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JET NOISE OF AN AUGMENTOR WING-ADVANCED SUPERSONIC TRANSPORT

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This information is being published in preliminary form in order to expedite its early release.

ABSTRACT

A preliminary mission study was made of the range and jet noise of an advanced supersonic transport (AST) employing an augmentor wing and four duct burning turbofan engines. The airplane weight and aerodynamic characteristics of the Boeing 2707-300 airplane with a gross weight of 750 000 pounds and 234 passengers was used for the study. Engine thrust was fixed at 58 000 pounds per engine and engine size was increased to obtain the required thrust at reduced power settings for jet noise reduction.

Turbofan engine core noise was reduced to FAR 36 noise levels and lower by proper selection of turbine inlet temperature, bypass ratio and fan pressure ratio. The study showed that an augmentor wing can reduce the bypass jet noise sufficiently so that total noise levels below FAR 36 can be attained without significant range penalties if the augmentor wing can be designed without severe weight and performance penalties.

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SUMMARY

A preliminary mission study was made of the range and jet noise of an advanced supersonic transport employing an augmentor wing concept and four duct burning turbofan engines. The results of the study show that noise levels 20 dB below those of FAR 36 can be achieved without severe range losses providing the augmentor wing would not be considerably heavier than a conventional AST wing. High duct burner temperatures (3100° F) are required posing a severe insulation problem of the wing bypass gas ducts. This problem may be reduced by ducting the unheated air through the wings and providing remote burners ahead of the wing discharge nozzles. Significant increases in wing thickness to accomodate the bypass ducts may not be necessary if sonic flow can be employed for the bypass gas.

INTRODUCTION

One of the major deficiencies of the Boeing SST when the program was stopped was excessive sideline noise. Several fixes were being considered. One was to use jet noise suppressors with afterburning turbojets. All efforts to date resulted in excessive range penalty (over 400 n.mi.). Another approach was to use oversize fan engines in combination with a modest jet noise suppressor (about 5 dB suppression). This study considers a more radical approach - duct burning turbofans in conjunction with an augmentor wing. During takeoff the fan flow is ducted to the wing and exhausted at the wing trailing edge through an ejector made up of the wing flaps. In addition to providing a high lift capability, mixing of the fan air with ambient air between the flaps provides a means of reducing the fan air jet noise so that only engine core noise would be the dominant airplane noise during takeoff. The engines would operate in the conventional manner during the rest of the flight.

This report presents the results of a preliminary mission study on the effect of duct-burning turbofan core-jet noise on the range of a Mach 2.7 advanced supersonic transport (AST) and the reductions in total jet noise that may be possible by the use of an augmentor wing concept. The data presented in this report provides some insight into the attractive possibilities for quiet engines for an AST if the augmentor wing concept can be employed without undue deterioration of airplane performance or weight penalties.

METHOD OF ANALYSIS

The analysis considered the variations of range and core noise first. The reduction in bypass jet noise and total jet noise using an augmentor wing were then estimated.

The Boeing 2707-300 airplane having a gross weight of 750 000 pounds and 234 passengers, was chosen as a typical fixed-wing AST design. The empty-weight estimate without engines is 237 700 pounds or 31.7 percent of the gross weight. The four duct-burning turbofan engines have an overall pressure ratio of 12 at the sea-level-static design point. The design turbine inlet temperature and duct-burner temperature are 2400^{o} and 3100^{o} F, respectively. The bypass ratio and fan pressure ratio were varied to determine their effect on core-jet noise and mission range. Installed engine weights varied with bypass ratio and fan pressure ratio and were estimated from an empirical equation from reference 1. A takeoff thrust of 58 000 pounds per engine was assumed to keep the lift-off distance within acceptable limits. To obtain the required thrust, engine size was increased as either duct burner or turbine inlet temperature was decreased from the design values for noise reduction. For the fixed gross weight, payload, and empty weight then, the variations in range are chiefly the result of the tradeoff between engine weight and performance.

