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Internal Combustion And Gas Turbines

(GAS TURBINES)

Department Of Mechanical Engineering

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CHAPTER 1. THEORY AND CONSTRUCTION OF AIRCRAFT ENGINES

For an aircraft to remain in level unaccelerated flight, a thrust must be provided that is equal to and opposite in direction to the aircraft drag. This thrust, or propulsive force, is provided by a suitable type of heat engine.

All heat engines have in common the ability to convert heat energy into mechanical energy, by the flow of some fluid mass through the engine. In all cases, the heat energy is released at a point in the cycle where the pressure is high, relative to atmospheric.

These engines are customarily divided into groups or types depending upon:

- The working fluid used in the engine cycle,
- the means by which the mechanical energy is transmitted into a propulsive force, and
- the method of compressing the engine working fluid

GENERAL

Engine Type

- Major Means of Compression
- Engine Working Fluid
- Propulsive Working Fluid

GENERAL

Turbojet.

- Turbine driven compressor.
- Fuel/air mixture.
- Same as engine working fluid.

Turboprop.

- Turbine driven compressor.
- Fuel/air mixture.
- Ambient air

GENERAL

Ram jet.

- Ram compression due to high flight speed.
- Fuel/air mixture.
- Same as engine working fluid.

Pulse jet.

- Compression due to combustion.
- Fuel/air mixture.
- Same as engine working fluid.

GENERAL

Reciprocating.

- Reciprocating action of pistons.
- Fuel/air mixture.
- Ambient air.

Rocket.

- Compression due to combustion.
- Oxidizer/fuel mixture.
- Same as engine working fluid.

GENERAL

- The propulsive force is obtained by the displacement of a working fluid (not necessarily the same fluid used within the engine) in a direction opposite to that in which the airplane is propelled. This is an application of Newton's third law of motion. Air is the principal fluid used for propulsion in every type of powerplant except the rocket, in which only the byproducts of combustion are accelerated and displaced.

- The propellers of aircraft powered by reciprocating or turboprop engines accelerate a large mass of air through a small velocity change. The fluid (air) used for the propulsive force is a different quantity than that used within the engine to produce the mechanical energy. Turbojets, ramjets, and pulse jets accelerate a smaller quantity of air through a large velocity change. They use the same working fluid for propulsive force that is used within the engine. A rocket carries its own oxidizer rather than using ambient air for combustion. It discharges the gaseous byproducts of combustion through the exhaust nozzle at an extremely high velocity.

GENERAL

Engines are farther characterized by the means of compressing the working fluid before the addition of heat. The basic methods of compression are:

1. The turbine driven compressor (turbine engine).
2. The positive displacement, piston-type compressor (reciprocating engine).
3. Ram compression due to forward flight speed (ramjet).
4. Pressure rise due to combustion (pulse jet and rocket).

A more specific description of the major engine types used in commercial aviation is given later in this chapter

Power and Weight

This conversion can be accomplished by using the formula:

thp = thrust x aircraft speed (mph) / 375

mile-pounds per hour

The value 375 mile-pounds per hour is derived from the basic horsepower formula as follows:

1 hp = 33,000 ft-lb per minute.

33,000 x 60 = 1,980,000 ft-lb per hour.

1,980,000 / 5,280 = 375 mile-pounds per hour.

Power and Weight

One horsepower equals 33,000 ft-lb per minute or 375 mile-pounds per hour. Under static conditions, thrust is figured as equivalent to approximately 2.6 pounds per hour.

If a gas turbine is producing 4,000 pounds of thrust and the aircraft in which the engine is installed is traveling at 500 mph, the thp will be:

(4000 x 500) / 375 = 5,333.33 thp

It is necessary to calculate the horsepower for each speed of an aircraft, since the horsepower varies with speed. Therefore, it is not practical to try to rate or compare the output of a turbine engine on a horsepower basis.

