



POWER PLANT

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VOLUME II
POWER PLANT
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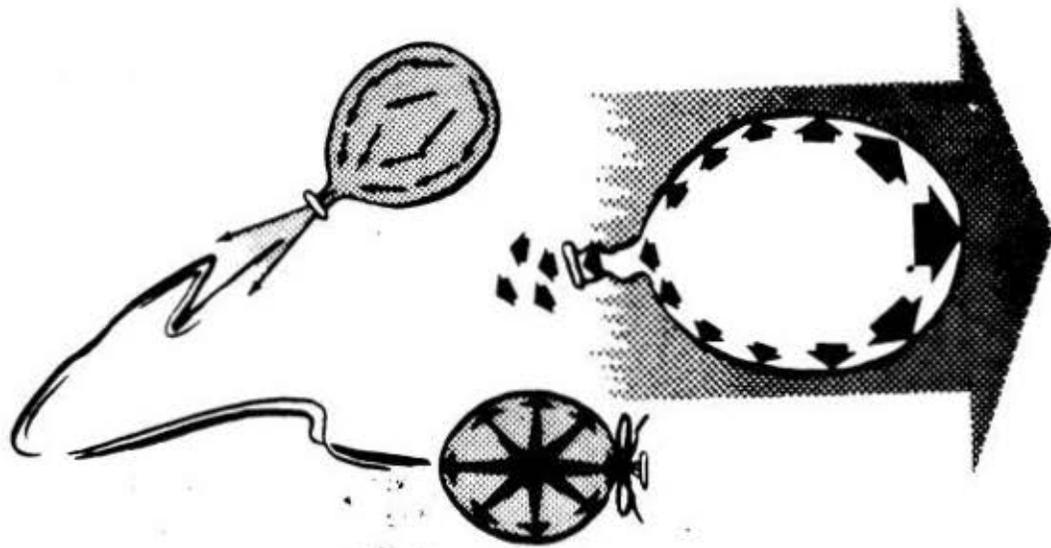
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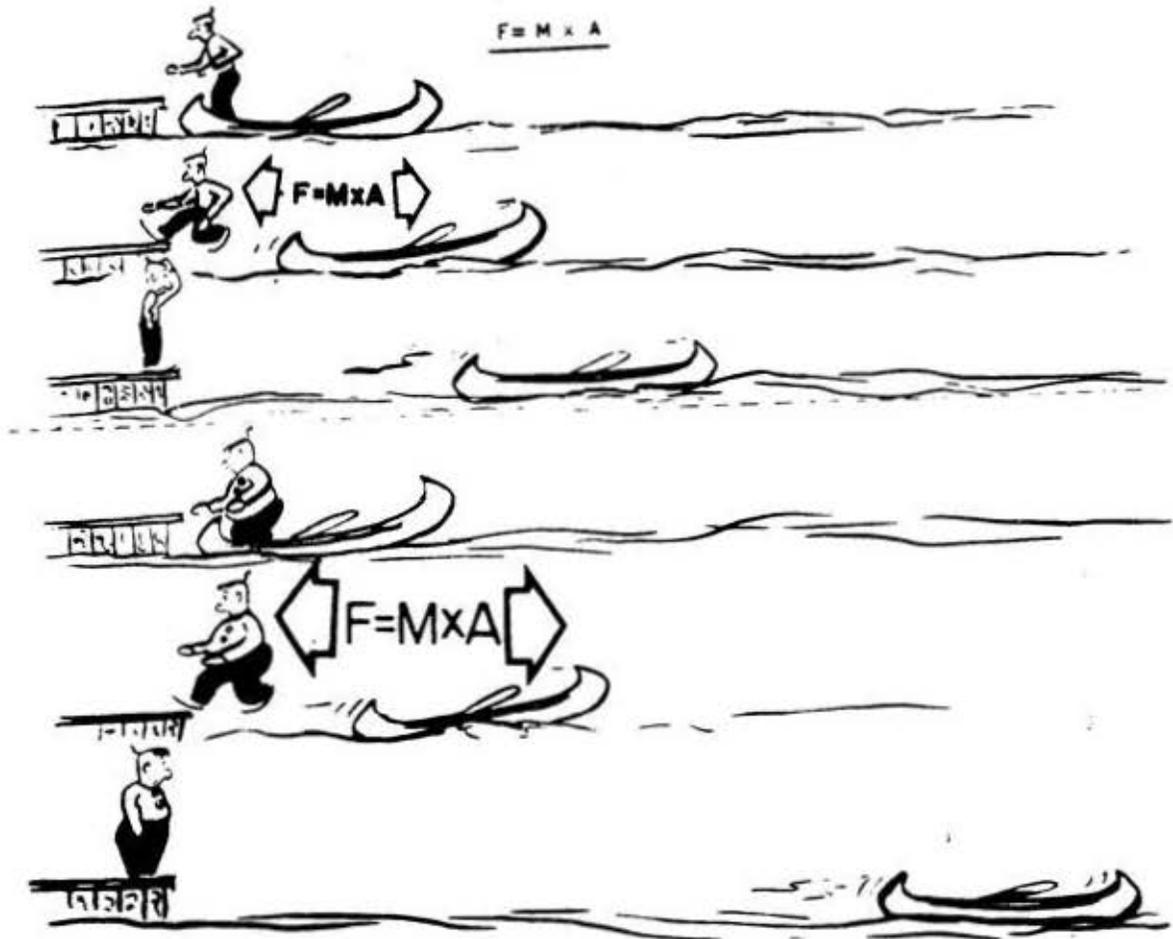
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$$F = M \times A$$



