United States Patent [19]

Exley

[11] **3,904,312**

[45] **Sept. 9, 1975**

[54] **RADIAL FLOW COMPRESSORS**

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[73] Assignee: **Avco Corporation**, Stratford, Conn.

[22] Filed: **June 12, 1974**

[21] Appl. No.: **478,481**

[52] **U.S. Cl.** **415/181**; 415/207; 415/211

[51] **Int. Cl.²** **F04D 21/00**; F04D 29/44

[58] **Field of Search** 415/119, 181, 204, 211, 415/207

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Primary Examiner—Henry F. Raduazo

Attorney, Agent, or Firm—Charles M. Hogan; Irwin P. Garfinkle; Edmund S. Lee

[57] **ABSTRACT**

A radial flow compressor is described in which the diffuser entrance is uniquely contoured to minimize losses attributable to the differences in absolute flow angle of the high velocity air discharged from the compressor impeller, such differences existing across the width of the impeller discharge flow path. The diffuser comprises a plurality of vanes which split the circumferential impeller discharge into discrete, tangential, diffusion channels. Each vane is wedge shaped and has suction and pressure surfaces on opposite sides of the leading edge thereof. The leading edge is angled, or swept, relative to the direction of air flow. The suction surface is angled relative to the impeller axis so that, marginally of the leading edge, it is more tangential at the shroud side of the flow path then at the hub side thereof and an essentially uniform impingement angle of approximately 0° is obtained along the width of the suction surface.

5 Claims, 14 Drawing Figures

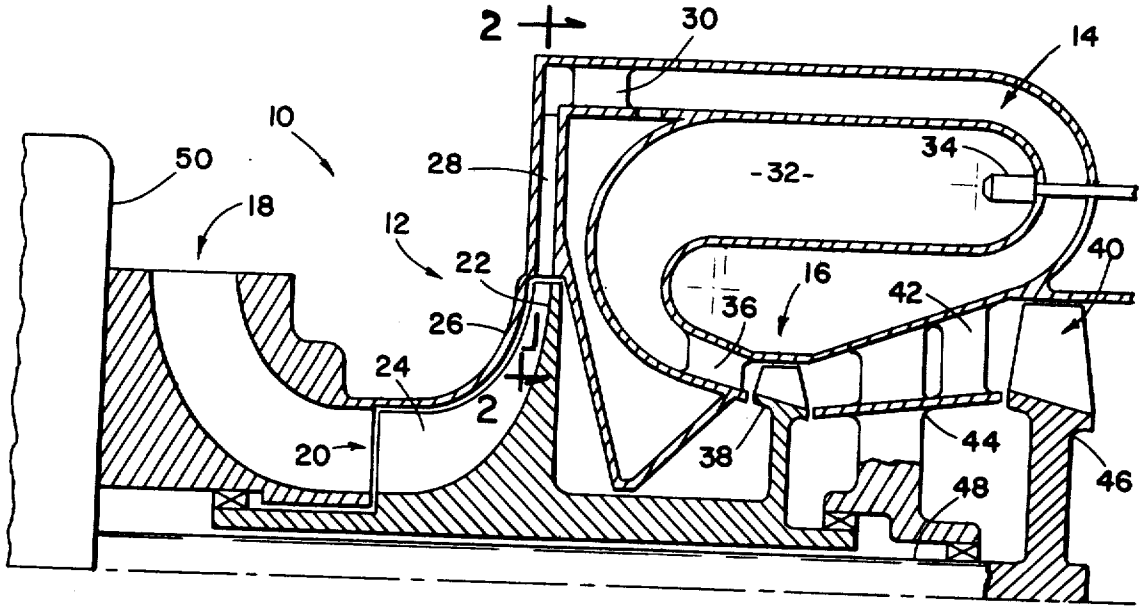
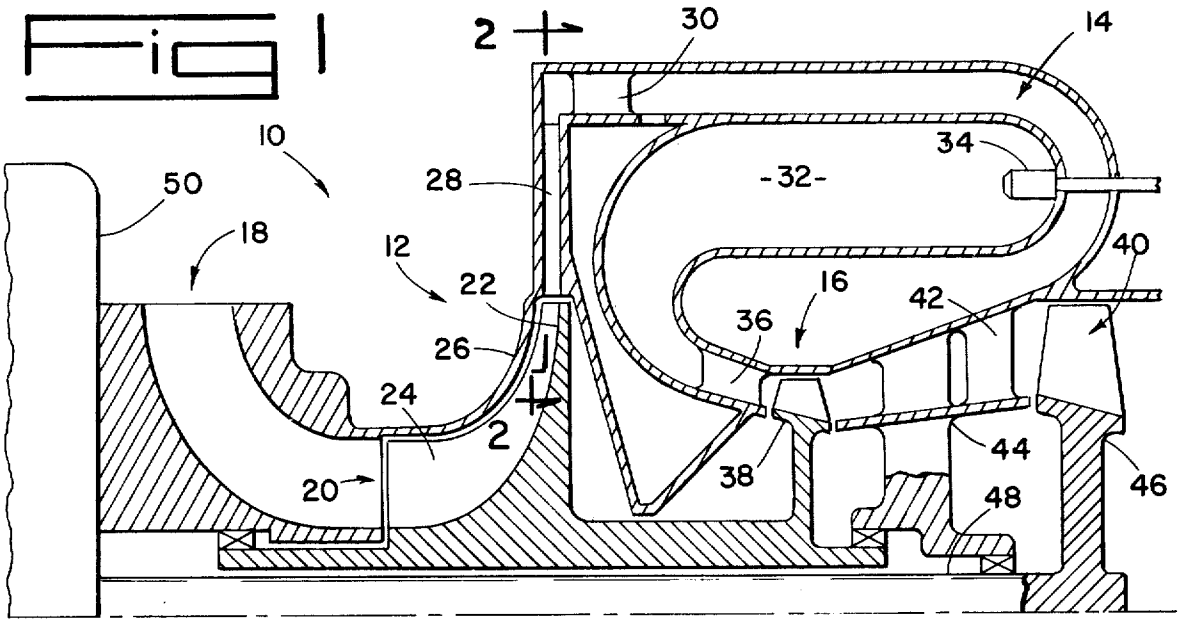


