# Converting an R/C Aircraft Engine for use with Hydrogen

FSU Senior Design
Group 13

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# SUMMARY

The goal of this project is to convert a small Radio Controlled Aircraft engine to be used with Hydrogen fuel. This report outlines the research and concepts that went into developing a feasible design to be implemented next semester. A 4-stroke engine was chosen to be the base engine for the project. Gaseous Hydrogen will be the working fuel and will be supplied to the engine through the use of a carburetor. Combustion of the Hydrogen will be aided by a Spark plug. This will use an ignition system, which utilizes a magnet and Hall Effect Sensor to achieve the proper timing. This engine will be cleaner for the environment and help facilitate a shift to alternative fuels.

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# 1.0    PROJECT SCOPE

With the world facing the growing problem of Global Warming, due to the millions of barrels of oil being consumed each day, alternative fuels are becoming more and more desirable. One alternative fuel that is becoming widely popular is Hydrogen. Hydrogen has the highest energy content per unit weight of any known fuel-52,000 Btu/lb (120.7 kJ/g). It burns cleanly with oxygen and the only byproducts are heat and water. In conjunction with the United States Air Force and the Air Force Research Laboratories (AFRL), and to broaden the FAMU/FSU College of Engineering's knowledge of the hydrogen economy, this project will show that a Remote Controlled aircraft engine, initially designed for use with a Nitromethane fuel, can be modified to run using Hydrogen. The rewards of using hydrogen fuel are that it gives off less pollution and requires a lower ignition spark.

The goal of this project is modify a remote control airplane engine to operate on hydrogen fuel. This engine should not just be able to run, but be able to run well, and for an extended period of time without wear, or seizing. Some problems that might arise are that the lower ignition energy of Hydrogen can lead to pre-ignition and backfire. Hydrogen also has a stronger potential to leak, due to its high diffusivity, which could pose serious problems if it were ignited.

The purpose of building this engine is to help educate others that Hydrogen powered vehicles are feasible and that does not mean a loss of power. In doing this project this group will become more knowledgeable and gain useful experience working with Hydrogen systems and corresponding with Sponsors and contacts.

# 2.0    PROJECT SPECIFICATIONS

The goal of this Project is to convert a small Radio Controlled Aircraft Engine to be able to use Hydrogen as a fuel. Current R/C Aircraft Engines have very poor emissions, making them bad for the environment. If they could be converted to run on Hydrogen, the only emission would be water vapor.

## Requirements

- The Engine should be safe to operate.
- The Engine should be able to run on Hydrogen alone.
- It should be efficient, wasting as little Hydrogen as possible.
- It should be able to run for extensive periods of time without seizing up.
- It should be lightweight because it is to be used on an Aircraft.
- The engine should have as close to the same power output as an unmodified engine as possible.

## Modifications Needed

- Most R/C engines require a certain amount of Lubrication content in the Fuel. Hydrogen does not have any lubricating properties; therefore a way to supply lubrication to the working parts of the engine needs to be developed.
- R/C Engines use a Glowplug as a means to aid in combustion. These devices are always on, which could lead to Pre-Ignition problems when running the engine on Hydrogen. To fix this, the Glowplug needs to be replaced with a Sparkplug.
- In order to have the Sparkplug operate correctly a timing mechanism needs to be developed, preferably one that can be adjusted allowing for precise timing.
- A battery system will have to be installed to run the Sparkplug as well as any Fuel Pump that might be required.
- A Fuel delivery system needs to be developed that can deliver the right amount of hydrogen to the engine at the right time.
- If possible there needs to be a way to adjust the Air/Fuel ratio.
- An efficient means of Hydrogen storage needs to be used, allowing for ease of use, and with little weight or cost.

# 3.0    BACKGROUND INFORMATION/ CONCEPT OVERVIEWS

## 3.1    Internal Combustion Conversion for Hydrogen Fuel

Hydrogen burning internal combustion engines, also known as H2ICE's, are the near future and bridge hydrogen fuel cells and internal combustion engines. Hydrogen burns clean with practically zero emissions and has efficiencies exceeding port fuel injection engines (PFI), and can potentially be integrated into the existing petroleum based infrastructure. With a small number of vehicles actually in use and the case-based modifications, it is difficult to explain how to repair them. Getting a hydrogen internal combustion engine to work is a relatively simple process, but getting it to run well is not.

Early attempts include a vacuum engine which atmospheric pressure drives the piston back against a vacuum to produce power. Burning a hydrogen and air mixture and allowing it to cool creates the vacuum. This was done in 1820 by Reverend W. Cecil. A second attempt was around 1865, with N. A. Otto (discoverer of the Otto cycle) who used a synthetic producer gas fuel, which had a Hydrogen content over fifty percent. Because of safety issues, gasoline pushed him towards a gaseous fuel until the invention of the carburetor which allowed for gasoline to be used safely and practically, leaving very little interest in other fuels. Hydrogen is used often in the space program because of its high energy to weight ratio (higher than any other fuels). Liquid hydrogen is used in the upper stages of launches for space vessels.

Hydrogen can be combusted with a wide range of air to fuel ratios in internal combustion engines with possibilities of lean mixtures. A lean mixture allows for a smaller amount of fuel (less than theoretical or stoichiometric) needed to combust in an engine. This will increase the fuel economy of the vehicle and reduce the amount of harmful emissions because the combustion reaction is more complete. Lean mixtures do reduce the power output due to the reduction in the volumetric heating value of the mixture.

There is a very small amount of energy needed to ignite hydrogen and the energy is significantly lower than that of gasoline, allowing for prompt ignition and use of lean mixtures. However, there are drawbacks to low ignition energy, both premature ignition and flashback can hurt performance allowing hot spots to form in the cylinder and hot gasses from other parts of the engine close to the air-fuel mixture. Flashback is pressure

forced back through the supply tubing. Premature ignition is when the mixture is ignited before the spark plug causes the ignition leading to large inefficiencies and backfire. Backfire is when the ignited flame travels back into the induction system usually when both the exhaust and intake valves are open at the same time. Premature ignition is the most common problem encountered when designing and running a hydrogen engine. The smaller quenching distance, the wide flammability range and lower ignition temperature properties of hydrogen are large factors affecting the pre-ignition problem. One of the causes of premature ignition is hot spots in the cylinder including the spark plug, exhaust valve, and carbon deposits. Hot spots are locations of higher heat on the inside of the cylinder walls due to the combustion process and friction from poor lubrication, and almost any mixture ratio can be ignited. Pyrolysis of oil, a heat induced chemical decomposition, in the combustion chamber can also lead to pre-ignition. The oil can leak past the top of the piston rings, past guide seals of the valves and through the intake manifold, into the combustion chamber.

Quenching distance is another factor to consider. Hydrogen flames burn closer to the cylinder walls than gasoline, and can increase backfire. Due to its molecular size, it is easier for a hydrogen-air mixture to bypass valves than a hydrocarbon-air mixture. This also applies to the flame speed, which is high in comparison to gasoline, and allows for the system to more closely reach a thermodynamically ideal engine cycle.

Autoignition temperature has implications as well, when burning hydrogen. With a high autoignition temperature, there are issues with the compression of the hydrogen-air mixture. However, it does allow for large compression ratios compared to gasoline. These factors are important and relate to the overall thermal efficiency of the system. The temperature rise during compression is related to the compression ratio and if the temperature rises beyond the autoignition temperature, then premature ignition occurs. Hydrogen is hard to ignite with compression because of the high autoignition temperature therefore making it hart to implement into a compression-ignition or diesel system.

Chemically, hydrogen has a high diffusivity and low density. High diffusivity helps to disperse the fuel in air quicker, avoiding or minimizing safety hazards. Also, it allows for the fuel mixture to become homogeneous more quickly giving a cleaner and

faster combustion reaction.  The density creates challenges including large storage tanks to contain hydrogen as a gas, and also has less power density because of the hydrogen-air mixture.

Determining the air to fuel ratio requires the inclusion of nitrogen because air is used instead of pure oxygen.  (For calculations, see Appendix A.)
For complete stoichiometric combustion of hydrogen in air, a ratio of 34:1 hydrogen to air is required.  Hydrogen engines can actually run on mixture ratios between 34:1 and 180:1 because of its wide range of flammability.  This is much higher than the 14:1 fuel to air ratio for gasoline.  With hydrogen as a gas at room temperature it disperses throughout the combustion chamber more completely than that of a liquid fuel displacing about thirty percent of the volume compared to approximately two percent of the volume displaced by a liquid fuel.  This can increase the power output by a range of eighty-five percent to one hundred twenty percent relative to gasoline depending on the fuel delivery system.

Pre-ignition can be reduced or eliminated by using advanced fuel delivery systems.  There are three methods for fuel delivery.  First is the central injection, or the use of a carburetor, which is the simplest method.  A carburetor uses a throttling valve to control fuel intake.  Through a vacuum created by a venturi, or a narrowing in the flow, the air intake is throttled to a higher velocity. A vacuum is created, drawing in a proportional amount of gasoline, resulting in the desired air to fuel mixture.  This is injected at the inlet of the air intake manifold.  Being able to function at low pressures and its ease of conversion from gasoline are advantages to this method.  Disadvantages are also present with this simple solution involving irregular combustion from pre-ignition and backfire (due to less control of the air-fuel mixtures), with higher concentrations of hydrogen in the mixture compounding the problem.

Next is port injection, which injects fuel just upstream of the intake valve at the intake port of each cylinder (compared to the central point of mixing, like the carburetor).  Conditions at this location are more conducive to reducing pre-ignition especially because there is less gas in the manifold at any given time.  Having the air injected into the combustion chamber before the fuel, allows for cooling of the hot spots and left over gasses.  However, there is a higher required inlet supply pressure than the central

injection system. Using a cam-operated device to time the fuel injection is part of the constant volume injection system. Solenoid valves at each cylinder are controlled electronically for an electronic fuel injection system. The constant volume injection system uses constant injection timing and the pressure varies, while the electronic fuel injection system uses variable injection timing and the pressure remains constant.

Last the direct injection system is the most complicated, but also the most power efficient and stoichiometrically efficient. Direct injection of the fuel into the combustion chamber after the air intake valve has closed, and mixes the air and fuel within the combustion chamber. One advantage of this method is the complete elimination of pre-ignition during the intake stroke and elimination of backfire, but there is still possibility of premature ignition within the combustion chamber. A high-pressure delivery system for the fuel is required with the direct injection system though. With the decreased time for mixture of the hydrogen and air, there is possibility of a non-homogeneous mixture ignition leading to increased emissions. Power outputs are increased by twenty percent over gasoline and over forty percent compared to carbureted hydrogen engines.

Decreasing the temperature of hot spots and reducing the peak combustion temperature are methods known to help reduce pre-ignition. A method called exhaust gas recirculation takes approximately twenty-five percent of the exhaust gasses and reintroduces them into the intake manifold, helping to reduce emissions. One downfall of this method is a decrease in power output. The pressure that is created by these gasses in the combustion chamber reduces the amount of fuel mixture that can be brought in, thus reducing the power output. Introducing water into the hydrogen stream before being mixed with air has a better power output rather than introducing it into the intake manifold. Also having its downfalls, extra care must be taken to keep the seals from leaking water into the oil in the lubrication system.

Instead of modifying an existing engine, it runs much smoother to design an entire engine for hydrogen use and is more thermodynamically efficient (with emphasis on the combustion chamber). Turbulence within the combustion chamber causes problems, and making a flat piston head and a flat chamber ceiling can reduce this turbulence. Using two small exhaust valves as opposed to one large valve will increase the excavation of the exhaust gasses with less air resistance from the combustion chamber reducing pre-

ignition. Implementation of a cooling system that can deliver a consistent flow to the areas of interest can increase efficiency and reduce pre-ignition.

Diesel engines, or a compression ignition system, are not able to use hydrogen without modifications because of the low ignition temperature of hydrogen. They can however be fitted with a spark plug, (this method is called a pilot ignition system) and is being utilized for natural gas in diesel engines but not for hydrogen.

At lean fuel-to-air ratios, flame velocity is greatly decreased and a dual spark plug configuration is preferred. Converting from a waste spark system should be avoided because it charges the spark each time the piston is at top dead center without regard to the compression stroke or exhaust stroke. Platinum spark plug tips cause hydrogen to oxidize with air because of its catalyst nature and should be avoided. Cold running spark plugs are beneficial in reducing pre-ignition because they transfer heat more quickly from the plug head to the cylinder head than a hot rated spark plug, increasing the precision of the timing. A hot-rated spark plugs' benefit is that it retains heat, keeping carbon from accumulating on the spark plug tip.

With the low ignition energy of hydrogen, ventilation of the crankcase is very important. It can avoid the ignition of hydrogen that has escaped past the piston rings. A minor complication is ignition in the crankcase, resulting in an engine fire causing abnormal noise and little damage. Pressure in the crankcase will increase with ignition requiring a relief valve to be installed. Hydrogen exhaust is water, and exhaust can escape past the piston rings also, this water needs to be ventilated before it mixes with the oil of the lubrication system to maintain minimal engine wear.

The Otto cycle engine has a theoretical thermodynamic efficiency based on the compression ratio and specific heat ratio of the fuel. (For calculations, see Appendix A.) Thermodynamic efficiency can be increased with increases in the compression ratio and specific heat ratio. Compression ratios are based on a fuels resistance to knock. Knock is when regular ignition occurs but a pocket of air-fuel mixture is ignited separately. These two combustion reactions collide causing a shockwave reverberating throughout the engine causing the "knock." Timing is then compromised and the ignition no longer occurs at the optimum point of the down stroke. Leaner mixtures have less chance of knock therefore tolerating higher compression ratios. Specific heat ratios are related to

the molecular structure of the fuel and the more complex the molecule, the lower the specific heat ratio. Hydrogen has a specific heat of 1.4 compared to gasoline, which has a specific heat of 1.1.

Hydrogen combusted with air does produce nitrogen oxides from the high temperatures, but the ideal combustion with hydrogen and oxygen produces pure water. Carbon oxides can form should some of the oil leak into the combustion chamber. Other factors that affect emissions are the air-fuel ratio, ignition timing, compression ratio of the engine, and the speed of the engine. A leaner mixture of hydrocarbons allows for a more complete combustion and leaves a lower amount of unburned hydrocarbons. Excess oxygen also combines with carbon monoxide creating carbon dioxide, a less harmful emission.

Taking volumetric ratios into account for the power output, carbureted fuel injection systems that mix the hydrogen and air before entering the combustion chamber allow less air for combustion to enter. This method will only give a theoretical power output fifteen percent lower than gasoline. With gasoline, a liquid fuel, it occupies less volume, allowing for larger amounts of fuel to burn each stroke of the engine. Direct injection gives one hundred percent of the combustion chamber volume to air and pressurizes the chamber with the excess hydrogen, putting a theoretical power output fifteen percent higher than gasoline. There are high operating temperatures for stoichiometric combustion exhausting high levels of nitrogen oxides, which is the cause of conversion from gasoline engines to hydrogen engines. Therefore, the actual power output of most hydrogen engines is approximately half of its gasoline counterpart, but this can be increased with the use of turbochargers and superchargers. A turbocharger, powered by exhaust gasses turning the compressor, increases the pressure in the combustion chamber allowing more air and fuel into the space per combustion cycle. A supercharger works the same as a turbocharger, but gets its power directly from the crankshaft.

Hydrogen cannot be stored in the same tanks as most fuels with the exception of natural gas. Storage is usually large and cumbersome when fuels are combined from separate tanks. Hydrogen is a gas at room temperature and atmospheric pressure and will not mix with a liquid fuel in the same tank. Another property, its low boiling point, will

actually cause freezing of liquid fuel if stored in the same tank. Usually these systems are impractical with the exception of the natural gas. Advantages of dual but separate systems allows for the use of hydrocarbon fuels when hydrogen is not available.

Research and development are focused on advanced spark ignition with direct injection. If implemented correctly, the efficiencies can reach that of a high efficiency diesel engine, with port fuel injected power densities. Direct injection of a mixture of hydrogen and air into the cylinder can potentially avoid problems associated with hydrogen engines including backlash and pre-ignition, also avoiding the power density losses because the fuel is injected after the intake valve has closed. Stoichiometrically, the direct injection hydrogen internal combustion engine can put out 115% of the power a gasoline internal combustion engine.

In an experiment, an automotive sized single cylinder engine with optical access for advanced laser-based optical diagnosis was used to study in-cylinder reactions. The Hydrogen needed to be injected at a high pressure of 200 bar. Using advanced forms of measurement, they were able to deduce quantitative measurements of in-cylinder mixing. In one experiment, the hydrogen is seeded with acetone, providing fuel to air ratios. This data allows for better injection strategies and chamber design.

A conglomerate of research facilities and companies are working together to convert a gasoline and natural gas engine to run on hydrogen. Their choices of motors include a 425cc single cylinder and 5.4 liter Ford V8 both using Direct injection of the hydrogen. The Ford V8 required custom fuel injectors but reduced modifications of the rest of the engine to being just the bolting in of the spark plug. Both engines were tested in a Polaris Ranger two-seater (Fig. 1).



Figure 1. Picture of Test Vehicle for the Hydrogen Conversion.
Picture courtesy of
http://www.cer.unlv.edu/research.php?sn=gas2h2

## 3.2   Overview of 2-Stroke and 4-Stroke Engines

2-Stroke Engine

Most applications of a 2-stroke engine are small and therefore work well in machines such as chain saws, lawn mowers and remote control engines.  A 2-stroke engine will also work without complications when upside down making it appealing to hand-held applications.

A 2-stroke engine has less moving parts and combines processes of a 4-stroke engine into half a revolution.  Therefore, a 4-stroke engine takes two complete revolutions to complete the cycle and produce the power stroke, while a 2-stroke engine can produce a power stroke every



Figure 2: 2-Stroke Engine at the Top of the Compression Stroke

revolution.  There are multiple processes happening during one revolution.  Starting with the power stroke, the piston is driven down and the air-fuel in the crankcase is compressed as seen in figure 3.  The position of the piston at the bottom of the power stroke allows a release of pressurized air-fuel mixture into the combustion chamber and forces out the exhaust gasses.  The piston acts as the valve for the exhaust and the crankcase as seen figure 4.  The compression of the air-fuel mixture as seen in figure 5, the piston drives the volume of the air-fuel mixture down increasing the pressure and temperature.  This also creates a vacuum that opens a one-way valve allowing more air-fuel mixture from the carburetor to enter the crankcase, still sealed off from the combustion chamber.  At the top of the compression stroke (called top dead center, TDC), the spark plug ignites the mixture, and the piston extracts energy from the combustion and is also driven back down as seen in figure 6.
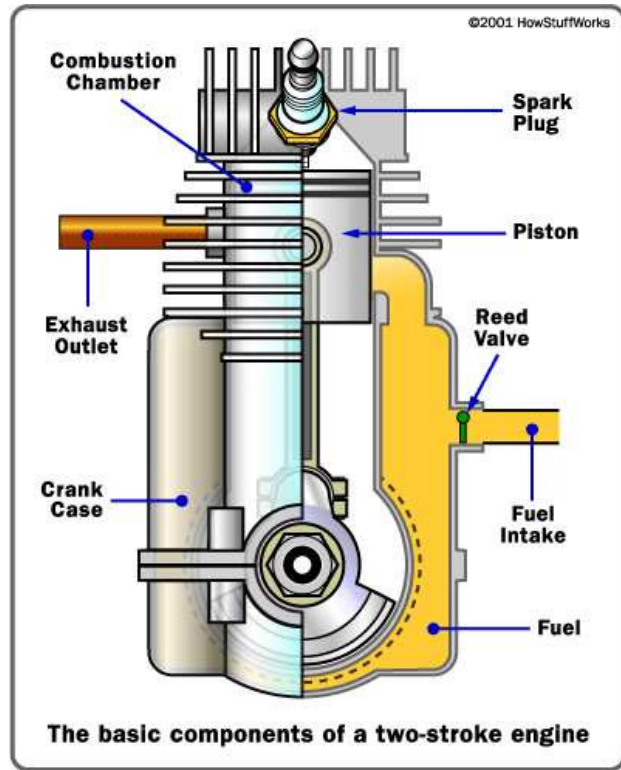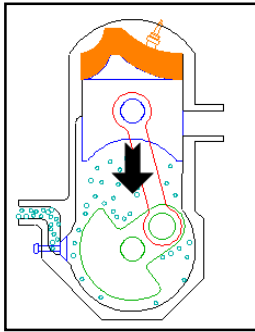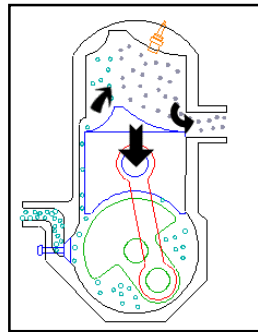
Figure 3: Power Stroke

Figure 4: Fuel intake and Exhaust
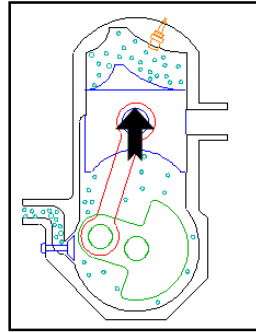
Figure 5: Compression Stroke
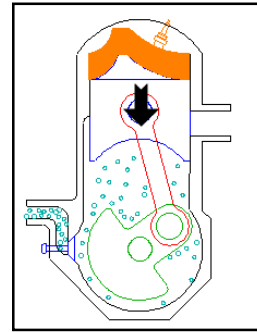
Figure 6: Ignition and Power Stroke

Pictures courtesy of Keveney.com

Disadvantages of a 2-stroke outweigh the extra power output. Because there are not valves for the intake and exhaust, some of the air-fuel mixture rushes through the combustion chamber and out with the exhaust leaking gas and oil into the environment. With emissions being the big issue with hydrocarbon fuels and engines today, 2-stroke engines emit much more harmful emissions than its 4-stroke counterpart. Energy efficiency is a big issue with the 2-stroke also for reasons including the wasted fuel that is not kept in the combustion chamber, and most do not utilize direct fuel injection.

Another disadvantage is the lubrication system. There is not one, the oil is injected with the fuel into the engine giving less lubrication than a separate system like the 4-stroke has, creating worse emissions and shorter lifespan due to ware. The implication of this in an automobile would require approximately four ounces of oil per gallon of gas, and this is not practical.

4-Stroke Engine
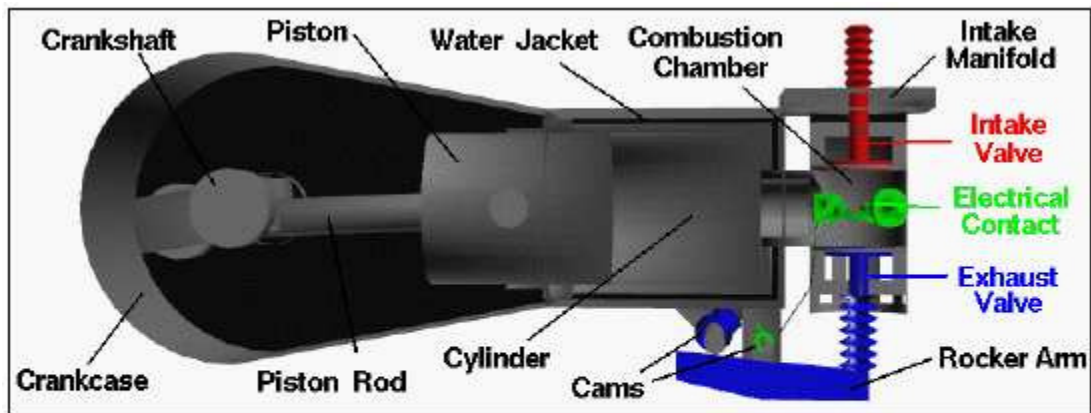


Figure 7: Otto Cycle Engine Parts

(Courtesy of http://wright.nasa.gov/airplane/engopt.html)

The Otto cycle as shown in figure 7, also known as a 4-stroke engine, uses valves and ignition timing to create power from combustion.  First, there is an intake stroke, where the piston is driven down and a vacuum is created and a valve is released to allow the air-fuel mixture to enter as shown in figure 8.  Next, there is the compression stroke, where the gas in the combustion chamber is compressed, decreasing the volume and increasing the pressure and temperature as seen in figure 9.  As the piston reaches the top, the timed spark plug ignites the fuel and the combustion drives the piston down outputting power as shown in figure 10.  Finally, there is another compression stroke, but instead a valve is opened allowing the exhaust gasses to be forced out from the combustion chamber as seen in figure 11.  Then the process repeats.

