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The Benefits of Using a Pre-Combustion Chamber that Utilises Turbulent Jet Ignition

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Abstract

Pre-combustion chambers that utilise turbulent jet ignition is an advanced combustion system that allows for improved fuel consumption, efficiencies and emissions. This report will look into the benefits as well as the disadvantages of using these advanced turbulent jet ignition pre-combustion chambers in the hope to amplify why using these systems would be extremely advantageous to the automotive industry.

Keywords: *Turbulent Jet Ignition, Pre-Combustion Chamber*

INTRODUCTION

This introduction gives a broad overview of internal combustion engines, it discusses relevant technologies, issues, legislations, and much more. This introduction's aim is to show an understanding of internal combustion engines and to develop onto a discussion on how using a pre combustion chamber, utilising turbulent jet ignition, can better improve efficiency, reduce emissions and help to comply with new legislations.

Early History

Internal combustion engines have been developed since the latter half of the 19th century, since then many different styles/techniques have been developed and tested in a constant search to improve power, efficiency and emissions. In 1867 Nikolaus Otto and Eugen Langen developed an engine that improved total efficiency to a new high of about 11%, resulting in a few thousand being manufactured. During these early years the engines being used where developed to operate on the four-stroke cycle design that is still being used in modern vehicles, Nikolaus Otto was given credit for this cycle because of the prototype engine he developed in 1876 [1].

During 1892 Rudolf Diesel developed and perfected a compression ignition engine that represents the commonly used diesel engine being used today. These early diesel engines consisted of a single-cylinder that was slow, large and noisy, however these early diesel engine tended to be more efficient than the spark ignition engines at the time. Additionally the development of small multi cylinder compression ignition engines were not commonly used in the automotive industry until the 1920s.

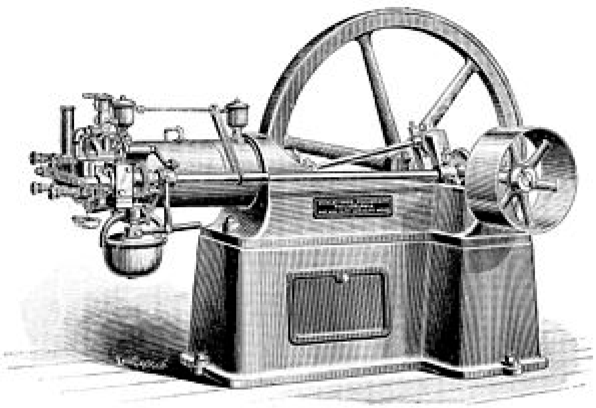

Figure 1 Example of an early Otto engine [2]

Engine Components

This section will give a brief overview of the key engine components that are found in most internal combustion engine.

Engine Block

The engine block contains the cylinders, and is normally made of cast iron or aluminium, some large engines may incorporate water jackets casted into the block and positioned around the cylinders to help with cooling.

Crankshaft

The crank shafts are placed within the engine block and are supported on the block by main bearings. The crankshaft itself is connected to the piston by a connecting rod, this allows the linear motion of the piston to be converted into rotary motion by the crankshaft, and this is due to the connecting rods being offset from the axis of rotation.

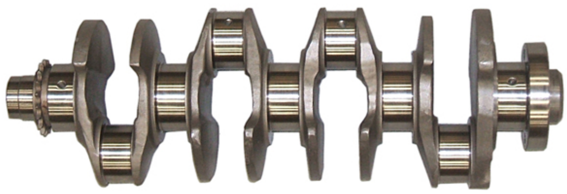

Figure 2 Crankshaft [8]

Connecting Rod

The connecting rod role is to join the piston with the crankshaft, where the big end of the connecting rod joins the crankshaft and the small end joins the piston.

Piston

The piston is placed within the cylinder and produces a linear motion due to pressure forces being applied to it during combustion phases. The sides of the pistons are called the skirts, one being the anti-thrust face and one being the thrust face. The thrust face is where most wear occurs due to it being forced more into the side of the cylinder during the power stroke, whereas the anti-thrust face only receives compression stroke. The face/top of the piston can vary a lot, some faces may be flat while others may consist of multiple contours to help with swirl and air-fuel mixing. Lastly the piston also holds the piston rings that are warped around the outside of the piston.

Piston Rings

The piston rings are fitted in circumferential grooves that are places around the outside of the piston. Compression rings are placed towards the top of the piston head, and their purpose is to help seal between the piston & cylinder walls, in an aid to stop high pressure gasses from the combustion chamber escaping around the piston (this is referred to as blow by).

Figure 3. Piston ring examples **[9]**

Camshaft

The camshaft is a rotating shaft that's main purpose is to push open the intake valves and exhaust valves, this can be done either using mechanical or hydraulic linkage. It should be noted that in a four stroke engine cycle the camshaft rotates at half the engine speed.

Cylinders

The cylinders are placed within the engine black, and house the pistons, allowing them to move up and down. The walls of cylinders need to be highly polished to help reduce friction between the piston faces and the cylinder walls. Additionally some cylinders have small grooved lines applied to the internal face, this helps the cylinder to hold a lubricant film on the wall.

Flywheel

The fly wheel is connected to the crankshaft, and has a very large moment of inertia, this allows the fly wheel to store energy, as well as produce a large angular moment that helps to keep the engine rotating between power strokes, and this also has an effect of smoothing out the engines operation.

Injectors

The injector's main role is to spray fuel into the combustion chamber, therefore allowing the air and fuel within the combustion chamber to mix correctly. These fuel injectors can be places in many different locations, for example in older engines fuel was injected into the intake valve ports or within the intake manifold inlet, however injectors have now been located so that they can spray fuel directly into the combustion chamber (direct injection).

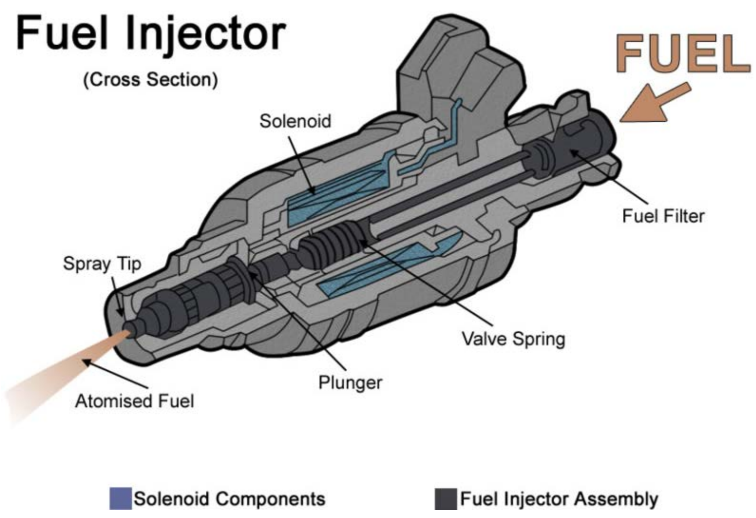

***Figure 4.** Fuel injector* [10]

Spark Plug

The spark plug is an electrical device that produces a high voltage discharge, which is used to trigger the combustion process.

