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ACOUSTICS AND AERODYNAMICS OF OVER-THE-WING THRUST REVERSERS

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ABSTRACT

As part of the Quiet Clean Short-Haul Experimental Engine (QCSEE) program, model tests were conducted to determine the effects of thrust reverser geometric parameters on noise and reverse thrust. The acoustic tests used a 1/6 scale model thrust reverser while the aerodynamic performance tests used a 1/12 scale model reverser. Parameters which were varied in both tests include blocker spacing, blocker height, lip angle, and lip length. The impact of these parameters on peak sideline noise and reverse thrust performance is presented.

INTRODUCTION

Commercial CTOL jet transports, although certified to stop without thrust reversers, do employ thrust reversers to decelerate the aircraft, to decrease wear on brakes, and to improve stopping on icy or wet runways. It is anticipated that future STOL aircraft will rely heavily on some type of thrust reversers to help decelerate the aircraft for the short (610 to 914 meter, 2000 to 3000 foot) runways into which they operate. It is also anticipated that future STOL aircraft will have to meet very stringent reverse thrust noise goals in addition to the noise goals at takeoff and approach which are currently being proposed.

As part of the Quiet Clean Short-Haul Experimental Engine (QCSEE) program currently underway at General Electric Company and which is sponsored by NASA Lewis Research Center, two engines for STOL aircraft are being built using advanced technology. Design rationale and background information for these engines are presented in Reference 1. Each engine has a different mode of thrust reversal. The Under-The-Wing (UTW) engine utilizes variable pitch fan blades to achieve reverse thrust. On the second QCSEE engine - an Over-The-Wing (OTW) engine version - reverse thrust will be achieved by deploying a target type thrust reverser which captures the fan and core exhaust flows and directs the jet upward and forward from the wing upper surface as shown in Figure 1. The OTW installation offers some unique advantages relative to the UTW installation which makes it attractive to STOL applications. The advantages include elimination of ground induced reingestion and incidence of foreign object damage, upward reverser discharge to provide an additional force on the landing gear for higher braking forces, and unobstructed interaction between freestream airflow and the wing flap system for aircraft landing configuration drag.

This paper is concerned with the design parameters which are important in selecting an OTW target reverser as demonstrated by model tests conducted under the QCSEE OTW thrust reverser development program. The design parameters were investigated from the viewpoint of aerodynamic performance and acoustics.

Three model test programs were utilized in studying target reverser design criteria. Initial tests by NASA Ames Research Center provided noise and performance data on a 1/3 scale model. Further acoustic testing under the QCSEE program was conducted at the General Electric Company Jet Engine Noise Outdoor Test Stand (JENOTS) using a 1/6 scale model of the OTW thrust reverser. It had provisions to vary target reverser parameters such as blocker spacing, blocker height, lip length, and lip angle. No thrust measurements were taken with these tests; however, airflow and pressure data were obtained. Also under the QCSEE program, reverse thrust aerodynamic performance was investigated on a 1/12 scale model at NASA Langley Research Center where thrust and performance were monitored for various target reverser geometries.

OTW TARGET REVERSER DESIGN CRITERIA

Design of a target thrust reverser for a STOL aircraft must consider two disciplines - aerodynamics and acoustics. The aerodynamic design must incorporate the thrust reverser into the nacelle in a manner which least compromises the forward flight performance. The upper portion of Figure 1 is a schematic of an OTW type thrust reverser shown stowed for forward thrust operation while the lower schematic shows the target actuated for reverse thrust. Target area or size relative to the nozzle area is determined by the reverse thrust level required. The effective discharge area of the thrust reverser must be sized to ensure that engine stall margin and turbine operating temperature limits are maintained for satisfactory engine operation.

Acoustically, the noise from other constituents such as fan inlet, fan exhaust, core, and turbine must be considered relative to the thrust reverser levels. Figure 2 compares the reverser noise constituents for a highly suppressed STOL-type aircraft engine. The reverser noise is a major contributor to the total system noise and thus is a prime candidate for noise reduction studies. The other sources, except fan inlet noise, are redirected by the target reverser and combine with the reverser noise to give the maximum sideline noise at a forward angle. Figure 3 compares forward thrust jet noise levels to the redirected thrust reverser PNL directivities and shows that not only is there a redirection of the noise into the forward quadrant, but also an increase in the peak level.

Since the reverser noise is a major constituent, techniques of lowering reverser noise should be evaluated. One means is to simply reduce the reverser pressure ratio which drops the jet velocity. This method offers the most potential. A second possibility is to vary reverser geometry.

The ultimate goal of the model tests and investigations of reverser design parameters is to obtain design information which will permit a given level of reverse thrust to be achieved at the lowest sideline noise consistent with engine performance requirements.

