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RESEARCH MEMORANDUM

PRELIMINARY INVESTIGATION OF THE EFFECTS OF RECTANGULAR VORTEX GENERATORS ON THE PERFORMANCE OF A SHORT 1.9:1 STRAIGHT-WALL ANNULAR DIFFUSER

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NATIONAL ADVISORY COMMITTEE
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SUMMARY

A preliminary investigation was conducted in a duct system having fully developed pipe flow to determine the effectiveness of vortex generators in improving the performance of a 21-inch-diameter straight-outer-wall annular diffuser having an over-all equivalent conical expansion angle of 15° and a 1.9:1 area ratio. The vortex generators used in this investigation were rectangular noncambered airfoils which were varied in chord, span, angle of attack, number, and location.

Without vortex generators, separation occurred at approximately 4 inches downstream of the cylinder-cone junction with consequent velocity fluctuations at the diffuser exit station of sufficient magnitude to render this diffuser useless for practical application. With vortex generators, the fluctuations were greatly reduced and higher static-pressure recoveries were obtained. Some vortex-generator arrangements completely eliminated the separation. The best vortex-generator arrangement increased the diffuser effectiveness approximately 17 percent at a maximum mean Mach number of 0.46 and a Reynolds number of 1.35×10^6 based on the hydraulic diameter.

INTRODUCTION

Research to determine an efficient combination of turbojet and afterburner indicates that improvements in the diffusion of gases from the turbine to the afterburner are necessary to realize more fully the potential of the power plant. The internal geometry of the system and space limitations lead to consideration of the short annular diffuser of which the annular diffuser of constant outer-wall diameter is typical.

Some data on the performance of annular diffusers of constant outer-wall diameter are available. Tests of annular diffusers with axial flow at the inlet and with negligible inlet boundary layer, at Mach numbers up to choking and Reynolds numbers up to 1.4×10^5, are reported in reference 1. The case of rotating flow at the inlet and small inlet boundary layer at Mach numbers up to 0.55 and Reynolds numbers up to 1.79×10^6 is reported in reference 2. The results of these investigations show that, because of flow separation from the inner body, performance of the annular diffuser is poor.

It has been clearly demonstrated, in references 3 and 4, that flow separation can be delayed or eliminated by reënergizing the boundary layer by intermixing low-energy air from inside the boundary layer with high-energy air from outside the boundary layer. This mixing can be accomplished by vortices shed from short airfoils mounted perpendicular to the solid boundary. This generating device has been used successfully in large wind tunnels for reducing power requirements by improving flow in the diffuser, reference 3, and more recently in a short conical diffuser for delaying separation, reference 4.

In order to investigate the prospect of improving the performance of annular diffusers through the use of vortex generators, a preliminary investigation was initiated using an available annular diffuser having a constant outer-wall diameter of 21 inches, an area ratio of 1.9:1, and an over-all equivalent conical expansion angle of 15°. The investigation was conducted with fully developed pipe flow at the diffuser inlet. For this flow condition the inlet total-pressure distribution resembles that at the inlet of a diffuser in a typical turbojet afterburner installation. Tests of this diffuser were made with no vortex generators, with vortex generators on the diffuser inner wall, and with vortex generators on both the diffuser inner and outer walls. The vortex-generator arrangements in each case were counterrotating and were NACA 0012 airfoils which were varied in chord, span, spacing, angle of attack, and location.

The data presented herein were obtained from investigations conducted in the Internal Aerodynamics Section of the Langley Aeronautical Laboratory. Mean inlet Mach number was varied from approximately 0.1 to 0.46, with resulting maximum Reynolds number based on the inlet hydraulic diameter of approximately 1.35×10^6.

SYMBOLS

p	static pressure
H	total pressure

$\bar{H}$ weighted total pressure $\left(\int_{r_1}^{r_2} 2\pi u H r \, dr \Big/ \int_{r_1}^{r_2} 2\pi u r \, dr\right)$

H_0 total pressure upstream of inlet screen

q_c impact pressure $(\bar{H} - p)$

u local velocity

U maximum velocity across an annular section at the diffuser inlet

y perpendicular distance from either the diffuser inner or outer wall

r radius of diffuser

D hydralic diameter $\left(\frac{4 \times \text{Cross-sectional area of duct}}{\text{Perimeter of duct}}\right)$

Δp wall static-pressure change between two stations

$\Delta\bar{H}$ integrated total-pressure change between two stations

$\Delta p_a/\Delta p_i$ diffuser effectiveness

$\Delta\bar{H}/q_c$ diffuser loss coefficient

δ boundary-layer thickness

δ^* boundary-layer displacement thickness $\left(\int_0^{\delta}\left(1 - \frac{u}{U}\right)dy\right)$

θ boundary-layer momentum thickness $\left(\int_0^{\delta}\frac{u}{U}\left(1 - \frac{u}{U}\right)dy\right)$

Subscripts:

a actually measured - average values

i ideal or theoretical - computed with one-dimensional relationships

0 upstream of inlet screen

1 reference to inner wall

2 reference to outer wall

APPARATUS AND PROCEDURE

Test equipment.- A schematic drawing of the experimental setup is shown in figure 1. A more detailed drawing of the immediate area of the diffuser is shown in figure 2.

The setup consisted of an annular diffuser of constant outer diameter preceded by a section of annular ducting approximately 27 feet long. The diffuser had an outer diameter of 21 inches, an area ratio of 1.9 to 1, and an over-all equivalent conical angle of expansion of 15°. The annular ducting consisted of available ducting which had a constant inner diameter of $14\frac{1}{2}$ inches and an outer diameter of 21 and 25 inches. The juncture between the inner cylinder and the cone of the diffuser was faired to a 16-inch radius. All internal surfaces for several feet upstream of the diffuser inlet and throughout the diffuser and tail pipe were filled and polished. Air entered the test apparatus through a 48-inch-diameter screened inlet bell and flowed through the 27 feet of annular ducting to the diffuser inlet. The quantity of air passing through the experimental setup was controlled by an exhauster connected downstream of the tail-pipe exit.

Instrumentation.- Stream total and static pressures were measured by remote-controlled survey instruments at the diffuser inlet, diffuser exit and tail pipe exit stations, figure 2. At the diffuser exit station shielded total-pressure tubes were used because of the velocity fluctuations at this station. Measurements were made at the tail-pipe exit station because there was an appreciable static-pressure rise between the diffuser exit and tail-pipe exit for some of the configurations tested. Flow surveys were made at only one station at a time so that there were no instruments in the stream ahead of the measuring station. These surveys were made at three positions on the circumference at each of the survey stations.

Three static orifices were spaced equally around the outer wall at the inlet station. Since these orifices were in the disturbance field of the vortex generators, three more orifices were installed at the reference station 6 inches farther upstream. The static-pressure rise, in all cases, is referred to the static pressures measured at this station. Six equally spaced static orifices were installed in the outer wall at both the diffuser exit and tail-pipe exit stations. Static orifices extending from upstream of the diffuser inlet station to beyond the tail-pipe exit station were installed along a single generatrix on the outer wall with approximately 4-inch spacing. Static orifices extending from upstream of the inlet station to a point 7 inches upstream of the diffuser exit station were located along three equally spaced generatrices on the inner wall of the diffuser at $1\frac{1}{2}$-inch intervals.

Small wool tufts were used to observe the flow in the diffuser. These tufts were fastened along three generatrices approximately 120° apart on both inner and outer walls of the diffuser. The tufts could be viewed through transparent windows in the outer wall of the diffuser.

Vortex generators.- In this investigation the size and arrangements of the vortex generators were varied. Vortex generators of 1-, 2-, and 3-inch chords and 0- to 1-inch spans were used. All vortex generators were of NACA 0012 airfoil sections. The angle-of-attack range covered extended from 5° to 20°. The spacing of the vortex generators was varied to accommodate from 0 to 48 units. In each case, adjacent vortex generators were set at opposite angles of attack, that is, in a manner to give counterrotation. A typical arrangement is shown in figure 3.

Vortex generators attached to the inner wall were located about 5 inches upstream of the line of separation or about 1 inch upstream of the cylinder-cone junction. This location was selected on the basis of results presented in reference 4. The longitudinal position of the vortex generators is referenced to a plane passing through the 30-percent-chord station.

Some tests were made with vortex generators on the outer wall as well as on the inner wall. In these tests, the location at single rows of vortex generators, which were affixed to the periphery of the outer wall, was varied. These rows were located at 2, 8, 10, and 16 inches downstream of the diffuser inlet. A complete list of all vortex-generator arrangements tested is given in table I.

Basis of comparison of the effectiveness of vortex generators.- The separated, rapidly fluctuating flow at the exit of a wide-angle diffuser prevents measurements necessary to determine the performance of the diffuser. When a tail pipe is attached to the downstream end of the diffuser, the flow at some point in the tail pipe becomes stable and uniform. The flattening of the velocity profile is accompanied by a static-pressure rise. In this investigation diffuser performance is based on pressure measurements made at a station in the tail pipe $15\frac{1}{2}$ inches (less than one diameter) downstream of the diffuser exit. For those conditions in which stable flow was achieved at the diffuser exit, as for many vortex-generator arrangements, diffuser performance is also referenced to the diffuser exit station.

The effectiveness of each vortex-generator configuration on the performance of the annular diffuser has been compared on the basis of the ratio of the actual static-pressure rise Δp_a to the ideal static-pressure rise Δp_i. The actual static-pressure rise in the diffuser has been calculated as the difference between the average of pressures measured by three equally spaced orifices at the reference station, figure 2, and the average of pressures measured by six equally spaced orifices located on the circumference of the outer wall at the diffuser exit. The static-pressure rise in the diffuser - tail-pipe combination was determined in a similar manner, using, however, orifices at the tail-pipe exit rather than at the diffuser exit. The ideal static-pressure rise was calculated using one-dimensional equations.

