

AUGMENTING EJECTOR ENDWALL EFFECTS

J. L. Porter and R. A. Squyers

Vought Corporation
Advanced Technology Center, Inc.
P.O. Box 6144, Dallas, Texas 75222

SUMMARY

Rectangular inlet ejectors which had multiple hypermixing nozzles for their primary jets were investigated for the effects of endwall blowing on thrust augmentation performance. The ejector configurations tested had both straight-wall and active boundary-layer control type diffusers. Endwall flows were energized and controlled by simple blowing jets, suitably located in the ejector. Both the endwall and BLC diffuser blowing rates were varied to determine optimum performance. High area ratio diffusers with insufficient endwall blowing showed endwall separation and rapid degradation of thrust performance. Optimized values of diffuser BLC and endwall nozzle blowing rates in an ejector augmentor are shown to achieve high levels of augmentation performance for maximum compactness.

SYMBOLS

A area
AR diffuser area ratio, $\frac{A_3}{A_2}$
ARL Aerospace Research Laboratory
ASME American Society of Mechanical Engineers
ATC antiseparation tailored contour
BLC boundary-layer control
 C_L centerline
F thrust
h ejector span
L total ejector length
 L_M constant area mixing length
 L_D axial diffuser length

\dot{m} mass flow, lb/sec

P pressure

W width

ϕ thrust augmentation ratio

Subscripts:

0 total, stagnation, condition

1 primary nozzle property

2,M mixing area exit plane

3,D diffuser exit plane

BLC boundary-layer control, diffuser wall

EW endwall property

isen isentropic

max maximum

S blowing slot condition

Superscripts:

' value for ideal expansion to ambient static pressure

INTRODUCTION

Proposed use of augmenting ejectors for V/STOL aircraft has placed emphasis on two-dimensional ejector designs in order to comply with constraints imposed by aircraft wing and body physical restrictions. In general, such restrictions also limit the ejector diffusion, and consequently augmentation possible, either by length or area ratio constraints. Achieving maximum augmentation and compactness for ejector configurations thus frequently means achieving maximum diffusion in the shortest length. Active boundary-layer control (BLC) has been shown to be one method of accomplishing this goal (refs. 1 and 2). Experiments at Vought Corporation Advanced Technology Center, Inc. have shown that for so-called "two-dimensional" ejector-diffuser configurations three-dimensional effects are significant. Thus, boundary-layer control must be used not only on the diffusing walls, but also must be applied to the endwalls whose flow must traverse the same static pressure gradient (ref. 3).

The objectives of this study were to investigate the effects of finite span ejector endwalls on the performance of rectangular inlet ejectors. Tests were performed on configurations with hypermixing primary nozzles for diffusers with straight (no BLC) walls and contoured (BLC) walls. Performance for varying amounts of endwall boundary-layer control was investigated.

EXPERIMENTAL APPARATUS

Experimental Setup

Testing for endwall effects was conducted in the suspended test bed of the ejector/augmenter facility which was located in the Vought High Speed Wind Tunnel Complex. A schematic of the basic ejector test bed is shown in figure 1. The location of the ejector endwall blowing jets is shown in the figure. Pressurized air supplied by storage tanks to the ejector test bed was measured using ASME calibrated orifice plate flowmeters. Endwall nozzle and endwall blowing corner jets used a common flowmeter and were measured separately from other system flows. The ejector test bed, shown in a front view in figure 2, has a constant area mixing region width of 10 in. and an aspect ratio of 6.0.

Instrumentation

Measurements of ejector endwall blowing parameters and internal flow qualities were obtained for evaluation and analysis. Hypermixing nozzle primary plenum pressures, blowing slot plenum pressures, and endwall jet nozzle plenum pressures were measured by calibrated gage pressure transducers. Ejector test bed total thrust was monitored through a six-component strain gage balance for determination of system thrust augmentation performance. Diffuser wall surface pressure distributions were sensed by flush mounted static pressure taps. Visualization of endwall flows was accomplished with streamwise flow tufts. Interaction of endwall and diffuser flows was determined by a multiprobe total pressure rake which traversed the internal flows.

Ejector/Diffuser Configurations

Planviews of the ejector/diffuser configurations investigated for endwall effects in the ejector test bed are shown in figure 3. Two straight-wall diffusers tested were the Air Force Aerospace Research Laboratories (ARL) Configuration "F" and an equivalent baseline model. Both had only endwall blowing for control of diffuser flows. The results from two compact BLC diffusers included both endwall and diffuser wall blowing slot flows for the optimization of thrust augmentation. All four configurations were tested at various diffuser area ratios for optimization of performance.

RESULTS AND DISCUSSION

The thrust augmentation ratio, ϕ , is defined as the total ejector thrust, F , divided by the thrust generated by an isentropic expansion of the primary mass from the driving pressure to the ambient total pressure. The general form for the ejectors being studied is

$$\phi = \frac{F}{F_{isen}} = F(\dot{m}_1 V_1' + \dot{m}_{BLC} V_{BLC}' + \dot{m}_{EW} V_{EW}')^{-1}$$

where \dot{m}_1 , \dot{m}_{BLC} , \dot{m}_{EW} are the mass flow rates from the hypermixing, boundary-layer control and endwall nozzles, respectively. The quantities V_1 , V_{BLC} , V_{EW} are the corresponding velocities achieved after isentropic expansions to ambient pressure from the measured total pressures P_{01} , P_{0BLC} and P_{0EW} .

Because the maximization of thrust augmentation was the primary goal, in some instances data were not obtained for the limiting cases of zero endwall blowing mass flow, \dot{m}_{EW} . Rather, low values of \dot{m}_{EW} , for which diffuser separation and rapid falloff of thrust occurred, were defined and then variations were investigated to determine the optimum values. Data were obtained for ejectors with straight-wall diffusers and for ejectors with specially contoured diffuser walls.

Straight-Wall Diffusers

Two straight-wall diffuser configurations were tested: (a) an Air Force Aerospace Research Laboratory (ARL) design with a 45-in. diffuser length, and (b) a shorter, 11.75-in. diffuser length, designed to provide baseline comparisons with the specially contoured ATC diffusers. As shown in figure 1, various area ratios and equivalent half-angles were available through a mechanical/flexible wall design.

Results (ref. 4) for the ARL diffuser are shown in figure 4 for a range of area ratios up to 2.5 and a range of primary jet pressures. As may be seen, with a long diffuser length a high value of augmentation can be achieved, $\phi_{max} = 2.10$.

The maximum area ratio achievable without flow separation was 1.5 for the shorter baseline straight-wall diffuser. At area ratios greater than 1.5, no amount of endwall blowing would prevent diffuser wall separation on this configuration. Figures 5 and 6 show the effects of \dot{m}_{EW} variations on the thrust augmentation of the baseline straight-wall ejector/diffuser configuration. As shown in these figures, the maximum thrust augmentation for both area ratios, 1.25 and 1.50, was achieved at approximately the same endwall blowing rate, $\dot{m}_{ew} \approx 0.15$ lb/sec. Data have shown that increasing the diffuser area ratio results in a lower mixing plane static pressure, a higher entrained secondary flow velocity and consequently a proportional change in the endwall boundary-layer momentum loss entering the diffuser. Because of the small change in straight-wall diffuser area ratio this apparent boundary-layer phenomena

impact on endwall blowing requirements was not readily quantified. Thus, while the adverse pressure gradient through the 1.5 area ratio diffuser is larger, the total energization as indicated by the \dot{m}_{ew} required was approximately the same as for the lower area ratio configuration, at the optimum condition.

