Chapter 3

Induction & Exhaust Systems

Reciprocating Engine Induction Systems

The basic induction system of an aircraft reciprocating engine consists of an air scoop used to collect the inlet air and ducting that transfers the air to the inlet filter. The air filter is generally housed in the carburetor heat box or other housing close by that is attached to the carburetor or fuel injection controller. The engine used in light aircraft is usually equipped with either a carburetor or a fuel-injection system. After air passes through the fuel metering device, an intake manifold with long curved pipes or passages is used to send the air-fuel mixture to the cylinders. An induction air scoop is shown in *Figure 3-1.* The air scoop is located on the engine cowling to allow maximum airflow into the engine's induction system. The air filter, shown in *Figure 3-2,* prevents dirt and other foreign matter from entering the engine. Filtered air enters the fuel metering device (carburetor/fuel injector) where the throttle plate controls the amount of air flowing to the engine. The air coming out of the throttle is referred to as manifold pressure. This pressure is measured in inches of mercury ("Hg) and controls engine power output.

Induction systems can consist of several different arrangements. Two that are used are the updraft and downdraft induction systems. An updraft induction system consists of two runners and a balance tube with intake pipes for each cylinder to deliver induction air to each cylinder's intake port. *[Figure 3-3]* The balance tube is used to reduce pressure imbalances between the two side induction runners. With carbureted engines, it is important to maintain a constant and even pressure in the induction system so that each cylinder receives equal amounts of fuel. On fuel-injected engines, the fuel is injected at the intake port just before the intake valve. It is important with this system to keep the pressure consistent at each intake port.

Figure 3-1. *Inlet scoop in engine cowling.*

A downdraft balanced induction system provides optimum airflow to each of the individual cylinders throughout a wide operational range. *[Figure 3-4]* Better matched air-fuel ratios provide a much smoother and more efficient engine operation. Air from the induction manifold flows into the intake ports where it is mixed with fuel from the fuel nozzles and then enters the cylinders as a combustible mixture as the intake valve opens.

Basic Carburetor Induction System

Figure 3-2 is a diagram of an induction system used in an engine equipped with a carburetor. In this induction system, carburetor normal flow air is admitted at the lower front nose cowling below the propeller spinner and is passed through an air filter into air ducts leading to the carburetor. A carburetor heat air valve is located below the carburetor for selecting an alternate warm air source (carburetor heat) to prevent carburetor icing. *[Figure 3-5]* Carburetor icing occurs when the temperature is lowered in the throat of the carburetor and enough moisture is present to freeze and block the flow of air to the engine. The carburetor heat valve admits air from the outside air scoop for normal operation, and it admits warm air from the engine compartment for operation during icing conditions. The carburetor heat is operated by a push-pull control in the flight deck. When the carburetor heat air door is closed, warm ducted air from around the exhaust is directed into the carburetor. This raises the intake air temperature. An alternate air door can be opened by engine suction if the normal route of airflow should be blocked by something. The valve is spring loaded closed and is sucked open by the engine if needed.

The carburetor air filter, shown in *Figure 3-6,* is installed in the air scoop in front of the carburetor air duct. Its purpose is

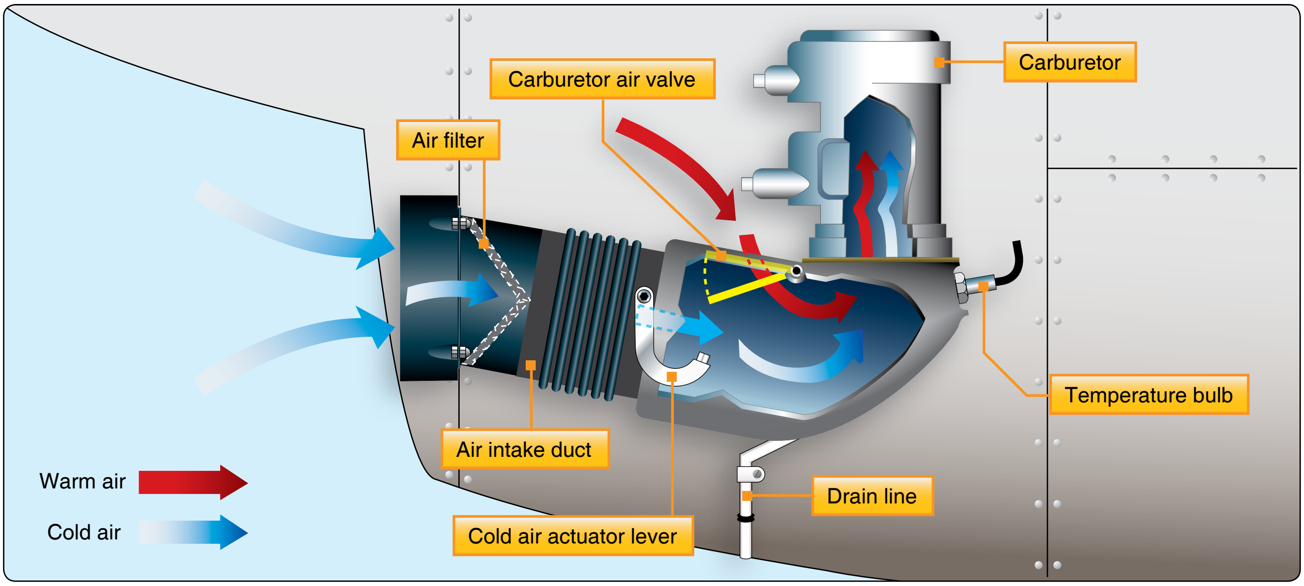

Figure 3-2. *Nonsupercharged induction system using a carburetor.*

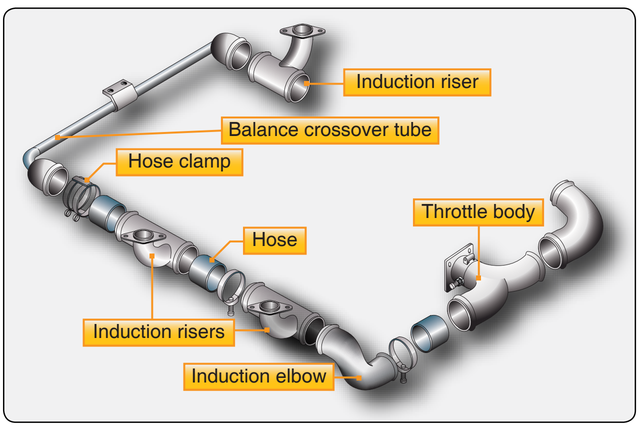

Figure 3-3. *Updraft induction system.*

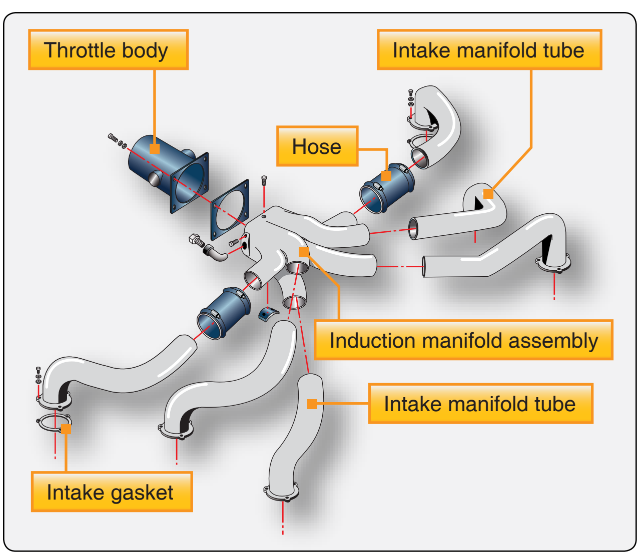

Figure 3-4. *Downdraft balanced induction system.*

Figure 3-5. *Location of a carburetor heat air valve.*

to stop dust and other foreign matter from entering the engine through the carburetor. The screen consists of an aluminum alloy frame and a deeply crimped screen, arranged to present maximum screen area to the airstream. There are several types of air filters in use including paper, foam, and other types of filters. Most air filters require servicing at regular intervals and the specific instructions for the type of filter must be followed. *[Figure 3-6]*

The carburetor air ducts consist of a fixed duct riveted to the nose cowling and a flexible duct between the fixed duct and the carburetor air valve housing. The carburetor air ducts normally provide a passage for outside air to the carburetor. Applying carburetor heat to an operating engine decreases the density of the air, which leans the air-fuel mixture. Air enters the system through the ram-air intake. The intake opening is located in the slipstream so the air is forced into the induction system giving a ram effect to the incoming airflow. The air passes through the air ducts to the carburetor. The carburetor meters the fuel in proportion to the air and mixes the air with

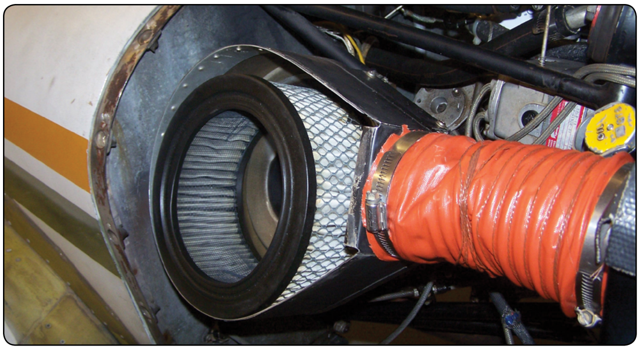

Figure 3-6. *Location of air filter.*

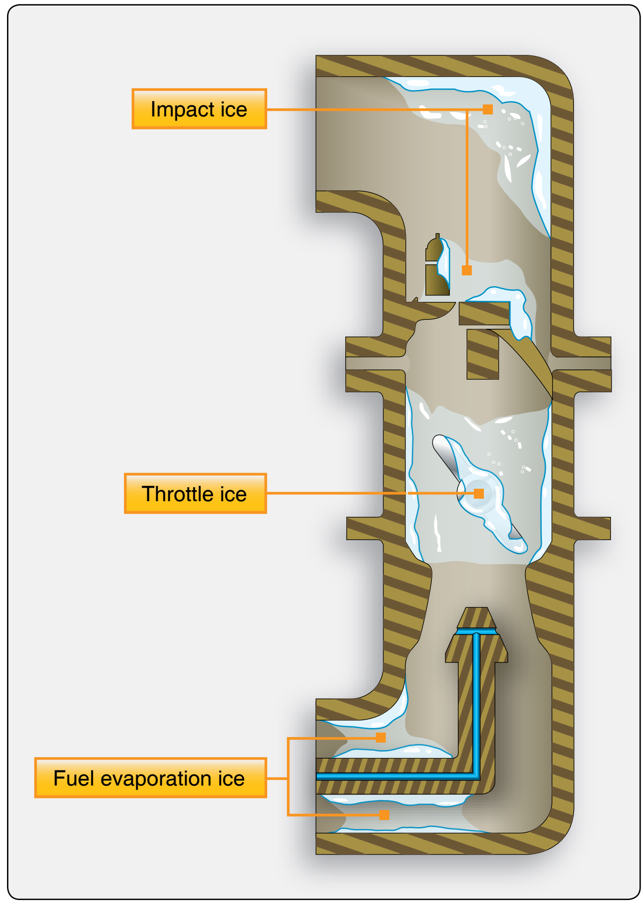

Figure 3-7. *Location of a carburetor heat air valve.*

the correct amount of fuel. The throttle plate of the carburetor can be controlled from the flight deck to regulate the flow of air (manifold pressure), and in this way, power output of the engine can be controlled.

Although many newer aircraft are not so-equipped, some engines are equipped with carburetor air temperature indicating systems which shows the temperature of the air at the carburetor inlet. If the bulb is located at the engine side of the carburetor, the system measures the temperature of the air-fuel mixture.

Induction System Icing

A short discussion concerning the formation and location of induction system ice is helpful, even though a technician is not normally concerned with operations that occur when the aircraft is in flight. *[Figure 3-7]* Technicians should know something about induction system icing because of its effect on engine performance and troubleshooting. Even when an inspection shows that everything is in proper working order and the engine performs perfectly on the ground, induction system ice can cause an engine to act erratically and lose power in the air. Many engine troubles commonly attributed to other sources are actually caused by induction system icing.

Induction system icing is an operating hazard because it can cut off the flow of the air-fuel charge or vary the air-fuel ratio. Ice can form in the induction system while an aircraft is flying in clouds, fog, rain, sleet, snow, or even clear air that has high moisture content (high humidity). Induction system icing is generally classified in three types:

- Impact ice,
- Fuel evaporation ice, and
- Throttle ice.

Induction system ice can be prevented or eliminated by raising the temperature of the air that passes through the system, using a carburetor heat system located upstream near the induction system inlet and well ahead of the dangerous icing zones. This air is collected by a duct surrounding the exhaust manifold. Heat is usually obtained through a control valve that opens
the induction system to the warm air circulating in the engine compartment and around the exhaust manifold.

Improper or careless use of carburetor heat can be just as dangerous as the most advanced stage of induction system ice. Increasing the temperature of the air causes it to expand and decrease in density. This action reduces the weight of the charge delivered to the cylinder and causes a noticeable loss in power because of decreased volumetric efficiency. If icing is not present when carburetor heat or induction system anti-icing is applied and the throttle setting does not change, the mixture will become richer. In addition, high intake air temperature may cause detonation and engine failure, especially during takeoff and high power operation. Therefore, during all phases of engine operation, the carburetor temperature must afford the greatest protection against icing and detonation.

When there is danger of induction system icing, the flight deck carburetor heat control is moved to the hot position. Throttle ice or any ice that restricts airflow or reduces manifold pressure can best be removed by using full carburetor heat.

If the heat from the engine compartment is sufficient and the application has not been delayed, it is only a matter of a few minutes until the ice is cleared.

When there is no danger of icing, the heat control is normally kept in the "cold" position. It is best to leave the control in this position if there are particles of dry snow or ice in the air. The use of heat may melt the ice or snow, and the resulting moisture may collect and freeze on the walls of the induction system. To prevent damage to the heater valves in the case of backfire, carburetor heat should not be used while starting the engine. Also, during ground operation only enough carburetor heat should be used to give smooth engine operation.

Part-throttle operation can lead to icing in the throttle area. When the throttle is placed in a partly closed position, it, in effect, limits the amount of air available to the engine. When the aircraft is in a glide, a fixed-pitch propeller windmills, causing the engine to consume more air than it normally would at this same throttle setting, thus adding to the lack of air behind the throttle. The partly closed throttle, under these circumstances, establishes a much higher than normal air velocity past the throttle, and an extremely low-pressure area is produced. The low-pressure area lowers the temperature of the air surrounding the throttle valve. If the temperature in this air falls below freezing and moisture is present, ice forms on the throttles and nearby units restricting the airflow to the engine causing it to quit. Throttle ice may be minimized on engines equipped with controllable-pitch propellers by the use of a higher than normal brake mean effective pressure (BMEP) at this low power. The high BMEP decreases the icing tendency because a large throttle opening at low engine revolutions per minute (rpm) partially removes the temperature-reducing obstruction that part-throttle operation offers.

Induction System Filtering

Dust and dirt can be a serious source of trouble to an aircraft engine. Dust consists of small particles of hard, abrasive material that can be carried by the air and drawn into the engine cylinders. It can also collect on the fuel-metering elements of the carburetor, upsetting the proper relation between airflow and fuel flow at all engine power settings. It acts on the cylinder walls by grinding down these surfaces and the piston rings. Then, it contaminates the oil and is carried through the engine, causing further wear on the bearings and gears. In extreme cases, an accumulation may clog an oil passage and cause oil starvation. Although dust conditions are most critical at ground level, continued operation under such conditions without engine protection results in extreme engine wear and can produce excessive oil consumption. When operation in a dusty atmosphere is necessary, the engine can be protected by an alternate induction system air inlet which incorporates a dust filter. This type of air filter system normally consists of a filter element, a door, and an electrically operated actuator. When the filter system is operating, air is drawn through a louvered access panel that does not face directly into the airstream. With this entrance location, considerable dust is removed as the air is forced to turn and enter the duct. Since the dust particles are solid, they tend to continue in a straight line, and most of them are separated at this point. Those that are drawn into the louvers are easily removed by the filter.

In flight, with air filters operating, consideration must be given to possible icing conditions which may occur from actual surface icing or from freezing of the filter element after it becomes rain soaked. Some installations have a spring-loaded filter door which automatically opens when the filter is excessively restricted. This prevents the airflow from being cut off when the filter is clogged with ice or dirt. Other systems use an ice guard in the filtered-air entrance.

The ice guard consists of a coarse-mesh screen located a short distance from the filtered-air entrance. In this location, the screen is directly in the path of incoming air so that the air must pass through or around the screen. When ice forms on the screen, the air, which has lost its heavy moisture particles, passes around the iced screen and into the filter element. The efficiency of any filter system depends upon proper maintenance and servicing. Periodic removal and cleaning of the filter element is essential to satisfactory engine protection.

Induction System Inspection & Maintenance

The induction system should be checked for cracks and leaks during all regularly scheduled engine inspections. The units of the system should be checked for security of mounting. The system should be kept clean at all times, since pieces of rags or paper can restrict the airflow if allowed to enter the air intakes or ducts. Loose bolts and nuts can cause serious damage if they pass into the engine.

On systems equipped with a carburetor air filter, the filter should be checked regularly. If it is dirty or does not have the proper oil film, the filter element should be removed and cleaned. After it has dried, it is usually immersed in a mixture of oil and rust-preventive compound. The excess fluid should be allowed to drain off before the filter element is reinstalled. Paper-type filters should be inspected and replaced as needed. The efficiency of any filter system depends upon proper maintenance and servicing. Periodic removal and cleaning of the filter element is essential to satisfactory engine protection. If the induction system air filter becomes excessively dirty, it will cause a loss of power or the engine will not start.

