15. FAN-DUCT DEVELOPMENT

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SUMMARY

The fan noise radiated from the fan discharge duct during the landing approach of current fan jet airplanes is the largest single contribution to the composite engine noise. The Boeing Company has designed and ground tested an acoustically treated long fan duct to reduce this component of engine noise. Data obtained during the tests show a reduction in the peak noise level of the treated duct over the existing duct of 9 to 16 PNdB for approach power settings at a distance of 370 feet. Engine thrust measurements indicate an increase in thrust of approximately 2 percent over the existing short duct. Flight-test fan ducts are being constructed for evaluation in mid-1969. It is estimated that the long treated fan ducts will increase the weight of each nacelle by approximately 750 pounds.

INTRODUCTION

The Boeing Company has been involved in the development and evaluation of a turbo fan nacelle modification to reduce fan noise since the fan whine emitted from the fan duct is the largest single contribution to the composite engine noise. The basic program goal is a 15-PNdB noise reduction of a Boeing 707-320B airplane during landing approach and is to be accomplished by attenuating the fan-duct component of noise by this amount.

The program for development of an acoustically treated fan duct was divided into three phases: (1) a trade study of various concepts was made to aid in the selection of a configuration; (2) a ground-test duct was designed and tested for performance evaluation; and (3) four flight-test ducts are being constructed for flight evaluation in mid-1969.

OBJECTIVES

An attenuation goal for the fan duct is shown in figure 1. The goal was selected to give the peak attenuation at the fan frequency during the approach condition. A peak attenuation of 30 dB is required and a suitable bandwidth was selected to obtain the required attenuation over the range of power settings associated with a normal approach. Figure 2 shows a typical sound level spectrum of the peak noise attributed to the fan duct at an engine speed of 5000 rpm. The data were obtained from ground tests of a production untreated duct and were adjusted to a 370-ft distance. The effects of the selected attenuation goal are also shown and indicate the sound level required to achieve a peak noise reduction of 15 PNdB.

The noise reduction must be accomplished without imposing a severe penalty on the performance of the airplane. The current production fan duct on the 707 airplane shown in figure 3 is very short in length. It was designed to minimize the weight and external drag of the nacelle. The limited length and cross-sectional area are not sufficient to install a significant amount of acoustic material. It is necessary to design a substantially longer duct to contain the required amount of acoustic material. This will mean an increase in the nacelle size and weight and will result in an increase in the internal and external drag of the nacelle. The short duct, however, discharges high-velocity air over the nacelle afterbody causing a significant amount of scrubbing drag. This drag can be reduced with a longer duct. A long duct design will require that the duct be bifurcated to clear the support strut at the top of the nacelle and the engine accessories at the bottom to maintain sufficient ground clearance.

TRADE STUDY

To obtain an insight into the most reasonable compromise of fan-duct length, cross-sectional area, and shape, a trade study was made. A number of duct design concepts were studied to determine the amount of acoustic treatment required and the effect on airplane performance. Three of the concepts studied are illustrated in figure 4. This study led to the selection of concept 3 for further development. Concept 1 extended to about seven-eighths of the length of the nacelle and had a kidney-shaped cross section and nozzle. Concept 2 was a full-length duct with a kidney-shaped cross section and nozzle. Concept 3 was also a full-length duct. The cross section was changed to an elongated kidney shape to reduce the internal turning losses and to decrease the separation distance of the acoustic material from approximately 9 to 7 inches. A coplanar annular nozzle was used. All the concepts had the duct divided into five channels on each side to control the turning losses and provide for the structural design. The trade between duct internal flow area and nacelle maximum diameter was studied by considering three duct flow areas at the nacelle maximum diameter. The areas provided for (1) a contraction from 828 sq in. at the fan exit to a flow area of 660 sq in., (2) a constant flow area for much of the duct length, and (3) an expansion from 828 sq in. at the fan exit to a maximum flow area of 900 sq in.

