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PERFORMANCE OF A LOW-PRESSURE-RATIO CENTRIFUGAL COMPRESSOR WITH FOUR DIFFUSER DESIGNS

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16. Abstract

A low-pressure-ratio centrifugal compressor was tested with four different diffuser configurations. One diffuser had airfoil vanes. Two were pipe diffusers. One pipe diffuser had 7.5° cone diffusing passages. The other had trumpet-shaped passages designed for linear static-pressure rise from throat to exit. The fourth configuration had flat vanes with elliptical leading edges similar to those of pipe diffusers. The side walls were contoured to produce a linear pressure rise. Peak compressor efficiencies were 0.82 with the airfoil vane and conical pipe diffusers, 0.80 with the trumpet, and 0.74 with the flat-vane design. Surge margin and useful range were greater for the airfoil-vane diffuser than for the other three.

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COMPRESSOR WITH FOUR DIFFUSER DESIGNS

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SUMMARY

The performance of a low-pressure-ratio centrifugal compressor was investigated with four diffuser configurations. For argon operation, design pressure ratio was 1.9 at a corrected weight flow of 0.263 kilogram per second.

One diffuser had airfoil vanes. Two were pipe diffusers with area ratios of 4.0 and length-diameter ratios (L/D) of 7.6. The diffusing passages of one pipe diffuser were 7.5° cones. The other pipe diffuser had trumpet-shaped diffusing passages designed for linear static-pressure rise. The fourth diffuser had flat vanes with elliptical leading edges similar to those of pipe diffusers. The side walls were contoured to provide a linear static-pressure rise. The original throat areas of the two pipe diffusers were 93 percent of the throat areas of the airfoil vane diffuser. The throats were then drilled out to approximately the same area as the airfoil-vane diffuser throats and the tests repeated. Throat area of the flat-vane diffuser was 95 percent of the airfoil-vane diffuser area.

Peak compressor efficiency obtained with the airfoil-vane diffuser was 0.82. With the pipe diffusers the peak efficiencies were 0.82 and 0.80 for the conical and trumpet designs, respectively. With the flat-vane diffuser, peak compressor efficiency was 0.74.

Compared to the airfoil-vane diffuser, the other three had lower useful ranges and surge margins. Reductions in surge margin were 78 and 63 percent for the conical and trumpet pipe diffusers, respectively. Reductions in useful range were 32 and 23 percent for the conical and trumpet shapes, respectively. Surge margin for the flat-vane diffuser was reduced by 91 percent, and useful range by 81 percent.

INTRODUCTION

Recently, there has been considerable interest in the pipe diffuser, principally for

use in high-pressure-ratio centrifugal compressors. The interest arises from the low manufacturing cost and the high peak compressor efficiencies that have been obtained with pipe diffusers. The pipe diffuser consists of a number of drilled and reamed holes arranged so that the centerline of each hole lies in a plane perpendicular to the axis of rotation. The centerlines are also tangent to a circle (usually the o.d. of the impeller). Each passage has a cylindrical hole which precedes the reamed diffuser section. Each cylindrical hole intersects adjacent cylindrical holes to form elliptical leading edges between passages. These elliptical leading edges form a semi-vaneless space which divides and guides the flow into cylindrical throat sections. The length of the throat section is selected by the designer. From the throat section the flow passes into the diffuser section, which is reamed to give the area variations and diffusion rate desired by the designer. In most cases, the diffuser section is conical. Other shapes that have been used or considered are the trumpet and the tulip or bell. For a given length-diameter ratio (L/D) and area ratio, the trumpet shape has a lower diffusion rate near the inlet than a cone and a higher diffusion rate near the exit. A pipe diffuser which has a static-pressure rise linear with centerline distance is a special case of the trumpet. Tulip-shaped diffusing passages have higher diffusion rates near the inlet than a cone and lower diffusion rates near the exit. Any diffuser with discrete passages of circular cross section is referred to as a pipe diffuser in this report.

According to reference 1, the high compressor efficiency obtained with pipe diffusers is attributed largely to elliptical leading edges. These leading edges are believed to suppress boundary-layer separation and to handle nonuniform flow better than the two-dimensional cascade diffuser.

An investigation was recently conducted at the Lewis Research Center to determine whether the performance of a low-pressure-ratio centrifugal compressor could be improved with either of two pipe diffuser configurations or with a flat-vane diffuser having elliptical leading edges. The impeller for the test compressor had a tip diameter of 10.8 centimeters and backward-curved blades; it is described in reference 2. Design compressor total-pressure ratio was 1.90 at a corrected weight flow of 0.263 kilogram of argon per second. The overall compressor performance with each of the diffuser configurations was compared with the performance with the original diffuser. As described in reference 2 the original diffuser had airfoil vanes. The two pipe diffusers had an area ratio of 4.0. One had a conical diffuser section consisting of a 7.5° cone. The other had a trumpet-shaped diffuser section designed to produce a linear static-pressure rise from the throat section to the exit. This static-pressure distribution was selected because of the results of turbine exit diffuser tests described in reference 3. In these tests, two turbine exit diffusers designed for linear static-pressure rise each improved overall turbine static efficiency at the design point by about 1.3 points. The original diffuser was a cone with the same area ratio and approximately the same L/D

as the two trumpet diffusers. The flat-vane compressor diffuser with the elliptical leading edge was also designed for a linear static-pressure rise from throat to exit. The intent of this design was to duplicate any aerodynamic advantage obtained from the leading-edge configuration of the pipe diffuser. The area ratio from throat to vane exit was 3.43. The required area variation was obtained by contouring the side walls.

Initially, the pipe diffuser throat areas were 93 percent of the throat areas of the original Brayton Cycle Rotating Unit (BRU) diffuser. After testing, the throat areas of both pipe diffusers were increased to approximately design value and the tests were repeated. The flat-vane diffuser was tested only with the original throat area, which was 95 percent of design.

This report presents the overall performance characteristics of a low-pressure-ratio centrifugal compressor when operated with four separate diffusers. Curves of overall total efficiency as functions of corrected argon weight flow are given. Variations in compressor useful range and surge margin are shown. In addition, the static-pressure distributions are presented for each diffuser.

COMPRESSOR DESCRIPTION

The original compressor is described in detail in references 2 and 4. The rotor has 15 blades with a 30° backsweep angle. Tip diameter is 10.8 centimeters. Inducer inlet hub-tip radius ratio is 0.612. Exit blade height is 0.521 centimeter. For operation with argon at an inlet temperature of 300 K, design rotative speed is 52 130 rpm.

