



Prifysgol Cymru
Y Drindod Dewi Sant
University of Wales
Trinity Saint David

A study of data interpretation of a turbo charged system, connecting rod analysis and team management roles within a race team.

BEng Advanced Engine Design

School of Engineering

Module: Major Project

M6X00417

Compiled by Alex Brannovic-Jones

P142455

2018

‘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:

Date: 24/04/2018



A special thank you to the members of Orthrus Racing, for making my time managing the team so memorable.

And to Lara, for giving me a purpose through it all.



CONTENTS

1. Abbreviations.....	4
2. Abstract.....	5
2.1. Connecting rod development	5
2.2. Forced induction concepts	5
2.3. Team management.....	5
3. Gantt chart.....	6
4. Connecting rod section.....	7
4.1. Aims and objectives.....	7
4.2. Research and literature review	7
4.3. Worked carried out.....	8
Cosworth pistons.....	8
Honda CBR600 pistons	9
Ford sigma naturally aspirated and turbo charged connecting rods.	9
Ford Fox pistons	10
Land Rover diesel connecting rod.	11
Auto cad.....	11
Aerodynamic study of the connecting rod	13
4.4. Results	17
4.5. Conclusions	17
4.6. Further work	17
5. Turbo section.....	18
5.1. Aims and objectives.....	18
5.2. Research and literature review	18
Kawasaki H2.....	18
Yamaha Australia MT09/10 turbo	19
CBR 600 turbo.....	20
5.3. Worked carried out.....	20
Turbo calculations	22
Turbine calculations	22
Enthalpy	22
Compressor calculations	28
Compressor efficiency	29
Energy of out the compressor.....	31
Wastegate.....	35
Flow bench data	35



Intercooler	37
Concepts for forced induction Suzuki SV650.	40
Single turbo charger set-up	42
Twin turbo set-up	42
Super charger set-up	43
5.4. Results	43
5.5. Conclusion	45
5.6. Further work	46
6. Team management transfer	47
6.1. Aims and objectives	47
6.2. Research and past experience	47
6.3. Worked carried out.....	49
6.4. Results	50
6.5. Conclusion	50
6.6. Further work	50
7. Overall conclusion.....	51
8. Bibliography and References	51

1. ABBREVIATIONS

ICE – Internal Combustion Engine

AM – Additive Manufacturing

CAD – Computer Aided Design

FEA – Finite Element Analysis

ACM – Advanced Computational Methods

FoMoCo – Ford Motor Company RPM

RPM – Revolutions Per Minute

CFD – Computational Fluid Dynamics

UWSTD - University of Wales Trinity Saint David

NA - Naturally Aspirated



2. ABSTRACT

This is a three-part dissertation comprising of development work on an ICE connecting rod, a motorcycle concept design for integration of a forced induction system and management roles within a student led race team.

2.1. CONNECTING ROD DEVELOPMENT

The connecting rod is a major area of interest for ICE development. Lightweight connecting rods have a knock-on effect to a number of other ICE components i.e. required crankshaft strength, piston design, etc.

For this dissertation, a number of areas were researched in relation to the connecting rod development. Calculations for connecting rod stress and strains for required thickness, effect of the connecting rod length or overall weight on inertia forces, and horizontal acceleration calculations to name a few.

An automated CAD process in Solidworks was also started. Streamlining the process for initial connecting rod design work could save time when a new component is being considered.

Design optimisation for AM is a particular area of interest, and one that will grow within the automotive industry. ICEs are a prime area for development in this sector.

2.2. FORCED INDUCTION CONCEPTS

Forced induction has become a major focus for car manufactures over the past decade as a response to pressure from several sectors to reduce tailpipe emissions. Turbo charging in particular has gained favour, with the majority of top manufactures releasing reduced capacity turbo charged models.

“improve fuel economy as much as 20 to 40 percent in gas and diesel engines” with turbo charged vehicles (Honeywell, 2014, 8.12)

Data interpretation from a Ford Ecoboost turbocharged ICE with help gain an understanding of the parameters associated with a forced induction system. Analysis of FoMoCo data will allow for a greater understanding of the likely requirements for adapting a NA motorcycle to a forced induction system. A Suzuki SV650 is used as a basis for the project as access to the motorcycle was possible over a long period of time.

Multiple concepts for converting to forced induction will be discussed.

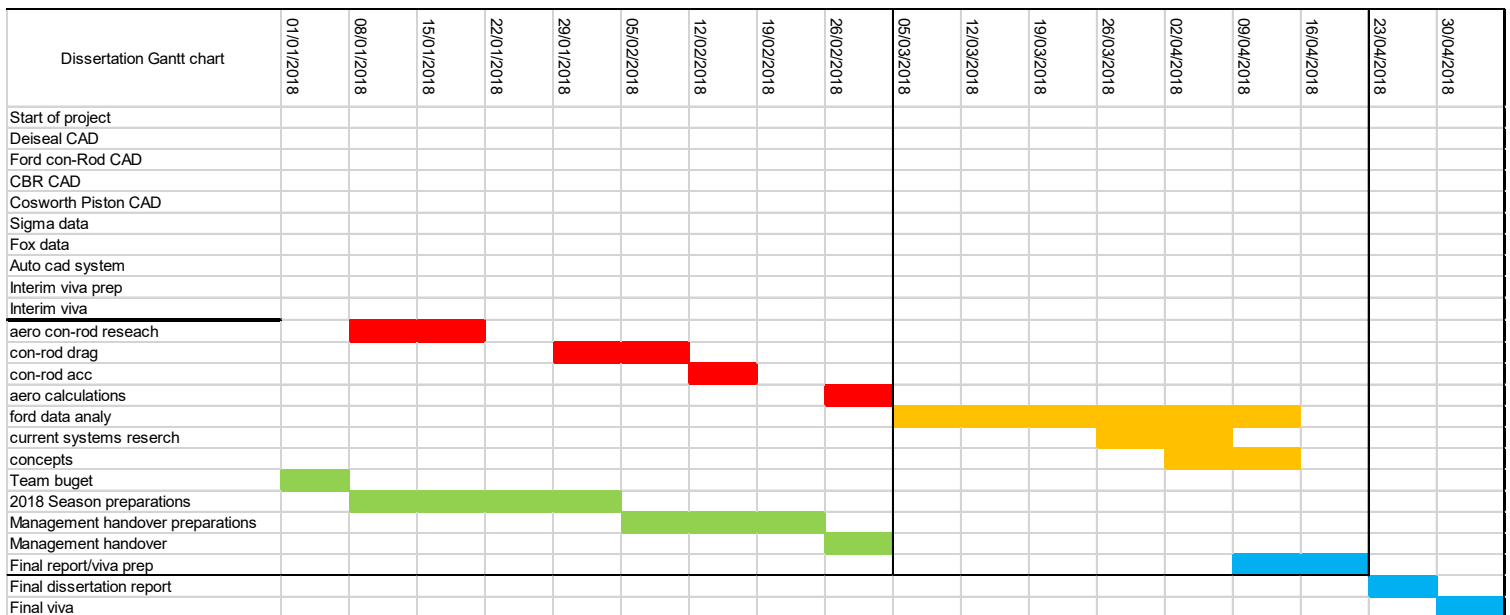
2.3. TEAM MANAGEMENT

Orthrus Racing was created in May 2015. The author has managed the team's development for nearly three years since then, growing the team significantly over that period.

This dissertation will follow the process of passing on management responsibilities to current and future member of the team, as well as preparations for the 2018 race season, including budgeting and seeking sponsorship



3. GANTT CHART



A Gantt chart is used to plan and record a project over the entire course of its running.

As can be seen, the sections in red are related to connecting rod development. This was work carried out from the start of the academic year until the end of February, which coincidentally coincided with the end of the team management transfer period (green sections). The yellow sections show the shift in focus to the forced induction portion of the project, which was carried out in the remaining two months.

Gaps in the connecting rod sections show race team obligations interrupting the project work. For example creating the team budget was reaching a conclusion by the end of January, and was



thus taking up much of the allotted time, while the first test day of the 2018 race season at Donington Park on 23rd February meant preparations took up much of the week (19th February).

4. CONNECTING ROD SECTION

Connecting rod optimisation is a major area for ICE designers to consider. The reduction in connecting rod mass can lead to a number of reductions in other ICE components due to the knock-on effect of less stress experienced. Being able to model this accurately will be derived from set parameters.

Creating 3D models, in Solidworks, of connecting rods, pistons and gudgeon pins from a number of manufactures creates a good basis to reach a general safety margin develop a new component from. These collective base parameters will form the backbone of the project.

4.1. AIMS AND OBJECTIVES

To develop a CAD system that will streamline the design process of the connecting rod and associate components (piston, gudgeon pin etc.)

To interpret real world data that will feed into this CAD system and aid in the creation of a base parameters set for a new component design. Including inputs from the user, i.e. I or H beam application, connecting rod length, bearing size (although this should be worked into the calculations at a later date)

To determine the aerodynamic effect of differing connecting rod designs. Looking at current market productions and interpreting the design used.

Taking a look at AM and its possible use in the automotive industry, particularly in terms of the wider ICE and the connecting rod.

4.2. RESEARCH AND LITERATURE REVIEW

CAD in the automotive industry (8.4-8.6). The availability of increased processing power and user friendly software applications has meant ACMS, in particular CAD and FEA, are now widely used within the automotive industry. This has allowed manufactures to produce lightweight, durable components in high tech ICEs. These simulations do not completely replace real world testing, but rather allows for a number of component designs to be put under the testing, in the understanding the software and simulate the real world reactions to a realistic degree. This process allows the manufacturer to test only the most promising designs, saving huge costs in prototype components.

Real world data. FoMoCo provided data and components, thus modelling of available components meant many parameters could be established.

Aero dynamic research of the connecting rod.
Falcon crankshaft components inc. use a 'knife' style connecting rod, used in drag racing. Limited number of 'aero' connecting rods are on the market, suggesting no advantage found by major developers. (8.7)



AM in the auto motive industry. (8.8)

Figure 1 –Falcon Knife connecting rod

“The application of 3D printing technologies, however, promises to merge rapid prototyping capabilities with the high-volume throughput of conventional manufacturing. Proponents believe that these processes may soon lead to the toolless production of finished goods and the mass production of individually customized parts” - David Bak, 2003, Rapid prototyping or rapid production? 3D printing processes move industry towards the latter

AM technology is a rapidly growing sector, with huge advantages made in the topic over the last decade. AM could produce components that are extremely lightweight weight just as strong as traditional (cast or milled) parts. This is due to areas of the component that would previously be required for the manufacturing process, not being required any more, for example draft angles for casting or areas that a milling tool cannot reach. Hollow component, or web like structures, can also be produced more freely due to the part being formed in layers. Surface finishing is often a drawback to the AM process, with post-processing often needed to produces a usable component, however with advancements in the 3D printing this is a rapidly improving area.

4.3. WORKED CARRIED OUT

The first step was to collect data to establish parameters for future component design. CAD models were created in Solidworks of connecting rods and pistons from physical examples available to the author.

To gain a good understanding of the requirments of the components a look at parts from a number of manufactours was undertaken.

COSWORTH PISTONS

A Cosworth piston was CADED (below, figure 2 and 3)

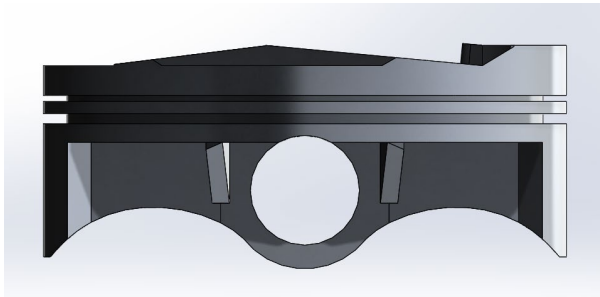


Figure 3 - Cosworth piston side view

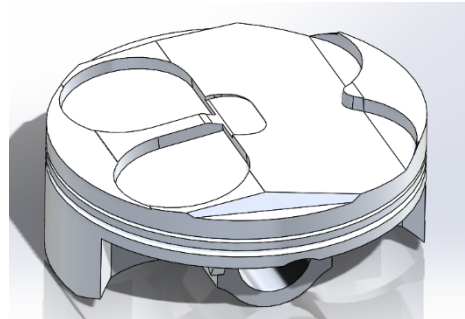
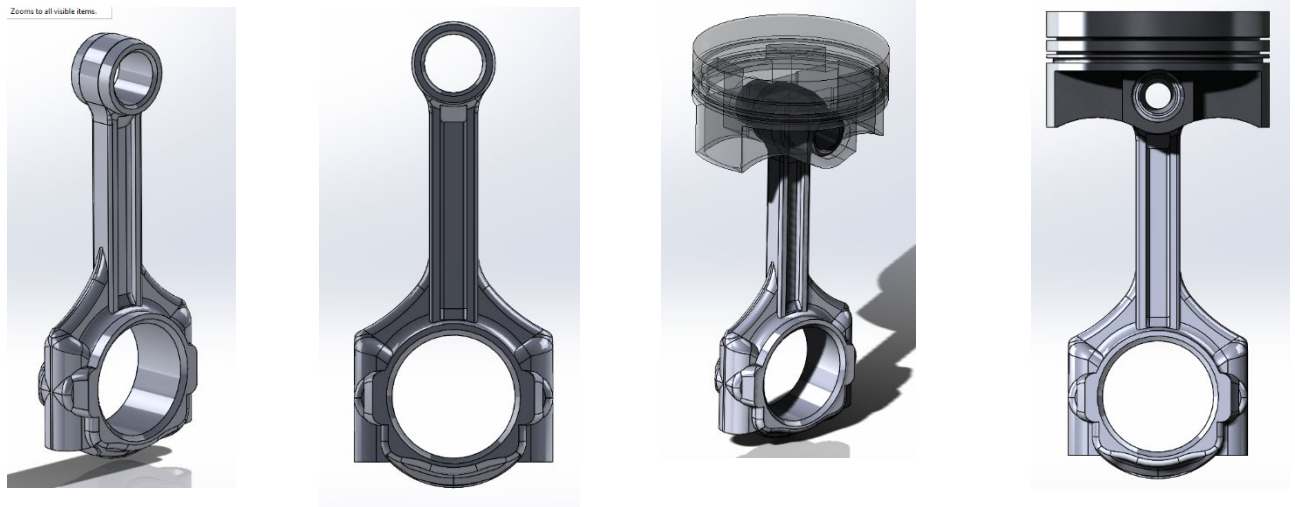


Figure 2 - Cosworth piston

This Cosworth piston is a high performance example, with aggressive valve cuts into the piston surface, short side skirts and minimum weight.



HONDA CBR600 PISTONS

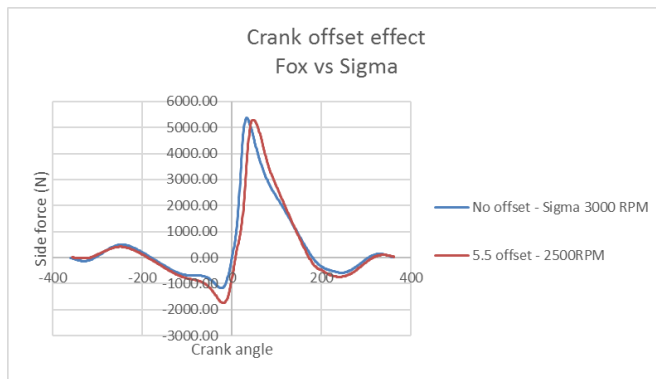


FORD SIGMA NATURALLY ASPIRATED AND TURBO CHARGED CONNECTING RODS.



Figure 4 - Comparison of Ford connecting rods.





Graph 1 - Offset effect on side thrust

The effect of chankshaft offset on side thrust force seen through the full four stroke cycle.

FORD FOX PISTONS



Figure 5 - Ford piston

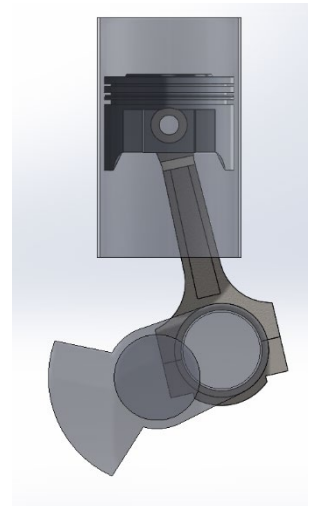


Figure 6 - complete ford assembly



LAND ROVER DIESEL CONNECTING ROD.

Note; to be able to remove the connecting rod cap the split is not perpendicular to the connecting rod axis. This is due it being a V configuration ICE. This will be weaker as a result.

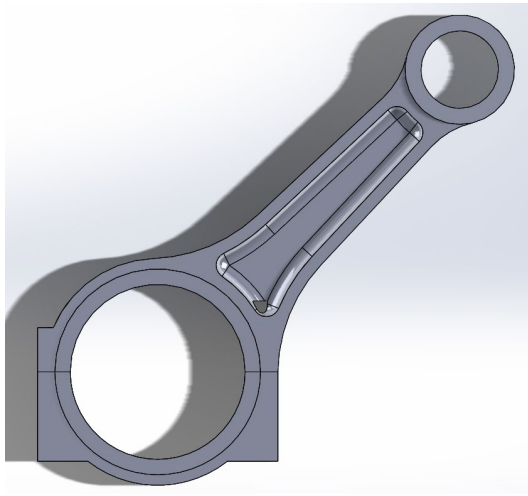


Figure 7 - JLR connecting rod

AUTO CAD

Once these CAD models were completed, a set of parameters was established. A streamlined CAD design system was started to reduce time import when first developing a component for future component designs. This was started by creating an excel worksheet of the common parameters used in each component design. This excel worksheet was then linked with Solidworks. This allowed parameter inputs to be sourced for the new component design. These parameters were created from the requirements established from the components created in CAD previously. Excel parameter outputs are based from the safety factors determined from creating CAD models from manufactures' parts. This combination of design parameters required and calculated parameters needed could then create a base model for consideration. This base model could then be refined as need to create a final component design. This process creates a base model built in the same way every time, which should mean ease of alteration by multiple people due to consistent build methods.



1 Design Table for: Auto Con-Rod 17	
2	Little end dia@Sketch1
3	Big end dia@Sketch1
4	Eye to eye length@Sketch1
5	Little end hoop thickness@Sketch1
6	Big end hoop thickness@Sketch1
7	Shaft width top@Sketch1
8	Shaft width base@Sketch1
9	D1@Sketch1
10	D2@Sketch1
11	D1@Con-Rod thickness
12	D1@Fillet1
13	D1@Fillet2
14	Bolt dia@Sketch2
15	D1@Sketch2
16	D1@Bolt length
17	Big end inner ring dia@Sketch4
18	D1@Cut-Extrude3
19	D1@Sketch3
20	D2@Sketch3
21	D3@Sketch3
22	D1@Internal shaft thickness
23	D1@Sketch5
24	D1@Cut-Extrude4
25	D1@Fillet3
26	D1@Chamfer1
27	D1@Chamfer2
28	D2@Chamfer2

1 Design Table for: Auto Con-Rod 17	
2	Little end dia@Sketch1
3	Big end dia@Sketch1
4	Eye to eye length@Sketch1
5	Little end hoop thickness@Sketch1
6	Big end hoop thickness@Sketch1
7	Shaft width top@Sketch1

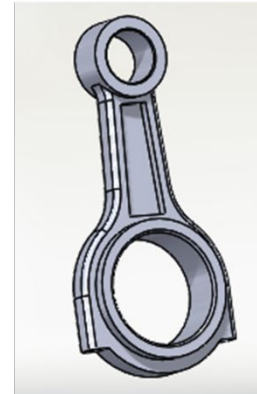
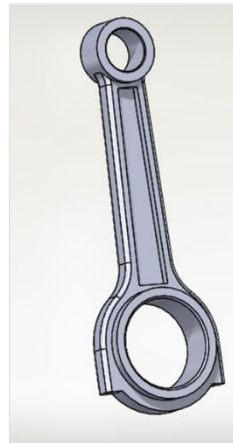


Figure 8 - excel driven Solidworks model. Note the alteration in length due to excel and Solidworks links.

All these parameters can be input, calculated and controlled from a single excel spreadsheet. This spreadsheet could also contain any number of components, all being interconnected through inclusive formulas. Therefore if one component is altered due to a different design requirement, all connected or affected component's parameters respond immediately. This altered spreadsheet can then update the Solidworks model or models, at both component or assembly level.

Following this update, analysis of the component models or a full assembly can

Table 1 - Complete excel table for several components linked to Solidworks CAD models

	A	B	C	D	E	F	G	H	I	J
1	Parameters	0	Piston	0	G-Pin	0	Con-Rod	0	Crank	0
2	Bore	71.9	Bore size@Sketch1	71.9	Inner dia@Sketch1	10	Little end dia@Sketch1	20	Crank throw@Sketch1	41
3	Con-Rod length	87	D1@Overall length	36	Outer dia@Sketch1	20	Big end dia@Sketch1	42	Main bearing@Sketch1	42
4	Crankshaft throw	41	D1@Skirt length	23	D1@GPin length	30	Eye to eye length@Sketch1	87	D1@Main bearing	11
5	G-Pin outer dia	20	GPin offset@Sketch3	0	length@Outside cham	0	Little end hoop thickness	5	D2@Main bearing	11
6	G-Pin length	30	GPin dia@Sketch3	20	angle@Outside cham	45	Big end hoop thickness	10		0
7	Little end thickness	16	Crown wall thickness@Sketch4	4	length@Inside cham	10	Shaft width top@Sketch1	20		0
8	Little end hoop dia	30	D1@Sketch4	0	angle@Inside cham	5	Shaft width base@Sketch1	25		0
9	Big end dia	42	Underside main brace wall thickness	15		0	D1@Sketch1	20		0
10		0	Skirt wall thickness@Sketch4	1		0	D2@Sketch1	10		0
11		0	D1@Crown thickness etc	3		0	D1@Con-Rod thickness	20		0
12		0	First ring from crown dia@Pressure ring	4		0	D1@Fillet1	20		0
13		0	Second ring from first@Pressure ring two	2		0	D1@Fillet2	10		0
14		0	Oil ring from second@Oil ring	2		0	Bolt dia@Sketch2	8		0
15		0	D1@Sketch8	2		0	D1@Sketch2	1		0
16		0	Ring depth@Sketch5	2		0	D1@Bolt length	25		0
17		0	PRing1 thickness@Pressure ring one cut	1		0	Big end inner ring dia@Sketch4	5		0
18		0	D2@Sketch6	0		0	D1@Cut-Extrude3	5		0
19		0	PRing two depth@Sketch6	2		0	Wall thickness internal	5		0
20		0	PRing2 thickness@Pressure ring two cut	1		0	Internal out from bottom	7		0
21		0	D2@Sketch7	0		0	Internal out from top@Sketch1	7		0
22		0	Oil Ring depth@Sketch7	2		0	D1@Internal shaft thick	4		0
23		0	Oil ring thickness@Oil ring cut	1		0	D1@Sketch5	0		0
24		0	GPin joint width@Sketch2	33		0	D1@Cut-Extrude4	2		0
25		0	Underside main width@Sketch2	20		0	D1@Fillet3	2		0
26		0	GPin joint length@Sketch2	33		0	D1@Chamfer1	1		0
27		0	GPin hole from joint bottom@Sketch3	15		0	D2@Chamfer1	45		0
28		0	Skirt edge width@Sketch3	0.2		0	D1@Chamfer2	1		0
29		0	Wave cut depth@Sketch3	10		0	D2@Chamfer2	45		0
30		0	GPin hoop thickness@Sketch9	3.5		0		0		0
31										
32										
33										

Figure 9 - Complete Solidworks model driven by excel



then be carried out. This analysis can then be fed back into the spreadsheet for any changes that need to be made. Solidworks can work through iterations of a model to determine an optimal balance given sets of parameters to work from.