An analysis of the airplane performance was made using a constant payload and field length to determine the effect on range. Consideration was given to the internal flow losses, weight, and external drag of the various concepts. The changes in range as compared with the range of the production airplane are shown in figure 5 for the various flow areas considered. Concept 3 with a maximum flow area of 900 sq in. has the least effect on airplane range.

The acoustic analysis of these concepts (fig. 6) determined the peak noise reduction as a function of the treatment length. The elongated kidney shape with the smaller treatment separation distance required approximately 67 inches of treatment length to meet the 30-dB peak attenuation goal; whereas, the kidney shape required an additional 15 inches. The analysis was based on experimental data obtained in duct flow tests. Other experimental and theoretical data indicate that an additional noise reduction of about 4 dB can be achieved with coplanar concentric nozzles. These results along with the performance analysis indicated the selection of concept 3 for further development.

The configuration selected (fig. 7) has an internal contour developed from the geometry indicated by the trade study. It was designed in four sections: A bifurcated section turns the flow from the annular fan exit to the bifurcated elongated kidney shape and also expands the flow from 828 sq in. at the fan exit to 900 sq in. A linear flow-area distribution was chosen to preclude a large local diffusion. The constant-area section will contain most of the acoustic material. The flow area is a maximum through this section to give a low velocity over the rough acoustic material and reduce the internal losses. The transition section provides the change from the elongated kidney shape to the annular nozzle, The flow area through this section was determined by the space available between the engine and the required external nacelle contour, The nozzle is annular and approximately coplanar with the primary nozzle.

A 1/5-scale model of the internal configuration of the duct was tested. Measurements of thrust, airflow, and pressure loss confirmed the estimated internal losses used in the trade study.

GROUND-TEST DUCT

A full-scale ground-test duct was constructed to verify the estimated acoustic and propulsion performance. The selected internal configuration was used and the duct was designed so that only minimum changes to the engine systems would be required. Each half of the duct was constructed in four sections as shown in figure 8. The bifurcated section was constructed of epoxy-fiber glass. The side cowl is constructed of polyimide-fiber glass sandwich honeycomb that is designed to provide for both the acoustic and structural requirements. A cost and weight study indicated the use of polyimide-fiber glass construction in this area. A thrust reverser was not developed for this configuration,. but a space provision was provided. The transition and nozzle section is constructed of aluminum sheet and frames. It has a 30-inch-long polyimide-fiber glass acoustic insert panel at the forward end. The panel is removable and will be used to determine the effect of extending the treatment length.

The acoustic treatment used in the side cowl consisted of double-layer treatment in the outside wall and single-layer treatment on the splitters and inside wall. The treatment depth selected to provide noise reduction over the selected bandwidth was 1.0 inch for the double layer and 0.5 inch for the single layer. The flow resistance of the material varies from 5 to 35 rayls for the double layer and from 6 to 30 rayls for the single layer. The value at any location is a function of the local sound pressure level and flow Mach number.

The acoustic treatment for the aft insert panel is the same as for the side cowl, except that the inside wall is not treated. Including the panel there is a total of 267 sq ft of acoustic treatment. This is in excess of the estimated amount required to account for manufacturing problems, accuracy of predictions, and possible deterioration in acoustic effectiveness due to contamination.

Ground tests were run on a test stand at a remote location. Baseline tests of the existing production short duct and the full-length treated ground-test duct have been completed. The tests were run both with and without suppressed inlet noise. The results obtained indicate that the inlet radiated noise interferes with the measurements of duct radiated noise when the inlet noise is not suppressed. All data shown were recorded with the inlet noise suppressed. Acoustic data were obtained from 24 far-field microphones (fig. 9) located around the engine in both horizontal and vertical planes.

Analysis of the data was made in preferred 1/3-octave bandwidths with a signal integration time of about 6 seconds. Perceived noise levels were computed for both horizontal and vertical measurements using sound-pressure-level corrections for distance, atmospheric absorption, and ground absorption when applicable. Noise levels measured from one engine at a distance of 200 ft were considered approximately equal to values for four engines at 370 ft (inverse square relationship and correction for atmospheric absorption).