Some of the aerodynamic design conditions for argon operation are

Corrected weight flow, $W\sqrt{\theta}/\delta$, kg/sec 0.263
Compressor total-pressure ratio, p_5'/p_1' 1.90
Corrected speed, $N/\sqrt{\theta}$, rpm 51 100

The original vaned diffuser is shown in figure 1. A vaneless space extends from the impeller tip at radius 5.398 centimeters to the vane leading edges at radius 5.613 centimeters. There are 17 vanes with a blade height of 0.541 centimeter.

Since the original vanes were an integral part of the scroll assembly, this assembly was modified to accept removable diffusers. Figure 2 shows one of the removable pipe diffusers. Figure 3 shows a removable diffuser mounted in the scroll assembly. Three removable diffusers were made.

Because of the known dynamic instability of the rotor, the shroud was covered with an abradable coating to protect the rotor. The coating composition was 63.75 percent nickel, 21.25 percent graphite, and 15 percent aluminum. The coating was applied by flame spraying and was 0.051 centimeter thick.

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Two pipe diffusers were built. These were identical except for the shape of the diffusing passages between the throat and the diffuser exit. The area ratio was 4.0. The L/D of the diffusing passage was 7.56. There were 28 passages. Following the customary practice, passage centerlines were tangent to the rotor tip. The cylindrical inlet portions of the passages were 0.541 centimeter in diameter. A cylindrical throat section 0.127 centimeter in length was included in the design, as shown in figure 4.

The flat-vane diffuser design is shown in figure 5. There are 18 full vanes with 18 additional splitter vanes at the exit. Area ratio provided by the vanes is 3.43. An elliptical leading edge is provided to duplicate any benefits obtained from pipe diffuser leading edges. The side walls are contoured to provide a linear static-pressure rise.

APPARATUS, INSTRUMENTATION, AND PROCEDURE

The compressor running gear and the test facility are described in reference 4.

Compressor

In the original compressor, the diffuser vanes were brazed into the scroll and shroud assembly. A cross section of this assembly is shown in figure 6, which was taken from reference 4. For the tests described in this report, it was necessary to alter the scroll and shroud assembly to accommodate removable diffusers. In addition, the shroud was made removable so that it could be replaced in the event that the abradable coating was damaged. The scroll, shroud, and diffuser assembly is shown in figure 3. One of the removable diffusers is shown in figure 2.

Instrumentation

Figure 6 shows the location of stations 1, 2, 4, and 5. The locations of stations 2, 3, and 4 are also shown in figures 4 and 5. The station 1 and 5 instrumentation is discussed in reference 4. Station 1 has three combination rake probes, providing a total of seven total pressures and six total temperatures. In addition, there are three static-pressure taps. Station 5 has four combination rake probes, providing a total of nine total pressures and eight total temperatures. In addition, there are four static-pressure taps. The total-pressure and -temperature measurements at stations 1 and 5 were used to compute overall compressor efficiency. The diffuser static-pressure taps are shown in figures 4 and 5. There are seven static taps for the two pipe diffusers and eight for

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the flat-vane diffuser. Static tap locations for the original compressor diffuser are given in reference 4.

Procedure

All tests were run with argon. Inlet total pressure was approximately 10.1 N/cm^2 absolute. Inlet total temperature was approximately 300 K. Tests were run at several values of corrected speed. With the original vaned diffuser, the highest corrected speed was 100 percent of design. With the pipe and flat-vane diffusers, corrected speed was limited to 95 percent of design because of rotor dynamic instability. This instability was not related to the type of diffuser being tested. Corrected weight flow was varied from a value close to choke to surge. The original pipe diffusers had throat areas that were 93 percent of the design values. After preliminary testing, the areas were enlarged to approximately design value by drilling and the tests were repeated.

Initially, compressor efficiencies were computed from both torque and temperature measurements. Temperature efficiencies were consistently two points higher than torque efficiencies. The torque measurements were abandoned because of two problems. First, rapid seal wear required frequent tare torque determinations. The tare torque is the torque caused by bearing and seal friction and shaft windage. Tare torque is subtracted from total torque to obtain aerodynamic torque. The second problem was discontinuities in the tare-torque-against-speed curve. These discontinuities were possibly caused by seal hydrodynamic lift-off. It was felt that these discontinuities might affect the reproducibility of the tare torque curve. Therefore, efficiency results presented in this report were obtained from temperature measurements. Temperature efficiencies are highly reproducible and will reflect small changes in performance caused by changes in diffuser design.

RESULTS AND DISCUSSION

The experimental results obtained from the investigation of four diffusers with a low-pressure-ratio impeller are presented in three sections. Static-pressure recovery is discussed in the first section; static-pressure distributions are shown for all diffusers tested. In the second section, overall compressor efficiency is shown as a function of corrected weight flow for the various diffusers. The third section gives the compressor useful range and surge margin characteristics for the four diffusers.

In this discussion, the pipe diffuser with the conical diffusing section is called the conical diffuser. The pipe diffuser designed for linear static-pressure rise in the diffusing section is called the trumpet diffuser.

Diffuser Static-Pressure Recovery

The diffuser inlet pressure p_4 is not shown on the static-pressure distributions presented in this section. This measurement was obtained on the hub side of the diffuser, while all other measurements were obtained on the shroud side. Any hub-to-tip static-pressure variation at the impeller exit would make this measurement inconsistent with the others.

Figures 7(a) and (b) show that, as the corrected weight flow decreases, the static-pressure rise increases in the semi-vaneless space upstream from the throat. The static-pressure rise in the diffusing passage decreases with decreasing weight flow. At a given Mach number, the amount of static-pressure rise in the semi-vaneless space depends on the change in absolute flow angle between the impeller exit and the diffuser throat ($\alpha_2 - \alpha_3$). The value of α_2 can be determined by an iteration procedure. A value is assumed for $(V/V_{cr})_2$. The value of α_2 required to satisfy continuity in the radial direction is then computed by using the measured value of p_4. By using α_2, we obtain $V_{u,2}$. This procedure is repeated until $V_{u,2}$ satisfies the relation: $UV_{u,2} = c_p(T_5' - T_1')$. At peak efficiency with the enlarged conical pipe diffuser, α_2 is 73°. The design value of α_2 for the original vaned diffuser is 71°. At the diffuser throat, the passage centerline angle ψ is 65°. Between the impeller exit and the diffuser throat, the flow would therefore have to turn about 8° toward the radial direction in order for the flow angle to match the passage centerline angle. At a given corrected speed, the corrected weight flow decreases as the compressor operating point moves toward surge. The resulting decreases in relative and radial velocities at the impeller exit produce an increase in α_2. Consequently, as the compressor operating point moves toward surge there is an increase in the turning angle, $\alpha_2 - \alpha_3$. The increase in the pressure rise in the semi-vaneless space that occurs with decreasing weight flow must be caused by the increase in turning angle.