A comparison was also made on the basis of loss coefficient, the ratio of change in weighted total pressure between the diffuser inlet and a downstream station to the mean impact pressure at the diffuser inlet $\Delta\bar{H}/q_c$. This comparison is based only on total-pressure measurements made at the diffuser inlet and at the tail-pipe exit. For some test configurations it was impossible to obtain reliable data at the diffuser exit because of unstable flow.

RESULTS AND DISCUSSION

It has been shown in reference 4 that performance of a wide-angle conical diffuser which has large regions of separated flow can be improved considerably by the use of vortex generators. Since the performance of this annular diffuser, like that of the conical diffuser of reference 4, was strongly affected by flow separation, some measure of improvement in diffuser performance was expected from the application of vortex generators to this diffuser.

Before the performance of a diffuser can be evaluated, the nature of the flow entering the diffuser must be known. Accordingly, pressure surveys were made at three equally spaced stations at the diffuser inlet. The velocity profiles and the tabulated values of boundary-layer properties for values of $p/\bar{H}$ of 0.935 and 0.88 are presented in figure 4. These measurements show that uniform, fully developed pipe flow existed at the diffuser inlet.

Diffuser with No Vortex Generators

Flow observations.- For this diffuser without vortex generators, visual observation of small tufts located on the inner and outer walls of the diffuser when operating at several Mach numbers in the range investigated revealed that the flow separated from the inner wall approximately 8 inches downstream of the diffuser inlet station but remained attached to the outer wall throughout the entire diffuser. The line of separation around the body was asymmetrical and unstable.

Diffuser performance.- The diffuser effectiveness $\Delta p_a/\Delta p_i$ of this bare diffuser is presented in figure 5 as a function of inlet pressure ratio, $p/\overline{H}$. The inlet pressure, measured 6 inches upstream of the inlet station, gives a somewhat conservative result as some of the pressure drop along the straight pipe is subtracted from the pressure rise considered as occurring in the diffuser. As can be noted from figure 5, the diffuser effectiveness of the diffuser itself is poor; however, when referenced to the tail-pipe exit station, considerable gain is indicated for the diffuser - tail-pipe combination.

Also used to express the diffuser performance is the diffuser loss coefficient $\Delta\overline{H}/q_c$. The variation of the loss coefficient with diffuser inlet pressure ratio $p/\overline{H}$ is shown in figure 6 for the diffuser - tail-pipe combination. Velocity fluctuations at the tail-pipe station caused considerable difficulty in obtaining reliable readings and account for the scatter of the data. At the diffuser exit station the velocity fluctuations were so large that reliable measurements were impossible. These fluctuations resulted from flow separation in the diffuser. The loss coefficients at the tail pipe are considered to be quite representative of the loss in the diffuser as the only expected loss in the tail pipe is from wall friction, which should be small. From the standpoint of diffuser effectiveness and loss-coefficient values alone, this diffuser does not appear too bad; however, velocity fluctuations at the diffuser exit station were large. These velocity fluctuations are considered of sufficient magnitude to render this diffuser useless for most practical applications.

Diffuser with Vortex Generators on Inner Body

A number of vortex-generator configurations were investigated in which the vortex generators were fastened to the inner wall 3 inches downstream of the diffuser inlet station, and effects on diffuser performance of vortex-generator angle of attack, span, chord, and number were determined.

Flow observation.- Every vortex-generator arrangement on the inner wall resulted in marked improvement over the bare diffuser, with some arrangements being far superior to others. The tufts indicated the line of separation to be shifted bodily downstream for some vortex-generator arrangements and to be completely eliminated for others. The flow along the outer wall, although more turbulent, remained attached.

Effect of vortex-generator angle of attack.- Tests were conducted and values of diffuser effectiveness determined for a test configuration consisting of twenty-four 2-inch-chord, 1-inch-span vortex generators in which the angle of attack was varied from $11\frac{1}{2}^{\circ}$ to $18\frac{1}{2}^{\circ}$. Results of this phase of the investigation are shown in figure 7(a). Higher performance was obtained with this configuration when vortex generators were set at 15° angle of attack, which value is in agreement with results of reference 4 determined for a wide-angle conical diffuser. Another arrangement consisting of twenty-four 3-inch-chord, $\frac{1}{2}$-inch-span vortex generators tested at angles of attack between $11\frac{1}{2}^{\circ}$ and 15°, figure 7(b), indicates no variation in performance with angle of attack in the range investigated. From this limited investigation one might conclude that vortex-generator angle of attack has a rather small effect on diffuser performance; therefore, unless otherwise noted, all results presented hereafter will be for configurations in which vortex-generator angle of attack is 15°.

Effect of vortex-generator span.- The variable "airfoil span" appears to be probably the one having the greatest influence on diffuser performance, as determined by this preliminary investigation. Its effects can be readily observed from a cross plot of span as a function of diffuser effectiveness, $\Delta p_a/\Delta p_i$, shown on figure 8. All data for developing this curve were obtained from an installation having twenty-four 2-inch-chord airfoils equally spaced around the inner wall. From this curve it can be noted that the $\frac{1}{4}$-inch span and $\frac{1}{2}$-inch span gave about equal pressure recoveries and about the maximum that was obtained by varying the span. These two values of airfoil span are, respectively, 20 and 40 percent of the distance from the inner wall to the point of maximum velocity in the annulus.

Effect of vortex-generator chord.- Three sets of 24 vortex generators of $\frac{1}{2}$-inch span, having chords of 1 inch, 2 inches, and 3 inches were tested. The effect of vortex-generator chord on diffuser effectiveness is shown in figure 9 as a function of diffuser inlet pressure ratio $p/\overline{H}$. Results of these tests indicate that variation of generator chord produces no significant effect upon diffuser effectiveness over the Mach number range investigated.

Effect of number of vortex generators.- The variation of diffuser effectiveness with number of vortex generators is presented in figure 10. The construction of this curve is based on limited data. Curves at two values of inlet pressure ratio $p/\overline{H}$ were faired from the no-generator configuration through values of diffuser effectiveness for 12 and 24 vortex generators of 3-inch chord and for 24 and 48 vortex generators of 1-inch chord. In fairing this curve it was assumed that the effect of vortex-generator chord was negligible throughout the Mach number range of these tests. The span of these vortex generators was 1/2 inch and the angle of attack 15°.

From figure 10 it is seen that the number of vortex generators has an appreciable effect on diffuser effectiveness. The addition of vortex generators increases diffuser effectiveness, which reaches a maximum when the number is about 24.

Longitudinal pressure gradients.- The effects of vortex generators on the longitudinal pressure gradients along the inner and outer wall of the diffuser are illustrated in figure 11 for the diffuser with no generators and for the vortex-generator installation consisting of twenty-four 3-inch-chord, $\frac{1}{2}$-inch-span vortex generators. Upstream of the separation point of the diffuser with no generators, that is, for the first 8 inches downstream of the diffuser inlet station, the two curves are practically identical with both configurations indicating a local acceleration region on the inner wall followed by a stronger adverse pressure gradient near the inlet. Even though the pressure-ratio curve for the diffuser without generators indicates separation, a small amount of diffusion is still accomplished in both the remainder of the diffuser and in the tail pipe. It is interesting to note from this figure that the pressure gradient along the outer wall is less intense than along the inner wall and that the acceleration of air flow noted near the inner wall does not occur near the outer wall.

Total-pressure profiles at diffuser exit station.- Typical total-pressure profiles at the diffuser exit station for two vortex-generator installations are shown in figure 12. The installations differed only in chord, one having a 3-inch chord and the other a 1-inch chord. Each contained 24 vortex generators of $\frac{1}{2}$-inch span set at 15° angle of attack. It should be noted that the location selected for installing vortex generators on the diffuser inner wall permits the trailing edge of the vortex generators having 2- and 3-inch chords to overhang the inner wall. This overhang, for a 3-inch-chord vortex-generator arrangement, can be seen in figure 3. In regions near the outer and inner walls the two profiles are similar, both indicating a very large boundary layer on the inner wall in comparison with that on the outer wall. In a region near the center of the annulus a deficit in total pressure occurs for the 3-inch-chord airfoils. The cause of this deficit is not known. This was also noted to a somewhat lesser extent for a 2-inch-chord vortex-generator arrangement. Similar phenomena were noted for surveys taken at other radial stations. Static pressures across this station were practically constant.

Diffuser with Vortex Generators on Inner and Outer Wall

Tests were conducted on the same annular diffuser with vortex generators on both the diffuser's inner and outer walls. In addition to the arrangement on the inner wall which consisted of 24 vortex generators of 3-inch chord, $\frac{1}{2}$-inch span, and set at $13\frac{1}{2}^{\circ}$ angle of attack, an arrangement on the outer wall consisting of 44 vortex generators of 1-inch chord, $\frac{1}{2}$-inch span, and set at 15° angle of attack was located at stations 8 and 10 inches downstream of the diffuser inlet. The diffuser effectiveness for the two locations is shown in figure 13. The addition of vortex generators at the 8-inch station resulted in increases in diffuser effectiveness varying from 5 percent at low speeds to practically 0 percent at high speeds, figure 14(a). The addition of vortex generators to the outer wall at the 2-, 10-, and 16-inch stations did not improve the diffuser effectiveness (fig. 13).

Other tests were made in which vortex generators were set at angles of attack of 5° and 10°, in which the chord was increased to 2 inches and at the same time the span was increased to 1 inch, and in which 30 and 22 vortex generators were used. (See table I.) Some of these tests were made with other arrangements of vortex generators on the inner wall. The results of these tests lead to the conclusion that, for the best of the inner-wall configurations tested, the addition of vortex generators to the outer wall produces slight additional increase in static-pressure rise. The extent of this improvement is shown in figure 14(a).