Figure 8: Intake Stroke

Figure 9: Compression Stroke
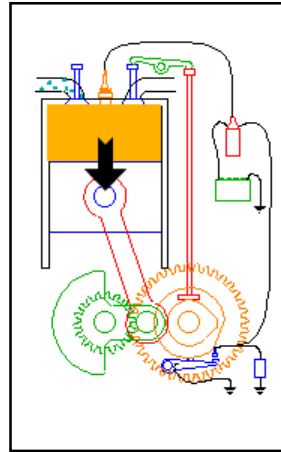
Figure 10: Power Stroke
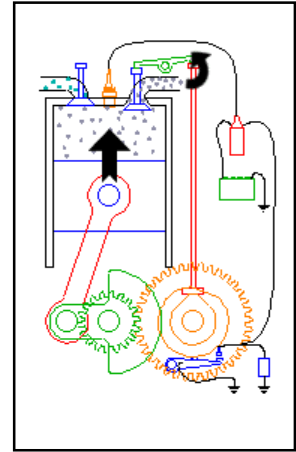
Figure 11: Exhaust Stroke

A 4-stroke engine utilizes two revolutions per power stroke, giving it half the power output of a 2-stroke. There are advantages though. First, there is a separate process for intake and exhaust so fuel is not excavated from the combustion chamber without being part of the comb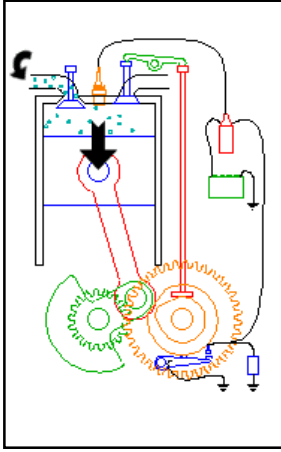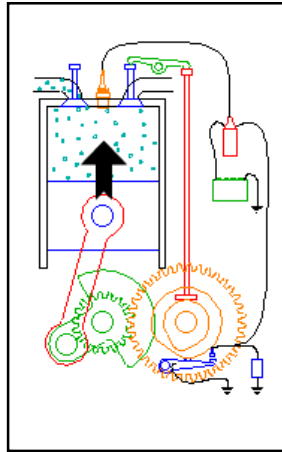ustion process. Second, there is a separate crankcase that allows for more durable oil, in a reservoir, to stay separate from the rest of the system, father reducing engine ware.

Timing can be an issue, but the use of a camshaft (a lobed rod pressing buttons at the correct times to release valves) can help to solve these problems. Camshafts are geared to rotate at one revolution per power stroke, or one revolution per two revolutions of the crankshaft. Spark plug timing is usually run from a computer chip, and is timed with only one cylinder igniting at a time, allowing for maximum smoothness. This also incorporates the camshaft timing.

Three major reasons for issues include a bad spark plug, a bad air-fuel mixture, or bad compression. First, the spark plug might have a snipped wire or worn out wire, causing a bad or no connection. Also, the spark timing might be off and power is being distributed at anything but the optimal timing. Second, the air intake could be clogged flooding the engine with fuel and there is no air for combustion, there might not be any gas and the engine is just getting air, or the mid ground where the air-fuel mixture is improperly proportioned. There can also be impurities in the fuel like water causing

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problems in the combustion process. Last, there could be bad or no compression occurring. If there were a leak at either of the valves, intake or exhaust, there would be less compression than required. At the top of the cylinder, where the spark plug is inserted, there could be a break down of the gasket that seals the cylinder, again causing a leak.

Power output can be increased with many options. Displacement can be increased, with the principle: the more volume displaced the more power per revolution. To accomplish this, more cylinders and or larger cylinders can be used. Compression ratios can be increased, with the problem of early ignition. High-octane fuels accommodate for early ignition from high compression ratios. Higher pressures in the combustion chambers will increase the amount of air and fuel in the cylinder per combustion cycle, increasing the power. If the incoming air is cooled, it occupies less space and will expand more increasing the power stroke. Also, airflow resistance into the cylinder will take away power from the power stroke to pull in the air lessening the power output. Lower pressure losses in the filter and valves can help offset the losses.

## 4.0    CONCEPT GENERATION

This project involves the modification of an existing R/C Aircraft Engine so that it can be run using Hydrogen Fuel. These engines operate using a Nitromethane Fuel with an oil content of approximately 18%, and can be either 2-stroke or 4-stroke. Most R/C engines are relatively small, with an output of around 1~2 hp. These engines use a Fuel/Oil mixture that acts as both the fuel and the lubrication for the engine. The fuel is allowed to fill the Crankcase before it enters the Combustion Chamber so that all of the internal parts are lubricated. Both of these engines would easily run by simply pumping Hydrogen into them; however neither would be very efficient and would seize very quickly due to heat from friction. Both types of engines would require modifications to be able to operate efficiently without seizing.

### Contents:

## 4.1    Engine

For the purpose of this project only one type of engine will be selected for modification. The modifications that would be required for both engines are discussed below. These engines are going to be studied further as well as the modifications they require at which point a choice will be made as to which engine will be selected for the Hydrogen Conversion.

### 2-Stroke Engine

The standard Two Stroke engine operates on the Two Stroke cycle. They fire once every revolution instead of once every other revolution as a Four Stroke does. Two Stroke engines do not have any valves, making them easier to construct. They have a much higher Power-to-Weight Ratio than most Four Stroke engines and can operate in almost any orientation.

Below is an example of an R/C Aircraft Two Stroke Engine



Figure 12. O.S. 91FX Two Stroke
Aircraft Engine

## 4-Stroke Engine

The Four Stroke engine is widely used in automotive applications as well as in some Airplane applications. It operates on the Otto cycle, where combustion occurs once every other revolution. Four Stroke engines operate using Valves that open and close as the Crankshaft rotates. These allow the piston to expel the exhaust gasses on one stroke, and then pull in fuel on the next stroke. These engines produce less power than Two Stroke engines, however they are much more efficient.

Below is an example of an R/C Aircraft Four Stroke Engine



Figure 13. O.S. FS 70-II Surpass Four Stroke
Engine

## 4.2    Fuel Delivery System

**Required By: Both the 2-Stroke and the 4-Stroke**

There are Three ways that Hydrogen can be introduced into the engine:

1)      Through the Carburetor

2)      A Port Injection System

3)      A Direct Injection System

Carburetor

This is the simplest method for delivering Hydrogen to the engine. It does not require that the Hydrogen have as high a supply pressure as in the other methods. Also, the R/C engines that are to be used in this Project are already equipped with Carburetors, making the modifications easier. The disadvantage of using this type of system is that it increases the risk of backfire and pre-ignition because of the larger amount of Air/Fuel in the intake manifold.

Port Injection System

This type of system injects the Hydrogen fuel into the intake manifold at each intake port. Air is first injected at the beginning of the Intake stroke which allows any residual gases to be diluted as well as cooling off any hot spots. The Hydrogen is then injected during the Intake stroke. This process allows a smaller amount of gas to be in the manifold at any one time, reducing the risk of pre-ignition and backfire. The inlet supply pressure for this type of system needs to be higher than for a carbureted system, but less than needed for a Direct Injection system.

Direct Injection

Direct Injection is the most sophisticated type of Fuel delivery that can be used. In this process the Hydrogen is injected during the Compression Stroke, after the Intake valve has closed. This completely eliminates the risk of Pre-ignition and backfire during the intake stroke. One downside of using this type of system is that there is reduced mixing time of the Air and Hydrogen, which leads to a non-homogenous mixture. The result of this



Figure 14. Quantum Technologies Gaseous Injector

is that it can lead to higher NOx emissions than that of other methods. This type of system requires a higher fuel pressure than that of any of the other methods.

For both the Port Injection System and the Direct Injection System an Electronic Control Unit will need to be used. This will allow the proper amount of fuel to be added at the precise time that is required.

## 4.3    Spark Plug and Timing

**Required By: Both the 2-Stroke and the 4-Stroke**

Most R/C engines run using a Nitromethane Fuel. This fuel has a higher Oxygen content than Gasoline, allowing it to combust with a smaller amount of available air. In the engines it is combusted through the use of a Glowplug. This is a constant temperature heat source. This works fine when running on a Nitromethane Fuel, however it poses a serious risk when using Hydrogen. The low Ignition Energy of Hydrogen means that it can be combusted by any hotspots in the engine. If a Glowplug were used with Hydrogen it would lead to severe Pre-ignition and Backfire problems.
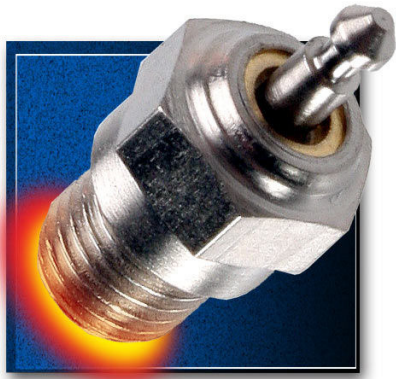
Figure 15. Glow Plug

To fix this, the Glowplug needs to be replaced with a Spark plug. This will only fire when it receives a charge from the ignition source and can be controlled so that the Hydrogen is only ignited when it is the right time.

This then leads to the issue of timing. With a Glowplug there is no need for a timing mechanism because it is always hot, however a Spark plug needs to be told when to fire. There are Two ways that Timing can be added onto the engine:

1) Use a Mechanical Timing Device
2) Use an Electrical Timing Device

Mechanical Timing

A Mechanical Timing mechanism would work by using a cam connected to the camshaft to mechanically activate a switch, sending a signal to the Spark plug telling it to spark. This solution would be a relatively cheap option, however it could prove difficult to implement, given the small size of the engine. It could also lead to pre-ignition and Backfire problems if the cam is not positioned correctly.
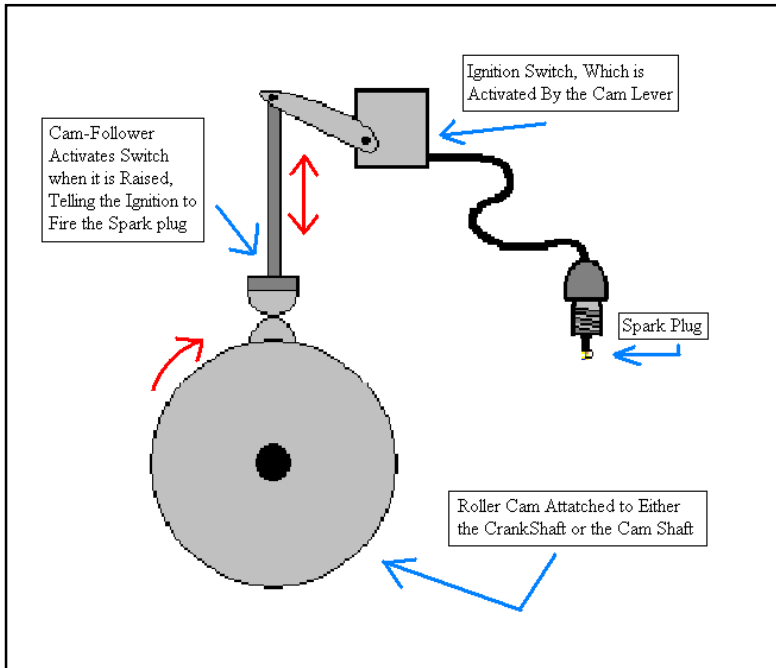
Figure 16. An Example of a Mechanical Timing Device

Electrical Timing

This Timing mechanism can built using a Hall-Effect Sensor and a magnet placed on the Prop Hub. When the shaft is spinning, the Prop Hub with the magnet on it will rotate as well. When the magnet passes under the Hall-Effect Sensor it will send a signal to the Ignition telling it that it needs to fire.
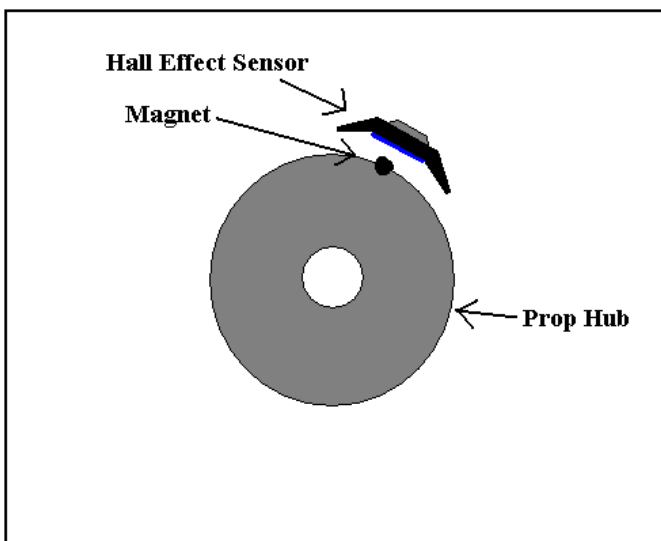


Figure 17. Diagram of an Electrical Timing Mechanism
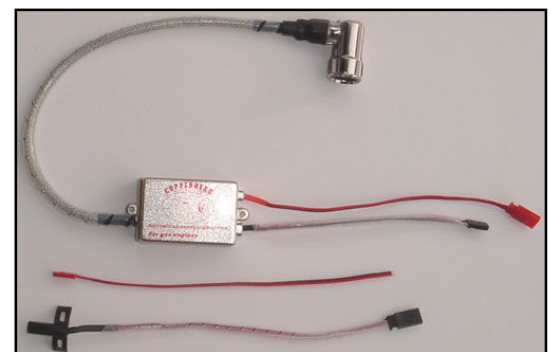


Figure 18. Copperhead Aviation RCEXL Electronic Ignition

An Electronic Ignition will also need to be added. These can be purchased from Hobby shops and require a small 4V battery to operate. One example is shown above, on the right.

## 4.4    Lubrication System

**Required By: Both the 2-Stroke and the 4-Stroke**

Both the 2-stroke and the 4-stroke engines will require some sort of lubrication system. R/C engines operate using a Nitromethane fuel containing a certain amount of oil content. This acts as both the Fuel and the lubrication for the engine. Because Hydrogen has no lubricating properties a way to supply oil to the moving parts of the engine needs to be developed.

In the 2-stroke engine the fuel passes through the engine body before it enters the carburetor, much like a reservoir. All of the moving parts are then lubricated as this fuel passes through the engine.

The 4 stroke engine is lubricated from air-fuel-oil and exhaust mixture that travels from the rocker cover, down the rocker arm retainer and into the crankcase. The mixture lubricates all moving parts (crankshaft, connecting rod and camshaft bearings, piston, and valve rocker) before it is routed back into the intake pipe.
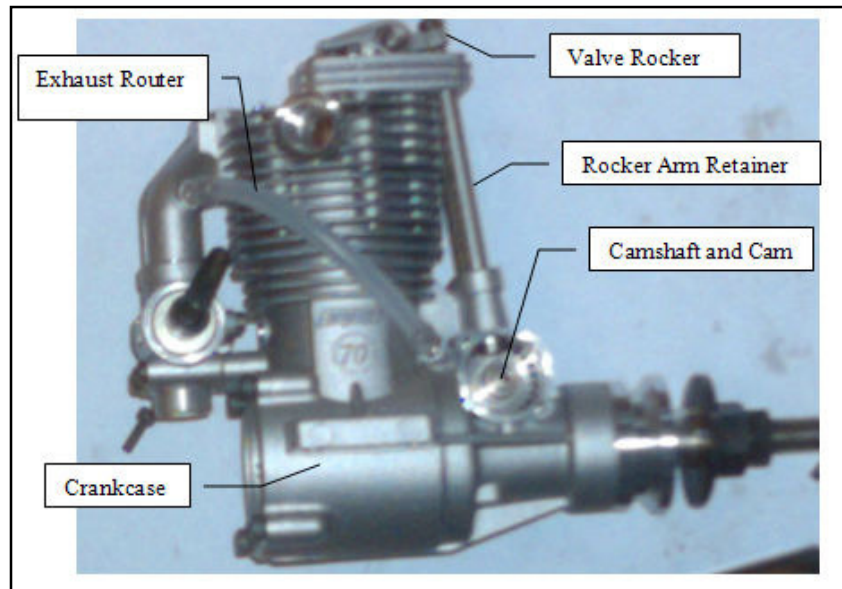


Figure 19. Picture of 4-Stroke Engine.

After looking at the two engines and studying how typical engines are lubricated, three methods were chosen as possible ways to lubricate the chosen engine. These are: a Wet Sump, a Dry Sump, and a Direct Oil Application method.

Wet Sump

The standard method of lubrication for 4 stroke cycle engines is the wet sump system. An oil reservoir is located beneath the crankcase, which supplies oil to the oil pump. The pump delivers oil to the main bearings, connecting rod bearings and piston pin through internal passages in the crankshaft and connecting rod (illustrated below). The oil pump also feeds into the camshaft and the valve rocker assembly.
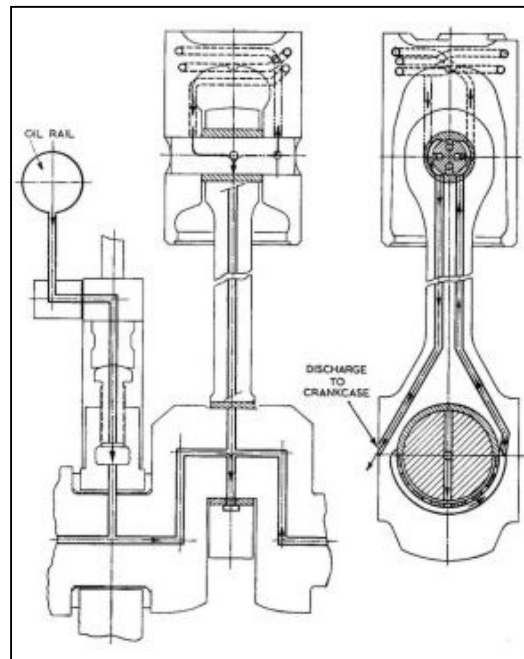


Figure 20. Traditional Lubrication System
(Courtesy of marinediesels.co.uk at
http://www.marinediesels.info/Basics/lubrication_system.htm)

This method would be the most complicated of the three methods because the internal passages that the oil flows through would have to be machined without doing damage to the engine.

Dry Sump

Another method is the Dry Sump, in which the oil that trickles back down into the oil pan
is then pumped into an external reservoir. This system needs an additional displacement
pump to move the oil into the reservoir, which can reduce engine power, but allows for a
smaller oil pan underneath the engine. From the external tank, the lubricant is pumped
out and supplied to the engine in the same manner as the wet sump.

For both of the above options a Sump will have to be added below the engine. An
example of this is seen in the picture below.
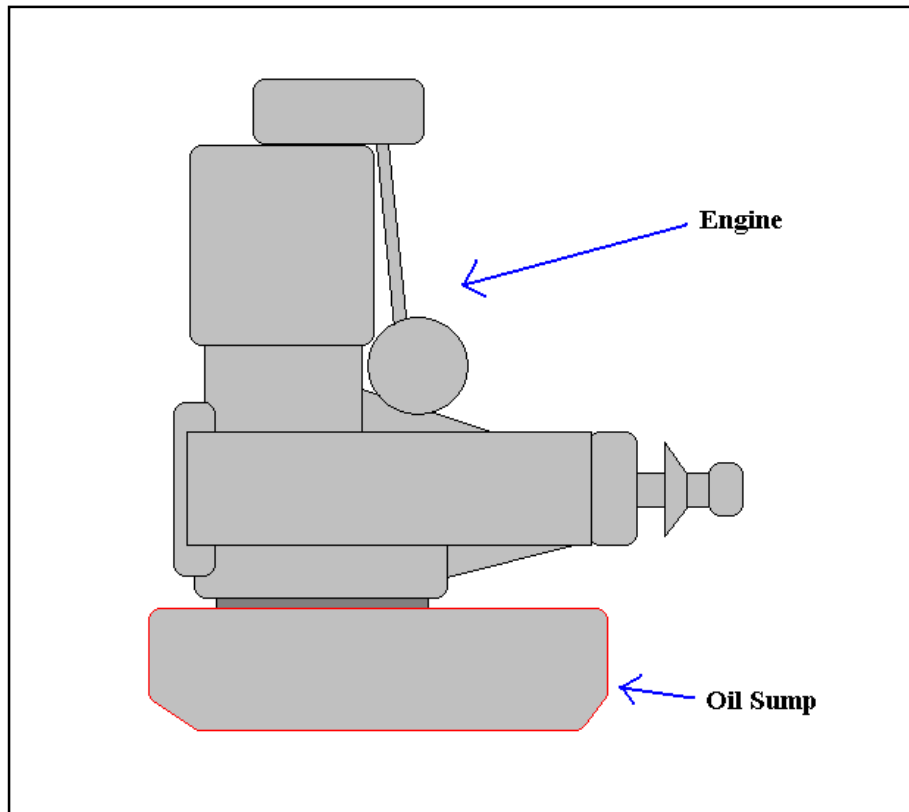


Figure 21. Example of Sump Placement

The sump can be made of thin aluminum and connected back to the top of the engine
through a small oil pump so that the oil will continue to circulate and supply adequate
lubrication.

<u>Direct Oil Application</u>

Due to the small size of the engines that are being used for this project, the two sump methods mentioned above might be too difficult to implement. One way to lubricate the engine without using an oil pump and sump would be to directly apply oil to the engine. This method would involve creating a small inlet into the crankshaft or camshaft and then filling the engine with enough oil to last one or two runs. The engine would then have to be checked after every couple of runs to determine the oil level and to refill if necessary. This method would not be the most efficient method but it would allow lubrication without the risk of permanently damaging the engine. Once the engine has been filled with the proper amount of oil the inlet will be plugged using a durable rubber stopper, or a metal plug with a rubber o-ring. This will prevent the oil from leaking during engine operation.

## 4.5    Piston Cylinder Lining

**Required By: 2-Stroke**

On the Two Stroke R/C engines, the Piston Cylinder is designed so that as the Piston moves up and down it pulls in Fuel from the Crankcase and expels exhaust out the Muffler. It does this through openings in the Piston Cylinder Lining. Since Hydrogen has no lubricating properties, there is no need for it to be allowed into the Crankcase. To stop the piston from pulling fluid in from the Crankcase the Piston Cylinder Lining will need to be sealed up or replaced.
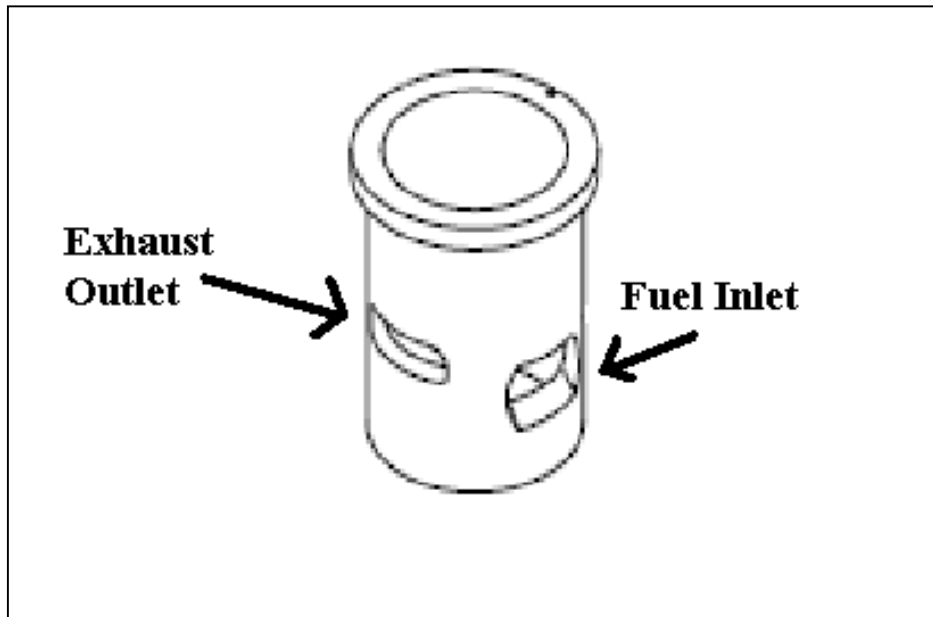


Figure 22. Piston Cylinder Lining

## 4.6    Type of Hydrogen Storage to be Used

Hydrogen is to be the fuel for these engines and needs to be safely supplied to them. There are Three main ways that this can be done.