Fig 1


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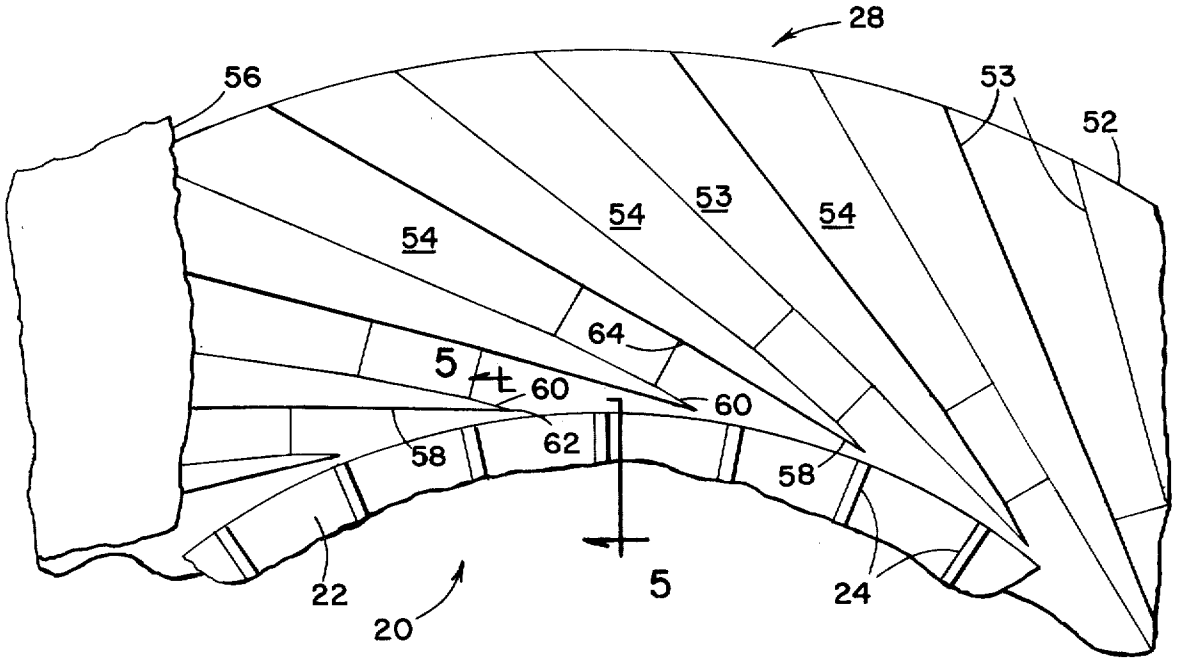