Preliminary results for the existing duct and the treated duct configuration for three test conditions are shown in figures 10, 11, and 12. The data from both the horizontal and vertical measurements were adjusted to a distance of 370 ft. The engine conditions shown correspond to static thrust settings that approximate in-flight thrust at approach, cutback, and take-off. Values of peak noise reduction between the existing duct and the treated duct configuration for both the horizontal and vertical planes are shown as a function of static thrust in figure 13. Estimated reductions in peak perceived noise level take into account the data scatter between runs and give both maximum and minimum values as shown in figure 14. Although the perceived noise levels computed from the horizontal measurements do not compare directly with the values computed from the vertical measurements, the reductions agree well.

Typical spectral data of the peak noise attributed to the fan duct are shown in figure 15. The data were recorded at 5000 rpm at 110° in the horizontal plane. The data are adjusted to a 370-ft distance. Data accumulated during the test indicate a reduction in peak noise level of 9 to 16 PNdB. The data also show a reduction of 2 to 6 dB in sound pressure level at the frequencies associated with the jet noise. This reduction is attributed to the coplanar annular nozzle configuration. The magnitudes of the peak frequencies have been reduced substantially more than the broadband level. This reduction indicates the presence of a broadband background noise in the 2 to 6 kHz range that limited the noise attenuation measured. Further testing of the treated long duct is planned to provide better definition of the broadband background noise. A more accuracte evaluation of the treated duct will be made when a fully treated nacelle is tested.

Measurements of thrust, fuel flow, and duct pressure losses were made to evaluate the internal performance. The propulsion performance of the engine with the treated duct is shown in figure 16. Gross thrust measurements indicate approximately a 2-percent increase in thrust over the standard production duct. The increase is attributed to the relatively small internal loss and the absence of a scrubbing drag.

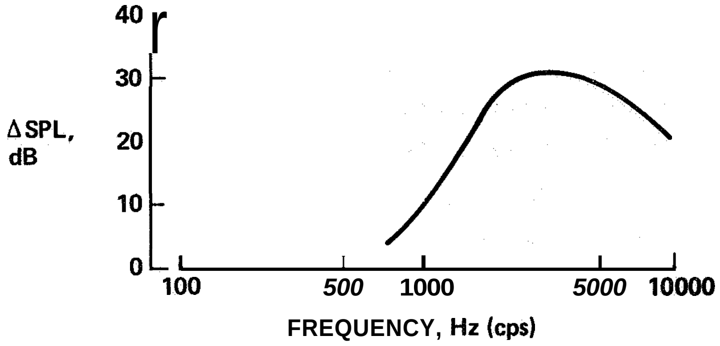
FLIGHT-TEST DUCT

A flight-test configuration of the duct (fig. 17) has been designed and is currently under construction. The design is similar to that for the ground test and uses much of the same tooling for manufacture. The internal contour has only minor changes and the external contour was modified to conform to flight requirements. Flight tests are planned for mid-1969.

The amount and location of the acoustic treatment are the same as for the ground test but treatment has been changed. Recent experimental data indicate that a suitable combination of single-layer treatment will meet the target attenuation. The single-layer treatment is much simpler to manufacture and less costly. The treatment depths are 0.75 inch on the outer walls, 0.50 inch in the splitters, and 0.30 inch on the inner wall. The aft acoustic panel has been modified to be part of the nacelle structure. The flow resistance of the acoustic treatment will vary from 18 to 30 rayls. It is estimated that the flight-test treated long duct will increase the weight of each nacelle by approximately 750 pounds. The design will also reduce ground clearance by approximately 3 inches.