Calculations for the augmentor wing were performed for a duct-burner temperature of 3100^{o} F and the fan pressure ratio that optimized range for minimum core noise for each bypass ratio. Simplified mixing calculations were performed to determine the exhaust velocities and thrust of the augmentor wing. The bypass gas was assumed to be discharged from a wing trailing edge slot through an ejector made up of the flaps. Perfect, constant-area mixing was assumed with a mass ratio of air to bypass gas of 2. Change in aircraft weight and aerodynamics due to the augmentor wing were not investigated.

The jet noise calculations followed the procedures outlined by the Society of Automotive Engineers. The noise of the Boeing SST was satisfactory except for sideline noise. Thus, in this study only noise at 0.35 n.mi. sideline was evaluated. The airplane was assumed to be at an altitude of 800 feet and a flight Mach number of 0.35, the approximate conditions for maximum sideline noise.

DISCUSSION

The augmentor wing provides a means of quieting the bypass gas jet noise and the core jet noise can be reduced by the proper selection of bypass ratio, fan pressure ratio, and turbine inlet temperature. The first part of the discussion considers the effect of these parameters on core jet noise and mission range. The effect of the augmentor wing on total jet noise and mission range and some of the problem areas are then discussed.

Core Jet Noise

Figure 1 illustrates the effect of duct-burner temperature and core noise on range for a bypass ratio of 1.5. The fan pressure ratio of 3.2 indicated in the figure resulted in the best range for the low noise levels required. Total jet noise is also shown for comparison (the dashed curve) indicating the rapid loss in range as engine size and weight must be increased with lower power settings to reduce jet noise. For this curve reduced power is obtained by reducing the duct-burner temperature, since the bypass noise is dominant, holding the turbine inlet temperature constant at 2400° F. When the bypass noise is ignored (solid curves), part-power operation is obtained with lower turbine inlet temperatures for each duct burner temperature. For a given noise level and takeoff thrust requirement, engine size is decreased with higher duct burner temperatures and since the bypass jet noise is ignored, the best range is obtained with the highest duct-burner temperature (DBT) of 3100° F. To meet the FAR 36 sideline noise level of 108 PNdB, engines with 3100° F DBT would be operated at 82 percent maximum power and engine size increased from 700 lb/sec airflow to 800 lb/sec, resulting in a range loss of only 40 n.mi..

For a noise level of FAR 36-10 dB, 66 percent maximum power would be required, increasing engine size to 1100 lb/sec airflow and a range penalty of 350 n.mi.. If practical limits force the use of lower duct exhaust temperatures, airplane performance suffers drastically. At 1000° F, there is a loss of 710 n.mi. at FAR 36 and FAR 36-10 dB cannot be attained at all. To achieve the desired high temperature levels may require exotic materials and/or insulation; although the problem is eased by the short-term nature of the heating (i.e., only during takeoff and landing). Alternatively, we might duct only unheated bypass air through the wing and provide a remote burner just ahead of the wing discharge nozzles. (Other duct problems associated with size are discussed later.)

Figure 2 shows the effect of duct burner temperature and core noise on range for a bypass ratio of 3. Since larger bypass ratios extract more energy from the core flow, reducing core jet velocity, the core jet noise for a bypass ratio of 3 is much less than that for a bypass ratio of 1.5. At full power the core noise is only 84 PNdB (FAR 36-24 dB) and there is only a modest range penalty of about 60 n.mi. compared to a bypass ratio of 1.5 and core noise of 108 PNdB. Although engine weight decreases with increasing bypass ratio, the cruise specific fuel consumption increases resulting in the range loss. Similar to the 1.5 bypass ratio there is a severe range penalty of 710 n.mi. incurred by reducing duct burner temperature from 3100° to 1000° F at a noise level of 84 PNdB.

Figure 3 shows a comparison of the range and core jet noise for bypass ratios (BPR) varying from 1 to 3. Also indicated are the best fan pressure ratios (FPR). To meet a core jet noise level of 108 PNdB, bypass ratios of 1.5 to 2 give the best range of about 4000 n.mi.. At bypass ratios below 1.5 there is a significant drop in range due to increased engine weight. The best fan pressure ratios are seen to increase with decreasing bypass ratios since core jet velocity and noise increase with decreasing bypass ratios but decrease with higher fan pressure ratios. For an FAR 36-10 dB noise level it is seen that bypass ratios between 2 and 3 would give the best range.

