Acoustical Design Features of Boeing Model 727

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Acoustic design features have contributed to the Boeing 727's acceptability to passengers and in operations at airports previously inaccessible to jet aircraft. The aircraft's JT8D-1 engine is inherently quiet, because of its low exhaust velocity and relatively large rotor-stator blade spacing. Further noise reduction is accomplished by wing shielding, inlet noise suppressors, and partial mixing of the turbine and fan exhausts. Low engine noise combined with high lift devices result in lower community noise levels than that from large-propeller aircraft during takeoff. Low interior noise levels have been maintained even though the 727 will operate in the noisy flight regime of high Mach numbers and low altitudes. To achieve this, the conventional double-wall treatment was supplemented with molded Fiberglas and perforated trim panels to improve absorption in critical areas and lead septum to reduce low-frequency noise in the aft section. Engine shock mounts were installed to minimize noise from engine vibration. The air-conditioning equipment, auxiliary power unit, hydraulic pumps, and light ballasts are examples of other equipment that was acoustically treated to make the 727 unusually quiet.

Introduction

THE field length capabilities of the Boeing 727 short-to-medium-range transport allow it to operate out of many airports that were, in the past, inaccessible to jet aircraft. To insure acceptance by the communities surrounding these airports, the external noise created by the aircraft had to be kept as low as possible.

It was also necessary to design carefully for low interior noise since the aircraft would, at times, be flown on short routes at the same Mach number as the bigger jets but at lower altitude. This particular flight regime could produce high aerodynamic noise in the cabin. At low speed, however, the cabin noise would be unusually low, especially in the forward sections of the aircraft. Extraneous noises, such as those from the air-conditioning system, hydraulic pumps, and transformers, could be annoying in a quiet cabin if they were not controlled.

Community Noise

Fully Ducted Fan Engine

The noise created by a jet engine is approximately proportional to the eighth power of the jet velocity. An excellent way, therefore, to keep an aircraft's noise level down is to select an engine with a low exhaust velocity.

The JT8D-1 engine used on the 727 has this characteristic. This engine is a fully ducted turbofan, which means that the fan discharge duct extends the full length of the engine and, in fact, shrouds the turbine exhaust section (Fig. 1). The velocity of the turbine exhaust is about 1700 fps, and that of the fan discharge is about 1150 fps. Partially mixed in the tail pipe, these two exhaust streams result in an average exhaust velocity of approximately 1460 fps.

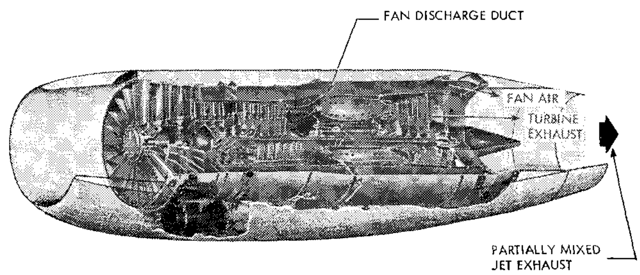

Fig. 1 Cross section of fully ducted fan engine.

For the sake of comparison, Table 1 lists the exhaust velocities, tail pipe areas, and jet noise reduction achieved by the turbofans. The JT3C-6 straight jet used as the noise reference is typical of nonfan-type engines used on jet transports.

Compressor Noise

The selection of a fan engine for an aircraft usually helps to ease the jet noise problem but, in turn, can create another problem. The compressor section is the source of the whine that is characteristic of turbofan aircraft on final approach. The compressor rotors interacting with the stators are important contributors to this source of noise. By judicious selection of rotor-stator blade spacing and number and the amount of work done by the fan section, the engine manufacturer has significantly reduced the compressor noise of the JT8D compared to previous fan engines.

To reduce the compressor noise further, an inlet noise suppressor was designed by Boeing for the 727. The suppressor is a band of absorptive lining located in the inlet forward of the compressor. The lining is essentially a tuned resonator designed for maximum absorption at the frequency of the compressor noise when the engine is at approach thrust. Figure 2 shows a cross section and the location of the lining in the inlet. Figure 3 is a plot of the absorptive characteristics of the lining as measured in the laboratory. It has been difficult to get consistent data on the sound attenuation characteristics of the suppressor as it is installed on the aircraft. Various checks show a reduction of the compressor noise spike of from 3 to 8 db. One set of data taken on an engine test stand is shown in Fig. 4. Narrow-band data, showing the significantly lower compressor noise of the JT8D as compared to that of an earlier fan engine, are illustrated in Fig. 5.

