April 13, 1965 L. W. CHILD 3,178,099

UNDER-BODY VENTILATING FAN UNITS

Filed Oct. 9, 1963 2 Sheets-Sheet 1

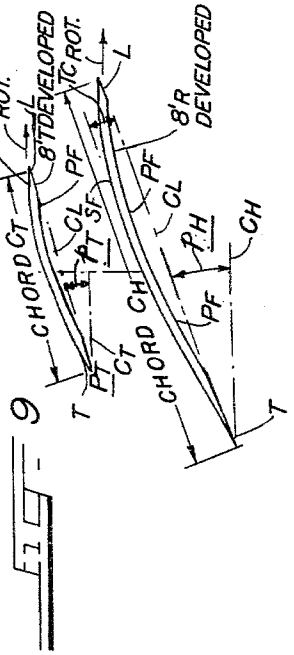


FIG - 9

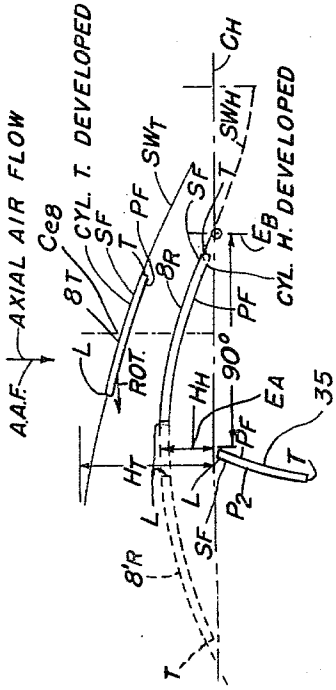


FIG - 3

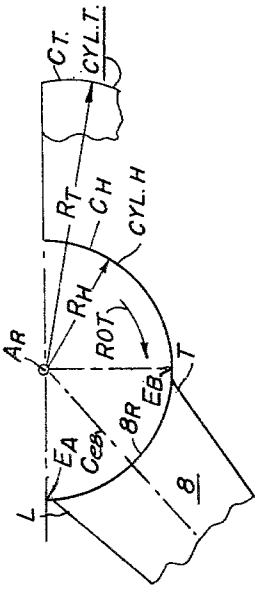


FIG - 1

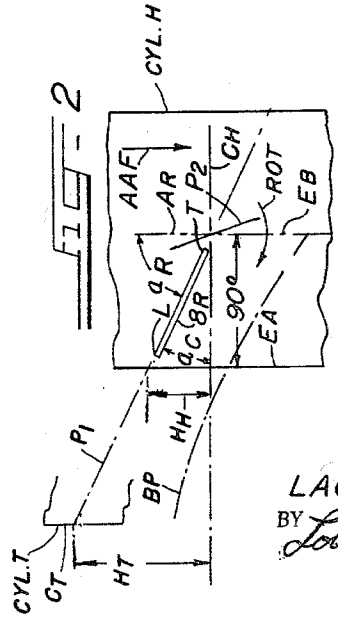


FIG - 2

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UNDER-BODY VENTILATING FAN UNITS

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FIG. 4

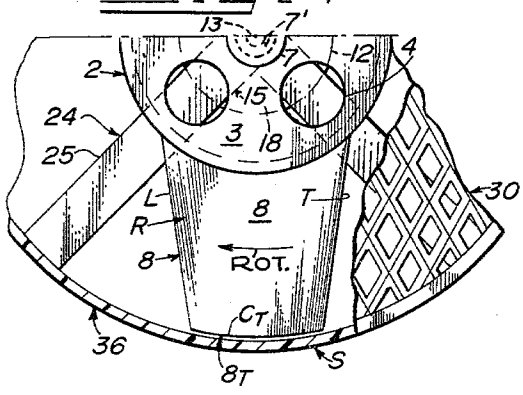


FIG. 5

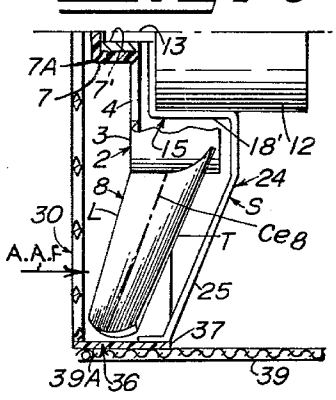


FIG. 6

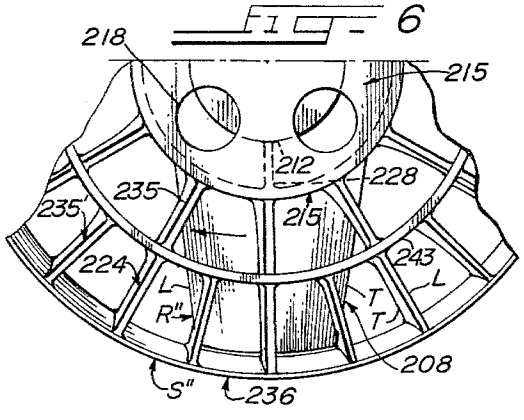


FIG. 7

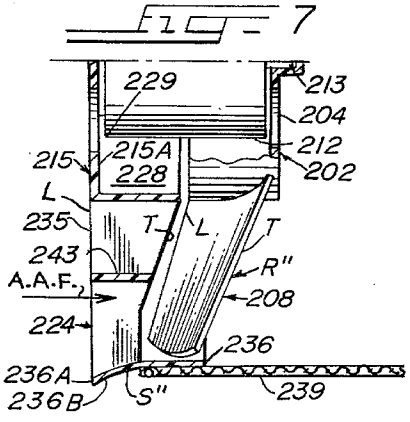


FIG. 5A

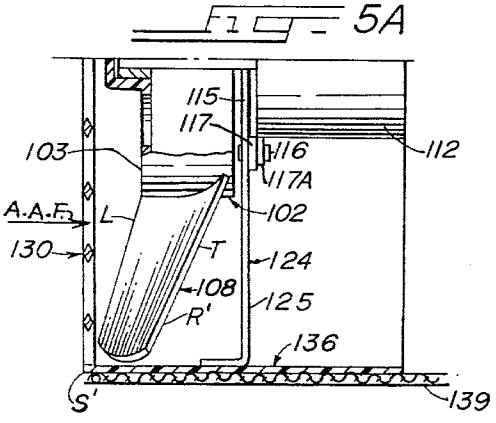
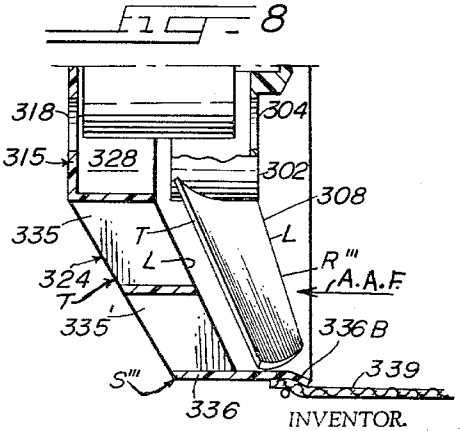


FIG. 8



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United States Patent Office 3,178,099 Patented Apr. 13, 1965

3,178,099

UNDER-BODY VENTILATING FAN UNITS

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Filed Oct. 9, 1963, Ser. No. 315,078
18 Claims. (Cl. 230—117)

This invention relates generally to certain improvements in low cost and efficient fan or blower units of the generally axial flow type with a direct-connected electric motor for forcing the circulation of air under a supported human body and, more particularly, to such axial flow fan units of small sizes and low actual air speeds and of the efficient but inherently unstable, high pressure type, such units preferably including a compact shroud-casing of short axial length and having the fan, the casing, and other parts of molded plastic for low cost and quietness.

