March 8, 1955 A. C. DOTY, JR., ET AL 2,703,556

ROTARY FAN AND FAN AND ORIFICE ASSEMBLY

Filed Oct. 9, 1948 3 Sheets-Sheet 1

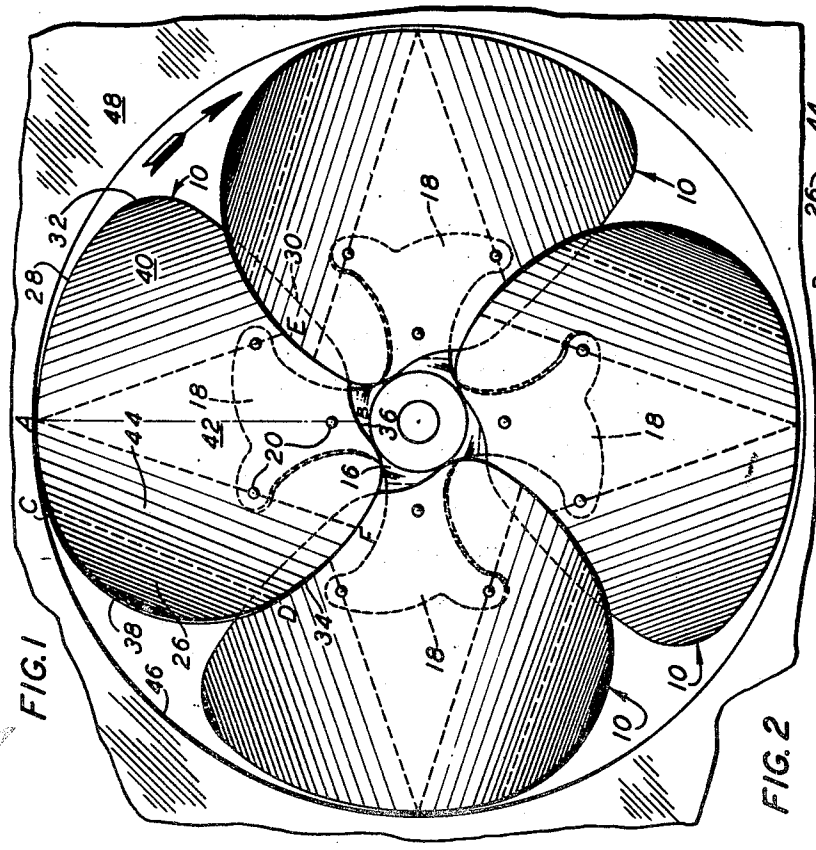


FIG. 1

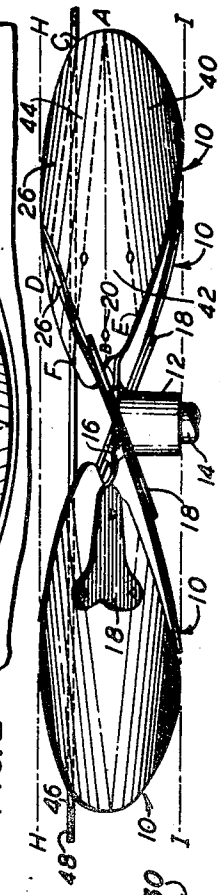


FIG. 2

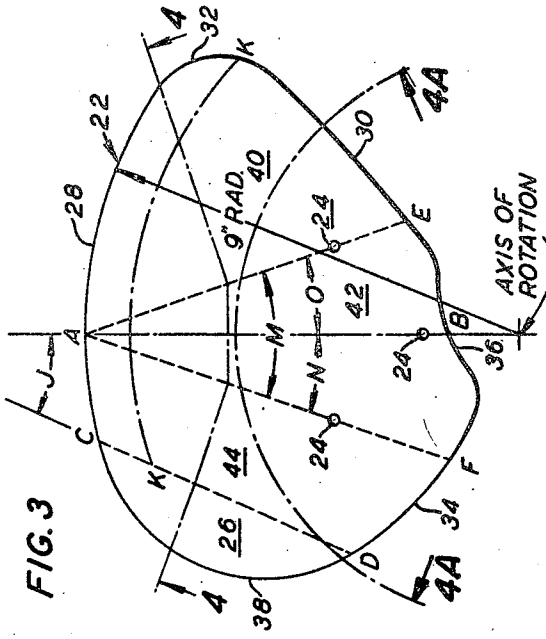


FIG. 3

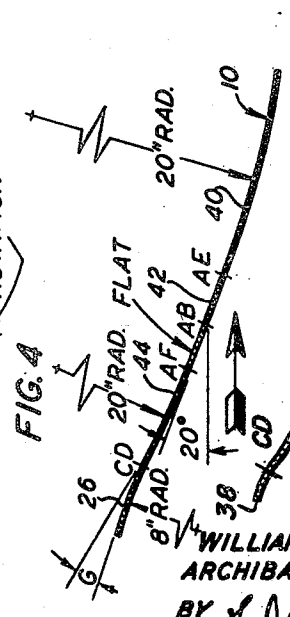


FIG. 4

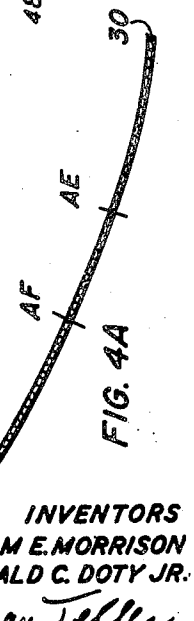


FIG. 4A

INVENTORS
WILLIAM E. MORRISON
ARCHIBALD C. DOTY JR.
BY S. Jay Teller
ATTORNEY

March 8, 1955 A. C. DOTY, JR., ET AL 2,703,556

ROTARY FAN AND FAN AND ORIFICE ASSEMBLY

Filed Oct. 9, 1948 3 Sheets-Sheet 2

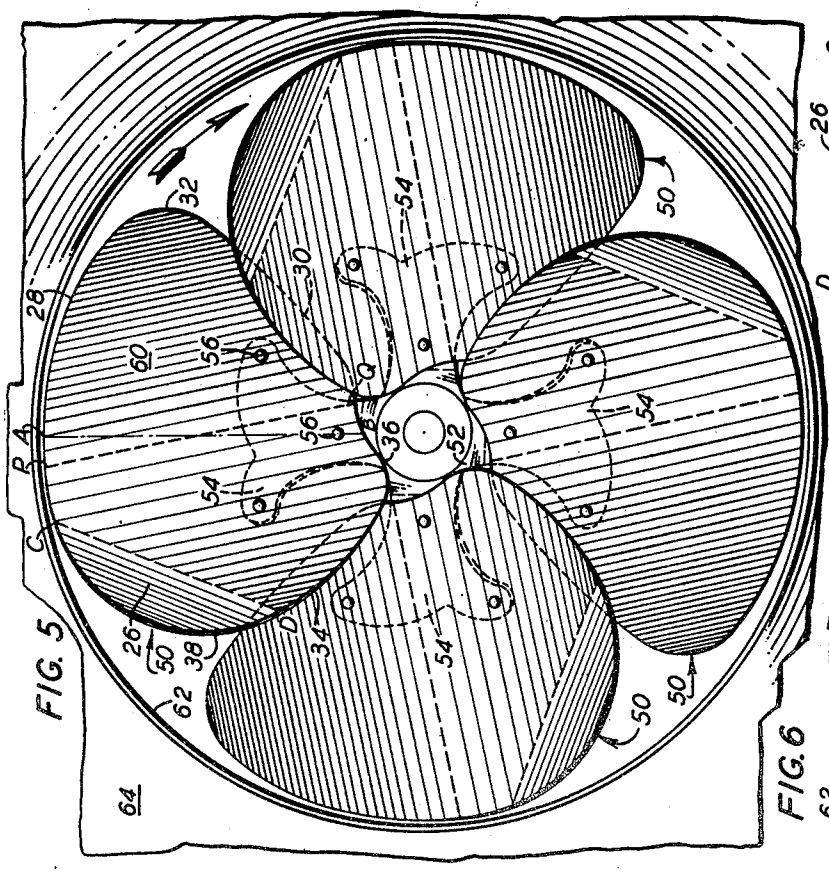


FIG. 5

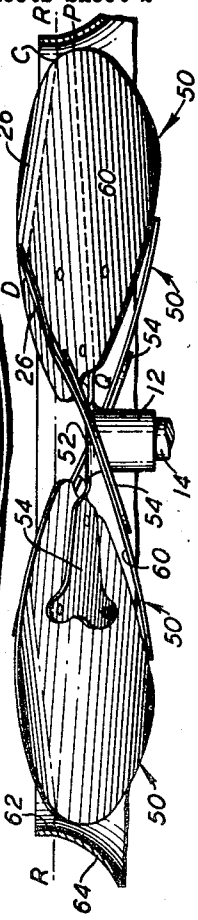


FIG. 6

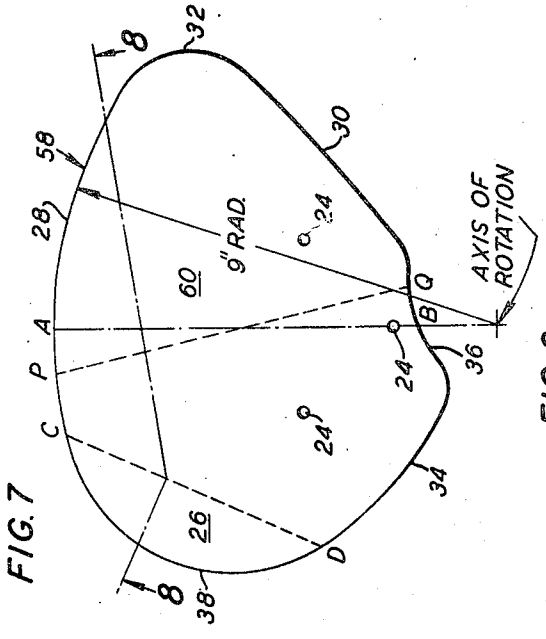


FIG. 7

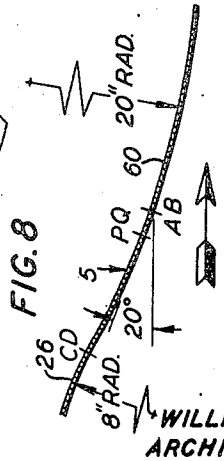


FIG. 8

INVENTORS
WILLIAM E. MORRISON
ARCHIBALD C. DOTY JR.
