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## [54] AXIAL FLOW DIFFUSER 5 Claims, 4 Drawing Figs.

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 415/199  
 [51] Int. Cl. .... F04d 19/00,  
 F04d 19/02  
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 208, 209, 219, 181; 138/40, 37, 39

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**UNITED STATES PATENTS**  
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**ABSTRACT:** A vaneless diffuser for turbomachinery wherein a pair of spaced-apart walls form three annular diffuser portions along a generally cylindrical downstream flow path. The walls converge together within a diffuser inlet portion, then diverge within a diffuser intermediate portion with a diffuser outlet portion being configured to maintain a condition of imminent boundary layer separation established by the first two portions. Although the diffuser is particularly described with reference to a cylindrical flow path, the flow path may also be generally conical for use in mixed flow turbomachinery, for example.

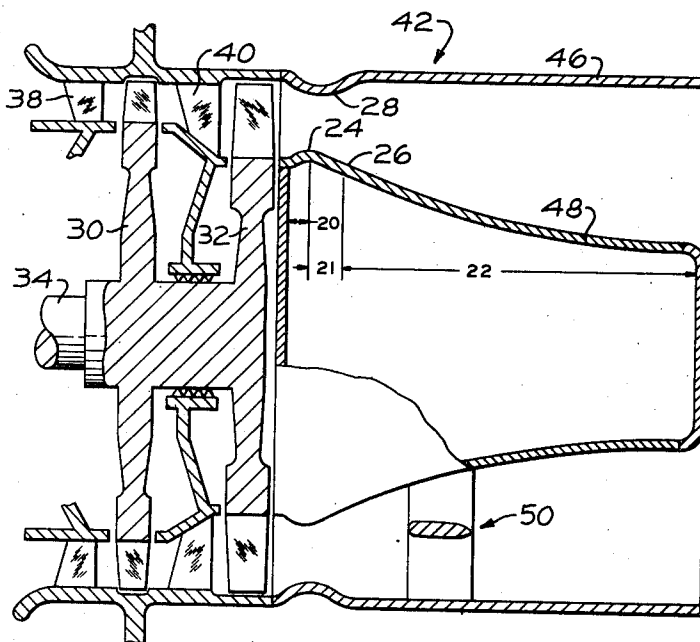
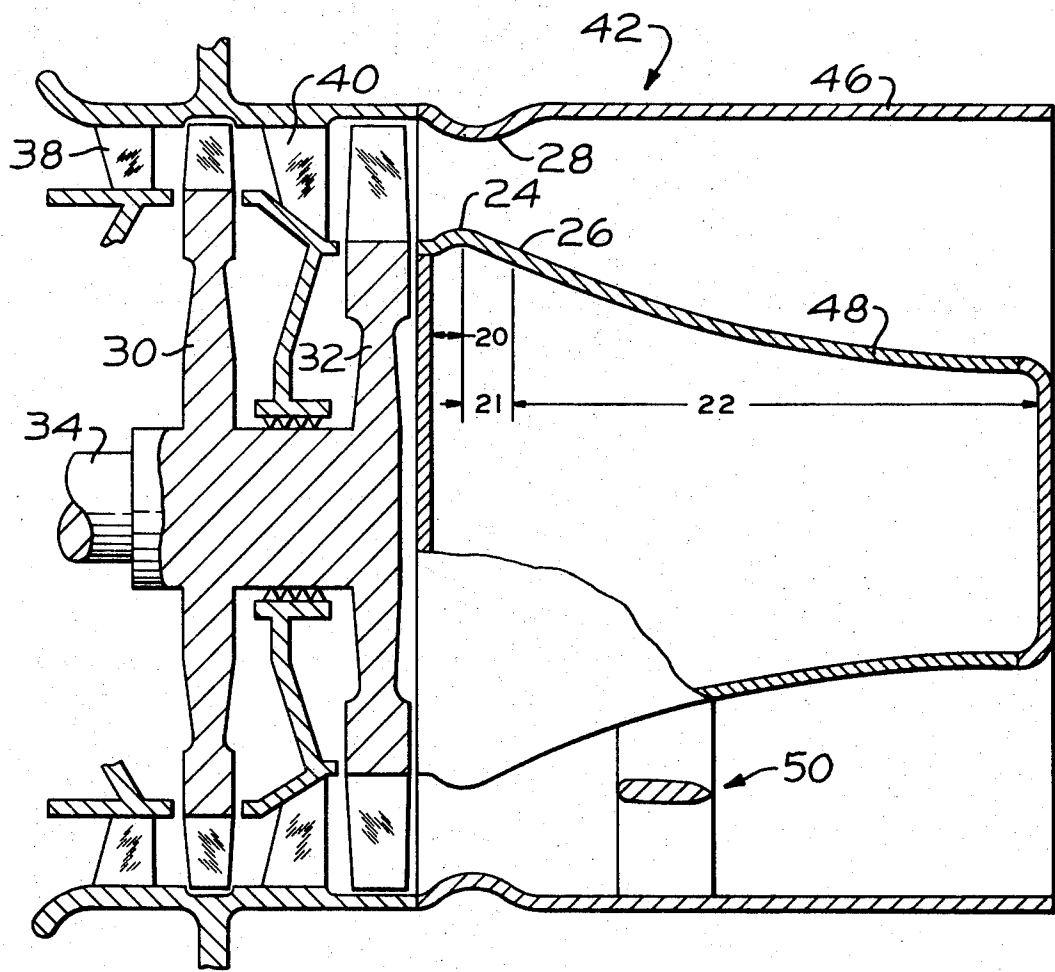