The general objects of this invention are to provide an improved fan unit of the type described above for use with or in forced air type under-body ventilating and human-body-supporting devices and, more particularly, to provide such small fan that is more compact and of lower cost, higher efficiency, and greater quietness.

Other and more specific objects are to provide:

A small generally axial flow type of such a fan or anti-swirl stator therefor, each of whose blades has at least a substantial portion of the area of at least one face thereof (preferably its lower pressure or intake-side face) being either a substantially true flat surface or plane or else a simply or two-dimensionally bent plane, with said plane inclined to the fan's axis of rotation so as to provide an effective airfoil shape relative to its path through the air and with both an effective pitch and an effective camber curvature of at least said one face thereof, both preferably increasing radially inward along said blade and, more particularly, said blade being of a thin and substantially uniform actual thickness and having both of its parallel faces lying in such inclined planes throughout substantially the entire area of said blade.

A fan of this general type having blades with generally flat planar surfaces tilted to the axis of rotation to provide at least an effective pitch to thin light blades which are more easily centrifugally balanced and hence provide a fan which has a lower noise level and lower cost for complete manufacture and which gives less loads to the direct-connected electric motor and to its shaft bearings, and, more particularly, such a fan having its blades cast integral with its hub and preferably of a suitable and light plastic.

A fan or an anti-swirl portion of this general type which has a minimum set-up, tooling, or mold cost and which is also more readily and more cheaply fabricated or cast because its blades are of thin, substantially flat sheets whose planes are tilted to the axis of rotation to provide at least an effective pitch.

Such a fan unit having its rotor portion or its stator portion (the latter providing a shroud-casing, an electric-motor support, and a spider which preferably includes an end grille and also anti-swirl blades) cast in one piece, preferably of plastic, and using a minimum weight and cost of cast material because its blades are integral with a hub and are thin, flat, and easily formed sheets whose planes are tilted to the axis of rotation to provide at least an effective airfoil pitch, said blades also preferably having progressively decreasing chords outward from their roots at said hub.

Such a fan unit having a generally flat or simply bent planar blade whose plane is tilted to provide at least an effective airfoil camber and, more particularly, such a blade of thin sheet material having such a camber curvature with its greatest effective airfoil thickness adjacent its leading edge.

An axial flow fan having rotary blades each lying in a plane or true flat surface which is tilted at an angle of more than 45 degrees to the axis of rotation; whose pitch and camber curvature along cylindrical sections are portions selected from sine wave curves; and, more particularly, wherein the selected effective pitch is less than the maximum pitch tilt available on such a sine wave curve and is in a portion of said sine wave curve providing an effective camber curvature on at least the low pressure airfoil surface, and preferably forming thin sheet, monoconvex effective airfoil sections throughout the extent of the blades.

Such a generally axial flow and tilted planar blade fan unit including a direct-connected electric motor and a shroud ring forming part of an outer casing of a minimum axial length wherein flat planes defining effective airfoil blade surfaces are tilted to have a pitch-forming tilt component and a tilt component toward the intake end of the axis of rotation, such blades preferably being tilted toward and with their outer ends overlying a direct-connected electric motor.

Such a fan unit having a minimum number of parts (exclusive of the direct-connected electric motor and electrical parts) and comprising a one-piece cast plastic axial flow type fan rotor unit with blades integral with its hollow hub as one piece, and its outer-casing-forming shroud ring (also preferably of cast plastic), integral with its shaft and motor-holding spider and its innermost motor support or cup, as a second and stator piece.

Such a fan unit having tilted plane blades which have an increasing effective camber width and an increasing actual sheet width radially inward to a hub of material diameter, such blades having, in particular, root sections of approximately 90 degrees of arc about the axis of rotation.

Other objects of this invention relate to improved construction arrangements in compact flow units, including the provision of a shroud ring outer casing having an integral end grille serving to hold an electric motor and also serving as a bladed anti-swirl stator member.

Such other objects also relate to the provision of a fan unit having two open cup-like and relatively oppositely rotating concentric and preferably open-end-to-open-end hub members substantially enclosing an electric motor between them, with one such hub member integrally carrying an entry-preventing end grille or the like which preferably forms an integral cylindrical outer shroud ring and in which there is a short or minimum overhang in the motor shaft connection to the rotor.

Still other such objects relate to the provision of such a unit having only two main connected portions (exclusive of the electric motor and electrical parts) and, more particularly, only two one-piece plastic moldings.

Other and more detailed objects and advantages of this invention, including cooperating or related features or arrangements, are set forth in, or will be apparent from, the attached specifications, drawings and claims.

It is to be noted that this invention may include certain features and advantages disclosed and claimed in my United States Patents No. 2,992,604 and No. 2,992,605, in which I am co-inventor. Accordingly, the disclosures of these patents are included herein by reference. This applies particularly to aspects of these prior patents relating to the axial flow fan, its characteristics, and combinations thereof with an under-body ventilating pad or layer including a fixed resistance, and also to aspects relating to two plastic motor-embracing hub cups.

In the attached drawings:

FIG. 1 is a schematic half end view looking axially at the inlet end of a cylinder, which here may be considered as the outer periphery of a fan hub with a blade shown

broken away, and also showing a portion of a cylinder for the blade tip paths;

FIG. 2 is a schematic side elevation showing the cylinder of FIG. 1 intersected by certain tilted planes, together with the root section of a fan blade defined by one such plane;

FIG. 3 is a schematic view showing the cylinders of FIG. 2 unrolled or developed in a clockwise direction to show their sine wave curve intersections of the planes, together with showings of certain airfoil blade sections thus developed;

FIG. 4 is a half (and partly broken-away and sectional) inlet end view of a first form of fan unit according to this invention;

FIG. 5 is a half (and partly broken-away and sectional) side elevational view of the unit of FIG. 4;

FIG. 5A is a side elevational view like FIG. 5, but showing a modification of interior parts thereof;

FIG. 6 is a view taken generally as in FIG. 4, but showing a second form of this invention;

FIG. 7 is a side view, taken as in FIG. 5, of the unit of FIG. 6;

FIG. 8 is a partly broken-away side elevational view taken like FIGS. 4 and 6, but showing another form of this invention; and

FIG. 9 shows cylindrically developed sections of fan blades like FIG. 3, but enlarged and with the camber curvatures and actual sheet thicknesses exaggerated for ease of illustration.

