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EFFECT OF WALL SUCTION ON PERFORMANCE OF A SHORT ANNULAR DIFFUSER AT INLET MACH NUMBERS UP TO 0.5

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16. Abstract

The performance of a short annular diffuser equipped with wall bleed (suction) capability was evaluated at inlet Mach numbers of 0.186 to 0.5. The diffuser had an area ratio of 4.0 and a length-to-inlet height ratio of 1.6. Test results show that the exit velocity profiles, typical of annular jet flow without suction, could be considerably flattened by application of wall suction. This improved performance was also reflected in diffuser effectiveness (static-pressure recovery) and total-pressure loss results. At the inlet Mach number of 0.5 diffuser static-pressure recovery was equal to or better than at lower inlet Mach numbers for comparable suction rates.

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SUMMARY

The performance of a short annular diffuser equipped with wall suction capability was evaluated at inlet Mach numbers of 0.186 to 0.5. The diffuser had an area ratio of 4.0 and a length-to-inlet height ratio of 1.6. The diffuser walls were of toroidal form with quarter circle cross section. Wall bleed (suction) flow was removed through two stepped slots continuous over the wall circumference, located at 20° and 40° of arc. The performance parameters that were determined included velocity profile shapes, diffuser effectiveness (static-pressure recovery) and diffuser total-pressure loss.

Test results show that the annular-jet exit velocity profiles, obtained without suction, could be considerably flattened by applying about 4 percent suction on the inner wall and 6 percent on the outer wall. Diffuser effectiveness at the lowest inlet Mach number was improved from about 25 percent without suction to 75 percent at a total suction rate of 15 percent.

At the 0.5 inlet Mach number diffuser effectiveness was equal to or higher than at lower Mach numbers for comparable suction rates. This implies that extrapolation of test rig performance data obtained at low Mach numbers to the higher engine design Mach numbers is justified for the diffuser geometry tested. Similar conclusions were reached from total-pressure loss results.

INTRODUCTION

An investigation was conducted to determine the performance over a range of inlet Mach numbers of a short annular diffuser provided with suction capability by means of peripheral step slots in the circular arc contour diffuser walls. A second but equally important objective was to establish whether diffuser performance testing at low Mach numbers would be indicative of performance at Mach numbers of 0.5.

The interest in high-Mach-number gas-turbine combustor diffusers arises from axial compressor design studies as discussed for example in reference 1. Such studies indicate that increasing axial and tangential velocities, which in turn yield higher flow Mach numbers relative to the compressor blades, would permit higher blade loading with significant gains in stage pressure ratio. As a result the number of stages to accomplish a given overall pressure ratio could also be reduced. For example, advanced compressors with design exit Mach numbers of 0.5 are being contemplated which would develop overall pressure ratios of 12:1 in as few as five stages. This rather drastic reduction from the usual design of eight or nine stages for this performance level, would bring about significant savings in compressor weight, complexity, and cost.

One requirement for successful integration of such advanced compressors with other gas turbine engine components is that combustor diffusers be able to operate at inlet Mach numbers of about 0.5 without incurring severe performance penalties. Diffuser designs that may meet this requirement feature high area ratio at minimum length, with some form of wall boundary-layer control such as suction (refs. 2 to 6). Of course, to conserve engine cycle efficiency, the bleed flow could also be used for additional functions such as turbine cooling or cabin air pressurization (as was suggested in ref. 2). Reference 2 employed a distributed deceleration scheme over diffuser walls of circular arc cross section with two circumferential suction slots which were flush with the wall surface. A Griffith diffuser with a concentrated deceleration region located between regions of constant velocity and favorable pressure gradient was used in reference 3, and references 4 and 5 report results obtained with dump diffuser geometries employing different techniques of flow control by wall edge suction. Reference 6 describes the performance of an asymmetric diffuser using suction.

In the present investigation a wall geometry similar to that of reference 2 was tested to evaluate performance over a range of inlet Mach numbers. The removable diffuser walls positioned between the diffuser inlet and exit passages were of toroidal form with quarter-circle cross section. Wall bleed flow was removed through two stepped suction slots, located at 20° and 40° of arc, which were continuous over the full wall circumference. With an area ratio of 4.0 at a length-to-inlet height ratio of only 1.6, the diffuser was even shorter than the vortex dump diffuser of reference 4. The inlet passage flow area was 304 square centimeters (47.12 $in.^2$).

Velocity profiles, diffuser effectiveness (static-pressure recovery) and diffuser total-pressure loss data were obtained for nominal inlet Mach numbers of 0.186, 0.200, 0.267, 0.410, and 0.500. At the lower inlet Mach number data were obtained at suction rates up to 15 percent representing an estimated maximum cooling requirement for advanced gas turbines. The maximum suction rate was 6 percent at inlet Mach numbers of 0.5. Nevertheless, sufficient data were obtained to yield an indication of the inlet Mach number effect on diffuser performance. All testing was conducted with air at near ambient pressure and temperature.

SYMBOLS

A area

AR diffuser area ratio, A_2/A_1

B bleed flow fraction of total flow rate

C_p specific heat at constant pressure

g_c dimensional constant

H diffuser-inlet passage height

L diffuser length

M average Mach number at an axial station

m mass flow rate

P average pressure at an axial station

p local pressure at a radial position

R gas constant for air

r wall contour radius

T temperature

V average velocity at an axial station

v local velocity at a radial position

X downstream distance

γ specific heat ratio

ϵ diffuser efficiency, eq. (5)

η diffuser effectiveness, eq. (3)

Subscripts:

i inner wall

m maximum

o outer wall

r local value at a given radial position

s isentropic condition

t total

0 stagnation

1 diffuser inlet station

2 diffuser exit station

APPARATUS AND INSTRUMENTATION

Flow System

The investigation was conducted in the test facility described in reference 2. A schematic of the facility flow system is shown in figure 1. Air, at a pressure of approximately 100 newtons per square centimeter (145 pia) and at ambient temperature, is supplied to the facility by a remotely located compressor station. This air feeds the three branches of the flow system.

The center branch, or main air line, is the source of airflow through the test diffuser. The air flowing through this branch is metered by a square-edged orifice installed with flange taps according to ASME standards. The air is then throttled to near atmospheric pressure by a flow control valve before entering a mixing chamber from which it flows through the test diffuser. The air discharging from the diffuser is exhausted to the atmosphere through a noise absorbing duct.

The other two branches of the flow system supply the two air ejectors which produce the required vacuum for the inner and outer wall diffuser bleed flows. The ejectors are designed for a supply air pressure of 68 newtons per square centimeter (100 psia) and are capable of producing absolute pressures down to 2.38 newtons per square centimeter (7.0 in. Hg).

The inner and outer diffuser wall bleed flows are also metered by square-edged orifices. These orifices are also installed with flange taps according to ASME specification in the suction flow lines that connect the inner and outer diffuser wall bleed chambers to their respective ejector vacuum chambers. The maximum suction flow rate is fixed by facility limitations. Hence, the suction rate capacity, expressed as a percentage of the diffuser flow rate, decreases from about 15 to 6 percent as the diffuser inlet Mach number is raised from 0.18 to 0.5.

