ACS COLLEGE OF ENGINEERING

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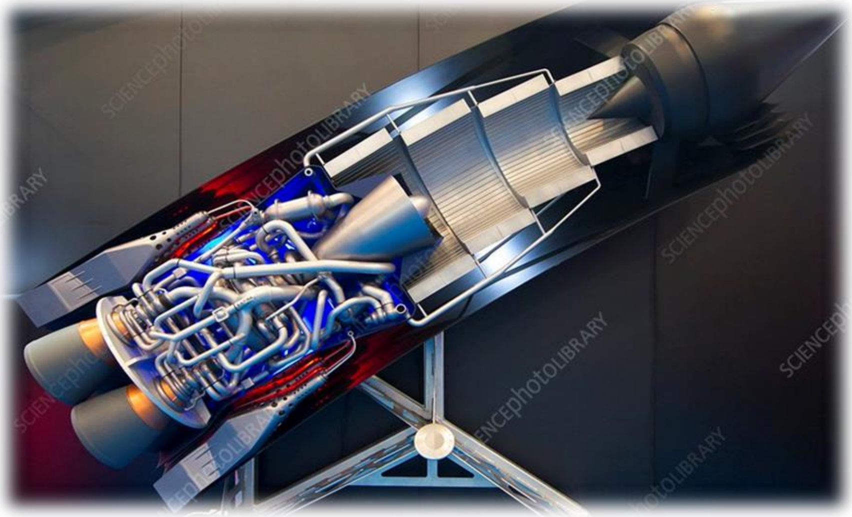
DEPARTMENT OF AERONAUTICAL ENGINEERING



Aircraft Propulsion Lab Manual

NAME : ....

USN : ....

SEMESTER &YEAR : ....

ACADEMIC YEAR : ....

LIST OF EXPERIMENTS

STUDY OF PISTON ENGINES

INTRODUCTION

A Piston engine is a heat engine that uses one or more pistons to convert pressure into a rotating motion. The main types are the internal combustion engine used extensively in motor vehicles, the steam engine which was the mainstay of the industrial revolution and the niche application Stirling engine.

There may be one or more pistons. Each piston is inside a cylinder, into which a gas is introduced, either already hot and under pressure (steam engine), or heated inside the cylinder either by ignition of a fuel air mixture (internal combustion engine) or by contact with a hot heat exchanger in the cylinder (Stirling engine). The hot gases expand, pushing the piston to the bottom of the cylinder. The piston is returned to the cylinder top (Top Dead Centre) either by a flywheel or the power from other pistons connected to the same shaft. In most types the expanded or "exhausted" gases are removed from the cylinder by this stroke. The exception is the Stirling engine, which repeatedly heats and cools the same sealed quantity of gas.

In some designs the piston may be powered in both directions in the cylinder in which case it is said to be double acting.

COMPONENTS AND THEIR FUNCTIONS

The major components seen are connecting road, crank shaft(swash plate), crank case, piston rings, spark plug, cylinder, flywheel, crank pin and valves or ports.

In all types the linear movement of the piston is converted to a rotating movement via a connecting rod and a crankshaft or by a swash plate. A flywheel is often used to ensure smooth rotation. The more cylinders a reciprocating engine has, the more vibration-free (smoothly) it can run also the higher the combined piston displacement volume it has the more power it is capable of producing.

A seal needs to be made between the sliding piston and the walls of the cylinder so that the high pressure gas above the piston does not leak past it and reduce the efficiency of the engine. This seal is provided by one or more piston rings. These are rings made of a hard metal which are sprung into a circular grove in the piston head. The rings fit tightly in the groove and press against the cylinder wall to form a seal.

ENGINE TERMINOLOGY

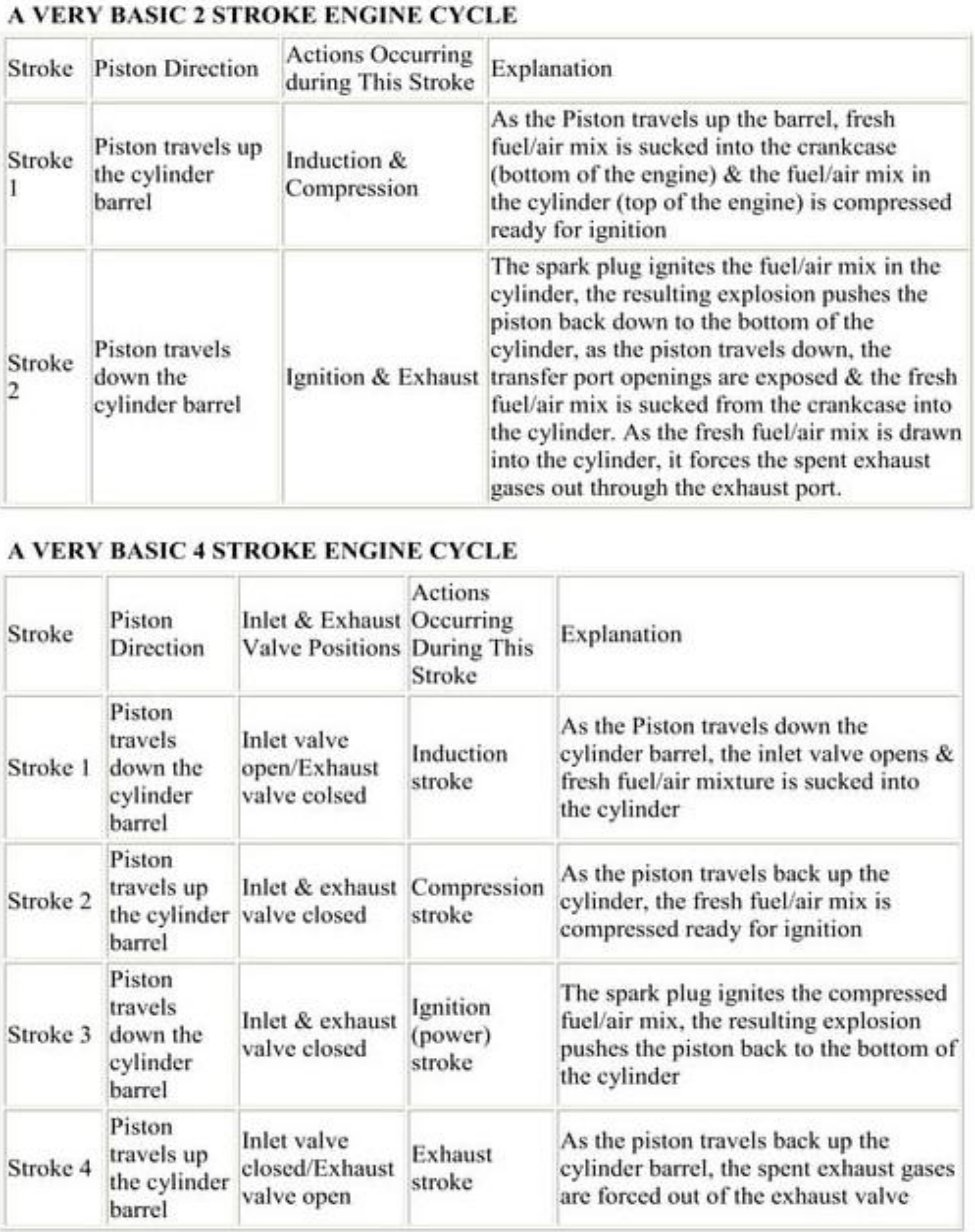
Stroke: Either the up or down movement of the piston from the top to the bottom or bottom to top of the cylinder (So the piston going from the bottom of the cylinder to the top would be 1 stroke, from the top back to the bottom would be another stroke)

Suction: As the piston travels down the cylinder head, it 'sucks' the fuel/air mixture into the cylinder. This is known also as 'Induction'.

Compression: As the piston travels up to the top of the cylinder head, it 'compresses' the fuel/air mixture from the carburetor in the top of the cylinder head, making the fuel/air mix ready for igniting by the spark plug. This is known as 'Compression'.

Ignition: When the spark plug ignites the compressed fuel/air mixture, sometimes referred to as the power stroke.

Exhaust: As the piston returns back to the top of the cylinder head after the fuel/air mix has been ignited, the piston pushes the burnt 'exhaust' gases out of the cylinder & through the exhaust system.



A VERY BASIC 2 STROKE ENGINE CYCLE

Stroke	Piston Direction	Actions Occurring during This Stroke	Explanation
Stroke 1	Piston travels up the cylinder barrel	Induction & Compression	As the Piston travels up the barrel, fresh fuel/air mix is sucked into the crankcase (bottom of the engine) & the fuel/air mix in the cylinder (top of the engine) is compressed ready for ignition
Stroke 2	Piston travels down the cylinder barrel	Ignition & Exhaust	The spark plug ignites the fuel/air mix in the cylinder, the resulting explosion pushes the piston back down to the bottom of the cylinder, as the piston travels down, the transfer port openings are exposed & the fresh fuel/air mix is sucked from the crankcase into the cylinder. As the fresh fuel/air mix is drawn into the cylinder, it forces the spent exhaust gases out through the exhaust port.

A VERY BASIC 4 STROKE ENGINE CYCLE

Stroke	Piston Direction	Inlet & Exhaust Valve Positions	Actions Occurring During This Stroke	Explanation
Stroke 1	Piston travels down the cylinder barrel	Inlet valve open/Exhaust valve colsed	Induction stroke	As the Piston travels down the cylinder barrel, the inlet valve opens & fresh fuel/air mixture is sucked into the cylinder
Stroke 2	Piston travels up the cylinder barrel	Inlet & exhaust valve closed	Compression stroke	As the piston travels back up the cylinder, the fresh fuel/air mix is compressed ready for ignition
Stroke 3	Piston travels down the cylinder barrel	Inlet & exhaust valve closed	Ignition (power) stroke	The spark plug ignites the compressed fuel/air mix, the resulting explosion pushes the piston back to the bottom of the cylinder
Stroke 4	Piston travels up the cylinder barrel	Inlet valve closed/Exhaust valve open	Exhaust stroke	As the piston travels back up the cylinder barrel, the spent exhaust gases are forced out of the exhaust valve

TYPES OF PISTON ENGINES

It is common for such engines to be classified by the number and alignment of cylinders and the total volume of displacement of gas by the pistons moving in the cylinders usually measured in cubic centimeters (cc).

IN-LINE ENGINE

This type of engine has cylinders lined up in one row. It typically has an even number of cylinders, but there are instances of three- and five- cylinder engines. An in-line engine may be either air cooled or liquid cooled. It is better suited for streamlining. If the engine crankshaft is located above the cylinders, it is called an inverted engine. Advantages of mounting the crankshaft this way include shorter landing gear and better pilot visibility. An in-line engine has a higher weight-to-horsepower ratio than other aircraft engines. A disadvantage of this type of engine is that the larger it is, the harder it is to cool. Due to this, airplanes that use an inline engine use a low- to medium-horsepower engine, and are typically used by light aircraft.

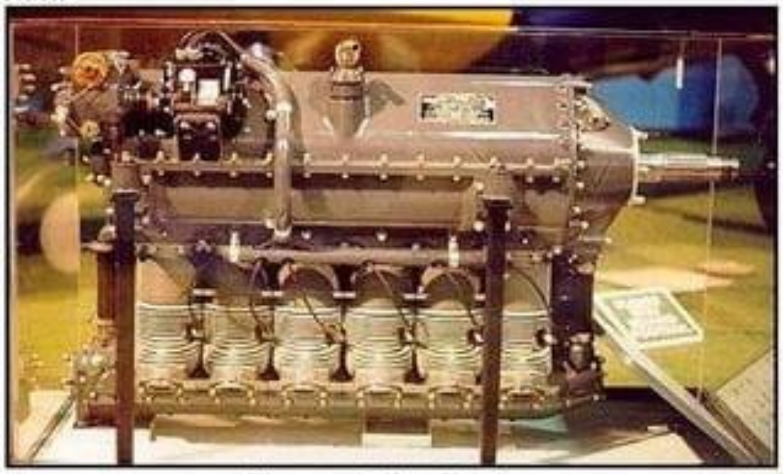


Figure: Inline Engine

OPPOSED ENGINE

A horizontally opposed engine, also called a flat or boxer engine has two banks of cylinders on opposite sides of a centrally located crankcase.

Figure: A ULPower UL260i horizontally opposed air-cooled aero engine

The engine is either air-cooled or liquid-cooled, but air-cooled versions predominate. Opposed engines are mounted with the crankshaft horizontal in airplanes, but may be mounted with the crankshaft vertical in helicopters. Due to the cylinder layout, reciprocating forces tend to cancel, resulting in a smooth running engine. Unlike a radial engine, an opposed engine does not experience any problems with hydrostatic lock.[citation needed]

V-TYPE ENGINE

Cylinders in this engine are arranged in two in-line banks, tilted 30-60 degrees apart from each other. The vast majority of V engines are water-cooled.

Figure: A Rolls-Royce Merlin V-12 Engine

The V design provides a higher power-to-weight ratio than an inline engine, while still providing a small frontal area. Perhaps the most famous example of this design is the legendary Rolls-Royce Merlin engine, a 27-litre (1649 in3) 60° V12 engine used in, among others, the Spitfires that played a major role in the Battle of Britain.

RADIAL ENGINE

This type of engine has one or more rows of cylinders arranged in a circle around a centrally located crankcase.

Figure: A Pratt & Whitney R-2800 Engine

Each row must have an odd number of cylinders in order to produce smooth operation. A radial engine has only one crank throw per row and a relatively small crankcase, resulting in a favorable power-to-weight ratio. Because the cylinder arrangement exposes a large amount of the engine's heat-radiating surfaces to the air and tends to cancel reciprocating forces, radials tend to cool evenly and run smoothly.

The lower cylinders, which are under the crankcase, may collect oil when the engine has been stopped for an extended period. If this oil is not cleared from the cylinders prior to starting the engine, serious damage due to hydrostatic lock may occur.

In military aircraft designs, the large frontal area of the engine acted as an extra layer of armor for the pilot. However, the large frontal area also resulted in an aircraft with a blunt and aerodynamically inefficient profile.

ROTARY ENGINE

Early in World War I, when aircraft were first being used for military purposes, it became apparent that existing inline engines were too heavy for the amount of power needed. Aircraft designers needed an engine that was lightweight, powerful, cheap, and easy to manufacture in large quantities. The rotary engine met these goals. Rotary engines have all the cylinders in a circle around the crankcase like a radial engine (see below), but the difference is that the crankshaft is bolted to the airframe, and the propeller is bolted to the engine case.

Figure:Le Rhone 9C rotary aircraft engine.

The entire engine rotates with the propeller, providing plenty of airflow for cooling regardless of the aircraft's forward speed. Some of these engines were a two-stroke design, giving them a high specific power and power-to-weight ratio. Unfortunately, the severe gyroscopic effects from the heavy rotating engine made the aircraft very difficult to fly. The engines also consumed large amounts of castor oil, spreading it all over the airframe and creating fumes which were nauseating to the pilots. Engine designers had always been aware of the many limitations of the rotary engine. When the static style engines became more reliable, gave better specific weights and fuel consumption, the days of the rotary engine were numbered.

STUDY OF JET ENGINE

BRAYTON CYCLE:

A Brayton-type engine consists of three components:

1. A gas compressor
2. A mixing chamber
3. An expander

In the original 19th-century Brayton engine, ambient air is drawn into a piston compressor, where it is compressed; ideally an isentropic process. The compressed air then runs through a mixing chamber where fuel is added, an isobaric process. The heated (by compression), pressurized air and fuel mixture is then ignited in an expansion cylinder and energy is released, causing the heated air and combustion products to expand through a piston/cylinder; another ideally isentropic process. Some of the work extracted by the piston/cylinder is used to drive the compressor through a crankshaft arrangement.

