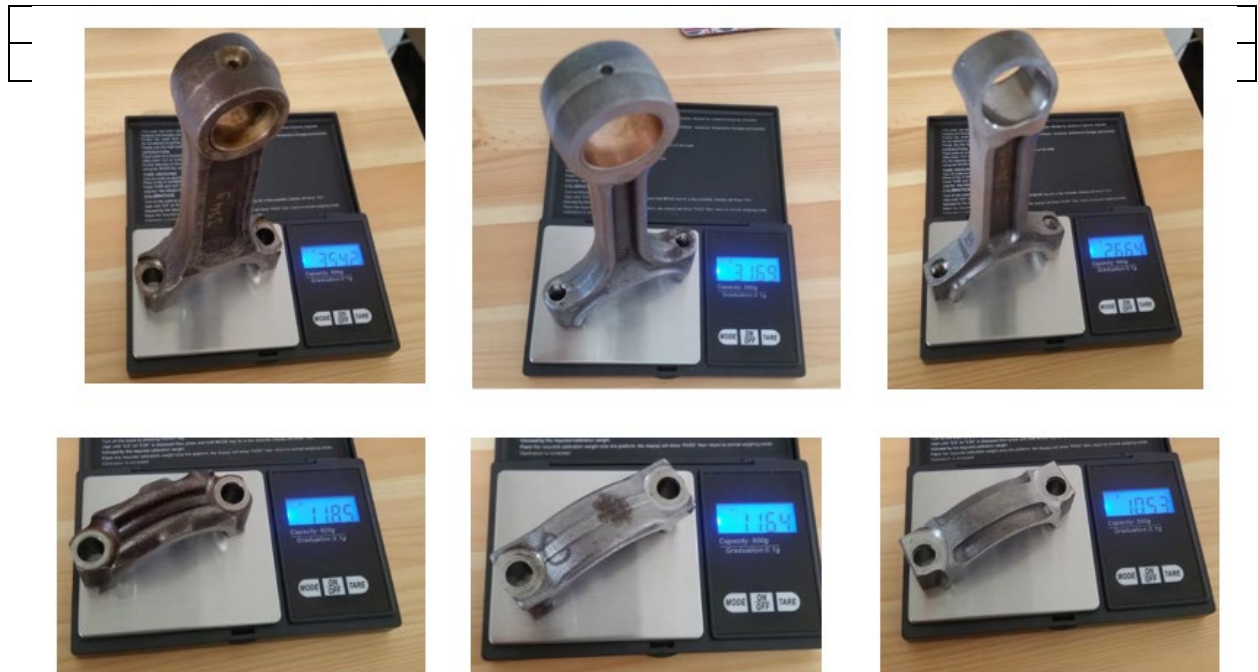
Figure 3-1 Piston, Gudgeon Pin & ring Mass including possible Hayabusa lightweight option (Evans, 2019)

Piston	323g	220g	250g
Pin	97g	58g	80g
Rings	21g	N/A	15g

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Connecting Rods		
4A-GE	Early EcoBoost	Late EcoBoost

Figure 3-2 Conrods & caps (Evans, 2019)



Bolts	
4A-GE	EcoBoost



Figure 3-3Bolts mass, notice the 4A-GE uses nut & bolt arrangement. (Evans, 2019)

32g inc nut	17.5g
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Big End Bearings	
4A-GE	EcoBoost



Design Considerations to Reduce Mass of Engine Internals

Figure 3-4 Big end bearings of 4A-GE, something actually lighter. (Evans, 2019)

26.6g (per rod)	27.4g (per rod)
-----------------	-----------------

Crankshafts	
4A-GE	EcoBoost



Figure 3-5 4A-GE & EcoBoost crank mass (Evans, 2019)

12.7kg	10.3kg
Flywheels	
4A-GE	EcoBoost

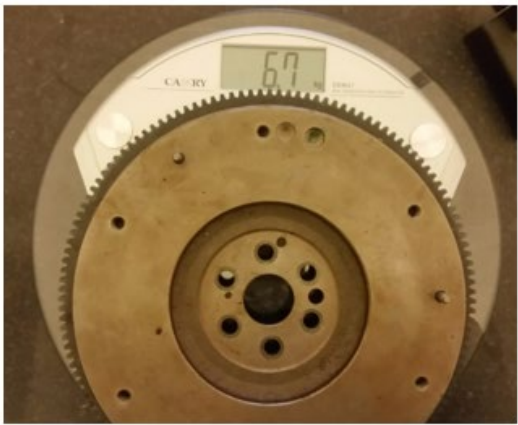


Figure 3-6 4A-GE & EcoBoost Flywheel Mass (Evans, 2019)

Below is a table of the masses from each of the engines with the differences in kg and as a percentage

Table 2 Mass comparison of components

Engine Data	EcoBoost (Kg)	4A-GE (Kg)	Difference	
			Kg	%
Piston Mass	0.25	0.32	0.07	22
Piston Ring Mass	0.02	0.02	0.01	26
Gudgeon Pin mass	0.08	0.10	0.02	18
Crank Mass	10.20	12.70	2.50	20
Con-rod mass	0.27	0.35	0.09	25
Con-rod cap mass	0.11	0.12	0.01	11
Crod bolt & nut mass	0.03	0.06	0.03	45
Big End Shells Mass	0.02	0.03	0.01	21
Reciprocating Mass	0.49	0.63	0.14	
Flywheel Mass	6.70	6.80	0.10	1
TOTAL	17.67	20.50	2.97	14

3.3 INERTIA FORCES

One of the highest forces exerted on the conrods is the inertia force, which is caused by the mass of the reciprocating piston and 1/3rd of the conrod which is changing direction @ TDC. The change in direction causes a large tensile force upon the conrod and being dependant on engine speed which is angular velocity (denoted by ω) where it sees its highest loading at maximum RPM. The author has calculated the force caused by the components of each engine and also included the Hybrid components to show the possible changes which can be made. So, both engines will have different inertia forces acting upon the crank assembly due to the different reciprocating masses and is dependant of the velocity of the moving components.

Where inertia is equal to;

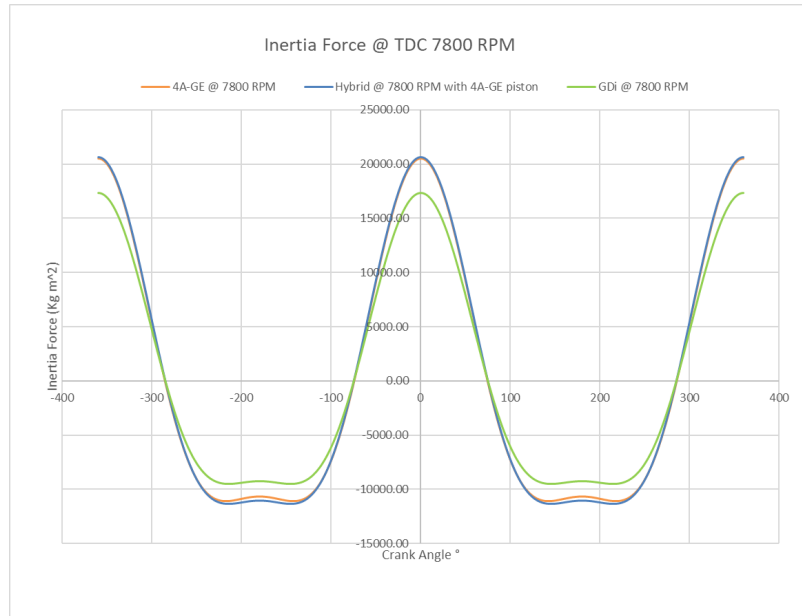
$$F_{inertia} = M_{Rec}(R\omega^2 \cos\theta) + \left(\frac{R}{l}\right) R\omega^2 \cos 2\theta \quad (2)$$

The above formula can be simplified as the calculation is done @ TDC we can replace $\cos 2\theta$ with a 1.

3.3.1 Inertia force (4A-GE Piston & Earlier EcoBoost Rod)

Below is a graph showing the total inertia force acting on the conrod at maximum RPM using a combination of the 4A-GE piston and Gudgeon pin coupled to an early EcoBoost conrod. It shows that the inertia force from the hybrid components remains more or less the same as the original 4A-GE setup. This shows that the piston and Gudgeon pin mass have the most dominant effect on the inertia force and ideally it would be beneficial if the mass could be reduced to lower the inertial force and therefore lowering the tensile stress seen by the conrod.

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Graph 4

3.3.2 Inertia force (Hayabusa Piston & Earlier EcoBoost Rod)

The author used the mass of a piston predominantly used in large motorcycle engine of a Suzuki Hayabusa (220g). It shares the same bore size of 81mm making it a possible option to be used within the Hybrid engine. For now, the author used the mass to give the results shown below in graph 2 and as can be seen, the inertia force has dropped considerably when compared to graph 1 above.

Figure 3-7 Inertia load from engines at a maximum RPM 7800, this is purely to compare max possible inertia loads. Hybrid components consisted of Hayabusa 220g piston and early EcoBoost rod,

Table 3 Engine data form the Ecoboost & 4A-GE

Engine Data	GDI	4-AGE	
Engine Disp/Cyl	0.000399	0.000397	M ³
Engine Disp total	0.001596	0.001587	M ³
Head Gasket Vol	0.00000392	0.00000000	M ³
Combustion Chamber Vol	0.00003600	0.00003600	M ³
Con-rod Length (L)	0.1340	0.1220	M
Cylinder Bore	0.0790	0.0810	M
Piston Stroke	0.0814	0.0770	M
Ratio of Bore/stroke	0.9705	1.0519	
Crank Radius (R)	1.0000	0.0385	M
Piston Mass	0.2510	0.3230	Kg
Piston Ring Mass	0.0155	0.0210	Kg
Gudgeon Pin mass	0.0800	0.0973	Kg
Crank Mass	10.2000	12.7000	Kg
Con-rod mass	0.2662	0.3543	kg
Con-rod cap mass	0.1052	0.1182	kg
Crod bolt & nut mass	0.0348	0.0638	kg
Reciprocating Mass	0.4889	0.6079	kg
Big End Shells Mass	0.0210	0.0266	kg

3.4 THE IDEA

With the initial calculations complete the author set about the idea of making the Ecoboost crank and conrods functional within the 4A-GE engine with the aim to lower the moving mass within the bottom end of the engine. The Ecoboost components will alter the engine displacement by means of increasing the stroke. there are, however, a few issues that need addressing before any actual work can begin. Mentioned previously, the engines use different dimensions to attain a similar cubic capacity and as can be seen from the data the Ecoboost uses a larger crank radius and conrod length, this will give an issue of the piston protruding out of the top of the block. Another issue is the possibility of the crank counter webs hitting the inside of the crankcase as from a visual inspection of the 4A-GE upon strip down the clearance between the crankcase and counter webs appeared to be close, approx. 5mm at the smallest section found. Below are dimensions taken from the engine components of the 4A-GE and Ecoboost and used to show the height difference issue. The Hybrid measurements consist of the Ecoboost crank and rod and 4A-GE piston or the Hayabusa piston and give the author an idea of how much different they are. (See figure 3-8 for the dimensions taken).