28
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Fig 2

Fig 3

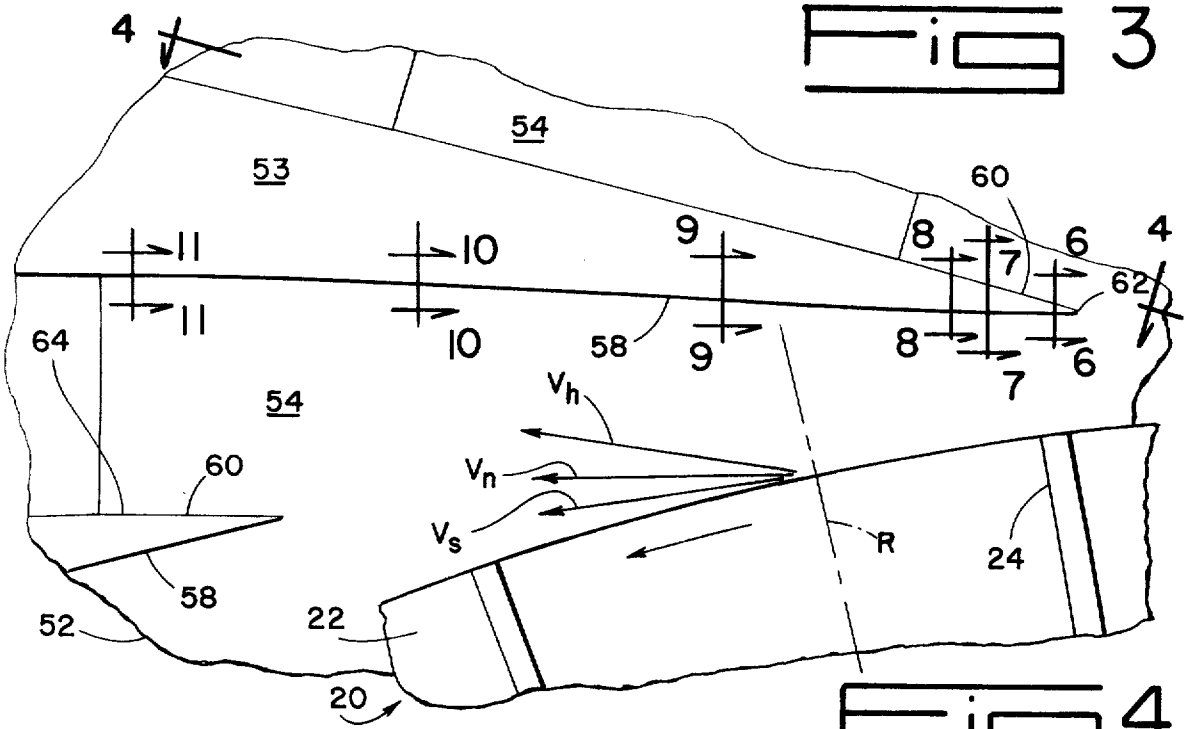
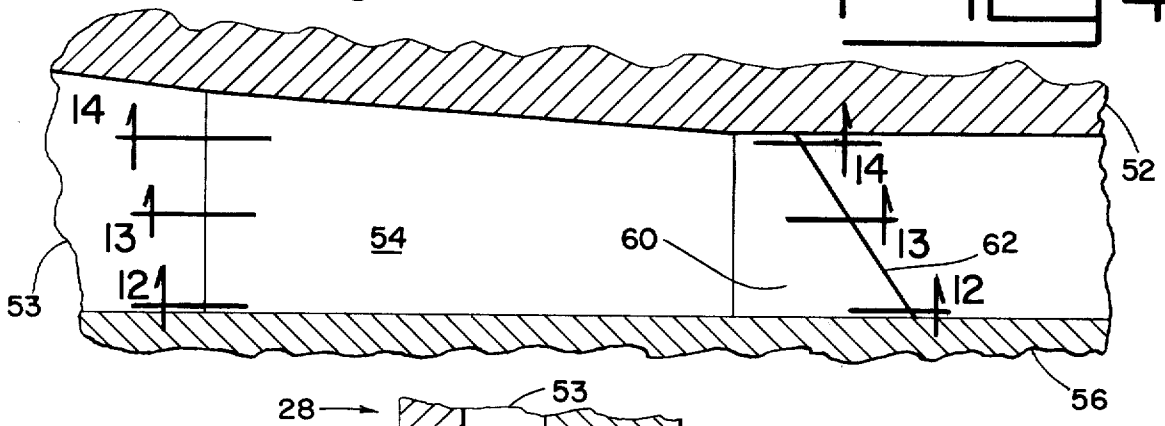