Diffuser Test Apparatus

The annular diffuser used was essentially that of reference 2, but for a few modifications. A cross-sectional sketch with pertinent dimensions is shown in figure 2. As in reference 2 the centerbody that forms the inner annular surface is cantilevered from support struts located 30 centimeters (12 in.) upstream of the diffuser inlet passage.

This construction minimized the possibility of strut flow separation having an effect on inlet velocity profile.

Diffuser Walls

The removable diffuser walls are positioned in the apparatus as shown in figure 2. The details of the stepped slot, quarter torus wall geometry are shown in figure 3, which represents an axial section along the annular flow passage. The stepped slot geometry permits drawing off the suction flow in a direction parallel to the wall. On both the inner and the outer wall, the 0.050-centimeter (0.020-in.) slots are located at 20° and 40° of arc measured from the start of the diverging passage. The suction flow from each of the suction slots enters the space inside the walls and is removed by 12 equally spaced short pipes of 1.5 centimeters (0.62 in.) inside diameter. These pipes duct the inner wall bleed flow to the inner wall suction plenum and the outer wall bleed flow to the outer wall suction manifold (fig. 2). The threads on these pipes also provide a method for mechanically fastening the diffuser walls in the desired position.

Diffuser Instrumentation

The essential diffuser instrumentation is indicated in figures 2 and 3. Diffuser-inlet total pressure was obtained from three five-point total-pressure rakes equally spaced around the annular circumference. Inlet static pressure was measured using wall taps in the vacinity of the inlet rakes.

Diffuser-exit total and static pressures were obtained by using three nine-point pitot static rakes that could be rotated in a circumferential direction and translated axially. The circumferential spacing between the rakes was fixed at 120°. For this investigation these rakes were positioned a distance equal to twice the inlet passage height from the start of the diffusing section, since this position was assumed to represent the location of the dome in an annular gas turbine-type combustor. All rake pressures were measured using three Scanivalves, each ducting pressures from a maximum of 48 ports to a flush mounted ±0.69 newton per square centimeter (±1.0 psid) strain gage transducer. The valve dwell time at each port was 0.2 second, or over three times the interval required to reach steady state. Continuous calibration of the Scanivalve system was provided by ducting known pressures to several ports. Visual display of pressure profiles was made available by also connecting all inlet rakes and two exit rakes to common well manometers. The manometer fluid was dibutyl phthalate (specific gravity, 1.04).

All other pressure data such as orifice line pressures for the main air line and the subatmospheric bleed-air lines were obtained by use of individual strain gage pressure transducers. The temperatures of the various flows were measured with copper constantan thermocouples.

All data were remotely recorded on magnetic tape for subsequent processing with a digital data reduction program. In addition any test parameter could be displayed in the facility control room by means of a digital voltmeter.

PROCEDURE

Performance Calculations

Using the digital data reduction program mentioned previously, the overall diffuser performance was evaluated in terms of the radial profile of exit velocity, diffuser effectiveness, total-pressure loss, and diffuser efficiency. The values of the last three figures of merit were expressed in percentages. Intermediate computations included average static and total pressures, local and average Mach numbers and local- to average-Mach-number ratios; that is, the equivalent of the local- to average-velocity ratios. The average pressures and Mach numbers at the diffuser exit P_2, P_{02}, and M_2 were computed by trapezoidal integration using area ratio weighed pressures at the various radial positions. At the diffuser inlet straight arithmetic averages were computed. Local Mach numbers for each pitot tube were computed from the compressible flow relation

$$M_r = \sqrt{\frac{2}{\gamma - 1}\left[\left(\frac{p_0}{p}\right)^{(\gamma-1)/\gamma} - 1\right]} \tag{1}$$

where p_0 and p represent the measured local total and static pressures and γ represents the specific heat ratio, set equal to 1.4 for the near ambient conditions of this investigation.

Diffuser and bleed airflow rates were computed from the respective orifice pressures and temperatures. As a check on the arithmetically averaged inlet Mach number, a mean effective inlet Mach number was also computed by iteration from inlet airflow rate, total pressure, temperature, and area data as shown hereinafter

$$M_1 = \frac{\dot{m}_1}{P_{01}A_1}\sqrt{\frac{RT_{01}}{\gamma g_c}}\left(1 + \frac{\gamma - 1}{2} M_1^2\right)^{(\gamma+1)/2(\gamma-1)} \tag{2}$$

The velocity ratios at each radial position, needed to generate velocity profiles, were obtained from the circumferential averages of the local- to average-Mach number ratios. A plotting routine was used to generate the velocity profiles by computer with output on microfilm.

Diffuser effectiveness was computed from the following relation:

$$\eta = \frac{P_2 - P_1}{(P_{01} - P_1)\left[1 - \left(\frac{1 - B}{AR}\right)^2\right]} \times 100 \tag{3}$$

Equation (3) is an approximation expressing the ratio of actual to ideal conversion of inlet dynamic pressure to exit static pressure for the case of compressible flows through a diffuser with wall bleed for $M \leq 0.5$ and $AR \geq 2$. For the conditions of the present study the use of equation (3) introduced an approximation error of less than 0.6 percent. A derivation of equation (3) and its limitations is shown in reference 6.

The total-pressure loss was defined as

$$\frac{\Delta P_0}{P_{01}} = \frac{P_{01} - P_{02}}{P_{01}} \times 100 \tag{4}$$

Diffuser efficiency was computed from the relation

$$\epsilon = \frac{\left(1 + \frac{\gamma - 1}{2} M_1^2\right)\left(\frac{P_{02}}{P_{01}}\right)^{(\gamma-1)/\gamma} - 1}{\frac{\gamma - 1}{2} M_1^2} \times 100 \tag{5}$$

Equation (5) was derived in reference 7 for the case where the diffuser-exit velocity is negligible. This restriction can be removed from equation (5) (as shown in ref. 6) by making a minor change in the definition and subsequent derivation of the diffuser efficiency parameter. Hence, equation (5) as used in this report, relates the total energy level available at the exit of a diffuser, to the upstream total energy level with the inlet static enthalpy being the reference.

Test Conditions

Typical diffuser-inlet conditions were

Total pressure, N/cm^2abs (psia)	10.1 to 11.1 (14.6 to 16.0)
Static pressure, N/cm^2abs (psia)	8.6 to 9.9 (12.5 to 14.4)
Temperature, K (^{o}F)	275 to 280 (35 to 44)
Mach number	0.185 to 0.51
Velocity, m/sec (ft/sec)	61 to 166 (200 to 545)
Reynolds number (based on inlet passage height)	2.2×10^5 to 6.0×10^5
Bleed rate, percent of total flow	0 to 15

The U. S. Customary system of units was used for primary measurements and calculations. Conversion to SI units (Système International d'Unités) is done for reporting purposes only. In making the conversion, consideration is given to implied accuracy, which may result in rounding off the values expressed in SI units.

RESULTS AND DISCUSSION

The performance of a short annular diffuser designed with wall suction capability was evaluated in terms of radial profiles of velocity, diffuser effectiveness and efficiency, and total-pressure loss for inlet Mach numbers ranging from 0.18 to 0.5. Because of facility limitations, the available suction rate decreased from about 15 percent at the lowest Mach number to about 6 percent at the Mach number of 0.5. This limitation is reflected in the data plots and in the summary of typical performance data shown in table I.

