SOME TESTS ON A SMALL-SCALE RECTANGULAR THROAT EJECTOR

W. N. Dean, Jr.* and M. E. Franke

Air Force Institute of Technology
Wright-Patterson AFB, OH 45433

ABSTRACT

A small-scale rectangular throat ejector with plane slot nozzles and a fixed throat area was tested to determine the effects of diffuser sidewall length, diffuser area ratio, and sidewall nozzle position on thrust and mass augmentation. The thrust augmentation ratio varied from approximately 0.9 to 1.1. Although the ejector did not have good thrust augmentation performance, the effects of the parameters studied are believed to indicate probable trends in thrust augmenting ejectors.

INTRODUCTION

In recent years much effort has been devoted to V/STOL research and development. Many of these programs have been concerned with the use of ejectors to achieve the thrust augmentation required for V/STOL type operations (refs. 1-6). To achieve high thrust augmentation with an ejector rapid mixing is important. This has led to studies of ways to improve mixing and the development of hypermixing nozzles (refs. 1 and 2). The effects of other design parameters on mixing and ejector performance are also still of interest; for example, the effects of diffuser area ratio, angle, and length, effects of fluid injection along the diffuser sidewalls, and effects of the position of plane sidewall, slot nozzles (private communication from P. M. Bevilaqua, 1977). The tests described herein were undertaken to provide some additional information and trends on the effects of the above indicated parameters on ejector performance.

The definitions of the augmentation ratios used in this study are as follows:

$$\text{thrust augmentation ratio } \phi = \frac{\text{measured ejector thrust}}{\text{reference thrust}}$$

where the reference thrust is defined as the thrust that would be obtained by the isentropic expansion of the primary mass flow from the primary nozzle reservoir pressure to ambient conditions.

$$\text{mass augmentation ratio} = \frac{\text{secondary mass flow rate}}{\text{primary mass flow rate}}$$

*2d Lt., USAF; presently, Air Force Flight Test Center, Edwards AFB, CA.

TEST APPARATUS AND PROCEDURE

Ejector

A two-dimensional sketch of the ejector is shown in figure 1. The diffuser throat had a width of 1.8 in. and a span of 5 in. The primary nozzles consisted of a central plane slot nozzle positioned at the center of the inlet and plane slot nozzles located along the sidewalls. The nozzles were sized so that the central nozzle (slot width of 0.09 in.) delivered approximately one-half of the primary flow. The two sidewall nozzles (slot width of 0.04 in. each) delivered the remaining amount of primary flow, except for a very small flow through endwall nozzles positioned at the throat that were used to reduce diffuser stall. Also, fillets were made to fit into the corners of the diffuser to help reduce stall. The sidewall nozzles were designed to enhance jet wall attachment to the diffuser sidewalls and thus possibly reduce flow separation and diffuser stall. The sidewall nozzles were located in cylinders that could be rotated independently of the interchangeable diffuser sidewalls.

Several ejector parameters were varied during the tests. Variables included the sidewall nozzle position (20° to 90°), diffuser sidewall length (1.3, 3.25, and 6.5 in.) and sidewall angle (0° to 25°).

Air Supply and Flow and Pressure Measurements

The primary airflow was supplied by two air compressors each capable of delivering approximately 1/2 lbm/sec at 40 psig. The pressure and flow rate to the ejector were adjusted during tests with a main valve and a bleed valve. The primary airflow rate was measured with a flange-type orifice meter with a 1.375-in. diam orifice in a 3-in. line. The upstream pressure, pressure drop, and temperature were measured with a pressure gage, mercury manometer, and a copper-constantan thermocouple, respectively.

The total pressure in the sidewall cylinders was measured with a pressure gage and checked with a total pressure probe at the sidewall slot nozzle exit. Preliminary tests showed a difference of no more than 1 psig between the two cylinders under operating conditions. The tests were run at a total pressure of approximately 20 psig in the sidewall cylinders.

The total mass flow rate at the diffuser exit was approximated from total and static pressure measurements at 3-18 equally spaced positions across the width at center span. The flow rates obtained were optimistic, since the effects of the endwalls were ignored. Preliminary tests showed, however, that the velocity was relative constant across the diffuser exit, except when diffuser stall occurred in which case large variations in velocity existed across the exit plane.