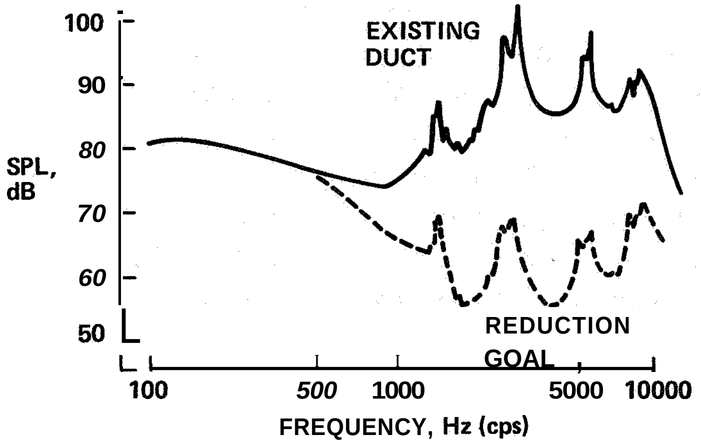
CONCLUDING REMARKS

The noise reduction goal of 15 PNdB for a Boeing 707-320B airplane during landing approach appears feasible. Ground tests indicate that the acoustically treated long fan duct will result in a gain in thrust of approximately 2 percent at take-off conditions. The fan-duct modification will result in a weight increase of approximately 750 pounds for each nacelle.