Table 1 Engine comparison data

Engine type	Exhaust velocity, fps at max cont. thrust	Tail pipe area, ft^2	Noise reduction, db
JT3C-6	2150	2.6	Ref.
JT3D-1	1700	3.8	7
JT8D-1	1460	4.7	10

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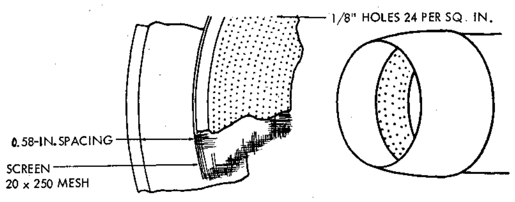


Fig. 2 Engine inlet lining.

Wing Shielding

The 727, with its aft-mounted engines, has an advantage over aircraft with wing-mounted engines in that the wing shields a ground observer from the sound while the aircraft is approaching. Although this effect does not reduce the peak noise that occurs just after the aircraft passes overhead, it does reduce the duration of the noise. Subjective noise tests run by Kryter and Pearson[1] show that, if the duration of a noise is reduced by half, it is judged to be about 4.5 db quieter than the longer-duration noise of equal amplitude. The attenuation obtained by wing shielding on the 727 is plotted in Fig. 6 as a function of angle from the axis of the engines. Figure 7 is a plot of the noise level as a function of time during an approach for the 727 and a typical jet aircraft with wing-mounted engines.

Community Noise Levels

As a result of its acoustical design and because it can take off and climb out quickly, the 727 is a relatively quiet airplane. Community noise levels generated by the 727 are compared in Fig. 8 with those of current medium-range jets.

The 727 noise levels are compared in Fig. 9 with those of a four-engine propeller-driven aircraft and a twin-engine medium-range jet. As can be seen, the comparison is very favorable for the 727 during the takeoff. During an approach, the advantage of altitude is lost since all of the aircraft follow a 3° glideslope, and the comparison with other aircraft is less impressive than for takeoff. When the subjective reduction produced by the short duration of the 727's approach noise is accounted for, it is seen (Fig. 10) that the 727 is considerably quieter than the bigger jets and comparable to the large-propeller aircraft.

Interior Noise

Although the 727 is very similar to the 707 in its internal configuration, some differences do exist in the acoustical treatment of these aircraft. Rear-mounted engines, installation of an auxiliary power unit near the landing-gear well, and a change in the air-conditioning system demanded special treatment in the 727 to keep the interior noise levels low.

Double-Wall Construction

As on the 707/720 aircraft, the 727 has a double-wall interior construction with Fiberglas, septa, and an air space between the walls. The inner wall, which consists primarily of the interior trim panel, is isolated from the outer wall (the

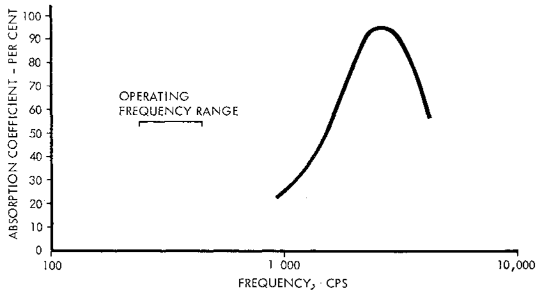


Fig. 3 Absorption properties of 727 inlet lining.

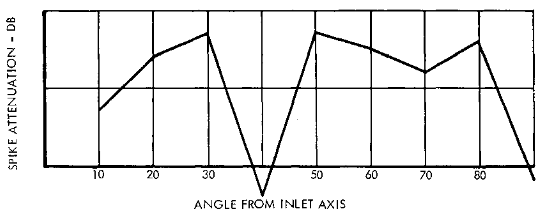


Fig. 4 Attenuation, inlet lining.

fuselage) by rubber mounts. A special rug and pad are used to increase the attenuation by the floor. The Fiberglas used in the aircraft has a fine fiber of 1-μ diameter that is especially efficient in attenuating high-frequency sound. The double-wall construction is an effective method of reducing low- and medium-frequency noise. Septa containing lead are used as required to increase the low- and midfrequency attenuation by the wall construction.