Thrust Measurement

Thrust was measured with the ejector suspended from two flexible air supply hoses as shown in figure 2. With the ejector free to swing, the thrust was obtained from two strain gages mounted on a flexure piece. The strain gages were bridged to compensate for temperature and were zeroed electronically prior to each run and checked for drift after each run. The system was preloaded to prevent movement during operation.

RESULTS

Thrust Augmentation

The effects of sidewall nozzle position (angle) θ on thrust augmentation ratio ϕ for different diffuser sidewall angles ψ and three different diffuser sidewall lengths (L/W = 0.7, 1.8, and 3.6) are shown in figures 3-5. The maximum value of the thrust augmentation ratio was approximately 1.1. Although the ejector did not give high thrust augmentation, the results are believed to be useful and also to indicate possible trends in higher performance augmenting ejectors.

The results (figs. 3-5) show that ϕ generally increased with increasing values of θ up to approximately 40° and generally decreased for values of θ above 60°. Thus, the sidewall nozzle was most effective between 40° and 60°. The effect of the absence of sidewall jets on ϕ is also shown in figures 3 and 4 for $\psi = 5°$ and 15°. Without sidewall jets, ϕ was considerably lower. It was also found that ϕ generally increased as ψ increased up to approximately 10° to 15°, then decreased at higher values of ψ where diffuser stall occurred in many cases. Diffuser stall conditions are noted in the figures. The trends with ψ are similar to those found by Foley (ref. 4).

The diffuser area ratio A_e/A_t (exit area to throat area) depends on ψ and the diffuser sidewall length L. Values of A_e/A_t are given in figures 3-5 for values of ψ and L. The effect of A_e/A_t on ϕ is shown in figure 6. Maximum ϕ occurred for A_e/A_t between 1.5 and 2, which is in general agreement with results given by Salter (ref. 3).

The effect of diffuser length L on ϕ is shown in figures 7-9 in terms of L/W for three different diffuser area ratios. Bevilaqua (ref. 6) infers that ϕ generally increases with length, since this allows increased mixing of primary and secondary airstreams. The results given in figures 7-9, in most cases, indicate an increase in ϕ with increase in L/W.

Mass Augmentation

The mass augmentation ratio was found to vary from 2 to 4, that is, the secondary airflow rate was generally 2 to 4 times the primary airflow rate. Mass augmentation ratio appeared to increase slightly with increases in θ

and with increases in diffuser area ratio. The results, however, are inconclusive because of the small number of static and total pressure measurements made at the diffuser exit. A more complete survey is needed to accurately measure the exit mass flow rate.

CONCLUSIONS

The results obtained in this study generally agree with those of previous studies regarding the effects of diffuser area ratio, sidewall angle, and length, in spite of the low augmenting performance of the ejector. This low performance is possibly due, in part, to the inlet design. The sidewall slot nozzle position in the range of 40-60° provided the highest augmentation ratio. The sidewall nozzles were not particularly effective for thrust augmentation when positioned closer to the throat or when directed toward the central primary nozzle at the higher angle positions.

REFERENCES

1. Fancher, R. B.: Low-Area Ratio, Thrust-Augmenting Ejectors. J. Aircraft, vol. 9, no. 3, 1972, pp. 243-248.

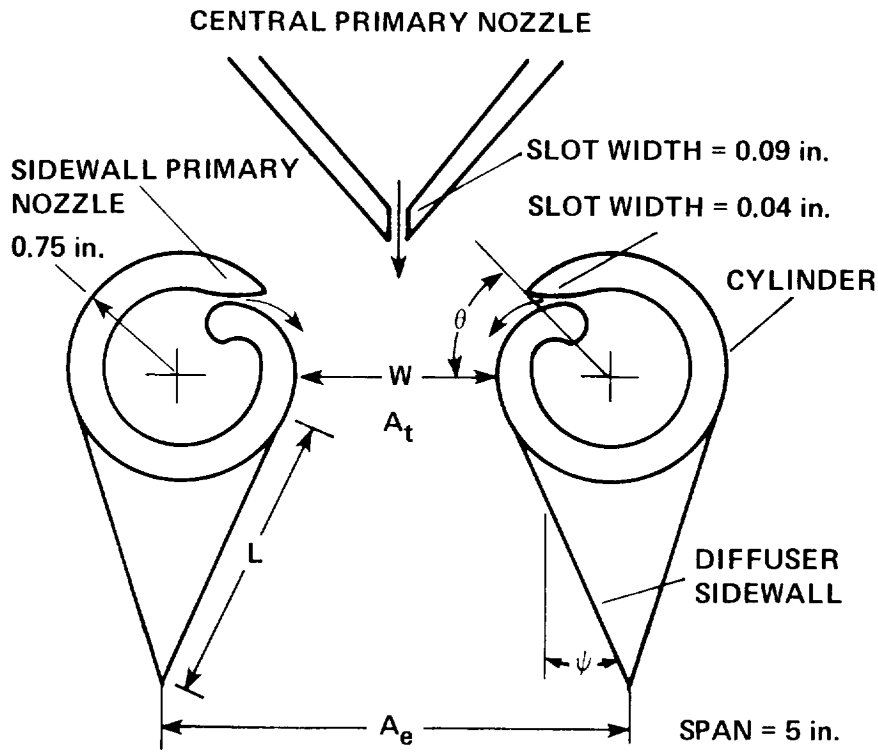
2. Bevilaqua, P. M.: Evaluation of Hypermixing for Thrust Augmenting Ejectors. J. Aircraft, vol. 11, no. 6, 1974, pp. 348-354.