AERODYNAMIC STUDY OF THE CONNECTING ROD.

While working on the Auto-CAD portion of the project, the use of I-beam and H-beam connecting rods were looked at. While conducting this research the question of aerodynamic drag of the differing designs was considered. This led onto a tangent of research for aerodynamic connecting rods.

To start this area of research some parameters were required to be calculated. The research was based on a Ford sigma turbo charged ICE connecting rod. The connecting rod acceleration and velocity were required for further calculations in aerodynamic resistance. As the connecting is transferring linear motion to angular motion the horizontal acceleration and velocity will be

differing at different points along the connecting rod length. Therefore calculations at a number of points were established.

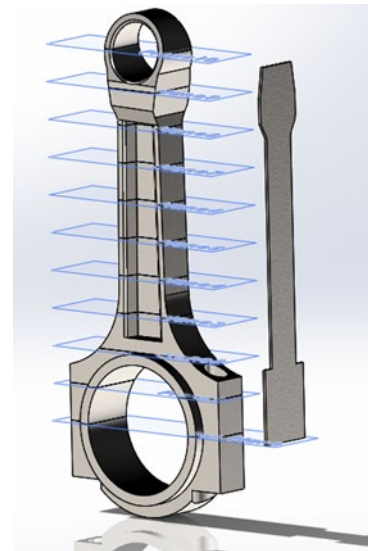


Figure 10 - segmented connecting rod

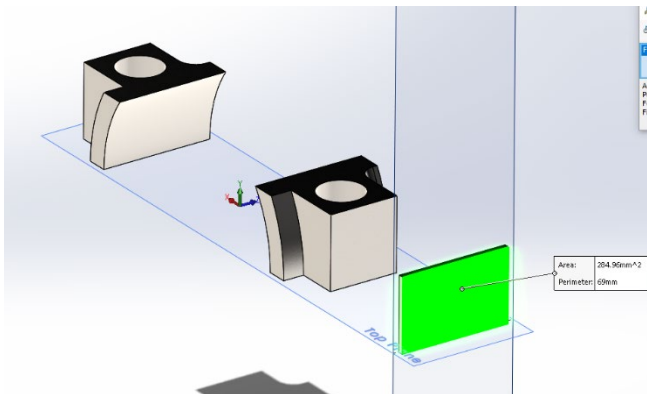


Figure 11 - element of the connecting rod showing projected area.

In Solidworks the connecting was split into a number of sections for these calculation. Each section's mass and frontal area could then be established.

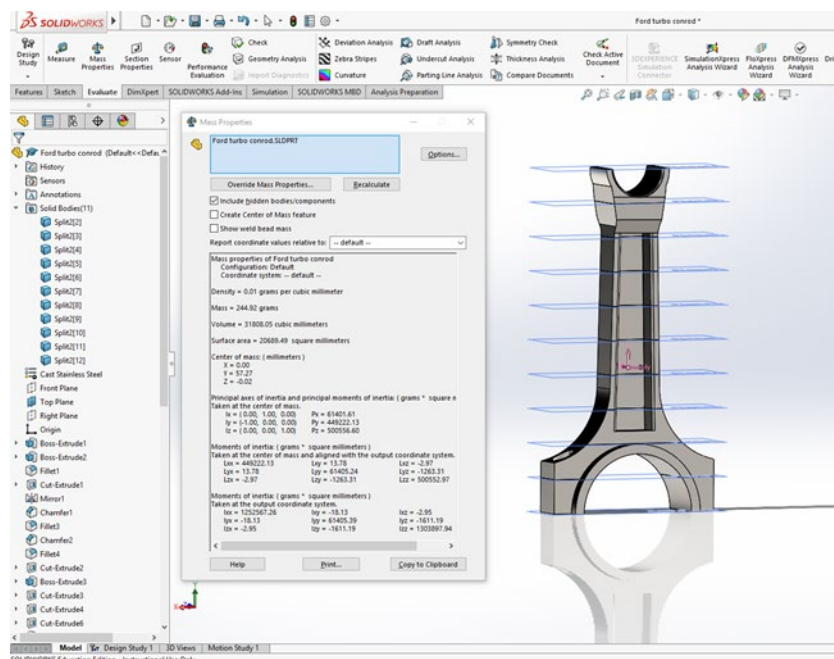


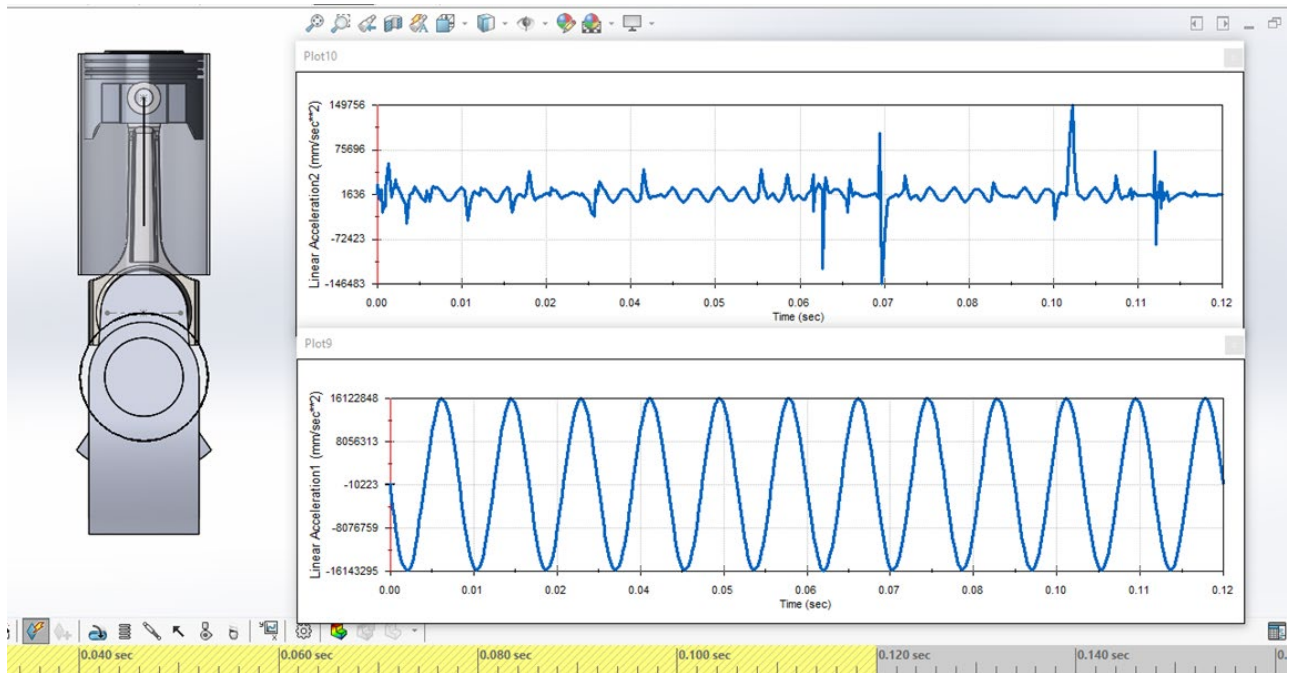
Figure 12 - elements of the connecting rod, sourcing mass for acceleration calculations



The divided connecting rod's acceleration was calculated for each section.

Table 2 - acceleration calculations

Crank angle	Rod angle	Elements									
		16067.49	14460.74	12853.99	11247.25	9640.50	8033.75	6427.00	4820.25	3213.50	1606.75
0	0.000	Big end acc	Element 2	Element 3	Element 4	Element 5	Element 6	Element 7	Element 8	Element 9	Element 10
1	0.005	281.87	253.69	225.50	197.31	169.12	140.94	112.75	84.56	56.37	28.19
2	0.010	563.66	507.29	450.93	394.56	338.20	281.83	225.46	169.10	112.73	56.37
3	0.016	845.27	760.75	676.22	591.69	507.16	422.64	338.11	253.58	169.05	84.53
4	0.021	1126.62	1013.96	901.30	788.64	675.97	563.31	450.65	337.99	225.32	112.66
5	0.026	1407.63	1266.87	1126.10	985.34	844.58	703.81	563.05	422.29	281.53	140.76



Graph 2 - Solidworks validation of acceleration calculations

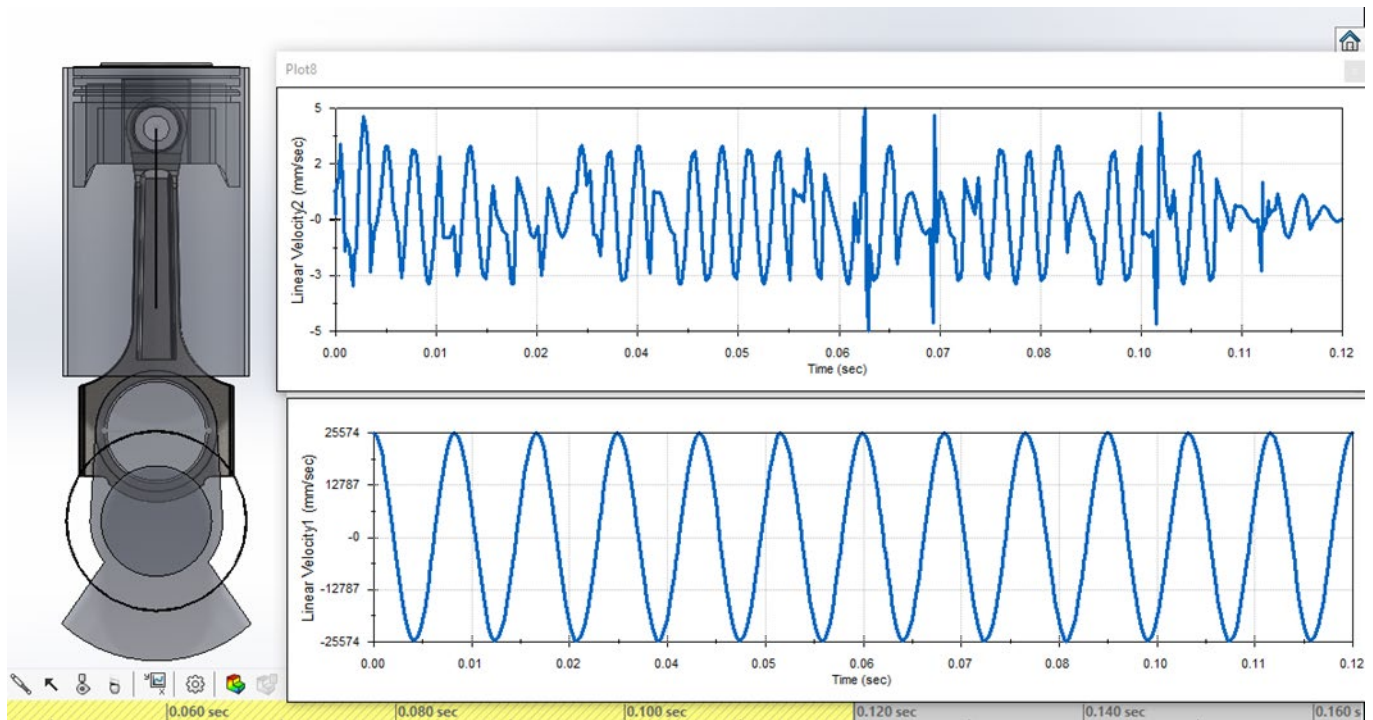
A Solidworks simulation confirms the excel calculations. In graph 2 It can be seen how the lower graph corresponds with element one from the excel calculation. The top graph should be showing the horizontal acceleration at the small end, which should be zero. However tolerances within the model means this is not the case, although only minimal movement is seen.

The velocity for each element is also calculated, with the corresponding Solidworks results also confirming good correlations.

Table 3 - connecting rod velocity calculations

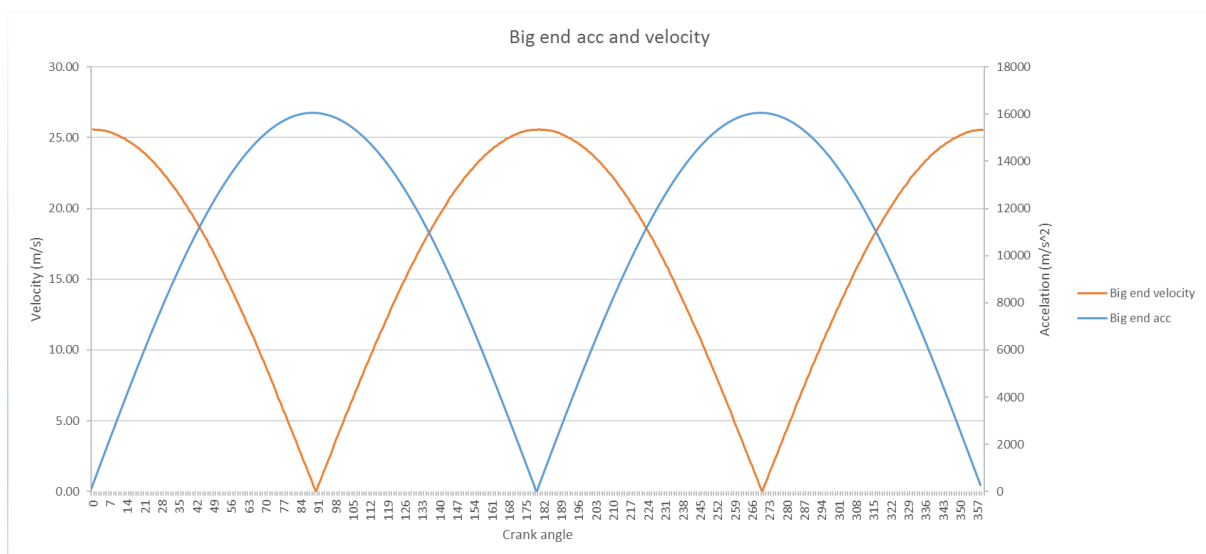
Crank angle	Rod angle	Elements (vel)									
		Big end Vel.	Element 2	Element 3	Element 4	Element 5	Element 6	Element 7	Element 8	Element 9	Element 10
0	0	0									
1	0.005184789	25.57	23.02	20.46	17.90	15.34	12.79	10.23	7.67	5.11	2.56
2	0.010368138	25.57	23.01	20.45	17.90	15.34	12.78	10.23	7.67	5.11	2.56
3	0.015548608	25.56	23.00	20.45	17.89	15.33	12.78	10.22	7.67	5.11	2.56
4	0.020724757	25.54	22.98	20.43	17.88	15.32	12.77	10.22	7.66	5.11	2.55
5	0.025895147	25.51	22.96	20.41	17.86	15.31	12.76	10.20	7.65	5.10	2.55





Graph 3 - Solidworks validation of velocity calculations

The graph below shown as expected the out of phase relationship between acceleration and velocity from the excel calculations worksheet.



Graph 4 - Out of phase acceleration and velocity graph for the connecting rod



Table 4 - connecting rod work done calculations

Work done per degree									
0.013698173	0.009985968	0.007013465	0.004698473	0.002958805	0.001712272	0.000876683	0.000369851	0.000109585	1.36982E-05
Work done 1	Work done 2	Work done 3	Work done 4	Work done 5	Work done 6	Work done 7	Work done 8	Work done 9	Work done 10
8.96551E-05	6.53585E-05	4.59034E-05	3.07517E-05	1.93655E-05	1.12069E-05	5.73792E-06	2.42069E-06	7.17241E-07	8.96551E-08
8.96141E-05	6.53287E-05	4.58824E-05	3.07376E-05	1.93566E-05	1.12018E-05	5.7353E-06	2.41958E-06	7.16913E-07	8.96141E-08
8.94913E-05	6.52392E-05	4.58196E-05	3.06955E-05	1.93301E-05	1.11864E-05	5.72744E-06	2.41627E-06	7.15931E-07	8.94913E-08
8.9287E-05	6.50902E-05	4.57149E-05	3.06254E-05	1.9286E-05	1.11609E-05	5.71436E-06	2.41075E-06	7.14296E-07	8.9287E-08
8.90015E-05	6.48821E-05	4.55687E-05	3.05275E-05	1.92243E-05	1.11252E-05	5.69609E-06	2.40304E-06	7.12012E-07	8.90015E-08
8.86354E-05	6.46152E-05	4.53813E-05	3.0402E-05	1.91453E-05	1.10794E-05	5.67267E-06	2.39316E-06	7.09083E-07	8.86354E-08
8.81897E-05	6.42903E-05	4.51531E-05	3.02491E-05	1.9049E-05	1.10237E-05	5.64414E-06	2.38112E-06	7.05517E-07	8.81897E-08
8.76651E-05	6.39079E-05	4.48845E-05	3.00691E-05	1.89357E-05	1.09581E-05	5.61057E-06	2.36696E-06	7.01321E-07	8.76651E-08
8.70628E-05	6.34688E-05	4.45762E-05	2.98626E-05	1.88056E-05	1.08829E-05	5.57202E-06	2.3507E-06	6.96503E-07	8.70628E-08
8.63842E-05	6.29741E-05	4.42287E-05	2.96298E-05	1.8659E-05	1.0798E-05	5.52859E-06	2.33237E-06	6.91073E-07	8.63842E-08

The calculated work done for each element is required for further calculations (table 4). With the frontal area established and the connection rod acceleration calculated, a basic assumption on drag could be found. A range of connecting rod shapes were accounted for.

Area	0.000274
Air density	1.225
Drag Co.	1.15
Total work done	4.143697
BHP loss?	0.005557

Short Cylinder →  1.15

Aerodynamic drag calculations for various connecting shapes.

Area	0.000274
Air density	1.225
Drag Co.	0.82
Stock BHP loss	0.005557
New BHP loss	0.003962
% dec.	28.69565

Long Cylinder →  0.82

Area	0.000274
Air density	1.225
Drag Co.	0.47
Stock BHP loss	0.005557
New BHP loss	0.002271
% dec. in loss	59.13043

Sphere →  Coefficient 0.47



Area	0.000274
Air density	1.225
Drag Co.	0.04
Stock BHP loss	0.005557
New BHP loss	0.000193
% dec. in loss	96.52174

Streamlined Body →  0.04

4.4. RESULTS

Auto cad outcome.

A basic system was produced, however a shift in project area meant this was not realised its full potential. Calculations for stress had started to be added to the excel spreadsheets. Analysis of the first connecting rods produced by the system were starting to be tested.

Aerodynamic calculations

Results show little to no gain when purely aero factors are looked at, however development and research for oil resistance could be pursued. Due to the minimal loss in power aerodynamic factors are not a concern, however it is interesting to note the 96.5% decline in power loss due to the use of the highly efficient tear drop shape when compared to a more common connecting rod configuration.

4.5. CONCLUSIONS

With advancement in computing power and the wider availability of easy to use software connecting design will only become more interconnected with ACMs.

The excel linked Solidworks parameter system could make a streamlined system for initial component design, not just for connecting rods but a multitude of parts or assemblies.

While the first results for the aerodynamic analysis of the connecting rod showed little benefit, further work could be carried out on the oil fluid dynamics influencing the connecting rod.

Structural optimisation and AM will play an increasingly important role in many industries, particularly the automotive industry. ICE components could be a major development area for AM production.

4.6. FURTHER WORK

Excel linked Solidworks designs focusing on key parameters. FEA of components produced is vital, possibly as an automated feature. Overall refinement of the system should be pursued. Incorporating a system for structural optimisation with regards to AM.

Fluid dynamics calculations to included and focus on oil resistance rather than air, as air resistance makes little to no difference. The calculation also assume a static body of air, which would not take into account turbulence within the crankcase, thus this would need to be simulated in an FEA environment software package.

Further researching AM and its effects on ICE component design.



5. TURBO SECTION

With the recent trend of downsizing and turbo charging ICEs, obtaining a good understanding of a forced induction system may prove useful in the future automotive industry.

5.1. AIMS AND OBJECTIVES

This portion of the project started with interpretation of FoMoCO data given in lectures. This is a key aspect of the project, to be able to interpret manufactures data sets into usable calculations. These calculations can then be utilised to determine the correct system required for other applications and vehicles. This of course is only limited to the type of systems used on the data sets given. For a better match between ICE and forced induction system, a range of induction system data sets would ideally be interpreted; however, it was not possible to attain such a range of data sets.

Due to only having turbo charger data a wider comparison of different forced induction types could not be carried out. A supercharger induction systems could also be tested, however due to availability it was not plausible.

Turbo charging is becoming more popular over the last decade with manufactures. This is due to chasing increases in fuel efficiencies and lowering emissions. However, this project will be focusing on packaging a forced induction system onto a race dedicated motorcycle, thus the aims and deemed successes will differ. While this mean seem to be make the data redundant, the hunt for turbo efficiently will be equally important for both mass production vehicles and race focused machines.

5.2. RESEARCH AND LITERATURE REVIEW

As mentioned in the previous the section, due to availability of components a turbo charging system was studied in detail. However, supercharged induction systems could also be studied for this project.

KAWASAKI H2

The Kawasaki H2 is a super charged, 998cc supersport class bike, producing 200 hp. The super charger used on the H2 is a centrifugal type system. The reasoning behinds Kawasaki's use of a centrifugal type super charger was to keep the air temperature after the compressor as cold as possible, therefor negating the need for an intercooler. Not requiring an intercooler was deemed of the upmost importance for the H2, as space is at a premium on a motorcycle. Hence, use of the centrifugal type was decided as increases in temperature from the compressor is less than a roots or twin-screw type system. Use of port injection is also used as an evaporative cooling effect is created to help reduce intake temperature.



While Kawasaki have gone to pains to negate the need of an intercooler, an aftermarket system is produced by Extreme Creations (Australia) (8.11). This is a stand-alone, water to air cooling system that includes a radiator, water pump and billet aluminium plenum with built-in intercooler that fits arounds the H2 architecture. The system claims a reduction of 35-50 °C intake temperature through the range, however more research showed a more constant 20-30 °C was seen in real world tests. This reduction however is still impressive when it is considered that the intake charge temperature at high load, high speed (180MPH) only reaches around 120 °C on the

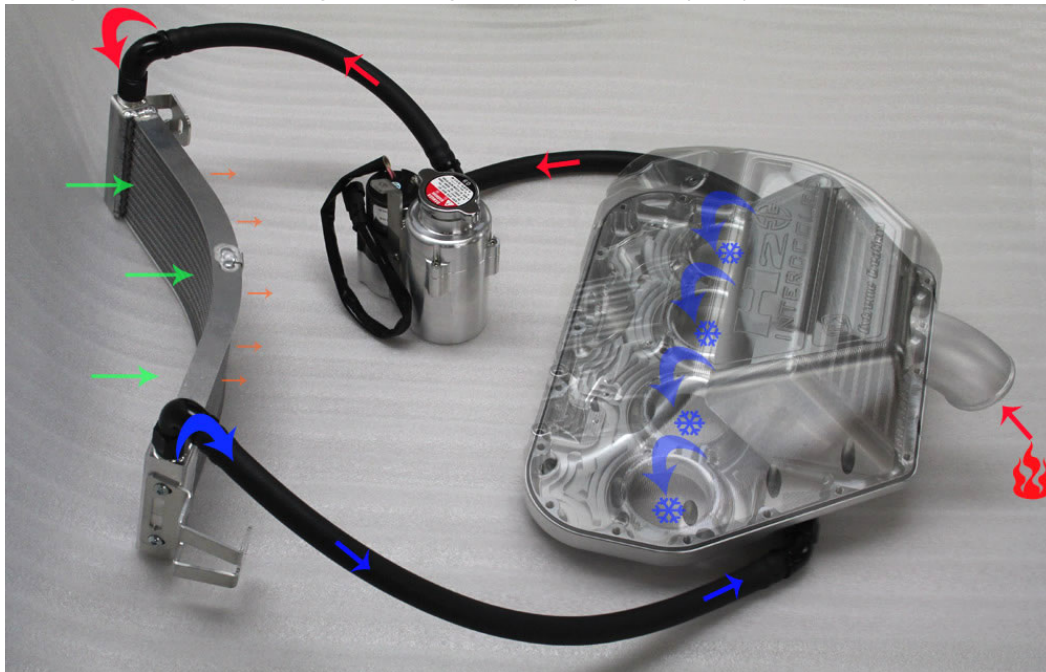


Figure 13 - Water to air intercooler, H2

standard H2 production bike.