Comparison of the results from the diffuser - tail-pipe combination for the configuration discussed in the preceding paragraph indicates about $1\frac{1}{2}$ percent improvement with vortex generators applied to the outer wall; however, this improvement vanishes at higher velocities.

A Comparison of Diffuser Performance with and without

Vortex Generators

By comparison with that of the diffuser having no vortex generators, the performance of the annular diffuser with vortex generators represents a substantial improvement, figure 14. The addition of vortex generators to the inner wall resulted in a gain in diffuser effectiveness of about 15 percent over the larger portion of speed range tested. Use of vortex generators on the outer wall, in combination with those on the inner wall, increased the diffuser effectiveness about 17 percent with resulting values of diffuser effectiveness above 90 percent for low speeds. The gains as measured at the tail-pipe station show some improvement, but, since effective diffusion was obtained in the diffuser with vortex generators, little additional pressure rise could be expected to occur in the tail pipe.

The effect of vortex generators on the diffuser-tail-pipe loss coefficient is also shown in figure 14(b). Because of flow instability, measurements of total-pressure loss could not be made at the diffuser exit station for the diffuser without vortex generators. The data obtained at the tail-pipe station show rather large loss in the low-speed range reaching a minimum at a Mach number of about 0.25 and increasing again with further increase in speed. The addition of vortex generators to the inner wall reduced the total-pressure loss coefficient to a minimum of about 3.5 percent at a Mach number of about 0.25. The total-pressure-loss coefficient over much of the speed range of these tests was less than 5 percent. Although no data are presented for the configuration with vortex generators on both the inner and outer walls, it is believed that any further increase due to the outer-wall vortex generators would be small.

CONCLUSIONS

The following conclusions are drawn as to the effect of various vortex-generator arrangements on the performance of an annular straight-wall diffuser with an outer diameter of 21 inches and an area ratio of 1.9 to 1 with fully developed pipe flow at the diffuser inlet. Rectangular noncambered airfoils were used as vortex generators and were varied in chord, span, angle of attack, number, and location. The results contained herein are preliminary and do not necessarily represent the maximum pressure recovery and flow stability obtainable with the generators employed, as the optimum station for mounting generators on the inner wall was not determined. It is felt, however, that a high percentage of that obtainable was realized.

1. Every vortex-generator configuration tested resulted in improved performance to some degree.

2. The vortex-generator configuration giving the best performance consisted of 24 equally spaced 3-inch-chord, $\frac{1}{2}$-inch-span airfoils at $13\frac{1}{2}^{\circ}$ angle of attack located on the inner wall 3 inches downstream of the diffuser inlet station and 44 equally spaced 1-inch-chord, $\frac{1}{2}$-inch-span airfoils at 15° angle of attack located on the outer wall 8 inches downstream of the diffuser inlet station. This arrangement improved the diffuser effectiveness over that for the bare diffuser by 17 percent or better throughout the Mach number range tested.

3. Better vortex-generator arrangements reduced velocity fluctuations sufficiently to permit reliable measurement of the flow at the diffuser exit station.

4. For this diffuser the vortex-generator arrangements on the inner wall producing best performance had vortex-generator spans 20 to 40 percent of the distance from the inner wall to the point of peak velocity in the annulus.

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TABLE I.- VORTEX-GENERATOR ARRANGEMENTS TESTED

Inner body wall				Outer duct wall				
Chord (in.)	Span (in.)	Angle of attack (deg)	Number	Chord (in.)	Span (in.)	Angle of attack (deg)	Number	Distance downstream of diffuser inlet station (in.)
2	1	15	24					
2	1	$11\frac{1}{2}$	24					
2	1	$18\frac{1}{2}$	24					
2	1	20	24					
3	1	$13\frac{1}{2}$	24					
3	1/2	$13\frac{1}{2}$	24					
3	1/2	$11\frac{1}{2}$	24					
3	1/2	15	24					
3	1/2	15	12					
1	1/2	15	24					
1	1/2	15	48					
1	1/2	10	48					
3	1	$11\frac{1}{2}$	24	2	1	15	30	2
3	1	$13\frac{1}{2}$	24	2	1	5	30	2
3	1	$13\frac{1}{2}$	24	2	1	10	30	2
3	1/2	$13\frac{1}{2}$	24	1	1/2	5	44	16
3	1/2	$13\frac{1}{2}$	24	2	1	5	22	16
3	1/2	$13\frac{1}{2}$	24	1	1/2	15	44	10
3	1/2	$13\frac{1}{2}$	24	2	1	5	22	10
3	1/2	$13\frac{1}{2}$	24	1	1/2	5	44	8
3	1/2	$13\frac{1}{2}$	24	1	1/2	15	44	8
2	3/4	15	24					
2	1/4	15	24					
2	1/2	15	24					
2	1/4	15	24	1	1/2	15	44	8

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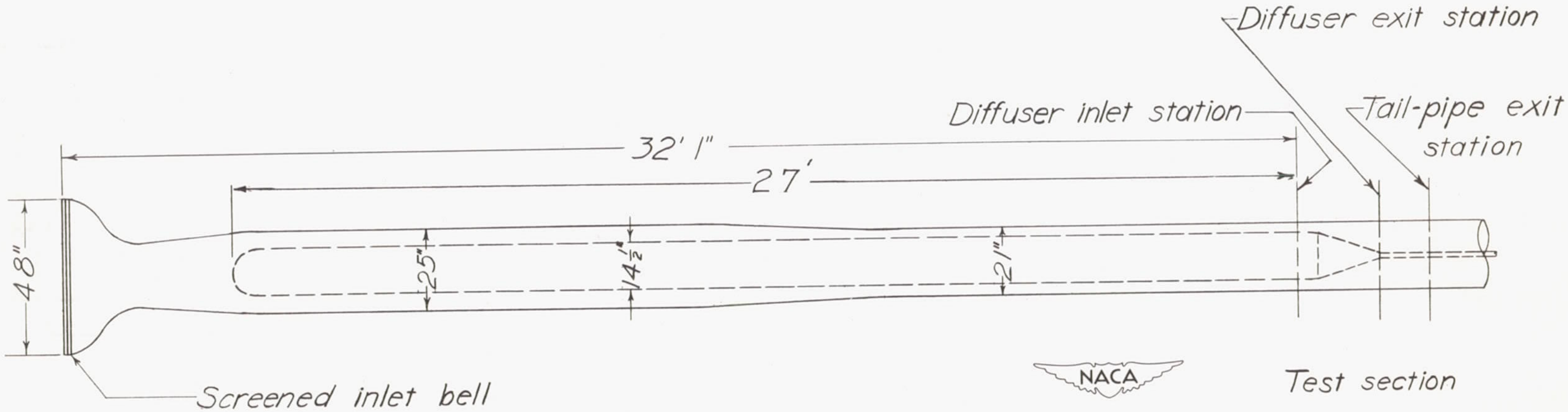


Figure 1.- Schematic diagram of experimental setup.

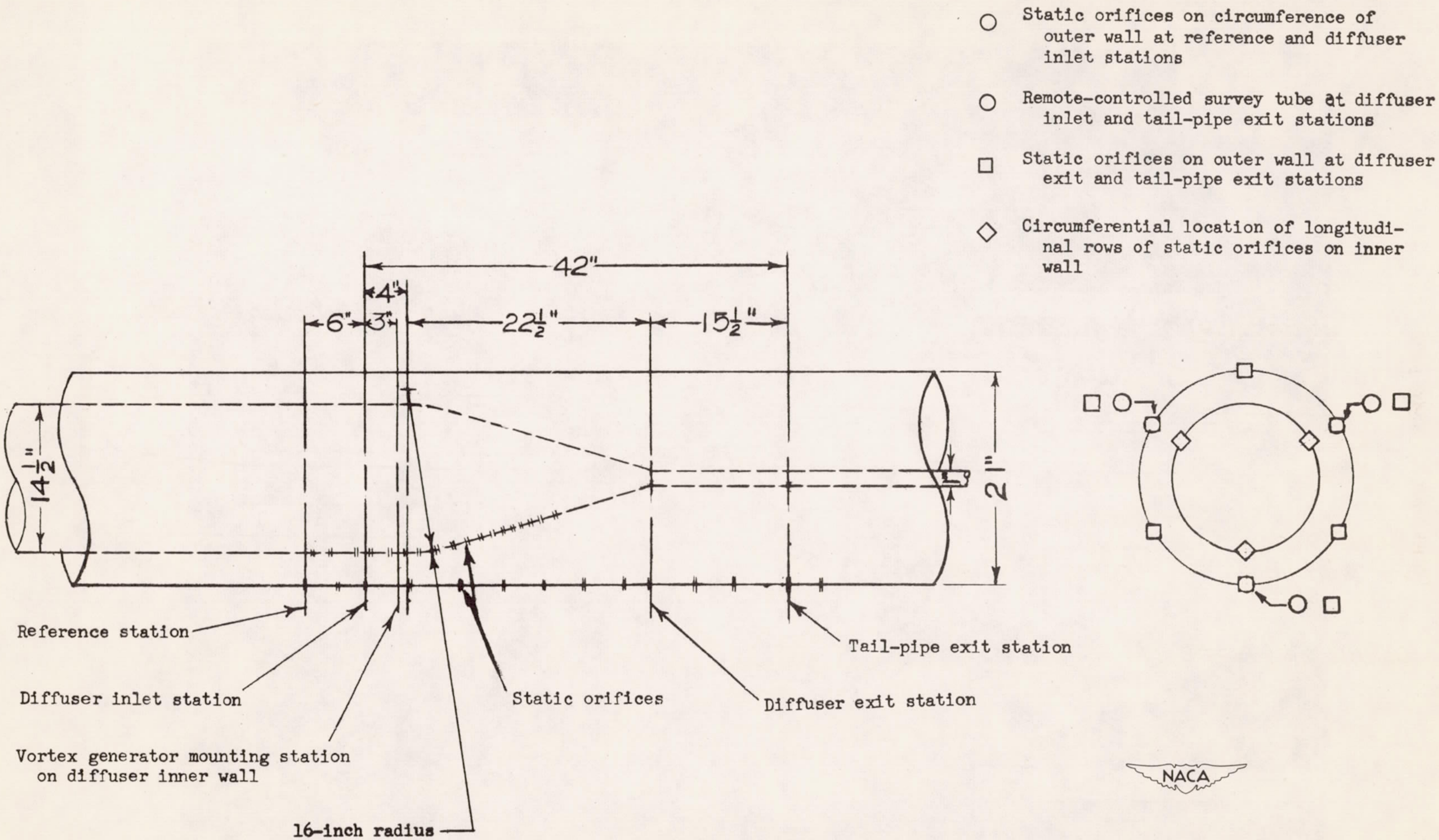


Figure 2.- Schematic diagram of the diffuser - tail-pipe combination tested.