Figure 8 shows the static-pressure distributions for peak efficiency from figures 7(a) and (b). In addition, the static-pressure distribution for the original vaned diffuser is shown. The vaned diffuser data were obtained from reference 4 at 100 percent of corrected speed, compared to 95 percent for the pipe diffusers. The static-pressure ratios shown for the original diffuser are therefore higher than for the pipe diffusers. The dashed line shows the result of scaling the 100-percent-speed curve to 95 percent of corrected speed. This was done in order to obtain a better comparison

with the pipe diffuser static-pressure distributions. The scaling was accomplished by assuming that specific work was proportional to the square of the corrected speed. It was also assumed that the efficiency did not change. For the original vaned diffuser, static-pressure rise is almost linear to a distance-to-length ratio (X/L) of approximately 0.4. Beyond this point the derivative of static pressure with respect to distance decreases continuously and the curve resembles that of a conical diffuser.

Figure 9 shows the static-pressure distributions of the three removable test diffusers with smaller-than-design throat areas. The conical and trumpet pipe diffusers have throat areas that are 93 percent of design, and the flat-vane diffuser has a 95-percent area. Distance-to-length ratio X/L is plotted against the ratio of local diffuser static pressure to compressor outlet static pressure p/p_5. The pipe diffuser curves are included for comparison with the flat-vane diffuser curve. In figure 5, the points d, f and e, g for the flat-vane diffuser are on different sides of the splitter vane. The diffuser outlet static pressures for the two pipe diffusers are about 99 percent of the static pressure at the scroll outlet. For the flat-vane diffuser, the diffuser outlet static pressure is only about 93 to 94 percent of the static pressure at the scroll outlet. This large pressure rise downstream of the diffuser is an indication that the flat-vane diffuser has a higher exit velocity than the pipe diffusers. Such high velocities could result from jet flow caused by separation. The constant static pressure from point d to point f is another indication of jet flow. In diffusers, high divergence angles tend to produce jet flow following separation. In the radial plane, the diffuser passage is a wedge with a 20° divergence angle. Additional vanes or longer splitter vanes to reduce the divergence angle might have improved pressure recovery significantly.

Overall Compressor Efficiency

Design throat area. - Figure 10 shows the overall compressor efficiency characteristics obtained with the original vaned diffuser and the two pipe diffusers with enlarged throat areas. Overall total efficiency is plotted against corrected weight flow for lines of constant corrected speed. Figure 10(a) shows the overall efficiency with the original vaned diffuser at 80, 90, and 100 percent of design corrected speed. By estimating weight flow for 95 percent speed by averaging the 90 and 100 percent speed values, a value of 0.233 kilogram per second was obtained for corrected weight flow at a peak efficiency of 0.820.

Figure 10(b) shows the total efficiency characteristics with the conical pipe diffuser with 98 percent of design throat area. At 95 percent speed, peak efficiency is 0.816 at a corrected weight flow of 0.225 kilogram per second.

Performance with the trumpet pipe diffuser with 101 percent of design throat area

is shown in figure 10(c). At 95 percent speed, peak efficiency was 0.802 at a corrected argon weight flow of 0.232 kilogram per second.

Peak compressor efficiencies obtained with the original vaned diffuser and the conical pipe diffuser were essentially the same. Corrected weight flow at peak compressor efficiency was 3.6 percent lower for the conical diffuser. If the conical diffuser throat enlargement had been sufficient to match the weight flow obtained with the vaned diffuser, peak efficiency might have been somewhat higher. Peak compressor efficiency obtained with the trumpet diffuser was two points lower than with the original vaned diffuser. Corrected weight flows at peak efficiency were the same for both trumpet and original diffusers.

The compressor efficiency obtained with the conical diffuser was 1.4 points higher than that obtained with the trumpet diffuser. This difference is apparently the result of higher losses in the trumpet diffusing passage. The peak efficiency static-pressure distributions shown in figure 8 for the conical and trumpet pipe diffusers were obtained at the same corrected weight flows of 0.229 kilogram per second. These weight flows are for actual experimental points and do not quite correspond with values obtained by interpolation from figure 10. Efficiencies corresponding to the figure 8 curves were 0.814 and 0.802 for the conical and trumpet diffusers, respectively. Since weight flows were the same, rotor efficiencies and rotor static-pressure ratios should have been the same for both diffusers. Pressure rise in the semi-vaneless space was nearly the same in both cases, indicating that total-pressure losses upstream from the throats should have been nearly the same. Figure 8 shows that the conical diffusing passage produced a greater static-pressure rise than the trumpet passage. The greater compressor efficiency obtained with the conical diffuser was caused by a higher overall total-to-total pressure ratio, rather than by a difference in compressor work.

Original throat areas. - Overall compressor performance for the original flat-vane and pipe diffusers before throat enlargement is shown in figure 11 for 95 percent of design corrected speed. Throat areas for the two pipe diffusers were 93 percent of design. Flat-vane throat area was 95 percent of design. Peak efficiencies for the cone and trumpet diffusers were 0.796 and 0.780, respectively. Peak efficiency for the flat-vane diffuser was only 0.743. Performance of the flat-vane diffuser is discussed under Overall Compressor Efficiency. Because of this poor performance, the flat-vane diffuser throat area was not enlarged.

Peak efficiency with the conical diffuser was 1.6 points greater than with the trumpet diffuser both before and after throat enlargement. Throat enlargement from 93 percent of design to approximately design value increased peak efficiency by two points for both diffusers. The compressor efficiency was more sensitive to area change with pipe diffusers than with the original vaned diffuser. With the original diffuser, a 14 percent decrease from design area caused only a 1.5 percent decrease in overall compressor

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efficiency. This value was obtained from unpublished data for 90 percent of design corrected speed. Area was reduced by changing the vane setting angle.