FAN-DUCT ATTENUATION GOAL
5000 rpm, 370 ft

Figure 1



FAN-DUCT PEAK NOISE REDUCTION
5000 rpm, 370 ft

Figure 2

EXISTING NACELLE

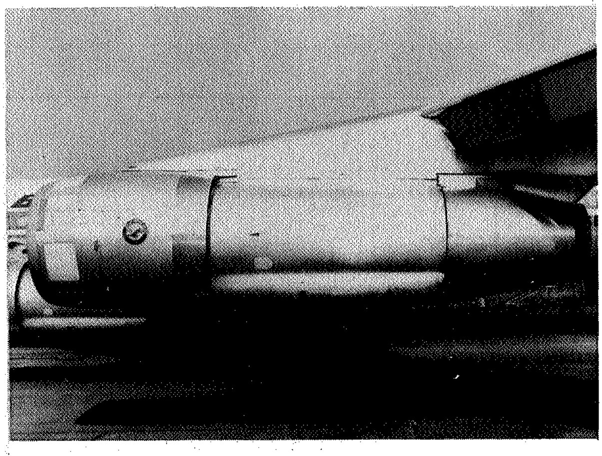


Figure 3 L-68-8573

TRADE STUDY CONCEPTS

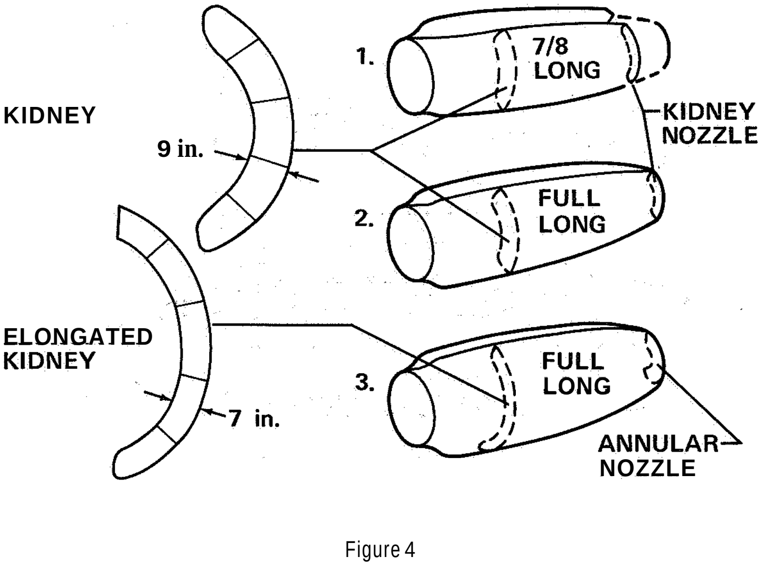


Figure 4

DUCT PERFORMANCE ANALYSIS

