

Extreme Downsizing Technology and its Impact on Volumetric Flow, Efficiency and Drivability of an Internal Combustion Engine.

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1.0 Abstract:

There is an ever-increasing demand to increase the efficiency of a vehicle's engine. The pressure has resulted in car manufactures looking into different methods to future proof their cars engines. One method is the downsizing of their engines. This technology means that they take their bigger litre engines and decrease the overall capacity to a smaller litre such as a 1.0 litre car, while trying to maintain the performance and feeling of the larger engine. The industry has invested heavily in this technology but have still come across some drawbacks. The downsizing of a car increases the efficiency of the engine, in terms of more mileage per fuel burnt, but can have some effect on its performance when compared to the bigger engine. This report will investigate whether downsizing increases the efficiency of an engine, and how the technology effects the feel and performance of the vehicle. Calculations will be carried out to look at the air flow into the higher capacity engine and the downsized equivalent. Live data will be collected and processed using excel spreadsheets. From this a suitable system to improve the downsized engines performance can be selected and packaged. Research into this subject has highlighted that the downsizing of an internal combustion engine in various layouts can improve the overall efficiency of the engine, while maintaining the drivability for the driver, and the performance of its larger engine counterpart.

The automotive industry is continually developing the Internal combustion engines efficiency in relation to its fuel consumption, its volumetric efficiency with combined fuel and air charge, and its volumetric flow. Downsizing of the internal combustion engines in vehicles has become a widely used technology by the automotive industry. A balance between increase in efficiency of the engine, drivability and the performance of the vehicle must be ensured. Data will be collected using Race-technologies DL1 data logger, from which the data collected will be processed using an Excel spreadsheet and developed into a duty cycle to support the packaging of a forced induction system for a downsized engine. In conjunction with the data, calculations on an engines volumetric flow, its volumetric flow once a forced induction system has been applied and the overall conditioning of the charge will be carried out. This data can also be processed using a spreadsheet format. The data and calculations can be used to validate the credibility of a downsized engine in comparison to its larger capacity counterpart. The drivability and performance can then be looked at, a suitable electronic forced induction system utilising an E-supercharger can be introduced to ensure transient performance. This system will be evaluated and compared to an existing system such as a turbocharger. The information researched will prove its application can improve a downsized engines efficiency, while maintaining its drivability and performance when compared to the larger capacity unit it intends to replace. It will also highlight the solution to the existing transient performance losses associated with an extreme downsized engine.

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2.0 Introduction:

The main issue for car manufactures regarding the internal combustion engines in a passenger vehicle is its efficiency, or lack of it. An engine has on average a 62.4 percent loss of its fuel energy during its internal combustion process (California energy commission, 2006). A modern internal combustion engine is becoming increasingly efficient, but on average a car only uses 10 to 15 percent of its installed horsepower performance (Cameron.K, 2014). Coupled with the size of the engines used, there is dramatic efficiency losses due many factors than need to be addressed to improve the internal combustion engines efficiency. The industries solution to these problems is engine downsizing, reducing losses associated with the larger engine sizes. The smaller engines reduce the losses through the bearings, piston ring friction and pumping losses (Cameron. K, 2014). This means compared to the larger capacity engines, there are less losses due to decreased overall surface areas.

Leading manufactures such as ford have utilised this technology and have set an example for one of the most successful downsized engines on the market. Fords Eco boost 1.0 litre engine is an example of such technologies. This 98-horsepower engine is capable of increasing the combined fuel economy by 6 percent according to (Matt Burt, 2016). Another example of a major part of the industry having success with downsized engine technology is MAHLE. This UK based company MAHLE powertrains has achieved a 50% downsizing from a 2.4L naturally aspirated to a 1.2L forced induction unit producing 120kw of peak power, all while maintaining a performance similar to the 2.4L engine. This means that the technology is effective in increasing the efficiency, while maintaining drivability through increasing volumetric flow. (Tran. H. et al, 2016).

Another major important factor that gives downsizing appeal to the industry is its ability to be able to deliver this technology without any major change to its manufacturing infrastructure, stated by (J.W.G Turner. Et al, 2015).

