SRINIVASAN ENGINEERING COLLEGE

(Approved By AICTE, New Delhi and Affiliated To Anna University, Chennai)

An ISO 9001:2008 Certified Institution

PERAMBALUR 621212

DEPARTMENT OF AERONAUTICAL ENGINEERING

PROPULSION LABORATORY MANUAL

Commented [A1]:

LIST OF EQUIPMENTS
(for a batch of 30 students)

SI.NO	REQUIRMENT	QUANTITY
1	PISTON ENGINES	2
2	JET ENGINE /ENGINE MODEL	1
3	FORCED CONVECTIVE APPARATUS	1
4	FREE CONVECTIVE APPARATUS	1
5	AXIAL COMPRESSOR BLADE ROW MODEL WITH PRESSURE TAPPING	1
6	WATERTUBE MANOMETERS (20 TUBES)	2
7	SUBSONIC WIND TUNNEL	1
8	PROPELLER MODEL STATIC AND TOTAL PRESSURE PROBES	4
9	2-D TRAVERS IN MECHANISM	2
10	FREEJET TEST SETUP	1
11	ALUMINIUM PLATES WITH DEFLECTION MECHANISMS	1

UNIVERSITY PRACTICAL EXAMINATION

ALLOTMENT OF MARKS

Internal assessment = 20 marks
Practical examination = 80 marks

INTERNAL ASSESSMENT [20 MARKS]

Staff should maintain the assessment register and the head of the department should monitor it.

SPLIT UP OF INTERNAL MARKS

RECORD NOTE	10 MARKS
MODEL EXAM	5 MARKS
ATTENDANCE	5 MARKS
TOTAL	**20 MARKS**

UNIVERSITY EXAMINATION

The examination will be conducted for 100 marks. Then the marks will be calculated to 80 marks.

ALLOCATION OF MARKS

AIM AND PROCEDURE	30 MARKS
MODELING	30 MARKS
SIMULATION	20 MARKS
RESULT	10 MARKS
VIVA VOCE	10 MARKS
TOTAL	**100 MARKS**

LIST OF EXPERIMENTS AS PER SYLLABUS

- ✓ Study of an aircraft piston engine. (Includes study of assembly of sub systems, various components, their functions and operating principles)
- ✓ Study of an aircraft jet engine (Includes study of assembly of sub systems, various components, their functions and operating principles)
- ✓ Study of forced convective heat transfer over a flat plate.
- ✓ Study of free convective heat transfer over a flat plate
- ✓ Cascade testing of a model of axial compressor blade row.
- ✓ Study of performance of a propeller.
- ✓ Determination of heat of combustion of aviation fuel.
- ✓ Combustion performance studies in a jet engine combustion chamber.
- ✓ Study of free jet.
- ✓ Study of wall jet.

TOTAL: 45 PERIODS

LIST OF EXPERIMENTS WITH REVISION STATUS

SI NO.	TITLE	PAGE NO.	ISSUE NO.	REVISION NO. WITH DATE									
				00	01	02	03	04	05	06	07	08	09
01	STUDY OF PISTON ENGINES												
02	STUDY OF JET ENGINES												
03	STUDY OF FREE CONVECTION APPARATUS												
04	STUDY OF FORCED CONVECTION APPARATUS												
05	BOMB CALORIMETER												
06	STUDY OF PERFORMANCE OF PROPELLER												
07	STUDY OF FREE JET												
08	COMBUSTION PERFORMANCE STUDIES IN A JET ENGINE COMBUSTION CHAMBER												

SI.NO	NAME OF THE EXPERIMENT	PAGE NO.
1	STUDY OF PISTON ENGINES	
2	STUDY OF JET ENGINES	
3	STUDY OF FREE CONVECTION APPARATUS	
4	STUDY OF FORCED CONVECTION APPARATUS	
5	BOMB CALORIMETER	
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8	COMBUSTION PERFORMANCE STUDIES IN A JET ENGINE COMBUSTION CHAMBER	

	SRINIVASAN ENGINEERING COLLEGE, PERAMBALUR – 621 212 DEPARTMENT OF AERONAUTICAL ENGINEERING PROPULSION LAB	ISSUE NO: 01 REVISION NO: 00 DATE : 12.12.12

EXP NO: 1 **DATE:**

STUDY OF PISTON ENGINES

AIM:

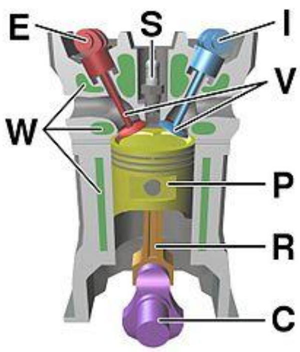
To study the basic operating principle of piston engine and its various types.

THEORY:

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 sterling 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 (sterling 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 sterling 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.



E -Exhaust Camshaft

I -Intake camshaft

S - Sparkplug

V - Valves

P - Piston

R - Connecting rod

C - Crankshaft

W - Water Jacket For Coolant Flow

Figure 1. Components of piston engine

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)

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

The following is an additional parameter for a 2 stroke engine

Transfer Port: The port (or passageway) in a 2 stroke engine that transfers the fuel/air mixture from the bottom of the engine to the top of the cylinder.

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.

Opposed Engine

An opposed-type engine has two banks of cylinders opposite each other. The crankshaft is located in the center and is being driven from both sides. The engine is either air cooled or liquid cooled, but air cooled versions are used mostly in aviation. It can be mounted either vertically or horizontally. The advantage of a horizontally-opposed engine is that it allows better visibility and eliminates fluid lock typically found on bottom cylinders. An opposed engine also has a relative advantage in being mostly free of vibration. This is due to the fact that the pistons are located left and right of the crankshaft and acts as balance weights for each other.

Figure 1.1 Inline opposed piston engine

V-Type Engine

Cylinders in this engine are arranged in two in-line banks, tilted 30-60 degrees apart from each other. The engine can be either air cooled or liquid cooled.

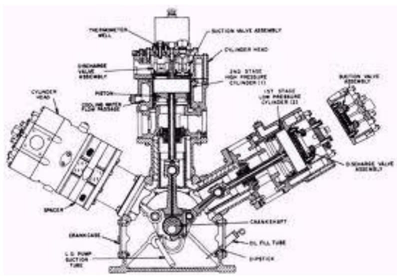


Figure 1.2 V-Type piston engines

Radial Engine

This type of engine has a row of cylinders arranged in a circle around a crankcase located in the middle. The combination of cylinders must be an odd number in each row and may contain more than one row. The odd number of cylinders allows for every other cylinder to be on a power stroke, allowing for smooth operation. The power output is anywhere from 100 to 3,800 HP.

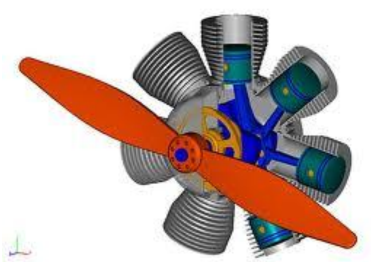


Figure 1.3 Radial piston engines

4 Stroke engine

Engines based on the four-stroke or Otto cycle have one power stroke for every four strokes (up-down-up-down) and are used in cars, larger boats, and many light aircraft. They are generally quieter, more efficient, and larger than their two-stroke counterparts. There are a number of variations of these cycles, most notably the Atkinson and Miller cycles. Most truck and automotive diesel engines use a four-stroke cycle, but with a compression heating ignition system. This variation is called the diesel cycle. The four strokes refer to intake, compression, combustion and exhaust strokes that occur during two crankshaft rotations per working cycle of Otto Cycle and Diesel engines. The four steps in this cycle are often informally referred to as "suck, squeeze (or squash), bang, blow."