The term Brayton cycle has more recently been given to the gas turbine engine. This also has three components:

1. A gas compressor
2. A burner (or combustion chamber)
3. An expansion turbine

IDEAL BRAYTON CYCLE:

- Isentropic process - Ambient air is drawn into the compressor, where it is pressurized.
- isobaric process - The compressed air then runs through a combustion chamber, where fuel is burned, heating that air—a constant-pressure process, since the chamber is open to flow in and out.
- isentropic process - The heated, pressurized air then gives up its energy, expanding through a turbine (or series of turbines). Some of the work extracted by the turbine is used to drive the compressor.
- isobaric process - Heat rejection (in the atmosphere).

ACTUAL BRAYTON CYCLE:

- adiabatic process - Compression.
- isobaric process - Heat addition.
- adiabatic process - Expansion.
- isobaric process - Heat rejection.

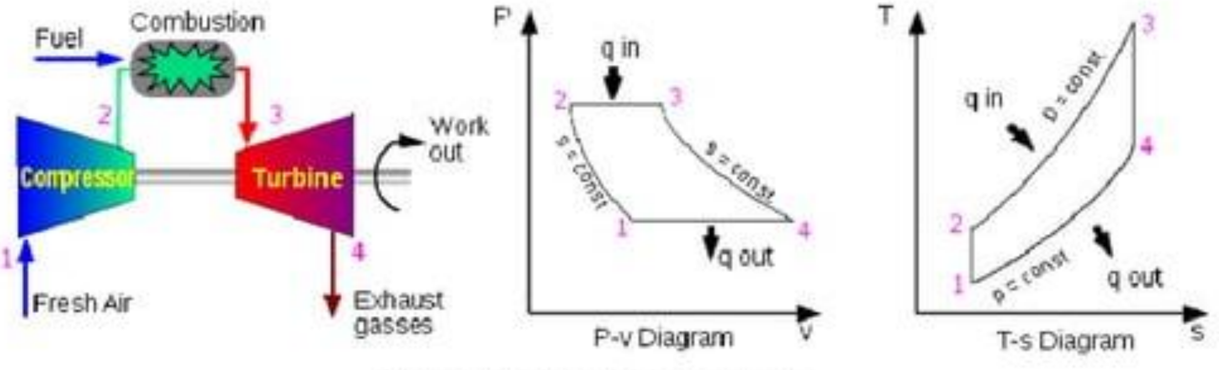


Figure: Idealized Brayton cycle

Since neither the compression nor the expansion can be truly isentropic, losses through the compressor and the expander represent sources of inescapable working inefficiencies. In general, increasing the compression ratio is the most direct way to increase the overall power output of a Brayton system.

The efficiency of the ideal Brayton cycle is , $\eta = 1 - \frac{T_1}{T_2} = 1 - \left(\frac{P_1}{P_2}\right)^{(\gamma-1)/\gamma}$

where γ is the heat capacity ratio.

Figure 1 indicates how the cycle efficiency changes with an increase in pressure ratio. Figure 2 indicates how the specific power output changes with an increase in the gas turbine inlet temperature for two different pressure ratio values.

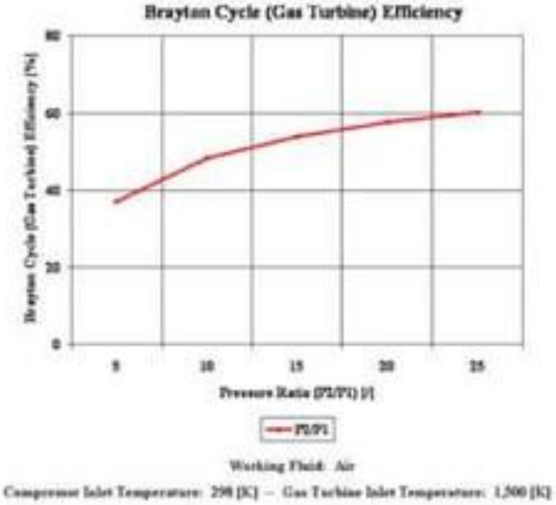


Figure 1: Brayton cycle efficiency

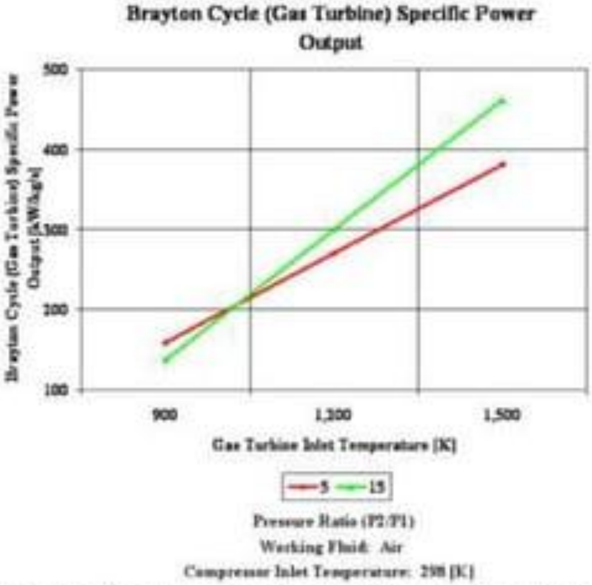


Figure 2: Brayton cycle specific power output

JET ENGINE:

A jet engine is a reaction engine that discharges a fast moving jet which generates thrust by jet propulsion in accordance with Newton's laws of motion. This broad definition of jet engines includes turbojets, turbofans, rockets, ramjets, and pulse jets. In general, most jet engines are internal combustion engines, but non-combusting forms also exist.

In common parlance, the term jet engine loosely refers to an internal combustion air breathing jet engine (a duct engine). These typically consist of an engine with a rotary (rotating) air compressor powered by a turbine ("Brayton cycle"), with the leftover power providing thrust via a propelling nozzle. These types of jet engines are primarily used by jet aircraft for long distance travel. Early jet aircraft used turbojet engines which were relatively inefficient for subsonic flight. Modern subsonic jet aircraft usually use high-bypass turbofan engines which offer high speed with fuel efficiency comparable (over long distances) to piston and propeller aero engines.

TYPES

There are a large number of different types of jet engines, all of which achieve forward thrust from the principle of jet propulsion.

AIRBREATHING:

Commonly aircraft are propelled by air breathing jet engines. Most air breathing jet engines that are in use are turbofan jet engines which give good efficiency at speeds just below the speed of sound.

TURBINE POWERED:

Gas turbines are rotary engines that extract energy from a flow of combustion gas. They have an upstream compressor coupled to a downstream turbine with a combustion chamber in-between. In aircraft engines, those three core components are often called the "gas generator." There are many different variations of gas turbines, but they all use a gas generator system of some type.

TURBOJET:

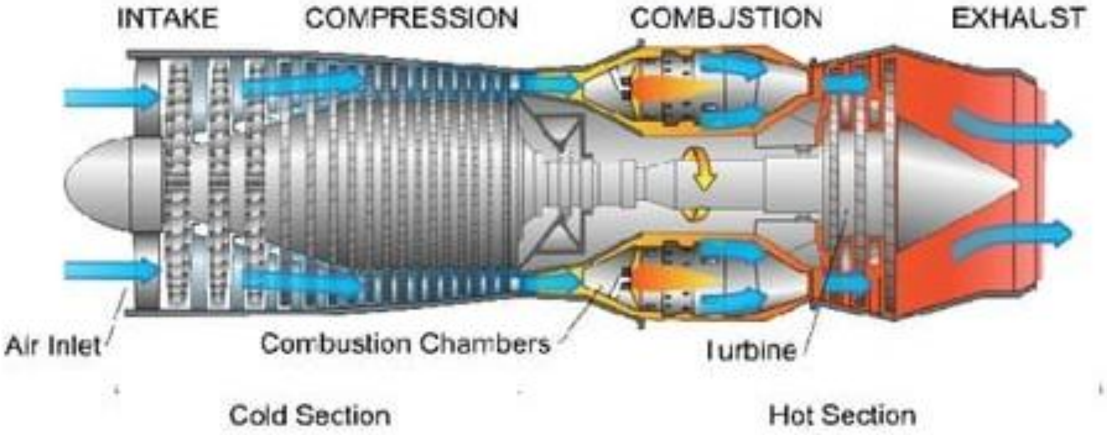


Figure: Turbojet engine

A turbojet engine is a gas turbine engine that works by compressing air with an inlet and a compressor (axial, centrifugal, or both), mixing fuel with the compressed air, burning the mixture in the combustor, and then passing the hot, high pressure air through a turbine and a nozzle. The compressor is powered by the turbine, which extracts energy from the expanding gas passing through it. The engine converts internal energy in the fuel to kinetic energy in the exhaust, producing thrust. All the air ingested by the inlet is passed through the compressor, combustor, and turbine, unlike the turbofan engine.

The turbojet is the oldest kind of general-purpose airbreathing jet engine. Two engineers, Frank Whittle in the United Kingdom and Hans von Ohain in Germany, developed the concept independently into practical engines during the late 1930s.

Turbojets consist of an air inlet, an air compressor, a combustion chamber, a gas turbine (that drives the air compressor) and a nozzle. The air is compressed into the chamber, heated and expanded by the fuel combustion and then allowed to expand out through the turbine into the nozzle where it is accelerated to high speed to provide propulsion.

Turbojets are quite inefficient if flown below about Mach 2[citation needed] and very noisy. Most modern aircraft use turbofans instead for economic reasons. Turbojets are still very common in medium range cruise missiles, due to their high exhaust speed, low frontal area and relative simplicity.

DESIGN

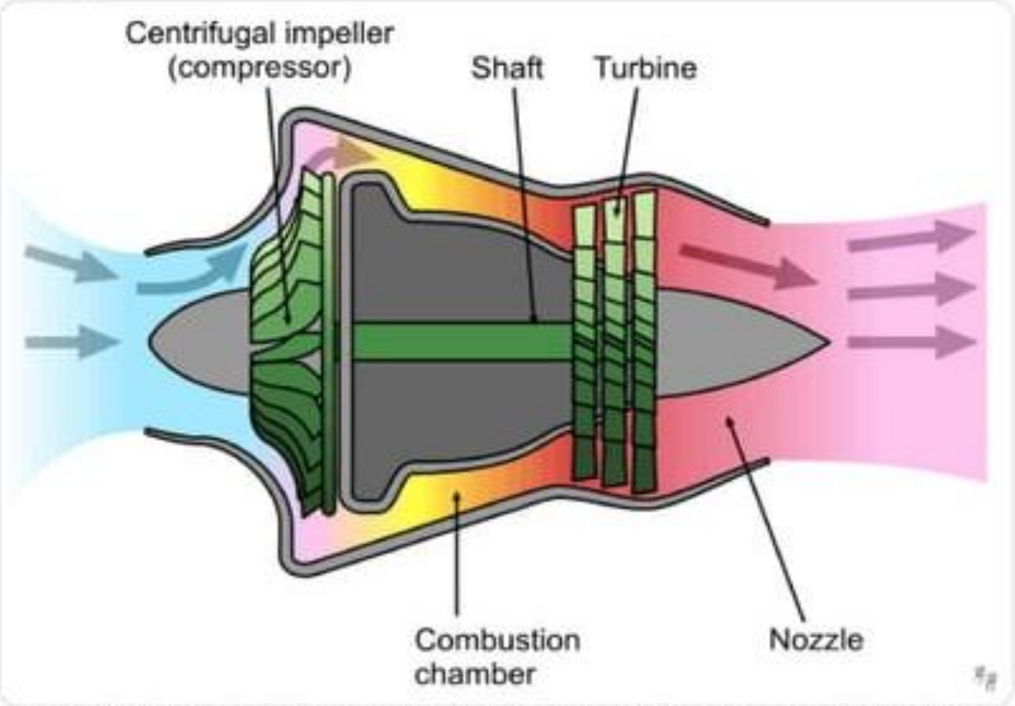


Figure: Schematic diagram showing the operation of a centrifugal flow turbojet engine

The compressor is driven via the turbine stage and throws the air outwards, requiring it to be redirected parallel to the axis of thrust.

AIR INTAKE

Preceding the compressor is the air intake (or inlet). It is designed to be as efficient as possible at recovering the ram pressure of the air stream tube approaching the intake. The air leaving the intake then enters the compressor. The stators (stationary blades) guide the airflow of the compressed gases.

COMPRESSOR

The compressor is driven by the turbine. The compressor rotates at very high speed, adding energy to the airflow and at the same time squeezing (compressing) it into a smaller space. Compressing the air increases its pressure and temperature.

In most turbojet-powered aircraft, bleed air is extracted from the compressor section at various stages to perform a variety of jobs including air conditioning/pressurization, engine inlet anti-icing and turbine cooling. Bleeding air off decreases the overall efficiency of the engine, but the usefulness of the compressed air outweighs the loss in efficiency.

Several types of compressor are used in turbojets and gas turbines in general: axial, centrifugal, axial-centrifugal, double-centrifugal, etc.

Early turbojet compressors had overall pressure ratios as low as 5:1 (as do a lot of simple auxiliary power units and small propulsion turbojets today). Aerodynamic improvements, plus splitting the compression system into two separate units and/or incorporating variable compressor geometry, enabled later turbojets to have overall pressure ratios of 15:1 or more. For comparison, modern civil turbofan engines have overall pressure ratios of 44:1 or more.

After leaving the compressor section, the compressed air enters the combustion chamber.

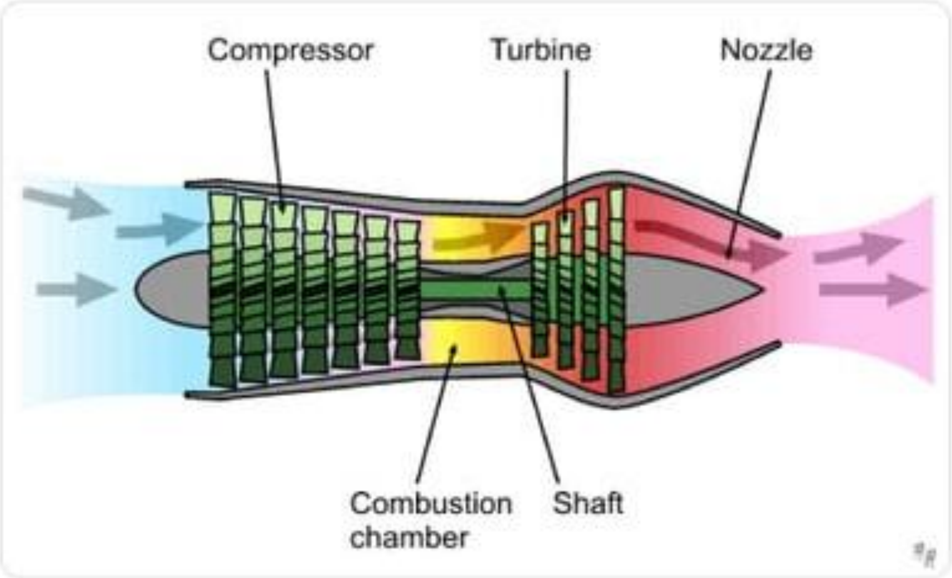


Figure: Schematic diagram showing the operation of an axial flow turbojet engine

COMBUSTION CHAMBER:

The burning process in the combustor is significantly different from that in a piston engine. In a piston engine the burning gases are confined to a small volume and, as the fuel burns, the pressure increases dramatically. In a turbojet the air and fuel mixture passes unconfined through the combustion chamber. As the mixture burns its temperature increases dramatically, but the pressure actually decreases a few percent.