Specially Contoured (ATC) Diffusers

The specially contoured diffusers were designed to achieve rapid diffusion in a short length through the use of boundary-layer energization on the diffusing walls as well as the endwalls. Figure 7 shows the effects of variations in the endwall blowing rate for a short, area ratio of 2.10, diffuser at two values of the diffuser wall BLC blowing rates, \dot{m}_{BLC} . As shown in the figure, although considerable data scatter occurred, peak performance was obtained for both values of \dot{m}_{BLC} at endwall blowing rate between 0.17 and 0.18 lb/sec. This value is close to the optimum value of 0.15 lb/sec found for the straight-wall diffusers of equivalent length. The increase is required by the more rapid diffusion of the specially contoured wall and the 30% increase in diffuser area ratio (2.1 vs 1.5). The tendency of the thinner endwall boundary layer, found at higher entrained velocities, to counteract the effect of adverse pressure gradient on the required blowing rate is apparently overcome at an area ratio between 1.5 and 2.1.

In the data of figure 8 the optimum value of endwall blowing rate was held fixed while the boundary-layer control on the diffusing wall was varied. Peak performance of $\phi = 1.88$ was obtained at \dot{m}_{BLC} slightly over 0.55 lb/sec; however, values as low as $\phi = 1.80$ were obtained for approximately the same \dot{m}_{BLC} . This difference appears to be due to a slight hysteresis effect wherein data taken as \dot{m}_{BLC} increases have slightly lower augmentation values due to incomplete boundary-layer energization. Once a value of \dot{m}_{BLC} high enough to completely energize the boundary layer has been achieved, a somewhat lower value is sufficient to maintain energization. The lower value of \dot{m}_{BLC} results in a lower value of the corresponding ideal thrust and hence a higher augmentation ratio.

Diffuser-Endwall Corner Effects

During the course of the experimental study, flow tuft visualization indicated that when diffuser separation occurred, it was generally initiated in the corners formed by the intersection of diffuser walls and endwalls. Consequently, corner "buttons" were added to the configuration, as shown in figure 9, to provide additional boundary-layer control in this area. The button flow was derived from the same source as the endwall blowing flow, at the same total pressure. While visual observations indicated that the button flow was effective in preventing corner separation, comparison of optimum peak augmentation values indicated that the optimum endwall/corner blowing configuration had not been obtained. Figures 10 and 11 show these peak augmentation values for two discrete values of \dot{m}_{EW} , which for figure 10 includes the button flow, as functions of the diffuser BLC flow, \dot{m}_{BLC} . While the total blowing flow rate for the maximum augmentation is approximately constant at

$\dot{m}_{BLC} + \dot{m}_{EW} = 0.76$ lb/sec, the configuration without buttons has the better maximum performance. Stated differently, increasing the diffuser wall BLC flow, which was at a higher total pressure than that for the endwall/button flow, was more effective in energizing the corner boundary layer than was increasing the endwall/button flow by the same amount. From these results it thus appears that while corner flow BLC is important, additional investigations are required to determine the optimum geometry and flow conditions for the corner jets.

Comparison of Straight- and Contoured-Wall Ejector/Diffuser Results

A summary comparison of the best performance obtained for all combinations of area ratio, mixing plus diffuser length, and endwall and diffuser wall blowing, is shown in figure 12. As may be seen in this figure, significant gains in ejector/diffuser compactness were achieved for the specially contoured wall diffusers with optimized BLC, over the straight-wall diffusers with only endwall BLC.

CONCLUSIONS

Two-dimensional (rectangular) ejector diffuser configurations experience significant three-dimensional flow effects on their endwalls. Providing boundary-layer control for the endwalls can significantly improve the performance of straight-wall diffusers. However, maximum gains in compactness for a given level of thrust augmentation can be achieved through the use of specially contoured, rapid-diffusion diffuser walls with both diffuser wall and endwall boundary-layer control. For the straight-wall diffusers, an optimum endwall blowing rate, \dot{m}_{EW} , exists. For the contoured-wall diffusers, an optimum combination of \dot{m}_{EW} and the diffuser wall blowing rate, \dot{m}_{BLC} , exists.

RECOMMENDATIONS

The significance of boundary-layer control, or the absence thereof, becomes even greater as experimental devices are pushed to full scale development. Use of ejector/diffuser configurations with actual engine exhaust supplying the primary driving flow frequently results in higher pressure and temperature conditions than were achieved experimentally. Mechanization of designs to comply with wing/fuselage structural constraints may also alter experimentally obtained optima. Recommendations to enable experimental data to be achieved on flightworthy configurations therefore take the following form:

- Optimum endwall and diffuser wall boundary-layer control (BLC) conditions should be investigated for scaling effects.
- Optimum BLC conditions should be determined for pressures and temperatures corresponding to current jet engine exhaust flow.

- Configurations corresponding to actual flight hardware should be investigated to determine optimum flow parameters.

REFERENCES

1. Squyers, R. A.: Feasibility Tests on Mating an Antiseparation Tailored Contour With a Large Area Ratio Thrust Augmenter. ATC Report No. B-94300/4TR-27, 1974.
2. O'Donnell, R. M.; and Squyers, R. A.: V/STOL Ejector Short Diffuser Study. NADC-77165-30, Naval Air Development Center, 1976.
3. Seiler, M. R.: An Investigation of Corner Separation Within a Thrust Augmenter Having Coanda Jets. NADC-76153-30, Naval Air Development Center, 1977.
4. Haight, C. H.; and O'Donnell, R. M.: Experimental Mating of Trapped Vortex Diffusers with Large Area Ratio Thrust Augmentors. ARL TR 74-0115, Air Force Systems Command, 1974.