Figure 3-9 Ecoboost rod pictured left & 4A-GE or right. (Evans, 2019)

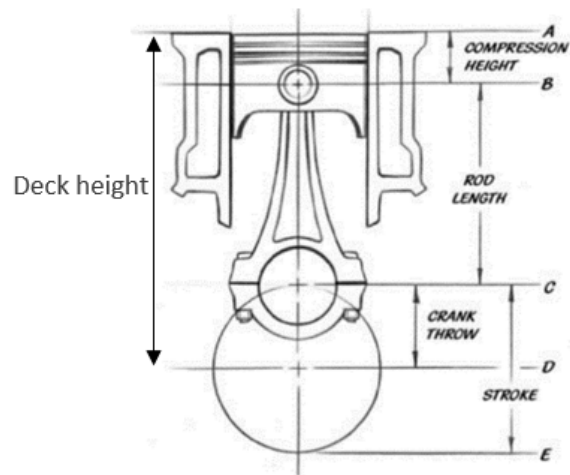


Figure 3-8 Image of dimensions needed to calculate height difference (Magda, 2017)

Table 4 Height comparison in Hybrid internals

	4A-GE (std)	EcoBoost (4A-GE piston)	EcoBoost (Hayabusa Piston)
Compression height A-B	30.3mm	30.3mm	24mm
Rod Length B-C	122mm	134mm	134mm
Crank throw C-D	38.5mm	40.7mm	40.7mm
Stroke C-E	77mm	81.4mm	81.4mm
TOTAL Height to deck	190.8mm	205	198.7mm
Height difference	N/a	14.2mm	7.9mm

Looking at table 4 it shows there is an issue with the height of the proposed internals and if using the original 4A-GE piston on the Ecoboost rod and crank the combination will protrude by 14.2mm.(see Fig 3-9) The Hayabusa piston has a lower compression height but still shows to be 7.9mm too high. To overcome this problem the author needed to use a suitable block as mentioned in Literature review and discussed below.

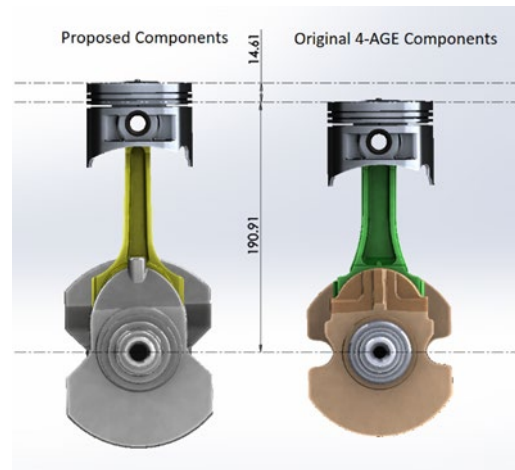


Figure 3-10 CAD Model of 4A-GE on right with proposed idea on left showing height difference. (Evans, 2019)

3.5 ALTERNATIVE BLOCK

To house the Ecoboost crank and rods a different block is to be used from an engine known as the 7A-FE, another Toyota offering which is interchangeable with the 4A-GE. It differs by use of a bigger crank radius & stroke of 85.5mm. as the stroke is longer the block is therefore taller to account for further piston travel along with longer connecting rods, also the block has extra space in the crank case for the larger radius. This makes it a possibility for the use in this project. The authors intentions were to acquire a 7A-FE block specifically for the project however, this proved to be difficult as very few remain. The 7A-FE engine resided in standard models of Toyotas and had no real enthusiast following unlike the 4A-GE. This presented a problem for the author to continue with the work especially as a CAD model of the engine block was required. It was decided the work would continue as the author did research into the 7A-FE engine and gathered dimensions of the components (See table 5). The engines are classed as belonging to the A series range, meaning they share many of the same dimensions and have interchangeable components e.g. cylinder head, bell housings and oil pumps have all the same bolt pattern.

Table 5 Dimensions of 7A-FE From (matrixgarage.com, 2018) compared to the smaller 4A-GE

	4A-GE	7A-FE
Bore	81mm	81mm
Bore Spacing	87.5mm	87.5mm
Stroke	77mm	85.5
Crank Radius	38.5mm	42.75mm
Con Rod Length	122mm	132.5mm
Main Bearing Diameter	48mm	48mm
Block height	191mm	205.5mm

From the table above it shows the crank radius of the 7A-FE to be 42.5mm giving it its cylinder capacity of 1762cc (1.8L). The increase in stroke means the block needs to accommodate the larger crank and longer conrods and makes this an ideal option to house the Ecoboost crank & rods and

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3.5.1 Engine Block Differences

Below are pictures of the both 7A & 4A blocks, from a quick glance they look identical however, there are dimensional differences to allow for the extra length of crank radius & conrod length. This means that the block is taller overall and wider at the crankcase.

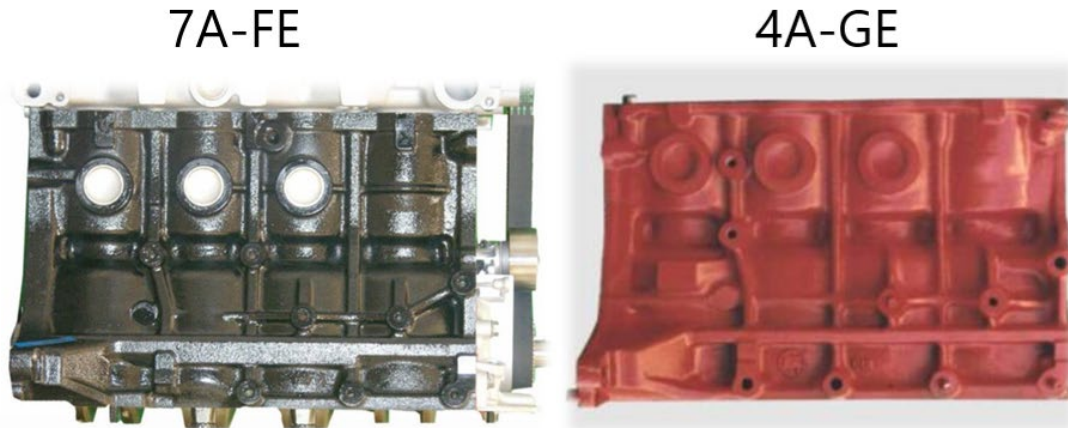


Figure 3-11 7A-FE engine in black showing & early 4A-GE block in red, notice the height difference above the 3 core plugs. (oreillyauto.com, 2018)



Figure 3-14 7A-FE crankcase, note the machined areas at the base of the bores for the conrods to clear.



Figure 3-12 4A-GE crankcase. No machined areas and smaller space so 7A-FE & Ecoboost cranks will not spin. (Evans, 2019)



Figure 3-13 Ecoboost crank sitting in 4A-GE Block. notice clearance issue on centre image. image on left shows centre main where thrust washer seats need machining to suit crank

3.6 CAD MODELS

The modelling of the engine components was completed by precisely measuring each component by hand using basic measuring devices such as;

- Vernier callipers
- Dti gauges
- Selection of radius gauges
- Selection of squares
- Steel rule
- Digital angle gauge

Using Solidworks provided a virtual way to check the feasibility of the idea and could enable the author to use the components in FEA to prove the components were adequate for the application. Also, it gave the author the opportunity to print full scale parts from a 3d printer allowing their design ideas to become real prototype parts to test fit.

3.6.1 Connecting Rods

The conrods were modelled very accurately ensuring the radii were also correct to ensure reliable results in FEA.



Figure 3-15 CAD Models of the conrods from left to right, 2nd Gen 4A-GE, 1st gen Ecoboost, 2nd Gen Ecoboost. (Evans, 2019)

3.6.2 Crankshafts

The cranks required detailed measurements to get an accurate representation of the mass, this included detailing the oil galleries.

THE ECOBOOST CRANKSHAFT



Figure 3-16 Ecoboost crankshaft modelled in Solidworks. (Evans, 2019)

THE 4A-GE CRANKSHAFT

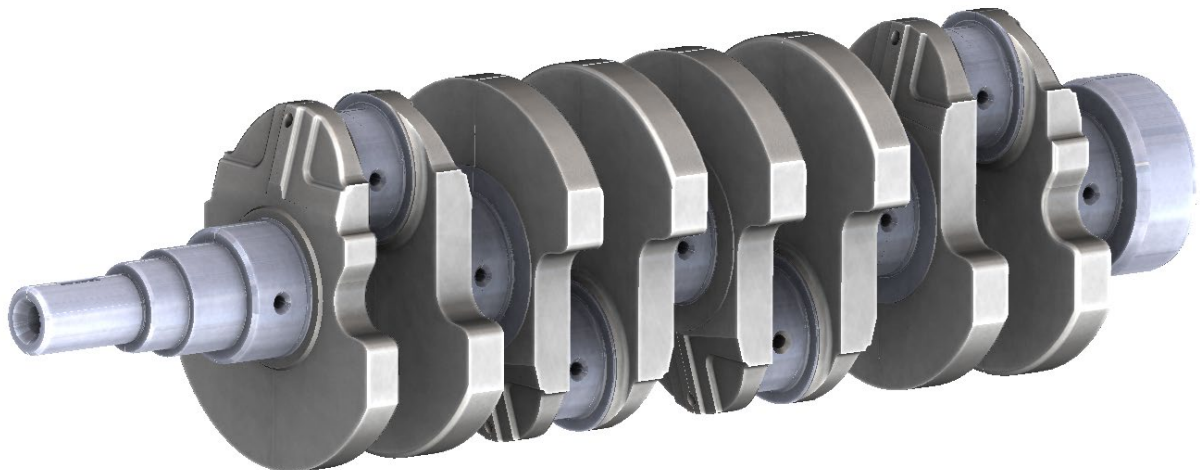


Figure 3-17 4A-GE modelled crankshaft (Evans, 2019)

To compare dimensions of the cranks to see how both differed the author sectioned the cranks to create a model where one half of each crank model mated to the faces of the centre of each crank, (see fig-17). This represented how the cranks would sit in the 4A-GE block as the crank was constrained laterally by a set of thrust washers located at the centre main bearing. From figure 17 notice how, the cranks differ on the flywheel side (left hand side), the faces are offset which is discussed in chapter 4.3 Flywheel design.

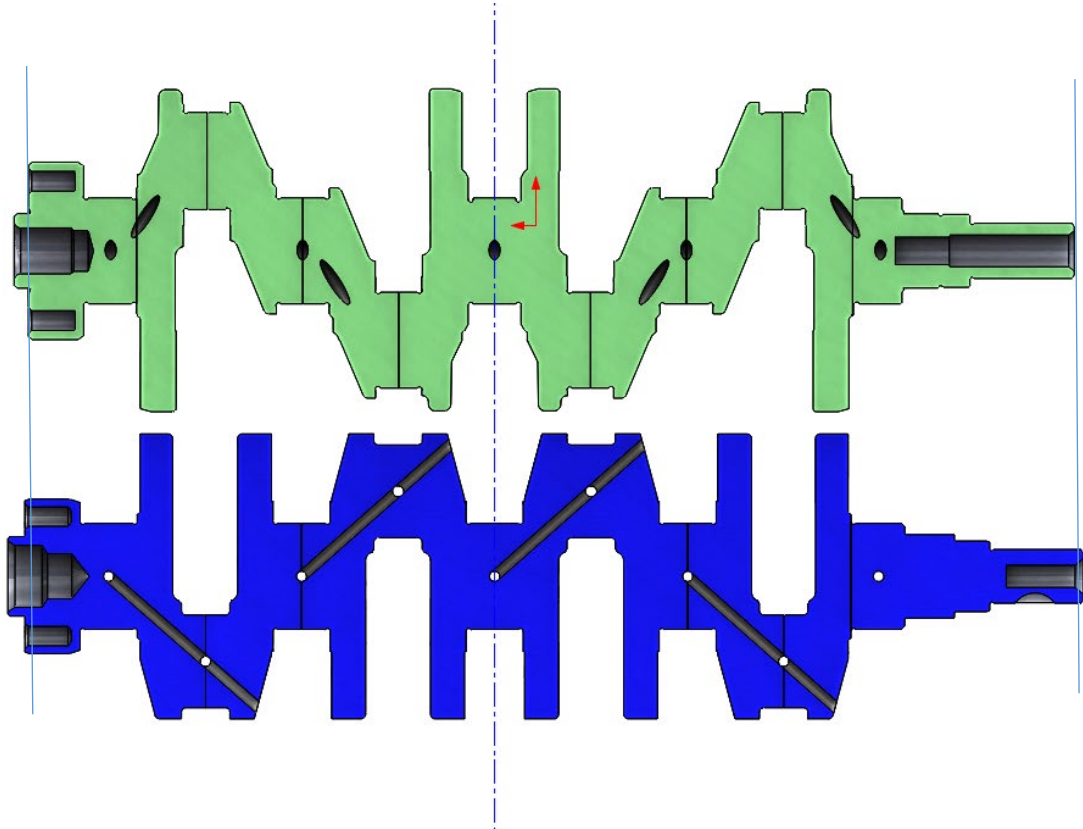


Figure 3-18 section view of both crank centres at centre main. Notice the difference in Counter webs and oils gallery drillings. (Evans, 2019)

3.6.3 The Pistons

The piston of the Ecoboost was not modelled as the Ecoboost bore is smaller at 79mm and had a different crown as it was destined for a direct injection application. The author had modelled the original 4A-GE along with the Suzuki Hayabusa piston. The model of the Hayabusa piston has been modified to use the same piston crown area as the 4A-GE with the same compression height so it can be used as a possibility although it is not an off the shelf option it has shown that the lighter piston would be more favourable than the heavier 4A-GE.