2 Stroke engine

The two-stroke internal combustion engine differs from the more common four-stroke engine by completing the same four processes (intake, compression, combustion, exhaust) in only two strokes of the piston rather than four. This is accomplished by using the beginning of the compression stroke and the end of the combustion stroke to perform the intake and exhaust functions. This allows a power stroke for every revolution of the crank, instead of every second revolution as in a four-stroke engine. For this reason, two-stroke engines provide high specific power, so they are valued for use in portable, lightweight applications such as chainsaws as well as large-scale industrial applications like locomotives. Two-stroke engines are still commonly used in high-power, handheld applications where light weight is essential, primarily string trimmers and chainsaws. To a lesser extent, these engines may still be used for certain small, portable, or specialized machine applications. These include outboard motors, high-performance, small-capacity motorcycles, mopeds, under bones, scooters, snowmobiles, karts, ultra lights, model airplanes (and other model vehicles) and lawnmowers. In the past, two-stroke cycles were experimented with for use in diesel engines, most notably with opposed piston designs, low-speed units such as large marine engines, and v8 engines for trucks and heavy machinery

A Very Basic 2 Stroke Engine Cycle

Stroke	Piston Direction	Actions Occurring during This Stroke	Explanation
Stroke1	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
Stroke2	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	Inlet valve open/Exhaust valve closed	Induction stroke	As the Piston travels down the cylinder barrel, the inlet valve opens & fresh fuel/air mixture is sucked into the cylinder

	barrel			
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

RESULT:

Thus the basic piston engine and the other types of piston engine are studied.

VIVA QUESTIONS:

- ✓ What are the different types of piston engines used in the aircraft?
- ✓ What are the differences between two stroke engine and four stroke engines?
- ✓ Explain the different strokes of the four stroke ic engine.
- ✓ What is inline engine?
- ✓ Explain the principle of operation of inline engine.
- ✓ What is opposed engine?
- ✓ Explain the principle of operation of opposed engine.
- ✓ What is v-type engine? Where it is used?
- ✓ Explain the principle of operation of v-type engine.
- ✓ What is radial engine?
- ✓ Explain the principle of operation of radial engine.
- ✓ What is rotary engine?
- ✓ Explain the principle of operation of rotary engine.

UNIVERSITY QUESTIONS:

- Explain about an aircraft piston engine.
- Explain the basic piston engine and its various types.
- Study the aircraft piston engine

	SRINIVASAN ENGINEERING COLLEGE, PERAMBALUR – 621 212 DEPARTMENT OF AERONAUTICAL ENGINEERING PROPULSION LAB	ISSUE NO: 01 REVISION NO: 00 DATE : 12.12.12

EXP NO: 2 **DATE:**

STUDY OF JET ENGINES

AIM:

To study the basic operating principle of jet engine and its various types.

THEORY:

A **jet engine** is a reaction engine that discharges a fast moving jet of fluid to generate thrust in accordance with Newton's third law of motion. This broad definition of jet engines includes turbojets, turbofans, rockets, ramjets, pulse jets and pump-jets, but in common usage, the term generally refers to a gas turbine Brayton cycle engine, an engine with a rotary compressor powered by a turbine, with the leftover power providing thrust. Jet engines are so familiar to the modern world that gas turbines are sometimes mistakenly referred to as a particular application of a jet engine, rather than the other way around. Most jet engines are internal combustion engines but non combusting forms exist also.

Jet engines are primarily used by jet aircraft for long distance travel. The early jet aircraft used turbojet engines which were inefficient. Modern jet aircraft usually use high-bypass turbofan engines which help give high speeds as well as, over long distances, better fuel efficiency than many other forms of transport. A large proportion of the world's oil consumption (about 7.2% in 2004) is burnt in jet engines.

MAJOR COMPONENTS OF A JET ENGINE AND THEIR FUNCTIONS

The major components of a jet engine are similar across the major different types of engines, although not all engine types have all components.

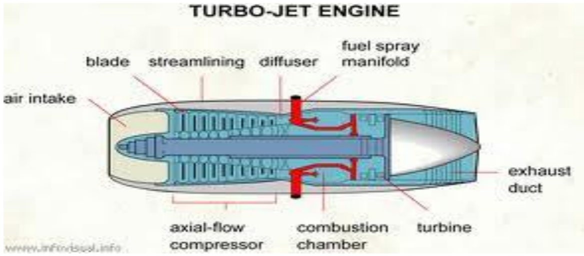


Figure 2. Components of turbojet engine

Cold Section:

- **Air intake (Inlet)** — The standard reference frame for a jet engine is the aircraft itself. For subsonic aircraft, the air intake to a jet engine presents no special difficulties, and consists essentially of an opening which is designed to minimize drag, as with any other aircraft component. However, the air reaching the compressor of a normal jet engine must be traveling below the speed of sound, even for supersonic aircraft, to sustain the flow mechanics of the compressor and turbine blades. At supersonic flight speeds, shockwaves form in the intake system and reduce the recovered pressure at inlet to the compressor. So some supersonic intakes use devices, such as a cone or ramp, to increase pressure recovery, by making more efficient use of the shock wave system.
- **Compressor** or **Fan** — The compressor is made up of stages. Each stage consists of vanes which rotate, and stators which remain stationary. As air is drawn deeper through the compressor, its heat and pressure increases. Energy is derived from the **turbine** (see below), passed along the **shaft**.

Common:

- **Shaft** — The shaft connects the **turbine** to the **compressor**, and runs most of the length of the engine. There may be as many as three concentric shafts, rotating at independent speeds, with as many sets of turbines and compressors. Other services, like a bleed of cool air, may also run down the shaft.

Hot section:

- **Combustor** or **Can** or **Flame holders** or **Combustion Chamber** — This is a chamber where fuel is continuously burned in the compressed air.
- **Turbine** — The turbine is a series of bladed discs that act like a windmill, gaining energy from the hot gases leaving the **combustor**. Some of this energy is used to drive the **compressor**, and in some turbine engines (i.e. turboprop, turbo shaft or turbofan engines), energy is extracted by additional turbine discs and used to drive devices such as propellers, bypass fans or helicopter rotors. One type, a **free turbine**, is configured such that the turbine disc driving the compressor rotates independently of the discs that power the external components. Relatively cool air, bled from the compressor, may be used to cool the turbine blades and vanes, to prevent them from melting.
- **Afterburner** or **reheat** (chiefly UK) — (mainly military) Produces extra thrust by burning extra fuel, usually inefficiently, to significantly raise Nozzle Entry Temperature at the **exhaust**. Owing to a larger volume flow (i.e. lower density) at exit from the afterburner, an increased nozzle flow area is required, to maintain satisfactory engine matching, when the afterburner is alight.
- **Exhaust** or **Nozzle** — hot gases leaving the engine exhaust to atmospheric pressure via a nozzle, the objective being to produce a high velocity jet. In most cases, the nozzle is convergent and of fixed flow area.
- **Supersonic nozzle** — if the Nozzle Pressure Ratio (Nozzle Entry Pressure/Ambient Pressure) is very high, to maximize thrust it may be worthwhile, despite the additional weight, to fit a convergent-divergent (de Laval) nozzle. As the name suggests, initially this type of nozzle is convergent, but beyond the throat (smallest flow area), the flow area starts to increase to form the divergent portion. The expansion to atmospheric pressure and supersonic gas velocity continues downstream of the throat, whereas in a convergent nozzle the expansion beyond sonic velocity occurs externally, in the exhaust plume. The former process is more efficient than the latter.

The various components named above have constraints on how they are put together to generate the most efficiency or performance. The performance and efficiency of an engine can never be taken in isolation; for example fuel/distance efficiency of a supersonic jet engine maximizes at about Mach 2, whereas the drag for the vehicle carrying it is increasing as a square law and has much extra drag in the transonic region. The highest fuel efficiency for the overall vehicle is thus typically at Mach ~0.85.

For the engine optimization for its intended use, important here is air intake design, overall size, number of compressor stages (sets of blades), fuel type, number of exhaust stages, metallurgy of components, amount of bypass air used, where the bypass air is introduced, and many other factors. For instance, let us consider design of the air intake.

TYPES, DESCRIPTION, ADVANTAGES AND DISADVANTAGES OF JET ENGINES:

There are a large number of different types of jet engines, all of which achieve propulsion from a high speed exhaust jet.

