# 14. TREATED INLETS

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## SUMMARY

The fan noise radiated from the inlet during approach of a Boeing 707-320B airplane is 5 PNdB lower than the noise radiated from the fan exhaust duct. Available information indicates that the inlet noise suppression of 10 PNdB required for an overall airplane fan noise suppression goal of 15 PNdB can be achieved with an acoustically treated inlet. The Boeing Company has designed and is manufacturing acoustically treated inlets for ground and flight tests in mid-1969.

## INTRODUCTION

The development of technology to reduce the fan-generated noise of the Boeing 707-320B airplane by 15 PNdB has been the task of the Boeing Company under contract no. NAS1-7129 since May 1967.

Studies of the peak perceived noise levels (PNdB) associated with the JT3D-3B turbofan engine with which the airplane is equipped indicate that with the airplane at an altitude of 400 feet, the contribution of the inlet noise to the total perceived noise level is 5 PNdB lower than the fan exhaust noise. Component noise levels and their relationship to the total are shown in figure 1. To meet a target of 15 PNdB reduction in peak perceived noise, it is therefore required to reduce the forward radiated noise contribution by 10 PNdB.

The reduction of fan inlet noise sound pressure levels (SPL) required to achieve a 10 PNdB reduction in perceived noise level is shown in figure 2. The effect of this attenuation on a typical sound pressure level spectrum of the noise radiated from the inlet is shown in figure 3. The peak noise level after treatment occurs at about 5 or 6 thousand cycles per second. This level is acceptable since these frequencies have less influence on perceived noise level as measured in PNdB than the lower frequencies have. At the start of the program it was expected that a sonic or near-sonic inlet would be required to accomplish the required 10 PNdB suppression of inlet noise. Tests by McDonnell Douglas have demonstrated that this much noise reduction can be achieved with a treated inlet. It was therefore decided to postpone flight testing of a sonic or near-sonic inlet and to design and flight test treated inlets in combination with the acoustically treated fan ducts already under development at Boeing.

# CONCEPTS

In the evaluation of any concept designed to meet the target attenuation, consideration must be given to the effect on the propulsion performance of the inlet. Small decreases in pressure recovery can cause significant changes in the performance of the airplane. In general, the performance of the inlet can be influenced by the amount of acoustic material used, the length of the inlet required, and the flow diffusion efficiency. It is desirable to use the least amount of acoustic material required and to arrange it in a configuration that provides the minimum pressure loss.

The quantity of treatment required in an inlet to meet the target noise reduction depends upon the radial distribution of the acoustic pressure level in the inlet, the cross-sectional areas of the flow channels formed by the insertion of the acoustic material, and the separation distance of the acoustic material. Experimental data have shown that the sound pressure level near the outer wall of the inlet is higher than that near the center. To obtain uniform acoustic performance across the inlet, the amount of attenuation provided must also vary across the inlet.

Since the effect of an acoustic lining in an engine inlet is very dependent upon the distribution of treatment across the inlet, a number of different configurations were studied before the 2-ring inlet, similar to the inlet tested by McDonnell Douglas and identified as concept **1** in figure **4**, was selected for design development. Some of the other concepts studied are also shown. In all cases acoustic treatment was used on the inlet wall and on the center body and an increase in the length of the typically short Boeing inlet was required.

The first concept studied was a 2-ring inlet similar to concept **1** but with only three untreated radial struts. Three struts would give adequate support to the treated rings. However, it was found, through coordination with Pratt & Whitney, that the wakes from three struts, if strong enough, would set up harmonic frequencies in certain compressor blades and could develop unacceptably high blade stress. Coordination with Pratt & Whitney established that the minimum number of struts that could be used without extensive testing or analysis to assure no adverse effect on blade stresses was eight. This information led to studies of the other configurations.

By using the prediction techniques developed in the flow duct and full-scale tests of the fan-exhaust duct program, the amount of acoustic treatment required to meet the target attenuation was estimated for each configuration. It was found that treated radial struts would require more acoustic treatment than rings would require to produce the same attenuation. This effect is due to the fact that the radial splitters have the largest treatment separation distance at the cowl wall where the maximum attenuation is required.