YAMAHA AUSTRALIA MT09/10 TURBO

While popular in the 1980s, turbo charged production motorcycles have not been a high priority. However, aftermarket systems can still be found. Another product created by Extreme Creations (Australia) is a turbo charging kit for both the Yamaha MT09 and MT10. This system was researched as it offered packaging considerations for later use in the project development.

The systems use a Garrett ball bearing turbo with a 7 psi wastegate. A billet plenum is also used in this system. This produces 60 hp over the stock MT-09 (up to 192hp), and 75hp on the MT-10 production bike (202hp).

The turbo systems described don't come with an intercooler as standard, however a side mounted air to air add-on can be bought. This reduces the intake charge temperature by an average of 40°C. A lower induction temperature will reduce the chance of engine knock, or detonation.

Both the research for the super charger and turbo charger systems could be adapted for use in the project. This will be explored in the concept section of the project.



CBR 600 TURBO

The Honda CBR 600 is a widely used motorcycle, with high numbers being used for racing, at club, national and international level. As such, with high numbers available, after market systems are developed. Smaller turbo chargers then the systems for the MT-09/10 are needed for the lower capacity bike. These turbo chargers will be more suited to the Suzuki SV650 used in this project, due to the closer air-flow rates seen.

5.3. WORKED CARRIED OUT

Ford data analysis

The data analysis of the provided FoMoCo data sets was done in parallel with the research of the differing forced induction systems.

The data sets that were studied would have been created by recording a large number of different sensors output on the ICE while being tested on a dyno set-up. This would have been done thousands of times to establish the limits on the ICE, with alterations made until the optimum ranges were reached. These data sets can then be used further down the line for other calculations, often in terms of finding efficiencies, monitoring how component changes effect the overall ICE and creating recommendations for further alterations.

Table 5 - Ford test sheet -

		Engine: CM13929 / SCE3539 / C022 Test Date: 2012-06-19 125PS, C344, T301A, 02_Non_PATS, 200Nm, CM13929	
		Index	
PAGE SHEET NAME		PAGE SHEET NAME	
2	Test Details & Comments	63	Combust GMEP CV
3	TEST INFO	64	FMS to LMP Relationship
4	Eng Oil Temp	65	Combust NMEP ME
5	Eng Oil Press	66	Combust IMEP
6	Eng Coolant Press & Temp	67	Over Advancing Spark
7	Spark 1	68	Overlap
8	Spark 2	69	Knock 1
9	Indicoin	70	Knock 2
10	Performance 1	71	Knock 3
11	Performance 2	72	Knock 4
12	Torque	73	ECU Ref Tq Efficiencies
13	Fuel 1	74	ECU Ref Tq Efficiencies & Lims
14	Fuel 2	75	Boost Cnt ECU Press Des vs Act
15	Fuel 3	76	Boost Cnt Forward Path
16	miles & misol	77	Additional Info
17	AF11	78	Injection Timing
18	AF12		
19	Smoke		
20	ECU Spk Retard via Knock Cnt		
21	Turbo 1		
22	Turbo 2		
23	VVT in Timing Req vs Act		
24	VVT in Timing Act Variability		
25	VVT Exh Timing Req vs Act		
26	VVT Exh Timing Act Variability		
27	Residual Gas Frc: m vs mref		
28	Inlet Pressure 1		
29	Inlet Pressure 2		
30	Inlet Pressure 3		
31	Inlet Temperature 1		
32	Inlet Temperature 2		
33	Inlet Port Temperatures		
34	Inlet Pressure TCT 1		
35	Inlet Pressure TCT 2		
36	Total Pressure Losses 1		
37	Total Pressure Losses 2		
38	Exhaust Pressure 1		
39	Exhaust Pressure 2		
40	Exhaust Temperature 1		
41	Exh Temp Manifold		
42	Emissions 1		
43	Emissions 2		
44	Throttle & Pedal		
45	Ambient Conditions		
46	Airmass 1		
47	ECU Load		
48	Knock Cnt MFBS0%		
49	Combust GMEP ME		
50	Combust GMEP SD		
51	Combust GMEP Variability Range		
52	Combust PMAK ME		
53	Combust PMAK MX		
54	Combust Burn Duration		
55	Burn Duration 0 - 10s		
56	Burn Duration 10 - 90s		
57	Combust FRI4		
58	Combust FRI5		
59	Combust Mefire		
60	Combust APMAK ME		
61	Combust RPDMAK ME		
62	Combust GMEP LV		
Engine: CM13929 / SCE3539 / C022 Test Date: 2012-06-19 125PS, C344, T301A, 02_Non_PATS, 200Nm, CM13929		Layout File For: GTEK CalVal Bosch216 CM13929_024_0073.gdt, CM13929_024 Print Date: 2012/06/20 10:30:09	
			
Engine: CM13929 / SCE3539 / C022 Test Date: 2012-06-19 125PS, C344, T301A, 02_Non_PATS, 200Nm, CM13929			
Combustion Transducer Type: In-cylinder pressure transducer			
Hardware Level: C346			
I Burn Pressure (bar)		I Burn number	
		I RPM Number	





Engine: CM14721 / SCE3676 / C025

Test Date: 2014-07-21

B299N FOX BXME5 1p1 27JUN14

P TURBOT deg C																	
	900	1000	1250	1500	1750	2000	2250	2500	2750	3000	3500	4000	4500	5000	5500	6000	6500
FL	428.6	577.8	658.5		860.5		885.0	879.9	881.6	898.9	929.7	939.9	961.6	971.1		943.7	913.2
200								915.5	916.7	937.1	941.3	941.8					
190					851.8		893.2	900.3	920.3	924.9	913.7	964.5					
180					836.1		880.6	885.4	906.9	927.8	959.6	1000.1	948.3				
170				786.0	820.8		860.1	863.5	884.9	902.3	928.7	972.9	1010.5	982.8			
160				773.7	820.8		860.1	863.5	884.9	902.3	928.7	972.9	1010.5	982.8			
150				755.8	796.6	816.2	839.7	845.8	863.3	878.6	905.2	952.5	967.8	969.1	951.3		
140				734.2	774.6	794.5	822.5	832.4	843.7	854.4	876.3	906.6	930.3	944.0	948.0	949.5	
130				711.6	749.0	774.4	800.2	809.7	820.0	831.5	846.6	864.4	897.3	916.0	929.6	952.2	970.3
120			647.8	694.4	728.9	756.5	778.1	788.0	795.9	809.8	820.4	838.2	860.1	878.7	902.4	926.7	949.4
110			639.8	680.3	711.4	735.0	758.0	759.8	770.9	782.5	797.7	811.5	832.0	855.2	881.3	905.3	933.8
100		577.7	633.6	665.8	691.6	710.9	731.0	731.0	747.2	760.8	773.7	792.1	812.7	833.0	858.6	882.1	912.0
90		569.5	616.0	647.5	662.0	677.3	698.8	698.0	719.1	732.7	755.8	773.9	798.4	814.0	837.1	861.1	890.4
80		557.7	604.4	623.9	645.6	665.2	691.0	692.4	702.3	715.1	741.4	768.3	785.7	803.2	823.6	843.6	868.8
70		533.3	592.6	612.5	642.9	655.8	683.5	673.7	685.0	701.2	730.4	755.9	777.7	796.1	813.4	829.6	855.2
60		491.6	571.9	556.4	573.8	592.6	620.8	645.9	667.6	688.0	717.3	744.1	772.7	790.5	811.2	827.0	848.9
50		446.1	485.7	515.4	545.6	563.9	599.7	621.7	644.7	666.4	697.1	726.7	764.5	782.9	804.3	821.8	841.9
40	407.2	417.4	457.8	489.6	526.2	549.4	578.7	598.4	621.2	631.9	679.8	712.3	748.9	759.5	785.4	805.1	828.9
30	395.2	418.8	458.8	492.9	526.6	550.3	571.2	589.6	606.5	625.1	660.8	697.1	726.1	753.1	769.3	787.4	812.7
20	375.7	392.9	449.5	470.1	506.1	538.4	560.5	577.7	601.7	613.1	655.3	684.2	714.2	753.1	765.1	780.7	795.0
10	363.0	367.6	434.5	473.4	513.6	543.6	571.6	573.9	600.5	623.0	637.4	669.1	699.3	717.9	729.6		780.4
5	265.2										654.0	673.3	698.0				763.6
2			282.7			472.2											

Above is an example of the data sets produced by these dyno test sections. This section is for the measured temperature before the turbine side of the turbo charger, or the pre-turbine temperature. It can be seen how an upper limit can be set to show up potential problem areas. For this example a temperature of over 1000 °C will be highlighted. This allows for easy pinpointing of areas that need to be addressed, either by altering the component itself, or a related part. It may also be deemed that this breach over parameters is to an acceptable level, as alterations may force another area over its respective limit, this however depends on a number of factors including the margin of safety deemed necessary for a particular model.

This data was transferred into an excel worksheet for ease of use in further calculations (table 6 below).

Pre turbine (°c)		RPM																
		900	1000	1250	1500	1750	2000	2250	2500	2750	3000	3500	4000	4500	5000	5500	6000	6500
L O A D	FL	428.6	577.8	658.5		860.5		885	879.9	881.6	898.9	929.7	939.9	961.6	971.1		943.7	
	200								930.7	944.4	898.3							
	190							915.5	916.7	937.1	941.3	941.8						
	180					851.8		893.2	900.3	920.3	924.9	913.7	964.5					
	170				786	836.1		880.6	885.4	906.9	927.8	959.6	1000.1	948.3				
	160				773.7	820.8		860.1	863.5	884.9	902.3	928.7	972.9	1010.5	962.8			
	150				755.8	796.6	816.2	839.7	845.8	863.3	878.6	905.2	952.5	967.8	969.1	951.3		
	140				734.2	774.6	794.5	822.5	832.4	843.7	854.4	876.3	906.6	930.3	944	948	949.5	
	130				711.6	749	774.4	800.2	809.7	820	831.5	846.6	864.4	897.3	916	929.6	952.2	970.3
	120			647.8	694.4	728.9	756.5	778.1	788	795.9	809.8	820.4	838.2	860.1	878.7	902.4	926.7	949.4
	110			639.8	680.3	711.4	735	758	759.8	770.9	782.5	797.7	811.5	832	855.2	881.3	905.3	933.8
	100		577.7	633.6	665.8	691.6	710.9	731	731	747.2	760.8	773.7	792.1	812.7	833	858.6	882.1	912
	90		569.5	616	647.5	662	677.3	698.8	698.9	719.1	732.7	755.8	773.9	798.4	814	837.1	861.1	890.4
	80		557.7	604.4	623.9	645.6	665.2	691	692.4	702.3	715.1	741.4	768.3	785.7	803.2	823.6	843.6	868.8
	70		533.3	592.6	612.5	642.9	655.8	663.5	673.7	685	701.2	730.4	755.9	777.7	796.1	813.4	829.6	855.2
	60		491.6	571.9	556.4	573.8	592.6	620.8	645.9	667.6	688	717.3	744.1	772.7	790.5	811.2	827	848.9
	50		446.1	485.7	515.4	545.6	563.9	599.7	621.7	644.7	666.4	697.1	726.7	764.5	782.9	804.3	821.8	841.9
	40	407.2	417.4	457.8	489.6	526.2	549.4	578.7	598.4	621.2	631.9	679.8	712.3	748.9	759.5	785.4	805.1	828.9
	30	395.2	418.8	458.8	492.9	526.6	550.3	571.2	589.6	606.5	625.1	660.8	697.1	726.1	753.1	769.3	787.4	812.7
	20	375.7	392.9	449.5	470.1	506.1	538.4	560.5	577.7	601.7	613.1	655.3	684.2	714.2	753.1	765.1	780.7	795
	10	363	367.6	434.5	473.4	513.6	543.6	571.6	573.9	600.5	623	637.4	669.1	699.3	717.9	729.6		780.4
	5	265.2										654	673.3	698				763.6
	2			282.7			472.2											

Table 6 - Ford data set

To aid in the interpretation of the data each table that was input into the excel worksheet from the provided data sets are highlighted in a sliding scale of colour. For this example table the table has a sliding scale from blue to red depending on the temperature given. This makes it immediately clear of any anomalies in the data, as well as what the limits are and should show



any easily identifiable patterns or clear affects created by parameters changes, i.e. higher recorded temperature with increases in either RPM or load.

TURBO CALCULATIONS

To start the calculations a number of data sets had to be transferred to a common excel spreadsheet. The data sets utilised will be described in detail as they are being used in the calculation paths followed.

TURBINE CALCULATIONS

To begin the analysis, the turbine temperatures were studied. This involved importing both pre

Table 7

Δt (°C)		RPM																	
L	O	800	1000	1250	1500	1750	2000	2250	2500	3000	3500	4000	4500	5000	5500	6000	6500		
		FL																	
L	O	200	103.9	91.4	102			146.3	143.3	148.7	144	136.5	134.5	128.3	142.1		136.2		
		190						139.7	131.5	125.3	134.6	133.4							
		180				140.8		130.5	124	117.8	128	124.6	134.1						
		170				125.5	130.1	118.6	113.8	106	104.1	104.3	112	129.4					
		160				121	121.7	110.8	106.6	98.4	95.9	93	99.2	109.8	133.7				
		150				114.6	111.6	106	104.6	96.7	89.1	86.9	83.9	90.3	91.6	125.5	124		
		140				104.5	104.2	100.1	98.8	87.3	80.3	77.1	73.4	77.4	77.6	107	115.4	122.7	
		130				98.4	96.7	93.2	84.5	76.5	71.3	69.2	64.1	65.1	66	93.9	102	112.9	120.7
		120				97.9	93.3	88.3	78.2	73.1	67.5	63.8	63.1	55.6	56.8	56.4	79.9	84.8	91.8
		110				92	87.7	71.8	67.3	68.5	61	58.4	51.9	48.8	51	48.2	48.3	76.1	81.8
		100				89.2	88.6	69.6	62.1	59.6	58.1	49.4	47.3	42.6	40.3	45.6	42.2	41.9	67.8
		90				64.6	63	49.6	32.5	35.8	44.9	42.2	40.1	40.2	39.8	39.4	39.2	37.2	60.2
		80				49.4	48	47.2	35.4	39.8	49.4	45.2	41.7	42.7	44.8	43.4	42.2	41.7	58.4
		70				67.4	57.6	58	44.5	47.8	50.8	46.5	41.7	43.8	46.8	47.1	45.3	44.1	57.7
		60				99.1	74.4	67.4	55.6	55.2	53	48	46.1	49.2	51.2	49.7	48.5	48	67.7
		50				102.6	99.3	74.7	66	63.3	59.2	54.3	53.7	60.5	59.3	56.3	54.3	49.8	67.7
		40				114.2	108.5	104.2	86.4	81.1	75.6	72.5	67	67.4	83.8	70.8	68.6	63.8	68.1
		30				130.7	143.8	125.1	121.6	110.4	107.1	101.2	92.3	90.6	109.5	87.4	81.9	77.2	69.8
		20				147.2	147.6	155	132.5	127	130.6	128.2	121.4	122.3	124.5	113.4	102.8	95.8	98
		10				175	169.1	192.2	118.9	162.5	172.3	114.5	91.7	97.6	104.3	118.2	121.2	118.5	91.3
		5				107.6										106.2	101.8	105.8	
		2				82.6													98.8

and post turbine temperature sets and comparing them, looking for the change in temperature between the two. This created a new table with the change in temperature shown (table7)

In caption for table – it can be seen how mid range mid RPM zone has a lower temperature difference. This zone is of interest in a later section.

From these two data sets it can start to be calculated how much energy is taken to spin the turbine from the exhaust gases. It should be noted this would not be 100% of the available energy from the exhaust system due to unwanted heat transfer and through mechanical losses.

ENTHALPY

Enthalpy of Formation tables are needed for calculating turbo efficiencies in this project and will be used in a number of sections.

For calculating the energy used to spin the turbine, Enthalpy of Formation tables of water (H₂O), carbon dioxide (CO₂) and nitrogen (N₂) need to be used. These table display the energy needed to take the desired molecule form 298 degrees kelvin to a specific temperature. Tabke 8 shows the Enthalpy of Formation for nitrogen. Water, carbon dioxide and nitrogen are used in this portion of the calculations as they are products of the combustion process, hence will be presence in the turbine half of the turbo charger as this is incorporated into the exhaust system.



Table 8

APPENDIX B THERMODYNAMIC PROPERTIES OF IDEAL GASES

Table B.7 N₂ (Molecular Weight = 28.013, Enthalpy of Formation at 298 K = 0 kJ/kmol)

T (K)	$\bar{c}_p$ (kJ/kmol·K)	$\bar{h}^\circ(T) - \bar{h}^\circ(298)$ (kJ/kmol)	$\bar{h}_f^\circ(T)$ (kJ/kmol)	$\bar{s}^\circ(T)$ (kJ/kmol·K)
200	28.793	-2841	0	179.959
298	29.071	0	0	191.511
300	29.075	54	0	191.691
400	29.319	2973	0	200.088
500	29.636	5920	0	206.662
600	30.086	8905	0	212.103
700	30.684	11,942	0	216.784
800	31.394	15,046	0	220.927
900	32.131	18,222	0	224.667
1000	32.762	21,468	0	228.087
1100	33.258	24,770	0	231.233
1200	33.707	28,118	0	234.146
1300	34.113	31,510	0	236.861
1400	34.477	34,939	0	239.402
1500	34.805	38,404	0	241.792
1600	35.099	41,899	0	244.048

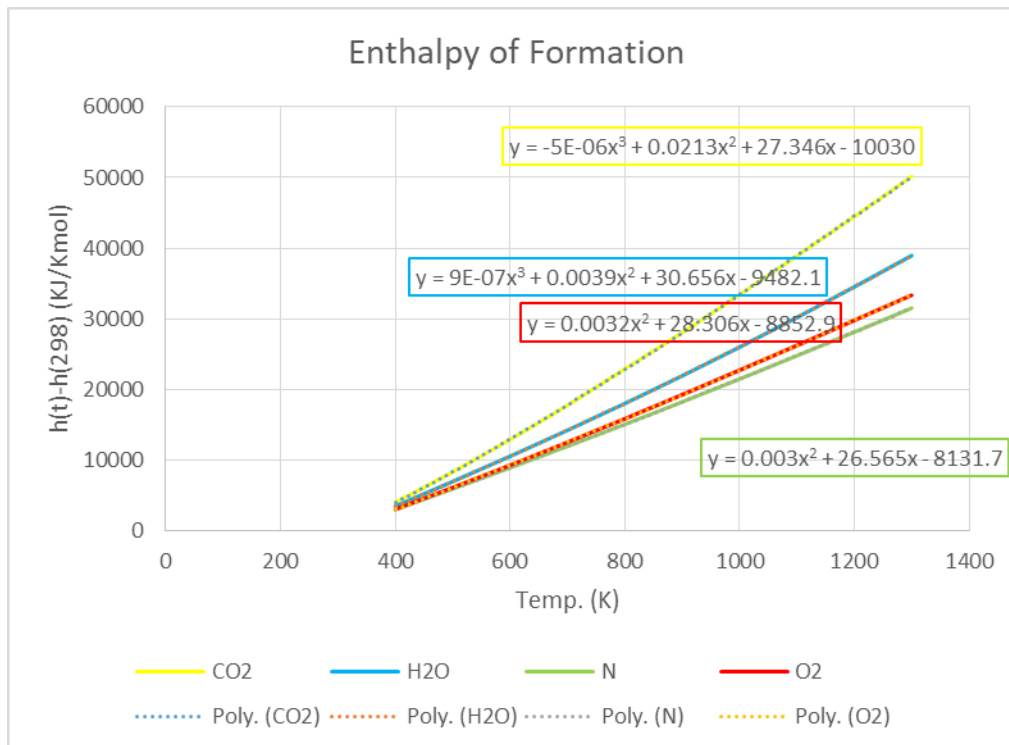
Table 9

		°C	K
Turbine	Min temp	157.6	430.75
	Max temp	1010.5	1283.65
Temp.	CO2	H2O	N2
K	h(t)-h(298)	h(t)-h(298)	h(t)-h(298)
400	4003	3458	2973
500	8301	6947	5920
600	12899	10528	8905
700	17749	14209	11942
800	22899	18005	15046
900	28047	21930	18222
1000	33425	25993	21468
1100	38911	30191	24770
1200	44488	34518	28118
1300	50149	38963	31510

This table can then be put into excel, as can be seen in table 9. It can be also be seen that the Enthalpy of Formation for water and carbon dioxide have been included at this point. The table also includes the minimum and maximum temperatures seen in the data sets for the pre and post turbine temperatures observed. Establishing this minimum and maximum value will allow a smaller portion the table to be used, which will later give a more accurate polynomial.

To create a polynomial these enthalpy figures have to be configured into a graph. This is done directly in excel and can be seen in graph 5. Once the scatter graph has been created from the Enthalpy of Formation tables, a polynomial is created that best fits the line created. Polynomials can be created to the sixth order, and this was found to be the best case fit to the enthalpy graph lines formed.



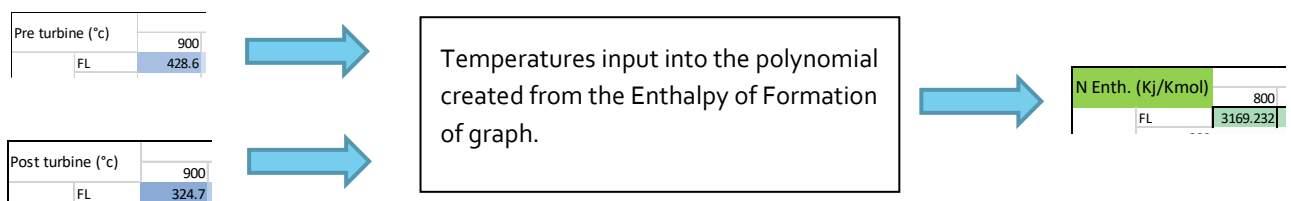


Graph 5 – Enthalpy of Formation graph. Note polynomial of only the third order, not sixth, for ease of viewing.-

A polynomial is required to find the specific temperature related to the direct sensor observation from the dyno test. For this the table of pre and post turbine temperatures are put though the polynomial formula created in Enthalpy of Formation of graph.

For example;

The exact temperature is included into the polynomial created from the Enthalpy of Formation of graph, which creates the required energy (Kj/Kmol) needed to get the element from 298 kelvin to the stated temperature. This polynomial will differ depending on the makeup of the molecules needed for the calculations used, in this instance nitrogen. Post turbine enthalpy is then taken away from pre turbine enthalpy, resulting in a net enthalpy per kj/kmol of nitrogen.



This process is carried out on the nitrogen as shown, but also on the carbon dioxide and water equivalents, thus creating three tables of enthalpy levels. Table 10 shows how this table looks once all temperatures from the original data set are included.



