JET ENGINE NOISE

Presented

at

1966 Inspection of the
Lewis Research Center
Cleveland, Ohio
October 4-7, 1966

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NOISE ∝ (VELOCITY)⁸
THRUST = MASS FLOW × VELOCITY

JET ENGINE NOISE

(Play turbojet tape.)

That is what a jet airplane sounds like as it comes in for a landing directly overhead. Jet aircraft noise has been around for sometime, but the problem is becoming more acute with the increased jet traffic and bigger engines. In the first jet transports introduced in 1958, turbojet engines were used. This is a quarter-scale model of the engine that is used on the original DC-8 and 707 airplanes. It is called a turbojet to distinguish it from the turbofan type, which is displayed here. In this turbojet, the air enters through the inlet. Then after a combination of compression and combustion, the exhaust air leaves the tail end as a high-speed jet. When that high-velocity jet exits, it creates the engine thrust that pushes the airplane forward through the air (fig. 1). Eventually the exhaust mixes with the surrounding air. The mixing process is turbulent and creates many small whirls or vortices. These act as sound generators and cause the jet noise. Lewis and other laboratories have done a lot of work on jet noise in years past. The conclusion of this work was that the jet was the major source of noise coming from a turbojet and there is not a lot that can be done to quiet a high-velocity jet without a significant loss in performance. Let me show you what I mean.

This model simulates the exhaust of a jet engine. We are going to blow compressed air out this nozzle to produce some thrust and will measure the noise. The model is hung by these wires so that the thrust pushes the model forward. This indicator shows how far the model moves and measures the thrust. The microphone will pick up the jet noise and feed it into a decibel meter up here.

(Demonstration)

At this thrust level, we get about 94 decibels of noise at that location. You noticed, I am sure, that the noise was of a much higher pitch than that of a big jet engine. That is because we have such a

small jet here. It is the same principle of scaling to small size that results in a little piccolo giving a much higher sound than a big tuba.

Some of the results of earlier work on jet noise are shown here. These are full-scale jet noise suppressors used on some of the 707's and DC-8's. We have built one to operate on our model.

(Show and then attach: perform demonstration.)

When we run this up to the same thrust level, the decibel meter is at about 91, or 3 to 4 db below what it was without the suppressor. That is the same kind of noise reduction that was obtained with these full-scale devices on airplanes. These suppressors are helpful. However, there are still a lot of complaints about noise from airport neighbors. We would like to reduce the noise much further. Research has taught us that noise is proportional to the velocity to the eighth power.

(Point to equation.)

The way to reduce jet noise is to have low velocity jets. Thrust from an engine is proportional to the product of the exhaust mass flow and exhaust velocity.

(Point to equation.)

You have to keep the same thrust to fly the airplane; therefore, as you lower this velocity you must increase the mass flow. That is exactly what a turbofan engine does.

(Move over to fan-jet model.)

This engine is built to handle more airflow. It is like a turbojet in many ways and is really a turbojet with a large fan hung on the front end. The large fan blows extra air out this nozzle for thrust. We get essentially the same thrust with this engine as with that turbojet but with lower exhaust velocities for higher mass-flow rates.

We have a nozzle here that will simulate a turbofan, which we can operate at the same thrust level as before. It has a larger nozzle

(Show nozzle to audience.)
to give us more flow at a lower velocity.

(Run engine.)

At the same thrust level as before, we get readings of the order of about 7 decibels less than that for a turbojet with a suppressor. Seven decibels is a fairly significant reduction in noise - one that airport neighbors appreciated, judging from the decrease in the number of complaints that occurred in 1960 when turbofans were introduced. Turbofan engines are not only quieter but they are more economical for subsonic airplanes. If you want to reduce the jet noise further, you just do more of the same - put larger fans on and handle more and more air through the fan only. From a jet noise standpoint, the fan should handle five to eight times as much air as the rest of the compressor. This continues to pay off in fuel economy for subsonic flight. All good things come to an end sooner or later, and eventually we begin to trade a jet-noise problem for a fan-noise problem.