Although the downsizing of engines has many advantages when compared to their larger capacity counter parts. The main problem with a lower capacity engine is its drivability due to its lower volumetric flow rate. The higher the percentage of downsizing, the greater the need for increased volumetric flow to maintain the performance of the vehicle. This challenge is addressed using a forced induction system. Implementing this technology has allowed manufactures to achieve similar steady state performance to the larger capacity engines. Due to the engines smaller capacity there is less exhaust flow present to operate the turbo along the transient performance models. (Tran. H. et al, 2016) This phenomenon is known as turbo lag, a delay in the spooling of the turbine of the turbo charger due to reduced exhaust gas flow at lower engine speeds (Kazuhiro. N. et al, 2013).

A method for reducing this problematic transient performance would be to introduce an electric powered booster known as an "electric supercharger" (Tran. H. et al, 2016). This device when compared to a conventional supercharger is analogues as stated by (Michael. B. et al, 2016). This means that the device is powered by an electrical system, usually a 48-volt system rather than a 12 volt system, allowing it to operate independently of the exhaust gas flow. Meaning that the electric supercharger can have rapid transient response and provide steady state functionality, like the conventional turbocharger system. Using electrical control systems and clever packaging, this technology could provide the necessary volumetric flow rate for a downsized engine, while maintaining the increased efficiency the technology has to offer when compared to the larger capacity engines.

This dissertation with the following taken into consideration has the following aims:

- Evaluate why the industry has downsized its internal combustion engines. Analyse the positives and the negatives of this technology, and how it effects the efficiency of an internal combustion engine.
- Evaluate methods to improve volumetric flow of a downsized internal combustion engine. Maintaining drivability and retaining the performance of the larger capacity counterpart.

3.0-Literature Review:

3.1- Volumetric flow:

Volumetric flow can be defined as the mass of air flow, which is a measure of the effectiveness of the induction process. The industry uses Volumetric flow as an engines capability to intake a certain volume of air in a set time, this is the amount of air that can pass into a cylinder in a given time. The volumetric efficiency is defined as followed; It is desirable to maximise the volumetric flow and efficiency of an engine, due to the amount of fuel that can be burnt, and the power produced for a given displacement is maximised according to (Colin. R. Ferguson, 2014).

For a four-stroke engine the volumetric efficiency can be found using the formula as followed:

$$e_v = \frac{2(m_a + m_f)}{p_i V_d N}$$

- m_f = Is the flow rate of the fuel inducted.
(Colin. R. Ferguson, 2014).

3.2 Industry and its downsizing technologies:

The industry has carried out millions of pounds worth of research and development on downsizing of their engine units, due to it being considered as an effective way of improving a vehicles powertrain efficiency (Oliver Lang, 2004). The definition of this technology is as a process where the operational load point of the engine is shifted to a higher, more efficient region utilising a reduction in swept volume of the unit (M. Bassett. Et al, 2016).

The analysis of the results by companies such as MAHLE have shown the degree of downsizing is defined as:

$$\text{Degree Of Downsizing} = \frac{SV_o - SV_{DS}}{SV_o}$$

(Bassett. Et al, 2016).

The term of which are also stated by (Bassett. Et al, 2016) where SV_o represents swept volume of the original engine and SV_{DS} represents the swept volume of the downsized engine.

The industry has developed the downsizing technology due to its key attributes in improving the efficiency of their internal combustion engines. Improvements such as overall reduction in CO2 and NO2 emissions due to decreased fuel consumption when compared to the larger engine units. (Chinmay Patil. Et al, 2017).

3.3 Forced induction systems:

Forced induction systems such as turbochargers and superchargers operate by introducing air (or air/ fuel mixture) known as a charge, into an engine's cylinder at a density greater than ambient. This allows a proportional increase in fuel that can be burnt hence raising the potential power output of an internal combustion engine, as defined by (N. Watson, 1986).

A Turbo charger is a specific method of supercharging. The energy of the hot exhaust gases that would usually be lost on a naturally aspirated engine are used to drive the compressor turbine of the turbocharger. This technology doesn't get something for nothing, but merely uses that energy that would usually be lost to compress the air above ambient pressure. The ideal available exhaust energy can be seen in 'figure 1' below. The energy consists of a 'blow down energy'. This energy is resulted from adiabatic expansion from condition 1 when the exhaust valve is opened, to ambient pressure at point 2. Points 3, 4, 5 and 6 display the work done by the piston within the cylinder in terms of displacing the remaining exhaust gases (N. Watson, 1986).