Effect of Augmentor Wing on Total Jet Noise and Range

The figures presented up to this point have shown the major benefits when the large noise normally associated with a hot bypass jet exhaust is arbitrarily ignored. As previously mentioned, it is hoped that such quieting of the bypass stream can be obtained in practice through slowing of the exhaust gas discharging from the wing slot by means of mixing it with ambient air between the flaps of an augmentor wing. (Additional quieting may occur due to enhanced atmospheric attenuation of the higher frequency spectrum by the use of multi-element slots and acoustic lining of the flaps (ref. 2).)

Figure 4 shows the results of this mixing study and illustrates the possible reduction in total jet noise if an augmentor wing scheme can be used for an AST. The calculations indicated that the augmentor wing would provide little or no thrust augmentation at the Mach number of 0.35 flight speed so that engine sizes are about the same as for a conventional wing. However, it is seen that total jet noise is greatly reduced by 20 to 35 PNdB. FAR 36 noise levels could be met with bypass ratios of 1.5 to 2 with little range penalty and FAR 36-10 dB would require bypass ratios from 2 to 3.

One of the major drawbacks of an augmentor wing AST would be problems in airplane design to provide space for the bypass gas ducts and wing trailing edge slot since the wings of supersonic aircraft are relatively thin for aerodynamic efficiency.

Figure 5 shows duct sizes for subsonic and sonic duct flow in comparison to a typical AST wing shape for bypass ratio of 3 engines. The engine size would be 780 lb/sec, and the total jet noise is 91.5 PNdB. For the duct burning cases indicated in the figure it is assumed that duct burning takes place in the engine duct burners and the hot gases are ducted to the wing trailing edge flaps. For no duct burning it is assumed that bypass air is ducted to some type of wing trailing edge burners where heat is added and the hot gas is then discharged through the wing flaps. Except for sonic ducts with no duct burning the large duct sizes shown would require considerable enlargement of the wing. Sonic ducts are considerably smaller and may fit in the wing without significantly affecting the wing height, especially if non-circular ducts could be employed. Some enlargement of the wing may be required to provide space for the ducts; however, reductions in engine weight as a result of larger wings and lower takeoff wing loading have been reported by Whitlow (ref. 3). Also a means of reducing duct weight and storage problems would be the use of collapsible ducts such as the silicone-impregnated-nylon fabric ducts suggested for the STOL augmentor wing. During takeoff the inflated ducts protrude from the bottom surface of the wing. After takeoff the ducts are collapsed inside the wing and hinged fairings are retracted to cover the opening.

A continuous trailing edge slot would be about 6 inches high for sonic velocities. If multi-element slots are used, this dimension could be more than 12 inches. From figure 5 it is seen that the wing rear spar thickness is on the order of 12 inches at inboard locations indicating that a trailing edge slot may not require a significant increase in the wing thickness. This, however, would depend on the particular design such as single-slot versus multi-element slots, element spacing, etc..

CONCLUSIONS

Turbofan engines used with an augmentor wing provide an attractive means for reducing the jet noise of an AST if the wing design can accomodate the bypass flow ducts and trailing edge slots without severe weight and airplane performance penalties.

Proper selection of the bypass ratio and fan pressure ratio resulted in core jet noise levels compatible with FAR 36 and lower without significant range penalties. Bypass ratios of 1.5 to 2 and fan pressure ratios from 3.2 to 2.7 resulted in the best range of 4000 n.mi. for FAR 36 noise levels. A bypass ratio of 3 and fan pressure ratio of 2.7 resulted in a somewhat lower range (3950 n.mi.) but a core noise of FAR 36-24 dB. Employment of an augmentor wing with ideal mixing reduced the bypass jet noise to about the same level as the core noise for the same range for bypass ratios of 1.5 to 2. At the bypass ratio of 3 the total jet noise (FAR 36-16.5) was about 6.5 dB higher than the core noise for the same range.

High duct burner temperatures (3100^{o} F) are required so that some means of insulating the bypass flow ducts is required. An alternate method would be to inject the fuel for the bypass flow at remote burners just ahead of the trailing edge slot. Both methods would involve insulation problems though.