Table 10

N Enth. (Kj/Kmol)		RPM															
		800	1000	1250	1500	1750	2000	2250	2500	3000	3500	4000	4500	5000	5500	6000	6500
L O A D	FL	3169.232	2875.012	3254.484		4785.6177		4841.8855	4739.664	4917.41	4778.1	4555.944	4497.677	4308.211	4773.644		4556.782
	200								4645.782	4441.517	4820.201						
	190								4650.2772	4381.274	4191.313	4502.043	4462.733				
	180					4635.3632			4330.9551	4122.527	3931.791	4271.858	4151.71	4502.96			
	170				4089.584	4275.3906			3931.5609	3777.104	3533.472	3482.954	3508.169	3789.98	4335.103		
	160				3935.886	3991.5874			3662.525	3527.042	3270.003	3197.046	3114.953	3345.397	3722.522	4488.407	
	150				3717.903	3647.9998	3478.6524	3447.244	3192.456	2952.378	2887.576	2801.22	3037.235	3088.441	4220.437	4158.167	
	140				3380.139	3395.0669	3274.2103	3247.9985	2877.787	2653.835	2553.486	2440.847	2586.232	2603.201	3588.837	3870.437	4113.785
	130				3171.551	3138.414	3039.5386	2770.5389	2514.187	2348.569	2284.369	2122.469	2161.982	2203.981	3138.156	3414.329	3790.038
	120				3118.633	2999.131	2857.597	2545.6314	2389.8483	2211.721	2094.072	2076.264	1834.055	1879.218	1873.073	2656.61	2829.714
	110				2927.924	2813.275	2319.7381	2184.5232	2232.3999	1989.943	1909.32	1701.261	1604.349	1680.391	1594.168	1603.837	2532.205
	100				2806.351	2817.344	2230.424	2000.9011	1927.5365	1886.1026	1604.929	1541.447	1392.218	1320.323	1498.098	1391.796	1386.794
	90				2034.011	2001.511	1587.066	1044.3427	1153.2611	1450.8748	1363.987	1301.093	1307.511	1299.882	1290.984	1289.978	1227.7
	80				1554.173	1523.789	1503.994	1133.7966	1278.8114	1593.3717	1458.832	1348.718	1384.132	1458.793	1420.144	1385.257	1373.096
	70				2106.839	1822.821	1842.316	1423.3402	1532.0744	1630.0905	1495.499	1344.487	1416.087	1520.65	1537.333	1484.525	1450.022
	60				3062.884	2341.45	2116.272	1753.5846	1747.2677	1686.912	1535.643	1481.031	1586.083	1659.047	1618.419	1587.545	1576.172
	50				3141.143	3065.404	2325.227	2068.281	1991.19	1875.6888	1728.37	1716.71	1940.648	1913.088	1826.553	1773.91	1632.841
	40	3464.489	3300.416	3197.159	2672.683	2528.1956	2368.6587	2285.0416	2120.733	2142.504	2665.065	2274.483	2217.358	2076.729	1772.338	2230.241	2221.633
	30	3948.444	4359.533	3831.082	3750.823	3431.9637	3345.9195	3176.2343	2909.635	2865.71	3469.508	2793.64	2636.738	2499.624	2272.516	2541.72	2318.929
	20	4421.17	4448.989	4723.333	4063.924	3925.5782	4061.2373	4004.8018	3807.555	3853.17	3930.196	3612.203	3295.426	3089.948	3182.575	3421.535	3094.74
	10	5226.622	5058.517	5816.473	3654.24	5012.563	5341.3775	3589.3175	2882.207	3081.549	3305.064	3750.778	3867.787	3803.771	2947.996	3399.73	3479.337
	5	3169.724															
	2			2449.144			4098.9415										3214.364

Enthalpy calculations do not take into account for number of molecules yet. For a stoichiometric burn this would require multiplying by a calculated number, as seen in table 11

Fuel equiv.	1
CO ₂	8
H ₂ O	9
N	47

Taking into account fuel equivalence, related to lambda.

Table 11

Fuel equiv.	0.9	0.91	0.92	0.93	0.94	0.95	0.96	0.97	0.98	0.99	1
CO ₂	7.2	7.28	7.36	7.44	7.52	7.6	7.68	7.76	7.84	7.92	8
H ₂ O	8.1	8.19	8.28	8.37	8.46	8.55	8.64	8.73	8.82	8.91	9
N	47	47	47	47	47	47	47	47	47	47	47
O ₂	1.25	1.125	1	0.875	0.75	0.625	0.5	0.375	0.25	0.125	0
	1818.6	1819.74	1820.88	1822.02	1823.16	1824.3	1825.44	1826.58	1827.72	1828.86	1830
Fuel equiv.	1	1.01	1.02	1.03	1.04	1.05	1.06	1.07	1.08	1.09	1.1
CO ₂	8	7.83	7.66	7.49	7.32	7.15	6.98	6.81	6.64	6.47	6.3
H ₂ O	9	9.09	9.18	9.27	9.36	9.45	9.54	9.63	9.72	9.81	9.9
N	47	47	47	47	47	47	47	47	47	47	47
CO	0	0.25	0.5	0.75	1	1.25	1.5	1.75	2	2.25	2.5
	1830	1831.14	1832.28	1833.42	1834.56	1835.7	1836.84	1837.98	1839.12	1840.26	1841.4

Running below stoichiometric (lean) will require including oxygen into the calculations, while running above stoichiometric will include carbon monoxide.

The fuel equivalence is calculated from the lambda data set provided (table 12 below).



Table 12

Lambda		RPM																
		900	1000	1250	1500	1750	2000	2250	2500		3000	3500	4000	4500	5000	5500	6000	6500
		1.00	1.02	1.01		1.00		0.95	0.92	***	0.90	0.91	0.95	0.90	0.87		0.80	0.80
L O A D	FL																	
	200								1.00	0.99	0.90							
	190							1.00	1.00	1.00	0.98	0.93						
	180					1.00		1.00	1.00	1.00	0.98	0.93	0.93					
	170				1.01	1.00		1.00	1.00	1.00	1.01	1.00	1.00	0.90				
	160				1.01	1.00		1.00	1.00	1.00	1.00	1.01	1.01	1.00	0.88			
	150			1.01	1.00	1.00	1.00	1.00	1.01	1.00	1.01	1.01	1.01	1.00	0.93	0.90		
	140				1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.93	0.86	
	130				1.00	1.00	1.00	1.00	1.01	1.00	1.00	1.00	1.00	1.00	0.96	0.94	0.91	0.88
	120			1.01	1.01	1.00	1.01	1.00	1.01	1.01	1.01	1.00	1.01	1.01	0.97	0.96	0.95	0.91
	110			1.01	1.01	1.01	1.00	1.00	1.01	1.01	1.01	1.00	1.01	1.00	1.00	0.97	0.96	0.95
	100		1.02	1.01	1.01	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.97	0.96	0.96
	90		1.02		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.97	0.97	0.97
	80		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.97	0.97
	70		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.01	1.00	1.00	1.00	1.01	0.99
	60		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	50		1.00	1.00	1.00	1.00	1.01	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	40	1.00	1.00	1.00	1.00	1.00	1.00	1.01	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	30	1.00	1.00	1.00	1.00	1.00	1.00	1.01	1.00	1.00	1.00	1.00	1.00	1.01	1.00	1.00	1.00	1.00
	20	1.00	1.00	1.00	1.00	1.00	1.00	1.01	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	10	0.99	1.00	1.00	1.00	1.00	1.00		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00		1.00
	5	0.98											1.00	1.00	1.00			1.00
	2			0.98				0.99										

From the lambda ratio the fuel equivalence can be found using equation 1.

$$Fuel\ equiv. = \frac{1}{\lambda}$$

Equation 1 - Fuel equivalence equation

The following table shows the fuel equivalence calculated from the lambda table. This table is then incorporated into the enthalpy energy calculations for further adjustment.

Table 13

Fuel equivalence		RPM															
		800	1000	1250	1500	1750	2000	2250	2500	3000	3500	4000	4500	5000	5500	6000	6500
		1.00	0.98	0.99		1.00		1.05	1.09	1.11	1.10	1.05	1.11	1.15		1.25	1.25
L O A D	FL																
	200								1.00	1.01							
	190							1.00	1.00	1.00	1.02						
	180					1.00		1.00	1.00	1.00	1.02	1.08					
	170				0.99	1.00		1.00	1.00	1.00	0.99	1.00		1.00			
	160				0.99	1.00		1.00	1.00	1.00	1.00	0.99	1.00				
	150				0.99	1.00	1.00	1.00	0.99	1.00	0.99	0.99	1.00	1.08			
	140				1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.05	1.08		
	130				1.00	1.00	1.00	1.00	0.99	1.00	1.00	1.00	1.00	1.04	1.06		
	120			0.99	0.99	1.00	0.99	1.00	0.99	0.99	0.99	1.00	0.99	1.03	1.04	1.05	1.10
	110			0.99	0.99	0.99	1.00	1.00	0.99	0.99	1.00	0.99	1.00	1.00	1.03	1.04	1.05
	100		0.98	0.99	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.03	1.04	1.04
	90		0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.03	1.03	1.03
	80		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.01	1.03	1.03
	70		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.00	1.00	0.99	1.01
	60		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	50		1.00	1.00	1.00	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	40	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	30	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.00	1.00	1.00	0.99	1.00	1.00	1.00	1.00	1.00
	20	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	10	1.01	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00		1.00
	5	1.02										1.00	1.00	1.00			1.00
	2			1.02			1.01										

Energy per kg of exhaust mass calculated

N Enth. (Kj/Kmol)	800	1000
FL	3169.232	2875.012

→

Fuel equivalence	800	1000
FL	1.00	0.98

→

N Enth. (Kj/Kmol)	800	1000
FL	148953.91	135125.57



Once these enthalpies have been calculated for each element type, they can be combined to create a total enthalpy table.

Table 14

Total Enthalpy (KJ)		RPM															
		800	1000	1250	1500	1750	2000	2250	2500	3000	3500	4000	4500	5000	5500	6000	6500
L O A D	FL	223891.30	204279.12	232391.83	344402.40			348672.23	341280.43	354068.33	344208.71	328468.28	324345.43	310837.71	344432.18		328627.41
	200								334942.03	320331.73	347230.67						
	190							335150.25	315802.95	302265.62	324669.38	321842.15					
	180					333530.44		312008.17	297067.54	283472.41	307984.88	299260.44	324887.51				
	170			293275.51	307541.62			283191.39	272114.71	254714.40	250780.07	253165.91	273672.13	312692.92			
	160			282161.61	287035.68			263702.68	253984.60	235624.31	230466.34	224681.66	241091.66	268848.70	323828.29		
	150			266403.61	262177.58	250176.93	248088.55	229442.87	212650.76	207727.61	201642.97	218822.87	222935.68	304556.27	299965.60		
	140			242448.95	243858.48	235342.00	233656.71	207115.91	191074.19	183907.48	175896.70	186491.12	187805.01	258903.63	279216.13	296757.41	
	130			227324.77	225259.82	218360.68	199222.43	180568.45	169008.62	164444.75	152860.46	155772.53	158915.80	226293.60	246256.43	273445.43	293103.73
	120			222610.03	214506.54	204990.77	182524.65	171763.17	158766.45	150364.38	149146.20	132013.45	135105.60	134737.13	191441.03	204012.99	221724.42
	110			208952.42	201125.42	166088.24	156800.22	160356.62	142736.96	137007.15	122132.50	115417.80	120735.40	114793.26	115556.10	182495.53	196961.05
	100		199410.36	201021.88	159423.24	143409.44	138256.14	135383.49	115218.38	110724.54	100056.14	94930.06	107761.79	100177.74	99871.41	162006.47	171329.09
	90		145605.52	143005.70	113579.83	74808.65	82654.04	104049.24	97823.36	93382.97	93886.79	93409.64	92822.50	92816.49	88375.74	143346.10	149968.55
	80		110777.22	108853.64	107533.53	81158.70	91602.44	114225.93	104594.77	96741.03	99324.54	104771.78	102085.53	99631.40	98806.71	138711.42	147558.90
	70		149914.46	130116.48	131625.80	101854.20	109685.37	116731.43	107145.23	96376.29	101565.36	109170.66	110282.74	106740.77	104317.83	136777.91	135583.60
	60		217248.84	166904.50	150764.00	125069.38	124730.38	120580.35	109896.15	106084.34	113691.07	119043.43	116237.10	114125.23	113368.57	160248.66	163825.17
	50		222164.24	217351.50	165263.40	147044.28	141920.66	133929.06	123545.03	122833.19	138959.33	137151.28	131093.81	127478.59	117415.16	160024.19	162240.94
	40	244318.40	232952.12	226279.38	189621.08	179762.47	168390.39	162945.13	151389.20	153099.58	190460.43	162915.90	159025.76	149141.80	127345.50	160340.40	159815.48
	30	278056.47	307363.39	270982.02	265885.12	243829.95	237679.07	226248.33	207492.53	204532.26	247728.45	199880.11	188648.74	179329.93	163208.52	182613.69	166719.61
	20	310725.84	313063.86	333566.43	287585.92	278442.77	288123.72	284907.94	271165.29	274734.28	280364.39	258240.45	235931.30	221508.40	228456.34	245678.31	222365.23
	10	366596.44	355010.44	409823.41	258757.56	355318.69	379172.10	255589.79	205381.88	219838.13	235993.07	267906.60	276627.97	272401.47	211379.44	243810.43	249947.83
	5	221204.63										241973.88	233089.32	243484.63			230816.66
	2			171340.53			290091.48										

Once total enthalpy is known the energy per kg of flow can be calculated. Using the table below for total mass with regards to fuel equivalence can be calculated.

Table 15

Fuel equiv.	0.9	0.91	0.92	0.93	0.94	0.95	0.96	0.97	0.98	0.99	1
CO2	7.2	7.28	7.36	7.44	7.52	7.6	7.68	7.76	7.84	7.92	8
H2O	8.1	8.19	8.28	8.37	8.46	8.55	8.64	8.73	8.82	8.91	9
N	47	47	47	47	47	47	47	47	47	47	47
O2	1.25	1.125	1	0.875	0.75	0.625	0.5	0.375	0.25	0.125	0
Total mass	1818.6	1819.74	1820.88	1822.02	1823.16	1824.3	1825.44	1826.58	1827.72	1828.86	1830

The following table shows how equation 2 is used to calculate the energy being used.

$$\frac{\text{Total enthalpy}}{\text{total mass}} = \text{Energy to spin turbine}$$

Table 16

Energy out of turbine (kJ/kg)		RPM															
		800	1000	1250	1500	1750	2000	2250	2500	3000	3500	4000	4500	5000	5500	6000	6500
L O A D	FL	122.34	111.63	126.99		188.20		190.53	186.49	193.48	188.09	179.49	177.24	169.86	188.21		179.58
	200								183.03	175.04	189.74						
	190							183.14	172.57	165.17	177.41	175.87					
	180					182.26		170.50	162.33	154.90	168.30	163.53	177.53				
	170				160.26	168.06		154.75	148.70	139.19	137.04	138.34	149.55	170.87			
	160				154.19	156.85		144.10	138.79	128.76	125.94	122.78	131.74	146.91	176.96		
	150				145.58	143.27	136.71	135.57	125.38	116.20	113.51	110.19	119.58	121.82	166.42	163.92	
	140				132.49	133.26	128.60	127.68	113.18	104.41	100.50	96.12	101.91	102.63	141.48	152.58	162.16
	130				124.22	123.09	119.32	108.86	98.67	92.35	89.86	83.53	85.12	86.84	123.66	134.57	149.42
	120			121.64	117.22	112.02	99.74	93.86	86.76	82.17	81.50	72.14	73.83	73.63	104.61	111.48	121.16
	110			114.18	109.90	90.76	85.68	87.63	78.00	74.87	66.74	63.07	65.98	62.73	63.15	99.72	107.63
	100		108.97	109.85	87.12	78.37	75.55	73.98	62.96	60.51	54.68	51.87	58.89	54.74	54.57	88.53	93.62
	90		78.99	78.15	62.07	40.88	45.17	56.86	53.46	51.03	51.30	51.04	50.72	50.72	48.29	78.33	81.95
	80		60.53	59.48	58.76	44.35	50.06	62.42	57.16	52.86	54.28	57.25	55.78	54.44	53.99	75.80	80.63
	70		81.92	71.10	71.93	55.66	59.94	63.79	58.55	52.66	55.50	59.66	60.26	58.33	57.00	74.74	74.09
	60		118.72	91.20	82.38	68.34	68.16	65.89	60.05	57.97	62.13	65.05	63.52	62.36	61.95	87.57	89.52
	50		121.40	118.77	90.31	80.35	77.55	73.19	67.51	67.12	75.93	74.95	71.64	69.66	64.16	87.44	88.66
	40	133.51	127.30	123.65	103.62	98.23	92.02	89.04	82.73	83.66	104.08	89.03	86.90	81.50	69.59	87.62	87.33
	30	151.94	167.96	148.08	145.29	133.24	129.88	123.63	113.38	111.77	135.37	109.22	103.09	97.99	89.18	99.79	91.10
	20	169.80	171.07	182.28	157.15	152.15	157.44	155.69	148.18	150.13	153.20	141.12	128.92	121.04	124.84	134.25	121.51
	10	200.33	193.99	223.95	141.40	194.16	207.20	139.67	112.23	120.13	128.96	146.40	151.16	148.85	115.51	133.23	
	5	120.88										132.23	127.37	133.05			
	2			93.63			158.52										



Table 17

Total energy to spin (Kw)		RPM															
		800	1000	1250	1500	1750	2000	2250	2500	3000	3500	4000	4500	5000	5500	6000	6500
L O A D	FL	0.65	1.60	2.54		7.97		10.25	11.21	#VALUE!	13.48	14.29	15.08	16.07	18.97		20.15
	200								11.28	11.85	13.59						
	190							9.96	10.17	10.69	12.55	14.02					
	180					7.40		8.60	8.97	9.43	11.16	12.01	15.32				
	170				5.25	6.37		7.29	7.61	7.89	8.53	10.09	12.78	15.44			
	160				4.74	5.55		6.27	6.57	6.75	7.18	8.21	10.30	13.36	17.08		
	150				4.13	4.66	4.91	5.46	5.59	4.63	5.97	6.81	8.76	9.97	14.86	15.88	
	140				3.46	4.00	4.23	4.76	4.62	4.62	4.82	5.38	6.69	7.58	11.56	13.77	16.65
	130				2.96	3.34	3.59	3.69	3.68	3.74	3.94	4.24	4.97	5.89	9.20	11.24	14.02
	120			2.28	2.53	2.76	2.77	2.90	2.98	3.05	3.27	3.34	3.96	4.51	7.07	8.50	10.14
	110			1.93	2.13	2.01	2.15	2.46	2.39	2.54	2.41	2.67	3.21	3.45	3.95	6.99	8.26
	100		1.42	1.71	1.52	1.56	1.67	1.85	1.72	1.85	1.78	1.96	2.60	2.73	3.11	5.62	6.57
	90		0.90	1.04	0.98	0.73	0.89	1.25	1.28	1.38	1.47	1.73	2.00	2.31	2.48	4.47	5.17
	80		0.60	0.70	0.79	0.69	0.87	1.21	1.25	1.26	1.38	1.71	1.97	2.21	2.45	3.92	4.58
	70		0.67	0.74	0.86	0.79	0.93	1.09	1.15	1.12	1.26	1.60	1.86	2.09	2.32	3.40	3.78
	60		0.83	0.82	0.84	0.80	0.89	0.98	1.02	1.06	1.25	1.55	1.76	1.95	2.22	3.56	4.13
	50		0.73	0.85	0.79	0.83	0.87	0.96	0.98	1.07	1.32	1.52	1.70	1.92	1.96	3.08	3.55
	40	0.57	0.61	0.75	0.76	0.84	0.90	0.99	1.01	1.12	1.35	1.55	1.74	1.92	1.86	2.70	3.00
	30	0.54	0.60	0.80	0.88	0.95	1.05	1.11	1.15	1.23	1.45	1.52	1.72	1.88	1.95	2.50	2.63
	20	0.46	0.50	0.71	0.72	0.81	0.98	1.07	1.15	1.28	1.26	1.56	1.71	1.90	2.20	2.64	2.74
	10	0.39	0.38	0.57	0.40	0.74	0.84	0.63	0.58	0.68	0.81	1.21	1.50	1.71	1.41	1.83	
	5	0.17										0.96	1.13	1.38			
	2			0.14			0.47										

Adding measured air mass and fuel mass to calculate total mass. Given as kg per h (kg/h) this is then divided by 3600 to give kg per second for use in calculating the usable energy in Kw to spin the turbine.

Table 18

Total mass (kg/sec)		RPM															
		800	1000	1250	1500	1750	2000	2250	2500	3000	3500	4000	4500	5000	5500	6000	6500
L O A D	FL	0.005292	0.014369	0.019994		0.042367		0.053778	0.060128	#VALUE!	0.07165	0.079619	0.085092	0.094633	0.100806	0.112214	0.097222
	200								0.061644	0.067711	0.071597						
	190							0.054411	0.058936	0.064697	0.070761	0.079736					
	180					0.040614		0.050431	0.055269	0.060889	0.066319	0.073425	0.086269				
	170				0.032753	0.037906		0.047092	0.051189	0.056661	0.062211	0.0729	0.085461	0.090358			
	160				0.030731	0.035408		0.043489	0.04735	0.052439	0.057042	0.066831	0.078211	0.090939	0.096503		
	150				0.028381	0.032528	0.035881	0.040247	0.044614	0.039822	0.052636	0.061803	0.073289	0.081808	0.089267	0.096889	
	140				0.0261	0.03	0.032911	0.037303	0.040781	0.044231	0.047981	0.056003	0.065672	0.073836	0.081739	0.090261	0.102703
	130				0.023814	0.027169	0.030081	0.033853	0.037269	0.040544	0.043872	0.050742	0.058333	0.067806	0.074439	0.083536	0.093803
	120			0.018739	0.021578	0.024639	0.027761	0.030883	0.034386	0.037064	0.040067	0.046281	0.053636	0.061319	0.067558	0.076239	0.083722
	110			0.016939	0.019375	0.0222	0.025089	0.028089	0.030583	0.033914	0.036142	0.042331	0.048586	0.055078	0.062631	0.070097	0.076703
	100		0.013006	0.015569	0.017444	0.019853	0.022147	0.025031	0.027286	0.030528	0.032642	0.03775	0.044206	0.049936	0.057011	0.063508	0.070142
	90		0.011375	0.013347	0.015756	0.017778	0.019683	0.021914	0.024019	0.027053	0.028628	0.033978	0.039483	0.045447	0.051361	0.057042	0.063119
	80		0.009869	0.011775	0.013528	0.015581	0.017392	0.019353	0.021942	0.023786	0.025422	0.029878	0.035294	0.040578	0.045361	0.051658	0.056786
	70		0.008236	0.010436	0.01195	0.014208	0.015578	0.017122	0.019711	0.021317	0.022622	0.026756	0.030925	0.035794	0.040669	0.045517	0.050975
	60		0.006986	0.009008	0.010139	0.011653	0.013053	0.014864	0.017003	0.018344	0.020158	0.023842	0.027675	0.031217	0.035853	0.040647	0.045944
	50		0.006006	0.007164	0.008739	0.010283	0.011206	0.01305	0.014567	0.015994	0.017364	0.020333	0.023728	0.027589	0.030622	0.035175	0.039986
	40	0.004281	0.004817	0.006094	0.007372	0.008561	0.009778	0.011117	0.012189	0.013347	0.012992	0.017419	0.020067	0.023544	0.026756	0.030775	0.0344
	30	0.003539	0.003567	0.005381	0.006064	0.007133	0.008083	0.008978	0.010167	0.010969	0.0107	0.013942	0.016703	0.019172	0.021908	0.025094	0.028836
	20	0.002736	0.002944	0.003894	0.004581	0.005322	0.006214	0.006867	0.007758	0.008531	0.008206	0.011028	0.013256	0.015667	0.017658	0.019683	0.022567
	10	0.001964	0.001964	0.002558	0.002825	0.003806	0.004044	0.004489	0.005142	0.005647	0.006272	0.008294	0.009897	0.011503	0.012189	0.013708	0.0201
	5	0.001431										0.007253	0.008889	0.010344			0.017128
	2			0.001519			0.002975										

COMPRESSOR CALCULATIONS

The compressor takes air flow into the turbo charger and compresses it to increase the volume of air being forced into the combustion chamber.