Fig 4



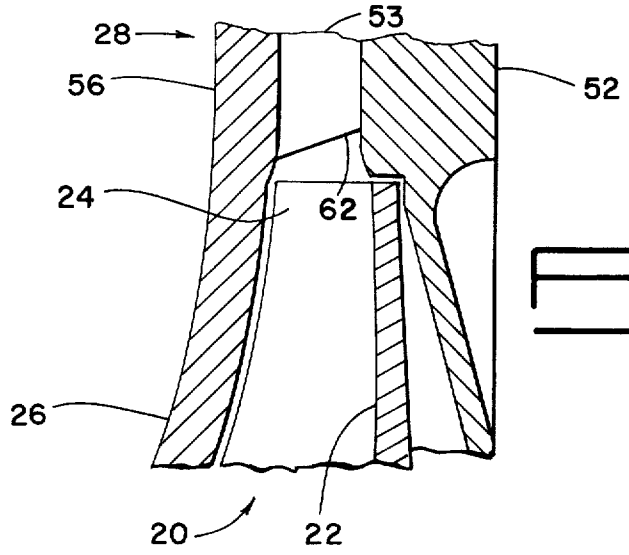


Fig 5

Fig 8

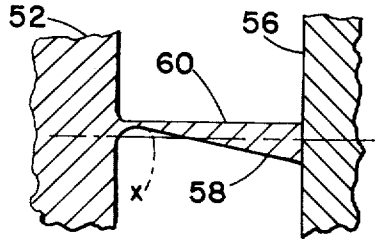


Fig 7

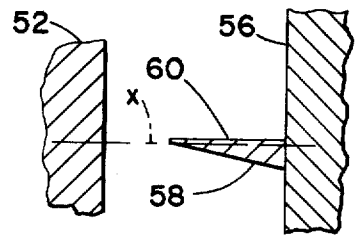


Fig 6

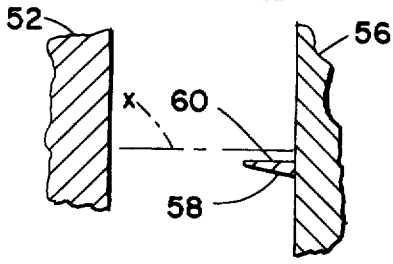


Fig 11

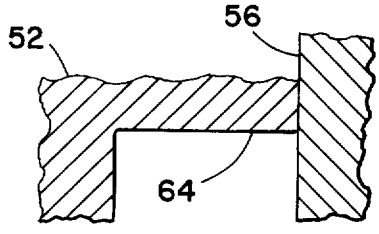


Fig 10

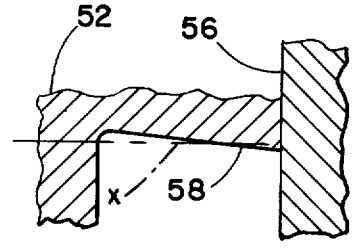


Fig 9

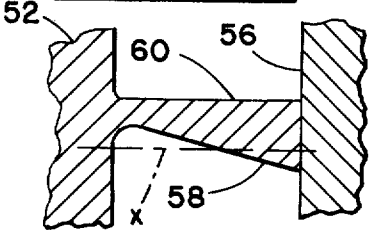


Fig 12

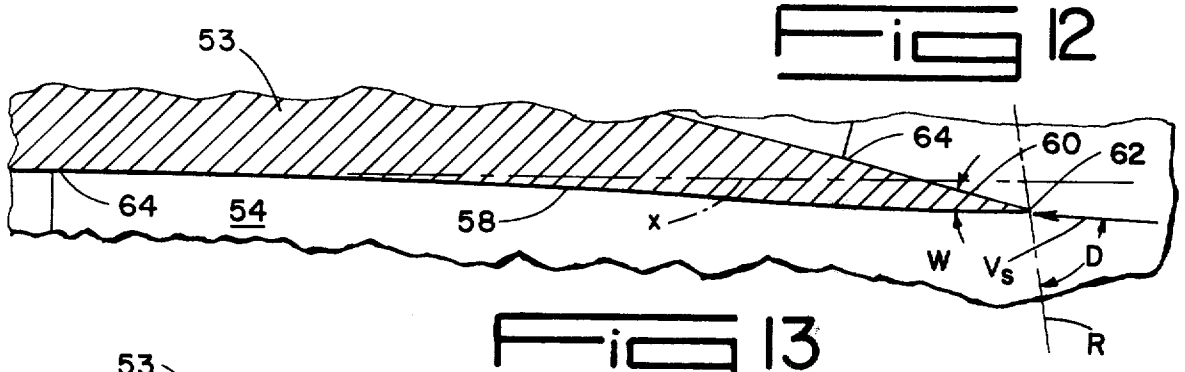


Fig 13

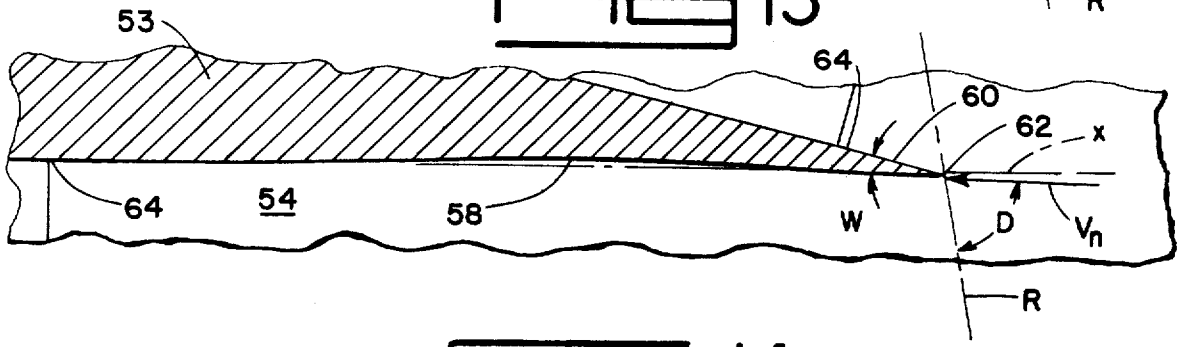
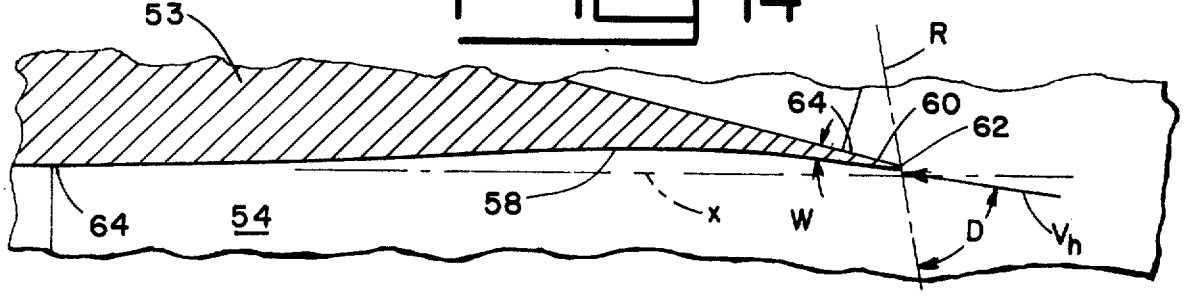