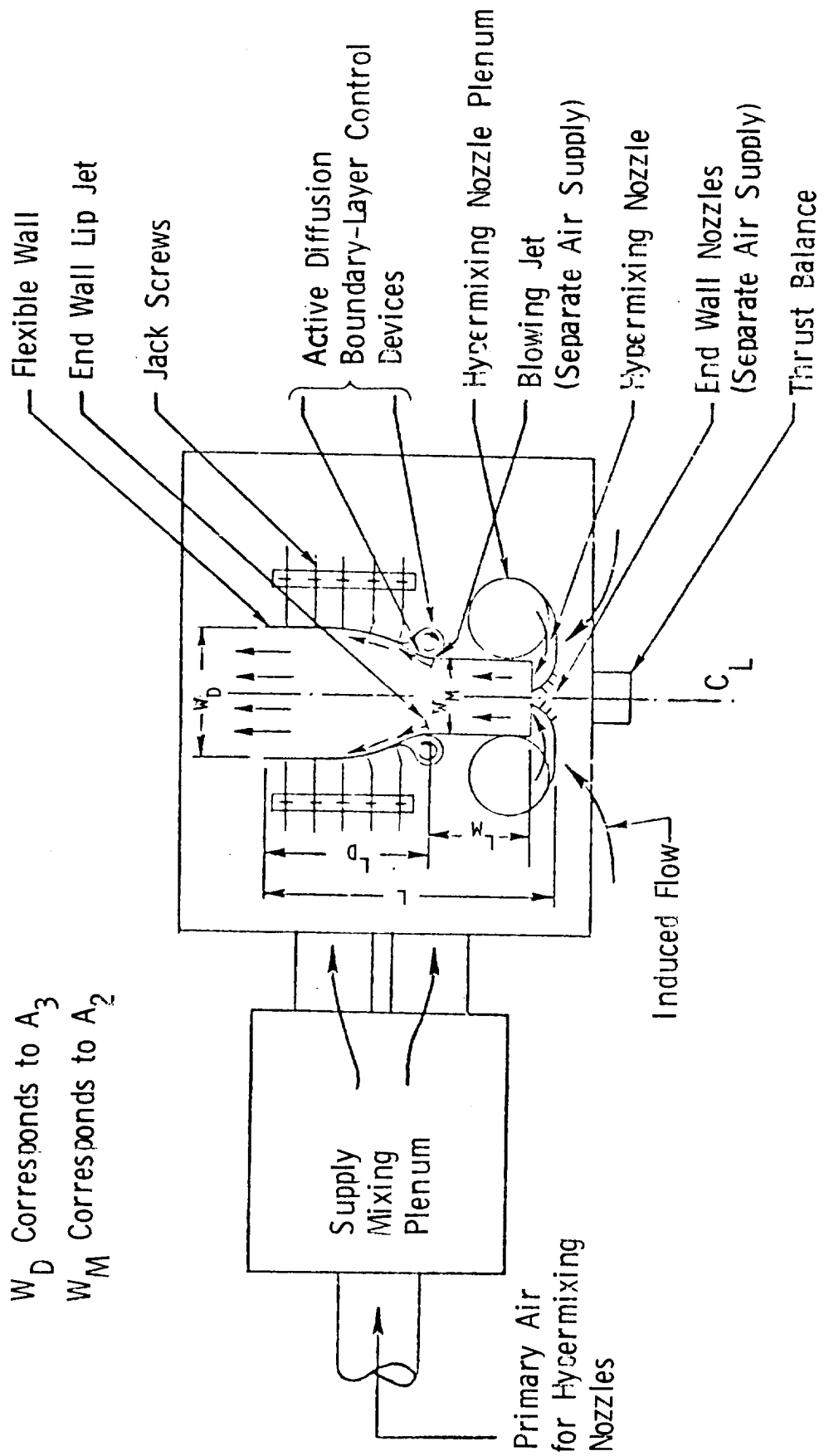


Figure 1.- Schematic of ejector/diffuser test bed.

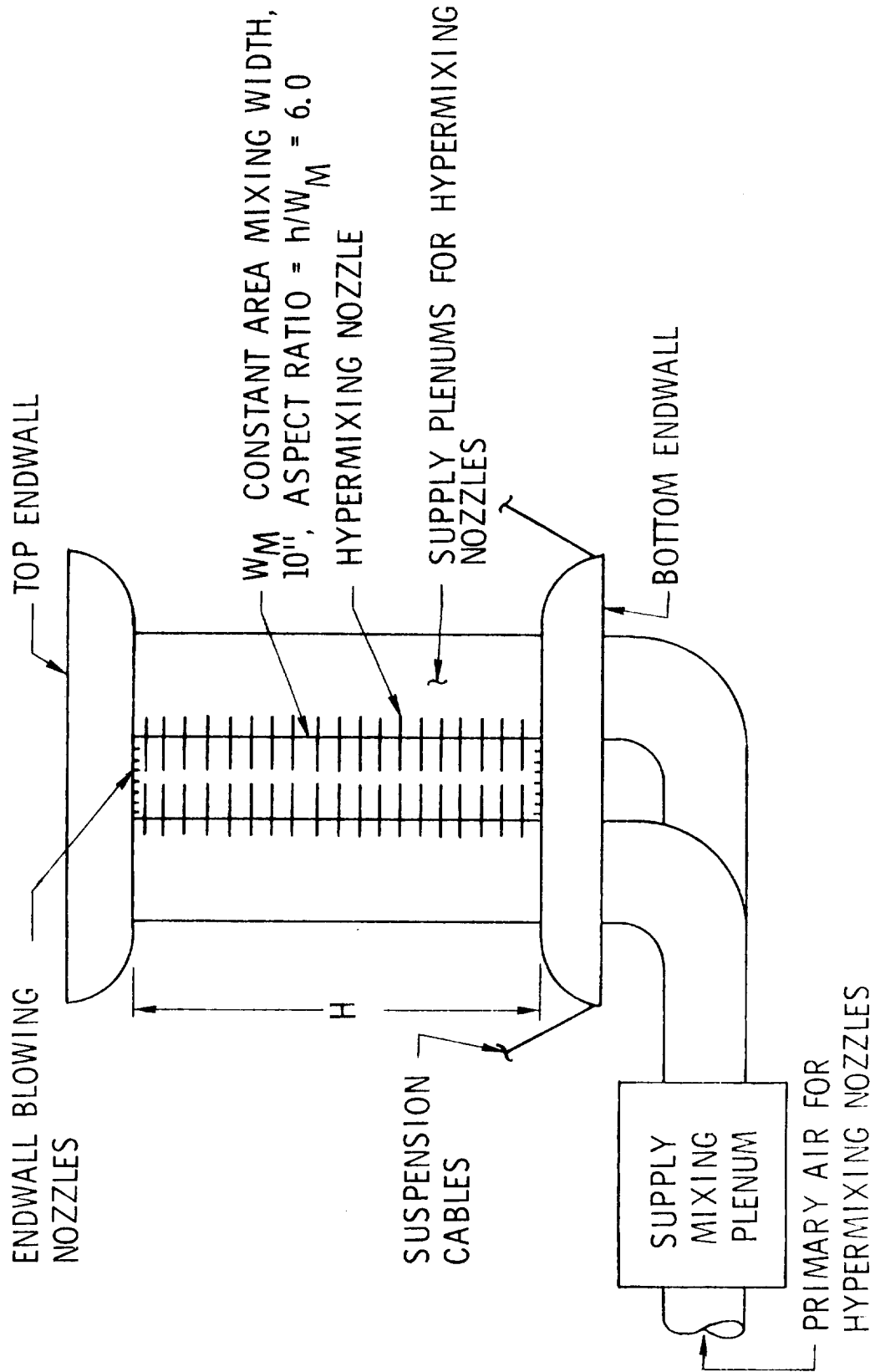


Figure 2.- Front view of ejector test bed (looking downstream).