BY S. Jay Teller
ATTORNEY

March 8, 1955 A. C. DOTY, JR., ET AL 2,703,556

ROTARY FAN AND FAN AND ORIFICE ASSEMBLY

Filed Oct. 9, 1948 3 Sheets-Sheet 3

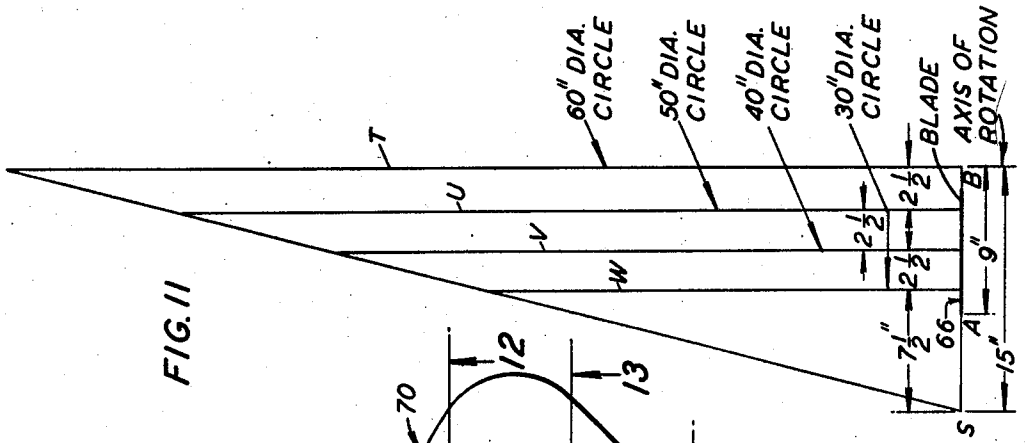


FIG. 11

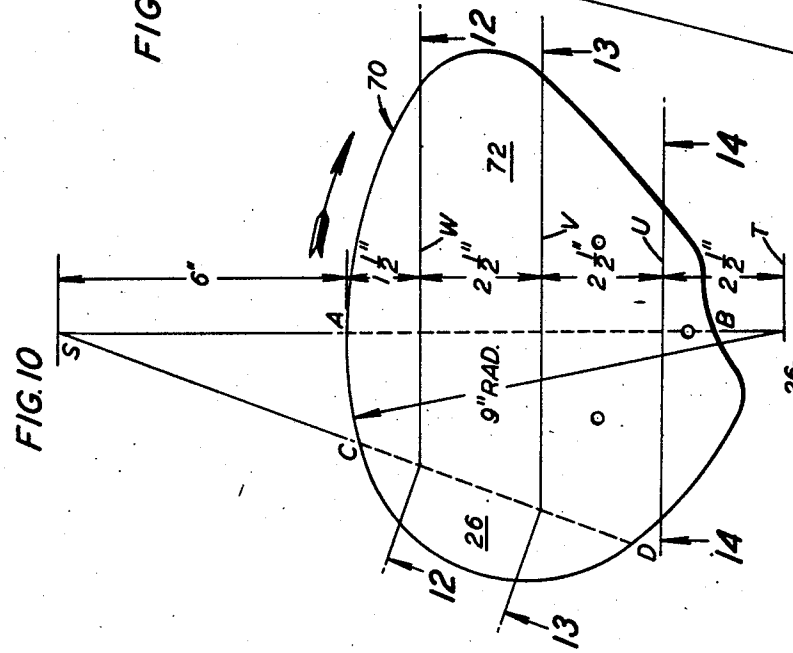


FIG. 10

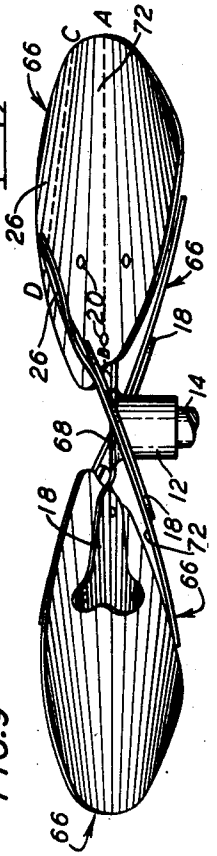


FIG. 9

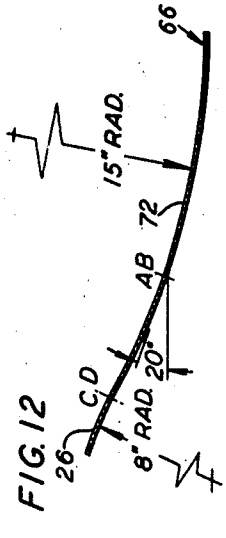


FIG. 12

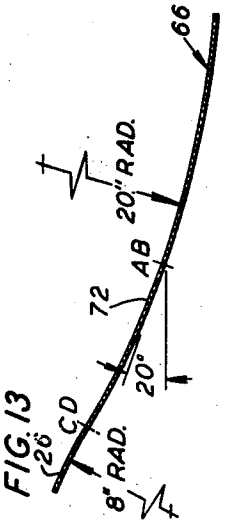


FIG. 13

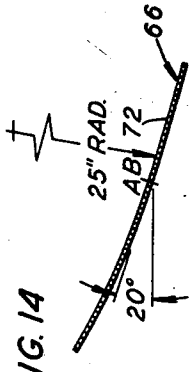


FIG. 14

INVENTORS
WILLIAM E. MORRISON
ARCHIBALD C. DOTY JR.
BY S. Jay Teller
ATTORNEY

United States Patent Office 2,703,556 Patented Mar. 8, 1955

2,703,556

ROTARY FAN AND FAN AND ORIFICE ASSEMBLY

Archibald C. Doty, Jr., Milton, and William E. Morrison, Torrington, Conn., assignors to The Torrington Manufacturing Company, Torrington, Conn., a corporation of Connecticut