Efficiency and weight flow results for 95 percent of design corrected speed are summarized in table I. Peak compressor efficiencies with the original vaned diffuser and the conical pipe diffuser with 98 percent of design area were essentially equal. Peak efficiency with the trumpet pipe diffuser with 101 percent of design throat area was about two points lower. For 93 percent of design throat area, peak compressor efficiencies with the conical and trumpet pipe diffusers were each two points less than for the enlarged throat areas. Peak compressor efficiency with the flat-vane diffuser was four to six points less than for pipe diffusers with comparable throat areas.

Useful Range and Surge Margin

For this report, range is arbitrarily defined as follows:

$$R_1 = \frac{W_{corr, 70} - W_{corr, s}}{W_{corr, pk}}$$

For a given speed, this is a rough measure of the range of corrected weight flows for useful operation. The value of 70 percent efficiency for the limit of useful operation was arbitrarily selected. The R_1 parameter is similar to the frequently used operating range which is based on the difference between maximum flow and surge. For the subject compressor, operating range is not a good measure of useful flow range since maximum flow occurs at very low efficiencies. If the ranges for various diffusers are determined near design speed, the same relations tend to be maintained at lower speeds. Range R_1 at 95 percent speed is therefore a general measure of tolerance for off-design operation.

Another important weight flow parameter is the surge margin R_2. This parameter is defined as follows:

$$R_2 = \frac{W_{corr, pk} - W_{corr, s}}{W_{corr, pk}}$$

It is a measure of the difference in equivalent weight flow between peak efficiency and surge. A low surge margin requires careful matching of the compressor with other equipment. There is less tolerance to changes in operating conditions and to transient disturbances. Useful ranges R_1 and surge margins R_2 are shown in table II for all

four diffusers.

Compared to the original design with airfoil vanes, values of R_1 were lower by 32 and 23 percent for the conical and trumpet pipe diffusers, respectively. Surge margin values R_2 were lower by 78 and 63 percent for the conical and trumpet pipe diffusers, respectively. Operation with the flat-vane diffuser caused a decrease of 81 percent in R_1 and 91 percent in R_2.

For given values of $W_{corr,pk}$ and $W_{corr,70}$, the values of R_1 and R_2 are largely dependent on the corrected weight flow at surge $W_{corr,s}$. Obviously, low values of $W_{corr,s}$ tend to produce large surge margins and operating ranges. Figure 12 shows curves of overall compressor total-pressure ratio p_5'/p_1' as a function of corrected weight flow $W\sqrt{\theta}/\delta$ for the original diffuser at 90 and 100 percent of design corrected speed and for the enlarged conical pipe diffuser at 90 and 95 percent of design corrected speed. Weight flows corresponding to peak efficiency and to $W_{corr,s}$ are indicated. With the original vaned diffuser, values of $W_{corr,s}$ are much lower than the values obtained with the conical pipe diffuser. Consequently, useful range and surge margin are much larger with the original vaned diffuser. At 90 percent speed, $W_{corr,s}$ is 0.142 with the original vaned diffuser and 0.197 with the conical pipe diffuser. Surge will not occur until total-pressure losses increase sufficiently to produce a positive slope in the pressure ratio - weight flow curve. The R_1 and R_2 values in table II are thus a measure of the rate at which diffuser losses increase as weight flow is reduced below the value corresponding to peak efficiency.

Figure 7(a) shows that for the conical pipe diffuser there is relatively little difference between the static-pressure distributions for peak efficiency and surge. With the trumpet diffuser shown in figure 7(b), the static-pressure distribution changes drastically between peak efficiency and surge. The pressure rise in the semi-vaneless space is much higher at surge, and the diffusing passage pressure rise is much lower. This difference in pressure distribution at surge for the two diffusers can be explained in terms of the discussion in the section Diffuser Static-Pressure Recovery. In that section, it is stated that $\alpha_2 > \alpha_3$; that is, the flow must turn more toward the radial direction between the impeller exit and the diffuser throat. It is also stated that the angle through which the flow turns $(\alpha_2 - \alpha_3)$ increases with decreasing weight flow. This causes the pressure rise in the semi-vaneless space to increase steadily as the flow rate is reduced. The inlet of the trumpet diffusing passage is nearly cylindrical near the throat. This shape causes the flow to turn so that it is more nearly parallel to the passage centerline than for a conical passage. If ψ is the passage centerline angle at the throat measured from the radial direction, and if we define a deviation angle φ so that $\alpha_3 - \psi = \varphi$, then $\alpha_2 - \alpha_3 + \varphi = \alpha_2 - \psi$. With the trumpet diffuser, as weight flow is reduced, φ will necessarily increase more slowly than for the cone. The turning angle $\alpha_2 - \alpha_3$ will increase more rapidly and the pressure rise in the semi-

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vaneless space will increase more rapidly than for the cone.

Surge is probably induced by diffuser stall. In the case of the trumpet diffuser, stall in the diffusing passage will occur principally because of the high blockage at the throat resulting from diffusion in the semi-vaneless space. In the case of the conical diffuser, the pressure rise in the semi-vaneless space is less, but the relatively high deviation angle φ will produce an aerodynamic loading. This loading will cause stall to occur more readily than it would for a zero deviation angle.

SUMMARY OF RESULTS

The performance of a low-pressure-ratio compressor was investigated with the original diffuser and three research diffusers. The compressor impeller has a 10.8-centimeter tip diameter and backswept blading. For argon design point operation, the compressor total-pressure ratio is 1.90 at a corrected weight flow of 0.263 kilogram of argon per second with a total-to-total efficiency of 0.80. After testing the compressor with the original vaned diffuser, three research diffusers were investigated. Two were pipe diffusers with area ratios of 4.0 and length-diameter ratios (L/D) of 7.6. One pipe diffuser had a conical diffusing passage with a 7.5° cone angle. The other had a trumpet-shaped diffusing passage designed for linear static-pressure rise. The two pipe diffusers were tested at 93 percent of original diffuser design throat area. Both were then tested at throat areas closer to design. The third research diffuser had flat vanes with side walls contoured to produce a linear static-pressure rise. The vanes had elliptical leading edges similar to those in a pipe diffuser. The flat-vane diffuser was tested only at 95 percent of design throat area. The following results apply to 95 percent of design corrected speed:

1. With the two pipe diffusers, peak efficiency increased by two points when throat areas were increased from 93 percent of design to 98 percent for the conical pipe diffuser and to 101 percent for the trumpet pipe diffuser.

2. Peak compressor efficiency with the original diffuser was 0.82. With the enlarged throat areas, peak efficiency was 0.82 with the conical pipe diffuser and 0.80 with the trumpet pipe diffuser. With 95 percent of design throat area, the peak efficiency with the flat-vane diffuser was 0.74.