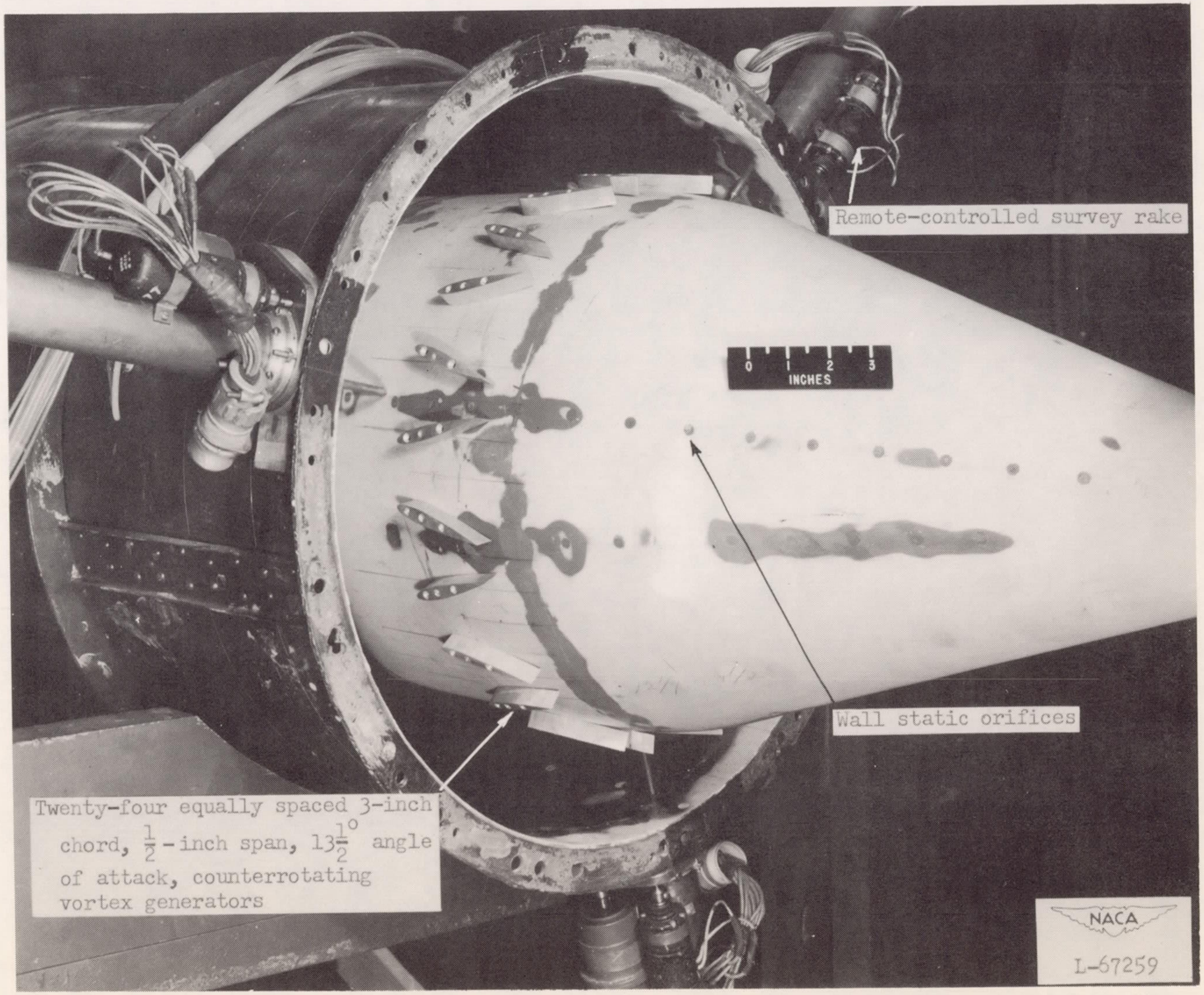


Figure 3.- View of annular diffuser in vicinity of diffuser inlet station.

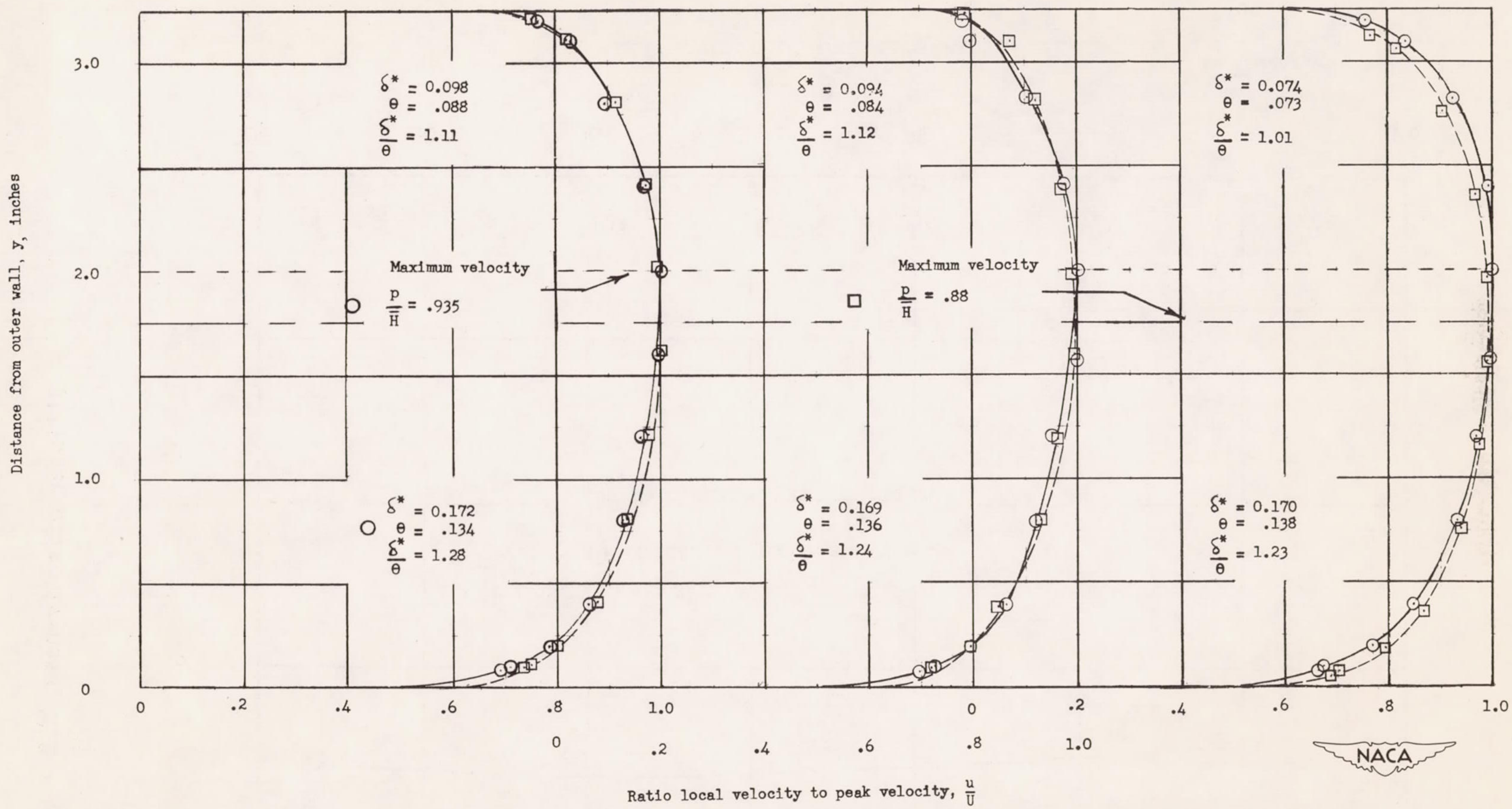


Figure 4.- Velocity profiles at three equally spaced sections around the diffuser inlet station at two different speeds.