Application October 9, 1948, Serial No. 53,724

14 Claims. (Cl. 120—120)

The invention relates to a rotary fan. A fan embodying the invention has some of the characteristics of the fan disclosed in the copending application of William E. Morrison for Fan Blade and Its Formation, Serial No. 792,130, filed December 17, 1947, now Patent No. 2,581,873 dated January 8, 1952.

In a fan embodying the invention, the blades are shaped, formed and mounted in such manner that the fan is adapted for a wide variety of uses. Furthermore, the fan may be constructed with the blades at a wide variety of pitch angles. The fan may be used either as a free air fan or as a pressure fan, and when used as a pressure fan the pressure may be varied over a wide range. For whatever purpose used and with the blades at various pitch angles, the fan provides large air delivery with high efficiency and with a minimum of sound or noise.

In accordance with one aspect of the invention, each blade of the fan has a rearward curved trailing portion which joins the main portion along a juncture line spaced in the trailing direction from a radial line through the center of the blade and diverging in the inward direction from the said radial line. The blade has a substantially concentric peripheral edge and a substantially radial trailing edge and the rearward curved trailing portion is bounded by an arcuate edge tangent to the said peripheral edge and also tangent to the said radial trailing edge.

In accordance with another phase of the invention, each blade of the fan has a concave main portion with novel characteristic, which main portion may be combined with the aforesaid rearward curved trailing portion. The concavity of the main portion of the blade varies in extent from the periphery to the root, being greater at the periphery so as to provide greater pitch angles in the outer region of the blade than in the root region thereof. The variation in concavity may be attained in various ways, as for instance by providing the main portion of the blade with two forward curved substantially cylindrical sections both tangent to a flat intermediate section which is substantially narrower at the periphery than at the root. Alternatively, the variation in concavity may be attained by forming the main portion of the blade as a section of a cone having its apex spaced outwardly from the blade periphery.

In accordance with a further aspect of the invention, the fan, when used as a pressure fan, is combined with an orifice in such a way as to provide maximum air delivery combined with high efficiency. The orifice is so located with respect to the fan that the rear or air receiving end of that portion of the orifice having a minimum diameter is in a transverse plane in substantial register with the outer ends of the juncture lines between the main portions of the blades and the rearward curved trailing portions thereof.

Additional important aspects of the invention will be apparent from the following specification and claims.

In the drawings we have shown in detail three embodiments of the invention, but it will be understood that various changes may be made from the constructions shown, and that the drawings are not to be construed as defining or limiting the scope of the invention, the claims forming a part of this specification being relied upon for that purpose. It will be particularly understood that all angles and dimensions as given in the specification and on the drawings are intended primarily for clarity of explanation, and that the invention is limited to particular angles and dimensions only to the extent set forth in the claims.

Of the drawings:

Fig. 1 is a front view of a fan embodying the invention, the view also showing a portion of a wall having an orifice with which the fan cooperates.

Fig. 2 is a side view of the fan shown in Fig. 1, the wall being shown in section.

Fig. 3 is a front view of an unformed blank for one of the blades of the fan.

Fig. 4 is a sectional view taken along the line 4—4 of Fig. 3 but showing a blade formed from the blank and positioned at the same pitch angle as the blades shown in Figs. 1 and 2.

Fig. 4A is a sectional view taken in the outward direction along the line 4A—4A of Fig. 3, the extent of blade curvature being somewhat exaggerated.

Fig. 5 is a view similar to Fig. 1 but showing an alternative embodiment of the invention.

Fig. 6 is a side view of the fan shown in Fig. 5, the wall being shown in section.

Fig. 7 is a front view of an unformed blank for one of the blades of the fan shown in Figs. 5 and 6.

Fig. 8 is a sectional view taken along the line 8—8 of Fig. 7 but showing a blade formed from the blank and positioned at the same pitch angle as the blades shown in Figs. 5 and 6.

Fig. 9 is a side view similar to Figs. 2 and 6 but showing another alternative embodiment of the invention.

Fig. 10 is a front view of an unformed blank for one of the blades of the fan shown in Fig. 9.

Fig. 11 is a diagrammatic view which includes a section of the blade blank, which section is taken looking toward the right along the line A—B of Fig. 10.

Figs. 12, 13 and 14 are sectional views taken respectively along the lines 12—12, 13—13 and 14—14 of Fig. 10, but showing a blade formed from the blank and positioned at the same pitch angles as the blades shown in Fig. 9.

Fan shown in Figs. 1 to 4A

Referring to the drawings, particularly Figs. 1 to 4A thereof, the blades of the fan are shown at **10, 10.** The fan as illustrated has four blades, but a larger or smaller number of blades may be provided. The blades **10, 10** are connected with a rotatable hub **12** which may be supported and driven by a rotatable shaft **14.** As shown, the blades **10, 10** are connected with the hub **12** by means of a spider **16.** The spider **16** is or may be formed of sheet metal and its central portion is rigidly connected with the hub **12.** The spider has integral arms **18, 18** corresponding in number to the blades **10, 10** and the inner portions of these arms are bent or deformed so as to bring the main portions thereof at suitable pitch angles with respect to the central portion of the spider which is in a plane perpendicular to the axis of rotation.

The main portions of the spider arms **18, 18** are shown as having flat faces, and the blades **10, 10** are suitably secured to the said main portions of the arms, as for instance by means of rivets **20, 20.** As shown, there are three triangularly spaced rivets for each blade. In general the blades have the same pitch angles as the spider arms but different portions of the blades have different pitch angles as the result of the forming of the blades as hereinafter described. The pitch angles of the spider arms may vary according to performance requirements through a range ordinarily running from about 10° to about 40°.

Each blade **10** is formed from a blank **22** as shown in Fig. 3, the blank being shown as having triangularly spaced holes **24, 24** for the rivets **20, 20.** For convenience of description, the view of the blank is marked with lines A—B, C—D, A—E and A—F, and for clarity the same lines are also marked on Fig. 1. The line A—B extends approximately through the center of the blank and when the rivet holes are arranged as shown the said line also extends through the inner rivet hole **24.** The said line A—B is preferably radial when the blade **10** has been formed and has been secured to its spider arm. The line C—D is spaced in the trailing direction from the center line A—B. The portion of the blade at the leading

side of the line C—D will be designated as the main portion, and the portion of the blade at the trailing side of the line C—D will be designated as the trailing portion as indicated at 26. The line C—D will be referred to as the juncture line. It is to be understood that in the following description of the blank and of the formed blanks or blades, all references to proportions and angles, unless otherwise stated, will be based upon a face view of the blank or blade and not upon a projected view with the blank or blade at a pitch angle. The pressure or air delivery side of each blade is herein designated as the front side, and the suction or air intake side of each blade is herein designated as the rear side.