3. Compared to the original diffuser, useful range was lower by 32 percent for the conical pipe diffuser, lower by 23 percent for the trumpet pipe diffuser, and lower by 81 percent for the flat-vane diffuser.

4. Compared to the original diffuser, surge margin was 78 percent less with the conical pipe diffuser, 63 percent less with the trumpet diffuser, and 91 percent less with the flat-vane diffuser.

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    National Aeronautics and Space Administration,
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APPENDIX - SYMBOLS

c_p specific heat at constant pressure, J/(kg)(K)

D diffuser throat diameter, m

L total diffuser length along centerline, m

N rotative speed, rpm

p static pressure, N/cm^2

p' total pressure, N/cm^2

R_1 compressor useful range for a given corrected speed, $(W_{corr, 70} - W_{corr, s})/W_{corr, pk}$

R_2 compressor surge margin for a given corrected speed, $(W_{corr, pk} - W_{corr, s})/W_{corr, pk}$

T' total temperature, K

U impeller speed at exit, m/sec

V absolute gas velocity, m/sec

W mass flow rate, kg/sec

W_{corr} corrected flow rate, $W\sqrt{\theta}/\delta$, kg/sec

$W_{corr, 70}$ for a given corrected speed, corrected flow rate higher than $W_{corr, pk}$, corresponding to 70 percent compressor efficiency

X distance along diffuser passage centerline, m

α absolute flow angle measured from radial direction, deg

γ ratio of specific heats

δ ratio of compressor inlet total pressure to U.S. standard sea-level pressure, p_1'/p^*

η compressor overall adiabatic temperature rise efficiency

θ ratio of compressor inlet total temperature to NASA standard sea-level temperature, T_1'/T^*

φ difference between absolute flow angle at throat and passage centerline angle, $\alpha_3 - \psi$, deg

ψ passage centerline angle at throat measured from radial direction, deg

Subscripts:

cr   condition corresponding to Mach number of unity

pk   corresponding to compressor peak efficiency

u   tangential component

s   corresponding to compressor operation at surge

1   station at compressor inlet

2   station at diffuser inlet

3   station at diffuser throat

4   station at diffuser exit

5   station at scroll exit

70   corresponding to compressor operation at an efficiency of 0.70

Superscript:

*   U.S. standard sea-level conditions (temperature, 288.15 K; pressure, 10.13 N/cm^2 abs)

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TABLE I. - COMPARISON OF DIFFUSER EFFICIENCIES

AND WEIGHT FLOWS

Diffuser	Percent of design throat area	Peak efficiency	Corrected weight flow at peak efficiency, kg/sec
Vane	100	0.820	0.233
Cone	93	.796	.222
	98	.816	.225
Trumpet	93	.780	.215
	101	.802	.232
Flat vane	95	.742	.233

TABLE II. - COMPRESSOR USEFUL RANGE AND SURGE MARGIN FOR FOUR DIFFUSERS

Diffuser	Percent of design area	Compressor useful range, R_1		Compressor surge margin, R_2	
		Value	Percent of original design	Value	Percent of original design
Cone	98	0.36	68	0.07	22
Trumpet	101	.41	77	.12	37
Flat vane	95	.10	19	.03	9
Original design	---	.53	100	.32	100

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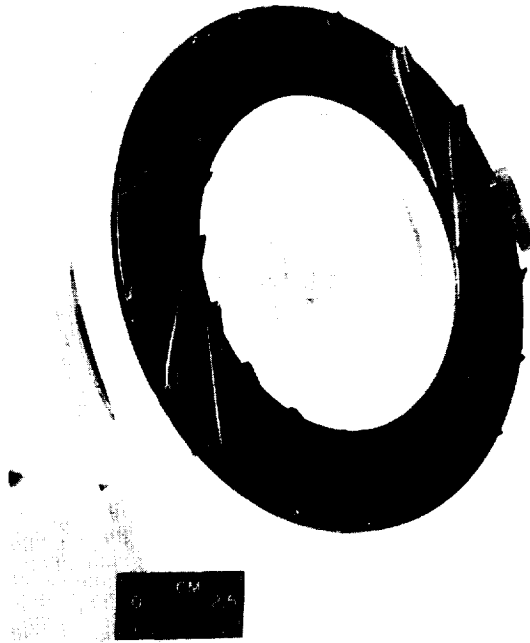
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Figure 1. - Original vaned diffuser.

C-72-2938

Figure 2. - Removable pipe diffuser.

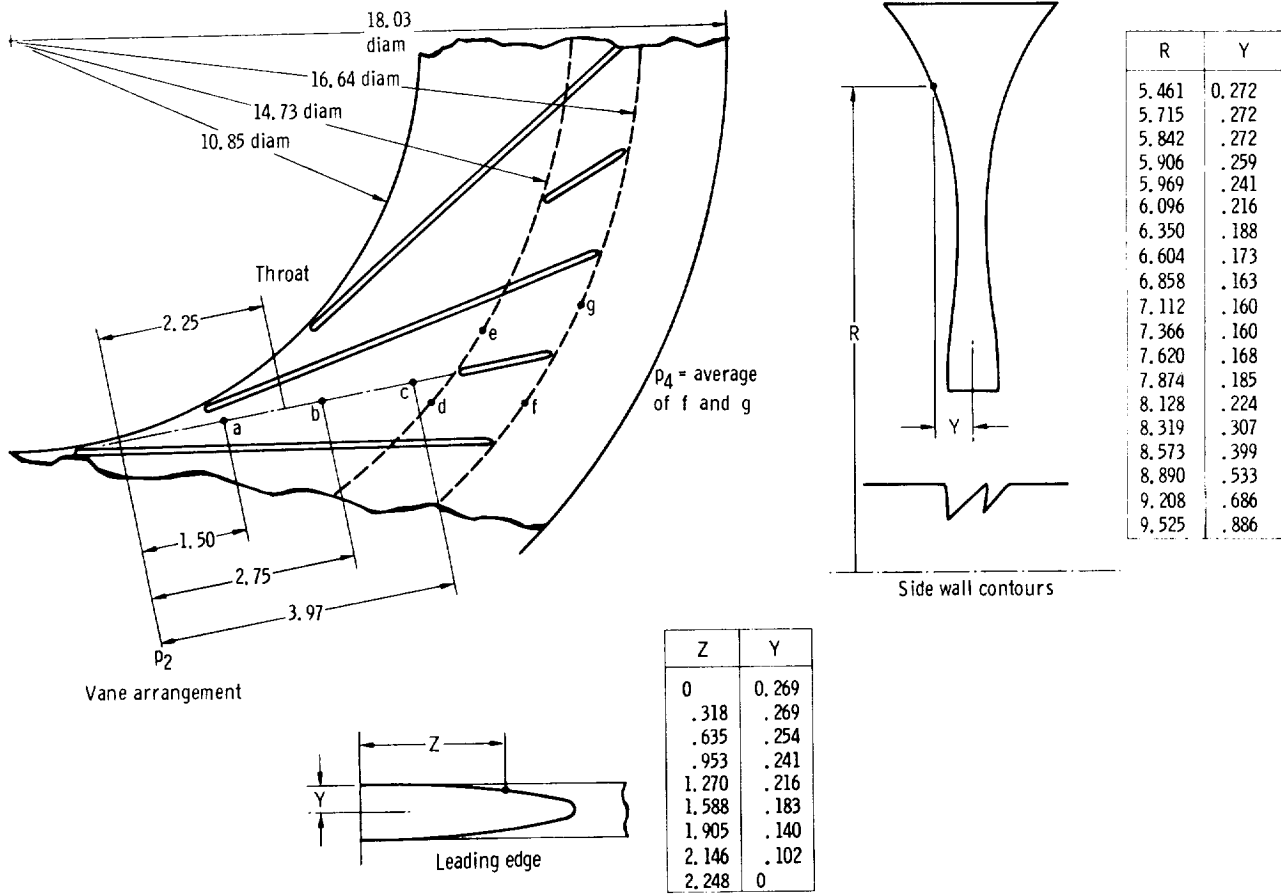Figure 4. - Pipe diffuser flow passages and static-pressure tap locations. (All dimensions are in cm.)