1) Liquid Hydrogen Storage
2) Gaseous Hydrogen Storage
3) Metal Hydride Storage

Liquid Hydrogen

Liquid Hydrogen would not be very feasible because it would have to be super-cooled. This would require a cooling mechanism as well as insulation, which would add lots of weight as well as cost to the project.
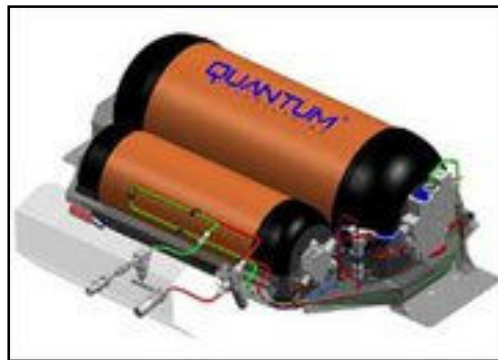


Figure 23. Quantum Technologies Automotive Liquid
Hydrogen Tank

Gaseous Hydrogen

This method involves compressing the Hydrogen in storage tanks. This would be relatively cheap and weigh less than the Liquid Hydrogen storage. It would not require any external devices other than a pressure regulator.



Figure 24. Two Types of High Pressure
Hydrogen Tanks

Metal Hydride Storage

This type of storage uses cylinders that contain a metal hydride powder. This powder absorbs the Gaseous hydrogen and then releases it when the tank is heated. This method is the safest method for Hydrogen storage because if there is a leak the hydrogen does not rapidly shoot out, but instead very slowly disperses as it evaporates out of the metal hydride. These are more expensive though, as well as being slightly heavier than using compressed Hydrogen.
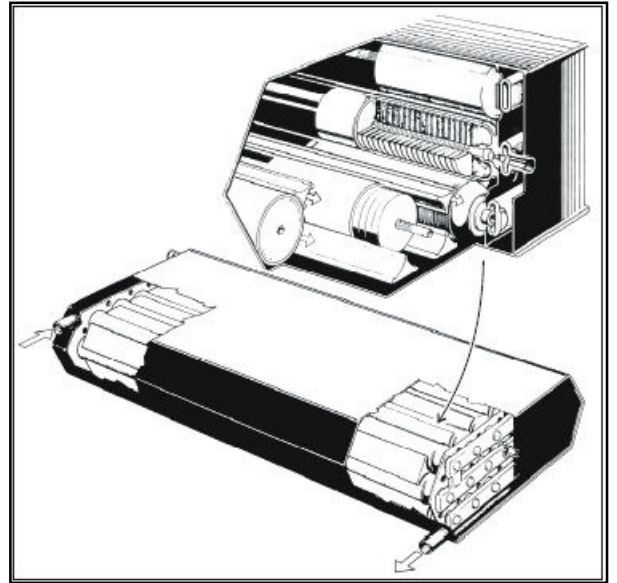


Figure 25. Metal Hydride Vehicle Storage Tank, Sectioned

## 5.0    DESIGN SELECTION

This section describes the selection process that was used when determining which designs to use for the modification of the R/C engine. It also presents the choices made in a Design Matrix format, so that the selection process can be easily understood. In order to make a good choice certain criteria need to be taken into account. In each section the criteria that have been chosen will be explained followed by the Decision Matrix quantifying them. These matrices use a scale from 1 to 5, where 1: Worst and 5: Best. The selected choice will be the item with the highest total score.

### Contents:

## 5.1    Type of Engine to Modify

This decision is an important one, given that the type of engine chosen will ultimately determine what type of modifications are required. Both engines were looked at thoroughly and ran using Nitromethane, so that there operation could be better understood. The criteria that were chosen as a basis for the choice of engine are as follows:

Ease of Modification

This criterion deals with how easy it will be to make the actual modifications on the selected engine. A high score means that the modifications will be relatively easy to perform and a low score means that the modifications will require extensive work.

Power Output

This criterion was included because even though this project is essentially a Proof-of-Concept, the engine should still be able to provide adequate power for an aircraft. When switching to a Hydrogen fuel the power output can change from 25% below to 15% above what the original output is. It is better to start with a higher output engine so that if the power output is reduced it will still have enough power to perform adequately.

Safety

Safety is a major concern. Given Hydrogen's nature if there are any leaks or hot spots it could lead to a serious problem. For the purpose of this decision, the safety aspect deals with how safe the selected engine will be when used with hydrogen. Since the 4-stroke has valves as opposed to the 2-stroke, which merely has openings, it would be a safer choice.

Fuel Efficiency

This criterion was selected because the underlying purpose of this project is to help the environment. An engine that has a better fuel efficiency will have a higher power output while at the same time using up less fuel.

Engine Cost & Proposed Modification Cost

Since this project is on a budget it is necessary for the Cost of the parts to be taken into account when determining which one to modify.

Engine Selection Decision Matrix

(1-5; 1: Worst, 5: Best)

| Engine | Ease of Modifiation | Power Output | Safety | Fuel Efficiency | Engine Cost | Proposed Modification Cost | Total |
|---|---|---|---|---|---|---|---|
| 2-Stroke | 2 | 5 | 3 | 3 | 4 | 2 | 19 |
| 4-Stroke | 4 | 3 | 4 | 4 | 4 | 3 | 22 |

Figure 26

**Decision: The 4-Stroke Engine has been Selected for Modification**

## 5.2    Type of Fuel Delivery System to Use

The Type of Fuel Delivery to use will determine what the power output of the Engine will be. It will also help determine the type of Hydrogen storage that is to be used and the pressure that it needs to be at.

Ease of Addition

This criterion is based on how easy it will be to install the selected Fuel Delivery device as well as how easy it will be to set it up properly. The injectors would have to put the correct amount of fuel in the engine at precisely the right time. To do this an Electronic Control Unit would have to be added. This would increase the difficulty of using those systems on the selected engine.

Proposed Cost

As stated before the Cost of the components is a determining factor due to the limited budget of this project.

Safety

When using different types of Fuel Delivery devices, its safety is its ability to successfully limit Backfire and Pre-ignition. These are two of the major problems encountered when using Hydrogen fueled I.C.E.'s, therefore any method that reduces that risk is a good method to use.

Efficiency

The Efficiency of the Fuel Delivery device is its ability to put Fuel into the combustion chamber at precisely the right time, and in the precise amount required. If this is not done properly the timing of the engine will be thrown off and it will be more susceptible to Pre-ignition and backfire problems.

Fuel Delivery System Decision Matrix

(1-5; 1: Worst, 5: Best)

| Type of Fuel Delivery | Ease of Addition | Proposed Cost | Safety | Efficiency | Total |
|---|---|---|---|---|---|
| Direct Injection | 1 | 1 | 4 | 5 | 11 |
| Port Injection | 2 | 2 | 3 | 3 | 10 |
| Carburetor | 4 | 5 | 2 | 2 | 13 |

Figure 27

**Decision: The Use of a Carburetor has been Chosen as the Means of Fuel Delivery for the Selected Engine.**

## 5.3    Type of Ignition/ Timing Mechanism to Use

The Ignition/ Timing mechanism will regulate the firing of the Spark plug. It is necessary to have an accurate timing and ignition device so that the engine fires exactly when it is supposed to.

Ease of Addition

This criterion deals with how easy it will be to add the timing mechanism to the selected engine. Ultimately the best option will be the one that requires a minimal amount of machining, and can be installed easily.

Proposed Cost

Again cost is an important aspect of every part of this project.

Adjustability

This criterion refers to the ability of the timing mechanism to be adjusted. This is necessary so that it can be fine tuned to match the need of the engine. Depending on what type of fuel delivery system is used as well as the type of the spark plugs, the timing will change. The timing mechanism needs to be easily adjustable so that if any changes are made to the engine it will not require extensive work to set it properly.

Ignition/ Timing Decision Matrix

(1-5; 1: Worst, 5: Best)

| Type of Ignition/Timing | Ease of Addition | Proposed Cost | Adjustablity | Total |
|---|---|---|---|---|
| Mechanical | 1 | 4 | 1 | 6 |
| Electrical | 4 | 2 | 5 | 11 |

Figure 28

**Decision: The Use of an Electrical Timing Device was Chosen as the Best Option for this Project.**

## 5.4    Method of Engine Lubrication

Lubrication is a major aspect of this design project. Without properly lubricating all of the parts of the engine it could seize from extreme temperatures. The engines chosen for this project though, are very small and could prove very difficult to lubricate with a sump and oil pump. A good medium between performance and ease of installation needs to be the basis for the chosen method of lubrication.

Efficiency
The efficiency of the lubrication method is very important. If the engine is not properly lubricated it will get very hot due to friction. This will cause very parts of the engine to seize up, making the engine unusable.

Ease of Modification
As stated above, the small size of these engines would make any extensive modification quite difficult. When the modification is made it needs to be done on a way that will not damage the engine.

Cost
Again, cost is a very important criterion and should be taken into account for every decision that needs to be made.

Lubrication Method Decision Matrix
(1-5; 1: Worst, 5: Best)

| Lubrication Method | Efficiency | Ease of Modification | Cost | Total |
|---|---|---|---|---|
| Wet Sump | 5 | 2 | 2 | 9 |
| Dry Sump | 4 | 2 | 2 | 8 |
| Direct Oil Application | 3 | 5 | 5 | 13 |

Figure 29

**Decision: The chosen method of lubrication is to use the Direct Application Method.**

## 5.5    Type of Hydrogen Storage

The method of Hydrogen storage is very important. Given that the engine being modified is for use on board an R/C aircraft the fuel tank should be lightweight, and be able to carry enough fuel for an adequate period of time. It should also be safe, because it will be containing Hydrogen, which is dangerous.

Safety

Safety is one of the biggest concerns when dealing with Hydrogen fuel. If any leaks develop or if too high of a temperature is present, it could be disastrous. The best method of Hydrogen storage will be one that is safe to operate, allowing for a minimal chance of failure.

Cost

Again, cost is always a deciding factor.

Weight

Weight is also a major concern, because it needs to be light enough to fit on an R/C airplane without reducing its airworthiness.

Hydrogen Storage Decision Matrix
(1-5; 1: Worst, 5: Best)

| Type of Storage | Safety | Cost | Weight | Total |
|---|---|---|---|---|
| Liquid Hydrogen | 3 | 3 | 2 | 8 |
| Gaseous Hydrogen | 2 | 4 | 3 | 9 |
| Metal Hydride | 4 | 1 | 2 | 7 |

Figure 30

**Decision: Gaseous Hydrogen Tanks were Chosen as the Best Option for Storing Hydrogen Fuel.**

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## 6.0    DETAILED DESIGN

In this section all of the choices that have been made concerning the selected engine's modification will be explained further. This will also serve as a guide as to how the device should be assembled and run. These decisions were made after extensive research and are believed to be the best possible setup for this project. Once the engine has been set up it will be run to determine the effectiveness of this setup, whereupon modifications and/or additions will made.

### Contents:

## 6.1    Fuel Inlet

For the purpose of this design it was decided that the use of a carburetor would be the best way to feed Hydrogen into the selected engine. Although this is not the most efficient decision it is the best option given the small size of the R/C engine being used.



Figure 31. Compressed Gas Cylinder

The Hydrogen will be supplied to the engine by a small compressed gas cylinder, such as the one at right, which is available at www.FuelCellStore.com. The hydrogen flows out of the cylinder and through a regulator so that the pressure is decreased to a level that is good for the carburetor. The Hydrogen will flow into the Carburetor through the fuel inlet port on the top. It will then mix with air and be fed into the combustion chamber.

The carburetor sown in the following picture is the one that came with the selected engine. This will be the first Carburetor to be tested with the system, due to the unavailability of small gaseous carburetors. The Carburetor will be tested with a variety of pressures and any modifications that are needed will be made.
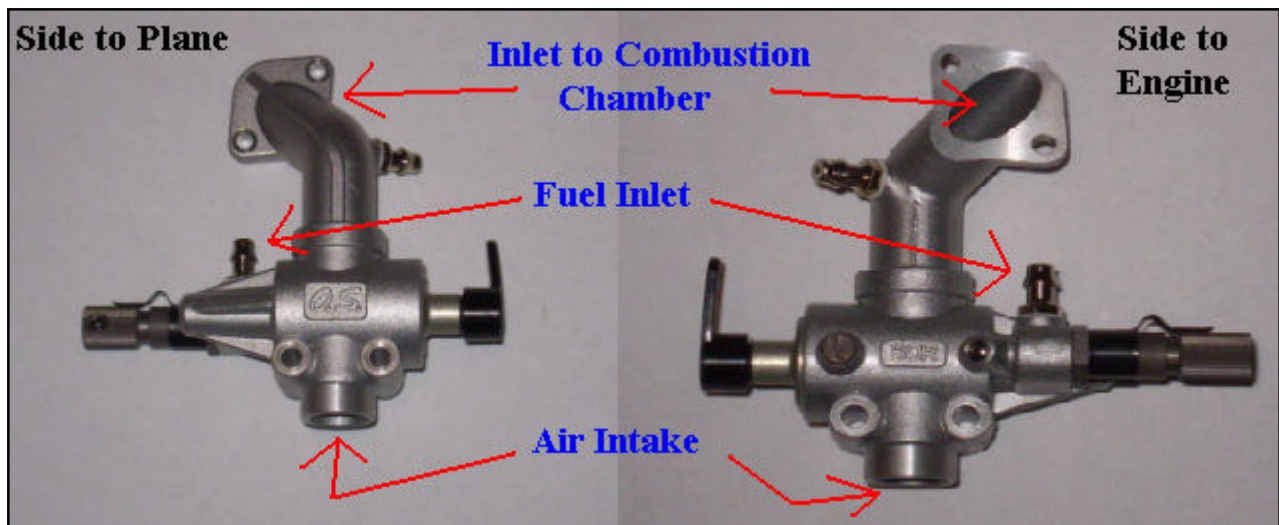


Figure 32. Two Views of the Carburetor Supplied with the Purchased Engine, with Descriptions.

## 6.2    Ignition/Timing Setup

The ignition source for the Spark plug will be supplied via an Electronic Ignition Unit purchased from Copperhead Aviation. This ignition runs on a 4.8V battery. The ignition will supply the spark plug with a charge every time that it is triggered by the Hall Effect sensor. A Hall Effect sensor is a type of sensor that can detect when a magnetic source passes by it. For the purpose of this design the magnet will be installed on the Prop Hub (seen below) and the sensor will be placed in a sensor housing that is secured to the engine. When the Prop Hub rotates, as the engine runs, the magnet will pass under the Hall Effect sensor triggering the ignition module to send a pulse to the spark plug.
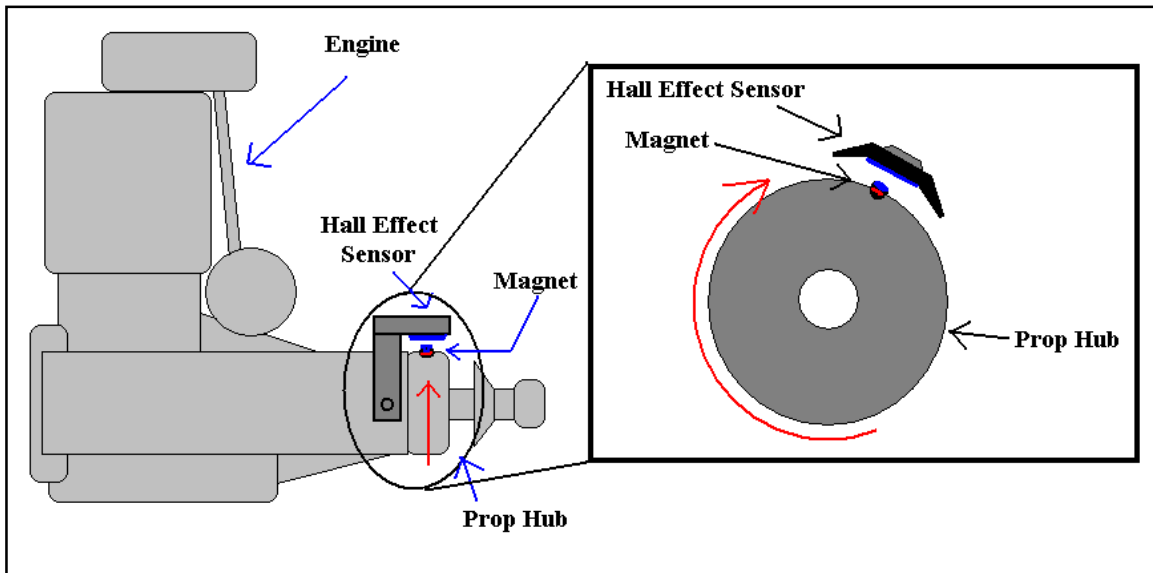


Figure 33. Hall Effect Sensor and Magnet Placement
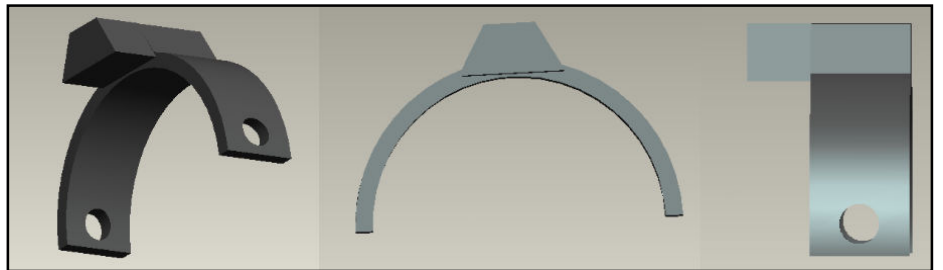




Figure 35. Multiple Views of Hall Effect Sensor Mount

Figure 34. Prop Hub

## 6.3 Lubrication System

Ideally the engine would be able to have a sump system with an oil pump as the lubrication system, however since the engine is so small this was deemed unfeasible. Instead the engine will be lubricated by directly applying oil into the engine through an access port. Every time the engine is done being run it will need to be checked to determine if more oil needs to be added. The temperature of various parts of the engine will also be monitored constantly to ensure that the lubrication system is working. If at any time the engine gets too hot it will be cut off and allowed to cool. It will then be cleaned out and refilled with oil.

The engine will be tested with various amounts of oil to determine the optimal amount needed. Ideally there should be a minimal amount of oil, while still being able to fully lubricate all parts of the engine.

The access port chosen is part of the existing design. There is a blow-by line, which allows fuel that is in the camshaft/crankshaft area to feed back into the inlet so that the pressure does not get to high. The inlet side of the line will be plugged, and the camshaft/crankshaft side will be used as the access port. This was decided as the best option because it did not require drilling into the engine body.
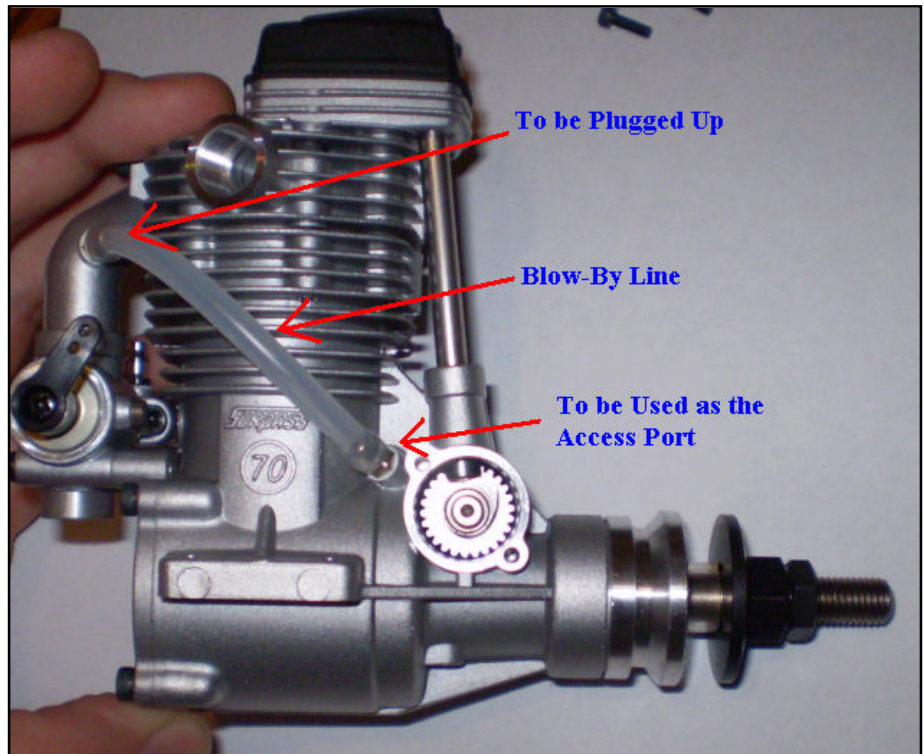


Figure 36. Blow-By Line Detail

## 6.4　Mounting Setup

Once all of the modifications have been made they will need to be setup so that the engine can be run. Many different configurations were thought up, and probably more than one will be used. The first setup was a preliminary drawing to help establish a general layout. The second is a design that is based around the fact that the system is being designed for use on an R/C airplane, so everything should fit into the space that one of these planes would allow.
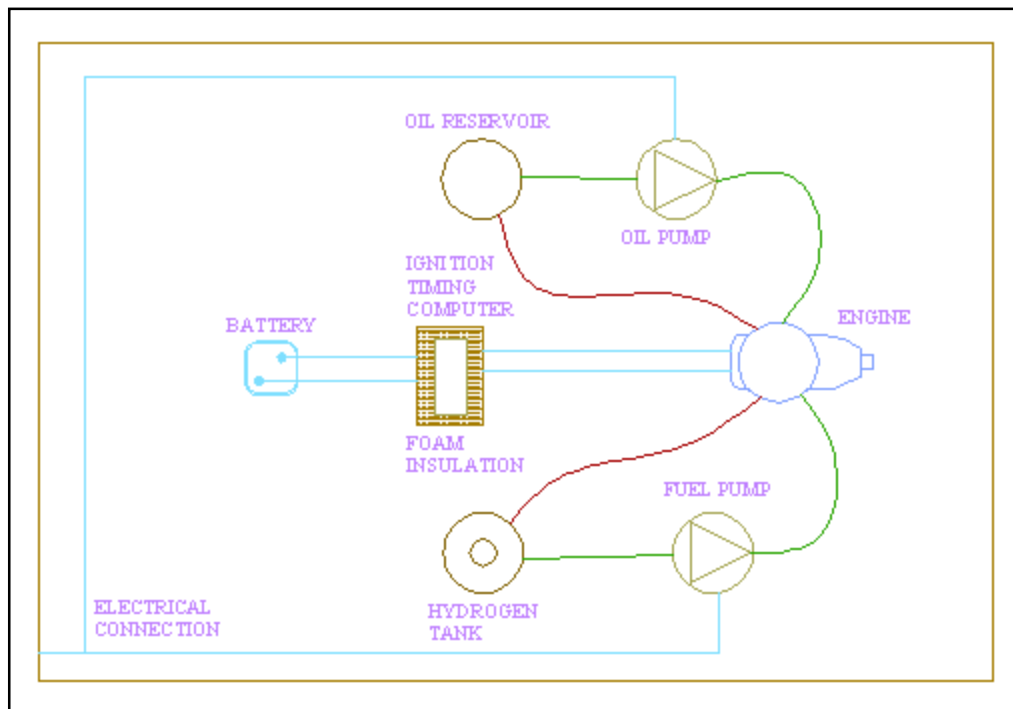
Figure 37. Initial Mounting Setup
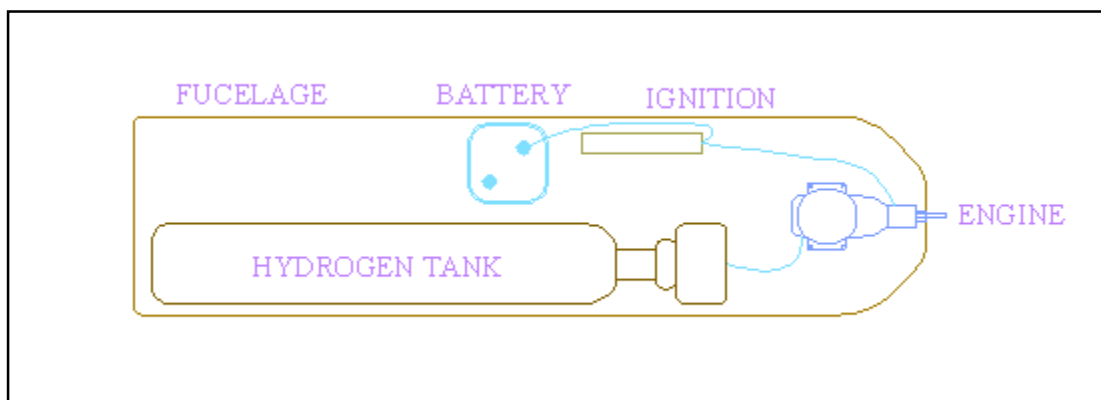
Figure 38. Second Mounting Setup

## 7.0 HYDROGEN SAFETY

The safety of hydrogen is known to be vital to the further development of the hydrogen economy. The development and introduction of hydrogen technologies, as well as the level of public acceptance of hydrogen applications, are presently being constrained by safety barriers. Hydrogen is perceived to be dangerous because it has properties that make its behavior during accidents different from that of most other combustible gases. It may cause material embrittlement and diffuses more easily through many conventional materials used for pipelines and vessels. Gaps that are normally small enough to seal other gases safely are found to leak hydrogen profusely. Unlike other combustible gases, it has a Joule-Thompson inversion temperature (i.e. the temperature leads to warming instead of cooling), which is well below that of many applications involving gaseous hydrogen. This makes hydrogen more inclined to ignition after sudden releases from high-pressure containment. When hydrogen's greatest safety asset, buoyancy, is not properly taken into account in the design of infrastructures and technologies for production, storage, transportation and consumption, it becomes more dangerous than conventional fuels such as gasoline, LPG and natural gas. Fortunately hydrogen has been used with great success for over 50 years in applications ranging from welding beams to launching NASA's shuttles.