The inlet pressure loss for each configuration was estimated by computing the friction drag of the inlet from the flow velocity, the wetted area, and the local skin-friction coefficient. The velocity distribution through the inlet was based upon one-dimensional net area distribution. The skin-friction coefficient for the acoustic material was based upon experimental data that indicated a value 1.5 times greater than that for a smooth flat plate. The results are presented in table I along with the estimated weight of the various configurations. The pressure loss study did not account for diffusion losses or losses that might be generated by any local flow separation or turbulence.

## CONCEPT SELECTION

The trade study results show that the ring concept requires significantly less acoustic treatment than radial struts. Consequently, the inlet flow losses are smaller and the weight increase is less. The ring concept was selected for further development.

A ring-placement trade study was made to optimize the radial spacing of the rings and to determine the length of treatment required. A computer program was run to determine the noise reduction obtained from various radial spacings of the rings. The results were based upon various selected flow channel lengths and the center body and cowl wall configuration selected from flow studies. The study indicated that maximum attenuation is achieved with approximately equal spacing of the rings.

By using lining technology developed in the fan-exhaust-duct program, the depth of treatment was selected as 0.3 inch and 0.6 inch on opposite walls of each flow channel to obtain the attenuation over the required freque'ncy bandwidth. The treatment depths were arranged to give the thinnest rings. The flow resistance of the acoustic material was varied with channel length to conform to changes in local sound pressure level due to progressive attenuation. The configuration is shown in figure 5. Boeing developed polyimide-fiber-glass sandwich was selected as the acoustic material. The acoustic sandwich is made of porous sheets, with the selected flow resistance, bonded to honeycomb of the size and thickness selected to provide the required resonance chamber and then bonded to an impervious sheet or, in the case of the rings, to an impervious septum. These sandwiches, in addition to providing noise attenuation, are the basic structures of the cowl wall and both rings. Treatment on the center body is nonstructural.

For the flight-test program a conservative lip design was selected to assure adequate take-off performance since the design would have little effect on the noise reduction and the cruise performance of a more optimum configuration can be reasonably well estimated. The wall contour at the throat is a 2.5 to 1 ellipse and the contraction ratio is 1.25. The throat area is the same as the current production inlets.

The internal cowl contour was developed from consideration of the flow area through the inlet. It was found that a 31-inch-long production 707 center body modified to accept acoustic treatment would provide adequate treatment length and reasonable flow channel heights. Acoustic requirements determined the approximate radial location,' thickness, and length of the rings. The station locations of the rings and the cowl wall contour were adjusted to provide a nearly linear flow area distribution through the inlet as shown in figure 6. The length and thickness of the acoustic treatment in the rings was carefully controlled so that the cowl wall angle would be small. An inlet length of 45 inches was selected so that the wall angle would not exceed 9°. The exact shape and placement of the rings were determined from potential flow studies. A computerized relaxation procedure solving the incompressible and compressible potential flow problem was used to map out the streamline patterns and surface velocity distributions for the basic cowl and nose dome configuration. The rings were then fitted to specific streamlines. The complete inlet configuration was then examined by use of the potential-flow program and a boundary-layer program to analyze the flow characteristics at both cruise and take-off conditions. The results showed that in the region of the rings, there was no significant change in the streamline patterns for take-off and cruise conditions. The effects of a crosswind were estimated for take-off conditions from a two-dimensional Streamline pattern with the flow center line. It was concluded from comparing the respective flow patterns that a maximum 3° change in angle would exist at the leading edge of the inner ring and that there would be no appreciable angle difference at the outer ring. The leading- and trailing-edge contour of the ring are based on NACA 64 series airfoil sections and the strut contours are based on NACA 0012 airfoil sections. The basic contour for the external lines was selected as a NACA 1 series with a length of 60 inches and a maximum height of 6.40 inches. However, because of the noncircular shape of the nacelle and the 3.50 droop of the inlet, only the horizontal profile can exactly comply with this requirement. The remainder of the contour was faired as necessary to account for the diameter variations.

The scheduling of this part of the program has precluded any preliminary tests, model or full scale, of this design. The inlet will be ground tested prior to flight to insure adequate flight performance. The estimated performance of the treated inlet, based upon one-dimensional-flow analysis, indicates 1.2 percent less pressure recovery than the current production inlet. The take-off performance should be equal to that of the production inlet.