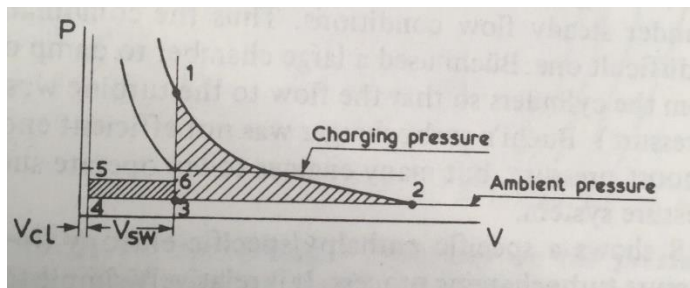


Figure 1: Work available from ideal exhaust process, (N. Watson, 1986).

A supercharger operates via a mechanical connection usually from the crankshaft. The principle is the same as the supercharger in the way it increases the pressure of the air above ambient pressure, which without the aid of a super charger would rely on the pumping action of the engine's pistons on intake stroke.

Turbo charger Information	Supercharger information
• Uses exhaust gas energy to operate the turbine which in turn spins the compressor.	• Uses crank-shaft for the energy to operate the compressor.
• The system is not directly connected to the engine.	• The system is mechanically connected to the engine.
• No parasitic drain to consider when calculating power increases.	• Due to the mechanical connection parasitic drain does have to be considered when calculating power increases.

Table 1: Differences between a turbocharger and a supercharger, (Pro Car Mechanics, 2018).

3.4- Available Alternative Forced Induction system:

The companies MAHLE and Aeristech have pioneered a new development in the boosting of an internal combustion engine by hybridising the air intake systems, stated by (Aeristech, 2018). Aeristech have been developing a compact and cost effective electric machine, for variable high-speed applications, for the past six years (Bassett, et al, 2016).



Figure 2: e-supercharger development and packaging, (Aeristech, 2018).

A conventional forced induction system such as a turbocharger or supercharger discussed in section '3.3' has inherent efficiency losses. This is due to the systems being measured by the amount of airflow the device creates after factoring out the power requirement to drive it, and the extent to which it heats up the air while creating the flow and pressure (Corky Bell, 1997). The power losses inherent with a turbocharger are much less than that of a supercharger. But the supercharger is driven by a belt which decreases its efficiency. The downside to both means it either comprises between turbo-lag and higher heat losses, or transient power gains but increased mechanical losses through a pulley system.

With these efficiency losses in mind, this is where the E-supercharger technology comes into its own. The E-supercharger can accelerate from an idle speed of $30,000 \text{ mins}^{-1}$ to its maximum of $120,000 \text{ mins}^{-1}$ in under 0.5 seconds. This allows it to address the low-speed turbo lag of a downsized engine (Bassett, et al, 2016). This technology also eliminates the belt driven system of a conventional supercharger, which requires brake horse power to run when the boosted pressure is needed to increase the volumetric flow due to it being powered by an electric motor (Aeristech, 2018).



Figure 3: E-supercharger example (Aeristech, 2018).

An electronic supercharger implemented in the industries downsizing of the internal combustion engine can introduce a net reduction in unit costs and the complexity of a forced induction system in the boosting of a heavily downsized engine. Adapted from (Bassett, et al, 2016).

3.5 Proposed vehicle:



Figure 4: Suzuki Swift Sport, (Daniel, Salathiel, 2018).

<u>Specification:</u>	<u>Information:</u>
Capacity (Cubic Centimetres)	1586 cc
Bore x Stroke (mm)	78 x 83
N/a efficiency %	78% (0.78)
Maximum Rpm	7000

Table 2: Suzuki Swift Sport specification, (En.wikipedia.com, 2018).

4.0 Proposed Methodology:

The methodology for this project will use techniques in the form of live data collection using a DL1 logger, the data collected will be processed using Race-technologies software and further evaluation of the collected data will be carried out in an excel spreadsheet. From the processing of this data in the spreadsheet, a duty cycle for the route can be made to assist in the evaluation of the efficiency. This will be further researched later in the project.



Figure 5: DL1 Data logger, (Race-technologies.com, 2018).