The fuel-air mixture must be brought almost to a stop so that a stable flame can be maintained. This occurs just after the start of the combustion chamber. The aft part of this flame front is allowed to progress rearward. This ensures that all of the fuel is burned, as the flame becomes hotter when it leans out, and because of the shape of the combustion chamber the flow is accelerated rearwards. Some pressure drop is required, as it is the reason why the expanding gases travel out the rear of the engine rather than out the front. Less than 25% of the air is involved in combustion, in some engines as little as 12%, the rest acting as a reservoir to absorb the heating effects of the burning fuel.

Another difference between piston engines and jet engines is that the peak flame temperature in a piston engine is experienced only momentarily in a small portion of the full cycle. The combustor in a jet engine is exposed to the peak flame temperature continuously and operates at a pressure high enough that a stoichiometric fuel-air ratio would melt the can and everything downstream. Instead, jet engines run a very lean mixture, so lean that it would not normally support combustion. A central core of the flow (primary airflow) is mixed with enough fuel to burn readily. The cans are carefully shaped to maintain a layer of fresh unburned air between the metal surfaces and the central core. This unburned air (secondary airflow) mixes into the burned gases to bring the temperature down to something a turbine can tolerate.

TURBINE:

Hot gases leaving the combustor are allowed to expand through the turbine. Turbines are usually made up of high temperature metals such as inconel to resist the high temperature, and frequently have built-in cooling channels.

In the first stage the turbine is largely an impulse turbine (similar to a pelton wheel) and rotates because of the impact of the hot gas stream. Later stages are convergent ducts that accelerate the gas rearward and gain energy from that process. Pressure drops, and energy is transferred into the shaft. The turbine's rotational energy is used primarily to drive the compressor. Some shaft power is extracted to drive accessories, like fuel, oil, and hydraulic pumps. Because of its significantly higher entry temperature, the turbine pressure ratio is much lower than that of the compressor. In a turbojet almost two-thirds of all the power generated by burning fuel is used by the compressor to compress the air for the engine.

NOZZLE:

After the turbine, the gases are allowed to expand through the exhaust nozzle to atmospheric pressure, producing a high velocity jet in the exhaust plume. In a convergent nozzle, the ducting narrows progressively to a throat. The nozzle pressure ratio on a turbojet is usually high enough for the expanding gases to reach Mach 1.0 and choke the throat. Normally, the flow will go supersonic in the exhaust plume outside the engine.

If, however, a convergent-divergent de Laval nozzle is fitted, the divergent (increasing flow area) section allows the gases to reach supersonic velocity within the nozzle itself. This is slightly more efficient on thrust than using a convergent nozzle. There is, however, the added weight and complexity since the convergent-divergent nozzle must be fully variable in its shape to cope with changes in gas flow caused by engine throttling.

AFTERBURNER:

An afterburner or "reheat jetpipe" is a device added to the rear of the jet engine. It provides a means of spraying fuel directly into the hot exhaust, where it ignites and boosts available thrust significantly; a drawback is its very high fuel consumption rate. Afterburners are used almost exclusively on supersonic aircraft – most of these are military aircraft. The two supersonic civilian transports, Concorde and the TU-144, also utilized afterburners but these two have now been retired from service. Scaled Composites White Knight, a carrier aircraft for the experimental Space Ship One suborbital spacecraft, also utilizes an afterburner.

THRUST REVERSER:

A thrust reverser is, essentially, a pair of clamshell doors mounted at the rear of the engine which, when deployed, divert thrust normal to the jet engine flow to help slow an aircraft upon landing. They are often used in conjunction with spoilers. The accidental deployment of a thrust reverser during flight is a dangerous event that can lead to loss of control and destruction of the aircraft (see LaudaAir Flight 004). Thrust reversers are more convenient than drogue parachutes, though mechanically more complex and expensive.

NET THRUST

The net thrust F_N of a turbojet is given by,

$$F_N = (\dot{m}_{air} + \dot{m}_f)V_j - \dot{m}_{air}V$$

where:

$\dot{m}_{air}$	is the rate of flow of air through the engine
$\dot{m}_f$	is the rate of flow of fuel entering the engine
V_j	is the speed of the jet (the exhaust plume) and is assumed to be less than sonic velocity
V	is the true airspeed of the aircraft
$(\dot{m}_{air} + \dot{m}_f)V_j$	represents the nozzle gross thrust
$\dot{m}_{air}V$	represents the ram drag of the intake

If the speed of the jet is equal to sonic velocity the nozzle is said to be choked. If the nozzle is choked the pressure at the nozzle exit plane is greater than atmospheric pressure, and extra terms must be added to the above equation to account for the pressure thrust

The rate of flow of fuel entering the engine is very small compared with the rate of flow of air. If the contribution of fuel to the nozzle gross thrust is ignored, the net thrust is:

$$F_N = \dot{m}_{air}(V_j - V)$$

The speed of the jet V_j must exceed the true airspeed of the aircraft V if there is to be a net forward thrust on the airframe. The speed V_j can be calculated thermodynamically based on adiabatic expansion. A simple turbojet engine will produce thrust of approximately: 2.5 pounds force per horsepower (15 mN/W).

TURBOFAN

A turbofan engine is a gas turbine engine that is very similar to a turbojet. Like a turbojet, it uses the gas generator core (compressor, combustor, turbine) to convert internal energy in fuel to kinetic energy in the exhaust. Turbofans differ from turbojets in that they have an additional component, a fan. Like the compressor, the fan is powered by the turbine section of the engine. Unlike the turbojet, some of the flow accelerated by the fan bypasses the gas generator core of the engine and is exhausted through a nozzle. The bypassed flow is at lower velocities, but a higher mass, making thrust produced by the fan more efficient than thrust produced by the core. Turbofans are generally more efficient than turbojets at subsonic speeds, but they have a larger frontal area which generates more drag.

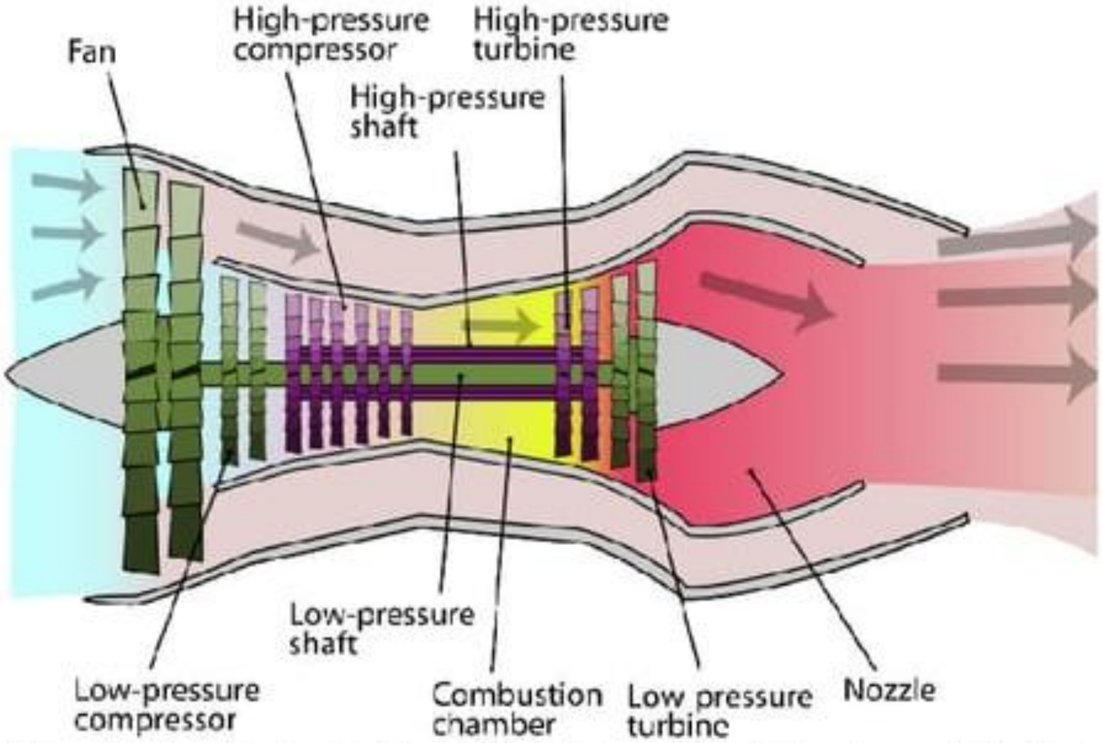


Figure: Schematic diagram illustrating the operation of a low-bypass turbofan engine

There are two general types of turbofan engines, low bypass and high bypass. Low bypass turbofans have a bypass ratio of around 2:1 or less, meaning that for each kilogram of air that passes through the core of the engine, two kilograms or less of air bypass the core.

Low bypass turbofans often used a mixed exhaust nozzle meaning that the bypassed flow and the core flow exit from the same nozzle. High bypass turbofans have larger bypass ratios, sometimes on the order of 5:1 or 6:1. These turbofans can produce much more thrust than low bypass turbofans or turbojets because of the large mass of air that the fan can accelerate, and are often more fuel efficient than low bypass turbofans or turbojets.

TURBOPROP

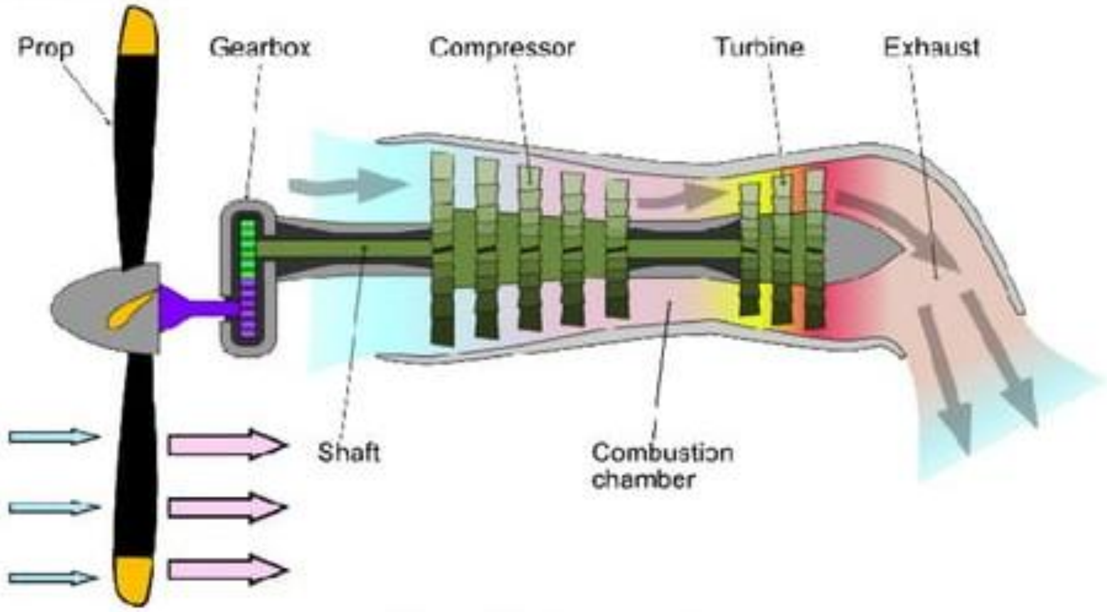


Figure: Turboprop engine

A turboprop engine is a type of turbine engine which drives an aircraft propeller using a reduction gear. The gas turbine is designed specifically for this application, with almost all of its output being used to drive the propeller. The engine's exhaust gases contain little energy compared to a jet engine and play only a minor role in the propulsion of the aircraft.

The propeller is coupled to the turbine through a reduction gear that converts the high RPM, low torque output to low RPM, high torque. The propeller itself is normally a constant speed (variable pitch) type similar to that used with larger reciprocating aircraft engines.

Turboprop engines are generally used on small subsonic aircraft, but some aircraft outfitted with turboprops have cruising speeds in excess of 500 kt (926 km/h, 575 mph).

Turboprop engines are jet engine derivatives, still gas turbines, that extract work from the hot-exhaust jet to turn a rotating shaft, which is then used to produce thrust by some other means. While not strictly jet engines in that they rely on an auxiliary mechanism to produce thrust, turboprops are very similar to other turbine-based jet engines, and are often described as such. In turboprop engines, a portion of the engines' thrust is produced by spinning a propeller, rather than relying solely on high-speed jet exhaust. As their jet thrust is augmented by a propeller, turboprops are occasionally referred to as a type of hybrid jet engine. While many turboprops generate the majority of their thrust with the propeller, the hot-jet exhaust is an important design point, and maximum thrust is obtained by matching thrust contributions of the propeller to the hot jet. Turboprops generally have better performance than turbojets or turbofans at low speeds where propeller efficiency is high, but become increasingly noisy and inefficient at high speeds.

TURBOSHAFT

Turbo shaft engines are very similar to turboprops, differing in that nearly all energy in the exhaust is extracted to spin the rotating shaft, which is used to power machinery rather than a propeller, they therefore generate little to no jet thrust and are often used to power helicopters.

A turboshaft engine is a form of gas turbine which is optimized to produce free turbine (see graphic at right) shaft power, rather than jet thrust. In concept, turboshaft engines are very similar to turbojets, with additional turbine expansion to extract heat energy from the exhaust and convert it into output shaft power.

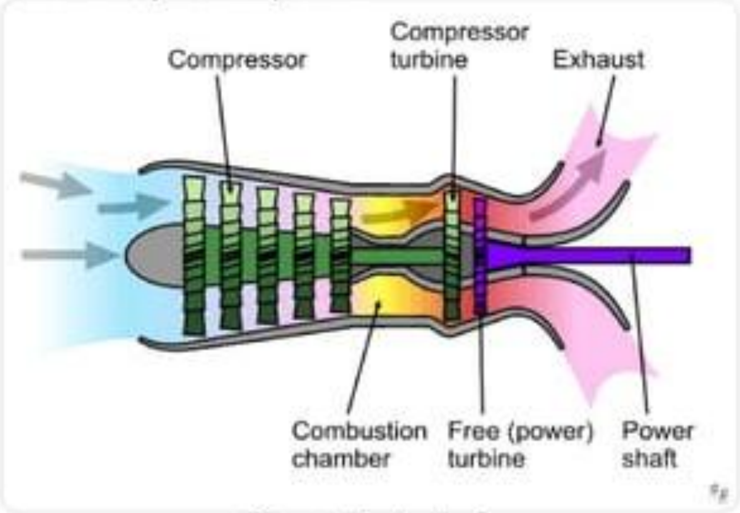


Figure: Turboshaft

A turboshaft engine is made up of two major parts assemblies: the gas generator and the power section. The gas generator consists of the compressor, combustion chambers with ignitors and fuel nozzles, and one or more stages of turbine. The power section consists of additional stages of turbines, a gear reduction system, and the shaft output. The gas generator creates the hot expanding gases to drive the power section. Depending on the design, the engine accessories may be driven either by the gas generator or by the power section.

RAM POWERED ENGINES:

Ram powered jet engines are airbreathing engines similar to gas turbine engines and they both follow the Brayton cycle. Gas turbine and ram powered engines differ, however, in how they compress the incoming airflow. Whereas gas turbine engines use axial or centrifugal compressors to compress incoming air, ram engines rely only on air compressed through the inlet or diffuser. Ram powered engines are considered the most simple type of air breathing jet engine because they can contain no moving parts.

RAMJET

Ramjets are the most basic type of ram powered jet engines. They consist of three sections; an inlet to compressed oncoming air, a combustor to inject and combust fuel, and a nozzle expel the hot gases and produce thrust.

