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EXHAUST SECTION

CONSTRUCTION AND PRINCIPLES OF OPERATION

The exhaust section of the gas turbine engine consists of several components

Although the components have individual purposes, they also have one common function:

- they must direct the flow of hot gases rearward

in such a manner as to prevent:

- turbulence
- and, at the same time, impart a high final or exit velocity to the gases.

The exhaust section is located;

- directly behind the turbine section and ends when the gases are ejected at the rear in the form of a high velocity exhaust gases

The components of the exhaust section include the:

- exhaust cone
- tailpipe (if required)
- exhaust nozzle

1, the exhaust cone

The exhaust cone :

- collects the exhaust gases discharged from the turbine section and gradually converts them into a solid flow of gases.
- In performing this, the velocity of the gases is decreased slightly and the pressure increased
- This is due to the diverging passage between the outer duct and the inner cone; that is, the annular area between the two units increases rearward

The exhaust cone assembly consists of an:

- outer shell
- inner cone
- three or four radial hollow struts or fins
- tie rods to aid the struts in supporting the inner cone from the outer duct

This element collects the exhaust gases and delivers them directly to the exhaust nozzle.

The outer shell or duct is usually

- made of stainless steel
- is attached to the rear flange of the turbine case.

The duct must be constructed to include such features as a predetermined number of;

- thermocouple bosses for installing exhaust temperature thermocouples, and there must also be insertion holes for the supporting tie rods

In some cases, tie rods are

- not used for supporting the inner cone
- the struts being spot welded in position to the inside surface of the duct and to the inner cone, respectively.

The radial struts actually have a twofold function:

- support the inner cone in the exhaust duct,
- they also perform the important function of straightening the swirling exhaust gases

My statement: (radial struts)

The radial struts in this exhaust system have two main functions:

1. Support: They hold the inner cone steady within the exhaust duct, keeping it positioned correctly.

2. Gas Flow Straightening: They reduce the swirling motion of the exhaust gases. Without these struts, the gases would leave the turbine at a 45° angle, creating turbulence. The struts straighten this flow, helping direct the gases smoothly out of the exhaust.

Additionally, the inner cone fits closely against the turbine disk, further reducing turbulence as gases exit the turbine.

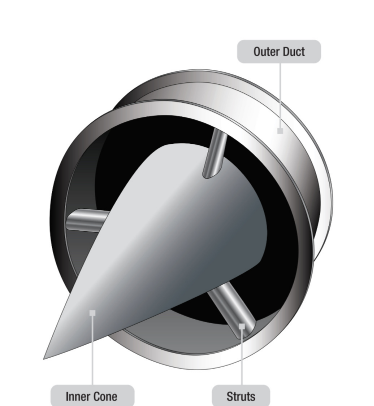


Figure 7-1. Exhaust collector with welded support struts.

In some configurations a small hole is located in the :

- exit tip of the cone.

This hole allows ;

- cooling air to be circulated from the aft end of the cone,
- where the pressure of the gases is relatively high, into the interior of the cone and consequently against the face of the turbine wheel

My statement: (cone exit tip hole):

In some setups, there's a small hole at the tip of the inner cone. This hole allows cooling air to flow into the cone. Here's how it works:

1. Cooling Air Flow: The air enters through this hole because the pressure at the back of the cone is higher than inside the cone. This high-pressure area pushes air through the hole into the inner cone.

2. Air Circulation for Cooling: Once inside, the air moves toward the turbine wheel, where the pressure is lower due to the wheel's rotation. This difference in pressure ensures a steady flow of air, which cools the turbine wheel by circulating around it.

This setup provides continuous cooling to the turbine wheel, helping to manage temperatures inside the exhaust system.

The gases used for cooling the turbine wheel return to the :

- main path of flow by passing through the clearance between the turbine disk and the inner cone

Meaning (my statement):

- Return to Main Exhaust Flow: After cooling the turbine wheel, the air doesn't just stay there. It flows back to the main exhaust path through a small gap between the turbine disk and the inner cone.

2, The tailpipe

The tailpipe is usually constructed so that it is :

- semi flexible.