The calculations indicated an augmentor wing may not provide thrust augmentation at the flight conditions for maximum sideline noise (Mach number - 0.35, altitude - 800 ft) so that engine weight would not be reduced. However, more detailed studies of the ejector characteristics of an augmentor wing at this flight condition are required to verify this result.

If the bypass gas flow is restricted to sonic velocities, the reduced duct sizes may not require appreciable increases in wing thickness compared to conventional wings of a typical AST airplane like the Boeing 2707-300. This would depend on the room available in the wing when the room for other equipment, fuel tanks, etc. is considered.

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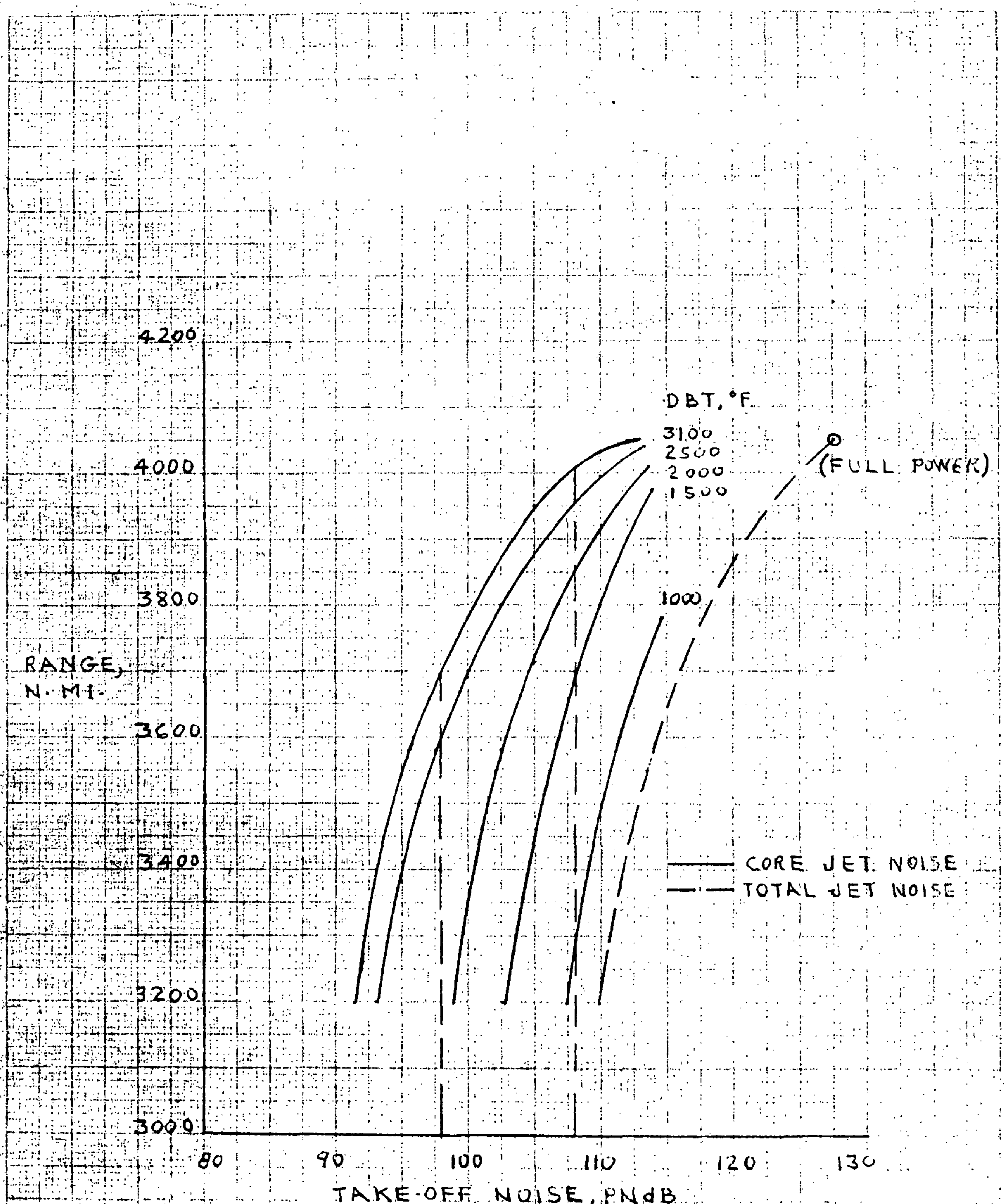