Hydrogen safety is the most important function of this design. The benefits of having lower $CO_2$ emissions do not outweigh a higher rate of accidents due to improperly handling hydrogen. When people go about routine work they can develop a relaxed attitude and a dull alertness, which can lead to horrible accidents. One of the root causes of hydrogen related accidents are that people view hydrogen like many other gases they are accustomed to using. Hydrogen simply acts different than other gases in use today. Without informing the inexperienced to the ever-present hazards of dealing with Hydrogen, lethargy and misconceptions deepen and the odds of an accident occurring can increase.

The sudden interest in using hydrogen is caused by the concern of global warming from greenhouse gas concentrations being increased due to human activity. One example is the $CO_2$ emissions given off by gasoline burning engines. If the change was made from

gasoline to hydrogen, they would only produce electricity (fuel cell application), heat, and pure water; noticeably reducing the carbon dioxide emissions

Properties of hydrogen are: it is odorless and tasteless making it very difficult to detect a leak. Its buoyancy, diffusivity, and small molecular size make it difficult to contain and its low radiant heat lowers the possibility of secondary fires. Some of the combustive properties consist of a wide range of flammability limits (4 – 74%), explosion limits (18.3 – 59.0), ignition energy (.02mJ), flame temperature (2045 deg C), and Stoichiometric  air/fuel ratio (29%).

General types of hazards associated with the use of hydrogen can be characterized as physiological (frostbite, respiratory ailment, and asphyxiation), physical (phase changes, component failures, and embrittlement), and chemical (ignition and burning), or a combination of such hazards. The primary hazard is involuntarily producing a flammable or detonable mixture, leading to a fire or detonation. To avoid explosions it is best to avoid leaks inside the system and to the surroundings. Wherein, leaks can occur from deformed seals or gaskets, valve misalignment, or failures of flanges or the equipment. There is also the concern of storage vessel failures, ventilation, purging, vaporization system failure, condensation of air, and hydrogen embrittlement.

The primary safety concern for burning Hydrogen in an R/C engine is premature ignition. With hydrogen's lower ignition energy and wider flammability range premature ignition can occur when the fuel mixture in the combustion chamber becomes ignited before the spark plug ignites the mixture and results in an inefficient rough running engine. This form of premature ignition can be resolved by using a cold-rated spark plug and insuring that the fuel does not enter near the exhaust port (valve). Also if premature ignition occurs near the fuel intake valve and a flame travels back into the induction system it causes backfire conditions. If there is any non-burnt fuel that enters the crankcase through bypassing the piston rings there is a greater probability of it igniting in the crankcase and could be remedied with proper ventilation of the crankcase. When ignition within the crankcase occurs it will be a loud startling noise and the pressure within the crankcase will rise. One good way to protect against this is to use a pressure relief valve to stabilize the pressure. Lean mixtures of hydrogen are hard to ignite despite

its large flammability limits and could cause a misfire in the engine, which increases un-burned fuel and will cause more pollution than expected.

The first concern when dealing with Hydrogen Storage is the tank. Much development has been done over the years in tank development. One of the best tanks being developed right now is a carbon fiber reinforced 10,000psi compressed hydrogen tank that consists of a gas penetration barrier a high molecular weight polymer. The center layer of the tank is a carbon fiber-epoxy resin composite shell that is placed over the liner and acts as the gas pressure load-bearing component of the tank. The outer shell is placed on the tank for impact and damage resistance with a pressure regulator located inside the tank as well as a temperature sensor. Most of today's hydrogen tanks can withstand a drop from 90 ft in the trunk of a car with the only damage being surface marks.

Vaporization system failure occurs in the pipe ventilation system when the vapor build-up in a localized area is not released which can result in a fire or explosion. For example, many countries have building codes that require garages to have ventilation openings near the ground to remove gasoline vapors. As a result, even very slow releases of hydrogen in a poorly ventilated building will inevitably lead to the formation of an explosive mixture, initially at the ceiling-level

A present day comparison of hydrogen vehicles and gasoline vehicles results in shocking information. The storage tank on a gasoline car is nothing but annealed sheet metal and could bend under smaller forces than that of the three layered carbon-fiber reinforced hydrogen tanks. If a leak were started on both vehicles a gasoline engine car would continue to leak fuel until all the fuel has been leaked out, whereas the hydrogen tank would leak for only a short while because of 4 different leak protection devices: pressure release valves, excess flow valves, leak sensors, and fuel flow.

As long as the proper safety devices are implemented there will be no problems using Hydrogen for this project, as well as any other applications. Hydrogen has been safely produced, stored, transported, and used in large amounts in industry by following established standard practices. As long as these methods of production, storage, and use are properly followed, Hydrogen can be a safe fuel for use in many applications, with the added benefit of being completely environmentally friendly.

## 8.0    EXPECTED PERFORMANCE

The proposed design modifications for hydrogen fuel is expected to under perform the purchased engine which is set-up for a Nitromethane/methanol fuel mixture.  For an ideal Otto cycle, the modified engine is expected to produce 8.98% less work per cycle using carbureted hydrogen fuel at wide open throttle assuming both engines run at stoichiometric air-to-fuel ratios (see calculations in Appendix A).  This reduction in work output is due to the fact that hydrogen has a low density and therefore displaces more oxygen in the combustion chamber.  It should be noted that direct injection is the most ideal fuel delivery system for hydrogen since it is injected after the intake valve is closed, allowing more air into the combustion chamber and eliminating backflash through and open intake valve (direct injection can produce 26.9% more work per cycle than the same engine running on the Nitromethane/methanol fuel mixture).  Because of the size of the engines used for R/C airplanes, which are typically the size of a fist with a 25 mm bore, there is no space in the cylinder head to install a fuel injector.

Next semester, the RC engine that was selected for modification will be tested on a dynamometer to measure the rotational speed and torque before and after the modification to examine actual performance results.  The expected results were obtained from calculations for an ideal Otto cycle with the respective fuel properties and delivery method, but factors such as

timing loss will affect the actual results due to the difference in the fuel properties.  The Otto cycle assumes that the heat release from the fuel is instantaneous, but in the actual cycle there is a loss in work output because this process is not instantaneous, known as time loss (indicated on the figure at right).
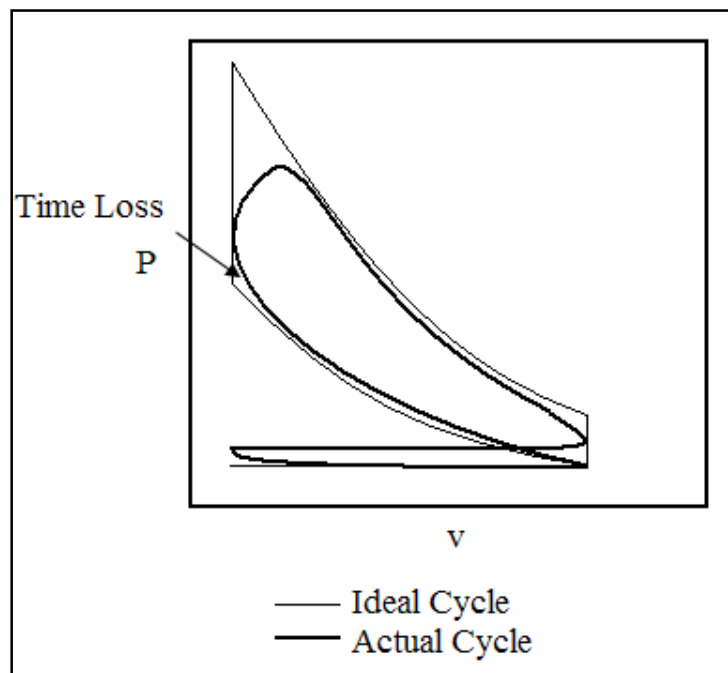


Figure 39. PV Diagram for Ideal Otto Cycle and Actual Cycle

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This factor is important because hydrogen has a relatively fast flame speed (3.24 to 4.4 m/s compared to 0.43 m/s for methanol) at stoichiometric mixtures, which will reduce the time loss and performance margin (Gasoline FAQ – Part 4 of 4).
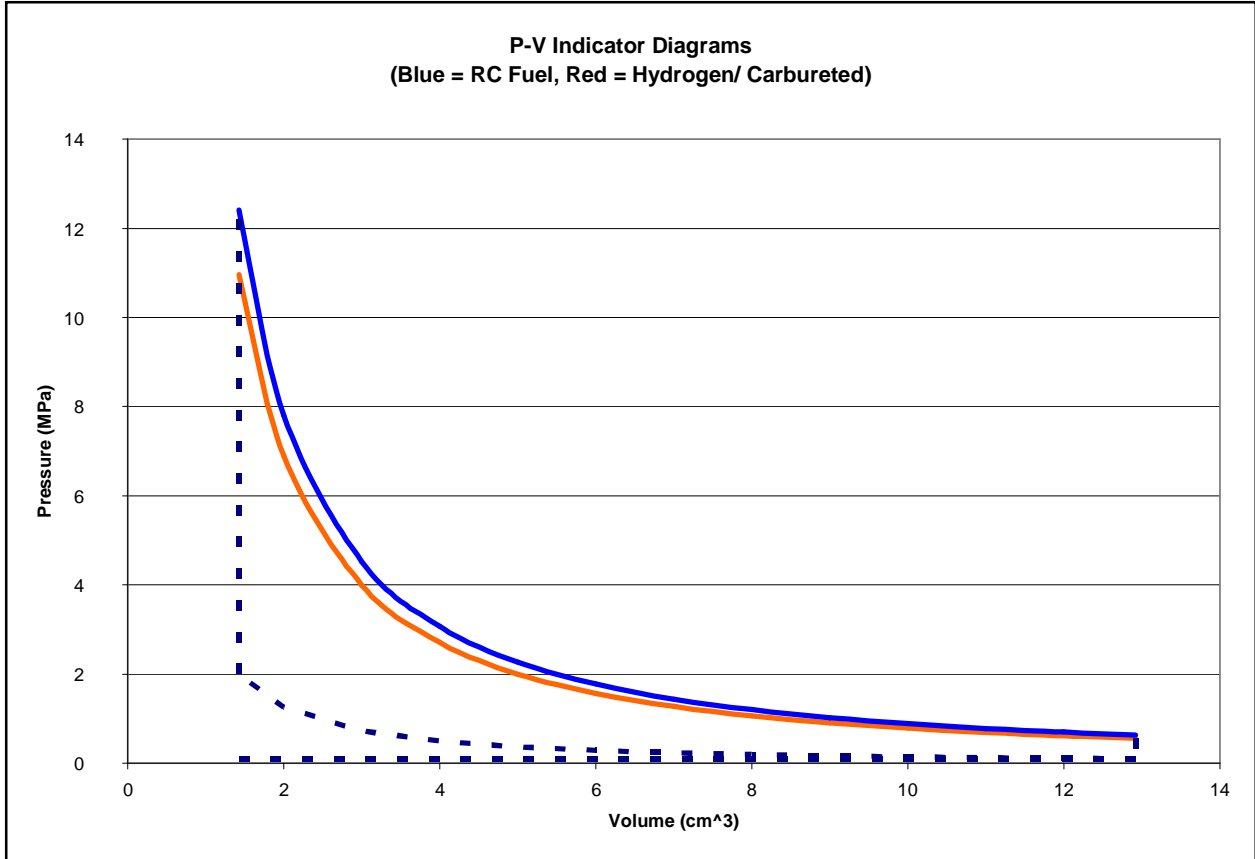


Figure 40.

## 9.0    REFERENCES

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**APPENDICES**

**Appendix A – Calculations**

**Appendix B – Product Manuals**
      **B.1 – R/C Engine Manual**
      **B.2 – Ignition/Timing Mechanism Manual**

**Appendix C - Budget**

**Appendix D –Previous Design Project**

**Known:**

| | |
|---|---|
| Displacement Volume: | $V_d := 11.5 \text{cm}^3$ |
| Density of Hydrogen: | $\rho_H := 0.08376 \dfrac{\text{kg}}{\text{m}^3}$ |
| Lower Heating Value of Hydrogen: | $Q_{HV} := 119.93 \dfrac{\text{KJ}}{\text{gm}}$ |

**Assumptions:**

| | |
|---|---|
| Constant Volume Specific Heat of Air: | $c_v := 0.821 \dfrac{\text{kJ}}{\text{kg}\cdot\text{K}}$ |
| Ratio of Specific Heats: | $\gamma := 1.35$ |
| Air inlet temperature: | $T_i := 300\text{K}$ |
| Air inlet pressure: | $P_i := 1\text{atm}$ |

Assuming that there is no pressure loss in the intake flow when operating at wide open throttle (the engine selected has a short intake manifold, so the frictional losses in the flow are assumed to be low), then the pressure at the start of compression ($P_1$) is equal to the pressure at the inlet:

$$P_1 := P_i$$

$$T_1 := T_i$$

For the ideal otto cycle, compression and expansion are both isentropic processes, where:

$$P_1 \cdot v_1{}^\gamma = P_2 \cdot v_2{}^\gamma \qquad \text{and} \qquad T_1 \cdot v_1{}^{\gamma-1} = T_2 \cdot v_2{}^{\gamma-1}$$

The pressure at P2 is:

$$P_2 = P_1 \cdot \left(\frac{v_1}{v_2}\right)^\gamma$$

$- v_1$ is at bottom dead center (BDC) while $v_2$ is at top dead center (TDC), so $v_1/v_2$ is equal to the compression ratio $r_c$.

$$r_c := 9.1$$

- The manual that came with the 4 stroke engine that was chosen (O.S. Engines FS 70 II Surpass) for the conversion does not specify the compression ratio. An email reply from the distributor stated that the typical compression ratio for their engines was 9.1

$$P_2 := P_1 \cdot r_c{}^\gamma$$

$$P_2 = 1.997\,\text{MPa}$$

$T_2 := T_1 \cdot r_c{}^{\gamma-1}$

$T_2 = 649.809 \text{ K}$

For the ideal otto cycle, the fuel is ignited and burned instantaneously at TDC after the compression stroke (at a constant volume). The tempurature after combustion, $T_3$, can be found.

$m_f \cdot Q_{HV} = m_m \cdot c_v \cdot (T_3 - T_2)$      Where $m_f$ is the mass of fuel (hydrogen) and $m_m$ is the mass of the air-fuel mixture. The mass of the mixture can be found since it is an ideal gas.

$P \cdot V = m \cdot R \cdot T$      $R := \gamma \cdot c_v - c_v$      $R = 0.287 \dfrac{\text{kJ}}{\text{kg} \cdot \text{K}}$

The volume at BDC is:      $V_c + V_d = V_{BDC} = V_1$      $r_c = \dfrac{V_c + V_d}{V_c} = 1 + \dfrac{V_d}{V_c}$

$V_1 := \dfrac{V_d}{r_c - 1} + V_d$      $V_c := \dfrac{V_d}{r_c - 1}$

$V_1 = 12.92 \text{ cm}^3$

The mass of the air-fuel mixture is:

$m_{air} := \dfrac{P_1 \cdot V_1}{R \cdot T_1}$

$m_{air} = 1.519 \times 10^{-5} \text{ kg}$

For direct injection fuel delivery, only air is present in the chamber at the end of the intake stroke . After the intake valve is closed, hydrogen is injected into the chamber during the compression stroke.

**Directed Injection:**

For a stoichiometric mix the air-to-fuel ratio is      $AF := 34$

$m_{hydrogen} := \dfrac{m_{air}}{AF}$      $m_{hydrogen} = 4.466 \times 10^{-7} \text{ kg}$

$T_{3DI} := \dfrac{m_{hydrogen} \cdot Q_{HV}}{(m_{air} + m_{hydrogen}) \cdot c_v} + T_2$

$T_{3DI} = 4.823 \times 10^3 \text{ K}$

$P_{3DI} := \dfrac{(m_{air} + m_{hydrogen}) \cdot R \cdot T_{3DI}}{V_c}$      At point 3, the chamber volume is the clearance volume, $V_c$, since the piston is still at TDC.

$P_{3DI} = 15.261 \, \text{MPa}$

The power stroke (process from 3 to 4) is isentropic for the ideal otto cycle.

$$T_{4DI} := T_{3DI} \cdot \left( \frac{1}{r_c} \right)^{\gamma - 1}$$

$T_{4DI} = 2.227 \times 10^3 \, \text{K}$

$$P_{4DI} := P_{3DI} \cdot \left( \frac{1}{r_c} \right)^{\gamma}$$

$P_{4DI} = 774.246 \, \text{kPa}$

For a gaseous pre-mixed solution (air-fuel mixture enters during intake stroke), the mass of air and the mass of hydrogen can be found knowing that hydrogen occupies 29.6 % of the chamber volume at stoichiometric air-to-fuel mixture (http://www1.eere.energy.gov/hydrogenandfuelcells/tech_validation/pdfs/fcm03r0.pdf).

$V_{hydrogen} := 29.6\% \cdot V_1$ $\qquad$ $m_h := \rho_H \cdot V_{hydrogen}$ $\qquad$ $m_h = 3.203 \times 10^{-7} \, \text{kg}$

$V_{air} := (100\% - 29.6\%) \cdot V_1$ $\qquad$ $m_a := 1.207 \, \frac{\text{kg}}{\text{m}^3} \cdot V_{air}$ $\qquad$ $m_a = 1.098 \times 10^{-5} \, \text{kg}$

**Carborated or Port Injection:**

$$T_{3PI} := \frac{m_h \cdot Q_{HV}}{(m_a + m_h) \cdot c_v} + T_2$$ $\qquad$ $$P_{3PI} := \frac{(m_a + m_h) \cdot R \cdot T_{3PI}}{V_c}$$

$T_{3PI} = 4.791 \times 10^3 \, \text{K}$ $\qquad$ $P_{3PI} = 10.956 \, \text{MPa}$

Isentropic expansion from 3 to 4:

$$T_{4PI} := T_{3PI} \cdot \left( \frac{1}{r_c} \right)^{\gamma - 1}$$ $\qquad$ $$P_{4PI} := P_{3PI} \cdot \left( \frac{1}{r_c} \right)^{\gamma}$$

$T_{4PI} = 2.212 \times 10^3 \, \text{K}$ $\qquad$ $P_{4PI} = 555.851 \, \text{kPa}$

**Ideal Net Work for Direct Injection:**

$$W_{netDI} = W_{3to4} - W_{1to2}$$

$$W_{netDI} := \left(m_{air} + m_{hydrogen}\right) \cdot \left[\frac{R \cdot \left(T_{4DI} - T_{3DI}\right)}{1 - \gamma} + \frac{R \cdot \left(T_2 - T_1\right)}{1 - \gamma}\right]$$

$$W_{netDI} = 28.836\,J$$

**Ideal Net Work for Carborated or Port Injection:**

$$W_{netPI} := \left(m_a + m_h\right) \cdot \left[\frac{R \cdot \left(T_{4PI} - T_{3PI}\right)}{1 - \gamma} + \frac{R \cdot \left(T_2 - T_1\right)}{1 - \gamma}\right]$$

$$W_{netPI} = 20.68\,J$$

$$\%difference := \frac{W_{netDI} - W_{netPI}}{W_{netPI}}$$

$\%difference = 39.437\,\%$      Direct Injection has the potential to increase the amount of net work per cycle by 39.437% over a carborated fuel delivery system.

$Q_{inDI} := m_{hydrogen} \cdot Q_{HV}$      $Q_{inDI} = 53.566\,J$

$Q_{inPI} := m_h \cdot Q_{HV}$      $Q_{inPI} = 38.416\,J$

$$\frac{W_{netDI}}{Q_{inDI}} = 0.538 \qquad\qquad \frac{W_{netPI}}{Q_{inPI}} = 0.538$$

$\dfrac{m_{hydrogen} - m_h}{m_h} = 39.437\,\%$      Likewise, 39.437% more hydrogen is required per cycle for stoichiometric direct injection.

The intended fuel for the engine selected is a nitromethane and methanol mixture. The stoichiometric air-to-fuel ratio and lower heating value for varying mixtures can be found on page 24( of "Analysis of combustion in a small homogeneous charge compression assisted ignition engine" by H. Ma, K. Kar, R. Stone, and H. Thorwarth (http://www.eng.ox.ac.uk/ice/papers/IJERSmallEnginePaper.pdf). The intended fuel is a 10% nitromethane mixture,

Lower Heating Value of Methanol:
$$Q_{HVmethanol} := 19.6 \frac{MJ}{kg}$$

LHV multiplier at 10% nitromethane:
$$a := 0.96$$

Stoichiometric air-to-fuel ratio at 10% nitromethane:
$$AF_{rcfuel} := 5.77$$

Lower Heating value of rc fuel mixture:

$$Q_{HVrcfuel} := a \cdot Q_{HVmethanol} \qquad Q_{HVrcfuel} = 18.816 \frac{MJ}{kg}$$

The temperatures and pressures are the same as those calculated for the hydrogen fuel at the start and end of compression (points 1 and 2) because the fuel has not been yet been ignited.

$$T_1 = 300\,K \qquad\qquad P_1 = 101.325\,kPa$$

$$T_2 = 649.809\,K \qquad\qquad P_2 = 1.997\,MPa$$

Knowing that $m_{fuel} \cdot Q_{HV} = m_{mixture} \cdot c_v \cdot (T_3 - T_2)$ $T_3$ can be calculated.

$$m_{mixture} = m_{air} + m_{fuel} \qquad\qquad AF = \frac{m_{fuel}}{m_{air}}$$

$$\frac{m_{mixture}}{m_{fuel}} = AF + 1 \qquad\qquad m_m := \frac{P_1 \cdot V_1}{R \cdot T_1}$$

$$Q_{HVrcfuel} = (AF + 1) \cdot c_v \cdot (T_3 - T_2)$$

$$T_{3rcfuel} := \frac{Q_{HVrcfuel}}{(AF_{rcfuel} + 1) \cdot c_v} + T_2 \qquad\qquad P_{3rcfuel} := \frac{m_m \cdot R \cdot T_{3rcfuel}}{V_c}$$

$$T_{3rcfuel} = 4.035 \times 10^3\,K \qquad\qquad P_{3rcfuel} = 12.402\,MPa$$

As explained before, the expansion process is ideally isentropic, so:

$$T_{4rcfuel} := T_{3rcfuel} \cdot \left(\frac{1}{r_c}\right)^{\gamma-1} \qquad\qquad P_{4rcfuel} := P_{3rcfuel} \cdot \left(\frac{1}{r_c}\right)^{\gamma}$$

$$T_{4rcfuel} = 1.863 \times 10^3 \, K \qquad\qquad P_{4rcfuel} = 0.629 \, MPa$$

Net Indicated Work per Cycle:

$$W_{netrcfuel} = W_{3to4} - W_{1to2}$$

$$W_{netrcfuel} := m_m \cdot \left[ \frac{R \cdot (T_{4rcfuel} - T_{3rcfuel})}{1 - \gamma} + \frac{R \cdot (T_2 - T_1)}{1 - \gamma} \right]$$

Ideal Net Work per Cycle:

RC Fuel Blend: $\qquad\qquad\qquad\qquad\qquad\qquad\qquad W_{netrcfuel} = 22.721 \, J$

Carborated Hydrogen Fuel Delivery: $\qquad\qquad\qquad W_{netPI} = 20.68 \, J$

Direct Injection Hydrogen Fuel Delivery: $\qquad\qquad W_{netDI} = 28.836 \, J$

These values are for ideal net work (before mechanical losses), which provides the maximum expected performance of the engine. The real cycle will have losses in timing (fuel does not burn instantaneously at a constant volume), heat loss to the cylinder walls and exhaust blowdown loss (exhaust valve starts opening before bottom dead center causing a pressure drop toward atmospheric pressure). Though the values are the absolute maximum possible for the assumptions made at wide open throttle and the actual indicated work (as seen at the cylinder before mechanical losses) will be lower, they provide a good estimate of how each fuel or method will perform in comparison to one another. As decided earlier, direct injection of hydrogen into the cylinder after the intake stroke will provide more work per cycle than a carbureted hydrogen engine of the same characteristics (found to produce 39.4% more work than the carbureted system for an ideal cycle at stoichiometric mixtures). The direct injection method is also expected to perform better than the than the same engine with the current RC fuel blend set-up (nitromethane and methanol blend) by up to 26.9%. The carbureted hydrogen system would be expected to have a 8.98% reduction in ideal work per cycle.