Type	Description	Advantages	Disadvantages
Water jet	Squirts water out the back through a nozzle	Can run in shallow water, powerful, less harmful to wildlife, (indeed used by squid)	Can be less efficient than a propeller, more vulnerable to debris
Motor jet	Most primitive air breathing jet engine. Essentially a supercharged piston engine with a jet exhaust.	Higher exhaust velocity than a propeller, offering better thrust at high speed	Heavy, inefficient and underpowered

Turbojet	Generic term for simple turbine engine	Simplicity of design, efficient at supersonic speeds (~M2)	A basic design, misses many improvements in efficiency and power for subsonic flight, relatively noisy.
Turbofan	First stage compressor greatly enlarged to provide bypass airflow around engine core, and it provides significant amounts of thrust. Most common form of jet engine in use today- used in airliners like the Boeing 747 and military jets, where an afterburner is often added for supersonic flight.	Quieter due to greater mass flow and lower total exhaust speed, more efficient for a useful range of subsonic airspeeds for same reason, cooler exhaust temperature.	Greater complexity (additional ducting, usually multiple shafts), large diameter engine, need to contain heavy blades. More subject to FOD and ice damage. Top speed is limited due to the potential for shockwaves to damage engine.
Rocket	Carries all propellants and oxidants on-board, emits jet for propulsion	Very few moving parts, Mach 0 to Mach 25+, efficient at very high speed (> Mach 10.0 or so), thrust/weight ratio over 100, no complex air inlet, high compression	Needs lots of propellant- very low specific impulse — typically 100-450 seconds. Extreme thermal stresses of combustion chamber can make reuse harder. Typically requires carrying

		ratio, very high speed (hypersonic) exhaust, good cost/thrust ratio, fairly easy to test, works in a vacuum-indeed works best exoatmospheric which is kinder on vehicle structure at high speed, fairly small surface area to keep cool, and no turbine in hot exhaust stream.	oxidizer on-board which increases risks. Extraordinarily noisy.
Ramjet	Intake air is compressed entirely by speed of oncoming air and duct shape (*divergent*)	Very few moving parts, Mach 0.8 to Mach 5+, efficient at high speed (> Mach 2.0 or so), lightest of all air-breathing jets (thrust/weight ratio up to 30 at optimum speed), cooling much easier than turbojets as no turbine blades to cool.	Must have a high initial speed to function, inefficient at slow speeds due to poor compression ratio, difficult to arrange shaft power for accessories, usually limited to a small range of speeds, intake flow must be slowed to subsonic speeds, noisy, fairly difficult to test, finicky to keep lit.
Turboprop (Turbo shaft similar)	Strictly not a jet at all — a gas turbine engine is used as power plant to drive propeller shaft (or rotor	High efficiency at lower subsonic airspeeds (300 knots plus), high shaft power to weight	Limited top speed (airplanes), somewhat noisy, complex transmission

	in the case of a helicopter)		
Propfan/Unducted Fan	Turboprop engine drives one or more propellers. Similar to a turbofan without the fan cowling.	Higher fuel efficiency, potentially less noisy than turbofans, could lead to higher-speed commercial aircraft, popular in the 1980s during fuel shortages	Development of prop fan engines has been very limited, typically more noisy than turbofans, complexity
Pulsejet	Air is compressed and combusted intermittently instead of continuously. Some designs use valves.	Very simple design, commonly used on model aircraft	Noisy, inefficient (low compression ratio), works poorly on a large scale, valves on valved designs wear out quickly
Pulse detonation engine	Similar to a pulsejet, but combustion occurs as a detonation instead of a deflagration, may or may not need valves	Maximum theoretical engine efficiency	Extremely noisy, parts subject to extreme mechanical fatigue, hard to start detonation, not practical for current use
Air-augmented rocket	Essentially a ramjet where intake air is compressed and burnt with the exhaust from	Mach 0 to Mach 4.5+ (can also run exoatmospheric), good efficiency at Mach 2 to 4	Similar efficiency to rockets at low speed or exoatmospheric, inlet difficulties, a relatively undeveloped and

	a rocket		unexplored type, cooling difficulties, very noisy, thrust/weight ratio is similar to ramjets.
Scramjet	Similar to a ramjet without a diffuser; airflow through the entire engine remains supersonic	Few mechanical parts, can operate at very high Mach numbers (Mach 8 to 15) with good efficiencies[5]	Still in development stages, must have a very high initial speed to function (Mach >6), cooling difficulties, very poor thrust/weight ratio (~2), extreme aerodynamic complexity, airframe difficulties, testing difficulties/expense
Turbo rocket	A turbojet where an additional oxidizer such as oxygen is added to the air stream to increase maximum altitude	Very close to existing designs, operates in very high altitude, wide range of altitude and airspeed	Airspeed limited to same range as turbojet engine, carrying oxidizer like LOX can be dangerous. Much heavier than simple rockets.

The motion impulse of the engine is equal to the air mass multiplied by the speed at which the engine emits this mass:

$$\mathbf{I = m\ c}$$

Where m is the air mass per second and c is the exhaust speed. In other words, the plane will fly faster if the engine emits the air mass with a higher speed or if it emits more air per second with the same speed. However, when the plane flies with certain velocity v, the air moves towards it, creating the opposing ram drag at the air intake:

Most types of jet engine have an air intake, which provides the bulk of the gas exiting the exhaust. Conventional rocket motors, however, do not have an air intake, the oxidizer and fuel both being carried within the airframe. Therefore, rocket motors do not have ram drag; the gross thrust of the nozzle is the net thrust of the engine. Consequently, the thrust characteristics of a rocket motor are completely different from that of an air breathing jet engine.

The air breathing engine is only useful if the velocity of the gas from the engine, c, is greater than the airplane velocity, v. The net engine thrust is the same as if the gas were emitted with the velocity c-v. So the thrust is actually equal to

$$\mathbf{S = m\,(c-v)}$$

Turboprops have a wide rotating fan that takes and accelerates the large mass of air but by a relatively small amount. This low speed limits the speed of any propeller driven airplane. When the plane speed exceeds this limit, propellers no longer provide any thrust ($c-v < 0$).

Turbojets and other similar engines accelerate a much smaller mass of the air and burned fuel, but they emit it at the much higher speeds possible with a de Laval nozzle. This is why they are suitable for supersonic and higher speeds.

Low bypass turbofans have the mixed exhaust of the two air flows, running at different speeds (c_1 and c_2). The thrust of such engine is

$$\mathbf{S = m_1\,(c_1 - v) + m_2\,(c_2 - v)}$$

Where m_1 and m_2 are the air masses, being blown from the both exhausts. Such engines are effective at lower speeds, than the pure jets, but at higher speeds than the turbo shafts and propellers in general. For instance, at the 10 km attitude, turbo shafts are most effective at about 0.4 mach, low bypass turbofans become more effective at about 0.75 mach and true jets become more effective as mixed exhaust engines when the speed approaches 1 mach - the speed of sound.

Rocket engines are best suited for high speeds and altitudes. At any given throttle, the thrust and efficiency of a rocket motor improves slightly with increasing altitude (because the back-pressure falls thus increasing net thrust at the nozzle exit plane), whereas with a turbojet (or turbofan) the falling density of the air entering the intake (and the hot gases leaving the nozzle) causes the net thrust to decrease with increasing altitude. Rocket engines are more efficient than even scramjets above roughly Mach 15.

For all jet engines the propulsive efficiency (essentially energy efficiency) is highest when the engine emits an exhaust jet at a speed that is the same as the airplane velocity.

RESULT:

Thus the basic jet engine and the other types of jet engine are studied.

VIVA QUESTIONS:

- ✓ What is jet engine?
- ✓ Jet engine works on which cycle?
- ✓ What are the components of brayton type engine?
- ✓ What is isentropic process?
- ✓ What is isobaric process?
- ✓ What is adiabatic process?
- ✓ What are the differences between ideal and actual brayton cycles?
- ✓ What is ts diagram? What are its uses?
- ✓ What is pv diagram? What are its uses?
- ✓ Write the pv and ts diagram of brayton cycle.
- ✓ What are open and closed type brayton cycles?
- ✓ Write the equation of efficiency of ideal brayton cycle.
- ✓ What is capacity ratio?
- ✓ How efficiency varies with pressure ratio in brayton cycle?
- ✓ What is turbojet? Explain its principle of operation
- ✓ What are compressors? Explain different types of compressors.
- ✓ What are turbines? What are its uses in jet engine?
- ✓ What is combustion chamber?
- ✓ What is nozzle?
- ✓ What is afterburner?
- ✓ What is thrust reverser?
- ✓ What is thrust?
- ✓ What is the working principle of turbofan?