The main portion of the blank 22 has an arcuate peripheral edge 28 which has a curvature such that it is substantially concentric with the axis of rotation when the blade has been formed and mounted. The fan as shown has a diameter of 18" or a radius of 9", and the edge 28 therefore has a radius of at least 9". The radius may be slightly greater than 9" to compensate or partly compensate for the reduction in the projected radius of curvature due to the pitch angle. The main portion of the blank 22 has a substantially radial and preferably substantially straight leading edge 30, this leading edge being connected with the peripheral edge 28 by a convexly curved edge 32 having a relatively small radius. The main portion of the blank 22 has a generally radially extending trailing edge 34, which may be convexly curved as shown. The angular spacing between the trailing edge 34 and the center line A—B is substantially greater than the angular spacing between the leading edge 30 and the said center line A—B. When the blank is to be used for the blades for a four-bladed fan, the included angle between the leading edge 30 and the trailing edge 34 is at least 90° and is preferably about 100°. The leading edge 30 is at an angle of approximately 45° to the radial center line A—B and a median line through the curved trailing edge 34 is at an angle of about 55° to the said center line A—B. The inner ends of the leading and trailing edges are connected by an edge 36 which is preferably concavely curved to clear the inner portion of the corresponding spider arm. The trailing edge 34 is not only more widely spaced from the radial line A—B than is the leading edge 30 but the said trailing edge also extends inward to a greater extent so that its inner end is substantially closer to the axis of rotation than is the inner end of the leading edge 30.

The trailing portion 26 of the blade is bounded by a curved edge 38 which preferably conforms to a substantially circular arc, the outer end of which is tangent at C to the arcuate peripheral edge 28 of the main portion of the blade and the inner end of which is tangent at D to the substantially radial trailing edge 34 of the main portion of the blade. When the radius of the fan is 9" the radius of the edge 38 may be on the order of 3½".

Each blank is so shaped and proportioned that the maximum dimension of each blade in the direction of rotation is substantially greater than its maximum radial dimension. When the blades are shaped as shown and described and when there are four blades, the blades overlap to a small extent, the trailing edge 34 of each blade overlapping the leading edge 30 of the next following blade.

When the blank 22 is formed to constitute a blade 10, the trailing portion 26 is given a substantial rearward curvature along arcuate lines perpendicular to the juncture line C—D. A representative arcuate line is that represented in Fig. 3 by that portion of the section line 4—4 which is at the left of the juncture line C—D. The curvature along the last said line is shown in Fig. 4. The rearward curved trailing portion is preferably a section of a cylinder tangent to the main portion of the blade along the line C—D. For a fan having a diameter of 18" the radius of rearward curvature of the trailing portion 26 is preferably about 8". In fact the radius of curvature may advantageously be on the order of 8" for a wide range of fan diameters, but there may be substantial departure from the said 8" radius. For fans within the diameter range of 8" to 30" the radius of curvature of the trailing portion may range from 5" to 15". The radii may vary somewhat proportionately with the diameters, but there may be wide variation from exactitude of proportion. It is preferable, however, that the radius of curvature be such that the angle G be at least 4° and not more than 12°, the said angle G as shown in Fig. 4 being the angle between a line tangent to the tip of the trailing portion of the blade and a line tangent to the trailing end of the main portion of the blade.

The location of the line C—D is important. The point C at the outer end of the said line C—D is substantially spaced in the trailing direction from the point A on the radial center line A—B, and the said line extends generally inward from the said point C. The locations of the points C on the several blades are such that, when the blades are positioned at suitable pitch angles, as shown for instance in Fig. 2, the said points C bear a proper relationship to planes H—H and I—I, passing respectively through the extreme forward edges and the extreme rearward edges of the several blades as indicated in Fig. 2. The points C are spaced from the plane H—H by a distance ranging from 25% to 40% of the distance between the two planes. As shown, they are spaced from the plane H—H by a distance of about 28% of the distance between the planes.

The point D at the inner end of the line C—D is located at a distance from an extension of the arc of the peripheral edge 28 which is at least 30% and not more than 45% of the distance from the last said arc to the axis of rotation. As shown, the point D is at about 38% of the distance from the said arc to the said axis.

With the points C and D located as described, the line C—D substantially diverges from the said radial line A—B. The angle of divergence is indicated at J in Fig. 3, the said angle in projection being somewhat less, varying with the pitch angle of the blades. The angle J may be varied, but it should not be less than 20° nor more than 35°. Fig. 3 of the drawing shows an angle of about 24° but an angle of about 27° is ordinarily preferred. The line C—D is so located and the curvature of the edge 38 is such that the area of the trailing portion 26 is at least 5% and not more than 15% of the total area of the blade.

The main portion of each blade 10 at the leading side of the juncture line C—D is generally concave at the forward side along arcuate lines such as K—K and L—L concentric with the axis of rotation. The formation of the blade to provide concavity may be varied, but one suitable formation is shown in Figs. 1 to 4 and will be now described.

The lines A—E and A—F substantially diverge in the inward direction from the periphery of the blade. As shown, the said lines intersect at a point A located at the periphery. The angle M between the said lines A—E and A—F is shown in Fig. 3 on the order of 40°. In projection the angle M is somewhat less, the projected angle varying with the pitch angle of the blades. The angle M may be varied but it should not be more than 60°. As shown, each of the angles N and O between the line A—B and the respective lines A—E and A—F is one-half of the angle M, but this is not essential and the last said angles need not be exactly equal. However, neither of the angles N or O should be more than 30°. When there are three rivet holes 24, 24 arranged as shown, the lines A—E and A—F may advantageously extend through the two outer rivet holes.

The lines A—E, A—B and A—F divide the main portion of the blade into three areas designated respectively as 40, 42 and 44. The areas 40 and 42 are approximations of triangles, the said triangles being in relatively inverted positions.

When the blank 22 is formed to constitute a blade, the area 42 remains flat, this being substantially narrower at the periphery than at the root and being shown as a triangle having its apex at the periphery. The leading area of the blank, that is, the area 40, is so shaped that it becomes a substantially cylindrical section which is concave at the front, or air delivery side, and is tangent to the flat area 42. When the blade is mounted the cylindrical section 40 is tangent not only to the flat area 42 but also to the substantially pitched plane of the face of the corresponding spider arm 18. The line of tangency of said section 40 is the aforesaid line A—E, which line is at the angle O to the radial line A—B with its outer end trailing. The expression "outer end trailing" is intended to signify that the line is inclined in the trailing direction with its outer end angularly spaced in the trailing direction from its inner end.

For a fan having a diameter of 18" the radius of the cylindrical area 40 is preferably about 20". In fact the radius of the cylindrical area may advantageously be on the order of 20" for a wide range of fan diameters,

but there may be substantial departure from the said 20" radius. For fans within the diameter range of 8" to 30" the radius of the cylindrical area may range from 16" to 35". It is preferable for fans as illustrated that the radius be at least 100% of the diameter of the fan and not more than 200% of the said diameter.

As already stated, each arm **18** of the spider has a flat mounting face. The area **42** of each blade between the lines A—E and A—F is flat and this area is therefore adapted for direct engagement with the flat face of the corresponding spider arm. The blade may be secured in place by rivets **20, 20** as already stated.

Each blade **10** is so formed that the area **44** thereof between the lines A—F and C—D is a substantially cylindrical section which is concave at the front and is tangent to the flat area **42**. When the blade is mounted the cylindrical area **44** thereof is tangent not only to the flat area **42** but also to the substantially pitched plane of the face of the corresponding spider arm **18**. The line of tangency of said area **44** is the aforesaid line A—F, which line is at the angle N to the radial line A—B with its outer end leading. The expression "outer end leading" is intended to signify that the line is inclined in the leading direction with its outer end angularly spaced in the leading direction from its inner end.