JET PROPULSION



FUNDAMENTALS OF JET PROPULSION

INTRODUCTION.

Down through the pages of aviation history many ideas have been advanced on the possibility of adapting the known principles of jet propulsion to aircraft. Devices depending upon this type of propulsion have been used for centuries either for instruments of war or for the amusement of man. The basic principles of jet propulsion, therefore, are not new.

In the late 1600's, Sir Issac Newton developed the laws of motion which account for the principles by which all reaction engines operate. The basic principles common to jet propulsion are expressed in Newton's second and third laws of motion.

The second law states,

An unbalanced force acting on a body causes the body to accelerate in the direction of the force, and the acceleration is directly proportional to the unbalanced force and inversely proportional to the mass of the body.

Stated mathematically, the law may be written as

$$F = M A$$

where

F = force

M = mass

A = acceleration.

It is only logical, then, that of two identical objects, the one acted upon by the larger force experiences the greater acceleration. Again, if equal forces can be applied to objects of unequal mass (weight), unequal rates of acceleration result and the lighter object receives the greater acceleration.

Newton's third law states,

For every action (force), there is an equal and opposite reaction.

The term "action" (or force) means the force one body exerts on a second body, while reaction force means the force the second exerts on the first. There can never be a force acting in nature unless two bodies are involved, one exerting the force and one on which the force is exerted. The second law indicates the magnitude of thrust and the third law explains why thrust is obtained from the ejection of mass through a nozzle. A given thrust forward can be produced by ejecting rearward either a large mass of material at low velocity during a given period of time, or a smaller mass of material at higher velocity in the same time period.

These facts can be demonstrated with a toy balloon that has been inflated. As long as the stem is kept closed, the air inside the balloon exerts static pressure. This means the pressure is pushing out in all directions with equal force. If the stem is released, there is less force pushing on the stem side of the balloon than on the opposite side. The larger force moves the balloon in the direction opposite the stem. The movement is erratic because the nozzle is not stabilized in any direction. If a supply of air could be stored under pressure in the balloon, the balloon would continue to move. Basically, that is what happens in gas turbine engines.

During operation, the gas turbine engine draws in air and compresses it. Fuel is added to the compressed air and then ignited. The rapid release of energy is accomplished by a process of combustion. Energy (in the form of heat) is transferred to the air passing through the engine to create the force necessary to accelerate the airflow. Thrust, then, is the reaction of the acceleration of the mass of air and burning gases.

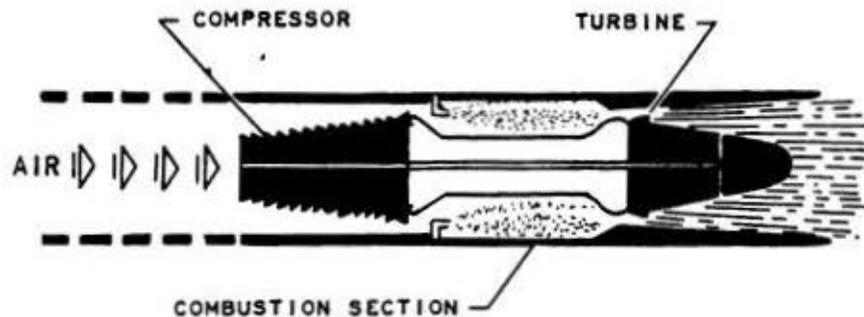
TURBOJET ENGINE OPERATION.

The basic gas turbine engine is made up of three primary sections: the compressor section, the combustion section, and the turbine section. Atmospheric air is drawn through the engine air inlet into a compressor which increases the pressure many times above atmospheric value. Theoretically, the greater the mass of air inducted, the greater is the thrust produced by the engine. The increase in air pressure ratios, however, is limited by

compressor efficiency.