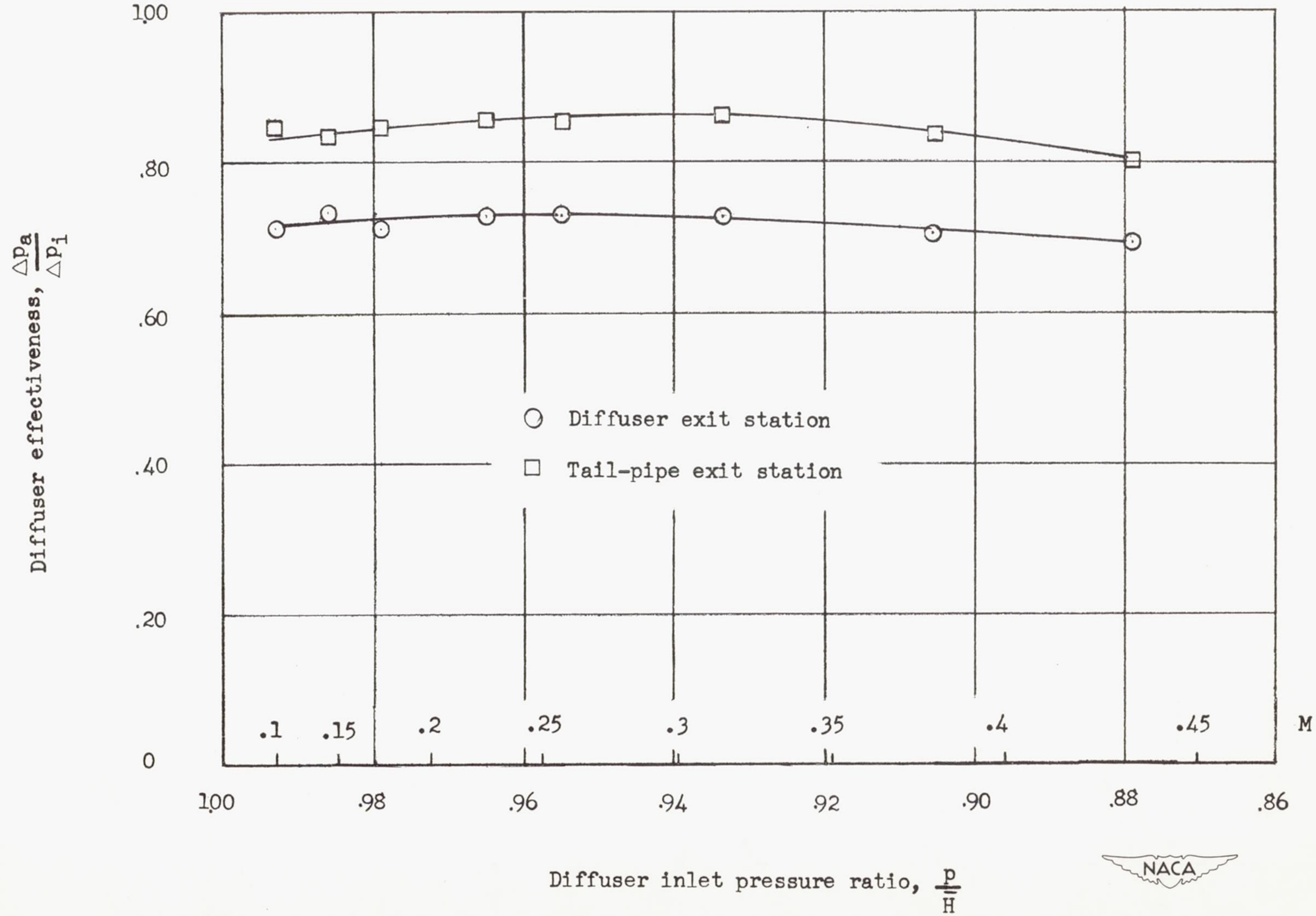


Figure 5.- Variation of diffuser effectiveness with pressure ratio for original condition.

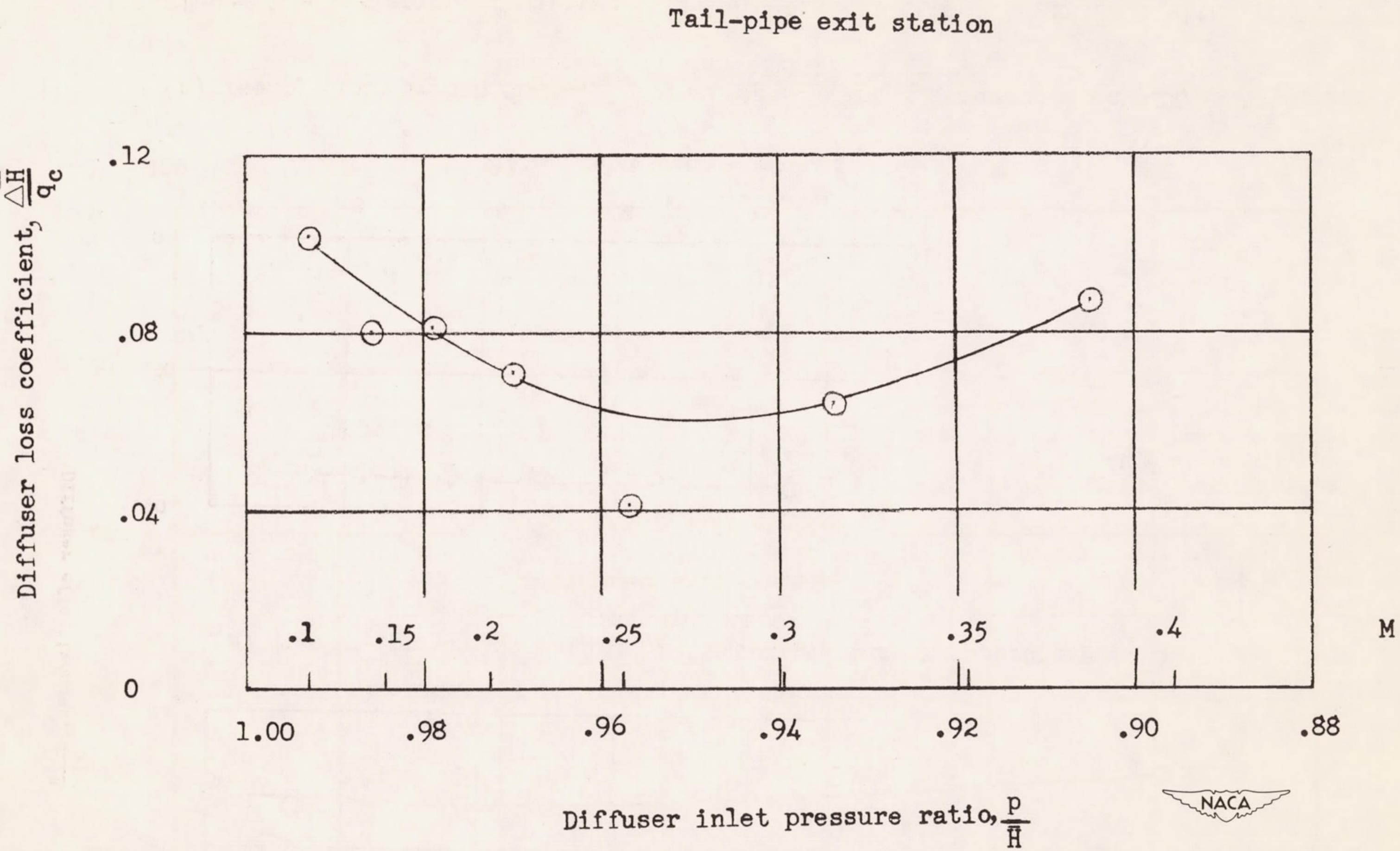
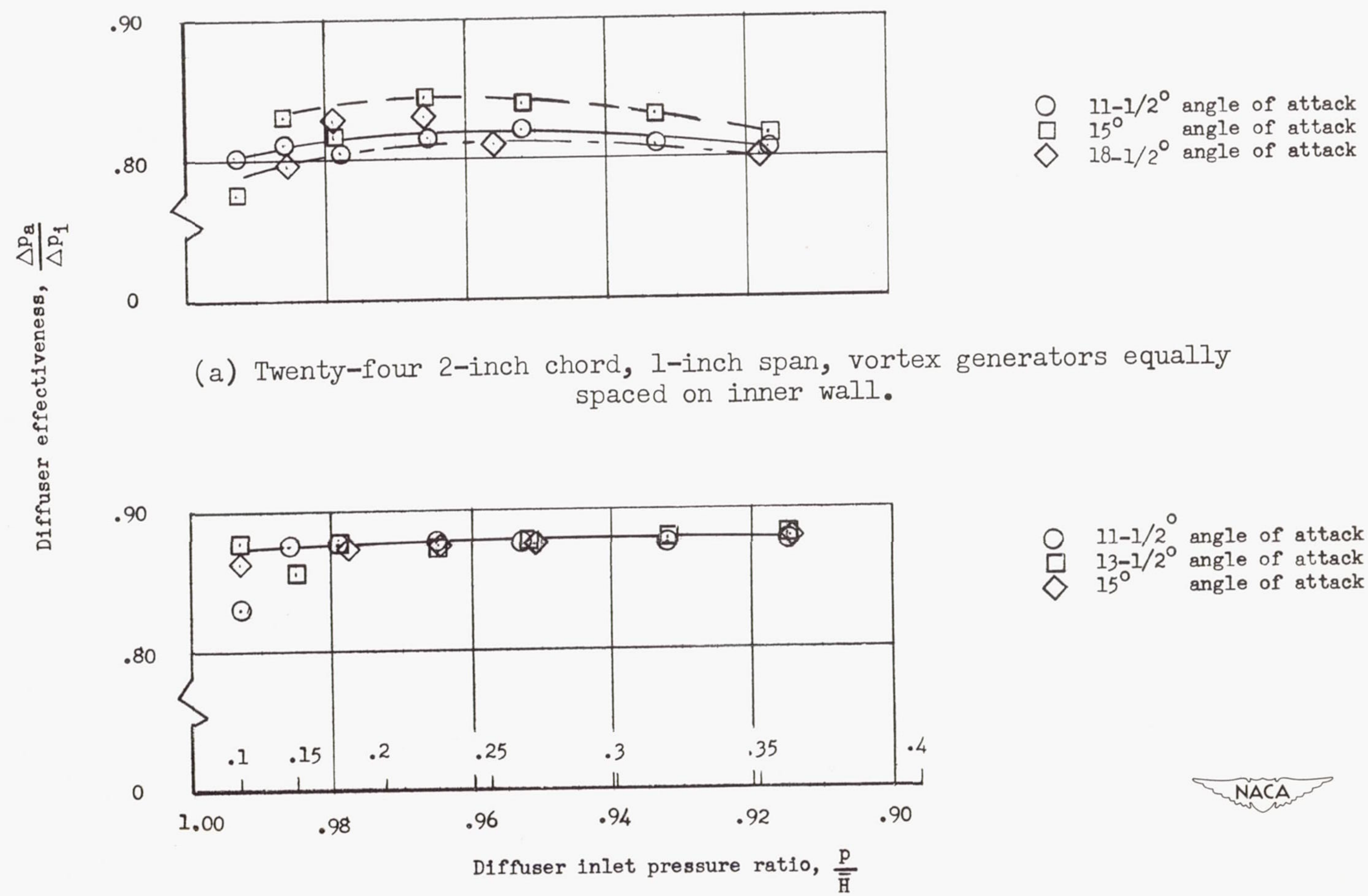