The radius of curvature of the cylindrical area **44** is preferably the same as the radius of curvature of the leading cylindrical area **40**, and may be varied through the same range.

When the main portion of the blade has a trailing cylindrical section **44** which is tangent to the flat area **42** along the line A—F, the juncture line C—D between the trailing portion **26** and the cylindrical section **44** is preferably substantially parallel to the said line A—F and it may be exactly parallel. Thus the cylindrical section constituting the trailing portion **26** is substantially parallel with the cylindrical section **44**.

When the main portion of the blade is formed as shown and described the pitch angles along each circular arc concentric with the axis of rotation progressively increase in the trailing direction from the leading edge **30**. The arc 4A—4A in Fig. 3 may be taken as an example of a circular arc concentric with the axis of rotation, Fig. 4A being a sectional view taken along the said arc with the curvature somewhat exaggerated. By reference to Fig. 4A it will be observed that the pitch angles are progressively greater at the following zones spaced in the trailing direction: the zone immediately adjacent the leading edge **30**, the zone midway between the leading edge **30** and the line A—E, the zone between the lines A—E and A—F, the zone midway between the lines A—F and C—D, and the zone immediately adjacent and at the leading side of the line C—D. The pitch angles similarly increase progressively along each other arc concentric with the axis rotation and beyond or spaced outwardly from the root area.

When the main portion of the blade is formed with two cylindrical sections such as **40** and **44** which are tangent to an intermediate flat section such as **42** narrower at the periphery than at the root, the concavity of the said main portion is different along different arcuate lines such as K—K and L—L. The extent of concavity decreases progressively from the periphery of the blade to the root thereof. For instance, the line K—K near the periphery intersects only a very narrow portion of the flat area **42** and the degree of concavity along the said line is substantial. The line L—L which is much nearer the root of the blade intersects a much wider portion of the flat area **42** and the degree of concavity along the last said line is considerably less. An arcuate line close to the root would chiefly intersect the flat area **42** and there would be practically no concavity.

While a fan embodying the invention is of general utility, it is particularly adapted for use in delivering air through an orifice having a minimum diameter but little greater than that of the fan. Figs. 1 and 2 show the fan located in an orifice **46** in a thin flat wall **48**. The fan rotates in the clockwise direction as viewed in Fig. 1, and the air therefore moves in the upward direction through the orifice as viewed in Fig. 2. In this case the orifice has a uniform diameter which is its minimum diameter. The rear or air intake end of that portion of the orifice having the uniform minimum diameter is at a plane coincident with the rear face of the wall **48**.

As has been stated, the point C on each blade is at a distance from the plane H—H which is from 25% to 40% of the distance between the planes H—H and I—I. For maximum air delivery and high efficiency the fan is so located with respect to the orifice **46** that the rear end of that portion of the orifice having a minimum diameter is in a transverse plane in substantial register with the points C on the several blades, that is, with the outer ends of the juncture lines C—D. In other words, the plane of the rear face of the wall **48** is in substantial register with the points C. Thus the main portions of the several blades are chiefly at the rear of the aforesaid plane, and the trailing portions **26** of the several blades are entirely at the front of the said plane.

Fan shown in Figs. 5 to 8

Figs. 5 to 8 of the drawings show a fan which is generally similar to that shown in Figs. 1 to 4A, but which differs in certain important details. The fan has blades **50, 50** which are similar to the blades **10, 10** and it has a spider **52** which is similar to the spider **16** except that the mounting faces of the arms **54, 54** thereof are concave instead of flat. The blades are connected to the spider arms by suitable means such as rivets **56, 56**. As shown, there are three triangularly spaced rivets for each blade.

Each blade **50** is formed from a blank **58** which is or may be exactly the same as the blank **22** for each blade **10**, the blank having similar rivet holes **24, 24**. For convenience of description the blank **58** is marked with lines A—B, C—D and P—Q, and for clarity the same lines are also marked on Fig. 5. The lines A—B and C—D correspond respectively to the similarly designated lines on the blank **22** and repetition of the description is unnecessary. The blank has a trailing portion **26** at the trailing side of the line C—D and has a main portion **60** at the leading side of the said line. The trailing portion **26** is or may be the same as that of the blank **22** and the said trailing portion is similarly provided with a rearward curvature when the blank is formed to constitute a blade.

The blade **50** differs from the blade **10** in that the entire area **60** of the main portion thereof is formed to provide a single cylindrical section concave at the front. This is in contrast with the blade **10**, the main portion of which comprises two separate cylindrical sections **40** and **44** with an interposed flat area **42**. The radius of curvature of the said cylindrical section constituting the main portion of each blade **50** is preferably the same as the radii of the cylindrical sections **40** and **44** of each blade **10** and may be varied through the same range.

Each blade **50** is so mounted that the cylindrical section **60** thereof is tangent to a substantially pitched plane, that is, a plane at a substantial angle to a plane perpendicular to the axis of rotation. The said section **60** is tangent to the said pitched plane along the line P—Q intersecting the radial line A—B through the center of the blade at a substantially projected angle not greater than 30° which line of tangency has its outer end trailing. The line P—Q intersects the line A—B about midway of the latter.

As already stated each arm **54** of the spider has a concave mounting face. The concavity of this mounting face is such that the said face exactly conforms to the rear convex face of the blade when the blade is positioned as described.

Figs. 5 and 6 show the fan located in a bell-mouth orifice **62** in a wall **64**. The orifice extends from the wall in the forward direction and the forward portion of the orifice at the front of the transverse plane R—R is or may be cylindrical. In any event the plane R—R is at the rear or air intake end of that portion of the orifice having a minimum diameter. For maximum air delivery and high efficiency the fan is so located with respect to the orifice **62** that the plane R—R is in substantial register with the points C on the several blades, that is, with the outer ends of the juncture lines C—D. Thus the main portions of the several blades are chiefly at the rear of the said plane, and the trailing portions **26** of the several blades are entirely at the front of the said plane.

Fan shown in Figs. 9 to 14

Figs. 9 to 14 of the drawings show another fan which is generally similar to those shown in Figs. 1 to 4A and

in Figs. 5 to 8, but which differs as to blade formation. The fan has blades 66, 66 which are similar to the blades 10, 10 and 50, 50 and it has a spider 68 which is similar to the spider 52, except that the concave faces of the spider arms are somewhat differently shaped to conform to the different shape of the blades 66.

Each blade 66 is formed from a blank 70 which is or may be exactly the same as the blanks 22 and 58. The blade 66 is similar to the blade 50 but differs therefrom in that the main portion 72 thereof at the leading side of the juncture line C—D is a section of a cone instead of being a section of a cylinder. The trailing section 26 may be and preferably is substantially as hereinbefore described, but as shown the angle of divergence of the line C—D is slightly less, being approximately 22°.

The main portion 72 of the blank 70 is a section of a cone formed by a straight generatrix line passing through an apex S spaced outwardly from the periphery of the blade and following a base circle T near the axis of rotation. The apex S and the circle T, as viewed edgewise, are shown in Fig. 11. The apex S may lie in a line constituting an extension of the radial line A—B and it is so shown, but as to this there may be variation. The base circle T is tangent to the pitch plane of the blade and is preferably in a plane substantially perpendicular to the said pitch plane. The said plane of the circle T may also be substantially perpendicular to the radial line A—B and it is so shown, but as to this there may be variation. For clarity of understanding of the disclosed embodiment of the invention, the base circle T may be assumed to be in a plane so located that the axis of rotation lies within it. Circles U, V and W, as viewed edgewise, are also shown in Fig. 11, these circles representing transverse sections of the cone and having diameters that are successively smaller than the diameter of the base circle T.