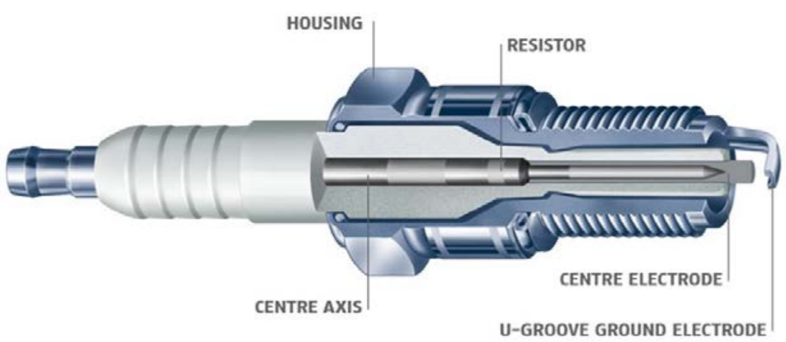

Figure 5 Spark Plug [11]

Engine Arrangements & Classifications

This section will look into giving a basic understanding to typical arrangements and classifications that are used for internal combustion engines.

Spark Ignition

A spark ignition engine uses a spark plug to commence the combustion cycle, the spark plug works by producing an electrical discharge between two electrodes. Which in result ignites the air-fuel mixture that surrounds the spark plug within the combustion chamber.

Compression Ignition

The compression ignition process is the result of the air-fuel mixture self-igniting due to high compression rations that result in high temperatures, allowing the combustion to occur. A typical fuel used for compression ignition is diesel.

Four-Stroke Cycle

The four stroke cycle is a basic principle, it consists of four piston movements over two crankshaft revolutions per cycle. The first stoke is often referred to as suck, it consists of the air-fuel mixture being sucked into the cylinder. The second stroke is the compression of the air-fuel mixture (squeeze). The third stroke is the power stroke where the ignited air-fuel mixture drives the piston downwards as the ignited gases expand (bang). The last stoke happens as the piston rises and forces the hot gasses in the cylinder out through the exhaust valve opening (blow).

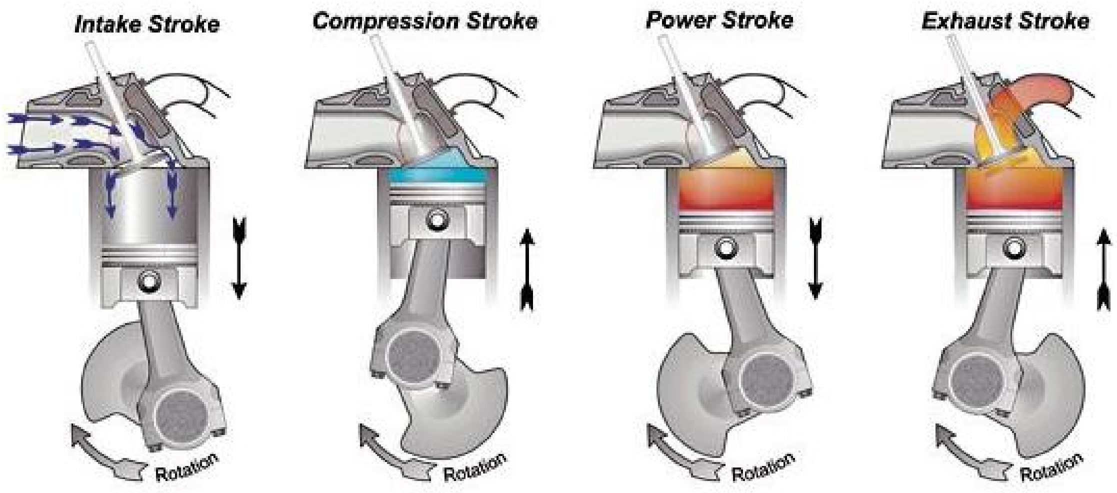

Figure 6. Four stroke cycle [3]

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Two-Stroke Cycle

The two stroke cycle consists of two piston movements over one crankshaft revolution per cycle. The first stroke/piston movement of the cycle consists of the induction & compression of the air-fuel mixture, while the second stroke/piston movement consists of the ignition of the air-fuel mixture and the exhaust of the hot gasses in the cylinder due to the ignition **(see figure 7 below).**

Rotary Engine

A rotary engine consists of an engine block that encloses a non-concentric rotor and crankshaft, additionally the engine block of the rotary engine has inbuilt combustion chambers. An example of a rotary engine is a Wankel engine.

Single Cylinder

A single cylinder engine is a simple design, as the name suggests it consists of one cylinder and piston which is connected to the crankshaft.

In-line Cylinders

An in-line cylinder engine as the name suggests consists of cylinders that are positioned in a straight line along the length of the crankshaft. In-line engines are very common in the automotive industry, many everyday vehicles consists of an in-line four engine.

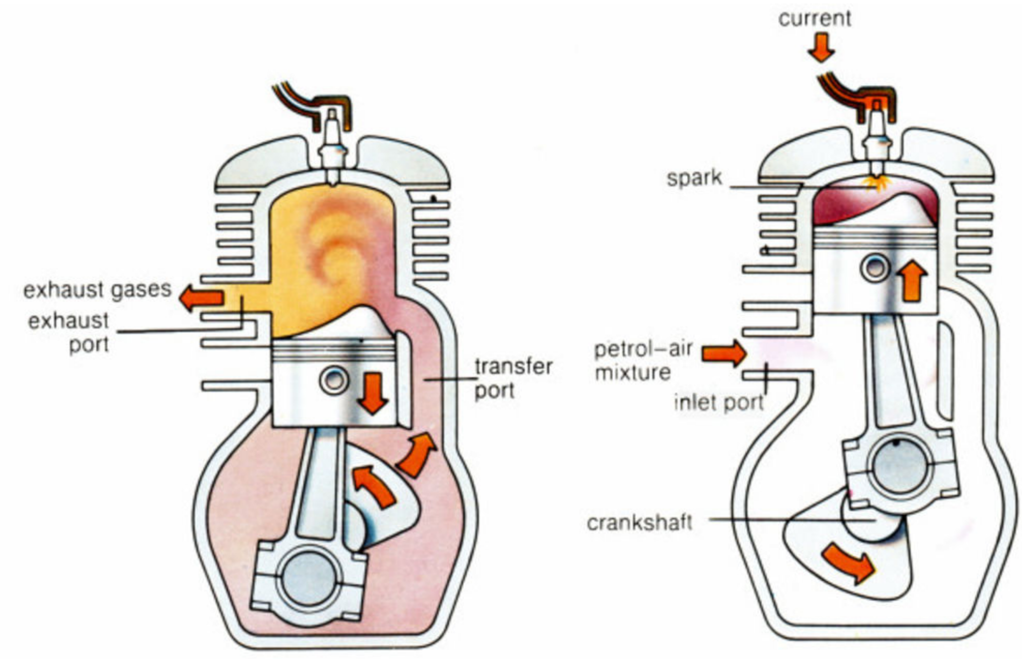

***Figure 7 Two stroke cycle* [4]**

V Cylinder Engine

A V cylinder engine consists of two banks of cylinders that are positioned along the crankshaft at angles to each other. These angles between the cylinders typically range between 60 degrees to 90 degrees, additionally these V cylinder engines consist of an even number of cylinders. Some applications can go up to 18 cylinders or even 20, such as Cummins high horse power diesel engines used for generators, haul trucks and boats. In the automotive industry V6 and V8 are commonly used and some high performance sport cars may consist of a V12 engine.