3. Salter, G. R.: Method of Analysis of V/STOL Aircraft Ejectors. J. Aircraft, vol. 12, no. 12, 1975, pp. 974-978.

4. Foley, W. H.: An Investigation of 3-Dimensional Effects on Augmentors. Rockwell International Report prepared for the Naval Air Development Center, NADC-76153-30, 1977.

5. Viets, H.: Thrust Augmenting Ejector Analogy. J. Aircraft, vol. 14, no. 4, 1977, pp. 409-411.

6. Bevilaqua, P. M.: Lifting Surface Theory for Thrust-Augmenting Ejectors. AIAA J., vol. 16, no. 5, 1978, pp. 475-481.



θ – SIDEWALL NOZZLE POSITION (VARIABLE: 20° TO 90°)

ψ – DIFFUSER SIDEWALL ANGLE (VARIABLE 0° TO 25°)

L – DIFFUSER SIDEWALL LENGTH (VARIABLE 1.3 in., 3.25 in., and 6.5 in.)

W – THROAT WIDTH = 1.8 in.

A_t – THROAT AREA = 9 in.^{2}

A_e – DIFFUSER EXIT AREA (VARIABLE: DEPENDS ON L AND ψ)

$\frac{A_e}{A_t}$ – DIFFUSER AREA RATIO

Figure 1.- Two-dimensional sketch of ejector.