Fig. 1.



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Fig-2-

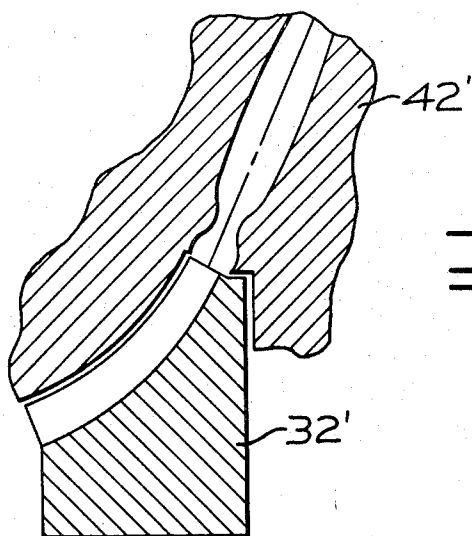
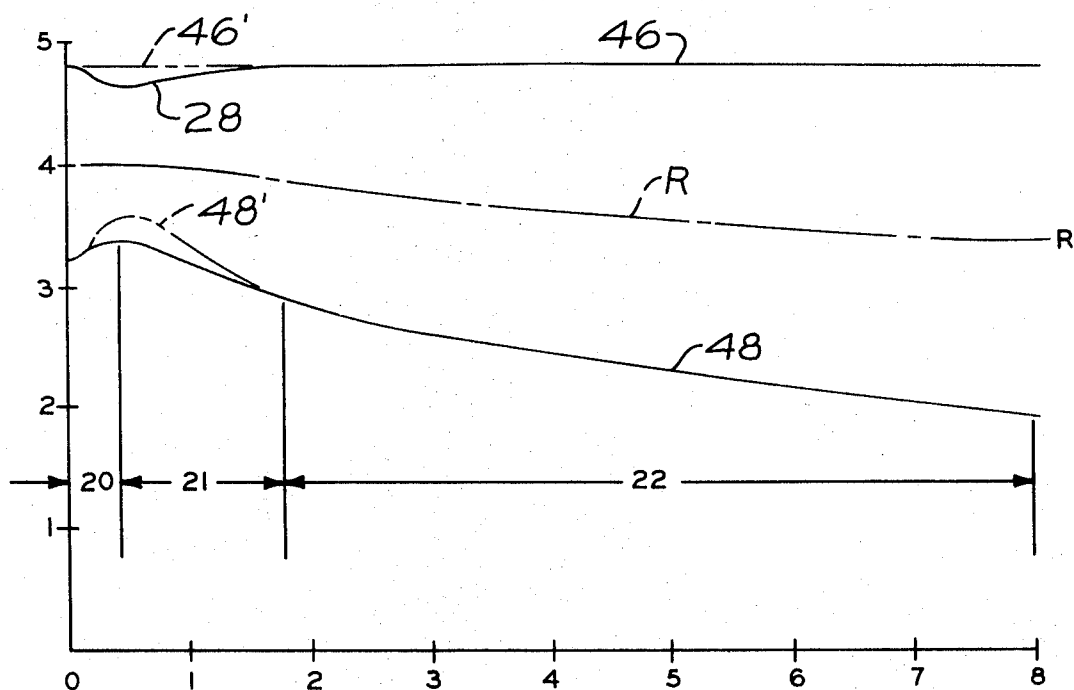
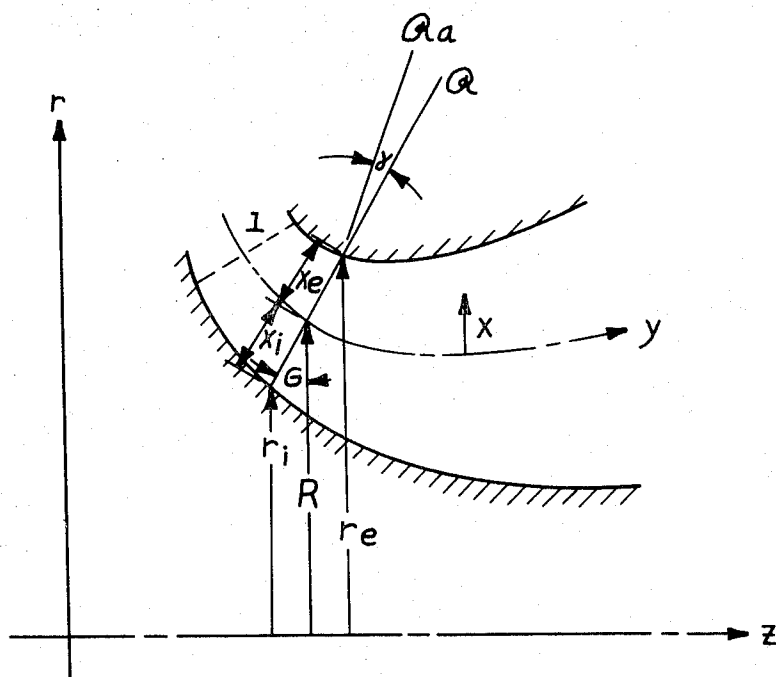


Fig-3-

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Fig 4



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## AXIAL FLOW DIFFUSER

## RELATED U.S. PATENTS

The present invention is described having reference to an earlier filed patent application, now U.S. Pat. No. 3,289,921 issued Dec. 6, 1966 to Shao L. Soo and assigned to the assignee of the present invention.

The present invention relates to a diffuser for use in turbomachinery including a compressor rotor or turbine. The invention particularly relates to the contouring of the diffuser walls for increasing the efficiency of the turbine and/or compressor section.

The diffuser of the present invention includes a pair of spaced-apart walls which form a generally cylindrical downstream flow from the rotor outlet. The flow path of the diffuser includes an inlet portion wherein the walls converge together, an intermediate portion wherein the walls diverge relatively rapidly and a diffuser outlet portion configured to maintain a condition of imminent boundary layer separation and thus provide for optimum pressure recovery within the diffuser. The diffuser of the present invention is designed to achieve a condition of imminent boundary layer separation within a short distance along the downstream flow path, at a point generally between the diffuser intermediate and outlet portions. The configuration of the diffuser outlet portion permits optimum pressure recovery within the diffuser.