Flat Cylinder Engine

A flat cylinder engine or also referred to as an opposed cylinder engine consists of two banks of cylinders that are opposite to each other along the crankshaft. This flat engine has an inherent low centre of gravity, is well balanced and is commonly used by Porsche. **See Figure: 8**

W Cylinder Engine

A w engine consists of three banks of cylinders along the same crankshaft, it is not a commonly used engine but has been used in racing applications as well as in the automotive industry used by Bugatti and Bentley.

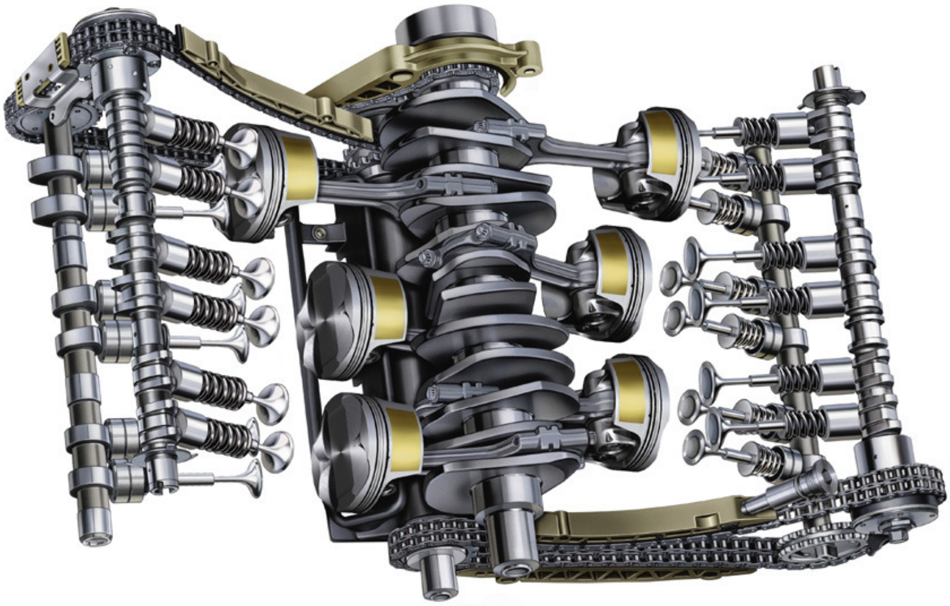

Figure 8 Flat cylinder engine [5]

Engine Emissions and Pollution

Naturally by burning the air-fuel mixture pollutants are produced, theses pollutants have played a major role in the current air pollution problem that the world is experiencing. It was not until the 1970s that it was widely recognised that vehicle emissions is a growing problem.

The main pollutants produced by internal combustion engines, which are nitrogen oxides (NOx), carbon monoxides (CO), and hydrocarbons (He). The nitrogen oxides are generally produced in engines that have high combustion temperatures, resulting in N_2 to separate into monatomic (consisting of one atom) nitrogen, that then reacts and combines with the oxygen. Additionally the Carbon monoxide is the result of not enough oxygen being present to allow the carbon to fully react into CO_2.

Engine Emission Reduction Methods

One of the main methods of reducing these emissions/pollutants is the development of engine and fuel technologies, allowing for better combustion to take place resulting in fewer emissions being produced. In particular this report looks into the developing technologies of pre combustion chambers and turbulent jet ignition in a hope to reduce emissions (further discussed in Chapter 2).

The second source of reducing emissions is by the use of catalytic converters that allow chemical reactions from the exhaust gasses to take place, the chemical reactions allow the pollutants discussed above to be converted into CO_2, H_2O, and lastly N_2.

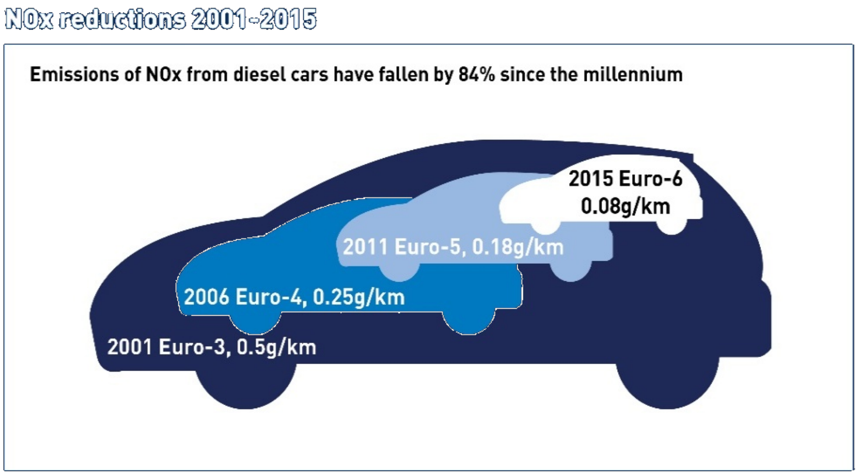

Figure 9 Illustration of the reduction of NOx due to legislations

Legislations

In an effort to reduce emissions the discussed legislations have been developed forcing manufactures to achieve them, these legislations have set constraints on the amount of emissions that can be produced. Each new legislation that is introduced produces a push in new technology developments in the effort to achieve the legislations emission criteria. An example of a current legislation is the Euro 6 legislation that is currently being used in the UK.

Charging

In an effort to raise the pressure of the air entering the combustion chamber charging techniques can be used the raise the air pressure, this allows for more fuel to be added, since there is a higher concentration of air for it to mix with. This section will analyse how Turbocharging and Supercharging can be used to increase the air pressure.

Supercharging

A supercharger is mechanically driven of the engines crankshaft, this allows for a quick response, resulting in little lag from the supercharger. However being mechanically driven by the engines crankshaft results in power losses, not all the power can be directed to the wheels, some must be used to turn the compressors. Additionally compared to turbochargers, superchargers generally tend to weigh more.