The dimensions of the cone may be widely varied, but when the blade has a radius of 9" and when the cone is shaped and positioned as shown, the apex S of the cone may be 15" from the axis of rotation and the diameter of the base circle T may be 60". With the circles U, V and W located as shown, it follows that their diameters are respectively 50", 40" and 30".

Figs. 12, 13 and 14 are sections taken respectively along the lines 12—12, 13—13 and 14—14, the leading portions of these section lines being so located that they are respectively in the planes of the circles U, V and W.

When the apex S of the cone is located as shown in an extension of the line A—B, the juncture line C—D may advantageously be so located that it coincides with a generatrix line of the cone, but this is not essential.

It will be seen that the blade 66 is similar to the blade 10 in that the extent of concavity of the main portion 72 decreases progressively from the periphery of the blade to the root thereof. The section along the line 12—12 has a substantial concavity represented by a relatively small radius, as for instance 15". The section along the line 13—13 has a smaller concavity represented by a larger radius, as for instance 20". The section along the line 14—14 has a still smaller concavity represented by a still larger radius, as for instance 25".

Explanation of fan operation

Extensive laboratory tests have been made of fans embodying the invention and comparable tests have been made of various prior fans representing the best known prior practice. These tests have shown that, under all normal operating conditions, the percentage of efficiency of fans embodying the invention is at least 20% greater than the percentage of efficiency of any of the said prior fans. The reasons for the great superiority shown by the tests are not fully understood, but the advantages of the various features of the fans as disclosed will be now explained as fully and as clearly as now appears possible.

In the explanation the term "pitch angle" refers to the actual angle between any specified blade portion and a plane perpendicular to the axis of rotation, such angle being measured along an arcuate line concentric with the axis of rotation. The term "constant pitch" refers to a pitch such as would be provided by a true helicoidal surface. With "constant pitch" the "pitch angle" at points along any radial line decreases uniformly from the root to the periphery.

The fan blades in each embodiment of the invention are wide, each blade having its maximum dimension in the direction of rotation greater than its maximum radial dimension. Each blade has substantially radial leading and trailing edges and the wide outer portions of the blades are closely spaced in the direction of rotation. The said wide outer portions of the blades, which are the most effective portions, cooperate with other features which will be pointed out.

In each embodiment of the invention there is a close approximation of constant pitch along the leading edge of each blade. Referring particularly to the fan shown in Figs. 1 to 4A, the leading edge 30 of each blade is substantially radial and substantially straight. On account of the described inclination of the axis of the substantially cylindrical section 40, the radial leading edge 30 intersects the said cylindrical section at points which, in the outward direction, are spaced successively farther from the plane of the flat area 42. The angle of the line of tangency A—E and the radius of cylindrical curvature are such that the portion of the leading cylindrical section of the blade which is adjacent the radial leading edge 30 has a close approximation of constant pitch. Each blade has a close approximation of constant pitch not only immediately adjacent the leading edge 30 but also along all radial lines through the leading cylindrical section 40 of the blade.

What has been said about substantially constant pitch in the leading portions of the fan shown in Figs. 1 to 4A is also entirely applicable to the fan shown in Figs. 5 to 8 and is also applicable in substance to the fan shown in Figs. 9 to 14.

For each fan the pitch angle of the spider arms may be widely varied as has been stated, and the actual pitch angle of the leading edge portion correspondingly varies. However, the formation of the blades of each fan is such as to provide the best performance characteristics at intermediate spider arm pitch angles such as are more commonly used but to nevertheless provide good performance characteristics at smaller and larger spider arm pitch angles.

While there is an approximation of constant pitch at the leading portions of the blades of each fan, the pitch angle in each instance increases along arcuate lines from the leading edge to the line C—D at which the rearward curved trailing portion 26 joins the main portion. Referring particularly to the fan shown in Figs. 1 to 4A, the pitch angle of the forward curved cylindrical section 40 continuously increases in the trailing direction. The central area 42, being flat, does not have an approximately constant pitch, but the said area has a pitch angle which is greater than the mean pitch angle of the cylindrical section 40. The trailing cylindrical section 44 does not have an approximately constant pitch, but the pitch angle thereof increases in the trailing direction. The mean pitch angle of the cylindrical section 44 is greater than that of the flat area 42. From the foregoing it will be evident that from the leading edge 30 to the line C—D there is an increasing pitch angle measured along any arcuate line such as the lines K—K and L—L, or in other words there is increasingly greater departure along such lines from an imaginary helicoidal surface tangent to the blade at the said leading edge.

What has been said about the fan shown in Figs. 1 to 4A concerning increases in the pitch angle from the leading edge to the line C—D is also applicable in substance to the fans shown in Figs. 5 to 8 and in Figs. 9 to 14. The leading portion of the main cylindrical area 60 of each blade of the fan shown in Figs. 5 to 8 has a close approximation of constant pitch, and there is also a close approximation of constant pitch at points along radial lines spaced in the trailing direction from the leading edge. However, as the center of the blade is approached and passed, there is increasing departure from constant pitch. Furthermore, there is a gradual increase in pitch angle from the leading edge to the line C—D. The leading portion of the main conical area 72 of each blade of the fan shown in Figs. 9 to 14 has a close approximation of constant pitch, and there is also a close approximation of constant pitch at points along radial lines spaced in the trailing direction from the leading edge. However, as the radial line A—B is approached and passed, there is increasing departure from constant pitch. Furthermore, there is a gradual increase in pitch angle from the leading edge of the line C—D.

It is well known that in a fan of the present type, the outer portions of the blades are most effective, this apply-

ing more particularly to the outer approximately one-third portions, these outer portions serving to provide a tubular or annular stream of forward moving air. It has already been stated that each blade of the fan shown in Figs. 1 to 4A has varying concavity, the concavity being greater at the periphery. This is due to the angular relationship of the cylindrical sections **40** and **44** with the flat area **42** between them. As to the result of the said varying concavity, the total increase in pitch angle from the leading edge to the line C—D is substantially greater in outer portions of the blades, more particularly in the aforesaid outer approximately one-third portions. As each blade rotates, the leading edge portion of the cylindrical section **40** engages the air and starts the movement thereof in the forward direction. The air thus started in motion is accelerated by the successively following areas **42** and **44** of the main portion of the blade, which areas have successively increasing pitch angles, more particularly in the outer portions thereof. Thus the air is started in motion relatively slowly and is gradually and increasingly accelerated. By reason of the greater increase in pitch angles in the said outer portions of the blades, the described acceleration of the air is greatest in the last said portions to thus give greater acceleration to the aforesaid tubular or annular stream of forward moving air.

What has been said about the fan shown in Figs. 1 to 4A concerning varying concavity in the blades and concerning a greater increase in pitch angle in the outer portions of the blades, is also applicable in substance to the fan shown in Figs. 9 to 14.

In order to materially reduce the power required to handle a given amount of air and for other reasons, the beforedescribed rearward curved trailing portions **26** are provided, these being located chiefly within the area of the aforesaid tubular or annular stream of air, that is, in the region of greatest air velocity and greatest pressure. The rearward curved portions **26** eliminate or at least very substantially reduce the drag and resultant power loss which would otherwise result from tip vortices at the trailing edges of the blades in the said area of maximum velocity and pressure. Furthermore, the rearward curved trailing portions permit a smooth take-off of the positively axially impelled air stream and prevent all but a negligible minimum of turbulence, thus materially reducing noise. This result is greatly enhanced by the distinctly wide blades and by the well rounded curvature of the trailing edge. It will be observed that, while the trailing portions **26** have rearward curvature, they nevertheless have substantial pitch angles, as will be apparent from Figs. 4, 6, 12 and 13.