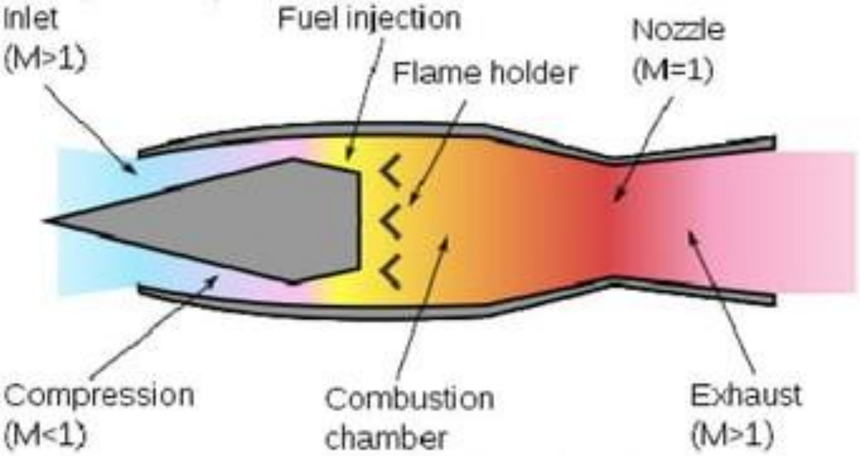


Figure: A schematic of a ramjet engine, where "M" is the Mach number of the airflow

Ramjets require a relatively high speed to efficiently compress the oncoming air, so ramjets cannot operate at a standstill and they are most efficient at supersonic speeds. A key trait of ramjet engines is that combustion is done at subsonic speeds. The supersonic oncoming air is dramatically slowed through the inlet, where it is then combusted at the much slower, subsonic, speeds. The faster the oncoming air is, however, the less efficient it becomes to slow it to subsonic speeds. Therefore ramjet engines are limited to approximately Mach 5.

SCRAMJET:

Scramjets are mechanically very similar to ramjets. Like a ramjet, they consist of an inlet, a combustor, and a nozzle. The primary difference between ramjets and scramjets is that scramjets do not slow the oncoming airflow to subsonic speeds for combustion, they use supersonic combustion instead.

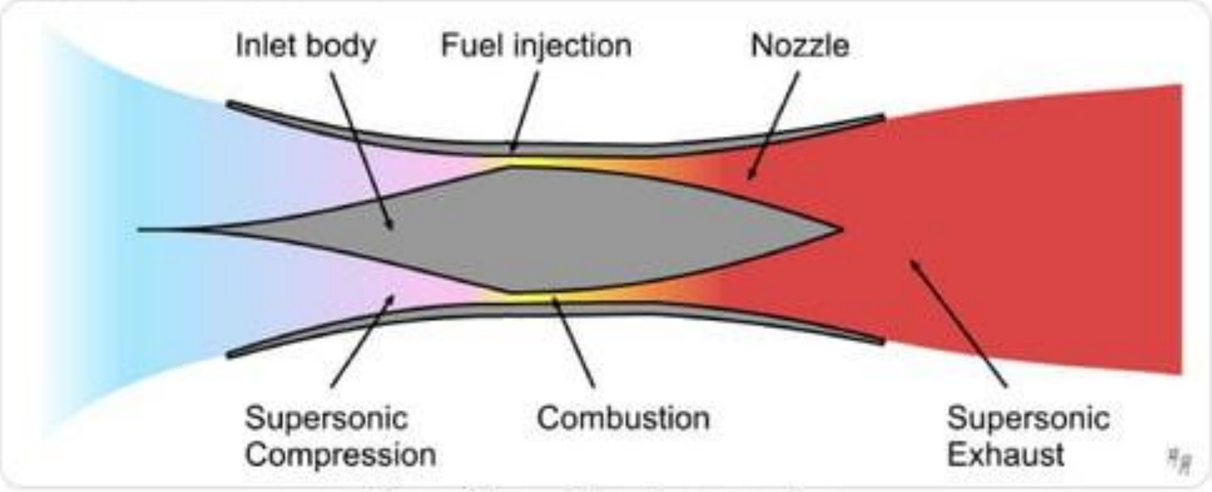


Figure: Scramjet engine operation

The name "scramjet" comes from "supersonic combusting ramjet." Since scramjets use supersonic combustion they can operate at speeds above Mach 6 where traditional ramjets are too inefficient. Another difference between ramjets and scramjets comes from how each type of engine compresses the oncoming air flow: while the inlet provides most of the compression for ramjets, the high speeds at which scramjets operate allow them to take advantage of the compression generated by shock waves, primarily oblique shocks.

STUDY OF FORCED CONVECTIVE HEAT TRANSFER OVER A FLAT PLATE

Aim: To determine the forced convective heat transfer coefficient for flow of air inside a horizontal pipe.

Theory: Convective heat transfer between a fluid and a solid surface takes place by the movement of fluid particles relative to the surface. If the movement of fluid particles is caused by means of external agency such as pump or blower that forces fluid over the surfaces, then the process of heat transfer is called forced convection.

In convection heat transfer there are two flow regions named laminar and turbulent. The non-dimensional number called Reynolds number is used as criterion to determine change from laminar to turbulent flow. For smaller value of Reynolds number viscous forces are dominant and the flow is laminar and for larger value of Reynolds numbers the inertia forces become dominant and the flow is turbulent. Dittus-boelter correlation for fully developed turbulent flow in circular pipes is: **$Nu = 0.023(R_e)^{0.8} (P_r)^n$**

Where: n = 0.4 for heating of fluid

n = 0.3 for cooling of fluid

Nu = Nusselt number = $\frac{hD}{k}$

Re = Reynolds Number = $\frac{Vd}{\gamma} = \frac{eVd}{\mu}$

Pr = PrandtlNumber = $\frac{\mu C_P}{k}$

Description of The Apparatus: The apparatus consists of a blower to supply air. The air from the blower passes through a flow passage, heater and then to the test section. An orifice meter placed near the test section measures airflow. A heater placed around the tube heats the air, heat input is controlled by a dimmer stat. Temperature of the air at inlet and at outlet are measured using thermocouples. The surface temperature of the tube wall is measured at different sections using thermocouples embedded in the walls. Test section is enclosed by a water jacket where the circulation of water removes heat from outer surface tube.

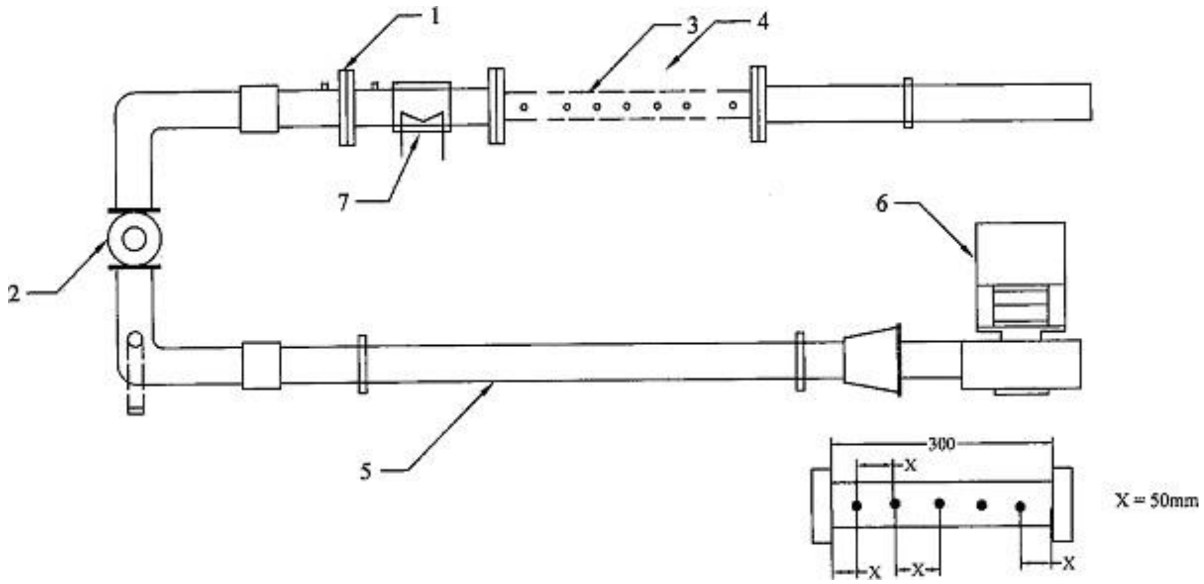


Figure: FORCED convection heat transfer over a Flat plate.

Specifications:

Specimen	:	Brass Tube
Specimen Dimension	:	25 mm × 500 mm (I.D × Length)
Heater	:	Nichrome wire internally heated
Voltmeter	:	300 V, 2 A, Digital type
Ammeter	:	300 Volts, 2 Amps, Digital type
Dimmer Stat	:	0 – 230 Volts, 2 Amps
No of thermocouples	:	4
Centrifugal Blower	:	230 V, 1.5 A, 50 Hz, 3000 rpm, 2.3 m^3/min
Measuring Jar Capacity	:	500 ml
Orifice Diameter	:	20 mm

Precautions:

1. Never switch on main power supply before ensuring that all ON/OFF switches given on the panel are at OFF position.
2. Never run the apparatus if power supply is less than 180 or higher than 230 volts.
3. Before switch ON main power supply ensure that variac knob is at zero position, provided on the panel.
4. Operate the thermocouple selector knob and variac knob gently.

Procedure:

1. Start the blower after keeping the valve open, at desired rate.
2. Put on the heater and adjust the voltage to a desired value and maintain it as constant.
3. Start the water circulation.
4. Allow the system to stabilize and reach a steady state.
5. Note down all the temperatures T_1 to T_7, Voltmeter reading Ammeter reading flow rate of water and manometer readings.
6. Repeat the experiment for different heat input and flow rate.

Observations & Tabulation:

Sl. No	**Heat input**			**Diff. In Manometer reading $h_w$mm**	**Air Temp In ^{0}C**		**Thermocouple Readings^{0}C**				
	V Volts	**I Amps**	**V X I Watts**		**In T_1**	**Out T_7**	**T_2**	**T_3**	**T_4**	**T_5**	**T_6**

Specimen Calculations:

1. Mass density of air: $e_a = \frac{P}{RT_a}$ kg/m^3

Where P = Atmospheric pressure = 101325 N/m^2

R = Gas constant for air = 287 J/kg-K

T_a = Room temperature in K

2. Pressure drop across orifice meter in 'm' of air: $h_a = \frac{\rho_w h_w}{P_a}$

Where ρ_a = Mass density of water = 1000 kg/m^3

h_w = Differential manometer reading in 'm' of mercury

d_0 = Dia of the orifice

d_p = Dia of the pipe

3. Velocity of air at the orifice: $V_0 = C_d \sqrt{\dfrac{2gh_a}{\left[1 - \dfrac{d_0}{d_P}\right]^4 \times 1000}}$ m/s d_o→dia of the orifice

d_o→dia of the pipe.

Where $C_d = 0.62$

4. Velocity of air in the tube: $V_a = \dfrac{V_0 \pi d_0^{\,2} / 4}{\pi d_P^{\,2} / 4} = \dfrac{V_0 d_0^{\,2}}{d_P^{\,2}}$

5. Average surface temperature of the tube: $T_s = \dfrac{T_2 + T_3 + T_4 + T_5 + T_6}{5}$ ^{0}C

6. Mean temperature of air: $T_f = \left[\dfrac{T_1 + T_7}{2}\right]$ ^{0}C or $= \left[\dfrac{T_i + T_0}{2}\right]$ ^{0}C

Properties of Air are taken at T_f

At temperature T_f, kinematic viscosity ν , Prandtl Number Pr and thermal conductivity K are taken from properties of air table

7. Reynolds Number: $R_e = \dfrac{V_0 d}{\gamma \times 1000}$

8. Nusselt number: $Nu = 0.023\, R_e^{0.8}\, Pr^{0.3}$ (When Re>2300 flow is turbulent)

9. Nusselt number: $Nu = \dfrac{hD}{k}$

Forced convective heat transfer $h = \dfrac{Nu \times k}{D}$ W/m^2-K

10. Rate of heat transfer: $Q = hA\,(T_f - T_s)$

$$Q = \frac{h\pi dL(T_f - T_s)}{10^6} \text{ Watts}$$

Result:

STUDY OF FREE CONVECTIVE HEAT TRANSFER OVER A FLAT PLATE

AIM :

To determine the heat transfer co-efficient in natural convection for Flat Plate.

Introduction:

Heat transfer can be defined as the transmission of energy form one region another as a result of temperature difference between them. There are three different modes of heat transfer; namely conduction, convection and radiation

Conduction: The property which allows passage for heat energy, even though their parts are not in motion relative to one another.

Convection: is the transfer of heat within the fluid by mixing one portion of fluid with another.

Heat Radiation: The property of emit or to absorb different kind of ratio of electromagnetic waves. Out of these types of heat transfer the convective heat transfer which of concern, divides into twocategories viz.,

Natural Convection: If the motion of fluid caused only due to difference in density resulting from temperature gradients without the use of pump or fan, then the mechanism of heat transfer is known as "natural or free convection".

Forced convection: If the motion of fluid is induced by some external means such as a pump or blower.

The Newton"s law of cooling in convective heat transfer is given

byQ=h A Δ T, where Q=heat transfer rate in watts

- A=surface area of heat flow in m2
- ΔT=over all temperature difference between the wall and fluid
- h= convection heat transfer co-efficient in watts
- This setup has been designed to study heat transfer by natural or free convection

Apparatus:

1. A metallic tube of diameter (d) 45 mm and length (L) 450mm with a electrical heater coil alongthe axis of the tube.
2. Seven thermocouple are fixed on the tube surface.
3. Control panel instrumentation consists of multichannel digital display
   a. Temperature indicator to measure surface temperature T1 to T7 of the tube and ambienttemperature T8.
   b. Digital ammeter and voltmeter to measure power input to the heater.
   c. Regulator to control the power input to the heater.
4. Front transparent acrylic enclosure for safety of the tube when not in use.

Operational Procedure:

1. Switch ON the mains and the control.
2. Set the regulator to set the heat input.
3. Wait for sufficient time to allow temperature to reach steady values.
4. Note down temperatures T1 to T8 using channel selector and digital temperature indicator.
5. Note down the Ammeter and Voltmeter readings.
6. Tabulate the heat input and transfer co-efficient using the procedure.
7. Calculate the convection heat transfer co-efficient using the procedure given below.
8. Repeat the experiment by changing the heat input.

Tabulation:

Sl.NO	Heat Input			Temperature along the tube							Average tube Temperature	Ambient Temperature	Convective heat transfer coefficient	
	V	I	Q	T1	T2	T3	T4	T5	T6	T7	T_{av}	T8	h_t h	h_{ex}
1														
2														
3														

Calculations:

Determination of experimental heat transfer co-efficient: For steady state condition, heat given to heater = Heat lost from the tube surface by natural convection.

$$\text{Therefore, } Q = h\, A_s (T_s - T_\infty)$$

Where,

Q = (Ammeter reading) x (Voltmeter reading), in watts

D= Diameter of tube= mm

L= length of the tube = mm

As=surface area = π D L m^2

Ts= (T1+T2+T3+T4+T5+T6+T7)/7 = °C

T_∞= T8 = Ambient air temperature=T8= °C

Therefore,

Heat transfer co-efficient, hexpt = $Q/As (Ts-T\infty) =$ W/m^2K

Determination of Theoretical heat transfer co-efficient: The theoretical value of the natural heat transfer co-efficient is calculated given by: Note down the properties of air t from data hand book

$Tm = (Ts+ T\infty)/2 =$ °C

RESULTS

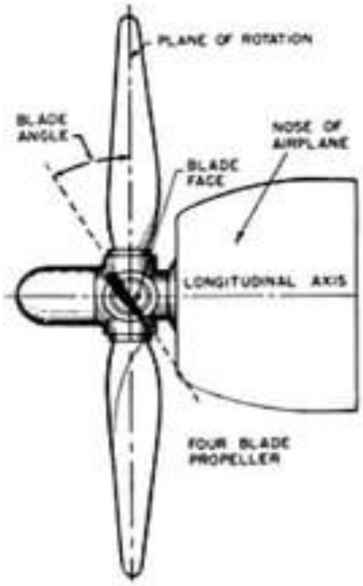
The heat transfer coefficient for natural convection over the flat plate was determined to be ___ $W/m^2 \cdot K$ under the given experimental conditions.