## CONCLUDING REMARKS

The acoustic design of the inlet was based upon meeting the target attenuation. Consideration has been given to possible loss of acoustic effectiveness due to experimental variations and manufacturing problems and a conservative approach to acoustic design has been used. It is expected that the inlet will meet the noise reduction goal. The estimated inlet performance shows some pressure recovery loss. This loss, the weight increase due to increased inlet length, and the addition of ring struts will result in reduced airplane performance.

TABLE I

## TRADE STUDY RESULTS

### 20-dB PEAK ATTENUATION

| CONCEPT | TREATMENT REQUIRED, ft $^2$ | PRESSURE RECOVERY LOSS, % | WEIGHT INCREASE, lb | LENGTH INCREASE, in. |
|---|---|---|---|---|
| 1 | 84 | 1.2 | 93 | 10.5 |
| 2 | 113 | 1.3 | 134 | 10.5 |
| 3 | 119 | 1.5 | 143 | 10.5 |
| 4 | 157 | 1.7 | 201 | 17.5 |

## TURBOFAN NOISE

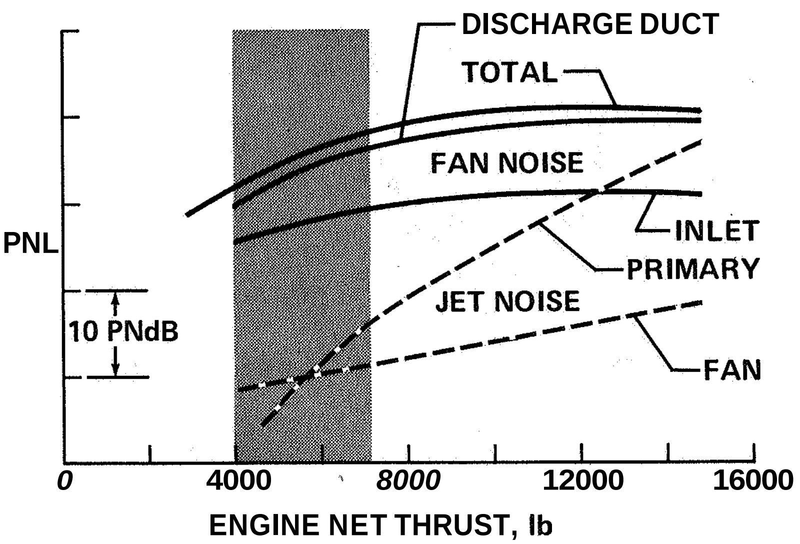


Figure 1

## INLET NOISE REDUCTION GOAL

5000 rpm

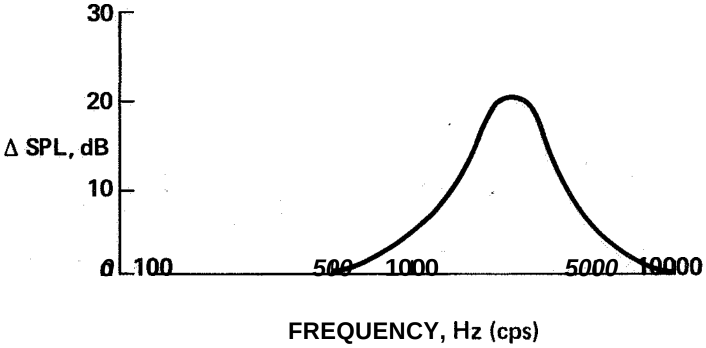
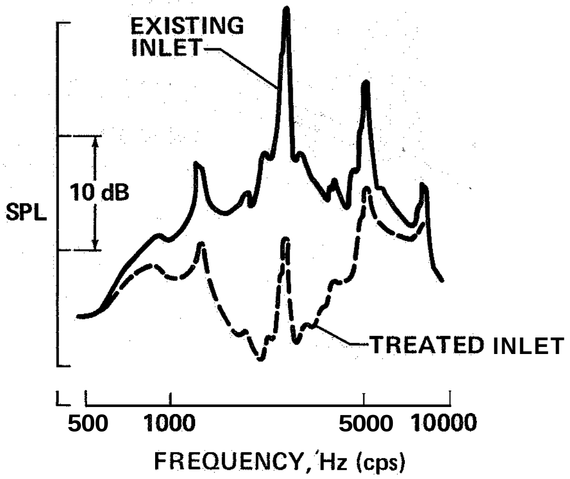