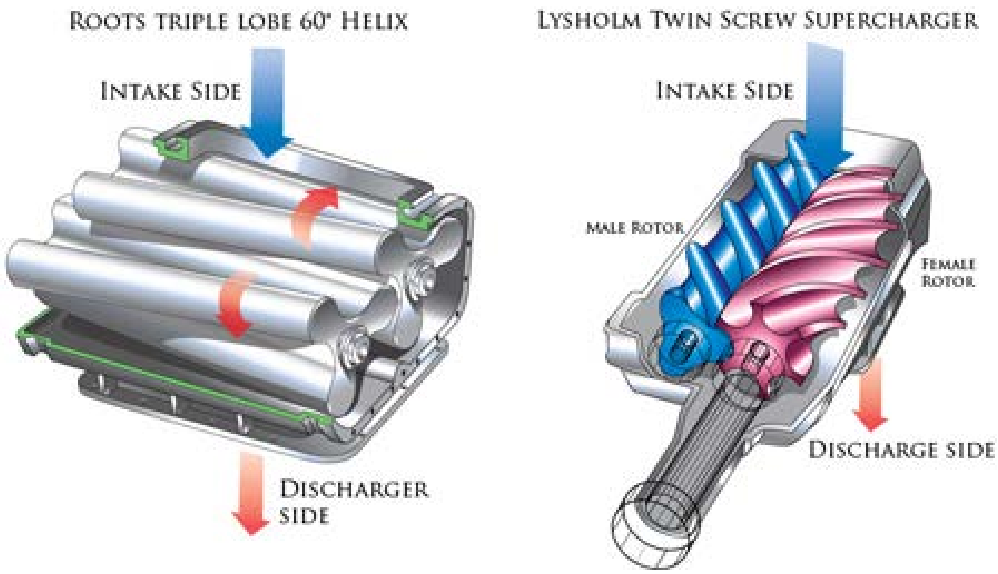

***Figure 10 Supercharger illustration* [12]**

Turbocharging

A turbo charger consists mainly of a turbine wheel and a compressor wheel that are directly connected by a shaft, were the turbine wheel drives the compressor wheel. The turbine wheel is mounted in conjunction with the exhaust flow of the engine, this allows the turbine wheel to be driven by the high velocity exhaust gases. Utilising these exhaust gases allows for less energy to be lost from the engine system. However placing the turbocharger in the exhaust flow causes some restricted flow, this has the effect of marginally increasing the pressure in the exhaust ports, which results in a slight engine power reduction. However the overall power gain for using the turbocharger out ways these slight power losses.

Turbochargers do experience spooling lag, this occurs at low rpms when the engine is feeding the turbine wheel a lot less. However there has been many improvements in recent years in an effort to reduce turbo lag, for example using lightweight ceramic turbine wheels that have very low mass inertia allows the turbocharger to spool up quicker. Furthermore Formula 1 teams in recent years have been using electric motors to spool up the turbocharger at low rpms so that it can reach peak performance much quicker and not suffer from lag.

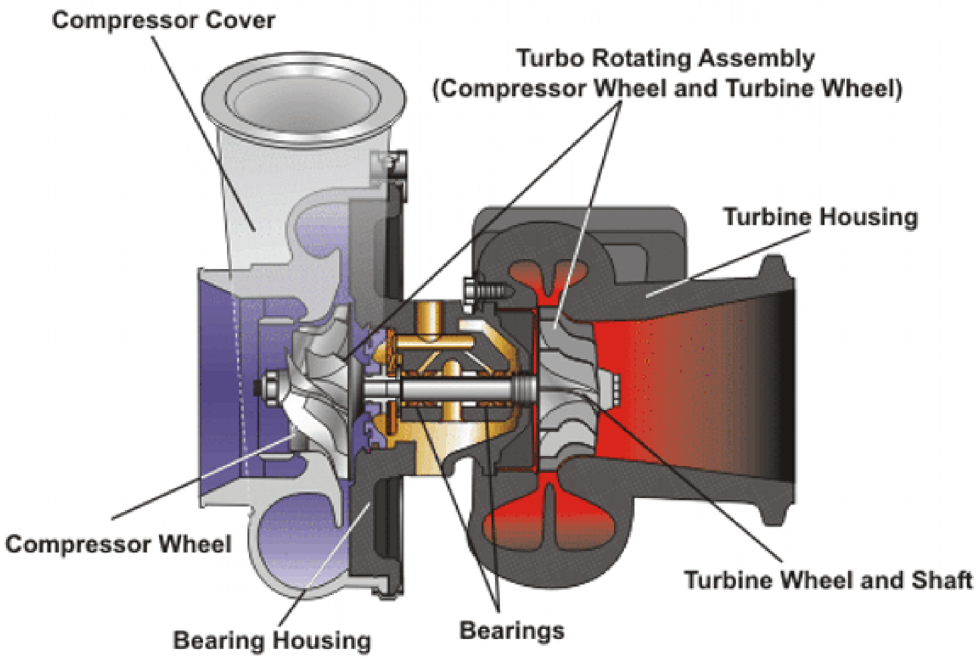

Figure 11 Turbocharger Illustration [13]

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DISCUSSION

This chapter will go inter a greater detail on how pre combustion chambers and turbulent jet ignition can be used to help improve efficiency as well as reduce the formation of pollutants.

Main and Secondary Combustion Chambers

By dividing the combustion chamber into a large main chamber and a second smaller chamber allows for two different air-fuel mixtures to be used. The main combustion chamber consists of a lean mixture and the secondary (smaller) chamber consists of a rich mixture. The main and secondary combustion chambers are generally connected by small orifices, this allows for a flame to pass though from the secondary combustion chamber to the main combustion chamber. A basic example of an engine with a main and secondary combustion chamber can be seen in the figure below.

The main combustion chamber generally contains 80% if the total clearance volume, and the secondary combustion chamber generally contains 20% of the clearance volume. Additionally the secondary combustion chamber contains a spark plug that starts the combustion process of the rich air-fuel mixture within the chamber, this produces a flame to expand through the orifice's connecting the two chambers. The flame from the secondary combustion chamber ignites the lean air-fuel mixture within the main combustion chamber.

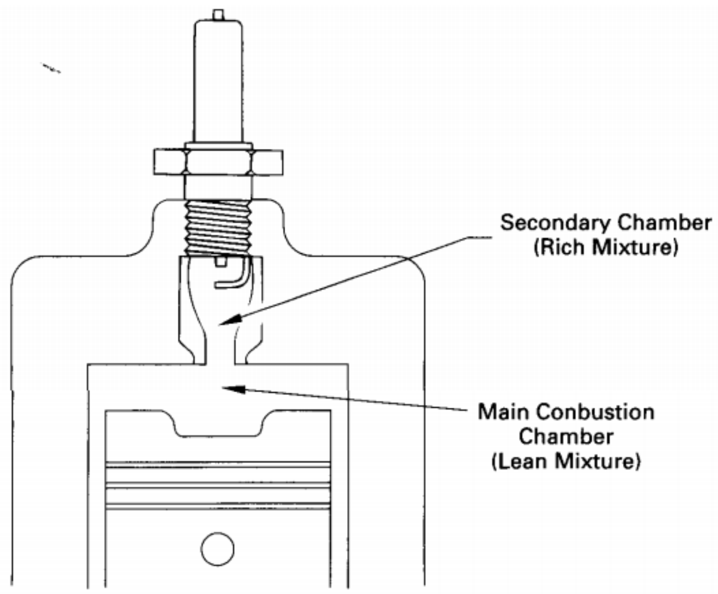

Figure 12 Main and secondary combustion chamber **[1]**

Main and Secondary Chambers Air-fuel Mixtures

As discussed above the main combustion chamber and secondary combustion chamber consist of two different air-fuel mixtures, were one is a rich air-fuel mixture and the other is a lean air-fuel mixture, this section will look into why it is required to utilise both air fuel mixture.