From the compressor the air enters the combustion chamber where a portion of it is mixed with fuel injected into the combustion chambers through spray nozzles. The release of the heat energy of the fuel causes the air to expand.

The heated gases accelerate toward the rear and enter the turbine section at high velocity. A part of the energy of the gasses is transformed by the turbine into mechanical energy to drive the compressor and accessories.



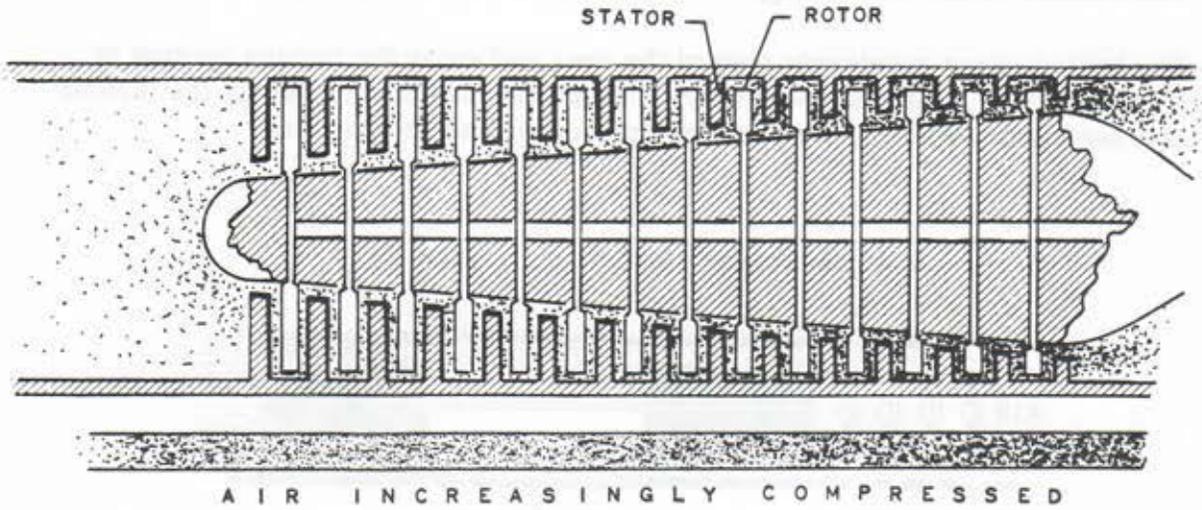
The balance of the energy of the gasses is utilized to create a high-velocity jet.

TYPES OF COMPRESSORS.

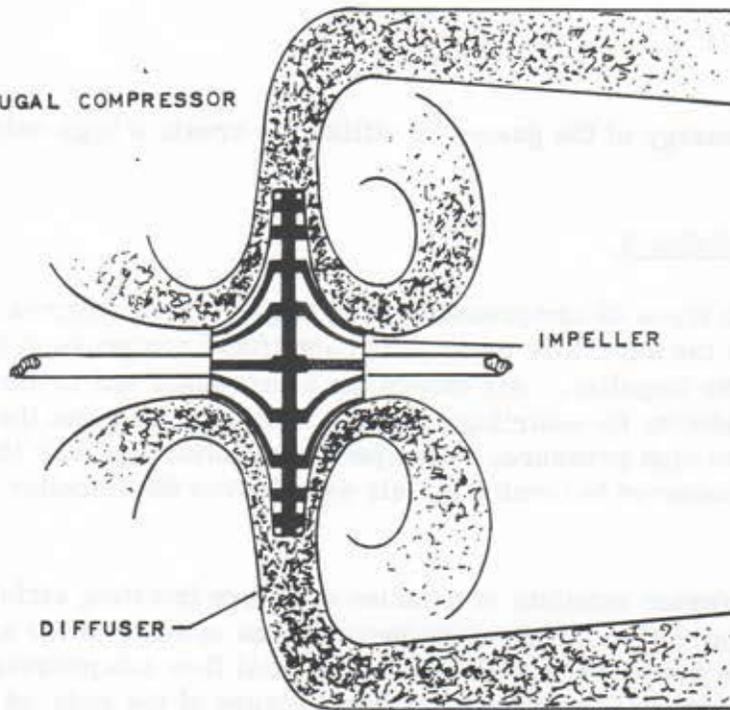
There are two basic types of compressors used in gas turbine engines, the centrifugal type and the axial flow type. The centrifugal compressor air intake is at the center of the impeller. Air enters the compressor and is moved outward at a high velocity by centrifugal force. A diffuser changes the airflow from high velocity to high pressure. The specific disadvantage with this type of compressor is encountered in turning the air as it leaves the impeller going into the diffuser.