On some tailpipes a bellows arrangement is incorporated in its constructionallowing movement in :

- installation,
- maintenance,
- and in thermal expansion

Meaning (my statement) :

the bellows design allows the part to

- stretch and contract as needed,
- making it more durable and easier to work with during temperature changes or adjustments or maintenance.

The bellows arrangement eliminates:

- stress and warping which would otherwise be present.

The heat radiation from the exhaust cone and tailpipe could:

- damage the airframe components surrounding these units
- Due to this reason protection must be provided

There are several suitable methods of protecting the fuselage structure;

1, insulation blankets

2, shrouds

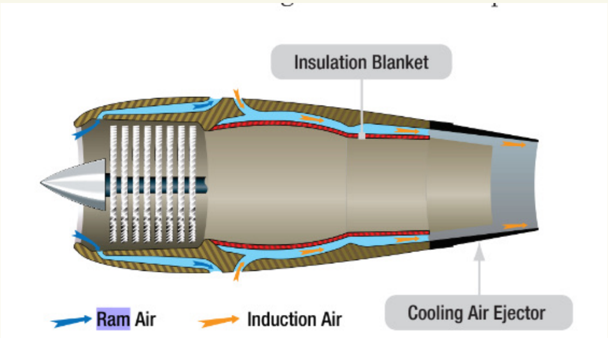


Figure 7-2. Exhaust system insulation blanket.

Insulation Blanket

3, exhaust nozzle

There are two types of exhaust nozzle designs:

- the converging design for subsonic gas velocities
- the converging diverging design for supersonic gas velocities.

The exhaust nozzle opening may be of either:
1, fixed
or
2, variable area

1, The fixed area type is the

- simpler of the two exhaust nozzles
- since there are no moving parts.

The outlet area of the fixed exhaust nozzle is very critical to engine performance.
Ex:
1, If the nozzle area is too large:

- thrust is wasted

2, if the area is too small:

- the engine could choke or stall

2, variable area exhaust

To understand afterburner watch this:

https://youtu.be/vpsifCZJvl4?si=WDD8fru6lkwE0rFC

A variable area exhaust nozzle is used when an

- augmenter or afterburner is used due to the increased mass of flow when the afterburner is activated.

It must increase its open area when:

- the afterburner is selected

When the afterburner is off:

- the exhaust nozzle closes to a smaller area of opening.

EXHAUST NOZZLE SHAPES

Turboshaft engines in helicopters can have an exhaust nozzle that forms a divergent duct:

- This type of nozzle provides no thrust

Turbofan engines tend to fall into either:
1, ducted fan
or
2, unducted fan engines.

1, Ducted fan engines

- take the fan airflow and direct it through closed ducts along the engine Then, it flows into a common exhaust nozzle

2, The unducted fan has

- two nozzles, one for the fan airflow and one for the core airflow.

My statement

1, The ducted exhaust engine mixes the air. It combines the air from the fan with the exhaust gases before releasing it, improving efficiency and reducing noise.

- as the book states: The fan air is either mixed with the exhaust gases before it is discharged (mixed or common nozzle) is this ducted

2, The unducted exhaust engine does not mix the air. The exhaust gases and air remain separate, as the exhaust is open without a cover, focusing on fuel efficiency rather than mixing.

- it passes directly to the atmosphere without prior mixing (separate nozzle).

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 exit vanes with as little turbulence as possible

My statement (unducted engine):

In an unducted engine or separate nozzle engine, a large fan pulls in a huge amount of air to generate most of the thrust—about 80-85% of it. Here's what's important:

1. Directing Air Smoothly: Since the fan creates almost all the thrust, the airflow needs to move smoothly to avoid energy loss. The air is directed through exit vanes, which are special fins that guide the flow out the back in a straight line.

2. Reducing Turbulence: If the air leaving the fan gets too turbulent (swirling or chaotic), it won't produce as much thrust. The exit vanes help keep the airflow steady and straight, making the engine more efficient and giving it maximum thrust.

In simple terms, the exit vanes act like guides, making sure the air flows out smoothly for maximum power.

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 (15-20 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.