It can be seen in the table below (table 18) the pre compressor temperatures. No great variation in temperatures can be noted due to being ambient air flow into the compressor.



Table 19

Pre compressor (°c)		RPM																
		800	1000	1250	1500	1750	2000	2250	2500	3000	3500	4000	4500	5000	5500	6000	6500	
L O A D	FL	26.5	28.1	29.1		29.5		28.9	29	27.7	29.7	30	31.1	24.7	31.8		26.7	25.9
	200								28.8	28.6	29.6							
	190							29	28.8	28.6	29.3	29.7						
	180					29.5		28.8	28.8	28.4	29	29.7	30.9					
	170				29.7	25		25.5	26.2	27.2	25.8	25.3	25	30.6				
	160				29.6	25.3		25.4	26	26.9	25.6	25.3	25.3	25.5	31.8			
	150				29.5	24.7	25.1	25.4	25.9	26.7	25.4	25.2	25.1	24.3	31.8	26.6		
	140				29.3	25.3	25	25.4	25.6	26.6	25.1	25.1	24.9	25.8	31.4	30.7	26.8	
	130				29.2	24.6	25	25	25.5	26.4	25	25	25.3	24.5	31	30.4	26.7	25.9
	120			28.7	28.9	25.5	25.3	25	25.4	26.2	25.1	25	24.7	25.1	30.6	30.2	26.5	25.7
	110			28.3	28.7	24.5	24.7	25	25.2	25.9	25.1	25.1	25.2	25.5	25.5	30.1	26.4	25.6
	100		27.6	28.4	28.5	25	24.8	25	25	25.8	24.9	25.1	25	24.7	25.2	29.8	26.2	25.2
	90		27.5	28	28.1	25.3	24.9	25.1	24.9	25.5	24.9	25	24.7	25.6	24.9	29.8	26	25.1
	80		27.3	27.8	27.9	24.1	25.3	24.9	24.7	25.2	25	24.8	25.1	24.4	25.2	29.5	25.7	24.9
	70		27	27.8	27.9	25.6	24.6	25.1	24.6	25.2	25.1	24.6	24.8	25.3	24.6	28.9	25.6	25
	60		27	27.5	27.9	24.9	25	25	24.9	25.3	25.2	24.8	24.7	24.7	25.1	28.8	25.3	24.7
	50		26.9	27.7	27.8	24	24.7	24.5	25.1	25.3	25.3	24.8	24.8	24.8	24.7	28.7	25	24.7
	40	26.7	27.1	27.9	27.9	25.7	24.9	24.9	24.9	25.1	25.4	24.8	24.8	24.8	24.6	28.7	24.9	24.5
	30	26.6	26.9	27.9	28	24.8	24.9	25.2	24.9	25.1	25.6	24.8	24.8	24.8	25.1	28.6	24.9	24.3
	20	26.3	26.9	28.1	28.1	24.2	25	25	24.7	24.8	25.7	24.3	24.7	24.7	24.7	28.7	24.9	24.1
	10	26.4	27.4	28.3	28.7	24.6	25	24.9	24.8	25.3	26.3	24.1	24.9	24.8	25.1	29.4		24.1
	5	26.5										24.5	24.3	24.8				24.6
	2			28.9			25.1											

A clear pattern forms once the air has been compressed (table 20), with a marked increase in temperature above half load, with an increase also seen with RPM increase, however to a lesser extent.

Table 20

Post compressor (°C)		RPM																
		900	1000	1250	1500	1750	2000	2250	2500	3000	3500	4000	4500	5000	5500	6000	6500	
L O A D	FL	42.6	52.9	81.3		156.3		153.3	151.3	149.4	150.4	145.7	143.7	139.3	157.9		149.4	
	200								157.8	154.5	150.3							
	190							157	150	146.9	149.3	146.2						
	180					148.6		142.6	138.7	136.6	138	131.9	147.3					
	170				128.9	133.4		130.3	126.6	126.9	124.2	125.1	137.5	139.4				
	160				121.3	121.6		117.5	114.9	115.5	111.9	111.8	122.5	133.6	145.4			
	150				110.6	107.2	106.3	105.7	103	103.1	100.6	100.9	111.8	113.8	130.3	124.9		
	140				95.1	95	93.5	94.7	92.8	91.7	89	88.2	96.2	100.1	114.5	119.2	128.6	
	130				81.9	78.7	79.8	79.8	79.1	78.8	76.5	75.3	80.8	86.8	100.5	107	113.1	124.4
	120			73.6	69.6	65.1	68.5	66.9	68.8	65.4	64.3	64.3	69.9	73.6	85.2	91.9	94.2	106.9
	110			61.2	58.1	54.2	56.1	56.2	52.9	55	52.9	55.3	59.9	62.7	68.8	82.1	83.9	90.9
	100		57.8	53.7	48.8	44	45.3	45.5	42.7	45.4	43.8	45.5	51.1	52.7	58.6	70	71.3	78.3
	90		44.9	43.7	41.2	36.3	38.2	38.6	38.5	40.2	40.6	41.6	43.2	46.9	49.3	58	58.6	65.1
	80		39	39.6	39.4	34.9	38	38.1	38	39.2	39.8	40.1	42.1	43.9	46.5	54	51.6	53.9
	70		38.9	39.6	39.4	34.9	37.2	37.9	37.9	39.1	39.7	38.9	40.2	42.5	44.3	51.4	49.5	51
	60		42.2	39.8	39.9	35.1	37.1	37.3	37.8	38.8	39.4	39.2	39.4	41.1	43.7	54.5	53.1	53.9
	50		42.9	44.9	40.3	34.8	36.7	37.1	37.7	38.3	38.7	38.3	38.2	39.9	41.2	51.4	49.8	52.3
	40	43	43.2	44.5	40.5	35.4	37	37.3	37.4	37.9	38.1	37.6	36.9	38.1	40.2	48.7	46.7	48.7
	30	42.1	42.3	43.8	40.6	34.8	36.7	37.4	37.4	37.6	38.1	37.2	36.4	37	38.3	45.4	43.3	45.5
	20	41.6	42.3	43.4	41.2	34.8	36.9	37.6	37.6	37.6	38.8	36.8	36	36.1	35.9	42.6	39.5	39.8
	10	42.4	43.5	44.5	46.1	36.1	38.6	41.9	42	42	43.1	38.4	38.4	37.8	40	45.8		37.6
	5	43.8										42.1	42.3	42.1				39.3
	2			47.6			43.3											

COMPRESSOR EFFICIENCY

To find compressor efficiency the perfect temperature out has to be calculated. This is done by using equation 3, where

$$T_{out\ perfect} = T_{in} * \left(\frac{P_{in}}{P_{out}} \right)^{\frac{\gamma-1}{\gamma}}$$



Table 21

Pre compressor (Kpa)		RPM															
		800	1000	1250	1500	1750	2000	2250	2500	3000	3500	4000	4500	5000	5500	6000	6500
L O A D	FL	101.7	101.7	101.6		101.6		101.5	101.5	101.6	101.1	101	101.3	100.9		100.9	100.9
	200							101.5	101.5	101.6	101.1						
	190							101.5	101.5	101.6	101.1	101					
	180					101.6		101.6	101.5	101.6	101.1	101.1	101				
	170				101.6	101.2		101.2	101.3	101.2	101.2	101.4	101.3	101			
	160				101.6	101.2		101.2	101.3	101.2	101.3	101.4	101.3	101.3	101		
	150				101.6	101.3	101	101.2	101.3	101.2	101.4	101.4	101.3	101.4	101	101	
	140				101.6	101.2	101	101.2	101.3	101.3	101.4	101.5	101.4	101.4	101	101	101
	130				101.7	101.1	101.1	101	101.3	101.3	101.4	101.5	101.4	101.4	101.1	101	100.9
	120			101.7	101.7	101.1	101.1	101.1	101	101.3	101.3	101.5	101.4	101.4	101.1	101	101.1
	110			101.7	101.7	101.2	101.2	101.2	101.1	101	101.1	101.5	101.5	101.4	101.5	101	101.2
	100		101.7	101.7	101.7	101.2	101.2	101.2	101.2	101.1	101.2	101.4	101.5	101.4	101.5	101.1	101.2
	90		101.7	101.7	101.7	101.2	101.2	101.3	101.3	101.2	101.3	101.2	101.5	101.4	101.6	101.1	101.1
	80		101.7	101.7	101.7	101.3	101.3	101.3	101.3	101.3	101.2	101.2	101.3	101.4	101.6	101.1	101.3
	70		101.7	101.6	101.8	101.3	101.3	101.3	101.3	101.3	101.4	101.3	101.6	101.6	101.1	101.3	101.1
	60		101.7	101.6	101.7	101.3	101.4	101.4	101.3	101.3	101.3	101.4	101.3	101.6	101.6	101.1	101.3
	50		101.7	101.6	101.7	101.3	101.4	101.4	101.3	101.4	101.3	101.4	101.6	101.6	101.6	101.2	101.3
	40	101.7	101.7	101.6	101.7	101.3	101.4	101.4	101.4	101.4	101.4	101.5	101.6	101.6	101.6	101.2	101.3
	30	101.7	101.7	101.6	101.7	101.3	101.4	101.4	101.4	101.4	101.4	101.4	101.6	101.6	101.7	101.2	101.4
	20	101.7	101.7	101.6	101.7	101.3	101.4	101.4	101.4	101.5	101.4	101.4	101.6	101.6	101.7	101.2	101.4
	10	101.7	101.7	101.7	101.7	101.4	101.4	101.4	101.4	101.5	101.4	101.4	101.6	101.6	101.6	101.2	101.3
	5	101.7							101.4	101.5		101.4	101.6	101.6			101.3
	2			101.7			101.4						101.6	101.6			101.3

Again it can be seen how no discernible pattern can be seen in pressure pre compressor, with a pattern only being formed post compressor.

Table 22

Post compressor (Kpa)		RPM															
		800	1000	1250	1500	1750	2000	2250	2500	3000	3500	4000	4500	5000	5500	6000	6500
L O A D	FL	102.8	125.3	143.5		231.8		235.9	237.3 ***	234.7	230	224.2	230.3	235.4		222.3	193.8
	200								245.3	245.2	234.7						
	190							240.2	235.3	234.9	233.5	231.2					
	180					223		223.2	221.2	221.7	219.3	212.3	229.6				
	170				196.6	209.3		209.7	206.5	207.3	208.1	212.7	229.3	217.5			
	160				187.8	195.7		194.3	192.1	193	192.4	194.9	208.7	221.1	219.6		
	150				176.1	195.7	180.1	180.5	178	178	178.4	180.8	194.8	196.8	200.7	200.2	
	140				160.4	179.9	165.6	157.9	166.3	164.4	164.3	164.8	174.9	177.3	181.3	185.3	200.2
	130				147.1	166.2	150.6	151.4	150.7	149.8	149.5	148.9	155	161.6	164.8	171.1	182.3
	120			136.6	134.7	149.5	138.3	137.1	137.2	134.8	135.2	135.8	142.3	145.2	146.8	152.8	158.9
	110			124.6	130	134.7	125.4	125.3	122.1	123.4	122.1	125.2	129.8	131.1	136.2	140.1	145.4
	100		120.4	117.4	113.6	123.5	113.6	113.8	110.9	112.7	111.8	113.4	119.2	119.9	124.5	127.1	131.4
	90		108.5	107.6	106.1	113.2	105.9	106.2	106.3	107.1	108.2	109.2	110.4	112.8	114.3	114.3	118.2
	80		102.9	103.3	103.9	104.7	105.4	105.7	105.6	106.3	107.3	108.3	109.8	111.8	113.2	112.2	112.5
	70		102.4	103	103.5	103.8	104.7	104.3	104.3	105.5	106.2	104.5	105.7	108.5	111.6	111.6	112.5
	60		104.2	102.6	102.6	102.2	102.4	102.5	102.8	103.2	103.6	104.2	104.4	105.3	106.2	108	109
	50		103.2	103.8	102.1	101.7	101.9	102.2	102.5	102.8	103	103.7	103.8	104.8	105.5	107	108
	40	102.4	102.6	103.2	101.9	101.5	101.7	101.9	102.1	102.3	102.1	103.1	103.1	103.9	105.1	105.9	107
	30	101.9	101.9	102.7	101.7	101.3	101.4	101.5	101.7	101.8	101.6	102.5	102.6	103.1	104	104.3	105.5
	20	101.7	101.8	101.9	101.6	101.2	101.3	101.4	101.4	101.4	101.4	101.8	101.9	102.3	102.6	102.6	103.6
	10	101.7	101.7	101.9	101.6	101.3	101.3	101.3	101.3	101.3	101.3	101.6	102.3	102.4	102.8	101.8	102.3
	5	101.8										101.9	103.2	103.4			101.7
	2			101.8			101.7										

With these pressure tables now added to the excel worksheets, the perfect temperature of the compressor can be found.



Table 23

Tout perfect (deg C)		RPM															
		800	1000	1250	1500	1750	2000	2250	2500	3000	3500	4000	4500	5000	5500	6000	6500
L O A D	FL	26.58	29.83	32.12		37.34		36.77	36.96		37.78	37.95	39.06	31.23	40.51		33.46
	200								37.06	36.79	37.65						
	190							37.09	36.62	36.34	37.22	37.63					
	180					36.93		36.06	35.98	35.49	36.18	36.71	39.07				
	170				35.86	30.77			31.40	32.11	33.38	31.70	31.26	31.57	38.10		
	160				35.28	30.55			30.60	31.22	32.35	30.75	30.49	31.10	31.87	39.70	
	150				34.52	29.81	29.61	29.97	30.43	31.37	29.85	29.73	30.26	29.37	38.69	32.34	
	140				33.38	29.82	28.79	28.84	29.50	30.55	28.81	28.83	29.10	30.27	37.11	36.51	32.59
	130				32.45	28.35	28.01	28.07	28.56	29.52	27.93	27.89	28.56	27.99	35.64	35.34	31.61
	120			31.22	31.32	28.52	27.67	27.27	27.72	28.43	27.26	27.17	27.21	27.81	34.04	33.99	30.15
	110			29.99	30.79	26.59	26.26	26.57	26.60	27.43	26.49	26.65	27.03	27.44	27.74	33.05	29.28
	100		28.96	29.59	29.42	26.46	25.63	25.85	25.66	26.61	25.62	25.92	26.17	25.91	26.71	31.81	28.23
	90		28.01	28.45	28.44	26.12	25.22	25.44	25.25	25.92	25.37	25.55	25.31		25.75	30.86	27.18
	80		27.39	27.92	28.07	24.33	25.59	25.20	25.00	25.55	25.42	25.29	25.68	26.32	25.99	30.39	26.48
	70		27.05	27.91	28.03	25.78	24.83	25.30	24.81	25.49	25.44	24.81	25.10	25.78	25.27	29.73	26.38
	60		27.19	27.58	27.97	24.96	25.07	25.08	25.00	25.43	25.36	24.99		24.95	25.42	29.35	25.84
	50		27.01	27.87	27.83	24.03	24.73	24.56	25.18	25.40	25.42	24.96	24.95	25.02	24.97	29.16	25.46
	40	26.75	27.17	28.02	27.92	25.71		24.94	24.95	25.16	25.45	24.91	24.90	24.96	24.84	29.07	25.29
	30	26.61	26.92	27.99	28.00	24.80	24.90	25.21	24.92	25.13	25.61	24.88	24.87	24.90	25.26	28.85	25.18
	20	26.30	26.91	28.12	28.09	24.19	24.89	25.00	24.70	24.79	25.70	24.33	24.72	24.75	24.76	28.81	25.05
	10	26.40	27.40	28.32	28.69	24.59	24.99	24.89	24.79	25.29	26.29	24.11	24.95	24.86	25.18	29.45	
	5	26.51										24.53	24.41	24.92			
	2			28.91			25.12										

This of course is an ideal temperature, and will not be reached due to the act of the air being compressed in the first place.

If table 20 (measured post compressor temperature) and the table above (table 23, perfect post compressor temperature) are compared, then the compressor efficiency can be calculated. This is shown below in table 24

Table 24

Comp eff. (%)		RPM															
		800	1000	1250	1500	1750	2000	2250	2500	3000	3500	4000	4500	5000	5500	6000	6500
L O A D	FL	62.40	56.38	39.50		23.89		23.99	24.43		25.12	26.05	27.18	22.42	25.65		22.40
	200								23.48	23.81	25.05						
	190							23.63	24.41	24.74	24.93	25.74					
	180					24.85		25.29	25.94	25.98	26.22	27.83	26.53				
	170				27.82	23.06		24.10	25.37	26.31	25.52	24.99	22.96	27.33			
	160				29.08	25.12		26.05	27.17	28.01	27.48	27.27	25.39	23.86	27.30		
	150				31.21	27.81	27.86	28.35	29.54	30.43	29.67	29.46	27.06	25.81	29.70	25.90	
	140				35.10	31.39	30.80	30.46	31.78	33.31	32.37	32.68	30.25	30.24	32.41	30.63	25.34
	130				39.62	36.03	35.11	35.17	36.11	37.46	36.51	37.04	35.35	32.25	35.47	33.03	27.95
	120			42.42	44.99	43.80	40.39	40.77	40.30	43.47	42.39	42.25	38.93	37.79	39.95	36.99	32.01
	110			49.00	52.99	49.05	46.81	47.28	50.28	49.86	50.08	48.19	45.13	43.77	40.31	40.26	34.90
	100		50.11	55.10	60.28	60.14	56.58	56.82	60.10	58.62	58.49	56.96	51.22	49.17	45.59	45.45	39.59
	90		62.39	65.11	69.03	71.96	66.02	65.91	65.57	64.47	62.50	61.42	58.60		52.24	53.21	46.38
	80		70.24	70.52	71.25	69.71	67.34	66.15	65.78	65.18	63.87	63.06	61.01	59.96	55.89	56.28	51.32
	70		69.54	70.48	71.15	73.87	66.76	66.76	65.45	65.20	64.08	63.79	62.45	60.66	57.04	57.84	53.29
	60		64.43	69.29	70.10	71.12	67.57	67.23	66.15	65.55	64.37	63.76		60.71	58.17	53.85	48.65
	50		62.97	62.07	69.06	69.04	67.40	66.19	66.80	66.32	65.69	65.17	65.32	62.71	60.60	56.73	51.13
	40		62.89	62.98	68.93	72.64		66.85	66.71	66.39	66.80	66.25	67.49	65.51	61.79	59.70	54.16
	30	61.90	63.63	63.89	68.97	71.26	67.85	67.40	66.63	66.83	67.23	66.87	68.32	67.31	65.96	63.54	58.16
	20	62.47	63.61	64.80	68.18	69.52	67.46	66.49	65.69	65.94	66.24	66.11	68.67	68.56	68.98	67.64	63.43
	10	63.46	62.99	63.63	62.24	68.12	64.75	59.41	59.03	60.20	61.00	62.80	64.97	65.76	62.96	64.30	
	5	62.52											58.28	57.70	59.20		
	2			60.73			58.02										

Note values above 70% are marked in red text. This is due to efficiency in real world conditions rarely reaching above 70%, and figures should be treated with care. However, as these highlighted valves aren't excessively over 70% the results from the calculation should be reliable.

ENERGY OF OUT THE COMPRESSOR

To calculate the energy the compressor makes, much of the steps are the same as calculating the energy taken to spin the turbine side of the turbo charger, with some minor differences.

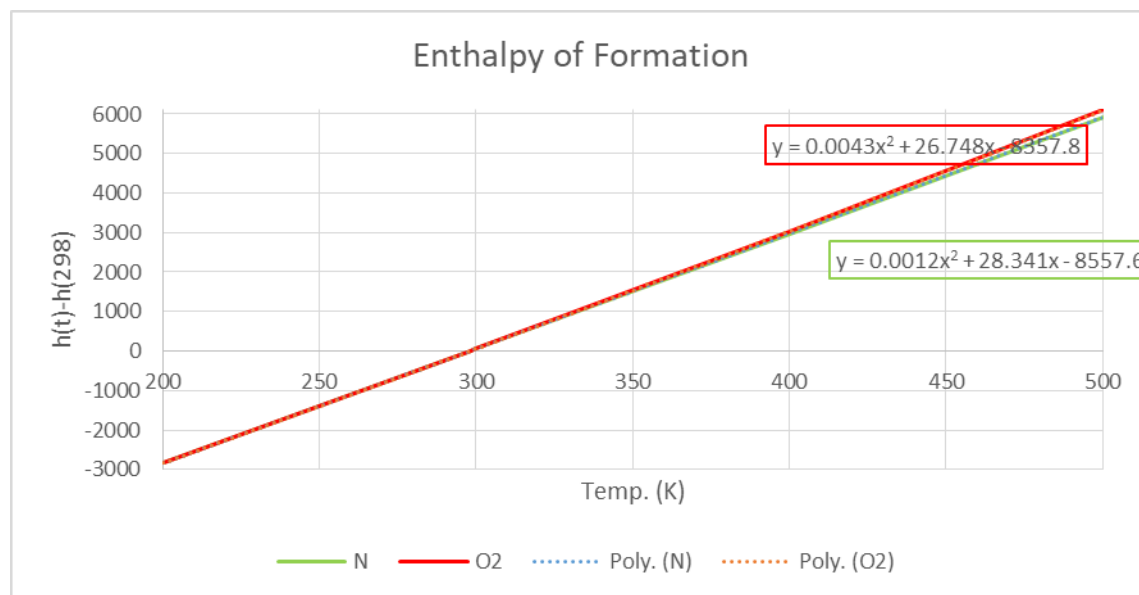


To begin with the element composition will be different, as each half of the turbo charger is sealed from the other half. The turbine will only see exhaust gas flow, with the compressor side will be made up of atmospheric air, and is therefore made up of mostly nitrogen and oxygen.

Table 25

		°C	K
Comp. temp	Min temp	24	297.15
	Max temp	157.9	431.05
	Temp.	N2	O2
	K	h(t)-h(298)	h(t)-h(298)
	200	-2841	-2836
	298	0	0
	300	54	54
	400	2973	3031
	500	5920	6097

The same process was followed as before, wherein the Enthalpy of Formation tables of both nitrogen and oxygen were formed into a graph with a polynomial being created from the graph.



Graph 6

The measured temperatures are then input into the polynomial to form the total enthalpy. No adjust for mixture ratio is needed as no fuel is added at this point.