In the foregoing drawings and in their descriptions, the same or similar reference characters are used in connection with the several forms illustrated for ease in following the disclosure. Accordingly, differing or modified parts in succeeding modified forms are distinguished by the use of the same reference number increased by 100. It is also to be noted that FIGS. 1 through 3 and FIG. 9 in particular (and generally as to the other figures) are not fully accurate as to pitch and camber or other angles or curvatures, but are somewhat exaggerated or off-scale for purposes of illustration. The same applies to the axial and other clearances.

Referring again to the drawings, and having in mind that points on a rotary fan blade having equal air (absolute) speeds sweep through a cylindrical path or line on a cylinder (and similarly for stator blades), the cylinder CYL_H and the circle C_H thereon of FIG. 1 (both having a radius R_H to the hub O.D.) are schematically shown in FIG. 2 as intersected by the tilted plane P_1 which intersects the axis A_R of the cylinder (here the axis of rotation of the fan) at an acute angle a_R. It will be noted that the complement a_C of this angle a_R is the maximum angle between the plane P_1 and any element of the cylinder CYL_H, or between P_1 and any plane tangential to the cylinder along the intersection of P_1 and CYL_H. It is also noted that angle a_C may be considered as a pitch-forming angle, as commented on below.

The cylinder CYL_H is typical of any cylindrical relative air flow path or section through any of the tilted-plane blades of the present invention. However, CYL_H may, for convenience, be considered as corresponding to the roots of the blades or to the outer periphery of a generally cylindrical hub, or may be considered as generally the hub radius in that portion of the hub. It is to be noted that the hub or hubs need not be cylindrical in all cases, since they may be conical, dish-shaped, or of other shapes, so long as they are fully open at one end and have a shaft-connecting, partly-closed portion at the other end.

This intersection of plane P_1 and cylinder CYL_H, shown in FIG. 3, is a sine (or cosine or harmonic motion) type wave curve SW_H in which the periphery of the cylinder is unrolled or developed along the abscissa (circle C_H), so that axial dimension H of FIG. 2 is the maximum ordinate H of FIG. 3.

In FIGS. 1, 2, and 3, the rotary motion of the root blade section 8_R is shown by arrows ROT. The rotary

air flow relative to the blade is in the opposite direction. In the general case of a relatively contra-rotating blade (including the cases of a contra rotor fan or a swirl-removing set of stator blades), the blade motions and the relative rotary air flow directions are in opposite directions, but the intake ends and the camber curvatures are the same.

In FIG. 3, the abscissa values E_A and E_B in curve SW_H (for the hub or root sections of a blade) are 90 degrees apart and correspond to the similarly designated cylinder elements of FIGS. 1 and 2. Further, portions of this curve SW_H may be considered as showing cylindrical sections through a very thin and actually true flat blade forming a mono-convex effective airfoil, or else as showing one surface (preferably the lift or low pressure surface) of a thicker and perhaps bi-convex blade.

A proper minimum or limiting hub diameter is selected, as discussed below. Then a true flat sheet or plane (at least one for each blade) is tilted to the axis of rotation A_R at a suitable angle a_R, providing the complement or maximum pitch angle a_C. This maximum pitch angle a_C is not used for the whole blade length or span under this invention.

The desired effective pitch at and near the blade tips is usually materially less than a_C when following this invention. As an example only, and as illustrated, a_C may be in the general order of over 30 degrees to give the desired lesser root pitch to a rotating blade. This angle a_C may be more, or less, depending of course on the over-all fan size, the hub diameter, and the particular fan results desired. It will be apparent that the hub diameter should be a large percentage of the tip diameter for the proper ratio of hub effective pitch to tip pitch.

A material portion (and preferably all) of the length and/or area of such an axial flow type blade has along its radial length suitable chordal widths which lie on curves like SW_H along concentric cylinders like CYL_H. Particularly in the case of rotary blades, it is preferable that they have radially inwardly increasing chords along such sine wave curves. One blade of uniform chord throughout its span or radial length would thus form progressively angularly shorter arcs radially outward or along increasing diameter cylinders. That is, the radially outer arcs (across the pitch tilted blade chords) would subtend progressively smaller angles about the axis of rotation.

It will be understood that here the effective chord (and the effective camber or camber curvature) of a section through an airfoil blade in relative rotation with respect to a fluid or air (and especially about a relatively small or short radius) will be along the surface of an imaginary cylinder, corresponding to the particular radius at that section. This cylinder then may be considered as the effective curved path of such a blade section relative to the fluid or air. Thus, effective blade sections are here taken on such cylinders, and such cylindrical sections are referred to herein in connection with the effective pitch or the effective camber, camber width, camber curvature, camber thickness, or the like.

Looked at another way, the portion of the tilted plane defining the blade surface (or both surfaces forming the preferred thin sheet, mono-convex airfoil) may be regarded as having a so-called two-way tilt. More accurately, it has two components of one tilt. One is a pitch-forming component. The other extends axially of the fan and forms the camber curvature and also produces additional or effective pitch. This effective pitch has the pitch given by the pitch-forming component increased by the camber.

Put another way, all of the lines in the tilted plane of a rotating blade and which also pass through the axis of rotation are inclined at an acute angle (which is the camber forming component) to the axis of rotation.

A typical such effective blade section is shown by the sheet thickness-indicating double lines for the blade root

section 8_R which has at least one (or its low-pressure) surface lying on curve SW_H and located between the points or elements E_A and E_B, which correspond respectively to maximum plane or sheet pitch and to no sheet or plane pitch.

It will thus be seen that root sections such as 8_R, of a maximum practical and yet efficient chord width, will subtend angles about A_R of approximately or approaching 90 degrees. This requires a large ratio of hub diameter to tip diameter. Put another way, the trailing end of 8_R approaches the ogee straight portion at E_B but here does not go through E_B, at least not in the preferred forms of this invention, since if the curve extends materially beyond E_B it would have a reverse curvature. In some cases, for maximum blade areas the trailing edge of a root section may extend through or past E_B, as long as the reversed curvature is not material.

In contrast, having the leading edge portion of such a blade section extend over or across the point E_A has no such reverse curvature limitation. A blade section so chosen (to lie across the points of greatest change in curvature on either side of E_A) may be desirable in certain cases under this invention. For root sections, this last permits greater chord which, if desired, may thus be somewhat over 90 degrees arc with the blade section trailing end at E_B. For all sections, this practice gives more camber curvature and camber thickness. Thus, this practice is useful for tips which would otherwise have too little camber. In this last case, the limiting factor will obviously be too much curve hook or camber thickness (usually adjacent the leading edge). It is of particular interest to note that this practice materially increases the effective camber.

It is to be noted that such a location and such a selected chord or chord width also provide an effective and desirable camber or camber curvature which is more clearly shown and exaggerated (as to camber thickness and camber curvature) in the enlarged FIG. 9.

