March 1, 1966 T. H. TROLLER 3,237,850

AXIAL FLOW FAN WITH BOUNDARY LAYER CONTROL

Filed Aug. 24, 1964

2 Sheets-Sheet 1

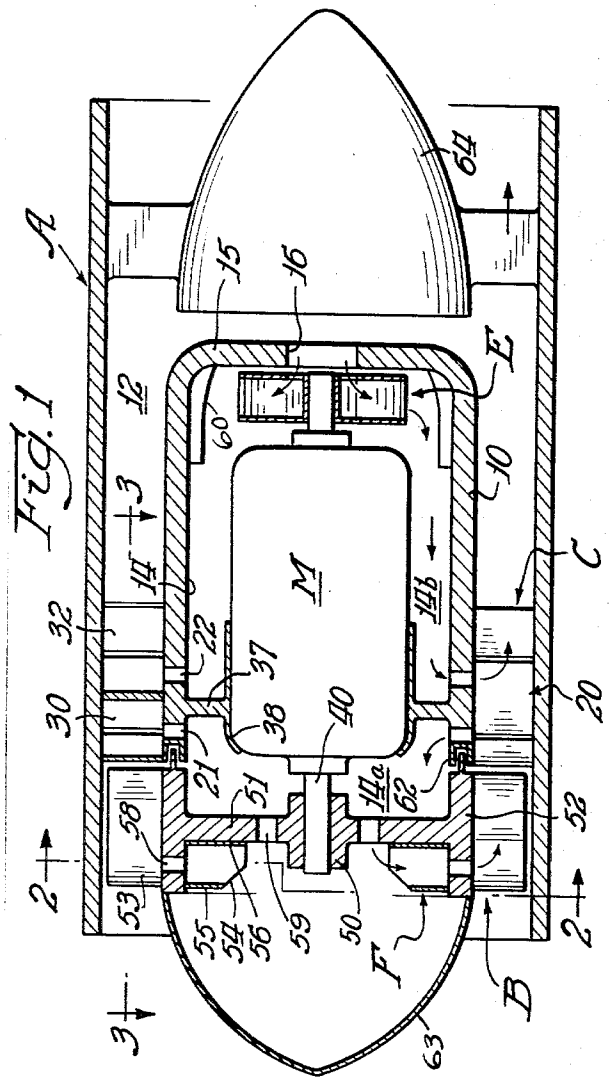


Fig. 1

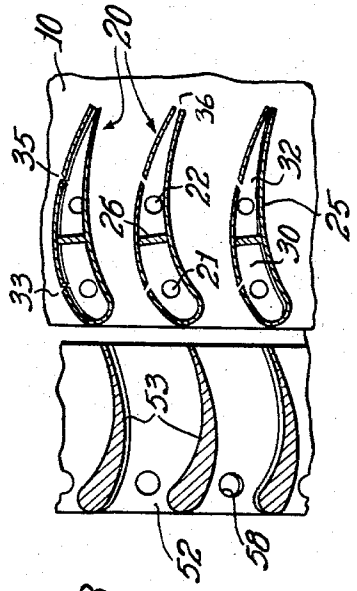


Fig. 3

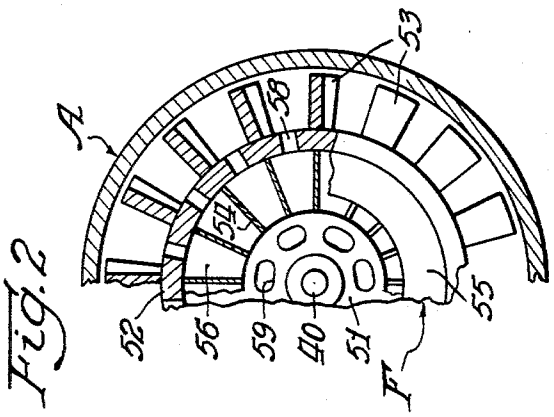


Fig. 2

Inventor:
Theodor H. Troller

By: Thomas B. Hunter
Atty.

