UNIT I FUNDAMENTALS OF AIR BREATHING ENGINES.

Operating principles of piston engines

Four-stroke cycle used in gasoline/petrol engines. 1 = Intake, 2 = Compression, 3 = Power, 4 = Exhaust. The right blue side is the intake port and the left brown side is the exhaust port. The cylinder wall is a thin sleeve surrounding the piston head which creates a space for the combustion of fuel and the genesis of mechanical energy.

A four-stroke engine (also known as four cycle) is an internal combustion (IC) engine in which the piston completes four separate strokes while turning a crankshaft. A stroke refers to the full travel of the piston along the cylinder, in either direction. The four separate strokes are termed:

Intake: This stroke of the piston begins at top dead center (T.D.C.) and ends at bottom dead center (B.D.C.). In this stroke the intake valve must be in the open position while the piston pulls an air-fuel mixture into the cylinder by producing vacuum pressure into the cylinder through its downward motion.

Compression: This stroke begins at B.D.C, or just at the end of the suction stroke, and ends at T.D.C. In this stroke the piston compresses the air-fuel mixture in preparation for ignition during the power stroke (below). Both the intake and exhaust valves are closed during this stage.

Power: This is the start of the second revolution of the four stroke cycle. At this point the crankshaft has completed a full 360 degree revolution. While the piston is at T.D.C. (the end of the compression stroke) the compressed air-fuel mixture is ignited by a spark plug (in a gasoline engine) or by heat generated by high compression (diesel engines), forcefully returning the piston to B.D.C. This stroke produces mechanical work from the engine to turn the crankshaft.

Exhaust: During the exhaust stroke, the piston once again returns from B.D.C. to T.D.C. while the exhaust valve is open. This action expels the spent air-fuel mixture through the exhaust valve.

An Otto Engine from 1920's US Manufacture

Nikolaus August Otto as a young man was a traveling salesman for a grocery concern. In his travels he encountered the internal combustion engine built in Paris by Belgian expatriate Jean Joseph Etienne Lenoir. In 1860, Lenoir successfully created a double-acting engine that ran on illuminating gas at 4% efficiency. The 18 litre Lenoir Engine produced only 2 horsepower. The Lenoir engine ran on illuminating gas made from coal, which had been developed in Paris by Philip Lebon.In testing a replica of the Lenoir engine in 1861 Otto became aware of the effects of compression on the fuel charge. In 1862, Otto attempted to produce an engine to improve on the poor efficiency and reliability of the Lenoir engine.

He tried to create an engine that would compress the fuel mixture prior to ignition, but failed as that engine would run no more than a few minutes prior to its destruction. Many other engineers were trying to solve the problem, with no success.In 1864, Otto and Eugen Langen founded the first internal combustion engine production company, NA Otto and Cie (NA Otto and Company). Otto and Cie succeeded in creating a successful atmospheric engine that same year.[1] The factory ran out of space and was moved to the town of Deutz, Germany in 1869 where the company was renamed to Deutz Gasmotorenfabrik AG (The Deutz Gas Engine Manufacturing Company).[1] In 1872, Gottlieb Daimler was technical director and Wilhelm Maybach was the head of engine design. Daimler was a gunsmith who had worked on the Lenoir engine. By 1876, Otto and Langen succeeded in creating the first internal combustion engine that compressed the fuel mixture prior to combustion for far higher efficiency than any engine created to this time.

Daimler and Maybach left their employ at Otto and Cie and developed the first high-speed Otto engine in 1883. In 1885, they produced the first automobile to be equipped with an Otto engine. The Daimler Reitwagen used a hot-tube ignition system and the fuel known as Ligroin to become the world's first vehicle powered by an internal combustion engine. It used a four-stroke engine based on Otto's design. The following year Karl Benz produced a four-stroke engine automobile that is regarded as the first car.In 1884, Otto's company, then known as Gasmotorenfabrik Deutz (GFD), developed electric ignition and the carburetor. In 1890, Daimler and Maybach formed a company known as Daimler Motoren Gesellschaft. Today, that company is Daimler-Benz.

The Atkinson Gas Cycle

The Atkinson cycle engine is a type of single stroke internal combustion engine invented by James Atkinson in 1882. The Atkinson cycle is designed to provide efficiency at the expense of power density, and is used in some modern hybrid electric applications.