Radial Profiles of Velocity

The velocity profiles at the diffuser inlet and exit stations shown in figures 4 and 5 were generated by plotting the ratio of local velocity at a radial position to the average velocity at a particular station (inlet or exit) as a function of radial span position. The local velocity at a given radius was obtained by taking the arithmetic average of three local velocities at the same radius but at three separate circumferential positions. Circumferential deviations from these average profiles were ±2 percent for the inlet profiles and about ±30 percent for the exit profile.

Figure 4 shows the relative invariance of profile shapes with inlet Mach number for zero suction rate. In particular, the inlet profiles in figure 4 representing inlet Mach numbers of 0.2, 0.41 and 0.5 were practically the same, all showing a small degree of hub bias imposed on the flow by the particular annular geometry of the inlet passage.

The exit profiles, plotted on the same figures, also show a striking resemblance to each other. This observation agrees with the one dimensional analysis of reference 6 indicating that compressibility effects at $M_1 = 0.5$ and $AR = 4$ are negligible.

The effect of suction on the velocity profiles at various inlet Mach numbers is shown in figure 5. Again, the inlet profiles are practically identical, indicating that the effects of suction on the diffuser walls do not propagate upstream to influence the inlet profile in the Mach range investigated.

Suction does have an effect on the exit velocity profile. The exit velocity profile for an inlet Mach number of 0.507 with 2.9 percent suction on the inner and 3.3 percent suction on the outer wall is shown in figure 5(a). Compared with the zero suction profiles of figure 4 this profile is less peaked, indicating that a larger portion of the exit passage has become filled. Figure 5(b) shows further profile flattening, indicative of flow spreading with a slight increase in wall suction rates achieved by decreasing the diffuser inlet flow velocity to $M_1 = 0.41$. A profile quite similar to that of figure 5(b) is shown in figure 5(c). The suction rates for this profile were close to those of 5(b), but the inlet Mach number was only 0.27. The high degree of similarity between the two profiles indicates that the exit velocity profiles depend only on the wall geometry and suction rate and that they are unaffected by inlet Mach number. The exit profile shown for $M_1 = 0.27$ in figure 5(d), indicates that the flow essentially fills the entire duct with inner and outer wall suction rates of approximately 3.8 percent and 6.1 percent, respectively. Further increases in suction rate will not result in significant improvements in exit velocity profile as indicated in figure 5(e), which represents a low inlet Mach number condition. It should be noted that the profiles of figures 5(d) and (e) were made symmetrical about the midspan position by maintaining an inner-to-outer suction rate ratio of approximately 2/3, that is, by applying about 40 percent of the combined suction rate on the inner wall and 60 percent on the outer wall. The higher suction rate on the outer wall is necessary because the higher outer wall surface area accumulates a larger amount of retarded boundary layer flow which must be removed. Figure 5(f) shows that if more than 40 percent of the total suction rate is applied on the inner wall, the flow becomes hub biased. Of course, the converse is also true. Figure 5(g) shows a tip biased profile obtained by excess suction rate on the outer wall, also for a low inlet Mach number condition.

The ability to control the exit velocity profile hub bias or tip bias at low inlet Mach numbers raises the question whether such control is also possible at the high inlet Mach number condition. To answer this question exit velocity profile measurements were conducted at an inlet Mach number of approximately 0.5 and at inner to outer suction rate ratios conducive to producing hub biased and tip biased exit velocity profiles. Typical results of these measurements are shown in figures 5(h) and (i). With an excess of inner wall suction (fig. 5(h)), the exit velocity profile tends to become hub biased. Conversely, with an excess of outer wall suction (fig. 5(i)), the exit velocity profile tends toward tip bias. Of course, the hub and tip bias in figures 5(h) and (i) is less pronounced than that observed at low inlet Mach number (figs. 5(f) and (g)). This is due to the previously mentioned suction rate limitation at high inlet Mach numbers, which restricted the individual wall suction rates to much lower values than those available at low inlet Mach numbers. Nevertheless the trends shown in figures 5(h) and (i) suggest that for the range of conditions tested, the effect of suction rate on diffuser exit velocity profile is independent of inlet Mach number.

The velocity profiles of figures 4 and 5 illustrate some typical flow conditions. Essential profile information such as exit velocity profile peak position and peak value for all test points of this study is included in table I.

Diffuser Effectiveness

Diffuser effectiveness, as defined by equation (3) expresses the ratio of the actual to the ideal conversion of dynamic pressure to static pressure between the diffuser inlet and exit stations. The effect of suction rate on diffuser effectiveness is shown in figure 6 for the various inlet Mach numbers in this test program. For the high inlet velocities the effectiveness increases from about 25 percent without suction to about 57 percent at a suction rate of 7 percent. These high velocity diffuser effectiveness results can be correlated approximately by a parabolic curve of the form

$$\eta = 21 + 0.333S_t + S_t^{0.5} \tag{6}$$

with the data scatter probably being due to local intermittent separation effects. Fully attached flow was not achieved at the high velocity conditions due to the previously mentioned suction rate limitation.

The low inlet Mach number data (0.18 to 0.27 range) fall somewhat below the curve (eq. (6)) correlating the high Mach number data, and they also show increased data scatter. Some of this data scatter can be attributed to inaccuracies of the pressure transducers which were sized for the high Mach number inlet condition. The slightly lower effectiveness values may be due to the greater boundary-layer thickness associated with the lower Mach number (i.e., lower Reynolds number) flows. This trend is also mentioned in reference 3, where it was found that the suction rate required for a certain effectiveness level decreased with increasing inlet velocity. At a total suction rate of 15 percent the average of low Mach number effectiveness values agrees with the 72.5 percent value predicted by equation (6).

Regarding the possible extrapolation of diffuser effectiveness results from low inlet Mach number data to inlet Mach numbers up to 0.5, the results of figure 6 indicate that such extrapolation should yield conservative estimates and is therefore justified. Moreover the analysis of reference 6 also indicates that the compressibility effect is negligible for high area ratio diffusers at inlet Mach numbers up to 0.5.

Diffuser Efficiency

The isentropic diffuser efficiency as defined by equation (5) is a measure of total enthalpy conservation between the diffuser inlet and exit stations. The relation between diffuser efficiency and diffuser total pressure loss is discussed in reference 6. Values of diffuser efficiency for the test conditions of this study are shown in table I.

Diffuser Total Pressure Loss

The decrease in total pressure loss with suction rate is shown in figure 7 for the range of inlet Mach numbers tested. This reduction in total pressure loss is due to reductions in diffuser wall separation losses and reduced diffuser mass flow rate downstream of the suction slots. The reduction in wall separation losses accounts for about 55 to 60 percent of the overall reduction in total pressure. For example, at an inlet Mach number of 0.5 the total-pressure loss is reduced from about 10.1 percent without suction to 7.5 percent at a total suction rate of 6 percent. Of the overall reduction of 2.6 percent, about 1.2 percent is due to reduced diffuser mass flow rate and therefore 1.4 percent is attributed to reduced wall separation losses. Similar reductions in diffuser total-pressure loss occur at the other inlet Mach number conditions with suction rate. As shown in figure 8, when each of the four sets of total-pressure loss data is normalized by the square of the particular inlet Mach number at which the data point was obtained, the resulting values fall on a single curve. Hence, total-pressure loss data obtained at low inlet Mach numbers can be extrapolated to inlet Mach numbers up to 0.5 for the diffuser geometry tested.