As best seen in $8'_R$ in FIG. 9, these airfoil profile shapes or blade camber curvatures have their maximum camber thickness T_C desirably well forward of the middle of the chord and toward the leading edge L. Put another way, a sine wave type curve, such as SW_E, is an ogee curve as it reverses its curvature through the increasingly straight portions adjacent or toward E_B. The rear or trailing portion of the effective blade sections is toward point E_A, so that the effective blade curvature becomes straighter or flatter toward its trailing edge T. This provides a desirable airfoil profile or camber curvature.

Such effective camber curvatures for thin sheets give adequate efficiency, like early and low air-speed, thin, mono-convex airplane wings. Here they permit the making of airfoils from true flat or planar sheets, or with actual sheet thickness substantially only that required by strength to resist the centrifugal load, lift load, and other loads and vibrations. There are resulting advantages in ease of fabrication, cost, and the like. Good, practical aerodynamic efficiencies are obtained at suitably low relative air speeds. Thus, flat-sheet tilted and mono-convex fan blade portions according to this invention are intended for relative tip air speeds of less than about 150 feet per second.

In certain small or other fans, the lower cost of the fan is more important than a relatively small reduction in efficiency. Thus, higher tip speeds may be used if the noise level permits. Better over-all results and a lower noise level (which is important where such a fan is unsilenced and is close to the person to whom it supplies under-body ventilating air, especially in a quiet room) are obtained by materially lower tip velocities. As noted in my said prior patents, the preferred high pitch but unstable tip fan with its lower speed is desirably materially quieter.

In this connection, it may be noted as an exemplary disclosure of certain suitable properties and values that the small and low cost under-body ventilating fan unit illustrated herein has a blade tip diameter of about 4¼ to 4¾ inches, a rated speed of 6000 r.p.m., and a hub O.D. or blade root diameter of about 2¼ to 2½ inches. Thus, the blade root diameter is over half of the tip diameter. The micro-size electric motor shown is in the order of about 1⅛ inch O.D. (materially smaller than the hub O.D.) and about 1⅜ inches long, exclusive of shaft length. Other sizes of motors, including smaller ones, may of course be used. It is to be noted that in these sizes and types of motor, the motor O.D. being materially smaller than the hub I.D. permits a flow of cooling air inside of the hub along the metal motor casing, as discussed in more detail below.

These fan units are of the relatively high pitch, high pressure, and high efficiency, but inherently unstable type disclosed in my prior Patent No. 2,992,605. Further, such units are designed to operate against pressures in the order of those disclosed in my said prior patent, and have effective angles of attack and effective pitches of the same order. In the exemplary form illustrated, and also for the small under-body ventilating fan units according to this invention, the effective tip pitch for the rotating blades (along cylindrical sections) is preferably in the range of about 18 to 30 degrees (as set forth in my said prior patents) and here is preferably in the narrower range of about 20 to about 25 degrees. Thus, as noted above, the maximum pitch-forming angle A_C will be about 30 degrees or more, and in all rotating blade cases hereunder, angle a_R will be over 45 degrees.

As best shown in FIG. 9, the effective pitch angles, such as p_R and p_T, for each cylindrical section are measured between the chord line C.L. (lying tilted along a rotation path cylinder) and the rotation path circles such as C_H and C_T for the particular blade radius being considered.

The measurement of the effective angle of attack is analogous. The angle of attack is of course a smaller angle because of the material axial component of the relative air velocity. It will thus be seen that the effective pitch is progressively greater toward the root section. In other words, it desirably increases progressively for radially inward sections toward the limiting and large hub diameter. It will be seen that this radially inward effective pitch increase along a blade having a constant pitch-forming angle component (or a constant angle a_R) is given by the camber curvature along the selected region of the curve SW for each radius. Put another way, the radially inwardly increasing effective camber curvature also gives an increasing effective pitch. This is true even through all of the airfoil blade surface or surfaces actually lie in (or are parallel to) one flat plane.

The foregoing is true for blades of constant actual chord width (or constant effective chord) along their spans or radial lengths. It is even more so, or is accentuated by, the preferred and illustrated tapering actual blade widths. The corresponding taper in the chord widths desirably provides greater strength and stiffness to resist centrifugal force and also to resist bending loads generally transverse to the blade planes. This taper also gives a desirably greater chord for the slower relative air speed airfoil sections toward the blade roots.

From the foregoing, it will be seen that there is a specific or generally limiting fan blade I.D. or hub O.D. for the best aerodynamic and structural arrangement. In the types shown, the hub O.D. is about half (and preferably more) of the blade tip diameter. As explained above, it is not feasible nor desirable to increase the chord of the blades at their roots more than so much, or here much over 90 degrees of arc. There is a certain compromise between the most desirable root and tip sections along a given tilted plane. It will be seen that blades tilted according to this invention are best suited to fans having a relatively large ratio of blade root or hub diameter to tip diameter, and thus are very well suited to small size fan units of the type described herein for under-body

ventilation. It is to be noted that the blades shown have a root chord which is materially greater (here about 1⅞ inches) than the maximum blade span or length out from the hub (here about 1¼ inches at the leading edge). In general, such fans may be under 6 inches in tip diameter and with tip speeds and pitches as described above for rotor blades. Stator blades according to this invention will of course have effective tip pitches of nearly 90 degrees because of the large axial component of relative air flow velocity.

The practice of this invention will be apparent from this disclosure to those skilled in this art, and they will readily appreciate its advantages and use for any particular and suitable fan application. This includes the use of chords (by the above-described taper along the radial lengths of the blades) and the location of the blade cylindrical sections along a suitable SW curve (given by the a_C tilt angle) to give the best camber curvatures for each radial section and for the desired best over-all lift coefficients along the radial blade lengths for a fan of a particular speed and for a particular pressure. At this point, reference is again made to the disclosures in this regard in my above-referred to two prior patents.

While of course not necessary in all cases under this invention, good results have been obtained with the structurally simple, stronger, and preferred form illustrated, in which the tapered chord blades are generally centrally radial in actual end view. That is, as shown, the center lines of the axially projected blade chord widths are generally radial for a more easily tooled and simpler, stronger arrangement.

Turning again to the cylindrically developed FIGS. 3 and 9 in particular, it will be noted that the cylindrical or effective airfoil or blade section 8_R (taken at or near the root) has the largest camber curvature and the largest camber thickness. This is true, first, because of its actually greater chord length, which is given here by the above described blade width taper. It is also due to the camber-forming tilt component, and would also be true if such a blade had the same actual sheet widths throughout its radial length or if it had the tip width throughout. As shown by cylindrical section 8_T (taken at or near the tip of the same mono-convex and mono-tilted plane blade), the radially outer sections as shown have a progressively decreasing camber curvature and thickness and a resulting and desirable decrease in effective pitch angle.

To the extent that the blades are of very thin sheets, the shapes of the leading and trailing edges make little difference. Hence FIG. 3 shows these edges cut off about normal to the blade plane. As a refinement, or when the blade sheet is thicker, the blade sheet may have its leading and trailing edges formed as shown in FIG. 9, where they are illustrated as sharp and as made by using the effective chord line CL to terminate the sheet at either edge.