Figure 6.- Variation of diffuser tail-pipe loss coefficient with pressure ratio for original condition.



(a) Twenty-four 2-inch chord, 1-inch span, vortex generators equally spaced on inner wall.

(b) Twenty-four 3-inch chord, 1/2-inch span, vortex generators equally spaced on inner wall.

Figure 7.- Variation of diffuser effectiveness at the diffuser exit with angle of attack for two different vortex-generator arrangements.

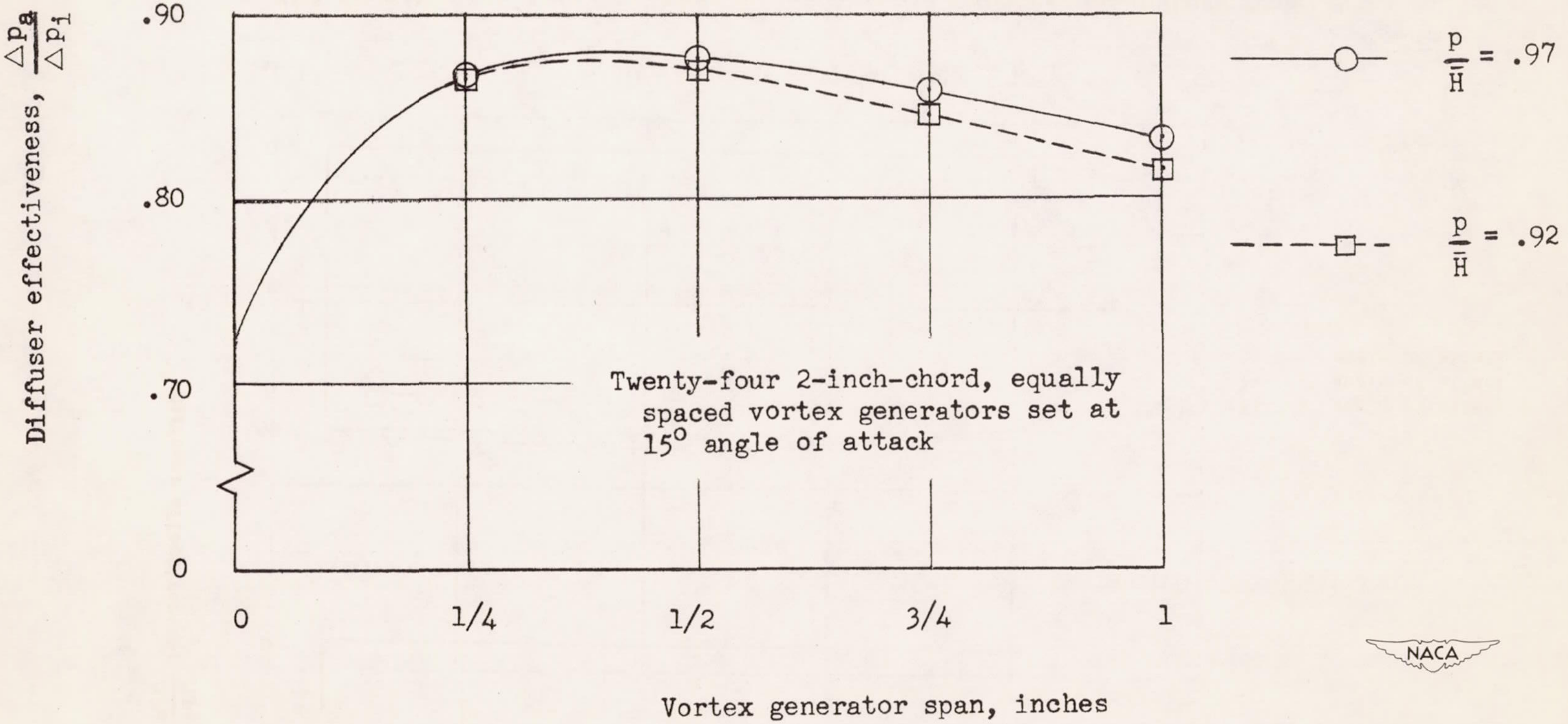


Figure 8.- Variation of diffuser effectiveness with vortex-generator span.

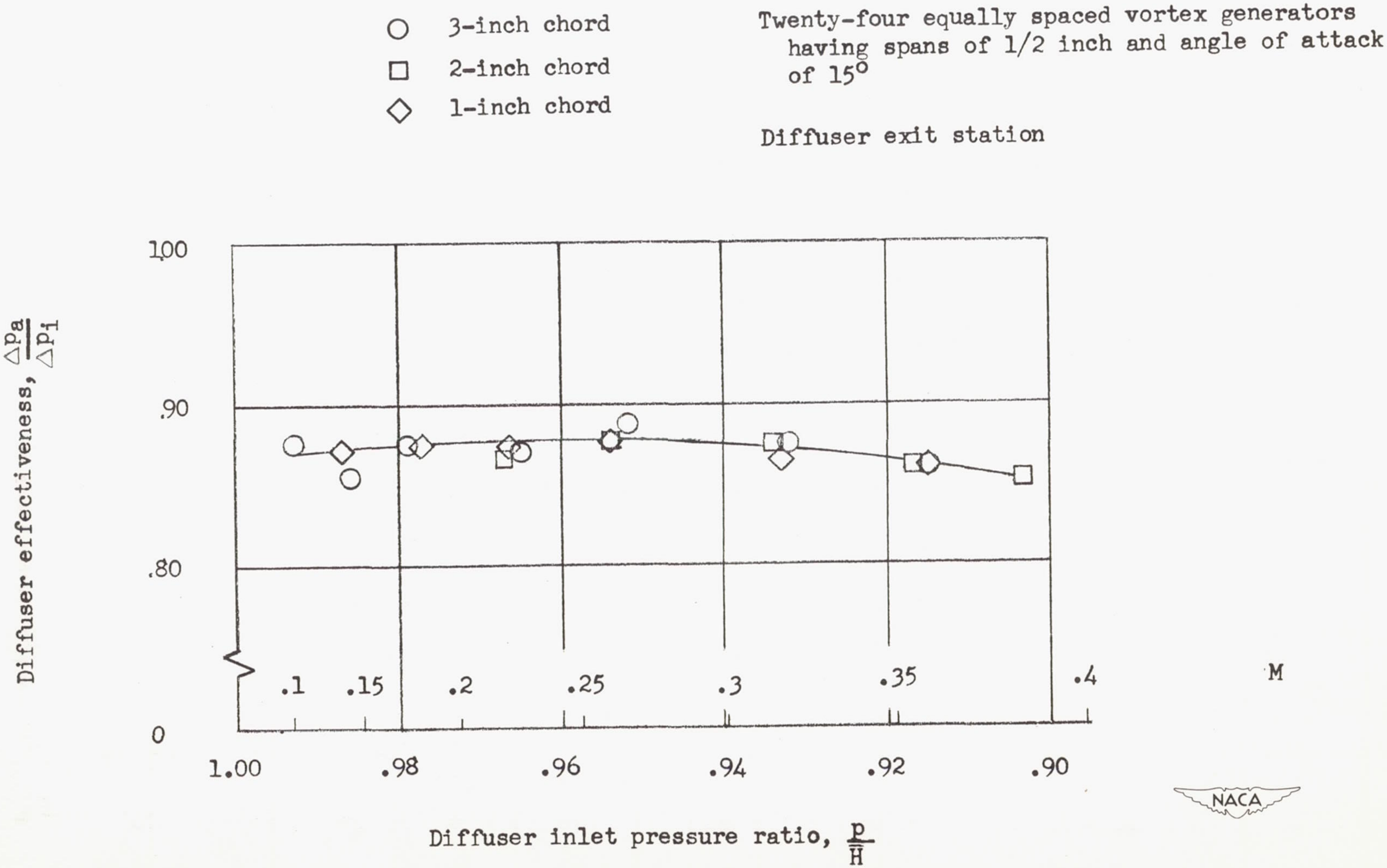


Figure 9.- Variation of diffuser effectiveness with pressure ratio for vortex generators of different chords.