Figure 3-20 4A-GE Piston Modelled in Solidworks (Evans, 2019)



Figure 3-19 Modified Hayabusa piston (Evans, 2019)

3.6.4 The 7A-FE Block

The author had access to a 4A-GE block to model in Solidworks. However, no access to a 7A-FE block so the decision was made to use the 4A-GE block as a base to allow model to be drawn, from this the author could then modify the model to suit the measurement of the 7A-FE block which had been acquired from reputable source.

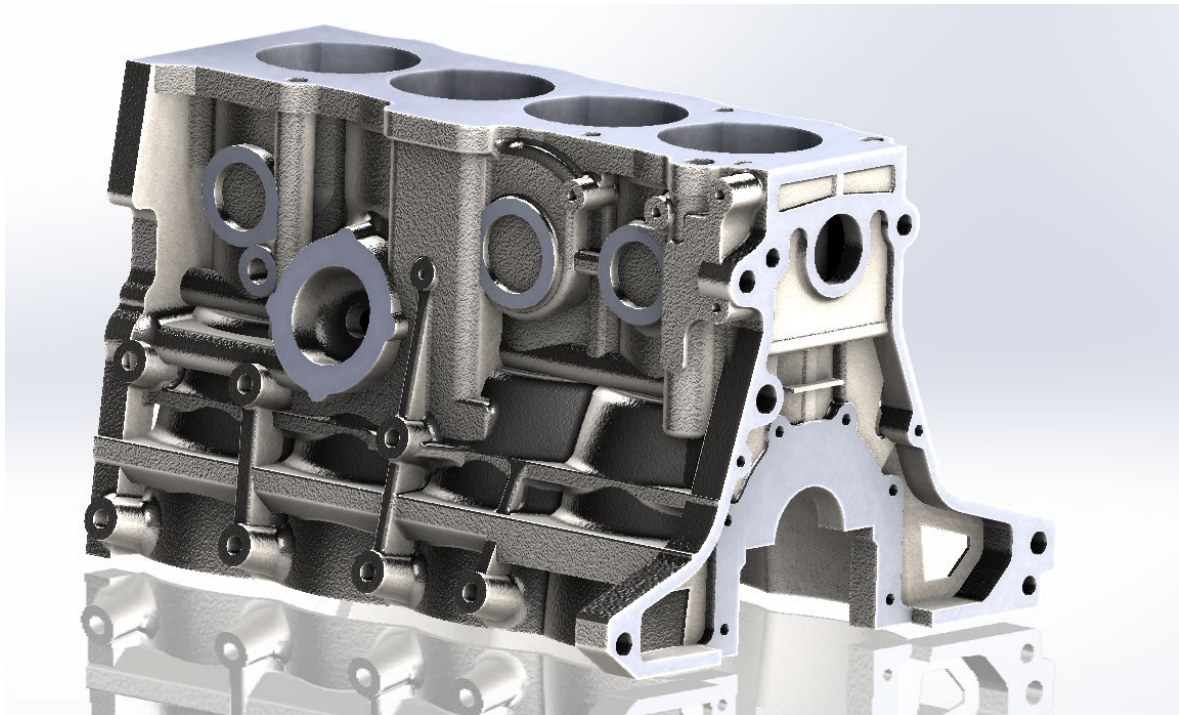


Figure 3-21 7A-FE block modelled using 4A-GE dimensions

4 DESIGN CONSIDERATIONS

With the CAD models complete there are some issues regarding the fitment of the Ecoboost crank Pistons & Conrods. The author has addressed these issues as follows;

4.1 BORE SPACING

The engines have a slightly different bore space by 0.5mm (see table 6) this presents an issue where the conrod will not sit central to the piston (see fig 4-1). Although this is a very small measurement of 0.75mm on the outer pistons and 0.25mm on the inners it will create a moment about the conrod meaning a possibility of unequal force from the combustion gas acting on the piston causing a possible excessive wear issue on the rings and skirt due to increased friction. A solution to overcome this negative issue is to reposition the bores by offset re-boring. Measurements taken from the centre main bearing location outwards were recorded to calculate the differences (see table 6).

by re-boring the block the piston size would increase to 83mm, increasing displacement further by 84cc overall and therefore increasing torque further.

Table 6 Bore spacing difference where the 4A-GE is 87.5mm & Ecoboost 87mm

	Bore 1	Bore 2	Centre Main	Bore3	Bore 4
4A-GE	131.25mm	43.75mm	0mm	43.75mm	131.25mm
Ecoboost	130.5mm	43.5mm	0mm	43.5mm	130.5mm
Difference	0.75mm	0.25mm	0mm	0.25mm	0.75mm

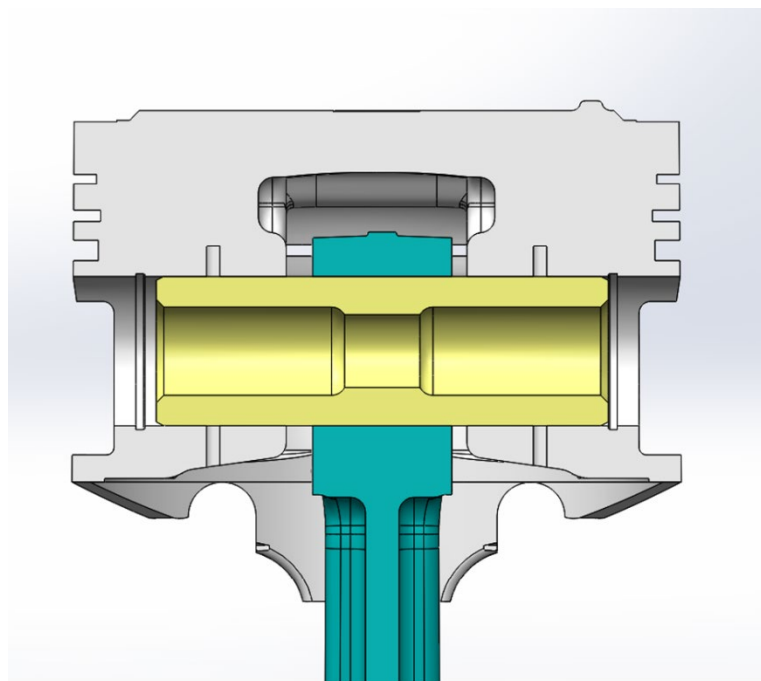


Figure 4-1 section view of 4A piston and Ecoboost rod, notice rod is offset to the right (Evans, 2019)

The difference in length of the offset will induce a moment which will be unequal as show below;

4.2 REAR OIL SEAL HOUSING

The Ecoboost crank has a larger diameter flange for the flywheel which means the 4A-GE rear oil seal housing is too small to be used as it not possible to increase the size of the oil seal hole (see Fig4-2). A new piece would need to be made so the author modelled one suitable in Solidworks and 3d printed a sample to prove design. (see Fig4-2). The author sized and sourced a suitable oil seal for the application as the originals would not fit due to the newly designed oil seal housing. More info on seal selection can be found in appendix. The size required was 100mm*80mm*10mm and can be seen fitted to crank and housing.

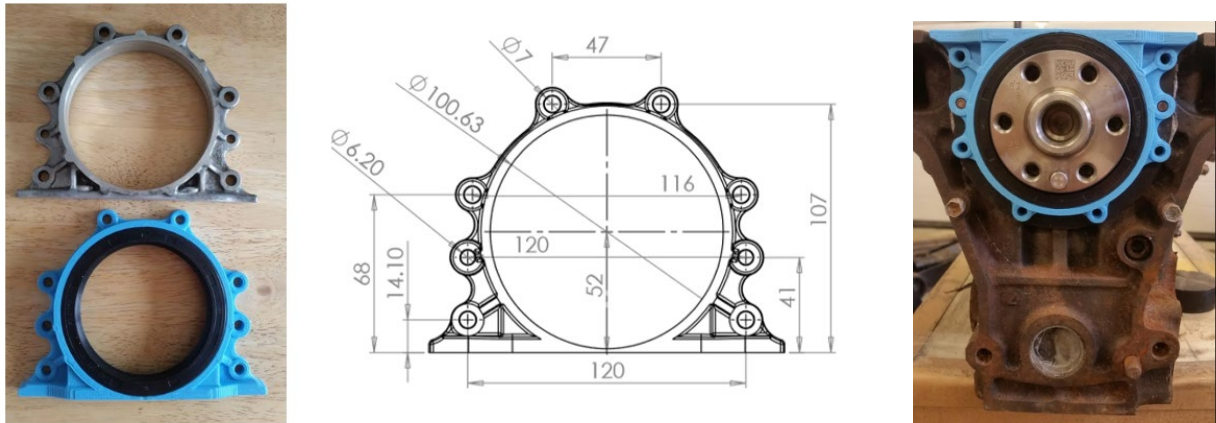


Figure 4-2 Original oil seal housing was too small. A new part needed to be modelled, 3d printed prototype proved fitment. Middle image, a dimensioned drawing, for a detailed Engineers drawing see appendix. On right 3d printed part fitted on block with oil seal. (Evans, 2019)

4.3 FLYWHEEL DESIGN

The flywheel used in the project was believed to be an Ecoboost flywheel, however later research concluded it belonged to an earlier naturally aspirated sigma/zetec engine. The Ecoboost is mated to a Dual Mass Flywheel in standard form which has a much larger mass than the sigma (6.7kg) whereas the DMF is a hefty 11.6kg. (titan.uk.net, 2018) see appendix for details.

With the main aim of the project is to reduce the rotating mass and a large contributor to the rotating mass is the standard flywheels and this mass is required to smooth out the firing intervals from the engine and as the engine now resides in a car which is track focused this absorption of firing intervals is not an issue so the use of a lightened flywheel is preferred as this will aid the projects goal. The dimensions differed on the flywheel side of both cranks, the Ecoboost flywheel mounting face was shorter than the 4A-GE face when comparing dimensions from the centreline of centre main bearing of the cranks (see fig 4-3). This would mean the flywheel would set the clutch too far away from the concentric slave cylinder causing a possible incorrect clutch operation. This problem makes both flywheels differ considerably making them both unusable, main differences include;

- PCD of hub face – the ford uses 6 bolts to secure the flywheel to the crank the 4A-GE uses 8 bolts to cope with the higher maximum revs.
- Starter ring gear offset is different so would place the ring gear in incorrect position.
- Diameter of the flywheel & ring gear of Ecoboost is larger than 4A-GE which fouls the Toyota gearbox bell housing.