The aircraft engine operates at a relatively high percentage of its maximum power output throughout its service life. The aircraft engine is at full power output whenever a takeoff is made. It may hold this power for a period of time up to the limits set by the manufacturer. The engine is seldom held at a maximum power for more than 2 minutes, and usually not that long. Within a few seconds after liftoff, the power is reduced to a power that is used for climbing and that can be maintained for longer periods of time. After the aircraft has climbed to cruising altitude, the power of the engine's is further reduced to a cruise power which can be maintained for the duration of the flight.

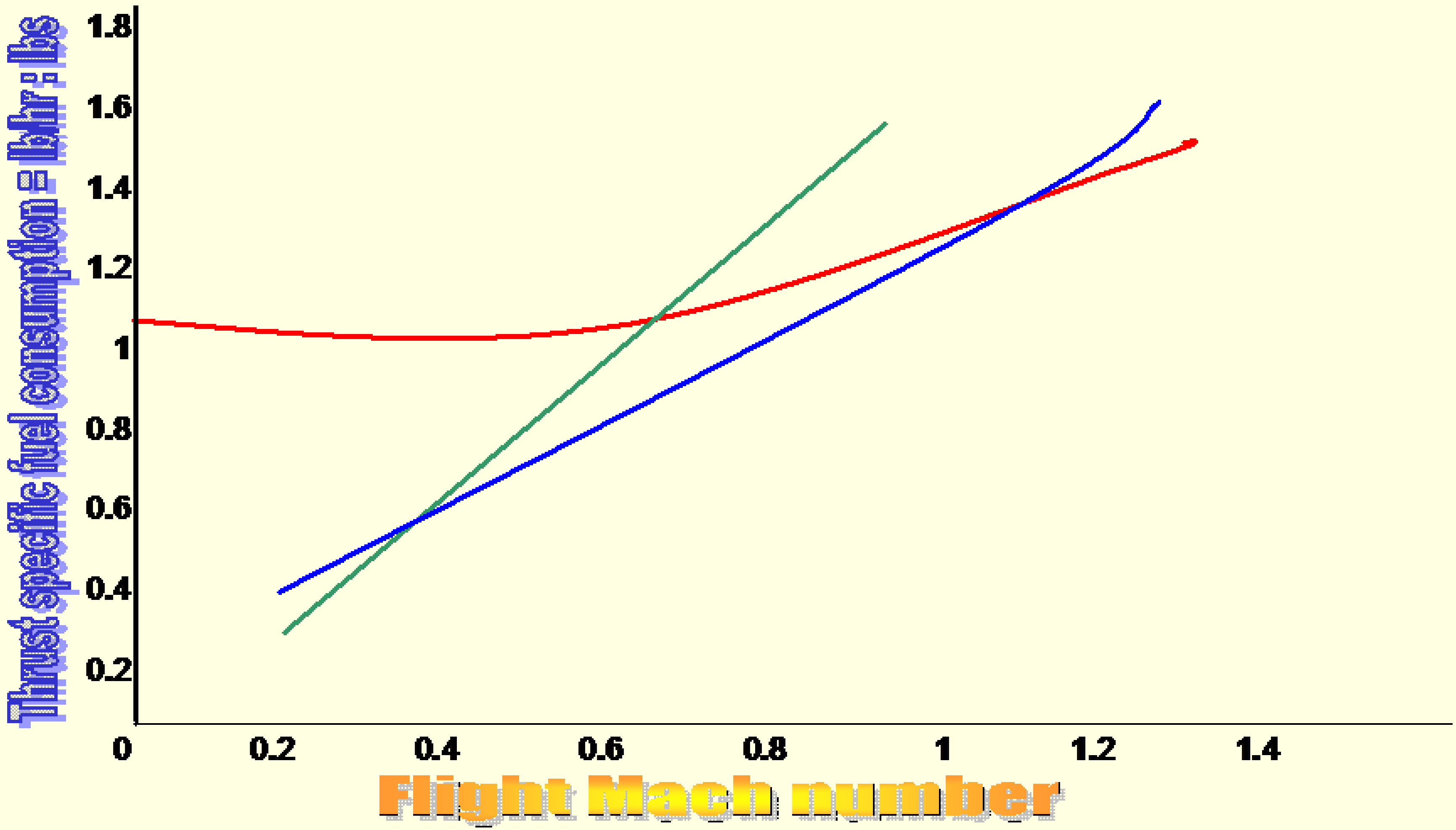
Fuel Economy

The basic parameter for describing the fuel economy of aircraft engines is usually specific fuel consumption. Specific fuel consumption for turbojets and ramjets is the fuel flow (lbs/hr) divided by thrust (lbs), and for reciprocating engines the fuel flow (lbs/hr) divided by brake horsepower. These are called "thrust specific fuel consumption" and "brake specific fuel consumption," respectively. Equivalent specific fuel consumption is used for the turboprop engine and is the fuel flow in pounds per hour divided by a turboprop's equivalent shaft horsepower. Comparisons can be made between the various engines on a specific fuel consumption basis.

Fuel Economy Continued