March 1, 1966 T. H. TROLLER 3,237,850

AXIAL FLOW FAN WITH BOUNDARY LAYER CONTROL

Filed Aug. 24, 1964

2 Sheets-Sheet 2

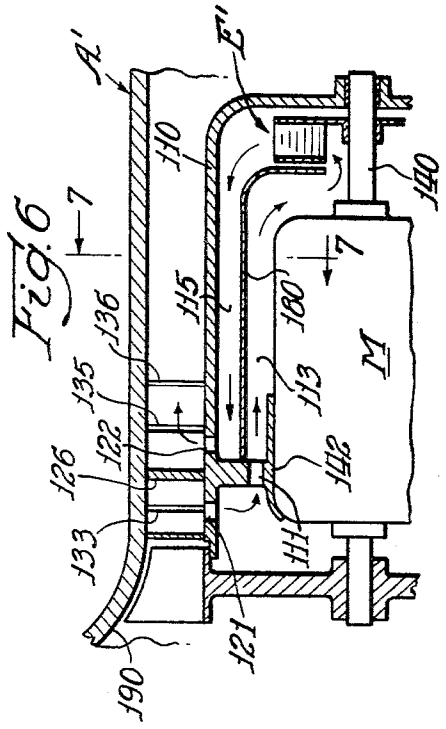


Fig. 6

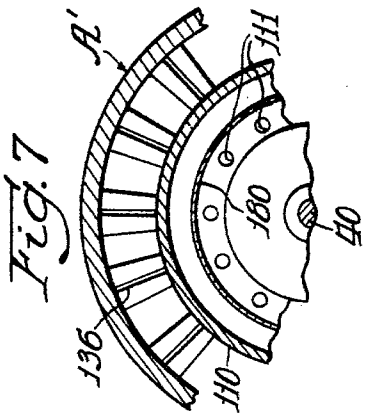


Fig. 7

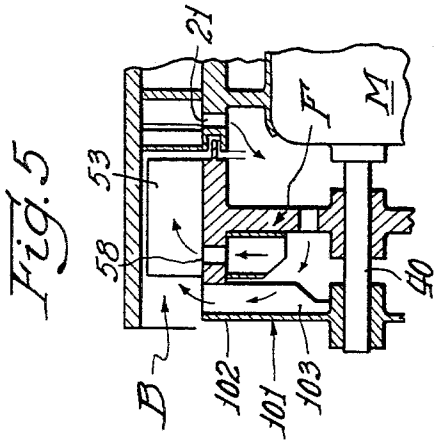


Fig. 5

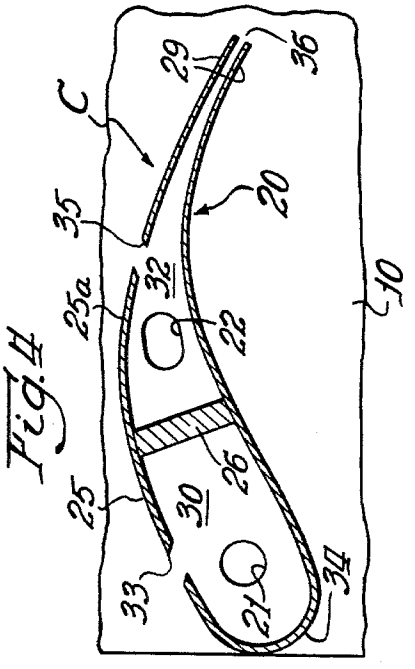


Fig. 4

Inventor:
Theodor H. Troller
By: Thomas B. Hunter
Atty.

United States Patent Office 3,237,850 Patented Mar. 1, 1966

3,237,850

AXIAL FLOW FAN WITH BOUNDARY LAYER CONTROL

Theodor H. Troller, Portal, Ariz., assignor to Borg-Warner Corporation, Chicago, Ill., a corporation of Illinois

Filed Aug. 24, 1964, Ser. No. 391,414
7 Claims. (Cl. 230—122)

This invention relates to improvements in fans or blowers, and more specifically to an improved axial flow fan having boundary layer control.

