

June 22, 1937.

E. A. STALKER

2,084,462

COMPRESSOR

Filed June 5, 1933

2 Sheets-Sheet 1

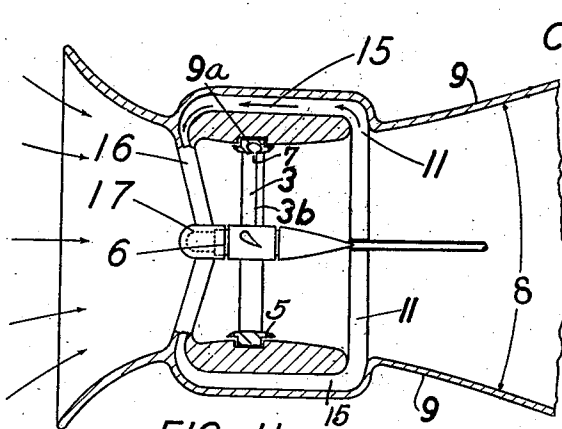


FIG. 11

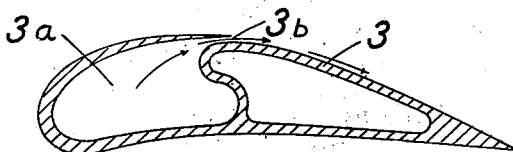


FIG. 4

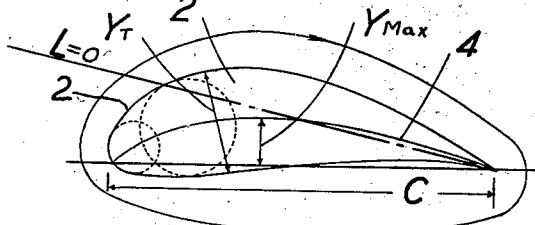


FIG. 3

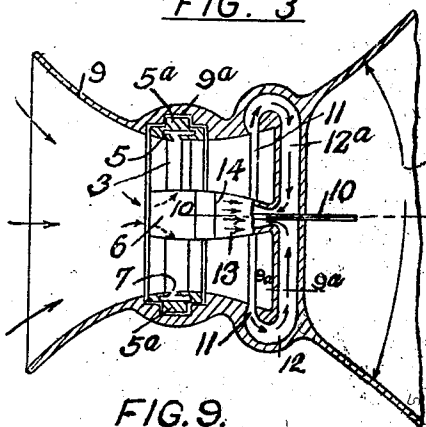


FIG. 9.

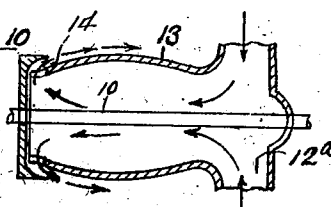


FIG. 10.