As seen in FIG. 3, a reverse pitch blade section such as $8'_R$ lies in the same tilted plane P_1 with 8_R and 8_T but in the next adjacent 90 degree quadrant or on the other side of A to reverse the pitch-forming component of the tilt angle. However, $8'_R$ has the same direction and component of axial tilt and the same direction of effective camber as 8_R and 8_T. Thus such reverse pitch blades are tilted to the same angular component toward the intake end of the fan unit.

Blades with sections like $8'_R$ and 8_R, having oppositely directed effective pitches, are well adapted for contra-rotating (equal and opposite) sets of blades. This is further illustrated by $8'_R$ and $8'_T$ of FIG. 9. Such oppositely pitched blades are also useful for the generally similar case of an anti-swirl stator set of blades. Such a stator blade section is shown (out of position) by 35_T, which corresponds to blades 235 and 335 of FIGS. 6, 7, and 8. This blade 35_T lies in a plane generally like P_2 of FIG. 2. In this last case, the anti-swirl stator blades should desirably be of a very much greater effective pitch angle (nearly 90 degrees), which also preferably increases inwardly because of the major axial component of the relative air velocity. In certain cases, radially outer parts (or even all) of such thin anti-swirl stator blades may be substantially radial planes or sheets.

While tilted thin sheet and effectively mono-convex airfoil blades are preferred, yet certain advantages of this invention may be realized by bent plane blades or by thickened blades in which portions of the blades are not of a uniform thin sheet or are not uniformly tilted. For example, the tip section $8'_T$ of FIG. 9 may be thickened and have its high pressure face actually curved to give a biconvex airfoil, which is more suitable for the higher relative air speeds near the tips of a larger diameter or higher speed fan having its otherwise planar blades so modified out near their tips. As will be apparent, this effectively bi-convex airfoil requires a greater actual convexity on the pressure side of the otherwise sheet-like blade, and this may be achieved by a pressure side thinning out or curvature, giving a convex higher pressure surface on the other side of the chord line CL.

Turning now to other aspects of this invention and to the exemplary combinations or arrangements of FIGS. 4 through 8, it is to be noted that certain of their features and advantages may be employed either with or without the tilted plane and cambered aspects hereof.

Where the absolute minimum axial length is desired for such a small and shroud-cased axial flow type fan unit, or in certain other cases, an arrangement of the general type of FIGS. 4 and 5 may be employed. Here there is an omission of the features of the axially elongated, anti-swirl stator blades and the multi-function end grille which includes the motor-holding spider.

For purposes of illustration, the fan rotor and its blades are shown as the same in each of the four forms of FIGS. 4 and 5, 5A, 6 and 7, and 8, except of course for the opposite axial tilt directions relative to the open end of the fan rotor hub, and similarly as to the stator hub.

FIGS. 4 and 5 show a one-piece or truly unitary and light weight, low cost plastic molded rotor which is designated as a whole by R. This rotor comprises the hub, designated as a whole by **2**, and the integral thin-sheet blades, each designated as a whole by **8**.

The O.D. of the hub **2** and the corresponding roots (or I.D.) of the blades **8** lie on the circle C_R of FIGS. 1, 2, and 3, since the hub is here shown as of true cylindrical shape for ease of molding and better air flow. As noted above, other generally dished or open-end hub shapes may be used. The blade tips 8_T lie on, or close to, the tip circle C_T of FIGS. 1, 2, and 3, and the low pressure faces of these blades **8** lie in planes like P_1 of FIG. 2, with a uniform sheet thickness giving a close and actually parallel low pressure face. As disclosed above, the blades **8** of FIGS. 4 and 5 lie in a tilted plane, or may be considered as tilted in two components, one of which is toward the inlet end of the fan unit (here designated as a whole by **1**) and thus toward the connected or partly closed (and here flat, axially outer end of the exposed) end wall **3** of the molded hub.

For better motor cooling or, more specifically, to remove heat from the adjacent metal end and sides (as well as the far end) of the small and usually high speed electric motor **12**, holes or openings such as **4** are suitably formed in (and preferably initially molded into) the end wall **3**. This permits motor cooling air to be sucked through the cup of hub **2** into the higher velocity and lower pressure down-stream region, as shown here.

As shown in FIG. 4, the blades **8** are of the above-noted dimensions and are tapered in width by straight side edges forming the leading edge L and the trailing edge T, to thus provide the above-noted and important progressively inwardly increasing effective chords and actual widths. The tips 8_T may, if desired, be outwardly terminated by circular arcs lying in the planes of the blades themselves. This is easier and cheaper to form and here gives but

little deviation from circle C_T. In fact, this difference is too small to effectively illustrate here.

The center of the outermost axial (or partly closed) end of hub 2 and, in particular, its end wall 3 is suitably connected to the threaded end of shaft 13 of motor 12. For this purpose, there is a small generally cylindrical outer extension 7 having an inner coaxial shaft-fitting hole 7' of suitable length, in which the shaft is suitably held by threads plus cement, or in other known ways.

An internally-threaded and cast-in-metal insert 7A is used here for added local strength in the case of a plastic hub. The hub wall thicknesses (like the blades) are only those needed for strength and rigidity.

As shown in FIG. 5, the axial component of tilt of the blades 8 provides that they have their tip portions extending materially axially toward the intake end and also beyond the hub end 3, or beyond the blade roots. These blade roots are nearly co-extensive in axial length with hub 2. However, the major part (or well over half) of the blade areas and weights are here shown as axially overlying the hub 2 for better strength and balance.

The several preferably integral (or else separate and suitably rigidly interconnected) stator parts are here designated as a whole by S, and include the motor 12, its cup-like holding means or hub (designated as a whole by 15), the motor-locating spider or the like (designated as a whole by 24), the finger-entry-preventing or other suitable entry grille for the outer or exposed end (designated as a whole by 30), and the connected outer-casing-forming blade tip shroud ring (designated as a whole by 36).

Here, for minimum axial length, the motor-holding means 15 comprises the cup-like inner hub portion formed by the simple bends or the molded-to-shape arms of the cruciform axially-thin spider 24. This may be made of one piece of simply bent sheet metal or plastic, or else of molded plastic. It has suitable means to connect it to the motor. Part 15 provides open end portions 18 to permit cooling air through holes 4 to hit the end and flow along the sides of motor 12, between the spider arm portions 18', which in this form tightly engage and help hold the sides of the motor 12.

The flat outer end portions 25 of the four arms of this one-piece spider 24 are sloped or bent as shown along the trailing edges T of blades 8, and may be cast integral with the outer shroud ring casing 36, or else be suitably connected thereto. It will be noted that the portions 18' of the motor-holding cup part 15 of the spider engage or cover only part of the periphery of the axial end of the motor to permit cooling air to flow between them and hit uncovered portions.