It is a principal object of the present invention to provide a more efficient axial flow fan or blower which permits lower operating speeds, thereby resulting in less noise, longer service life, and greater over-all reliability.

It is another object of the invention to provide an improved axial flow fan with boundary layer control characterized by a compact organization of elements forming a completely self-contained unit.

It is still another object of the invention to provide a fan in which means for supplying boundary layer control fluid is driven concurrently with the impeller by the same drive means, thereby eliminating an auxiliary power source for providing pressure and/or suction.

Other and more particular objects and advantages will be apparent from the following detailed description taken in conjunction with the appended drawings, wherein:

FIGURE 1 is a cross-sectional view of an axial flow fan constructed in accordance with the principles of the present invention;

FIGURE 2 is a partial cross-sectional view taken along the plane of line 2—2 in FIGURE 1;

FIGURE 3 is a partial cross-sectional view taken along the plane of line 3—3 of FIGURE 1;

FIGURE 4 is an enlarged cross-sectional view through one of the stator vanes;

FIGURE 5 is a cross-sectional view of the forward or intake portion of a modified fan;

FIGURE 6 is a partial cross-sectional view of another modification of an axial flow fan; and

FIGURE 7 is a section taken along the plane of line 7—7 of FIGURE 6.

Briefly described, the subject matter of the invention concerns an apparatus commonly referred to as a vane axial fan or blower. In a preferred embodiment, this fan utilizes a basic single stage, axial flow design including a driven impeller or rotor and a series of stator vanes positioned downstream from the impeller. The impeller supplies energy to the air in the form of added velocity and a portion of this velocity energy is converted to static pressure energy in the stator vane region. The broadest concept of the present invention is the addition of means to accomplish this energy conversion in the stator section to a higher degree than ordinarily possible.

Whenever a viscous fluid flows past a solid body, the layers of fluid nearest the boundary are subjected to shearing forces causing the velocity of these layers to be reduced. As the boundary is approached, the velocity continuously decreases until the boundary is reached, at which point the fluid is at rest relative to the body.

The stagnation of air at the boundary layer seriously affects the efficiency and performance of the fan by retarding the flow of air over the airfoil surface. Under extreme conditions the boundary layer separates from the surface so that the aerodynamic utility of such surface is lost. Boundary layer separation is often accompanied by flow reversal caused by an adverse pressure gradient, i.e., increasing pressure in the downstream direction. When the boundary layer is turbulent, separation occurs further downstream, or not at all.

The development of the boundary layer is affected by

the geometric design of the body. Various factors, such as surface roughness and continuity, play an important part in determining the particular characteristics of the boundary layer. Since the amount of control by purely geometric methods is limited, various attempts have been made in the prior art to use more sophisticated techniques to minimize the effects of boundary layer stagnation. One of these techniques is called blowing boundary layer control, in which air or some other fluid is ejected adjacent the boundary layer to continuously assist the movement of air in the same direction as the major flow path. Another method is sucking boundary layer control which is characterized by the inclusion of means, usually in the form of a series of openings, to permit withdrawal of the stagnant boundary layer in through the airfoil surface.

In the present invention, a combination of these boundary layer control principles are employed on the straightener vanes, hereinafter called stator vanes, positioned behind the impeller. Moreover, the present invention proposes to utilize a self-contained system to provide the necessary means to withdraw and eject the fluid in the manner just described, rather than utilizing complex ducting arrangements and auxiliary pressure and suction sources independent of the fan.

Referring to FIGURE 1, one fan embodying the principles of the present invention comprises a cylindrical shell or housing A; impeller means B; a reaction element C including a plurality of stator vanes; a motor M drivingly connected to the impeller means; an auxiliary blower E for providing a source of pressure, also driven by said motor; and a centrifugal fan F associated with the impeller for providing suction to the stator stage.