This problem required a new design of flywheel which needed to;

Design Considerations to Reduce Mass of Engine Internals

- Account for the new offset mentioned.
- Allow the use of the original clutch setup
- Maintain the same diameter and position as the original ring gear on the 4A-GE.

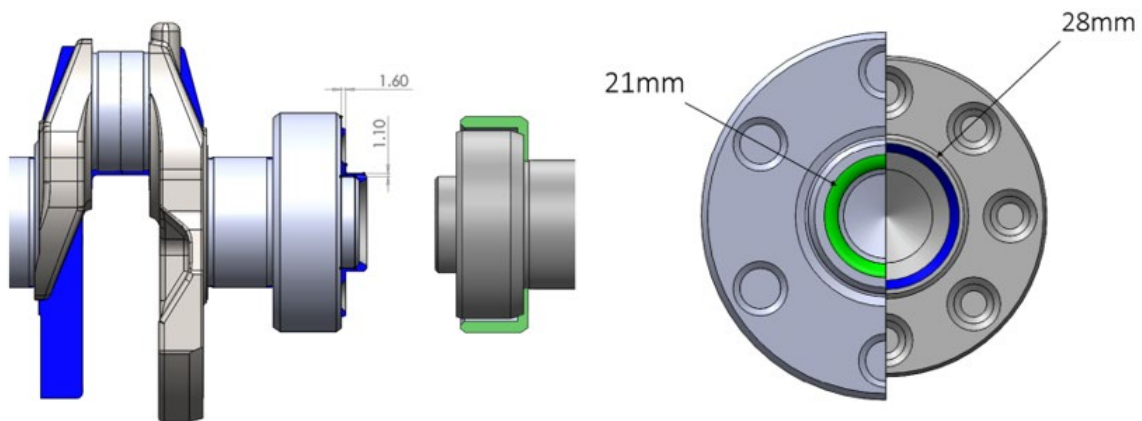


Figure 4-3 Solidworks half models of each crank mated together to show variations in design (Evans, 2019)



Figure 4-5 Actual DMF belonging to an Ecoboost. (ebay.co.uk, 2019)



Figure 4-4 Ecoboost aftermarket Solid flywheel to replace the original dual mass flywheel. (ttvracing.com, 2019)



Figure 4-6 New design of flywheel to required dimensions of hybrid 4A-GE see appendix for Engineers drawing (Evans, 2019)

Table 7 Dimensions of spigot bearing from 4A-GE crank with required size for Ecoboost.

	D	d	B
4A-GE	28mm	12mm	8mm
Ecoboost	21mm	12mm	-

The 4A-GE utilises a spigot bearing to support the gearbox input shaft of the rear wheel drive gearbox. The aperture on the Ecoboost crank does not allow the fitment of a suitably sized bearing. The only option is to have the crank machined out to the correct size of the original bearing in the 4A-GE crank

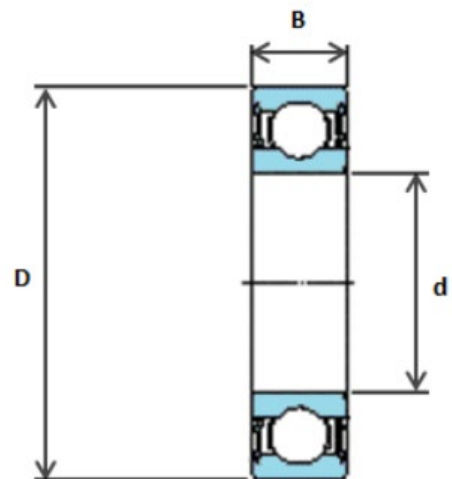


Figure 4-7 Bearing dimension guide, (bearingboys.co.uk, 2019)

4.4 MAIN BEARINGS

The main journals on both cranks are a diameter of 48mm but differ in width with the 4A-GE being wider (see table) the author believes the Ecoboost has narrower main bearings is to reduce friction while allowing for a slightly narrower crank overall to aid with modern demands of packaging. This presented an issue as the 4A-GE bearings being wider by 4mm would see the bearings overlapping the contact surface and nearing the outer radii of the fillets. Another issue was presented as the original Ecoboost main bearing shells could not be used as a retrofit item as the wall thickness of the bearings were too deep.

Research into bearings commenced and finding an engine bearing manufacturer called Glyco who offered their whole range of products in a downloadable PDF catalogue, the author found an alternative bearing which was deemed suitable for use. (See fig 4-8) further details can be found in the appendix. A suitable alternative was found and originally a Toyota item used in their 1zz-fe engines, the tolerances matched up correctly and the basic dimensions were acceptable.

Toyota 4AGE, 4AGZE (Incl. 20v engines) Engine Bearings

YOU ARE HERE: ENGINES/VEHICLES > TOYOTA > 4AGE 4AGZE > ENGINE BEARINGS

ENGINE BEARINGS

CON ROD BEARING SET				MAIN BEARING SET			
Part#				Part#			
4B1780H	4B1780HX			5M1695H	5M1695HX		
Sizes	STD, .025, .25, .50	STD		STD, .025, .25, .50	STD		
Oil Clearance	Standard	+ 0.001" Extra		Standard	+ 0.001" Extra		
Half Type	Identical Halves			Upper & Lower			
Material	Tri-metal			Tri-Metal			
	Hardened steel backs						
Min Std Shaft Size	1.6529" / 41.985mm			1.8892" / 47.985mm			
Max Std Shaft Size	1.6535" / 42.000mm			1.8998" / 48.000mm			
Min Std Tunnel Size	1.7717" / 45.000mm			2.0480" / 52.020mm			
Max Std Tunnel Size	1.7728" / 45.024mm			2.0492" / 52.050mm			
Max Wall at Crown	0.0585" / 1.487mm	0.0580" / 1.474mm		0.0788" / 2.001mm		0.0783" / 1.988mm	
Max Overall Length	0.673" / 17.10mm			0.784" / 19.90mm			

Notes

Diagram

(Top View)

UPPER

LOWER

<http://www.aclperformance.com.au/us/Toyota4AGZEBearingsus.htm>

THRUST WASHER SET

Part#	2T1695	Material	Aluminum Tin
Sizes	STD	Notes	Upper & Lower

Position	Pairs & PN	Pairs & PN	Quantity	Crankshaft Diameter	Housing Bore	Wall Thickness	Bearing Width
AM	AM	AM	5	47.998 / 47.988	52.001 / 52.014	1.999	16.901
MS375U	MS375L						

Figure 4-8 4A-GE Bearing dimension on left and 1zz-fe bearings on right.

4.4.1 Thrust washer problem.

As mentioned earlier regarding the narrower Ecoboost main bearings and the overall crank length meant that there was an issue with the thrust washer fitment. The cranks only use one main clamp to utilise the thrust washers as their sole intension is to keep the crank central and to restrict lateral movement from the force exerted from the operation of the clutch. The 4A-GE main journal centre locating mount was too wide for the crank to successfully fit meaning the block would require machining to accept the crank with correctly gapped thrust washers

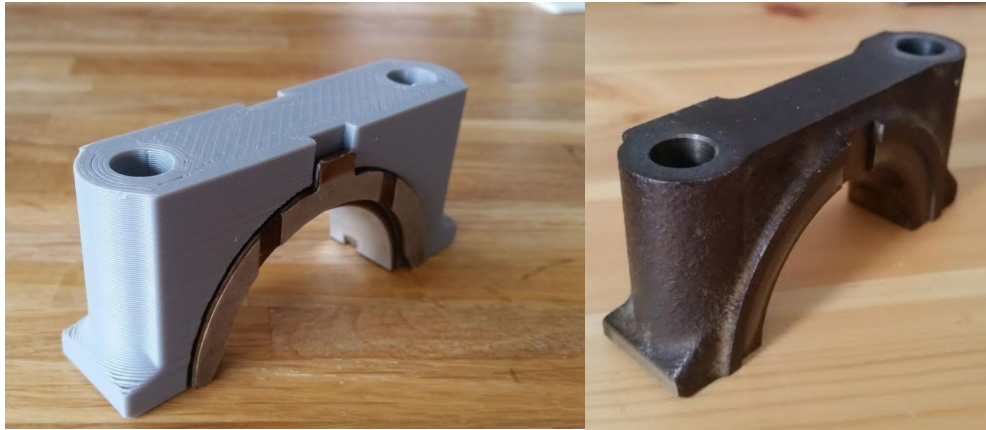


Figure 4-9 3d printed modified centre main bearing cap to allow for thrust washers to fit Ecoboost crank & original 4A-GE (Evans, 2019)

4.5 OIL PUMP

The oil pumps are driven by the front of the crankshafts and have a machined section where the oil pump impeller sits. There was a difference in locations of these sections on the both crankshaft which meant that the original 4A-GE oil pump would not fully seat on the Ecoboost crank. It was decided that an external oil pump would be an ideal solution to overcome this problem, this meant that the original oil pump would not be installed so a new blank would need to be made which could also maintain an oilway to flow the oil from the sump to the new pump then to the filter. Once modelled the author intended to print a prototype 3d model to make sure the part would fit correctly and prove design.

4.6 Analysis of components

The author produced detailed CAD models of the engine components of the 4A-GE and Ecoboost along with the 4A-GE engine block with the aim of calculating the stresses upon the components seen in each engine, this will give an idea as to how well suited the components would be, the main component of concern is the conrod. Originally the authors aim was to use the 2nd generation Ecoboost conrod due to its lightweight powder forged construction and also due to the fact that the author was unaware there was a 1st gen conrod available. There were concerns over the conrod structure mainly at the little end area (see fig 4-8) which were;

- Lack of material, the 2nd gen rod is of powdered forge steel which is a less dense material than forged steel. The design of the little end area is aimed at providing an extra stiff Gudgeon pin to cope with the extreme pressure seen on the Ecoboost and not ideal for higher rpm application
- Lack of bronze bushing for Gudgeon pin, the Ecoboost uses no bronze bush as the Gudgeon pin is “Diamond Like Coated” making it a hard surface so a bronze bush is omitted along with the oil hole for lubrication. This makes it even less ideal for the Hybrid 4A-GE.



Figure 4-10 pictured left, 1st gen Ecoboost rod & right, a 2nd gen rod.

So, the discovery of a 1st gen Ecoboost conrod which used forged steel for construction is an ideal option for a higher rpm with a downside of a heavier mass. To ensure it can endure the expected higher rpm and extra mass from the use of the 4A-GE pistons calculations of the conrod needed to be completed. For this the rod was split up into sections to allow critical areas to be assessed. See fig 4-11.

4.6.1 Crankshafts

As the crankshafts from both engines rotate at different maximum RPM's the author needed to some investigation into whether the Ecoboost crank would be able to endure a higher than standard Max RPM. Though research proves the standard cranks are capable of up to 8500Rpm (see appendix 8-11) according to (pumaspeed.co.uk, 2019). The new maximum RPM of the Hybrid should theoretically be approx. 7400. Which should be safe, however calculations shall be made to prove this, the calculations shall include bending stress with fatigue followed by a factor of safety.

The tensile forces seen by the crank are to be taken as the inertia caused by the reciprocating mass along with the inertia from the rotating mass and the calculations take into account the max RPM of 7400.

