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EFFECT OF INDUCER INLET AND DIFFUSER THROAT AREAS ON PERFORMANCE OF A LOW PRESSURE RATIO SWEPTBACK CENTRIFUGAL COMPRESSOR

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16. Abstract

A low-pressure-ratio centrifugal compressor was tested with nine combinations of three diffuser throat areas and three impeller inducer inlet areas which were 75, 100, and 125 percent of design values. For a given inducer inlet area, increases in diffuser area within the range investigated resulted in increased mass flow and higher peak efficiency. Changes in both diffuser and inducer areas indicated that efficiencies within one point of the maximum efficiency were obtained over a compressor specific speed range of 27 percent. An analysis was made of the performance of an assumed two-spool open-cycle engine using the 75 percent area inducer with a variable area diffuser.

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EFFECT OF INDUCER INLET AND DIFFUSER THROAT AREAS ON PERFORMANCE OF A LOW PRESSURE RATIO SWEPTBACK CENTRIFUGAL COMPRESSOR

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SUMMARY

The effect on overall compressor performance of changing diffuser throat area and impeller inducer inlet area was investigated in argon with a 10.8-centimeter swept-back centrifugal compressor and a design pressure ratio of 1.9. Three diffuser throat areas and three impeller inducer inlet areas of 75, 100, and 125 percent of design were investigated in nine combinations. Performance data were obtained at corrected speeds of 60, 80, and 95 percent of design.

The results of this investigation show that for all three inducer inlet areas, increasing the diffuser area from 75 to 125 percent of design, increased flow and peak efficiency while pressure ratio decreased only slightly. The variation in the peak efficiency increase ranged from 4.3 to 7.6 efficiency points, while the flow at peak efficiency increased about 40 percent for all three inducer areas. The optimum diffuser area for all three inducer areas was 125 percent of design or larger. Within the range investigated, the flow range from surge to peak efficiency for a continuously variable diffuser is about 2.5 times that for a fixed-geometry diffuser. The variation in maximum compressor efficiency with flow or compressor specific speed was about 1 efficiency point for about a 27 percent change in specific speed.

A two-spool gas-turbine engine was assumed using the 75 percent area inducer and a variable area diffuser as the gas generator compressor. Reduction of diffuser area from 125 to 75 percent of disign area at 25 percent engine power increased engine efficiency from 0.26 to 0.30. This represents a part power fuel economy improvement of 15 percent.

INTRODUCTION

The gas-turbine engine is often required to operate over a range of power output as great as 15 to 1. It is difficult to maintain high compressor and cycle efficiencies over a wide range of power output. In open-cycle gas-turbine engines power output is usually varied by varying aerodynamic speed, which in turn varies mass flow. As speed is reduced, cycle pressure ratio is also reduced, and cycle efficiency is sacrificed.

Recently, variable inlet guide vanes for compressors have been proposed as an alternative to speed variations. Response to power demands is quicker because the speed does not change. However, at reduced power, cycle pressure ratio is reduced and cycle efficiency is also sacrificed by this method.

Another method of flow variation is to vary compressor diffuser throat area. This method makes use of the fact that the flow range of a centrifugal impeller without a diffuser is much larger than that of an impeller operated with a vaned diffuser. A change in diffuser area will move the impeller-diffuser operating range to a different part of the impeller operating curve. Speed and pressure ratio are maintained at relatively high values. Response to power demands is faster than if the flow variation is achieved by speed variations. This method may have an advantage where the duty cycle of the engine requires a significant amount of operating time at low power with intermittent bursts to peak power.

In a closed-cycle gas-turbine power system, power output can be controlled by varying the pressure level. Cycle pressure ratios and temperature ratios are maintained. The cycle efficiency is not penalized. However, the range of power output variation may be restricted by physical limitations on minimum or maximum pressure levels. In this case a change in diffuser throat area could extend the power range beyond the levels available from changing pressure level only. For a given mission the required power range during operation may not be any larger than that obtainable from pressure variations only. In this case a diffuser with a larger or smaller throat area could be installed to establish a new power level. When the power range is larger than that obtainable with pressure variations only, a compressor with a variable diffuser would have to be installed.

The purpose of this investigation was to determine experimentally the effect of diffuser throat area on compressor performance. In addition, the variation in inducer inlet area was investigated to determine if there was an optimum combination of diffuser and inducer area. This investigation parallels the investigation of reference 1 in which the small radial turbine designed to drive this compressor and a 10-kilowatt alternator was studied with various stator and exducer areas. Also, the effect of diffuser area on gas-turbine engine performance was investigated analytically.

The compressor impeller used for this investigation was backswept with a 10.8-centimeter tip diameter. The diffuser was a vane island design. This compressor was originally designed for a closed-loop space-power system. Inducer inlet and diffuser throat areas were varied over a range of ±25 percent of design. It is recognized that for maximum efficiency, other design changes should accompany diffuser throat area and inducer inlet area changes. For a rigorous investigation an attempt should be made to optimize flow passage design throughout the compressor for each inducer-diffuser area combination. Such changes were beyond the scope of this program.

Three inducer inlet and three diffuser throat areas of 75, 100, and 125 percent of design were investigated. The nine possible combinations were tested. No changes other than blading changes were made. Total pressure ratio and overall total efficiency were obtained at 60, 80, and 95 percent of design speed. Velocity diagrams are shown for the 100 percent area impeller.

COMPRESSOR DESCRIPTION

The original compressor is described in detail in references 2 and 3. The impeller has 15 blades with a 30° backsweep from radial. Tip diameter is 10.8 centimeters. Inducer inlet hub-tip radius ratio is 0.553. Exit blade height is 0.521 centimeter. Conditions at the design operating point for argon operation are

Corrected mass flow, $w\sqrt{\theta}/\delta$, kg/sec 0.263
Overall total pressure ratio, P_5'/P_1' 1.90
Corrected speed, $N/\sqrt{\theta}$, rpm 51 100

The original compressor was modified to accept removable test diffusers. Figure 1 is a photograph of a removable diffuser bolted in place. Three diffusers were built. All diffuser blades were identical to the original. Throat areas were 75, 100, and 125 percent of design. The desired throat areas were obtained by adjusting blade setting angles. The blading with 100 percent of design area is shown in figure 2. Figure 3 shows the blade setting angles for the three diffuser throat areas together with the diffuser dimensions.

Tests were conducted with impeller inducer inlet areas equal to 75, 100, and 125 percent of design. The 100 percent impeller with the 100 percent inducer was the original equipment. The 125 percent inducer was obtained by reducing the inducer length of the 100 percent impeller. The 75 percent impeller was obtained by extending the 125 percent impeller. Figure 4 shows the meridional contours of the three impellers. Between the axial locations corresponding to 125 and 100 percent of design area, the extension was identical to the original impeller. Between the locations corresponding to 100 and 75 percent of design area, the blade angle β_b was gradually increased to produce the desired area. The impeller with the 125 percent of design inducer inlet area is shown in figure 5. The extension with the 75 percent of design area is shown in figure 6. The impeller with the 75 percent extension installed is shown in figure 7.

TEST FACILITY

Figure 8 shows the compressor test facility. Argon pressure upstream of the flow orifice was regulated with a remotely operated valve. An electric heater between this valve and the orifice maintained a constant compressor-inlet temperature. Compressor-inlet pressure was controlled with a remotely operated valve downstream from the orifice. Compressor flow was controlled by a remotely operated valve on the compressor discharge. The argon was discharged into the laboratory exhaust system.