Figure 3. - Removable diffuser in scroll.

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R	Y
5.461	0.272
5.715	.272
5.842	.272
5.906	.259
5.969	.241
6.096	.216
6.350	.188
6.604	.173
6.858	.163
7.112	.160
7.366	.160
7.620	.168
7.874	.185
8.128	.224
8.319	.307
8.573	.399
8.890	.533
9.208	.686
9.525	.886

Side wall contours

Z	Y
0	0.269
.318	.269
.635	.254
.953	.241
1.270	.216
1.588	.183
1.905	.140
2.146	.102
2.248	0

Figure 5. – Flat-vane diffuser flow passages and static-pressure tap locations. (All dimensions are in cm.)

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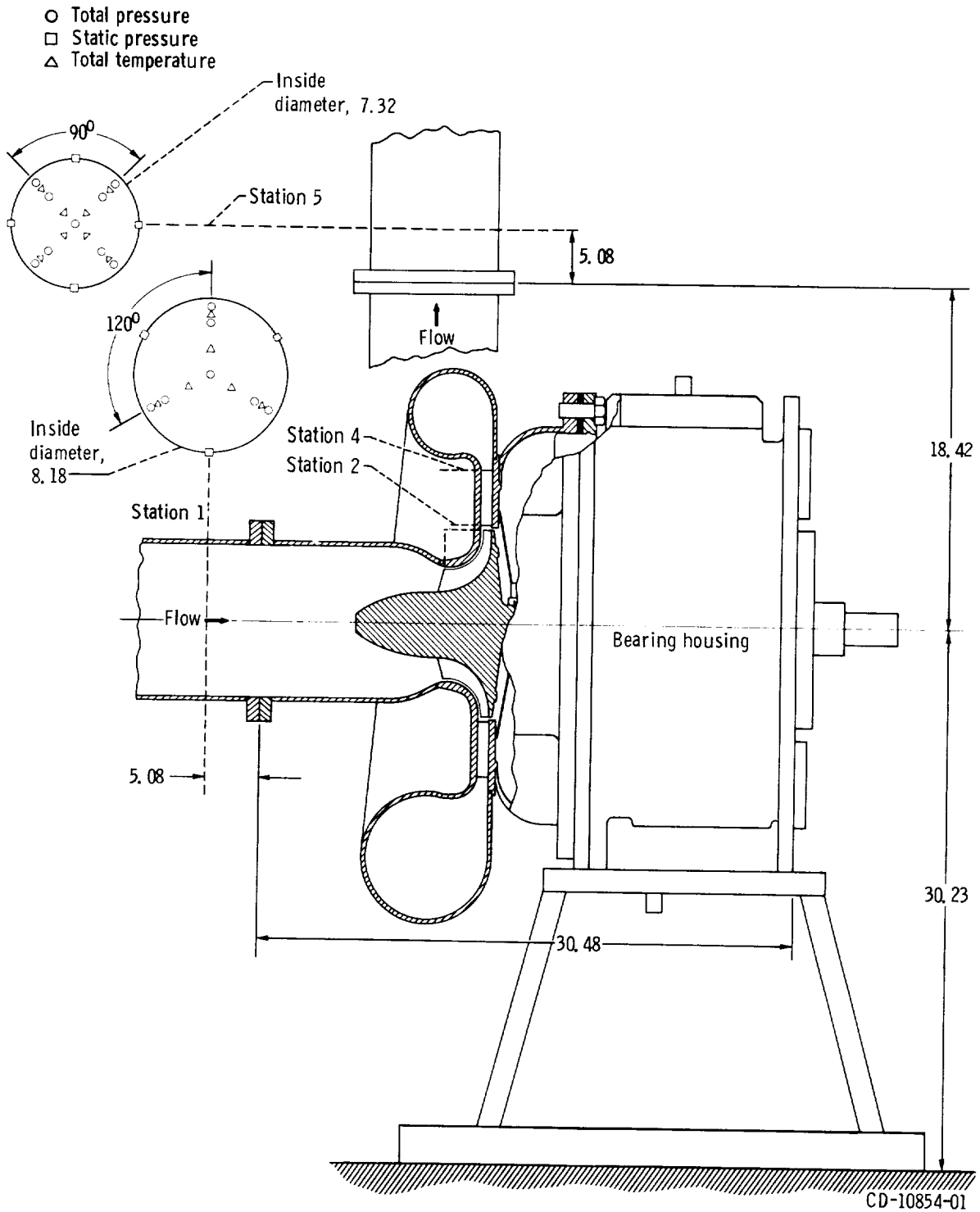