The diffuser of the present invention has an internal profile developed through the application of generally known formulas to produce a condition of optimum flow therethrough. The efficiency of fluid flow through a confined space such as a diffuser is determined largely by boundary layer conditions for the action of the fluid adjacent the walls defining the confined space. Under suitable conditions, flow at the main or central portion of the fluid stream is relatively uniform, while the boundary layer or flow adjacent the passage walls varies considerably under different conditions of velocity, pressure, temperature, density and other factors. The characteristics of such boundary layer conditions are described in greater detail within U.S. Pat. No. 3,289,921 which is referenced above.

The diffuser of the present invention is particularly described in one embodiment as having a generally cylindrical downstream flow path suitable for use with axial flow turbomachinery. It is to be noted that the overall flow path may generally converge or diverge in a downstream direction with the flow path being generally conical.

Accordingly, it is an object of the present invention to provide a diffuser for achieving optimum pressure recovery efficiency within axial and mixed flow turbomachinery.

It is a further object to provide such a diffuser wherein a condition of imminent boundary layer separation is achieved within a relatively short distance along the downstream flow path through the diffuser.

Other objects and advantages of the present invention are made apparent in the following description having reference to the accompanying drawings.

In the drawings:

FIG. 1 is a centrally sectioned view of a turbomachine including a turbine and a diffuser embodying the present invention;

FIG. 2 is a graphical representation of the diffuser flow path profile;

FIG. 3 is a fragmentary sectioned view of a portion of a compressor rotor and a diffuser representing an alternate embodiment of the present invention; and

FIG. 4 is a graphical representation of a general coordinate system employed within a exemplary computational procedure set forth within the following description.

The turbine portion of a gas turbine engine is illustrated in FIG. 1. First and second axial turbine rotors 30 and 32 are secured to a shaft 34 to form a rotating assembly for driving a compressor and load (not shown) in a conventional manner. Combustion gases travel in a rightwardly direction through

first and second stationary nozzles 38 and 40 into a high efficiency exit diffuser 42 which embodies the present invention.

The diffuser 42 comprises an outer wall 46, an inner wall 48 and a plurality of support struts, one of which is indicated at 50. The walls 46, 48 are spaced apart to provide a downstream flow path through the diffuser. The flow path is generally of cylindrical shape. However, it will be noted in FIG. 1 that the cylindrical flow path generally converges in a downstream direction toward the axis of the turbine rotor shaft to have a generally conical configuration figure.

The flow path through the diffuser may also tend to diverge generally outwardly from the rotor axis as is common within a mixed flow turbomachine. Such an alternate embodiment is illustrated for example in FIG. 3 which includes a mixed flow compressor rotor 32' and a diffuser 42'. The characteristics of a diffuser constructed according to the present invention and described below with particular reference to FIG. 1 and FIG. 2 may also be applied to a mixed flow embodiment of the type illustrated in FIG. 3.

Referring again to FIG. 1, the diffuser may be considered as having three portions dividing the downstream flow path into three generally annular sections. The first portion is a diffuser inlet portion indicated by the numeral 20. The diffuser inlet portion is followed by an intermediate portion 21 and an outlet portion 22, through which fluid may exit from the diffuser flow path. The walls 46, 48 converge toward each other within the inlet portion 20 and then diverge relatively rapidly within the intermediate portion 21. The convergent-divergent configuration within these two portions forms a throat indicated at 24. The convergent-divergent configuration of these two portions is also selected to achieve a condition of imminent boundary layer separation within a relatively short distance along the diffuser flow path. This condition is preferably achieved at a location between the diffuser intermediate and outlet portions, that location being generally indicated by the numeral 26.

The outer wall 46 defines the diffuser envelope and is illustrated as being a cylinder which is substantially parallel about its periphery with the axis of the compressor rotor shaft 34. The inner wall 48 is shaped to provide the convergent-divergent configuration within the flow path. The outer wall 46 includes an annular indentation indicated at 28 which assists in forming the convergent-divergent configuration for the inlet and intermediate diffuser portions.