Fig 14



RADIAL FLOW COMPRESSORS

The present invention relates to improvements in radial flow, fluid compressors and more particularly to improved diffusers for such compressors.

The motivating environment for the present invention is in the field of gas turbine engines, particularly high performance engines as are used in the propulsion of aircraft. In such engines, the compressor is an essential component in pressurizing air, as a preliminary step to the generation of a high energy, hot gas stream. Radial flow compressors, wherein the pressurized air is discharged from the compressor impeller in a plane radial of the impeller axis, are advantageously employed in such engines because of their relative simplicity and reliability, their compactness, and other characteristics recognized by those skilled in the art.

In passing through the compressor impeller, energy is imparted to the air primarily in the form of increased velocity. The air velocities attained at the impeller exit are too great for practical utilization in supporting combustion of fuel in the combustors of such engines. In fact, in more advanced engines, these velocities will usually be supersonic.

It is therefore accepted practice to provide a diffuser, at the impeller exit, which decellerates the discharge air to relatively low velocities and converts a major portion of the velocity energy to static pressure energy. In radial flow diffusers, the circumferential, impeller discharge air is split into a plurality of discrete, tangential channels in which the flow path area is increased in a controlled fashion to reduce flow velocity and obtain a static pressure increase with a minimum of energy loss.

More conventionally, wedge shaped vanes are employed to define diffuser channels of rectangular cross section. The leading edges of the vanes face the impeller exit to split the air flow and are normally parallel to the impeller axis. There is, of necessity, a vaneless region between the leading edges of the vane wedges and the impeller exit. It has long been recognized that this vaneless region and the splitting of the air into discrete flow paths is a major source of energy losses, particularly where flow velocities are supersonic.

Such losses reduce the overall efficiency of the compressor as well as the engine in which it is incorporated. This in turn reduces the efficiency of the propulsion system powdered by the engine. This is significant in that relatively small increases in engine component efficiency produce substantial increases in such parameters of the propulsion system as fuel consumption, load capacity, weight and others, dependent on the design objectives of the system. Thus what might otherwise be considered minor advances in connection with an engine component, per se, in the present instance the compressor, are, in fact, of the greatest importance because their effect is multiplied in useable value in the end application of a propulsion system. With this in mind, it will be apparent that there is a great incentive to improve the efficiency of compressors, which incentive has existed for a long period of time.

Many such improvements have been made and proposed, such as in the number and spacing of the vanes, their angularity and the extent of the vaneless region. Some of these are to be preferred over others and some have particular utility under given operating conditions. So-called pipe diffusers have somewhat recently been proposed as being effective in reducing losses in the vaneless region of a diffuser. These diffusers are characterized by diffusion channels of circular cross section which open into a rounded groove encircling the impeller exit. Nonetheless, there still remains room for further improvement in the efficiency of radial flow compressors and diffusers therefor.

The primary object of the present invention is to reduce the losses and improve the efficiency of radial flow compressors and particularly the diffuser component or portion thereof.

A more specific object of the invention is to reduce energy losses in the vaneless region of diffusers, for radial flow compressors, wherein the air is split into discrete flow paths, and particularly to reduce such losses where the air discharged from the compressor impeller is at super sonic velocities.

These ends are attained by a unique contour of the suction surfaces of the vanes which define the diffusion channels. This is the surface defining one side of the vane wedge and facing towards the impeller axis. The opposite side of the vane wedge faces outwardly of the impeller axis and is referenced as the pressure surface. Pressure and suction surfaces of adjacent vanes extend from the leading edges thereof to the throat section of the diffusion channel.

In accordance with the present invention, the suction surface, marginally of the leading edge, is more tangential at the shroud side of the impeller discharge than at the hub side thereof and preferably oriented so that there is a uniform, or approximately uniform, angle of incidence, approximating 0°, of the discharge air on the entire width of the suction surface. In this fashion variations in the absolute flow angle of the impeller discharge air, across the width of its flow path, are compensated for to reduce shock wave and boundary layer losses, which would otherwise result from the incidence angle being too great at one point and too small, or negative, at another point. Downstream of these marginal edge portions, the suction surface is faired into the normal plane of the throat section.