The original Atkinson cycle piston engine allowed the intake, compression, power, and exhaust strokes of the four-stroke cycle to occur in a single turn of the crankshaft and was designed to avoid infringing certain patents covering Otto cycle engines.

Due to the unique crankshaft design of the Atkinson, its expansion ratio can differ from its compression ratio and, with a power stroke longer than its compression stroke, the engine can achieve greater thermal efficiency than a traditional piston engine. While Atkinson's original design is no more than a historical curiosity, many modern engines use unconventional valve timing to produce the effect of a shorter compression stroke/longer power stroke, thus realizing the fuel economy improvements the Atkinson cycle can provide.

Diesel cycle

Audi Diesel R15 at Le Mans

The diesel engine is a technical refinement of the 1876 Otto Cycle engine. Where Otto had realized in 1861 that the efficiency of the engine could be increased by first compressing the fuel mixture prior to its ignition, Rudolph Diesel wanted to develop a more efficient type of engine that could run on much heavier fuel. The Lenoir, Otto Atmospheric, and Otto Compression engines (both 1861 and 1876) were designed to run on Illuminating Gas (coal gas). With the same motivation as Otto, Diesel wanted to create an engine that would give small industrial concerns their own power source to enable them to compete against larger companies, and like Otto to get away from the requirement to be tied to a municipal fuel supply. Like Otto, it took more than a decade to produce the high compression engine that could self-ignite fuel sprayed into the cylinder. Diesel used an air spray combined with fuel in his first engine.

During initial development, one of the engines burst nearly killing him. He persisted and finally created an engine in 1893. The high compression engine, which ignites its fuel by the heat of compression is now called the Diesel engine whether a four-stroke or two-stroke design.

The four-stroke diesel engine has been used in the majority of heavy duty applications for many decades. It uses a heavy fuel containing more energy and requiring less refinement to produce. The most efficient Otto Cycle engines run near 30% efficiency.

Thermodynamic Analysis

The idealized four-stroke Otto cycle p-V diagram: the intake (A) stroke is performed by an isobaric expansion, followed by the compression (B) stroke, performed by an adiabatic compression. Through the combustion of fuel an isochoric process is produced, followed by an adiabatic expansion, characterizing the power (C) stroke. The cycle is closed by an isochoric process and an isobaric compression, characterizing the

Exhaust (D) stroke.

The thermodynamic analysis of the actual four-stroke or two-stroke cycles is not a simple task. However, the analysis can be simplified significantly if air standard assumptions [5] are utilized. The resulting cycle, which closely resembles the actual operating conditions, is the Otto cycle.

During the normal operation of the engine as the fuel mixture is being compressed an electric arc is created to ignite the fuel. At low rpm this occurs close to TDC (Top Dead Centre). As engine rpm rises the spark point is moved earlier in the cycle so that the fuel charge can be ignited while it is still being compressed. We can see this advantage reflected in the various Otto engines designs. The atmospheric (non-compression) engine operated at 12% efficiency. The compressed charge engine had an operating efficiency of 30%.

Fuel Considerations

The problem with compressed charge engines is that the temperature rise of the compressed charge can cause pre-ignition. If this occurs at the wrong time and is too energetic, it can damage the engine. Different fractions of petroleum have widely varying flash points (the temperatures at which the fuel may self-ignite). This must be taken into account in engine and fuel design.

The tendency for the compressed fuel mixture to ignite early is limited by the chemical composition of the fuel. There are several grades of fuel to accommodate differing performance levels of engines. The fuel is altered to change its self-ignition temperature. There are several ways to do this. As engines are designed with higher compression ratios the result is that pre-ignition is much more likely to occur since the fuel mixture is compressed to a higher temperature prior to deliberate ignition. The higher temperature more effectively evaporates fuels such as gasoline, which increases the efficiency of the compression engine. Higher Compression ratios also mean that the distance that the piston can push to produce power is greater (which is called the Expansion ratio).

The octane rating of a given fuel is a measure of the fuel's resistance to self-ignition. A fuel with a higher numerical octane rating allows for a higher compression ratio, which extracts more energy from the fuel and more effectively converts that energy into useful work while at the same time preventing engine damage from pre-ignition. High Octane fuel is also more expensive.