Reciprocating mass is taken as 1/3rd of the conrod plus the piston mass (including Gudgeon pin & rings). The rotating mass is considered to be the 2/3rd of conrod plus the 2 bolts and 2 big end bearings, minus the big end cap.

$$Finertia = M_{Rec}(R\omega^2\cos\theta)) + \left(\left(\frac{R}{l}\right)R\omega^2\cos2\theta\right)$$

As max inertia force will occur at TDC we can replace $\cos2\theta$ with a 1.

Therefore;

$$Finertia_{rec} = 0.583(0.0407 * 775^2)) + \left(\left(\frac{0.0407}{0.134}\right) * 0.0407 * 775^2 * 2\right)$$

Inertia force for reciprocating mass = 29101 kgm²

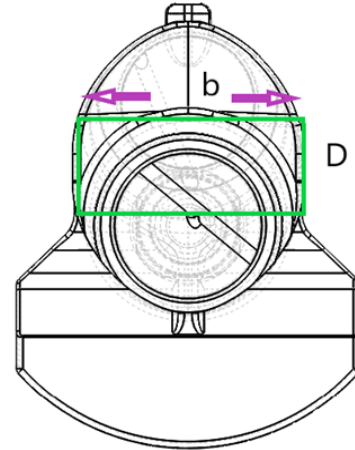
Design Considerations to Reduce Mass of Engine Internals

$$Finertia_{rec} = 0.211(0.0407 * 775^2)) + (\frac{0.0407}{0.134}) * 0.0407 * 775^2 * 2)$$

Inertia force for rotating = 20007 kgm²

First the 2nd moment of inertia can be calculated.

Now the bending moment must be calculated @ point A as it endures maximum downforce from the combustion



$$b = \frac{\text{main} + \text{crank pin diameter}}{2} \\ \frac{48 + 44}{2} = 46$$

$$D = \text{crankweb thickness} = 21\text{mm} \\ I = \frac{bD^3}{12} = \frac{46 * 21^3}{12} = 35500.5\text{mm}^4$$

Calculation Results	Ecoboost	CA	Hybrid	4AGE
Max Pressure (N/M^2)	9560600.00	18	6710300.00	6710300.00
Max Fgas (N)	46862.91	15	34578.16	34578.16
Max Finertia (N)	15577.75	-360	18585.66	18490.10
Max Fnet (N)	32702.29	19	17131.57	17235.36

Figure 4-12 results from excel model

Point A @ Tdc

The bending moment at point A is calculated by multiplying half the inertia force by the length from centre of main bearing to outer edge of big end bearing, where the fillet is situated.

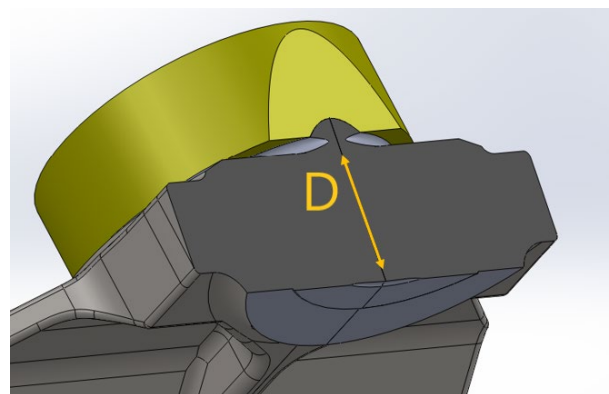


Figure 4-11 Simple Beam Idea for calculations

Design Considerations to Reduce Mass of Engine Internals

$$M = \left(\frac{F_{net} * R^2}{2} \right)$$

Figure 4-13 Sectioned view of crank for D of second moment of area (Evans, 2019)

$$M = \left(\frac{17131 * 31.5}{2} \right) = 269813.3 \text{ Nmm}$$

Bending stress;

$$\sigma_B = \frac{My}{I} = \frac{* 10.5}{35500.5} = 107.53 \text{ N/mm}^2$$

Shear stress;

$$\sigma_\tau \text{ at Point A} = \frac{11542}{\frac{\pi * 44^2}{4}} = 7.6 \text{ N/mm}^2$$

Resultant stress;

$$\sigma_R = \sqrt{107.53^2 + (2 * 7.6)^2} = 108.6 \text{ N/mm}^2$$

Now the Inertia forces @tdc ;

Bending Moment;

$$M = \left(\frac{12212 * 31.5}{2} \right) = 192339 \text{ Nmm}$$

Bending Stress;

$$\sigma_B = \frac{My}{I} = \frac{192339 * 10.5}{35500.5} = 56.89 \text{ N/mm}^2$$

Shear stress;

$$\sigma_\tau \text{ @Point A} = \frac{6109.25}{\frac{\pi * 44^2}{4}} = 4.03 \text{ N/mm}^2$$

resultant stress;

Design Considerations to Reduce Mass of Engine Internals

$$\sigma_R = \sqrt{56.89^2 + (2 * 8.03)^2} = 57.03 \text{ N/mm}^2$$

Maximum & minimum Stress;

$$\sigma_{Max} = 107.53 \text{ N/mm}^2$$

$$\sigma_{Min} = -70.14 \text{ N/mm}^2$$

mean stress;

$$\sigma_{mean} = \frac{210.33 + (-70.14)}{2}$$

$$\sigma_{mean} = 70.1 \text{ N/mm}^2$$

range of stress;

$$\sigma_{Range} = 210.33 - (-70.14)$$

$$\sigma_{Range} = 280.47 \text{ N/mm}^2$$

The endurance limit was now calculated from that a Goodman diagram could be completed.

The material of the crank is believed to be spheroidal graphite and has a UTS of approximately 750N/mm². For the radius factor, the Kt values will be assumed to be 1.6. again, the endurance limit will use the value of 0.45*750 = 337.5N/mm².

$$\text{So; } \quad \text{Final Endurance limit} = \frac{337.5}{1.6} = 210.9 \text{ N/mm}^2$$

Bending Moment;

$$M = \left(\frac{14550.5 * 31.5}{2} \right) = 229170 \text{ Nmm}$$

Figure 4-14 2nd moment of area dimension (Evans, 2019)

Bending Stress @ point A;

$$\sigma_B = \frac{My}{I} = \frac{229170 * 10.5}{35500.5} = 67.78 \text{ N/mm}^2$$

Design Considerations to Reduce Mass of Engine Internals

Shear stress;

$$\sigma_{\tau} @ Point A = \frac{14550.5}{\frac{\pi * 44^2}{4}} = 9.57 \text{ N/mm}^2$$

resultant stress;

$$\sigma_R = \sqrt{67.78^2 + (2 * 9.57)^2} = 70.43 \text{ N/mm}^2$$

Maximum & minimum Stress;

$$\sigma_{Max} = 210.33 \text{ N/mm}^2$$

$$\sigma_{Min} = -70.43 \text{ N/mm}^2$$

mean stress;

$$\sigma_{mean} = \frac{210.33 + (-70.43)}{2}$$

$$\sigma_{mean} = 69.95 \text{ N/mm}^2$$

range of stress;

$$\sigma_{Range} = 210.33 - (-70.14)$$

$$\sigma_{Range} = 280.47 \text{ N/mm}^2$$

5 CONCLUSION

The authors work to date shows there is much involved in the initial idea of retro fitting an alternative crank from another ICE. Initially the authors idea was to compare both engines to see how both differed, being from different eras it was clear to see how little the components have changed regarding the basic principles. What was noticed however, was the difference in masses of components which prompted the authors initial idea of implementing the Ecoboost crank. As the 4A-GE crank was a forged steel material it could be regarded as stronger but comes with a downside of being heavier compared to a spheroidal iron type like Fords Ecoboost crank however the Ecoboost one has been considered fit to use in a turbo application where it sees large pressure charging and from the research conducted engine tuners claim over 400BHP on the standard crank which is impressive.

The author believes that the idea has led to a better understanding of the requirements for the design of engine components, and how each detail will have an effect on others, the idea of implementing the ford crank into the Toyota engine has given a great insight into the thought and design of the engine as a whole package. The initial project idea of using the EcoBoost crank in the 4A-GE was meant to be a reality however, it is unlikely that it will be so. Mainly due to the many considerations and alterations that need to be done to allow a perfectly functioning engine. concerns include the main bearing locations due to the bore spacings being slightly different. The idea of enlarging the bore to compensate for the offset of the pistons seems reasonable but in practice it would take a lot of effort for an engine machine shop to do and this will lead to great cost. All may be achievable, but cost vs actual gain must be considered. From this the author will take valuable learning and use it to create more unique ideas.

6 FURTHER WORK

The author wants to believe the idea is still possible however, with the work completed to date proves that there is a large amount of work involved to make a fully operational engine let alone a reliable one. The cost of all the work and parts totally exceed the potential gain. Further work on the idea would include balancing the complete crankshaft to ensure the heavier pistons are not causing an out of balance effect and it would also be beneficial to create a fully working motion simulation model of the hybrid engine to see the full effects of the changes and possibly compare the results to the original 4A-GE.

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8 APPENDIX

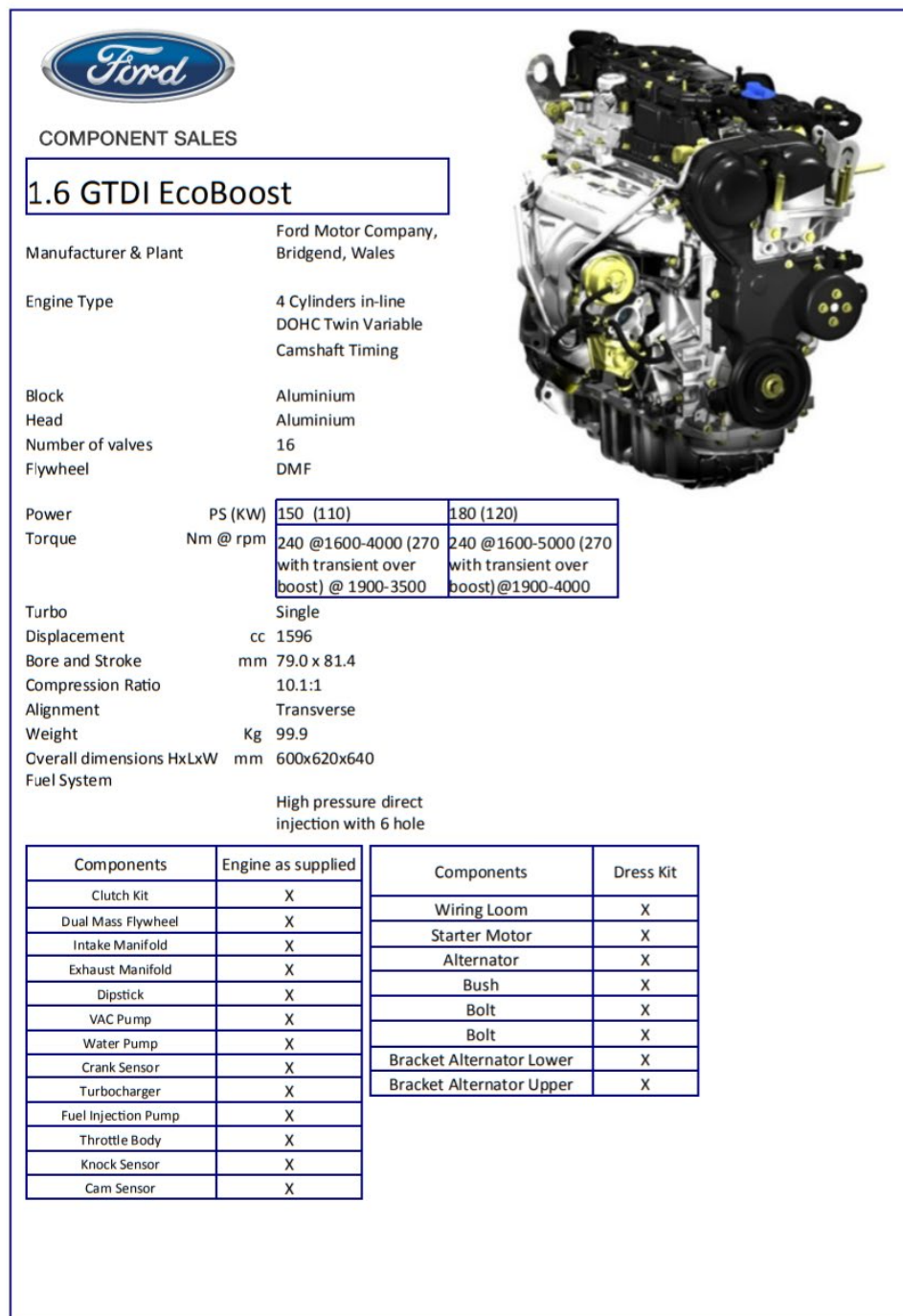


Figure 8-1 Engine data of EcoBoost from Ford (Ford-Uk, 2017)