INSTRUMENTATION

The instrumentation stations are shown in figure 9. Compressor inlet measurements were taken at station 1. The instrumentation consisted of three combination total-pressure - total-temperature probes spaced 120° apart and three static taps 120° apart. Compressor discharge measurements were taken at station 5. The instrumentation for these measurements consisted of four combination total-temperature - total-pressure probes spaced 90° apart and four static taps 90° apart. Figure 10 shows one of the combination total-temperature - total-pressure rake probes. Compressor efficiencies were computed from total-temperature and total-pressure measurements obtained from stations 1 and 5.

All pressures were measured with strain gage pressure transducers. Temperatures were measured with bare spike copper-constantan thermocouples. Flow was measured with an ASME thin-plate orifice.

PROCEDURE

All tests were run with argon. Inlet total pressure was approximately 10.1 newtons per square centimeter absolute. Inlet total temperature was approximately 300 K. Tests were performed with three impellers with inducer inlet areas of 75, 100, and 125 percent of design. With each impeller tests were performed with diffusers with 75, 100, and 125 percent of the design inlet throat area. All nine impeller-diffuser combinations were tested at 60, 80, and 95 percent of design corrected speed. The 95 percent speed limitation was imposed because of rotor dynamic instability. At each speed the compressor was operated over a range of corrected mass flows. Flow was adjusted with the control valve on the compressor discharge line.

RESULTS AND DISCUSSION

Compressor Performance Maps

A compressor performance map for each of the nine compressor configurations is shown in figure 11. Pressure ratio is plotted against corrected mass flow for 60, 80, and 95 percent of design corrected speed. Constant efficiency lines and surge lines are shown.

Compressor Performance Characteristics at 95 Percent Corrected Speed

Efficiency and pressure ratio characteristics. - The following table shows the effect of diffuser throat area and inducer inlet area on peak efficiency and peak pressure ratio at 95 percent design corrected speed:

Percent of design rotor inducer area	Percent of design diffuser throat area	Peak overall total efficiency	Peak pressure ratio	Mass flow at peak efficiency, $w\sqrt{\theta}/\delta$, kg/sec
75	75	0.768	1.93	0.164
	100	.809	1.90	.208
	125	.811	1.87	.227
100	75	.758	1.91	.180
	100	.800	1.89	.227
	125	.807	1.87	.248
125	75	.725	1.88	.177
	100	.772	1.86	.235
	125	.801	1.85	.270

This table shows that for each inducer area peak efficiency increased and peak pressure ratio decreased with increased diffuser area. Also, the changes in pressure ratio are small, and the changes in efficiency are 4.3, 4.9, and 7.6 points for the 75, 100, and 125 percent inducer, respectively. Further, pressure ratios at peak efficiency also decreased slightly as diffuser area was increased.

The cause for the trends may be found in the impeller velocity diagrams. Figure 12 shows approximate rotor inlet and exit velocity diagrams for the 100 percent inducer with the 75 and 125 percent diffusers. Both diagrams are for peak compressor efficiency at 95 percent of design corrected speed. (The method of computing these diagrams is given in appendix B.) The decrease in diffuser area from 125 to 75 percent caused the relative velocity ratio W_2/W_1 to decrease from 0.75 to 0.56. This represents a large increase in rotor diffusion. The diffusion increase is probably a major factor in the efficiency decrease from 0.803 at 125 percent diffuser area to 0.758 at 75 percent area. The tangential velocity $V_{U,2}$ decreases as diffuser area is increased from 75 to 125 percent of design value. A reduction in impeller outlet tangential velocity with increased weight flow is a characteristic of backswept impellers. This decreases the work input into the fluid, which in turn reduces the pressure ratio. Because the efficiency did increase, the change in pressure ratio is not as large as that which would occur with the same work input decrease at constant efficiency.

Mass flow characteristics. - The effect of diffuser throat area and inducer inlet area variations on compressor mass flow characteristics is shown in figures 13 and 14, where total efficiency is plotted as a function of corrected mass flow.

Figure 13 shows the mass-flow - efficiency characteristics obtained when the inducer inlet area was held constant and the diffuser throat area was varied. For all three inducer areas the flow and efficiency increased as diffuser throat area was increased. The flow variation at peak efficiency was about 40 percent for the three inducer areas. Unfortunately, the range of diffuser area covered was not large enough to establish optimum diffuser area for all three inducer areas. For the 75 percent inducer inlet area, the optimum diffuser area appears to be near 125 percent of design area because there is little change in efficiency from the 100 to the 125 percent diffuser throat areas. From the increase in efficiency from 100 to 125 percent diffuser throat areas for the 100 and 125 percent inducer inlet areas (fig. 13(b) and (c)), it is speculated that the optimum diffuser areas are slightly and significantly above 125 percent, respectively. Above 125 percent diffuser throat area significant increases in efficiency may or may not be achievable.

The effect of using continuously variable diffuser geometry on compressor flow range is shown by figure 13. With continuously variable diffuser geometry there is an infinite number of diffuser throat areas between 75 and 125 percent of design. There is also an infinite number of curves similar to those of figure 13. Each curve has a point of tangency on the dashed line in figure 13. The curve produced by the dashed line and the solid parts of the curves on either end represents the flow range from surge to choke with continuously variable diffuser geometry. It also represents the envelope of maximum compressor efficiency for diffuser throat areas between 75 and 125 percent of design. It should be noted that end clearance effects have not been included and may affect the shape and level of these curves. Comparison of the fixed and variable geometry curves from surge to peak efficiency shows that the flow range is increased by a factor of about 2.5 when continuously variable diffuser geometry is used.

Figure 14 shows the mass-flow - efficiency characteristics obtained when the diffuser area was held constant and the inducer inlet area was varied. Two general observations can be made from this figure. First, the efficiency decreases as inducer inlet area is increased. Second, the mass flow increases as the inducer inlet area is increased. The two exceptions to the last observation are for the 75 and 100 percent diffusers (figs. 14(a) and (b)). When the inducer area was increased from 100 to 125 percent of design the flow did not increase, probably because the impeller and diffuser are poorly matched causing large losses. The range of inducer area covered by this investigation was not large enough to establish the optimum inducer area for each diffuser area investigated. The curves do, however, show that for a given diffuser area the optimum inducer area favors the smallest inducer area tested. Further increases in efficiency may or may not be achievable with further decreases in inducer inlet area. Additional decreases in mass flow are achievable with additional decreases in inducer area.

The trends observed for optimum inducer area with a given diffuser area and for optimum diffuser area with a given inducer area are probably related to diffuser incidence and impeller velocity ratio. As discussed earlier, the larger the diffuser area, the closer the impeller relative velocity ratio is to unity. This results in lower diffusion in the impeller blade surfaces.

Specific speed characteristics. - The maximum compressor efficiency as a function of specific speed is indicated by the dashed curve in figure 15. The curve was derived from data obtained with 125 percent of design diffuser area. For a given inducer inlet area, peak efficiency is highest with the 125 percent diffuser. From the low end of the dashed curve, specific speed was increased about 27 percent with only a one point variation in compressor efficiency. With additional refinements in blade passage design, the optimization of impeller velocity ratio, and the optimization of impeller and diffuser incidence, the variation of maximum compressor efficiency with specific speed would be flatter and wider than indicated by these results.

Effect of Diffuser Area on Engine Performance

In an open-cycle engine, power output is usually regulated by adjusting fuel flow rate. Aerodynamic speed decreases with power and fuel flow. An alternative method is to adjust mass flow by changing diffuser throat areas. Both methods are discussed in the INTRODUCTION. In this section, these two methods of power control are compared.