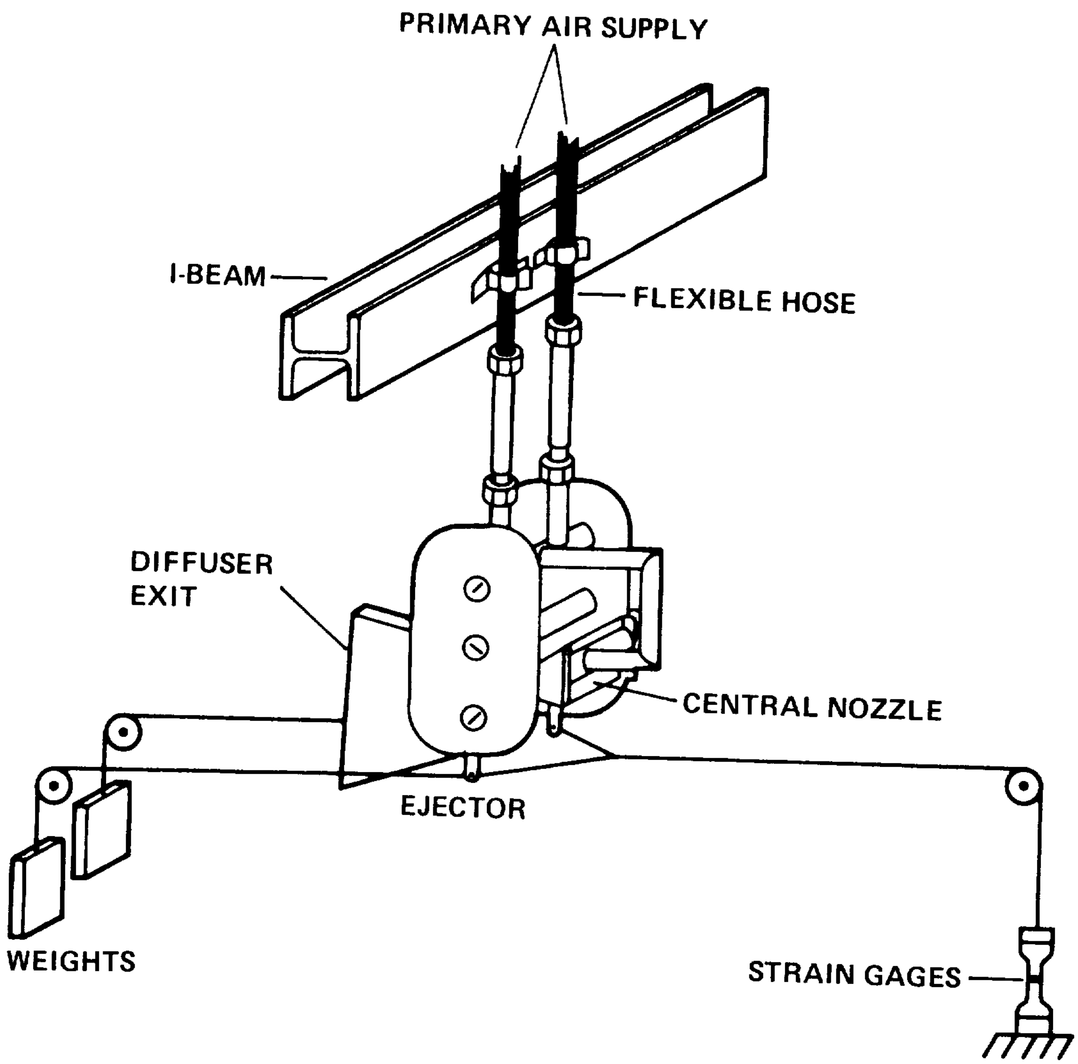


Figure 2.- Thrust measuring system.