Rich Air-Fuel Mixture

One of the main reasons for the rich air-fuel mixture within the secondary combustion chamber is to help ignite the lean air-fuel mixture within the main chamber, these lean air-fuel mixtures can be difficult to ignite. It should be noted that using a rich pre combustion chamber has a greater influence on igniting the lean mixture within the main chamber than the pre combustion chambers size and orifice length.

Lean Air-Fuel Mixture

The lean air-fuel mixture within the main combustion chamber allows for much higher thermal efficiencies as well as reducing exhaust emissions. In particular the lean air-fuel mixture allows for a great reduction in NOx emissions in particular. These lean air-fuel mixtures are typically slow burning and can be hard to ignite, therefore it is essential to use techniques to help increase the burning rate or produce a strong flame kernel, and these techniques will help to extend the lean limit.

Pre Combustion Chamber Flame Jet

As stated above the main combustion chamber and secondary combustion chamber is divided by very small orifices. One of the main purposes of the orifices is to allow the burning mixture within the secondary chamber to be accelerated through the small orifice, this allows a flame get to develop deep into the main chamber. This flame jet also produces multiple ignition sites, additionally the smaller the orifice size the more the flame jet can penetrate into the main combustion chamber.

Combined Injector, Sparkplug and Combustion Chamber

In particular MAHLE has developed a jet ignition system that allows for ultra-lean combustion in gasoline engines. One of the key features behind the jet ignition system that MAHLE has developed is the ability to replace the standard spark plug with a jet ignition chamber arrangement. An example of the MAHLE pre-combustion chamber assembly can be seen in the figure below.

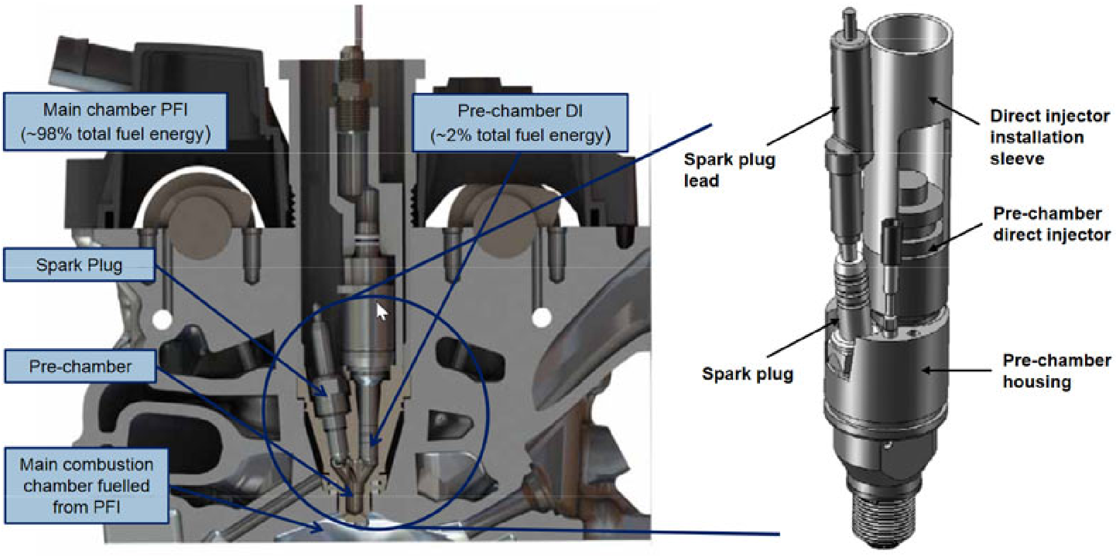

Figure 13 MAHLE pre-combustion chamber assembly **[6]**

NOx and Ultra-Lean Combustion [7]

The process of burning an ultra-lean air-fuel mixture means that there is considerably high volume of air available for the combustion process, this means that the heat capacity of the air-fuel mixture increases resulting in lower combustion temperatures. As discussed above more NOx's are produced at higher combustion temperatures, therefore running an ultra-lean air-fuel mixture helps to reduce the NOx levels.

Additionally exhaust gas recirculation (EGR) can be used to help decrease the content of oxygen within the main combustion chamber, by decrease the amount of oxygen within the main combustion chamber allows for the flame temperature to drop. Reducing the flame temperature also helps to reduce NOx levels as the amount of NOx produced is exponentially proportionate to the flame temperature.

Ultra-Lean Combustion Applications/Benefits [7]

These ultra-lean combustion air-fuel mixtures that can be used due to the pre-combustion chamber turbulent jet ignition process allows for a huge benefit for certain applications. For example applications that require the throttle to open for a long periods of time benefit from ultra-lean combustion since pumping losses are much less.

Another benefit of using ultra-lean air-fuel mixtures is that air is a much better gas to transfer the work energy due to the combustion onto the piston than exhaust gas, this is due to the gases ratio of specific heat. Additionally engines that use ultra-lean air-fuel mixtures can make use of higher compression ratios allowing for greater performance.

Formula 1 Applications

It has been accepted that Formula 1 teams have developed pre-combustion chambers as well as utilised turbulent jet ignition to burn ultra-lean air-fuel mixtures, in efforts to increase efficiency and reduce fuel consumption. It is known that MAHLE supply Ferrari with this type of system and it has allowed them better increase their engine performance and efficiency.

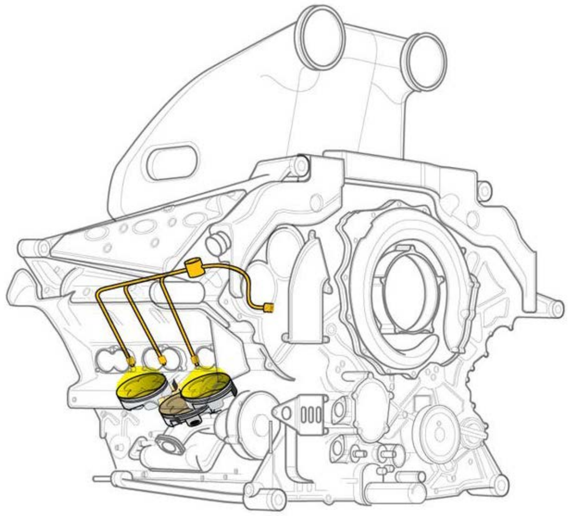

Figure 14 Illustration of the Formula 1 V6 turbocharged engines utilising ultra-lean air-fuel methods

As discussed in Chapter 2 using pre-combustion chambers to utilise turbulent jet ignition has multiple effects that help to improve engine efficiency, fuel consumption and emissions. This chapter will look at these effects in more detail, multiple papers have been referenced to show experimental results and effects of using pre-combustion chambers and turbulent jet ignition.

Results from Paper 1 [14]

This section will look into the study that was conducted by MAHLE Powertrain, titled ‘A Turbulent Jet Ignition Pre-Chamber Combustion System for Large Fuel Economy Improvements in a Modern Vehicle Powertrain’. The papers objectives are to:

- Compare the effects on fuel consumption and emissions when comparing spark ignition combustion system to a turbulent jet ignition combustion system

- Compare the combustion burn parameters between spark ignition and turbulent jet ignition.