Engine performance map. - Figure 16 shows the effects of compressor diffuser throat area and aerodynamic speed on the performance of an assumed gas-turbine engine. A schematic of this engine is shown in figure 17. Aerodynamic speed varies from 60 to 95 percent of design. Diffuser throat area varies from 75 to 125 percent of design. Inducer area is 75 percent of design. It should be noted that the analysis was made neglecting blade-end clearance effects in a variable diffuser. Engine performance is presented in terms of percent power and thermodynamic efficiency. Efficiency is defined as gross power turbine specific work output divided by specific heat input. In figure 16 engine efficiency, $\eta_E = (T'_e - T'_f)/(T'_d - T'_c)$, is plotted as a function of percent power. In addition, curves of constant compressor corrected mass flow and pressure ratio are shown.

The gas generator compressor performance is the same as that of the subject compressor with the 75 percent inducer. The selection of this inducer is discussed in appendix C. The compressor is assumed to operate at peak efficiency at every aerodynamic speed. This can only occur if variable turbine geometry is used. Gas generator turbine-inlet temperature is 1311 K. Other design assumptions are discussed in appendix C. The power output at 95 percent of design flow with the 125 percent diffuser is defined as 100 percent power. The corrected mass flow at this point is defined as reference mass flow.

In figure 16 the operating curves for constant diffuser area represent power adjustment by changing aerodynamic speed only. The constant speed lines represent power adjustment by changing diffuser area only.

Engine efficiency. - For a given power level and with diffuser areas between 75 and 125 percent of design, decreasing diffuser area increases engine efficiency over the range of diffuser areas tested. At 50 percent power efficiency increases from 0.330 to 0.371 as diffuser area is decreased from 125 to 75 percent. This results from the decreased mass flow, which resulted from decreased diffuser area. When flow is reduced, compressor pressure ratio must rise to maintain a given power setting. The increased pressure ratio results in higher engine efficiency. At the same time line losses decrease because of lower mass flow and higher pressures.

If an engine operates at constant power, diffuser area can be changed by simply replacing the diffuser. If an engine is operated over a range of power levels, a variable area diffuser is required. A variable area diffuser may have losses caused by leakage through the clearance spaces between the vanes and sidewalls, which have not been accounted for in this analysis; consequently, the efficiency gains due to decreased diffuser areas may be somewhat less than indicated by figure 16.

Sudden power increases. - Starting at a given power level, an engine with a variable area compressor diffuser has the potential for increasing power output more rapidly than an engine with a fixed area diffuser. With a fixed area diffuser and for a given combustor temperature, power can be increased only by increasing gas generator rotor speed. With a variable area diffuser, power increase can be obtained by simply increasing diffuser area. For example, figure 16 shows that operation at 80 percent speed with the 75 percent diffuser corresponds to 47 percent power. For maximum response to power demand, diffuser area should be increased to the maximum 125 percent. If this could be done instantly, the power would immediately increase from 47 to 60.5 percent. If a fixed area diffuser was used, the same power increase could only be obtained by increasing aerodynamic speed from 73 to 80 percent. The time advantage that can be gained by using a variable area diffuser is not necessarily significant; it depends on the time required to change the diffuser setting and the rate at which the gas generator rotor can be accelerated.

SUMMARY OF RESULTS

A 10.8-centimeter sweptback centrifugal compressor with a design pressure ratio of 1.9 was tested in argon with nine combinations of three diffuser throat areas and three impeller inducer inlet areas of 75, 100, and 125 percent of design. The effects on compressor efficiency and corrected mass flows obtained from various combinations of these areas were evaluated. The following summarizes the results obtained at 95 percent of design corrected speed:

1. For each inducer area mass flow and peak efficiency increased, and peak pressure ratio decreased slightly when diffuser throat area was increased within the range covered by this investigation. The peak efficiency increase varied from 4.3 to 7.6 efficiency points; the flow at peak efficiency increased about 40 percent for all three inducer areas.

2. The optimum diffuser throat area for each inducer inlet area was 125 percent of design or larger.

3. The flow range from surge to peak efficiency for a continuously variable diffuser was about 2.5 times that for a fixed-geometry diffuser.

4. The variation in maximum compressor efficiency with compressor specific speed was about 1 efficiency point with a 27 percent change in specific speed.

An analysis was made of an open-cycle engine, which operates over a wide range of power settings and, consequently, must operate over a range of aerodynamic speeds. A design was assumed for a two-spool engine using the 75 percent area inducer and a variable area diffuser. The following results were obtained for diffuser areas between 75 and 125 percent of design.

1. At a given engine power level, engine efficiency increased as diffuser throat area was reduced. At 50 percent power engine efficiency increased from 0.330 to 0.371

as diffuser area was decreased from 125 to 75 percent. This efficiency increase was due to increased compressor pressure ratio and decreased line losses.

2. At a given compressor aerodynamic speed, engine power increased as diffuser throat area was increased. At 80 percent of design corrected speed, power increased from 47 to 60.5 percent as diffuser throat area was increased from 75 to 125 percent of design.

Lewis Research Center,
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Cleveland, Ohio, August 16, 1974,
501-24.

APPENDIX A

SYMBOLS

c_p	specific heat at constant pressure, J/(kg)(K)
E	recuperator effectiveness, $(T'_c - T'_b)/(T'_f - T'_b)$
H'	isentropic specific work based on total pressure ratio, J/kg
N	rotative speed, rpm
P	pressure, N/cm^2 abs
T	temperature, K
U	blade velocity, m/sec
V	absolute gas velocity, m/sec
W	relative gas velocity, m/sec
w	mass flow, kg/sec
α	absolute gas flow angle measured from meridional direction, deg
β	relative gas flow angle measured from meridional direction, deg
β_b	blade angle measured from meridional direction, deg
δ	ratio of inlet total pressure to U.S. standard sea-level pressure, P'_1/P^*
η	compressor or turbine overall total efficiency
η_E	engine thermodynamic efficiency
θ	ratio of compressor inlet total temperature to U.S. standard sea-level temperature, T'_1/T^*
ω	rotative speed, rad/sec

Subscripts:

a	compressor inlet, two-spool engine
b	compressor discharge, two-spool engine
c	recuperator high-pressure outlet, two-spool engine
d	gas generator turbine inlet, two-spool engine
e	gas generator turbine discharge, two-spool engine
f	power turbine discharge, two-spool engine
g	recuperator low pressure outlet, two-spool engine

i station at inducer inlet, mean radius

m meridional component

u tangential component

1 station at compressor inlet

2 station at rotor exit

5 station at scroll exit

Superscripts:

' absolute total state

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

APPENDIX B

VELOCITY DIAGRAMS

No pressure measurements were taken at the inducer inlet or impeller exit. To obtain approximate velocity diagrams at the inducer inlet, isentropic flow was assumed between station 1 and the inducer. Static pressures for approximate impeller exit diagrams were obtained from static pressure ratio versus corrected mass flow data from previous tests with conical diffusers. An iteration procedure was used that satisfied continuity and the relation $UV_u = c_p(T_5' - T_1')$. It is believed these diagrams are accurate enough to illustrate the effects of changing diffuser area.

APPENDIX C

ASSUMED ENGINE

The purpose of this hypothetical engine is to illustrate the effect of compressor diffuser throat area variation on the performance of a gas-turbine engine. Compressor-inlet temperature is 288 K. Recuperator effectiveness E is 0.87. Gas generator turbine-inlet temperature is 1311 K. Efficiency of both turbines is constant at 0.87. The cold recuperator exit stream is at ambient static pressure with essentially zero velocity. Flow through the recuperator is laminar. Other flows are turbulent. At 100 percent power (see fig. 17), system total pressure losses are as follows:

$$\frac{P'_b - P'_c}{P'_b} = 0.015$$

$$\frac{P'_c - P'_d}{P'_c} = 0.032$$

$$\frac{P'_f - P'_g}{P'_f} = 0.023$$

These pressure loss values are approximately equal to those of the Brayton cycle space-power engine described in reference 2. They are believed to be reasonable values for gas-turbine propulsion engines.