At low speed, the reciprocating and turbopropeller engines have better economy than the turbojet engines. However, at high speed, because of losses in propeller efficiency, the reciprocating or turbo propeller engine's efficiency becomes less than that of the turbojet. Figure 1-2 shows a comparison of average thrust specific fuel consumption of three types of engines at rated power at sea level.

Fig.1-2 Compararison of the fuel consumption for three type of engines at rated power at sea level



Durability and Reliability

Durability and reliability are usually considered identical factors since it is difficult to mention one without including the other. An aircraft engine is reliable when it can perform at the specified ratings in widely varying flight attitudes and in extreme weather conditions. Standards of powerplant reliability are agreed upon by the FAA, the engine manufacturer, and the airframe manufacturer. The engine manufacturer ensures the reliability of his product by design, research, and testing. Close control of manufacturing and assembly procedures is maintained, and each engine is tested before it leaves the factory.

Durability and Reliability

Durability is the amount of engine life obtained while maintaining the desired reliability. The fact that an engine has successfully completed its type or proof test indicates that it can be operated in a normal manner over a long period before requiring overhaul. However, no definite time interval between overhauls is specified or implied in the engine rating. The TBO (time between overhauls) varies with the operating conditions such as engine temperatures, amount of time the engine is operated at high power settings, and the maintenance received.