An axial flow compressor consists of a series of rotors (rotating airfoils) and stators (stationary airfoils). The rotors increase the velocity of the air and the stators increase the pressure by diffusion. The axial flow compressor decreases in cross-sectional area in the direction of flow because of the reduced volume of air as compression progresses from stage to stage.

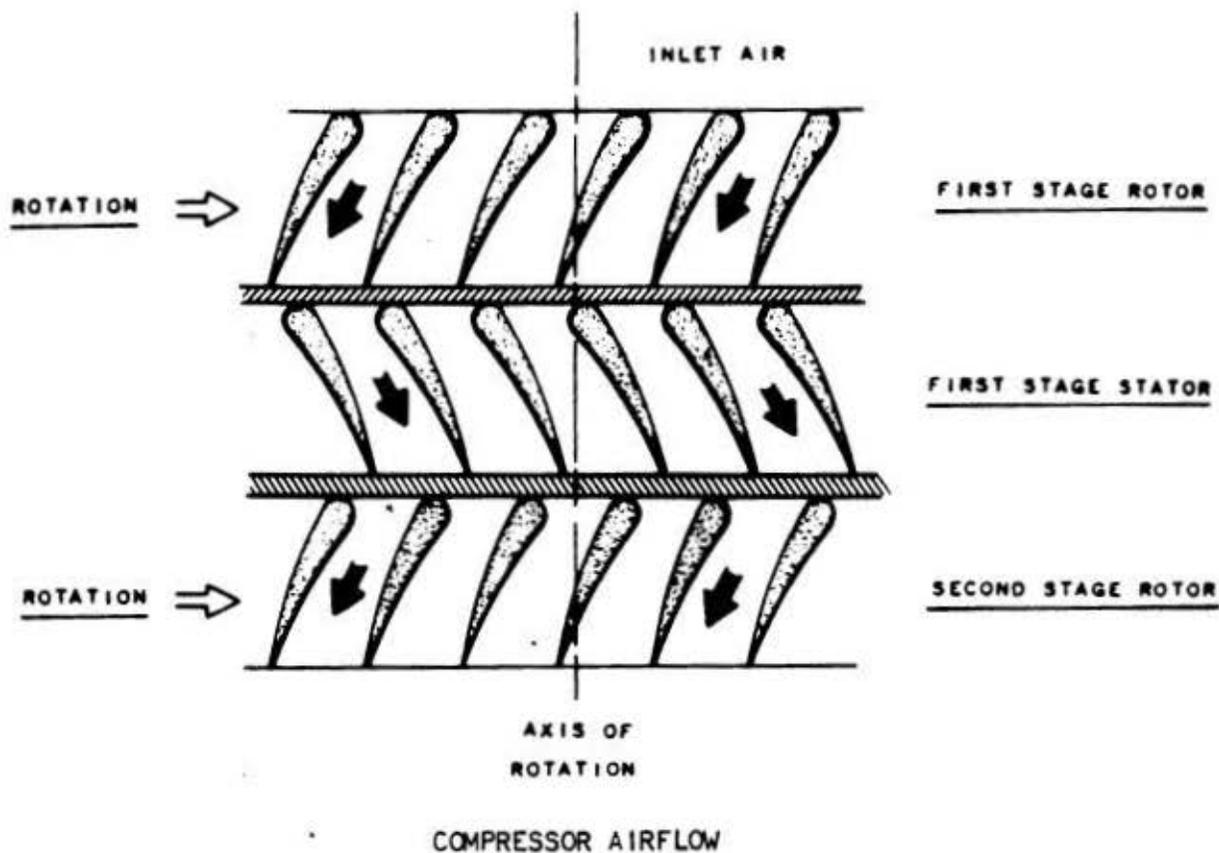
AXIAL FLOW COMPRESSOR



CENTRIFUGAL COMPRESSOR



TYPES OF COMPRESSORS

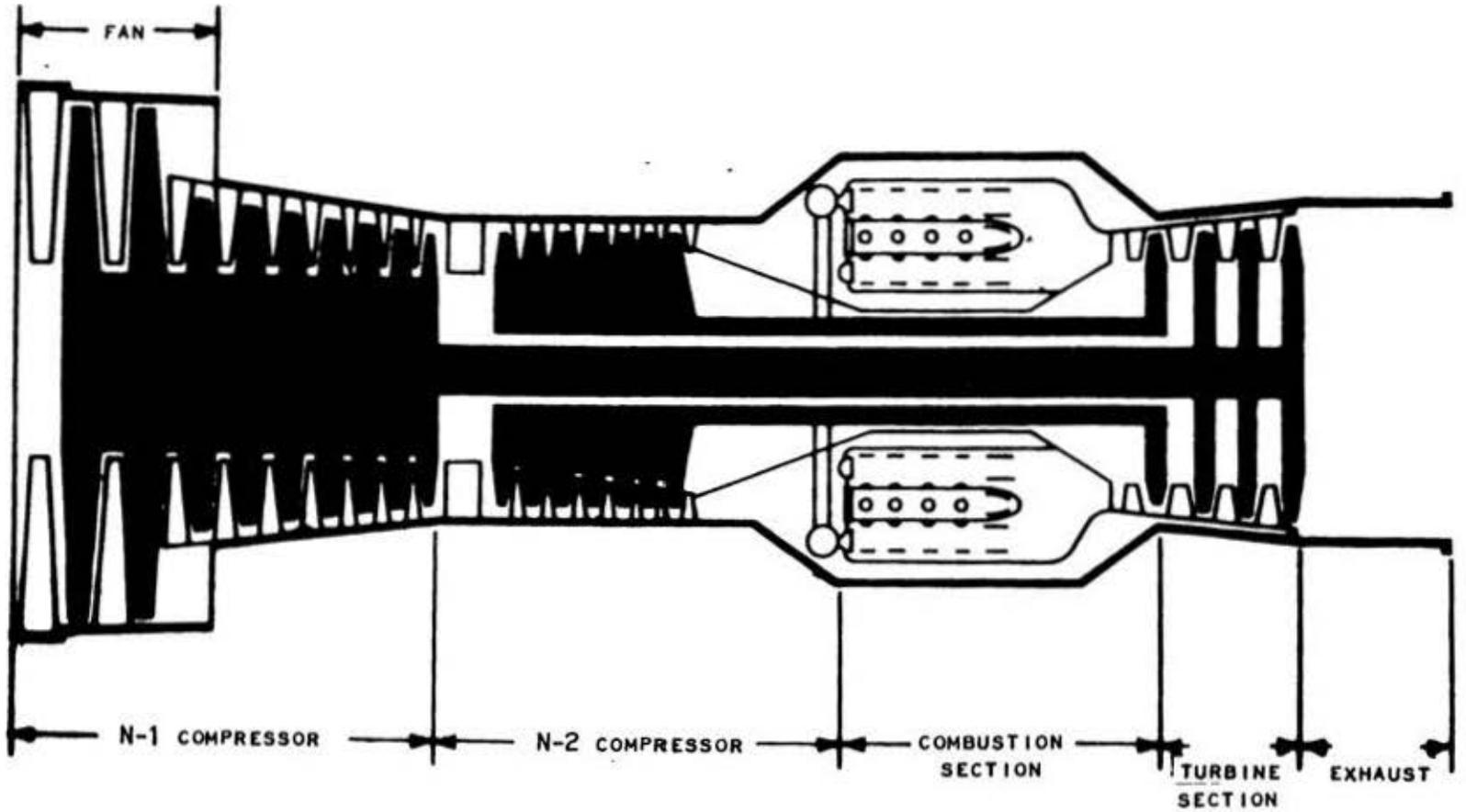


Dual-spool axial flow compressors operate on the same principles as single-spool axial compressors. The main advantage is that higher pressure ratios are attained with minimum total compressor weight and frontal area.

For example, if a single axial-flow compressor were built of as many stages as necessary to produce a required pressure ratio, at specific rotor speeds, the rearmost stages of the compressor would operate inefficiently, and the forward stages would be overloaded. This condition would produce compressor stall. Stalling could be prevented by unloading or bleeding air from the compressor, but this action would be excessively wasteful.

For greater compressor efficiency with high pressure ratios and with less weight, dual type compressors are used.

The high pressure compressor (N2) has shorter blades than the low pressure compressor (N1) and is lighter in weight. The N2 compressor rotor is speed-governed by fuel flow to the engine. With the N2 compressor turning at governed speed the N1 compressor is rotated by its turbine at whatever speed



TURBOFAN ENGINE

will ensure optimum airflow through the compressor. With the compressors working in harmony, increased pressure ratios are obtained without decreasing efficiency. The compressors also adjust themselves to lower power settings (fuel flows) with a minimum of interstage or compressor bleeding (unloading) to prevent stalls.

COMPRESSOR STALL.