More specifically these ends are attained by maintaining the pressure surface in its normal plane parallel to the impeller axis. The suction surface is then angled relative to an intermediate point away from a plane parallel to the impeller axis, disposing the shroud side of the suction surface closer to the impeller axis and the hub side thereof further therefrom. This results in two further advantages. First, the vane leading edge becomes angled, or swept, relative to the air flow. This swept reduces losses in the shock wave which is generated when the air flow impinging thereon has a super sonic velocity. Secondly, the wedge angle of the vane is substantially decreased at the hub side of the discharge flow path. Air velocity is somewhat greater at the hub side and since shock losses are proportional to wedge angle, the decreased angle in the region of highest velocity further reduces such losses.

The above and other related objects and features of the present invention will be apparent from a reading of the following description of the disclosure of a preferred embodiment, in which reference is made to the accompanying drawings, and the novelty thereof pointed out in the appended claims.

In the drawings:

FIG. 1 is a simplified, longitudinal, half section of a gas turbine engine of the type in which the improved

compressor of the present invention may advantageously be incorporated;

FIG. 2 is a view, on an enlarged scale, taken on line 2—2 in FIG. 1, showing portions of this compressor and its diffuser in particular, in greater detail;

FIG. 3, is a view, on a further enlarged scale, also taken on line 2—2 in FIG. 1, showing the entrance portions to the diffuser channels in further detail;

FIG. 4 is a section taken on line 4—4 in FIG. 3;

FIG. 5 is a section taken on line 5—5 in FIG. 2;

FIG. 6 is a section taken on line 6—6 in FIG. 3;

FIG. 7 is a section taken on line 7—7 in FIG. 3;

FIG. 8 is a section taken on line 8—8 in FIG. 3;

FIG. 9 is a section taken on line 9—9 in FIG. 3;

FIG. 10 is a section taken on line 10—10 in FIG. 3;

FIG. 11 is a section taken on line 11—11 in FIG. 3;

FIG. 12 is a section taken on line 12—12 in FIG. 4;

FIG. 13 is a section taken on line 13—13 in FIG. 4, and

FIG. 14 is a section taken on line 14—14 in FIG. 4.

Reference will first be made to FIG. 1 for a description of a gas turbine engine of the type in which the compressor of the present invention finds particular utility. Such engines are well known to those skilled in the art and FIG. 1 is therefore greatly simplified, omitting structural details.

The engine, indicated generally by reference character **10**, comprises, as basic units, a radial flow compressor **12**, a combustor **14** and a turbine **16**, which are sometimes collectively referred to as a gas generator.

Air is induced into the compressor **12** through an inlet **18** which turns it in an axial direction for entrance into the compressor **12**. The latter comprises an impeller **20** having a hub **22** and blades **24**. The hub **22** and a shroud **26** define an annular, outwardly curved flow path of progressively reduced area. As the impeller rotates, the blades **24** propel the air at increasing velocities to the radial, outwardly facing, circumferential impeller exit and discharge the air therefrom at a substantially increased total pressure.

The impeller discharge air then enters a radial flow diffuser **28** (later described in detail) from which it is turned into an axial direction to enter an axial diffuser, or guide vanes, **30**, which properly direct the air towards the combustor **14**, which is of the reverse flow type. The pressurized air flows into an annular combustion chamber **32** where it supports combustion of fuel, discharged from fuel nozzles **34**, in the generation of a high energy, hot gas stream. This hot gas stream is then turned inwardly through an angle of approximately 180° to the nozzle diaphragm **36** of the turbine **16**. The hot gas stream is then directed through a bladed turbine rotor **38** which is directly coupled to the compressor rotor **20**. The turbine **16** extracts a portion of the energy of the hot gas stream in thus driving the compressor rotor of the gas generator.

The majority of the remaining energy of the hot gas stream is then converted to a useful output, as by being discharged through a propulsion nozzle, or, as herein illustrated, by driving a power turbine **40**. The latter comprises a nozzle diaphragm **42**, mounted on a frame member **44**, which directs the hot gas stream through a bladed turbine rotor **46**. The power turbine rotor **46** is mounted on a forwardly extending shaft **48**, which, generally speaking, has a rate of rotation too great to be directly coupled to a driven unit. Therefore it is usual procedure to provide a gear box **50** on the front end of the engine **10**. The input to this gear box, from shaft **48**, is reduced in speed, and motive power then derived from an output shaft (not shown) of the gear box.

The improvements of the present invention are found in the diffuser **28** which will now be described in greater detail with reference to FIGS. **2** and **5**. The diffuser **28** comprises a frame member **52** having integral vanes **53** which define a plurality of generally tangential channels **54**. A plate **56**, which may be an extension of the impeller shroud **26**, forms the front wall of these channels to define closed flow paths for the impeller discharge air. The inner, wedge ends of the vanes **53** are defined by suction and pressure surfaces, **58** and **60** respectively, which diverge from sharp, leading edges **62**. Opposed suction and pressure surfaces, of adjacent vanes **53**, extend downstream to a throat section **64** in each channel **54**. From the throat section **64** there is a two stage increase in channel area (see also FIG. **4**) which provides for controlled diffusion of the high velocity, impeller discharge air with a minimum of losses in a minimum flow path length as its velocity energy is transformed to static pressure energy. The diffuser, as thus far described, is conventional and its function well known to those skilled in the art.