Referring now to FIG. 2, a diffuser flow path similar to that of FIG. 1 is shown in profile. A center line for the diffuser flow path profile is represented at R. As may be seen from FIG. 2, the center line R tends to converge toward a central axis. However, it will be apparent that the center line about which the walls 46, 48 are configured may also be parallel or divergent with respect to such a longitudinal axis. The embodiment of FIG. 2 further illustrates a variation from FIG. 1 wherein the outer wall 46 may be a true cylinder. In such a variation, the annular indentation 28 would be replaced by a true cylindrical portion indicated at 46'. In order to compensate for the cylindrical portion 46', the inner wall 48 would necessarily include a more severely angled relationship between its inlet and intermediate portion. The compensating shape for the inner wall is represented in broken lines at 48'.

The following presents one application of known formulas to illustrate the detailed computation procedure followed in producing the diffuser profile for optimum flow. Other procedures could be followed to produce similar profiles.

## A. Nomenclature

The location in the diffuser passage is specified by the curvilinear coordinates  $x$ ,  $y$ , and  $\Phi$  with the corresponding mean velocity components  $U$ ,  $V$ , and  $W$ . The coordinate system is graphically described in FIG. 4. Free stream conditions, outside the wall boundary layers, are noted by the absence of subscripts; conditions within the boundary layers are noted by the subscript B; wall conditions are noted by the subscripts  $e$ , and  $i$

for the external and internal walls respectively; and the free stream inlet conditions are noted by the subscript 1. All of the wall equations are written in terms of the external wall and require only a change of subscript to apply to the internal wall unless otherwise specified.

The fluid properties are:

Pressure,  $p$

Density,  $\rho$

Temperature,  $t$

Kinematic viscosity,  $\nu$

Boundary layer thickness,  $\delta$

Wall shear stress,  $\tau$

Other geometric parameters are:

Radius to general location,  $r$

Radius to passage centerline,  $R$

Radius of curvature,  $R_c$

### B. Equations of fluid mechanics

Beginning with the Navier-Stokes equations and the equation of conservation of mass in curvilinear coordinates, the assumptions of steady, incompressible, axisymmetric, boundary layer flow results in the following momentum integral equation, relative to the external wall:

$$\frac{1}{V^2 r_e} \frac{d}{dy} [r_e V^2 \theta] + \frac{\delta^*}{V} \frac{dV}{dy} - \frac{1}{r_e} \frac{dr_e}{dy} \frac{W^2}{V^2} \left[ \left( 1 + \frac{\delta^* x}{\theta} \right) \frac{\theta_\phi}{\theta} \right] \theta - \left[ 1 + \left( \frac{dR}{dz} \right)^2 \right]^{-2} \frac{dx_e}{dy} \frac{d^2 r_e}{dz^2} \left( 1 + \frac{\delta}{\theta} \right) \theta = \tau_e / \rho V^2 \quad (1)$$

(for the inner wall, replace  $r_e$  by  $r_i$  and  $x_e$  by  $x_i$ ) where

$$\begin{aligned} \theta &= \int_{x_0}^{x_e-\delta} \frac{\rho_B V_B}{\rho V} \left( 1 - \frac{V_B}{V} \right) dx \\ \delta^* &= \int_{x_e}^{x_e-\delta} \left( 1 - \frac{\rho_B V_B}{\rho V} \right) dx \\ \theta_\phi &= \int_{x_0}^{x_e-\delta} \frac{\rho_B W_B}{\rho W} \left( 1 - \frac{W_B}{W} \right) dx \\ \delta_\phi^* &= \int_{x_0}^{x_e-\delta} \left( 1 - \frac{\rho_B W_B}{\rho W} \right) dx \end{aligned}$$