As shown in FIG. 5, the suitably larger diameter cup-like hub 2 of the rotor (which has a diameter as described above) has the concentric and smaller diameter cup-like stator hub portion 15 nested within it axially close to the inner end of hub 2, with only needed working clearance axially. This gives a very compact and short arrangement. It also provides for the passage of ventilating air therethrough. The diamond-patterned plastic grille 30 may be separate and fitted into the end of shroud 36.

Referring again to FIG. 5, particularly where its inner and duct-holding end 37 is to be retained and covered by a suitable similarly shaped and sized duct end 39 to lead the flow of forced air through an under-body-ventilating device, the axial length of ring 36 is preferably short. It is shown here as little more than the axial length of the blade tips 8_T. This is feasible when the inner motor end is covered by a rigid or a preferred fully-flexible or cloth-like duct 39 which will not collapse too much. Such a duct 39 may form part of an under-body ventilating pad for use on automobile seats or on other surfaces. It may fully cover any desired length of shroud ring 36 and may be secured or held thereon by suitable means, including an elastically contracting duct end 39A.

For cases where the air flow obstruction by the flat spider arm portions 25 is to be avoided, or where the absolute minimum axial length is not desired, FIG. 5A shows a simpler and entirely flat form of spider 124, in which the inner motor-holding portion 115 is not cup-like but is flat or in the same plane with the rest of spider 124. The axial end view of FIG. 5A would be generally like FIG. 4. Hence it is not shown.

The motor 112 is here air-cooled substantially as described above. The flat inner motor-holding central portion 115 of the cross spider is riveted at 116 through thin spacers 117 to lugs 117A fixed on the end of the motor, as shown. The outer ends 125 of its four arms are spaced and connected and disclosed in FIG. 5. In this modification of FIG. 5A, the flat spider 115–124 may be in a suitable arrangement close against the closed end of the rotor hub 102 or else, as shown, spaced slightly from the open end of the rotor hub cup 102. The shroud casing 136 may be as shown in FIG. 5.

In other uses, or where the fan unit is to have its motor end exposed, the cylindrical shroud ring of FIG. 5A or FIG. 5 (which forms the only outer casing) may be axially lengthened to overlie the discharge end of the motor. In such a case, a finger-entry-preventing or other suitable discharge end grille (which may also comprise anti-swirl blades) may be integrally or detachably secured to the discharge end of such a shroud casing. The discharge end may be exposed in the case of a small unit fan or blower to be used by itself, or where air is sucked out of a duct like 39 from an under-body ventilating device with a reversed direction of air flow therethrough.

Turning to FIGS. 6 and 7, the one-piece molded plastic rotor R'' may be just like R of FIGS. 4 and 5 except for an opposite axial tilt of its blades, and so may include the same parts, which are similarly numbered but which are not again described nor listed here. In FIGS. 6 and 7, however, the rotor hub 202 is directly over the discharge end (which in this case is also the non-exposed or duct end) of the motor 212. Also, blades 208 are tilted toward the intake end and thus overlie the motor beyond the open end of hub cup 202. They also partly overlie the hub portion of the stator.

However, here the stator S'' (exclusive of the similar motor 212, its shaft 213, and other electrical parts) consists of only a one-piece plastic molding which includes the following as integral parts thereof: the motor-holding-cup hub portion, designated as a whole by 215; the motor-locating spider (which also forms the finger-entry-preventing grille, as well as the anti-swirl blades), designated as a whole by 224; and the outer casing shroud ring, designated as a whole by 236.

The stator portion 215 is a cup generally like the rotor or hub cup 2 and is here shown as having the same I.D. and O.D. as 202. Obviously, different diameters may be used. Cooling air flows in through openings 204 in rotor hub 202, over the ends and sides of motor 212, and out through openings 218 in stator hub 215.

It will be noted that the two hubs 202 and 215 together overlie substantially the entire length of the motor except for a normal clearance between them. The distance between the inner hub ends is little more than the motor length. This, taken with the particularly desirable feature of having the tilted fan blades overlie the motor length, provides the shortest possible axial length of the entire unit for a given length of motor, and also provides a minimum length of outer shroud casing, which here overlies only part of the motor.

Suitable means are provided to locate and retain the motor in stator hub 215. As shown, the interior sides of hub 215 are molded with integral ribs 228 to extend in and frictionally engage the sides of the motor. These ribs, which permit air cooling, include end steps 229 to space the outer or intake end of the motor from the end 215A of hub 215. Other suitable or known securing means may be employed to fix the motor here.

The stator spider portion 224 comprises the anti-swirl and aerodynamic-efficiency-increasing blades 235

and 235'. They are preferably tilted and formed as described above in connection with FIGS. 1, 2, and 3. A suitable number of inner such blades 235 are close enough together to form a finger-entry-preventing grille when taken with the stator hub end 215A and the intermediate ring 243. A number of such rings like 243 may be employed if desired. There are more of the outer blades 235' (of which some may be radially continuous with the inner blades 235) to provide the outer part of the finger-entry-preventing grille arrangement. All these blades are cast in one piece of plastic integral with hub 215, ring 243, and the outer shroud ring 236. It will be apparent that other or decorative arrangements may be employed for the functions of blades 235, 235', or the like, rings 243, and hub end 215A with its holes 218.

For the best utilization of axial space in an axially compact arrangement and for a flat exposed end, the stator blades 235 and 235' are shown as having their outer and leading edges terminated flush with the outer end of casing shroud 236. While difficult to illustrate here, their planes may have the above-described axial component of tilt in the same axial direction as the rotor blades (but with a different slope), even though they are also shown as being tapered or of progressively wider chord widths (and axial dimensions) toward hub 215. This uses up substantially all of the axial space along the motor length and inside of shroud 236, aside from normal clearances. Here the tapered trailing edges of the stator blades are generally close to the leading edges of the tapered rotor blades. However, it will be appreciated that the leading edges of the stator blades may also be sloped so that end 215A of stator hub 215 is axially inward of the outer ends of the rotor blade tips and of the axially outer end of the shroud ring at 236A.

The duct 239 here is like 39 of FIG. 5. However, in this form the air entry end of shroud 236 is shown as outwardly curved at 236B to provide a smooth flow, inwardly-constricting air entry path to increase efficiency and to reduce noise in this region.

The insert 7A of FIGS. 4, 5, and 5A has been omitted in FIGS. 7 and 8 for simplicity of illustration.

The desirable features and the axial compactness of having the tilted rotor blades axially overlie the motor, as in the preferred arrangement of FIGS. 6 and 7, may be utilized in other ways. One such other way is indicated in FIG. 8, which also illustrates the grille, spider, and anti-swirl blades as a unit on the discharge side, which is here exposed for uses such as those discussed above. It will be appreciated that a suitable grille end of the anti-swirl blades may be employed at either or both ends.