Diesel engines by their nature do not have concerns with pre-ignition. They have a concern with whether or not combustion can be started. The description of how likely Diesel fuel is to ignite is called the Cetane rating. Because Diesel fuels are of low volatility, they can be very hard to start when cold. Various techniques are used to start a cold Diesel engine, the most common being the use of a glow plug.

Design and engineering principle, Power output limitations

The four-stroke cycle

1=TDC 2=BDC A: Intake B: Compression C: Power D: Exhaust

The maximum amount of power generated by an engine is determined by the maximum amount of air ingested. The amount of power generated by a piston engine is related to its size (cylinder volume), whether it is a two-stroke or four-stroke design, volumetric efficiency, losses, air-to-fuel ratio, the calorific value of the fuel, oxygen content of the air and speed (RPM). The speed is ultimately limited by material strength and lubrication. Valves, pistons and connecting rods suffer severe acceleration forces. At high engine speed, physical breakage and piston ring flutter can occur, resulting in power loss or even engine destruction. Piston ring flutter occurs when the rings oscillate vertically within the piston grooves they reside in. Ring flutter compromises the seal between the ring and the cylinder wall, which causes a loss of cylinder pressure and power. If an engine spins too quickly, valve springs cannot act quickly enough to close the valves. This is commonly referred to as 'valve float', and it can result in piston to valve contact, severely damaging the engine. At high speeds the lubrication of piston cylinder wall interface tends to break down. This limits the piston speed for industrial engines to about 10 m/s.

Intake/exhaust port flow

The output power of an engine is dependent on the ability of intake (air–fuel mixture) and exhaust matter to move quickly through valve ports, typically located in the cylinder head. To increase an engine's output power, irregularities in the intake and exhaust paths, such as casting flaws, can be removed, and, with the aid of an air flow bench, the radii of valve port turns and valve seat configuration can be modified to reduce resistance. This process is called porting, and it can be done by hand or with a CNC machine

Supercharging

One way to increase engine power is to force more air into the cylinder so that more power can be produced from each power stroke. This can be done using some type of air compression device known as a supercharger, which can be powered by the engine crankshaft.

Supercharging increases the power output limits of an internal combustion engine relative to its displacement. Most commonly, the supercharger is always running, but there have been designs that allow it to be cut out or run at varying speeds (relative to engine speed). Mechanically driven supercharging has the disadvantage that some of the output power is used to drive the supercharger, while power is wasted in the high pressure exhaust, as the air has been compressed twice and then gains more potential volume in the combustion but it is only expanded in one stage.

Turbocharging

A turbocharger is a supercharger that is driven by the engine's exhaust gases, by means of a turbine. It consists of a two piece, high-speed turbine assembly with one side that compresses the intake air, and the other side that is powered by the exhaust gas outflow.

When idling, and at low-to-moderate speeds, the turbine produces little power from the small exhaust volume, the turbocharger has little effect and the engine operates nearly in a naturally aspirated manner. When much more power output is required, the engine speed and throttle opening are increased until the exhaust gases are sufficient to 'spool up' the turbocharger's turbine to start compressing much more air than normal into the intake manifold.

Turbocharging allows for more efficient engine operation because it is driven by exhaust pressure that would otherwise be (mostly) wasted, but there is a design limitation known as turbo lag. The increased engine power is not immediately available due to the need to sharply increase engine RPM, to build up pressure and to spin up the turbo, before the turbo starts to do any useful air compression. The increased intake volume causes increased exhaust and spins the turbo faster, and so forth until steady high power operation is reached. Another difficulty is that the higher exhaust pressure causes the exhaust gas to transfer more of its heat to the mechanical parts of the engine.

Rod and piston-to-stroke ratio

The rod-to-stroke ratio is the ratio of the length of the connecting rod to the length of the piston stroke. A longer rod reduces sidewise pressure of the piston on the cylinder wall and the stress forces, increasing engine life. It also increases the cost and engine height and weight.

A "square engine" is an engine with a bore diameter equal to its stroke length. An engine where the bore diameter is larger than its stroke length is an over square engine, conversely, an engine with a bore diameter that is smaller than its stroke length is an under square engine.