Centrally positioned within the housing A is an inner casing **10** which defines an annular fluid passage **12** between the casing and the housing, and also forms a motor receiving cavity **14**. The inner casing **10** includes a radially inwardly extending portion **15** at the rear end thereof which is provided with a central fluid opening **16**. The casing **10** may be supported within the housing in any convenient manner, but is illustrated as being carried on the radially inner portion of the stator vanes **20**.

Stator vanes **20** are of a hollow construction and are fabricated from a relatively thin sheet metal shell **25** shaped in a slightly curved, airfoil conformation. Each of the stator vanes is provided with an internally disposed panel member or septum **26** partitioning off the space enclosed by the housing, the casing and the vane shell into a forward compartment **30** and an aft compartment **32**.

As perhaps best shown in FIGURE 4, the convex or low-pressure surface **25***a* of each stator vane is provided with a first, relatively narrow slot **33** extending lengthwise of the vane between the leading edge **34** and a point approximately intermediate the leading and trailing edges. This first slot, it will be noted, is directed tangentially forward and provides a fluid passage interconnecting the space adjacent the forward portion of the vane with the interior of the forward compartment **30**. A second, tangentially rearwardly directed slot **35** is provided on the low-pressure surface of the vanes downstream of said first slot and approximately intermediate the septum and the trailing edge **29**. This second slot provides a flow path for blowing or ejection fluid and affords communication between the interior of the aft compartment **32** and the exterior thereof. At the point where the trailing edge portions **29** of both the low-pressure and high-pressure sides of the vane shells intersect, they are separated slightly to define a third, rearwardly directed, trailing edge slot **36** opening from the aft compartment **32**.

It will be noted that a plurality of apertures are provided through the inner casing **10** on both sides of a combined motor support-partition member **37**. A first set

of these apertures **21** terminates inside of the forward compartment **30** of each stator vane fluidly interconnecting the latter with the forward section **14***a* of the motor receiving cavity **14**. The second set of apertures **22** terminates inside the aft compartment **32** of the stator vanes thereby affording communication between the latter and the rear section **14***b* of the motor cavity. The purpose of this arrangement will be obvious upon reading the description of the operation.

The drive means, which may be in the form of an electric motor M, is supported within the inner casing **10** by an annular member **37** which has the additional function of dividing the motor receiving cavity **14** into a forward section **14***a* and a rear section **14***b*. The motor may be secured in any well known manner, but is illustrated as, being held within the axially extending ring portion **38** of the annular member **37**, the edge of which is crimped over the end of the motor casing.

The drive shaft **40** of the motor includes front and rear extensions carrying the impeller B and a centrifugal blower E respectively. Impeller B includes a central hub **50** connected to the motor shaft, a web **51**, a rim **52**, and a plurality of circumferentially spaced vanes **53**. In a preferred form, the entire impeller is cast as a single unit, so that the vanes, the rim, the web, and the hub are integral. Received under the axially forwardly extending portion of the rim **52** is a centrifugal blower element F having a plurality of radially extending blades **54** positioned between the pair of annular plates **55**, **56**. The blower element F may be mounted on the impeller in any well known manner; or it may be formed integrally therewith. A first series of apertures **58** is provided in the rim **52** between each of the vanes and a second series of apertures **59** is formed in the web near the hub, the function of which will be clear from a detailed description of the operation. Means for providing an air seal between the impeller and casing **10** are indicated at **62**. In addition, a generally conical fairing **63** is attached to the impeller, while similar means **64** are provided at the downstream end of the fair to augment the aerodynamic characteristics thereof.

As best shown in FIGURE 1, the rear mounted centrifugal blower E is driven by a rear extension and the motor drive shaft **40** and is positioned within the casing **10** between the motor and the inwardly extending portion **15** of the casing. The intake of the blower E is disposed coaxially with and immediately adjacent to the central opening **16** in the casing **10**, so that air is drawn in through said inlet and propelled outwardly and forwardly through the annular space **14***b* between the casing **10** and the motor. It is desirable to include suitable flow guide means **60** on the inside of the casing to guide the air, discharged radially from the blower E, towards the stator vane section.