UNIVERSITY QUESTIONS:

- Explain about an aircraft turbojet engine.
- Explain the principle of air-breathing engine and its various types.
- Study the jet engine

	SRINIVASAN ENGINEERING COLLEGE, PERAMBALUR – 621 212 DEPARTMENT OF AERONAUTICAL ENGINEERING PROPULSION LAB	ISSUE NO: 01 REVISION NO: 00 DATE : 12.12.12

EXP NO: 3 **DATE:**

STUDY OF FREE CONVECTION APPARATUS

AIM:

To determine the theoretical and actual heat transfer co-efficient using natural convection apparatus.

THEORY:

Convection is a mode of heat transfer where by a moving liquid transfer's heat from a surface. When the fluid movement is caused by density differences in the fluid, due to temperature variations, it is called **FREE OR NATURAL CONVECTION**. This provides students with a sound information about the features of free convection heat transfer from a heated vertical rod a vertical rod duct is fitted with a heated vertically placed cylinder air gets heated and dense around this cylinder, causing it to rise. This in turn gives rise to continuous flow of air upward in the duct. The instrumentation provides the heat input and temperature at different point on the heated cylinder.

Convection is the concerted, collective movement of ensembles of molecules within fluids (e.g., liquids, gases) and rheids. Convection of mass cannot take place in solids, since neither bulk current flows nor significant diffusion can take place in solids. Diffusion of heat can take place in solids, but is referred to separately in that case as heat conduction. a good model for convection is when you take a heat source (e.g. Bunsen burner) and place it at any side of a glass full of a liquid, you then can feel the different levels of heat in the glass.

Convective heat transfer is one of the major modes of heat transfer and convection is also a major mode of mass transfer in fluids. Convective heat and mass transfer take place through both diffusion – the random motion of individual particles in the fluid – and by advection, in which matter or heat is transported by the larger-scale motion of currents in the fluid. In the context of heat and mass transfer, the term "convection" is used to refer to the sum of advective and diffusive transfer. Note that in common use the term convection may refer loosely to heat transfer by convection, as opposed to mass transfer by convection, or the convection process in general. Sometimes "convection" is even used to refer specifically to "free heat convection" (natural heat convection), as opposed to forced heat convection. However, in mechanics the correct use of the word is the general sense, and different types of convection should be properly qualified for clarity.

Convection can be qualified in terms of being natural, forced, gravitational, granular, or thermomagnetic. It may also be said to be due to combustion, capillary action, or marangoni and Deisenberg effects. Due to its role in heat transfer, natural convection plays a role in the structure of earth's atmosphere, its oceans, and its mantle. Discrete convective cells in the atmosphere can be seen as clouds, with stronger convection resulting in thunderstorms. Natural convection also plays a role in stellar physics.

APPLICATIONS OF CONVECTION:

Heat transfer:

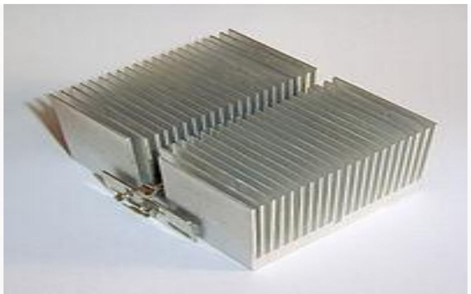


Figure 3. Convection heat transfer

Convective heat transfer is a mechanism of heat transfer occurring because of bulk motion (observable movement) of fluids. heat is the entity of interest being advected (carried), and diffused (dispersed). this can be contrasted with conductive heat transfer, which is the transfer of energy by vibrations at a molecular level through a solid or fluid, and radiative heat transfer, the transfer of energy through electromagnetic waves.

Heat is transferred by convection in numerous examples of naturally occurring fluid flow, such as: wind, oceanic currents, and movements within the earth's mantle. Convection is also used in engineering practices to provide desired temperature changes, as in heating of homes, industrial processes, cooling of equipment, etc.

The rate of convective heat transfer may be improved by the use of a heat sink, often in conjunction with a fan. For instance, a typical computer CPU will have a purpose-made fan to ensure its operating temperature is kept within tolerable limits.

Convection cells:

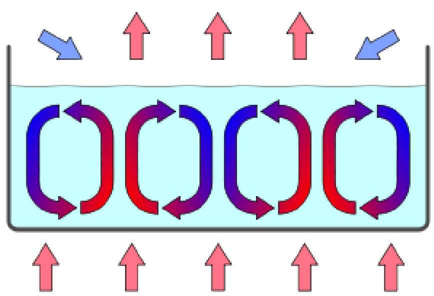


Figure 3.1 Convection cells

A **convection cell**, also known as a **bénard cell** is a characteristic fluid flow pattern in many convection systems. a rising body of fluid typically loses heat because it encounters a cold surface. In liquid this occurs because it exchanges heat with colder liquid through direct exchange. In the example of the earth's atmosphere, this occurs because it radiates heat. Because of this heat loss the fluid becomes denser than the fluid underneath it, which is still rising. Since it cannot descend through the rising fluid, it moves to one side. At some distance, its downward force overcomes the rising force beneath it, and the fluid begins to descend. As it descends, it warms again and the cycle repeats itself.

APPARATUS REQUIRED:

Natural convection apparatus

SPECIFICATIONS:

Rod length L = 500mm

Rod diameter d = 40mm

FORMULA USED:

Actual method:

Average temperature of heater $= (T_2+T_3+T_4+T_5) / 4$

Average temperature of air $= (T_1+T_6) / 2$

Power input of heater 'Q' $= VI = hA\Delta T$

Overall heat transfer co-efficient 'h' $= Q / A\Delta T$

Where ΔT – (avg temp of heater rod) – (avg temp of air)

Theoretical method:

$Nu = hl_c /K = 0.53(G_r P_r)^{1/4}$ for $G_r P_r < 10^5$

G_r – grashoff's number – $\beta g\Delta T L^3 / \gamma^2$

P_r– prandtl number

γ – kinematic viscosity

β – 1 / (mean temp of air + 273)

K – Thermal conductivity

Nu– Nusette's number = hl */K*

$Nu = hl /K = 0.56 (G_r P_r)^{1/4}$ for $10^5 < G_r P_r < 10^8$

$Nu = hl /K = 0.13 (G_r P_r)^{1/3}$ for $10^8 < G_r P_r < 10^{12}$

PROCEDURE:

- Switch on the unit and adjust the regulator to provide suitable power input.
- Allow some time for the unit to reach steady state condition
- Note the specimen temperature (T_2,T_3,T_4,T_5) and note down the inlet temperature (T_1) and outlet temperature (T_6)
- Note ammeter and voltmeter reading.
- Repeat the procedure and take 3 sets of readings
- Calculate the theoretical and actual heat transfer co-efficient using the given formula.

TABULATION:

Voltmeter Reading in volts	Ammeter Reading in ampere	Q = VI watts	Thermocouple readings (^0C)							Actual heat transfer co-efficient	Theoretical heat transfer coefficient
			T_1	T_2	T_3	T_4	T_5	T_6	ΔT		

RESULT:

Thus the theoretical and actual heat transfer co-efficient using natural convection apparatus are calculated.

VIVA QUESTIONS:

- ✓ Define conduction?
- ✓ Define convection?
- ✓ Define radiation?
- ✓ What is forced convection?
- ✓ What is free convection?
- ✓ What is convection heat transfer coefficient?

UNIVERSITY QUESTIONS:

- ➢ Determine the theoretical and actual heat transfer co-efficient using natural convection apparatus.
- ➢ Determine the overall heat transfer co-efficient using natural convection apparatus.
- ➢ Determine the heat transfer co-efficient for a flat plate using natural convection over a flat vertical plate.
- ➢ Determine the heat transfer co-efficient for a flat plate using natural convection over a flat horizontal plate.

	SRINIVASAN ENGINEERING COLLEGE, PERAMBALUR – 621 212 DEPARTMENT OF AERONAUTICAL ENGINEERING PROPULSION LAB	ISSUE NO: 01 REVISION NO: 00 DATE : 12.12.12

EXP NO: 4 **DATE:**

STUDY OF FORCED CONVECTION APPARATUS

AIM:

To determine the theoretical and actual heat transfer coefficient using forced convection apparatus.