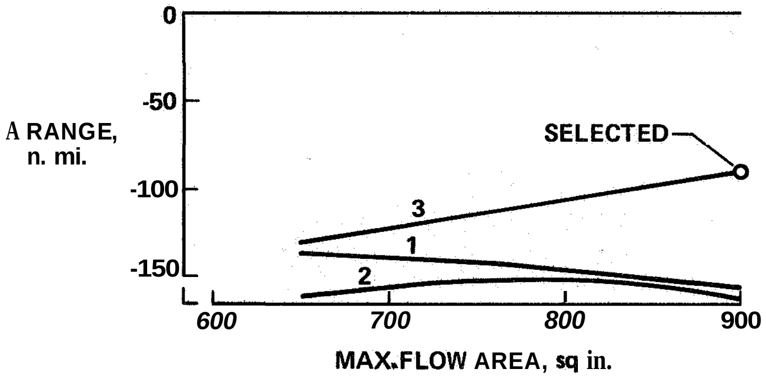


Figure 5

ACOUSTIC ANALYSIS

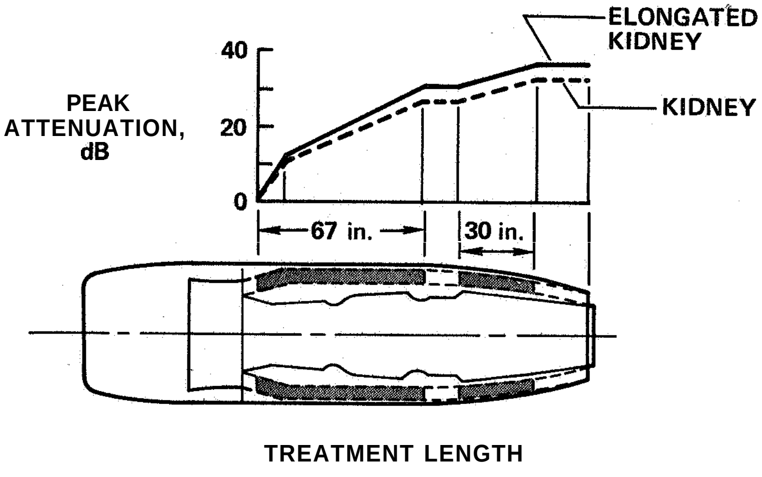


Figure 6

SELECTED DUCT CONFIGURATION

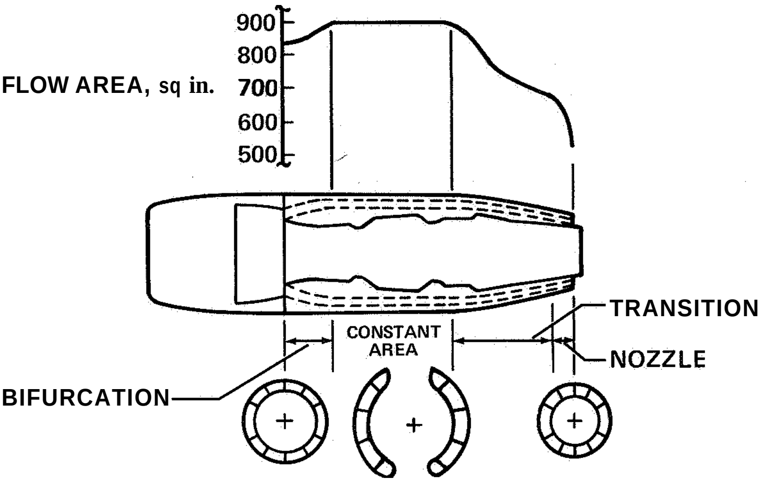


Figure 7

GROUND-TEST CONFIGURATION

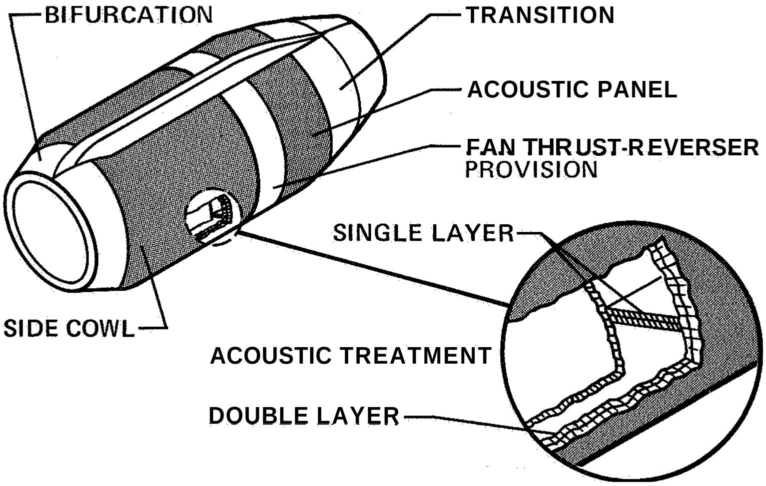


Figure 8

FAR-FIELD MICROPHONES