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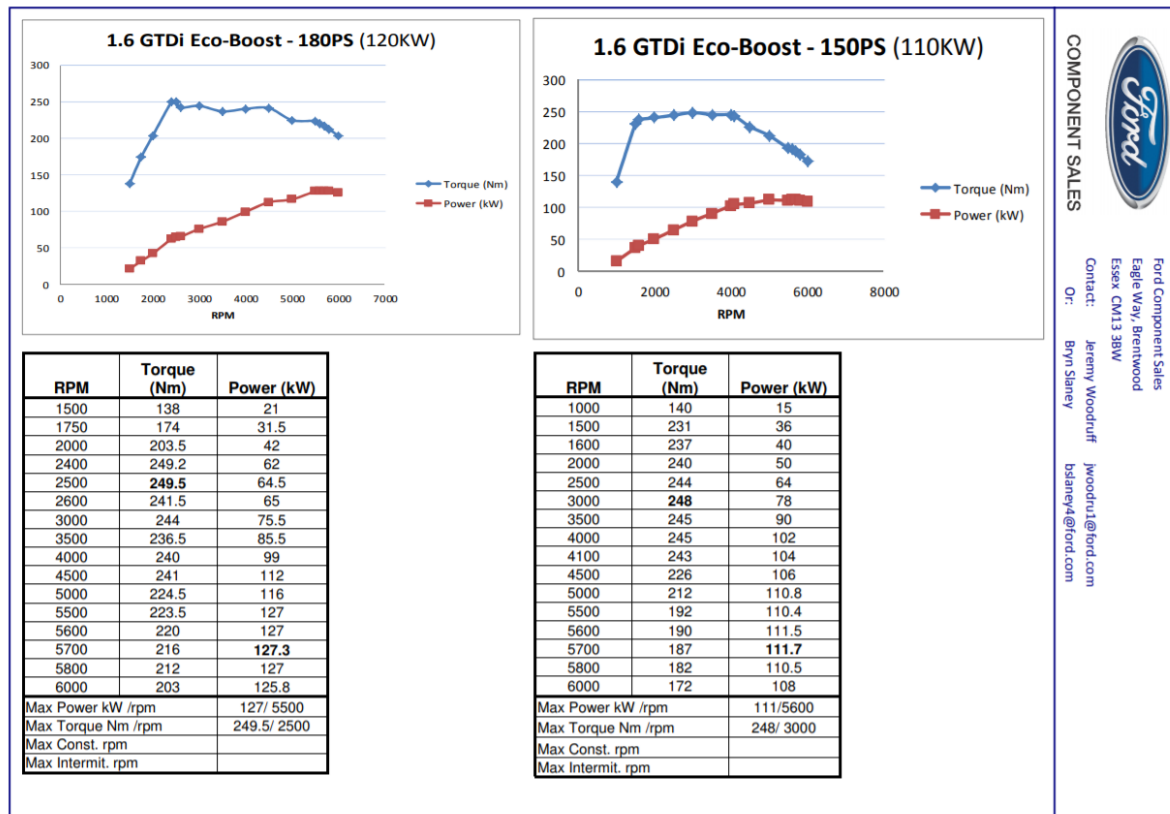


Figure 8-2 Ford Ecoboost GDi Data from Ford (Ford-Uk, 2017)

Ausferritic Spheroidal Graphite Iron (ADI)

Durham Foundry manufactures ausferritic spheroidal graphite iron, or ADI, to BS ISO 17804. Within this standard are a range of grades which can be certified by ultimate tensile strength and 0.2% proof stress in N/mm² and percentage elongation. There is no chemical data in the standard. Chemical analyses can be supplied but they would be for information only. If castings are ordered with a test certificate, a mechanical test is all that would be normally supplied unless the chemical analysis is specifically requested. The following table shows the grades that we supply as standard.

Grade	0.2% Proof Stress (N/mm ²)	Tensile Strength (N/mm ²)	Elongation (%)
BS ISO 17804/JS/800-10	500	800	10
BS ISO 17804/JS/800-10RT			
BS ISO 17804/JS/900-8	600	900	8
BS ISO 17804/JS/1050-6	700	1050	6
BS ISO 17804/JS/1200-3	850	1200	3
BS ISO 17804/JS/1400-1	1100	1400	1

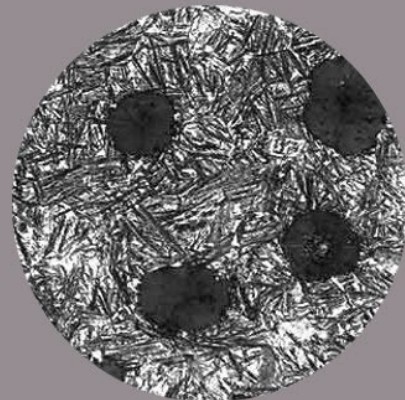


Figure 8-3 Information on Spheroidal Graphite Iron, the material used in the Ecoboost crankshaft construction.

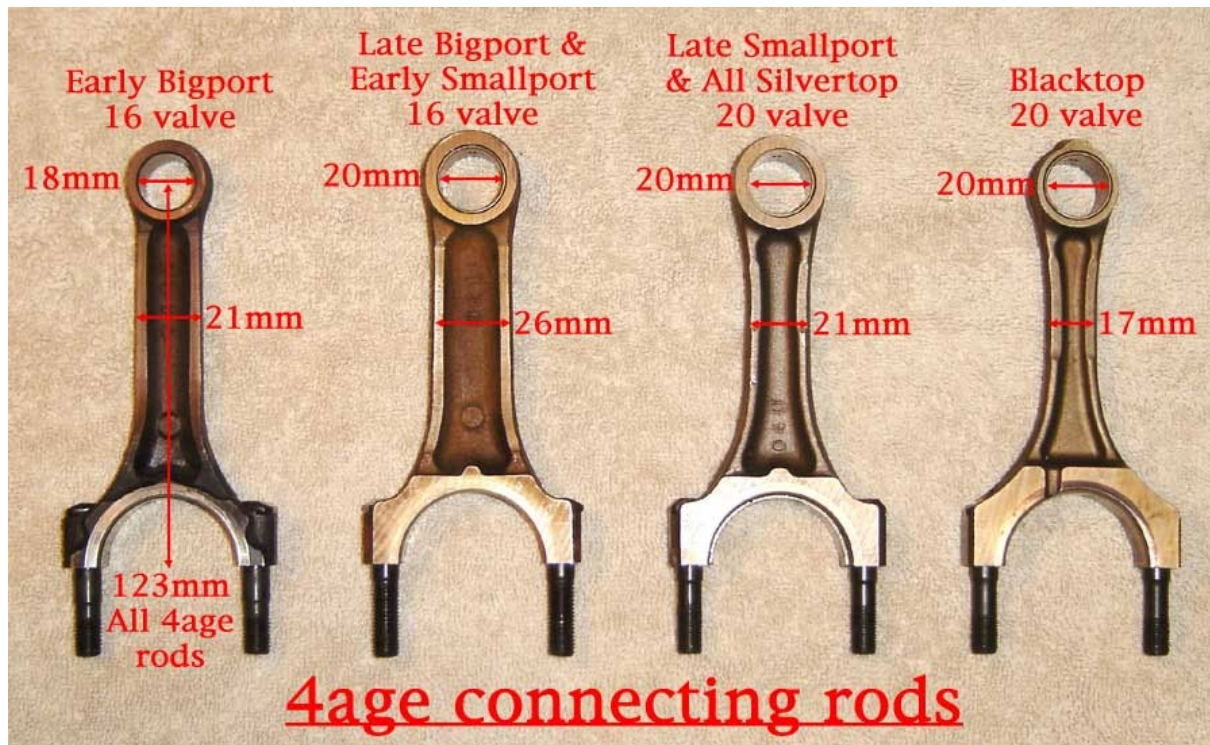


Figure 8-4 Toyota 4A-GE Conrods, different iterations with earliest on the left. Notice the difference in shank size.



Figure 8-5 Toyota 4A-GE late spec (stronger Block, more ribs) 1.6l Engine block & cylinder head