CONVERGENT EXHAUST NOZZLE

- The exhaust nozzle starts with a divergent (wider) section to reduce turbulence, allowing the exhaust gases to flow smoothly. Then, it moves into a convergent (narrower) section that squeezes the gases through a smaller opening, increasing their speed as they exit.

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:

1, If the nozzle opening is too big, thrust is being wasted

2, If it is too little, the flow is choked in the other components of the engine

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
- 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

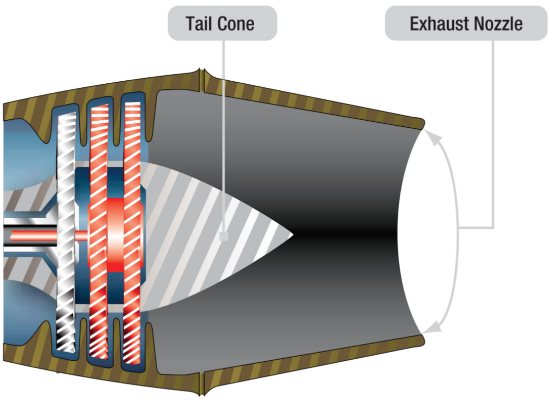


Figure 7-6. Exhaust gases exit the rear of the engine through the exhaust nozzle.

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

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 maintain a constant flow of gas at supersonic speeds,

- the rear part of a supersonic exhaust duct is enlarged (forming a divergent section)
- to handle the increased volume, ensuring efficient nozzle operation.

In the convergent-divergent, or C-D nozzle,

1, 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.

2, The divergent section 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

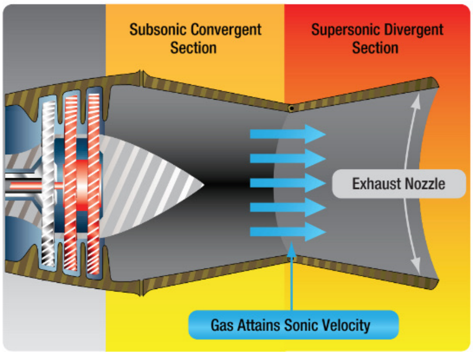


Figure 7-7. A convergent-divergent nozzle can be used to help produce more thrust when exhaust gas velocities are greater than Mach 1.

ENGINE NOISE SUPPRESSION

There are three sources of noise involved in the operation of a gas turbine engine:

- The engine air intake
- 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

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.

My statement (Engine Exhaust Noise)

The noise from an engine exhaust is mainly due to turbulence in the high-speed jet stream as it moves through the quiet surrounding air, which creates loud noise at different frequency depending on distance.

1. Near the Nozzle: Right behind the engine, the jet stream is moving extremely fast, with very little mixing with the surrounding air. The turbulence here is small and intense, producing loud, high-frequency (higher-frequency) noise. This happens because of the “shearing” effect—the big difference in speed between the fast jet and the still air.
2. Farther Away: As the jet stream moves farther from the nozzle, it begins to slow down and mix with the atmosphere. The turbulence becomes larger and rougher, creating loud, lower-frequency (lower-frequency) noise. Finally, as the energy fades, big, slow swirls form, producing a deep, low-frequency sound near the lowest range of what we can hear.

In short, close to the nozzle, you get loud, high-frequency noise from fine turbulence, while farther away, as the jet slows, loud, deeper, low-frequency noise is created from larger swirls mixing with the air.

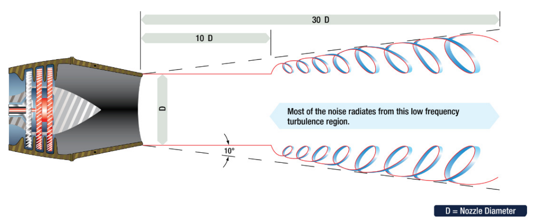


Figure 7-8. Engine noise from engine exhaust is created by the turbulence of a high velocity jet stream moving through the relatively quiet atmosphere.