Operation

Having thus far described the general mechanical construction of the invention, the following detailed description should facilitate an understanding of the operation thereof.

When the motor is energized to drive the impeller and the rear centrifugal blower, the major portion of the air is drawn into the inlet and propelled rearwardly by the impeller through the annular passage **12**. At the same time, two secondary air flow circuits are set up. The first of these, induced by the impeller mounted centrifugal element F, causes air to be sucked through slots **33**, down through apertures **21**, and through apertures **59**, **58** to be returned to the main air stream between the impeller vanes **53**. This results in a removal of the stagnant boundary layer adjacent the forward section of the stator vanes.

The other secondary air flow circuit is induced by the rear centrifugal fan E. A portion of the main air stream is withdrawn through the space defined by the end portion **15** of the casing **10** and member **64**, sucked into the rear blower inlet through opening **16**, and propelled through the annular passage **14***b* between the motor and the casing and through apertures **22** into the aft compartment **32** of each stator vane. This circuit is completed when the air is ejected out of the rear compartment through slots **35** and the trailing edge slots **36**, into the main air stream. Ejection through slots **33** and **35** effectuates the continuous moving along of the stagnant layer while the trailing edge ejection tends to minimize the co-called wake effect, i.e., drag-forming turbulence caused by the separated streams of air coming back together at the trailing edge of the airfoil.

A modified form of a fan or blower is illustrated in FIGURE 5. Under certain conditions, it is possible to improve the suction within the forward compartment and also obtain beneficial reintroduction of control air into the main stream by adding an auxiliary fluid translating device. This may be in the form of a centrifugal fan element **101** preferably mounted on the motor shaft just ahead of the impeller F, so that at least a portion of the control air is reintroduced just ahead of the leading edge of the impeller vanes. Centrifugal fan **101**, which may be of any conventional design, is illustrated as comprising an annular plate **102** mounted for conjoint rotation on the forward extension of motor shaft **40** and a plurality of radially extending impeller vanes **103** terminating at the periphery of the plate **102**. The auxiliary centrifugal fan unit **102** may be used alone or in combination with centrifugal fan element F as described in connection with the first embodiment. When fan element **101** is used alone, it is, of course, unnecessary to provide the apertures **58** through the rim of the impeller unit.

Still another modification shown in FIGURES 6 and 7 utilizes a flow divider element in the form of a partition **180** so that both suction and blowing boundary layer control are provided by a single fan unit E′. As shown most clearly in FIGURE 6, the motor M is secured within casing **110** by an annular retaining element **142** corresponding roughly to retainer **37** in FIGURE 1. A single centrifugal fan element E′ is mounted on the rear extension of motor shaft **140** and is adapted to draw air through suction slots **133** in the forward portion of each of the stator vanes, through apertures **121** in the inner casing **110** and a series of apertures **111** in the annular retaining member **142**, to the inlet of the fan by way of the annular space **113** defined by partition **180** and the motor housing. Air under pressure is delivered from the discharge side of the fan, through the annular space **115** defined between partition **180** and casing **110**, through apertures **122** in said casing, and into the aft compartment of the hollow stator vanes to permit ejection from blowing slot **135** and trailing edge slot **136**. Thus, it will be seen that this modification provides a relatively simple unit, especially adapted for larger installations, which accomplishes substantially the same function as the more complex combinations disclosed in FIGURES 1 through 5.

Another feature disclosed in FIGURE 6 is the bell-shaped inlet **190** which results in a material improvement of the performance characteristics of the fan. The bell-shaped inlet, of course, may be adapted for use in the other modifications disclosed in this application.

In summary then, in order to improve the basic fan structure, it is necessary to create within a self-contained structure an effective boundary control air flow without excessive energy expenditure. This is achieved by connecting suitable air intake and/or outlet slots to other points within the fan wherein pressure or suction is generated. By means of the above-described arrangement, there has been provided a novel and improved axial flow fan in which the efficiency and performance are noticeably improved without the necessity of utilizing an additional source of energy.