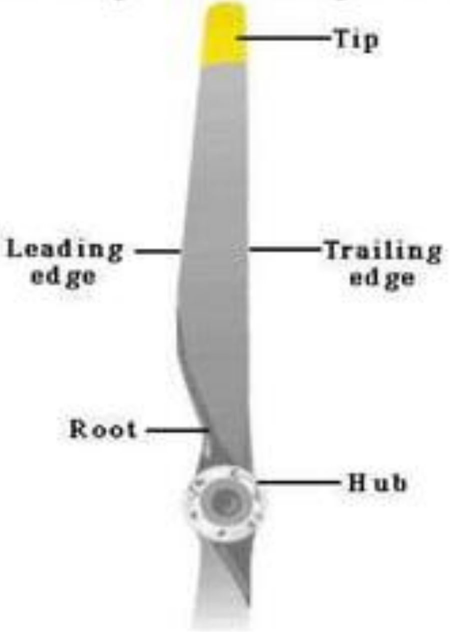
STUDY OF PERFORMANCE OF A PROPELLER

Aim: 1) To study the performance of a propeller at different speeds and measure the thrust force
2) To find the propulsion efficiency of the propeller

Basic Propeller Principle

The aircraft propeller consists of two or more blades and a central hub to which the blades and are attached. Each blade is essentially of rotating wing. As a result of their construction, propeller blade produce forces/thrust to pull or push the aero plane through air. Power to rotate the propeller blades is furnished by the engines. Low powered engine propeller is mounted on the propeller shaft and that is geared to the engine crank shaft.





Fixed-pitch one-piece wood propeller.

Propeller Nomenclature

In order to explain the theory and construction of propellers it is necessary first to define the parts of various types of propellers and give the nomenclature associated with the propeller.

The cross section of a propeller blade is shown in the figure the leading edge of the blade trailing edge, the cambered side, or back and the flat side or face. The blade has an aerofoil shape similar to that of an aeroplane wing; it is through that it is a small wing; which has been reduced in length, width and thickness (small wing shape). When the blade start rotating, airflows around the blade fast as it flows around the wing of an aeroplane and blade is lifted forward

The nomenclature of an adjustable propeller is illustrated in the figure. This is metal propeller with two blades clamped into a steel hub assembly. The hub assembly is supporting unit for the blades, and it provides mounting structure in which propeller is attached to the engine propeller shaft. The propeller hub is split on a plane parallel to the plane of rotation of the propeller to allow for the installation of the blades. The sections of the hubs are held in place by means of clamping rings secured by means of bolts.

BLADE STATION

Blade stations are designated distances in inches measured along the blade from the centre of the hub the figure shows the location of a point on the blade at the 42 inches in each station this division of blade into station provides a convenient means of discussing the performance of the propeller blade locating blade marking and damage finding the proper point for measuring the blade angle and locating anti-glare areas

BLADE ANGLE: Blade angle is defined as the angle between the chord particular blade section and the plane of rotation

BLADE PITCH: Blade pitch is the distance advanced by the propeller in one revolution

GEOMETRIC PITCH: The propeller would have been advanced in one revolution

EXPERIMENTAL MEAN PITCH: The distance traveled by the propeller in one revolution without producing thrust

EFFECTIVE PITCH: Actual distance advanced by the propeller in one revolution

PITCH DISTRIBUTION: The angle gradually decreases towards the tip and towards the shank

ANGLE OF ATTACK: This is the angle formed between the chord of the blade and direction of relative air flow

PROPELLER SLIP: Slip is defined as difference between the geometric pitch and the effective pitch

FORCES ACTING ON A PROPELLER

1) Thrust force
2) Centrifugal force
3) Torsion or twisting force
4) Aerodynamic twisting force
5) Aerodynamic twisting movement (ATM)
6) Centrifugal twisting movement (CTM)

THRUST FORCE: Thrust force is a thrust load that tends to bend propeller blade forward as the aircraft is pulled through the air

CENTRIFUGAL FORCE: Centrifugal force is the physical force that tends to throw the rotating propeller blades away from the hub

TORSION OR TWISTING FORCE: Torsion force is the force of air resistance tends to bend the propeller blade in a direction that is opposite to the direction of rotation

AERODYNAMIC TWISTING FORCE: It is the force that tends to turn the blade to higher blade angle

AERODYNAMIC TWISTING MOMENT: It is the force that tends to turn the blade angle towards low blade angle

PROPELLER EFFICIENCY: Propeller efficiency has been achieved by use of this aerofoil section near the tips of the propeller blades and very sharp leading and trailing edge

Propeller efficiency = thrust horsepower / torque horse power

It is the ratio of thrust horse power to the torque horse power. Thrust horse power is the actual amount of horse power that an engine propeller transforms multiplied by thrust

Specifications:

Type of propeller	:	Wooden 2- bladed with constant pitch
Dia of the propeller	:	680 mm
Motor	:	D.C Motor, drive by thyristor drive with controller
Thrust	:	By Linear bearing system connected to load cell and measured by digital force indictor.
Speed	:	By Proximity sensor connected to digital speed indicator.
Air flow	:	By digital Anemometer
Power	:	By D.C. Voltmeter and D.C. Ammeter

Construction

The basic propeller test rig consists of a wooden propeller with two blades & with a constant pitch. & it is dynamically balanced. The propeller is coupled to D.C motor & mounted on a base plate and the whole unit is mounted on linear bearing and it is connected to load cell for thrust measurement. The speed of the propeller is sensed by a rpm sensor & it is connected to digital rpm indicator. The power consumed by the propeller is measured by the D.C. voltmeter and Ammeter. The experiment can be done for different speed. There is a isolated control panel which houses all the measurement units like digital force indicator, digital speed indicator, D.C. motor thyristor drive and speed control knob, Voltmeter and Ammeter. Air flow measurement before and after the propeller is done using handy digital anemometer.

Procedure

1) Ensure the propeller blade is firmly locked in position and mesh guard is safe enough to protect.
2) Connect the power cable and observe the 'MAINS ON' indicator to glow.
3) Ensure the speed controller knob is set to zero position.
4) Switch on force indicator and press the tare button, to set it to zero and keep it in normal position.
5) Slowly increase the speed by operating the speed control knob to some desired rpm value. Max 2000rpm (Max ammeter reading A=8amps)
6) Note down the rpm indicator reading and thrust force reading by putting the switch to peak position (keep the switch always in normal position while running the test rig).
7) Record the air flow measurement at inlet and outlet of the propeller.
8) Repeat the experiment at different speed.
9) Draw graph of thrust Vs rotational speed, Thrust Vs inlet velocity of air, Thrust Vs outlet velocity of air, RPM Vs propulsion efficiency.

Precautions

1) It is safe to run the propeller at a fixed pitch and relatively low speed.
2) Before starting, ensure all the screws, bolts and nuts are firmly tight and mesh guard in secured position.
3) While doing experiment, be always little away from the propeller and control the speed of the propeller gradually by carefully observing the vibrations.

Table of Reading

S.N.	Speed of the propeller in rpm	Thrust force In Newton T_{act}	Air flow measurement in m/s		Voltmeter Reading (Volts)	Ammeter Reading (Amps)
			Inlet (V_{in})	Outlet (V_{out})		
1	600					
2	800					
3	1000					
4	1200					
5	1400					
6	1600					
7	1800					
8	2000					

Calculations:

1) Power input to the propeller P_{in} in KW = $\frac{V \times I}{1000 \times \eta_m}$, Where $\eta_m = 75\%$
2) Theoretical Thrust generated by the propeller T_{th} in Newton= $\rho A V_{in}(V_{out} - V_{in})$

   Where ρ = Density of air at Room temperature

   A= Cross sectional area of Duct, D=700mm
3) Propulsion efficiency $\eta_p = \frac{2}{1+\left(\frac{V_{out}}{V_{in}}\right)}$

Result Table

S. N.	Speed in rpm	Power input to the Propeller in KW	Actual Thrust (T_{act}) in N	Theoretical Thrust (T_{th}) in N	Propulsion Efficiency (η_p)

BOMB CALORIMETER

AIM: To determine the calorific value of solid fuels

APPARATUS: The Bomb Calorimeter mainly consists of the following:

1. Stainless steel Bomb
2. Calorimeter Vessel with Bomb support and insulating base
3. Water Jacket with outer body
4. Lid for water Jacket
5. Stirrer assembly with F.H.P. motor
6. Bomb firing unit with Electronic Digital Temperature Indicator
7. Pellet Press
8. Stand and dial pressure gauge
9. Connecting tubes(copper tubes O2 Cylinder to pressure gauge & pressure gauge to bomb)
10. Connecting electrical leads(Firing unit to water jacket & water jacket to bomb)
11. Crucible Stainless steel
12. Gas release valve
13. Oxygen cylinder valve

EXPERIMENTAL SETUP:

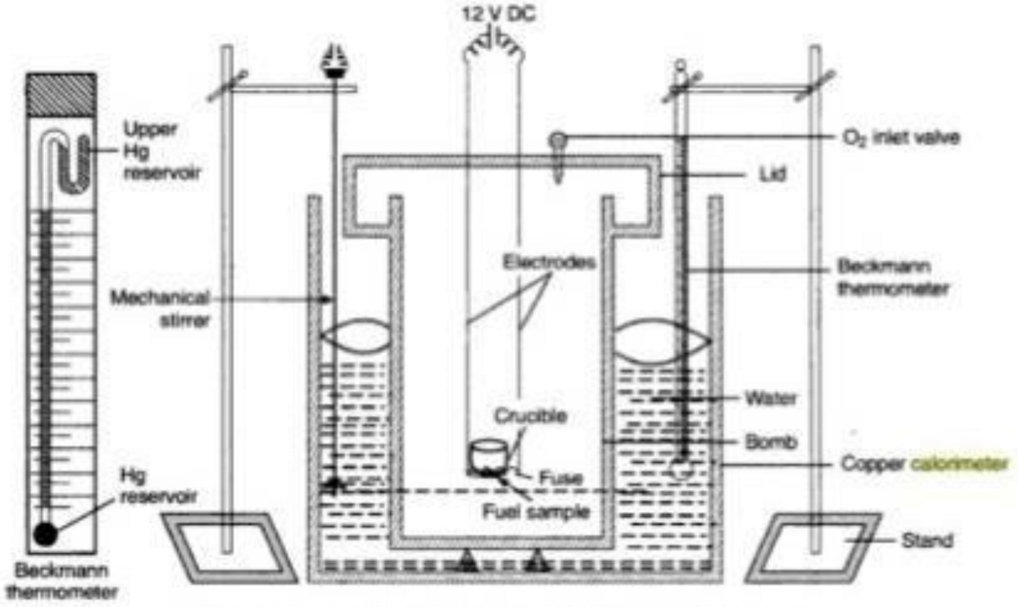


Figure: Experimental setup of Bomb Calorimeter

DISCRIPTION:

A bomb calorimeter is a type of constant-volume calorimeter used in measuring the heat of combustion of a particular reaction. Bomb calorimeters have to withstand the large pressure within the calorimeter as the reaction is being measured. Electrical energy is used to ignite the fuel; as the fuel is burning, it will heat up the surrounding air, which expands and escapes through a tube that leads the air out of the calorimeter. When the air is escaping through the copper tube it will also heat up the water outside the tube. The temperature of the water allows for calculating calorie content of the fuel.

13. Insert the stirrer unit into the calorimeter vessel in proper position through the shell lid and secure it; connect the stirrer unit with the firing unit, also insert the thermocouple sensor into the calorimeter vessel through the shell lid and connect it to the firing unit.
14. Connect the Bomb firing unit to an electrical source of 230v, 50Hz, 5 amps keeping all the switches on the firing unit in "OFF" position.
15. Switch "ON" the main switch of the firing unit. Now the temperature indicator indicates the temperature sensed by the thermocouple.
16. Switch "ON" the stirrer unit.
17. Press the "green" button on the firing unit to check the continuity in the Bomb unit, observe the indicator glow.
18. Wait till the temperature in the calorimeter vessel, stabilize and record it as initial temperature. Press the "red" button on the firing unit to fire the sample inside the Bomb.
19. Now the temperature of the water in the calorimeter vessel starts rising, note and record the rise in temperature at every one-min. interval until the rise in temperature stabilizes or starts dropping.
20. Tabulate all the readings and calculate the calorific value of the solid fuel under test.
21. To close the experiment switch "OFF" the stirrer and main switch, open the shell lid and take out the Bomb assembly from the calorimeter vessel. Release all the flue gases from the Bomb with the help of release valve, unscrew the cap open the lid and observe all the fuel sample is burnt completely.
22. Clean the Bomb and crucible with clean fresh water and keep it dry.

GIVEN DATA:

1. Weight of nichrome wire taken (10 cm weighs aprox) = 18.4 mg
2. Weight of the cotton thread (10 cm weighs aprox) = 5 mg

OBSERVATION:

1. Weight of the empty SS crucible, $m_1 =$ gm
2. Weight of the Benzoic acid sample taken, $m_2 =$ gm
3. Weight of Benzoic acid sample pallet and weight of the crucible, $m_3 =$ gm
4. Initial temperature of water before firing, $T_1 =$ °C
5. Final temperature of water after firing (after 8 to 10 min), $T_2 =$ °C

CALCULATION:

Actual weight of the sample (M) $= m_3 - m_1 =$ gm

Maximum rise in temperature (T) $= T_2 - T_1 =$ °C

To calculate water equivalent of calorimeter:

$$W = \frac{H \times M + (E_1 + E_2)}{T}$$

Where;

Water equivalent of Calorimeter (W) in Cal/ °C
Calorific value of Standard Benzoic Acid (H) = 6319 Cal /grm
Heat liberated by Nichrome wire (E_1) =0.335 Cal/mg X weight of Nichrome wire
Heat liberated by cotton thread (E_2) = 4.180 Cal/mg X weight of cotton thread
T= Rise in temperature due to combustion of solid fuel inside the Bomb ^{0}C.

A Bomb Calorimeter will measure the amount of heat generated when matter is burnt in a sealed chamber (Bomb) in an atmosphere of pure oxygen gas.

A known amount of the sample is burnt in a sealed chamber. The air is replaced by pure oxygen. The sample is ignited electrically. As the sample burns, heat is produced. The rise in temperature is determined. Since, barring heat loss the heat absorbed by calorimeter assembly and the rise in temperature enables to calculate the heat of combustion of the sample.

The water equivalent is calculated using the formula

$$\mathbf{H x M = W x T}$$

Where

W Water equivalent of the calorimeter assembly in calories per degree centigrade (2330 cal / ^{0}C)
T Rise in temperature (registered by a sensitive thermometer) in degree centigrade
H Heat of combustion of material in calories per gram
M Mass of sample burnt in grams

PROCEDURE:

1. Install the equipment on a plain flat table near a 230V, 50Hz, 5amps electrical power source and 15mm tap size water source.
2. Weigh the empty S.S. crucible and record.
3. Weigh exactly 1 gm of powdered dry fuel sample, pour it into the pellet press and press it to form a briquette (tablet / pellet), put it into the crucible and weigh it again to get the exact weight of the solid fuel sample.
   i.e. weight of (crucible + sample) – (empty crucible)
4. Open the bomb lid, keep it on the stand; insert the S.S. crucible into the metallic ring provided on one of the electrode stud.
5. Take a piece of ignition wire of about 100 mm length, weigh it and tie it on the electrode studs, in such a way that the wire touches the fuel pellet, but not the sides of the S.S. crucible.
6. Insert a piece of cotton thread of known weight on to the ignition wire without disturbing it.
7. Lift the Bomb lid assembly from the stand, insert it into the S.S. Bomb body and secure it with the cap.
8. Fill water into the outer shell to its full capacity, insert a glass thermometer with rubber cork. Keep the insulating base in position inside the shell.
9. Fill oxygen gas to about 20 atmospheres into the Bomb with the help of copper tubes with end connectors through pressure gauge from an oxygen cylinder (Oxygen cylinder is not in the scope of supply).
10. Fill water into the calorimeter vessel up to half its capacity and place the assembled Bomb unit, charged with oxygen into it in position. Top up with more water to bring the water level in the calorimeter vessel up to the Bomb lid level.
11. Keep the entire vessel assembly on the insulated base already placed in the outer shell. This should be carried out without disturbing the vessel assembly.
12. Connect the bomb unit to the Bomb firing unit with the electrical leads (connecting wires) and close the shell lid.