Extinguishing Engine Fires

In all cases, a fireguard should stand by with a CO_2 fire

Probable Cause	Isolation Procedure	Correction
1 Engine fails to start		
a Induction system obstructed	Inspect air scoop and air ducts	Remove obstructions
b Air leaks	Inspect carburetor mounting and intake pipes	Tighten carburetor and repair or replace intake pipe
2 Engine runs rough		
a Loose air ducts	Inspect air ducts	Tighten air ducts
b Leaking intake pipes	Inspect intake pipe packing nuts	Tighten nuts
c Engine valves sticking	Remove rocker arm cover and check valve action	Lubricate and free sticking valves
d Bent or worn valve push rods	Inspect push rods	Replace worn or damaged push rods
3 Low power		
a Restricted intake duct	Examine intake duct	Remove restrictions
b Broken door in carburetor air valve	Inspect air valve	Replace air valve
c Dirty air filter	Inspect air filter	Clean air filter
4 Engine idles improperly		
a Shrunken intake packing	Inspect packing for proper fit	Replace packing
b Hole in intake pipe	Inspect intake pipe	Replace defective intake pipes
c Loose carburetor mounting	Inspect mount bolts	Tighten mount bolts

Figure 3-8. *Common problems for troubleshooting induction systems.*

extinguisher while the aircraft engine is being started. This is a necessary precaution against fire during the starting procedure. The fireguard must be familiar with the induction system of the engine so that in case of fire, they can direct the CO_2 into the air intake of the engine to extinguish it. A fire could also occur in the exhaust system of the engine from liquid fuel being ignited in the cylinder and expelled during the normal rotation of the engine.

If an engine fire develops during the starting procedure, continue cranking to start the engine and blow out the fire. If the engine does not start and the fire continues to burn, discontinue the start attempt. The fireguard then extinguishes the fire using the available equipment. The fireguard must observe all safety practices at all times while standing by during the starting procedure.

Induction System Troubleshooting

Figure 3-8 provides a general guide to the most common induction system troubles.

Supercharged Induction Systems

Since aircraft operate at altitudes where the air pressure is lower, it is useful to provide a system for compressing the air-fuel mixture. Some systems are used to normalize the air pressure entering the engine. These systems are used to regain the air pressure lost by the increase in altitude. This type of system is not a ground boost system and it is not used to ever boost the manifold pressure above 30 inches of mercury. A true supercharged engine, called ground boosted engines, can boost the manifold pressure above 30 inches of mercury. In other words, a true supercharger boosts the manifold pressure above ambient pressure.

Since many engines installed in light aircraft do not use any type of compressor or supercharging device, induction systems for reciprocating engines can be broadly classified as supercharged or nonsupercharged. *[Figure 3-9]* Supercharging systems used in reciprocating engine induction systems are normally classified as either internally driven or externally driven (turbosupercharged). Internally driven superchargers compress the air-fuel mixture after it leaves the carburetor, while externally driven superchargers (turbochargers) compress the air before it is mixed with the

Figure 3-9. *An example of a naturally aspirated reciprocating engine.*

metered fuel from the carburetor.

Internally Driven Superchargers

Internally-driven superchargers were used almost exclusively in high horsepower radial reciprocating engines and are engine driven through a mechanical connection. Although their use is very limited, some are still used in cargo carriers and spray planes. Except for the construction and arrangement of the various types of superchargers, all induction systems with internally driven superchargers were very similar. Aircraft engines require the same air temperature control to produce good combustion in the engine cylinders. For example, the charge must be warm enough to ensure complete fuel vaporization and, thus, even distribution. At the same time, it must not be so hot that it reduces volumetric efficiency or causes detonation. All reciprocating engines must guard against intake air that is too hot. As with any type of supercharging (compressing intake air), the air gains heat as it is compressed. Sometimes this air requires cooling before it is routed to the engine's intake ports. With these requirements, most induction systems that use internally driven superchargers must include pressure and temperature-sensing devices and the necessary units required to warm or cool the air.

The simple internally driven supercharger induction system is used to explain the location of units and the path of the air and air-fuel mixture. [*Figure 3-10]* Air enters the system through the ram air intake. The intake opening is located so that the air is forced into the induction system, giving a ram effect caused by the aircraft moving through the air. The air passes through ducts to the carburetor. The carburetor meters the fuel in proportion to the air and mixes the air with the correct amount of fuel. The carburetor can be controlled from the flight deck to regulate the flow of air. In this way, the power output of the engine can be controlled. The manifold pressure gauge measures the pressure of the air-fuel mixture before it enters the cylinders. It is an indication of the performance that can be expected of the engine. The carburetor air temperature indicator measures either the temperature of the inlet air or of the air-fuel mixture. Either the air inlet or the mixture temperature indicator serves as a guide so that the temperature of the incoming charge may be kept within safe limits. If the temperature of the incoming air at the entrance to the carburetor scoop is 100 °F, there is approximately a 50 °F drop in temperature because of the partial vaporization of the fuel at the carburetor discharge nozzle. Partial vaporization takes place and the air temperature falls due to absorption of the heat by vaporization. The final vaporization takes place as the mixture enters the cylinders where higher temperatures exist. The fuel, as atomized into the airstream that flows in the induction system, is in a globular form. The problem, then, becomes one of uniformly breaking up and distributing the fuel, remaining in globular form to the various cylinders. On engines equipped with a large number of cylinders, the uniform distribution of the mixture becomes a greater problem, especially at high engine speeds when full advantage is taken of large air capacity.

One method used mainly on radial reciprocating engines of improving fuel distribution is shown in *Figure 3-11*. This device is known as a distribution impeller. The impeller is attached directly to the end of the rear shank of the crankshaft by bolts or studs. Since the impeller is attached to the end of the crankshaft and operates at the same speed, it does not materially boost or increase the pressure on the mixture

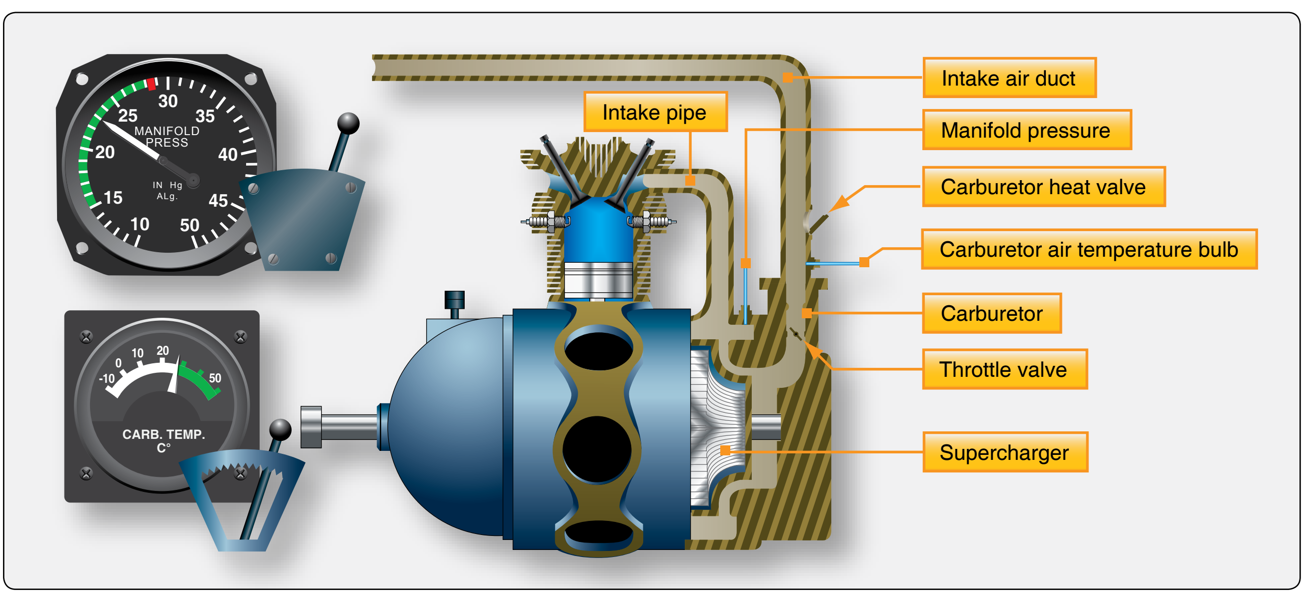

Figure 3-10. *Internally-driven supercharger induction system.*

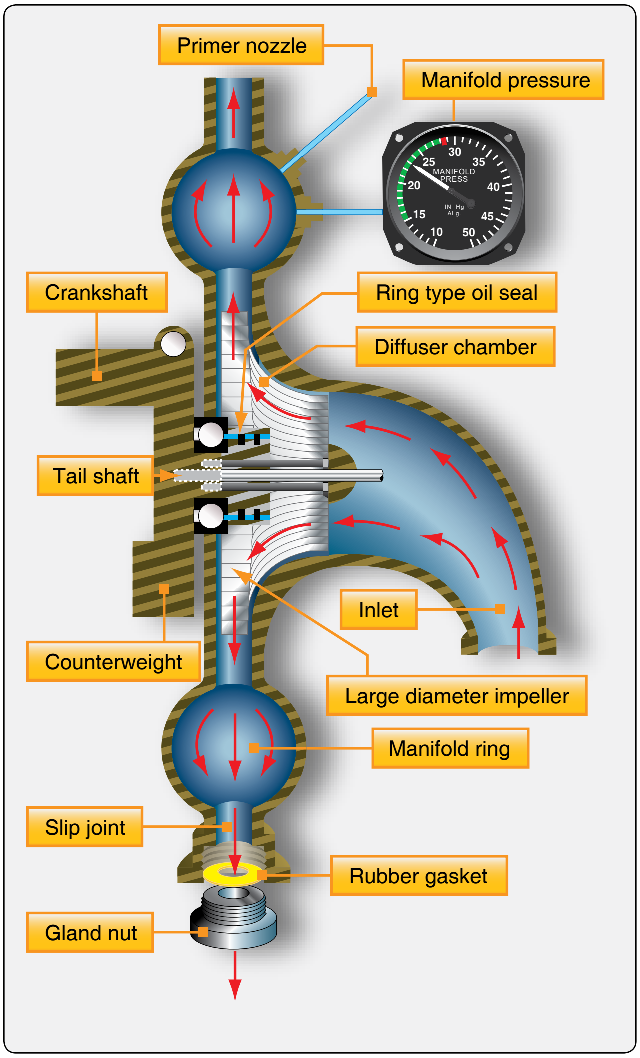

Figure 3-11. *Radial engine distribution impeller.*

flowing into the cylinders. But, the fuel remaining in the globular form is broken up into finer particles as it strikes the impeller, thereby coming in contact with more air. This creates a more homogeneous mixture with a consequent improvement in distribution to the various cylinders, especially on acceleration of the engine or when low temperatures prevail.

To obtain greater pressure of the air-fuel mixture within the cylinders, the diffuser or blower section contains a high speed impeller. Unlike the distribution impeller, which is connected directly to the crankshaft, the supercharger, or blower impeller, is driven through a gear train from the crankshaft.

Turbosuperchargers

Externally driven superchargers (turbosuperchargers) are designed to deliver compressed air to the inlet of the carburetor or air-fuel control unit of an engine. Externally driven superchargers derive their power from the energy of engine exhaust gases directed against a turbine that drives an impeller that compresses the incoming air. For this reason, they are commonly called turbosuperchargers or turbochargers. To be a true supercharger, it must boost the manifold pressure above 30 "Hg.

The typical turbosupercharger, shown in *Figure 3-12,* is composed of three main parts:

1. Compressor assembly,
2. Turbine wheel assembly, and
3. A full floating shaft bearing assembly.

Detail examples of a turbosupercharger are shown in *Figure 3-13.* In addition to the major assemblies, there is a baffle between the compressor casing and the exhaust-gas turbine that directs cooling air to the pump and bearing casing, and also shields the compressor from the heat radiated by the turbine. In installations where cooling air is limited, the baffle is replaced by a regular cooling shroud that receives its air directly from the induction system.

The compressor assembly is made up of an impeller, a diffuser, and a casing. The air for the induction system enters through a circular opening in the center of the compressor casing, where it is picked up by the blades of the impeller, which gives it high velocity as it travels outward toward the diffuser. The diffuser vanes direct the airflow as it leaves the impeller and also converts the high velocity of the air to high-pressure.

Motive power for the impeller is furnished through the impeller's attachment to the turbine wheel shaft of the exhaust-gas turbine. This complete assembly is referred to as the rotor. (The rotor revolves on the oil feed bearings.*)* The exhaust gas turbine assembly consists of the turbocharger and waste gate valve. *[Figure 3-14]* The turbine wheel, driven by exhaust gases, drives the impeller. The turbo housing collects and directs the exhaust gases onto the turbine wheel, and the waste gate regulates the amount of exhaust gases directed to the turbine. The waste gate controls the volume of the exhaust gas that is directed onto the turbine and thereby regulates the speed of the rotor (turbine and impeller). *[Figure 3-15]*

If the waste gate is completely closed, all the exhaust gases are "backed up" and forced through the turbine wheel. If the waste gate is partially closed, a corresponding amount of exhaust gas is directed to the turbine. The exhaust gasses, thus directed, strike the turbine blades, arranged radially around the outer edge of the turbine, and cause the rotor (turbine and impeller) to rotate. The gases, having exhausted most of their energy, are then exhausted overboard. When the waste gate is fully open, nearly all of the exhaust gases pass overboard providing little or no boost.