SUMMARY OF RESULTS

The performance of a short annular diffuser with wall suction capability was evaluated in terms of diffuser velocity profiles, diffuser effectiveness and total-pressure loss for nominal inlet Mach numbers ranging from 0.18 to 0.50. The results were as follows:

1. The inlet velocity profile was not affected by inlet Mach number or suction rate.

2. Although the exit velocity profiles were also invariant with inlet Mach number they did change with suction; the typical annular jet flow obtained without suction could be changed to a flow that was attached to both diffuser walls by respectively applying 3.8 percent and 6.1 percent suction on the inner and the outer diffuser wall.

3. Diffuser effectiveness (ratio of actual to ideal static pressure recovery) could be increased from about 25 percent without suction to about 72 percent at a total suction rate of 15 percent.

4. Diffuser total-pressure loss at an inlet Mach number of 0.5 was reduced from 10.1 percent without suction to about 7.5 percent at a total suction rate of 6 percent. Of the overall reduction of 2.6 percent about 1.2 percent is due to reduced diffuser mass flow and 1.4 percent to reduced wall separation losses.

5. The diffuser test program also revealed that diffuser performance results obtained at low inlet Mach numbers can be extrapolated to inlet Mach numbers up to 0.5 for high area ratio diffusers of the type tested.

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TABLE I. - DIFFUSER PERFORMANCE DATA

Diffuser inlet Mach number	Airflow rate		Inlet pressure				Inlet total temperature		Suction rate, percent			Exit profile peak		Diffuser effectiveness, percent	Diffuser efficiency, percent	Total-pressure loss, $\Delta P/P$, percent	Normalized total pressure loss, $\frac{1}{M_1^2}\frac{\Delta P}{P}$
	kg/sec	lb/sec	Total		Static		K	^{o}F	Inner wall	Outer wall	Total	Position, percent of annular span	Value, v/V				
			N/cm^2	psia	N/cm^2	psia											
0.488	6.00	13.22	11.05	16.02	9.04	13.11	275.1	35.5	0	0	0	40	2.78	26.36	33.28	10.22	42.9
.490	6.03	13.28	11.05	16.03	9.04	13.11	275.2	35.7	0	0	0	40	2.78	26.81	33.40	10.28	42.8
.488	6.01	13.23	11.05	16.03	9.12	13.23	275.1	35.5	0	0	0	40	2.75	26.25	33.28	10.22	42.9
.505	5.94	13.08	10.67	15.48	8.72	12.65	275.5	36.3	2.28	3.08	5.36	50	2.08	48.95	52.23	7.88	30.9
.501	5.92	13.03	10.68	15.49	8.70	12.62		36.3	2.30	3.10	5.40	60	2.10	50.88	50.75	8.00	31.8
.503	5.93	13.06	10.67	15.48	8.70	12.62		36.2	2.31	3.09	5.40	50	1.97	49.40	51.43	7.95	31.4
.503	5.92	13.05	10.67	15.48	8.72	12.64		36.3	2.28	3.08	5.37	50	1.96	48.83	51.62	7.92	31.3
.510	6.00	13.22	10.70	15.52	8.68	12.59	275.6	36.5	2.26	3.06	5.32	60	2.18	51.01	51.16	8.20	31.5
.509	5.99	13.19	10.69	15.51	8.64	12.53	275.6	36.5	2.27	3.08	5.35	50	2.04	50.85	51.60	8.10	31.3
.511	5.99	13.19	10.68	15.49	8.73	12.66	276.0	37.1	2.56	3.32	5.88	60	1.95	48.34	52.26	8.05	30.8
.512	6.00	13.22	10.69	15.50	8.67	12.58	276.1	37.3	2.55	3.31	5.85	60	1.89	51.63	50.48	8.37	31.9
.500	6.02	13.27	10.91	15.83	8.92	12.93	276.3	37.6	3.30	0	3.30	30	2.43	45.72	50.94	7.94	31.76
.498	6.01	13.24	10.92	15.84	8.91	12.92		37.6	3.30	0	3.30	30	2.43	45.46	49.47	8.11	32.70
.500	5.98	13.18	10.84	15.82	8.82	12.79		37.7	0	3.39	3.39	70	2.68	45.54	44.74	8.91	35.6
.503	6.01	13.24	10.84	15.72	8.82	12.79		37.6	0	3.39	3.39		2.64	45.28	45.88	8.83	34.9
.509	6.01	13.23	10.74	15.58	8.72	12.65	276.5	38.0	2.04	3.30	5.37		2.34	47.41	48.63	8.58	33.1
.510	6.01	13.24	10.75	15.59	8.69	12.60	276.5	38.0	2.04	3.33	5.37		2.32	47.90	48.27	8.67	33.3
.508	5.99	13.20	10.74	15.58	8.72	12.65	276.7	38.4	2.60	2.06	4.65	50	2.36	49.16	52.90	7.86	30.5
.508	5.99	13.20	10.75	15.59	8.70	12.62	276.8	38.5	2.60	2.08	4.68		2.33	49.94	51.72	8.05	31.2
.496	6.03	13.29	10.99	15.94	9.03	13.09	276.4	37.8	0	0	0		2.60	27.70	38.01	9.81	39.9
.497	6.04	13.31	11.00	15.95	9.02	13.08	276.3	37.7	0	0	0		2.63	27.81	37.60	9.91	40.1
.496	5.87	12.93	10.73	15.56	8.82	12.79	277.9	40.6	1.40	2.03	3.43		2.60	40.07	46.62	8.49	34.5
.494	5.86	12.90	10.74	15.57	8.81	12.78	277.9	40.6	1.40	2.03	3.44		2.58	40.61	46.87	8.39	34.4
.501	5.92	13.05	10.75	15.59	8.78	12.74	278.1	41.0	1.39	2.03	3.42		2.63	41.16	46.93	8.60	34.3
.502	5.93	13.06	10.75	15.59	8.78	12.74	278.1	41.0	1.39	1.99	3.38		2.62	41.00	47.13	8.60	34.1
.506	5.91	13.01	10.66	15.46	8.68	12.59	279.2	42.9	2.92	3.32	6.24		2.13	52.93	55.15	7.44	29.1
.507	5.92	13.03	10.66	15.46	7.66	12.56	279.2	42.9	2.91	3.33	6.24		2.07	52.74	55.26	7.45	30.0
.507	5.91	13.01	10.65	15.44	8.65	12.54	279.0	42.6	2.70	3.09	5.79		2.14	52.54	55.75	7.37	28.7
.492	5.92	13.05	10.90	15.81	8.96	12.99	279.2	42.9	2.77	0	2.77	40	2.42	43.49	49.61	7.91	32.7
.493	5.92	13.05	10.89	15.80	8.96	13.00	279.3	43.1	2.78	0	2.78	40	2.39	43.67	50.26	7.84	32.3
.499	5.95	13.11	10.85	15.74	8.90	12.91	279.1	42.8	0	3.15	3.15	70	2.52	42.83	46.53	8.60	34.5
.497	5.93	13.06	10.85	15.73	8.92	12.94	279.1	42.8		3.17	3.17	70	2.56	42.45	46.79	8.56	34.7
.411	5.02	11.06	10.63	15.42	9.29	13.48	279.7	43.9		0	0	50	2.59	27.41	38.03	6.91	40.9
.411	5.02	11.05	10.63	15.41	9.30	13.49	279.6	43.7		0	0		2.63	27.09	38.59	6.85	40.6
.413	4.92	10.83	10.36	15.03	9.01	13.07	279.7	43.9	3.15	3.70	6.85		1.87	57.67	57.78	4.79	28.1
.416	4.94	10.89	10.36	15.03	9.07	13.15	279.7	43.9	3.14	3.66	6.81		1.86	54.56	58.02	4.83	27.9
.413	5.01	11.04	10.57	15.33	9.25	13.42	279.7	43.9	3.98	0	3.98	40	2.28	46.25	53.47	5.27	30.9
.417	5.04	11.10	10.54	15.29	9.20	13.35	279.8	44.0	0	4.02	4.02	70	2.56	44.58	48.31	5.95	34.2
.199	2.44	5.38	9.92	14.39	9.63	13.97	279.0	42.7	7.52	7.41	14.93	40	1.73	71.37	67.54	.89	22.5
.198	2.44	5.37	9.92	14.39	9.61	13.94	279.1	42.8	7.54	7.43	14.98	40	1.72	77.36	69.06	.84	21.4
.206	2.57	5.65	10.02	14.54	9.70	14.07	278.7	42.1	0	0	0	50	2.64	29.96	40.90	1.73	40.8
.186	2.30	5.07	9.95	14.42	9.69	14.05	280.2	44.3	4.78	7.05	11.82		1.75	60.54	58.27	1.00	28.9
.187	2.30	5.08	9.94	14.41	9.68	14.04	280.1	44.2	5.70	8.97	14.68		1.78	68.40	67.41	.79	22.6
.186	2.29	5.06	9.94	14.41	9.67	14.03	280.1	44.1	5.72	8.95	14.67		1.70	70.0	67.90	.77	22.3
.183	2.33	5.13	10.14	14.71	9.90	14.36	275.5	35.9	0	0	0	40	2.7	25.17	40.44	1.38	41.2
.185		5.14	10.10	14.68	9.86	14.31	277.0	38.6	1.95	5.12	7.07	70	1.94	47.36	56.55	1.03	30.1
.185		5.14	10.10	14.65	9.85	14.29	277.4	39.4	2.61	3.22	5.83	40	1.73	47.16	52.32	1.13	33.0
.185		5.14	10.09	14.64	9.85	14.28	277.7	39.9	3.90	5.18	9.08	50	1.49	53.5	56.98	1.02	29.8
.186		5.15	10.08	14.62	9.84	14.27	277.8	40.0	4.77	7.12	11.89		1.33	60.33	59.95	.96	27.7
.185		5.14	10.08	14.62	9.83	14.25	277.8	40.0	4.78	7.17	11.95		1.43	62.06	59.94	.95	27.8
.185	2.32	5.12	10.07	14.61	9.79	14.21	277.8	40.0	5.72	8.94	14.66		1.46	74.70	63.75	.86	25.1
.231	3.28	7.22	10.01	14.52	9.42	13.66	292.0	62.8	2.76	3.94	6.70	60	1.74	51.4	57.67	2.19	29.0
.276	3.29	7.25	10.02	14.53	9.42	13.66	292.0	62.8	2.75	3.92	6.67	50	1.83	51.2	57.39	2.22	29.0
.264	3.28	7.22	10.22	14.82	9.68	14.04	282.2	48.0	2.35	3.37	5.72	40	1.85	45.23	49.68	2.40	34.4
.264	3.29	7.26	10.28	14.91	9.77	14.17	282.2	48.0	2.76	0	2.76	30	2.70	34.07	45.03	2.62	37.6
.262	3.25	7.17	10.23	14.84	9.73	14.11	282.2	48.0	0	6.67	6.67	70	2.52	44.53	50.00	2.35	34.2
.267	3.30	7.27	10.15	14.72	9.60	13.92	279.6	43.3	3.81	6.20	10.01	60	1.46	60.24	59.10	2.00	28.1
.267	3.33	7.34	10.30	14.94	9.78	14.19	278.4	41.2	0	0	0	40	2.67	19.89	35.96	3.07	43.7
.270	3.34	7.37	10.17	14.75	9.61	13.94	278.5	41.3	3.97	6.38	10.35	50	1.54	61.42	63.78	1.81	24.8
.272	3.32	7.31	10.0	14.52	9.45	13.70	278.8	41.8	3.77	6.12	9.89	50	1.49	59.13	58.73	2.09	28.2