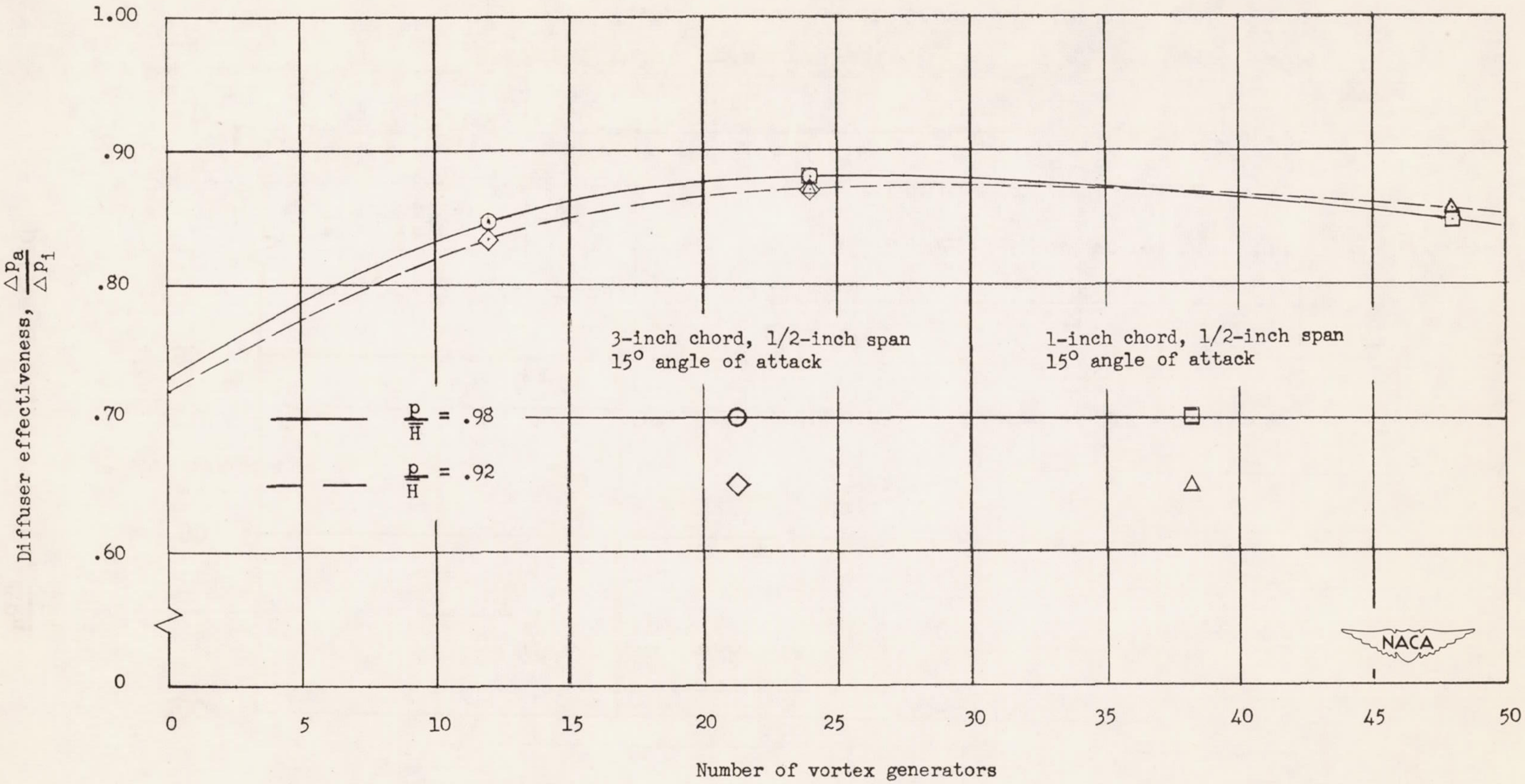


Figure 10.- Variation of diffuser effectiveness at the diffuser exit station with number of vortex generators.

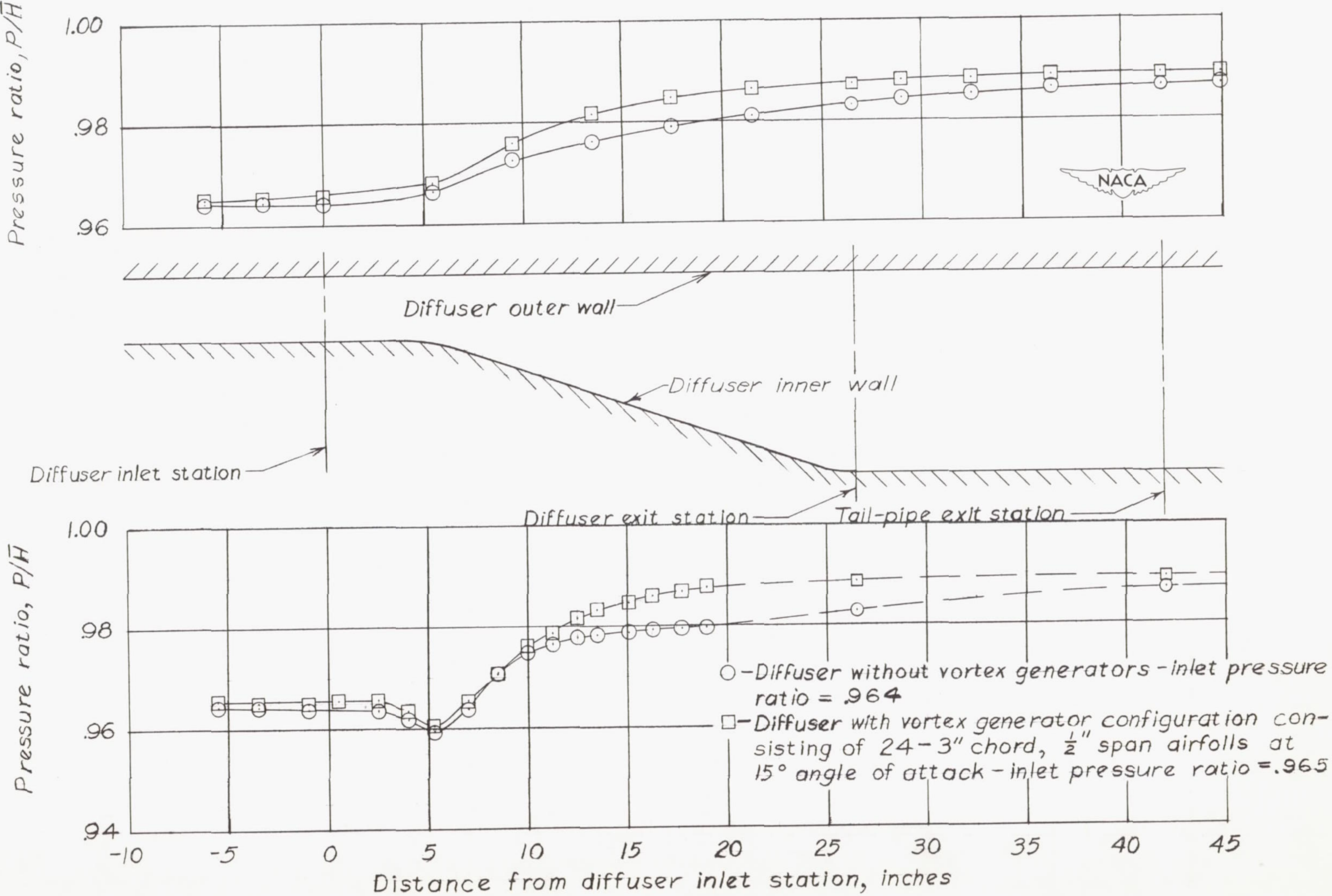


Figure 11.- Static pressure variation along inner and outer diffuser walls.