## PRODUCT MANUALS

The following pages are the product manuals for the main components that were purchased for this project. The first is the manual for the 4-stroke engine that was purchased. It was bought from www.TowerHobbies.com. The second manual is for the electronic ignition and timing mechanism. It was purchased from Copperhead Aviation.

# O.S.ENGINE   FS-70SⅡ, 91SⅡ & FS-91SⅡ-P

## FOUR CYCLE ENGINE
## OWNER'S INSTRUCTION MANUAL

It is of vital importance, before attempting to operate your engine, to read the general **'SAFETY INSTRUCTIONS AND WARNINGS'** section on pages 2-4 of this booklet and to strictly adhere to the advice contained therein.

● Also, please study the entire contents of this instruction manual, so as to familiarize yourself with the controls and other features of the engine.

● Keep these instructions in a safe place so that you may readily refer to them whenever necessary.

● It is suggested that any instructions supplied with the aircraft, radio control equipment, etc., are accessible for checking at the same time.
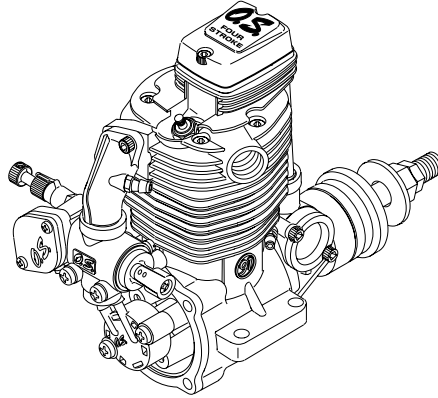
# CONTENTS

# SAFETY INSTRUCTIONS AND WARNINGS ABOUT YOUR O.S. ENGINE

Remember that your engine is not a " toy ", but a highly efficient internal-combustion machine whose power is capable of harming you, or others, if it is misused or abused. As owner, you, alone, are responsible for the safe operation of your engine, so act with discretion and care at all times.

If at some future date, your O.S. engine is acquired by another person, we would respectfully request that these instructions are also passed on to its new owner.

■ The advice which follows is grouped under two headings according to the degree of damage or danger which might arise through misuse or neglect.

## ⚠ WARNINGS

These cover events which might involve serious ( in extreme circumstances, even fatal ) injury.

## ⚠ NOTES

These cover the many other possibilities, generally less obvious sources of danger, but which, under certain circumstances, may also cause damage or injury.

## ⚠ WARNINGS

● Never touch, or allow any object to come into contact with, the rotating propeller and do not crouch over the engine when it is running.

● A weakened or loose propeller may disintegrate or be thrown off and, since propeller tip speeds with powerful engines may exceed 600 feet(180 metres) per second, it will be understood that such a failure could result in serious injury, (see 'NOTES' section relating to propeller safety).

● Model engine fuel is poisonous. Do not allow it to come into contact with the eyes or mouth. Always store it in a clearly marked container and out of the reach of children.

● Model engine fuel is also highly flammable. Keep it away from an open flame, excessive heat, sources of sparks, or anything else which might ignite it. Do not smoke or allow anyone else to smoke, near to it.

● Never operate your engine in an enclosed space. Model engines, like automobile engines, exhaust deadly carbon-monoxide. Run your engine only in an open area.

● Model engines generate considerable heat. Do not touch any part of your engine until it has cooled. Contact with the muffler(silencer), cylinder head or exhaust header pipe, in particular, may result in a serious burn.

## ⚠ NOTES

● This engine was designed for model aircraft. Do not attempt to use it for any other purpose.

● Mount the engine in your model securely, following the manufacturers' recommendations, using appropriate screws and locknuts.

● Be sure to use the silencer (muffler) supplied with the engine. Frequent exposure to an open exhaust may eventually impair your hearing.
Such noise is also likely to cause annoyance to others over a wide area.

● Fit a top-quality propeller of the diameter and pitch specified for the engine and aircraft. Locate the propeller on the shaft so that the curved face of the blades faces forward-i.e. in the direction of flight. Firmly tighten the propeller nut, using the correct size wrench.

● Always check the tightness of the propeller nut and retighten it, if necessary, before restarting the engine, particularly in the case of four-stroke-cycle engines. A safety locknut assembly is provided. Always use it. This will prevent the propeller from flying off in the event of a "backfire", even if it loosens.

● If you fit a spinner, make sure that it is a precision made product and that the slots for the propeller blades do not cut into the blade roots and weaken them.

● Discard any propeller which has become split, cracked, nicked or otherwise rendered unsafe. Never attempt to repair such a propeller: destroy it. Do not modify a propeller in any way, unless you are highly experienced in tuning propellers for specialized competition work such as pylon-racing.

● Use an electric starter for this engine. The wearing of safety glasses is also strongly recommended.

# ⚠ NOTES

- Take care that the glow plug clip or battery leads do not come into contact with the propeller.
  Also check the linkage to the throttle arm. A disconnected linkage could also foul the propeller.

- After starting the engine, carry out any needle-valve readjustments from a safe position behind the rotating propeller. Stop the engine before attempting to make other adjustments to the carburettor.

- Adjust the throttle linkage so that the engine stops when the throttle stick and trim lever on the transmitter are fully retarded. Alternatively, the engine may be stopped by cutting off the fuel supply. Never try to stop the engine physically.

- Take care that loose clothing (ties, shirt sleeves, scarves, etc.) do not come into contact with the propeller.
  Do not carry loose objects (such as pencils, screwdrivers, etc.) in a shirt pocket from where they could fall through the propeller arc.

- Do not start your engine in an area containing loose gravel or sand. The propeller may throw such material in your face and eyes and cause injury.

- For their safety, keep all onlookers (especially small children) well back (at least 20 feet or 6 meters) when preparing your model for flight. If you have to carry the model to the take-off point with the engine running, be especially cautious. Keep the propeller pointed away from you and walk well clear of spectators.

- Warning! Immediately after a glowplug-ignition engine has been run and is still warm, conditions sometimes exist whereby it is just possible for the engine to abruptly restart if the propeller is casually flipped over compression WITHOUT the glowplug battery being reconnected. Remember this if you wish to avoid the risk of a painfully rapped knuckle!

## INTRODUCTION

The O.S. FS-70SⅡ, FS-91SⅡ and FS-91SⅡ-P are built, like all O.S. engines, to the highest engineering standards, by a company that was established in 1936 to manufacture 2-stroke engines and which pioneered the production of four-stroke-cycle model aircraft engines 40 years later.

The FS-91SⅡ-P is fitted with the new O.S. PD-07 diaphragm type fuel pump and matching Type 60N carburettor incorporating a built-in pressure regulator. These features ensure that fuel/air mixture strength is maintained at a constant level through maneuvers, for consistent performance and reliable throttle response.

In the interests of improved durability, certain steel parts that are particularly susceptible to corrosion in four-stroke engines, have a corrosion resistant plating and, for the same reason, a special grease-packed twin-sealed rear ball-bearing is used.

To maintain the four-stroke engine's reduced noise levels, the FS-70SⅡ, FS-91SⅡ and FS-91SⅡ-P are supplied with an O.S. Type F-4020 baffled silencer (muffler) of substantially enlarged volume, as standard equipment. Where installation calls for a separate exhaust pipe and silencer, these parts are available as optional extras.

## INSTALLING THE GLOW PLUG

Carefully insert plug, with washer, fingertight only, before final tightening with the correct size plug wrench.

Glow plug
Washer

FS-91SⅡ-P

Rocker Cover
Glow plug Type F
Cylinder Head
Push Rod Cover
Propeller Washer
Propeller Nut
Lock Nut
Drive Hub
Carburettor Type 60N
Cover Plate
Crankcase
Beam Mount
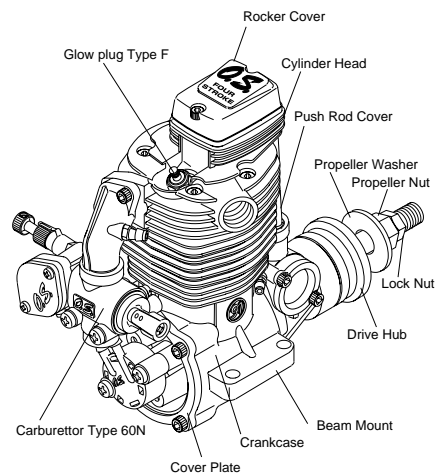
## RELOCATION OF CARBURETTOR CONTROLS

As supplied, the FS-70SⅡ, FS-91SⅡ and FS-91SⅡ-P have their throttle lever on the right hand side and needle-valve control on the left. However, where more convenient for certain installations, these positions may be reversed after rotating the carburettor through 180˚ horizontally.

Proceed as follows:

1. Remove the intake pipe mounting screws from the cylinder head (taking care not to lose the flange gasket [91SⅡ/91SⅡ-P] ) and the carburettor mounting screws from the crankcase cover plate bracket.

2. Detach short tube connecting carburettor to pump unit (FS-91SⅡ-P) and gently rotate the carburettor through 180° without separating it from the intake pipe or removing the enclosed O-ring seal.

3. Re-install the complete sub-assembly of intake pipe and carburettor, making sure that adjoining surfaces are clean. Tighten screws evenly and firmly but not excessively.

4. Remove pump mounting screws from the crankcase cover plate lugs, carefully rotate the pump clockwise one-quarter turn and attach it to the second pair of lugs provided, taking care that the central tube connecting the crank chamber to the pump diaphragm chamber is not twisted.

5. Finally, make sure that all external tube connections are secure and do not leak.

### FS-91SⅡ-P



- Intake Pipe Mounting Screw
- Intake Pipe
- Needle Valve
- Pressure Regulator
- Carburettor Mounting Screw
- Fuel Inlet
- Pump Fixing Screw
- PD-07 Pump
- Throttle Lever

## FUEL TANK

A fuel tank of approximately 300cc capacity is suggested. This allows up to 12-13 minutes flying time, dependent upon the type of fuel used, the size of the propeller and on the proportion of full-throttle to part-throttle operation through the flight. Make sure that the tank is well rinsed out with methanol or glow fuel before installation and that the pickup weight is well clear of the bottom of the tank when held vertically (see sketch). To prevent the pickup from adhering to the tank wall under suction and restricting fuel flow, slots may be filed in the end of the weight as shown. Alternatively, a Bubbless type weight (Code No. 71531000) may be used.



- For filling or emptying tank
- Air vent
- Use thick-walled sillcone tubing
- To fuel inlet
- 10~15mm

## INSTALLATION

Because these are powerful, large-displacement, single-cylinder four-stroke-cycle engines, it is essential to use very substantial engine mounting. Conventional wooden mounting beams should be of rigid hardwood and of at least 15mm or 5/8-in square section.

Make sure that these mounting beams are accurately aligned and firmly integrated with the airframe, reinforcing the adjacent structure to absorb vibration. 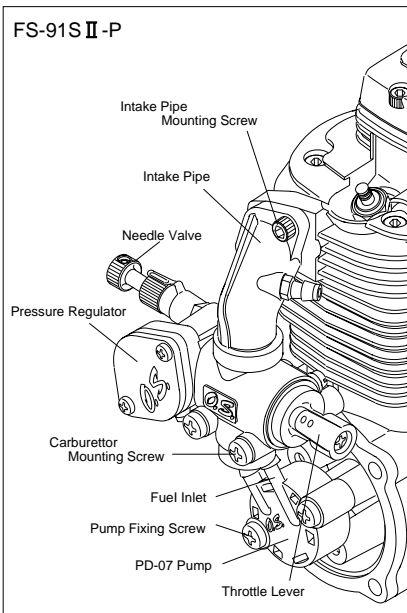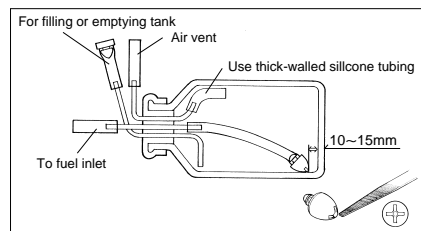Use 3.5mm or larger steel screws, preferably Allen type hexagon socket head cap screws, with washers and locknuts, for bolting the engine to the bearers.

As an alternative to wooden beam mounting, a special O.S. cast aluminium radial motor mount, complete with 3.5mm mounting screws, is available as an optional extra part, where front bulkhead (firewall) type mounting is called for. Engine installation should, in any case, be made in such a way that basic maintenance can be conveniently carried out.

**Make sure that the mounting beams are parallel and that their top surfaces are in the same plane.**



CORRECT — INCORRECT
- Front view
- Side view
- Top surfaces are in the same plane.
- Top surfaces are not in the same plane.
- Re-align the surfaces as necessary
- Opposite beam
- Top surfaces are not in the same plane.
- **Engine does not rest firmly.**
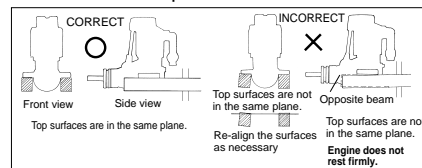
**How to fasten the mounting screws.**



- Tighten second nut firmly down onto first nut.
- 3.5mm steel nuts
- Spring washer or lock washer
- Tighten this nut first.
- 15mm min.
- 15mm min.
- Hardwood such as cherry or maple.
- Steel washer
- 4mm steel screw
- **Hardwood mounting beams**
- 3.5mm steel Allen screw
- Spring washer
- **O.S. radial motor mount (cast aluminum)**
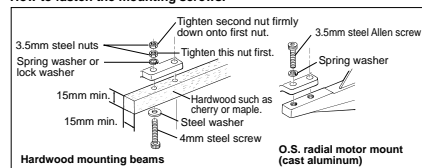
## EXHAUST HEADER PIPE & SILENCER

Fit these in the following sequence.
Screw the header pipe into the cylinder head until it " bottoms ", then unscrew sufficiently to achieve the desired exhaust angle and tighten the locknut securely with a 14mm wrench.
Screw the silencer onto the outer end of the header pipe and tighten the other locknut.
The application of a heatproof silicone sealant to the threads of the exhaust system is recommended to reduce the risk of joints loosening and the leakage of exhaust gases and oil residue.

**Reminder:**
**Model engines generate considerable heat and contact with the header pipe or silencer may result in a serious burn.**
**If you need to tighten the silencer joints, which may loosen when they are hot, use a thick folded cloth for protection.**

## THROTTLE LINKAGE

Before connecting the throttle to its servo, make sure that the throttle arm and linkage safely clear any adjacent part of the airframe structure, etc., as the throttle is opened and closed.
Connect the linkage so that the throttle is fully closed when the transmitter throttle stick and its trim lever are at their lowest settings and fully open when the throttle stick is in its fully-open position..
Carefully align the appropriate holes in the throttle arm and servo horn so that they move symmetrically and smoothly through their full travel.

## NEEDLE-VALVE EXTENSION

The needle-valve supplied with this engine is designed to accept an extension so that, when the engine is enclosed in a cowling, the needle-valve may be adjusted from the outside.
An L-shaped rod, of appropriate length, may be inserted in the needle-valve knob centre hole and secured by tightening the set-screw with a 1.5mm Allen key.

## FUEL LINES
### 〈FS-70SⅡ, FS-91SⅡ〉

For fuel line, use, heavy-duty silicone-rubber tubing of approximately 2.5mm inside and 5.0mm outside diameter.

It is advisable to fasten connections with tube clips or secure binding.

**Note: Be sure to use a muffler-pressurized fuel feed system.**

### 〈FS-91SⅡ-P〉

The function of the various tubes connected to the engine and tank (see sketch) are as follows:

**Pipe A:** To draw fuel from tank to pump nipple marked 'IN'.

**Pipe B:** To deliver fuel from pump nipple marked 'OUT' to carburettor.

**Pipe C:** To connect crankcase breather nipple (behind camshaft housing) to intake pipe.

**Pipe D:** To deliver crankcase pressure pulses to pump diaphragm.

**Important**

**Pipes B, C and D are already installed when the engine is shipped from the factory. If any of these pipes should need to be replaced, due to damage or installation problems, be sure to use tubing of the same dimensions and quality as the originals.**

For Pipe A (tank to pump) use similar heavy-duty silicone-rubber tubing of approximately 2.5mm bore and 5.0mm outside diameter.

**Note: Since the FS-91SⅡ-P has a positively pumped fuel supply, it does NOT require muffler pressurization.**



Make sure there is adequate ventilation.
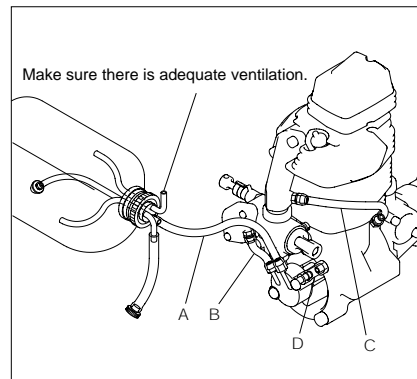
## CARE OF FUEL PUMP & REGULATOR
### 〈FS-91SⅡ-P〉

A short preliminary period of part-throttle running is required to ensure that the pump system functions correctly during the running-in process. Set the throttle 75% open from the fully-closed position and run the engine for 2-3 minutes. This will ensure that the engine becomes rich enough when the needle-valve is opened at full throttle during running-in.

- NEVER disassemble the fuel pump or pressure regulator. Their original performance may not be restored after reassembly.

- DO NOT obstruct the small rectangular hole in the side of the regulator cover.

- DO NOT allow foreign matter to enter the fuel system. Dirt inside the pump or regulator, no matter how small, may obstruct the flow of fuel and prevent these components from working properly.

- NEVER insert anything into the inlet or outlet nipples in an attempt to clear a suspected obstruction. (See CARE & MAINTENANCE section at the back of this booklet.)

- ALWAYS use fuel filters. Keep the fuel tank scrupulously clean and filter all fuel as it enters the tank (e.g.via an O.S.'Super-Filter' Code No.72403050) and use a good quality in-line filter between the tank and pump. Remember to inspect filter screens at regular intervals and rinse clean as necessary.

- NEVER use gasoline, kerosene, diesel fuel or other petroleum products for cleaning the pump, regulator or fuel lines. Silicone-rubber parts will be ruined by these materials. Use only alcohol (methanol) or glow fuel for cleansing these items.

## PROPELLERS

The choice of propeller depends on the design and weight of the aircraft and on the type of flying in which you will be engaged. Determine the best size and type after practical experimentation.

As a starting point, refer to the props listed in the accompanying table.

Slightly larger, or even slightly smaller, props than those shown in the table may be used, but remember that propeller noise will increase if blade tip velocity is raised, due to higher revolutions or a larger-diameter / smaller-pitch prop.

**Warning:**

**Make sure that the propeller is well balanced. An unbalanced propeller and / or spinner can cause serious vibration which may weaken parts of the airframe or affect the safety of the radio-control system.**

**DO NOT forget the WARNINGS and NOTES on propeller and spinner safety given on pages 2,3 and 4.**

FS-70SⅡ

| Type | Size (DxP) |
|---|---|
| Stunt planes | 11x9-10, 12x7-8, 12.5x6 |
| Scale models | 13x8, 14x7, 11x7(3-blade) |

FS-91SⅡ/91SⅡ-P

| Type | Size (DxP) |
|---|---|
| Stunt planes | 11x11-12, 12x10-12, 13x9 |
| Scale models | 13x9, 14x7, 15x6, 16x6 12x8(3-blade) |

## GLOWPLUGS

The FS-70SⅡ, FS-91SⅡ and FS-91SⅡ-P are supplied with an O.S. Type F glowplug, specially designed for O.S. four-stroke engines.

### The role of the glowplug

With a glowplug engine, ignition is initiated by the application of a 1.5-volt power source. When the battery is disconnected, the heat retained within the combustion chamber remains sufficient to keep the plug filament glowing, thereby continuing to keep the engine running. Ignition timing is 'automatic' : under reduced load, allowing higher rpm, the plug becomes hotter and, appropriately, fires the fuel/air charge earlier; conversely, at reduced rpm, the plug become cooler and ignition is retarded.

### Glowplug life

Particularly in the case of very high performance engines, glowplugs must be regarded as expendable items.

However, plug life can be extended and engine performance maintained by careful use, i.e.:

- Fit a plug suitable for the engine.

- Use fuel containing a moderate percentage of nitromethane unless more is essential for racing events.

- Do not run the engine too lean and do not leave the battery connected while adjusting the needle.

### When to replace the glowplug

Apart from when actually burned out, a plug may need to be replaced because it no longer delivers its best performance, such as when:

- Filament surface has roughened and turned white.

- Filament coil has become distorted.

- Foreign matter has adhered to filament or plug body has corroded.

- Engine tends to cut out when idling.

- Starting qualities deteriorate.

## FUEL

The FS-70SⅡ, FS-91SⅡ and FS-91SⅡ-P should be operated on a methanol based fuel containing not less than 18% castor-oil, or a top quality synthetic lubricant (or a mixture of both), plus a small percentage (5-15%) of nitromethane for improved flexibility and power. The carburettor is adjusted at the factory for a fuel containing 20% lubricant and 10% nitromethane.

Some commercial fuels also contain coloring additives as an aid to fuel level visibility. In some cases, these additives have indicated slightly negative effects on performance. We would suggest that you use such fuels only if you are satisfied that they do not adversely affect running qualities when compared with familiar standard fuels.

When changing to a fuel brand or formula that is different from the one to which you are accustomed, it is a wise precaution to temporarily revert to in-flight running-in procedures, until you are sure that the engine is running entirely satisfactorily.

**Reminders:**

**All model engine fuel is poisonous.Do not allow it to come into contact with the eyes or mouth. Always store it in a clearly marked container and out of the reach of children.**

**Though not as volatile as gasoline, model engine fuel is also highly inflammable.**

**Keep it away from on open flame, excessive heat, sources of sparks, or anything else that might ignite it. Smoking is firmly discouraged.**

## PROPELLER & SPINNER ATTACHMENT

There is a risk, particularly with powerful four-stroke engines, of the propeller flying off if the prop nut loosens due to detonation ("knocking") in the combustion chamber when the engine is operated too lean, or under an excessively heavy load.