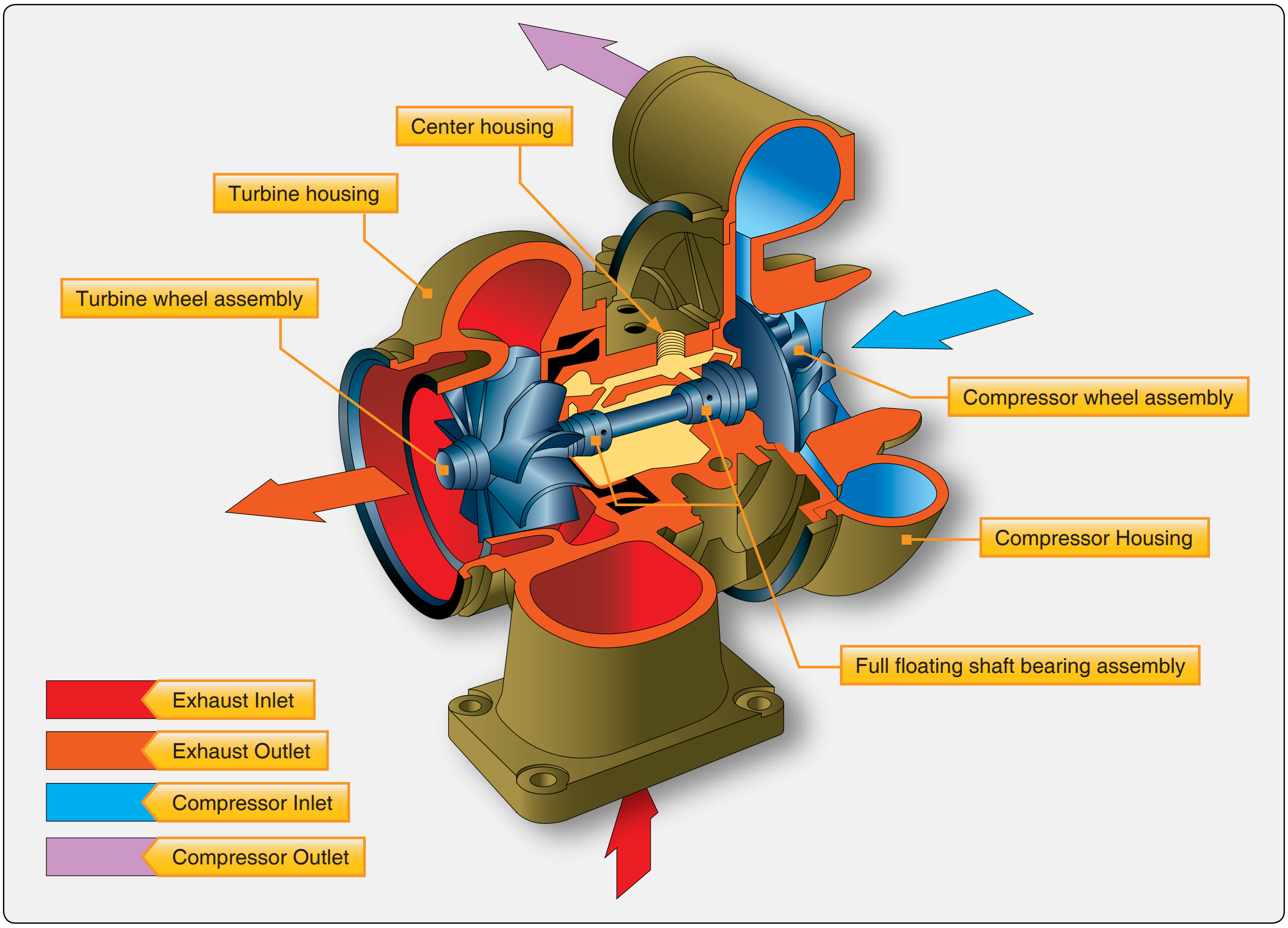

Figure 3-12. *A typical turbosupercharger and its main parts.*

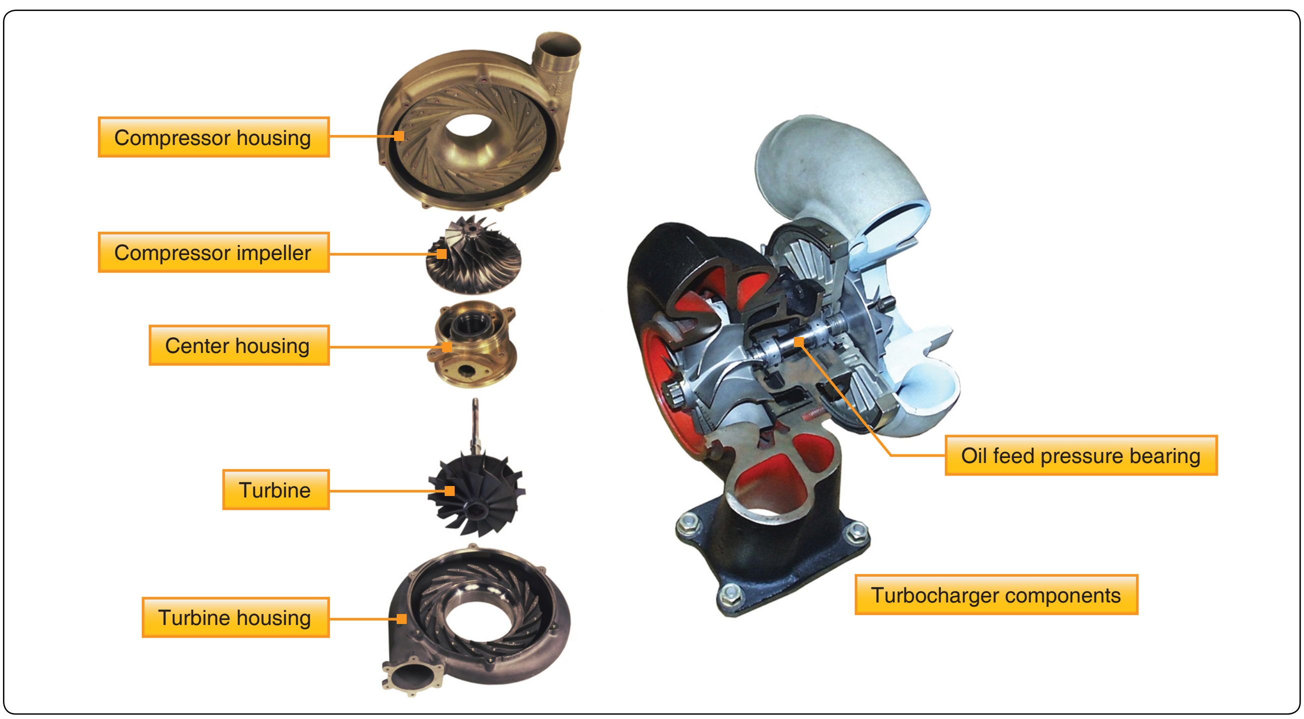

Figure 3-13. *Detail examples of the main components of a turbosupercharger.*

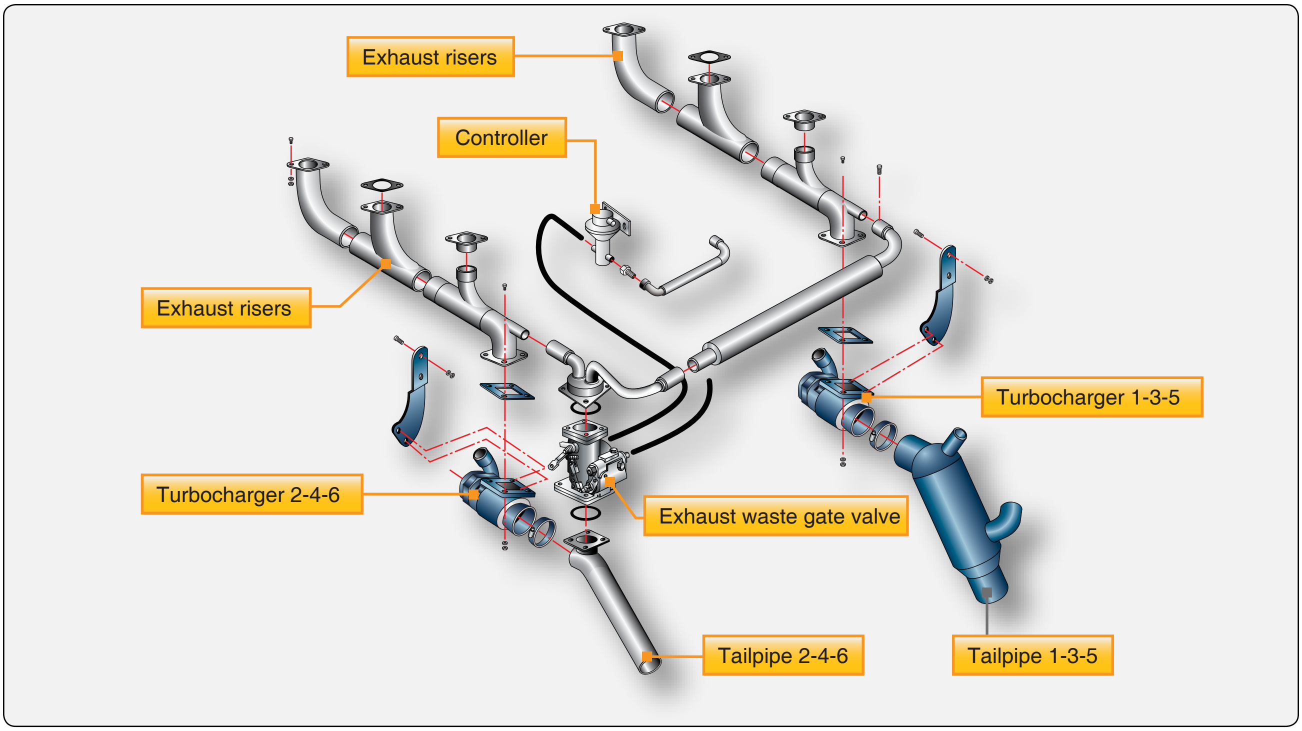

Figure 3-14. *Exhaust gas turbine assembly.*

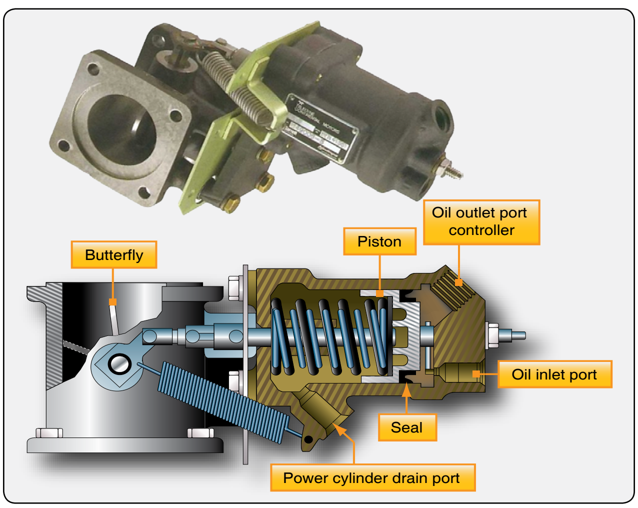

Figure 3-15. *Waste gate control of exhaust.*

Normalizer Turbocharger

Some engines used in light aircraft are equipped with an externally driven normalizing system. These systems are powered by the energy of exhaust gases and are usually referred to as "normalizing turbocharger" systems. These systems were not designed to be used as a true supercharger (boost manifold pressure over 30 "Hg). They compensate for the power lost due to the pressure drop resulting from increased altitude. On many small aircraft engines, the turbocharger (normalizing) system is designed to be operated only above a certain altitude, 5,000 feet for example, since maximum power without normalizing is available below that altitude. The location of the air induction and exhaust systems of a typical normalizing turbocharger system for a small aircraft is shown in *Figure 3-16.*

Ground-Boosted Turbosupercharger System

Some ground-boosted (sea level) turbosupercharged systems are designed to operate from sea level up to their critical altitude. These engines, sometimes referred to as sea level-boosted engines, can develop more power at sea level than an engine without turbosupercharging. As was mentioned earlier, an engine must be boosted above 30 "Hg to truly be supercharged. This type of turbocharger accomplishes this by increasing the manifold pressure above 30 "Hg to around 40 "Hg.

The turbosupercharger air induction system consists of a filtered ram-air intake located on the side of the nacelle. *[Figure 3-17]* An alternate air door within the nacelle permits compressor suction automatically to admit alternate air (heated engine compartment air) if the induction air filter becomes clogged. In many cases, the alternate air door can be operated manually in the event of filter clogging.

Almost all turbocharger systems use engine oil as the control fluid for controlling the amount of boost (extra manifold pressure) provided to the engine. The waste-gate actuator and controllers use pressurized engine oil for their power supply. The turbocharger is controlled by the waste gate and waste gate actuator. The waste gate actuator, which is physically connected to the waste gate by mechanical linkage, controls

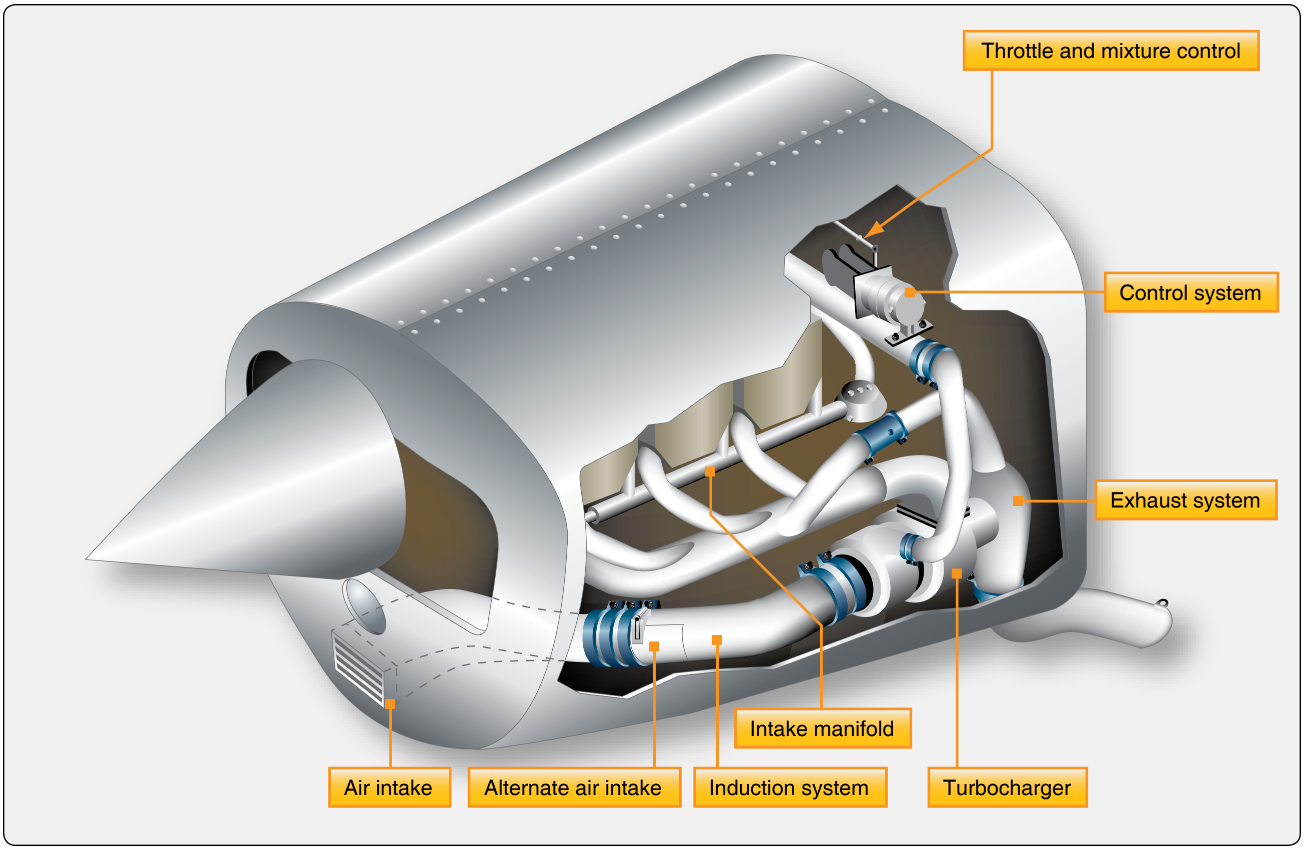

Figure 3-16. *Typical location of the air induction and exhaust systems of a normalizing turbocharger system.*

the position of the waste gate butterfly valve. The waste gate bypasses the engine exhaust gases around the turbocharger turbine inlet. By controlling the amount of exhaust gases that pass through the turbine of the turbocharger, the speed of the compressor and the amount of intake boost (upper deck pressure) is controlled. Engine oil is also used to cool and lubricate the bearings that support the compressor and turbine in the turbocharger. Turbocharger lubricating oil is engine oil supplied through the engine oil system. An oil supply hose from the rear of the oil cooler directs oil to the turbocharger center housings and bearings. Oil hoses return oil from the turbochargers to the oil scavenge pump located on the rear of the engine. The one-way check valve in the oil supply line prevents oil from draining into the turbocharger while the engine is not operating. Piston ring-like oil seals are used on the compressor wheel shaft to prevent the lubricating oil from entering the turbine and compressor housings from the center housing.

The position of the waste gate is controlled by adjusting the oil pressure in the waste gate actuator. Several different types of controllers are used to provide the correct pressure in the waste gate actuator. This is done either by restricting the oil flow or by allowing the oil to return to the engine. The more the oil is restricted, the more pressure is in the waste gate actuator and the more closed the waste gate is. This causes the exhaust gases to pass through the turbine, increasing the speed of the compressor raising the inlet pressure. The reverse happens if the oil is not restricted by the controllers and boost is reduced. The pressure from the outlet of the compressor of the turbocharger to the throttle is referred to as deck pressure or upper deck pressure.

A Typical Turbosupercharger System

Figure 3-18 is a schematic of a sea level booster turbosupercharger system. This system used widely is automatically regulated by three components:

- Exhaust bypass valve assembly,
- Density controller, and
- Differential pressure controller.

By regulating the waste gate position and the "fully open" and "closed" positions, a constant power output can be maintained. When the waste gate is fully open, all the exhaust gases are directed overboard to the atmosphere, and no air is compressed and delivered to the engine air inlet. Conversely, when the waste gate is fully closed, a maximum volume of exhaust gases flows into the turbocharger turbine, and maximum supercharging is accomplished. Between these

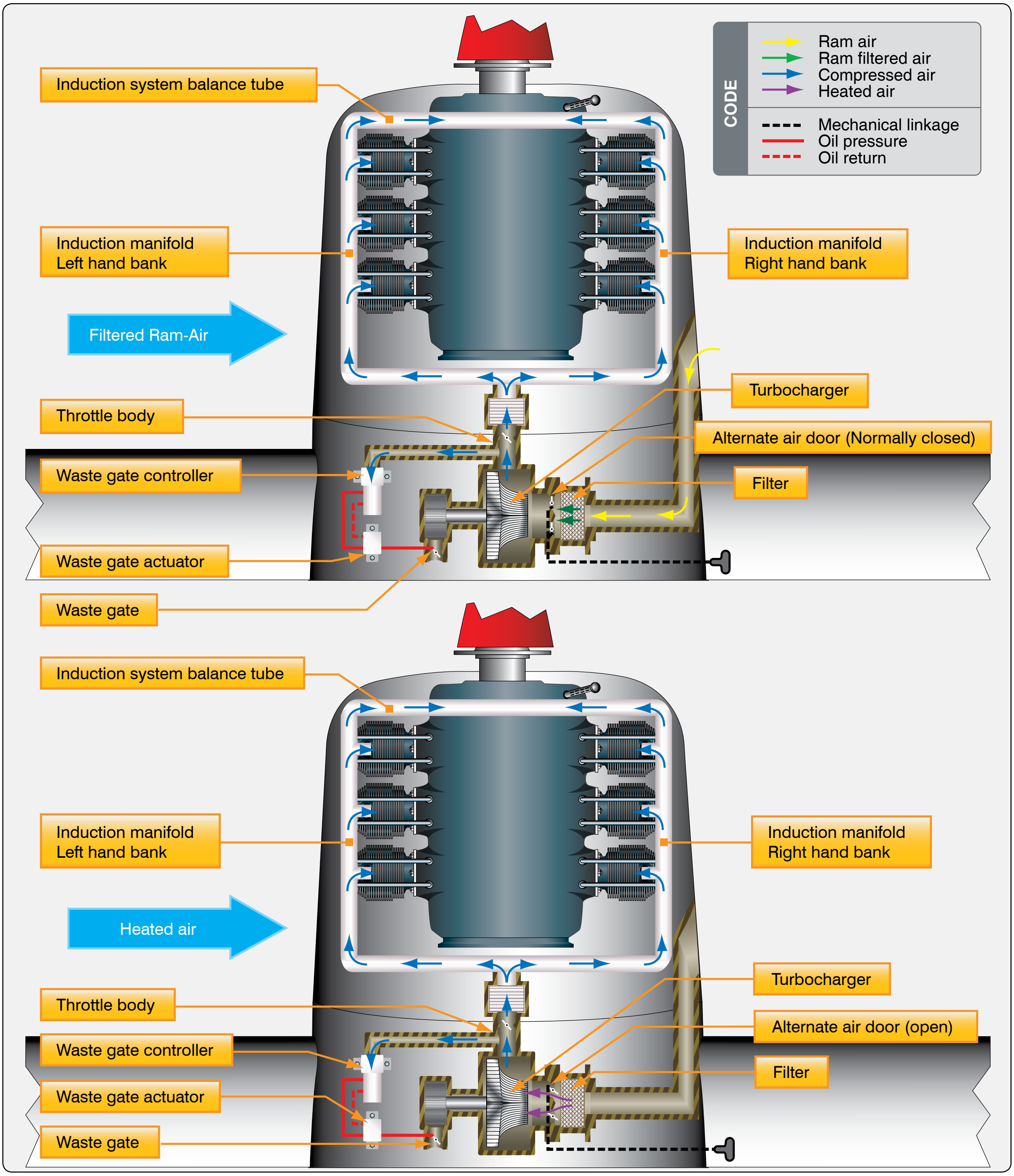

Figure 3-17. *A turbocharger air induction system.*

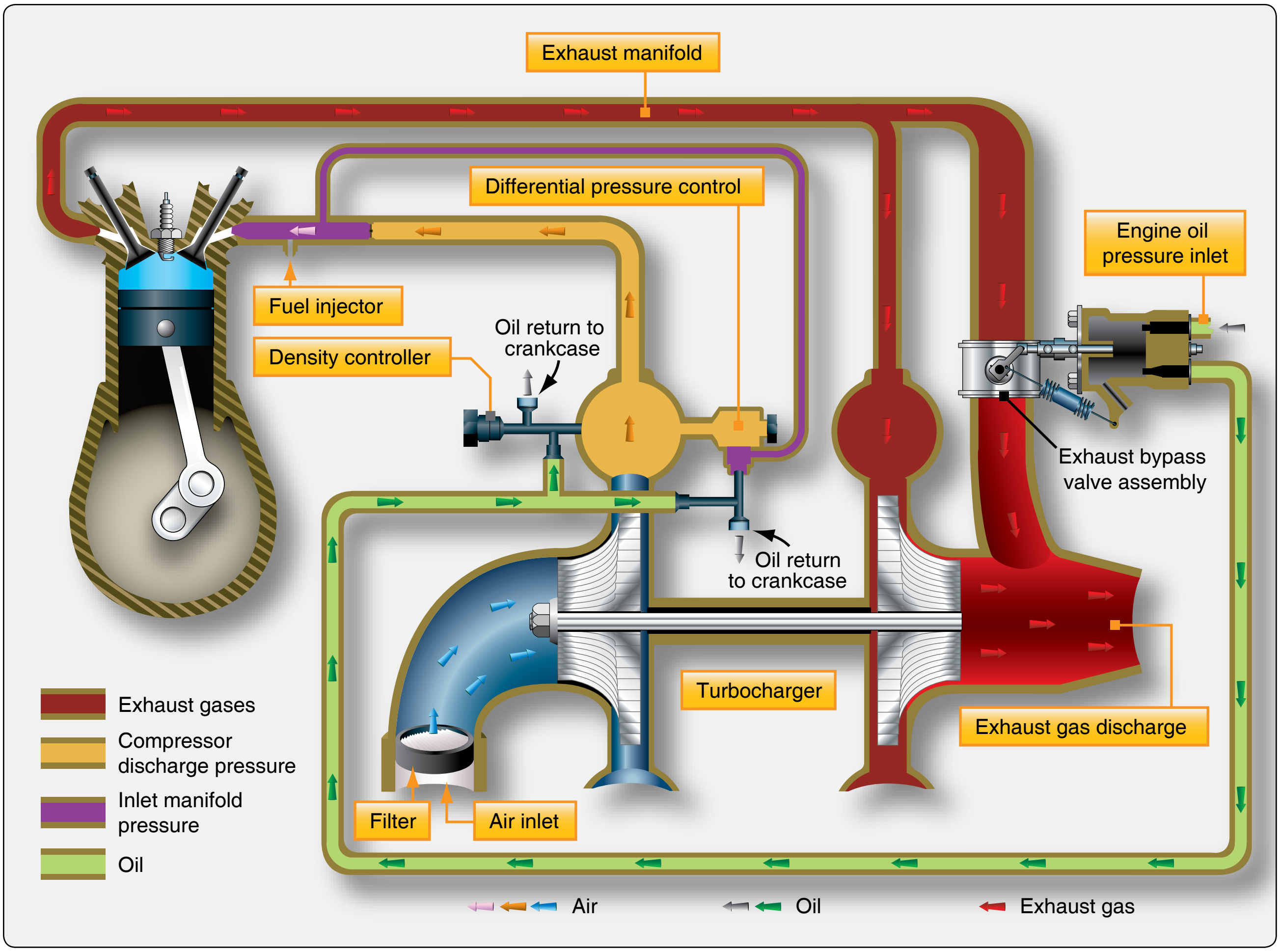

Figure 3-18. *Sea level booster turbosupercharger system.*

two extremes of waste gate position, constant power output can be achieved below the maximum altitude at which the system is designed to operate. An engine with a critical altitude of 16,000 feet cannot produce 100 percent of its rated manifold pressure above 16,000 feet. Critical altitude means the maximum altitude at which, in standard atmosphere, it is possible to maintain, at a specified rotational speed, a specified power or a specified manifold pressure.