OBSERVATION:

Diameter of smaller hole of burner = 1.8 mm (6 No.)
Diameter of larger hole of burner = 2.5 mm (1 No.)

TABULAR COLUMN:

S.N.	Flow rate of air in LPM	Flow rate of gas in LPM	Cone angle, α
1			
2			
3			
4			

CALCULATIONS:

1) Effective area of burner $A_e = \frac{\pi d^2}{4}$ m^2

Where d= Diameter of burner : Φ2.5mm hole 1No. + Φ 1.8mm 6 No.

$$A_e = \frac{\pi}{4}\left[\left(2.5\times10^{-3}\right)^2 + 6\left(1.8\times10^{-3}\right)^2\right] = 2.0179\text{x}10^{-5}\ \text{m}^2$$

2) Total mass flow rate to the burner, $Q_{total} = Q_{air} + Q_{gas}$ = m^3/s

3) Mass flow rate of air, $Q_{air} = \frac{\text{Volume of air supplied in LPM}}{60\times1000}$ = m^3/s

4) Mass flow rate of gas, $Q_{gas} = \frac{\text{Volume of gas supplied in LPM}}{60\times1000}$ = m^3/s

5) Flow velocity, $V_u = \frac{Q_{total}}{A_e}$ = m/s

6) Burning Velocity of flame, $S_{L,u}$ = Vu Sin α

Where α = Semi included angle of flame in degrees

RESULTS:

Burning velocity of flame = m/s

CONCLUSIONS:

MEASUREMENT OF BURNING VELOCITY OF PREMIXED FLAME

Aim:

To measure the burning velocity of the premixed flame.

Apparatus: Small Gas cylinder with gas, Bunsen burner, Air flow rotameter, Glass chamber, flame cone angle measurement protractor, mixing chamber, gas rotameter.

Theory:

The Laminar burning velocity - The classical device to generate a laminar premixed flame is Bunsen burner shown in figure (a).Gaseous fuel from the fuel supply enters through an orifice into the mixing chamber into which air is entrained through adjustable openings from outside. The cross sectional area of fuel orifice may be adjusted by moving the needle through an adjustment screw into the orifice. Thereby the velocity of the jet entering into the mixing chamber may be varied and entrainment of the air and the mixing can be optimized. The mixing chamber must be long enough to generate a premixed gas issuing from the Bunsen tube into the surroundings. If the velocity of the issuing flow is larger than the laminar burning velocity to be defined below, a Bunsen flame tube cone establishes itself at the top of the tube. It represents a steady premixed flame propagating normal to itself with the burning velocity into the unburnt mixture.

The kinematic balance of this process is illustrated for a steady oblique flame as shown in the figure(b).The oncoming flow velocity vector V_u of the unburnt mixture(subscript $_u$) is split into a component $V_{t,u}$ which is tangential to the flame and into a component $V_{n,u}$ normal to the flame front. Due to a thermal expansion within the flame front the normal velocity component is increased, since the mass flow "ρv" through the flame must be the same in the unburnt mixture and in the burnt gas (subscript b).

$$\rho\,(V_n)_u = \rho(V_n)_b, \quad \text{--}1$$

$$V_{n,b}=V_{n,u}\,(\rho_u/\rho_b) \quad \text{--}2$$

The tangential velocity component V_t is not affected by gas expansion and remains the same

$$V_{t,b}=V_{t,u} \text{--} 3$$

Vector addition of the velocity components is the burnt gas in figure(b) then leads to V_b which points into a direction which is deflected from the flow direction of the unburnt mixture. Finally, since the flame front is stationary in this experiment the burning velocity,

$$S_{L,u}=V_{n,u} \text{--} 4$$

With the Bunsen flame cone angle in fig 6.1 denoted by α the normal velocity is

$V_{n,u}=V_u \sin\alpha$ and it follows , $S_{L,u}=V_u \sin\alpha$ -- 5

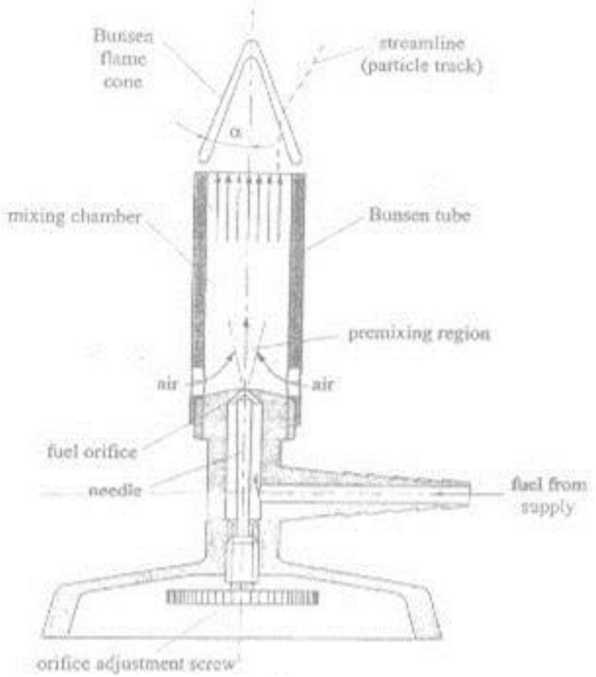


Figure (a): The Bunsen burner.

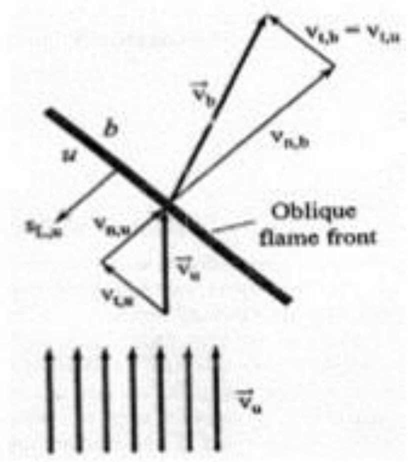


Figure (b): Kinematic balance for a steady oblique flame.

This allows to experimentally determine the burning velocity by measuring the cone angle α under the condition that the flow velocity V_n is uniform across the tube exit. If this is not the case the flame angle also varies with radial distance since the burning velocity $S_{L,u}$ is essentially constant.

A particular phenomenon occurs at the flame tip. If the tip is closed which is in general the case for hydrocarbon flames the burning velocity at the tip being normal and therefore equal to the flow velocity, is by a factor ($1/\sin\alpha$) larger than the burning velocity through the oblique part of the cone. This analysis also includes the effect of non-unity Lewis number by which, for instance, the difference between lean hydrogen and lean hydrocarbon flames can be explained. Finally, it is shown in figure (b) that flame is detached from the rim of the burner. This is due to conductive heat loss to the burner whichleads in regions very close to the rim to temperatures at which combustion cannot be sustained.

Another example for an experimental device to measure laminar burning velocities is the combustion bomb within which the flame is initiated by a central spark. Spherical propagation of flame then takes place which may optically be detached through quartz windows and the flame propagation velocity (drf/dt) may be recorded. Now the flame front is not stationary. If the radial flow velocities are defined positive inward direction, the velocities of the front must be subtracted from these in the mass flow balance.

Procedure:

1. First ensure all the valves of the rotameter, gas cylinder, and compressor are all closed.
2. Then open regulator valve of the LPG cylinder slightly.
3. Simultaneously open the rotameter valve, fire the burner using the matchstick or lighter.
4. By observing the flame through the glass window, adjust the rotameter valve so as to get the quality blue flame (Ensure the laminar flow condition).
5. Now the flame cone is established
6. Measure the cone angle with respect to the centerline of the cone (flame) by using angle protractor (First set the angle protractor to 90 degrees position and by holding in same position bring the protractor arm tangential to the flame boundary the lock the scale by turning the locking knob on the protractor, now observe & note down the reading from the circular scale).
7. Repeat the same procedure by changing the gas and airflow rate.
8. After the reading are taken, ensure that all the valves (LPG cylinder, rotameter, etc. are closed).

<u>Formulas used:</u>

1) Mass flow of air(m^3/s) = Air flow Rota meter reading in LPM/(1000×60)

2) Velocity of air (V_u, m/s) = Mass flow of air /Area of burner

3) Area of burner =Л×$d^2/4$

Where d=diameter of burner, d=5mm

Area of burner= Л×$(0.005)^2/4$=1.9637e10^{-5} m^2

Tabulation:

S.No	LPG flow rate in LPM	Air flow rate in LPM	Cone angle
1	0.01	0.5	3degree (Laminarflow, blue flame)

Calculations:

Mass flow of air =Air flow Rota meter reading in LPM/(1000×60)

=0.5/(1000×60) m^3/s

=8.333E10^{-6} m^3/sec

Velocity of air =mass flow rate of air/Area of burner (m^3/sec)

=8.33E10^{-6}/1.9637E10^{-6}

=0.4243m/sec

Results:

The semi cone angle of the premixed flame was found to -----degrees and hence theburning velocity was calculated to be -- m/sec.

STUDY OF FREE JET

AIM: To determine the velocity profile (or decaying velocity) of the free jet of different sizes

INTRODUCTION:

A high velocity fluid stream, forced under pressure, out of a small diameter opening such as a nozzle is called a jet. The Jet of the fluid has been extensively studied for its numerous occurrences in the engineering system including flow through an opening. The flow, of jet differs from the other kind of fluid flow because of jet is surrounded in one or more sides by a free boundary of the same fluid. The free air jet is a term used to describe a flow of air using an opening or a nozzle into an air space where the static pressure to influence the flow pattern and the static pressure of surrounding space. As the jet leaves the opening, a shear layer develops around its boundary. This is usually referred to as "free stream layer".

Velocity of the jet is calculated using in the formula, $V = \sqrt{2gh}_{a}$

In general, the free jet is formed when fluid is discharged from a nozzle or slot into large stagnant environments. The entrainment of the jet on the stagnant environments makes the jet width grow along the stream wise direction to some distance and finally dissipate.

The development of the free jet can be divided into four different zones according to the decay of centerline velocity, as shown in Figure. In the first zone (potential core), the centerline velocity is equal to inlet jet velocity where uniform velocity is assumed. The second zone is called the developed zone where the centerline velocity begins to decrease. Beyond these zones is a fully developed or established zone. Note that the irregularities of the edges are due to the mixing process and entrainments of the flow from the still ambient air. The last zone is called the terminal zone in which the centerline velocity rapidly decreases.

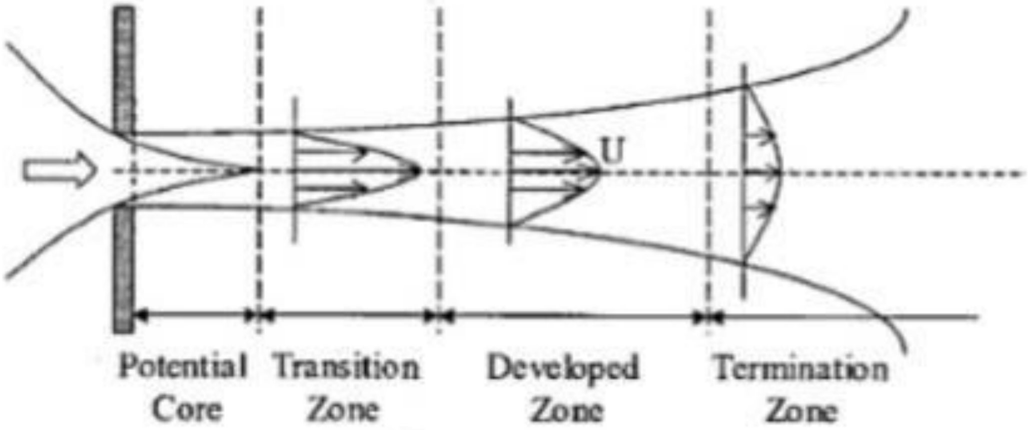
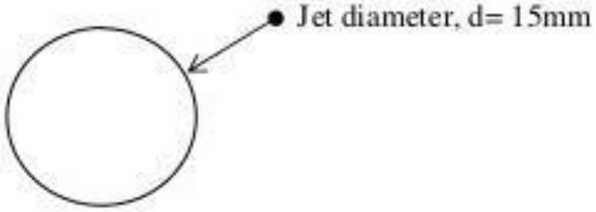


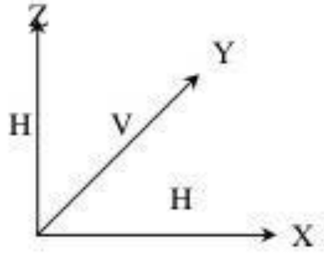
Fig. Sketch of the free jet

DISCRIPTION ABOUT THE SETUP

The setup basically consists of blower unit, a venture section (test section), orifice arrangement, wall jet arrangement, and flow measurement on control panel consisting of blower starter console, Mains ON Indicator, Differential manometer & multibank manometer & discharge measurement with orifice plate. The blower unit coupled to A.C motor and discharge can be controlled by Inlet valve plate closing. This blower unit is fixed below the control panel and it is connected to the section by a rubber hose and pipe line. The venture section or test section unit consists of an inlet and outlet conical section in between settling chamber with a Honeycomb and mesh so that a laminar and constant air velocity is achieved.

Nozzle with pressure tapings (10no) & connected to multibank manometer. The velocity of jet is measured by a pitot tube with X-Y-Z co-ordinate measurement arrangement. The wall jet consists of a M.S place with adjustable positioning to the orifice.





PROCEDURE:

1) Switch on the mains and observe the red indicator is ON, then Switch on console and blower.
2) Then slowly operate the inlet plate and lock to some position.
3) Then scan the pitot tube across the orifice & note down the readings.
4) Then move the pitot tube in X direction slowly and note down the flow readings.
5) Repeat the experiment for different flow.
6) Repeat the procedure for different values of Y axis also.
7) For wall jet experiments bring the wall near the orifice and note down the force exerted by the jet on the wall at different positions of X axis.
8) **Draw a graph of velocity Vs X distance, at different values of Y- axis.**

OBSERVATION:

Water tube manometer reading, $h_1 =$ mm
Water tube manometer reading, $h_2 =$ mm
Difference in water column of water tube manometer: $h_w = h_1 \sim h_2 =$ ________in meters
Atmospheric pressure, $p_a = 1.01325$ Bar $= 1.01325 \times 10^5$ N/m^2
Real gas constant, $R = 287$ J/Kg^{o}K
Room temperature, $T_a =$ ^{o}C
Acceleration due to gravity, $g = 9.81 m/s^2$

CALCULATIONS:

1) Discharge through the orifice $Q_{in} = C_d \dfrac{\pi d^2}{4}\sqrt{2gh_a}$ m^3/s

where d= 25mm= .025m
$g = 9.81 m/s^2$

$$h_a = \frac{h_w \rho_w}{\rho a} \text{ in meters of air}$$

$$\rho_{air} = \frac{p_a}{RT_a}$$

Where ρ_{air} = Density of air in Kg/m^3
p_a = Atmospheric pressure = 1.01325 Bar = 1.01325×10^5 N/m^2
R = Real gas constant = 287 J/Kg^{o}K
T_a = Room temperature

2) Velocity of the jet is calculated using the formula, $V = \sqrt{2gh_a}$

Here, $h_a\rho_a = h_{mercury}\rho_{mercury}$, or $h_a = \frac{h_m \rho_m}{\rho a}$

Where, ρ_m = Densisty of mercury = 13550 Kg/m^3

TABULAR COLUMN:

S. N.	Distance from jet in mm	Mercury manometer reading at different distances along Y direction ($h_{mercury}$) in mm			
			h_1	h_2	$h = h_1 \sim h_2$
1	X=0mm	At y=			
		At y=			
		At y=			
		At y=			
		At y=			
		At y=			
		At y=			
2	X=20mm	At y=			
		At y=			
		At y=			
		At y=			
		At y=			
		At y=			
		At y=			
3	X=40mm	At y=			
		At y=			
		At y=			
		At y=			
		At y=			
		At y=			
		At y=			
4	X=60mm	At y=			
		At y=			
		At y=			
		At y=			
		At y=			
		At y=			
		At y=			

RESULTS:

1) Discharge through the orifice, Q_{in} = m^3/s
2) Velocity of the jet at the centre line, V_{center} = m/s

Water equivalent of calorimeter is found to be W= 2330 Cal/ °C under standardization experiment.