ACOUSTIC TEST RESULTS

The model used for investigating reverser geometric variations on noise was a 1/6 scale model of the QCSEE OTW engine. Detailed analysis of the results will be reported in a contractor report at a later date. The test vehicle included a forward thrust nozzle and a target reverser with provisions for varying blocker spacing, blocker height, lip length, and lip angle. Figure 4 shows the reverser model as installed at the General Electric Company JENOTS test site. The design parameters in nondimensional form are defined in Figure 5 along with the range of each variable which was investigated.

Of the four parameters investigated, lip angle and blocker height variations had minimal effect on the farfield noise signature of the thrust reverser. Their effect was individually less than 1 PNdB over the range of each variable.

Both blocker spacing and lip length variation resulted in significant changes in noise. Figure 6 shows the effect of blocker spacing on peak sideline noise at three reverser pressure ratios where pressure ratio is the charging station (see Figure 5) total pressure divided by ambient. There are two effects which must be considered when examining Figure 6, the noise generated within the reverser and that generated external to the reverser. The latter is equivalent to jet noise generation caused by turbulent mixing of the jet with ambient air. The primary means of reducing this type of noise is to reduce the pressure ratio across the reverser which reduces the velocity. Figure 7 represents data taken at constant blocker spacing from Figure 6 and shows the variation of target reverser noise as a function of velocity. The peak sideline PNL varies with the 6th power of velocity, hence any reduction of the operating pressure ratio of the reverser has a significant reduction in noise level. This is consistent with the results observed in Reference 2. Also shown in Figure 7 are peak sideline PNL's scaled from noise tests of a similar target thrust reverser at NASA Ames Research Center. These levels agree with the 6th power dependency on velocity.

Noise generated within the reverser is associated with the turning losses and interaction of the flow with the target. In the limit, if the flow is reversed slowly at low velocities with no pressure losses, then the reverser noise would be equivalent to that of a redirected forward thrust nozzle at the same pressure ratio. Figure 3 has shown this not to be the case. The geometric shape of the reverser elements used to capture the flow influences the internal noise generation. If Figure 6 is examined at constant pressure ratio, spacing is seen to have a direct effect upon the internal noise generation. Closer spacing produces less noise because there is a reduction in airflow (backpressure effect) at a given pressure ratio and hence a reduction in the velocity hitting the target. Therefore, a low noise target reverser will be one which maintains as low as possible velocity into the reverser consistent with fan exhaust duct flowpath requirements.

Lip length effects on noise are presented in Figure 8. At constant lip length, L/D_{TH}, the dependence on velocity is similar to that shown at constant blocker spacing. Longer lips increase noise; but, as will be discussed later, improve the level of reverse thrust achieved. Thus, a trade must be made between desired performance and acoustic consideratons in choosing the optimum lip length for a given reverser.

AERODYNAMIC RESULTS

Aerodynamic tests on a 1/12 scale model target thrust reverser and forward thrust nozzle were conducted at NASA Langley Research Center in support of the QCSEE OTW design studies. Results will be reported in a contractor report at a later date. The exhaust system was designed to meet the QCSEE OTW engine area requirements in forward thrust, to have excellent jet/flap flow turning characteristics during low speed aircraft operation, and to provide a viable thrust reversing system for use during the landing roll. Encompassed in the reverser test matrix were not only the reverser geometric parameters of blocker spacing, blocker height, lip angle, and lip length that were tested acoustically at JENOTS but also blocker door inclination angle, side skirt geometry, and side skirt rotation angle. The parameters are defined in Figure 9 which is a schematic of the 1/12 scale Langley aerodynamic model. Generally, only the parameters common to both model tests are discussed in this paper.

Primary considerations in target reverser design (or any reverser design) are to efficiently turn the exhaust flow in the direction required to achieve the objective thrust level and to achieve an acceptable engine operating condition for both the forward and reverse thrust modes. Referring to Figure 9, the backpressure effects or stall margin on the engine are controlled primarily by the spacing of the target from the charging station plane. Blocker spacing was investigated to establish the airflow matching characteristics (airflow in reverse divided by forward thrust airflow at a given pressure ratio, W_{RE}/W_{FWD}), and the effect on reverse thrust. Reverse thrust is defined as the ratio of the reverse thrust divided by the forward thrust at takeoff, $F_{REV}/F_{FWD\ T/O}$. Figure 10 shows that an increase in blocker spacing results in a decrease in the level of reverse thrust achieved. An increase in the airflow was observed with the increased blocker spacings indicating less backpressure effect and increased stall margin on the engine. This airflow increase is attributed to higher blocker target spillage rate out the sides.

Lip geometry of a target reverser can be either fixed or articulated upon reverser deployment through some appropriate kinematic arrangement. Lip length has a significant effect on reverser thrust as shown in Figure

11. While gains in reverse thrust are evident all the way to $L/D_{TH} = 0.8$, mechanical design constraints on an engine configuration would probably not permit such long lengths. The airflow ratio remains relatively constant for the variations in lip length shown. A favorable change in reverse thrust was achieved by increasing the blocker inclination angle and modifying the side skirt geometry as presented in Figure 11. An obvious and beneficial result is that for a given lip length, a level of reverse thrust can be achieved at a lower pressure. It was shown earlier that lower pressure ratios result in lower reverser noise; therefore, judicious selection of blocker inclination angle and side skirt geometry has potential in lowering reverser noise levels.