The interior configuration of the 727 has been improved acoustically by 1) simplified design of molded Fiberglas panels, which makes it possible to achieve a better acoustic seal around window structure; 2) an additional layer of lead septum installed in the aft quarter of the aircraft to attenuate low-frequency noise; 3) a low curved ceiling constructed of honeycomb paneling with more air space between structure and ceiling than on earlier aircraft; and 4) use of acoustic interior paneling in critical areas to absorb noise in the speech interference bands. A cross section of the 727 interior construction is shown in Fig. 11.

Acoustic Interior Paneling

Although the hard surface of the conventional paneling used in commercial aircraft is, unfortunately, a poor sound absorber, its other advantages (durability, ease of cleaning, rigidity, attractive appearance, etc.) make it a very functional material. A Boeing-designed acoustic paneling used in some areas of the 727 retains the advantages of the conventional paneling but also has a high coefficient of absorption in the critical speech interference frequencies.

The paneling is designed on the same tuned-resonator principle as the engine inlet lining, but materials have been carefully selected to retain the attractive appearance of the interior. This paneling is used in potentially noisy areas such as those adjacent to entry doors and the galley. Actual air-

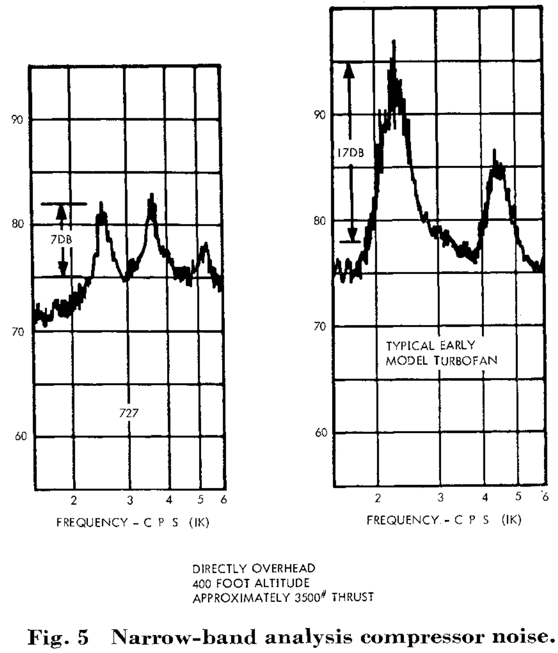


Fig. 5 Narrow-band analysis compressor noise.

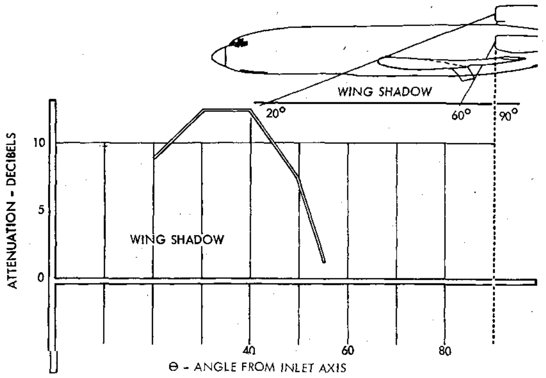


Fig. 6 Wing shielding.

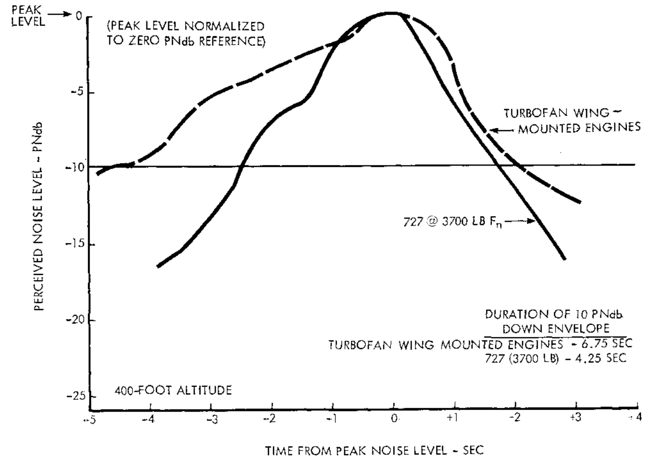


Fig. 7 Approach noise duration, 10 perceived noise decibel (PNdb) down envelope.

line service tests of this material before its use on the 727 demonstrated that it is easy to clean, retains its acoustic properties with age, and structurally withstands the abuses of everyday use. The method of construction and the absorption characteristics of the paneling are illustrated in Fig. 12.