Near the Nozzle: Right behind the engine, the exhaust gases are moving very fast. At this point, there’s very little mixing with the surrounding air, so the air flows are almost separate. The turbulence in the fast-moving jet stream is small and intense, causing rapid, small-scale swirling. This results in loud, high-pitched (high-frequency) noise. The high pitch comes from the “shearing” effect—this is the result of the fast jet stream moving at a much higher speed compared to the still air around it, which causes friction and turbulence at the boundary. This rapid movement and friction lead to high-frequency sound.

Farther Away: As the jet stream moves farther from the engine nozzle, it starts to slow down and mix with the surrounding air. The turbulence becomes bigger and more chaotic, which creates louder, lower-pitched (lower-frequency) noise. This happens because the jet stream’s energy starts to dissipate, and the smaller, faster swirls turn into larger, slower ones. These larger swirls produce a deep, low-pitched sound, which is closer to the lowest sounds we can hear. The noise here is much deeper and less sharp compared to the high-pitched sound near the nozzle.

The lower the frequency of the noise:

- 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

High frequency noise is :

- weakened more rapidly than low frequency noise

both by :

- distance and the interference of buildings, terrain, and atmospheric disturbances

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 after burning produces a gas stream of high velocity and,
- therefore, high noise levels.

larger engine, handling more air, is

- quieter at the same thrust.

Thus, the noise level can be reduced considerably by

- operating the engine at lower power settings,
- large engines operating at partial thrust are less noisy than smaller engines operating at full thrust.

The noise suppressors in current use are either of the: Soud reducing system

- corrugated perimeter type,

or

- the multi tube type.

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.

2. High frequencies 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

My statement

This explanation is describing how the size of the turbulence (called eddies) in the exhaust stream affects the noise produced by the engine:

1. Change in Frequency and Audibility: As the size of the turbulence decreases with distance from the nozzle, the frequency of the sound changes. This means that some of the higher-frequency sounds can become too high-pitched for the human ear to hear, putting them outside the range of what we can hear (above our hearing threshold).
2. Attenuation of High Frequencies: High-frequency sounds (higher-pitched noises) tend to be absorbed more by the atmosphere as they travel. This means that, although high-pitched sounds might be more annoying up close, they lose their intensity (loudness) more quickly as they move further away. In contrast, low-frequency sounds (lower-pitched noises) are less affected by the atmosphere and can travel longer distances with less loss of volume.

So, in short, at a distance from the aircraft, high-pitched noise decreases more rapidly in volume, while lower-pitched noise travels farther and remains louder.

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
- في مقصور المحرك، تحتوي المنطقة بين المحرك والغطاء على بطانات صوتية تحيط بالمحرك. تحول مادة البطانة الممتصة للضوضاء هذه الطاقة الصوتية إلى حرارة

TURBINE ENGINE EMISSIONS

Lowering exhaust emissions from gas turbine, especially oxides of nitrogen (NOX), continue to require improvement. Most of the research has centered around the combustion section of the engine

One manufacturer has a design called the
- Twin Annular, Premixing Swirler (TAPS) combustor

THRUST REVERSER'S

Most thrust reverser systems can be divided into two categories:
1, mechanical blockage
2, aerodynamic blockage

1, Mechanical 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

one of they above not all of them
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.

Before


After

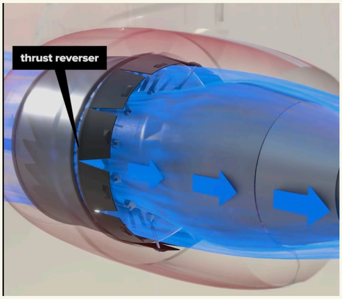

2, aerodynamic blockage

In the aerodynamic blockage type of thrust reverser used mainly with:
- unducted turbofan engines, only fan air is used to slow the aircraft

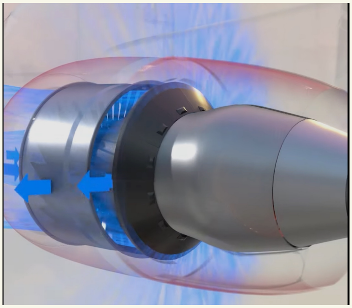
modern aerodynamic thrust reverser system consists of a:
- translating cowl,
- blocker doors
- cascade vanes that redirect the fan airflow to slow the aircraft

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

Before



After



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