The 75 percent inducer was chosen because it produces higher compressor efficiencies than the 100 and 125 percent inducers. However, the data in the compressor performance table in the section RESULTS AND DISCUSSION show that there is little difference in performance between the 75 and 100 percent inducers. An engine performance map using the 100 percent inducer would be very similar to figure 16. With the 125 percent inducer efficiency is poor for diffuser areas of 75 and 100 percent.

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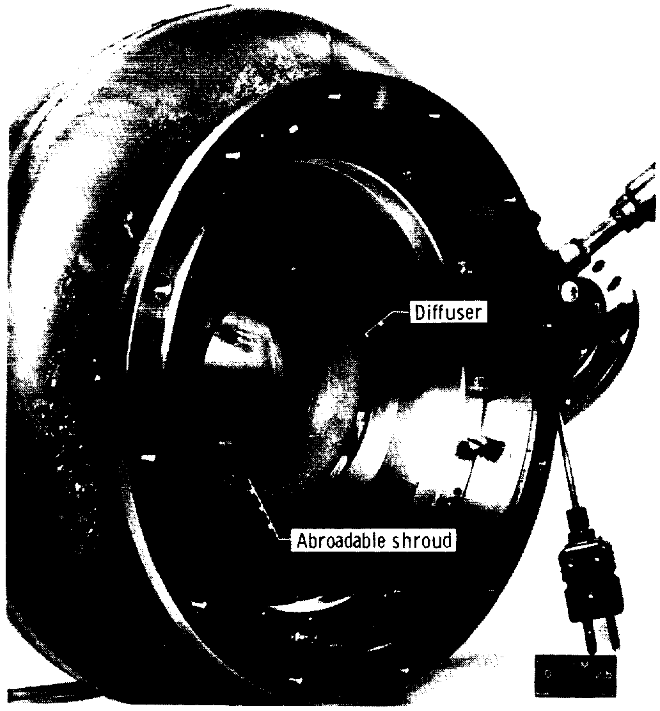

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Figure 1. - Removable diffuser mounted in scroll assembly.

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Figure 2. - Diffuser blading with 100 percent of design throat area.

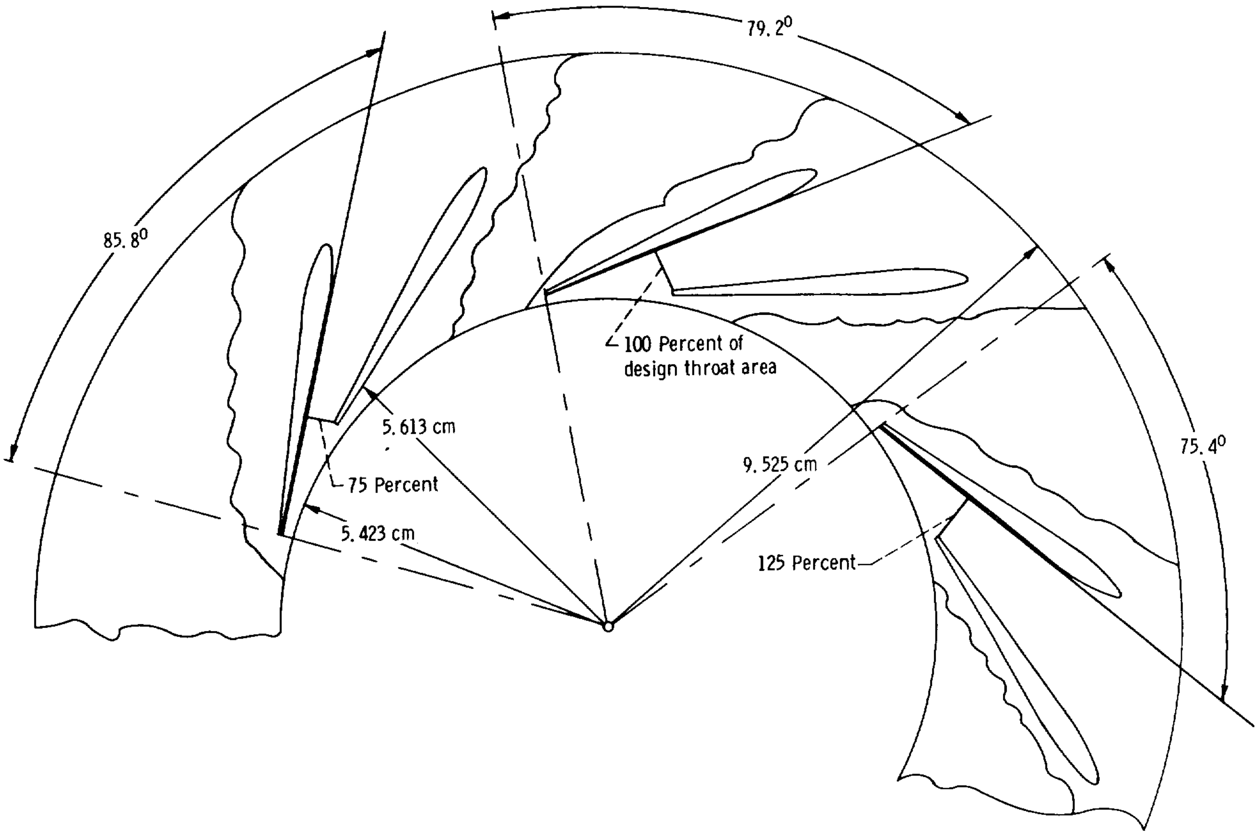


Figure 3. - Diffuser blade settings.

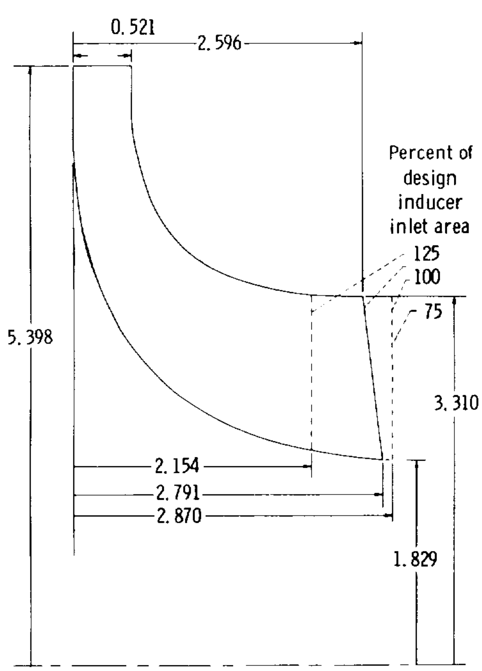


Figure 4. - Meridional view of impeller blade. (Linear dimensions are in cm.)

Figure 5. - Impeller with 125 percent of design inducer inlet area.

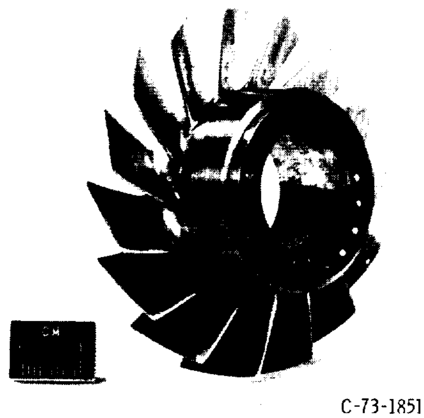


Figure 6. - Inducer extension with 75 percent of design inducer inlet area.