Ventilation and Drain System Noise

Cabin air is exhausted overboard from the galley and lavatory areas during flight. At cruise altitude, the air-pressure differential between the inside and outside of the airplane forces air through the vent systems at relatively high velocity. This air flow can generate an annoying hissing noise

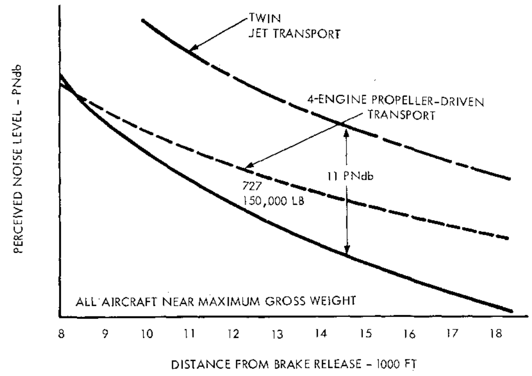


Fig. 9 Community noise comparison, 727 vs prop and twin-jet transport.

at the vent inlets and at sharp angles and restrictions in the ducts. The 727 ventilation and drain systems are designed to minimize this noise.

The lavatory drain-vent system is used both to carry away odors and to keep water drain lines from freezing. Since water as well as air passes through the ducts, the use of absorptive mufflers is not possible. Air velocity in the various lines is controlled by the use of selected orifices and supplementary air inlets. Sharp bends are eliminated wherever possible to reduce turbulence in the ducts. Inlets directly exposed to occupied areas, such as the drinking-fountain drain and wash-basin overflow, incorporate a special decoupling device. This device consists of an open funnel attached to the main vent system into which the drain line is emptied. The funnel is mounted in an inclosure that dissipates noise radiating from the system before it reaches passenger-occupied spaces. Only a small part of the air entering the funnel is drawn through the drain line; similarly, very little of the noise from the funnel is propagated up the drain line. Figure 13 is a schematic drawing of the 727 drain-vent system.

The galley-vent system carries only air, and, therefore, absorptive mufflers may be used. Two mufflers are installed in series to provide adequate absorption and also to simplify the installation. Noise generated downstream of the mufflers, principally at the exit venturi, is absorbed while permitting the high airflow necessary to achieve adequate ventilation.

Fluorescent Light Ballasts

Ballasts and transformers can be an annoying source of noise in an aircraft's passenger cabin. They tend to emit a shrill hum at frequencies that are harmonics of the excitation frequency.

To keep the noise produced by the cove light ballasts at a low level in the 727 aircraft, maximum permissible noise levels

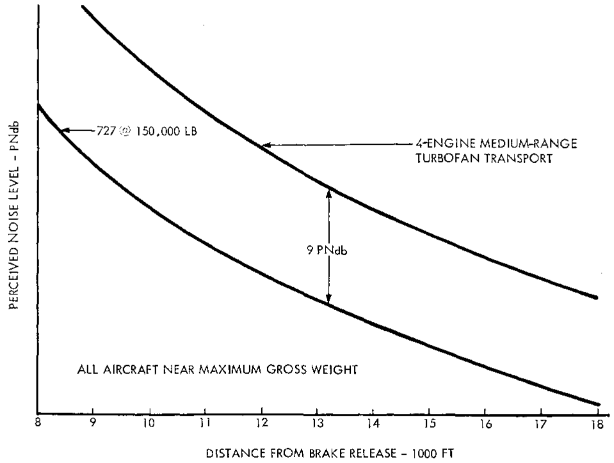


Fig. 8 Community noise comparison, 727 vs larger jet.

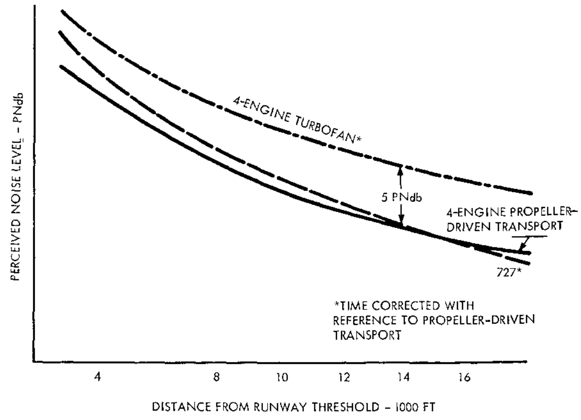


Fig. 10 Comparison approach noise.