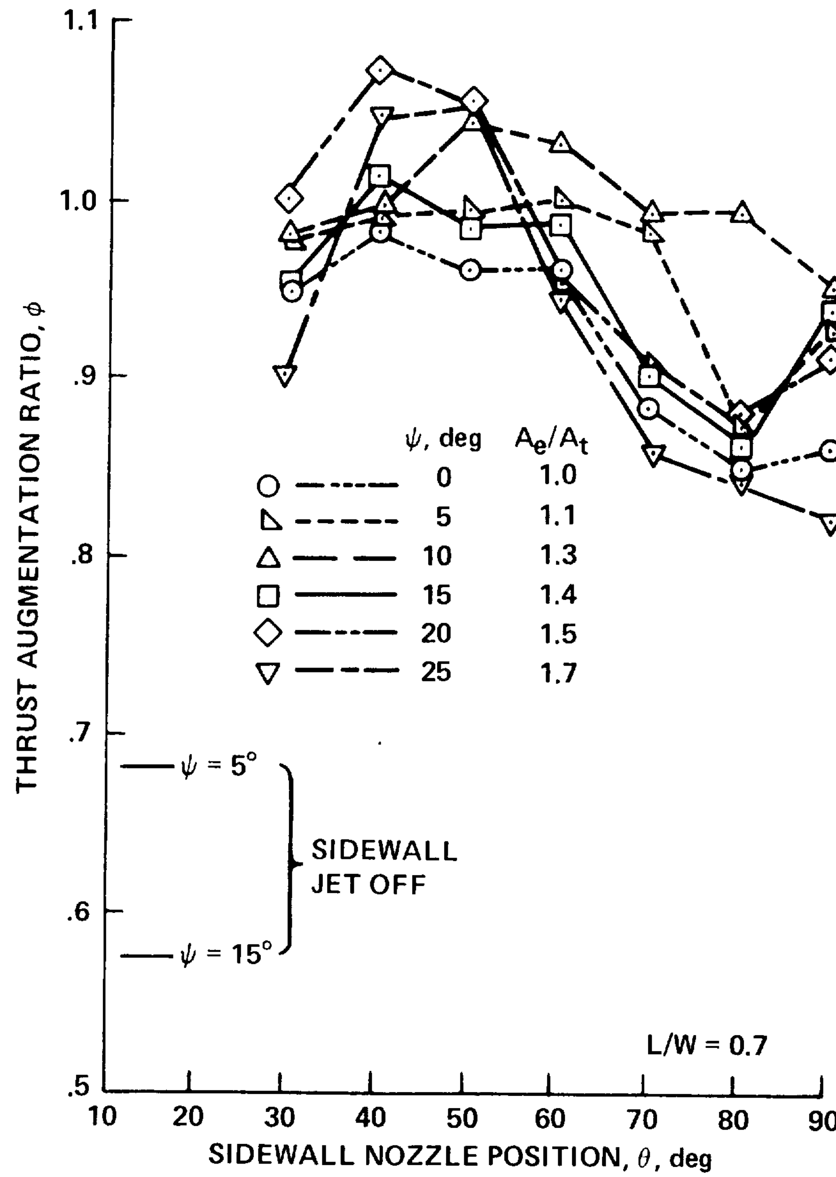


Figure 3.- Effect of sidewall nozzle position on thrust augmentation ratio for L/W = 0.7 and various diffuser area ratios.

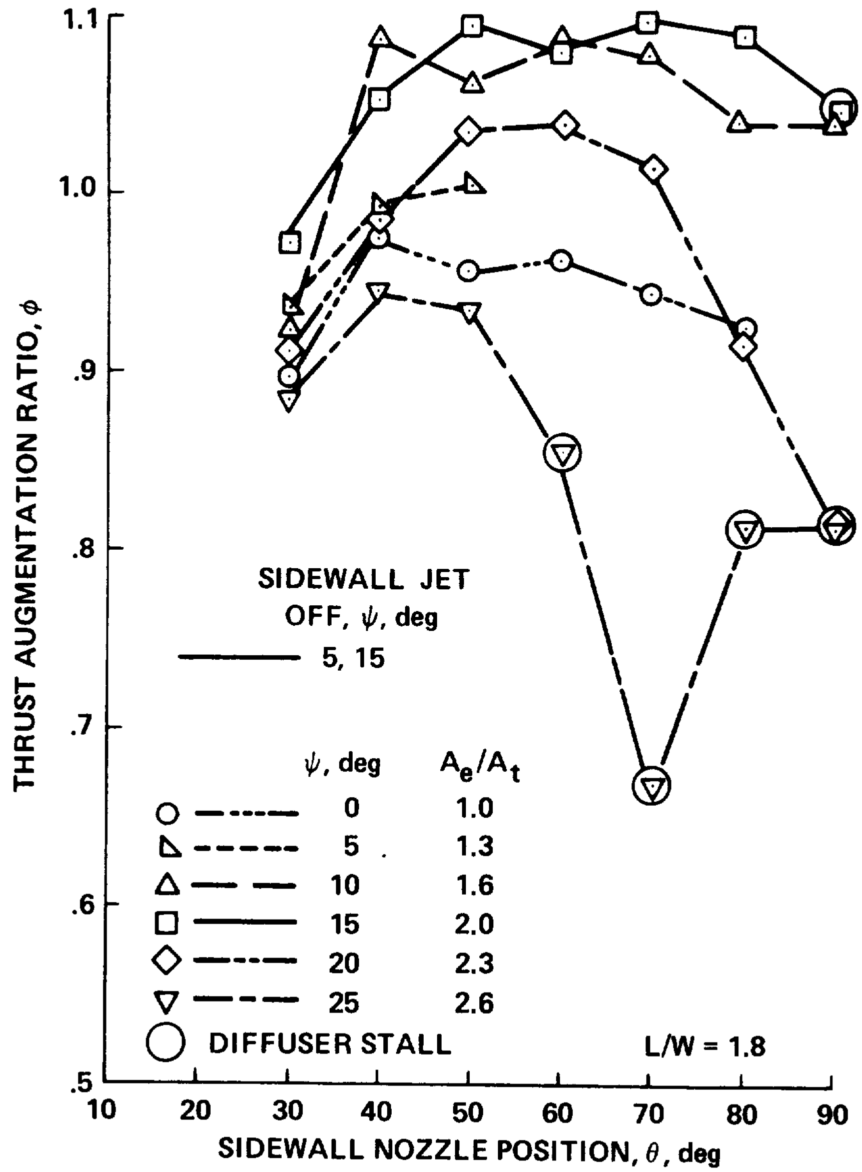


Figure 4.- Effect of sidewall nozzle position on thrust augmentation ratio for L/W = 1.8 and various diffuser area ratios.