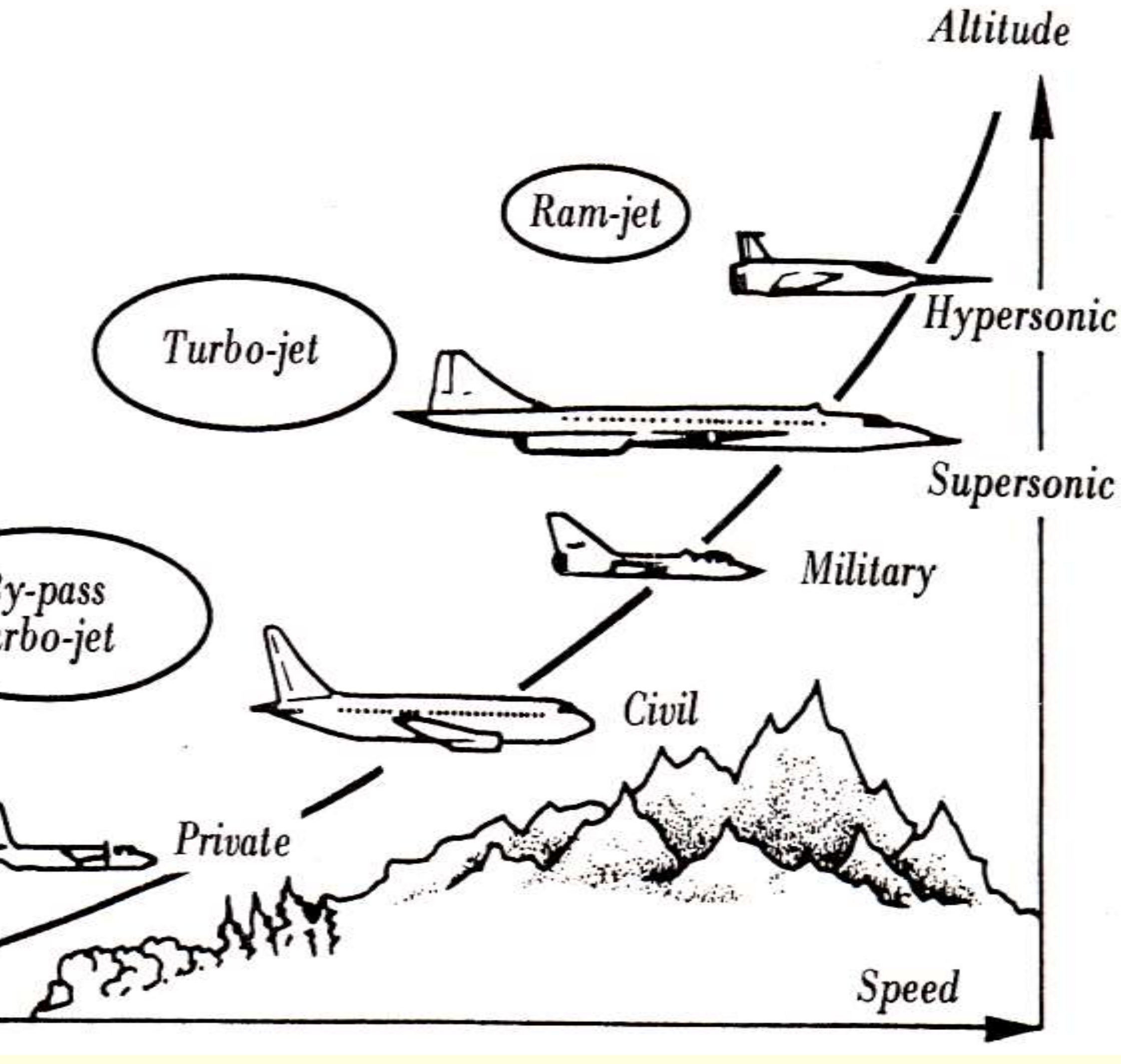
Durability and Reliability

Reliability and durability are thus built into the engine by the manufacturer, but the continued reliability of the engine is determined by the maintenance, overhaul, and operating personnel. Careful maintenance and overhaul methods, thorough periodical and preflight inspections, and strict observance of the operating limits established by the engine manufacturer will make engine failure a rare occurrence.

Powerplant Selection

AERO-ENGINES

Several types of power-plant may be used according to the flight envelope and performance required.



TURBINE ENGINE CONSTRUCTION

In a reciprocating engine the functions of intake, compression, combustion, and exhaust all take place in the same combustion chamber; consequently, each must have exclusive occupancy of the chamber during its respective part of the combustion cycle. A significant feature of the gas turbine engine, however, is that a separate section is devoted to each function, and all functions are performed simultaneously without interruption

TURBINE ENGINE CONSTRUCTION

A typical gas turbine engine consists of:

- (1) An air inlet.
- (2) Compressor section.
- (3) Combustion section.
- (4) Turbine section.
- (5) Exhaust section.
- (6) Accessory section.
- (7) The systems necessary for starting, lubrication, fuel supply, and auxiliary purposes, such as anti-icing, cooling, and pressurization

TURBINE ENGINE CONSTRUCTION

The major components of all turbine engines are basically the same; however, the nomenclature of the component parts of various engines currently in use will vary slightly due to the difference in each manufacturer's terminology. These differences are reflected in the applicable maintenance manuals

TURBINE ENGINE CONSTRUCTION

The greatest single factor influencing the construction features of any gas turbine engine is the type compressor (axial flow or centrifugal flow) for which the engine is designed. Later in the chapter a detailed description of compressors is given, but for the time being examine figure 1-32 and figure 1-33. Notice the physical effect the two types of compressors have on engine construction features. It is obvious that there is a difference in their length and diameter

Note

- That in the axial flow engine the air inlet duct is one of the major engine components; on the other hand, in the centrifugal flow engine, air enters the air inlet and is directed to the compressor inducer vanes through circumferential inlets located in front and back of the impeller. The inlets are screened to prevent entry of foreign objects that could cause serious damage to the metal components if allowed to enter the compressor.
- The accessories of the two types of engines are located at different points on the engines. This is necessary because of engine construction. The front of the axial flow engine is utilized for air entrance; consequently, the accessories must be located elsewhere.
- Other than the features previously mentioned, there is little visual dissimilarity between the remaining major components of the two engines.