There are many different types of compressor stall that can be experienced by turbojet engines. Compressor stall is the breakdown or interruption of airflow through the compressor. Since the compressor blades are tiny airfoils similar to those of an aircraft wing, stalls can occur when operating at too high an angle of attack. Any change or variation in airflow or distribution of airflow to the compressor will change the angle of attack on the blades and cause compressor stall. Examples of this are turbulence at the inlet of the engine, increased airflow into the engine, and abrupt and sharp changes in maneuvering the aircraft.

Many different types of engine malfunctions can cause a stall. Compressor blade damage, damage to engine components or accessories, and improper fuel scheduling are a few causes. During engine acceleration, if fuel scheduling is too great for compressor airflow, combustion pressure will increase and interrupt the airflow through the compressor, and a stall will occur.

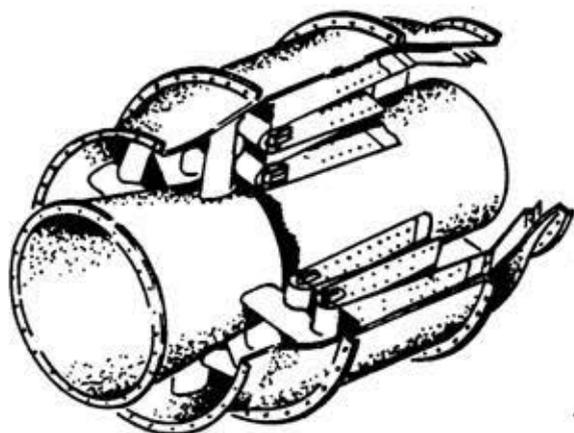
The means for preventing or avoiding compressor stall are proper fuel scheduling and a means for unloading the compressor. Proper fuel scheduling, handled by the fuel control will be discussed in the section on engine fuel system. By unloading or bleeding air from the compressor, increased air flow results which prevents pressure buildup and reduces the pressure ratio across the compressor. This minimizes the tendency of compressor stall. Both of the above mentioned methods are used on the JT3D (TF-33).

COMBUSTION SECTION TYPES.

The combustion section of an axial flow engine usually uses can-annular type burner cans. The multiple can-type used with centrifugal-type compressors has the advantage of short flame length. The annular type used in some axial flow engines has the advantage of even temperature distribution. In the JT3D (TF-33), by combining the two types into a can-annular combustion section, the advantages of short flame length and even heat distribution are obtained. Fuel nozzles fit into the front of the can and spray fuel toward the rear of the can. Air to be used for combustion is admitted into the can through slots and holes. To prevent the can from damage due to high temperatures, cooling air is vented through a series of baffles. This cooling air forms a blanket along the sides of the liner, keeping the flame centered and away from the sides of the can. Satisfactory fuel-air mixture is gained by baffling on the inlet end of the can. A

fuel-air mixture for combustion is about 15:1.

Another important advantage of can-annular combustion sections is their ease of maintenance. Parts are also easily removed and replaced.



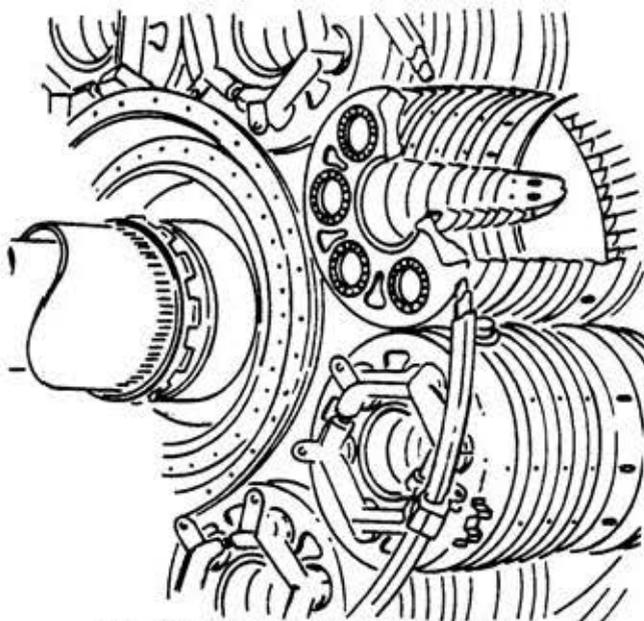
ANNULAR COMBUSTION CHAMBER

Ignition of the fuel-air mixture is accomplished by use of ignitor plugs. Usually there are two plugs placed opposite each other in the ring of burner cans. After initial ignition takes place, the flame is spread to remaining burner cans by cross-over tubes which interconnect the cans.