Table 26

Total Enthalpy (KJ)		RPM																		
		800	1000	1250	1500	1750	2000	2250	2500	3000	3500	4000	4500	5000	5500	6000	6500			
L O A D	FL	26951.21	41547.42	87619.66		213891.68		209793.92	206226.79	205172.15	203526.15	195039.00	189802.08	193037.01	212765.06		206844.52	-43233.05		
	200								217614.10	212336.07	203523.48									
	190							215918.71	204351.90	199419.29	203235.97	196390.15								
	180					200801.97		191782.21	185162.50	182268.50	183640.15	172122.91	196251.07							
	170				167037.60	182526.60	176434.82	168994.08	167830.11	165597.31	167957.77	189481.09	183339.15							
	160				154330.97	162030.34		154923.02	149520.66	149030.73	145115.40	145447.90	163554.28	182029.79	191517.74					
	150				136394.71	138674.73	136485.08	134969.66	129572.36	128403.53	126355.24	127196.21	145782.28	150502.19	165896.88	165445.26				
	140				110549.24	117070.07	115040.94	116396.70	112856.94	109329.44	107284.59	105935.88	119763.76	124842.19	139811.42	148935.63	171379.72			
	130				88462.99	90766.57	91950.06	91950.06	89935.37	87925.35	86394.20	84374.48	93132.55	104579.07	116819.89	128803.79	145305.44	165768.86		
	120			75326.28	68263.13	66383.72	72433.83	70245.34	72771.09	65717.50	65708.00	65875.19	75791.23	81346.57	91680.63	103645.28	113713.80	136495.81		
	110			55148.15	49272.58	49748.86	52603.70	52270.02	46396.94	48750.88	46564.13	50592.04	58148.55	62350.63	72603.89	87294.26	96515.28	1209652.38		
	100		50608.67	42388.13	34000.30	31805.57	34319.02	34319.92	29626.86	32814.71	31637.55	34152.73	43711.22	46897.27	55965.29	67430.27	75637.96	89089.99		
	90		29133.72	26286.11	21929.54	18404.78	22255.26	22590.81	22757.70	24602.12	26275.39	27783.64	30966.34	#REF!	40859.02	47264.56	54627.68	67052.50		
	80		19582.06	19750.85	19248.59	18067.06	21251.54	22087.78	22254.67	23428.59	24768.02	25604.94	28454.24	30634.79	35662.05	41051.58	43379.69	48576.56		
	70		19916.27	19750.85	19248.59	15559.28	21082.12	21418.45	22254.38	23261.09	24433.31	23929.21	25772.47	28790.14	32977.14	37692.50	40024.12	43543.46		
	60		25444.79	20587.62	20086.14	17064.46	20245.93	20580.84	21585.36	22591.41	23763.60	24097.34	24599.53	27447.45	31135.57	43061.70	46565.35	48911.02		
	50		26785.05	28799.23	20923.48	18066.82	20077.68	21081.84	21083.51	21753.97	22423.92	22589.92	22422.44	25269.91	27614.99	38027.04	41530.48	46226.10		
	40	#REF!	26953.34	27794.24	21091.28	16229.14	#REF!	20748.03	20915.49	21418.45	21251.82	21417.60	20245.40	22254.96	26106.83	33498.05	36498.95	40521.45		
	30	27454.31	25779.59	26620.97	21091.56	16729.42	19743.31	20413.92	20915.49	20916.04	20917.42	20747.76	19408.17	20412.85	22088.36	28132.07	30799.56	35490.19		
	20	26447.80	25779.59	25616.07	21929.54	17732.48	20078.21	21083.23	21584.79	21417.60	21922.61	20913.84	18905.61	19073.04	18738.18	23271.81	24432.67	26272.62		
	10	25442.78	26954.40	27125.21	29138.32	19240.23	22758.00	28453.50	28788.24	27952.29	28123.56	23927.64	22590.22	21752.54	24935.86	27464.43		22587.84		
	5	26616.06												29457.35	30126.83	28955.81		24599.21		
	2	73198.63		31318.82				30465.18												

Note a couple of cells have a reference error; this was due to missing data from the original data sets.

Table 27

Air mass (kg/h)		RPM																
		900	1000	1250	1500	1750	2000	2250	2500	3000	3500	4000	4500	5000	5500	6000	6500	
L O A D	FL	17.8	48.4	67.3		142.5		180.2	201.1	***	239.2	266	283.9	315.9	335.7		371.3	350
	200								207.3	227.6	239							
	190							183	198.2	217.6	237.6	266.8						
	180					136.6		169.6	185.9	204.8	222.7	245.7	288.7					
	170				110.2	127.5		158.4	172.2	190.6	209.3	245.2	287.4	301.6				
	160				103.4	119.1		146.3	159.3	176.4	191.9	224.8	263.2	305.9	321.8			
	150				95.5	109.4	120.7	135.4	147.3	132	177.1	207.9	246.6	275.2	298.8	323.4		
	140				87.8	100.9	110.7	125.5	137.2	148.8	161.4	188.4	220.9	248.4	274	302	341.8	
	130				80.1	91.4	101.2	113.9	125.4	136.4	147.6	170.7	196.2	228.1	249.7	279.8	313.3	349.4
	120			63	72.6	82.9	93.4	103.9	115.7	124.7	134.8	155.7	180.5	206.3	226.7	255.7	280.5	317.2
	110			57	65.2	74.7	84.4	94.5	102.9	114.1	121.6	142.4	163.5	185.3	210.7	235.2	257.2	284.9
	100		43.8	52.4	58.7	66.8	74.5	84.2	91.8	102.7	109.8	127	148.7	168	191.8	213.1	235.3	260.5
	90		38.3	44.9	53	59.8	66.2	73.7	80.8	91	96.3	114.3	132.8	152.9	172.8	191.4	211.8	235.3
	80		33.2	39.6	45.5	52.4	58.5	65.1	73.8	80	85.5	100.5	118.7	136.5	152.6	173.6	190.6	211.7
	70		27.7	35.1	40.2	47.8	52.4	57.6	66.3	71.7	76.1	90	104	120.4	136.8	153.1	171.5	190.6
	60		23.5	30.3	34.1	39.2	43.9	50	57.2	61.7	67.8	80.2	93.1	105	120.6	136.7	155.2	168
	50		20.2	24.1	29.4	34.6	37.7	43.9	49	53.8	58.4	68.4	79.8	92.8	103	118.3	134.5	150
	40	14.4	16.2	20.5	24.8	28.8	32.9	37.4	41	44.9	43.7	58.6	67.5	79.2	90	103.5	115.7	128.9
	30	11.9	12	18.1	20.4	24	27.2	30.2	34.2	36.9	36	46.9	56.2	64.5	73.7	84.4	97	110.8
	20	9.2	9.9	13.1	15.4	17.9	20.9	23.1	26.1	28.7	27.6	37.1	44.6	52.7	59.4	66.2	75.9	85.5
	10	6.6	6.6	8.6	9.5	12.8	13.6	15.1	17.3	19	21.1	27.9	33.3	38.7	41	46.1		67.6
	5	4.8										24.4	29.9	34.8				57.6
	2			5.1			10											

As no fuel is present at the compressor so only the air mass is taken into account when calculating the total energy in kw that is being used to spin the compressor.



Table 28

Total energy to spin (Kw)		RPM															
		800	1000	1250	1500	1750	2000	2250	2500	3000	3500	4000	4500	5000	5500	6000	6500
L O A D	FL	0.21	0.45					6.83		7.94	8.76	8.96	9.71	10.49			11.72
	200							8.02	8.21								
	190							6.93	7.20	7.67	8.74						
	180							5.77	6.14	6.57	7.30	8.04					
	170				3.45			4.92	5.21	5.69	6.57	7.81	9.25				
	160				2.98			3.99	4.27	4.63	5.28	6.20	8.10	9.48			
	150				2.42	2.71	2.99	3.22	2.77	3.68	4.25	5.08	6.49	7.28	8.68		
	140				1.81	2.10	2.34	2.59	2.72	2.86	3.27	3.79	4.82	5.54	6.83	8.24	
	130				1.31	1.49	1.70	1.87	1.99	2.10	2.39	2.68	3.44	4.23	5.29	6.53	8.22
	120			0.89	0.92	1.00	1.22	1.32	1.47	1.43	1.66	1.92	2.53	2.99	3.79	4.71	5.84
	110			0.58	0.60	0.68	0.80	0.87	0.86	0.96	1.07	1.34	1.74	2.13	2.76	3.63	4.45
	100		0.43	0.40	0.37	0.38	0.47	0.51	0.49	0.58	0.65	0.82	1.19	1.46	1.93	2.57	3.19
	90		0.21	0.23	0.21	0.20	0.27	0.30	0.34	0.38	0.49	0.60	0.77		1.27	1.62	2.08
	80		0.13	0.15	0.16	0.17	0.22	0.26	0.29	0.32	0.40	0.49	0.63	0.76	1.00	1.27	1.49
	70		0.11	0.13	0.15	0.13	0.20	0.23	0.26	0.29	0.36	0.40	0.50	0.64	0.82	1.05	1.23
	60		0.12	0.11	0.13	0.12	0.16	0.19	0.22	0.25	0.31	0.36	0.42	0.54	0.69	1.08	1.27
	50		0.10	0.14	0.12	0.11	0.14	0.17	0.18	0.21	0.25	0.29	0.34	0.42	0.53	0.83	1.01
	40		0.09	0.11	0.10	0.09		0.14	0.15	0.15	0.20	0.23	0.26	0.32	0.44	0.63	0.76
	30	0.05	0.08	0.09	0.08	0.07	0.10	0.11	0.12	0.12	0.16	0.19	0.20	0.24	0.30	0.44	0.55
	20	0.04	0.05	0.06	0.06	0.06	0.08	0.09	0.10	0.10	0.13	0.15	0.16	0.18	0.20	0.29	0.34
	10	0.03	0.04	0.04	0.06	0.04	0.06	0.08	0.09	0.10	0.13	0.13	0.14	0.14	0.19		
	5											0.14	0.17				
	2																

Now that the energy in kw's have been calculated for both the turbine and compressor sides of the turbo charger, thus the overall turbo efficiency can be calculated.

Table 29

Turbo efficiency (%)		RPM															
		800	1000	1250	1500	1750	2000	2250	2500	3000	3500	4000	4500	5000	5500	6000	6500
L O A D	FL	0.33	0.28					0.67			0.65	0.63	0.64	0.65			0.58
	200							0.71	0.69								
	190							0.70	0.71	0.72	0.70						
	180							0.67	0.68	0.70	0.65	0.67					
	170				0.66			0.67	0.69	0.72	0.77	0.77	0.72				
	160				0.63			0.64	0.65	0.69	0.74	0.76	0.79	0.71			
	150				0.58	0.58	0.61	0.59	0.49	0.80	0.71	0.75	0.74	0.73	0.58		
	140				0.52	0.52	0.55	0.54	0.59	0.62	0.68	0.70	0.72	0.73	0.59	0.60	
	130				0.44	0.44	0.47	0.51	0.54	0.56	0.61	0.63	0.69	0.72	0.57	0.58	0.59
	120			0.39	0.36	0.36	0.44	0.45	0.49	0.47	0.51	0.58	0.64	0.66	0.54	0.55	0.58
	110			0.30	0.28	0.34	0.37	0.35	0.36	0.38	0.44	0.50	0.54	0.62	0.70	0.52	0.54
	100		0.30	0.24	0.24	0.25	0.28	0.28	0.29	0.32	0.36	0.42	0.46	0.53	0.62	0.46	0.49
	90		0.24	0.22	0.22	0.27	0.30	0.24	0.26	0.28	0.33	0.34	0.38		0.51	0.36	0.40
	80		0.21	0.21	0.21	0.25	0.26	0.22	0.23	0.26	0.29	0.29	0.32	0.34	0.41	0.32	0.32
	70		0.17	0.17	0.17	0.17	0.21	0.21	0.22	0.26	0.28	0.25	0.27	0.31	0.35	0.31	0.33
	60		0.15	0.14	0.15	0.15	0.18	0.19	0.21	0.23	0.25	0.23	0.24	0.28	0.31	0.30	0.31
	50		0.14	0.16	0.15	0.13	0.16	0.18	0.19	0.19	0.19	0.19	0.20	0.22	0.27	0.27	0.28
	40		0.15	0.15	0.13	0.10		0.14	0.15	0.14	0.15	0.15	0.15	0.17	0.23	0.23	0.25
	30	0.10	0.13	0.11	0.09	0.08	0.09	0.10	0.11	0.10	0.11	0.12	0.12	0.13	0.15	0.18	0.21
	20	0.09	0.11	0.09	0.09	0.07	0.08	0.08	0.09	0.07	0.10	0.10	0.09	0.10	0.09	0.11	0.12
	10	0.07	0.10	0.07	0.15	0.06	0.07	0.13	0.15	0.14	0.16	0.11	0.09	0.08	0.13		
	5											0.15	0.15				
	2																

It can clearly be seen how higher loads produce greater efficiency.



Some the lower turbo efficiencies can be contributed to the use of the wastegate.

[illegible]

To calculate the energy that bypasses the turbo charger, which is excluded in the calculated overall turbo efficiency thus far, the flow of air need to be calculated through the wastegate. This data is not provided in the manufactures data sets. However this data could be gained through real world testing at UWTSD. The data was not gathered by the author, but by a follow student.

Litres per Second	
Range	Exhaust
1	19.5
2	37.1
3	75
4	148.5
5	219.6
6	284.6

$$= \text{range flow rate (litres per second)} * \text{Flow scale (\%)}$$

Table 31

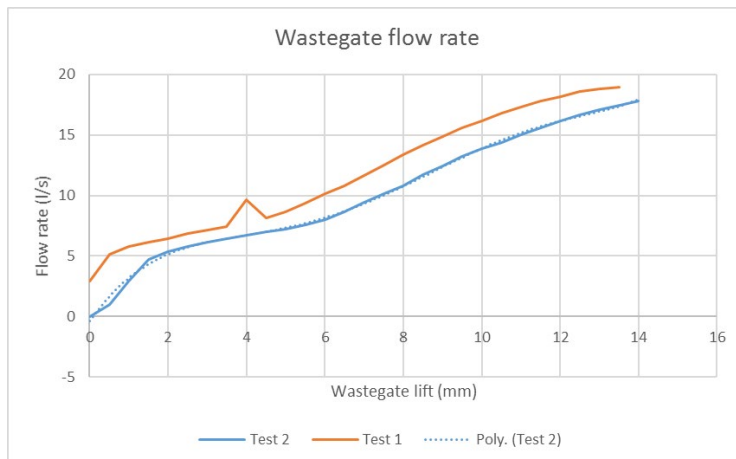
TEST 1					
Lift	Range	Flowscale	Flow	Flow	Flow
mm		%	l/s	CFM	M ³ /sec
0	1	0	0	0	0
0.5	1	0.15	2.925	6.185801	0.002925
1	1	0.262	5.109	10.80453	0.005109
1.5	1	0.295	5.7525	12.16541	0.005753
2	1	0.315	6.1425	12.99018	0.006143
2.5	1	0.33	6.435	13.60876	0.006435
3	1	0.35	6.825	14.43353	0.006825
3.5	1	0.365	7.1175	15.05211	0.007118
4	1	0.38	7.41	15.67069	0.00741
4.5	1	0.495	9.6525	20.41314	0.009653
5	1	0.418	8.151	17.23776	0.008151
5.5	1	0.444	8.658	18.30997	0.008658
6	1	0.48	9.36	19.79456	0.00936
6.5	1	0.52	10.14	21.44411	0.01014
7	1	0.555	10.8225	22.88746	0.010823
7.5	1	0.598	11.661	24.66073	0.011661
8	1	0.64	12.48	26.39275	0.01248
8.5	1	0.685	13.3575	28.24849	0.013358
9	1	0.724	14.118	29.8568	0.014118
9.5	1	0.764	14.898	31.50634	0.014898
10	1	0.8	15.6	32.99094	0.0156
10.5	1	0.827	16.1265	34.10438	0.016127
11	1	0.862	16.809	35.54773	0.016809
11.5	1	0.888	17.316	36.61994	0.017316
12	1	0.912	17.784	37.60967	0.017784
12.5	1	0.933	18.1935	38.47568	0.018194
13	1	0.952	18.564	39.25921	0.018564
13.5	1	0.964	18.798	39.75408	0.018798
14	1	0.973	18.9735	40.12523	0.018974
14.5	1	0.982	19.149	40.49637	0.019149
15	1	0.994	19.383	40.99124	0.019383
15.5	2	0.605	22.4455	47.46782	0.022446
16	2	0.61	22.631	47.86012	0.022631
16.5	2	0.615	22.8165	48.25242	0.022817
17	2	0.618	22.9278	48.48779	0.022928
17.5	2	0.616	22.8536	48.33088	0.022854
18	2	0.62	23.002	48.64471	0.023002
18.5	2	0.626	23.2246	49.11547	0.023225
19	2	0.631	23.4101	49.50776	0.02341
19.5	2	0.636	23.5956	49.90006	0.023596
20	2	0.63	23.373	49.42931	0.023373

TEST 2					
Lift	Range	Flowscale	Flow	Flow	Flow
mm		%	l/s	CFM	M ³ /sec
0	1	0	0	0	0
0.5	1	0.05	0.975	2.061934	0.000975
1	1	0.15	2.925	6.185801	0.002925
1.5	1	0.24	4.68	9.897281	0.00468
2	1	0.275	5.3625	11.34063	0.005363
2.5	1	0.295	5.7525	12.16541	0.005753
3	1	0.315	6.1425	12.99018	0.006143
3.5	1	0.331	6.4545	13.65	0.006455
4	1	0.343	6.6885	14.14486	0.006689
4.5	1	0.36	7.02	14.84592	0.00702
5	1	0.369	7.1955	15.21707	0.007196
5.5	1	0.389	7.5855	16.04184	0.007586
6	1	0.41	7.995	16.90785	0.007995
6.5	1	0.442	8.619	18.22749	0.008619
7	1	0.483	9.4185	19.91828	0.009419
7.5	1	0.52	10.14	21.44411	0.01014
8	1	0.555	10.8225	22.88746	0.010823
8.5	1	0.6	11.7	24.7432	0.0117
9	1	0.637	12.4215	26.26903	0.012422
9.5	1	0.677	13.2015	27.91858	0.013202
10	1	0.71	13.845	29.27946	0.013845
10.5	1	0.738	14.391	30.43414	0.014391
11	1	0.771	15.0345	31.79502	0.015035
11.5	1	0.799	15.5805	32.9497	0.015581
12	1	0.828	16.146	34.14562	0.016146
12.5	1	0.854	16.653	35.21782	0.016653
13	1	0.876	17.082	36.12508	0.017082
13.5	1	0.895	17.4525	36.90861	0.017453
14	1	0.913	17.8035	37.65091	0.017804
14.5	1	0.928	18.096	38.26949	0.018096
15	1	0.944	18.408	38.92931	0.018408
15.5	1	0.957	18.6615	39.46541	0.018662
16	2	0.584	21.6664	45.82018	0.021666
16.5	2	0.589	21.8519	46.21248	0.021852
17	2	0.598	22.1858	46.91861	0.022186
17.5	2	0.6	22.26	47.07553	0.02226
18	2	0.605	22.4455	47.46782	0.022446
18.5	2	0.605	22.4455	47.46782	0.022446
19	2	0.606	22.4826	47.54628	0.022483
19.5	2	0.612	22.7052	48.01704	0.022705
20	2	0.619	22.9649	48.56625	0.022965
20.5	2	0.622	23.0762	48.80163	0.023076

The flow bench used for this data gathering was a SuperFlow SF600.

A graph was created from the above tables (tables 31). An anomaly can clearly be seen in the data.





Graph 7

From this a graph a polynomial was created. The polynomial of the test two data as it was anomaly free, however this could be amended to give a more consistence data set.

Given the provided data from FoMoCo of the wastegate lift and the measured flow rate through the wastegate with use of the flow bench, a table can be compiled for the flow rate through the wastegate at set load and RPM.

Table 32

Wastegate flow (l/s)		RPM															
L O A D	FL	800	1000	1250	1500	1750	2000	2250	2500	3000	3500	4000	4500	5000	5500	6000	6500
		2.01						0.39	2.49	4.56	6.49	7.13	7.46	7.29		7.75	
	200								2.93	4.51							
	190							0.88	2.78	5.10	6.56						
	180							1.49	2.90	5.46	6.81	7.08					
	170							1.91	3.06	6.08	7.16	7.36	7.63	7.70			
	160							2.11	3.20	6.34	7.38	7.71	7.90	8.27			
	150						0.52	2.61	4.29	6.63	7.61	7.97	8.47	9.02	8.59		
	140							1.12	3.25	5.07	7.05	7.97	8.34	9.07	9.73	9.05	8.67
	130					0.09	2.67	5.10	6.34	7.57	8.98	9.19	9.81	11.06	9.70	9.56	9.24
	120				0.96	2.61	5.00	6.72	7.28	8.73	10.34	10.22	10.98	12.50	10.84	10.87	10.28
	110				2.93	5.93	7.04	7.82	9.30	11.39	12.33	11.93	12.85	14.34	11.85	11.85	11.68
	100			1.67	7.01	8.05	10.07	11.29	14.28	15.97	16.18	14.27	15.34	16.95	13.76	13.60	13.08
	90		6.48	8.19	13.67	16.93	17.31	17.32	17.32	17.26	17.27	17.27	17.21	16.95	16.82	16.22	15.22
	80		16.84	17.00	17.34	17.30	17.32	17.32	17.32	17.05	17.30	17.28	17.27	17.15	17.20	17.27	17.25
	70		17.32	17.33	17.33	17.30	17.32	17.32	17.32	16.96	17.26	17.26	17.26	17.14	17.14	17.07	17.18
	60		6.04	17.28	17.33	17.30	17.31	17.32	17.32	16.81	16.54	17.25	17.25	16.54	13.61	13.40	13.99
	50		1.63	1.41	17.33	17.30	17.31	17.32	17.32	16.81	16.52	17.26	17.26	17.16	14.97	14.06	13.48
	40	1.94	1.52	1.41	17.32	17.29	17.31	17.32	17.32	16.80	16.51	17.27	17.27	17.09	16.21	15.65	14.48
	30	1.98	1.04	1.34	17.17	17.30	17.31	17.32	17.32	16.76	16.50	17.27	17.27	17.13	17.07	16.64	15.50
	20	1.67	0.76	0.72	17.07	17.30	17.32	17.32	17.33	16.68	16.45	17.27	17.26	16.99	16.92	16.65	16.71
	10	1.74	0.64	0.72	12.83	17.29	17.32	17.35	17.36	16.67	14.79	8.92	11.15	9.84	13.43		16.49
	5	1.70															16.43
	2			0.56			0.72					10.37	6.30	7.11			

Unfortunately the wastegate flow analysis portion of the project was not completed due to time restraints, and it was not calculated how much the use of the wastegate flow affects the overall efficiency figures.

INTERCOOLER

An intercooler is widely used on forced induction systems. Calculations can be made to find the in relative cooling effect of this intercooler by using the data provided by FoMoCo. This however may only be relative to the model tested, and can be reliant on a number of parameters. For instance the flow of air over the intercooler could be restricted by the body panels on the vehicle, thus the intercooler is not being maximized by increased flow. The intercooler may also be in a hot engine bay, which will affect the heat transfer rate from the unit to the flow through it.



Adequate air flow at the lowest possible temperature will maximise the intercooler heat transfer rate and thus maximise efficiency.

Calculations are much the same as for the turbo efficiency calculation, in as much as Enthalpy of Formation tables are required for the energy transfer calculated in kw.