AIR ENTRANCE

The air entrance is designed to conduct incoming air to the compressor with a minimum energy loss resulting from drag or ram pressure loss; that is, the flow of air into the compressor should be free of turbulence to achieve maximum operating efficiency. Proper design contributes materially to aircraft performance by increasing the ratio of compressor discharge pressure to duct inlet pressure.

The amount of air passing through the engine is dependent upon three factors:

- (1) The compressor speed (rpm).
- (2) The forward speed of the aircraft.
- (3) The density of the ambient (surrounding) air.

AIR ENTRANCE

Inlets may be classified as:

1) Nose inlets, located in the nose of the fuselage, or powerplant pod or nacelle.
2) Wing inlets, located along the leading edge of the wing, usually at the root for single engine installations.
3) Annular inlets, encircling, in whole or in part, the fuselage or powerplant pod or nacelle.
4) Scoop inlets, which project beyond the immediate surface of the fuselage or nacelle.
5) Flush inlets, which are recessed in the side of the fuselage, powerplant pod, or nacelle.

AIR ENTRANCE

There are two basic types of air entrances in use:

the single entrance and the divided entrance. Generally, it is advantageous to use a single entrance with an axial flow engine to obtain maximum ram pressure through straight flow. It is used almost exclusively on internal or external installations where the unobstructed entrance lends itself readily to a single, short, straight duct

AIR ENTRANCE

A divided entrance offers greater opportunity to diffuse the incoming air and enter the plenum chamber with the low velocity required to utilize efficiently a double entry compressor. (The plenum chamber is a storage place for ram air, usually associated with fuselage installations.) It is also advantageous when the equipment installation or pilot location makes the use of a single or straight duct impractical. In most cases the divided entrance permits the use of very short ducts with a resultant small pressure drop through skin friction.

ACCESSORY SECTION

The accessory section of the turbojet engine has various functions. The primary function is to provide space for the mounting of accessories necessary for operation and control of the engine. Generally, it also includes accessories concerned with the aircraft such as electric generators and fluid power pumps. Secondary functions include acting as an oil reservoir and/or oil sump, and housing the accessory drive gears and reduction gears.

The arrangement and driving of accessories have always been major problems on gas turbine engines. Driven accessories are usually mounted on common pads either ahead of or adjacent to the compressor section, depending on whether the engine is centrifugal flow or axial flow. Figure 1-34 and figure 1-35 illustrate the accessory arrangement of a centrifugal flow engine and an axial flow engine, respectively.

ACCESSORY SECTION

The basic elements of the centrifugal flow engine accessory section are

(1) the accessory case, which has machined mounting pads for the engine driven accessories, and

(2) the gear train, which is housed within the accessory case.

The accessory case may be designed to act as an oil reservoir. If an oil tank is utilized, a sump is usually provided below the front bearing support for the drainage and scavenging of oil used to lubricate bearings and drive gears.

ACCESSORY SECTION

The accessory case is also provided with adequate tubing or cored passages for spraying lubricating oil on the gear train and supporting bearings.

The gear train is driven by the engine rotor through an accessory drive shaft gear coupling, which splines with a shaft gear and the rotor assembly compressor hub. The reduction gearing within the case provides suitable drive speeds for each engine accessory or component. Because the rotor operating rpm is so high, the accessory reduction gear ratios are relatively high. The accessory drives are supported by ball bearings assembled in the mounting pad bores of the accessory case.

ACCESSORY SECTION

The accessory gearbox has basically the same functions as the accessory case of the centrifugal flow engine. It has the usual machined mounting pads for the engine accessories, and it houses and supports the accessory drive gear trains. Also included are adequate tubing and cored passages for lubricating the gear trains and their supporting bearings.