THEORY:

The important relationship between Reynolds number, Prandtl number and nusette number in heat exchanger design may be investigated in this self-contained unit.

Convective heat transfer is a mechanism of heat transfer occurring because of bulk motion (observable movement) of fluids. heat is the entity of interest being advected (carried), and diffused (dispersed). this can be contrasted with conductive heat transfer, which is the transfer of energy by vibrations at a molecular level through a solid or fluid, and radiative heat transfer, the transfer of energy through electromagnetic waves.

Heat is transferred by convection in numerous examples of naturally occurring fluid flow, such as: wind, oceanic currents, and movements within the earth's mantle. Convection is also used in engineering practices to provide desired temperature changes, as in heating of homes, industrial processes, cooling of equipment, etc.

The rate of convective heat transfer may be improved by the use of a heat sink, often in conjunction with a fan. For instance, a typical computer CPU will have a purpose-made fan to ensure its operating temperature is kept within tolerable limits.

APPARATUS REQUIRED:

Forced convection apparatus.

EXPERIMENTAL SETUP:

The experimental setup consist of a tube through which air is sent in by the blower the test section consists of a long electrical surface heater on the tube., which serves as a contact heat flux source on the flowing medium. The inlet and outlet temperatures of the flow are measured by the thermocouples and also the temperatures at several locations along the surface of heater from which average temperature can be measured. An orifice meter in the tube is used to measure the air flow rate with a U-tube water manometer.

An ammeter and a voltmeter are provided to measure the power input to the heater. A power regulator is provided to vary the power input to the heater. A multi-point digital temperature indicator is provided to measure the above thermocouple's input. A value is provided to regulate the flow of air.

FORMULA USED:

Actual method:

Average temperature of heater = $(T_2+T_3+T_4+T_5) / 4$

Average temperature of air = $(T_1+T_6) / 2$

Power input of heater 'Q' = $VI = hA(LMTD) = mc_p\Delta T$

Where ΔT – (avg temp of heater) – (avg temp of air)

h – Heat transfer co-efficient

A – Heat transfer area = Π DL

D – Diameter of the tube

L – Length of the tube

LMTD – logarithmic mean temperature difference

$$= \frac{[(\text{avg temp of tube} - \text{outlet air temp}) - (\text{avg temp of tube} - \text{inlet air temp})]}{\ln [(\text{avg temp of tube} - \text{outlet air temp}) / (\text{avg temp of tube} - \text{inlet air temp})]}$$

m – Mass flow rate of air = ρAV

V – Velocity of air = Q / area of the tube

Cp – specific heat of air

Actual heat transfer co-efficient $h_{act} = Q / A(LMTD)m\ c_p\ \Delta T$

Where Q = volume of air flowing through the tube it can be calculated as follows

$$Q = C_d\ a_1 a_2 \sqrt{(2gh_0)} / \sqrt{(a_1^2 - a_2^2)}$$

Where C_d = 0.6

a_1 – area of the tube $= \Pi\ d_1^2 / 4$

a_2 – area of the orifice $= \Pi\ d_2^2 / 4$

d_1 – diameter of the pipe

d_2 – diameter of the orifice

h_0 – head of the air causing the flow

$= (h_1 - h_2)\ \rho_w / \rho_a$

ρ_w – density of water

ρ_a – density of air

Theoretical method:

Reynolds's number $R_e = VD / \gamma$

Nusette's number $Nu = hD / K$

Where D – Diameter of the tube

V – Velocity of air

γ – Kinematic viscosity

K – Thermal conductivity

Also Nu $= .023 \times R_e^{0.8} \times P_r^{\ 0.4}$

PROCEDURE:

- Switch on the mains.
- Switch on the blowers.
- Adjust the regulator to any desired power input the heater.
- Adjust the position of the valve to any desired flow rate of air.
- Wait till the steady state temperature is reached.
- Note manometer readings h1 and h2.
- Note the temperature along the tube.
- Note the air inlet and outlet temperatures.
- Note the voltmeter and ammeter readings.
- Adjust the position of the valve and vary the flow rate of air and repeat the experiment.
- For various valve openings and for various power inputs, the readings may be taken to repeat the experiment.

TABULATION:

Voltmeter Reading in volts	Ammeter Reading in ampere	Q = VI watts	Thermocouple readings (^0C)							Actual heat transfer co-efficient	Theoretical heat transfer coefficient
			T_1	T_2	T_3	T_4	T_5	T_6	ΔT		

RESULT:

The theoretical and actual heat transfer coefficients are determined using forced convection apparatus

VIVA QUESTIONS:

- ✓ Define conduction?
- ✓ Define convection?
- ✓ Define radiation?
- ✓ What is forced convection?
- ✓ What is free convection?
- ✓ What is convection heat transfer coefficient?
- ✓ Define Nussult number?
- ✓ Define Reynolds number?
- ✓ What is Prandtl number?
- ✓ What is thermal conductivity?
- ✓ What is kinematic viscosity?
- ✓ What is dynamic viscosity?
- ✓ What is laminar flow?
- ✓ What is turbulent flow?
- ✓ What is fluid film temperature?

UNIVERSITY QUESTIONS:

- ➢ Determine the theoretical and actual heat transfer co-efficient using forced convection apparatus.
- ➢ Determine the overall heat transfer co-efficient using forced convection apparatus.
- ➢ Determine the heat transfer co-efficient for a flat plate using forced convection over a flat vertical plate.
- ➢ Determine the heat transfer co-efficient for a flat plate using forced convection over a flat horizontal plate.

	SRINIVASAN ENGINEERING COLLEGE, PERAMBALUR – 621 212 DEPARTMENT OF AERONAUTICAL ENGINEERING PROPULSION LAB	ISSUE NO: 01 REVISION NO: 00 DATE : 12.12.12

EXP NO: 5 **DATE:**

BOMB CALORIMETER

AIM:

To determine the calorific value of the given solid or non-volatile liquid fuel using a bomb calorimeter

THEORY:

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

This isothermal bomb calorimeter provides a simple inexpensive yet accurate method for determination of heat of combustion (calorific value) of solid and liquid fuels. The outfit is complete for analysis as per method recommended by ISI (IS 1359-1954).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.

In more recent calorimeter designs, the whole bomb, pressurized with excess pure oxygen (typically at 30atm) and containing a weighed mass of a sample (typically 1-1.5 g) and a small fixed amount of water (to saturate the internal atmosphere, thus ensuring that all water produced is liquid, and removing the need to include enthalpy of vapourization in calculations), is submerged under a known volume of water (ca. 2000 ml) before the charge is electrically ignited. the bomb, with the known mass of the sample and oxygen, form a closed system - no gases escape during the reaction. The weighted reactant put inside the steel container is then ignited. Energy is released by the combustion and heat flow from this crosses the stainless steel wall, thus raising the temperature of the steel bomb, its contents, and the surrounding water jacket. The temperature change in the water is then accurately measured with a thermometer. This reading, along with a bomb factor (which is dependent on the heat capacity of the metal bomb parts), is used to calculate the energy given out by the sample burn. a small correction is made to account for the electrical energy input, the burning fuse, and acid production (by titration of the residual liquid). After the temperature rise has been measured, the excess pressure in the bomb is released.

Basically, a bomb calorimeter consists of a small cup to contain the sample, oxygen, a stainless steel bomb, water, a stirrer, a thermometer, the dewar or insulating container (to prevent heat flow from the calorimeter to the surroundings) and ignition circuit connected to the bomb. by using stainless steel for the bomb, the reaction will occur with no volume change observed.

Since there is no heat exchange between the calorimeter and surroundings → q = 0 (adiabatic) ; no work performed → w = 0 thus, the total internal energy change δu(total) = q + w = 0

Also, total internal energy change δu(total) = δu(system) + δu(surroundings) = 0 → δu(system) = - δu(surroundings) = $-c_v$ δt (constant volume → dv = 0)

Where c_v = heat capacity of the bomb

Before the bomb can be used to determine heat of combustion of any compound, it must be calibrated. the value of c_v can be estimated by c_v(calorimeter) = m (water). c_v (water) + m (steel). c_v (steel)

m (water) and m (steel) can be measured;

c_v (water)= 1 cal/g.k

c_v (steel)= 0.1 cal/g.k

In laboratory, c_v is determined by running a compound with known heat of combustion value: c_v = h_c/δt

Common compounds are benzoic acid (h_c = 6318 cal/g) or p-methyl benzoic acid (h_c = 6957 cal/g).