FIGURE 1. - EFFECT OF DUCT BURNER TEMPERATURE AND CORE JET NOISE ON RANGE - BPR, 1.5; OPR, 12; FPR, 3.2

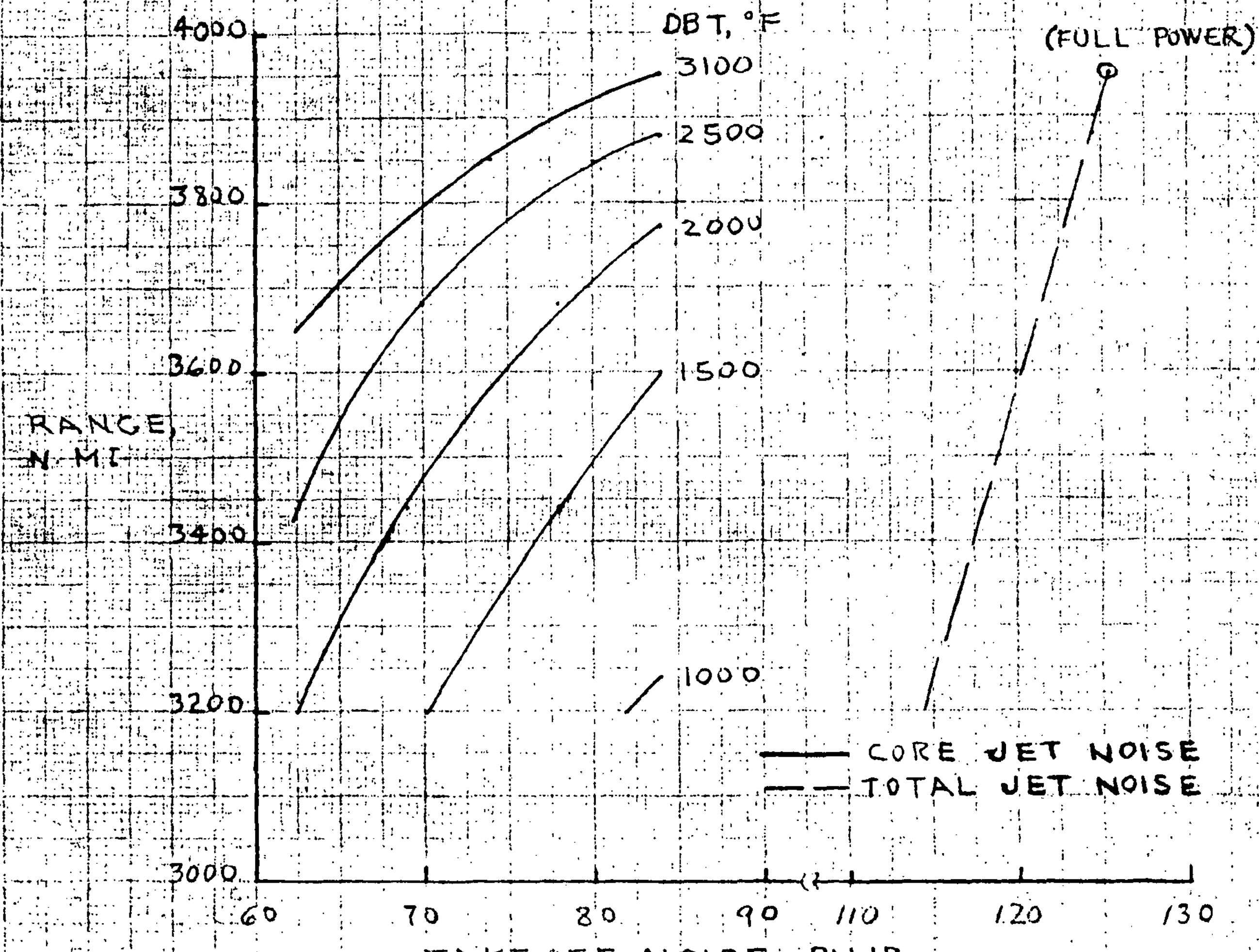

FIGURE 2. - EFFECT OF DUCT BURNER TEMPERATURE AND CORE JET NOISE ON RANGE - BPR, 3; OPR, 12; FPR, 2.7