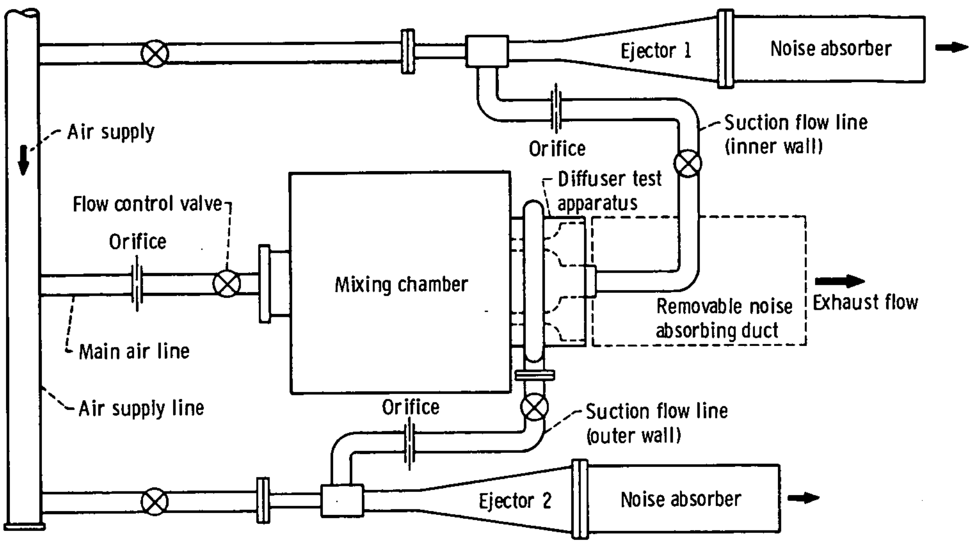


Figure 1. - Test facility flow system.