Reference is next made to FIG. **3** for an appreciation of the discharge flow characteristics of the compressor impeller, which is, itself, of conventional design. Primarily because of the necessary clearances between the impeller blades **24** and the shroud **26** (this is best shown in FIG. **5**) there is a relatively large variation in the absolute flow angle of the impeller discharge air between the shroud side and the hub side of the discharge air flow path as it enters the diffuser **28**. The vectors V_s and V_h in FIG. **3** respectively indicate the absolute flow angles of the impeller discharge air at the shroud and hub side of its flow path. An imtermediate, or nominal, absolute angle of discharge is also indicated by the vector V_n. These vectors are circumferential in extent and angled at any point relative to the radius plane of the axis of the impeller, as indicated by broken line R.

The suction surfaces **58** have been contoured so that the angle of incidence of the impeller discharge air thereon is essentially uniform and preferably at a zero degree angle of incidence, from the shroud side to the hub side of the impeller discharge air flow path. This desired relationship will be more apparent from FIGS. **12–14** which are, respectively, sections through a vane **53** at the shroud side, at the intermediate, or nominal plane and at the hub side thereof. FIG. **12**, at the shroud side, illustrates that the vector V_s approaches a tangential relationship with the radial plane R, at the leading edge **62**, with the angle D being in the order of 85°. In FIGS. **13** and **14** the vectors V_n and V_h become less tangential, or more radial, as the angle D decreases, relative to the radial plane R at the leading edge **62**. More importantly, the suction surface, marginally of the leading edge **62**, has this same relationship, being more tangential at the shroud side, FIG. **12**, and then less tangential at the nominal plane, FIG. **13**, and still less tangential at the hub side, FIG. **14**. Further, in each instance, these marginal portions of the suction surface **58** are essentially parallel with the vectors V_s, V_n and V_h so that there is at least approximately a 0° angle of incidence of the impeller discharge air on the suction surface across its width. Downstream of these marginal edge portions, the suction surface is

faired into the plane of the throat section **64** to minimize possible turbulence in the air flow therealong.

These contours are preferably obtained with the pressure surface **60** maintained in its normal plane parallel to the impeller axis and also parallel to the suction surface **58** at the throat section **64.** With the pressure surface thus oriented, the suction surface is then angled, relative to the impeller axis, from the intermediate or nominal plane so that the suction surface, and the leading edge **62,** are extended toward the impeller exit and also toward the impeller axis. These relationships are further shown in FIGS. **6** and **12** by broken line x which represents the plane of the suction surface **58** at the throat section **64.** FIGS. **7** and **13** and **8** and **14** then respectively illustrate that the suction surface **58** and leading edge **62** are further away from the impeller exit and axis in the nominal plane and hub side plane, coinciding with the throat section plane x in the nominal plane and being disposed outwardly of the throat section plane x in the hub side plane. FIGS. **9–11** further illustrate the manner in which the suction surface, as was previously mentioned, is faired from the portions marginally of the leading edge **62** into the plane of the throat section **64.** These last Figures also illustrate the radius provided between the suction surface **58** and the rear channel wall formed in the frame member **52** which lends structural strength as well as assisting in minimizing losses.

The described suction surface **58** provides the desired zero angle of impingement, relative to the impeller discharge air, across the width of the discharge flow path and thereby minimizes both boundary layer losses and shock wave losses. This contoured suction surface differs from conventional suction surfaces which are usually disposed in a plane parallel to the impeller axis and tangential to the nominal absolute velocity flow path vector. This conventional disposition of the suction surface, as can now be better appreciated, results in the angle of incidence being negative at the shroud side and too great at the hub side of the flow path and thus causes undue energy losses as the impeller discharge air is split into discrete flow paths.

It will also be noted that, in achieving the described advantages, other preferred features of existing diffusers are not effected. Thus it will be seen from FIG. **5** that the vaneless region is generally convergent towards the diffuser channel throat section. Beyond the throat section, the diffuser channel may increase in area in accordance with known design parameters. as desired. Further, the vaneless region may be preferably maintained relatively short, in the order of 5% of the diffuser channel length. It will also be noted that the impeller is designed for and rotates at speeds which produce supersonic exit velocities.

Not only are the higher losses associated with supersonic flow minimized by the desired incidence angle, relative to the suction surface, across the width thereof, but the preferred embodiment includes two further features which also contribute to the minimization of losses. First, angling of the suction surface **58,** relative to the impeller axis, produces a sweep aspect of the vane leading edge **62** (best seen in FIG. **4**) which breaks up the shock wave created by incidence thereon of supersonic flow, into delta waves which have less net overall loss than where the shock wave is created by impingement on an edge normal to the flow direction. Second, the included angle W of the vane wedge decreases from the shroud side to the hub side of the exit flow path, as will be evident from FIGS. **12–14.** It is fundamental that shock losses, in supersonic flow, are a function of the wedge angle on which they impinge, as well as the velocity of the air flow. It has been previously noted that the losses associated with the clearance between the impeller blades **24** and the shroud **26** create flow angle variations. These same losses also result in the absolute air velocity at the hub side being greater than at the shroud side of the discharge air flow. Thus the sharper wedge angle at the hub side, where the greater velocity is found, also contributes to the minimization of losses in this vaneless region.