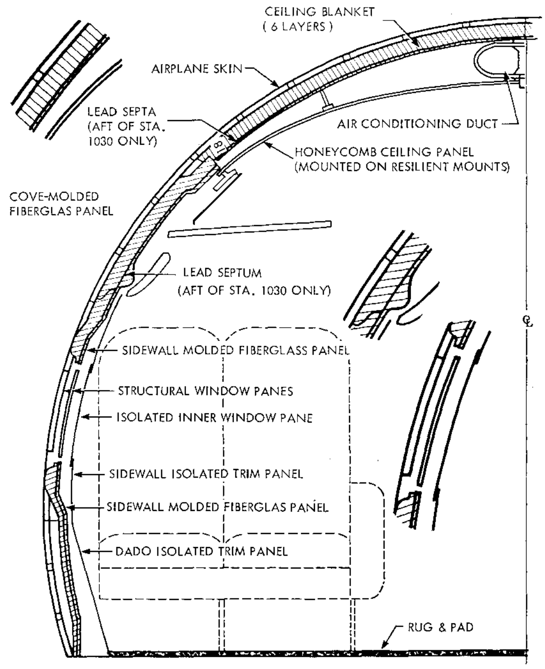


Fig. 11 Typical cross section, 727 interior.

were specified. The first ballasts developed for the airplane did not meet this requirement. Further development, however, resulted in a ballast that produced less noise than specified. This was achieved by optimizing the thickness of the transformer's steel laminations and then potting the unit in a silicon rubber compound. A cross-section drawing and representative noise levels of the ballasts are contained in Fig. 14.

Air-Conditioning System

Providing an ample, well circulating supply of conditioned air throughout the passenger cabin, without creating undue noise, is a difficult design problem. Air flowing through ducts and grills can create very annoying rumbling and hissing sounds.

In the model 727, the air is supplied to the passenger cabin through two separate systems: a sidewall system and an overhead system (Fig. 15). The sidewall system, which discharges air from the cove grill below the hatrack, is the primary system and is similar to that used in the Boeing 707 and 720 models. The overhead system is unique to the 727. It supplies air from a slot down the centerline of the ceiling.

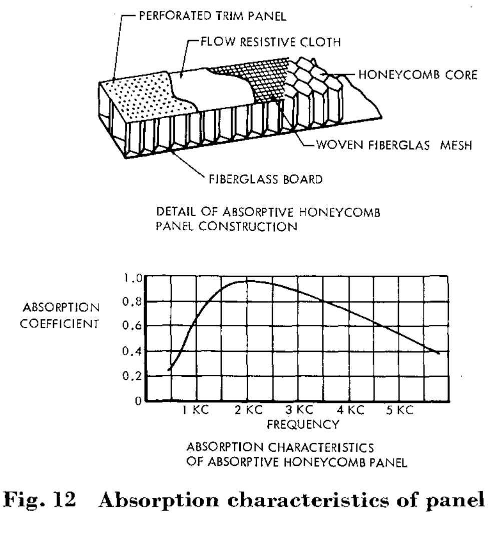


Fig. 12 Absorption characteristics of panel.

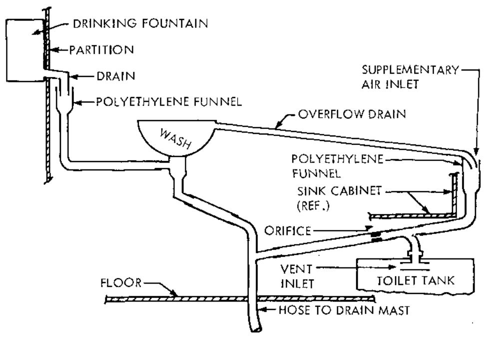


Fig. 13 Schematic 727 drain-vent system.

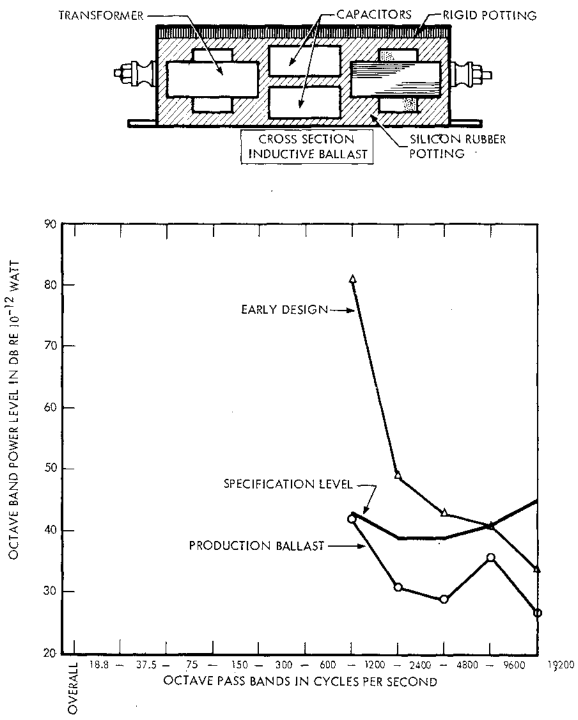


Fig. 14 Octave band sound power levels of inductive ballast units compared with specification levels.