A critical altitude exists for every possible power setting below the maximum operating ceiling. If the aircraft is flown above this altitude without a corresponding change in the power setting, the waste gate is automatically driven to the fully closed position in an effort to maintain a constant power output. Thus, the waste gate is almost fully open at sea level and continues to move toward the closed position as the aircraft climbs, in order to maintain the preselected manifold pressure setting. When the waste gate is fully closed (leaving only a small clearance to prevent sticking), the manifold pressure begins to drop if the aircraft continues to climb. If a higher power setting cannot be selected, the turbocharger's critical altitude has been reached. Beyond this altitude, the power output continues to decrease. If a turbocharger waste gate will not close fully, then the aircraft will not be able to reach its critical altitude.

The position of the waste gate valve, which determines power output, is controlled by oil pressure. Engine oil pressure acts on a piston in the waste gate assembly, which is connected by linkage to the waste gate valve. When oil pressure is increased on the piston, the waste gate valve moves toward the closed position, and engine output power increases. Conversely, when the oil pressure is decreased, the waste gate valve moves toward the open position, and output power is decreased as described earlier.

The position of the piston attached to the waste gate valve is dependent on bleed oil, which controls the engine oil pressure applied to the top of the piston. Oil is returned to the engine crankcase through two control devices, the density controller and the differential pressure controller. These two controllers, acting independently, determine how much oil is bled back to the crankcase and establishes the oil pressure on the piston.

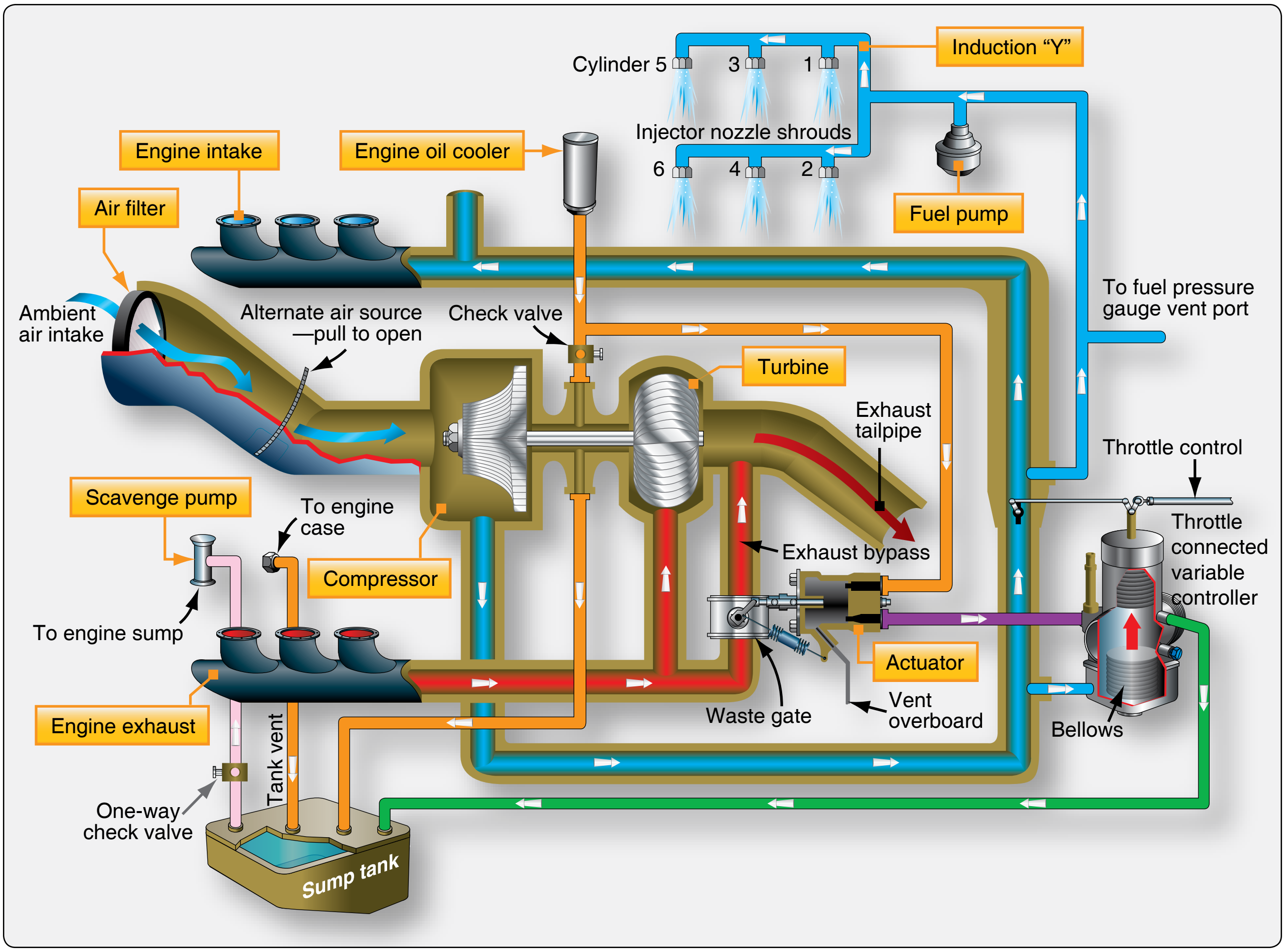

Figure 3-19. *Components of a turbocharger system engine.*

The density controller is designed to limit the manifold pressure below the turbocharger's critical altitude and regulates bleed oil only at the full throttle position. The pressure- and temperature-sensing bellows of the density controller react to pressure and temperature changes between the fuel injector inlet and the turbocharger compressor. The bellows, filled with dry nitrogen, maintain a constant density by allowing the pressure to increase as the temperature increases. Movement of the bellows repositions the bleed valve, causing a change in the quantity of bleed oil, which changes the oil pressure on top of the waste gate piston. *[Figure 3-18]*

The differential pressure controller functions during all positions of the waste gate valve other than the fully open position, which is controlled by the density controller. One side of the diaphragm in the differential pressure controller senses air pressure upstream from the throttle; the other side samples pressure on the cylinder side of the throttle valve. *[Figure 3-18]* At the "wide open" throttle position when the density controller controls the waste gate, the pressure across the differential pressure controller diaphragm is at a minimum and the controller spring holds the bleed valve closed. At "part throttle" position, the air differential is increased, opening the bleed valve to bleed oil to the engine crankcase and reposition the waste gate piston. Thus, the two controllers operate independently to control turbocharger operation at all positions of the throttle. Without the overriding function of the differential pressure controller during part-throttle operation, the density controller would position the waste gate valve for maximum power. The differential pressure controller reduces injector entrance pressure and continually repositions the valve over the whole operating range of the engine.

The differential pressure controller reduces the unstable condition known as "bootstrapping" during part-throttle operation. Bootstrapping is an indication of unregulated power change that results in the continual drift of manifold pressure. This condition can be illustrated by considering the operation of a system when the waste gate is fully closed. During this time, the differential pressure controller is not modulating the waste gate valve position. Any slight change in power caused by a change in temperature or rpm fluctuation is magnified and results in manifold pressure change since the slight change causes a change in the amount of exhaust gas flowing to the turbine. Any change in exhaust gas flow to the turbine causes a change in power output and is reflected in manifold pressure indications. Bootstrapping, then, is an undesirable cycle of turbocharging events causing the manifold pressure to drift in an attempt to reach a state of equilibrium.

Bootstrapping is sometimes confused with the condition known as overboost, but bootstrapping is not a condition that is detrimental to engine life. An overboost condition is one in which manifold pressure exceeds the limits prescribed for a particular engine and can cause serious damage. A pressure relief valve when used in some systems, set slightly in excess of maximum deck pressure, is provided to prevent damaging over boost in the event of a system malfunction.

The differential pressure controller is essential to smooth functioning of the automatically controlled turbocharger, since it reduces bootstrapping by reducing the time required to bring a system into equilibrium. There is still extra throttle sensitivity with a turbocharged engine than with a naturally aspirated engine. Rapid movement of the throttle can cause a certain amount of manifold pressure drift in a turbocharged engine. Less severe than bootstrapping, this condition is called overshoot. While overshoot is not a dangerous condition, it can be a source of concern to the pilot or operator who selects a particular manifold pressure setting only to find it has changed in a few seconds and must be reset. Since the automatic controls cannot respond rapidly enough to abrupt changes in throttle settings to eliminate the inertia of turbocharger speed changes, overshoot must be controlled by the operator. This can best be accomplished by slowly making changes in throttle setting, accompanied by a few seconds' wait for the system to reach a new equilibrium. Such a procedure is effective with turbocharged engines, regardless of the degree of throttle sensitivity.

Turbocharger Controllers & System Descriptions

Turbocharger system engines contain many of the same components mentioned with the previous systems. *[Figure 3-19]* Some systems use special lines and fittings that are connected to the upper-deck pressure for air reference to the fuel injection system and in some cases for pressurizing the magnetos. Basic system operation is similar to other turbocharger systems with the main differences being in the controllers. The controller monitors deck pressure by sensing the output of the compressor. The controller controls the oil flow through the waste gate actuator, which opens or closes the exhaust bypass valve. If a malfunction occurs causing the waste gate or controller to not be stable, it will cause the engine to surge due to an erratic manifold pressure. When deck pressure is insufficient, the controller restricts oil flow thereby increasing oil pressure at the waste gate actuator. This pressure acts on the piston to close off the waste gate valve,

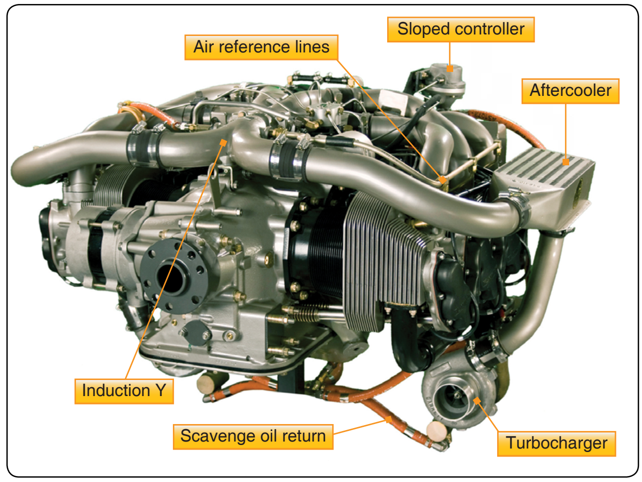

Figure 3-20. *An aftercooler installation.*

forcing more exhaust gas pulses to turn the turbine faster and cause an increase in compressor output. When deck pressure is too great, the opposite occurs. The exhaust waste gate fully opens and bypasses some of the exhaust gases to decrease exhaust flow across the turbine. An aftercooler is installed in the induction air path between the compressor stage and the air throttle inlet. *[Figure 3-20]*

Most turbochargers are capable of compressing the induction air to the point at which it can raise the air temperature by a factor of five. This means that full power takeoff on a 100 °F day could produce induction air temperatures exiting the compressor at up to 500 °F. This would exceed the allowable throttle air inlet temperature on all reciprocating engine models. Typically, the maximum air throttle inlet temperature ranges from a low 230 °F to a high of 300 °F. Exceeding these maximums can place the combustion chambers closer to detonation. The function of the aftercooler is to cool the compressed air, which decreases the likelihood of detonation and increases the charge air density, which improves the turbocharger performance for that engine design. On engine start, the controller senses insufficient compressor discharge pressure (deck pressure) and restricts the flow of oil from the waste gate actuator to the engine. This causes the waste gate butterfly valve to close. As the throttle is advanced, exhaust gas flows across the turbine increases, thereby increasing turbine/compressor shaft speed and compressor discharge pressure. The controller senses the difference between upper deck and manifold pressure. If either deck pressure or throttle differential pressure rises, the controller poppet valve opens, relieving oil pressure to the waste gate actuator. This decreases turbocharger compressor discharge pressure (deck pressure).

Variable Absolute Pressure Controller (VAPC)

The VAPC contains an oil control valve similar to the other

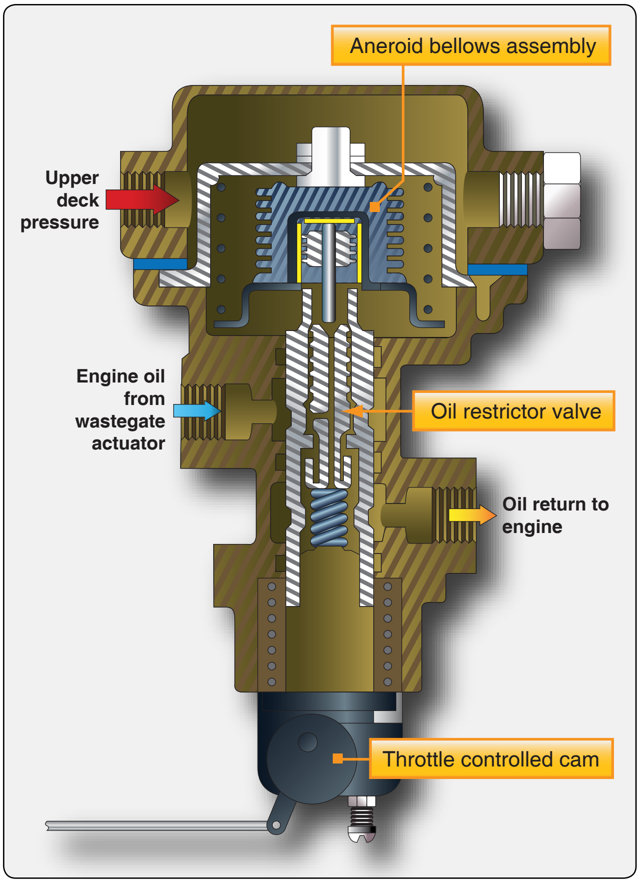

Figure 3-21. *A diagram of a variable absolute pressure controller (VAPC).*

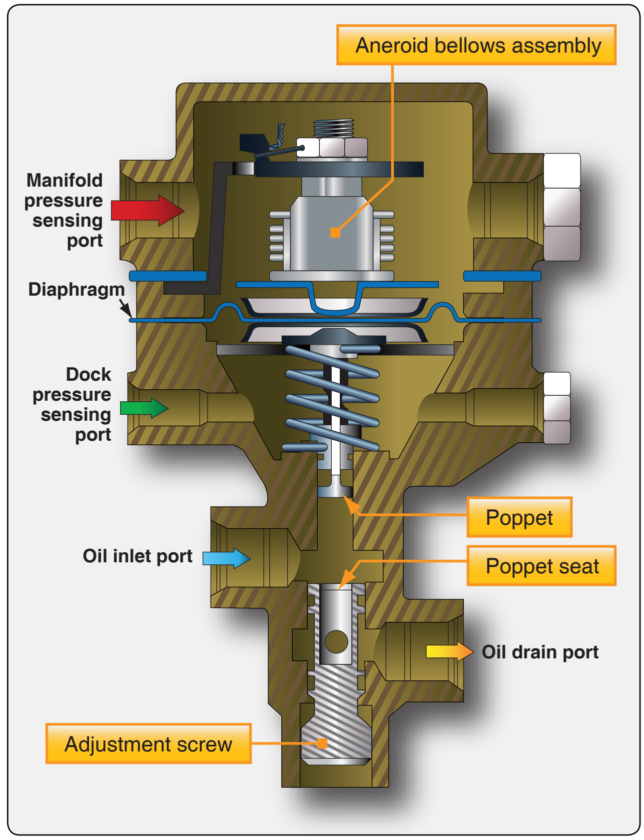

Figure 3-22. *A diagram of a sloped controller used to maintain the rated compressor discharge pressure at wide-open throttle.*

controllers that were discussed. *[Figure 3-21]* The oil restrictor is actuated by an aneroid bellows that is referenced to upper deck pressure. A cam connected to the throttle mechanism applies pressure to the restrictor valve and aneroid. As the throttle is opened to greater values, the cam applies a greater pressure to the aneroid. This increases the amount of upper deck pressure necessary to compress the aneroid and thereby open the oil restrictor valve. This means that the scheduled absolute value of upper deck pressure that is required to overcome the aneroid is variable by throttle position. As the throttle is opened wide, the manifold pressure and upper deck pressure requirements greatly increase.