Valve train

The valves are typically operated by a camshaft rotating at half the speed of the crankshaft. It has a series of cams along its length, each designed to open a valve during the appropriate part of an intake or exhaust stroke. A tappet between valve and cam is a contact surface on which the cam slides to open the valve. Many engines use one or more camshafts “above” a row (or each row) of cylinders, as in the illustration, in which each cam directly actuates a valve through a flat tappet. In other engine designs the camshaft is in the crankcase, in which case each cam usually contacts a push rod, which contacts a rocker arm that opens a valve, or in case of a flathead engine a push rod is not necessary. The overhead cam design typically allows higher engine speeds because it provides the most direct path between cam and valve.

Valve clearance

Valve clearance refers to the small gap between a valve lifter and a valve stem that ensures that the valve completely closes. On engines with mechanical valve adjustment, excessive clearance causes noise from the valve train. A too small valve clearance can result in the valves not closing properly, this results in a loss of performance and possibly overheating of exhaust valves. Typically, the clearance must be readjusted each 20,000 miles (32,000 km) with a feeler gauge. Most modern production engines use hydraulic lifters to automatically compensate for valve train component wear. Dirty engine oil may cause lifter failure.

Energy balance

Otto engines are about 30% efficient; in other words, 30% of the energy generated by combustion is converted into useful rotational energy at the output shaft of the engine, while the remainder being losses due to waste heat, friction and engine accessories.[6] There are a number of ways to recover some of the energy lost to waste heat. The use of a Turbocharger in Diesel engines is very effective by boosting incoming air pressure and in effect provides the same increase in performance as having more displacement. The Mack Truck Company, decades ago, developed a turbine system that converted waste heat into kinetic energy that it fed back into the engine's transmission. In 2005, BMW announced the development of the turbo steamer, a two-stage heat-recovery system similar to the Mack system that recovers 80% of the energy in the exhaust gas and raises the efficiency of an Otto engine by 15%. By contrast, a six-stroke engine may reduce fuel consumption by as much as 40%.

Modern engines are often intentionally built to be slightly less efficient than they could otherwise be. This is necessary for emission controls such as exhaust gas recirculation and catalytic converters that reduce smog and other atmospheric pollutants. Reductions in efficiency may be counteracted with an engine control unit using lean burn techniques.

In the United States, the Corporate Average Fuel Economy mandates that vehicles must achieve an average of 34.9 miles per gallon (mpg) compared to the current standard of 25 mpg. As automakers look to meet these standards by 2016, new ways of engineering the traditional internal combustion engine (ICE) have to be considered. Some potential solutions to increase fuel efficiency to meet new mandates include firing after the piston is farthest from the crankshaft, known as top dead centre, and applying the Miller cycle. Together, this redesign could significantly reduce fuel consumption and NOx emissions.

Top dead center, before cycle begins 1 – Intake stroke 2 – Compression stroke

Starting position, intake stroke, and compression stroke.

Fuel ignites 3 – Power stroke 4 – Exhaust stroke

Ignition of fuel, power stroke, and exhaust stroke.

Components

Valves

Cylinder head porting Corliss Intake Exhaust Multi Overhead Piston Poppet Side Sleeve Slide Rotary valve Variable valve timing Camless Desmodromic

Fuel supplies

Carburetor Gasoline direct injection Common rail

Mechanisms

Cam Camshaft Overhead camshaft Connecting rod Crank Crankshaft Scotch yoke Swashplate Rhombic drive

Linkages

Peaucellier–Lipkin Watt's

Antique City car Classic Compact Compact executive Compact MPV Compact SUV Crossover SUV Custom Hot rod Lead sled Lowrider Street rod T-bucket Economy Executive Family car (large) Full-size Grand tourer Hot hatch Kei Leisure activity vehicle Luxury Microcar Mid-size Mini MPV Mini SUV Minivan / Multi-purpose vehicle (MPV) Muscle luxury Pony Sport compact Sport utility vehicle (SUV) Sports car Subcompact Supercar Supermini Truck Ute Van Voiturette

Body styles

2+2 Baquet Barchetta Berlinetta Brougham Cabrio coach Cabriolet / Convertible Coupé Coupé de Ville Coupé utility Drophead coupe (Convertible) Fastback Hardtop Hatchback Landaulet Liftback Limousine Multi-stop truck Notchback Panel van Phaeton Pickup truck Quad coupé Retractable hardtop Roadster Runabout Saloon / Sedan Sedan delivery Sedanca de Ville (Coupé de Ville) Shooting-brake Spider / Spyder (Roadster) Station wagon Targa top Torpedo Touring car Town car (Coupé de Ville) T-top Vis-à-vis

Thrust is the force which moves an aircraft through the air. Thrust is generated by the propulsion system of the airplane.