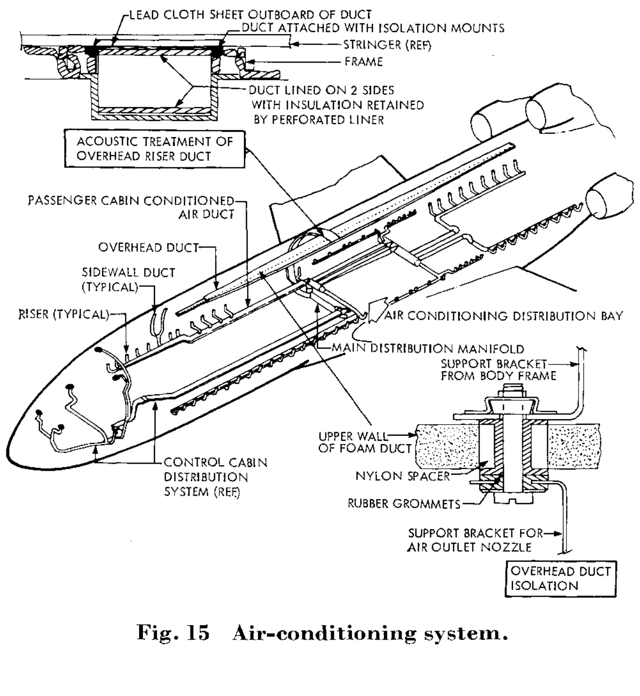


Fig. 15 Air-conditioning system.

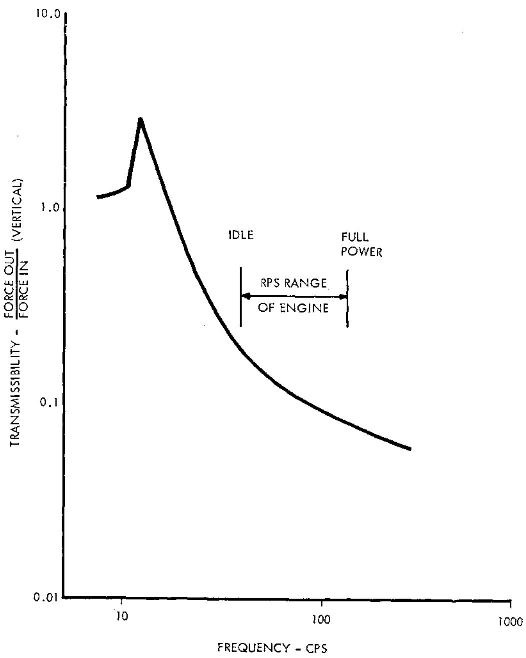
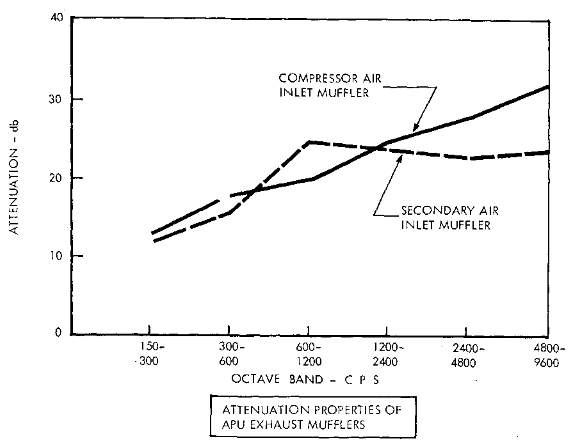


Fig. 16 Characteristics of 727 engine vibration isolators.

This system, which is designed primarily to permit more rapid temperature change when readying the airplane for flight, provides a continuous supply of low-velocity air during normal use. This makes possible a lower velocity, quieter airflow from the sidewall system, while improving the air circulation pattern. The overhead duct is of rigid foam sandwich construction, which provides a more rigid duct with internal damping to reduce duct rumble. Both the overhead duct and the riser supply duct are mounted with vibration isolators to reduce noise transmission. The riser duct is also lined with Fiberglas insulation retained by perforated sheet material.