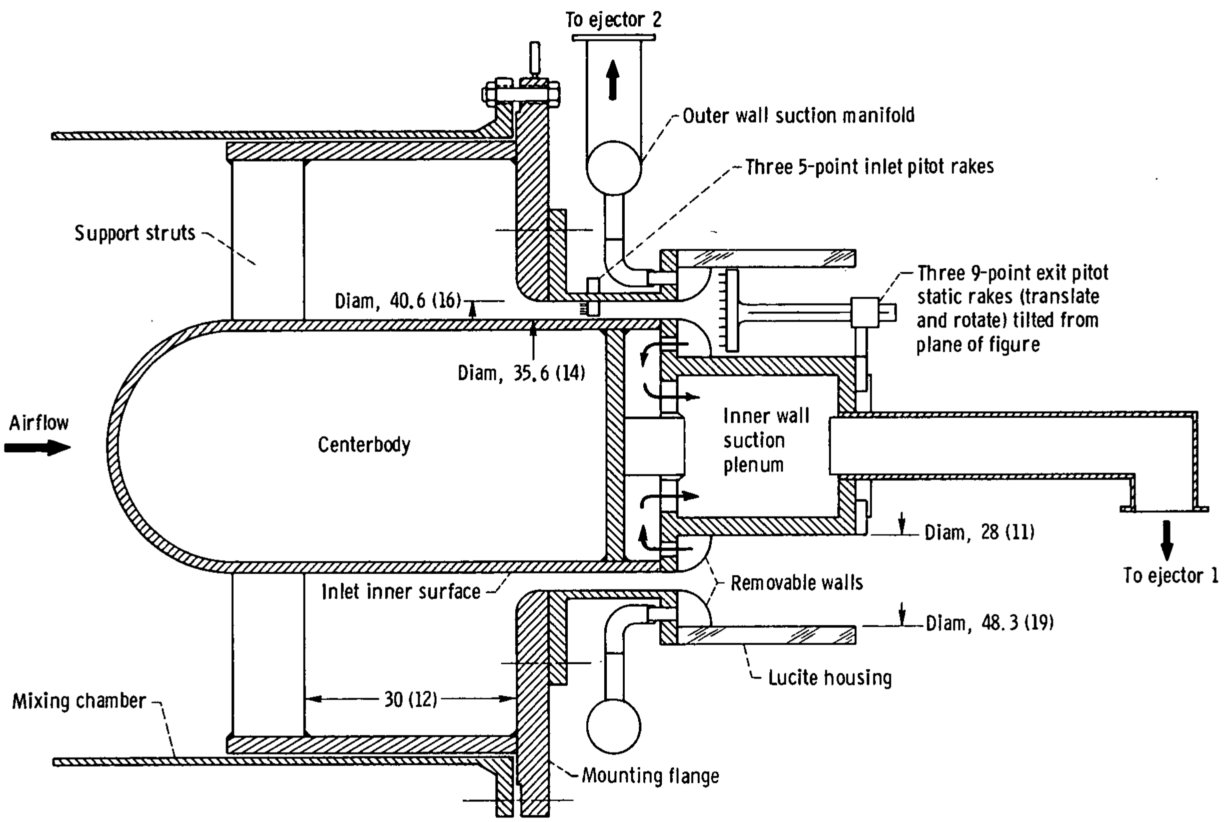


Figure 2. - Axial section of annular diffuser test apparatus. (Dimensions are in cm (in.).)

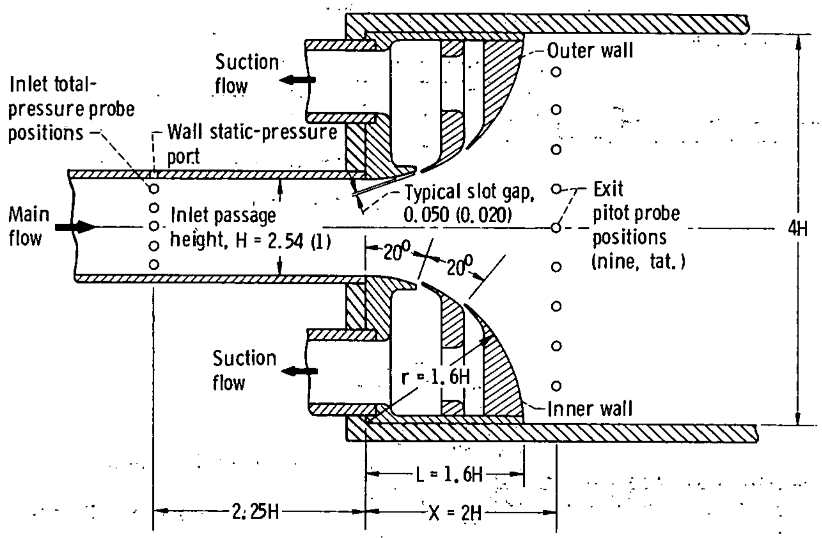


Figure 3. - Section through annular flow passage showing diffuser contour wall details. (Dimensions are in cm (in.) unless otherwise indicated.)

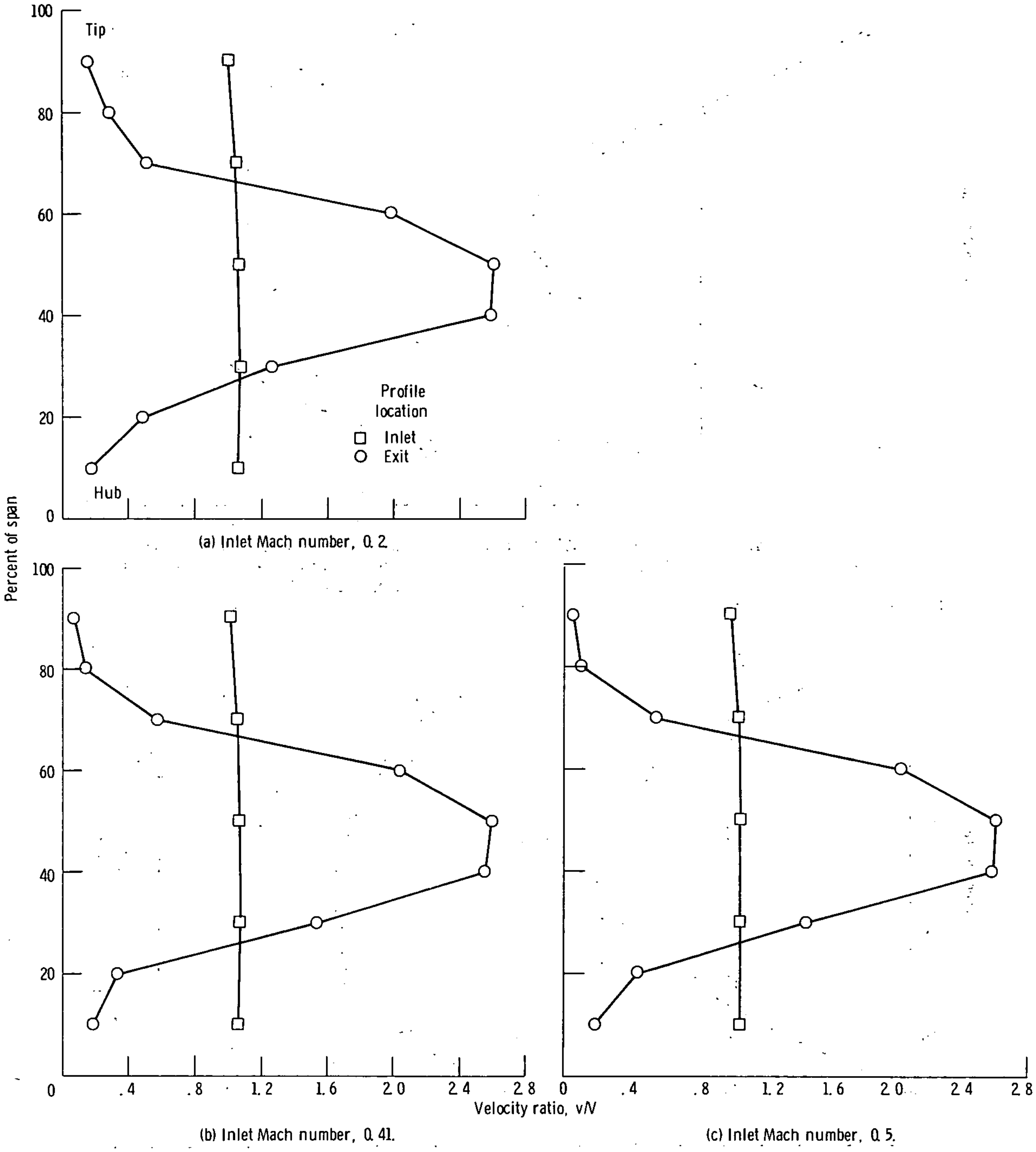


Figure 4. - Radial profiles of diffuser-inlet and exit velocity without suction.