Other reverser parameters such as blocker height and lip angle had little significant effect on the target reverser airflow capacity. Blocker height variations did not achieve any significant reverse thrust change; however, a favorable increase in reverse thrust was observed by decreasing the lip angle (or increasing flow turning) from 0.61 radians (35°) to 0.44 radians (25°).

Peak sideline noise was shown to vary with the sixth power of reverser velocity; therefore, low noise can most easily be obtained by meeting the desired level of reverse thrust at as low a reverser pressure ratio as possible. The variation of noise with reverse thrust is shown in Figure 12 for a given nominal configuration. Reverser geometric changes shift the curve up or down but generally keep the same slope.

CLOSING REMARKS

In the design of a target reverser system applicable to an OTW STOL aircraft installation, consideration must be given to acoustics, aerodynamic performance, and mechanical constraints.

Peak sideline noise increased and reverse thrust decreased with increased blocker spacing. This implies that close spacing is desirable. However, a spacing should be chosen consistent with retaining sufficient stall margin on the engine and yet coming closest to meeting the thrust and acoustic objectives.

Both reverse thrust and peak sideline noise increase with longer lip lengths. This necessitates a trade between thrust and acoustics to meet a given noise level; however, lip stowage limitations preclude use of excessively long lips.

The trends and tradeoffs discussed in this paper were evaluated and factored into the design of the QCSEE OTW target thrust reverser. However, acoustic model tests were conducted prior to the aerodynamic model tests and since the aerodynamic model included variations such as blocker inclination angle, side skirt geometry, actuator arm, and side skirt angle which were not evaluated by acoustic tests at JELOTS, acoustic model data on the final design were not obtained. Lack of time and monetary considerations precluded model testing of this final design. Both noise and aerodynamic performance will be measured on the full scale QCSEE engine when it is tested late this year.

NOMENCLATURE

Symbol or Abbreviation	Definition
D_{TH}	Charging station height
$F_{FWD\ T/O}$	Forward thrust at takeoff power setting
F_{REV}	Reverse thrust
H_B	Blocker height
L	Blocker lip length
PNL	Perceived noise level, PNdB
P_0	Ambient pressure
P_T	Charging station total pressure
V	Velocity
W_{FWD}	Forward thrust airflow as a function of pressure ratio
W_{REV}	Reverse thrust airflow as a function of pressure ratio
α	Blocker inclination angle
β	Lip angle

REFERENCES

1. Adamson, A.P., "Quiet Clean Short-Haul Experimental Engine (QCSEE) Design Rationale," SAE paper 750605, May 1975.

2. Stone, J.R., and Gutierrez, O.A, "Noise of Model Type Thrust Reversers for Engine Over-The-Wing Applications," NASA TM X-71621, November 1974.

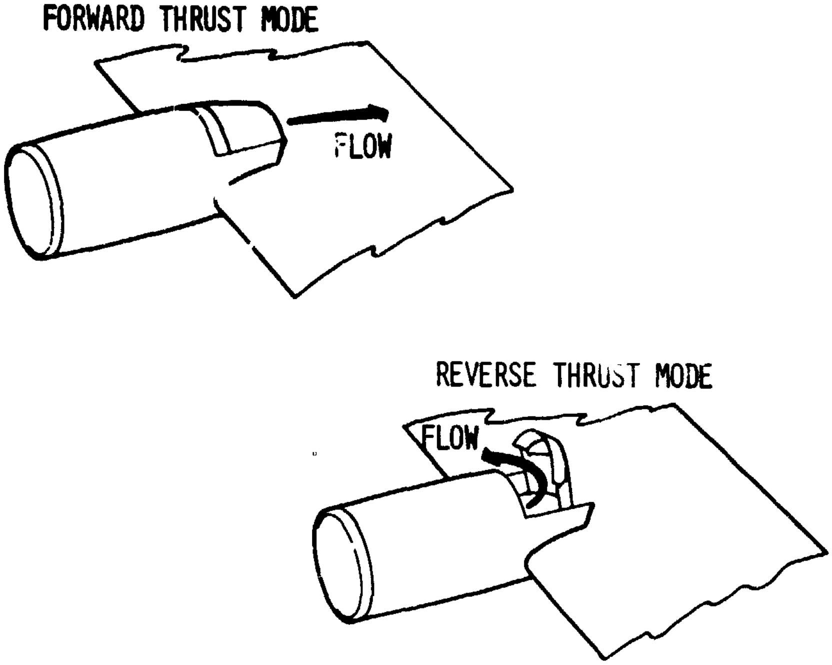

Figure 1.- OTW forward and reverse thrust schematics.