FIG. 9a

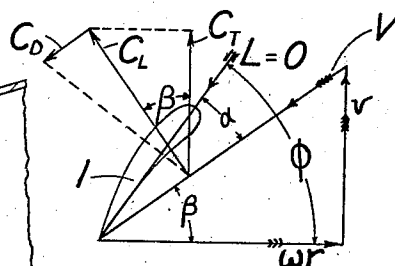


FIG. 1

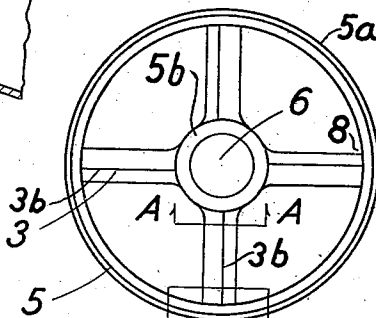


FIG. 5

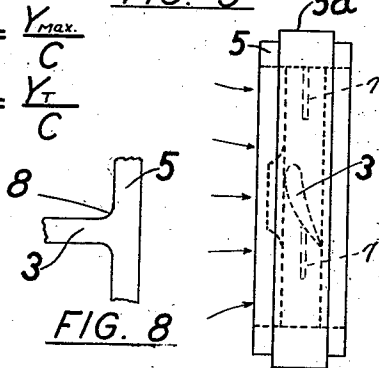


FIG. 6

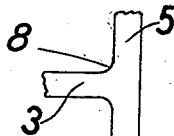


FIG. 8

$$H = \frac{Y_{max}}{C}$$

$$F = \frac{Y_T}{C}$$

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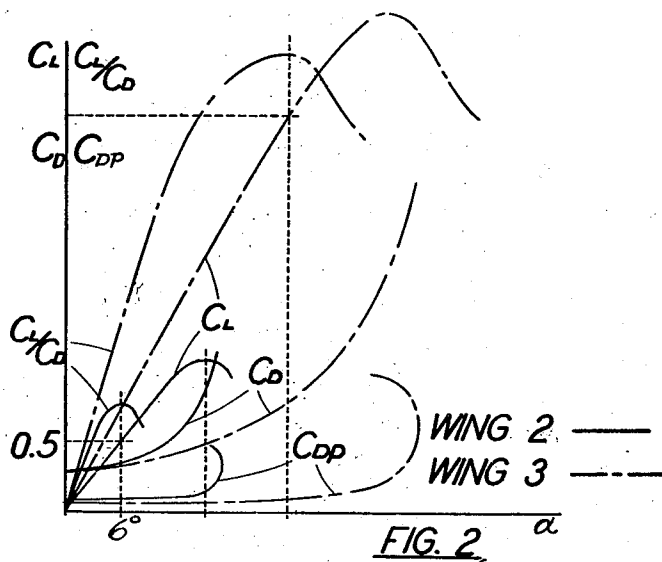
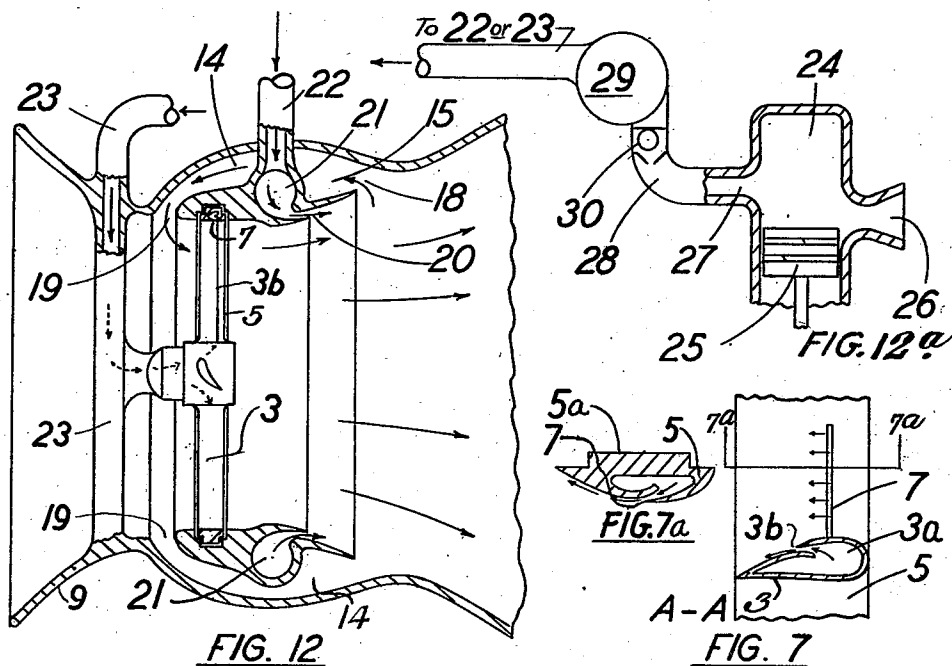
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2,084,462

COMPRESSOR

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Application June 5, 1933, Serial No. 674,342

10 Claims. (Cl. 230-120)

Fans with wing-like blades have been used for blowing against small pressures only. In small sizes the pressures have been correspondingly smaller because of the great rate of rotation required to obtain a high blade-tip speed.

This application contains subject matter in common with my application Serial No. 10,408, filed March 11, 1935. The present application is concerned with the energization of the boundary layer on the blades and on the casing or structure surrounding the blades. It also relates to the general use of the blades to energize the boundary layer on the casing wall. In contradistinction application Serial No. 10,408 relates to the use of the impeller of a plurality of impellers to energize the boundary layer on the conduit conducting fluid from one impeller to the other.