Alongside the data collection calculations using formula for volumetric flow and forced induction systems will be carried out to verify the performance and increased efficiency of the down sized engine compared with the original specified larger capacity engine.

These methods will evaluate the downsizing of an internal combustion engine and how it effects the efficiency, but also in reference to the improvement of volumetric flow and efficiency on the downsized engine to improve or match that of the high capacity original engine. Once the calculations for both the engines have been carried out, they can be used to determine the naturally aspirated volumetric flow of the higher capacity engine and the lower capacity engine. These formulas can be found in the sections below and will be used to look at the transient and steady state performance.

From the data and information gathered, a further evaluation of an electrified forced induction can be carried out. This will include calculations of the power needed in Kilowatts to compress the charge to achieve the desired performance, and the required heat treatment system to achieve an acceptable charge temperature. The packaging of the system will also be looked at, alongside the fitment design of the system, factors such as control methods using driver and load inputs need to be created to increase the efficiency of the vehicles engine during its duty cycle. Control methods such as an ECU controller for the activation of the E-supercharger under certain conditions will be created using a flow diagram of the various inputs and influences of the duty cycle created.

4.1 Volumetric flow formulas:

In this case the investigation will look at a chosen donor car, for this donor car a Suzuki swift sport with a 1600cc engine will be used. From the specification of the donor cars engine, the volumetric flow can be calculated, which can then be compared to a four-cylinder 800cc engine.

The following formula can be used to calculate the volumetric flow of an engine. When v is given as volume of the cylinder, n is the naturally aspirated efficiency of the engine, N is denoted as the engine speed in Revolutions per minute.

$$V = \frac{v \times n \times N}{2 \times 60}$$

Please reference section '3.1' for the efficiency equation (Colin. R. Ferguson, 2014).

Cylinder volume formula:

$$V_c = \text{Cylinder Area} \times \text{Stroke Length}$$

Figure 6: Volume of chamber formula (Thecartech, 2018).

4.2 Forced induction formula:

The main thing to consider when calculating the increase in volumetric flow from a forced induction system on an engine is the Pressure ration when boosted. The pressure ratio is calculated using the absolute compressor output pressure in PSI, added to gauge pressure of 14.7 PSI, divided by the inlet pressure which is ambient equalling 14.7 PSI. This is the same as the gauge pressure, as a gauge factors into the ambient pressure as well as the pressure reading.

$$PR = \frac{\text{Compressor outlet required PSI} + 14.7 \text{ PSI}}{\text{Inlet Pressure at 14.7 PSI}} \times 6$$

(Takemebeyondthehorizon.com, 2018)

Once the pressure ratio is calculated for the forced induction system, this can be simply times by the volumetric flow calculated for the naturally aspirated engine you wish to apply the boost to.

4.3- Temperature control of charge:

The current design of the intercooler system is still being evaluated and decided. Once a decision is made on what would be the most beneficial system to be used, calculations can be carried out using appropriate formula. These formulas will show the total decrease in charge temperature before and after the inline heat exchanger, using the outlet temperature for the selected charger, and the specification of the intercooler design.

5.0- Conclusion:

In conclusion this report has investigated the industries current downsizing technology, and the pros and cons of this technology. In terms of the technologies capability to increase the efficiency of the internal combustion engine, the findings in this report have validated that there is an increase in efficiency when downsizing an engine, making it a viable option for the industry. This will be further analysed in the ongoing investigation being carried out. Although there are many ways the technology can progress the internal combustion engine, there are always compromises that need to be considered. These compromises highlighted in this report will allow for further investigation into how the main aims outlined, and how they can be achieved, if at all. Data collection, calculations and the evaluation of the data sets will allow for a clear resolve of the issues faced by the industry when downsizing. In doing so, the investigation will be able to prove the technology outlined in this report can aid in the increase of the efficiency of an internal combustion engine, and prove the feasibility of using an electric powered forced induction system to aid in the problems faced with the transient performance of a turbocharged extreme downsized vehicle.

6.0 Bibliography:

Aeristech. (2018). *Electric Superchargers*. [online] Available at: <http://www.aeristech.co.uk/electric-supercharger/> [Accessed Oct. 2018].