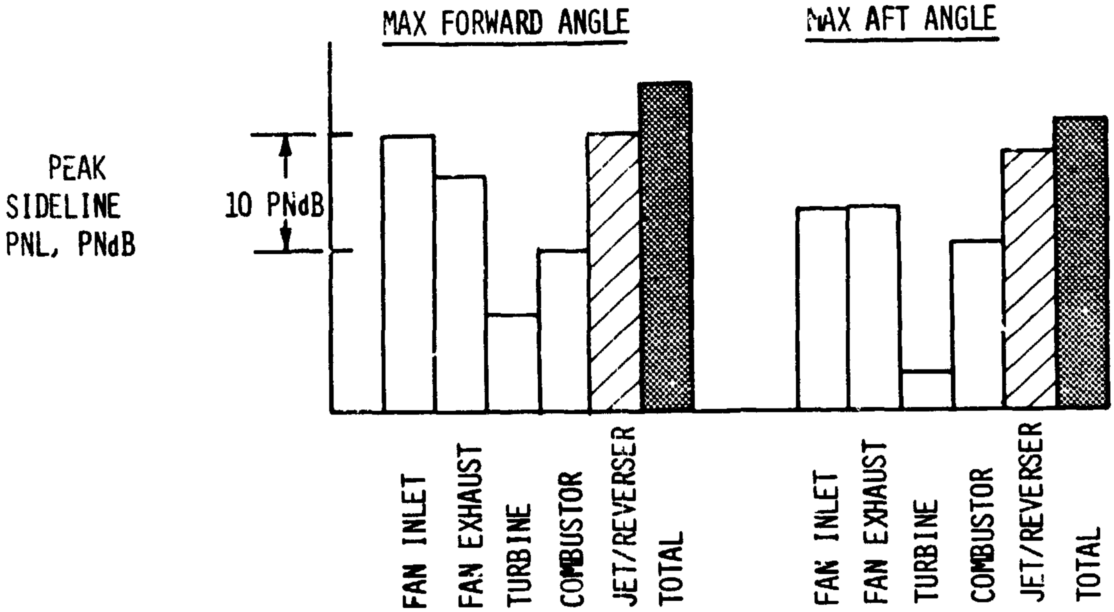

Figure 2.- Reverse thrust constituent noise levels. 152.4 m (500 ft) sideline; suppressed engine.

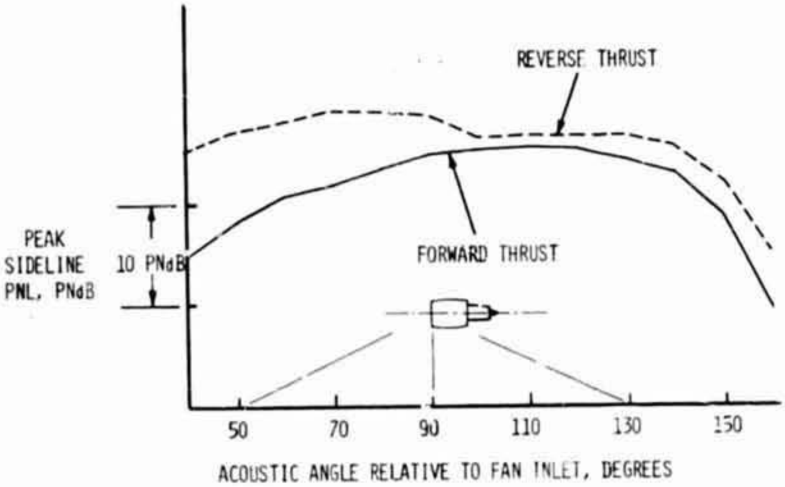

Figure 3.- Reverse and forward thrust PNL directivities.
1.30 pressure ratio; 152.4 m (500 ft) sideline.