Figure 6. - Compressor cross section, showing instrument locations at stations 1 and 5. (All dimensions are in cm.)
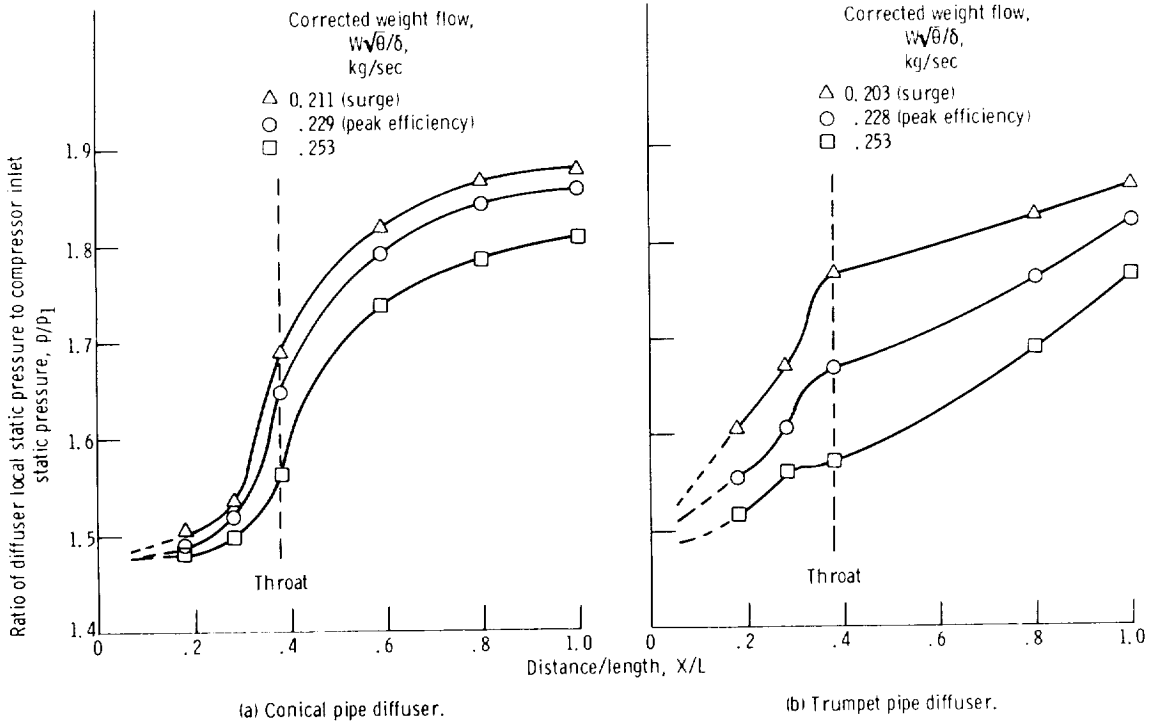
Figure 7. - Static-pressure distribution through conical and trumpet pipe diffusers. Corrected speed, 93 percent of design.
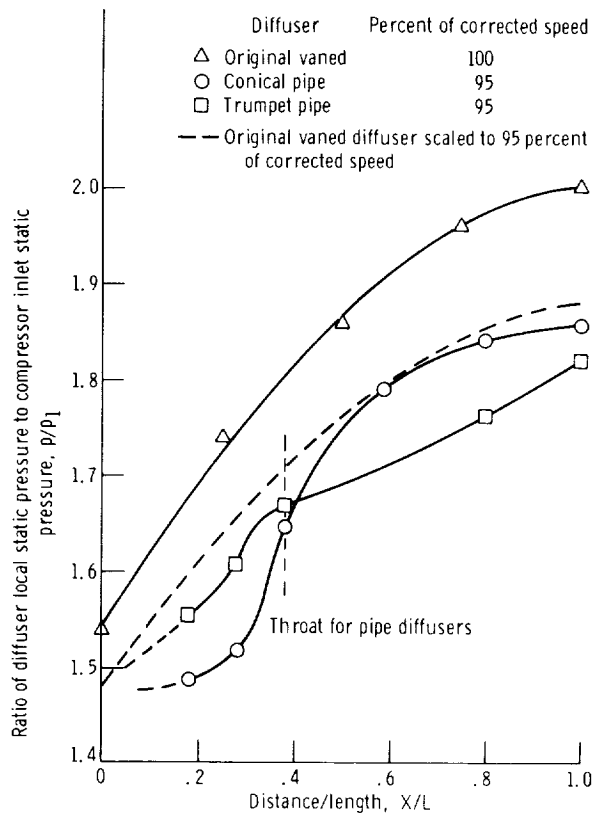
Figure 8. – Static-pressure distribution through three diffusers for peak compressor efficiency.
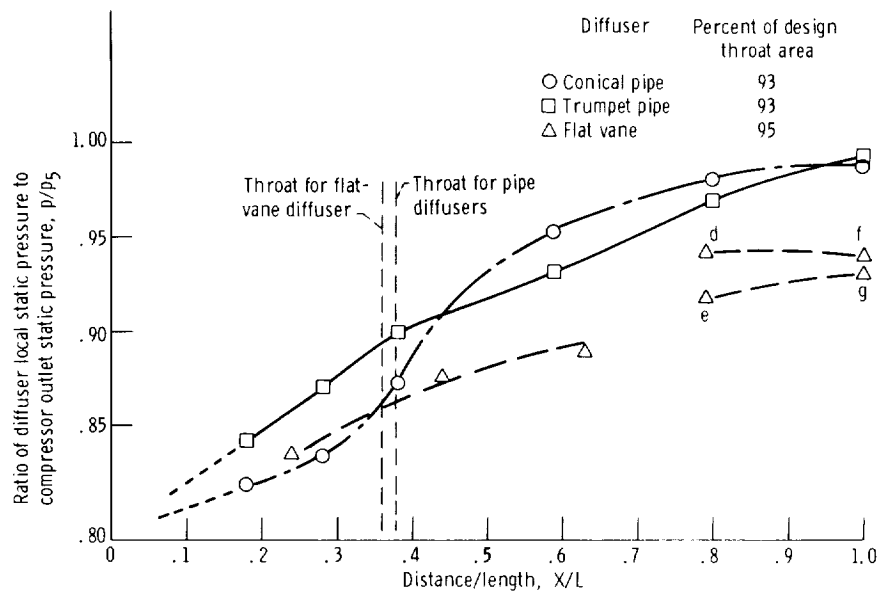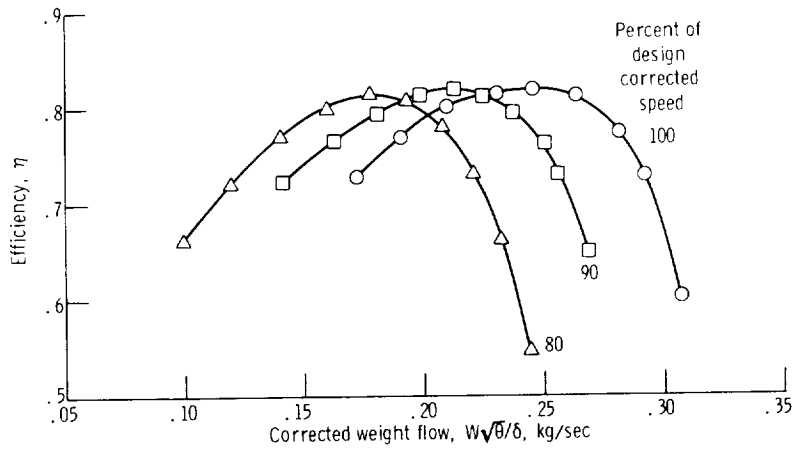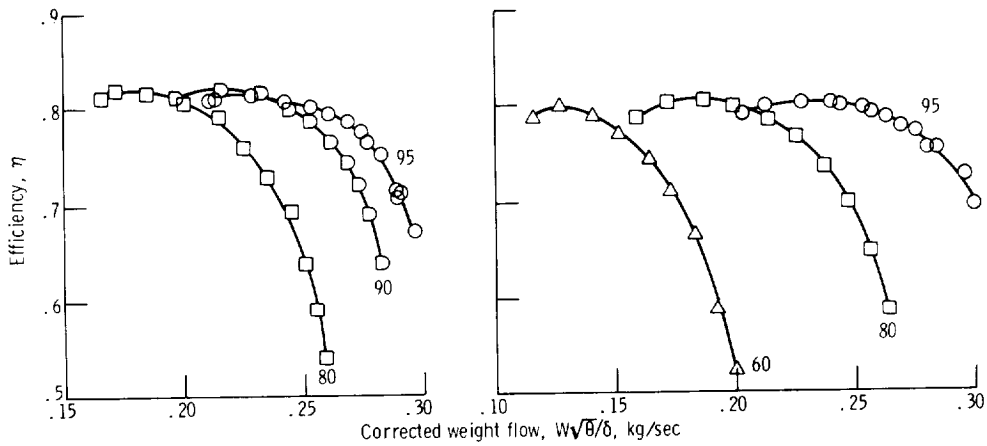