Fans are designed so that the blades operate with true angles of attack corresponding to the greatest ratio of lift to drag on the blade section. This means that the lift coefficient and the angle is small because the maximum ratio of lift to drag occurs at small values of the lift and angle. The chief reason that the maximum ratio of lift to drag occurs at small angles is that the induced drag increases as the lift squared. The induced drag, as is well known, arises because of the tips which permit a vortex system to form.

The lift of a wing is given by

$$L = C_L \frac{\rho V^2}{2} A \quad (1)$$

where C_L is the lift coefficient, A is the area, ρ is the mass density of the air and V is the wind velocity. Since the lift is proportional to the lift coefficient it is best to speak in terms of C_L because it is independent of the density, area and velocity. In a like manner the total drag of a wing is

$$D = C_D \frac{\rho V^2}{2} A \quad (2)$$

The drag may be separated into two parts, the induced drag due to the finiteness of the span, and the profile drag due to the air friction. That is,

$$D = (C_{Di} + C_{Dp}) \frac{\rho V^2}{2} A \quad (3)$$

where

$$C_{Di} = \frac{C_L^2}{\pi R}$$

and R is the aerodynamic aspect ratio.

In my fans I provide a tip shield at the ends of the blades which partly stops the formation of

the tip vortices. They will continue to form in part because the friction of the air with the surface of the shield dissipates some of the kinetic energy of the fluid as heat. Since the dynamic pressure of the fluid is equal to the kinetic energy, there is a loss of dynamic pressure which if present would prevent the air of greater pressure about the blade from flowing into the low pressure region near the blade surface and forming a vortex. Finally, by adding energy to the layer of fluid adjacent the surface of the tip shield I prevent entirely the formation of the tip vortex. The layer of fluid adjacent the surface of a body is called the boundary layer.

The elimination of the induced drag makes it possible to use lift coefficients, as high as 5 for the blade sections economically; and values still higher if pressure and rate of rotation are more important than the efficiency. An ordinary wing has a maximum lift coefficient of about 1.5 so that it is necessary to provide special blades to attain a value $C_L=5$. High lift coefficients are obtainable through alterations in the boundary layer.

The construction to obtain the elimination of the induced drag and create high values of C_L will be described in detail in connection with the drawings.

It is customary to refer to blades following helical paths in air as airscrews. For fluids generally the term fluidscrew is used herein. The length of a blade is the length measured at right angles to the relative fluid flow.

In view of the foregoing the objects of this invention may be described broadly as a means of improving the efficiency of fluidscrews, vane rotors, and rotary means of pumping by ensuring a smooth flow about the elements. Control of the boundary layer is used to accomplish this effect. The same means also makes possible the attainment of many times higher pressures than were heretofore possible with similar devices. I attain these objects by the constructions illustrated in the accompanying drawings in which—

Figure 1 pertains to the theory of fluidscrews and indicates the importance of the lift coefficient and the ratio of lift to drag.

Figure 2 depicts the characteristics of two types of blade sections, sometimes called wing sections or airfoil sections.

Figure 3 describes the important geometric parameters in airfoil sections.

Figure 4 shows an airfoil section to obtain high values of C_L .

Figure 5 is an axial view of a fluidscrew with

a peripheral ring shielding the blade tips; Figure 6 is a side view of this combination. Figure 7 is a fragmentary section of the fluidscrew and ring taken along the line 7-7 in Figure 5. Figure 7a is a fragmentary section of the ring or shield taken along the line 7a-7a in Figure 7. Figure 8 is a fragmentary view of the blade and ring at their junction.

Figure 9 is a longitudinal section of a screw encased in a tube to convert the velocity head to a static head. Figure 9a is a cross section of a tube of Figure 9 along the line 9a-9a.

Figure 10 is a fragmentary section along the line 10-10 in Figure 9.