To find the calorific value of given sample:

$$CV_s = \frac{(W \times T) - (E_1 + E_2)}{M}$$

Where CVs is Calorific value of given sample in Cal/°C

RESULT:

Calorific value of given sample is CVs= Cal/°C

CASCADE TESTING OF AXIAL COMPRESSOR AND TURBINE BLADE ROWS

Aim:

To evaluate the aerodynamic performance of axial compressor and turbine blade rows in a cascade setup by measuring pressure distribution and flow deviation angles.

Apparatus Required:

- Subsonic wind tunnel with a cascade test section
- Linear cascade model of compressor or turbine blades
- Pitot-static tubes and five-hole probes
- Manometers or pressure transducers
- Data acquisition system
- Angle measurement devices (e.g., protractors or inclinometers)
- Smoke generator or oil flow visualization setup

Theory:

In axial flow compressors and turbines, airflow passes through rows of rotating and stationary blades. To analyze the aerodynamic behaviour of these blades, a cascade setup is employed, wherein multiple blades are arranged in a linear or annular fashion to simulate the flow conditions in actual turbomachinery. The cascade allows for the study of two-dimensional flow characteristics in a controlled environment. Key parameters in cascade testing include the pressure loss coefficient (C_{pt}), which quantifies the total pressure loss across the blade row; the flow deviation angle, indicating the change in flow direction due to blade passage; blade loading, assessing the distribution of aerodynamic forces along the blade surface; and secondary flows, identifying complex flow structures that can lead to additional losses. Understanding these parameters aids in optimizing blade designs for improved performance and efficiency.

Procedure:

- Mount the cascade blade model securely in the wind tunnel test section.
- Calibrate instruments like Pitot-static tubes and five-hole probes before use.
- Start the wind tunnel and gradually increase airflow to the required velocity.
- Allow airflow to stabilize before taking pressure and angle measurements.
- Measure static and total pressures at multiple upstream and downstream points.
- Record pressure data at various spanwise and chordwise positions on the blades.
- Determine inlet and outlet flow angles using the five-hole probe accurately.

- Use smoke or oil flow techniques to visualize flow around the blade surfaces.
- Repeat the tests at different incidence angles and airflow velocities.

Calculations:

The pressure loss coefficient (C_{pt}) is calculated using the formula:

$$C_{pt} = \frac{P_{t1} - P_{t2}}{0.5 \cdot \rho \cdot V^2}$$

Flow Deviation Angle (Δθ):

The flow deviation angle indicates the change in flow direction due to the blade passage and is calculated as:

$$\Delta\theta = \theta_{out} - \theta_{in}$$

Pressure distribution along the blade surface is plotted, and flow visualization results are analyzed to identify regions of flow separation and secondary flows.

Results:

The pressure loss coefficient and flow deviation angle indicate the aerodynamic efficiency and flow turning of the blade cascade. Flow visualization shows the flow behaviour around the blades, highlighting key performance characteristics.

MESUREMENT OF NOZZLE FLOW

AIM: To determine the pressure distribution in a convergent nozzle.

INTRODUCTION:

The nozzle of a fluid is extensively useful in many engineering applications in the field of Aeronautical engineering. The study of nozzle helps us to know the velocity discharge & pressure distribution required for engineering applications. Nozzle is a device used to increase the kinetic energy of the fluid flowing through duct at the expense of the pressure energy or the enthalpy. Nozzle is used to produce thrust in aerospace vehicles by increasing the momentum of the fluid while passing through the duct. In the subsonic flow, nozzle is a convergent duct where the area of cross- section of flow decreases in the flow direction along the duct. In the case of supersonic flow, the nozzle is obtained by providing a convergent divergent duct.

The working of the nozzle at low speeds can be explained using the Bernoulli's equation.

$$\frac{P}{\rho g}+\frac{V^2}{2g}+Z=\text{Constant}$$

Assuming the flow is incompressible, that is the density is constant and there are no losses in the flow. In the above equation,

$\frac{P}{\rho g}$ = Pressure energy per unit weight of fluid or pressure head

$\frac{V^2}{2g}$ = Kinetic energy per unit weight or kinetic head

Z= Potential energy per unit weight or potential head.

According to the Bernoulli's equation, it is essential to demonstrate the working of the nozzle and study the velocity and pressure variations as the flow passes through the nozzle. A convergent nozzle with surface/static pressure taps along the length of the nozzle is provided to measure the static pressure variation as the flow passes through the nozzle. An orifice is provided in the upstream to measure the volume flow rate.

DESCRIPTION OF THE SETUP:

The setup consists of blower unit coupled to AC Motor & is connected to convergent nozzle through a settling chamber with a hose. The discharge can be controlled by inlet valve of the blower .The Pressure tapings (10 Nos) is made in the nozzle surface and is connected multibank manometer. The orifice plate is fitted in the pipeline of the blower outlet, to measure the discharge of flow and is connected to differential manometer. The control panel consists of the mains on indicator, console switch, A.C. motor blower switch, differential manometer & multi bank manometer. & the whole instrumentation is mounted on a self contained sturdy table & is isolated from the blower unit so that vibration should not transfer to the table.

PROCEDURE:

1) Switch on the mains & observe the mains on indicator is glow
2) Switch on the console switch and then blower.

3) Slowly increase the speed/discharge of the motor to the desired value by operating the inlet valve plate.
4) Note down the Differential Manometer & multi bank manometer readings.
5) Repeat the procedure for different flow rates.
6) Graphs: Pressure V/s Location

OBSERVATIONS:

1) Acceleration due to gravity, $g = 9.81\ m/s^2$
2) Density of water, $\rho_w = 1000\ Kg/\ m^3$
3) Diameter of orifice, $d = 25mm$
4) Coefficient of orifice, $C_d = 0.64$
5) Coefficient of pitot tube, $C_v = 0.98$
6) Real gas constant, $R = 287\ J/Kg^oK$
7) Atmospheric pressure, $p_a = 1.01325$ Bar

TABLE OF READINGS:

S.N	Velocity head (pitot tube)			Air flow across orifice			Pressure tapping reading along the nozzle in mm of water									
	h_1	h_2	h_w	h_1	h_2	h_w	h_1	h_2	h_3	h_4	h_5	h_6	h_6	h_8	h_9	h_{10}
1																
2																
3																
4																
5																

CALCULATIONS:

1) Area of orifice, $A = \frac{\pi d^2}{4}$
2) Discharge through the orifice, $Q = C_d A\sqrt{2gh_{air}}$
3) Velocity of air in the nozzle at particular location $V_x = \frac{Q}{A_x}$

   Where A_x is the cross sectional area at section X-X of the nozzle
4) Velocity at the centerline of the nozzle at the exit $V_{exit} = C_v\sqrt{2gh_{air}}$
5) Pressure at any point in the nozzle, $P_x = \rho g h_{air}$

$$\rho_{air} = \frac{p_a}{RT_a}$$

Where ρ_{air} = Density of air in Kg/m^3

p_a = Atmospheric pressure = 1.01325 Bar = $1.01325 \times 10^5\ N/m^2$

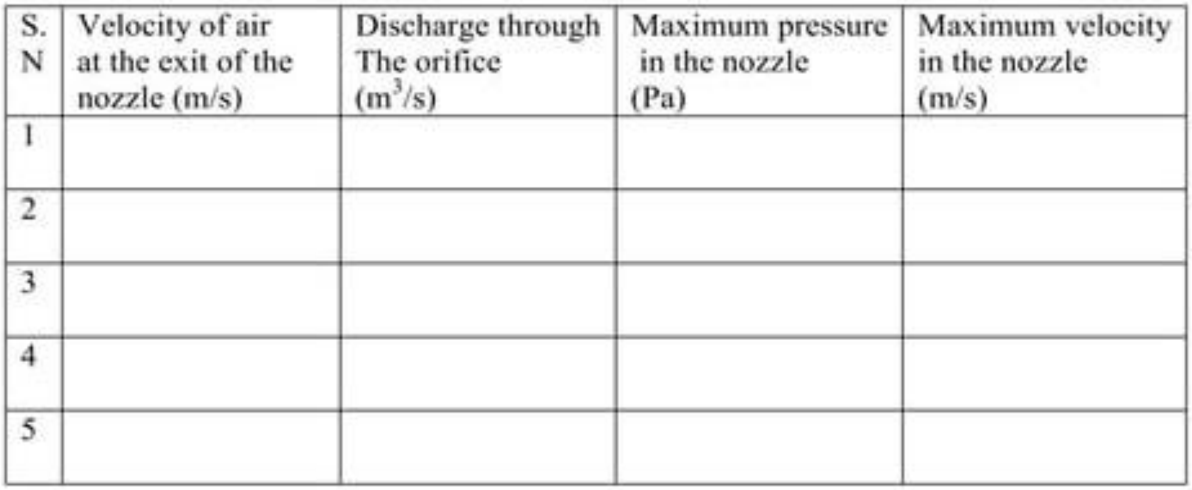
R = Real gas constant = $287\ J/Kg^oK$

T_a = Room temperature

Here, $h_a\rho_a = h_w\rho_w$, or $h_a = \frac{h_w\rho_w}{\rho a}$

Where, ρ_w = Densisty of water = $1000\ Kg/m^3$

RESULT TABLE:



S. N	Velocity of air at the exit of the nozzle (m/s)	Discharge through The orifice (m^3/s)	Maximum pressure in the nozzle (Pa)	Maximum velocity in the nozzle (m/s)
1				
2				
3				
4				
5				

CONCLUSION:

Study of the Flame Lift-Up and Fall-Back Phenomenon for Varied Air-Fuel Ratio

Aim

To study the phenomena of flame lift-up and fall-back in a laboratory combustor setup by varying the air-fuel ratio, and to understand the conditions under which the flame stabilizes, lifts off, or falls back.

Apparatus Required

- Laboratory-scale premixed or partially premixed gas burner
- Air supply with flow control (rotameter or mass flow controller)
- Fuel supply (e.g., LPG or methane) with flow control
- Transparent combustion chamber or test section
- Flame visualization setup (UV sensor or camera or visual inspection window)
- Ignition system
- Manometer or pressure gauge (optional)
- Infrared thermometer (optional)

3. Theory

In gas turbine and aircraft propulsion systems, flame stability is crucial for efficient and safe combustion. Two important flame instability phenomena are:

Flame Lift-Up: The flame moves away from the burner nozzle and detaches at high airflow velocities or lean mixtures. This can lead to flame blow-off or incomplete combustion.

Flame Fall-Back: Occurs when the flame moves toward the burner or upstream into the premixing zone due to low air velocities or overly rich mixtures. This can cause damage to the burner or backfire.

These phenomena are influenced by the air-fuel ratio (AFR), which determines the equivalence ratio (ϕ):

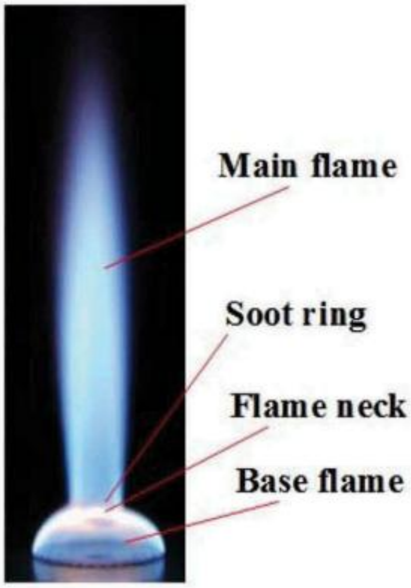
$$\phi = \frac{(F/A)_{\text{actual}}}{(F/A)_{\text{stoichiometric}}}$$

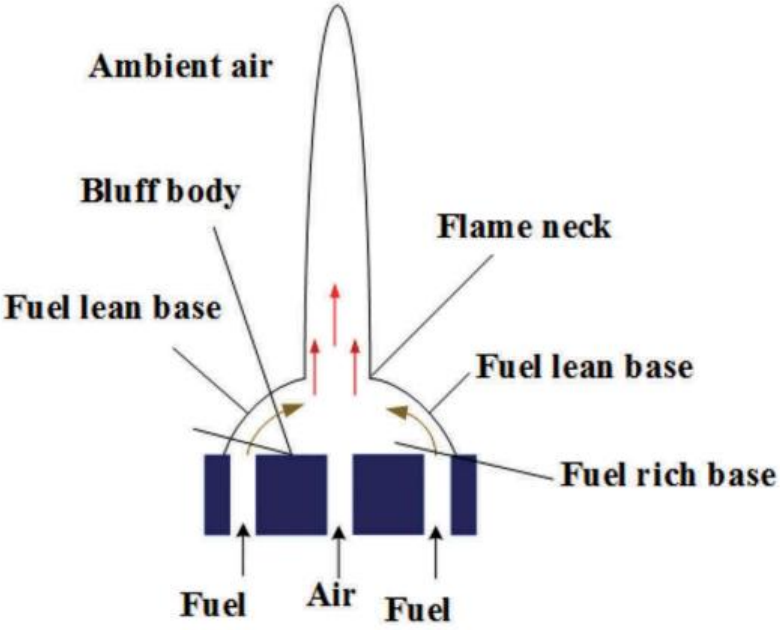
ϕ < 1: Lean mixture (more air)

ϕ = 1: Stoichiometric mixture

ϕ > 1: Rich mixture (more fuel)

The **velocity of the incoming flow** and the **laminar flame speed** determine the flame's position. If the flow velocity exceeds the flame speed, the flame lifts. If it's too low, the flame may fall back.





Procedure

- Ensure safety protocols are followed. Check all connections and ventilation.
- Set up the burner with proper air and fuel lines connected and leak-checked.
- Ignite the flame using the ignition system at a safe air-fuel ratio.
- Gradually increase the air flow rate, keeping fuel flow constant. Observe and record:
  - Flame appearance
  - Flame position (anchored, lifted, or blown off)

- Reduce the air flow and increase fuel to make the mixture richer. Observe and record:
    - Any fall-back of flame
    - Changes in flame stability
- Vary the air-fuel ratio systematically and record corresponding flame behaviors.
- Shut down the system safely after observations.

S. No	**Fuel Flow Rate (LPM)**	**Air Flow Rate (LPM)**	**Equivalence Ratio (ϕ)**	**Flame Behavior**	**Remarks**
1				Anchored	
2				Lifted up	
3				Fall-back	

Result

The flame was observed to lift up at high air-fuel ratios (lean mixtures) and fall back at low air-fuel ratios (rich mixtures).The critical values of air-fuel ratio for lift-up and fall-back were identified.