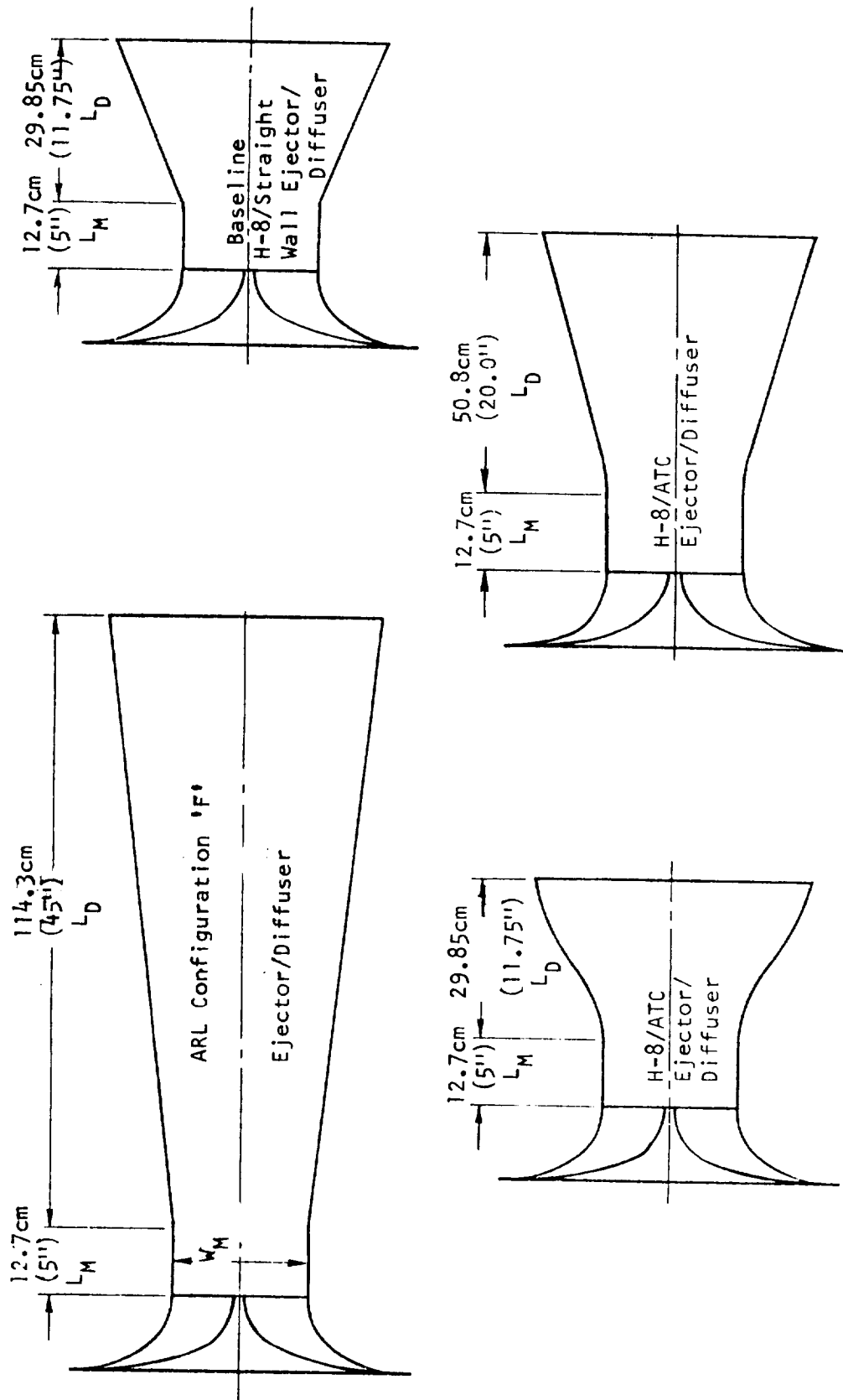


Figure 3.- Planviews of ejector/diffuser test configurations.

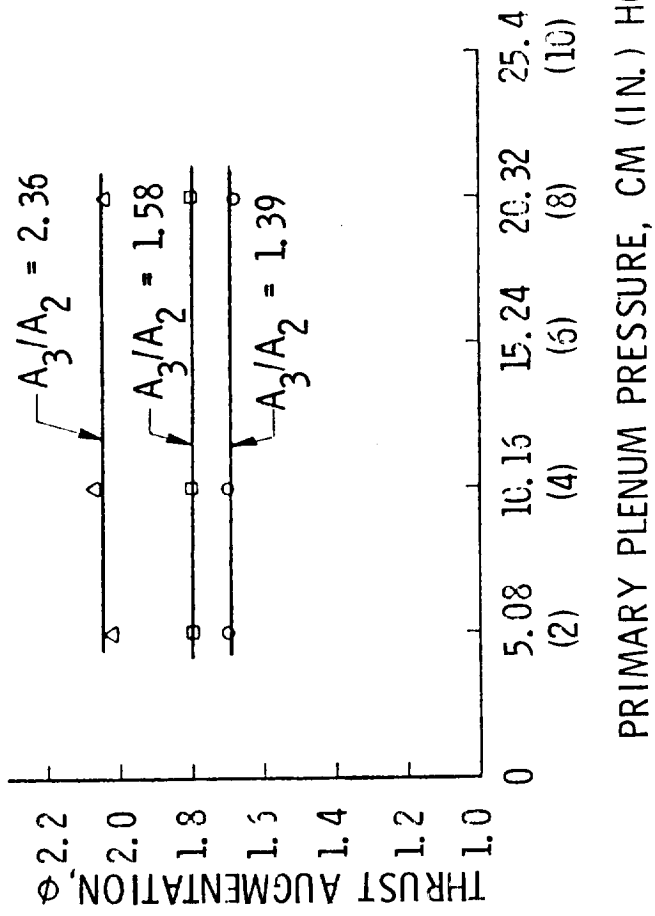
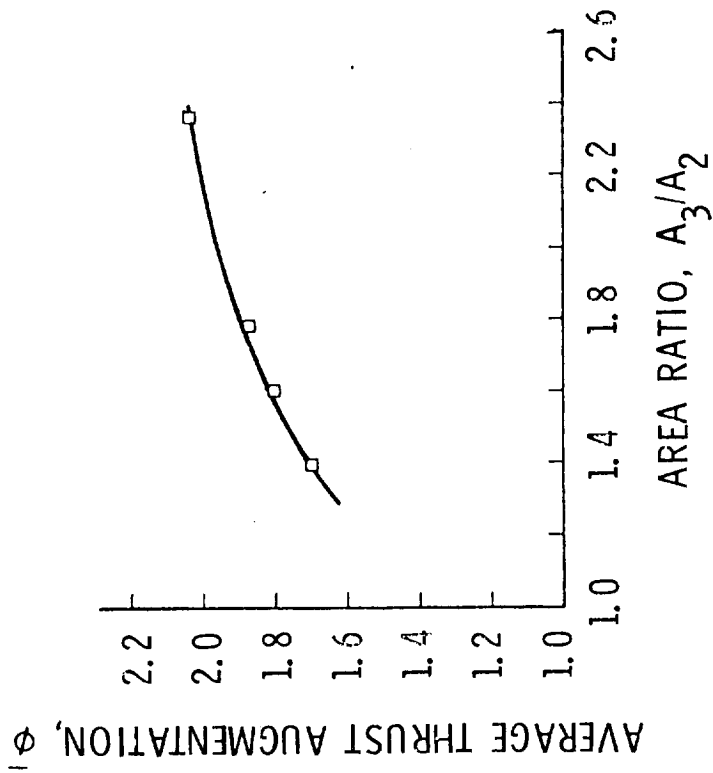


Figure 4.- Variation of thrust augmentation ratio with diffuser area ratio and pressure, for configuration "F", ARL/H-8 nozzles, from reference 4.