Temperature (t) is recorded every minute and δt = t (final) - t (initial)

A small factor contributes to the correction of the total heat of combustion is the fuse wire. Nickel fuse wire is often used and has heat of combustion = 981.3 cal/g

In order to calibrate the bomb, a small amount (~ 1 g) of benzoic acid or p-methyl benzoic acid is weighed. A length of nickel fuse wire (~10 cm) is weighed both before and after the combustion process. Mass of fuse wire burned δm = m (before) - m (after)

The combustion of sample (benzoic acid) inside the bomb $\delta h_c = \delta h_c$ (benzoic acid) x m (benzoic acid) + δh_c (ni fuse wire) x δm (ni fuse wire)

$\delta h_c = c_v. \delta t \rightarrow c_v = \delta h_c/\delta t$

Once c_v value of the bomb is determined, the bomb is ready to use to calculate heat of combustion of any compounds by $\delta h_c = c_v. \delta t$

A known amount of sample is burnt in a sealed chamber (bomb) the air is replaced by pure oxygen. The sample is ignited electrically. As the sample burns heat is generated. The raise in temperature is noted since baring loss of heat the amount of heat generated by burning of the sample must be equal to the amount of heat absorbed by the calorimeter assembly. By knowing the energy equivalent of the calorimeter and the temperature raise, the calorific value can be found out.

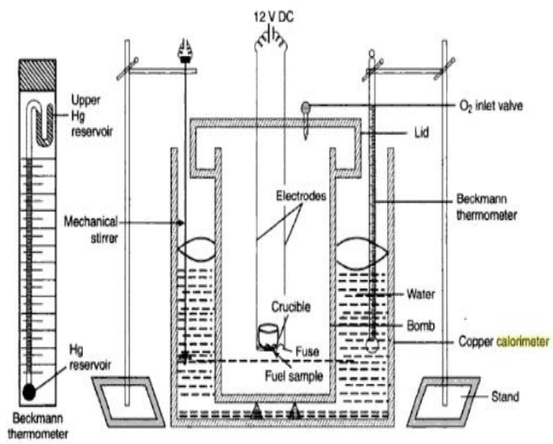


Figure 5. Bomb calorimeter setup

PROCEDURE:

- Find the weight of the empty crucible using a physical balance.
- A small quantity of liquid fuel (diesel) is taken in the crucible and is again weighed with fuel in it.
- The crucible with fuel is placed over the support. A fuse wire is connected between the electrodes.
- The bomb is closed air tight and is filled with oxygen at a pressure of about 25 bars.
- The bomb is placed inside the calorimeter vessel filled with water. Noted the initial temperature of water using the digital thermometer.
- The calorimeter water is stirred using a motor drive. The fuel is ignited electrically by passing a high voltage through the fuse wire which causes the fuse wire to burn.
- Heat liberated by the fuel causes the temperature to rise.
- After steady condition is reached the temperature raise is measured using the digital thermometer provided.

OBSERVATION:

Weight of the crucible without fuel (m_1) = gm

Weight of the crucible with fuel (m_2) = gm

Initial reading of the digital thermometer (t_1) = ^{0}C

Final reading of the digital thermometer (t_2) = ^{0}C

CALCULATION:

Mass of fuel burnt (m) = $m_2 - m_1$

Temperature rise (t) = $t_2 - t_1$

W = energy equivalent of the calorimeter assembly = 9735 J/°c

C_v = calorific value of fuel in J/gm or KJ/Kg

Then $W * t = C_v * m$

$C_v = W * t / m$

RESULT:

Thus the calorific value of given solid or nonvolatile liquid fuel is found using bomb calorimeter.

VIVA QUESTIONS:

- ✓ What is calorific value?
- ✓ Which are fuels used for aviation?
- ✓ What is the principle of working of bomb calorimeter?
- ✓ What is water equivalent of calorimeter? And how it is calculated?
- ✓ What is higher calorific value?
- ✓ What is lower calorific value?

UNIVERSITY QUESTIONS:

- ➢ Determine the calorific value of given nonvolatile liquid fuel is found using bomb calorimeter.
- ➢ Determine the calorific value of given solid.

	SRINIVASAN ENGINEERING COLLEGE, PERAMBALUR – 621 212 **DEPARTMENT OF AERONAUTICAL ENGINEERING** **PROPULSION LAB**	ISSUE NO: 01 REVISION NO: 00 DATE : 12.12.12

EXP NO: 6 **DATE:**

STUDY OF PERFORMANCE OF PROPELLER

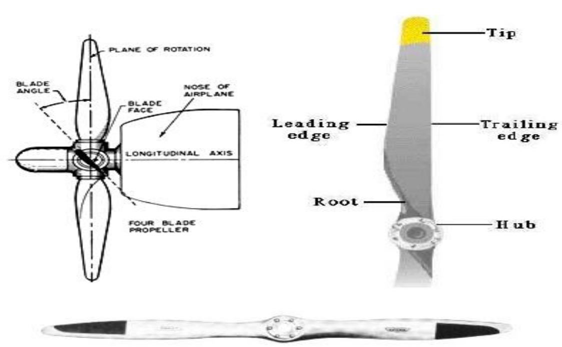
AIM:

To study the performance 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 aeroplane 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.

Figure 6. Fixed pitch 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.

NOMENCLATURE FOR A ROUND ADJUSTABLLE PROPELLER:

The figure shows two views of various cross sections of propeller blades. The blade shank is that portion of the blade near the butt of the blade it is usually made thick to give its strength, and it is cylindrical where it fits the hub barrel, but the cylindrical portion of the shank contributes little or no thrust. In order designs, the aero foil shape is carried to the hub by means of blade cuffs which are thin sheet metals and it function like cowling.

BLADE ELEMENT THEORY:

The theory for the design of aircraft propeller was known as blade element theory. It is some time referred to as the DRYE WIECKI theory as the polish scientist name is DRYE WIECKI.

The theory assumes to the tip of the blade is divided into various mall, rudimentary aerofoil sections. For example, if a propeller blade is 54 inch long and can be divided into 54 one-into aerofoil sections. Figure shows one of these aerofoil sections located at radius ‘r’, the chord ‘c’ will depend on the plan form or general shape of the blade.

According to the blade element theory, many aerofoil sections or elements being joined together side by side, unit to form an aerofoil (the blade) that can create thrust when revolving in a plane around central axis.

The thrust developed by a propeller is in accordance. With Newton's third law of motion. In the case of propeller the first action is acceleration of a mass of air to rear of the aeroplane. This means that if propeller is exerting a force of 200 pounds in accelerating a given mass of air, it is the same time exerting at a force of 2000 pounds in pulling the aeroplane in the direction of opposite that in which the aeroplane is pulled forward. The quantitative realization slip among mass, acceleration, and force can be determined by the use of formula Newton's second law.

$$F=m*a$$

True pitch propeller is one that makes use of the blade elemental theory. Each element of the blade travels at different rates of speed that is tip section travels faster than the section closer to the hub.

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 revolutio

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:

- Thrust force
- Centrifugal force
- Torsion or twisting force
- Aerodynamic twisting force
- Aerodynamic twisting movement (ATM)
- 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 id calculated = 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 x thrust

PROPELLER CHART:

For a given pitch angle B, the efficiency of the propeller is a function of dimensionless quantity T, the advance ratio such as a plot for a family of pitch angle that is valuable in a propeller can be plotted. This is called the propeller chart.

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 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 an 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:

- Ensure the propeller blade is firmly locked in position and mesh guard is safe enough to protect.
- Connect the power cable and observe the ‘mains on’ indicator to glow.
- Ensure the speed controller knob is set to zero position.
- Switch on force indicator and press the tare button, to set it to zero and keep it in normal position.
- Slowly increase the speed by operating the speed control knob to some desired rpm
- value, max 2000rpm (max ammeter reading a=8amps)
- 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).

- Record the air flow measurement at inlet and outlet of the propeller.
- Repeat the experiment at different speed.
- Draw graph of thrust vs. rotational speed, thrust vs. inlet velocity of air, thrust vs. outlet velocity of air, rpm vs. propulsion efficiency.