Figure 11 is a longitudinal section through a fan and tube and illustrates a mode of removing the boundary layer from an expansion tube so that a large diverging angle δ may be used. Figure 12 illustrates another form of the tube for the same purpose and depicts in fragmentary longitudinal section the relation of the fan and tube to a source of fluid pressure such as the cylinder of a fluid engine shown in Figure 12a. Figure 12a illustrates in fragmentary section a two cycle gas engine.

In Figure 1 an element 1 of the blade at radius r is shown. It has a peripheral velocity ωr relative to the air. The relative axial velocity is v . The magnitude and true air direction relative to the blade is then given by V . The angle of attack of the blade is then α measured between V and the wind direction for zero lift indicated as the line $L=0$. From the direction of the lift and drag coefficients C_L and C_D respectively it may be observed that C_L is the important quantity in producing an axial thrust while C_D is chiefly important in opposing the rotation of the fluidscrew. The drag coefficient C_D is composed of the induced drag coefficient C_{Di} and the profile coefficient C_{Dp} .

Figure 2 shows the plots of C_L , C_D and C_{Dp} against angle of attack for two wings whose airfoil sections are shown in Figures 3 and 4. Wing 2 has a section without means to energize the boundary layer while wing 3 is equipped with a slot through which a jet may be discharged to energize the boundary layer. Figure 3 also defines the geometric properties of any section. The mean camber line is indicated by 4 and its maximum ordinate is indicated by Y_{max} which may be expressed as a fraction H of the chord C . The ordinate is measured from the chord line subtending the mean camber line or arc. The maximum thickness Y_t expressed as a fraction of C is F . If a line be drawn through the trailing edge and the mid-point of the mean camber line, this line will represent the wind direction for zero lift. It is best to measure all angles from this line because when the angle of attack is zero the lift is then zero.

The reason that the lift reaches a maximum and then decreases is that a stagnant layer of air forms on the surface of a wing. This layer is called the boundary layer and it is well known in aerodynamics that by adding energy to the layer it may be made to disappear, in which case the lift continues to increase. If enough energy is added the value of C_L may become as high as 12. Energy must be added as velocity tangential to the wing surface or by drawing the boundary layer into the wing. Thus if fluid is blown out an opening to accomplish boundary layer energization the opening must be formed to discharge in the direction of the flow along

the surface. If the opening is formed to discharge normal to the surface or forward into the oncoming flow the flow will not be energized but deenergized for there will be no component of velocity added to the flow in the general direction of its normal movement. Rather the flow will become turbulent and dispersed in every direction. If the openings have axes normal to the surface, only suction to draw the boundary layer into the wing will result in energizing the boundary layer. In speaking of energizing the boundary layer the use of one of the above methods is meant.

Boundary layer energization is significant only where the surface tends to turn from the flow as on a curved surface or the diverging walls of a tube. It is only on such surfaces that there is a reduction in the fluid pressure which tends to tear the flow from the surface. On a surface turning toward the flow the impact pressure of the fluid always ensures that fluid adheres. I locate the openings or slots on the curve itself or so that they are followed by an expanse of surface turning from the surface where they are located.

I use the term slot to indicate an opening elongated in the direction transverse to the flow across a blade or body surface. A plurality of openings distributed in the same direction will be equivalent to a slot. The direction of a slot is the direction of the flow axis or the direction of the axis of the slot hole. For blowing to energize the boundary layer the slot axis should be nearly tangent to the body surface and directed to the trailing edge or downstream edge of a blade or vane.

Figure 4 shows a wing section 3 with a slot 3b through which air is blown. In Figure 2 the characteristics for wing 3 are shown for the same span as for wing 2 but with the tips of 3 shielded and with air blow out the slot 3b. It is to be noted that the maximum value of C_L is several times larger for the wing with boundary layer energization than for the plain wing. Also the ratio of lift to drag as indicated by the ratio of the coefficients is several times higher and the maximum value occurs at higher angles and high lift coefficients. This is a very desirable feature for the type of pumps here described because it permits the efficient operation of the blades at higher angles than heretofore employed. The fan type of pump then becomes suitable for much higher pressures than before. The improvement in the properties in Figure 2 is due to both the boundary layer energization of the wing and of its tip shield which will be described subsequently.