Propeller Washer

Propeller Nut
Lock Nut

Obviously, this can be very hazardous. To eliminate such dangers, the O.S. Safety Locknut Assembly was devised. Fit this as follows:

1. Ream the propeller shaft hole to 8.1mm bore with an appropriate reamer, checking that the hole is exactly centered.

2. Fit the prop to the engine shaft, followed by the retaining washer and prop nut and tighten firmly with a 14mm wrench.
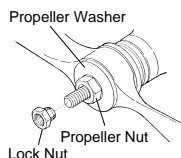
3. Add the special tapered and slotted locknut and secure with a 12mm wrench while holding the prop nut with the 14mm wrench.

Since the FS-70SⅡ, FS-91SⅡ and FS-91SⅡ-P are intended to be started with an electric starter, the addition of a spinner assembly for centering the starter sleeve is desirable. Special propeller locknut sets are available for use with spinners.

## TYPE 60R, 60P AND 60N CARBURETTOR

Two adjustable controls are provided on these carburettors. They are as follows:

● **The Needle Valve**
This is used to establish the fuel/air mixture strength required for full power when the throttle is fully open.

● **The Mixture Control Screw**
This is used to establish the mixture strength required for steady idling and a smooth transition to medium speeds. (The varying mixture strength required between part-throttle and full-throttle running is automatically adjusted by coupled movement of the throttle.)

The sequence in which these controls are adjusted is explained in the succeeding sections, under Starting, Running-in and Idling Adjustment.

## STARTING

The FS-70SⅡ, FS-91SⅡ and FS-91SⅡ-P are not fitted with manual choke controls, as they are intended for use with an electric starter only.

A high-torque electric starter not only makes starting the engine much easier, it dispenses with the need for a choke valve by turning the engine over fast enough to cause the fuel pump to prime the cylinder automatically.

1. Check that the current to the glowplug is switched off.

2. Check that the polarity of the starter battery leads rotates the engine counter-clockwise when viewed from the front.

3. Open the needle-valve 3-3.5 turns from the fully closed position and temporarily set the throttle in the fully open position.

4. Apply the starter and press the starter switch for 5-6 seconds, or until fuel is seen to emerge from the exhaust outlet, indicating that the cylinder is now primed.

5. Close the throttle-arm to within 15-20° of the fully closed position and slowly turn the prop "backwards" (clockwise) by hand approximately 1.5 turns until it is arrested by compression.This is to enable the kinetic energy of the prop to subsequently assist the starter through the compression stroke to start the engine.

6. Energize the glowplug and apply the starter. If the starter fails to rotate the engine completely, this may be due to the cylinder being over-primed, or to the starter battery being insufficiently charged.

7. Check these conditions and, instead of pressing the starter button after applying the starter, have the starter spinning before applying it to the engine, to give it a "running start". When the engine starts, slowly open the throttle, leaving the needle-valve at its rich starting setting to promote cool running conditions.
However, if the engine slows down because the mixture is excessively rich, the needle-valve may be closed a little to speed it up until it runs evenly.

8. Now disconnect current to the glowplug and gradually close the needle-valve so that revolutions are increased. Make adjustments to the needle in small steps. Abrupt changes at this stage are likely to cause the engine to stall. Restart the engine by simply applying the starter with the glowplug re-energized and the throttle at its starting setting.

## RUNNING-IN ("Breaking-in")

For long life and peak performance, every engine needs special treatment when new, known as "running-in" or "breaking-in". This is a process during which the engine is operated under strictly controlled conditions at the beginning of its life, in order to avoid the risk of immediate damage to certain components through becoming overheated or stressed and to help working surfaces to become smoothed and aligned for maximum mechanical efficiency thereafter.

With some engines, this can require a tediously protracted period of bench running, but, as O.S. engines are manufactured to fine tolerances and from the finest quality materials, a relatively brief running-in period is sufficient and can be completed with the engine installed in the aircraft. The recommended procedure is as follows :

1. Start and adjust the engine as detailed in the starting instructions.

2. Now open the throttle fully and run the engine for no more than 5 seconds with the needle-valve tuned to produce near maximum r.p.m., then, immediately, slow the engine down again by opening the needle-valve approximately one turn. The rich mixture, so induced, will cool the engine, at the same time providing increased of lubrication.

3. Allow the engine to run like this for about 10 seconds, then close the needle-valve again to speed it up to near maximum rpm for another 5 seconds.

4. Repeat this process, alternately running the engine fast and slow by means of the needle-valve, while keeping the throttle fully open, then begin to extend the short periods of high-speed operation until two full tanks of fuel have been consumed.

   **WARNING:**
   **When ground running the engine, avoid dusty or sandy locations. If dust or grit is drawn into the engine, this can have a ruinous effect, drastically shortening engine life in a matter of minutes.**

5. Following the initial running-in session, check for any looseness in the installation due to vibration, then allow the engine a period of moderately rich operation in flight.

6. For the first flight, have the needle-valve set on the rich side and adjust the throttle trim on the transmitter so that the engine does not stop when the throttle is closed to the idling setting.

7. With each successive flight, close the needle-valve very slightly until, at the end of about 10 flights, the needle is set for full power. Do not "over-lean" the mixture in an attempt to extract more power.

## RUNNING-IN (continued)

8. If overheating should be suspected at any time during flight (i.e.if the engine begins to "labor") reduce power by partially closing the throttle and land the aircraft to enable the needle-valve to be readjusted to a richer setting.

**Note:**
**Remember that, when the engine is not yet fully run-in, the carburettor cannot be expected to give its best response in flight. Abrupt operation of the throttle, for example, may cause the engine to stall. Therefore, at this time ,the aircraft should, as far as is possible, be flown at an altitude sufficient to enable an emergency landing to be safely made if the engine stops.**

9. Once the engine has demonstrated that it can be safely operated at full power, the carburettor can be adjusted for optimum throttle response, following the instructions given in the next section.

## IDLING MIXTURE ADJUSTMENT

1. Start the engine, open the throttle fully and set the needle-valve slightly rich (30-45°) from the highest r.p.m. setting.

2. Close the throttle to the idling position. Allow the engine to idle for about 5 seconds, then reopen the throttle. The engine should accelerate smoothly back to full speed.

3. If, instead, the engine responds sluggishly and emits an excess of white smoke from the exhaust, the idling mixture is too rich. Turn the mixture control screw approx. 45° clockwise to lean the idling mixture.

4. On the other hand, if the engine hesitates before picking up speed or even ceases firing completely, the idling mixture is likely to be too lean. Turn the mixture control valve 90° counter-clockwise to substantially enrich the mixture, then back again 45° clockwise.

5. In paragraphs 3 and 4 above, the 45° total movements are, of course, approximate. It will be necessary to fine-tune the mixture control screw 10-15° at a time to reach the best setting for optimum throttle response.

6. Continue re-checking the idling mixture setting until the engine responds smoothly and positively to operation of the throttle at all times.

**Realignment of Mixture Control Screw**

In the course of making readjustments, it is just possible that the mixture control screw may be inadvertently screwed in or out too far and thereby moved beyond its effective range.
The factory setting can be re-established as follows:
Set the throttle at the fully closed position.
Now carefully rotate the mixture control screw clockwise until it stops. Finally, turn the mixture control screw back exactly 3turns for the FS-70SⅡ, 2 1/2 turns for the FS-91SⅡ and 2 turns for the FS-91SⅡ-P.

## VALVE ADJUSTING

ALL O.S. four-stroke engines have their valve(tappet) clearances correctly set before they leave the factory. However, if, after many hours of running time have been logged, a loss of power is detected, or if the engine has to be disassembled or repaired as a result of an accident, valve clearances should be checked and readjusted, as necessary. O.S. Valve Adjusting Tool Kit is available as optional accessory.

The kit comes in a plastic case and includes:
(Code No.72200060)

   • Feeler gauge 0.04mm
   • Feeler gauge 0.1mm
   • Hex. key 1.5mm
   • Wrench 5mm

**Note:**
**Valve clearances of all O.S. four-stroke-cycle engines must be checked and reset ONLY WHEN THE ENGINE IS COLD. Procedure is as follows.**

**( I )**

1. Remove the cover from the rocker-box on top of the cylinder-head, using the correct size Allen hex key.

2. Turn the propeller counter-clockwise until compression is first felt, then turn it a futher quarter revolution. At this point, both valves should be closed. (If the prop driver ('drive hub') of your engine is engraved with a letter 'T', this mark should now be at the top.)

3. The standard valve clearance, on both inlet and exhaust valves, is between 0.04mm and 0.10mm(0.0015-0.004 inch), measured between valve stem and rocker arm. Use the 0.04mm and 0.10mm feeler gauges to check clearances. (See Fig.1.)

**Note:**
**If the gap is found to be less than 0.04mm, it is not necessary to readjust the clearance if the engine has good compression and starts easily.**

**Equally, if the gap exceeds 0.10mm but is not more than 0.14mm (i.e. the thickness of both feeler gauges inserted together), it is not essential to readjust the clearance if the engine runs satisfactorily.**



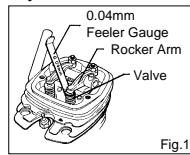0.04mm Feeler Gauge
Rocker Arm
Valve
Fig.1

**(II)** If a clearance is found to be outside either of these limits, it should be reset as follows.

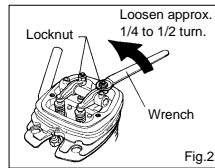1. Carefully loosen the locknut on rocker-arm 1/4-1/2 turn with 5mm wrench. (Fig.2.)



Loosen approx. 1/4 to 1/2 turn.
Locknut
Wrench
Fig.2

2. Turn adjusting-screw approx. 1/2 turn counter-clockwise to open gap, using appropriate tool -i.e. Allen hex key. (Fig.3.)



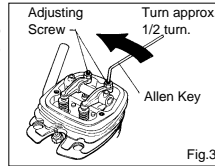Adjusting Screw
Turn approx. 1/2 turn.
Allen Key
Fig.3

3. Insert 0.04mm feeler gauge between valve stem and rocker-arm and gently turn adjusting screw clockwise until it stops.(Fig.4.)
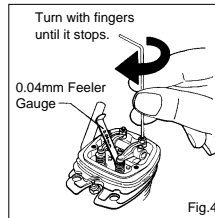


Turn with fingers until it stops.
0.04mm Feeler Gauge
Fig.4

4. Re-tighten locknut while holding adjusting screw stationary. (Fig.5.)
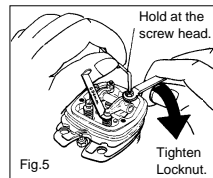
5. Remove 0.04mm feeler, rotate prop through two revolutions and recheck gap.



Hold at the screw head.
Fig.5
Tighten Locknut.

6. If clearance is correct, loosen the locknut on the other rocker-arm and repeat steps 1 to 5 above. Finally, replace rocker box cover.

**Remember:**
**Excessive valve clearance will cause loss of power, due to valve (s) not opening sufficiently. On the other hand, a total loss of clearance may cause difficult starting due to valves not closing properly, resulting in loss of compression.**

## CARE AND MAINTENANCE

Please pay attention to the matters described below to ensure that your engine serves you well in regard to performance, reliability and long life.
As previously mentioned, it is vitally important to avoid operating the engine in conditions where dust, disturbed by the propeller, may be deposited on the engine and enter its working parts. Also, remember to keep your fuel container closed to prevent foreign matter from contaminating the fuel.
Do not forget to clean the fuel filters periodically and, from time to time, unscrew the complete needle-valve assembly from the carburettor and remove any foreign matter that has accumulated in this area.
If these precautions are neglected, restriction of fuel flow may cause the engine to cut out, or the fuel/air mixture to become too lean causing the engine to overheat.

The use of modern high-performance alcohol based model engine fuels, while promoting cooler running, improved anti-detonation combustion and increased power, have the disadvantage of causing bottom end corrosion in a four-stroke engine. This is due to the acidic by produvts of combustion that accumulate in the engine's crankcase and are not flushed out by fresh air/fuel mixture as in the case of a two-stroke engine. The use of nitromethane in the fuel can also contribute to the problem. As noted earlier, the FS-70SII, FS-91SII and FS-91SII-P have their most vulnerable components protected against such attack but, as a primary defence, users are advised, once again, to avoid running the engine on too lean a mixture and by making sure that the engine is purged of contaminants as much as possible.

Do not leave unused fuel in the engine at the conclusion of a day's flying. Accepted practice is to cut off the fuel supply while the engine is still running - at full throttle  - then, expel as much fuel residue as possible by turning the engine over for 5-10 seconds with the electric starter.

Finally, inject some after-run oil through the glowplug hole and turn the engine over several times by hand.

When the engine is not to be used for some months (for example, as between flying seasons) a worthwhile precaution is to remove it from the airframe and, after washing off the exterior with alcohol (not gasoline or kerosene) to carefully remove the fuel pump, carburettor with intake pipe and all silicone tubes and put them safely aside.

Make sure that the engine is reasonably clean externally, then remove the glowplug and immerse the engine in a container of kerosene. Rotate the crankshaft while the engine is immersed. If foreign matter is visible in the kerosene, rinse the engine again in clean kerosene, before removing it, vigorously shaking off the excess and wiping it dry.

## CARE & MAINTENANCE (laying up)

The fuel pump assembly, carburettor/pressure-regulator and silicone tubes must be cleansed separately in methanol or glow fuel. On no account must they come  into contact with kerosene.

Before completely reassembling the engine, make sure  that no kerosene remains inside that could find its way into the pump unit, carburettor, etc. Inject, sparingly, preserving oils, rust inhibitors, etc. unless approved for silicone-rubber products.

An appropriate alternative here may be one of the high-quality synthetic lubricating oils.

Finally, seal the engine in a heavy polyethylene bag until required for refitting to the airframe.



Debris tends to accumulate in this area
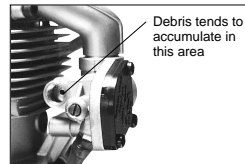
# O.S. GENUINE PARTS & ACCESSORIES

■ **RADIAL MOTOR MOUNT**
For FS-70S Ⅱ(71905000)
For FS-91S Ⅱ/S Ⅱ -P
(71901100)
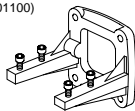
■ **O.S.GLOW PLUG TYPE F**
(71615009)

■ **EX EXHAUST HEADER PIPES**
(72109500)          (72109600)

Inside          Outside

■ **PROPELLER LOCKNUT SET**
(45910200 For Spinner)

■ **BOOSTER TERMINAL KIT**
(72200130)

■ **FLEXIBLE EXHAUST PIPES**

| Code.No. | Type | Length (mm) |
|---|---|---|
| 72108100 | 1111A | 120 |
| 72108110 | 1111B | 240 |
| 72108120 | 1111C | 170 |
| 72108130 | 1111D | 330 |

■ **BOOSTER CABLE SET**
(72200110)

■ **SUPER FILTER (L)**
(72403050)

■ **BUBBLESS WEIGHT**
(71531000)

■ **LONG SOCKET WRENCH WITH PLUG GRIP**
(71521000)

C. M2.6X12

C. M3.5X20

(C. M3.5X15)

C. M2.6X8

C. M2.6X8

C. M3.5X8

N. +M3X22

* Type of screw
C‥‥Cap Screw  B‥‥Binding Head Screw  M‥‥Oval Fillister-Head Screw
F‥‥Flat Head Screw  N‥‥Round Head Screw  S‥‥Set Screw

# FS-70SⅡ PARTS LIST

| No. | Code No. | Description |
|---|---|---|
| ① | 4 5913 000 | Screw Set |
| ② | 4 5904 210 | Rocker Cover |
| ③ | 4 5961 400 | Rocker Support Assembly |
| ③-1 | 4 5961 410 | Rocker Support |
| ③-2 | 4 5761 600 | Rocker Arm Retainer(2pc./1pair) |
| ④ | 4 5361 000 | Rocker Arm Assembly(1pair) |
| ④-1 | 4 5361 100 | Rocker Arm(1pc.) |
| ④-2 | 4 5061 202 | Tappet Adjusting Screw |
| ⑤ | 4 5960 001 | Intake Valve Assembly(1pair) |
| ⑤-1 | 4 5960 100 | Intake Valve(1pc.) |
| ⑤-2 | 4 5960 210 | Valve Spring(1pc.) |
| ⑤-3 | 4 5960 310 | Valve Spring Retainer(1pc.) |
| ⑤-4 | 4 5960 400 | Split Cotter(2pc./1pair) |
| ⑥ | 4 5960 011 | Exhaust Valve Assembly(1pair) |
| ⑥-1 | 4 5960 110 | Exhaust Valve(1pc.) |
| ⑥-2 | 4 5960 210 | Valve Spring(1pc.) |
| ⑥-3 | 4 5960 310 | Valve Spring Retainer(1pc.) |
| ⑥-4 | 4 5960 400 | Split Cotter(2pc./1pair) |
| ⑦ | 4 4004 110 | Cylinder Head |
| ⑧ | 4 4004 010 | Cylinder Head(w/valve) |
| ⑨ | 4 4068 000 | Intake Pipe Assembly |
| ⑨-1 | 4 4068 100 | Intake Pipe |
| ⑨-2 | 4 5771 000 | Breather Nipple |
| ⑩ | 4 4082 000 | Carburettor Complete(60R) |
| ⑪ | 4 4014 010 | Head Gasket |
| ⑫ | 4 4003 400 | Piston Ring |
| ⑬ | 4 4003 200 | Piston |
| ⑭ | 4 4006 000 | Piston Pin |
| ⑮ | 4 5605 000 | Connecting Rod |
| ⑯ | 4 4003 100 | Cylinder Liner |
| ⑰ | 4 4007 010 | Cover Plate |
| ⑱ | 4 4002 020 | Crankshaft |
| ⑲ | 4 5630 000 | Crankshaft Ball Bearing(R) |
| ⑳ | 4 4001 010 | Crankcase |
| ㉑ | 4 5771 000 | Breather Nipple |
| ㉒ | 4 5231 100 | Camshaft Ball Bearing(1pc.) |
| ㉓ | 4 5962 010 | Camshaft |
| ㉔ | 4 4001 100 | Cam Cover |
| ㉕ | 4 4066 000 | Push Rod(2pcs.) |
| ㉖ | 4 4066 100 | Push Rod Cover Assembly(2pcs.) |
| ㉖-1 | 4 4066 110 | Push Rod Cover(1pc.) |
| ㉖-2 | 2 4881 824 | Push Rod Cover "O" Ring(2pcs.) |
| ㉗ | 4 5564 000 | Cam Follower(2pcs.) |
| ㉘ | 2 6731 002 | Crankshaft Ball Bearing(F) |
| ㉙ | 4 6120 000 | Thrust Washer |
| ㉚ | 4 4008 000 | Drive Hub |
| ㉚-1 | 2 9008 219 | Woodruff Key |
| ㉛ | 4 5910 100 | Locknut Set |
|  | 4 5925 010 | Silencer(F-4020) |
|  | 4 5925 100 | Silencer Body |
|  | 4 5926 000 | Exhaust Header Pipe Assembly |
|  | 7 1615 009 | Glow Plug Type F |

The specifications are subject to alteration for improvement without notice.

# FS-91SⅡ EXPLODED VIEW



* Type of screw
C···Cap Screw  B···Binding Head Screw  M···Oval Fillister-Head Screw
F···Flat Head Screw  N···Round Head Screw  S···Set Screw

## FS-91SⅡ PARTS LIST

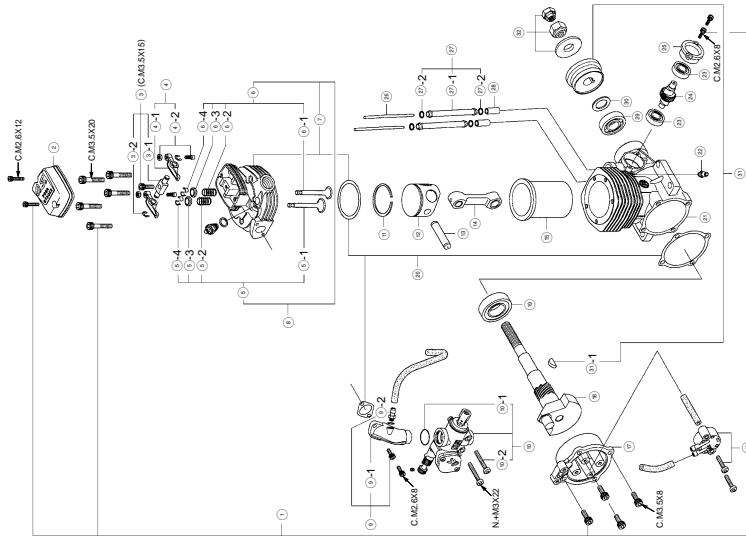| No. | Code No. | Description |
|---|---|---|
| ① | 4 5913 000 | Screw Set |
| ② | 4 5904 210 | Rocker Cover |
| ③ | 4 5961 400 | Rocker Support Assembly |
| ③-1 | 4 5961 410 | Rocker Support |
| ③-2 | 4 5761 600 | Rocker Arm Retainer(2pc./1pair) |
| ④ | 4 5361 000 | Rocker Arm Assembly(1pair) |
| ④-1 | 4 5361 100 | Rocker Arm(1pc.) |
| ④-2 | 4 5061 202 | Tappet Adjusting Screw |
| ⑤ | 4 5960 000 | Intake Valve Assembly(1pair) |
| ⑤-1 | 4 5960 100 | Intake Valve(1pc.) |
| ⑤-2 | 4 5960 200 | Valve Spring(1pc.) |
| ⑤-3 | 4 5960 300 | Valve Spring Retainer(1pc.) |
| ⑤-4 | 4 5960 400 | Split Cotter(2pc./1pair) |
| ⑥ | 4 5960 010 | Exhaust Valve Assembly(1pair) |
| ⑥-1 | 4 5960 110 | Exhaust Valve(1pc.) |
| ⑥-2 | 4 5960 200 | Valve Spring(1pc.) |
| ⑥-3 | 4 5960 300 | Valve Spring Retainer(1pc.) |
| ⑥-4 | 4 5960 400 | Split Cotter(2pc./1pair) |
| ⑦ | 4 5904 110 | Cylinder Head |
| ⑧ | 4 5904 010 | Cylinder Head(w/valve) |
| ⑨ | 4 5968 200 | Intake Pipe Assembly |
| ⑨-1 | 4 5968 210 | Intake Pipe |
| ⑨-2 | 4 5771 000 | Breather Nipple |
| ⑩ | 4 5984 000 | Carburettor Complete(60P) |
| ⑩-1 | 4 6115 000 | Carburettor Rubber Gasket |
| ⑩-2 | 4 5581 700 | Carburettor Fixing Screw(2pcs.) |
| ⑪ | 4 5903 400 | Piston Ring |
| ⑫ | 4 5903 200 | Piston |

| No. | Code No. | Description |
|---|---|---|
| ⑬ | 4 5906 000 | Piston Pin |
| ⑭ | 4 5605 000 | Connecting Rod |
| ⑮ | 4 6103 100 | Cylinder Liner |
| ⑯ | 4 5907 020 | Cover Plate |
| ⑰ | 4 5902 010 | Crankshaft |
| ⑱ | 4 5530 030 | Crankshaft Ball Bearing(R) |
| ⑲ | 4 5914 010 | Gasket Set |
| ⑳ | 4 5901 010 | Crankcase |
| ㉑ | 4 5771 000 | Breather Nipple |
| ㉒ | 4 5231 100 | Camshaft Ball Bearing(1pc.) |
| ㉓ | 4 5962 010 | Camshaft |
| ㉔ | 4 5901 110 | Cam Cover |
| ㉕ | 4 5966 000 | Push Rod(2pcs.) |
| ㉖ | 4 5966 100 | Push Rod Cover Assembly(2pcs.) |
| ㉖-1 | 4 5966 110 | Push Rod Cover(1pc.) |
| ㉖-2 | 2 4881 824 | Push Rod Cover "O"Ring(2pcs.) |
| ㉗ | 4 5564 000 | Cam Follower(2pcs.) |
| ㉘ | 2 6731 002 | Crankshaft Ball Bearing(F) |
| ㉙ | 4 6120 000 | Thrust Washer |
| ㉚ | 4 5908 000 | Drive Hub |
| ㉚-1 | 2 9008 219 | Woodruff Key |
| ㉛ | 4 5910 100 | Locknut Set |
|  | 4 5925 010 | Silencer(F-4020) |
|  | 4 5925 100 | Silencer Body |
|  | 4 5926 000 | Exhaust Header Pipe Assembly |
|  | 7 1615 009 | Glow Plug Type F |

The specifications are subject to alteration for improvement without notice.