While this invention has been described in connection with certain specific embodiments thereof, it is to be understood that this is by way of illustration and not by way of limitation, and the scope of this invention is de-

fined solely by the appended claims which should be constructed as broadly as the prior art will permit. Also, such terms such as forward, rear, upper, lower, etc. are to be regarded in their relative sense.

What is claimed is:

1. An axial flow fan assembly comprising an axial flow impeller; a plurality of stator vanes downstream from said impeller, each said stator vanes having a hollow construction and being divided into first and second compartments; means defining a suction slot in said first compartment; means defining a blowing slot in said second compartment; fan means driven conjointly with said impeller for supplying suction and pressure to said first and second compartments respectively.

2. The assembly as defined in claim 1 wherein said fan means comprises a single centrifugal fan unit having its intake side interconnected with said first compartment and its discharge side interconnected with said second compartment.

3. In an axial flow fan, the combination comprising a generally cylindrical housing having an inlet and an outlet; an axial flow impeller mounted in said housing adjacent said inlet; drive means connected to said impeller; a plurality of stator vanes spaced circumferentially on the inside of said housing downstream from said impeller, each said stator vanes including a hollow shell having an airfoil configuration; means dividing each of said shells into a forward compartment and an aft compartment; a first fan adapted to be driven by said drive means and having its suction side fluidly interconnected with said forward compartment; a second fan adapted to be driven by said drive means and having its discharge side fluidly interconnected with said aft compartment; means defining a suction slot in said stator vanes for inducing stagnant boundary layer fluid through said slot into said forward compartment; means defining an ejection slot in said stator vanes permitting pressurized fluid to be ejected along said boundary layer towards the trailing edge of said stator vanes; and means defining a trailing edge slot in each of said stator vanes for ejecting fluid rearwardly from said aft compartment.

4. An axial flow fan as defined in claim 3, wherein said first fan has its discharge side located immediately ahead of said axial flow impeller so that the stagnant boundary layer fluid withdrawn through said suction slot into said first compartment is re-introduced immediately upstream from said axial flow impeller.

5. An axial flow fan assembly comprising a rotatable impeller; a plurality of stator vanes downstream from said impeller, each of said stator vanes being formed with an airfoil cross-section and having a low-pressure side, a high-pressure side, a leading edge, and a trailing edge, said stator vanes extending radially outwardly in a plane generally parallel to the plane of rotation of said impeller; means for applying suction to the boundary layer on the low-pressure side of said vanes adjacent the leading edge thereof; and means for ejecting boundary layer control fluid on the low-pressure side of said vanes toward said trailing edge.

6. An axial flow fan assembly as defined in claim 5 including means for ejecting fluid at the trailing edge of said vanes where the low-pressure and high-pressure sides intersect.

7. An axial flow fan assembly as defined in claim 5 including an elongated suction slot on the low-pressure side of said vanes adjacent said leading edge and an elongated blowing slot on the low-pressure side thereof adjacent said trailing edge; drive means connected to said impeller; an auxiliary fan driven by said drive means, said auxiliary fan having a suction side and a discharge side; means defining a fluid passage interconnecting the suction side of said auxiliary fan to said suction slots; and means defining a fluid passage interconnecting said blowing slots to the discharge side of said auxiliary fan.

References Cited by the Examiner

UNITED STATES PATENTS

2,156,133	4/1939	Troller	170—172
2,294,586	9/1942	Troller.	
2,344,835	3/1944	Stalker	230—122
2,405,768	8/1946	Stalker	230—122
2,597,510	5/1952	McBride	170—172 X
2,618,433	11/1952	Loos et al.	230—122
2,637,487	5/1953	Sawyer	170—172 X
3,009,630	11/1961	Busquet	230—122 X

FOREIGN PATENTS

477,449	12/1937	Great Britain.

SAMUEL LEVINE, *Primary Examiner.*

JULIUS E. WEST, *Examiner.*