Figure 7. - Impeller with 75 percent of design inducer inlet area.

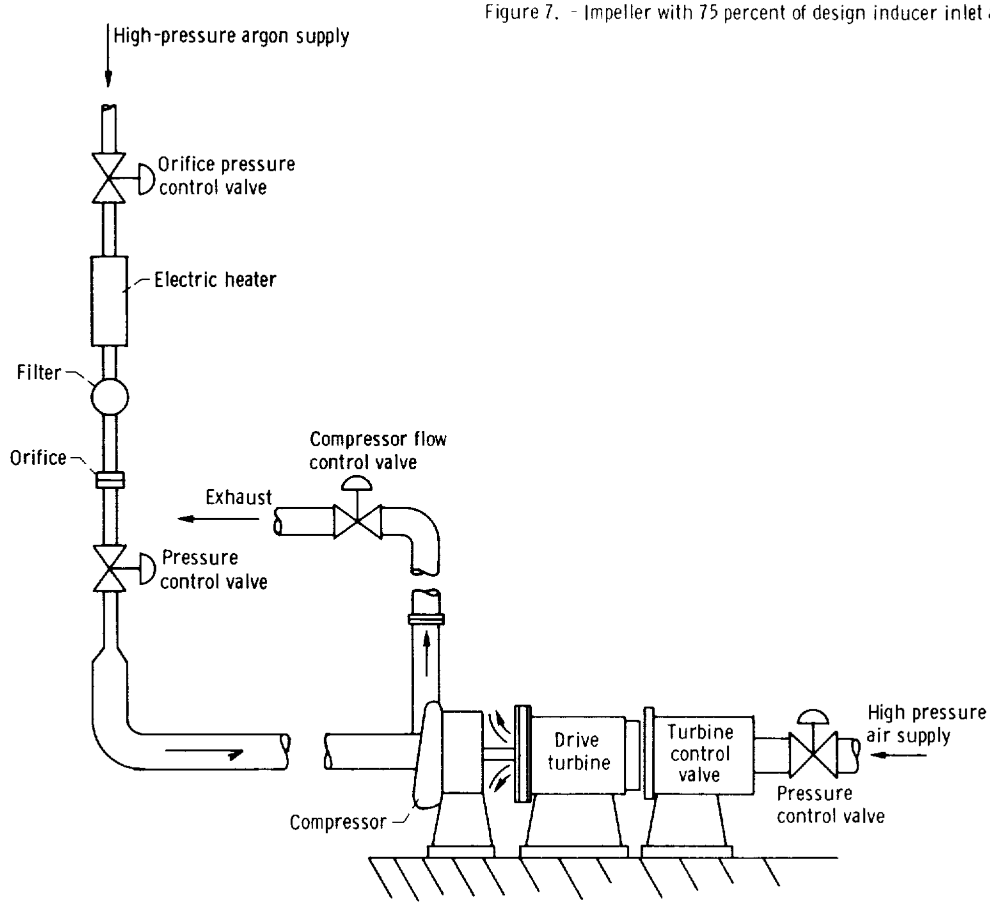


Figure 8. - Compressor test rig.

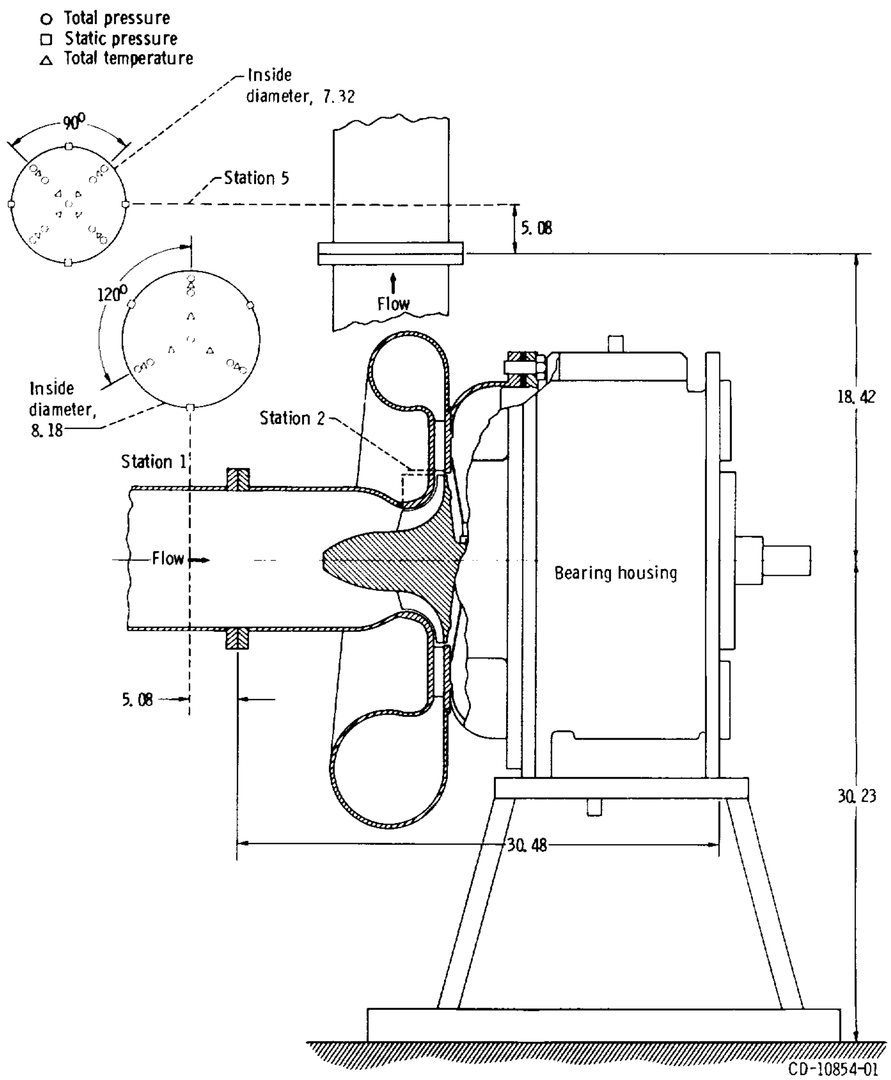


Figure 9. - Compressor cross section showing instrument locations at stations 1 and 5. (All dimensions are in cm.)

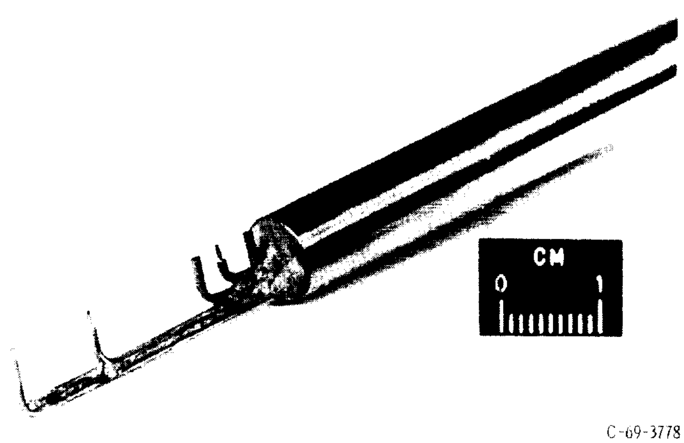


Figure 10. - Combination total-pressure and total-temperature rake.