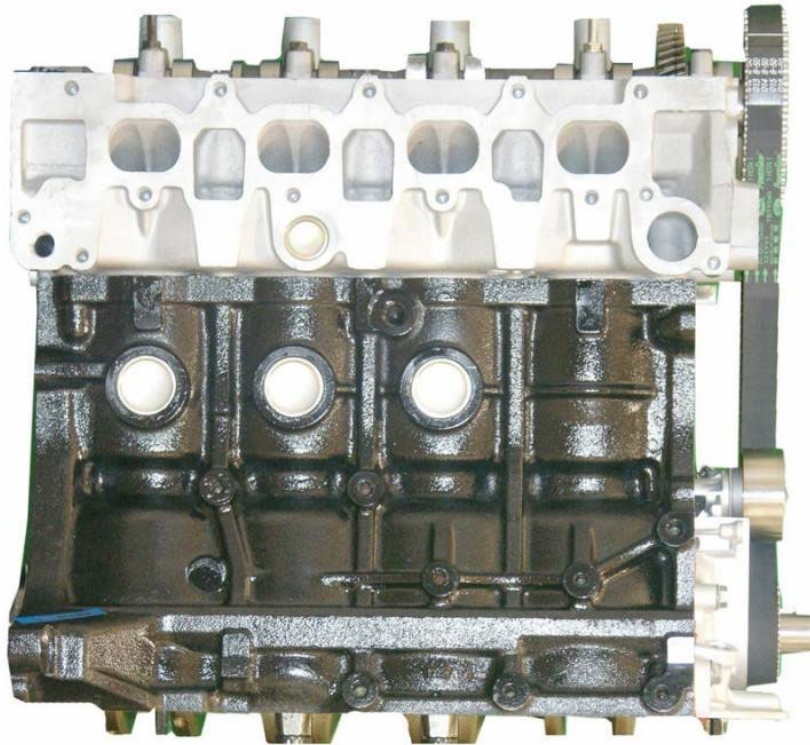


Figure 8-6 Toyota 7A-FE 1.8l engine block & cylinder head

Design Considerations to Reduce Mass of Engine Internals

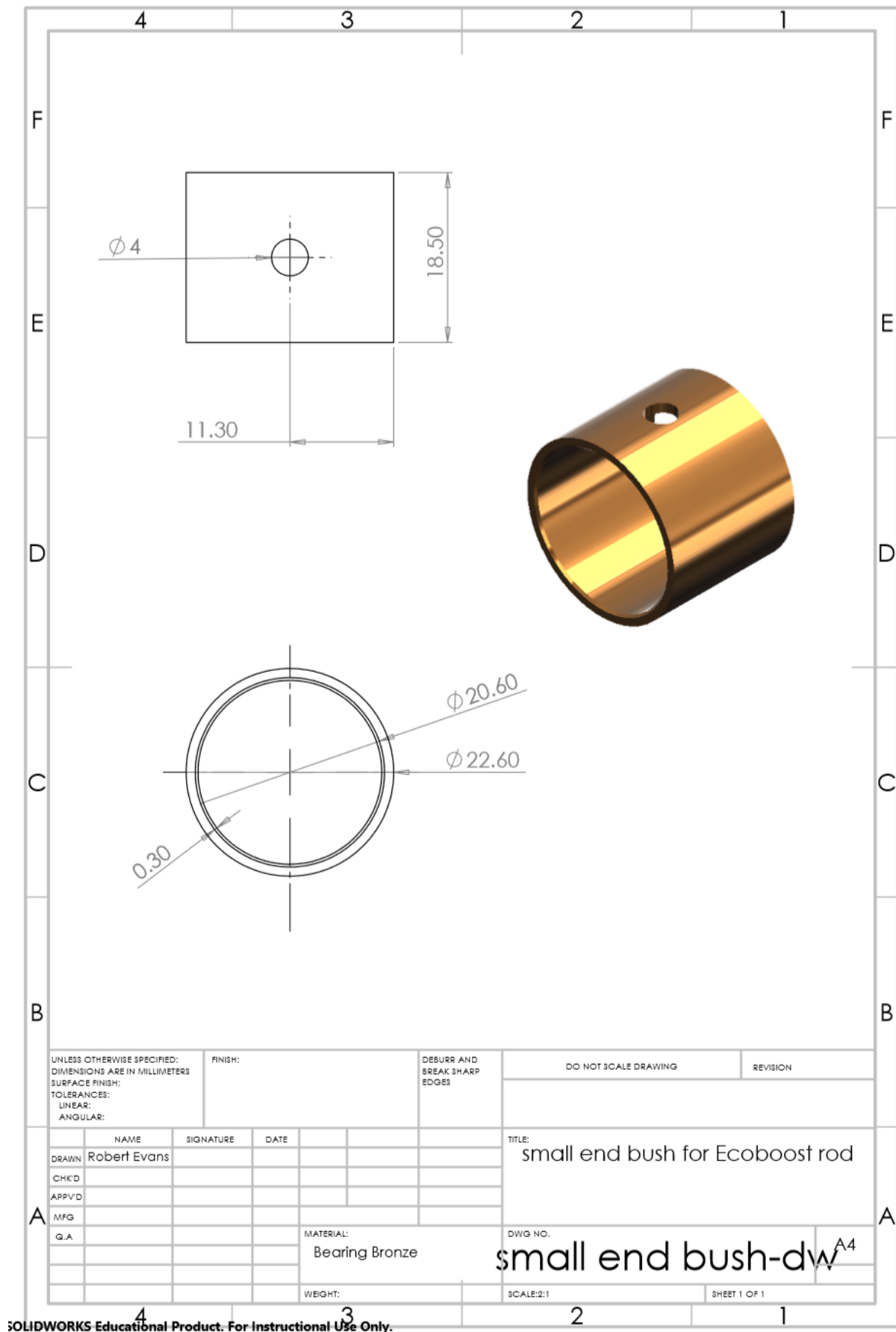


Figure 8-7 Small end bush for the fitment of Ecoboost conrod to 4A-GE piston (Evans, 2019)

Design Considerations to Reduce Mass of Engine Internals

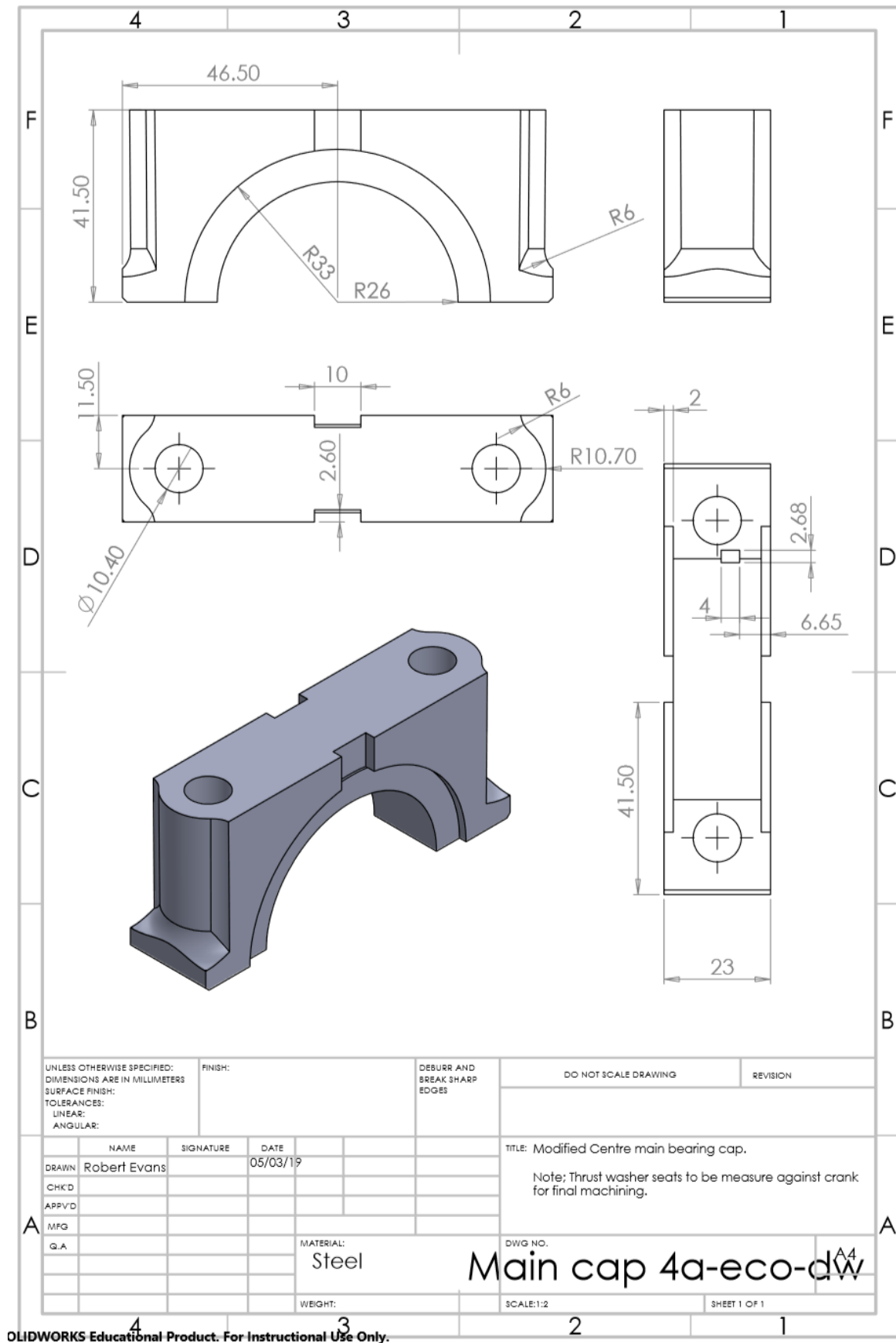
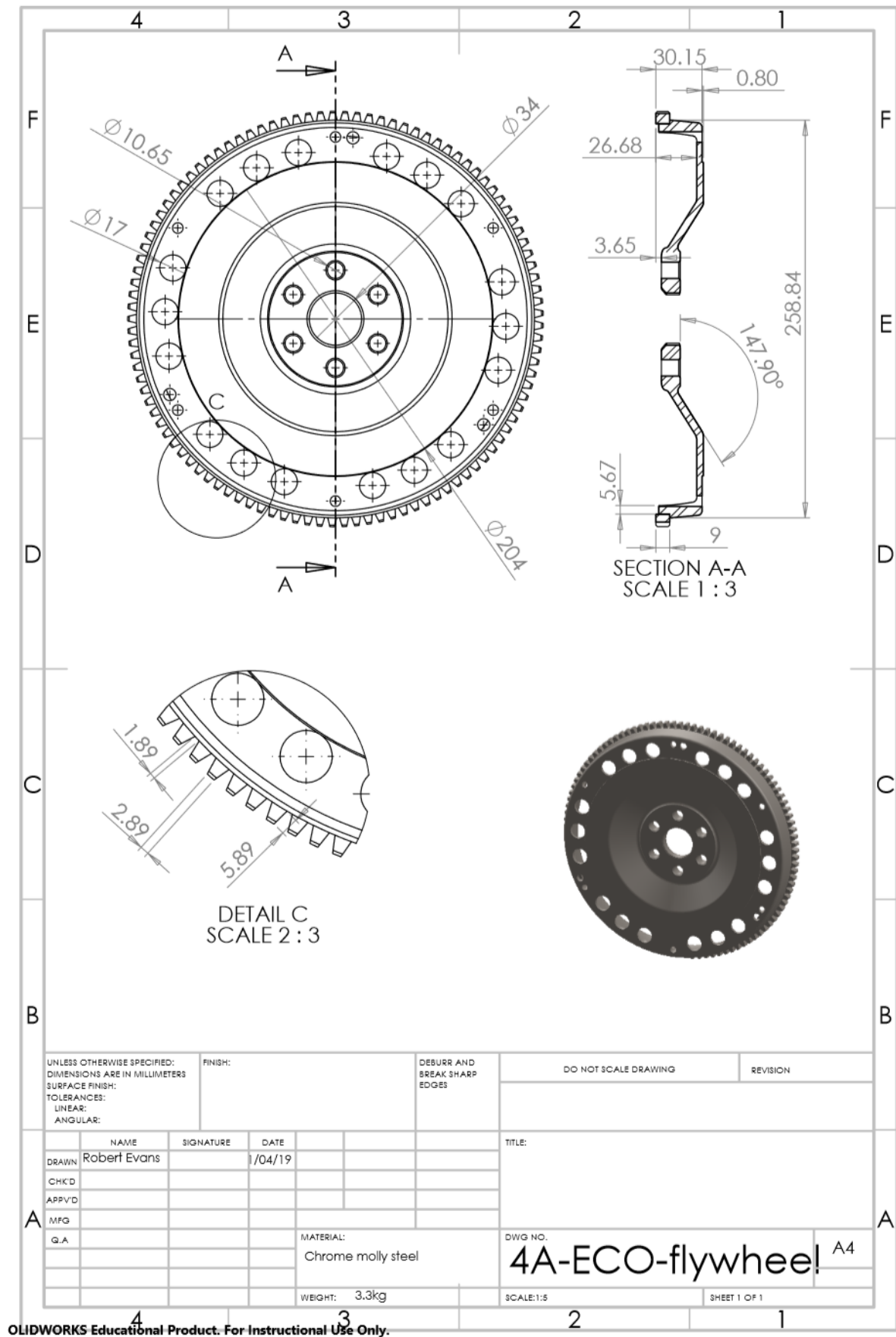


Figure 8-8 Modified Centre main cap required to allow the narrower Ecoboost crank to fitted using 4A-GE thrust washers (Evans, 2019)





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Figure 8-10 New design of flywheel for Hybrid 4A engine (Evans, 2019)

Design Considerations to Reduce Mass of Engine Internals

Our Pumaspeed Race Motors are Built with Attention to Detail Foremost. We take a customer supplied Long motor or Short motor and strip it down to check all tolerances (A Brand New Short motor can be supplied if required).