C.M2.6X12
C.M3.5X20
(C.M3.5X15)
C.M2.6X8
C.M2.6X8
C.M2.6X8
C.M3.5X8
C.M2.6X48
N.M3X22

* Type of screw
C···Cap Screw  B···Binding Head Screw  M···Oval Fillister-Head Screw
F···Flat Head Screw  N···Round Head Screw  S···Set Screw

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## FS-91SⅡ-P PARTS LIST

| No. | Code No. | Description |
|---|---|---|
| ① | 4 5913 000 | Screw Set |
| ② | 4 5904 210 | Rocker Cover |
| ③ | 4 5961 400 | Rocker Support Assembly |
| ③-1 | 4 5961 410 | Rocker Support |
| ③-2 | 4 5761 600 | Rocker Arm Retainer(2pc./1pair) |
| ④ | 4 5361 000 | Rocker Arm Assembly(1pair) |
| ④-1 | 4 5361 100 | Rocker Arm(1pc.) |
| ④-2 | 4 5061 202 | Tappet Adjusting Screw |
| ⑤ | 4 5960 000 | Intake Valve Assembly(1pair) |
| ⑤-1 | 4 5960 100 | Intake Valve(1pc.) |
| ⑤-2 | 4 5960 200 | Valve Spring(1pc.) |
| ⑤-3 | 4 5960 300 | Valve Spring Retainer(1pc.) |
| ⑤-4 | 4 5960 400 | Split Cotter(2pc./1pair) |
| ⑥ | 4 5960 010 | Exhaust Valve Assembly(1pair) |
| ⑥-1 | 4 5960 110 | Exhaust Valve(1pc.) |
| ⑥-2 | 4 5960 200 | Valve Spring(1pc.) |
| ⑥-3 | 4 5960 300 | Valve Spring Retainer(1pc.) |
| ⑥-4 | 4 5960 400 | Split Cotter(2pc./1pair) |
| ⑦ | 4 5904 110 | Cylinder Head |
| ⑧ | 4 5904 010 | Cylinder Head(w/valve) |
| ⑨ | 4 5968 000 | Intake Pipe Assembly |
| ⑨-1 | 4 5968 100 | Intake Pipe |
| ⑨-2 | 4 5771 000 | Breather Nipple |
| ⑩ | 4 5983 000 | Carburettor Complete(60N) |
| ⑩-1 | 4 6115 000 | Carburettor Rubber Gasket |
| ⑩-2 | 4 5581 700 | Carburettor Fixing Screw(2pcs.) |
| ⑪ | 4 5903 400 | Piston Ring |
| ⑫ | 4 5903 200 | Piston |

| No. | Code No. | Description |
|---|---|---|
| ⑬ | 4 5906 000 | Piston Pin |
| ⑭ | 4 5605 000 | Connecting Rod |
| ⑮ | 4 6103 100 | Cylinder Liner |
| ⑯ | 7 2508 001 | Pump Unit(PD-07) |
| ⑰ | 4 5907 010 | Cover Plate |
| ⑱ | 4 5902 010 | Crankshaft |
| ⑲ | 4 5530 030 | Crankshaft Ball Bearing(R) |
| ⑳ | 4 5914 010 | Gasket Set |
| ㉑ | 4 5901 010 | Crankcase |
| ㉒ | 4 5771 000 | Breather Nipple |
| ㉓ | 4 5231 100 | Camshaft Ball Bearing(1pc.) |
| ㉔ | 4 5962 010 | Camshaft |
| ㉕ | 4 5901 110 | Cam Cover |
| ㉖ | 4 5966 000 | Push Rod(2pcs.) |
| ㉗ | 4 5966 100 | Push Rod Cover Assembly(2pcs.) |
| ㉗-1 | 4 5966 110 | Push Rod Cover(1pc.) |
| ㉗-2 | 2 4881 824 | Push Rod Cover "O"Ring(2pcs.) |
| ㉘ | 4 5564 000 | Cam Follower(2pcs.) |
| ㉙ | 2 6731 002 | Crankshaft Ball Bearing(F) |
| ㉚ | 4 6120 000 | Thrust Washer |
| ㉛ | 4 5908 000 | Drive Hub |
| ㉛-1 | 2 9008 219 | Woodruff Key |
| ㉜ | 4 5910 100 | Locknut Set |
| | 4 5925 010 | Silencer(F-4020) |
| | 4 5925 100 | Silencer Body |
| | 4 5926 000 | Exhaust Header Pipe Assembly |
| | 7 1615 009 | Glow Plug Type F |

The specifications are subject to alteration for improvement without notice.

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# CARBURETTOR EXPLODED VIEWS & PARTS LIST
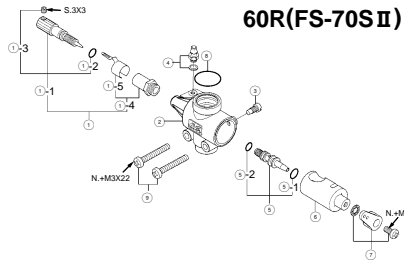
## 60R(FS-70SⅡ)
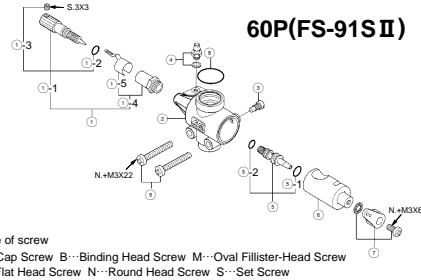
## 60P(FS-91SⅡ)

S.3X3
①-3
①-2
①-1
①-5
①-4
N.+M3X22
⑤-2
⑤
⑦
N.+M3X6
⑨

✱ Type of screw
C···Cap Screw  B···Binding Head Screw  M···Oval Fillister-Head Screw
F···Flat Head Screw  N···Round Head Screw  S···Set Screw

| No. | Code No. | Description |
|---|---|---|
| ① | 4 5984 900 | Needle Valve Assembly |
| ①-1 | 2 4081 970 | Needle |
| ①-2 | 2 4981 837 | "O" Ring (2pcs.) |
| ①-3 | 2 6381 501 | Set Screw |
| ①-4 | 2 7381 940 | Needle Valve Holder Assembly |
| ①-5 | 2 6711 305 | Ratchet Spring |
| ② | 4 4082 100 | Carburettor Body |
| ③ | 4 5581 820 | Rotor Guide Screw |
| ④ | 2 2681 953 | Fuel Inlet |
| ⑤ | 4 5582 300 | Mixture Control Valve Assembly |
| ⑤-1 | 4 6066 319 | "O" Ring (L) (2pcs.) |
| ⑤-2 | 2 4881 824 | "O" Ring (S) (2pcs.) |
| ⑥ | 4 4082 200 | Carburettor Rotor |
| ⑦ | 2 7881 400 | Throttle Lever Assembly |
| ⑧ | 4 6115 000 | Carburettor Rubber Gasket |
| ⑨ | 4 5581 700 | Carburettor Fixing Screw |

| No. | Code No. | Description |
|---|---|---|
| ① | 4 5984 900 | Needle Valve Assembly |
| ①-1 | 2 4081 970 | Needle |
| ①-2 | 2 4981 837 | "O" Ring (2pcs.) |
| ①-3 | 2 6381 501 | Set Screw |
| ①-4 | 2 7381 940 | Needle Valve Holder Assembly |
| ①-5 | 2 6711 305 | Ratchet Spring |
| ② | 4 5984 100 | Carburettor Body |
| ③ | 4 5581 820 | Rotor Guide Screw |
| ④ | 2 2681 953 | Fuel Inlet |
| ⑤ | 4 5582 300 | Mixture Control Valve Assembly |
| ⑤-1 | 4 6066 319 | "O" Ring (L) (2pcs.) |
| ⑤-2 | 2 4881 824 | "O" Ring (S) (2pcs.) |
| ⑥ | 4 5983 200 | Carburettor Rotor |
| ⑦ | 2 7881 400 | Throttle Lever Assembly |
| ⑧ | 4 6115 000 | Carburettor Rubber Gasket |
| ⑨ | 4 5581 700 | Carburettor Fixing Screw |

The specifications are subject to alteration for improvement without notice.

## 60N(FS-91SⅡ-P)

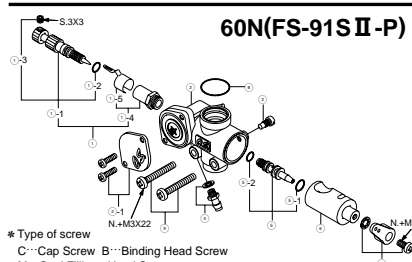S.3X3
①-3
①-2
①-1
①-5
N.+M3X22
⑤-2
⑧-1
N.+M3X6
⑦

✱ Type of screw
C···Cap Screw  B···Binding Head Screw
M···Oval Fillister-Head Screw
F···Flat Head Screw  N···Round Head Screw  S···Set Screw

| No. | Code No. | Description |
|---|---|---|
| ① | 2 7681 900 | Needle Valve Assembly |
| ①-1 | 2 7681 970 | Needle |
| ①-2 | 2 4981 837 | "O" Ring (2pcs.) |
| ①-3 | 2 6381 501 | Set Screw |
| ①-4 | 2 7381 940 | Needle Valve Holder Assembly |
| ①-5 | 2 6711 305 | Ratchet Spring |
| ② | 4 5983 100 | Carburettor Body |
| ②-1 | 4 5582 400 | 60N Regulator Cover |
| ③ | 4 5581 820 | Rotor Guide Screw |
| ④ | 2 2681 953 | Fuel Inlet |
| ⑤ | 4 5582 300 | Mixture Control Valve Assembly |
| ⑤-1 | 4 6066 319 | "O" Ring (L) (2pcs.) |
| ⑤-2 | 2 4881 824 | "O" Ring (S) (2pcs.) |
| ⑥ | 4 5983 200 | Carburettor Rotor |
| ⑦ | 2 7881 400 | Throttle Lever Assembly |
| ⑧ | 4 6115 000 | Carburettor Rubber Gasket |
| ⑨ | 4 5581 700 | Carburettor Fixing Screw |

The specifications are subject to alteration for improvement without notice.

# THREE VIEW DRAWING

## FS-70S II  Specifications

| | |
|---|---|
| ■ Displacement | 11.50cc/0.702cu.in. |
| ■ Bore | 25.8mm/1.016in. |
| ■ Stroke | 22.0mm/0.866in. |
| ■ PracticalR.P.M. | 2.000～12.000r.p.m. |
| ■ Output | 1.1bhp/11.000r.p.m. |
| ■ Weight | 580g/20.4oz. |

50

55.8   21

96.4

UNF5/16-24

20.3

39.6
58

66.3   44.7
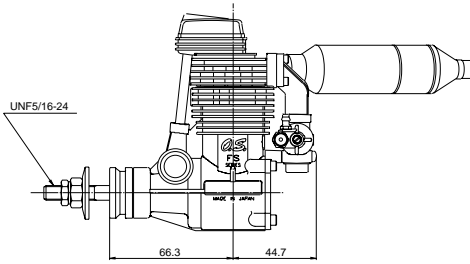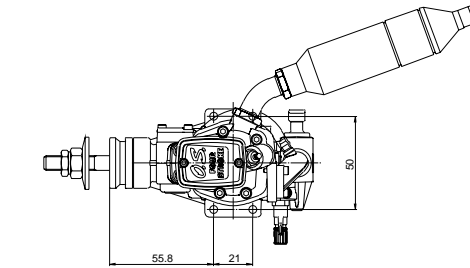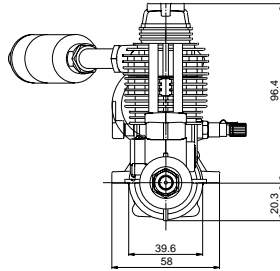
Dimensions(mm)

# THREE VIEW DRAWING

## FS-91S II  Specifications

| | |
|---|---|
| ■ Displacement | 14.95cc/0.912cu.in. |
| ■ Bore | 27.7mm/1.09in. |
| ■ Stroke | 24.8mm/0.976in. |
| ■ PracticalR.P.M. | 2.000～12.000r.p.m. |
| ■ Output | 1.6bhp/11.000r.p.m. |
| ■ Weight | 640g/22.6oz. |

4－φ4.2

52

54   25

101

UNF 5／16－24

22

42.6
60

66.5   48
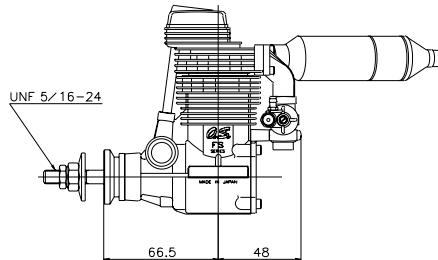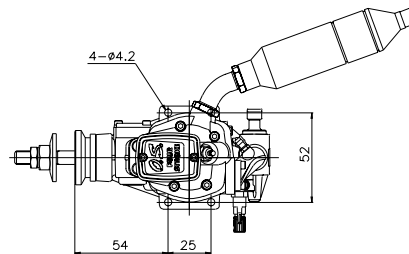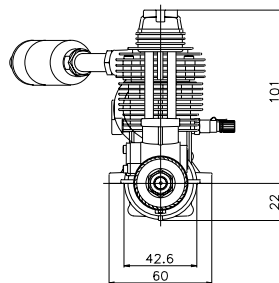
Dimensions(mm)

# THREE VIEW DRAWING

## FS-91SⅡ-P Specifications

| | | |
|---|---|---|
| ■ | Displacement | 14.95cc/0.912cu.in. |
| ■ | Bore | 27.7mm/1.09in. |
| ■ | Stroke | 24.8mm/0.976in. |
| ■ | PracticalR.P.M. | 2.000～12.000r.p.m. |
| ■ | Output | 1.6bhp/11.000r.p.m. |
| ■ | Weight | 650g/23.0oz. |
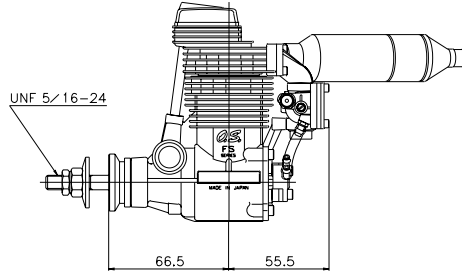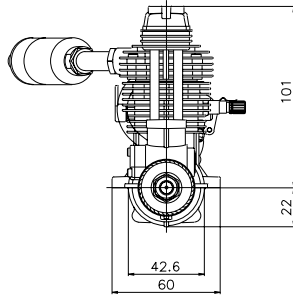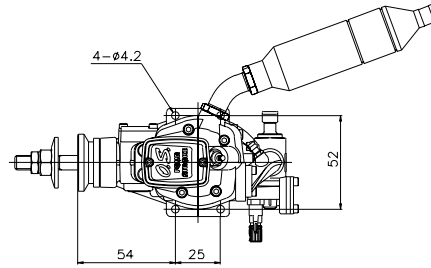
4−ø4.2

52

54    25

101

22

42.6

60

UNF 5/16−24

66.5    55.5

Dimensions(mm)

− 30 −

**O.S.**

UNEQUALLED QUALITY PRECISION & PERFORMANCE

ESTABLISHING THE STANDARDS OF EXCELLENCE

**Rcexl Ignitions by RCCDI**
**Distributed by Copperhead Aviation**
**Broadlands, Va. USA**

Thank you for purchasing our Rcexl Ignition! If installed properly and maintained, you will receive many years of good flying.

## Index

## 1.) Specifications

I.) **WARNING** - Rcexl ignitions were designed for use in model aircraft and should NEVER be used in a Human Carrying Vehicle!!

II.) BPMR 14mm Ignition:

Input voltage 4.8-6v
Output voltage 12-16 kV
Draw @8000 rpm - 650 ma
Case - ABS with Nickel plate
Weight Single: less battery - 4.4oz

Weight Twin: less battery - 6.1oz
Plug size - 14MM NGK (BPMR6F)
Warranty – 2 Years

III.) CM6 10mm Ignition:

Input voltage 4.8-6v
Output voltage 12-16 kV
Draw @8000 rpm - 650 ma
Case - ABS with Nickel plate
Weight Single: less battery - Single 4.4oz
Weight Twin: less battery - 6.1oz
Plug size - 10MM NGK (CM6)
Warranty - 2 year

## 2.) Selecting a Power Source

I.) 4.8 volt Packs:

The Rcxcel Ignition is rated 4.8 to a max of 6 volts. A 4 cell 4.8v pack with a minimum of 800 mAh is fine and creates a hot spark. The Rcexl ignition runs most efficiently on 4 cell packs. Do not use an old Pack!! If it's not good enough for your receiver, it's not good enough for your ignition.

II.) 6 +Volt Packs:

We have found that 5 cell packs at peak charge can be as high as 7 +v. If you are going to use a 5 cell pack you must use a voltage regulator. The Rcexl ignition runs more efficiently on 4 cell packs and will draw more current at around 6v, as well as operate at a higher temperature. You also have a higher chance of RFI interference. Once again, do not use an old pack to power your ignition!

## 3.) Installation

I.) Spiral Wrapping:

Use the supplied Spiral Wrapping included with your Ignition to protect the wires from heat and chafing. Wrap the braded Spark Plug Lead, Hall Sensor Harnesses and Battery Harnesses.

II.) Mounting:

Mount your Ignition on the engine box if possible. Wrap the ignition in foam to reduce the effects of engine vibration on the circuitry like you would do with your receiver. You can use the mounting tabs on the ignition but we recommend using zip ties or Velcro ties to secure it. Do not install your ignition in the fuselage. Keep the ignition as far away from you receiver as possible and never use the same power source to run your ignition and receiver jointly.

III.) Connecting the Battery:

The Rcexl ignition utilizes the Futaba style plug ends and comes with an additional pigtail to add to your ignition switch if necessary. Be sure to follow the color coding (Red +, Black -) when attaching you're your power source and on / off switch to your ignition power leads (see fig.1). Wrap you battery with foam and mount it as far away from the receiver as possible, preferably on the motor box.

fig 1.



IV.) Hall Effects Sensor:

Chose the Sensor housing the best suits your engine and determine the orientation of your magnet if unknown. (fig. 2) Most seem to be a south orientation. A quick way to determine the orientation is connect the hall sensor to the ignition, insert the plug and connect you power source. Quickly pass the sensor over the magnet without stopping over the magnet, this may damage the sensor. If the plug doesn't fire, flip the sensor over and repeat.

Fig 2.



Insert fully the sensor into the sensor housing. Use the supplied wedge to hold the sensor in its housing. (fig. 3) Warning!! The wedge provides a one way fit; make sure you have the proper sensor orientation before inserting the wedge as it will be very difficult to remove!

Fig. 3



If you are going to attempt to use your existing hall sensor, see (fig. 4) for the wire orientation.

Fig. 4



V.) Timing:

Timing will vary from manufacture to manufacture. Usually, 28o ~30o Top Dead Center (TDC) is recommended.

Mount the Degree Wheel to the Crank Shaft (fig. 5). Rotate the engine crankshaft so the piston is set at TDC. This can be ascertained by using a small wooden dowel to make contact with the piston top thru the spark plug hole. Rotate the crankshaft back and forth to get TDC as close as possible. For absolute accuracy, a dial indicator can be used but not necessary.

Without moving the Crank, move the Supplied Degree wheel so it reads 0 degrees TDC and lock it down.

Fig. 5



Turn the crankshaft clockwise (opposite to the engine rotation) until the wheel reads 28 degrees.

Connect the Battery to the ignition insuring that the Spark Plug is not in the cylinder. Warning!! Avoid turning the engine over with the ignition energized without the spark plug being attached to the H.T. lead. Failure to do so could damage the Hall sensor pickup.

For Adjustable Magnet Rings:

Turn magnet fixed ring Counter Clockwise. When you see the plug firing, stop and lock down the ring, the correct ignition timing is

now set. (28o ~30o.) The plug will fire as the magnet passes slightly past the Hall Sensor, this is a normal condition.

For Fixed Hall Sensors:

Try to use your existing hall sensor mounting holes, if this is a conversion you will need to estimate the hall sensor position and drill and tap your own. The holes on the hall sensor housing are ovular and allow for some adjustment.

## 4.) Trouble Shooting your Ignition.

I.) Battery:

Check the voltage on your battery and make sure it's healthy and fully charged. Insure that the voltage is 6v or less to the ignition.

II.) Connections:

Check that all connections are correct from the battery, to the switch, to the ignition. Use a volt meter on the switch to ensure the ignition is getting power and the polarity is correct.

III.) Hall Effects Sensor:

Ensure that the orientation of the hall sensor is correct with the orientation of your hub magnet. If you used your existing hall sensor, make sure that the wire orientation (fig. 4) is correct.

## 5.) Safety Precautions.

Never power the ignition with the plug in the head when you're working on your engine, it could fire off!! Always wear a glove when starting your engine!! After turning off your ignition, beware that the ignition could still have a charge and fire the motor. Always range check your model!!

## BUDGET

| Items Purchased | Price ($) | | Starting Budget |
|---|---|---|---|
| 2 Stroke Engine | 210 | | 1500 |
| 4 Stroke Engine | 210 | | |
| Engine Mount | 5 | | |
| Fuel Lines | 0.5 | | |
| Fuel Tank | 6 | | |
| Fuel (Nitromethane) | 3 | | |
| Electric Starter | 70 | | |
| Electronic Ignition/with timing sensor and magnet | 80 | | |
| Hydrogen Tank | 200 | | |
| Total | 784.5 | | |
| | | | |
| Remaining Budget | 715.5 | | |
| | | | |
| Hydrogen provided by faculty advisor | | | |
| | | | |
| Items to be Purchased by the Spring | | | |
| Spark plug | 10 | | |
| Graphite lubrication | 5 | | |
| Oil | 6 | | |
| Total | 21 | | |
| Remaining Budget for the Spring | 694.5 | | |

## PREVIOUS DESIGN PROJECT

The following paper was the original design project, the focus of which was the Photolysis of Hydrocarbon Fuels. After it was found to be unfeasible it was decided to switch to an alternate project. Both projects have the same overall purpose, which is to find ways to decrease the world's dependence on Fossil Fuels, which was the major concern of the sponsor.

# Report on the Feasibility of using Photolysis to Dissociate JP-8 into Molecular Hydrogen and Carbon Particulate for use as an On-Demand Hydrogen Supply for a Small Propulsion Engine

**Date Finished: 10/20/07**
**Performed by: FSU Senior Design Group 13**
**Greg Smith**
**Travis Watson**
**Joshua Mardis**
**John Lubatti**
**Sponsor: Ken Edwards, Eglin/AFRL**

# <u>SUMMARY</u>

This report looked into the Feasibility of using Photolysis to dissociate JP-8 into molecular Hydrogen and Carbon Particulates. This was to be done using a high enough powered Laser to break apart the bonds of the various hydrocarbons that make up JP-8 and then using a collector or separator to filter out the molecular Hydrogen for use as a fuel. It was determined that this process would not be feasible to build for our purposes. This was based on the amount of time involved and the size of the available budget. It was also determined that even though this process would be feasible to build, given ample time and funding, it would not be economically efficient. The amount of power required by the Lasers could potentially be greater than the energy given off during the combustion of Hydrogen.

# TABLE OF CONTENTS

## 1.0   PURPOSE

This Report Presents the results of a Study looking into the Feasibility of using Photolysis as a means of decomposing a Hydrocarbon Fuel, JP-8, to obtain molecular Hydrogen for use as a Fuel. This study was performed by the FAMU/FSU Senior Design Group 13 in conjunction with the United States Air Force and the Air Force Research Laboratories (AFRL). It contains all findings, research, and problems encountered, as well as recommendations for those wishing to do further study.

## 2.0   BACKGROUND

With the world facing the growing problem of Global Warming, due to the millions of barrels of oil being consumed each day, alternative fuels are becoming more and more desirable. One alternative fuel that is becoming widely popular is Hydrogen, which when burned releases water as its only byproduct. This study looks into the feasibility of using Photolysis to break down JP-8 (jet fuel) into molecular Hydrogen. The Hydrogen would be used as fuel, while the remaining carbon compounds would be collected and reused for other purposes. This would not be a definitive long-term solution, but would serve as an adequate intermediary step to help wean the U.S. Air Force off of hydrocarbon fuels.