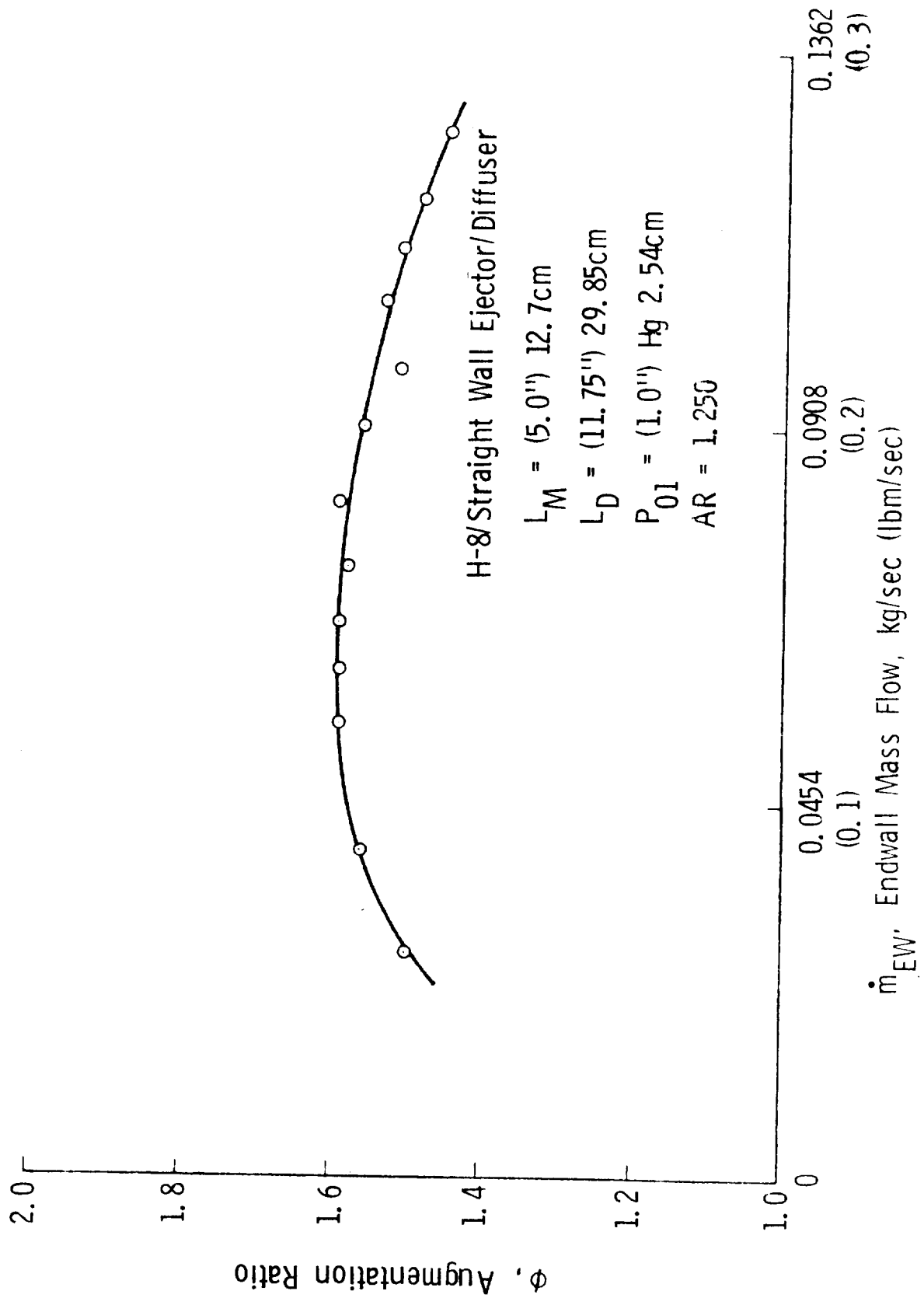


Figure 5.- Variations with endwall blowing for baseline straight-wall diffuser, $A_2/A_1 = 1.25$.

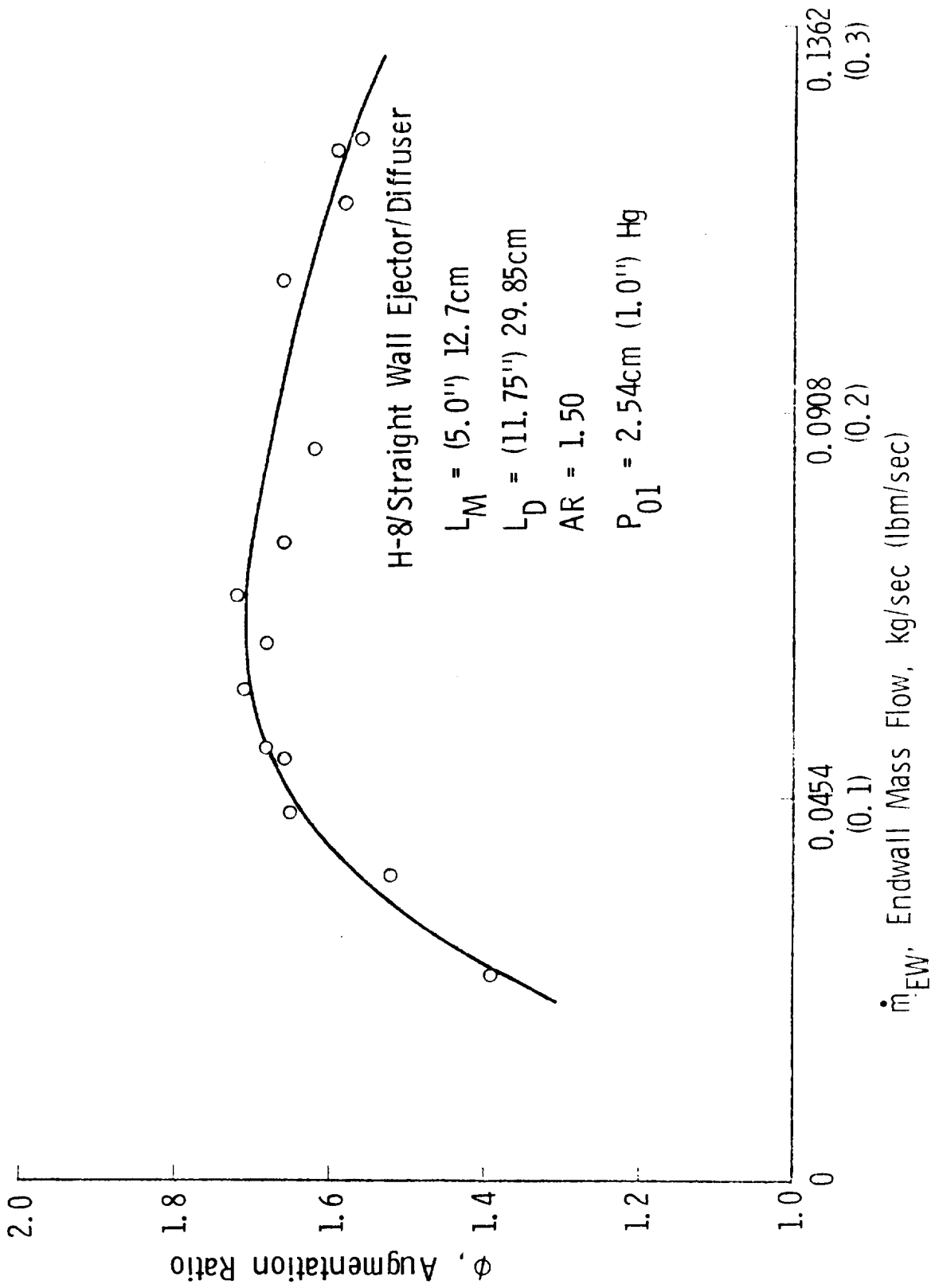


Figure 6.- Variations with endwall blowing for baseline straight-wall diffuser, $A_3/A_2 = 1.50$.