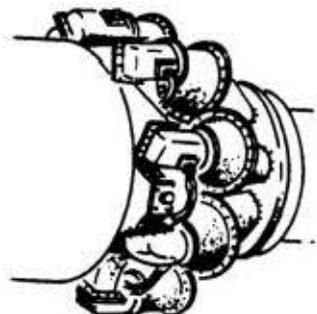
TURBINE SECTION.

The exhaust gasses from the combustion section are directed to the turbine inlet. Several stages can be used in the turbine; however, the number of turbine stages depends on compressor and accessory power requirements. On turbojet and turbofan engines, approximately three-fourths of the generated power is used to drive the compressor.

High-velocity exhaust gas from the combustion section is directed through stationary guide vanes at the entrance to the turbine section. These stationary nozzle guide vanes increase gas velocity and direct flow to the turbine blades. This convergent nozzle vane decreases the width of the gas stream and increases the gas velocity. The high-speed gas stream is directed onto the turbine blades

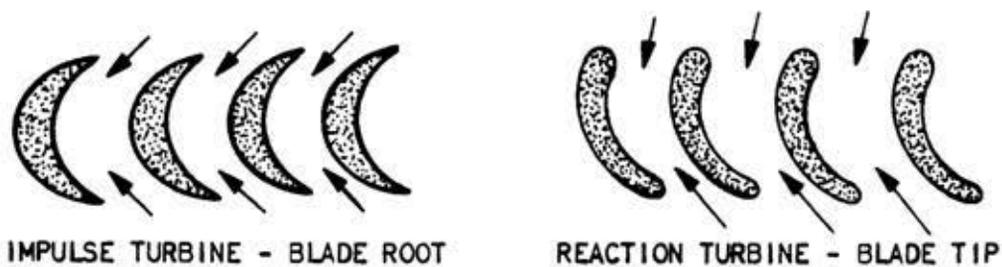


CAN-ANNULAR COMBUSTION CHAMBER



MULTIPLE-CAN-TYPE COMBUSTION CHAMBER

which are designed so that they extract energy from the gas stream in two ways: impulse and reaction.



Each blade is cup-shaped towards the root. Then the gas stream strikes the root section, it tends to push the blade. This is known as impact force.

The contour of the blade changes towards its tip. When the gas stream strikes this portion of the blade, the gases are directed in such a way that a lower pressure is developed on the opposite side of the blade and causes airfoil "lift." This is known as reaction force.

Turbine blades usually have shrouded tips. A shroud is a metal flange built into the tip of the blade. The shrouds interlock forming a continuous band around the outside diameter of the turbine wheel. This continuous band reduces blade vibration and improves airflow characteristics. Turbine blades can be made thinner because of the additional support provided by the shroud.

ENGINE COMPARISONS.

A turbojet engine gets its thrust by accelerating a mass of air through the engine. A high velocity of gases escaping from the engine is necessary to develop proper thrust. To maintain high velocity at the exhaust nozzle, the turbine is designed to extract only enough energy to drive the compressor and accessories. All thrust produced by a turbojet occurs within the engine.

Turboprop propulsion combines the thrust developed by the propeller and the thrust produced by exhaust gases at the exhaust nozzle. The turboprop turbine extracts the maximum possible energy from the gas stream. This energy is converted into shaft horsepower to drive the compressor, propeller and reduction gear, and accessories. The remaining energy, approximately 10 percent, produces jet thrust as the gases are forced out of the exhaust nozzle.

The turbofan is similar to the turboprop, except that the ratio of secondary airflow to primary (combustion airflow) is much lower. The geared propeller