As has been stated, a fan embodying the invention has general utility and is adapted for use throughout a wide pressure range. For free air use or for use with very low pressures, the fan utilizes the induction principle which is fully explained in the before-mentioned Morrison Patent No. 2,581,873. The tubular or annular stream of air impelled by the outer approximately one-third portions of the blades results in a pressure drop to produce a partial vacuum in the central area of the fan at the front thereof. The air pressure in the central area at the front or air delivery side is therefore lower and there is an induced flow of air from the relatively high pressure central area at the rear to the relatively low pressure central area at the front. The fan blades overlap to some extent, but there are wide spacings in the axial direction between the leading edges of the several blades and the trailing edges of the next preceding blades. These wide spacings permit induced air flow from the rear to the front as described. It is believed that the increased air delivery resulting from induction as described is attained with very little, if any, increased power, inasmuch as the energy necessary for such induction has theretofore been expended in the development of the velocity of the air stream impelled by the outer areas of the blades.

When the fan is used with higher pressures, the blades are effective to impel air throughout substantially their entire areas, and there is no induced flow in the central region. The formation and arrangement of the blades are such that the fan is also highly effective for the greater pressures. At higher pressures there is a tendency toward a pressure loss and a reduced volume of air, this resulting from a leak-back of air in the central area from the region of relatively high pressure at the front to the region of relatively low pressure at the rear. As already stated, the trailing edge **34** of each blade is more widely spaced from the radial line A—B than is the leading edge **30**, and the trailing edge **34** is extended so that its inner end is closer to the axis of rotation than is the inner end of the leading edge **30**. The described shape of the trailing root portion of each blade provides an extended region near the trailing edge **34**. The extended regions of the several blades results in an overlapping which of itself tends to prevent or reduce to a minimum any leak-back of air, inasmuch as there are practically no areas permitting direct axial air flow from front to rear. Furthermore, the blades are curved forward within the said extended regions so that they have increased pitch angles at the trailing edges. The extended regions therefore effectively impart forward movement to the air in the central area thus cooperating with the overlapping of the blades to prevent any possible leak-back of air.

From the two immediately preceding paragraphs it will be seen that a fan embodying the invention is well adapted for free air or low pressure use and also for high pressure use. For low pressures the induction principle is utilized and for higher pressures undesirable leak-back is prevented. A fan constructed in accordance with the invention is adapted for either high pressures or low pressures with good operating characteristics under all conditions.

When any of the described fans is to be used for pressure applications, the best results are attained by combining the fan with an orifice as shown in detail in Figs. 1 and 2 or as shown in Figs. 5 and 6. The rear or air intake end of that portion of the orifice having a minimum diameter is in a transverse plane substantially in register with the outer ends of the juncture lines C—D at which the rearward curved trailing portions of the blades join the main portions thereof. Approximately one-third of the depth of the fan is at the front of said transverse plane and approximately two-thirds of the depth of the fan is at the rear of the said plane. Thus the main portions of the blades are chiefly within a region of low pressure and can operate with maximum efficiency in picking up the air and accelerating it in the forward axial direction. The rearward curved trailing portions are entirely within a region of higher pressure and the air is delivered into the higher pressure region smoothly and with a minimum of turbulence. The peripheral wall of the orifice is closely adjacent the periphery of the fan, thus preventing any substantial leak-back of air outside the area of the fan, from the higher pressure region at the front to the lower pressure region at the rear. While the theory of operation is not fully understood, extensive tests have shown that the disclosed relationship between the fan and the orifice give much better results, particularly as to the volume of air delivery, than can be attained with any other relationship.

What is claimed is:

1. The combination in a fan, of a rotatable hub and a plurality of similar equally spaced blades secured thereto at substantial pitch angles each of which blades has its maximum dimension in the direction of rotation greater than its maximum radial dimension, each blade comprising a main portion provided with a peripheral edge approximately concentric with the axis of rotation and provided with generally radially extending leading and trailing edges and each blade also comprising a rearward curved trailing portion joining the said main portion along a substantially straight juncture line which extends generally inward from a point located at the said peripheral edge and substantially spaced in the trailing direction from a radial line through the center of the blade and which substantially diverges inwardly and in the trailing direction from the said radial line at an acute angle thereto so as to intersect the trailing edge of the main portion of the blade at a distance from the axis of rotation of the blade that is in the range of 30% to 45% of the distance from the said axis to an extension of the arc of the said peripheral edge of the blade, the said trailing portion having a trailing edge that is at least partly smoothly curved and convex and that is tangent at its outer end to the said peripheral edge of the main portion and tangent at its inner end to the said radially extending trailing edge of the main portion.

2. A fan as set forth in claim 1, wherein the trailing edge of said trailing portion substantially conforms throughout the length thereof to an arc of a circle.

3. A fan as set forth in claim 2, wherein the radius of the said arc of a circle is on the order of 39% of the

radius of the peripheral edge of the main portion of the blade.

4. A fan as set forth in claim 1, wherein the radially extending trailing edge of the main portion of each blade has its inner end substantially closer to the axis of rotation than is the inner end of the radially extending leading edge thereof.

5. The combination in a fan, of a rotatable hub and a plurality of similar equally spaced blades secured thereto at substantial pitch angles each of which blades has its maximum dimension in the direction of rotation greater than its maximum radial dimension, each blade comprising a main portion provided with a peripheral edge approximately concentric with the axis of rotation and provided with a generally radially extending trailing edge and each blade also comprising a rearward curved trailing portion which is a section of a cylinder tangent to the said main portion along a substantially straight juncture line which extends generally inward from a point located at the said peripheral edge and substantially spaced in the trailing direction from a radial line through the center of the blade and which substantially diverges inwardly and in the trailing direction from the said radial line at an acute angle thereto so as to intersect the said trailing edge of the main portion of the blade at a distance from the axis of rotation of the blade that is in the range of 30% to 45% of the distance from the said axis to an extension of the arc of the said peripheral edge of the blade, the radius of the said rearward curved trailing portion being such that there is an angle of at least 4° and not more than 12° between a line perpendicular to the said juncture line and there tangent to the main portion of the blade and a line perpendicular to the said juncture line and tangent to the said trailing portion at the trailing edge thereof, and the said trailing portion having a convex trailing edge tangent at its outer end to the said peripheral edge of the main portion and tangent at its inner end to the said radially extending trailing edge of the main portion.

6. The combination in a fan, of a rotatable hub and a plurality of similar equally spaced blades secured thereto at substantial pitch angles each of which blades has its maximum dimension in the direction of rotation greater than its maximum radial dimension, each blade comprising a main portion provided with a peripheral edge approximately concentric with the axis of rotation and provided with a generally radially extending trailing edge and each blade also comprising a rearward curved trailing portion which joins the said main portion along a substantially straight juncture line which extends generally inward from a point located at said peripheral edge and substantially spaced in the trailing direction from a radial line through the center of the blade and which diverges inwardly and in the trailing direction from the said radial line at an angle thereto which is at least 20° and not more than 35° so as to intersect the trailing edge of the main portion of the blade at a distance from the axis of rotation of the blade that is in the range of 30% to 45% of the distance from the said axis to an extension of the arc of the said peripheral edge of the blade, the said trailing portion having a convex trailing edge tangent at the outer end of the juncture line to the said peripheral edge of the main portion and tangent at the inner end of the juncture line to the said radially extending trailing edge of the main portion.