How is thrust generated?

Thrust is a mechanical force which is generated through the reaction of accelerating a mass of gas, as explained by Newton's third law of motion. A gas or working fluid is accelerated to the rear and the engine and aircraft are accelerated in the opposite direction. To accelerate the gas, we need some kind of propulsion system. We will discuss the details of various propulsion systems on some other pages. For right now, let us just think of the propulsion system as some machine which accelerates a gas.

From Newton's second law of motion, we can define a force F to be the change in momentum of an object with a change in time. Momentum is the object's mass m times the velocity V. So, between two times t1 and t2, the force is given by:

$$F = ((m * V)2 - (m * V)1) / (t2 - t1)$$

If we keep the mass constant and just change the velocity with time we obtain the simple force equation - force equals mass time acceleration a

$$F = m * a$$

If we are dealing with a solid, keeping track of the mass is relatively easy; the molecules of a solid are closely bound to each other and a solid retains its shape. But if we are dealing with a fluid (liquid or gas) and particularly if we are dealing with a moving fluid, keeping track of the mass gets tricky. For a moving fluid, the important parameter is the mass flow rate. Mass flow rate is the amount of mass moving through a given plane over some amount of time. Its dimensions are mass/time (kg/sec, slug/sec, ...) and it is equal to the density r times the velocity V times the area A. Aerodynamicists denote this parameter as m dot (m with a little dot over the top).

m dot = r * V * A

Note: The "dot" notation is used a lot by mathematicians, scientists, and engineers as a symbol for "d/dt", which means the variable changes with a change in time. For example, we can write Newton's second law as either

F = d(mv)/dt or F = (mv)dot

So "m dot" is not simply the mass of the fluid, but is the mass flow rate, the mass per unit time.

Since the mass flow rate already contains the time dependence (mass/time), we can express the change in momentum across the propulsion device as the change in the mass flow rate times the velocity. We will denote the exit of the device as station "e" and the free stream as station "0". Then

F = (m dot * V)e - (m dot * V)0

A units check shows that on the right hand side of the equation:

mass/time * length/time = mass * length / time^2

This is the dimension of a force. There is an additional effect which we must account for if the exit pressure p is different from the free stream pressure. The fluid pressure is related to the momentum of the gas molecules and acts perpendicular to any boundary which we impose. If there is a net change of pressure in the flow there is an additional change in momentum. Across the exit area we may encounter an additional force term equal to the exit area Ae times the exit pressure minus the free stream pressure. The general thrust equation is then given by:

F = (m dot * V)e - (m dot * V)0 + (pe - p0) * Ae

Normally, the magnitude of the pressure-area term is small relative to the m dot-V terms. Let us look at this equation very carefully, for it has some interesting implications.

We see that there are two possible ways to produce high thrust. One way is to make the engine flow rate (m dot) as high as possible. As long as the exit velocity is greater than the free stream, entrance velocity, a high engine flow will produce high thrust. This is the design theory behind propeller aircraft and high-bypass turbofan engines. A large amount of air is processed each second, but the velocity is not changed very much. The other way to produce high thrust is to make the exit velocity very much greater than the incoming velocity. This is the design theory behind pure turbojets, turbojets with afterburners, and rockets. A moderate amount of flow is accelerated to a high velocity in these engines. If the exit velocity becomes very high, there are other physical processes which become important and affect the efficiency of the engine. These effects are described in detail on other pages at this site.

There is a simplified version of the general thrust equation that can be used for gas turbine engines. The nozzle of a turbine engine is usually designed to make the exit pressure equal to free stream. In that case, the pressure-area term in the general equation is equal to zero. The thrust is then equal to the exit mass flow rate times the exit velocity minus the free stream mass flow rate times the free stream velocity.

F = (m dot * V)e - (m dot * V)0

The first term on the right hand side of this equation is usally called the gross thrust of the engine, while the second term is called the ram drag. It is a drag term because it is subtracted from the gross thrust.