- Determine the maximum level of diluent fraction without altering the combustion stability for spark ignition combustion and turbulent jet ignition.

- Develop an understanding on the sensitivity of the turbulent jet ignition has to the pre-combustion chamber timing, pre-combustion chamber injection timing, and pre-combustion chamber to main chamber fuelling ration.

- Develop an understanding on the sensitivity, reliability and robustness of the turbulent jet ignition system.

Specific Experimental Turbulent Jet Ignition Features

This paper states that the experiments consisted of six key features, which will be stated. Firstly it consisted of a very small pre-combustion chamber volume, with the aim to minimize heat loss and hydrocarbon emissions. Moreover it consisted of one or more orifices (small in nature) to connect the pre-combustion chamber to the main combustion chamber, this allows for flame quenching and good penetration into the main combustion chamber.

Additionally the pre-combustion chamber is separately fuelled, this allows a rich air-fuel mixture to be applied to the pre-combustion chamber, while the main combustion chamber contains a much leaner air-fuel mixture. Additionally by separating the main combustion chambers fuel with the pre-combustion chamber allows for homogeneous or stratified main chamber mixtures, this allows better control of hydrocarbons (HC) and nitrogen oxides (NOx) emissions control. In addition a spark plug has been placed within the pre-combustion chamber to initiate the air-fuel mixture. Lastly this experiment uses commercial fuels within the pre-combustion chamber and the main combustion chamber, this allows for a comparison to be made between current configurations.

Experimental Engine Setup

The configuration used in this experiment was taken from a current inline four cylinder engine, the experiment itself consists of a single cylinder (0.6 litre) based on the I4 that is a four stroke cycle, consisting of flat top piston crowns, double overhead camshaft, and four valves per cylinder. Additionally both the intake and exhaust valves utilise variable valve timing. The timing for this engine can be seen in the figure below, it shows the range at which the intake occurs over, the point when the pre-combustion chambers direct injection fuel event occurs, the point at which the pre-combustion chambers spark plug discharges, and the exhaust range.

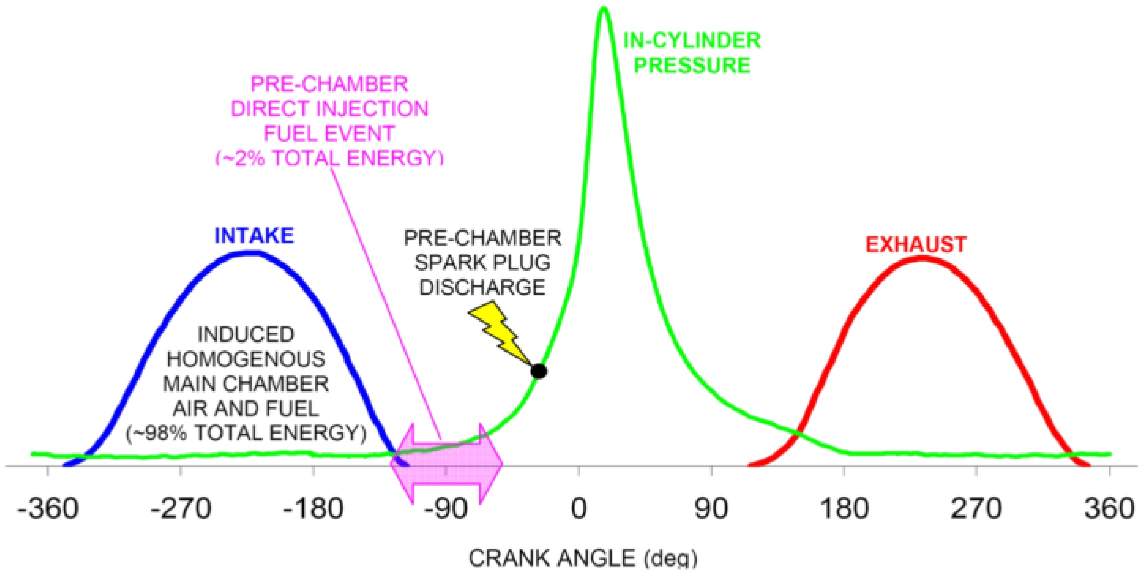

Figure 15 Timeline of the events over one full engine cycle **[14]**

Additionally the exhaust timing was fully advanced and the intake timing was fully retarded in an effort to allow for the exhaust gas residuals (EGR) to be maximised. The hot EGR's help to improve the combustion stability in ultra-lean air-fuel mixtures, this allows the fuels diluent fraction to be pushed further in an effort to help improve fuel economy and reduce NOx emissions.

The ranges that the variable valve timing allows for in the effort to help the intake and exhaust valve overlap timing to take place can be seen in the figure below.

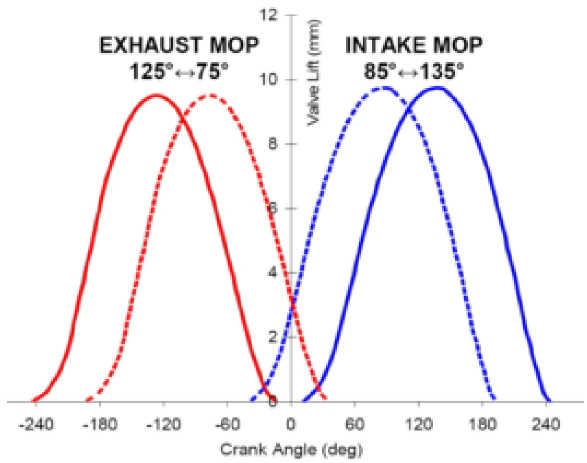

Figure 16 Variable valve timing, intake and exhaust event range **[14]**

This particular experiment defined the adequate combustion stability as being <10%Cov IMEPg, both the fuel used in the pre-combustion chamber and the main combustion chamber was diluted, by adding excess air or excess fuel until the combustion stability defined above was no longer achieved. The spark plug used for

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this experiment utilised an inductive system with 40mJ of ignition energy, the reason that this type of spark plug was chosen was because it can develop a flame kernel in these ultra-lean air-fuel mixtures being tested, this is mainly because the spark plug allows for a long spark duration, helping to increase the possibility of ignition of the mixture.

Multiple things where done in this particular experiment to increase the data's consistency, for example the engine out coolant temperature was regulated to 90^{o}C plus and minus 1.5^{o}C and the oil sump temperatures where regulated to 85^{o}C plus and minus 1.5^{o}C. Additionally the engines emissions during this experiment where continuously checked using a gas analyser.

Experimental Results

This section will look into the results that was found during the conducted experiments.

The figure below shows the stability comparison between the spark ignition and turbulent jet ignition up until the allowable combustion stability (10% Cov IMEPg). The results clearly shows that the turbulent jet ignition system can operate up to a lambda value of 2.1, whereas the spark plug ignition only operates up to a value of 1.4 lambda.