The noise associated with turbofan-engine operation at takeoff power is significantly lower than that of turbojet operation because the main source of noise is the jet. However, during approach for landing the pilot reduces the thrust supplied by the engine. When the thrust of the engine is reduced, the jet noise is reduced. The jet noise is the random noise not characterized by any particular tone or discrete frequency. When the jet noise is reduced, it is possible to hear the high-pitched whine caused by the compressor operation. The compressor whine is much more noticeable in a turbofan than in a turbojet engine because the compressor is larger and the jet noise background is lower. These effects combine to give us a noise problem on landing. We made some recordings out here on the runway of turbojet and turbofan airplanes coming in for landings directly overhead. It is difficult to reproduce these sounds faithfully in a hangar like this, but I think you can get the idea of the relative intensities.

First, we have a turbojet.

(Play tape.)

The high-pitched whine is present even in a turbojet. Now we will hear a turbofan land. That whine is quite a bit more noticeable. This discrete frequency, or single-tone noise, is generally more irritating than a sound of many frequencies.

We are working on fan noise because it's becoming more of a problem as the fans become larger. First, we need to understand exactly how noise is generated in a fan operation. This is quite complex, but, as a first approximation, the fan can be considered to behave like a siren in which the noise is generated by the interaction of stationary and rotating blades. The flow of air is disturbed in passing through the stators. These disturbances are something like a wake behind a boat. The disturbed flow hits the rotors as they pass through the wakes of the stators. This causes the forces on the rotors to change, and this variation in rotor forces becomes apparent as noise.

I would like to demonstrate that for you now. This is a small model of the first stage of a fan. It consists of a rotor with 10 blades like this, driven by an electric motor for test purposes. Here is a set of very simple stators. They are crude approximations to aerodynamically designed stator blades, but these simple cylindrical stators produce wakes which interact with the rotor blades.

I will operate the fan at 5000 rpm with the stators about 2 inches in front of the rotor. Then I will move the stators closer to the rotor. There will be no change in the noise level until the stators are very close to the rotor.

(Switch on motor.)

Eliminating the source by redesigning the fan is the best approach to noise reduction, and we and others are working on that. The other approach is to put a muffler or suppressor on the fan. The principles for the design of a suppressor have been worked out by others. We

have used these principles (fig. 2) and built a fan-noise suppressor. All the interior surfaces are made of a porous material like this with good sound-absorbing qualities. The material is strong and flexible but you can see light through it. The sound-absorbing surfaces are backed up with dead air space. These surfaces are the inside of the outer shroud, both surfaces of this splitter ring, and both surfaces of these struts, and the cylindrical part of the centerbody. We will operate the fan with the stators all the way in to generate the maximum amount of noise. Then we will slip on this noise suppressor and listen to its effect.

These same principles can be used to design a suppressor for a fan-jet engine. This Center has a B-57 airplane for various research purposes that is powered by two J-65 engines. Now the J-65 is a turbojet and does not have a significant compressor-noise problem. However, for research purposes, we have changed the first row of stators on both engines to produce a noise like that of a fanjet. We have left a standard inlet on the one engine on the port side of the airplane. For the starboard engine, we have built and installed a suppressor like this one.

This suppressor was built for noise research and represents some weight penalty for the airplane. Before one is incorporated into an airplane engine system ready to fly, a more complete study of all the effects of such a suppressor on the airplane's performance would have to be made.

We are going to operate these engines one at a time on the B-57 parked out here on the hangar apron. They will run at thrust level, simulating the landing-approach condition. At this condition, the compressors rotate at around 5000 rpm. You will see the engine rpm displayed on these meters. The overall noise level associated with the engine operation will be displayed on this decibel meter measuring the noise picked up by a microphone on the apron.

The engines on this airplane are started by using a powder charge starter. This kind of starter routinely results in a large

amount of black smoke that is exhausted out the side of the engine. During engine acceleration, there is a characteristic low-frequency drone, which will disappear at constant engine speeds. You will not hear me during the engine operation. Just observe the rpm dials and the decibel meter. The first engine without the suppressor should give about 95 decibels and the other one with the suppressor about 87 decibels. We will start the starboard engine while the port engine is decelerating. First, we will hear the port engine, the one without the suppressor.