The shape of the wing section plays an important role in determining the value of the maximum C_L and the amount of energy necessary to energize the boundary layer. The best results are obtained if the nose of the section is very blunt and the whole section quite thick. The maximum height of the mean camber line above the subtending chord should be large. That is, the value of F should be preferably greater than 15 per cent; the value of H should be greater preferably than 10 per cent; the nose radius should approach one-half the thickness which would result in a large angle between the radii to the sides of the nose circle where the remainder of the wing curve joins the circumference.

The characteristics of a fan are practically the same as the characteristics of the element of

the blade at a radius of two-thirds the maximum radius. In other words, the most important section of a fan is in the vicinity of the two-thirds point so that the forms of the blade sections on either side of this point are most important. In present-day fans the sections are thin and possessed of less mean camber height than 6 per cent. In my fans I prefer to form the central half of the blade so that the thickness ratio F is between 15 per cent and 50 per cent and the mean camber value H between 10 per cent and 40 per cent. That is, the wing sections to either side of the two-thirds point on the radius should have these values. In general the greater the value of H the greater the value of F should be. For instance, with a low value of H near 8 per cent the value of F is preferably about 15 per cent; while at large values of H near 40 per cent the value of F should be near 50 per cent. The value of H should be low for low pressures and high for high pressures for a given rate of rotation.

In present-day fans the value of α is of the order of 6 degrees or less, so that for fans operating with a speed ratio of one between the tips and the relative wind, the angle ϕ is about 51 degrees. This is the value of the angle between the plane of rotation and the zero lift line. In my fans the value of ϕ preferably exceeds 55 degrees and may be as much as 90 degrees.

Figure 5 shows an airscrew with end shield 5 at the tip of the blades indicated as 3 because they are of airfoil section similar to 3. In this instance the end shield is a ring extending about the airscrew. If desired it may extend only a short distance above and below the chord of the wing section. The shield would take this form on aircraft sustaining wings. A typical junction between the wing and an end shield is shown in Figures 7 and 8 while Figure 7a shows the cross section of the shield. The blades 3 are hollow and their interior compartments 3a communicate with the opening 6 into the hub 5b. The compartment 3a also communicates with the interior of the shield 5. When the fan is rotated there is a suction formed on the back of the blade. In the interior of the blade the pressure is due to the centrifugal force of rotation plus the impact pressure of the air flow against and entering the opening 6 in the hub. As a consequence of the large difference in pressure between the interior 3a and the exit of the slot 3b, a high velocity jet emerges from the slot and energizes the boundary layer on the blade. At the same time a jet is discharged rearward through the slot 7 in the shield and energizes the boundary layer on the shield. Hence the lift of the blade is continued entirely up to the shield surface and no vortex may be formed.

Since the efficiency of a fan is a maximum for a ratio of inflow velocity to peripheral velocity equal to unity, it is desirable to locate the fan at the throat of a Venturi tube 9 as shown in Figure 9 to speed up the flow through the fan. This figure is a longitudinal section through the Venturi tube. The fan blades are indicated by 3 and the tip shield by 5 as before. The shield regarded as a ring carries the projection 5a which fits snugly into a depression or groove 9a in the Venturi wall. On the inner surface the ring is slightly curved but forms a smooth continuation of the Venturi wall contour.

The Venturi tube increases the speed of the air at the fan and again expands the flow to a low velocity and a high static pressure. But the ordinary Venturi tube has an expansion segment with

an included angle δ equal to 5 to 7 degrees which makes an excessively long tube. If the angle δ is larger than about 7 degrees, the fluid does not follow the wall contours but streams through a central area in the expansion segment of the tube with a high loss of energy. The expansion segment of a Venturi tube or any tube is that part where the walls conducting the fluid enclose a cross sectional area of the flow which is increasing in magnitude in the direction of the flow. Such a conduit of divergent cross sectional area may be called an expansion tube, a diffuser, or a draft tube. These terms are in common use in connection with pumping machinery and water turbines. The failure of the fluid to follow the walls is due to the boundary layer phenomena described earlier. If the boundary layer is removed from the wall as by suction the stream will follow the wall. The withdrawn air may be placed back in the stream if energy is added to it or if it is placed at a considerable distance in from the wall. The stream near the wall will still follow it and the fluid may be expanded in a short tube with an expanding exit even exceeding 90 degrees.