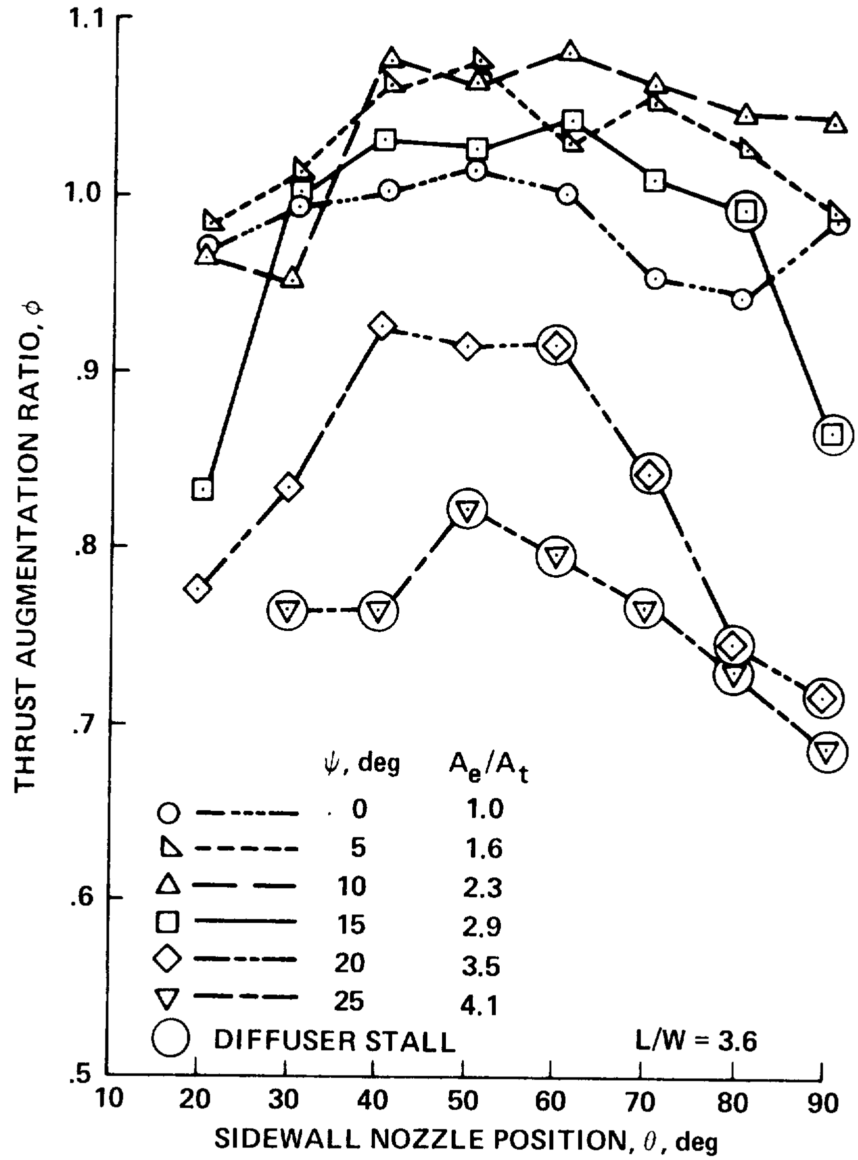


Figure 5.- Effect of sidewall nozzle position on thrust augmentation ratio for L/W = 3.6 and various diffuser area ratios.