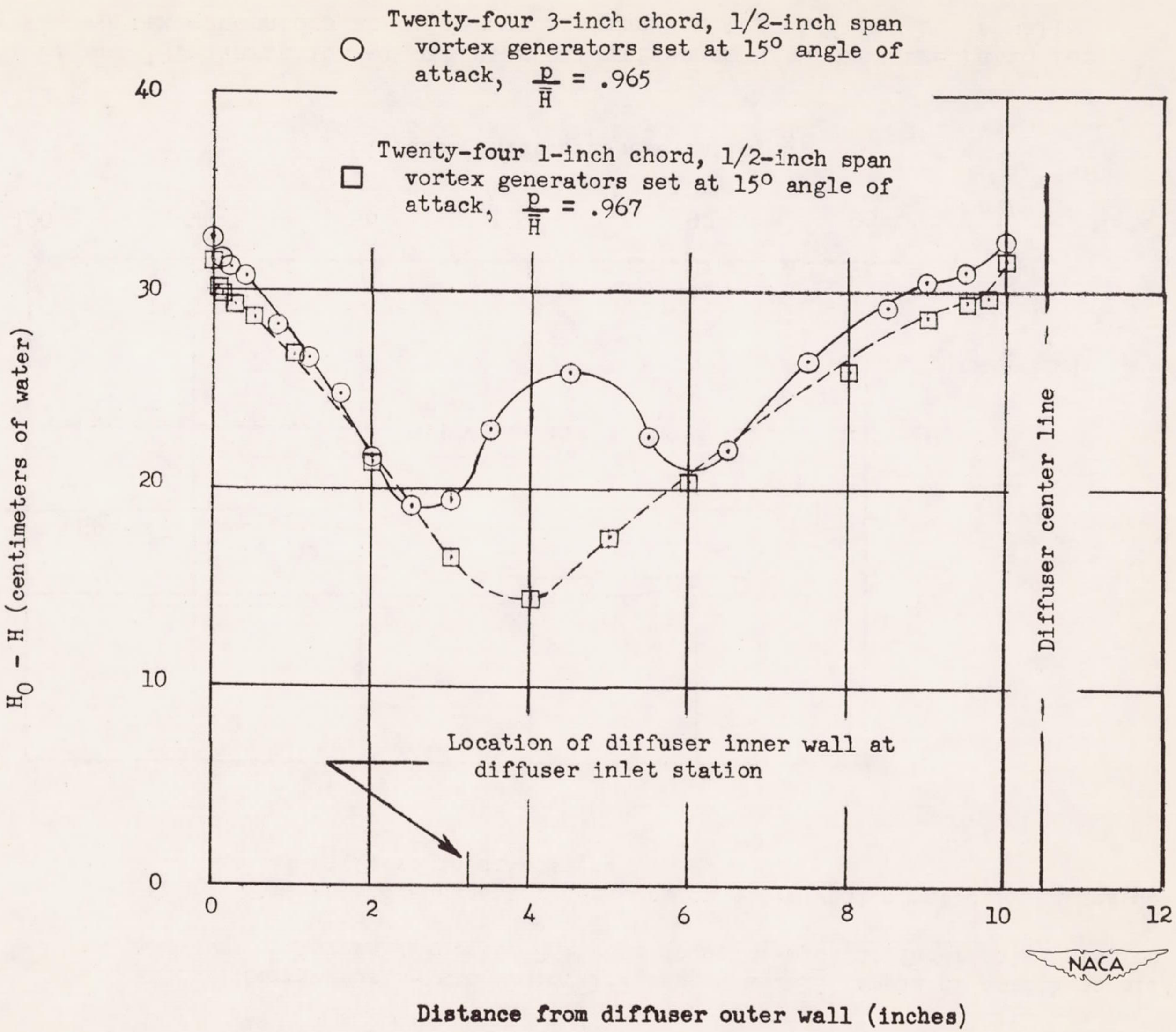


Figure 12.- Total pressure variation at diffuser exit station.

○ Twenty-four 3-inch chord, 1/2-inch span generators, 13-1/2° angle of attack on diffuser inner wall

and

Forty-four 1-inch chord, 1/2-inch span, 15° angle of attack on diffuser outer wall located 8 inches downstream of diffuser inlet station

□ Same as above except generators on outer wall mounted 10 inches downstream of diffuser inlet station

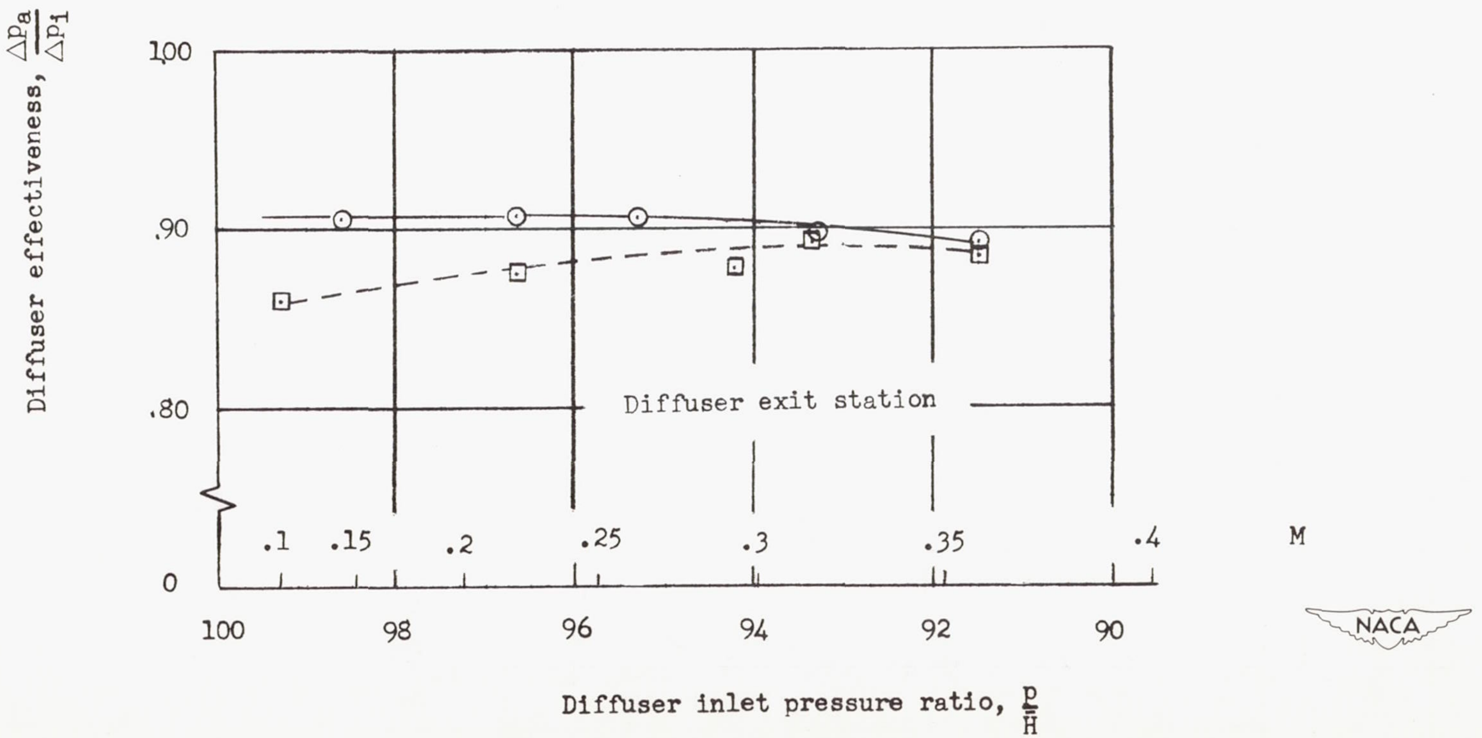
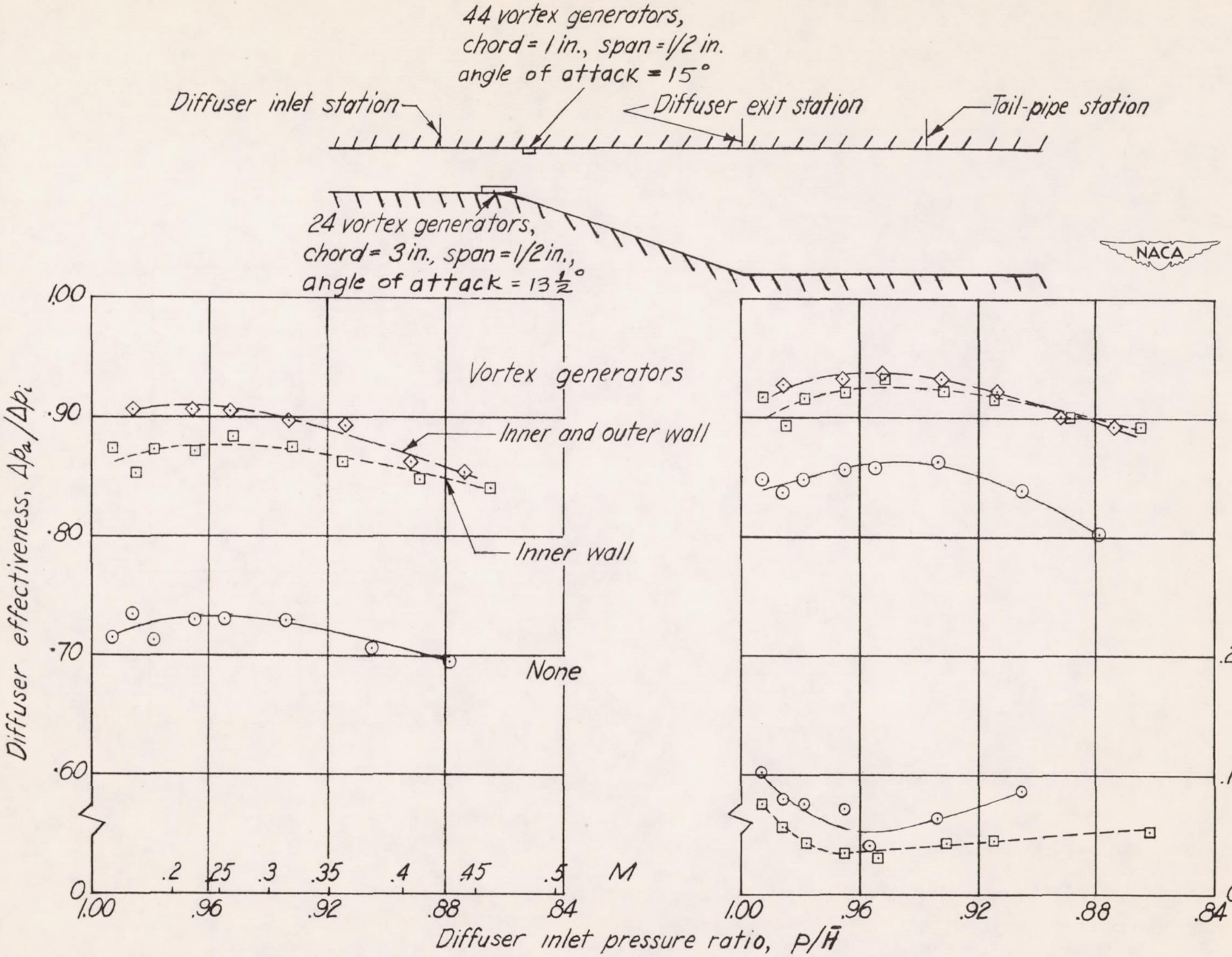


Figure 13.- Variation of diffuser effectiveness with pressure ratio for vortex generators at different stations on the diffuser outer wall.



(a) Diffuser exit.

(b) Tail-pipe exit.

Figure 14.- Variation of diffuser performance with inlet pressure ratio for diffuser without vortex generators and for diffuser with two different vortex-generator installations.

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