In Figure 9 I indicate one method of removing the boundary layer from the critical point where the expansion of the cross section begins. A circumferential aperture 11 in the Venturi wall opens into a conduit 12 encircling the Venturi tube. In the center of the venturi a conduit 12a connects 12 with the hub fairing 13. Figure 9a shows the cross section of tube 12a. Figure 10 which is a section of the fairing along 10-10 of Figure 9 shows that the interior of the fairing is hollow and has in its surface a peripheral slot 14. Since the slot lies on a streamline body and is located at a more reduced cross section of the venturi than the point 11, there will be more suction at 14 than 11 so that fluid will be removed at 11 and introduced into the stream at 14.

Figure 11 is a longitudinal section of a Venturi tube and illustrates another method of energizing the boundary layer at 11. In this instance a compartment 15 is formed in and encircles the venturi and a conduit 16 similar to 12a leads from the compartment to a stationary hollow hub 17 which communicates with the hub inlet 6. By this arrangement the centrifugal force in the blades draws the boundary layer from the peripheral aperture 11 and forces it out the blade and shield openings 3b and 7. Thus the fan energizes the blade, the shield and the venturi boundary layers.

It is to be noted also that the fluid which has passed the blade has a pressure higher than the fluid ahead of the blade so that the downstream or compressed fluid is most desirable for use in energizing the boundary layer on the blade.

Figure 12 shows still another arrangement that will permit very large values of the angle δ . The boundary layer is removed at 18 by the suction at the throat of the Venturi tube. The suction is communicated by the passage 14 to the peripheral opening 19. Since 18 is so far removed from the throat there is an appreciable pressure difference between the localities 18 and 19. By this arrangement the air removed from the wall at 18 is put back in the stream ahead of the fan and is therefore reenergized in passing through the fan.

Where the expansion of the venturi begins there is located a slot 20 which can discharge fluid tangentially to the Venturi wall. The discharge comes from the compartment 21 circumscribing the Venturi throat. If a very short Venturi tube is desired fluid may be supplied to the compart-

ment 21 by the pipe 22 coming from a pump maintained for this purpose. The jet issuing from 20 has a high velocity and energizes the boundary layer. It would be economical to maintain a pump for energizing service and part of the fluid could be fed to a central tube 23 which would lead to the blade interior for use in the openings 3b and 7 to which access would be gained through the hub entrance 6. The pump could be comparatively small. I prefer, however, to utilize the waste fluid under pressure that is so frequently available in industrial plants. As an example of the utilization of waste fluid under pressure, I show the cylinder 24 of a two cycle internal combustion engine. The piston is 25 and the normal exhaust port is 26. Just before the piston uncovers the exhaust port 26, a port 27 is uncovered. It communicates by means of the tube 28 with a container 29. A check valve 30 keeps the flow in the container and the latter serves as a means of steadying the flow to the ducts 21 and 23, to both of which 28 may be connected.

I use the term vane as a general term for wing or blade to indicate a body used to direct fluid.

Referring to the blades or vanes of an impeller I use the term upper and lower surfaces to mean the suction and pressure surfaces respectively. That is, the surface which attacks the fluid is the pressure surface or lower surface. The surface on the opposite side of the vane is the upper surface. It is also sometimes called the back of the blade.

The structure about the fan or impeller may in general be termed a housing or casing as well as a tube.

While the forms of the apparatus herein described constitute preferred embodiments of the invention, it is to be understood that changes may be made herein that do not depart from the scope of the invention which is defined in the appended claims.

What I claim is:

1. In combination, a rotatable fluidscrew having blades, a casing to encircle the fluidscrew and conduct a fluid flow through the fluidscrew, said casing having an entrance upstream from the fluidscrew to admit fluid and an exit downstream to emit the fluid, and a peripheral slot in the casing side wall to admit a relatively thin jet into the casing substantially tangentially to its inner surface at a locality substantially upstream of the plane of rotation of the trailing edge of said blades, said jet serving to energize the boundary layer on the casing between blade tips to maintain a high value of the blade lift near the tips.