Table 33

Post compressor (°C)		RPM																
L O A D	FL	900	1000	1250	1500	1750	2000	2250	2500	3000	3500	4000	4500	5000	5500	6000	6500	
		42.6	52.9	81.3		156.3		153.3	151.3	149.4	150.4	145.7	143.7	139.3	157.9		149.4	
	200								157.8	154.5	150.3							
	190							157	150	146.9	149.3	146.2						
	180					148.6		142.6	138.7	136.6	138	131.9	147.3					
	170				128.9	133.4		130.3	126.6	126.9	124.2	125.1	137.5	139.4				
	160				121.3	121.6		117.5	114.9	115.5	111.9	111.8	122.5	133.6	145.4			
	150				110.6	107.2	106.3	105.7	103	103.1	100.6	100.9	111.8	113.8	130.3	124.9		
	140				95.1	95	93.5	94.7	92.8	91.7	89	88.2	96.2	100.1	114.5	119.2	128.6	
	130				81.9	78.7	79.8	79.8	79.1	78.8	76.5	75.3	80.8	86.8	100.5	107	113.1	124.4
	120			73.6	69.6	65.1	68.5	66.9	68.8	65.4	64.3	64.3	69.9	73.6	85.2	91.9	94.2	106.9
	110			61.2	58.1	54.2	56.1	56.2	52.9	55	52.9	55.3	59.9	62.7	68.8	82.1	83.9	90.9
	100		57.8	53.7	48.8	44	45.3	45.5	42.7	45.4	43.8	45.5	51.1	52.7	58.6	70	71.3	78.3
	90		44.9	43.7	41.2	36.3	38.2	38.6	38.5	40.2	40.6	41.6	43.2	46.9	49.3	58	58.6	65.1
	80		39	39.6	39.4	34.9	38	38.1	38	39.2	39.8	40.1	42.1	43.9	46.5	54	51.6	53.9
	70		38.9	39.6	39.4	34.9	37.2	37.9	37.9	39.1	39.7	38.9	40.2	42.5	44.3	51.4	49.5	51
	60		42.2	39.8	39.9	35.1	37.1	37.3	37.8	38.8	39.4	39.2	39.4	41.1	43.7	54.5	53.1	53.9
	50		42.9	44.9	40.3	34.8	36.7	37.1	37.7	38.3	38.7	38.3	38.2	39.9	41.2	51.4	49.8	52.3
	40	43	43.2	44.5	40.5	35.4	37	37.3	37.4	37.9	38.1	37.6	36.9	38.1	40.2	48.7	46.7	48.7
	30	42.1	42.3	43.8	40.6	34.8	36.7	37.4	37.4	37.6	38.1	37.2	36.4	37	38.3	45.4	43.3	45.5
	20	41.6	42.3	43.4	41.2	34.8	36.9	37.6	37.6	37.6	38.8	36.8	36	36.1	35.9	42.6	39.5	39.8
	10	42.4	43.5	44.5	46.1	36.1	38.6	41.9	42	42	43.1	38.4	38.4	37.8	40	45.8		37.6
	5	43.8										42.1	42.3	42.1				39.3
	2				47.6			43.3										

Table 34

Inport temp (°c)		RPM																	
L O A D	FL	900	1000	1250	1500	1750	2000	2250	2500		3000	3500	4000	4500	5000	5500	6000	6500	
		39.2	30.3	37.2		41.5		41.9	41.9	42.1	42	41.7	41.7	41.3	51		51.2		
	200								41.6	41.9	42								
	190							41.9	41.9	41.8	42	42.1							
	180					41.6		41.8	41.8	41.6	42.2	42.1	41.6						
	170				41.4	41.1		41.6	41.9	42	41.6	41	41	41.6					
	160				41.5	41		41.6	41.7	41.8	41.6	41.2	41.3	41.1	50.7				
	150				41.7	40.9	41.5	41.6	41.7	41.8	41.6	41.2	41.1	41.2	46.5	46			
	140				41.9	42.2	42.6	42.9	43.3	43.3	42.7	41.6	41.2	41	41.8	41.7	51.1		
	130				38.3	36.9	38.1	38.9	39.2	39.4	38.7	36.8	36.9	37.3	41.7	42	51.3	51.2	
	120			33.9	33.7	32.8	33.4	33.3	33.8	33.5	32.9	32.4	32.4	32.4	32.8	33.2	41.6	50.9	
	110			34	33.8	32.7	33.3	33.5	33.4	33.4	33	32.4	32.2	32.2	32	32.9	41.7	41.7	
	100		31	34.1	34	32.7	33.5	33.6	33.5	33.5	33.1	32.5	32.3	32.3	32	33.1	37.3	41.7	
	90		31	34	33.9	32.4	33.3	33.2	33	33.2	32.9	32.2	32	31.9	31.7	32.7	36.8	40.9	
	80		32	34.6	34.6	32.6	33.4	33.1	32.8	32.9	32.7	32	31.7	31.5	31.3	32.2	36.2	39.8	
	70		34.1	35.7	35.4	32.6	33.8	33.2	32.7	33.2	33.3	32.2	31.6	31.3	31.1	32.1	36	38.9	
	60		36.6	37.6	37.1	34	34.7	33.5	32.9	33.5	33.6	33	32.4	31.9	31.2	32.1	35.8	38.1	
	50		39.2	40.8	39.2	34.6	35.3	34.2	34.1	34.3	34.2	33.5	32.9	32.5	32.2	32.9	36.4	38.1	
	40	46.7	45.8	44.1	42.9	37.6	36.3	35.4	35.7	36.1	39.7	34.8	34	32.7	31.9	33.3	38.2	38.6	
	30	45.6	42.6	43.8	41.7	37.3	36.5	36.8	37.2	37.8	38.6	38.8	37.3	34.8	31.6	33.2	35.1	38.3	
	20	43.9	43.6	42.9	41.2	36.2	36.8	38	38.1	37.4	36.6	36.3	34.9	33.6	31.5	33	31.2	36.9	
	10	45.1	44.6	44.8	43.6	37.3	39	41.6	42.5	39.6	37	35.4	34.2	33.6	31.9	32.3		35.4	
	5	43.3										35.5	33.7	32.9				34.9	
	2			45.1				40.5											



Table 35

O2 Enth. (Kj/Kmol)		RPM															
		800	1000	1250	1500	1750	2000	2250	2500	3000	3500	4000	4500	5000	5500	6000	6500
L O A D	FL	92.14	612.59	1202.06		3168.31		3073.23	3017.12	2958.42	2989.16	2865.60	2809.61	2697.41	2955.39		2711.36
	200								3207.75	3106.92	2986.36						
	190							3177.14	2980.66	2896.49	2958.32	2868.76					
	180					2949.55		2776.12	2667.09	2613.85	2636.69	2469.16	2913.12				
	170				2404.53	2538.10		2438.11	2326.92	2332.57	2268.27	2309.57	2655.25	2692.07			
	160				2190.35	2212.24		2082.10	2007.25	2021.18	1926.79	1934.86	2229.13	2543.68	2612.89		
	150				1888.06	1815.61	1774.45	1755.15	1677.79	1677.85	1614.21	1633.33	1937.57	1990.29	2305.19	2168.40	
	140				1454.33	1443.44	1391.26	1416.20	1352.99	1322.70	1264.65	1272.47	1503.64	1616.66	1993.44	2126.59	2132.86
	130				1188.75	1138.84	1136.53	1114.87	1087.54	1073.90	1029.80	1048.36	1196.46	1350.44	1608.74	1780.27	1696.71
	120				1080.25	976.20	877.56	954.23	913.21	951.62	866.83	853.01	866.53	1019.55	1120.80	1428.18	1601.68
	110				738.68	659.58	583.12	618.62	615.94	528.82	585.97	539.64	621.17	751.89	828.26	1000.28	1340.33
	100				727.08	531.66	401.14	305.98	319.62	322.35	249.10	322.34	289.74	352.08	509.60	553.12	721.86
	90				376.33	262.70	197.62	105.47	132.57	146.11	148.80	189.45	208.39	254.41	303.20	406.30	476.89
	80				189.37	135.34	129.92	62.19	124.45	135.27	140.67	170.47	192.12	219.17	281.48	335.70	411.65
	70				129.90	105.58	108.28	62.19	91.98	127.15	140.67	159.65	173.20	181.26	232.69	303.13	357.35
	60				151.69	59.58	75.82	29.75	64.94	102.80	132.55	143.41	156.96	167.76	189.40	248.97	338.38
	50				100.27	111.18	29.80	5.41	37.88	78.46	97.40	108.24	121.78	129.87	143.38	200.24	243.57
	40	-100.39	-70.54	10.85	-65.06	-59.54	18.94	51.42	46.01	48.72	-43.33	75.77	78.45	146.08	224.58	417.35	230.46
	30	-94.94	-8.13		-29.81	-67.65	5.41	16.24	5.41	-5.41	-13.54	-43.32	-24.36	59.52	181.23	330.45	222.10
	20	-62.37	-35.25	13.56		-37.87	2.71	-10.83	-13.54	5.41	59.56	13.53	29.76	67.62	118.97	259.90	224.53
	10	-73.24	-29.84	-8.14	67.83	-32.48	-10.83	8.13	-13.56	65.04	165.26	81.20	113.65	113.63	219.16	365.63	59.54
	5		13.56									178.74	232.84	249.05			119.10
	2			67.87			75.90										

Using the polynomial already created from the compressor calculations a new table for enthalpy can be created. Note the make-up of the air will still be atmospheric at this stage, the same as the compressor calculations.

$$\frac{Kj}{Kg} = \frac{Kj}{Kmol} * No.mol$$

Table 36

O2 Total Enth. (Kj/Kg)		RPM															
		800	1000	1250	1500	1750	2000	2250	2500	3000	3500	4000	4500	5000	5500	6000	6500
L O A D	FL	1151.74	7657.38	15025.72		39603.90		38415.40	37713.95	36980.21	37364.56	35819.97	35120.16	33717.61	36942.33		33891.99
	200								40096.87	38836.47	37329.51						
	190							39714.20	37258.25	36206.17	36979.05	35859.44					
	180					36869.34		34701.56	33338.63	32673.18	32958.62	30864.48	36414.01				
	170				30056.57	31726.22		30476.40	29086.56	29157.07	28353.42	28869.67	33190.63	33650.90			
	160				27379.42	27653.03		26026.23	25090.56	25264.72	24084.82	24185.71	27864.13	31795.96	32661.12		
	150				23600.74	22695.18	22180.67	21939.34	20972.42	20973.08	20177.60	20416.68	24219.58	24878.66	28814.88	27104.98	
	140				18179.17	18043.05	17390.77	17702.44	16912.44	16533.74	15808.16	15905.83	18795.44	20208.31	24918.01	26582.37	26660.69
	130				14859.35	14235.55	14206.65	13935.86	13594.27	13423.71	12872.49	13104.45	14955.69	16880.51	20109.20	22253.32	21208.93
	120				13503.09	12202.50	10969.47	11927.93	11415.12	11895.27	10835.34	10662.64	10831.57	12744.32	14009.96	17852.29	20021.05
	110				9233.50	8244.74	7288.95	7732.74	7699.19	6610.28	7324.59	6745.45	7764.56	9398.62	10353.25	12503.46	16754.14
	100				9088.50	6645.76	5014.25	3824.74	3995.31	4029.36	3113.70	4029.23	3621.77	4401.05	6370.06	6913.94	9023.25
	90				4704.17	3283.71	2470.22	1318.37	1657.15	1826.33	1860.06	2368.07	2604.91	3180.18	3789.99	5078.78	5961.19
	80				2367.16	1691.69	1623.97	777.35	1555.66	1690.89	1758.41	2130.82	2401.55	2739.63	3518.49	4196.19	5145.68
	70				1623.71	1319.75	1353.48	777.35	1149.77	1589.41	1758.35	1995.59	2164.95	2265.75	2908.60	3789.15	4466.92
	60				1896.08	744.72	947.77	371.87	811.70	1284.99	1656.94	1792.65	1961.99	2097.03	2367.46	3112.12	4229.70
	50				1253.42	1389.72	372.49	67.62	473.51	980.73	1217.55	1353.01	1522.21	1623.40	1792.31	2502.99	3044.66
	40	-1254.93	-881.75	135.64	-813.20	-744.20	236.80	642.69	575.07	608.99	-541.65	947.08	980.67	1826.04	2807.27	5216.87	2880.76
	30	-1186.72	-101.67		-372.65	-845.56	67.66	203.00	67.67	-67.68	-169.24	-541.50	-304.48	744.06	2265.32	4130.61	2776.22
	20	-779.57	-440.66	169.49		-473.43	33.83	-473.37	-169.21	67.68	744.49	169.14	371.98	845.24	1487.08	3248.77	2806.65
	10	-915.44	-372.99	-101.74	847.93	-405.95	-135.41	101.65	-169.45	812.97	2065.80	1014.95	1420.66	1420.39	2739.54	4570.40	744.20
	5	169.52										2234.24	2910.54	3113.11			1488.69
	2			848.33			948.79										

Using the air mass flow (kg/h) used in the compressor calculations the energy transfer in kw can be made into a table (table 37 below)



Table 37

FL	0.02	0.30	0.81	4.47	5.48	6.01	#VALUE!	7.08	7.55	7.91	8.45	9.81	9.97
200						6.58	7.00	7.07					
190					5.76	5.85	6.25	6.96	7.59				
180			3.99		4.67	4.92	5.31	5.82	6.02	8.33			
170		2.63	3.21		3.83	3.98	4.41	4.71	5.62	7.57	8.05		
160		2.25	2.62		3.03	3.18	3.54	3.68	4.32	5.83	7.72	8.33	
150		1.79	1.98	2.13	2.36	2.46	2.20	2.85	3.38	4.75	5.44	6.83	6.96
140		1.27	1.45	1.53	1.77	1.85	1.96	2.03	2.39	3.31	4.00	5.43	6.38
130		0.95	1.04	1.15	1.27	1.36	1.46	1.52	1.79	2.34	3.07	4.00	4.95
120		0.68	0.71	0.73	0.89	0.95	1.10	1.08	1.15	1.35	1.84	2.31	3.23
110		0.42	0.43	0.44	0.52	0.58	0.54	0.67	0.66	0.88	1.23	1.53	2.11
100	0.32	0.28	0.24	0.20	0.24	0.27	0.23	0.33	0.32	0.45	0.76	0.93	1.38
90	0.14	0.12	0.10	0.06	0.09	0.11	0.12	0.17	0.20	0.29	0.40	0.62	0.82
80	0.06	0.05	0.06	0.03	0.07	0.09	0.10	0.14	0.16	0.22	0.33	0.46	0.63
70	0.04	0.04	0.04	0.03	0.05	0.07	0.09	0.11	0.13	0.16	0.24	0.37	0.49
60	0.04	0.02	0.03	0.01	0.03	0.05	0.08	0.09	0.11	0.13	0.18	0.26	0.41
50	0.02	0.03	0.01	0.00	0.01	0.03	0.05	0.06	0.07	0.09	0.11	0.19	0.25
40	-0.01	-0.01	0.00	-0.02	-0.02	0.01	0.02	0.02	-0.02	0.04	0.05	0.12	0.20
30	-0.01	0.00	-0.01	-0.02	0.00	0.00	0.00	0.00	-0.02	-0.01	0.04	0.13	0.28
20	-0.01	0.00	0.00	-0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.04	0.07	0.17
10	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.03	0.02	0.04	0.04	0.09
5	0.00									0.04	0.07	0.09	
2		0.00			0.01								0.07

per m^3?	900	1000	1250	1500	1750	2000	2250	2500	3000	3500	4000	4500	5000	5500	6000	6500
FL	15.40919	278.5317	757.4975	4196.984		5149.284	5642.604	#VALUE!	6649.943	7092.522	7423.258	7933.568	9213.486		9356.131	
200							6180.609	6574.33	6638.21							
190						5404.283	5494.683	5863.868	6537.963	7121.112						
180				3748		4382.148	4616.291	4985.151	5467.228	5651.804	7824.381					
170		2469.393	3014.614			3598.527	3734.788	4143.729	4426.109	5279.56	7106.362	7559.175				
160		2112.083	2457.133			2841.637	2983.584	3326.576	3451.069	4059.852	5470.889	7248.475	7817.508			
150			1683.108	1854.816	2000.063	2219.34	2308.535	2068.775	2670.993	3172.693	4459.835	5111.532	6415.192	6534.835		
140			1193.604	1361.398	1439.773	1661.287	1735.353	1840.118	1908.921	2242.416	3104.731	3752.407	5096.686	5990.213	6787.988	
130			891.4459	974.9165	1077.028	1188.996	1277.004	1371.607	1423.678	1676.639	2198.206	2882.82	3753.168	4651.109	4956.577	6552.167
120			637.8891	664.5466	682.4918	835.8117	889.9402	1032.466	1013.972	1078.798	1265.859	1725.736	2167.543	3031.769	3832.519	3769.977
110			395.1001	403.6668	409.0586	490.2021	546.4672	511.0453	627.7818	616.2893	830.6055	1153.911	1440.224	1976.676	2952.774	2771.489
100		299.0127	261.6011	221.2123	192.1278	223.7863	255.0721	214.957	311.1111	299.0385	420.2614	711.8614	872.794	1299.758	2004.927	2040.546
90		135.4959	110.8618	98.46645	59.32975	82.5355	101.2643	113.0735	162.099	188.6952	273.4176	378.5372	583.8402	774.3093	1233.666	1176.661
80		59.13009	50.38822	55.57901	30.65713	68.46956	82.81884	97.6397	128.2432	154.4684	207.1357	314.1496	430.777	590.4251	963.8573	747.6457
70		33.83379	34.83911	40.92296	27.96586	45.32968	68.8804	87.71581	107.6417	123.9351	153.4238	227.5763	343.1602	459.5769	752.4228	589.6366
60		33.50049	16.96761	24.3028	10.96975	26.80841	48.34152	71.31091	83.20906	100.0662	126.524	165.8223	245.8141	383.6553	779.892	683.9454
50		19.03017	25.16478	8.232946	1.760487	13.42983	32.39243	44.88424	54.75962	66.8732	83.53965	107.6104	174.7399	235.8961	557.3253	459.0221
40	-13.5728	-10.7294	2.088762	-15.1562	-16.123	5.860465	18.08199	17.73639	20.56729	-17.7979	41.75112	49.80482	108.8142	190.0748	405.8333	250.4504
30	-10.6088	-0.91679		-5.71371	-15.267	1.384313	4.611286	1.74073	-1.87825	-4.5815	-19.0989	-12.8715	36.10586	125.6271	262.115	202.4741
20	-5.38893	-3.27776	1.66821		-6.37608	0.531858	-2.35167	-3.32137	1.460826	15.45361	4.720373	12.48237	33.5186	66.48271	161.7458	160.2816
10	-4.53891	-1.84926	-0.65723	6.050204	-3.9087	-1.38471	1.153527	-2.2028	11.61021	32.7676	21.29992	35.58866	41.35653	84.50201	158.42	
5	0.611285									40.99159	65.44627	81.48052				64.49693
2		3.248645				7.130107										

CONCEPTS FOR FORCED INDUCTION SUZUKI SV650.

An aspect of the project that was not fully realised in the end were the concept packaging plans for a Suzuki SV650. A number of packing of concepts were laid out, with research done into the feasibility of the various packages.

The Suzuki SV650 is a v configuration, twin cylinder 650cc motorcycle that was made in high numbers as a cheap commuter bike and proved very popular. As a result of its availability and low cost it has populated a



Figure 14



number of club level championships across the UK, often on the mini-twin or stock-twin championships.

The SV was picked as a focus for the project due to past use by Orthrus Racing UWSTD. With the motorcycle still kept at UWSTD it meant when considering packaging concepts they could be offered up the motorcycle in the flesh, making decisions for component placement and working out packing restraints more accurate.

The first technical consideration was the fuel supply system to the combustion chamber. The 1999 model used by Orthrus Racing is a twin carburettor system. While carburettors can be used with forced induction, and were for many years on most forms of vehicle, fuel injection systems are now more widely used due to more controllable fuelling needed for increased fuel efficiency. This increase in fuel quantity and timing control can also be utilised for easier adjustment when setting up ICE changes. Later model SVs converted to fuel injection systems. Retrofitting a fuel injection system to this model is possible, as little was changed in terms of the ICE internals. Wiring looms and ECUs would need to be switched, however with the addition of a forced induction system these would likely be replaced anyway.

Modern aftermarket ECUs are widely used when converting to a forced induction system. More commonly used is a complete replacement ECU, like the Helltech systems, which use either an adapter connector block to the original harness, or requires repining to the new ECU. These systems will then require additional information to run the new induction system, for example sensors like manifold pressure, or software updates like fuel injector flow rates for non-stock injectors.

The plastic air box could also be upgraded to an aluminium unit to aid in high pressure retention, however this would likely need to be an in-house made unit due to it being so unique. A CNC billet two piece air box would be the most feasible option due to low production numbers. Adjustments to cam timing may also be required. Longer cam duration for maximum air flow that is sort in naturally aspirated ICEs is not desirable in forced induction systems due to an increase in valve overlap. With a forced induction system this longer valve overlap will result in the induction charge being pushed straight through the combustion chamber and into the exhaust. The shorter overlap will likely reduce the cam open duration, however due to the increased flow from the forced induction this not a disadvantage.

A lower compression ratio of between 7.5:1 to 8.5:1, (8.10) is often stated for forced induction systems. This is to reduce the risk of auto ignition under the increased cylinder pressures created from forced induction. The compression ratio can be reduced through a number of processes, the most common being replacing the head gasket to a thicker diameter or altering the piston. Making the head gasket thicker is a simple alteration, however it is often not sufficient on its own and due to affecting the piston to cylinder head squish zone can have a negative effect on auto-ignition. A better option is to replace the piston with a dished style alternative. The SV650 has a compression ratio of 11.5:1, which should be ideally lowered to 8.5:1 if a forced induction system were to be introduced. However, research on the Extreme Creations Yamaha MT-09/10 turbo charger kit doesn't indicate a change in compression ratio is required, meaning the 11.5:1 ratio on the stock production engine is usable. Note this is with a boost pressure of 7 psi, while the Ford Ecoboost runs at 20 psi with a compression ratio of 10.5:1



Figure 15



There are several configurations to consider for a forced induction on the SV650 which be discussed in the following section.

SINGLE TURBO CHARGER SET-UP

The first to be considered will be a single turbo charger system.

Due to being a v-twin configured engine the placement of a single turbo is limited. The tightly packed layout makes it difficult to route a complex exhaust system, in particular around the rear cylinder, as it is encased by the frame, swingarm and rear suspension. This means routing the rear exhaust to the front on the bike would be very difficult. This leaves a system similar to the Extreme Creations Yamaha MT-09/10 turbo charger kit a more likely option. This positions the turbo charger low down, under the swingarm and right hand footrest, as circled in red in the diagram to the right (figure16) Figure 17 shows the MT-09 turbo charger position, in a similar position the Suzuki SV650 would require. This also allows for short oil feed lines from the engine.

The compressor feed would then be routed under the left hand footrest and through the frame into the air box.

A side mounted, air to air Intercooler could also be included on the left hand side of the motorcycle. This would mean the routing from the turbo could still follow the same path, but be flowed through the intercooler before being fed through the frame into the air box. It would be desirable to run an intercooler to reduce the induction charge temperature. This would reduce the auto ignition, or knock, point of the engine, allowing for safer combustion at the same boost pressure or to allow the ICE to reach higher levels of boost.

Data from the FoMoCo Ecoboost turbo charger could be used to determine if it would be appropriate to use such turbo the SV650. As the turbo is based off a much higher capacity ICE then it is unlikely to be a great fit.