PRECAUTIONS:

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

TABULATION:

S.N.	*SPEED OF THE PROPELLER IN RPM*	*THRUST FORCE IN NEWTON FACT*	*AIR FLOW MEASUREMENT IN*		*VOLTMETER READING (VOLTS)*	*AMMETER READING (AMPS)*
			INLET	*OUTLET*		
1	*600*					
2	*800*					
3	*1000*					
4	*1200*					
5	*1400*					
6	*1600*					
7	*1800*					
8	*2000*					

CALCULATION:

1) Power input to the propeller P_{in} in KW = $\frac{V \times I}{1000 \times \eta_m}$, Where η_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:

The following performance characteristic of the given propeller has been calculated.

- ✓ Speed = ……RPM
- ✓ Power input to the propeller = …… KW
- ✓ Actual thrust = …… N
- ✓ Theoretical thrust = …… N
- ✓ Propulsive efficiency =

VIVA QUESTIONS:

- ✓ What is a propeller? Why it is used?
- ✓ Define propulsion efficiency.
- ✓ What is basic principle of propeller?
- ✓ What are the basic parts of a fixed pitch propeller?
- ✓ What is leading edge?
- ✓ What is trailing edge?
- ✓ What is root?
- ✓ What is pitch in case of propeller?
- ✓ What are the differences between fixed pitch and variable pitch propellers/
- ✓ Define blade angle.
- ✓ Define blade pitch
- ✓ Define geometric pitch
- ✓ Define effective pitch
- ✓ Define angle of attack
- ✓ Define propeller slip
- ✓ What are the forces acting on a propeller?
- ✓ What is thrust force

UNIVERSITY QUESTIONS:

- Determine the propeller efficiency.
- Determine the propeller efficiency and thrust developed by the given propeller.
- Study the performance of a propeller.

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EXP NO: 7 **DATE:**

STUDY OF FREE JET

AIM:

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

THEORY:

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 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, $V=\sqrt{2gh}$

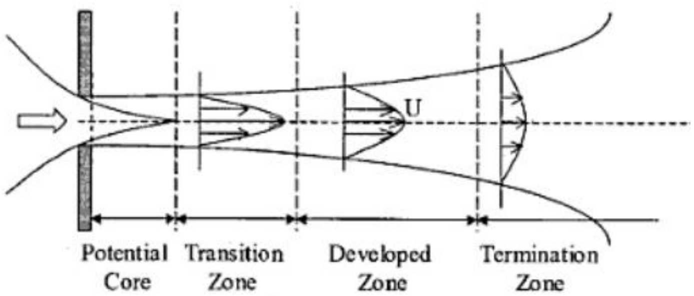
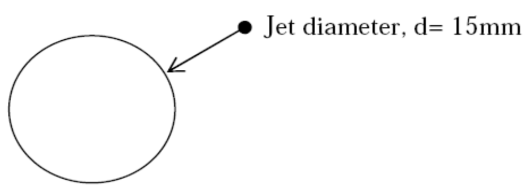


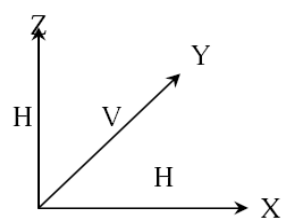
Figure 7. Free jet setup

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:

- Switch on the mains and observe the red indicator is on, then switch on console and blower.
- Then slowly operate the inlet plate and lock to some position.
- Then scan the pitot tube across the orifice & note down the readings.
- Then move the pitot tube in x direction slowly and note down the flow readings.
- Repeat the experiment for different flow.
- Repeat the procedure for different values of y axis also.
- 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.

- **Draw a graph of velocity vs x distance, at different values of y- axis.**

OBSERVATION:

Water tube manometer reading, $h1 =$ mm
Water tube manometer reading, $h2 =$ mm
Difference in water column of water tube manometer: $h_w = h1 \sim h2 =$ in meters
Atmospheric pressure, $pa = 1.01325$ bar $= 1.01325 \times 10^5$ N/m^2
Real gas constant, $R= 287$ J/Kg ^{o}k
Room temperature, $Ta =$ ^{o}C
Acceleration due to gravity, $g= 9.81$m/s

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= 9.81m/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 = Denisty of mercury = 13550 K

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

VIVA QUESTIONS:

- ✓ What is a jet?
- ✓ What is free jet?
- ✓ What is free stream layer?
- ✓ How velocity of jet is calculated?
- ✓ Sketch the velocity profile of free jet?
- ✓ What are transition zone, developed zone and termination zones?
- ✓ What is pitot tube? What is the working principle of pitot tube?
- ✓ How discharge through the pitot tube is calculated?

UNIVERSITY QUESTIONS:

- ➢ Determine the discharge through the free jet
- ➢ Explain and sketch the velocity profile of free jet.
- ➢ Determine the velocity of free jet and analyze its characteristics.
- ➢ Determine the velocity of wall jet and analyze its characteristics.

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EXP NO: 8 **DATE:**

COMBUSTION PERFORMANCE STUDIES IN A JET ENGINE COMBUSTION CHAMBER

AIM:

To study the combustion chamber performance of the jet engine.

INTRODUCTION:

The combustion chamber) has the difficult task of burning large quantities of fuel, supplied through the fuel spray nozzles, with extensive volumes of air, supplied by the compressor, and releasing the heat in such a manner that the air is expanded and accelerated to give a smooth stream of uniformly heated gas at all conditions required by the turbine This task must be accomplished with the minimum loss in pressure and with the maximum heat release for the limited space available.

The amount of fuel added to the air will depend upon the temperature rise required. However, the maximum temperature is limited to within the range Of 850 to 1700 deg. C. By the materials from which the turbine blades and nozzles are made. The air has already been heated to between 200 and 550 deg. C. By the work done during compression, giving a temperature rise requirement of 650 to 1150 deg. C from the combustion process. Since the gas temperature required at the turbine varies with engine thrust, and in the case of the turbo-propeller engine upon the power required, the combustion chamber must also be capable of maintaining stable and efficient combustion over a wide range of engine operating conditions.

Efficient combustion has become increasingly important because of the rapid rise in commercial aircraft traffic and the consequent increase in atmospheric pollution, which is seen by the general public as exhaust smoke.

COMBUSTION PROCESS:

Air from the engine compressor enters the combustion chamber at a velocity up to 500 feet per second, but because at this velocity the air speed is far too high for combustion, the first thing that the chamber must do is to diffuse it, i.e. Decelerate it and raise its static pressure. Since the speed of burning kerosene at normal mixture ratios is only a few feet per second, any fuel lit even in the diffused air stream, which now has a velocity of about 80 feet per second, would be blown away. A region of low axial velocity has therefore to be created in the chamber. So that the flame will remain alight throughout the range of engine operating conditions.

In normal operation, the overall air/fuel ratio of a combustion chamber can vary between 45:1 and 130:1, however, kerosene will only burn efficiently at, or close to, a ratio of 15:1, so the fuel must be burned with only part of the air entering the chamber, in what is called **a primary combustion zone**. This is achieved by means of a flame tube (combustion liner) that has various devices for metering the airflow distribution along the chamber.

Approximately 20 per cent of the air mass flow is taken in by the snout or entry section. Immediately downstream of the snout are swirl vanes and a perforated flare, through which air passes into the primary combustion zone. The swirling air induces a flow upstream of the centre of the flame tube and promotes the desired recirculation. The air not picked up by the snout flows into the annular space between the flame tube and the air casing.

Through the wall of the flame tube body, adjacent to the combustion zone, are a selected number of secondary holes through which a further 20 percent of the main flow of air passes into the primary zone. The air from the swirl vanes and that from the secondary air holes interacts and creates a region of low velocity recirculation. This takes the form of steroidal vortex, similar to a smoke ring, which has the effect of stabilizing and anchoring the flame. The recirculating gases hasten the burning of freshly injected fuel droplets by rapidly bringing them to ignition temperature.

It is arranged that the conical fuel spray from the nozzle intersects the recirculation vortex at its centre. This action, together with the general turbulence in the primary zone, greatly assists in breaking up the fuel and mixing it with the incoming air.