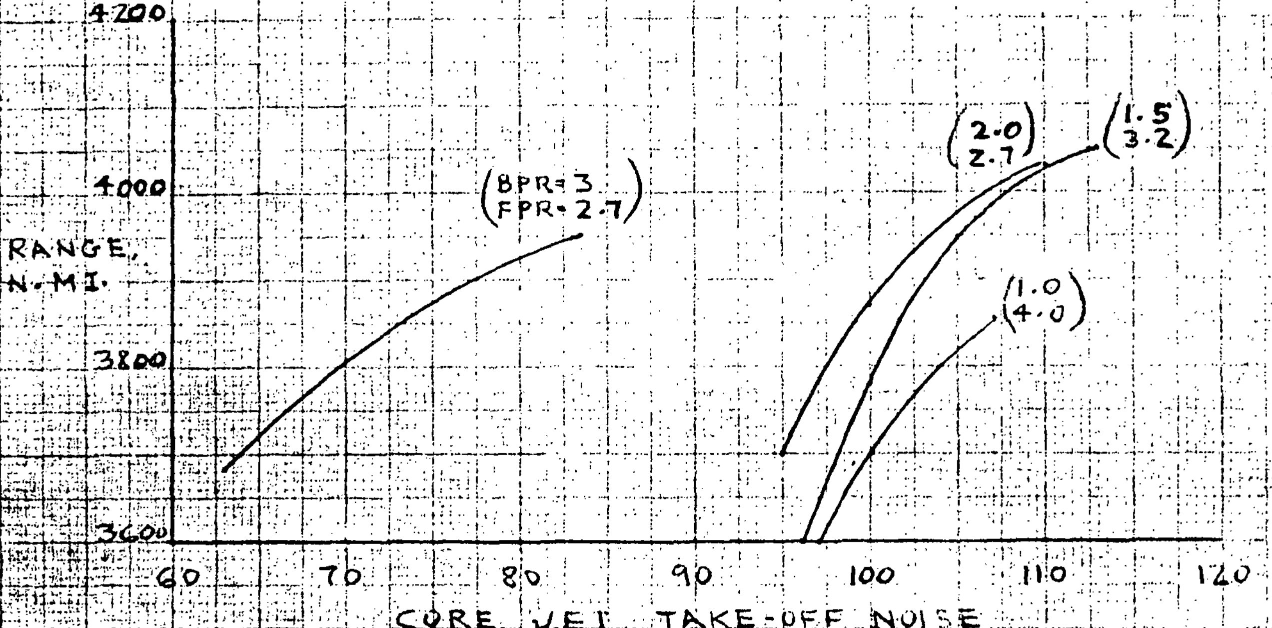

FIGURE 3 - EFFECT OF BYPASS RATIO ON RANGE AND CORE JET NOISE; DBT, 3100 °F

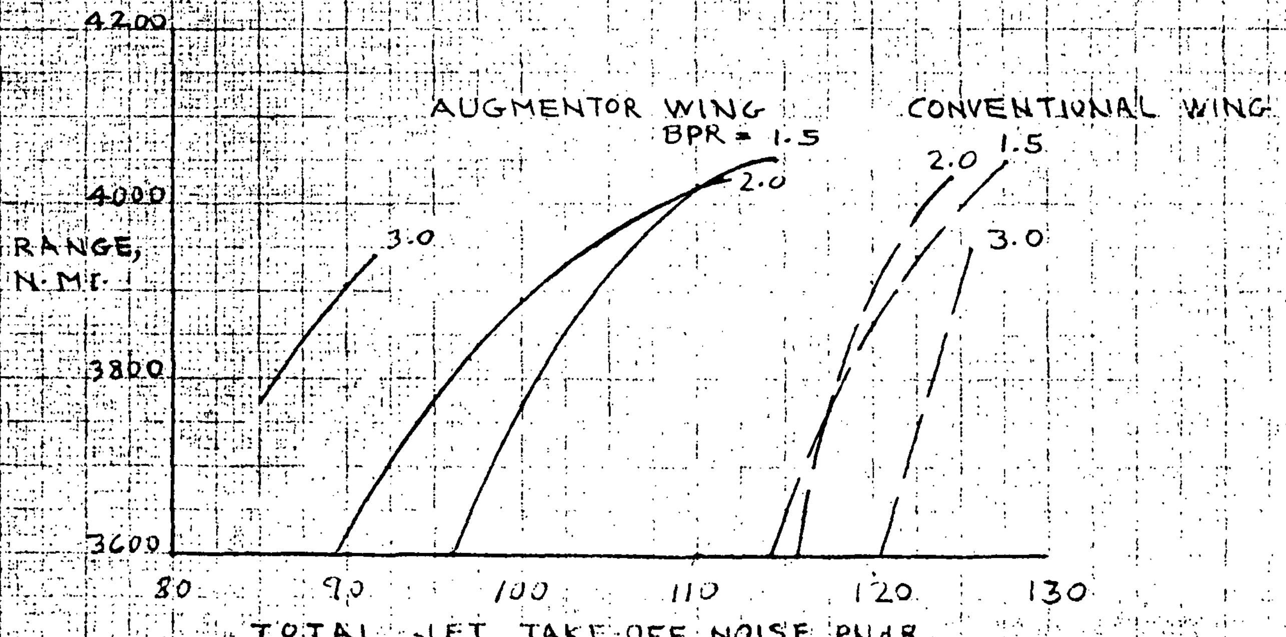

FIGURE 4 - EFFECT OF BYPASS GAS EJECTORS ON TOTAL