Tear Down

The Torn Down motor is then first inspected to see if there has been any deck creep as shown above (high mileage motors and those that have taken huge abuse can suffer from Deck Creep. This is where the very top 5-6mm of the Alloy Block which is unsupported between each cylinder moves and distorts. If the movement is too severe, this will be reported to the customer).

We then take the usable Block to the Hot Tank and clean it to remove all traces of Debris and Grease. The Block Deck is then micro re-surfaced and the Pumaspeed Block Mod installed. (Used cranks are measured and micro polished to maintain Stock Ford Tolerances, Pumaspeed do not use re-cut / re-ground cranks).

Engine Sleevling

The 1.6 EcoBoost Block has a weak spot as shown above, the manufacturing process allows the very top of the Block to distort between each Piston. Pumaspeed are changing at least one or two engines a week at the moment, and the main failure is the top area on the block, together with this problem we have also seen a few liner cracks. To overcome this whole issue we have specially commissioned a new Ductile Cast Liner (ASTM 536 - 84) with over 50% more thickness to cope with massive Boost and Stresses at very high revs. These Liners travel from the very bottom of the cylinder to the top with no Alloy left on the top, so no distortion, no flex and no gasket sealing issues.

Closed Deck

If the Sleevling option just isn't enough, then we have the option to fit a Closed Deck Brace. The Closed Deck Brace is normally fitted to cars that have Head Gasket issues associated to the top of the Cylinder Liner Flexing. Our experience building these motors since 2012 has shown us that this Closed Deck System has limited value as the Head Gaskets do not fail due to the Deck Creeping as found on other engines (but at a much lower cost than the sleeve option we do offer it).

Engine Balancing (Blueprinting)

Pumaspeed offer a full engine balancing service. All race motors come with the 4 Pistons balance matched and each rod matched end to end and shadow balanced so each Bore receives the same weight rotating units. An additional process is to take the Stock Crank and balance this to the Flywheel (either the stock or uprated version of your choice). The extra balancing allows to safer running of high revs 8500 peak. We will need a Flywheel and or Clutch of choice to allow us to do this.

Engine Build

Using Original Ford Bearings, the Fully Balanced Internal Piston and Rod Combo are built and mated to Fresh 2 Step Honed Bores. The 2 Step Process means the very best piston ring to Bore seal is achieved.

Figure 8-11 Taken from www.Pumaspeed.co.uk, Ford tuning specialists who are able to rebuild engines to reach a high RPM of 8500 with new pistons & Rods along with balancing. It also notes that the standard crank is used, proving it useable for the 4A-GE idea providing the inertia forces from the original 4A-GE pistons allow.

Design Considerations to Reduce Mass of Engine Internals

Toyota 4AGE, 4AGZE (Incl. 20v engines) Engine Bearings

YOU ARE HERE: [ENGINES/VEHICLES](#) > [TOYOTA](#) > [4AGE](#) [4AGZE](#) > [ENGINE BEARINGS](#)

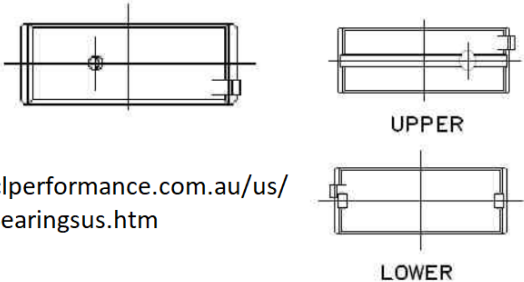
ENGINE BEARINGS					
	CON ROD BEARING SET		MAIN BEARING SET		
	Part#		Part#		
	4B1780H	4B1780HX	5M1695H	5M1695HX	
	Sizes	STD, .025, .25, .50	STD	STD, .025, .25, .50	STD
	Oil Clearance	Standard	+ 0.001" Extra	Standard	+ 0.001" Extra
Half Type	Identical Halves		Upper & Lower		
Material	Tri-metal Hardened steel backs		Tri-Metal		
Min Std Shaft Size	1.6529" / 41.985mm		1.8892" / 47.985mm		
Max Std Shaft Size	1.6535" / 42.000mm		1.8898" / 48.000mm		
Min Std Tunnel Size	1.7717" / 45.000mm		2.0480" / 52.020mm		
Max Std Tunnel Size	1.7726" / 45.024mm		2.0492" / 52.050mm		
Max Wall at Crown	0.0585" / 1.487mm	0.0580" / 1.474mm	0.0788" / 2.001mm	0.0783" / 1.988mm	
Max Overall Length	0.673" / 17.10mm		0.784" / 19.90mm		
Notes					
Diagram (Top View)					
http://www.ac1performance.com.au/us/Toyota4AGZEBearingsus.htm					
THRUSTWASHER SET					
Part#	2T1695	Material	Aluminum Tin		
Sizes	STD	Notes	Upper & Lower		

Figure 8-12 Toyota 4A-GE Main Bearing sizes



TOYOTA									
27	81.00 x 77.00								
4A-C	4 Cyl.		1587cc	52-67kW (71-91PS)		Petrol		TD3814	
4A-F	4 Cyl.		1587cc	66-79kW (90-107PS)		Petrol		TD3818	
4A-FE	4 Cyl.		1587cc	66-136kW (90-185PS)		Petrol		TD3820	
4A-GEC	4 Cyl.		1587cc	84-91kW (113-124PS)		Petrol		TD3826	
4A-L	4 Cyl.		1588cc	62-63kW (84-86PS)		Petrol		TD3831	
4A-LC	4 Cyl.		1587cc	52-58kW (71-79PS)		Petrol		TD3832	
BE/PL	8	39,990	43,020	17,100	1,491	AL-LF	64-043-1	01-4117/4 STD 0.25	
MB/HL 1-5	5	47,980	52,040	19,900	2,005	AL	63-043-1	H1068/5 STD 0.25 0.50	
MB/HL 1-5	5	47,980	52,040	19,900	2,005	AL	63-043-2		
TW/A	2	53,500	66,000		2,490	AL-LF	65-022-1	A186/4 STD	
TW/A	2	53,500	66,000		2,490	AL-LF	65-022-2		

Figure 8-13 4A-GE Main bearing data from GLYCO Bearing catalogue

Design Considerations to Reduce Mass of Engine Internals

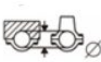
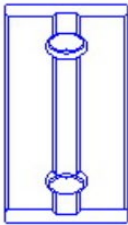
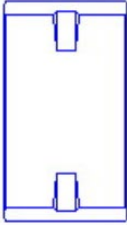
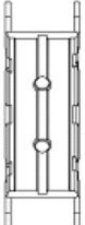
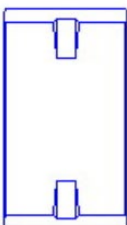
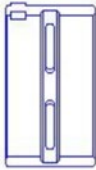
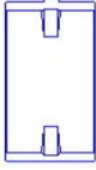
 Position	 Pairs & PN	 Pairs & PN	 Quantity	 Crankshaft Diameter	 Housing Bore	 Wall Thickness	 Bearing Width
1.2.4.5	AM 	AM 	4	48.001 / 47.981	54.021 / 54.039	3.012	16.101
3	M5009U AM 	M5009L AM 	1	48.001 / 47.981	54.021 / 54.039	3.012	23.881
	MK5009	M5009L					

Figure 8-14 Ecoboost Main Bearing dimensions. The wall thickness was too large to use in the 4A-GE Block

 MB5375AM 0.5 Oversize King Main Shell Bearings MB5375AM 0.5 Oversize For GM-TOYOTA 1.8 16V 1ZZFE- 2ZZGE							
 Position	 Pairs & PN	 Pairs & PN	 Quantity	 Crankshaft Diameter	 Housing Bore	 Wall Thickness	 Bearing Width
	AM 	AM 	5	47.998 / 47.988	52.001 / 52.014	1.999	16.901
	M5375U	M5375L					

Cross References

Make	Reference Number
ACL	5M1857

Figure 8-15 Toyota 1zz-fe main bearings, selected for width

Design Considerations to Reduce Mass of Engine Internals

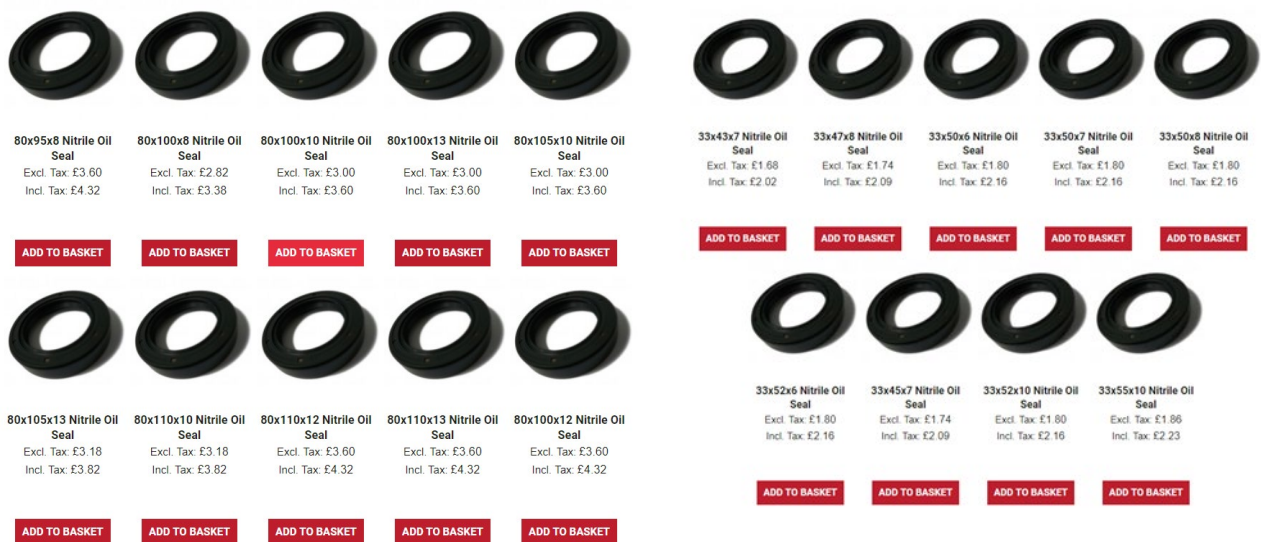


Figure 8-16 Oil seals needed to allow crank to be used in new rear oil seal housing and oil pump. <https://www.bearingsrus.co.uk/sealing-products/oil-seal/metric-oil-seals>



Figure 8-17 Toda Toyota 4A-GE from which the author has based their new designed flywheel on

Ford 1.6 EcoBoost Super Lightened Flywheel

This newly designed lightened flywheel for 1.6L EcoBoost engine boosts a drastic weight reduction of 7.8kg. While the standard dual massive unit weighs in at 11.4kg our flywheel weighs in at only 3.6kg this along with it being a single mass design eliminating moving parts increases potential problematic moving parts as well as reducing the rotating mass of the engine. This flywheel is designed to accept a 7.25Inch competition clutch which is perfect for the any racing application.

3.67kg in Weight - Single Mass Design - 7.25Inch Clutch

Part Number	Description	Price Each
E19-212-501-01-AT	EcoBoost Super Lightened Flywheel	£265.00



https://www.titan.uk.net/cdn/uploads/casestudies/112-ford_ecoboost_engine_products.pdf