Figure 9. – Static-pressure distributions for three test diffusers with throat areas less than design.

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(a) Original vaned diffuser; 100 percent of design throat area.

(b) Conical pipe diffuser; 98 percent of design throat area.

(c) Trumpet pipe diffuser; 101 percent of design throat area.

Figure 10. - Variation of total efficiency with corrected weight flow for original vaned diffuser and conical and trumpet pipe diffusers.
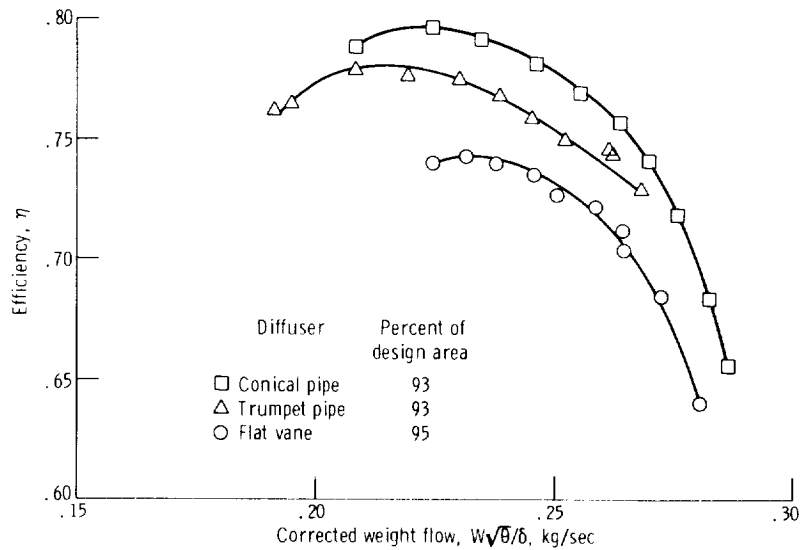
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Figure 11. - Variation of total efficiency with corrected weight flow for original test diffusers with less than design throat areas; 95 percent of design corrected speed.
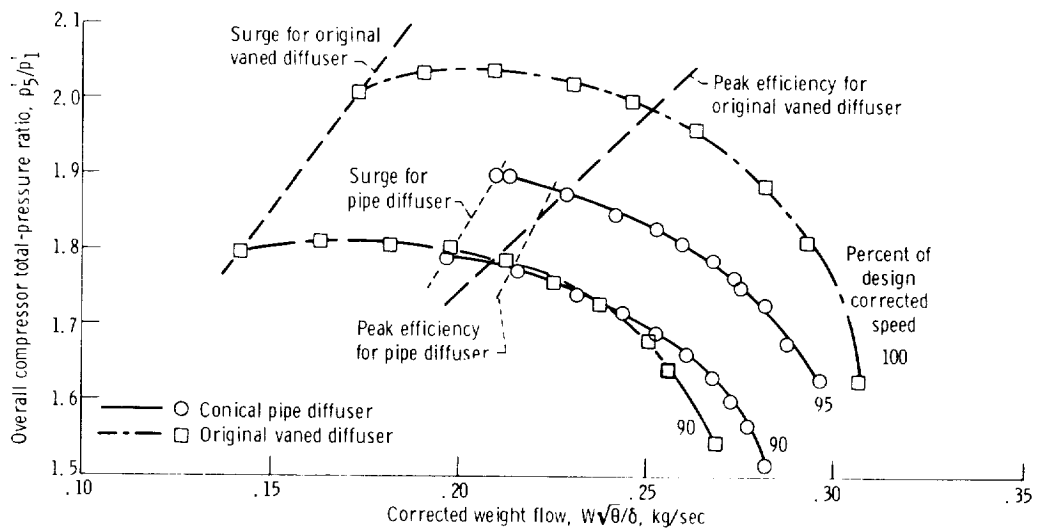

Figure 12. - Variation of total-to-total pressure ratio with corrected weight flow for original vaned diffuser and conical pipe diffuser.

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