The temperature of the gases released by combustion is about 1,800 to 2,000 deg. C., which is far too hot for entry to the nozzle guide vanes of the turbine. The air not used for combustion, which amounts to about 60 per cent of the total airflow, is therefore introduced progressively into the flame tube. Approximately a third of this is used to lower the gas temperature in the dilution zone before it enters the turbine and the remainder is used for cooling the walls of the flame tube. This is achieved by a film of cooling air flowing along the inside surface of the flame tube wall, insulating it from the hot combustion gases. A recent development allows cooling air to enter a network of passages within the flame tube wall before exiting to form an insulating film of air; this can reduce the required wall cooling airflow by up to 50 per cent. Combustion should be completed before the dilution air enters the flame tube, otherwise the incoming air will cool the flame and incomplete combustion will result. An electric spark from an igniter plug initiates combustion and the flame is then self-sustained.

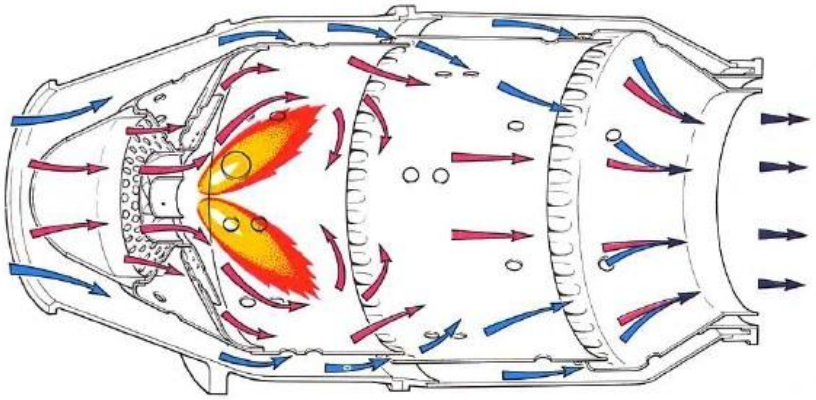

Figure 8.Flame stabilizing and general airflow pattern

TYPES OF COMBUSTION CHAMBER:

There are three main types of combustion chamber in use for gas turbine engines. These are the multiple chambers, the tubo-annular chamber and the annular chamber.

MULTIPLE COMBUSTION CHAMBERS:

This type of combustion chamber is used on centrifugal compressor engines and the earlier types of axial flow compressor engines. It is a direct development of the early type of whittle combustion chamber. The major difference is that the whittle chamber had a reverse flow But, as this created a considerable pressure loss, the straight-through multiple chamber was developed by Joseph Lucas limited.

The chambers are disposed around the engine and compressor delivery air is directed by ducts to pass into the individual chambers. Each chamber has an inner flame tube around which there is an air casing. The air passes through the flame tube snout and also between the tube and the outer casing. The separate flame tubes are all interconnected. This allows each tube to operate at the same pressure and also allows combustion to propagate around the flame tubes during engine starting.

TUBO-ANNULAR COMBUSTION CHAMBER:

The tubo-annular combustion chamber bridges the evolutionary gap between the multiple and annular types. A number of flame tubes are fitted inside a common air casing. The airflow is similar to that already described. This arrangement combines the ease of overhaul and testing of the multiple systems with the compactness of the annular system.

ANNULAR COMBUSTION CHAMBER:

This type of combustion chamber consists of a single flame tube, completely annular in form, which is contained in an inner and outer casing. The airflow through the flame tube is similar to that already described, the chamber being open at the front to the compressor and at the rear to the turbine nozzles.

The main advantage of the annular chamber is that, for the same power output, the length of the chamber is only 75 per cent of that of a tubo-annular system of the same diameter, resulting in consider-Able saving of weight and production cost. Another advantage is the elimination of combustion propagation problems from chamber to chamber.

In comparison with a tubo-annular combustion system, the wall area of a comparable annular chamber is much less; consequently the amount of cooling air required to prevent the burning of the flame tube wall is less, by approximately 15 percent.

This reduction in cooling air raises the combustion efficiency to virtually eliminate unburnt fuel, and oxidizes the carbon monoxide to non-toxic carbon dioxide, thus reducing air pollution.

The introduction of the air spray type fuel spray nozzle to this type of combustion chamber also greatly improves the preparation of fuel for combustion by aerating the over-rich pockets of fuel vapours close to the spray nozzle; this results in a large reduction in initial carbon formation.

COMBUSTION CHAMBER PERFORMANCE:

A combustion chamber must be capable of allowing fuel to burn efficiently over a wide range of operating conditions without incurring a large pressure loss. In addition, if flame extinction occurs, then it must be possible to relight. In performing these functions, the flame tube and spray nozzle atomizer components must be mechanically reliable.

The gas turbine engine operates on a constant pressure cycle; therefore any loss of pressure during the process of combustion must be kept to a minimum. In providing adequate turbulence and mixing, a total pressure loss varying from about 3 to8 per cent of the air pressure at entry to the chamber is incurred.

COMBUSTION INTENSITY:

The heat released by a combustion chamber or any other heat generating unit is dependent on the volume of the combustion area. Thus, to obtain the required high power output, a comparatively small and compact gas turbine combustion chamber must release heat at exceptionally high rates.

COMBUSTION EFFICIENCY:

The combustion efficiency of most gas turbine engines at sea-level take-off conditions is almost 100Per cent, reducing to 98 per cent at altitude cruise conditions.

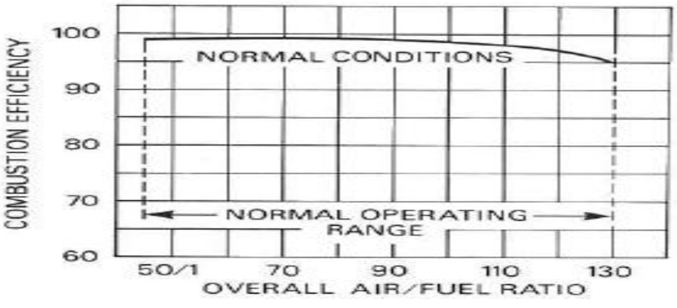

Figure 8.1Combustion efficiency and air/fuel ratio

COMBUSTION STABILITY:

Combustion stability means smooth burning and the ability of the flame to remain alight over a wide operating range.

For any particular type of combustion chamber there is both a rich and weak limit to the air/fuel ratio, beyond which the flame is extinguished. Extinction is most likely to occur in flight during a glide or dive with the engine idling, when there is a high airflow and only a small fuel flow, i.e. very weak mixture strength.

The range of air/fuel ratio between the rich and weak limits is reduced with an increase of air velocity, and if the air mass flow is increased beyond a certain value, flame extinction occurs. The operating range defined by the stability loop must obviously cover the air/fuel ratios and mass flow of the combustion chamber.

The ignition process has weak and rich limits. The ignition loop, however, lies within the stability loop since it is more difficult to establish combustion under 'Cold' conditions than to maintain normal burning.

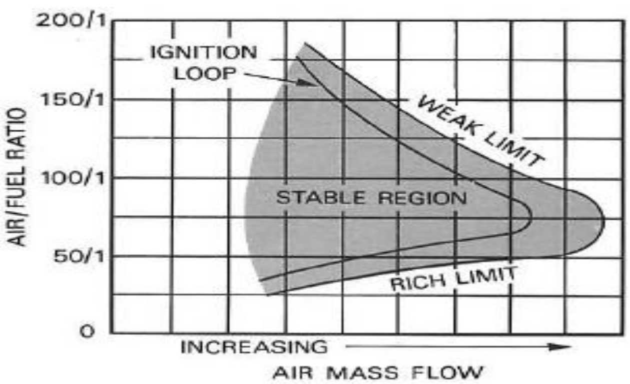

Figure 8.2Combustion stability limits

RESULT:

Thus the combustion chamber performance of the jet engine is studied.

VIVA QUESTIONS:

- ✓ What is combustion?
- ✓ What is combustion stability?
- ✓ What is primary combustion zone?
- ✓ What is swirl?
- ✓ What is combustion stability?
- ✓ What is combustion efficiency?
- ✓ What is combustion intensity?

UNIVERSITY QUESTIONS:

- ➢ Explain the performance of combustion chamber.

- ➢ What is a combustion chamber and explain its various types.