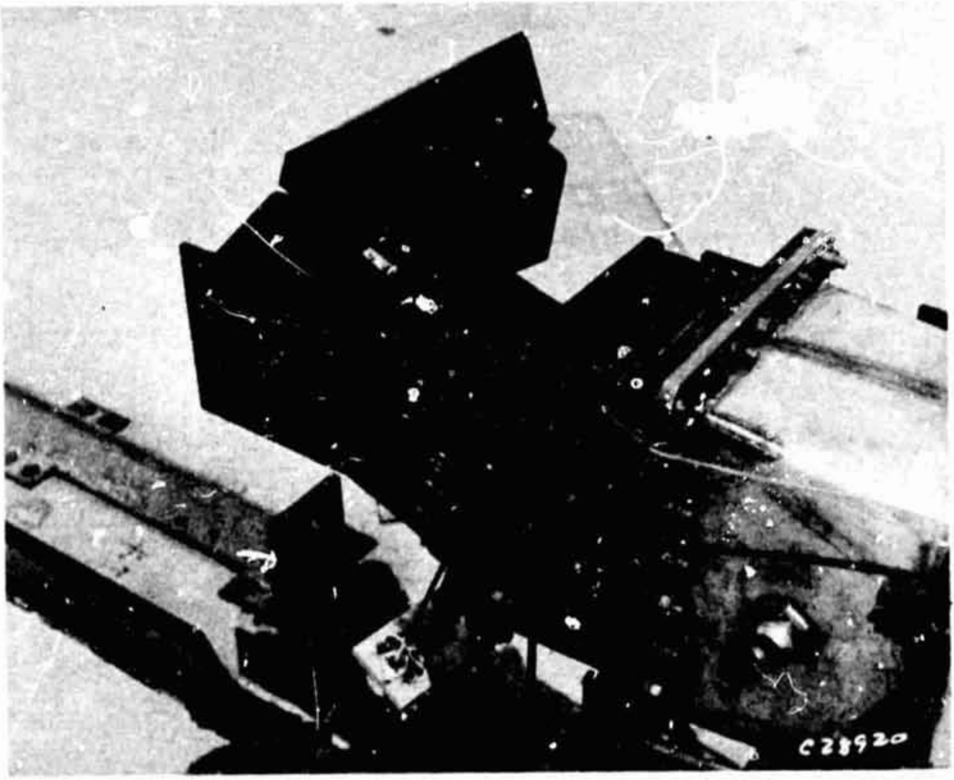

Figure 4.- Acoustic thrust reverser model.

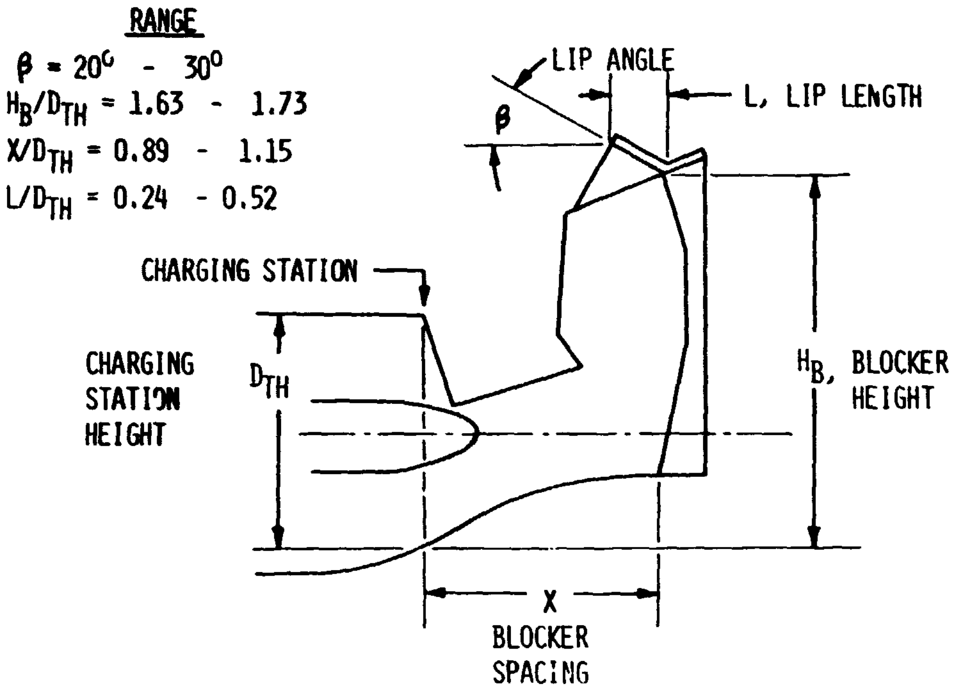

Figure 5.- Acoustic model thrust reverser parameters.