2. In combination, a fluidscrew bathed by a relative flow of fluid and having blades of hollow interior, said blade having a perforated upper surface to form an opening in communication with the blade interior, means of causing a flow through said opening to energize the boundary layer and create an augmented lift on the fluidscrew, said lift giving rise to a high induced drag, means to suppress the induced drag comprising an annular tip shield extending about the blades and having an opening in its inner surface with a flow therethrough to energize the boundary layer arising from said relative flow.

3. In a means of blowing, hollow blades whose mean camber maximum ordinate exceeds 10% of the chord, and whose thickness is greater than 15% of the chord a hollow end shield at the blade tips, openings in the upper surfaces of the blades and the inner surfaces of the shields, and means

to supply fluid to the openings, said shield being annular and extending around the blade tips.

4. In a compressor associated with a flow of fluid and having hollow vanes which have openings on their suction side in communication with their hollow interior, said openings in the vanes being succeeded by vane surfaces turning from the flow and being formed to discharge along the vane surface, and conduit means to supply a flow to the vane interiors for discharge through the said opening of fluid which has at least once passed by the external surfaces of said vanes.

5. In combination to form a means of pumping, a fluid impeller comprising a hub body and a hollow blade attached thereto to create the fluid flow, said hub having an inlet opening in communication with the blade interior, said blade having a rearward directed discharge slot in the upper surface in communication with the blade interior, said slot being succeeded by a blade surface turning from the flow so as to tend to cause a separation of the flow from the blade surface, said slot having side walls overlapping rearward to direct fluid rearward substantially along the surface and being extensive radially along a major portion of the radial length of the blade so as to be suitable for use in energizing the boundary layer, and a source of fluid supply under pressure in communication with the hub inlet so a fluid jet is dischargeable from the said discharge slot substantially along the surface to suppress the tendency to flow separation by boundary layer energization, said source of fluid supply being other than the pumped fluid and at a pressure substantially higher than said pumped fluid.

6. In combination to form a means of pumping fluid, a fluid impeller, a casing having an entrance and an exit for the flow of the pumped fluid and serving to conduct the fluid and comprising a throat portion and a diffuser, said diffuser having a perforated side wall to form an inlet opening said throat portion having a peripheral discharge opening, a conduit interconnecting the said inlet and discharge openings, and means to discharge a fluid jet through and along the casing wall, said fluid jet issuing into the interior of the casing at a wall locality situated between the said inlet and discharge openings.

7. A fluid compressor comprising in combination a casing containing fluid, a hollow rotatable blade to discharge fluid into the casing to compress the fluid therein and having a slot in the upper surface in communication with the blade interior, said slot extending radially along a major portion of the blade length and having sides overlapping rearward to direct fluid rearward substantially along the blade surface for use in energizing the boundary layer on the blade, and conduit means to convey fluid from a region of compressed fluid downstream from said blade to the blade interior for discharge from said slot to energize the boundary layer on the blade.

8. A tube having diverging walls, a pumping means incorporating a rotatable blade discharging its pumped fluid through said tube which has a peripheral slot situated downstream from said means of pumping, and means of communication between the slot and the inlet side of the pumping means so that it sucks off the boundary layer of the tube portion aft of the pumping means.

9. In combination, a blade of hollow interior rotatable about an axis to impel a main flow of fluid past itself, walls forming a casing to receive the impelled fluid from said blade and guide the fluid downstream said casing having an inlet and an

exit for said main flow and a wall surface turning from the main flow and a slot in said wall for the energization of the boundary layer formed by the contact of the fluid with the wall surface, said blade having an opening in the surface at a substantial distance from the said axis and in communication with the blade interior, and a conduit means communicating between the slot and the opening in the blade surface so that centrifugal action of the fluid in the blade induces a flow

through said slot to energize the boundary layer on the casing wall.

10. In a vane blower, a vane, a hollow shield at the tip end of the vane and transverse to its span, said shield having an opening in its surface in communication with its hollow interior, and means to cause a flow through the opening, said shield being annular in form and extending around the vane tips.

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