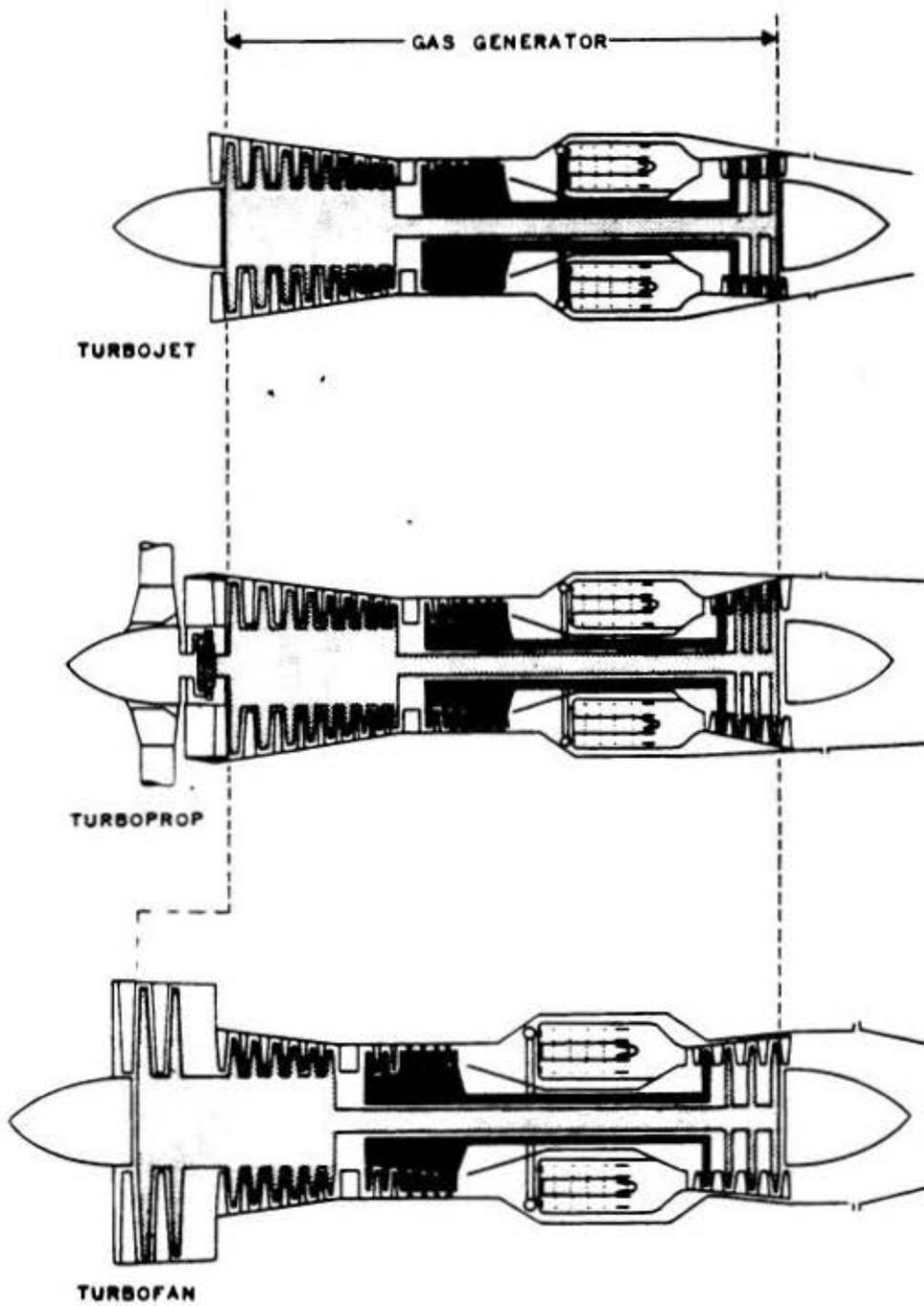
is replaced in the turbofan by an enclosed, axial-flow fan. The fan consists of one or more stages of extra large blades.

These fan blades are on the same shaft as the low pressure compressor (N1) and turn at N1 speed. The exhaust from the outer edge of the fan is directed through ducts along the outside of the compressor case. Inner diameter air flows rearward through the compressor of the engine. The fan provides extra thrust by accelerating a large mass of air.

Each of the three configurations has its limitations and advantages. Turbojet engines provide sustained power efficiency at high altitude and high airspeed. When used on long range aircraft it makes the climb to altitude worthwhile. Exceptionally high thrust at low airspeed and low altitude is not characteristic of turbojet engines. Therefore, they require long runways for take-off. Fuel consumption, compared with turboprop or turbofan engines, is high, although it decreases with an increase in altitude and airspeed.

The turboprop engine combines the gas turbine with the good propulsive characteristics of a propeller at low airspeeds. The turboprop can develop high thrust at low airspeeds and altitude which is possible because the propeller can accelerate large quantities of air. This ability makes turboprops ideal for short and medium-length runways. Also, the turboprop has a low fuel consumption at low airspeed. Propeller efficiency falls off at higher airspeeds. With its advantages and limitations the turboprop is best suited for short and medium takeoff runs, heavy loads, and airspeeds under 400 knots.

The turbofan performance falls between that of the turboprop and turbojet. While it is true that the turboprop loses performance with increase of airspeed, it is not true with the turbofan. Generally, the turbofan is not penalized by high speeds. It combines other features such as lower weight, increased ground clearance, and more economical flight speeds. Compared with the turbojet, a fan version of the same engine has higher static thrust at takeoff, more climb thrust, more cruise thrust, and lower fuel consumption at cruise. It is also somewhat quieter at takeoff.



GAS TURBINE ADAPPTIONS