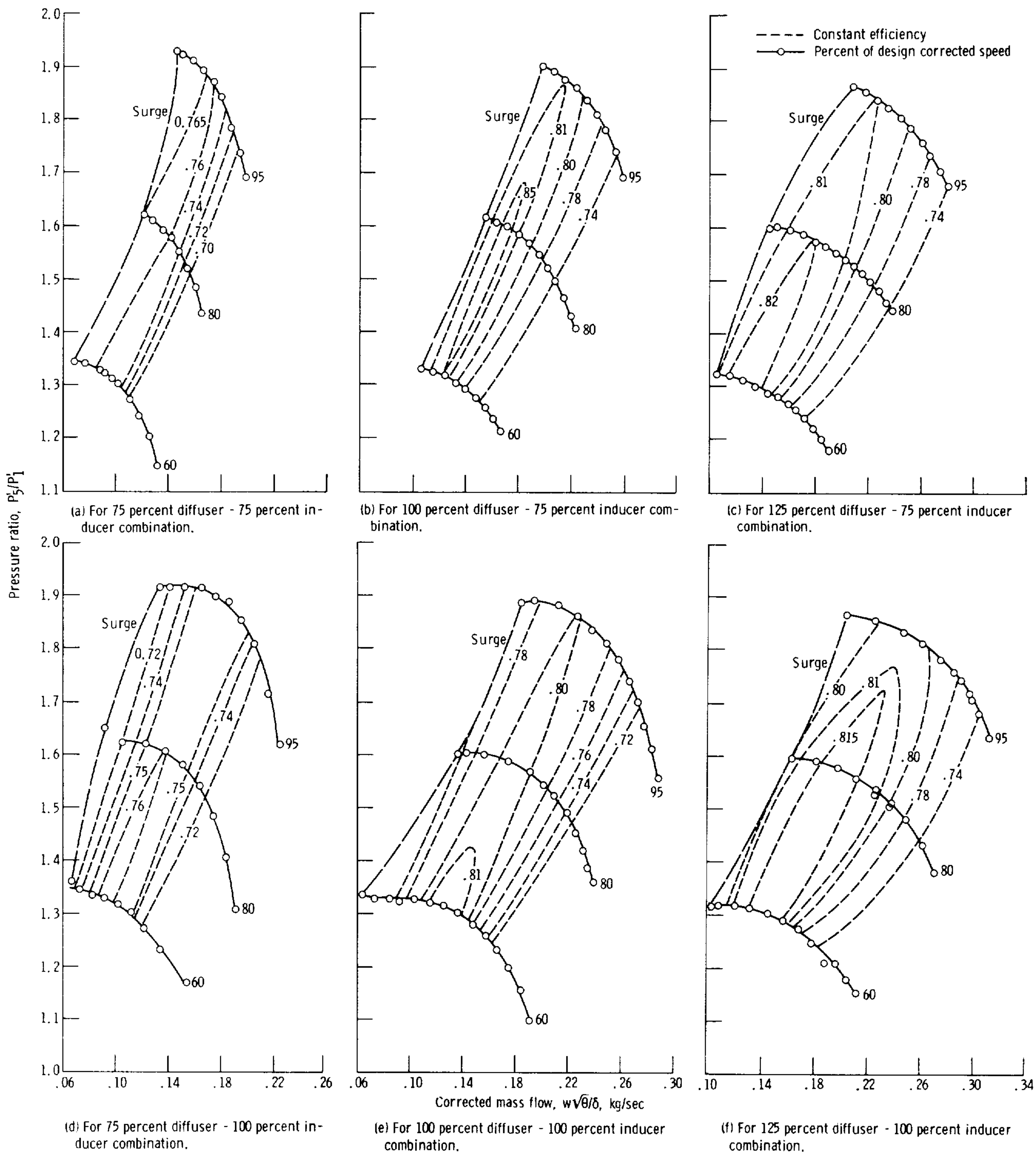
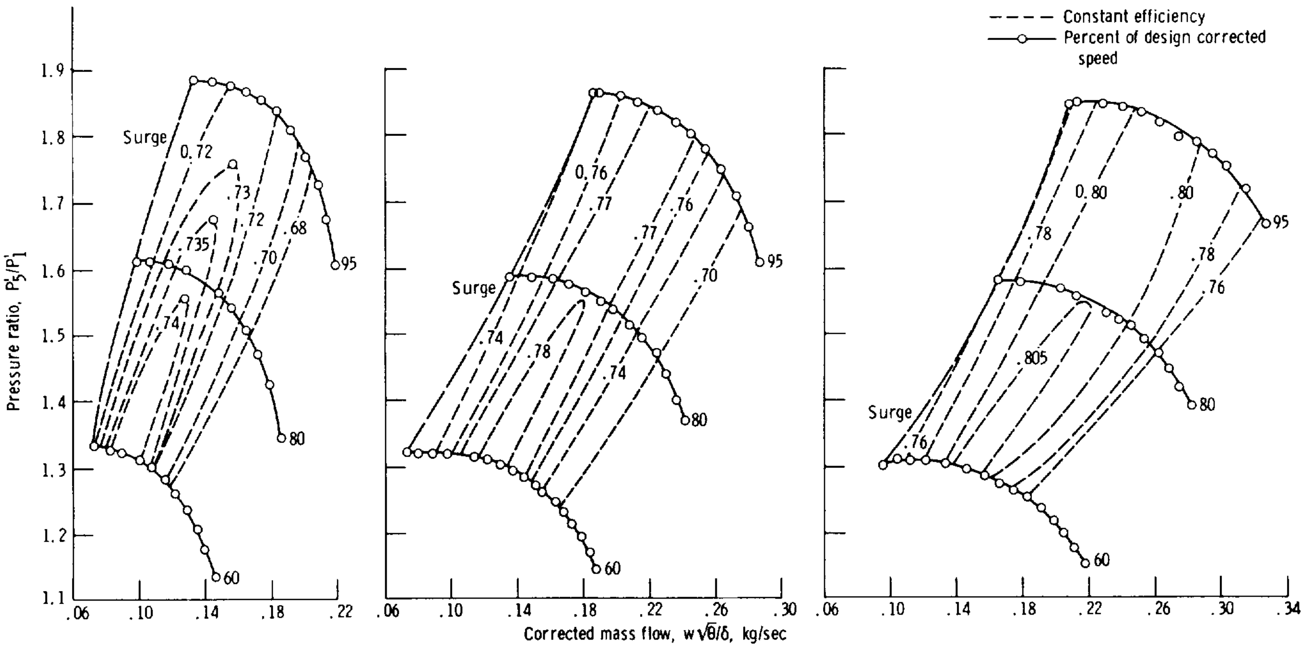


Figure 11. - Performance maps.

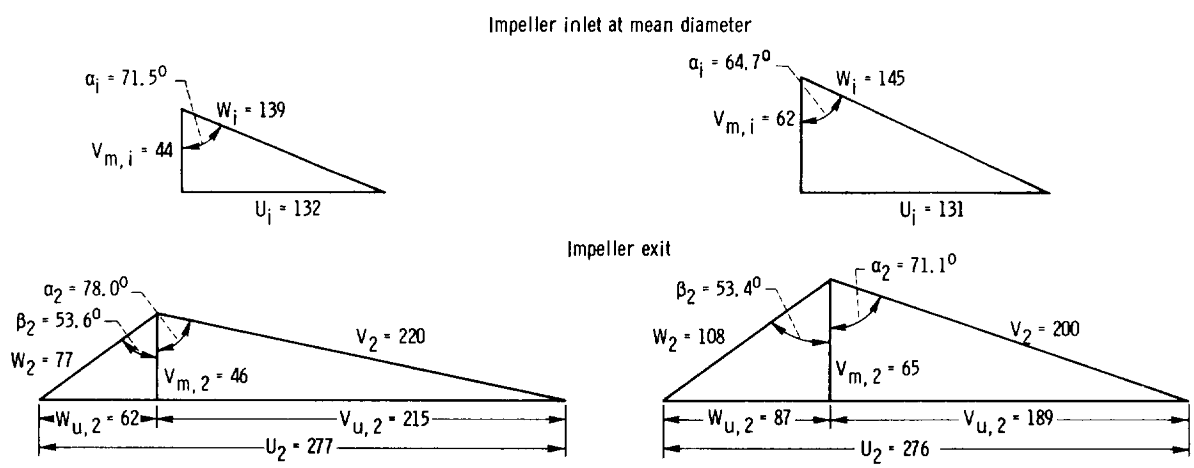


(g) For 75 percent diffuser - 125 percent inducer combination.