Sloped Controller

The sloped controller is designed to maintain the rated compressor discharge pressure at wide-open throttle and to reduce this pressure at part throttle settings. *[Figure 3-22]* A diaphragm, coupled with a spring-supported bellows for absolute pressure reference, is exposed to deck pressure and intake manifold pressure through ports located before and after the throttle, respectively. This arrangement constantly monitors deck pressure and the pressure differential between the deck and manifold pressure due to a partially closed throttle. If either deck pressure or throttle differential pressure rises, the controller poppet opens and decreases turbocharger discharge (deck) pressure. The sloped controller is more sensitive to the throttle differential pressure than to deck pressure, thereby accomplishing deck pressure reduction as the throttle is closed.

Absolute Pressure Controller

One device used to control the speed and output of the turbocharger, but controls the system only at maximum output, is the absolute pressure controller. The absolute pressure controller contains an aneroid bellows that is referenced to upper deck pressure. It operates the waste gate, which diverts, more or less, exhaust gas over the turbine. As an absolute pressure setting is reached, it bypasses oil, and relieves the pressure on the waste gate actuator. This allows the absolute pressure controller to control the maximum turbocharger compressor discharge pressure. The turbocharger is completely automatic, requiring no pilot action up to the critical altitude.

Turbocharger System Troubleshooting

Figure 3-23 includes some of the most common turbocharger system malfunctions together with their cause and repair. These troubleshooting procedures are presented as a guide only and should not be substituted for applicable

Trouble	Probable Cause	Remedy
Aircraft fails to reach critical altitude	Damaged compressor or turbine wheel	Replace turbocharger
	Exhaust system leaks	Repair leaks
	Faulty turbocharger bearings	Replace turbocharge
	Wastegate will not close fully	Refer to wastegate in the trouble column
	Malfunctioning controller	Refer to differential controller in the trouble column
Engine surges	Bootstrapping	Ensure engine is operated in proper range
	Wastegate malfunction	Refer to wastegate in the trouble column
	Controller malfunction	Refer to differential controller in the trouble column
Wastegate will not close fully	Wastegate bypass valve bearing tight	Replace bypass valve
	Oil inlet orifice blocked	Clean orifice
	Differential controller malfunction	Refer to controller in the trouble column
	Broken wastegate linkage	Replace linkage and adjust waste gate for proper opening and closing
Wastegate will not open	Oil outlet obstructed	Clean and reconnect oil return line
	Broken wastegate linkage	Replace linkage and adjust waste gate opening and closing
	Controller malfunction	Refer to controller in the trouble column
Differential controller malfunctions	Seals leaking	Replace controller
	Diaphragm broken	Replace controller
	Controller valve stuck	Replace controller
Density controller malfunctions	Seals leaking	Replace controller
	Bellows damaged	Replace controller
	Valve stuck	Replace controller

Figure 3-23. *Common issues when troubleshooting turbocharger systems.*

manufacturer's instructions or troubleshooting procedures.

Turbine Engine Inlet Systems

The engine inlet of a turbine engine is designed to provide a relatively distortion-free flow of air, in the required quantity, to the inlet of the compressor. *[Figure 3-24]* Many engines use inlet guide vanes (IGV) to help straighten the airflow and direct it into the first stages of the compressor. A uniform and steady airflow is necessary to avoid compressor stall (airflow tends to stop or reverse direction of flow) and excessive internal engine temperatures in the turbine section. Normally, the air-inlet duct is considered an airframe part and not a part of the engine. However, the duct is very important to the engine's overall performance and the engine's ability to produce an optimum amount of thrust.

A gas turbine engine consumes considerable more airflow than a reciprocating engine. The air entrance passage is correspondingly larger. Furthermore, it is more critical in determining engine and aircraft performance, especially at high airspeeds. Inefficiencies of the inlet duct result in successively magnified losses through other components of the engine. The inlet varies according to the type of turbine engine. Small turboprop and turboshaft engines have a lower airflow than large turbofan engines which require a completely different type of inlet. Many turboprop, auxiliary power units, and turboshaft engines use screens that cover the inlet to prevent foreign object damage (FOD).

Figure 3-24. *An example of a turbine engine inlet.*

As aircraft speed increases, thrust tends to decrease somewhat; as the aircraft speed reaches a certain point, ram recovery compensates for the losses caused by the increases in speed. The inlet must be able to recover as much of the total pressure of the free airstream as possible. As air molecules are trapped and begin to be compressed in the inlet, much of the pressure loss is recovered. This added pressure at the inlet of the engine increases the pressure and airflow to the engine. This is known as "ram recovery" or "total pressure recovery." The inlet duct must uniformly deliver air to the compressor inlet with as little turbulence and pressure variation as possible. The engine inlet duct must also hold the drag effect on the aircraft to a minimum.

Air pressure drop in the engine inlet is caused by the friction of the air along both sides of the duct and by the bends in the duct system. Smooth flow depends upon keeping the amount of turbulence to a minimum as the air enters the duct. On engines with low flow rates, turning the airflow allows the engine nacelle to be smaller and have less drag. On turbofan engines, the duct must have a sufficiently straight section to ensure smooth, even airflow because of the high airflows. The choice of configuration of the entrance to the duct is dictated by the location of the engine within the aircraft and the airspeed, altitude, and attitude at which the aircraft is designed to operate. To accomplish this, inlet ducts are designed to function as diffusers with a divergent shape, decreasing the velocity and increasing the static pressure of the air passing through them.

Divided-Entrance Duct

The requirements of high-speed, single- or twin-engine military aircraft, in which the pilot sits low in the fuselage and close to the nose, render it difficult to employ the older type single-entrance duct, which is not used on modern aircraft. Some form of a divided duct, which takes air from either side of the fuselage, has become fairly widely used. This divided duct can be either a wing-root inlet or a scoop at each side of the fuselage. *[Figure 3-25]* Either type of duct presents more problems to the aircraft designer than a single-entrance duct because of the difficulty of obtaining sufficient airscoop area without imposing prohibitive amounts of drag. Internally, the problem is the same as that encountered with the single-entrance duct: to construct a duct of reasonable length with as few bends as possible. Scoops at the sides of the fuselage are often used. These side scoops are placed as far forward as possible to permit a gradual bend toward the compressor inlet, making the airflow characteristics approach those of a single-entrance duct. A series of turning vanes is sometimes placed in the side-scoop inlet to assist in straightening the incoming airflow and to prevent turbulence.

Figure 3-25. *An example of a divided-entrance duct.*

Variable-Geometry Duct

The main function of an inlet duct is to furnish the proper amount of air to the engine inlet. In a typical military aircraft using a turbojet or low bypass turbofan engine, the maximum airflow requirements are such that the Mach number of the airflow directly ahead of the face of the engine is less than Mach 1. Airflow through the engine must be less than Mach 1 at all times. Therefore, under all flight conditions, the velocity of the airflow as it enters the air-inlet duct must be reduced through the duct before the airflow is ready to enter the compressor. To accomplish this, inlet ducts are designed to function as diffusers, decreasing the velocity and increasing the static pressure of the air passing through them. *[Figure 3-26]*

As with military supersonic aircraft, a diffuser progressively decreases in area in the downstream direction. Therefore, a supersonic inlet duct follows this general configuration until the velocity of the incoming air is reduced to Mach 1. The

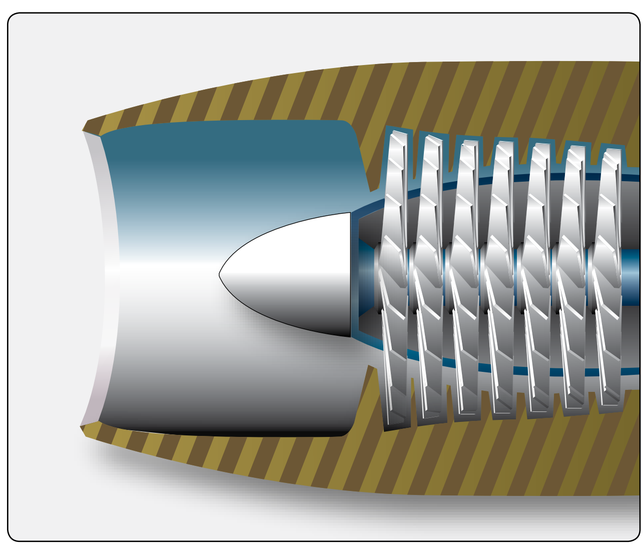

Figure 3-26. *An inlet duct acts as a diffuser to decrease the airflow velocity and to increase the static pressure of air.*

aft section of the duct then increases in area, since this part must act as a subsonic diffuser. *[Figure 3-27]* In practice, inlet ducts for supersonic aircraft follows this general design only as much as practical, depending upon the design features of the aircraft. For very high speed aircraft, the inside area of configuration of the duct is changed by a mechanical device as the speed of the aircraft increases or decreases. A duct of this type is usually known as a variable-geometry inlet duct. Military aircraft use the three methods described above to diffuse the inlet air and slow the inlet airflow at supersonic flight speeds. One is to vary the area, or geometry, of the inlet duct either by using a movable restriction, such as a ramp or wedge, inside the duct. Another system is some sort of a variable airflow bypass arrangement, which extracts part of the inlet airflow from the duct ahead of the engine. In some cases, a combination of both systems is used.

The third method is the use of a shock wave in the airstream. A shock wave is a thin region of discontinuity in a flow of air or gas, during which the speed, pressure, density, and temperature of the air or gas undergo a sudden change. Stronger shock waves produce larger changes in the properties of the air or gas. A shock wave is willfully set up in the supersonic flow of the air entering the duct, by means of some restriction or small obstruction which automatically protrudes into the duct at high flight Mach numbers. The shock wave results in diffusion of the airflow, which, in turn, decreases the velocity of the airflow. In at least one aircraft installation, both the shock method and the variable-geometry method of causing diffusion are used in combination. The same device that changes the area of the duct also sets up a shock wave that further reduces the speed of the incoming air within the duct. The amount of change in duct area and the magnitude of the shock are varied automatically with the airspeed of the aircraft.

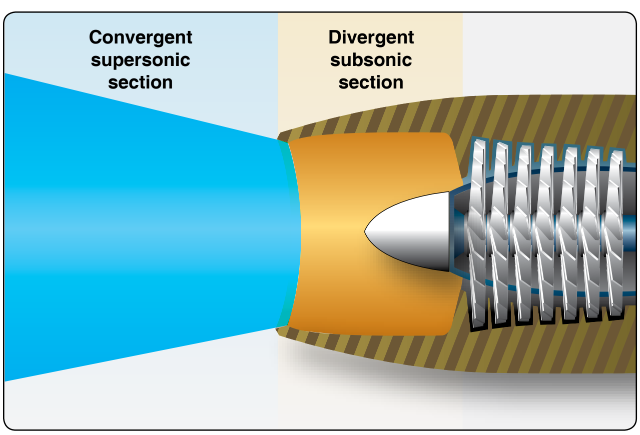

Figure 3-27. *The aft section of an inlet duct acting as a subsonic diffuser.*

Compressor Inlet Screens

To prevent the engine from readily ingesting any items that can be drawn in the intake, a compressor inlet screen is sometimes placed across the engine air inlet at some location along the inlet duct. Engines that incorporate inlet screens, such as turboprops *[Figure 3-28]* and APUs *[Figure 3-29]* are not as vulnerable to FOD. The advantages and disadvantages of a screen vary. If the engine is readily subjected to internal damage, as would be the case for an engine having an axial compressor fitted with aluminum compressor blades, an inlet screen is almost a necessity. Screens, however, add appreciably to inlet duct pressure loss and are very susceptible to icing. Failure due to fatigue is also a problem. A failed screen can sometimes cause more damage than no screen at all. In some instances, inlet screens are made retractable and may be withdrawn from the airstream after takeoff or whenever icing conditions prevail. Such screens are subject to mechanical failure and add both weight and bulk to the installation. In large turbofan engines having steel or titanium compressor (fan) blades, which do not damage

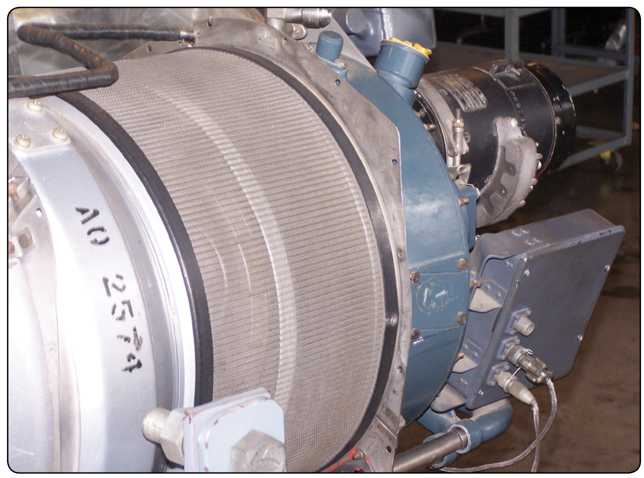

Figure 3-28. *An example of a turboprop engine that incorporates inlet screens.*

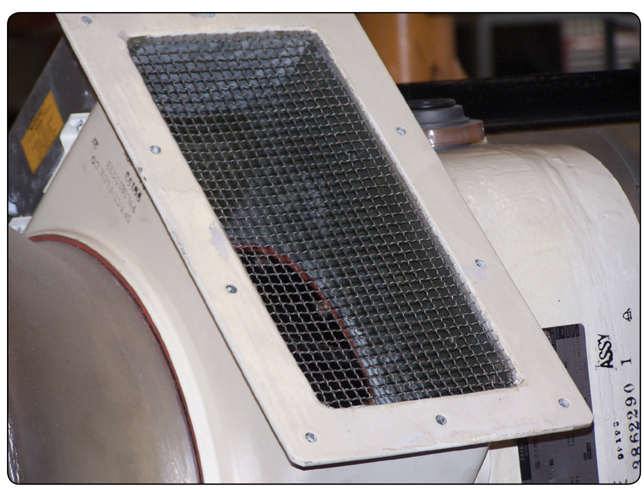

Figure 3-29. *An example of an inlet screen on an APU.*

easily, the disadvantages of compressor screens outweigh the advantages, so they are not generally used.

Bellmouth Compressor Inlets

A bellmouth inlet is usually installed on an engine undergoing testing in a test cell. For this reason, the bellmouth inlet duct is most often used on helicopter airframes. *[Figure 3-30]* It is generally equipped with probes that, with the use of instruments, can measure intake temperature and pressure (total and static). *[Figure 3-31]* During testing, it is important that the outside static air is allowed to flow into the engine with as little resistance as possible. The bellmouth is attached to the movable part of the test stand and moves with the engine. The thrust stand is made up of two components, one nonmoving and one moving. This is so the moving component can push against a load cell and measure thrust during the testing of the engine. The bellmouth is designed with the single objective of obtaining very high aerodynamic efficiency. Essentially, the inlet is a bell-shaped funnel having carefully rounded shoulders which offer practically no air resistance. *[Figure 3-30]* Duct loss is so slight that it is considered zero. The engine can, therefore, be operated without the complications resulting from losses common to an installed aircraft inlet duct. Engine performance data, such as rated thrust and thrust specific fuel consumption, are obtained while using a bellmouth inlet. Usually, the inlets are fitted with protective screening. In this case, the efficiency lost as the air passes through the screen must be taken into account when very accurate engine data are necessary.

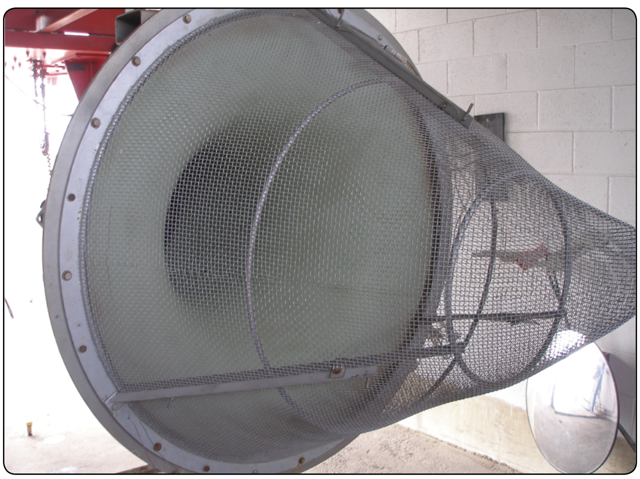

Figure 3-30. *A bellmouth inlet used during system tests.*

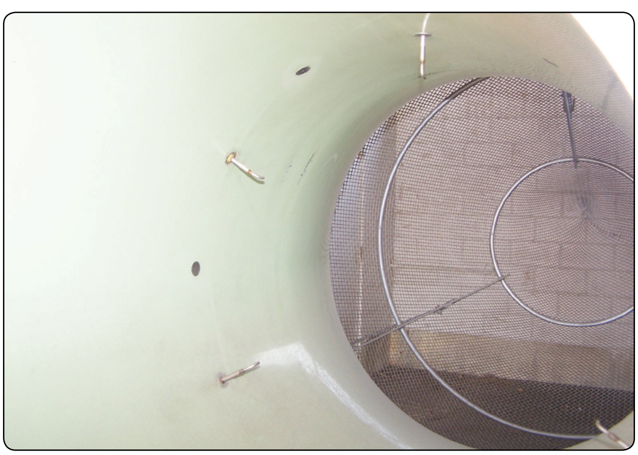

Figure 3-31. *Probes within a bellmouth inlet used to measure intake temperature and pressure.*

Turboprop & Turboshaft Compressor Inlets

The air inlet on a turboprop is more of a problem than some other gas turbine engines because the propeller drive shaft, the hub, and the spinner must be considered in addition to other inlet design factors. The ducted arrangement is generally considered the best inlet design of the turboprop engine as far as airflow and aerodynamic characteristics are concerned. *[Figure 3-32]* The inlet for many types of turboprops are anti-iced by using electrical elements in the lip opening of the intake. Ducting either part of the engine or nacelle directs the airflow to the intake of the engine. Deflector doors are sometimes used to deflect ice or dirt away from the intake. *[Figure 3-33]* The air then passes through a screen and into the engine on some models. A conical spinner, which does not allow ice to build up on the surface, is sometimes used with turboprop and turbofan engines. In either event, the arrangement of the spinner and the inlet duct plays an important function in the operation and performance of the engine.