In FIG. 8, the rotor R''' is generally like the rotor R of FIG. 5. It is turned end for end to have its intake and its leading edges toward its inner or its non-exposed end, as here illustrated. The one-piece rotor R''' includes the hub 302 and the blades 308, tilted as disclosed above. It will be understood that while these blades and the hub are shown as essentially the same in all of the illustrated forms, yet they may be modified in various ways. As only one example, the leading edges of blades 308 may lie in a flat plane (which may include the inner end of hub 302) and thus be generally like blades 235 and 235' in this respect. The hub 302 may be lengthened for this purpose, or else the blades may have tip portions cut away for the same reason.

The stator S''' (aside from the motor 312 and its parts) is a one-piece plastic molding which comprises the cup or hub portion 315, the spider, grille, and anti-swirl portion 324, and the casing shroud ring 336. Each of these three portions is like the corresponding portion of FIG. 7 (aside from the generally conical or truncated shape of the exposed end of the grille 324 and the trailing edges of its stator anti-swirl blades 335 and 335' as illustrated here), so that they need not be described in detail. It is noted that hub 315 may include internal motor-engaging ribs like hub 215. Both hubs 302 and 315 have the air cooling holes as described.

The radially inner stator blades 335 are tapered along both edges and are axially wider (or of greater chord) inwardly, as shown, so that their leading edges (and the leading edges of blades 335') are axially close to the trailing edges of rotor blades 308. This is generally like (but inverted from) the arrangement of FIG. 7. In FIG. 8 the shroud 336 has its smoothly curved-in and air-accelerating entry portion 336B at its upstream or entering end. The similar duct 339 is shown as embracing over only the inner end of 336 or 336B, in contrast to the partial covering by the duct in FIG. 7 and the substantially total axial covering in FIGS. 5 and 5A.

In general, it will be noted that the fan rotor, its blades, the direction of the axial air flow AAF, and the corresponding L and T edges of the moving and stator airfoils are the same in all of the forms shown except that of FIG. 8. In all the drawings, the blades are shown with their center line (Ce_3 of FIGS. 1 and 3) generally radical. This is not essential in all forms of the invention. In FIGS. 1 and 3, the tilt angle of plane P_2 for the stator blades (which are, in effect or relatively, contra-rotating blades) is shown out of proportion for clarity of illustration. As previously explained, P_2 is tilted in the same general direction (toward the intake end) as is P_1. Also, in view of the previously-explained exaggerated showing of axial clearances, it will be understood that the units shown herein may actually be materially shorter for a given motor length or fan length.

In the foregoing description, the rotor and stator blade surfaces (such as P_1 and P_2) have been considered as being true flat planes. However, as noted above in the objects, the broader aspects of this invention include the use of a simple or only two-dimensional bend or bends in such planes to modify the tilt effect in different radial sections. Such simple bends do not include warped or three-dimensionally-curved surfaces. However, they provide additional desirable results and may be used with the above-described and preferred blades of thin and uniform-thickness sheet material.

Numerous possible forms of simple bend curvatures may be used to give desired or better effective lift coefficients at particular cylindrical blade sections. One such form is schematically shown by the edge-on view of the bent plane BP in FIG. 2. This may be considered as showing plane P_1 displaced down and simply bent only along lines which are contained therein and which are parallel to its radial line A_R–E_R, with a curvature which increases radially outward, as shown. In other words, it is bent only along lines parallel to its line of greatest tilt angle, and across its contained true straight lines of no tilt or those parallel to A_R–E_R.

Thus blade sections located like 8_R and 8_T, but with their surfaces defined by BP, will be seen from FIG. 2 to have an actual camber curvature given by this two-dimensional curvature, which is convex toward the suction face or toward the axial air intake end. This is in addition to the above-discussed effective camber curvature, so that the total effective camber is increased. This camber increase is greater in blade regions away from E_A and toward E_B. It will be seen that bends or curves of the type of BP will provide a progressive decrease in angle a_C and in effective pitch for radially outer cylindrical airfoil sections. This is accompanied by a generally corresponding decrease in total (effective plus actual) camber curvature. Such arrangements are useful in giving a desirably greater contrast or change in both pitch and camber between root and tip blade sections than that given by a true flat plane like P_1. They help in permitting greater span lengths of efficient airfoil blades for a given hub.

Other useful forms of such bent planes include the simple bend curving of a tilted plane like P_1, generally along the length of the blade and in the direction shown

by BP. Such bending along the blade length is a preferred type of curving. This type of bending is shown by BP, wherein a blade like 8 will be simply bent diagonally across its chord widths. In other forms, this bending may, if desired, be along the blade center line Ce_8 or along a blade edge, such as L. It will be apparent that such bending along contained lines parallel to E_B, or along lines approaching this direction, will produce more actual camber curvature in blade regions near E_A and may be useful for this purpose in particular designs. However, in general this last is not preferred, since it tends to produce an effective tilt angle which is at least partly reversed and thus gives a partly or wholly reversed effective pitch and camber in blade regions near E_B.

To summarize, the simple bending, when used to modify the effects of a tilted plane, is preferably at least generally in a direction which will change the tilt angle between radially different airfoil sections. Often, but not necessarily in all cases, this bending may be used to provide effective pitch and camber which increase radially inwardly more than the increase given by just a tilted flat plane. Other uses are within the purview of this invention.

The above-noted simple bend curvatures for sheet-like blades may be provided by various known or suitable methods including the subsequent permanent bending of an initially flat blade or its complete or partial bending by centrifugal force in normal use. It is also to be noted that various other types and directions of simple bends may be used to modify the above-described effects of a tilted plane under the broader aspects of the invention and as will be apparent from this disclosure to those skilled in this and related arts.

It will be noted that there is a short motor shaft overhang or distance out from the motor end to is connection to the rotor in the three forms of FIGS. 4 and 5, FIGS. 6 and 7, and FIG. 8. This overhang is less in these last two forms, since the motor-holding portion 15 or the like is not between the motor and the rotor.

As noted briefly above, fan units according to this invention may in fact be used with their discharge ends exposed. One such case is where air is to be sucked out of the flexible duct from the under-body ventilating pad. It is intended that in these arrangements, the entry-preventing grille, which also preferably forms the motor-holding spider and the anti-swirl blades, be located on the exposed discharge end. It will be seen that this can readily be achieved on any exposed end; or, if both ends are exposed, two grilles may be used.

While only certain of the numerous possible forms and arrangements contemplated by this invention are specifically described in the foregoing specification, including the references to my said prior patents, it is to be understood that this invention may include, and is intended to cover by the appended claims, various other forms or arrangements including the use of only part of the advantages hereof or the use of features hereof in other relations, all within the teachings and spirit of this invention.

I claim as my invention:

1. An axial flow fan unit of the direct-connected electric motor type having a one-piece member comprising
a hollow, generally cylindrical, generally cup-like portion having at least one axial end which is partly closed to embrace over the axial end of an electric motor located at least in part within the axial length of said cup-like hub portion and
a plurality of integral blades thereon,
each blade being throughout a material part thereof a thin sheet whose surfaces contain true straight lines extending generally entirely across the blade chord width, said surfaces being tilted to the fan's axis of rotation to provide effective airfoil camber curvature as well as effective airfoil pitch.