(h) For 100 percent diffuser - 125 percent inducer combination.

(i) For 125 percent diffuser - 125 percent inducer combination.

Figure 11. - Concluded.



(a) 75 Percent of design diffuser throat area. Relative velocity ratio, W_2/W_i, 0.56; efficiency, 0.758; corrected mass flow, $w\sqrt{\theta}/\delta$, 0.176 kilogram per second.

(b) 125 Percent of design diffuser throat area. Relative velocity ratio, W_2/W_i, 0.75; efficiency, 0.803; corrected mass flow, $w\sqrt{\theta}/\delta$, 0.248 kilogram per second.

Figure 12. - Velocity diagrams for impeller with 100 percent inducer inlet area; inducer inlet temperature, 294 K.

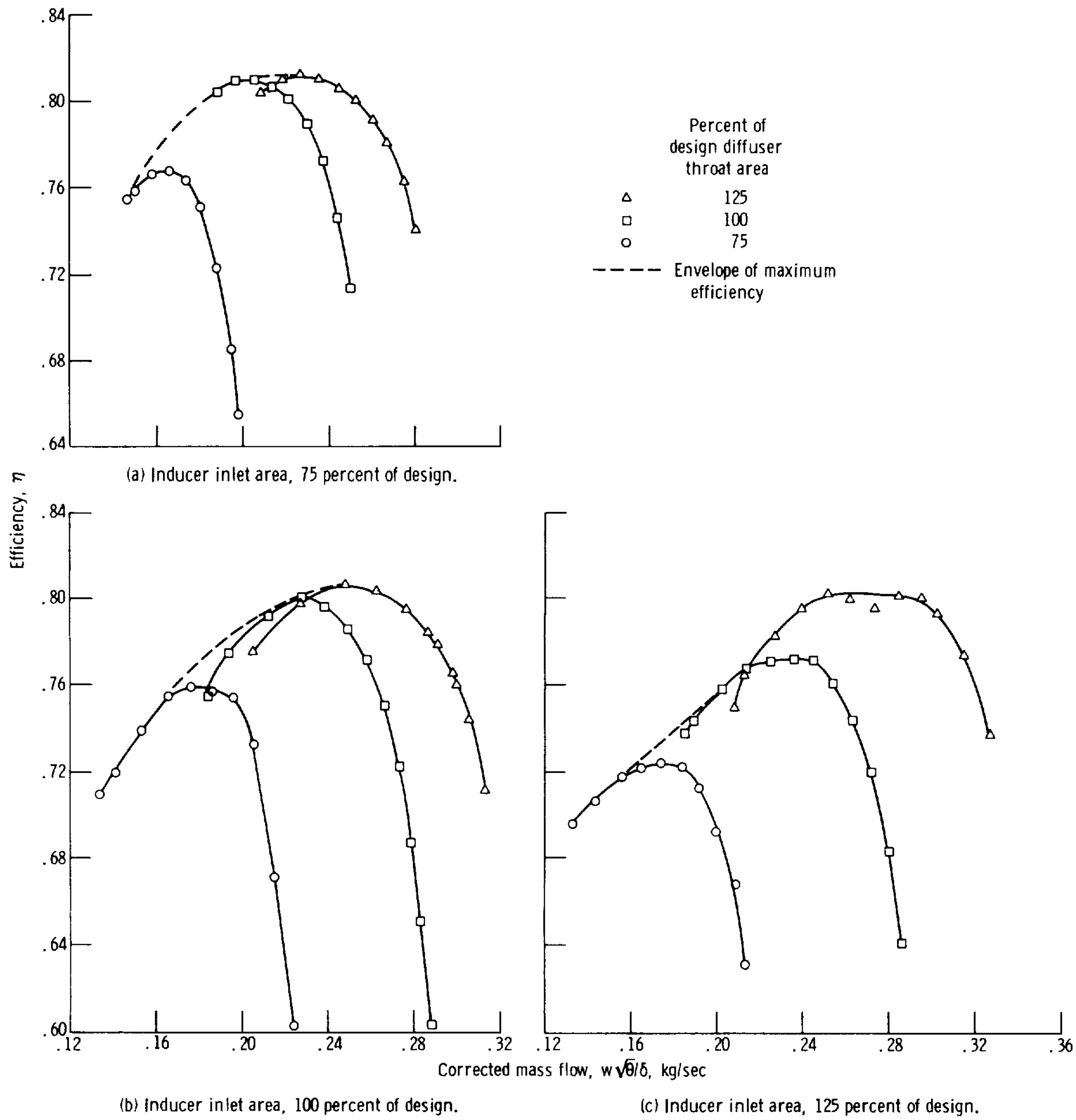
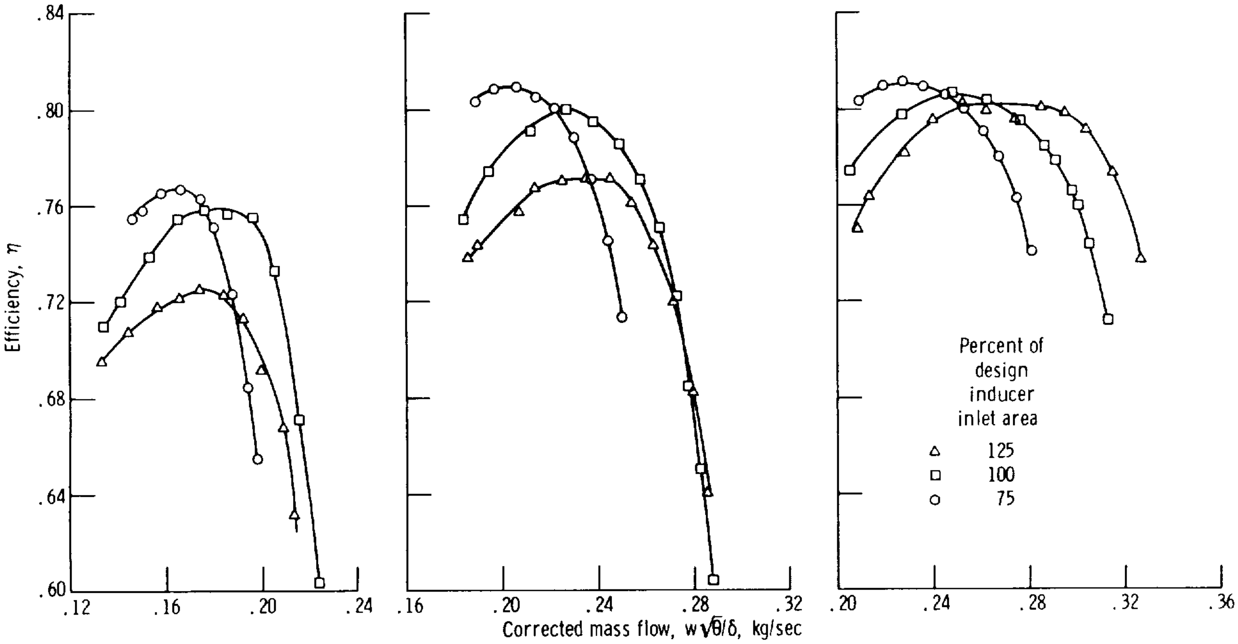


Figure 13. - Effect of diffuser throat area on efficiency - mass-flow characteristics for 95 percent of design speed.