Bassett, M., Hall, J., Hibbert, B., Borman, S. and Reader, S. (2018). *Heavily Downsized Gasoline Demonstrator*. [online] Doi-org.ezproxy.uwtsd.ac.uk. Available at: <https://doi-org.ezproxy.uwtsd.ac.uk/10.4271/2016-01-0663> [Accessed Oct. 2018].

Bell, C. (n.d.). *Maximum Boost- Designing, testing and installing Turbocharger systems*. 1st ed. Motor Racing Publications Limited, pp.7-8 & 12-14.

California Energy Commission. (2018). *Energy Losses in a Vehicle*. [online] Available at: http://www.scuolacascia.it/attivita/clil2/webquest/resources/consumerenergycenter/www.consumerenergycenter.org/transportation/consumer_tips/vehicle_energy_losses.html [Accessed Oct. 2018].

En.wikipedia.org. (2018). *Suzuki M engine*. [online] Available at: https://en.wikipedia.org/wiki/Suzuki_M_engine [Accessed Oct. 2018].

Ferguson, C. and Kirkpatrick, A. (2014). *Internal Combustion Engines*. 2nd ed. John Wiley & Sons, INC., pp.8-10

Ferguson, C. and Kirkpatrick, A. (2014). *Internal Combustion engines*. 2nd ed. John Wiley & Sons, INC, pp.8-10.

H, T., B, R., K, G. and bassett, M. (2018). *Developing a Performance Specification for an Electric Supercharger to Satisfy a Range of Downsized Gasoline Engine Applications*. [online] Doi-org.ezproxy.uwtsd.ac.uk. Available at: <https://doi-org.ezproxy.uwtsd.ac.uk/10.4271/2016-01-1041> [Accessed Oct. 2018].

k, c. (2018). Engine downsizing and efficiency. *Engine Downsizing*, pp.1-2.

Matt Burt. (2018). *Ford 1.0-litre Ecoboost engine to get fuel-saving cylinder deactivation* | Autocar. [online] Autocar.co.uk. Available at: <https://www.autocar.co.uk/car-news/new-cars/ford-10-litre-ecoboost-engine-get-fuel-saving-cylinder-deactivation> [Accessed Nov. 2018].

Nishikawi, K., Iezawa, M., Tanaka, H. and Goto, T. (2018). *Development of High-Speed Motor and Inverter for Electric Supercharger*. [online] Doi-org.ezproxy.uwtsd.ac.uk. Available at: <https://doi-org.ezproxy.uwtsd.ac.uk/10.4271/2013-01-0931> [Accessed Oct. 2018].

Oliver Lang, (2004), Turbocharged Engine with Gasoline Direct Injection, AutoTechnology, Volume 4, Issue 6, pp 56- 59.

Patil, C., Varade, S. and Wadk, S. (2018). *A Review of Engine Downsizing and its Effects* - Inpressco. [online] Inpressco.com. Available at: <http://inpressco.com/a-review-of-engine-downsizing-and-its-effects/> [Accessed 10 Nov. 2018].

Pro Car Mechanics. (2018). *Differences Between Superchargers And Turbochargers*. [online] Available at: <https://procarmechanics.com/differences-between-superchargers-and-turbochargers/>.

Race-technology.com. (2018). *DL1 CLUB - Race Technology Ltd - Automotive Technical Excellence*. [online] Available at: <https://www.race-technology.com/gb/racing/products/data-loggers/dl1-club> [Accessed Oct. 2018].

Takemebeyondthehorizon.wordpress.com. (2018). *Pressure Ratio | Take me beyond the Horizon*. [online] Available at: <https://takemebeyondthehorizon.wordpress.com/tag/pressure-ratio/> [Accessed Nov. 2018].

Thecartech.com. (2018). *Engine Formulas*. [online] Available at: http://www.thecartech.com/subjects/engine/engine_formulas.htm [Accessed Nov. 2018].

Turner, J., Popplewell, A., Marshall, D. and Johnson, T. (2018). *SuperGen on Ultraboost: Variable-Speed Centrifugal Supercharging as an Enabling Technology for Extreme Engine Downsizing*. [online] Doi-org.ezproxy.uwtsd.ac.uk. Available at: <https://doi-org.ezproxy.uwtsd.ac.uk/10.4271/2015-01-1282> [Accessed Oct. 2018].

Watson, N. and Janota, M. (1988). *Turbocharging the Internal Combustion Engine*. Machmillan.