Since the exit mass flow rate is nearly equal to the free stream mass flow rate, and the free stream is all air, we can call the mass flow rate through the engine the engine airflow rate.

$$F = (m\ dot)eng * (Ve - V0)$$

We can further simplify by absorbing the engine airflow dependence into a more useful parameter called the specific thrust Fs. Specific thrust only depends on the velocity change across the engine.

$$Fs = F /(m\ dot)eng = (Ve - V0)$$

There is a different simplified version of the general thrust equation that can be used for rocket engines. Since a rocket carries its own oxygen on board, there is no ram drag for a rocket engine. The general equation simplifies to:

$$F = (m\ dot * V)e + (pe - p0) * Ae$$

We have to include the pressure correction term since a rocket nozzle produces a fixed exit pressure which in general is different than free stream pressure. There is a useful rocket performance parameter called the specific impulse Isp, that eliminates the mass flow dependence in the analysis.

$$Isp = Veq / go$$

where Veq is the equivalent velocity, which is equal to the nozzle exit velocity plus the pressure-area term, and g0 is the gravitational acceleration.

For both rockets and turbojets, the nozzle performs two important roles. The design of the nozzle determines the exit velocity for a given pressure and temperature. And because of flow choking in the throat of the nozzle, the nozzle design also sets the mass flow rate through the propulsion system. Therefore, the nozzle design determines the thrust of the propulsion system as defined on this page. You can investigate nozzle operation with our interactive thrust simulator.

You can view a short movie of "Orville and Wilbur Wright" discussing the thrust force and how it affected the flight of their aircraft. The movie file can be saved to your computer and viewed as a Podcast on your podcast player.

Most modern passenger and military aircraft are powered by gas turbine engines, which are also called jet engines. The first and simplest type of gas turbine is the turbojet. How does a turbojet work?

On this slide we show a schematic drawing of a turbojet engine. The parts of the engine are described on other slides. Here, we are concerned with what happens to the air that passes through the engine. Large amounts of surrounding air are continuously brought into the engine inlet. In England, they call this part the intake, which is probably a more accurate description, since the compressor pulls air into the engine. We have shown here a tube-shaped inlet, like one you would see on an airliner. But inlets come in many shapes and sizes depending on the aircraft's mission. At the rear of the inlet, the air enters the compressor. The compressor acts like many rows of airfoils, with each row producing a small jump in pressure. A compressor is like an electric fan and we have to supply energy to turn the compressor. At the exit of the compressor, the air is at a much higher pressure than free stream. In the burner a small amount of fuel is combined with the air and ignited. In a typical jet engine, 100 pounds of air/sec is combined with only 2 pounds of fuel/sec. Most of the hot exhaust has come from the surrounding air. Leaving the burner, the hot exhaust is passed through the turbine. The turbine works like a windmill. Instead of needing energy to turn the blades to make the air flow, the turbine extracts energy from a flow of gas by making the blades spin in the flow. In a jet engine we use the energy extracted by the turbine to turn the compressor by linking the compressor and the turbine by the central shaft. The turbine takes some energy out of the hot exhaust, but the flow exiting the turbine is at a higher pressure and temperature than the free stream flow. The flow then passes through the nozzle which is shaped to accelerate the flow. Because the exit velocity is greater than the free stream velocity, thrust is created as described by the thrust equation. For a jet engine, the exit mass flow is nearly equal to the free stream mass flow, since very little fuel is added to the stream. The amount of mass flow is usually set by flow choking in the nozzle throat.

The nozzle of the turbojet is usually designed to take the exhaust pressure back to free stream pressure. The thrust equation for a turbojet is then given by the general thrust equation with the pressure-area term set to zero. If the free stream conditions are denoted by a "0" subscript and the exit conditions by an "e" subscript, the thrust F is equal to the mass flow rate m dot times the velocity V at the exit minus the free stream mass flow rate times the velocity.

F = [m dot * V]e - [m dot * V]0

This equation contains two terms. Aerodynamicists often refer to the first term (m dot * V)e as the gross thrust since this term is largely associated with conditions in the nozzle. The second term (m dot * V)0 is called the ram drag and is usually associated with conditions in the inlet. For clarity, the engine thrust is then called the net thrust. Our thrust equation indicates that net thrust equals gross thrust minus ram drag. If we divide both sides of the equation by the mass flow rate, we obtain an efficiency parameter called the specific thrust that greatly simplifies the performance analysis for turbine engines.