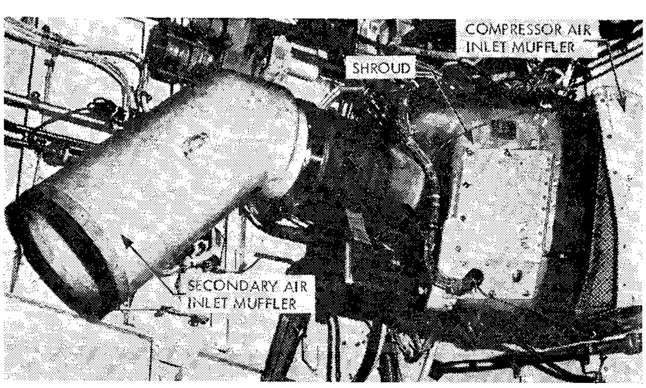
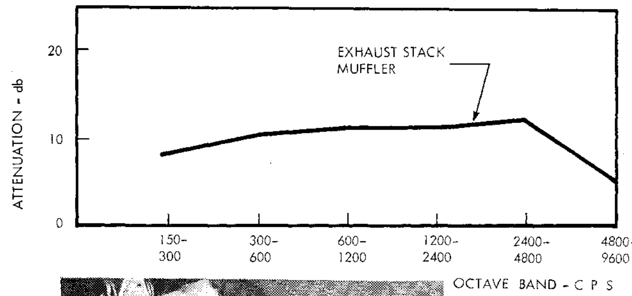


Fig. 17 Auxiliary power unit (APU) inlet mufflers.



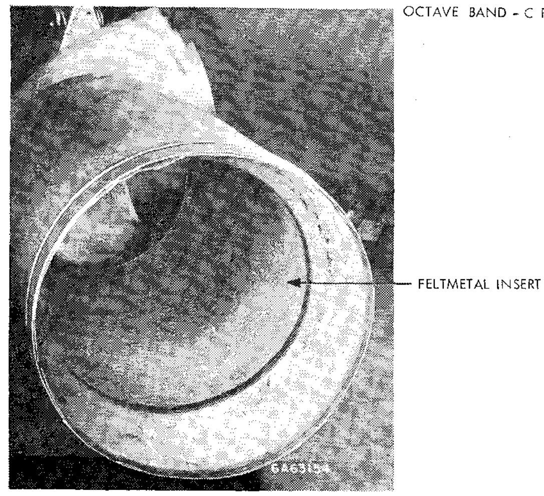


Fig. 18 Attenuation properties of APU mufflers.

This treatment absorbs mixing bay noise before it reaches the overhead duct.

Noise generated in high-velocity air-supply ducts is controlled with mufflers and Fiberglas blanket coverings. Restrictors in the mixing assembly and in distribution ducts are of perforated plates to minimize noise from these sources.

Equipment Isolation

Some types of aircraft equipment, especially those containing rotating or oscillating components, can, by means of structure-borne vibrations, create undesirable noise in the

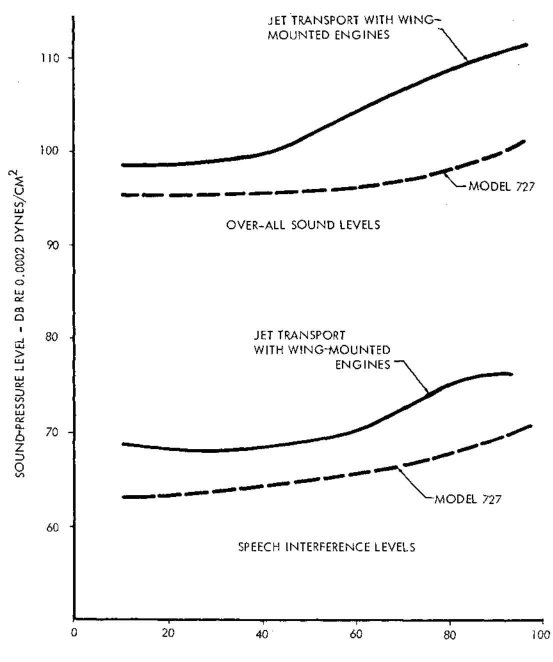


Fig. 19 Comparison of takeoff maximum sound levels.