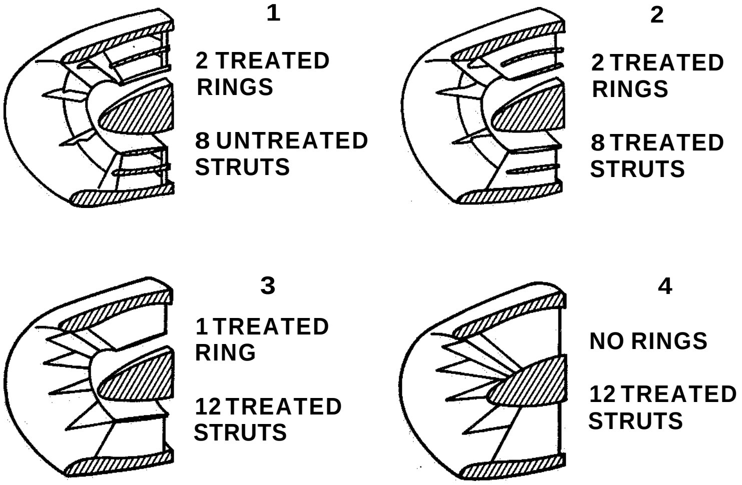
Figure 2



INLET PEAK NOISE REDUCTION

*5000* rpm

Figure 3



INLET CONCEPTS

Figure 4

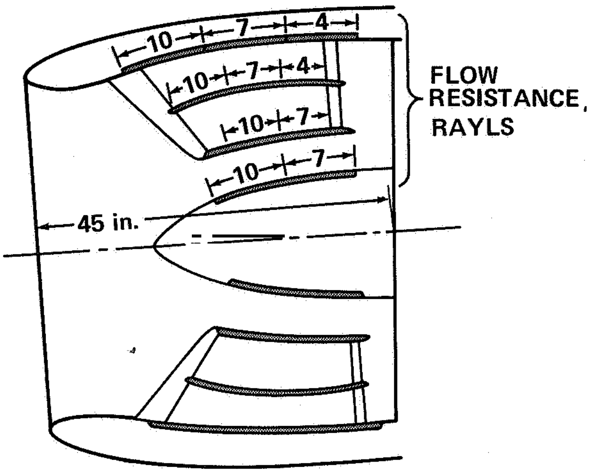

CONFIGURATION

Figure 5

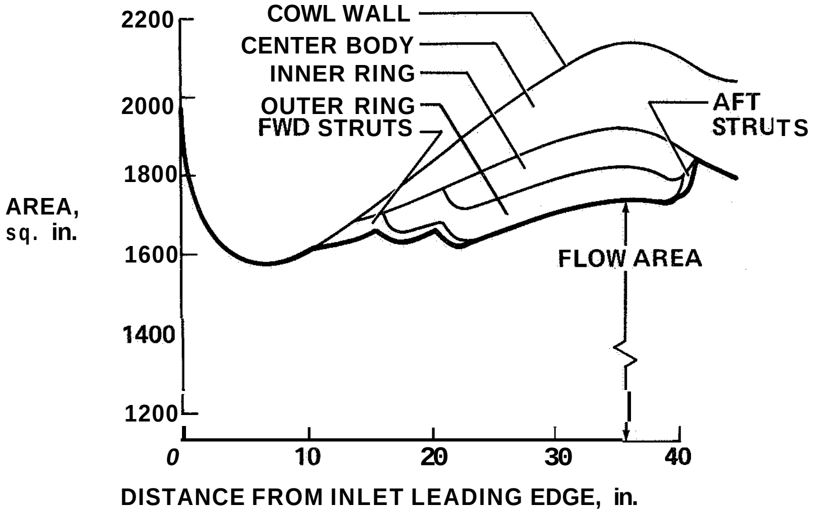

INLET AREA DISTRIBUTION

Figure 6