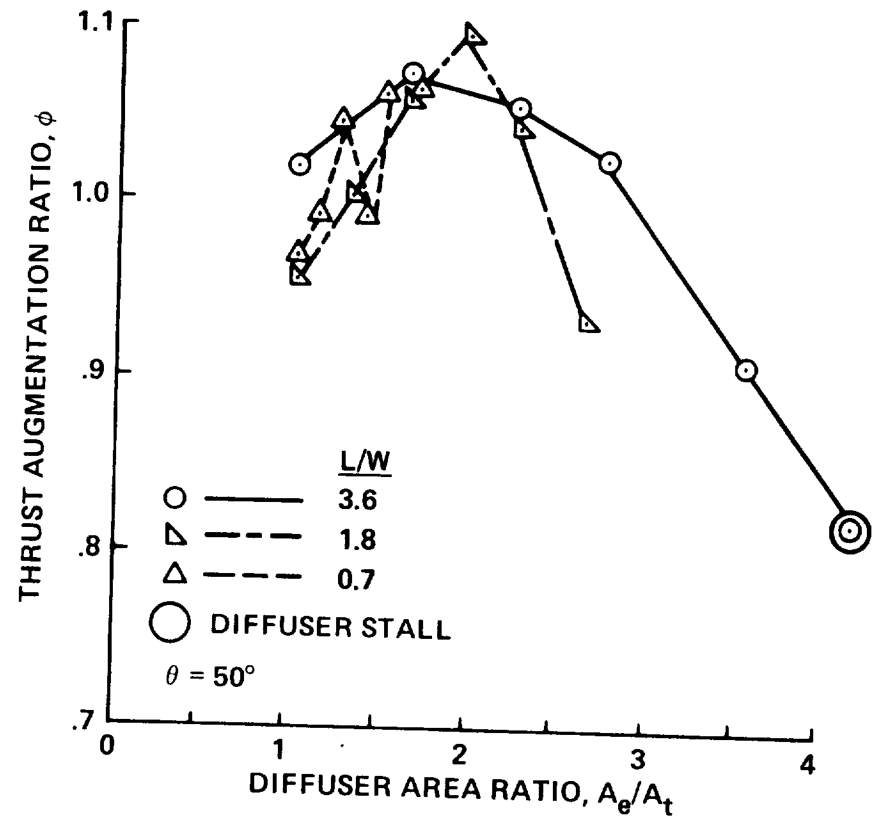


Figure 6.- Effect of diffuser area ratio on thrust augmentation ratio for constant sidewall nozzle position θ.

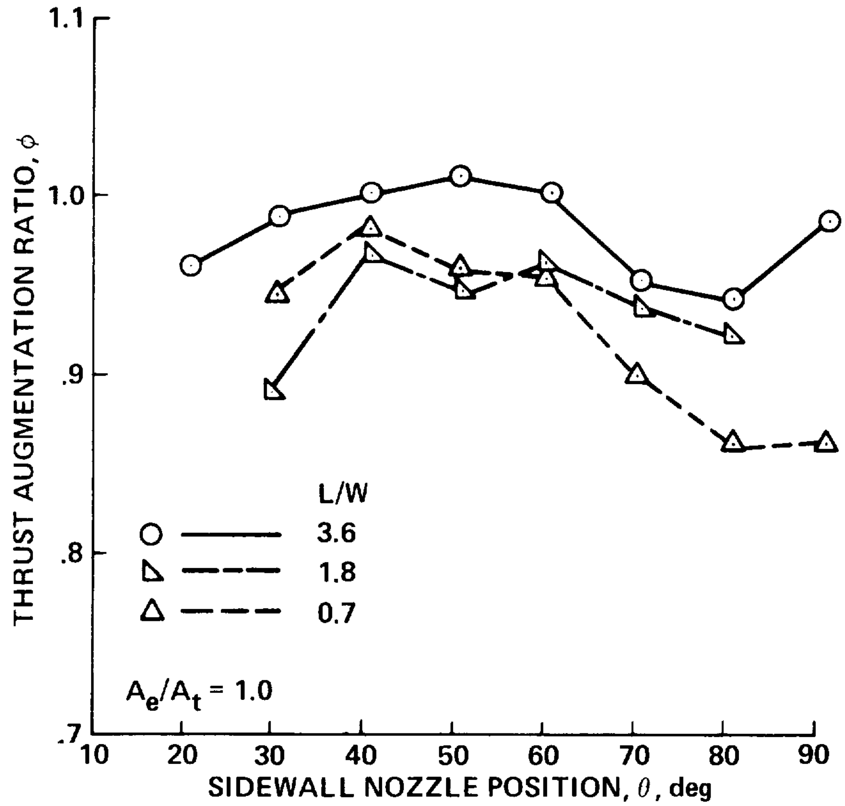


Figure 7.- Effect of diffuser sidewall length on thrust augmentation ratio for diffuser area ratio = 1.0.