Performance Studies on a Scaled Jet Engine

Aim

To evaluate the performance characteristics of a scaled-down turbojet engine through experimental measurements and analysis, focusing on parameters such as thrust, fuel consumption, exhaust temperature, and specific fuel consumption (SFC).

Apparatus Required

- Scaled Turbojet Engine Test Rig (e.g., JetCat or equivalent)
- Fuel supply system (usually kerosene or Jet A1)
- Air intake with flow conditioning
- Thrust measurement system (load cell or thrust stand)
- RPM sensor (optical or Hall-effect)
- Thermocouples
- Pressure sensors
- Data acquisition system or manual measurement instruments

Theory

A turbojet engine works on the principle of Newton’s third law, generating thrust by accelerating a mass of air and fuel through the combustion process and exhausting it at high speed.

The basic thermal cycle is based on the Brayton cycle, involving:

1. **Isentropic compression** in the compressor
2. **Constant-pressure heat addition** in the combustion chamber
3. **Isentropic expansion** in the turbine
4. **Jet acceleration** in the nozzle

The key performance parameters include:

Thrust:

$$T = \dot{m}_{air}(V_{exit} - V_{inlet}) + (P_{exit} - P_{ambient})A_{exit}$$

Specific Fuel Consumption (SFC):

$$\text{SFC} = \frac{\dot{m}_{fuel}}{T} \quad \left[\frac{\text{kg of fuel}}{\text{N of thrust} \cdot \text{s}}\right]$$

Thermal Efficiency (η_{th}):

$$\eta_{th} = \frac{\text{Kinetic energy of exhaust jet}}{\text{Fuel energy input}}$$

These values vary with **rotor RPM**, **ambient temperature**, **fuel flow rate**, and **altitude.**

Procedure

- Ensure the test rig is securely mounted and all safety protocols are in place.
- Connect all measurement sensors: thrust, temperature, pressure, and RPM.
- Prime the fuel line and perform pre-start checks.
- Start the engine using the electric starter and stabilize at idle RPM.
- Gradually increase the throttle in steps (e.g., 50%, 75%, 100% RPM).
- At each step, record:
    - RPM
    - Thrust (N)
    - Inlet and Exhaust Temperatures (°C)
    - Fuel Flow Rate (mL/min or kg/s)
    - Inlet and Exit Pressures (Pa)
- Allow the engine to cool down after the test.
- Shut off fuel, disconnect sensors, and clean the test area.

S. No	**RPM (%)**	**Thrust (N)**	**Fuel Flow Rate (g/s)**	**Tinlet (°C)**	**Texit (°C)**	**SFC (g/N·s)**	**Remarks**
1							
2							
3							
4							
5							

Calculations

- Convert all temperatures to Kelvin.
- Calculate **Specific Fuel Consumption** at different thrust values.
- Estimate **thermal efficiency** using calorific value of fuel.
- Plot **Thrust vs RPM** and **SFC vs RPM** graphs.

Result

- The thrust output and fuel consumption were measured at different throttle settings.
- The **optimum RPM** and **minimum SFC** were determined.
- The engine's thermal performance under scaled conditions was analyzed.

Study of Fuel Injection Characteristics

Aim

To study the fuel injection characteristics in a gas turbine engine combustion system by analyzing parameters such as spray cone angle, droplet size, atomization quality, and penetration length under varying injection pressures and nozzle configurations.

Apparatus Required

- Fuel injection test rig or spray test chamber
- Fuel injector (pressure swirl, air blast, or pintle-type)
- High-speed camera or shadowgraph imaging system (for spray visualization)
- Laser diffraction or Phase Doppler Particle Analyzer (PDPA) (if available, for droplet sizing)
- Graduated scale or calibrated screen for spray pattern analysis
- Pressure gauge and regulator
- Fuel tank and delivery system (Diesel/Kerosene/Jet A1)
- Safety equipment: gloves, fire extinguisher, fume extraction

Theory

Efficient combustion in aircraft engines requires **fine atomization** of fuel, ensuring better mixing with air and rapid evaporation. Fuel injection systems are designed to:

- Produce uniform spray patterns
- Generate small droplets (improving evaporation)
- Control flow rate and spray penetration
- Adapt to varying pressure and altitude conditions

1. Spray Cone Angle (θ)

The angular spread of the fuel spray, which affects the combustion chamber coverage and air-fuel mixing.

2. Sauter Mean Diameter (SMD)

A measure of the average droplet size, balancing surface area and volume:

$$\mathrm{SMD} = \frac{\sum D_i^3}{\sum D_i^2}$$

Smaller SMD leads to better atomization and faster combustion

3. Spray Penetration (L)

The axial distance reached by the fuel jet from the nozzle tip. Excessive penetration can lead to wall wetting and poor combustion.

The injection characteristics depend on:

- Fuel injection pressure
- Nozzle design (orifice size, swirl angle)
- Ambient air conditions (pressure, temperature)

Procedure

- Ensure the spray chamber is clean, ventilated, and properly illuminated.
- Fill the fuel reservoir with test fuel and remove air from lines.
- Mount the injector in the vertical or horizontal position for visualization.
- Adjust the fuel pressure using the regulator (e.g., 2 to 10 bar).
- Activate the injector briefly and capture the spray using:
    1. **High-speed imaging** for cone angle and penetration length
    2. **Laser diffraction** or **PDPA** (if available) for droplet size
- Repeat the test for different pressures and nozzle configurations.
- Record all observations and measurements.
- Clean the equipment and shut down the system safely.

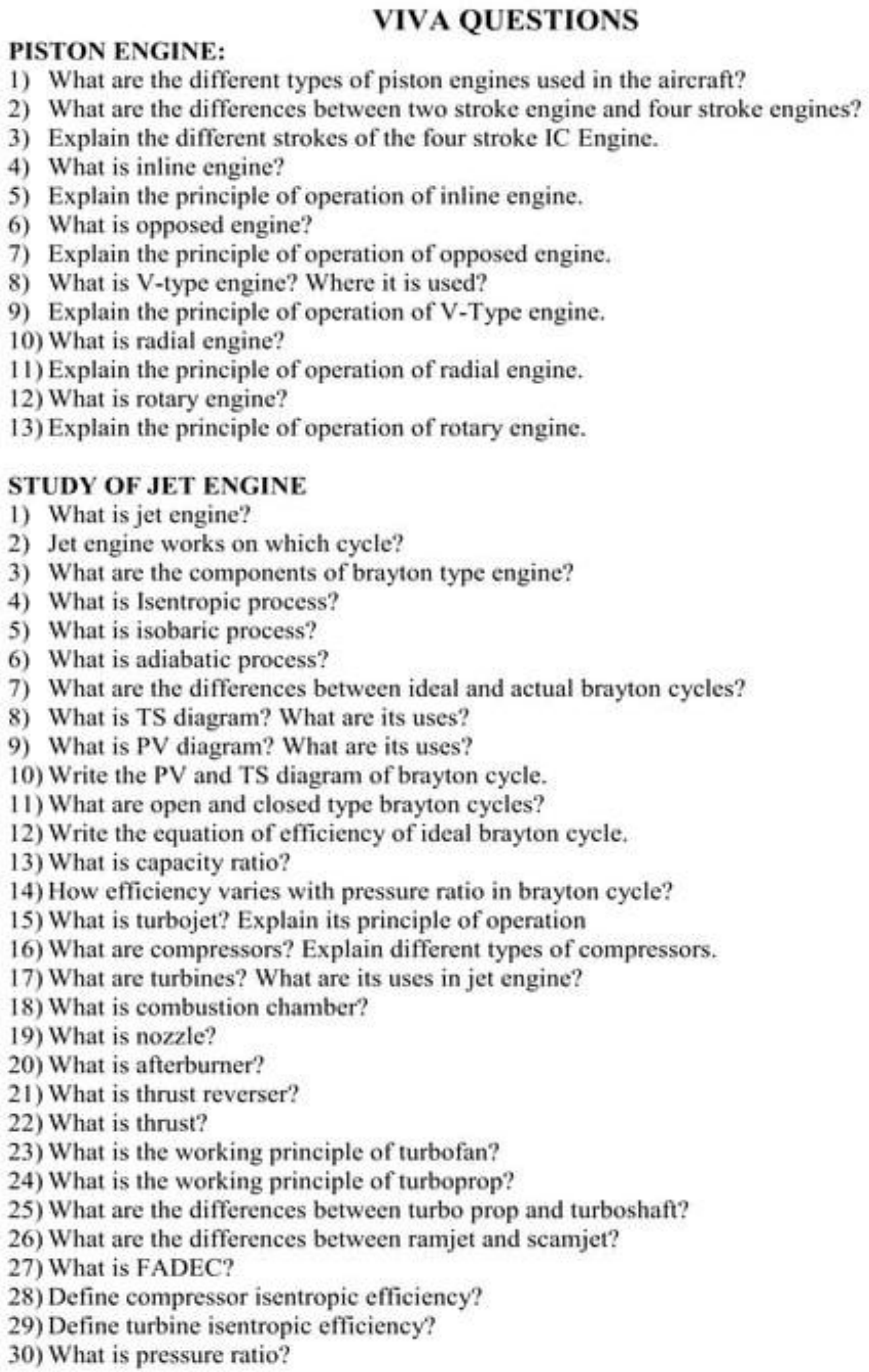
Sl. No.	Injection Pressure (bar)	Spray Cone Angle (°)	Penetration Length (mm)	Mean Droplet Diameter (µm)	Remarks
1					
2					
3					
4					
5					

Calculations

- Calculate **SMD** (if droplet sizing data is available).
- Determine the variation of cone angle and penetration length with pressure.
- Plot:
  - Spray Cone Angle vs. Injection Pressure
  - Droplet Size vs. Injection Pressure
  - Penetration Length vs. Time (if time-resolved data available)

Result

Fuel injection characteristics such as **spray angle**, **droplet size**, and **penetration** were successfully measured. Increasing injection pressure led to **wider cone angles** and **finer atomization**. Data supports the design requirements for efficient atomization in gas turbine combustion chambers.



VIVA QUESTIONS

PISTON ENGINE:

1) What are the different types of piston engines used in the aircraft?
2) What are the differences between two stroke engine and four stroke engines?
3) Explain the different strokes of the four stroke IC Engine.
4) What is inline engine?
5) Explain the principle of operation of inline engine.
6) What is opposed engine?
7) Explain the principle of operation of opposed engine.
8) What is V-type engine? Where it is used?
9) Explain the principle of operation of V-Type engine.
10) What is radial engine?
11) Explain the principle of operation of radial engine.
12) What is rotary engine?
13) Explain the principle of operation of rotary engine.

STUDY OF JET ENGINE

1) What is jet engine?
2) Jet engine works on which cycle?
3) What are the components of brayton type engine?
4) What is Isentropic process?
5) What is isobaric process?
6) What is adiabatic process?
7) What are the differences between ideal and actual brayton cycles?
8) What is TS diagram? What are its uses?
9) What is PV diagram? What are its uses?
10) Write the PV and TS diagram of brayton cycle.
11) What are open and closed type brayton cycles?
12) Write the equation of efficiency of ideal brayton cycle.
13) What is capacity ratio?
14) How efficiency varies with pressure ratio in brayton cycle?
15) What is turbojet? Explain its principle of operation
16) What are compressors? Explain different types of compressors.
17) What are turbines? What are its uses in jet engine?
18) What is combustion chamber?
19) What is nozzle?
20) What is afterburner?
21) What is thrust reverser?
22) What is thrust?
23) What is the working principle of turbofan?
24) What is the working principle of turboprop?
25) What are the differences between turbo prop and turboshaft?
26) What are the differences between ramjet and scamjet?
27) What is FADEC?
28) Define compressor isentropic efficiency?
29) Define turbine isentropic efficiency?
30) What is pressure ratio?

FORCED CONVECTIVE HEAT TRANSFER

1) What is heat transfer?
2) Define conduction?
3) Define convection?
4) Define radiation?
5) What is forced convection?
6) What is free convection?
7) What is convection heat transfer coefficient?
8) Define nussult number?
9) Define reynolds number?
10) What is prandtl number?
11) What is thermal conductivity?
12) What is kinematic viscosity?
13) What is dynamic viscosity/
14) What is laminar flow?
15) What is turbulent flow?
16) What is fluid film temperature/

PERFORMANCE OF A PROPELLER

1) What is a propeller? Why it is used?
2) Define propulsion efficiency.
3) What is basic principle of propeller?
4) What are the basic parts of a fixed pitch propeller?
5) What is leading edge?
6) What is trailing edge?
7) What is root?
8) What is pitch in case of propeller?
9) What are the differences between fixed pitch and variable pitch propellers/
10) Define blade angle.
11) Define blade pitch
12) Define geometric pitch
13) Define effective pitch
14) Define angle of attack
15) Define propeller slip
16) What are the forces acting on a propeller?
17) What is thrust force?
18) What is centrifugal force?
19) What is twisting force?
20) What is aerodynamic twisting force/
21) Define propeller efficiency
22) What is anemometer?
23) How theoretical thrust is calculated for propeller?

BOMB CALORIMETER

1) What is calorific value?
2) Which are fuels used for aviation?
3) What is the principle of working of bomb calorimeter?

4) What is water equivalent of calorimeter? And how it is calculated?
5) What is higher calorific value?
6) What is lower calorific value?

Calorific Value:
It can be defined as the amount of heat liberated in KJ or Kcal by the complete combustion of 1 Kg of fuel.
There are two types of calorific values
Higher calorific value (HCV) = It is the total heat liberated in KJ or Kcal by the complete combustion of 1 Kg of fuel.
Lower calorific value (LCV) = It is the difference of Higher calorific value and heat absorbed by water vapors.
LCV = (HCV – x.588.76) Kcal/Kg
Where 'x' is the fraction of water vapors

STUDY OF FREE JET

1) What is a jet?
2) What is free jet?
3) What is free stream layer?
4) How velocity of jet is calculated?
5) Sketch the velocity profile of free jet?
6) What are transition zone, developed zone and termination zones?
7) What is pitot tube? What is the working principle of pitot tube?
8) How discharge through the pitot tube is calculated?

MEASUREMENT OF BURNING VELOCITY

1) What is burning velocity of a flame?
2) What is laminar flow?
3) How Bunsen burner works?
4) What is tangential velocity of flame?
5) How burning velocity is calculated?
6) How do you measure the cone angle of flame?
7) What is normal velocity of flame?
8) What is air-fuel ratio?
9) How blue flame is achieved in Bunsen burner?
10) How do you obtain the blue flame in your test setup?
11) What is the range of semi included cone angle for laminar flow?

MESUREMENT OF NOZZLE FLOW

1) What is a nozzle?
2) What is convergent nozzle?
3) What is divergent nozzle?
4) Write the Bernoulli's equation. Explain its terms.
5) What is compressible fluid?
6) What is incompressible fluid? Give examples.

Flame Lift-Up and Fall-Back Phenomenon for Varied Air-Fuel Ratio

1. What is meant by flame lift-up and fall-back?
2. How does air-fuel ratio affect flame stability?
3. What is the difference between premixed and diffusion flames?
4. What are the practical implications of flame instability in aircraft engines?
5. Why is it important to maintain a proper air-fuel ratio in combustion chambers?

Performance Studies on a Scaled Jet Engine

1. What is the working principle of a turbojet engine?
2. Define thrust and specific fuel consumption.
3. What is the importance of SFC in aircraft engines?
4. How does RPM affect thrust in a turbojet engine?
5. What are the limitations of scaled-down engine testing?

Study of Fuel Injection Characteristics

1. Why is atomization important in aircraft engine combustion?
2. What factors affect spray cone angle and droplet size?
3. Define Sauter Mean Diameter and explain its significance.
4. How does injection pressure affect fuel spray characteristics?
5. What is the difference between air-blast and pressure-swirl injectors?