(a) Diffuser throat area, 75 percent of design.

(b) Diffuser throat area, 100 percent of design.

(c) Diffuser throat area, 125 percent of design.

Figure 14. - Effect of inducer area on efficiency - mass-flow characteristics for 95 percent of design speed.

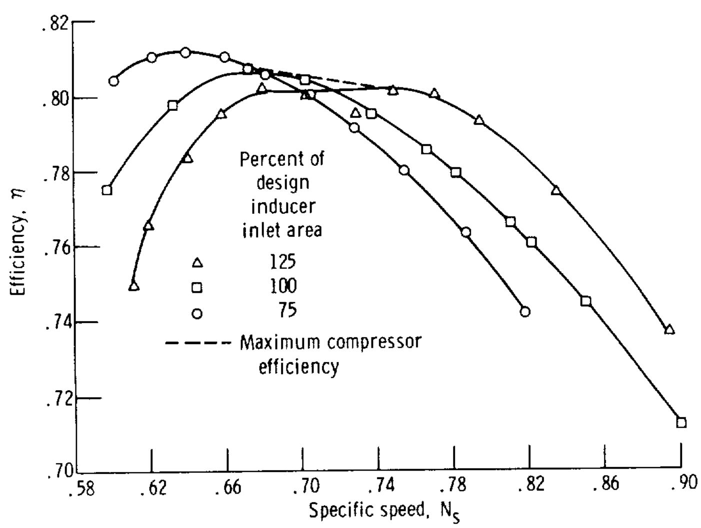


Figure 15. - Effect of inducer inlet area on specific speed - mass flow characteristics at 95 percent of design aerodynamic speed; diffuser throat area, 125 percent of design.

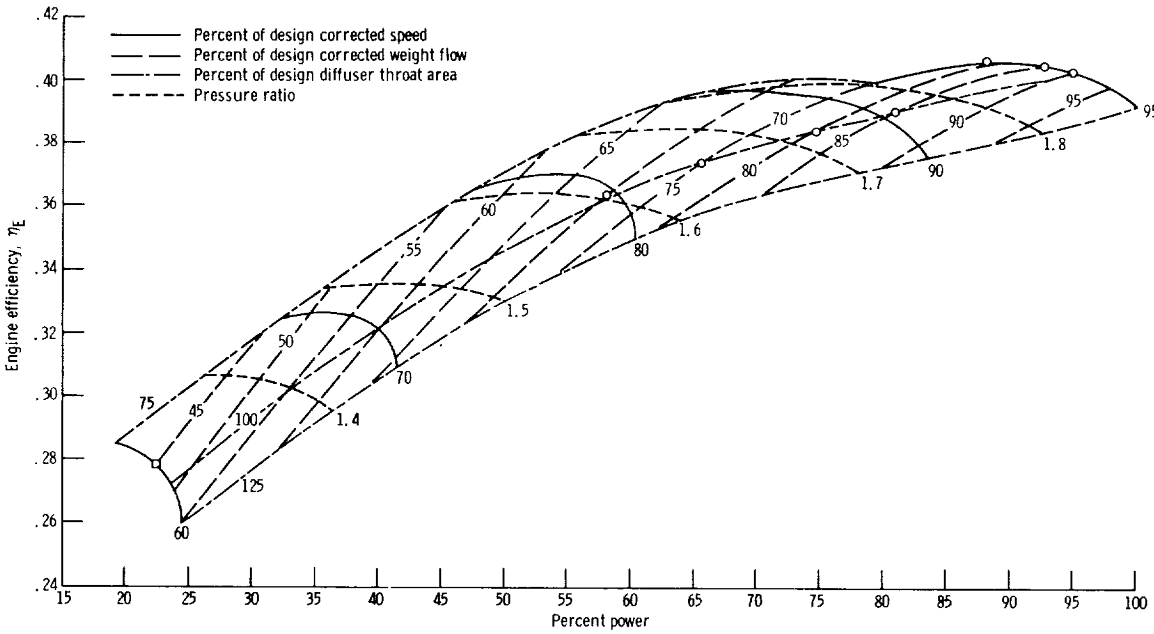


Figure 16. - Variation of engine efficiency with percent power for diffuser throat areas with 75, 100, and 125 percent of design area; inducer inlet area, 75 percent of design.

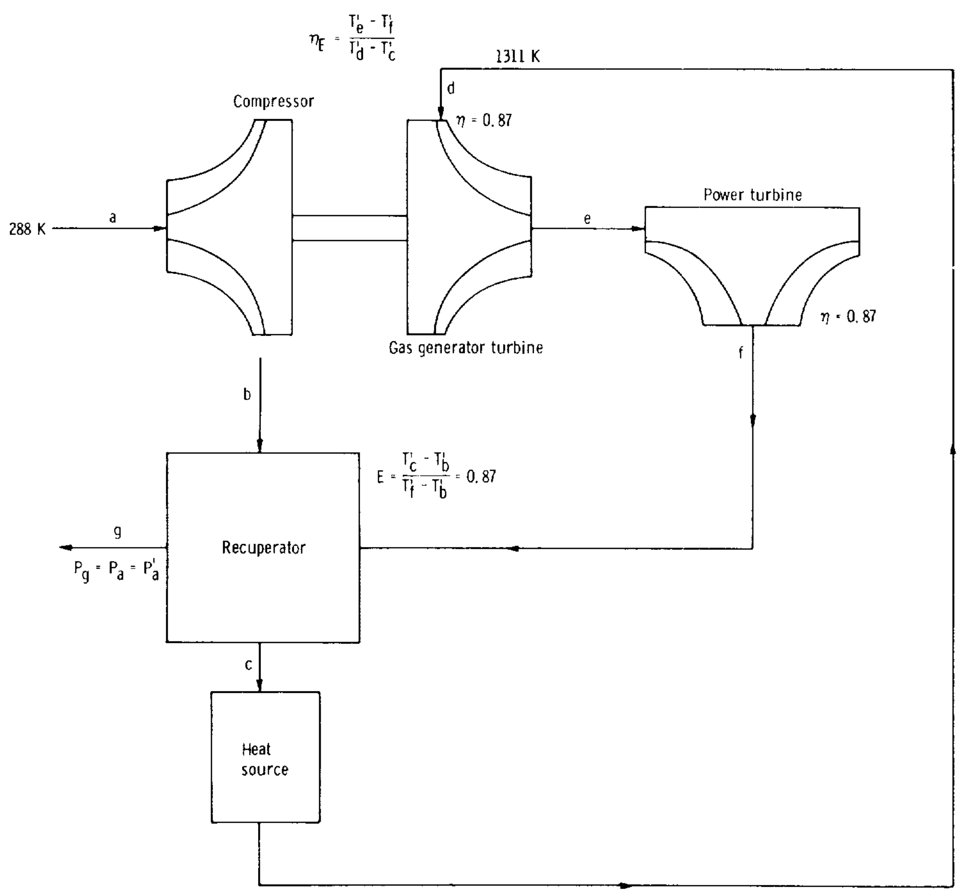


Figure 17. - Assumed gas-turbine engine.

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