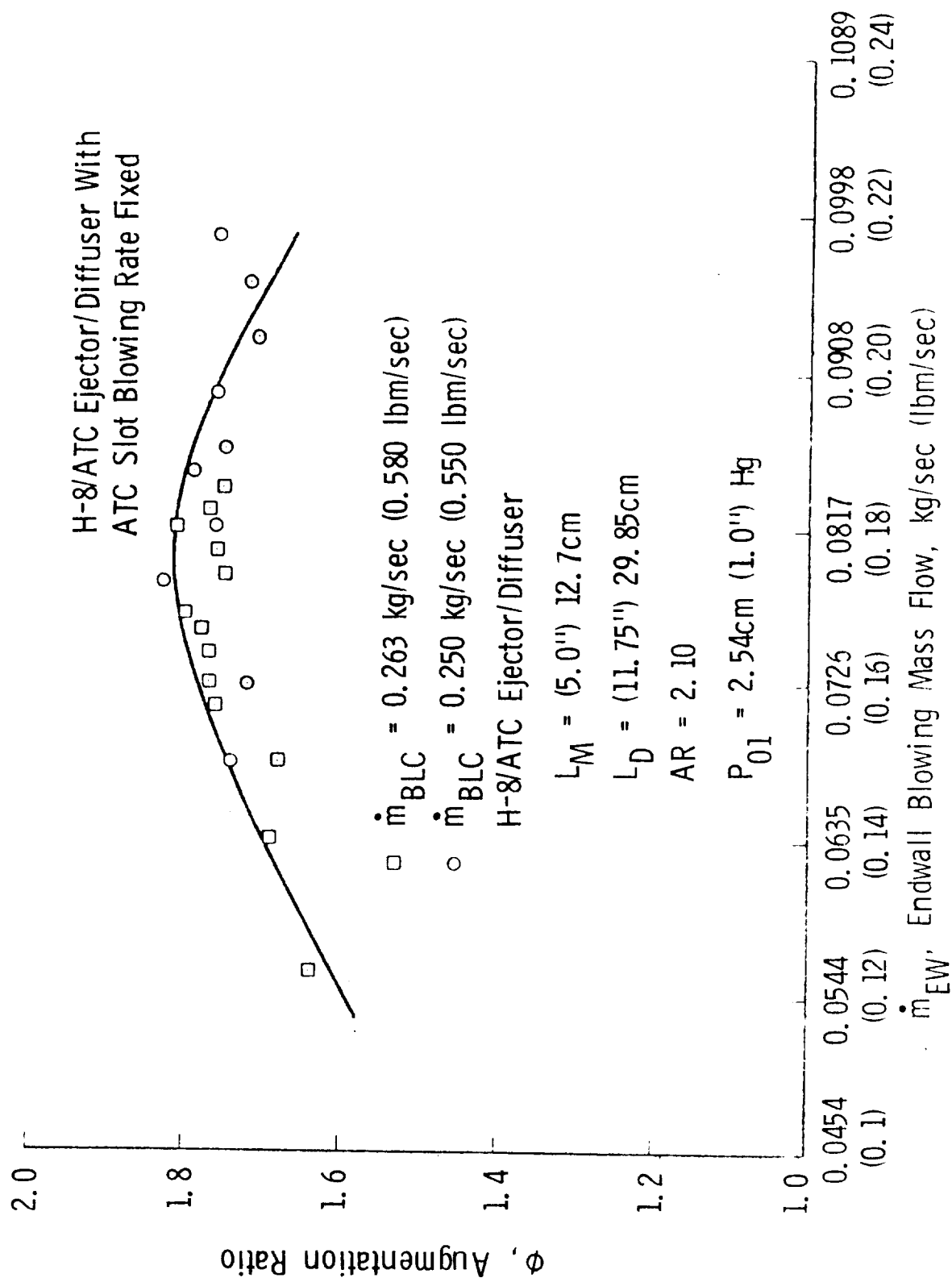


Figure 7.- Optimization of endwall blowing for a specially contoured (ATC) diffuser.

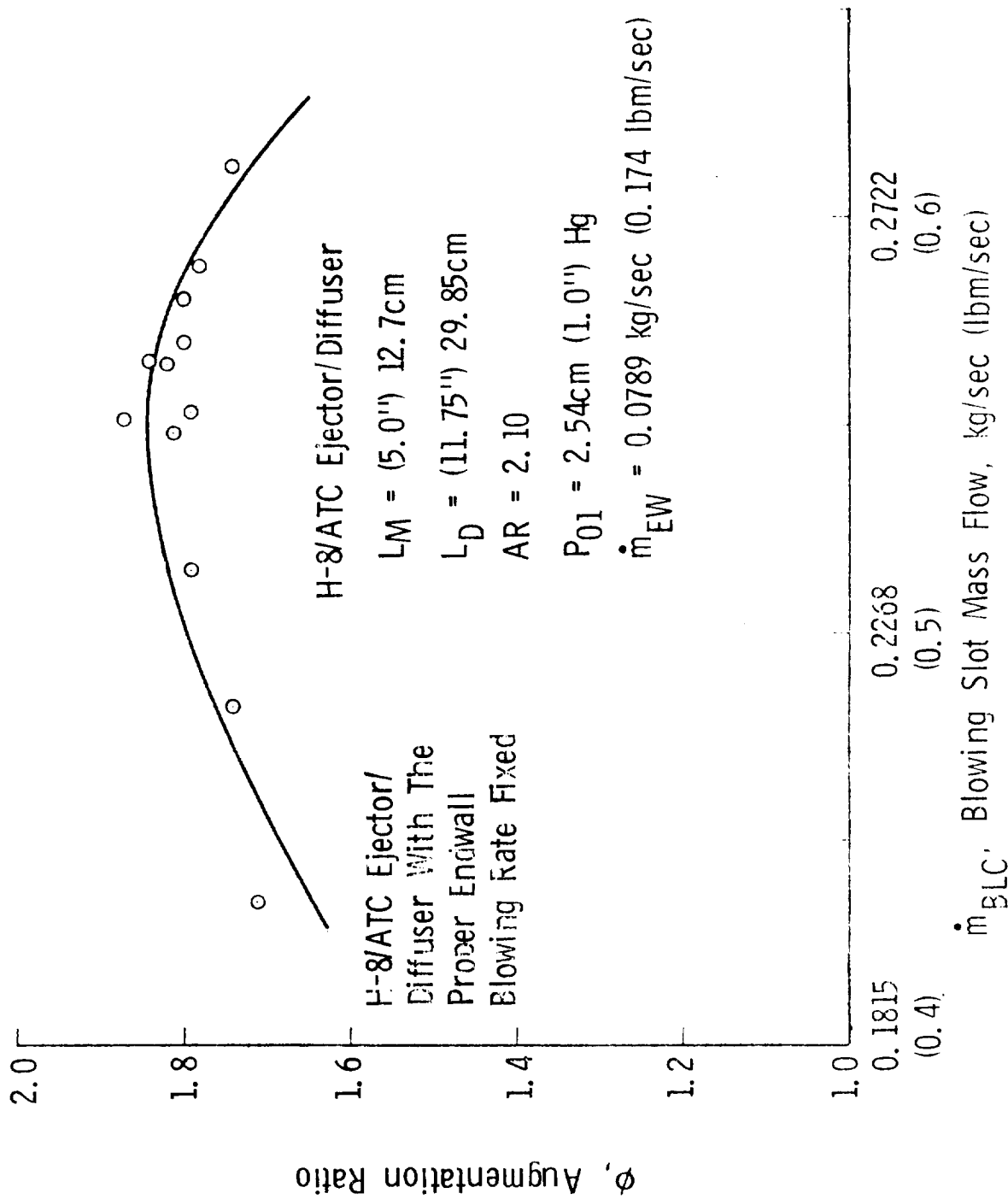


Figure 8.- Optimization of diffuser wall blowing for a specially contoured (ATC) diffuser.