JET NOISE; RATIO OF SECONDARY AIR FLOW TO BYPASS GAS FLOW, 2; DBT, 3100 °F; OPR, 12

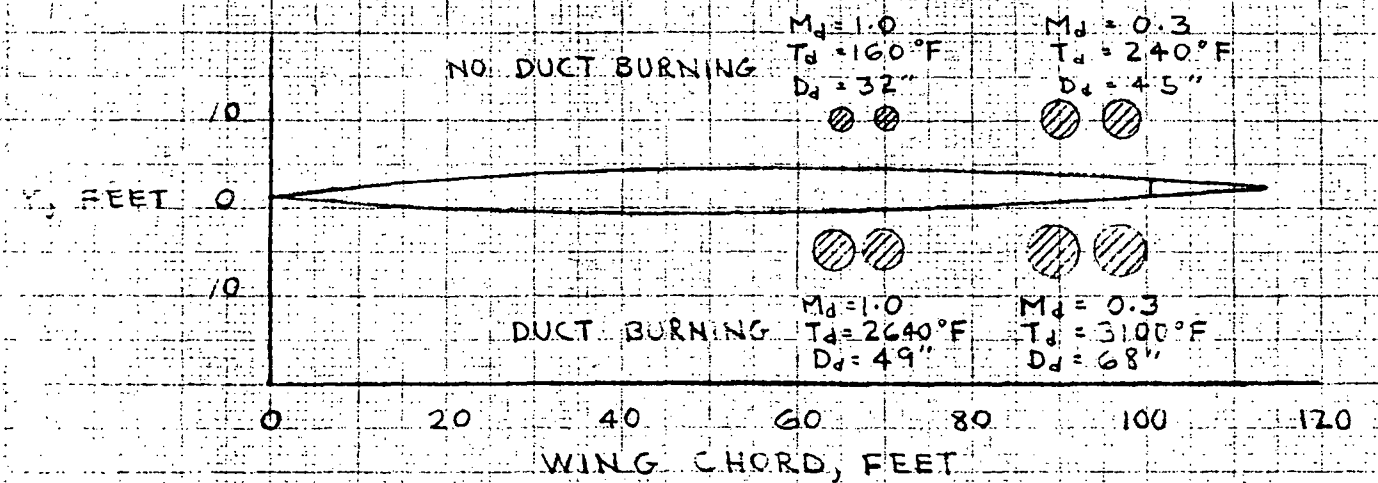

FIGURE 5. - COMPARISON OF BYPASS GAS DUCT SIZES WITH A TYPICAL AST WING SHAPE. BPR, 3; OPR, 12; FPR, 2.7