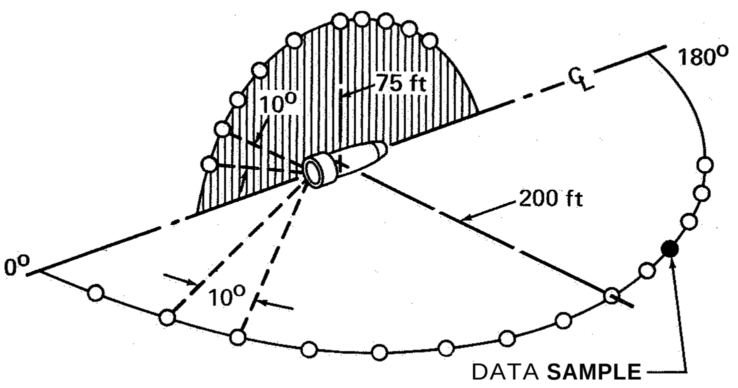


Figure 9

FAN-DUCT NOISE

5000 rpm; 370ft

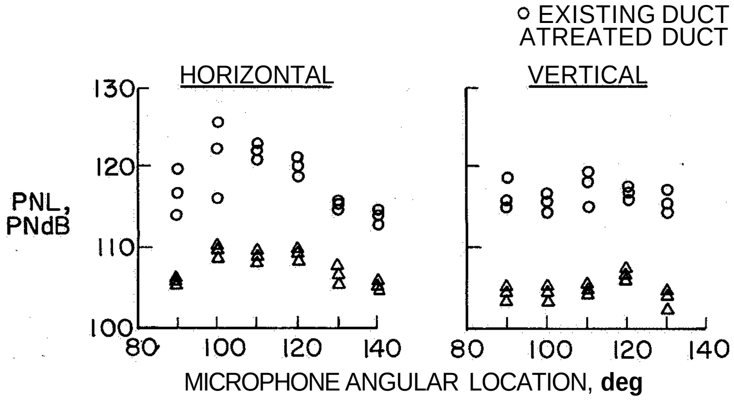


Figure 10

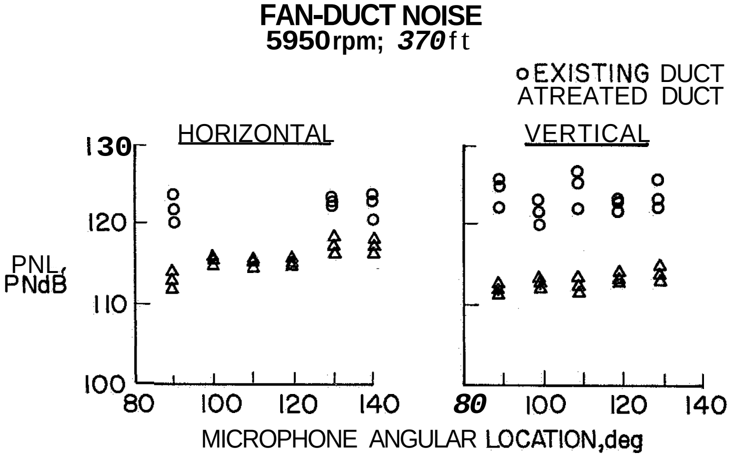


Figure 11

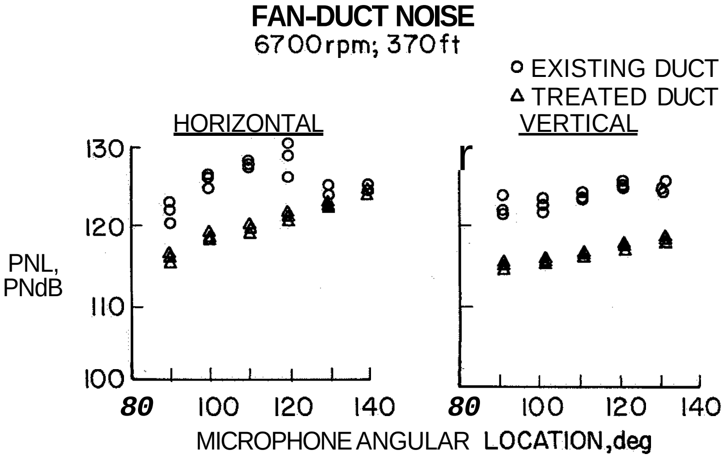


Figure 12

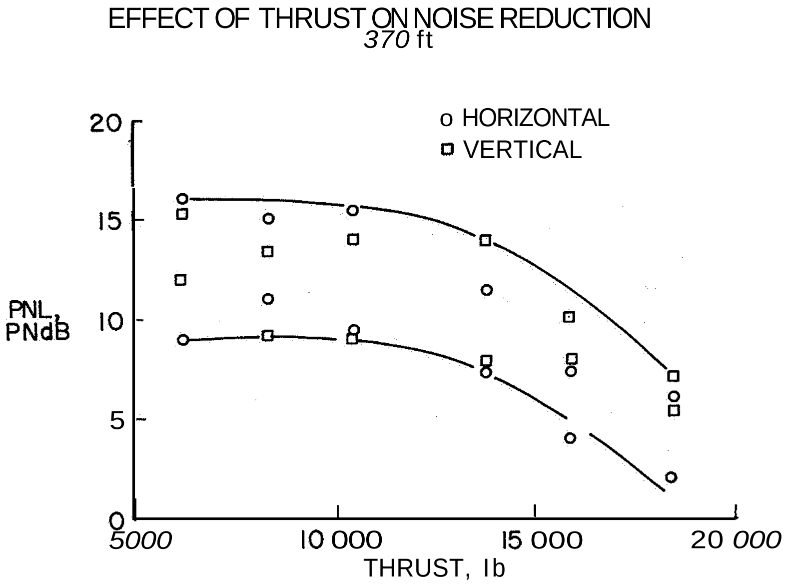


Figure 13