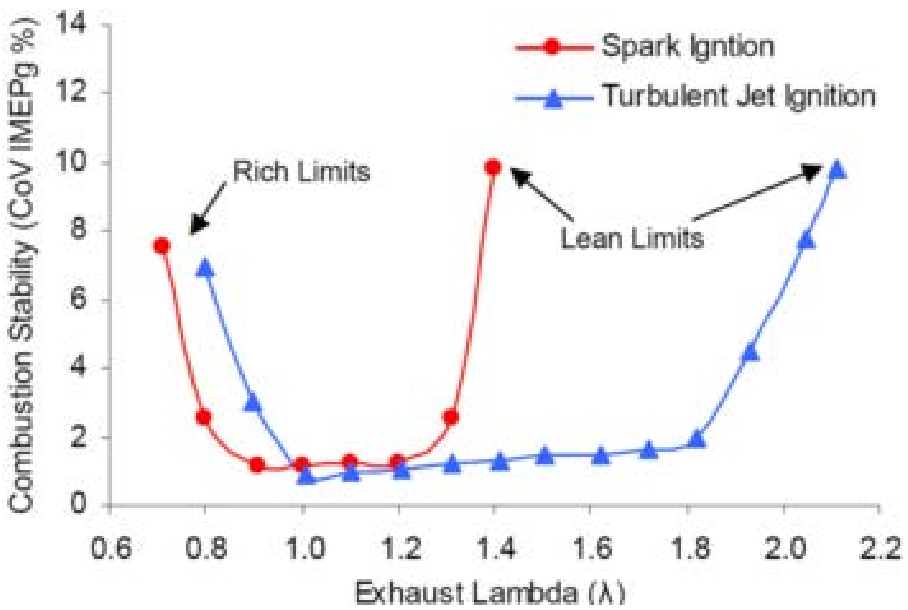

Figure 17 Combustion stability compared to Lambda values **[14]**

Figure 18 clearly shows the emissions between the spark plug ignition and the turbulent jet ignition. It clearly shows that the NOx emissions for the turbulent jet ignition is a lot lower than the spark ignition, one of the main reasons for this is that the peak combustion temperatures are lower (NOx are produced at high temperatures. This allows the NOx emissions to be extremely close to zero (less than 10 ppm), when the exhaust gas lambda values are greater than 1.8. The main contribution of the NOx most likely occurs in the pre-combustion chamber, since there is a much richer air-fuel mixture resulting in higher peak combustion temperatures, however the results clearly show that this has little effect on the overall amount of NOx being developed.

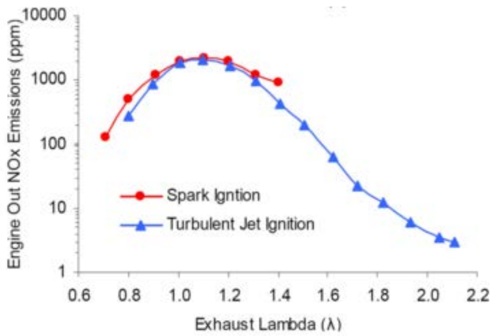

***Figure 18 NOx emissions for spark ignition and turbulent jet ignition* [14]**

The experiments also demonstrated that the turbulent jet ignition resulted in much lower exhaust temperature, up to 20-40°C lower than the conventional spark plug ignition, these lower exhaust temperatures are due to the high concentration of air in the ultra-lean mixture. These lower temperatures are also close to the limits required for hydrocarbon and carbon monoxides to oxidise. These results can be seen in the figure below.

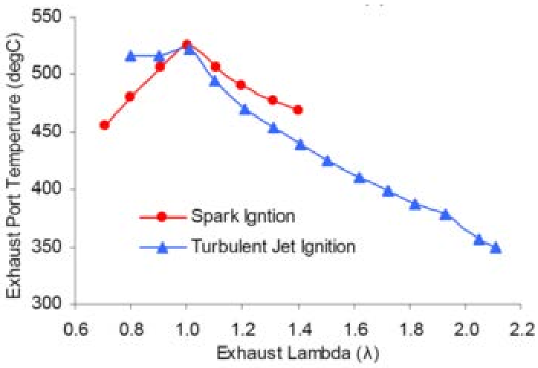

Figure 19 Exhaust port temperatures against Lambda for spark ignition and turbulent jet ignition [14]

Figure 20 shows that there is an increase in carbon monoxides and hydrocarbons when using rich and lean air-fuel mixtures for both spark plug ignition and turbulent jet ignition. The hydrocarbon emissions are lowest for both spark ignition and turbulent jet ignition at around 1.1-1.2 lambda. The high hydrocarbon emissions for the rich air-fuel mixtures are mainly due to incomplete combustion, whereas the leaner air-fuel mixtures have high hydrocarbon emissions due to the lower combustion temperatures. This results in lower cylinder wall temperatures meaning that less hydrocarbons are burnt during each power stroke and exhaust stoke.

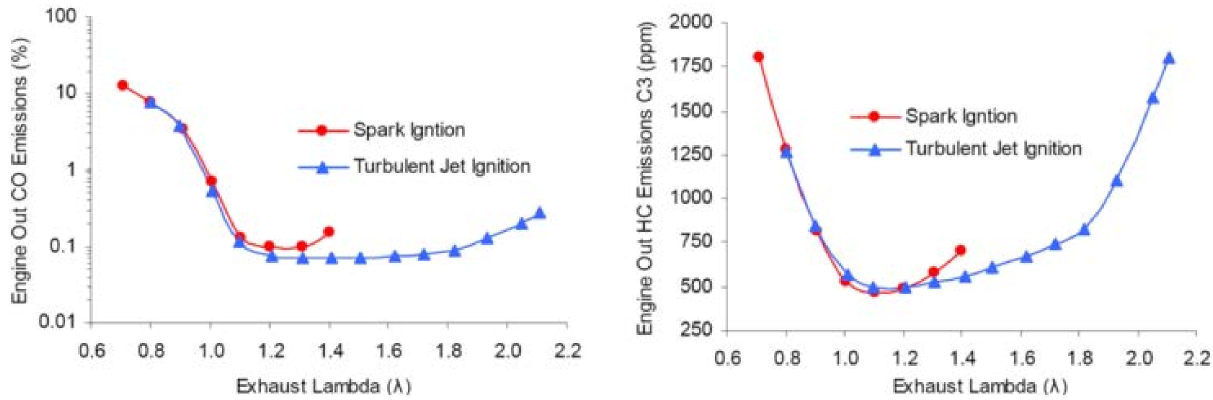

***Figure 20 Carbon monoxide and Hydrocarbon emissions for spark ignition and turbulent jet ignition* [14]**

Experimental Dilution Comparison

It is clear in the results displayed below in figure 21 that the turbulent jet ignition system is capable of reaching up to 54% dilution at its upper most lean stability limit, this in comparison to the spark plug ignition system is considerably higher.