Extending the well-known method of Buri for two-dimensional incompressible flow, the following is derived from Equation (1) for turbulent flow:

$$\frac{dY}{dy} + \frac{5}{4} Y \left[ \frac{d(\ln r_e)}{dy} \left( 1 + \frac{W_1^2 R_1^2}{V^2 r_e^2} \right) G - \left[ 1 + \left( \frac{dR}{dz} \right)^2 \right]^{-2} \frac{dx_e}{dy} \frac{d^2 r_e}{dz^2} (1+H) \right] = \frac{\rho_e}{\rho} F(\Gamma) \quad (2)$$

where

$$\begin{aligned} Y &= \theta \left( \frac{V\theta}{\nu} \right)^{1/4} \\ G &= - \left( 1 + \frac{\delta_\phi^* x}{\theta} \right) \frac{\theta_\phi}{\theta} \\ H &= \frac{\delta^* x}{\theta} \\ \Gamma &= \frac{\rho}{\rho_e} Y \left( \frac{dV}{V dy} \right) \\ F(\Gamma) &= a - b\Gamma \end{aligned}$$

Using the definition of  $\Gamma$  in equation 2, a linear differential equation of the first order in  $\Gamma$  results

$$\begin{aligned} 5 \quad \frac{d\Gamma}{dy} + \Gamma \left\{ - \frac{d}{dy} \ln \left( \frac{dV}{V dy} \right) + \frac{5}{4} \left( \frac{d(\ln r_e)}{dy} \right) \left( 1 + \frac{W_1^2 R_1^2 x_e^2}{V^2 r_e^2 x_{e0}^2} G \right) \right. \\ \left. - \frac{5}{4} \left[ 1 + \left( \frac{dR}{dz} \right)^2 \right]^{-2} \frac{dx_e}{dy} \frac{d^2 R}{dz^2} (1+H) + b \frac{d(\ln V)}{dy} \right\} \\ 10 \quad = a - \frac{d(\ln V)}{dy} \quad (3) \end{aligned}$$

Integration of equation 3, in terms of  $\Gamma$ , gives

$$15 \quad \Gamma \exp M_o(y) \Big|_{\Gamma_1}^{\Gamma} = a \int_0^y \exp [M_o(y)] \frac{d(\ln V)}{dy} dy \quad (4)$$

where

$$\begin{aligned} 20 \quad \exp [M_o(y)] \\ = \left( \frac{d(\ln V)}{dy} \right)^{-1} V^{b r_e^{5/4}} \exp \left\{ \frac{5}{4} \frac{W_1^2}{V_1^2} \int \frac{R^2 x_e^2}{r_e^2 x_{e0}^2} G \frac{d(\ln r_e)}{dy} dy \right. \\ 25 \quad \left. - \frac{5}{4} \int \left[ 1 + \left( \frac{dR}{dz} \right)^2 \right]^{-2} \frac{d^2 R}{dz^2} (1+H) \frac{dx_e}{dy} dy \right. \\ \left. - b \frac{W_1^2}{V_1^2} \int \frac{R^2 x_e^2}{r_e^2 x_{e0}^2} \frac{d(\ln r_e)}{dy} dy \right\} \end{aligned}$$

### C. Diffuser Profile

The diffuser profile illustrated in FIG. 2 may be obtained by successive numerical integrations of equation 4 for various prescribed diffuser wall shapes. The diffuser design requirements, expressed in terms of the required pressure rise, establish the length of the diffuser. This length is found by numerically integrating the following equation, for both the internal and external surfaces individually, until the pressure increase requirement is satisfied:

$$\begin{aligned} 40 \quad \frac{1}{\rho} \frac{dp}{dy} = - \frac{1}{2} \frac{d}{dy} (V^2) + \frac{V^2 \left( \frac{dx}{dy} \right)}{\left[ 1 + \left( \frac{dR}{dz} \right)^2 \right]^2} \frac{d^2 r}{dz^2} \\ 45 \quad - (W_1^2) \frac{d}{dy} \left( \frac{R_1^2}{r^2} \right) - \frac{1}{4} C_f \frac{V^2 r}{R_x} \end{aligned}$$

where

$$\begin{aligned} C_f (RV_1/\nu)^{1/5} = 0.246 \times 10^{-0.678H} \left[ \frac{d(\ln V)}{dy} \right. \\ \left. - \frac{W_1^2 R^2 X^2 (\ln r)}{V_1^2 r^2 x_{e1}^2} \frac{V}{V_1 R_1} \right]^{1/5} \end{aligned}$$