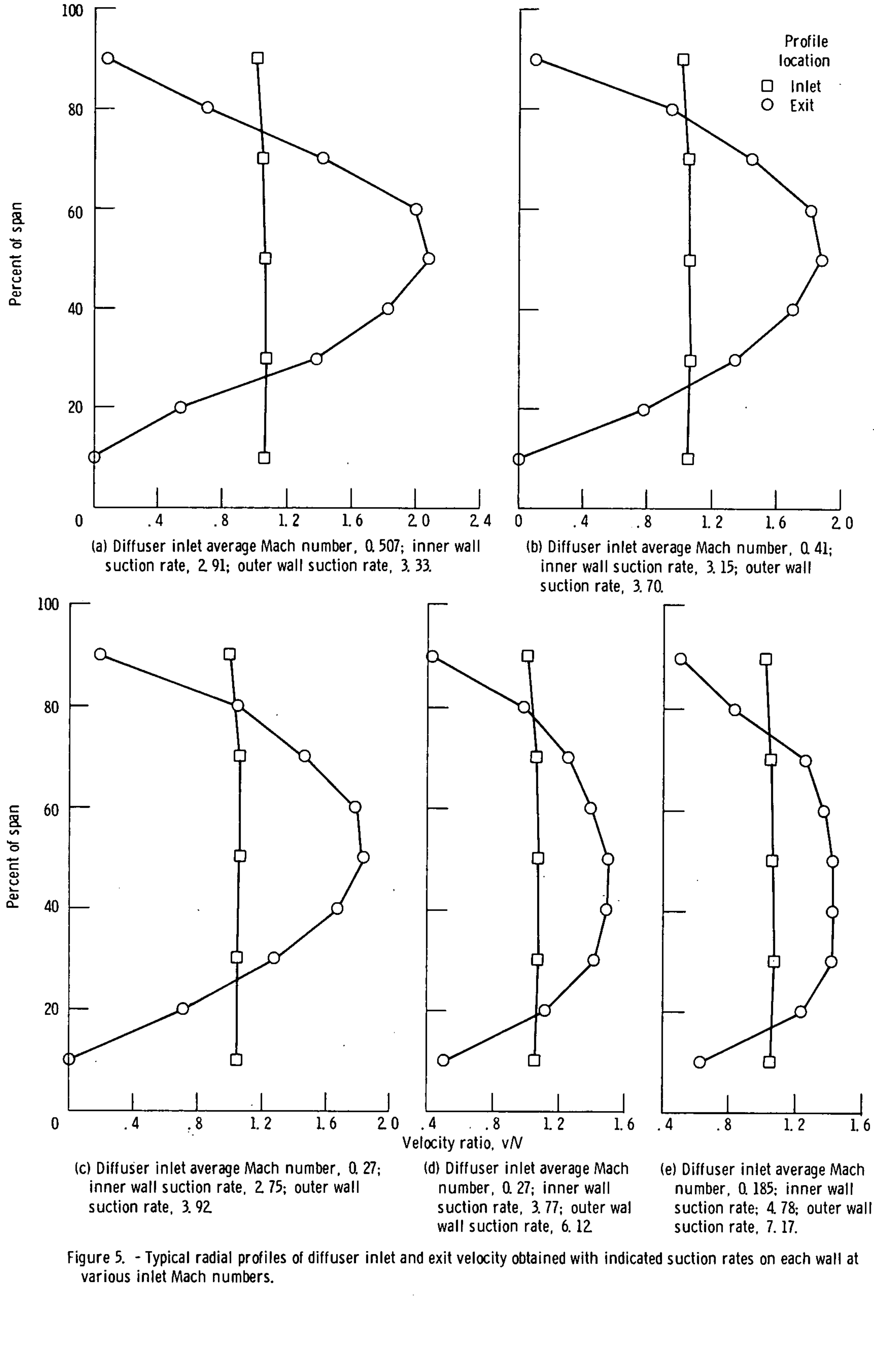
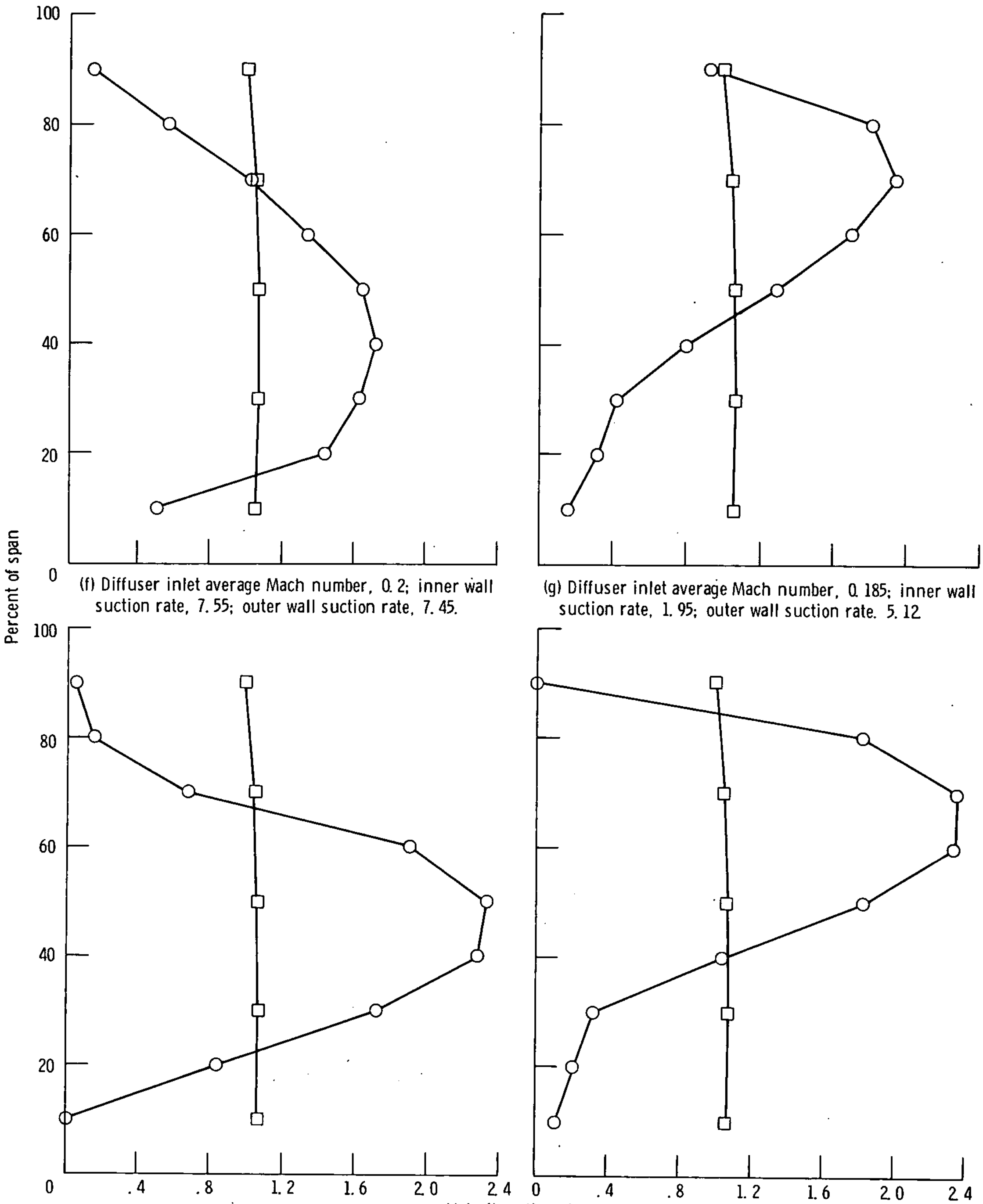