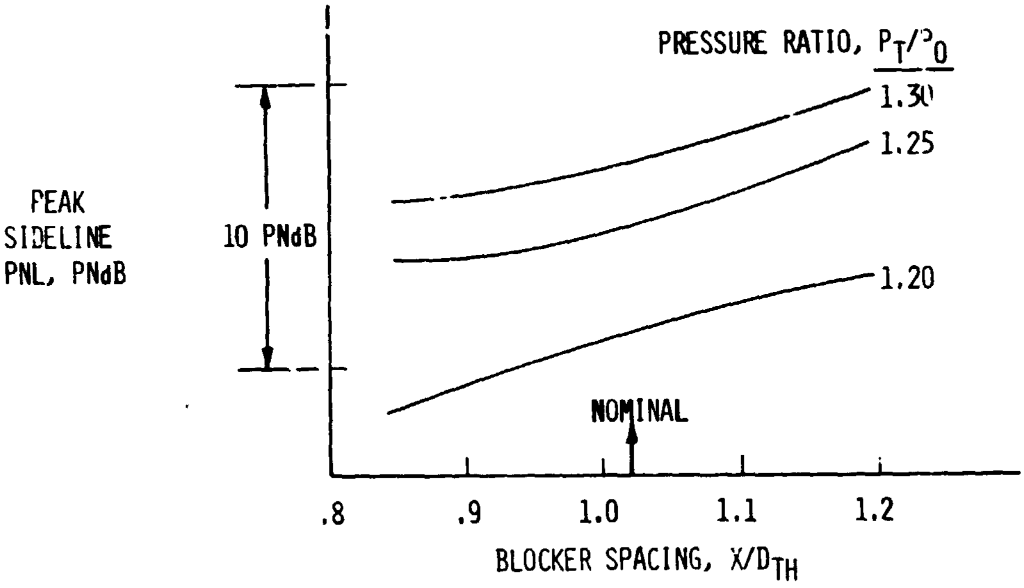

Figure 6.- Blocker spacing effect on peak sideline noise. 152.4 m (500 ft) sideline.

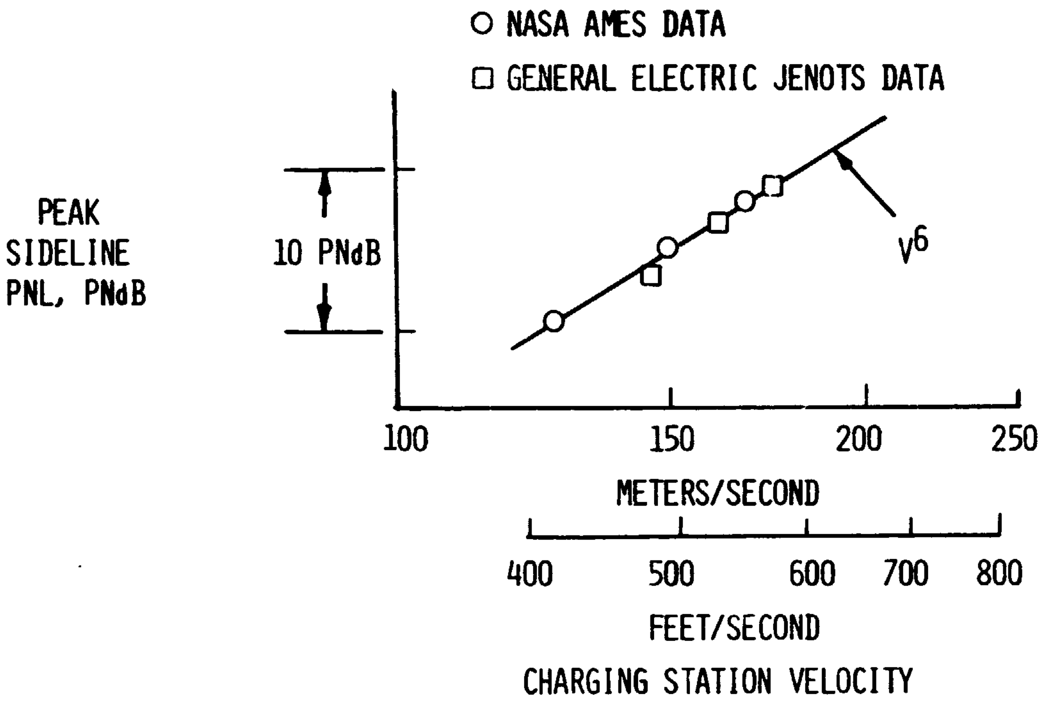

Figure 7.- Charging station velocity effect on target reverser noise. 152.4 m (500 ft) sideline.