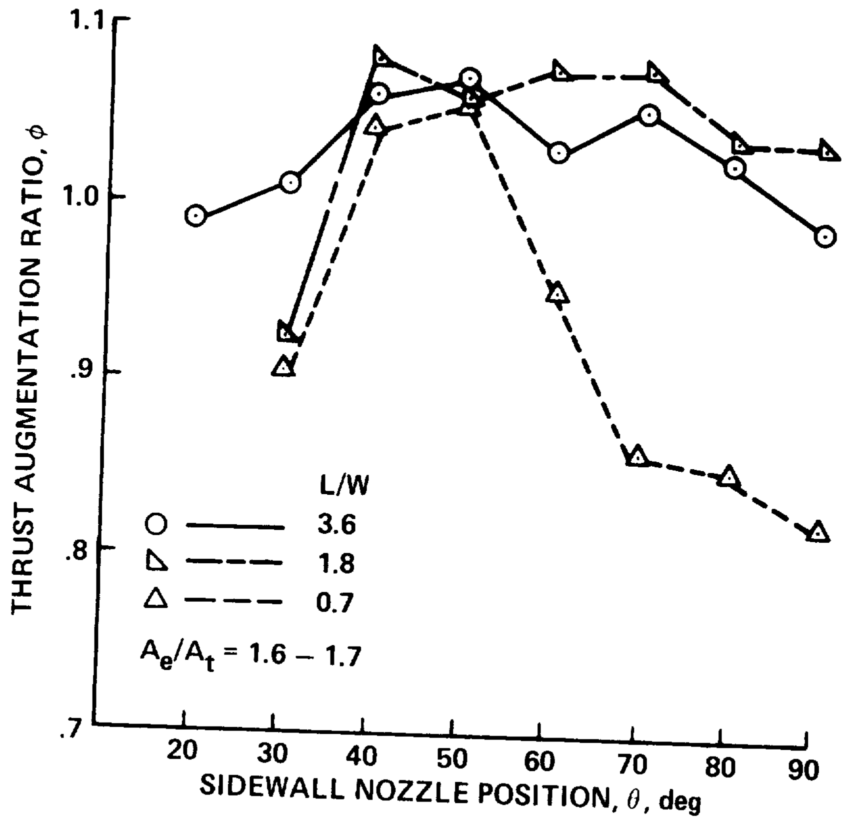


Figure 8.- Effect of diffuser sidewall length on thrust augmentation ratio for diffuser area ratio = 1.6 to 1.7.

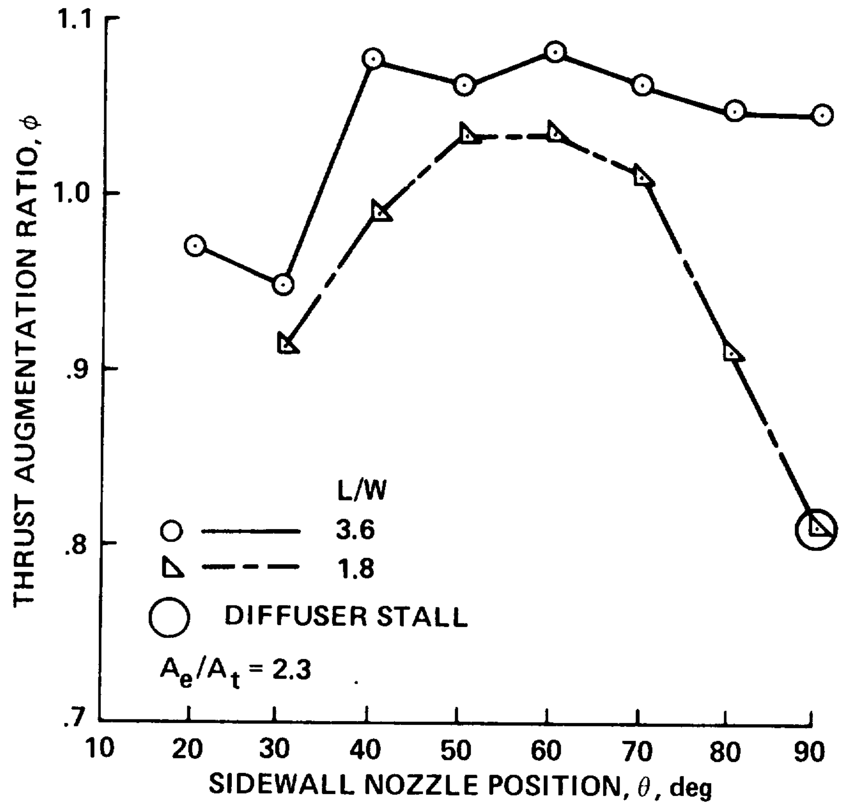


Figure 9.- Effect of diffuser sidewall length on thrust augmentation ratio for diffuser area ratio = 2.3.