7. The combination in a fan, of a rotatable hub and a plurality of similar equally spaced blades secured thereto at substantial pitch angles each of which blades has its maximum dimension in the direction of rotation greater than its maximum radial dimension, each blade comprising a main portion with a peripheral edge and with a generally radially extending trailing edge and each blade also comprising a rearward curved trailing portion which joins the said main portion along a substantially straight juncture line extending generally inward from a point located at the said peripheral edge and substantially spaced in the trailing direction from a radial line through the center of the blade and which diverges inwardly and in the trailing direction from the said radial line so as to intersect the said trailing edge of the main portion of the blade at a distance from the axis of rotation that is at least 55% and not more than 70% of the distance between the said axis and the said peripheral edge of the blade, the said trailing portion having a convex trailing edge tangent at the outer end of the juncture line to the said peripheral edge of the main portion and tangent at the inner end of the juncture line to the said radially extending trailing edge of the main portion.

8. The combination in a fan, of a rotatable hub and a plurality of similar equally spaced blades secured thereto at substantial pitch angles each of which blades has its maximum dimension in the direction of rotation greater than its maximum radial dimension and each of which blades comprises a main portion provided with a peripheral edge approximately concentric with the axis of rotation and provided with a rearward curved trailing portion, the main portion of each blade having generally radially extending leading and trailing edges and having substantially constant pitch adjacent the said leading edge and the said main portion of each blade having pitch angles which progressively increase in the trailing direction from the leading edge and having increasing concavity from the root to the periphery so that the outer region of the main portion has a greater increase of pitch angles than the root region thereof, the said rearward curved trailing portion of each blade joining the said main portion along a substantially straight juncture line which extends generally inward from a point at the peripheral edge of the main portion and substantially spaced in the trailing direction from a radial line through the center of the blade and which substantially diverges inwardly and in the trailing direction from the said radial line at an acute angle thereto so as to intersect the said trailing edge of the main portion of the blade at a distance from the axis of rotation of the blade that is in the range of 30% to 45% of the distance from the said axis to an extension of the arc of the said peripheral edge of the blade, the said trailing portion having a convex trailing edge which conforms throughout its length to an arc of a circle and is tangent at its outer end to the said peripheral edge of the main portion and is tangent at its inner end to the said radially extending trailing edge of the main portion.

9. The combination in a fan, of a rotatable hub and a plurality of similar equally spaced blades secured thereto each of which blades comprises a main portion and a rearward curved trailing portion, the main portion of each blade having generally radially extending leading and trailing edges and being generally concave at the front and the leading and trailing areas of the said main portion being substantially cylindrical sections tangent to a plane having a substantial pitch angle, the said leading cylindrical section being tangent at its rear to the said plane along a line which intersects a radial line through the center of the blade at a substantial angle with its outer end trailing and the said trailing cylindrical section being tangent at its front to the said plane along a line which intersects the said radial line at a substantial angle with its outer end leading, and the rearward curved trailing portion of each blade being a cylindrical section tangent to and substantially parallel with the said trailing cylindrical section of the main portion.

10. The combination in a fan, of a rotatable hub and a plurality of similar equally spaced blades secured thereto at substantial pitch angles each of which blades has its maximum dimension in the direction of rotation greater than its maximum radial dimension, each blade comprising a main portion provided with a peripheral edge approximately concentric with the axis of rotation and provided with generally radially extending leading and trailing edges and each blade also comprising a rearward curved trailing portion, the entire main portion of each blade being a substantially cylindrical section tangent to a plane having a substantial pitch angle and being so tangent along a line which intersects a radial line through the center of the blade at a substantial angle with its outer end trailing, the said rearward curved trailing portion joining the said main portion along a substantially straight juncture line which extends generally inward from a point located at the said peripheral edge and substantially spaced in the trailing direction from a radial line through the center of the blade and which substantially diverges inwardly and in the trailing direction from the said radial line at an acute angle thereto so as to intersect the said trailing edge of the main portion of the blade at a distance from the axis of rotation of the blade that is in the range of 30% to 45% of the distance from the said axis to an extension of the arc of the said peripheral edge of the blade, the said trailing portion having a convex trailing edge tangent at its outer

end to the said peripheral edge of the main portion and tangent at its inner end to the said radially extending trailing edge of the main portion.

11. The combination in a fan, of a rotatable hub and a plurality of similar equally spaced blades secured thereto at substantial pitch angles each of which blades has its maximum dimension in the direction of rotation greater than its maximum radial dimension, each blade comprising a main portion provided with a peripheral edge approximately concentric with the axis of rotation and provided with generally radially extending leading and trailing edges and each blade also comprising a rearward curved trailing portion, the said main portion being a forward curved section of a cone tangent to a plane having a substantial pitch angle which cone has its apex spaced outwardly from the periphery of the blade and has its base circle near the axis of rotation, the said rearward curved trailing portion joining the said main portion along a substantially straight juncture line which extends generally inward from a point located at the said peripheral edge and substantially spaced in the trailing direction from a radial line through the center of the blade and which substantially diverges inwardly and in the trailing direction from the said radial line at an acute angle thereto so as to intersect the said trailing edge of the main portion of the blade at a distance from the axis of rotation of the blade that is in the range of 30% to 45% of the distance from the said axis to an extension of the arc of the said peripheral edge of the blade, and the said trailing portion having a convex trailing edge tangent at its outer end to the said peripheral edge of the main portion and tangent at its inner end to the said radially extending trailing edge of the main portion.

12. A fan as set forth in claim 11, wherein the said juncture line for the rearward curved trailing portion coincides with a generatrix line of the said cone.

13. A fan and orifice assembly comprising in combination a rotatable hub, means for supporting and rotating the hub, a plurality of similar equally spaced blades secured to the hub at substantial pitch angles, each blade comprising a main portion and also comprising a rearward curved trailing portion which joins the said main portion at a juncture line extending generally inward from a point located at the peripheral edge of the blade and substantially spaced in the trailing direction from a radial line through the center of the blade which juncture line substantially diverges from the said radial line at an acute angle thereto, and means surrounding the blades and provided with an orifice the peripheral wall of which is closely adjacent the blades, the air receiving end of that portion of the orifice having a minimum diameter being in a plane in substantial register with the outer ends of the said juncture lines on the several blades.

14. A fan and orifice assembly comprising in combination a rotatable hub, means for supporting and rotating the hub, a plurality of similar equally spaced blades secured to the hub at substantial pitch angles, each blade in projection having its maximum dimension in the direction of rotation greater than its maximum dimension in the radial direction and each blade comprising a main portion and also comprising a rearward curved trailing portion which joins the said main portion along a juncture line which substantially diverges inwardly from a radial line through the center of the blade, the outer ends of the said juncture lines of the several blades being spaced from a plane passing through the front edges of the blades by a distance which is at least 25% and not more than 40% of the distance between the said plane and a plane passing through the rear edges of the blades, and means surrounding the blades and provided with an orifice the peripheral wall of which is closely adjacent the blades, the air receiving end of that portion of the orifice having a minimum diameter being in a plane in substantial register with the said outer ends of the said juncture lines on the several blades.

References Cited in the file of this patent

UNITED STATES PATENTS

652,123	Lavigne	June 19, 1900
1,668,462	Oswald	May 1, 1928
1,806,345	Halvorsen	May 19, 1931
1,993,158	Funk	Mar. 5, 1935
2,023,111	Alsing	Dec. 3, 1935
2,056,547	Weber	Oct. 6, 1936
2,240,597	Whitefield	May 6, 1941
2,370,652	Frisbie	Mar. 6, 1945
2,390,804	McLean	Dec. 11, 1945
2,536,130	Herrman	Jan. 2, 1951
2,581,873	Morrison	Jan. 8, 1952

FOREIGN PATENTS

18,719	Great Britain	1894