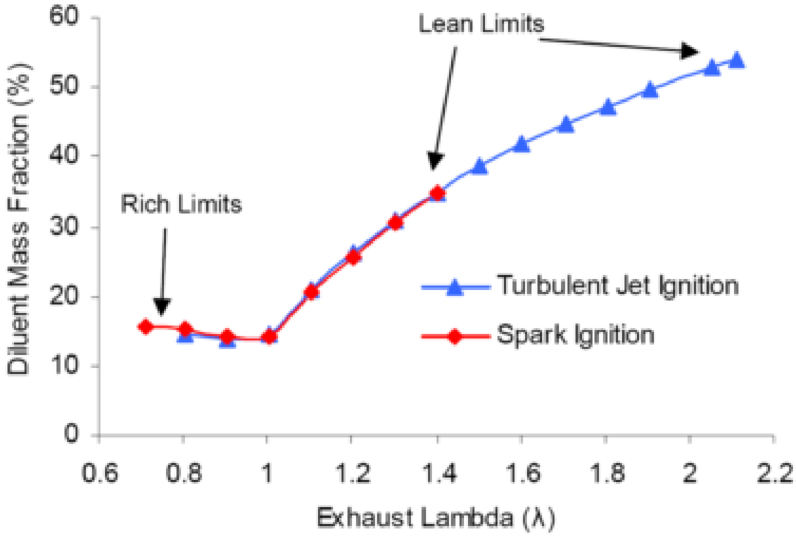

***Figure 21 Diluent mass fraction against Lambda for spark ignition and turbulent jet ignition* [14]**

Combustion Control

This section looks into the benefit of using turbulent jet ignition as a system to control combustion phase. The pre-combustion chamber spark plug timing, fuel injection timing, the fuel ration between the main chamber and the secondary chamber can be used to optimise the combustion system. The figure below shows that at 1.8 Lambda the indicated mean effective pressure (IMEPn) only varied by plus or minus 1% over a 30^{o} spark timing array, it can also be seen that combustion stability was achieved over a 40^{o} spark timing array.

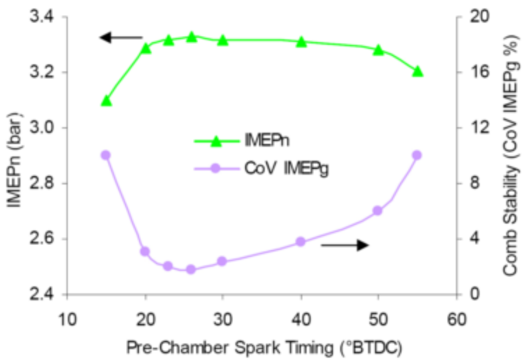

***Figure 22 IMEPn and Stability at 1.8 Lambda for turbulent jet ignition* [14]**

It can be seen in Figure 23 that at 1.8 Lambda with 25^{o} BTDC spark plug timing resulted in an optimal pre-combustion chamber fuel energy of about 2%, this was at the best combustion stability and best independent mean effective pressure (IMEPn). However these values can be greatly dependant on the air-fuel mixture, where a leaner main combustion chamber requires more fuel within the pre-combustion chamber to sustain the combustion within the main chamber.

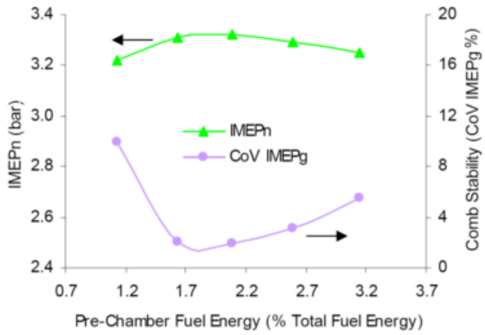

***Figure 23 IMEPn and Stability at 1.8 Lambda against pre-combustion chamber fuel energy* [14]**

Figure 24 shows that the optimal pre-combustion chamber end of injection timing was between 70-80^{o} of BTDC which correlates to about a 50^{o} crank angle before the spark discharge, this advanced timing allows for the pre-combustion chambers air-fuel mixture to full mix before it exits the orifice.

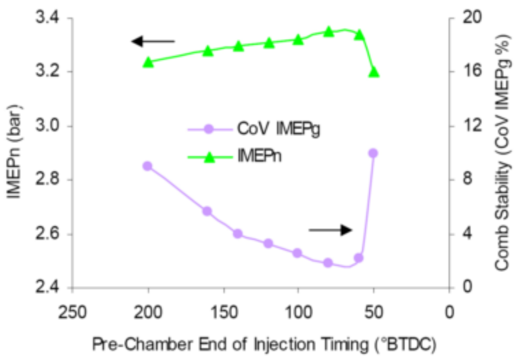

***Figure 24 Pre-combustion chamber fuel injection timing comparison* [14]**

CONCLUSION

This report discusses in detail the benefits of using a next generation pre-combustion chamber that utilises turbulent jet ignition to help reduce fuel consumption and emissions. It discusses in detail the benefits and disadvantages of using a pre-combustion chamber and turbulent jet ignition as well as backing up these advantages with the analysis of specific experiments.

Additionally it was seen in the results that these pre-combustion chambers and turbulent jet ignition are capable of achieving an 18% improvement in fuel consumption when compared to a traditional spark plug ignition configuration. Moreover the results demonstrated efficiency improvements of the system due to the enhanced combustion process. Partly due to the low combustion temperatures that also allowed for drastically lower NOx emissions, with acceptable and controllable Hydrocarbon (HC) and Carbon monoxide (CO) emissions.

As discussed Formula 1 teams have utilised these systems to help improve engine power, efficiency and fuel consumption. Moreover the results from the experiments allow the conclusion to be made that the development of pre-combustion chambers and utilising turbulent jet ignition will be a key part to in the future to helping allow everyday vehicles to achieve better fuel efficiencies and produce lower emissions. Allowing for enhanced emission legislations to be developed and achieved.

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ABBREVIATIONS AND ACRONYMS

The following abbreviations and acronyms are commonly used within the automotive and engine industry, and therefore will be used throughout the entirety of this report.

Top Dead Centre (TDC):

The position at which the piston is at its upper most limit away from the crankshaft, referring to the top of the stroke, it should be noted that the piston has stopped at this point.

Bottom Dead Centre (BDC):

The position at which the piston is at its closest point to the crankshaft, it should be noted that the piston also stops at this point before it starts moving back towards TDC.

Direct Injection (DI):

When fuel is injected directly into the main combustion chamber of the engine, the combustion chamber may consist of a main chamber and a smaller secondary chamber.

Indirect Injection (IDI):

This is a result of fuel being injected into the secondary chamber of an engine that has been divided into a two combustion chambers, a secondary (smaller) and main chamber.

Spark Ignition (SI):

The use of a spark plug to initiate the combustion process

Bore:

The diameter of the piston

Stroke:

The maximum distance that the piston travels, for example TDC to BDC

Clearance Volume:

Relates to the minimum volume within the cylinder when the piston is at TDC

Compression Ignition (CI):

Compression ignition relates to the combustion process due to high compressions and temperatures.

Brake Maximum Torque (BMT):

The rpm at which the maximum torque occurs

Wide Open Throttle (WOT):

This is the point at which the engine is operating with the throttle valve fully open, allowing for maximum power.

Engine Control Unit (ECU):

Relates to the electronics that are being used to control the engine maps etc