In summary, the present invention provides many of the advantages of pipe diffusers in reducing losses in the vaneless region while retaining the advantages of diffuser channels of rectangular cross section which minimizes changes in flow direction during the diffusion process.

While the present embodiment represents an idealized situation wherein the contour of the suction surface is modified to provide the desired zero incidence angle across the entire width of the exit flow path, from the shroud side to the hub side thereof, there may be design limitations which prevent full attainment of such condition. Nonetheless, any suction surface contour following the present teachings which substantially approximates this flow relationship will provide significant improvements in compressor efficiency.

Also, while, in the present embodiment, the vanes **53** are formed integrally with the frame member **52,** which also forms the rear wall of the diffuser channels **54,** it is to be recognized that these vanes could be formed as separate elements. In such case, the radii at the juncture of the suction surface **58** and the rear wall of the diffuser channel (FIGS. **8–10**) could be reduced to a sharp angle if desired. However, it is believed preferable that some radius be provided at this juncture to minimize boundary layer losses.

The present embodiment has been described in combination with a gas turbine engine of the type employed in the propulsion of aircraft. However, the invention is applicable to radial flow compressors for compressable fluids, generally, at least in its broader aspects.

The above and other variations from the preferred embodiment herein described, will become apparent to those skilled in the art within the spirit and scope of the present invention concepts, which are to be derived from and limited by only the following claims.

Having thus described the invention, what is claimed as novel and desired to be secured by Letters Patent of the United States is:

1. A supersonic radial flow, fluid compressor comprising

an impeller having a hub,

a shroud surrounding said hub and defining, in combination with said hub, an annular flow path of progressively reduced area, which curves outwardly to a circumferential discharge exit between the exit planes of the hub and shroud, which planes are generally normal to the impeller axis,

said impeller having blades projecting from the hub into close proximity with said shroud, for propelling fluid along said flow path and discharging same tangentially from said exit at supersonic velocity

a diffuser encircling said impeller discharge exit and having side walls generally aligned with the planes

of said hub and shroud and further including vanes, disposed between said side walls, which define, in combination therewith, a plurality of diffusion channels extending generally tangentially of said discharge exit,

each of said vanes including a wedge portion having a leading edge facing said discharge exit and spaced therefrom to define the outer bounds of a vaneless region of the diffuser, said wedge portion having, on one side, a suction surface facing the impeller axis and a pressure surface on the opposite side thereof, the suction and pressure surfaces of adjacent vanes extending downstream to the throat section of the diffusion channel, characterized in that in each vane

the pressure surface is disposed in a plane parallel to the impellor axis, and

the edge portions of the suction surface, marginally downstream of said leading edge, are more tangential, relative to a radial plane from the impeller axis thereat, at the shroud side of the vane than at the hub side thereof and further that said marginal suction surface portions are generally parallel with the absolute flow angle of the impeller discharge fluid from the hub side to the shroud side of the discharge exit, whereby, across the width of the vane leading edge, there is an essentially uniform angle of incidence, approximating 0°, of the impeller discharge air on the suction surface.

2. A radial flow, fluid compressor as in claim 1 wherein:

the leading edge of each vane is angled relative to the impeller axis and thus swept with respect to the impeller discharge air impinging thereon.

3. A radial flow, fluid compressor as in claim 1 wherein:

the pressure surface of each vane is parallel to the suction surface of the adjacent vane at the throat section of the diffusion channel,

the said marginal portions of each vane are disposed in a plane intersecting the plane of the suction surface at said throat section, at an intermediate, nominal point across the discharge exit flow path, the plane of said marginal surface portions further being angled relative to the impeller axis to dispose the suction surface nearer the impeller axis at the shroud side of the discharge air flow path than at the hub side thereof,

whereby each leading edge is swept from a point nearer the impeller exit, at the shroud side, to a more remote point at the hub side, and the included wedge angle at the hub side is less than that at the shroud side and further wherein:

the suction surfaces marginally of each leading edge are smoothly faired into the plane of the downstream throat section.

4. A radial flow, fluid compressor as in claim 3 wherein:

the flow path length of the vaneless region is approximately 5% of the total length of the flow path length through the diffuser to the exit of a diffusion channel.

5. A radial flow, fluid compressor as in claim 4 wherein:

said vanes are formed integrally with a frame member which also defines the hub side wall of the diffusion channels, and

radii are formed at the juncture of the suction surfaces and the said rear wall, which progressively become more sharp toward each throat section.

* * * * *

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 3,904,312

DATED : September 9, 1975

INVENTOR(S) : John T. Exley

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

In the Abstract, line 15, "then" should read -- than -- .

Col. 1, line 47, "powdered" should read -- powered -- .

Col. 2, line 51, "swept reduces" should read

-- swept feature reduces -- .

Col. 6, line 48, "invention" should read -- inventive -- .

Signed and Sealed this

sixteenth Day of *December 1975*

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents and Trademarks