## 3.0    PROPOSED DESIGN

### 3.1    Design Specifications

- Device must be able to dissociate JP-8 into Carbon particulates and molecular Hydrogen to provide an on-demand fuel source for a small propulsive engine.
- It should be able to separate the Hydrogen from the Carbon Particulate.
- It should be able to collect and store the Carbon Particulate for later removal and possible use for other applications, e.g. carbon fiber, carbon bricks, etc.
- It should be as lightweight as possible as it is to be used onboard an aircraft.
- It's emissions should contain very little or no Carbon Products.
- It should be relatively cheap to build because the budget is small.

Below is a flow chart outlining the main processes involved with the design.

```
                    ┌──────────────────┐
                    │     JP-8         │
                    │  (Jet Fuel)      │
                    └──────────────────┘
                              │
                    ┌──────────────────┐
                    │ Photolysis Occurs,│
                    │ Creating Molecular│
                    │ Hydrogen and Carbon│
                    │   Byproducts     │
                    └──────────────────┘
                              │
                       ┌──────────┐
                       │ Separator │
                       └──────────┘
                         ╱       ╲
          ┌──────────────────┐   ┌──────────────────┐
          │ Carbon Byproduct is│ │ Hydrogen is Sent to│
          │ Collected for Later│ │ Engine and Burned as│
          │ Removal and Use   │ │      Fuel         │
          └──────────────────┘   └──────────────────┘
```
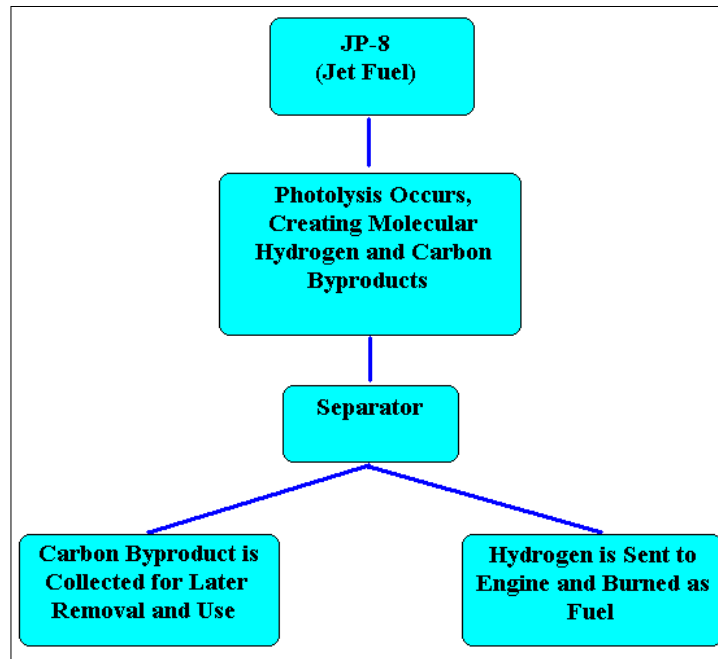
### 3.2    What is Photolysis?

This project involves the use of Photolysis to break apart a hydrocarbon fuel to obtain molecular Hydrogen. Before designs can be made it is necessary to understand what Photolysis is and how it is done.

Photolysis is a process by which molecules are dissociated into smaller parts using light energy. One very good example is in plants. Photolysis is the part of photosynthesis where light energy breaks apart water into Oxygen and Hydrogen.

Though Photolysis of water occurs in both nature and in the laboratory, research regarding its use on hydrocarbons is very limited. Some studies were found that involved the use of Photolysis to initiate the transfer of a Hydrogen ion from a hydrocarbon to a metal, however these were very small-scale, controlled reactions.

Different ways to initiate Photolysis involve direct exposure to sunlight, the use of a Laser, or through the use of Plasma. **For the purpose of this design it was decided that a Laser would be the best and most efficient way to supply the high wavelengths and energy required for Photolysis**. The use of direct sunlight would be the cheapest option, however it requires substantial amounts of time, and is not feasible for a system onboard an aircraft.

## 3.3    Proposed Design

The proposed design involves the implementation of the previously mentioned process. It was determined that in order to thoroughly photolyze the hydrocarbon fuel it would be better to have more than one laser. This would allow a wider area of the fuel stream to be bombarded by the Laser, resulting in a higher dissociation rate.

Once the fuel has been dissociated it needs to be separated out so that only the hydrogen proceeds on to the engine. The best way to do this would be to use a collection plate that would absorb the Carbon Particulate, or to use a membrane that only allows Hydrogen to permeate through. This process needs to be immediate because once the fuel has been dissociated it immediately wants to reform. To solve this it was decided that the collection/absorption process should take place in the same area that the Laser is bombarding the fuel.

(An illustration of this Design is Presented Below)
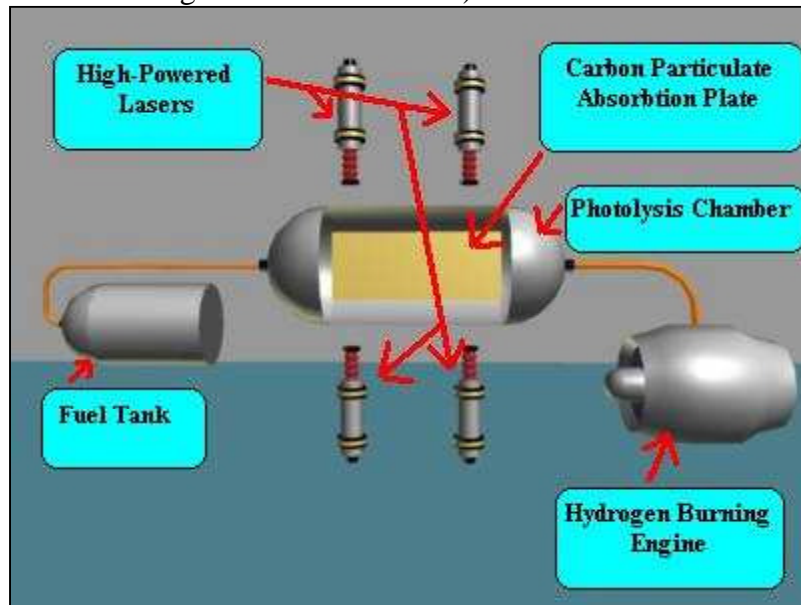
# 4.0    PROBLEMS ENCOUNTERED

Although this process is theoretically feasible, it involves many complexities and potential problems that would hinder it from being physically possible.

## 4.1    Complexity of JP-8 (Jet Fuel)

JP-8 is the main type of fuel that is used by the U.S. Air Force. Since this project is being done in conjunction with the Air Force, it is the type of fuel that is to be used in this design.

JP-8 is a very complex fuel, containing a number of different hydrocarbons as well as many additives.

Composition of JP-8

| Compound | % in JP-8 |
|---|---|
| ■Isooctane | 3.66% |
| ■Methylcyclohexane | 3.51% |
| ■M – Xylene | 3.95% |
| ■Cyclooctane | 4.54% |
| ■Decane | 16.08% |
| ■Butylbenzene | 4.72% |
| ■1,2,4,5 – Tetramethylbenzene | 4.28% |
| ■Tetralin | 4.14% |
| ■Dodecane | 22.54% |
| ■1 – Methylnaphthalene | 3.49% |
| ■Tetradecane | 16.87% |
| ■Hexadecane | 12.22% |

**Additives**
■Stabilizers
■Corrosion
■Ice inhibitors
■Anti – static
■Biocides
■Gum cleaner
■Varnish cleaner

Because of the complexity of JP-8 and the number of different compounds involved the wavelength of the Laser used needs to be high enough so that it can fully dissociate all the compounds involved. If this were not done the amount of Hydrogen obtained would not be the full amount available, decreasing the efficiency of the process.

## 4.2    Use of Lasers

In order to determine the type of Laser to be used in the process, the wavelength required for Photolysis to occur needs to be determined.

Since the main bonds that we are trying to break are the Carbon-Hydrogen bonds, it is necessary to determine what wavelength is required to break them.

This was done by the following:

- ~    C-H bond has a bond energy of about 413 kJ/mol
- ~    Converting this to energy using $E = hc/\lambda$
- ~    Therefore the required wavelength is $\lambda = 290$ nm (in the ultra violet spectrum)

With this wavelength calculated, a laser that can produce photons at that wavelength is required.  Lasers that are within this range, called eximer lasers, are usually used for LASIK surgery and remote atmospheric sensing.

The AVIA 266-3 laser uses Cerium doped Lithium Strontium Aluminum Fluoride as the working fluid.  Another laser is the GAM EX100 has options of different working fluids resulting in a range of wavelengths from 157nm – 351nm.  Most were in the price range of seventy to eighty thousand dollars, with a gas half-life of less than ninety days.

Many things need to be considered when turning wavelengths to equivalent energy to break bonds.  This wavelength of 290 nm is for an individual C-H bond and our problem uses a stream of hydrocarbons, meaning the intensity will need to be increased to handle the mass flow rate.  Intensity is the number of photons per unit time.  It was not easy to calculate the intensity from the laser product specifications.  Intensity is in units of lumens and we need lumens per meter squared, also known as lux.  Lux would allow calculation of the beam size and intensity for the needed point of beam incidence or if there are multiple angles and beams required.

Problems with this idea:

- ~    Beam size were on the scale of 10mm x 10mm
- ~    To maximize bond breaks there would need to be multiple angles of incidence
- ~    This would require many lasers at a high cost
- ~    This only accounts for single C-H bonds
- ~    Does not include frequencies for other C-R bonds (R = Radical)
- ~    There is a large amount of energy needed to make a photon
- ~    Incident lasers needed until the molecular hydrogen has been separated

## 4.3    Uncertainty of the Photolysis Reaction

(Most of the discussion on this topic comes from an email correspondence with Dr. Bruce Locke P.E. Chem. Engineering, a professor at the FAMU/FSU College of Engineering. A copy of the letter can be found in the Appendix.)

Though Photolysis seems like a pretty straightforward process it is actually very complex. When Photolysis occurs a photon is absorbed by a molecule, which leads to the formation of an excited state species. What happens to the molecule after the excitation, however, depends on the chemical compound and the amount of energy involved. These could include:

- Photoionization (formation of an ionic species) - This occurs when the actual wavelength is shorter than the  required wavelength
- The excited state could emit a photon (known as luminescence)
- Molecular dissociation (The process that this Design requires)
- Other random Chemical Processes

If molecular dissociation was obtained and Hydrogen was released there is still the problem of reactivity. The compounds created from the dissociation are very reactive and unstable and will readily reform into other compounds. Unless a suitable environment, one that favors the production of molecular Hydrogen, is available, then the chemicals will randomly form different compounds, which are undetermined.

If molecular Hydrogen is created, then what happens to the carbon needs to be considered. It will react and form compounds, which will also be random in nature, unless catalysts are added to encourage it to join a certain way.

The presence of Oxygen in the reaction chamber needs to be addressed as well. Once the Laser begins operating, it will create high temperatures. JP-8 itself is not readily flammable, but molecular Hydrogen is, as well as other compounds that could possibly form during the process. If there were any Oxygen present during the reaction process it could lead to an explosion.

**These processes are very unpredictable, and need to be completely controlled to prevent unwanted chemicals from forming, and to prevent catastrophic failure.**

## 4.4    Separation Techniques

The last major problem that has arisen is the means of separating the molecular Hydrogen from the Carbon particulate.

There are two methods that could be used for this process.

➢ A collection plate that absorbs the Carbon particulate
➢ A membrane that would only allow the Hydrogen to permeate through

The first method would be beneficial because it could be placed in the reaction chamber were the Photolysis is occurring, reducing the possibility of the carbon reacting or reforming with the Hydrogen. In order for them to be the most effective, there should be more than one to increase the absorption area.

Compounds that could be used for this type of collector plate are known to exist, however research on them proved very difficult, therefore not much is known about their makeup or availability for the purpose of this study.

The second method was easier to research, and is commercially available. The type of material that would be used is called Palladium. In order for the membrane to work the Palladium is stretched very thin, on the order of a couple microns thick. The drawback of using this type of separator is that the flow has to pass through it, so the fuel would have to pass through it after the Photolysis reaction has occurred. This would allow more time for unwanted reactions to occur, leading to a decrease in efficiency.

These two processes could be used together to combine their strengths, however this would lead to increased complexity, resulting in more weight and more cost.

# 5.0    CONCLUSION

Due to the complexity of this process, and the cost that such a design would require, it is determined that Photolysis of a Hydrocarbon fuel for Hydrogen production is not a feasible process to pursue at this time. Many of the chemical processes involved are very complex and need to be studied further to understand how they would affect the overall process. Suitable environments, favoring molecular Hydrogen production, need to be determined, however this can only be done through experimentation. With the intensity and number of Lasers required, as well as the required separation materials, the cost of such a project would be very high.

The process is theoretically feasible, and through extensive research and experimentation it could be made to work. However, it is determined that the process will not be an economically viable option. The process would require enormous amounts of energy for it to completely dissociate all the hydrogen, meaning that it could possible require more energy than will be given off during the combustion of Hydrogen as a fuel. That energy would have to come from somewhere, and could cause as much or more greenhouse gas to be emitted as is being curtailed by the Photolysis process.

# APPENDIX

## Correspondence With Dr. Bruce Locke P.E. Chem. Engineering

      **This is a copy of the correspondence that we had with Dr. Bruce Locke, all of our comments are in *Italics,* while all of Dr. Locke's are in standard format. The questions that we asked him are in bold, followed by their response.**

  **From** Locke <locke@eng.fsu.edu>

  **Date** Fri, 28 Sep 2007 15:59:45 -0500
    **To** Gregory Smith <ges03d@fsu.edu>
**Subject** Re: ME Senior Design Project

Greg - here are a few preliminary comments.

Gregory Smith wrote:
*Dr. Locke,*

*Our project is Photolysis of hydrocarbons (specifically JP-8 jet fuel and is mostly kerosene).  The focus is to separate the hydrogen from the other atoms to be collected (possibly stored) and used as fuel in a combustion process.*

Make sure you understand that you should be considering the production of molecular hydrogen (**H2**) not atomic hydrogen (**H**).  You are unlikely to have any process to separate atomic hydrogen, as it is not a stable species and will rapidly react in most environments.  Your aim should be to form molecular hydrogen (**H2**) by chemical reaction from the hydrocarbon feed.  The molecular hydrogen would need to be separated from the mixture you create and that may be accomplished using membranes or adsorption processes.  Molecular hydrogen can in turn be used as a fuel in combustion with water.  Please carefully understand the difference between molecular and atomic hydrogen.

*Our attempt is to use a laser to facilitate the process.*

*Research we have found includes H-C bond energy at 411kJ/mol*

*This divided by Avogadro's Number to find the wavelength and energy required to break the bonds. The result wavelength was 289.64 nm l(in the UV spectrum)*

*Also we are looking into the process to break the C-C bonds (single,*

9

*double, and/or triple)*

*We have found Lasers that can produce most wavelengths near our desired wavelength.*

Your approach considers the use of a UV photon to dissociate the hydrocarbon. This is a photochemical process. Typically a photon is absorbed by a molecule leading to the formation of an excited state species. What happens to the molecule after the excitation depends strongly on the species and the energy. For example, the excited state can emit a photon (luminescence), it can lead to molecular dissociation (what you want), and it can lead to many other chemical processes. This is quite a complex problem, and I think some literature review may be necessary to find the energy level diagrams for a typical hydrocarbon in your fuel. In general alkanes absorb at about **144 nm** and can lead to the formation of **H2** (again the gas environment should be considered) by such reactions as

**RCH2R + hv --> RCR + H2**
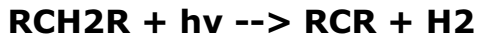
where **R** is the remainder of the hydrocarbon and **hv** is the photon. Other free radicals from the carbon are also possible.

You also have to consider what happens when the bonds are broken. When a chemical species is dissociated by a photon of energy, that species can then react with others in the mixture. You have to provide a suitable environment that favors the production of the species you want
        - namely molecular hydrogen and other compounds. You will need to consider what happens to the carbon. For example, one well known pathway for the production of hydrogen from methane is at high temperature with a catalyst:

**CH4 + H2O --> CO + 3H2**
**CO + H2O --> CO2 + H2**
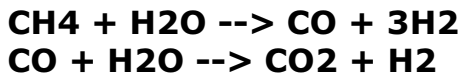
This is called steam reforming. With higher hydrocarbons, you may make **H2** without complete conversion to carbon dioxide, but then you may have all kinds of deposits of various carbon species.

## Questions:

### Do you think this process is feasible?

It is certainly physically and chemically feasible to dissociate hydrocarbons with photons and it is likely some hydrogen can be formed. I cannot say about the cost of such a process and the difficulty of performing the separations and dealing with any byproducts you may not want.

### Does the wavelength need to be precise?

For a pure component the wavelength can be precise and that is one of the advantages of photons is that you can have high selectivity. However, if you have a mixture of hydrocarbons as in your fuel source, you probably would want a range of wavelengths.

### Can it just be a higher energy?

I am not sure what you mean. If you want to use photons, you need photons with sufficient energy to excite the given species and lead to dissociation. The energy of the photons would be defined by the quantum state of the molecule to be dissociated. You may use a higher intensity or larger number of photons with given energy. Alternatively, high enough thermal energy can dissociation the hydrocarbon (see the reforming reaction given above).

### What is the intensity required?

I do not know. This would depend upon the amount of hydrocarbon to be processed in a given time.

### How do you calibrate the effect of intensity on the reaction?

There are theories for determining reaction rates in photochemical reactors. These involve integrating the UV (photon) flux over all possible directions and over the wavelengths of the sources. This theory is known, but the process can be complex. There are some experimental ways to do this too - this experimental process is called chemical actinometry.

### What is the frequency of the bonds?

Each chemical bond in the species in your mixture will have a different energy, and thus the frequency or energy of the photon would be different.  I cannot say at the moment what it would be for your components, but methane absorbs UV at 144 nm and higher alkanes absorb at higher wavelengths.  Shorter wavelengths can lead to photoionization (formation of ionic species).

### What is absorption and does it affect the reaction?

Again, the absorption of energy or a UV photon is the key in exciting the HC so that the reaction can proceed.

### How does this process work on a molecular and molar level?

As mentioned above a molecular absorbs a photon of a given energy.  Only photons with energy of the same quantum level as the electrons in the molecule will have an effect.  This absorption process raises the energy of the molecule by causing an electron to go from a lower energy state to a higher energy state.  The electron in the higher energy state (an excited state) can lead to many possible processes (as mentioned above) and what you want is to cause dissociation whereby one hydrogen atom is released from the hydrocarbon.  There are many so-called potential energy diagrams which show this process and it would be of interest to find one such diagram for a typical molecule in your mixture.

### How efficient could this process be?  ( percent of hydrogen out of total input)

Not sure, but typically photochemical processes are not highly efficient in terms of the energy required to produce a photon.  Once a photon is produced the efficiency of that photon exciting a given molecule can be high.  There are many factors that would be considered, including the subsequent chemistry and separation of final products.  I think that using a laser would be very inefficient since the cost of lasers can be large.

***Overall, what are the limiting factors?***

I think one key factor is to make sure you have the chemical environment suitable - for example if you dissociate a hydrocarbon into a hydrogen atom and a free radical, you do not want these species to recombine and go back to the starting material and you do not want to create a lot of undesirable chemicals from the free radical recombinations.  You have to get the hydrogen atom to recombine to make molecular hydrogen.

***Are there any other avenues to pursue to achieve this desired result? (separation of hydrogen from hydrocarbons)***

As mentioned above, thermal processes (steam reforming) at high temperature and with catalysts are used.  Another emerging process is using a plasma.

I will look for a few references that may be of help to you and give some more consideration to your problem.

BL


*Thanks for your help.*
*Sincerely,*

*Greg Smith*
*Travis Watson*
*Josh Mardis*
*John Lubatti*

--
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## Diagram of the Electromagnetic Spectrum
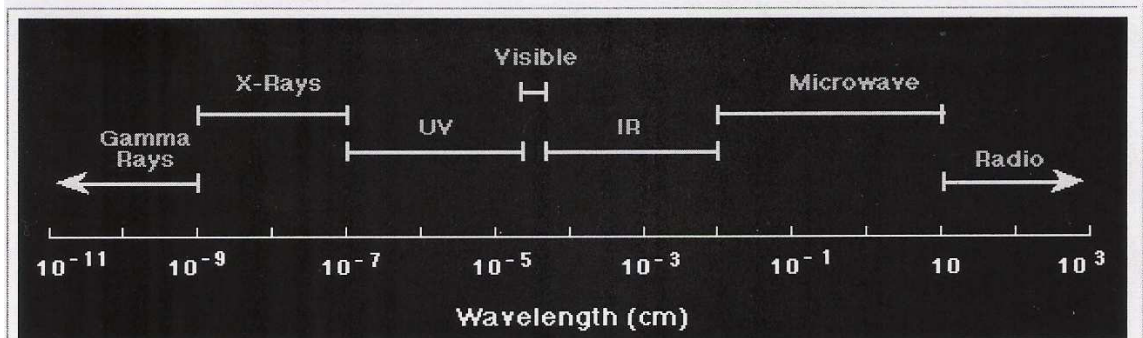


The electromagnetic spectrum

**Spectrum of Electromagnetic Radiation**

| Region | Wavelength (Angstroms) | Wavelength (centimeters) | Frequency (Hz) | Energy (eV) |
|---|---|---|---|---|
| Radio | $> 10^9$ | $> 10$ | $< 3 \times 10^9$ | $< 10^{-5}$ |
| Microwave | $10^9 - 10^6$ | $10 - 0.01$ | $3 \times 10^9 - 3 \times 10^{12}$ | $10^{-5} - 0.01$ |
| Infrared | $10^6 - 7000$ | $0.01 - 7 \times 10^{-5}$ | $3 \times 10^{12} - 4.3 \times 10^{14}$ | $0.01 - 2$ |
| Visible | $7000 - 4000$ | $7 \times 10^{-5} - 4 \times 10^{-5}$ | $4.3 \times 10^{14} - 7.5 \times 10^{14}$ | $2 - 3$ |
| Ultraviolet | $4000 - 10$ | $4 \times 10^{-5} - 10^{-7}$ | $7.5 \times 10^{14} - 3 \times 10^{17}$ | $3 - 10^3$ |
| X-Rays | $10 - 0.1$ | $10^{-7} - 10^{-9}$ | $3 \times 10^{17} - 3 \times 10^{19}$ | $10^3 - 10^5$ |
| Gamma Rays | $< 0.1$ | $< 10^{-9}$ | $> 3 \times 10^{19}$ | $> 10^5$ |

## Bond Energies for Various Bonds

### Bond Energies kJ/mol

| | | H | C | N | O | S | F | Cl | Br | I |
|---|---|---|---|---|---|---|---|---|---|---|
| H | Single Bond | 432 | | | | | | | | |
| C | Single Bond | 411 | 346 | | | | | | | |
| | Double Bond | | 602 | 615 | | | | | | |
| | Triple Bond | | 835 | 887 | | | | | | |
| N | Single Bond | 386 | 305 | 167 | | | | | | |
| | Double Bond | | | 418 | | | | | | |
| | Triple Bond | | | 942 | | | | | | |
| O | Single Bond | 459 | 358 | 201 | 142 | | | | | |
| | Double Bond | | 745 (799 in $CO_2$) | 607 | | | | | | |
| | Triple Bond | | 1072 | | | | | | | |
| | $O_2$ | | | | 494 | | | | | |
| S | Single Bond | 363 | 272 | – | – | 226 | | | | |
| S | $SO_2$ | | | | 532 | | | | | |
| S | $SO_3$ | | | | 469 | | | | | |
| F | Single Bond | 565 | 485 | 283 | 190 | 284 | 155 | | | |
| Cl | Single Bond | 428 | 327 | 313 | 218 | 255 | 249 | 240 | | |
| Br | Single Bond | 362 | 285 | – | 201 | 217 | 249 | 216 | 190 | |
| I | Single Bond | 295 | 213 | – | 201 | – | 278 | 208 | 175 | 149 |

# References and Links

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