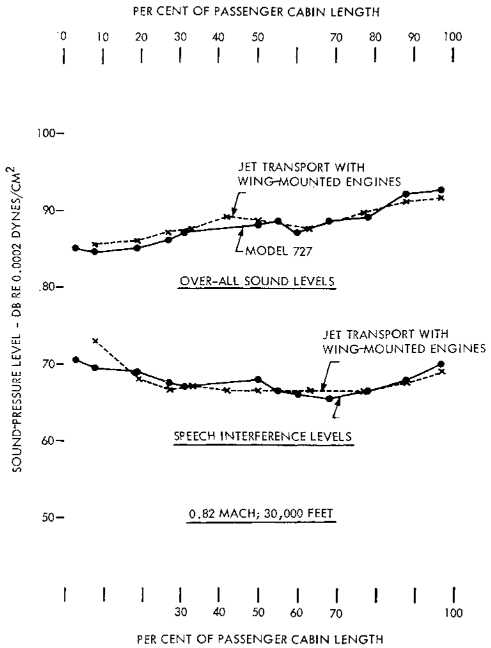


Fig. 20 Comparison of sound levels during cruise.

inhabited areas of the aircraft. In the Model 727, the noise from this type of equipment has been reduced by the use of vibration isolators.

Some examples of equipment that have been mounted on vibration isolators are the three turbofan engines, the auxiliary power unit, water coolers, hydraulic pumps, and air-conditioning ducts. The transmissibility curve for the engine vibration isolators is plotted in Fig. 16.

Auxiliary Power Unit Installation

An onboard auxiliary power unit installation improves the versatility of the 727 airplane, but it also creates many design problems to be overcome in providing a comfortable environment to passengers on the ramp and in the aircraft. Vibration levels caused by equipment rotation and sound energy radiated from the unit, from the compressor inlet, and from the exhaust must be controlled to provide the required passenger comfort. In the 727 installation, the unit is structurally isolated from the fuselage to reduce vibration levels in the cabin and has a shroud designed to be both a fire inclosure and an acoustical barrier. Compressor and cooling air and exhaust gases are passed through suitable mufflers.

Mufflers are designed for compressor inlet and cooling air passages using open-cell polyurethane foam covered with open-weave Fiberglas cloth (Fig. 17). The foam material absorbs acoustical energy, and the Fiberglas cloth serves two purposes: to protect the foam from erosion and to act as a mass-loaded diaphragm on the foam. This mass loading improves the low-frequency absorption properties of the foam, whereas the open-weave construction permits absorption of the high-frequency acoustical energy in the foam structure. Attenuation curves for these mufflers are also plotted in Fig. 17.

An exhaust muffler of sintered stainless steel has been designed for the auxiliary power unit, although it is not installed as standard equipment (Fig. 18). The sintered stainless steel is made with controlled acoustical properties from metal fibers ranging in diameter from 1 to 10 mils. In the production process, the metal fibers are felted to produce an interlocked nonwoven body sintered at high temperatures to produce microscopic metallic diffusion bond welds at all of the interfiber contact points. Acoustical energy is dissipated in this muffler by the oscillating passage of air through the resulting microscopic structure. The acoustic characteristics of the exhaust muffler are as shown in Fig. 18.

Interior Noise Levels

The passenger cabin of the 727 is particularly quiet during takeoff, climb-out, and approach. It is during these low-speed flight regimes that the rear mounting of the engines is most advantageous from an acoustic viewpoint. Comparative cabin noise levels for the 727 and a typical jet transport with wing-mounted engines during takeoff are shown in Fig. 19.

At the normal cruising speeds of Mach 0.8, or slightly higher, the 727 has about the same cabin noise levels as other modern jet transports. At these speeds, boundary-layer turbulence is the dominant source of noise, and the advantage of rear-mounted engines is nullified. Attenuation of the boundary-layer noise is achieved by the double-wall construction typical of the fuselage in all of the Boeing jets. Cabin noise levels during cruise are compared in Fig. 20.

Conclusion

The target for the acoustical design of the 727 has been to control noise both inside and outside of the plane. Noise sources have been identified and means selected to eliminate or reduce the most objectionable factors. This attention to noise control, when added to high performance and the natural advantage of having the engines mounted to the rear, has produced a sound level that has proved readily acceptable to the public.

Reference

[1] Kryter, K. D. and Pearson, K. S., "Some effects of spectral content and duration on perceived noise level," NASA TN D-1873 (April 1963).