Figure 5. - Typical radial profiles of diffuser inlet and exit velocity obtained with indicated suction rates on each wall at various inlet Mach numbers.



(f) Diffuser inlet average Mach number, 0.2; inner wall suction rate, 7.55; outer wall suction rate, 7.45.

(g) Diffuser inlet average Mach number, 0.185; inner wall suction rate, 1.95; outer wall suction rate. 5.12

(h) Diffuser inlet average Mach number, 0.508; inner wall suction rate, 2.6; outer wall suction rate, 2.08.

(i) Diffuser inlet average Mach number, 0.509; inner wall suction rate, 2.00; outer wall suction rate, 3.3.

Figure 5. - Concluded.

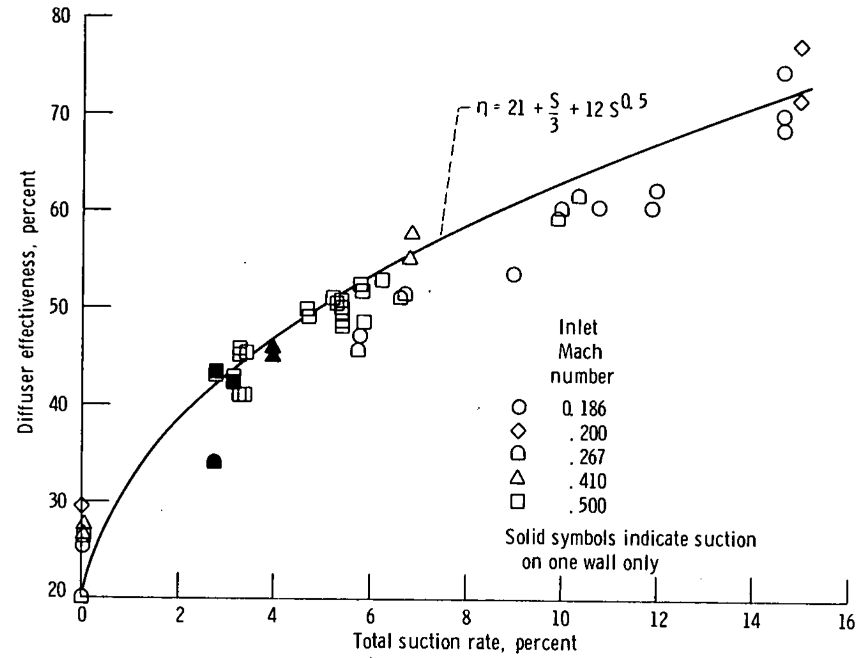


Figure 6. - Effect of suction on diffuser effectiveness at various inlet Mach numbers.

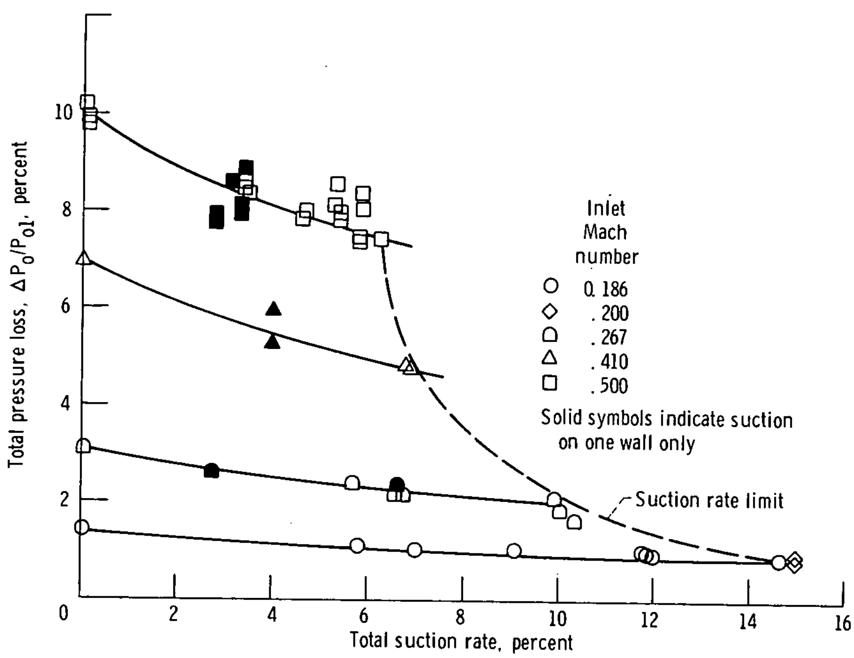


Figure 7. - Effect of suction on diffuser total-pressure loss at various inlet Mach numbers.

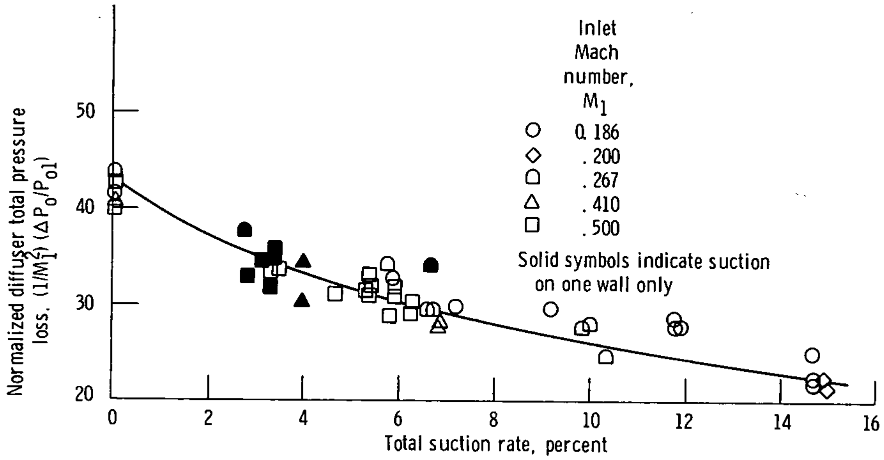


Figure 8. - Effect of suction on diffuser total-pressure loss normalized by square of inlet Mach number.

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