2. The unit of claim 1 in which
said member is a fan rotor,
said surfaces are simply bent planes,
said blades have an effective tip pitch in the efficient but inherently unstable range of from 20 to 25 degrees to supply under-body ventilating air flow against an always present minimum and stall-preventing restriction, and
said blades have chords not decreasing radially inward.

3. The unit of claim 1 in which
said unit is an anti-swirl stator and also a grille for the exposed axial end of said fan unit.

4. The unit of claim 1 in which
each tilted blade is of plastic and has at least the leading edge portion of its tip regions tilted toward and extending materially axially beyond the air intake axial end of said hub portion,
the actual thickness of each thin, flat sheet blade being only that thickness needed for strength, and
said blades being flat throughout substantially their entire areas to form a mono-convex cambered airfoil.

5. The unit of claim 1 in which
at least part of the tip portion of each tilted blade is axially offset toward and beyond the connected axial end of said hub portion, and
each blade is tapered to provide chords increasing radially inwardly toward a limiting hub diameter to provide a root section of approximately 90 degrees of arc.

6. The unit of claim 1 in which
at least part of the tip portion of each blade is axially offset toward and beyond the non-connected, fully open end of said cup-like hub portion, and
each blade is tapered to provide radially inwardly increasing chords whose centers lie generally on a radial plane through the axis of rotation.

7. The unit of claim 1 having
two such one-piece members, each of plastic, one being a fan rotor and the other being an anti-swirl stator, and each having a hub portion,
at least one of said hub portions having motor-cooling opening means through its connected end.

8. An axial flow, high pitch and inherently unstable type fan unit for relative tip air velocities of less than 150 feet per second to force under-body ventilating air flow, said unit having
airfoil blades, each of which comprises
a thin sheet which is substantially flat and planar between its leading and trailing edges and throughout at least a substantial portion of its radial length,
the substantially parallel planes of the two faces of said sheet being spaced by a sheet thickness substantially only adequate for strength,
said two planes intersecting the fan's axis of rotation at an angle which in part determines the effective pitch of the blade along its radial length
and which also tilts the radial length of the blade axially toward the inlet end of the fan,
whereby each blade has an increasing effective camber curvature along cylindrical sections of decreasing diameter in its rotary path relative to the air.

9. The fan unit of claim 8 in which
said blades are rotary fan blades of plastic, and
said angle is an acute angle of more than 45 degrees.

10. An under-body ventilating unit comprising
an unstable, high pitch type of axial flow fan rotor

in a stator shroud ring forming part of an outer casing for the unit,

an inner, motor-holding portion rigidly connected to said shroud ring and

having therein an electric motor with a shaft at one axial end,

a generally cup-like rotor hub portion secured on said motor shaft and extending over at least the shaft end of said motor, and

airfoil fan blades fixed to said rotor hub portion,

each blade including a thin sheet whose surfaces contain straight lines extending generally across the chord widths of the blade substantially from its leading edge to its trailing edge, said surfaces being tilted to the fan's axis of rotation to provide effective pitch as well as effective camber curvature throughout a material portion of the radial air flow sections through the blade,

the axial lengths of at least the tip portions of said blades being within the axial length of said shroud ring casing.

11. The unit of claim 10 in which

each blade is a substantially flat and tilted sheet throughout substantially all of the radial air flow sections through the blade,

the maximum tilt angle of the extended plane of each such blade sheet is greater than the effective pitch angle of at least the tip portion of said blade,

said motor-holding portion is generally cup-like and embraces the non-shaft end of said electric motor,

said rotor and stator parts are each one-piece moldings of noise-vibration-damping plastic,

the diameter of said hub has a minimum value which determines the root section pitch of each said blade, and

the effective chord widths of said blades at different radii in part determine the effective pitch and effective camber at each radial section of the blade.

12. In a generally axial flow type fan unit for forcing the flow of under-body ventilating air,

airfoil blade portions to act on relatively moving air,

in each of which blade portions at least one of its high and low pressure surfaces is a flat plane extending substantially from the leading edge to the trailing edge of the blade inclined to the fan's axis of rotation and also axially toward the fan unit's inlet end to provide an effective pitch, and an effective camber.

13. The fan blade portions of claim 12 which are of plastic,

substantially flat on both faces throughout substantially their entire extent,

have an effective tip pitch in the efficient but inherently unstable range of from about 20 to 25 degrees,

have an effective airfoil camber curvature, and

have radially inwardly increasing chords and actual sheet widths.

14. A compact and axially short, axial flow fan unit of the direct-connected electric motor type having an inner axial end to be retained in the exposed open end of a duct or the like to force the flow of air therethrough and under a supported human body, said unit comprising

an electric motor having a shaft at its inner end,

an axial flow type fan rotor having blades on and secured on said shaft by an integral cup-like portion at least in part axially overlying and embracing the inner end of said motor,

said fan rotor being a first, one-piece plastic molding,

a motor-holding stator having an integral cup-like portion embracing and at least in part axially overlying the outer and exposed end of said motor,

a motor-locating spider also forming a finger-entry-preventing outer end grille integral with said motor-holding portion, and

a shroud ring also forming a radially outer casing

integral with said grille and axially overlying at least the tips of said fan blades and also axially overlying said motor,

said stator, aside from said motor, being essentially a second one-piece plastic molding.

15. The unit of claim 14 in which

at least material portions of said fan blades are flat sheets inclined to the fan's axis of rotation and toward its intake end to provide an effective pitch, and

said end grille has its radially-extending portions forming anti-swirl blades,

material portions of which are also flat sheets inclined to the fan's axis of rotation and toward its intake end to provide an effective pitch opposite to that of said fan blades.

16. An axially short, compact, and low cost axial flow type fan unit comprising

an electric motor having a shaft,

an axial flow fan rotor having a first generally cup-like hub portion embracing and overlying an axial end of said motor and rigidly connected to its shaft close to said motor for a minimum overhang,

fan blades fixed on said sub and at least in part axially overlying said motor, and

a stator including said motor and a motor-holding second generally cup-like hub portion, concentric with said first cup-like hub portion, embracing and overlying an axial end of said motor and connected thereto,

a motor-locating spider at least in part overlying said stator hub portion and fixed thereto, and

a cylindrical outer shroud ring fixed to said spider and forming the entire outer casing, said shroud ring axially overlying at least the tip portions of said rotor blades and being materially axially shorter than said motor.

17. The unit of claim 16 in which

said rotor member and said stator member are each one piece plastic moldings, and

said fan blades are flat sheets,

having a thickness only substantially that needed for strength and

having both their planes tilted to the fan's axis of rotation to provide an effective camber curvature forming a selected part of a sine wave type curve taken along each cylindrical section, and

having a pitch which is less at the blade tips than the complement of the maximum angle between each said plane and the axis of rotation.

18. The unit of claim 16 in which

said two cup-like hub portions are over opposite axial ends of said motor and are arranged open-end-to-open-end to substantially overlie the axial length of said motor, and

said spider also forms an entry-preventing axial end grille.

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