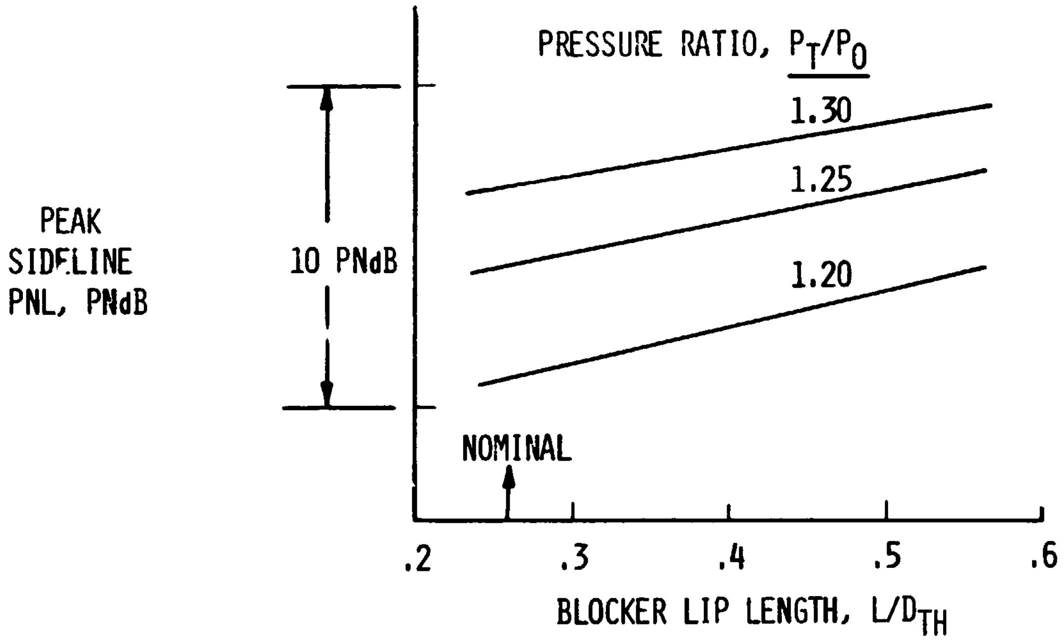

Figure 8.- Blocker lip length effect on peak sideline noise. 152.4 m (500 ft) sideline.

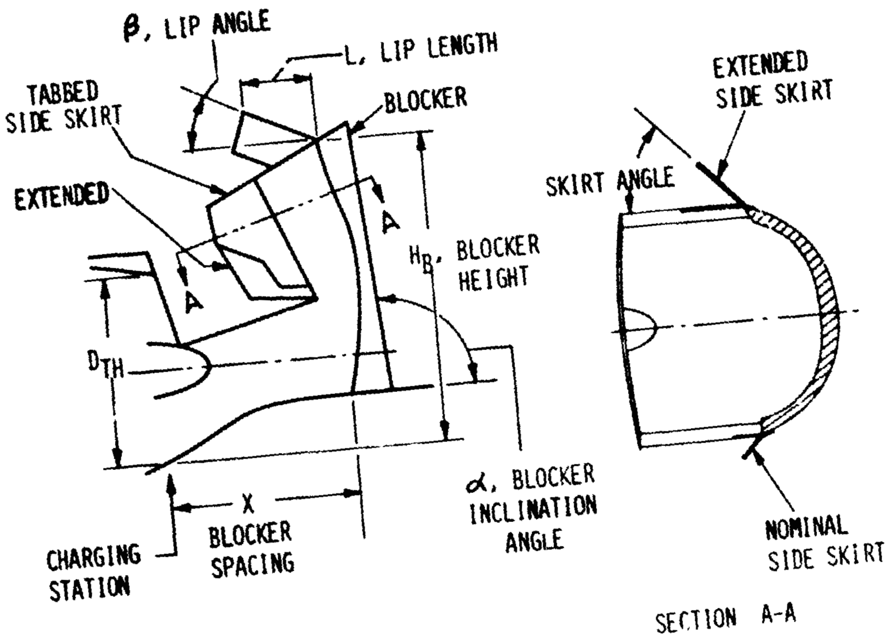

Figure 9.- Aerodynamic thrust reverser model.

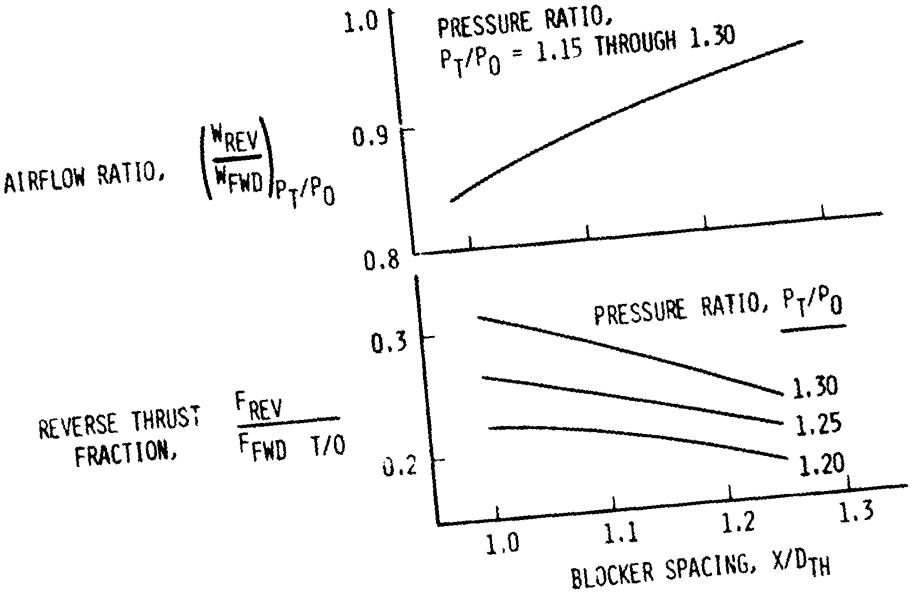

Figure 10.- Blocker spacing effect on flow and reverse thrust.