The accessories usually provided on engines are the fuel control with its governing device; the high pressure fuel pumps; Oil pressure pump and scavenge pump's; auxiliary fuel pump and sometimes a starting fuel pump; and several engine accessories including starter, generator, and tachometer. Although these accessories are for the most part essential, the particular combination of engine driven accessories depends upon the use for which the engine is designed.

The accessories mentioned above (except starters) are the engine driven type. Also associated with the engine systems are the non driven accessories, such as ignition exciters, fuel or oil filters, barometric units, drip valves, compressor bleed valves, and relief valves.

COMPRESSOR SECTION

The compressor section of the turbojet engine has many functions. Its primary function is to supply air in sufficient quantity to satisfy the requirements of the combustion burners. Specifically, to fulfill its purpose, the compressor must increase the pressure of the mass of air received from the air inlet duct and then discharge it to the burners in the quantity and at the pressures required. A secondary function of the compressor is to supply bleed air for various purposes in the engine and aircraft.

COMPRESSOR SECTION

The bleed air is taken from any of the various pressure stages of the compressor. The exact location of the bleed ports is, of course, dependent on the pressure or temperature required for a particular job. The ports are small openings in the compressor case adjacent to the particular stage from which the air is to be bled; thus, varying degrees of pressure or heat are available simply by tapping into the appropriate stage. Air is often bled from the final or highest pressure stage, since at this point, pressure and air temperature are at a maximum. At times it may be necessary to cool this high pressure air. If it is used for cabin pressurization or other purposes where excess heat would be uncomfortable or detrimental, the air is sent through a refrigeration unit.

COMPRESSOR SECTION

Bleed air is utilized in a wide variety of ways, including driving the previously mentioned remote driven accessories. Some of the current applications of bleed air are:

(1) Cabin pressurization, heating, and cooling.

(2) Deicing and anti-icing equipment.

(3) Pneumatic starting of engines.

(4) Auxiliary drive units (ADU).

(5) Control booster servo systems.

(6) Power for running instruments

Compressor Types

The two principal types of compressors currently being used in turbojet aircraft engines are centrifugal flow and axial flow. The compressor type is a means of engine classification. Much use has been made of the terms "centrifugal flow" and "axial flow" to describe the engine and compressor. However, the terms are applicable to the flow of air through the compressor.

In the centrifugal flow engine, the compressor achieves its purpose by picking up the entering air and accelerating it outwardly by centrifugal action. In the axial flow engine, the air is compressed while continuing in its original direction of flow, thus avoiding the energy loss caused by turns. From inlet to exit the air flows along an axial path and is compressed at a ratio of approximately 1.25:1 per stage. The components of each of these two types of compressors have their individual functions in the compression of air for the combustion action

Centrifugal Flow Compressors

The centrifugal flow compressor consists basically of an impeller (rotor), a diffuser (stator), and a compressor manifold, illustrated in figure 1-37. The two main functional elements are the impeller and the diffuser. Although the diffuser is a separate unit and is placed inside and bolted to the manifold; the entire assembly (diffuser and manifold) is often referred to as the diffuser. For clarification during compressor familiarization, the units are treated individually.

The impeller is usually made from forged aluminum alloy, heat treated, machined, and smoothed for minimum flow restriction and turbulence. In some types the impeller is fabricated from a single forging. This type impeller is shown in figure 1-37(A). In other types the curved inducer vanes are separate pieces as illustrated in figure 1-38.

Centrifugal Flow Compressors

The impeller, whose function is to pick up and accelerate the air outwardly to the diffuser, may be either of two types - single entry or double entry. Both are similar in construction to the reciprocating engine supercharger impeller, the double entry type being similar to two impellers back to back. However, because of the much greater combustion air requirements in turbojet engines, the impellers are larger than supercharger impellers.

The principal differences between the two types of impellers are the size and the ducting arrangement. The double entry type has a smaller diameter, but is usually operated at a higher rotational speed to assure sufficient airflow. The single entry impeller permits convenient ducting directly to the impeller eye (inducer vanes) as opposed to the more complicated ducting necessary to reach the rear side of the double entry type. Although slightly more efficient in receiving air, the single entry impeller must be large in diameter to deliver the same quantity of air as the double entry type. This, of course, increases the overall diameter of the engine.