Turbofan Engine Inlet Sections

High-bypass turbofan engines are usually constructed with the fan at the forward end of the compressor. A typical turbofan intake section is shown in *Figure 3-34.* Sometimes, the inlet cowl is bolted to the front of the engine and provides the airflow path into the engine. In dual compressor (dual spool) engines, the fan is integral with the relatively slow-turning, low-pressure compressor, which allows the fan

Figure 3-32. *An example of a ducted arrangement on a turboprop engine.*

Figure 3-33. *Deflector doors used to deflect ice or dirt away from the intake.*

Figure 3-34. *A typical turbofan intake section.*

blades to rotate at low tip speed for best fan efficiency. The fan permits the use of a conventional air inlet duct, resulting in low inlet duct loss. The fan reduces engine damage from ingested foreign material because much of any material that may be ingested is thrown radially outward and passes through the fan discharge rather than through the core of the engine. Warm bleed air is drawn from the engine and circulated on the inside of the inlet lip for anti-icing. The fan hub or spinner is either heated by warm air or is conical as mentioned earlier. Inside the inlet by the fan blade tips is an abraidable rub strip that allows the fan blades to rub for short times due to flightpath changes. *[Figure 3-35]* Also, inside the inlet are sound-reducing materials to lower the noise generated by the fan.

The fan on high-bypass engines consists of one stage of rotating blades and stationary vanes that can range in diameter from less than 84 inches to more than 112 inches. *[Figure 3-36]* The fan blades are either hollow titanium or composite materials. The air accelerated by the outer part of

Figure 3-35. *Rubber stripping inside a turbofan engine inlet allows for friction for short periods of time during changes in the flightpath.*

the fan blades forms a secondary airstream, which is ducted overboard without passing through the main engine. This secondary air (fan flow) produces 80 percent of the thrust in high-bypass engines. The air that passes through the inner part of the fan blades becomes the primary airstream (core flow) through the engine itself. *[Figure 3-36]*

The air from the fan exhaust, which is ducted overboard, may be discharged in either of two ways:

1. To the outside air through short ducts (dual exhaust nozzles) directly behind the fan. *[Figure 3-37]*

2. Ducted fan, which uses closed ducts all the way to the rear of the engine, where it is exhausted to the outside air through a mixed exhaust nozzle. This type engine is called a ducted fan and the core airflow and fan airflow mix in a common exhaust nozzle.

Figure 3-36. *The air that passes through the inner part of the fan blades becomes the primary airstream.*

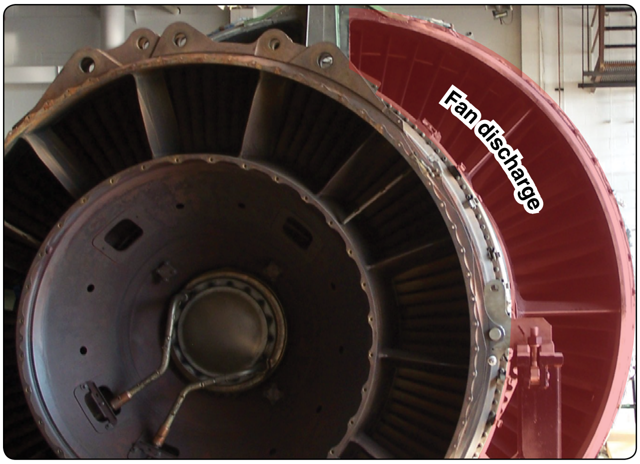

Figure 3-37. *Air from the fan exhaust can be discharged overboard through short ducts directly behind the fan.*

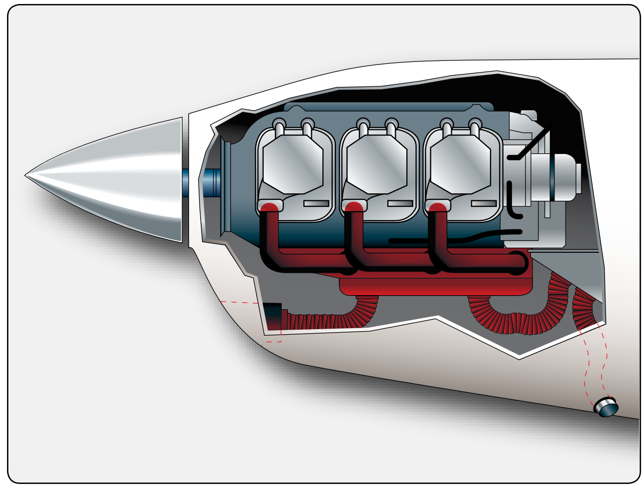

Figure 3-38. *Location of a typical collector exhaust system.*

Reciprocating Engine Exhaust Systems

The reciprocating engine exhaust system is fundamentally a scavenging system that collects and disposes of the high temperature, noxious gases being discharged by the engine. Its main function is to dispose of the gases with complete safety to the airframe and the occupants of the aircraft. The exhaust system can perform many useful functions, but its first duty is to provide protection against the potentially destructive action of the exhaust gases. Modern exhaust systems, though comparatively light, adequately resist high temperatures, corrosion, and vibration to provide long, trouble-free operation with minimum maintenance.

There are two general types of exhaust systems in use on reciprocating aircraft engines: the short stack (open) system and the collector system. The short stack system is generally used on nonsupercharged engines and low-powered engines where noise level is not too objectionable. The collector system is used on most large nonsupercharged engines and on all turbosupercharged engines and installations on which it would improve nacelle streamlining or provide easier maintenance in the nacelle area. On turbosupercharged engines, the exhaust gases must be collected to drive the turbine compressor of the supercharger. Such systems have individual exhaust headers that empty into a common collector ring with only one outlet. From this outlet, the hot exhaust gas is routed via a tailpipe to the turbosupercharger that drives the turbine. Although the collector system raises the back pressure of the exhaust system, the gain in horsepower from turbosupercharging more than offsets the loss in horsepower that results from increased back pressure. The short stack system is relatively simple, and its removal and installation consists essentially of removing and installing the hold-down nuts and clamps. Short stack systems have limited use on most modern aircraft.

In *Figure 3-38,* the location of typical collector exhaust system components of a horizontally opposed engine is shown in a side view. The exhaust system in this installation consists of a down-stack from each cylinder, an exhaust collector tube on each side of the engine, and an exhaust ejector assembly protruding aft and down from each side of the firewall. The down-stacks are connected to the cylinders with high temperature locknuts and secured to the exhaust collector tube by ring clamps. A cabin heater exhaust shroud is installed around each collector tube. *[Figure 3-39]*

The collector tubes terminate at the exhaust ejector openings at the firewall and are tapered to deliver the exhaust gases at the proper velocity to induce airflow through the exhaust

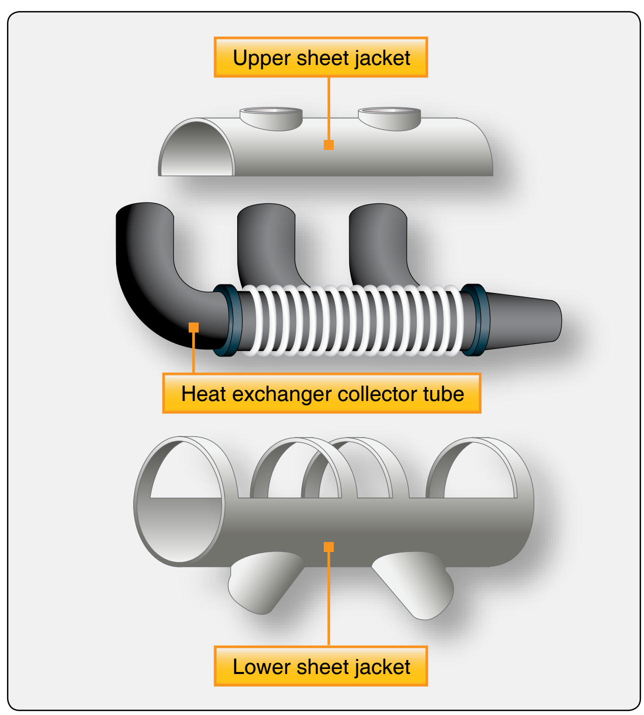

Figure 3-39. *A cabin heater exhaust shroud.*

ejectors. The exhaust ejectors consist of a throat-and-duct assembly that utilizes the pumping action of the exhaust gases to induce a flow of cooling air through all parts of the engine compartment (augmenter tube action).

Radial Engine Exhaust Collector Ring System

Figure 3-40 shows the exhaust collector ring installed on a 14-cylinder radial engine. The collector ring is a welded corrosion-resistant steel assembly manufactured in seven sections, with each section collecting the exhaust from two cylinders. The sections are graduated in size. *[Figure 3-41]* The small sections are on the inboard side, and the largest sections are on the outboard side at the point where the tailpipe connects to the collector ring. Each section of the collector ring is bolted to a bracket on the blower section of the engine and is partly supported by a sleeve connection between the collector ring ports and the short stack on the engine exhaust ports. The exhaust tailpipe is joined to the collector ring by a telescoping expansion joint, which allows enough slack for the removal of segments of the collector ring without removing the tailpipe. The exhaust tailpipe is a welded, corrosion-resistant steel assembly consisting of the exhaust tailpipe and, on some aircraft, a muff-type heat exchanger.

Manifold & Augmentor Exhaust Assembly

Some radial engines are equipped with a combination exhaust manifold and augmentor assembly. On a typical 18-cylinder engine, two exhaust assemblies and two augmentor assemblies are used. Each manifold assembly collects exhaust gases from nine cylinders and discharges the gases into the forward end of the augmentor assembly. The exhaust gases are directed into the augmentor bellmouths. The augmentors are designed to produce a venturi effect to draw an increased airflow over the engine to augment engine

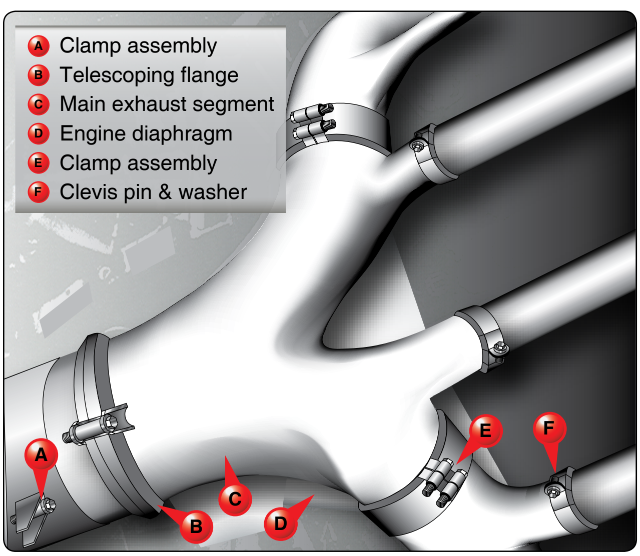

Figure 3-40. *Elements of an exhaust collector ring installed on a radial engine.*

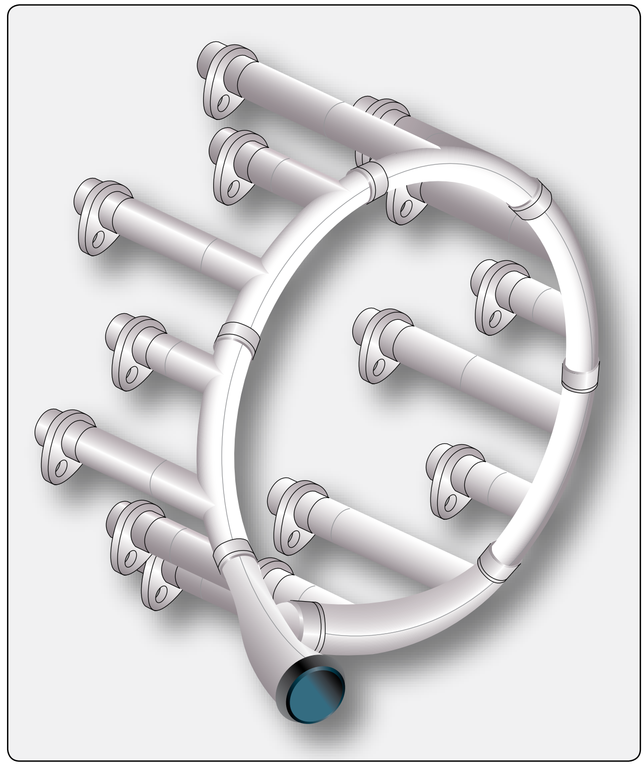

Figure 3-41. *A radial engine exhaust collector ring is graduated in size from the inboard side to the outboard side.*

cooling. An augmentor vane is located in each tailpipe. When the vane is fully closed, the cross-sectional area of the tailpipe is reduced by approximately 45 percent. The augmentor vanes are operated by an electrical actuator, and indicators adjacent to the augmentor vane switches in the flight deck show vane positions. The vanes may be moved toward the "closed" position to decrease the velocity of flow through the augmentor to raise the engine temperature. This system is only used with older aircraft that generally use radial engines.

Reciprocating Engine Exhaust System Maintenance Practices

Any exhaust system failure should be regarded as a severe hazard. Depending on the location and type of failure, an exhaust system failure can result in carbon monoxide poisoning of crew and passengers, partial or complete loss of engine power, or an aircraft fire. Cracks in components, leaking gaskets, or complete failure can cause serious problems in flight. Often, these failures can be detected before complete failure. Black soot around an exhaust gasket shows the gasket has failed. The exhaust system should be inspected very thoroughly.

Exhaust System Inspection

While the type and location of exhaust system components vary somewhat with the type of aircraft, the inspection requirements for most reciprocating engine exhaust systems are very similar. The following paragraphs include a discussion of the most common exhaust system inspection items and procedures for all reciprocating engines. *Figure 3-42* shows the primary inspection areas of three types of exhaust systems.

When performing maintenance on exhaust systems, never use galvanized or zinc-plated tools on the exhaust system. Exhaust system parts should never be marked with a lead pencil. The lead, zinc, or galvanized mark is absorbed by the metal of the exhaust system when heated, creating a distinct change in its molecular structure. This change softens the metal in the area of the mark, causing cracks and eventual failure.

After the installation of a complete exhaust system and all pieces of engine cowl are installed and secured, the engine should be operated to allow the exhaust system to heat up to normal operating temperatures. The engine is then shut down and the cowling removed to expose the exhaust system. Each clamped connection and each exhaust port connection should be inspected for evidence of exhaust gas leakage.

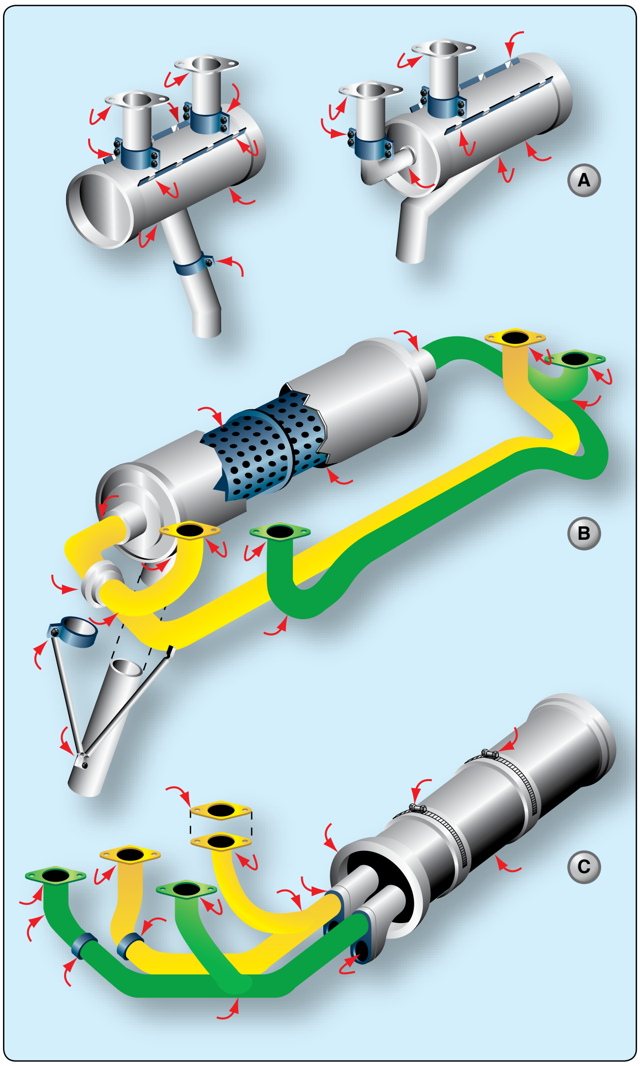

Figure 3-42. *Primary inspection areas of three types of exhaust systems.*

An exhaust leak is indicated by a flat gray or a sooty black streak on the pipes in the area of the leak. An exhaust leak is usually the result of poor alignment of two mated exhaust system members. When a leaking exhaust connection is discovered, the clamps should be loosened, and the leaking units repositioned to ensure a gas-tight fit.

After repositioning, the system nuts should be retightened enough to eliminate any looseness without exceeding the specified torque. If tightening to the specified torque does not eliminate looseness, the bolts and nuts should be replaced since they have probably stretched. After tightening to the specified torque, all nuts should be safetied. With the cowling removed, all necessary cleaning operations can be performed. Some exhaust units are manufactured with a plain sandblast finish. Others may have a ceramic-coated finish. Ceramic-coated stacks should be cleaned by degreasing only. They should never be cleaned with sandblast or alkali cleaners.

During the inspection of an exhaust system, close attention should be given to all external surfaces of the exhaust system for cracks, dents, or missing parts. This also applies to welds, clamps, supports, support attachment lugs, bracing, slip joints, stack flanges, gaskets, and flexible couplings. Each bend should be examined, as well as areas adjacent to welds. Any dented areas or low spots in the system should be inspected for thinning and pitting due to internal erosion by combustion products or accumulated moisture. An ice pick or similar pointed instrument is useful in probing suspected areas.

The system should be disassembled as necessary to inspect internal baffles or diffusers. If a component of the exhaust system is inaccessible for a thorough visual inspection or is hidden by nonremovable parts, it should be removed and checked for possible leaks. This can often be accomplished best by plugging the openings of the component, applying a suitable internal pressure (approximately 2 psi), and submerging it in water. Any leaks cause bubbles that can readily be detected. The procedures required for an installation inspection are also performed during most regular inspections. Daily inspection of the exhaust system usually consists of checking the exposed exhaust system for cracks, scaling, excessive leakage, and loose clamps.

Muffler & Heat Exchanger Failures

Approximately half of all muffler and heat exchanger failures can be traced to cracks or ruptures in the heat exchanger surfaces used for cabin and carburetor heat sources. Failures in the heat exchanger surface (usually in the outer wall) allow exhaust gases to escape directly into the cabin heat system. These failures, in most cases, are caused by thermal and vibration fatigue cracking in areas of stress concentration. Failure of the spot-welds, which attach the heat transfer pins, can result in exhaust gas leakage. In addition to a carbon monoxide hazard, failure of heat exchanger surfaces can permit exhaust gases to be drawn into the engine induction system, causing engine overheating and power loss.