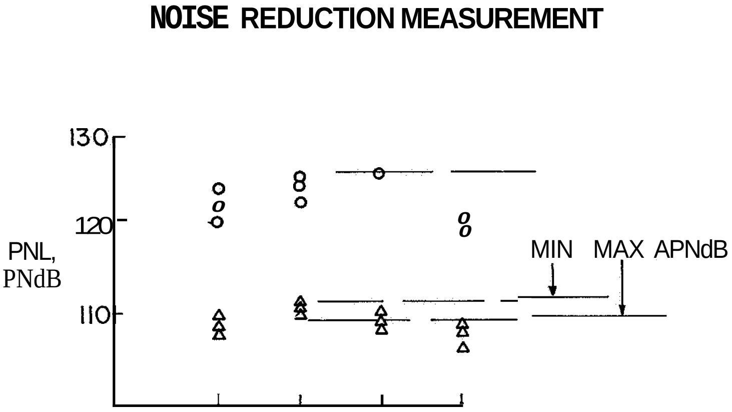


Figure 14

ACOUSTIC RESULTS GROUND-TEST DUCT

5000 rpm, 370 ft

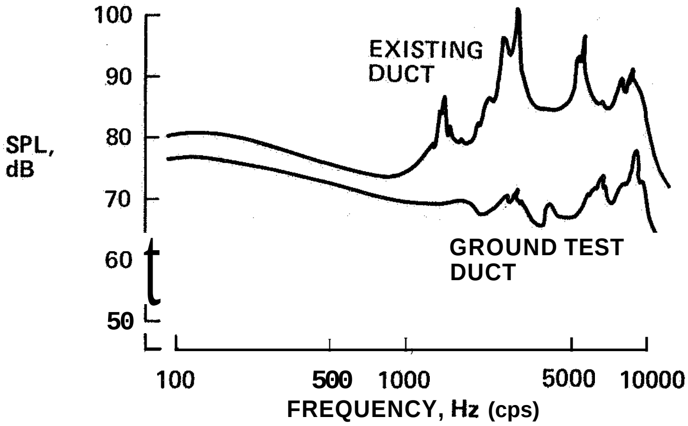


Figure 15

GROUND-TEST ENGINE PERFORMANCE

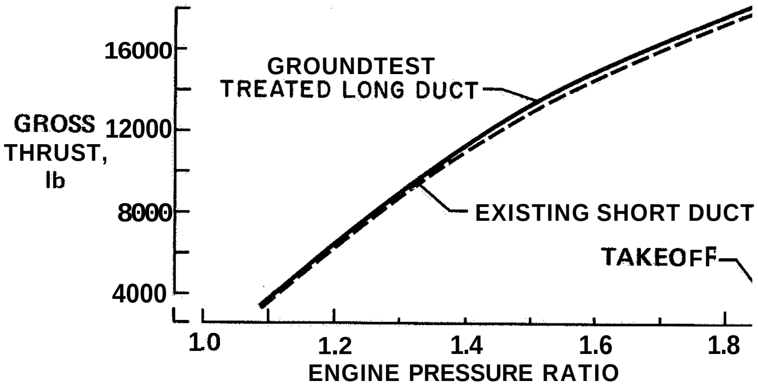


Figure 16

FLIGHT-TEST FAN DUCT

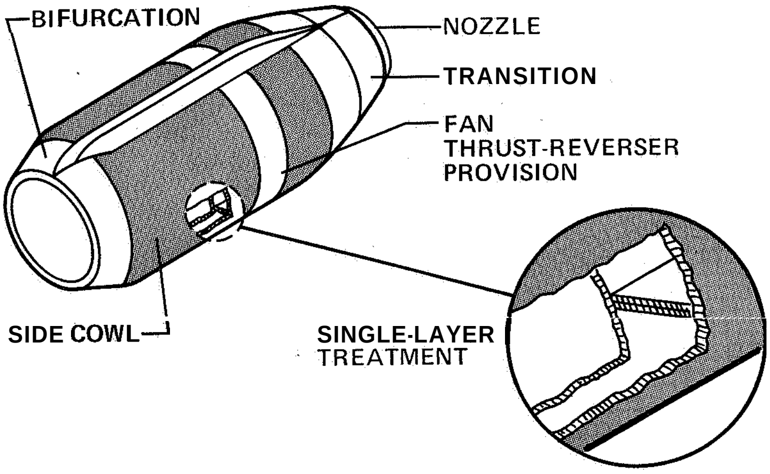


Figure 17