You may move over here to see the airplane but please stay behind the rope.

(Start port engine; cut port engine; cut starboard engine.)

You are welcome to take a look at the suppressor installation on the airplane after we tow it in, or any of the other exhibits here in the hangar.

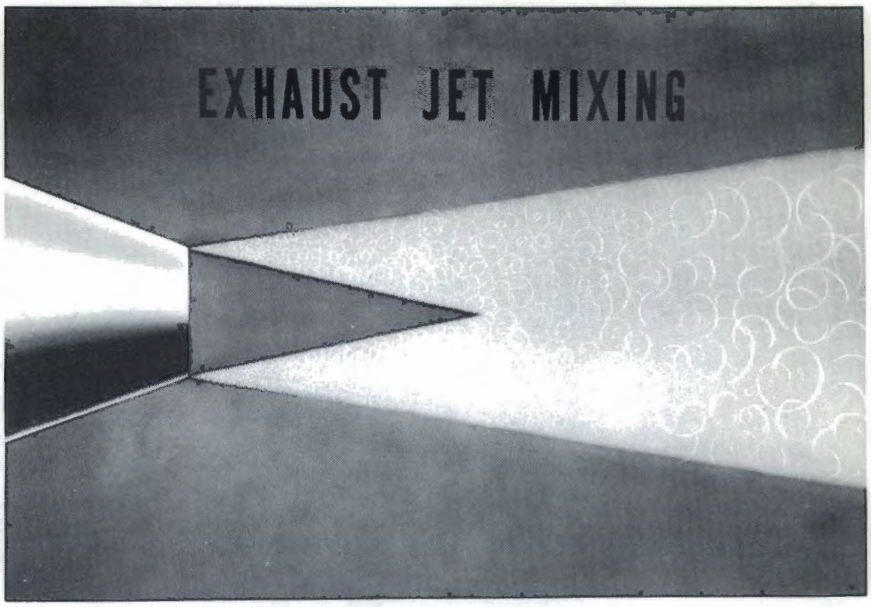

Figure 1

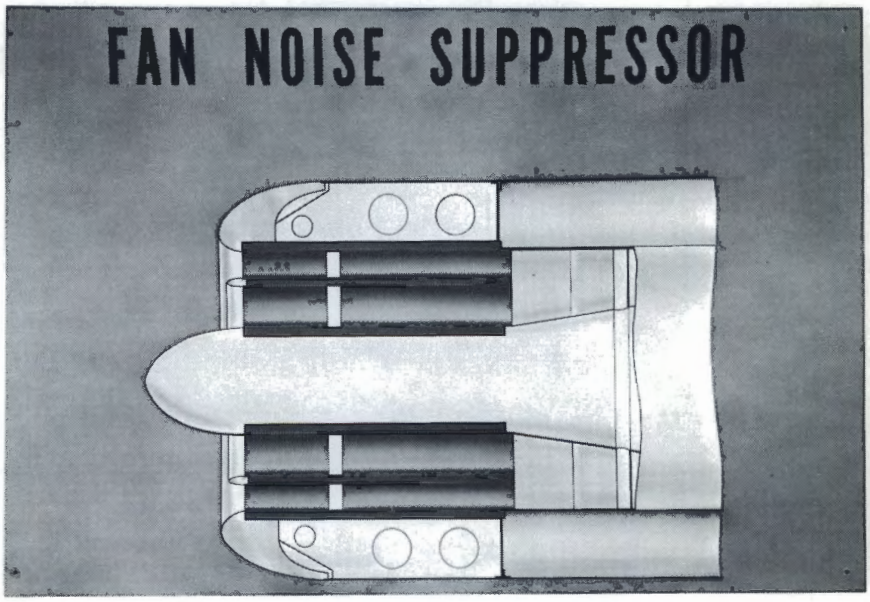

Figure 2

NASA
C-66-3904