THRUST AUGMENTATION

General

Increasing engine power cannot be achieved just by adding more fuel; this would simply change the air to fuel ratio and result in unburnt fuel being wasted and passing through the

exhaust. More power means adding more air and fuel.Boosters are a type of forced air induction system; they work by compressing the air flowing into the engine. The advantage

of this is that more air (approximately 50%) is fed into the engine, and more air means that more fuel can be added. More air and fuel means more power is developed by the engine, this can significantly improve the power-to-weight ratio for the engine

There are two types of booster: -

Supercharging and Turbocharging

Supercharging

This is an air compressor driven by the engine mechanically via a gear train or belt drive. Superchargers can take approximately 20% of the engine power to drive them, but can

increase overall engine power up to 50% or more, giving a net gain of 30%+ power.

Turbocharging This is a similar air compressor driven by the engine exhaust gases passing through a turbine. Turbo's take very little power from the engine to drive them, therefore the net gain in power is relatively greater. Operating Differences Turbochargers can suffer from what is known as 'turbo-lag', this is where boost power is required but because of the low

engine rpm, there is insufficient energy in the exhaust to power up the turbine and therefore the air compressor. This can be overcome by fitting smaller turbos that come into

operation at earlier engine rpm, but these can then suffer excessive rotational speeds at higher throttle settings. These smaller turbos are protected from overspeeding by a 'wastegate';

this opens at a set maximum boost pressure and allows some exhaust gases to bypass the turbine, thereby restricting their maximum rpm. Superchargers do not suffer lag but can be ineffective at low rpm's. Different types of 'blowers' can be fitted which are more

effective at lower rpm's; these can be viewed via the internet. 3

THRUST AUGMENTATION – System

Booster location

They are fitted in the intake system of the engine between the air filter and the fuel controller.

The supercharger is normally fitted on the engine at the free end of the crankcase. In the case of the Merlin, the front end of the crankshaft drove the propeller, so the supercharger was fitted to the rear end of the engine. Turbo chargers can be fitted anywhere, but for convenience, they are usually fitted on the exhaust side of the engine. Either can be fitted as an aftermarket upgrade, all that is required is a change to the inlet and, for the turbo, exhaust pipe work.

Intercooling (not shown below) Compressing air increases its temperature, this can increase the risk of premature detonation, i.e. before the spark plug ignites the mixture. Reducing the temperature can improve the efficiency of the boost. Intercoolers are fitted in the induction system between the booster and fuel controller and work exactly the same as engine cooling radiators, both use ambient, or slipstream air as the cooling medium.

Intercoolers have air both sides, with the ambient air cooling the compressed air from the booster.

Water or Water/Alcohol Injection Fluid injection systems were introduced primarily to cool the boosted air to the engine, thereby reducing detonation, also termed pre-ignition, knocking, or pinging. Pre-ignition can cause severe damage to the engine such as splitting and holing pistons. Adding fluid, either at the inlet to the intercooler, beginning of the inlet manifold or just before the inlet valve, reduces the heat of the inlet air to the engine.

This protects against detonation and allows more fuel to be added. The extra fuel can be either the alcohol additive or an increase in the normal fuel. Fluid injection systems have disadvantages which outweigh the advantages, except for specific applications, such as military aircraft or racing aircraft. WWII fighters often incorporated the system to enable fast take off and climb to intercept enemy bombers.

Operation

Irrespective of the way in which the compressor is driven, the compressor works by using centrifugal force. This spins the air between the rotor vanes, forcing it from the centre out to the rim, where the exit area is smaller than the inlet area, then pushes the air through the static fins or stator vanes, arranged around the rim of the rotor. Half of the pressure rise across the whole of the booster is achieved by the rotor, the other half being ahcieved in the

stator vanes. This compressed air is then piped to the fuel controller (via and intercooler if fitted), and then to the engine. General Engine boosting helps at high altitudes, where the air is less dense. Normal engines will experience reduced power at high altitudes because for each stroke of the piston, the engine will get a smaller mass of air. Boosting and engines power can restore engine power due to the effects of altitude. This makes sense when you consider

that airplanes spend most of their time at high altitudes, where significantly less oxygen is available for combustion. With the introduction of superchargers, airplanes were able to fly higher without losing engine performance One of the most famous engines from WWII featured a supercharger, the MERLIN, fitted to the Spitfire, Hurricane,