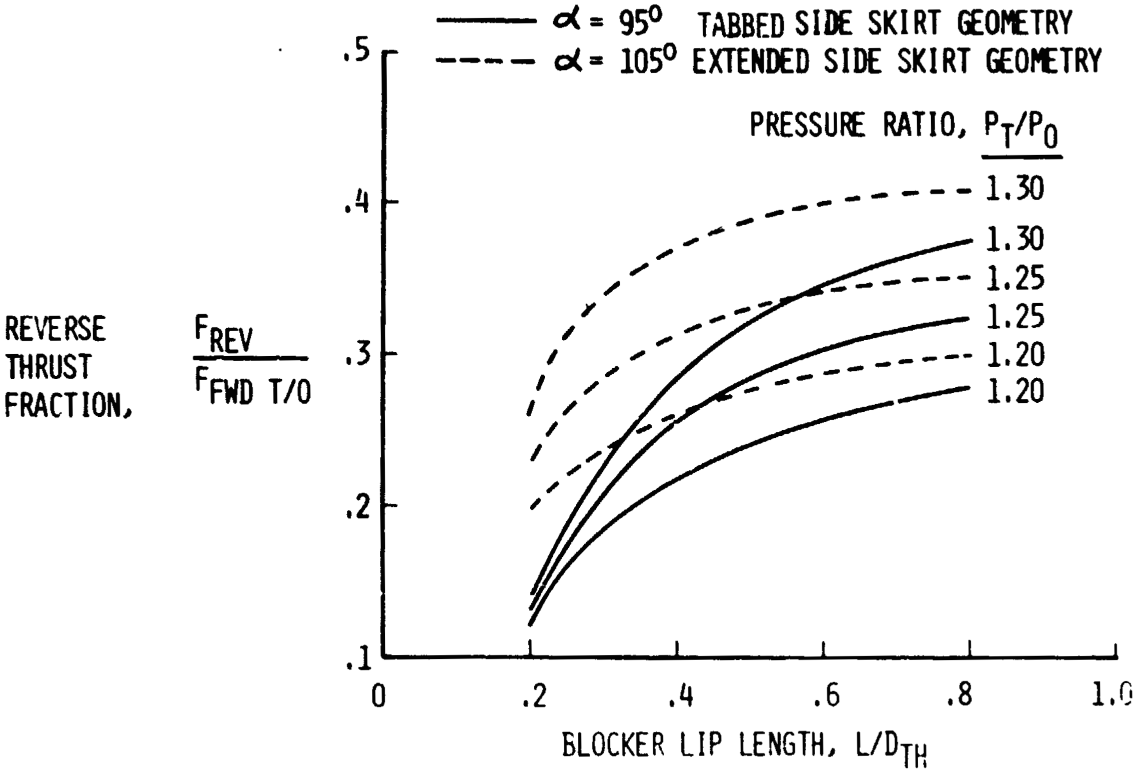

Figure 11.- Blocker lip length effect on reverse thrust.

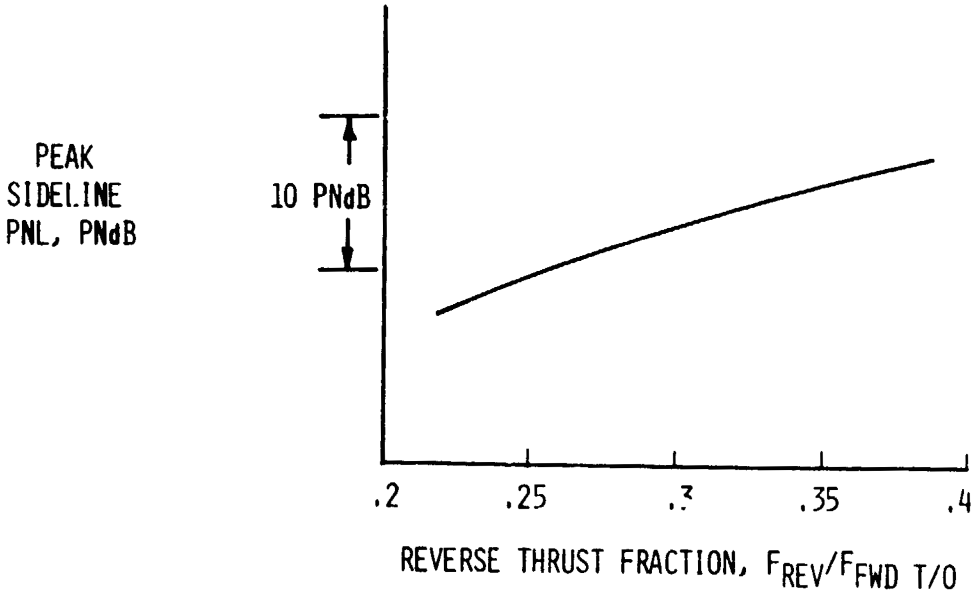

Figure 12.- Peak sideline PNL variation with reverse thrust.