Exhaust Manifold & Stack Failures

Exhaust manifold and stack failures are usually fatigue failures at welded or clamped points (e.g., stack-to-flange, stack-to-manifold, and crossover pipe or muffler connections). Although these failures are primarily fire hazards, they also present carbon monoxide problems. Exhaust gases can enter the cabin via defective or inadequate seals at firewall openings, wing strut fittings, doors, and wing root openings.

Internal Muffler Failures

Internal failures (baffles, diffusers, etc.) can cause partial or complete engine power loss by restricting the flow of the exhaust gases. If pieces of the internal baffling breaks loose and partially or totally blocks the flow of exhaust gases, engine failure can occur. *[Figure 3-43]* As opposed to other failures, erosion and carburization caused by the extreme thermal conditions are the primary causes of internal failures. Engine backfiring and combustion of unburned fuel within the exhaust system are probable contributing factors. In addition, local hot-spot areas caused by uneven exhaust gas flow can result in burning, bulging, or rupture of the outer muffler wall.

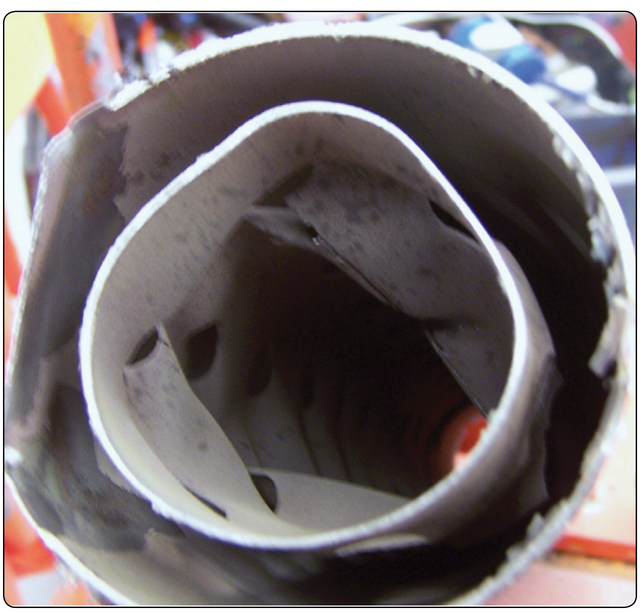

Figure 3-43. *An example of internal muffler failure. Muffler failure can be caused by erosion and carbonization, which in turn can lead to breakage blocking exhaust flow.*

Exhaust Systems with Turbocharger

When a turbocharger or a turbosupercharger system is included, the engine exhaust system operates under greatly increased pressure and temperature conditions. Extra precautions should be taken in exhaust system care and maintenance. During high-pressure altitude operation, the exhaust system pressure is maintained at or near sea level values. Due to the pressure differential, any leaks in the system allow the exhaust gases to escape with torch-like intensity that can severely damage adjacent structures. A common cause of malfunction is coke deposits (carbon buildup) in the waste gate unit causing erratic system operation. Excessive deposit buildups may cause the waste gate valve to stick in the "closed" position, causing an overboost condition. Coke deposit buildup in the turbo itself causes a gradual loss of power in flight and low manifold pressure reading prior to takeoff. Experience has shown that periodic de-coking, or removal of carbon deposits, is necessary to maintain peak efficiency. Clean, repair, overhaul, and adjust the system components and controls in accordance with the applicable manufacturer's instructions.

Augmentor Exhaust System

On exhaust systems equipped with augmentor tubes, the augmentor tubes should be inspected at regular intervals for proper alignment, security of attachment, and general overall condition. Even where augmentor tubes do not contain heat exchanger surfaces, they should be inspected for cracks along with the remainder of the exhaust system. Cracks in augmentor tubes can present a fire or carbon monoxide hazard by allowing exhaust gases to enter the nacelle, wing, or cabin areas.

Exhaust System Repairs

It is generally recommended that exhaust stacks, mufflers, tailpipes, etc., be replaced with new or reconditioned components rather than repaired. Welded repairs to exhaust systems are complicated by the difficulty of accurately identifying the base metal so that the proper repair materials can be selected. Changes in composition and grain structure of the original base metal further complicate the repair. However, when welded repairs are necessary, the original contours should be retained; the exhaust system alignment must not be warped or otherwise affected. Repairs or sloppy weld beads that protrude internally are not acceptable as they cause local hot spots and may restrict exhaust gas flow. The proper hardware and clamps should always be used when repairing or replacing exhaust system components. Steel or low temperature, self-locking nuts should not be substituted for brass or special high temperature locknuts used by the manufacturer. Old gaskets should never be re-used. When disassembly is necessary, gaskets should be replaced with new ones of the same type provided by the manufacturer.

Turbine Engine Exhaust Nozzles

Turbine engines have several different types of exhaust nozzles depending upon the type of engine. Turboshaft engines in helicopters can have an exhaust nozzle that forms a divergent duct. This type of nozzle would not provide any thrust, all engine power going to rotate the rotors, improving helicopter hovering abilities. Turbofan engines tend to fall into either ducted fan of unducted fan engines. Ducted fan engines take the fan airflow and direct it through closed ducts along the engine. Then, it flows into a common exhaust nozzle. The core exhaust flow and the fan flow mix and flow from the engine through this mixed nozzle. The unducted fan has two nozzles, one for the fan airflow and one for the core airflow. These both flow to ambient air separate from each other and have separate nozzles. *[Figure 3-44]*

The unducted engine or the separate nozzle engine handles high amounts of airflow. The fan air which creates most of the thrust (80–85 percent total thrust) must be directed through the fan blades and exit vanes with little turbulence as possible. *[Figure 3-45]* The core airflow needs to be straightened as it comes from the turbine. Through the use of a converging nozzle, the exhaust gases increase in velocity before they are discharged from the exhaust nozzle. Increasing the velocity of the gases increases their momentum and increases the thrust produced (20–15 percent total thrust). Most of the energy of the gases have been absorbed to drive the fan through the low-pressure turbine stages.

Turboprop exhaust nozzles provide small amounts of thrust (10–15 percent) but are mainly used to discharge the exhaust gases from the aircraft. Most of the energy has been transferred to the propeller. On some turboprop aircraft, an exhaust duct is often referred to as a tailpipe, although the duct itself is essentially a simple, stainless steel, conical or cylindrical pipe. The assembly also includes an engine tail cone and the struts inside the duct. The tail cone and the struts add strength to the duct, impart an axial direction to the gas flow, and smooth the gas flow. In a typical installation, the tailpipe assembly is mounted in the nacelle and attached at its forward end to the firewall. The forward section of the tailpipe is funnel shaped and surrounds but does not contact the turbine exhaust section. This arrangement forms an annular gap that serves as an air ejector for the air surrounding the engine hot section. As the high-velocity exhaust gases enter the tailpipe, a low-pressure effect is produced which causes the air around the engine hot section to flow through the annular gap into the tailpipe. The rear section of the tailpipe is secured to the airframe by two support arms, one on each side of the tailpipe. The support arms are attached to the upper surface of the wing in such

Figure 3-45. *Fan air is directed through the fan blades and exit vanes.*

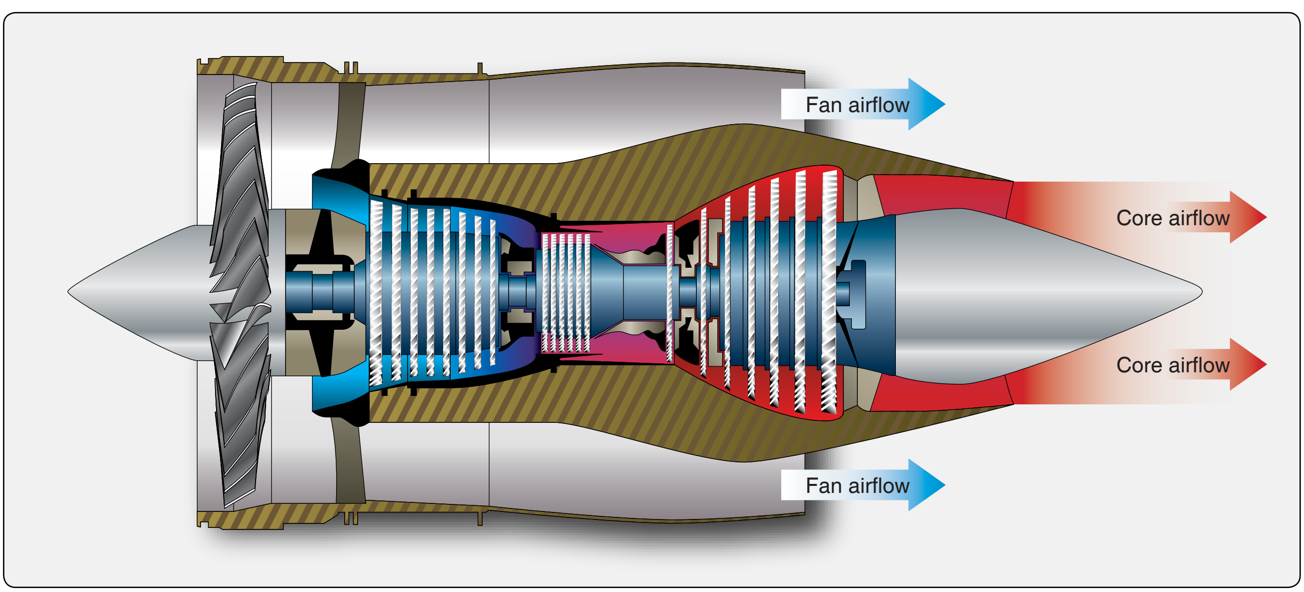

Figure 3-44. *Path of both core exhaust flow and fan flow from the engine to separate nozzles.*

a way that allow movement fore and aft to compensate for expansion. The tailpipe assembly is wrapped in an insulating blanket to shield the surrounding area from the high heat produced by the exhaust gases. Such blankets may be made of a stainless steel laminated sheet on the outside and fiberglass on the inside. This is used when the engine exhaust is located some distance from the edge of the wing or aircraft structure.

Immediately aft of the turbine outlet, and usually just forward of the flange to which the exhaust duct is attached, the engine is instrumented for turbine discharge pressure. One or more pressure probes are inserted into the exhaust duct to provide adequate sampling of the exhaust gases. In large engines, it is not practical to measure the internal temperature at the turbine inlet, so the engine is often also instrumented for exhaust gas temperature at the turbine outlet.

Convergent Exhaust Nozzle

As the exhaust gases exit the rear of the engine, they flow into the exhaust nozzle. *[Figure 3-46]* The very first part of the exhaust nozzle and the exhaust plug form a divergent duct to reduce turbulence in the airflow, then the exhaust gases flow into the convergent component of the exhaust nozzle where the flow is restricted by a smaller outlet opening. Since this forms a convergent duct, the gas velocity is increased providing increased thrust. The restriction of the opening of the outlet of the exhaust nozzle is limited by two factors. If the nozzle opening is too big, thrust is being wasted. If it is too little, the flow is choked in the other components of the engine. In other words, the exhaust nozzle acts as an orifice, the size of which determines the density and velocity of the gases as they emerge from the engine. This is critical to thrust performance. Adjusting the area of the exhaust nozzle changes both the engine performance and the exhaust gas temperature. When the velocity of the exhaust gases at the nozzle opening becomes Mach 1, the flow passes only at this speed—it does not increase or decrease. Sufficient flow to maintain Mach 1 at the nozzle opening and have extra flow (flow that is being restricted by the opening) creates what is called a choked nozzle. The extra flow builds up pressure in the nozzle, which is sometimes called pressure thrust. A differential in pressure exists between the inside of the nozzle and the ambient air. By multiplying this difference in pressure times the area of the nozzle opening, pressure thrust can be calculated. Many engines cannot develop pressure thrust because most of the energy is used to drive turbines that turn propellers, large fans, or helicopter rotors.

Convergent-Divergent Exhaust Nozzle

Whenever the engine pressure ratio is high enough to produce exhaust gas velocities which might exceed Mach 1 at the engine exhaust nozzle, more thrust can be gained by using a convergent-divergent type of nozzle. *[Figure 3-47]* The advantage of a convergent-divergent nozzle is greatest at high Mach numbers because of the resulting higher pressure ratio across the engine exhaust nozzle.

To ensure that a constant weight or volume of a gas flows past any given point after sonic velocity is reached, the rear part of a supersonic exhaust duct is enlarged to accommodate the additional weight or volume of a gas that flows at supersonic rates. If this is not done, the nozzle does not operate efficiently. This is the divergent section of the exhaust duct.

When a divergent duct is used in combination with a conventional exhaust duct, it is called a convergent-divergent exhaust duct. In the convergent-divergent, or C-D nozzle, the convergent section is designed to handle the gases while they remain subsonic, and to deliver the gases to the throat of the nozzle just as they attain sonic velocity. The divergent section

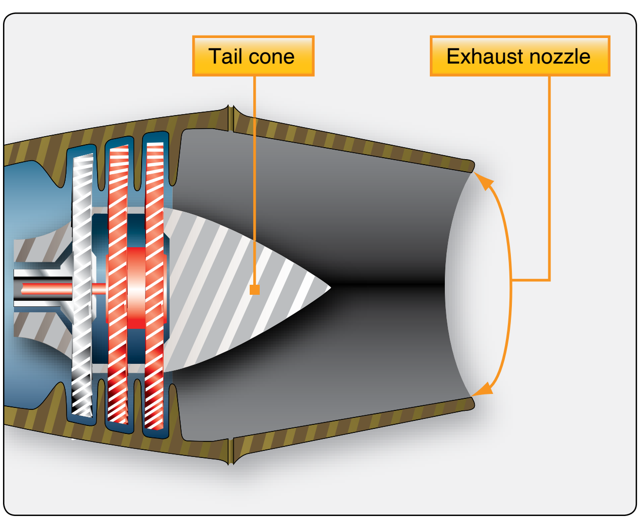

Figure 3-46. *Exhaust gases exit the rear of the engine through the exhaust nozzle.*

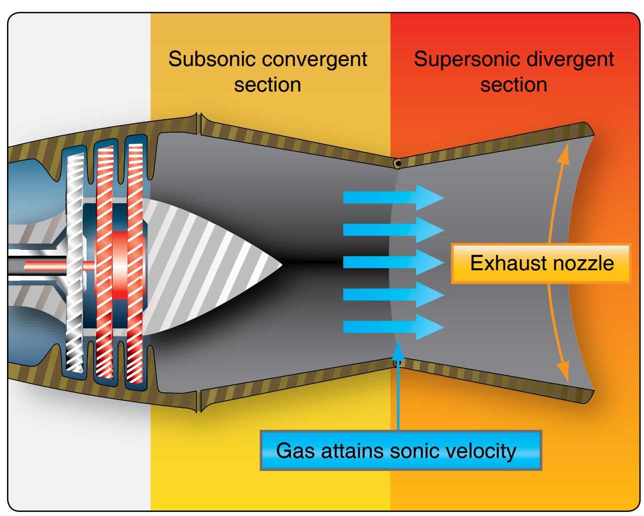

Figure 3-47. *A convergent-divergent nozzle can be used to help produce more thrust when exhaust gas velocities are greater than Mach 1.*

handles the gases, further increasing their velocity, after they emerge from the throat and become supersonic. As the gas flows from the throat of the nozzle, it becomes supersonic (Mach 1 and above) and then passes into the divergent section of the nozzle. Since it is supersonic, it continues to increase in velocity. This type of nozzle is generally used on very high speed aerospace vehicles.

Thrust Reversers

As aircraft have increased in gross weights with higher landing airspeeds, the problem of stopping an aircraft after landing has greatly increased. In many instances, the aircraft brakes can no longer be relied upon solely to slow the aircraft within a reasonable distance, immediately after touchdown. Most thrust reverser systems can be divided into two categories: mechanical-blockage and aerodynamic-blockage. Mechanical blockage is accomplished by placing a removable obstruction in the exhaust gas stream, usually somewhat to the rear of the nozzle. The engine exhaust gases are mechanically blocked and diverted at a suitable angle in the reverse direction by an inverted cone, half-sphere, or clam shell. *[Figure 3-48]* This is placed in position to reverse the flow of exhaust gases. This type is generally used with ducted turbofan engines, where the fan and core flow mix in a common nozzle before exiting the engine. The clamshell-type or mechanical-blockage reverser operates to form a barrier in the path of escaping exhaust gases, which nullifies and reverses the forward thrust of the engine. The reverser system must be able to withstand high temperatures, be mechanically strong, relatively light in weight, reliable, and "fail-safe." When not in use, it must be streamlined into the configuration of the engine nacelle. When the reverser is not in use, the clamshell doors retract and nest neatly around the engine exhaust duct, usually forming the rear section of the engine nacelle.

In the aerodynamic blockage type of thrust reverser, used mainly with unducted turbofan engines, only fan air is used to slow the aircraft. A modern aerodynamic thrust reverser system consists of a translating cowl, blocker doors, and cascade vanes that redirect the fan airflow to slow the aircraft. *[Figure 3-49]* If the thrust levers are at idle position and the aircraft has weight on the wheels, moving the thrust levers aft activates the translating cowl to open, closing the blocker doors. This action stops the fan airflow from going aft and redirects it through the cascade vanes, which direct the airflow forward to slow the aircraft. Since the fan can produce approximately 80 percent of the engine's thrust, the fan is the best source for reverse thrust. By returning the thrust levers (power levers) to the idle position, the blocker doors open and the translating cowl closes.

A thrust reverser must not have any adverse effect on engine operation either deployed or stowed. Generally, there is an indication in the flight deck with regard to the status of the reverser system. The thrust reverser system consists of several components that move either the clam shell doors or the blocker door and translating cowl. Actuating power is generally pneumatic or hydraulic and uses gearboxes, flexdrives, screwjacks, control valves, and air or hydraulic motors to deploy or stow the thrust reverser systems. The systems are locked in the stowed position until commanded to deploy by the flight deck. Since there are several moving parts, maintenance and inspection requirements are very important. While performing any type of maintenance, the reverser system must be mechanically locked out from deploying while personnel are in the area of the reverser system.