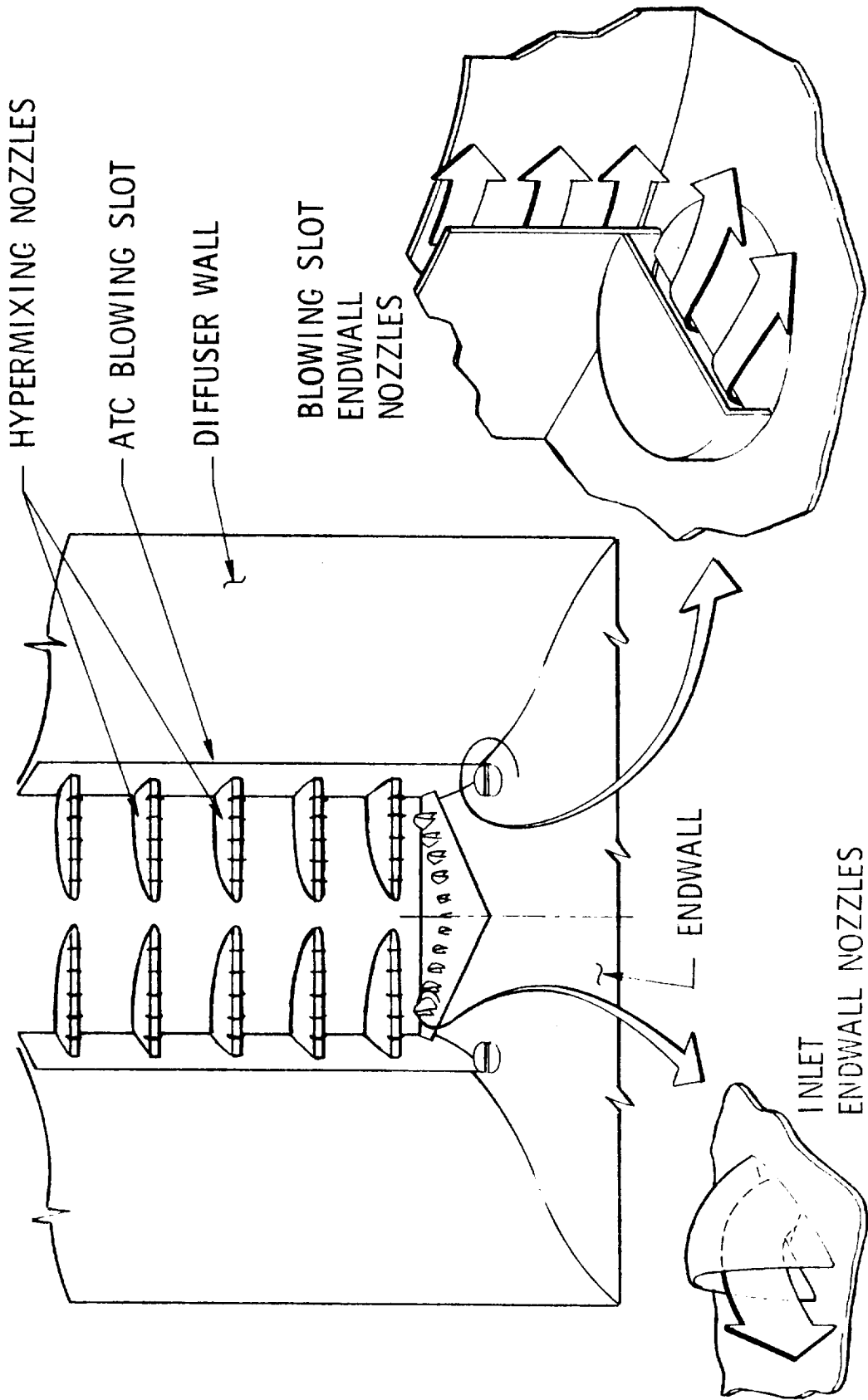


Figure 9.- View of ejector test configuration showing special endwall blowing nozzles (looking upstream).

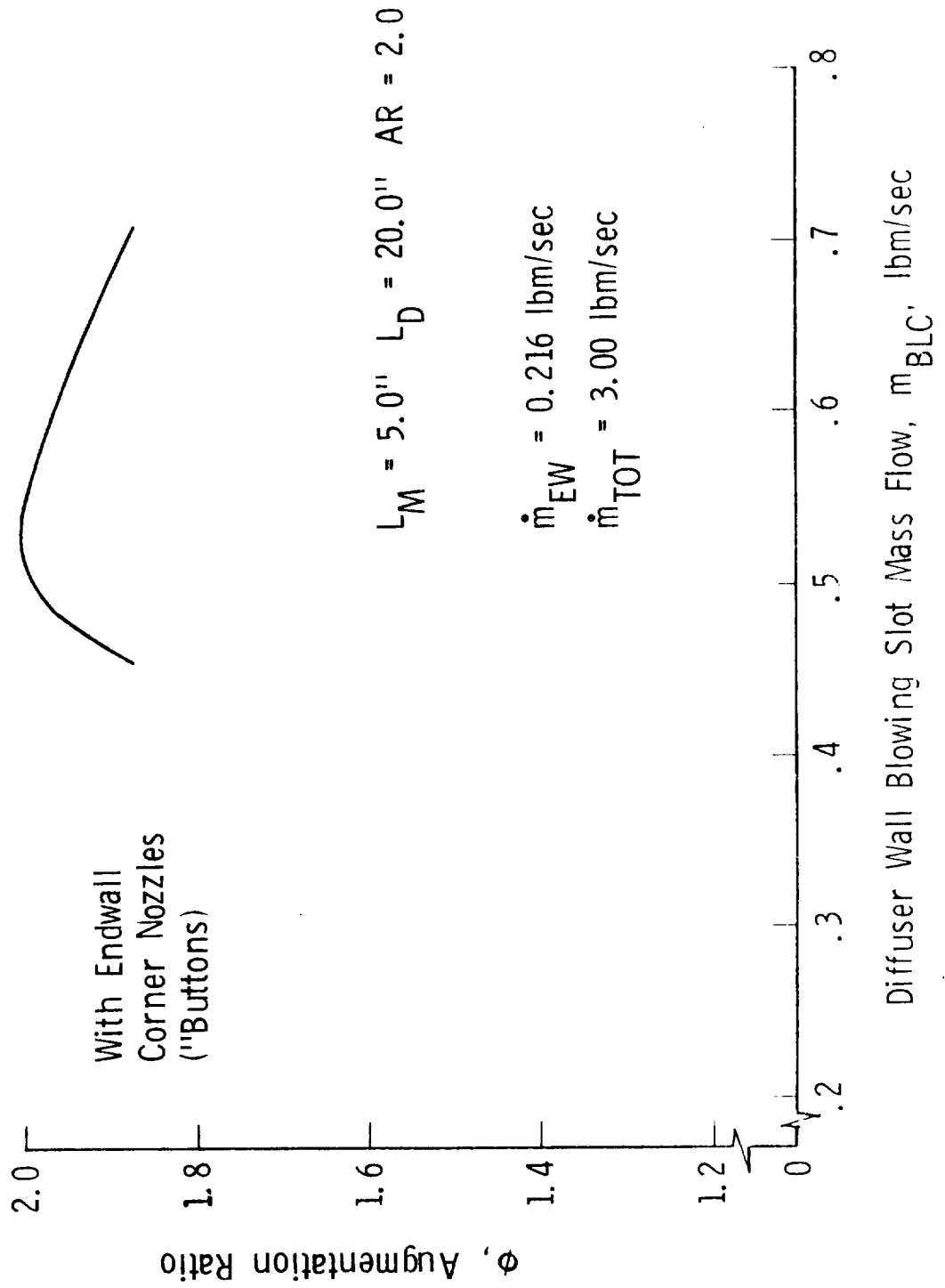


Figure 10.- Variation of peak augmentation ratio with diffuser wall slot mass flow, for no corner blowing.