The appropriate design criteria for regions 20, 21, and 22 of FIG. 2 can be expressed in terms of  $\Gamma$ . Using Buri's data,  $\Gamma$  is restricted to the range

$$\Gamma > -0.06 \text{ (separation)}$$

A typical design criterion for the wall spacing in region 20 would be to specify a converging wall profile such that the calculated value of  $\Gamma$  is less than 0.01 at a minimum area section (throat) of the diffuser. The wall shape in region 21 may be proportioned according to the annular diffuser results of Sovran and Klomp as follows:

$$65 \quad \exp \left\{ \frac{r_1 L}{r_{21} L_{21}} - 1 \right\} = -2.365 \exp \left\{ \frac{Y - Y_{21}}{L_{21}} \right\}^{1.205}$$

where  $L$  is the diffuser wall spacing and the conditions at the throat are identified by the subscript 21.

Region 21 is defined by the value of the surface length coordinate where the value of  $\Gamma$  reaches  $-0.055$ , the imminent separation value. The wall shape is prescribed in region 22 so that the value of  $\Gamma = -0.055 = \text{constant}$  so as to maintain imminent boundary layer separation to the diffuser discharge.

The above example is presented as an illustration only. Other procedures could be used to obtain the nonseparating vanless

diffuser profiles shown generally by FIG. 2 and FIG. 3. Further, the diffuser flow could be treated as unsteady or nonsymmetric. The boundary layer flow could be laminar as well as turbulent. References:

1. G. Sovran, "Fluid Mechanics of Internal Flow," Elsevier, 1967.

What is claimed is:

1. A vaneless diffuser for axial and mixed flow turbomachinery, comprising a pair of spaced-apart walls forming a generally annular downstream flow path from a peripheral outlet of a rotor, said walls being spaced apart along a generally cylindrical path generated from a line coplanar with the axis of the rotor, said downstream flow path being divided into three portions and including a diffuser inlet portion adjacent the rotor outlet in which portion the walls converge in a downstream direction for accelerating and reducing turbulence of fluid flow therein, a diffuser intermediate portion downstream of the inlet portion in which intermediate portion the walls diverge in a downstream direction to define an annular area of increasing cross section to a point in the downstream flow where boundary layer separation is imminent and a diffuser outlet portion having means in communication with the intermediate portion at the point of imminent boundary layer separation, said means the walls which define a passage shaped to maintain the condition of imminent boundary layer separation along the downstream flow path of the diffuser outlet portion.

2. The diffuser of claim 1 wherein the rotor outlet is generally axially oriented and the line coplanar with the rotor axis tends to converge therewith in a downstream direction.

3. The diffuser of claim 2 wherein a portion of the coplanar

line is generally parallel with the rotor axis within the inlet portion of the diffuser whereby the outer diffuser wall varies from its cylindrical form within the diffuser inlet portion and is maintained in cylindrical form through the diffuser intermediate and outlet portions.

4. A vaneless diffuser for use in a turbomachine including an axial flow rotor, comprising inner and outer walls spaced apart to form an annular downstream flow path from the rotor, the outer wall being a cylinder of substantially constant cross section, the inner wall being of generally conical construction, the spaced-apart walls being configured to form the downstream flow path in three portions including a diffuser inlet portion adjacent the rotor outlet with the walls converging in a downstream direction for accelerating and reducing turbulence of fluid flow therein, a diffuser intermediate portion downstream of the inlet portion with the walls diverging in a downstream direction to define an annular area of increasing cross section to a point in the downstream flow path where boundary layer separation is imminent and a diffuser outlet portion having means in downstream communication with the intermediate portion at the point of imminent boundary separation, said means comprising the walls which define a passage within the outlet portion the passage being shaped for maintaining the condition of imminent boundary layer separation along the downstream flow path of the diffuser outlet portion.

5. The invention of claim 4 wherein the outer walls form an annular indentation at the intersection of the diffuser inlet and intermediate portions for partially forming the convergent-divergent configuration of the downstream flow path.

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