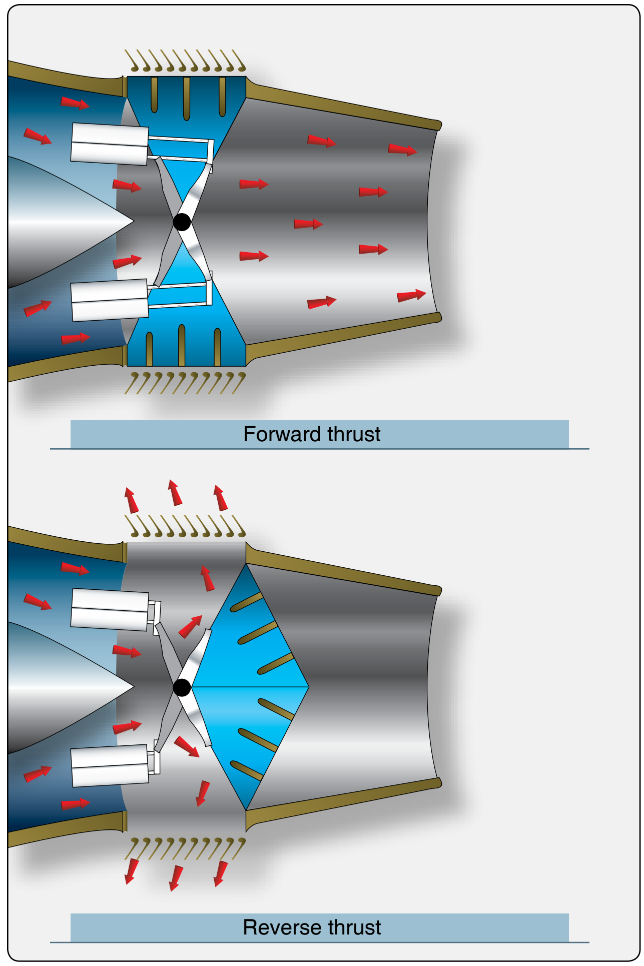

Figure 3-48. *Engine exhaust gases are blocked and diverted in a reserve direction during thrust reversal.*

Afterburning/Thrust Augmentation

The terms afterburning and thrust augmentation generally pertain to military engine applications. The terms are used to describe the same system. Normally, this is used to increase the thrust of the engine up to double the original thrust. The required additions to the exhaust nozzle for this system are a flame stabilizer, fuel manifold, flame holder, igniter, and a

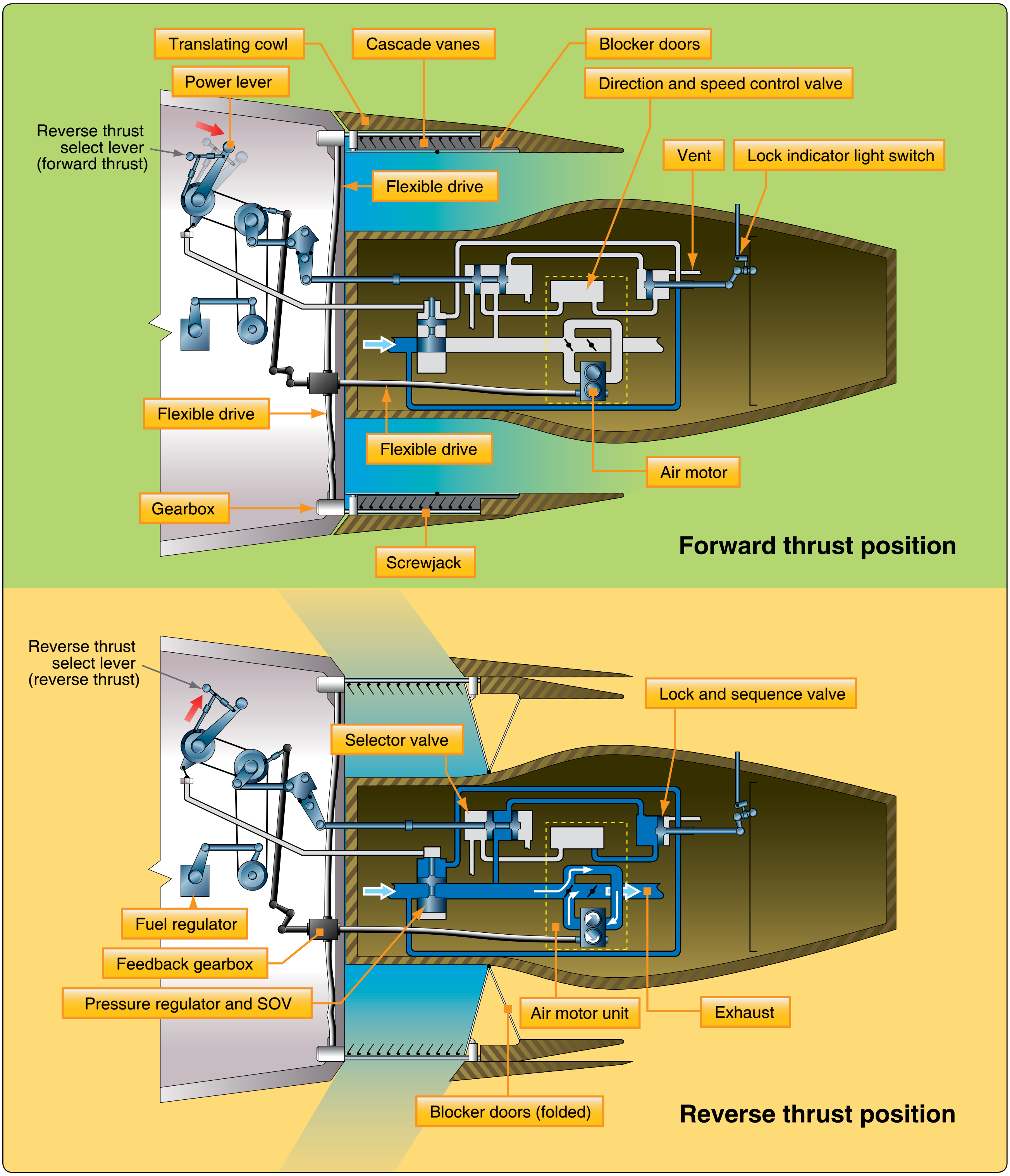

Figure 3-49. *Components of a thrust reverser system.*

variable area exhaust nozzle. *[Figure 3-50]* After the engine has reached full power under normal operation, the power lever can be advanced to activate the afterburner. This allows more fuel to flow into the exhaust nozzle where it is ignited and burned. As energy and mass are added to the gas flow, the exhaust nozzle must open wider to allow greater flow. As the power lever is moved back out of the afterburner, the exhaust nozzle closes down again. Some low-bypass turbofan engines used in military aircraft use bypass (fan air) to flow into the exhaust nozzle. Just as in a ducted fan, this air is used in the afterburner. It contains more oxygen and assists combustion in the afterburner. Since fuel is being burned in the exhaust nozzle, the heat buildup around the nozzle is a problem. A special type of liner is used around the nozzle to allow cooler air to circulate around the nozzle. This operates somewhat like a single burner can combustion chamber. Operation in the afterburner mode is somewhat limited by high fuel consumption, which can be almost double normal consumption.

Thrust Vectoring

Thrust vectoring is the ability of an aircraft's main engines to direct thrust other than parallel to the vehicle's longitudinal axis, allowing the exhaust nozzle to move or change position to direct the thrust in varied directions. Vertical takeoff aircraft use thrust vectoring as takeoff thrust and then change direction to propel the aircraft in horizontal flight. Military aircraft use thrust vectoring for maneuvering in flight to change direction. Thrust vectoring is generally accomplished by relocating the direction of the exhaust nozzle to direct the thrust to move the aircraft in the desired path. At the rear of a gas turbine engine, a nozzle directs the flow of hot exhaust gases out of the engine and afterburner. Usually, the nozzle points straight out of the engine. The pilot can move, or vector, the vectoring nozzle up and down by 20°. This makes the aircraft much more maneuverable in flight. *[Figure 3-51]*

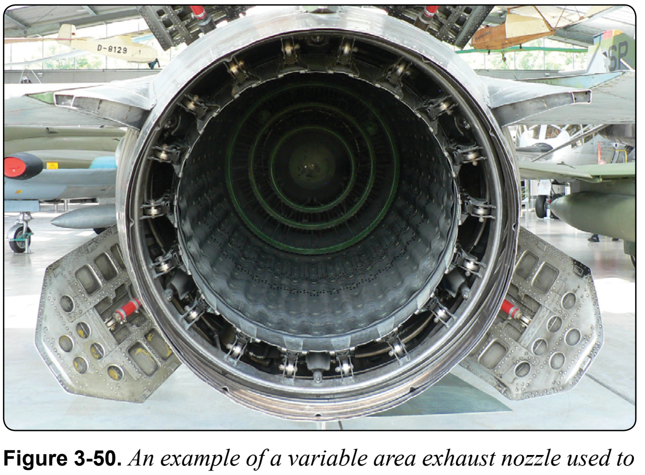

Figure 3-50. *An example of a variable area exhaust nozzle used to increase or decrease exhaust flow during afterburn.*

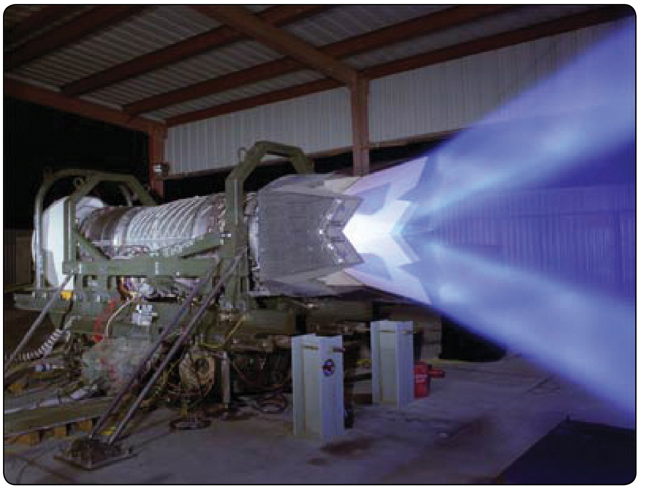

Figure 3-51. *A pilot can direct thrust via the vectoring nozzle 20° up or down to increase flight maneuverability.*

Engine Noise Suppression

Aircraft powered by gas turbine engines sometimes require noise suppression for the engine exhaust gases when operating from airports located in or near highly populated areas. Several types of noise suppressors are used. A common type of noise suppressor is an integral, airborne part of the aircraft engine installation or engine exhaust nozzle. Engine noise comes from several sources on the engine, the fan, or compressor and the air discharge from the core of the engine. There are three sources of noise involved in the operation of a gas turbine engine. The engine air intake and vibration from engine housing are sources of some noise, but the noise generated does not compare in magnitude with that produced by the engine exhaust. *[Figure 3-52]* The noise produced by the engine exhaust is caused by the high degree of turbulence of a high-velocity jet stream moving through a relatively quiet atmosphere. For a distance of a few nozzle diameters downstream behind the engine, the velocity of the jet stream is high, and there is little mixing of the atmosphere with the jet stream. In this region, the turbulence within the high speed jet stream is very fine grain turbulence and produces relatively high-frequency noise. This noise is caused by violent, turbulent mixing of the exhaust gases with the atmosphere and is influenced by the shearing action caused by the relative speeds between the velocity and the atmosphere.

Farther downstream, as the velocity of the jet stream slows down, the jet stream mixes with the atmosphere and turbulence of a coarser type begins. Compared with noise from other portions of the jet stream, noise from this portion has a much lower frequency. As the energy of the jet stream finally is dissipated in large turbulent swirls, a greater portion of the energy is converted into noise. The noise generated as the exhaust gases dissipate is at a frequency near the low end of the audible range. The lower the frequency of the noise,

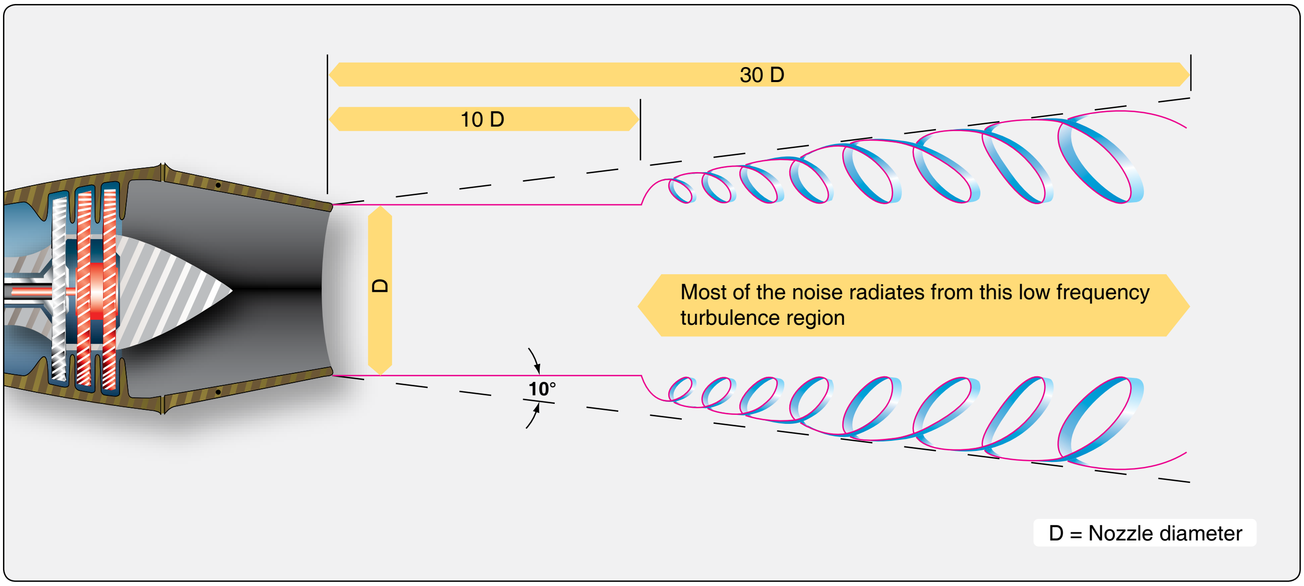

Figure 3-52. *Engine noise from engine exhaust is created by the turbulence of a high velocity jet stream moving through the relatively quiet atmosphere.*

the greater the distance the noise travels. This means that the low-frequency noises reach an individual on the ground in greater volume than the high-frequency noises, and hence are more objectionable. High-frequency noise is weakened more rapidly than low-frequency noise, both by distance and the interference of buildings, terrain, and atmospheric disturbances. A deep-voiced, low-frequency foghorn, for example, may be heard much farther than a shrill, high-frequency whistle, even though both may have the same overall volume (decibels) at their source.

Noise levels vary with engine thrust and are proportional to the amount of work done by the engine on the air that passes through it. An engine having relatively low airflow but high thrust due to high turbine discharge (exhaust gas) temperature, pressure, and/or afterburning produces a gas stream of high velocity and, therefore, high noise levels. A larger engine, handling more air, is quieter at the same thrust and large engines operating at partial thrust are less noisy than smaller engines operating at full thrust. Thus, the noise level can be reduced considerably by operating the engine at lower power settings. Compared with a turbojet, a turbofan version of the same engine is quieter during takeoff. The noise level produced by a fan-type engine is lower, principally because the exhaust gas velocities ejected at the engine tailpipe are slower than those for a turbojet of comparative size.

Fan engines require a larger turbine to provide additional power to drive the fan. The large turbine, which usually has an additional turbine stage, reduces the velocity of the gas and, therefore, reduces the noise produced because exhaust gas noise is proportional to exhaust gas velocity. The exhaust from the fan is at a relatively low velocity and, therefore, does not create a noise problem. Because of the characteristic of low-frequency noise to linger at a relatively high volume, effective noise reduction for a turbojet aircraft must be achieved by revising the noise pattern or by changing the frequency of the noise emitted by the jet nozzle.

The noise suppressors in current use are either of the corrugated-perimeter type, or the multi-tube type. *[Figure 3-53]* Both types of suppressors break up the single, main jet exhaust stream into a number of smaller jet streams. This increases the total perimeter of the nozzle area and reduces the size of the air stream eddies created as the gases are discharged into the open air. Although the total noise-energy remains unchanged, the frequency is raised considerably. The size of the air stream eddies scales down at a linear rate with the size of the exhaust stream. This has two effects: 1) the change in frequency may put some of the noise above the audibility range of the human ear, and 2) high frequencies

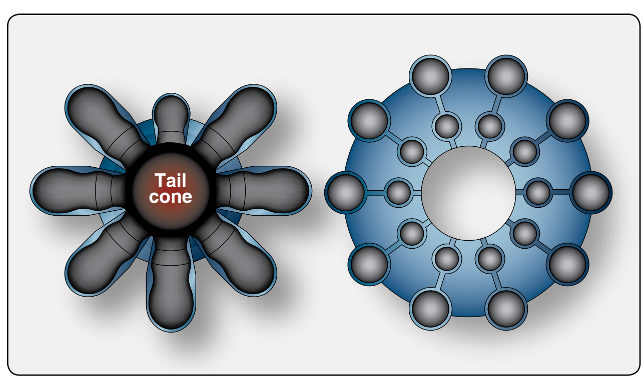

Figure 3-53. *Noise suppressors currently in use are corrugated-perimeter type, or multi-tube type.*

within the audible range, while perhaps more annoying, are more highly attenuated by atmospheric absorption than are low frequencies. Thus, the falloff in intensity is greater and the noise level is less at any given distance from the aircraft. In the engine nacelle, the area between the engine and the cowl has acoustic linings surrounding the engine. This noise-absorbing lining material converts acoustic energy into heat. These linings normally consist of a porous skin supported by a honeycomb backing and provide a separation between the face sheet and the engine duct. For optimum suppression, the acoustic properties of the skin and the liner are carefully matched.

Turbine Engine Emissions

Engineers are introducing new combustion technology that has dramatically reduced emissions from gas turbine engines. Lowering exhaust emissions from gas turbine, especially oxides of nitrogen (NO_X), continue to require improvement. Most of the research has centered around the combustion section of the engine. New technology with unique combustor design has greatly reduced emissions. One manufacturer has a design called the Twin Annular, Pre-mixing Swirler (TAPS) combustor. Most advanced designs rely on a method of pre-mixing the air-fuel before it enters the combustion burner area. In the TAPS design, air from the high-pressure compressor is directed into the combustor through two high-energy swirlers adjacent to the fuel nozzles. This swirl creates a more thorough and leaner mix of fuel and air, which burns at lower temperatures than in previous gas turbine engine designs. Most of the NO_X is formed by the reaction of oxygen and nitrogen at high temperatures. The NO_X levels are higher if the burning air-fuel mixture stays at high temperatures for a longer time. Newly designed combustors also produce lower levels of carbon monoxide and unburned hydrocarbons. The increases in gas turbine engine component efficiencies have resulted in fewer emissions from gas turbine engines.