TWIN TURBO SET-UP

A twin turbo configuration will have advantages and disadvantages compared to the single turbo system which will be discussed. The first advantage allows for the turbo chargers to be situated closer to the exhaust ports of each cylinder, especially the front cylinder. As can be seen in the diagram to the right (figure 19), the front turbo charger would shorten the turbine feed by at least a foot, creating greater efficiency due to a greater heat stock being available. The rear turbo charger would



Figure 16



Figure 17

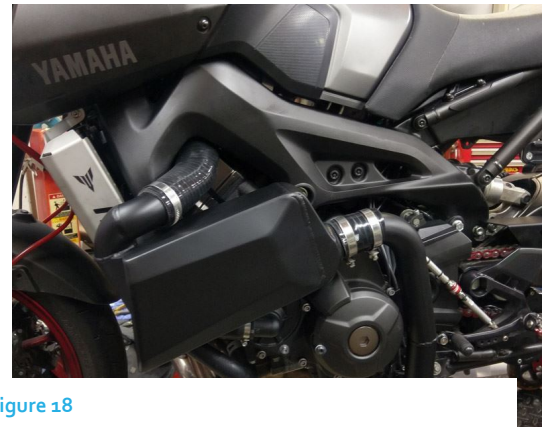


Figure 18



Figure 19



also be smaller, thus would be able to be positioned higher within the bike, increasing ground clearance.

The induction charge from the compressor could still be routed to the side of the motorcycle, using the same side mounted intercooler position.

The main disadvantage to a twin turbo charger system would be the added complexity to the configuration. The oil feeds to both turbo chargers would need routing and pressurising, while ideally the ECU would need separate information feeds for both cylinders separately to maximise the system. The cost for this system would also likely be greater due the increased number of components. However due to each cylinder having its own turbo, and while it would require more work, the system could be uncompromising when it comes to tuning due to the ability to turn each cylinder individually. This may be more advantageous in the v-twin configuration, compared to a more common inline four cylinder, due to the rear cylinder naturally running at a higher temperature due to it being so enclosed. Fitting the twin turbo charger system under full race fairings may also be an issue to consider, as well as clearance under heavy braking, when the front suspension compresses, effectively reducing the area between the wheel and front cylinder.



Figure 20

The Garret GT06 pictured to the right (figure 20) shows how small a turbo charger commonly used on ICEs between 100cc and 500cc can be. This would likely be the style used if a twin turbo set-up was used.

SUPER CHARGER SET-UP

A super charger uses a pulley, chain or gears system driven off the crankshaft to spin a compressor. This means the compressor speed is often directly proportional to engine speed, and experiences no lag like the turbo charger system does. This also creates more linear power delivery than a turbo charger system.

No production motorcycle has used a supercharger before, or since, the Kawasaki H2, released in 2015. As such it will be used as a guide for the supercharged concept produced for this project.



Figure 21

The super charger would be required to fit within the frame alongside the cylinder head (location indicated in figure 21, red circle), taking drive from the crankshaft via a chain. This would involve major work on the ICE to include a drive off the crankshaft, with a sealed unit to the supercharger. With the carburetors being replaced with fuel injections more space within the frame should be available, with a small supercharger being positioned as indicated. It would use a centrifugal type compressor for lower heat generation during compression.

While the system is space sensitive the inclusion of an intercooler would be preferable. A water to air system with a built in heat transfer in the air box and bolt on radiator in front of or below the stock radiator (location in figure 21, blue rectangle) would be the most space efficient solution.

5.4. RESULTS



The analysis for the turbo charger data sets provided by FoMoCo meant an overall turbo efficiency could be calculated, shown in the table below (table 40). This shows how efficient a turbo is under higher loads. However, the lower efficiency can be partly attributed to the use of the wastegate in the mid to low load points. Highlighted in table 39, it can be clearly shown this high wastegate use in the low to mid zones. This will be as a results of the ICE not requiring high boost levels under part load, thus the energy is being released straight down the exhaust.

Table 38

Wastegate flow (l/s)		RPM															
		800	1000	1250	1500	1750	2000	2250	2500	3000	3500	4000	4500	5000	5500	6000	6500
L O A D	FL	2.01						0.39	2.49	4.56	6.49	7.13	7.46	7.29		7.75	
	200								2.93	4.51							
	190							0.88	2.78	5.10	6.56						
	180							1.49	2.90	5.46	6.81	7.08					
	170							1.91	3.06	6.08	7.16	7.36	7.63	7.70			
	160							2.11	3.20	6.34	7.38	7.71	7.90	8.27			
	150						0.52	2.61	4.29	6.63	7.61	7.97	8.47	9.02	8.59		
	140						1.12	3.25	5.07	7.05	7.97	8.34	9.07	9.73	9.05	8.67	
	130					0.09	2.67	5.10	6.34	7.57	8.98	9.19	9.81	11.06	9.70	9.56	9.24
	120				0.96	2.61	5.00	6.72	7.28	8.73	10.34	10.22	10.98	12.50	10.84	10.87	10.28
	110				2.93	5.93	7.04	7.82	9.30	11.39	12.33	11.93	12.85	14.34	11.85	11.85	11.68
	100			1.67	7.01	8.05	10.07	11.29	14.28	15.97	16.18	14.27	15.34	16.95	13.76	13.60	13.08
	90		6.48	8.19	13.67	16.93	17.31	17.32	17.32	17.26	17.27	17.27	17.21	16.95	16.82	16.22	15.22
	80		16.84	17.00	17.34	17.30	17.32	17.32	17.32	17.05	17.30	17.28	17.27	17.15	17.20	17.27	17.25
	70		17.32	17.33	17.33	17.30	17.32	17.32	17.32	16.96	17.26	17.26	17.26	17.14	17.14	17.07	17.18
	60		6.04	17.28	17.33	17.30	17.31	17.32	17.32	16.81	16.54	17.25	17.25	16.54	13.61	13.40	13.99
	50		1.63	1.41	17.33	17.30	17.31	17.32	17.32	16.81	16.52	17.26	17.26	17.16	14.97	14.06	13.48
	40	1.94	1.52	1.41	17.32	17.29	17.31	17.32	17.32	16.80	16.51	17.27	17.27	17.09	16.21	15.65	14.48
	30	1.98	1.04	1.34	17.17	17.30	17.31	17.32	17.32	16.76	16.50	17.27	17.27	17.13	17.07	16.64	15.50
	20	1.67	0.76	0.72	17.07	17.30	17.32	17.32	17.33	16.68	16.45	17.27	17.26	16.99	16.92	16.65	16.71
	10	1.74	0.64	0.72	12.83	17.29	17.32	17.35	17.36	16.67	14.79	8.92	11.15	9.84	13.43		16.49
	5	1.70									10.37	6.30	7.11				16.43
	2			0.56			0.72										

Taking a closer look at the turbo efficiency with the lower efficiency mid zone highlighted (table 40) it can be seen how a large portion of the calculations could be improved by combining the 'lost' energy going through the wastegate to the overall efficiencies.

Table 39

Turbo efficiency (%)		RPM															
		800	1000	1250	1500	1750	2000	2250	2500	3000	3500	4000	4500	5000	5500	6000	6500
L O A D	FL	0.33	0.28					0.67			0.65	0.63	0.64	0.65			0.58
	200								0.71	0.69							
	190							0.70	0.71	0.72	0.70						
	180							0.67	0.68	0.70	0.65	0.67					
	170				0.66			0.67	0.69	0.72	0.77	0.77	0.72				
	160				0.63			0.64	0.65	0.69	0.74	0.76	0.79	0.71			
	150				0.58	0.58	0.61	0.59	0.49	0.80	0.71	0.75	0.74	0.73	0.58		
	140				0.52	0.52	0.55	0.54	0.59	0.62	0.68	0.70	0.72	0.73	0.59	0.60	
	130				0.44	0.44	0.47	0.51	0.54	0.56	0.61	0.63	0.69	0.72	0.57	0.58	0.59
	120			0.39	0.36	0.36	0.44	0.45	0.49	0.47	0.51	0.58	0.64	0.66	0.54	0.55	0.58
	110			0.30	0.28	0.34	0.37	0.35	0.36	0.38	0.44	0.50	0.54	0.62	0.70	0.52	0.54
	100		0.30	0.24	0.24	0.25	0.28	0.28	0.29	0.32	0.36	0.42	0.46	0.53	0.62	0.46	0.49
	90		0.24	0.22	0.22	0.27	0.30	0.24	0.26	0.28	0.33	0.34	0.38		0.51	0.36	0.40
	80		0.21	0.21	0.21	0.25	0.26	0.22	0.23	0.26	0.29	0.29	0.32	0.34	0.41	0.32	0.32
	70		0.17	0.17	0.17	0.21	0.21	0.21	0.22	0.26	0.28	0.25	0.27	0.31	0.35	0.31	0.33
	60		0.15	0.14	0.15	0.15	0.18	0.19	0.21	0.23	0.25	0.23	0.24	0.28	0.31	0.30	0.31
	50		0.14	0.16	0.15	0.13	0.16	0.18	0.19	0.19	0.19	0.19	0.20	0.22	0.27	0.27	0.28
	40		0.15	0.15	0.13	0.10		0.14	0.15	0.14	0.15	0.15	0.15	0.17	0.23	0.23	0.25
	30	0.10	0.13	0.11	0.09	0.08	0.09	0.10	0.11	0.10	0.11	0.12	0.12	0.13	0.15	0.18	0.21
	20	0.09	0.11	0.09	0.09	0.07	0.08	0.08	0.09	0.07	0.10	0.10	0.09	0.10	0.09	0.11	0.12
	10	0.07	0.10	0.07	0.15	0.06	0.07	0.13	0.15	0.14	0.16	0.11	0.09	0.08	0.13		
	5											0.15	0.15				
	2																



It can be seen from this that the low load efficiencies are still low even with the wastegate loses are taken into consideration. This will be due to very low flow rate from the combustion process struggling to spin the turbine, with low boost being generated as a result.

Post compressor (°C)		RPM															
		900	1000	1250	1500	1750	2000	2250	2500	3000	3500	4000	4500	5000	5500	6000	6500
L O A D	FL	42.6	52.9	81.3		156.3		193.3	151.3	149.4	150.4	145.7	143.7	139.3	157.9		149.4
	200								157.8	154.5	150.3						
	190								157	150	146.9	149.3	146.2				
	180								148.6	142.6	138.7	136.6	138	151.9	147.3		
	170								128.9	131.4	130.3	126.6	126.9	124.2	125.1	137.5	136.4
	160								121.3	121.6	117.5	114.9	115.5	111.9	111.8	122.5	133.6
	150								110.6	107.2	106.3	105.7	103	103.1	100.6	100.9	111.8
	140								95.1	95	93.5	94.7	92.8	91.7	89	88.2	96.2
	130								81.9	78.7	79.8	79.1	78.8	76.5	75.3	80.8	100.5
	120								73.6	69.6	65.1	68.5	66.9	68.8	65.4	64.3	69.9
L O A D	110								61.2	58.1	54.2	56.1	56.2	52.9	55	52.9	55.3
	100																
	90																
	80																
	70																
	60																
	50																
	40																
	30																
	20																
L O A D	10																
	5																
	2																

Wastegate flow (l/s)		RPM															
		900	1000	1250	1500	1750	2000	2250	2500	3000	3500	4000	4500	5000	5500	6000	6500
L O A D	FL	2.01						0.39	2.49	4.56	6.49	7.13	7.46	7.29		7.75	
	200								2.93	4.51							
	190								0.88	2.78	5.10	6.56					
	180								1.49	2.90	5.46	6.81	7.38				
	170								1.91	3.06	6.08	7.16	7.36	7.63	7.70		
	160								2.11	3.20	6.34	7.38	7.71	7.90	8.27		
	150																
	140								0.52	2.61	4.29	6.63	7.61	7.97	8.47	9.02	8.99
	130								1.12	3.25	5.07	7.05	7.97	8.34	9.07	9.79	9.05
	120								0.09	2.07	5.10	6.34	7.57	8.98	9.39	9.81	11.06
L O A D	110								0.96	2.61	5.00	6.72	7.28	8.73	10.34	10.22	10.98
	100																
	90																
	80																
	70																
	60																
	50																
	40																
	30																
	20																
L O A D	10																
	5																
	2																

An interesting observation would be to compare the highlighted wastage flow table and the post compressor temperature table above. The pattern of high flow rates through the wastegate seem to translate into a low temperature zone in the post compressor table. This can also be observed in a number of other tables in the project. This could be a result of flow still being put through the compressor side of the turbo charger, creating a cooling effect, while little boost is needed, hence the energy being released through the wastegate, creating lower overall temperatures.

5.5. CONCLUSION

Data interpretation.

The data made available from FoMoCo, and the subsequent calculations carried out, could be utilised when implementing forced induction in other applications. The work carried out in calculating the overall turbo efficiency gives a firm understanding of the parameters needed to be taken into account when developing a forced induction system. The Ecoboost turbo charger has a high efficiency, resulting in a vehicle with good fuel economy while delivering power figures of a much larger naturally aspirated ICE.

Forced induction concepts.

The single turbo charger set-up would unlikely be able to use the available components, i.e. the Ford Ecoboost turbo charger and intercooler. This would mean sourcing new components, which would not come with the same large amounts of data sets that were available from FoMoCo.

The packaging of the single turbo system would also be difficult, but not implausible. The size of the turbo charger would likely interfere with the swing arm operation on the SV650 without careful placement. The location works better for the MT-09/10 due to an arched swinging arm. An altered swinging arm in SV650 could be fabricated.

A twin turbo system would be much more difficult to set-up due to having to route everything twice, as well the added complications of configuring a software package to run two turbo chargers separately. However, being able to use smaller turbo chargers would allow for better packaging in the limited space available, while being able to tune each cylinder would maximise performance.

Adding a turbo charger increases the temperatures seen at the cylinder heads. This may be an issue for the rear cylinder as it is so enclosed within the bike. This will be an issue for both turbo charger concepts.



The super charger concept has the potential to provide a very neat, space efficient solution, however, a great deal of alterations to the ICE would need to be carried out.

The water to air intercooler discussed would require a heat transfer section within the billet aluminium air box. This is a very complex component that would be difficult to manufacture in-house, as well as alterations to the crankcases, meaning the super charger concept would be unlikely to be considered.

If one of the concepts could be brought to fruition, the twin turbo configuration would be the sort after option. Having the small turbo chargers creates a tight packaging option. This concept would require more set-up work as routing the system is doubled. This is however counteracted by the advantage of being able to tune each cylinder, at the cost of a more complex system.

The SV650 used in the project is a race orientated motorcycle, thus is used most often in a higher RPM range. A turbo charger system would therefore be suited to this application. This of course is not the same requirements a production vehicle would be targeting.

Another conclusion is that the Suzuki SV650 is not the best motorcycle to turbo charge. This is because the v-twin configuration is tightly packaged within the frame, offering little room for routing a forced induction system. The researched induction systems were all on in-line ICE configurations.

5.6. FURTHER WORK

The flow bench data gathered had an anomaly, as well as the two tests giving varied results of flow, although the line gradient was similar between the two. Another test to get an average of the data sets would lead to greater accuracy.

The Ecoboost intercooler heat transfer rate could be real world tested in a controlled environment. This could then be compared to the FoMoCo data to see if the intercooler position affects the transfer rate.

Full CAD designs for the forced induction concepts need to be created. This would aid in the visualisation of the concepts, as well as giving a better idea about the packaging restraints that would be met.

The fuel injector size used on the SV650 would ideally be calculated for the increased flow rate of the forced induction system. An increased induction rate requires more fuel, which stock fuel injectors may not be able to deliver. The flow rate can be tested with a simple testing rig to measure the quantity released by the stock injectors vs other injector types.



6. TEAM MANAGEMENT TRANSFER



Orthrus Racing was created in May 2015. The team is student led, student run.

The team was formed to allow a basis for students to apply theory to a real world situation, creating valuable experiences that could be invaluable later in the automotive industry.

The author of this dissertation started and managed the team from its inception. As the degree draws to an end, so the management has to be passed on. This will provide the team with the best opportunity to maintain University of Wales Trinity Saint David links, which will mean staying student orientated, maintaining its core values.

6.1. AIMS AND OBJECTIVES

Management transfer due to final year work being impacted and unknown availability after graduation.

The transfer of management to team members from lower years who can carry it forward over the short to medium term. To secure the team in terms of funding, targets and team structure for the short to medium term, with aims of long term success. Finalising the 2018 budget, gaining and confirming current sponsorship agreements.

6.2. RESEARCH AND PAST EXPERIENCE

With the focus of this section being the handing over of the management responsibilities of the team, a brief outline of the development of the structure of the team will be established. The structure of typical club level teams will be discussed, with comparison to larger national teams.



The following a breakdown of the growth of the team over a three year period.

- 2016 - Saw the first outing for Orthrus racing, competing in the North Gloucester Road Racing series, in the Mini-Twins championship. The Team consisted of a single Suzuki SV650 and seven team members. The team experienced a steep learning curve during this first year of competition.
- 2017 - The team developed quickly over the off season, taking on more workshop space at UWTSD and expanding both team membership and the number motorcycles. At the start of the 2017 season the team consisted of three race motorcycles and twelve members. The university also supported Orthrus Racing by allowing use of a UWTSD owned Yamaha R6. Half way through the season one of the new riders chose to stop competing, hence 2017 ended with two motorcycles and seven members associated with the team. The team also gained a good number of sponsorship agreements with well-known companies, including EBC, FUCHS and NGK. Orthrus Racing competed in Thundersport GB, the most competitive club level series in the UK, in the Stock-Twin (SV650) and Pre-national Sport 600 (R6) championships.
- 2018 team – Orthrus Racing maintained a two bike structure, but grow in membership to ten due to interest from new students joining UWTSD. The ageing SV650 was replaced with a Kawasaki ZX6R, competing in the Pre-national Sport 600 championships. UWTSD also increased support by providing a budget for aspects that couldn't be found through sponsorship agreements. Ohlins was gained as a sponsor, resulting in a major upgrade to the suspension systems of the motorcycles.



The aims and set goals of a club level team and a national team can vary greatly. These goals are often directly influenced by both internal team and external pressures, the motivations of the team members and the team's view of a successful season. Looking at Club level teams, in series such as Thundersport GB, Bemsee (The British Motorcycle Racing Club) or North Gloucester Road Racing, the aims of a race season are often less results orientated than a National team. This is not to say club level teams do not strive to win, but that winning is not the sole reason to compete in their respective championships. Often the aim of a race weekend is to participate in a sport that they are passionate about. While this passion is present at National level also, the pressures on the team create a more results based focus. These pressures can come in a multitude of forms. For club level teams the pressures are normally self-imposed by the rider, seeking good results as a direct factor of competing in the first place. However, external



pressures can start to effect the team at a certain stage, often with sponsorship starting to be a factor. This is an aspect that can be seen in high level club racing, but is more common at national level, where higher levels of sponsorship are required to meet increased funding demands. These aims, pressures and motivations will determine the viewed success of a team.

The increased need for results at national level, aided by larger team budgets, will naturally result in more defined team roles within a team structure, with that structure being larger in number also. So where a club level team will often consist of a rider and mechanic filling in all roles within a team, a national team will see separate roles for management, crew chef, data analysis, tyre organiser, mechanic etc., as well as a split in race weekend staff and day to day management.

These structures and aims between club and national levels of course can be blurred, with same rider mechanic teams competing at BSB, and multi bike well-structured time competing in Thundersport GB.

Combining the motivations of a student team with the enthusiasm of competing in a club level series makes for a unique team environment. The Orthrus Racing team structure always for separate, dedicated roles, while it is still small enough for every member to be involved in most aspects of the team to a greater or lesser extent.

6.3. WORKED CARRIED OUT

Establishing a budget for the 2018 season was a main task for preparations of transferring management responsibilities. This would create a good foundation for the new management to base themselves off, allowing them to build the team up how they desired without creating unnecessary pressure from longer term duties like budget or sponsorship, allowing themselves to get established before these tasks need completing for the 2019 season.

The first steps were to confirm sponsorship level for the team, and the number of race entries for each rider. This would result in an understanding of the budget requirements and how much further support the team required.

Sponsorship for the season was mainly a continuation of the 2017 season (EBC, FUCHS, Black Widow, JHS, and NGK), with the addition of Ohlins suspension as a major supporter. This combined sponsorship package contributed around ten thousand pounds worth of components or consumables to the team. This alleviated a degree of pressure for finding funding for the 2018 season. Increased support from UWTSD meant a proposal budget was needed to be put forward for approval. This proposal budget was completed over a long time frame due to a number of factors. Firstly the release of the 2018 Thundersport GB calendar meant the number of race rounds could not be certain until January, this however was estimated from last season's program. Secondly the confirmation from sponsors were late for a number of companies. This meant the remaining budget required was not confirmed. Lastly the level of commitment for the final year students meant it had to be established how involved they could afford to be. This would impact the number of entries that the R6 could be in, directly affecting the budget through entry fees, tyre costs, bike maintenance etc. For a more accurate budget many of these aspects had to be estimated until late into the process.



[illegible]

	A	B	C	D	E
1					
2					
3					
4					
5					
6					
7					
8	Date	Circuit	Testing	Race	
9					
10	Feb	Cartagena	400		
11	23-Feb	Donington	190		
12	04-Mar	Cadell	140		
13	23/25	Mard Donington	140	245	
14	20/21	April Oulton	130	245	
15	25/28	May Cadwell	130	225	
16	1/24	June Mallory	125	225	
17	27/29	July Brands Hatch	125	225	
18	25/27	Auglesey	125	225	
19	21/23	Sept Cadwell	80	165	
20	19/21	Oct Snetterton	140	245	
21		Sub-total	1735	1600	
22		Total	3535		

6.4. RESULTS

It's felt the wider aims of the team were also met. New and continuing students have a chance for a practical experience of the theories of the subjects lectured at the university, in the process gaining invaluable experience and knowledge of the subject which can be utilised when entering the automotive or motorsport industries.

The team continues to operate well going into third round of the 2018 race season, with its future secure at least until the end of the season. Any new management team will run an operation how they see fit, and while that can be difficult to observe once that step back it taken, its often not for the worse thing to happen. New management can bring fresh ideas not seen by the team before.

Aiming for BSB in the 2020/21

Road racing and the Manx focus

More development work on the bikes, continuing to put into practice the theory put forward by UWTSD

Involving young engineering students and gaining interest from high school students wanting to find a path to engineering.

7. OVERALL CONCLUSION

Splitting the dissertation focus meant either part was not carried out to its full potential. However, the results gathered have concluded in a broad knowledge base.

The overall project resulted in a good knowledge in a range of areas within the ICE, with an appreciation of the wider workings of the automotive design process, including use of ACMs, and the industry as a whole. Using manufacture's data meant gaining a good understanding of what manufacturers look for when testing an ICEs.

8. BIBLIOGRAPHY AND REFERENCES

- 8.1. Various lectures by Kelvin Lake, January 2018, UWTSD.
- 8.2. Rapid prototyping casebook, 2001, professional engineering publishing .
- 8.3. Maximum boost, 1997, Corky Bell, Bentley publishers.
- 8.4. CAD in Automotive Industry Market Size, Application Analysis, Regional Outlook, Competitive Strategies and Forecasts, 2016 To 2024
- 8.5. Concept design CAD for the automotive industry
- 8.6. A roadmap for parametric CAD efficiency in the automotive industry
- 8.7.
- 8.8. Rapid prototyping or rapid production? 3D printing processes move industry towards the latter
- 8.9. Industry 4.0: hope, hype or revolution?, Lorenzo Bassi
- 8.10. <https://www.turbodynamics.co.uk/technical/turbocharging-normally-aspirated-car/>
- 8.11. <http://www.extremecreations.com.au/>
- 8.12. <https://honeywell.com/country/in/News/Pages/HoneywellGlobalTurboForecastProjects49MillionTurbochargedVehicleSalesPerYearBy2019.aspx>