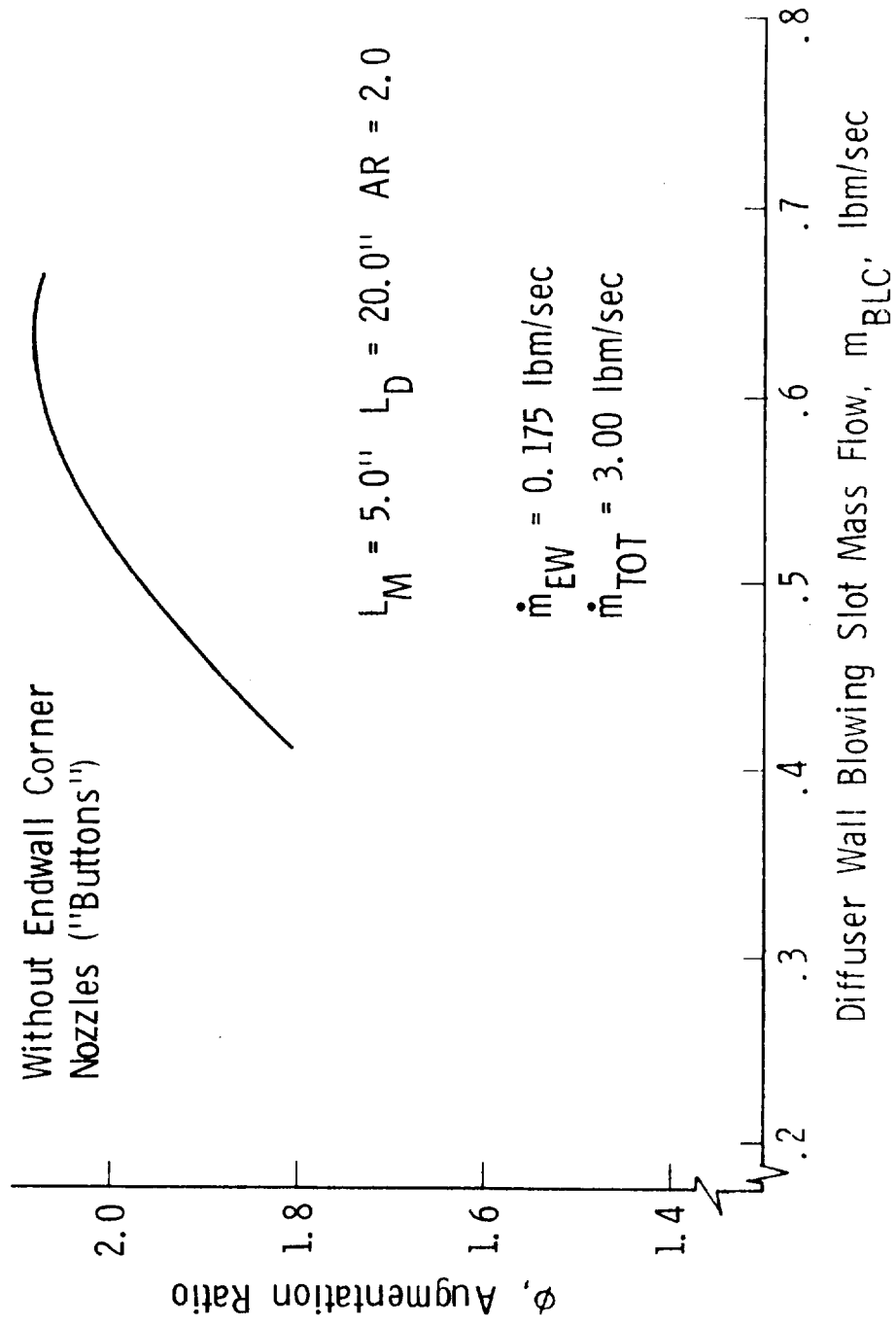


Figure 11.1.- Variation of peak augmentation ratio with diffuser wall slot mass flow, for no corner blowing.

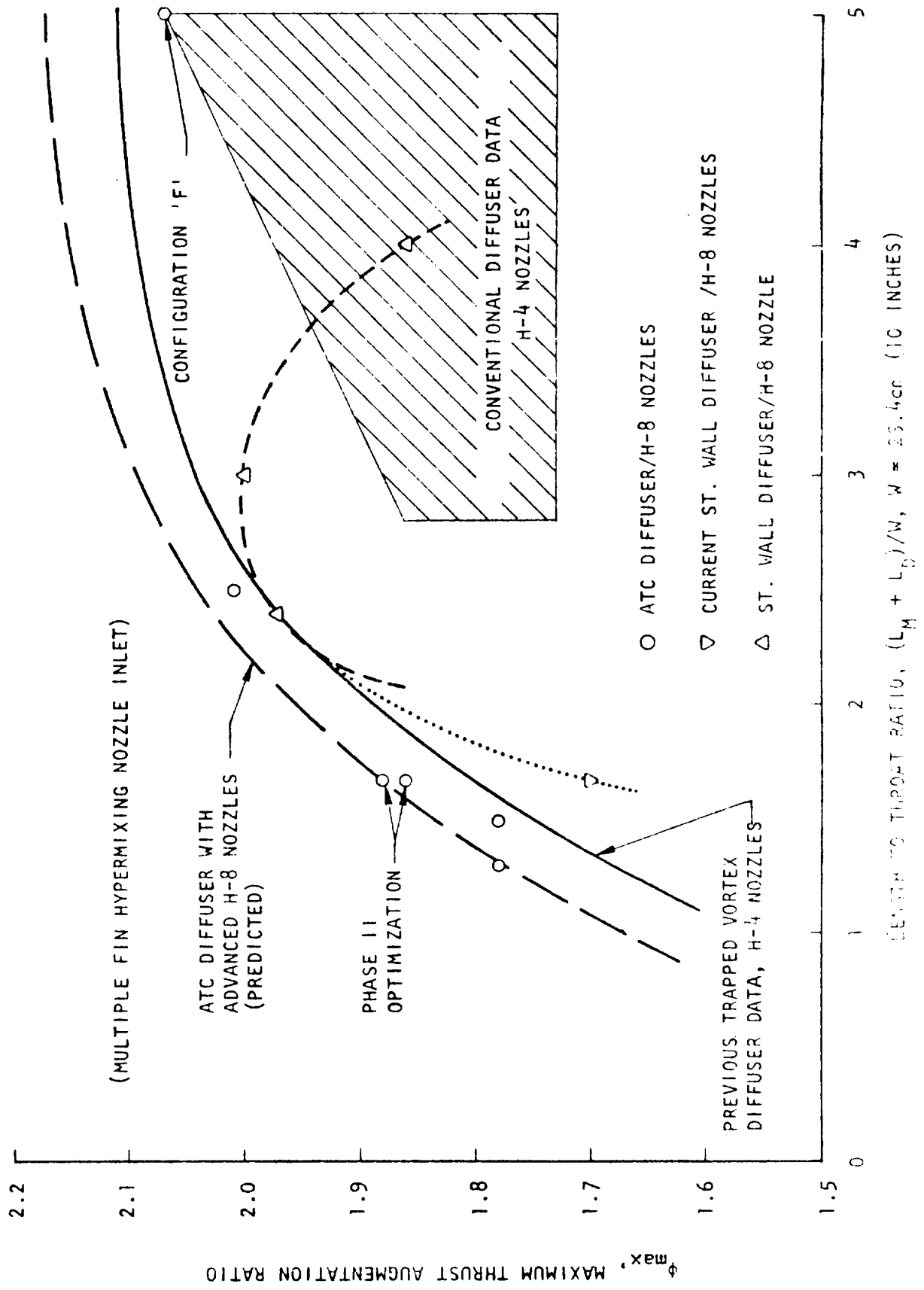


Figure 12.- Comparison of maximum augmentation ratios for ATC and conventional diffusers.