

[54] FLEXIBLE FAN

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[51] Int. Cl. F01d 5/28

[58] Field of Search 416/132, 240, 241 A

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[57]

ABSTRACT

A fan which, because of the particular construction of its blades, will automatically "unload" by flexure of portions only of its blades as its speed of rotation is increased, whereby the volume of air moved by the fan does not increase proportionally as the speed of the fan increases. Each of the identical blades has a reverse twist and consists of a stiff leading region formed as a portion of a cone, a resiliently flexible trailing region formed as a portion of a cylinder, and an intermediate region formed as a continuation of the same cylinder and rectilinearly extending from an area near the trailing edge of the blade root to an area near the leading edge of the blade tip, the axis of the cylinder being parallel with the intermediate region. Ideally, the fan is an integral plastic molding and the difference in flexibility of the several regions is achieved by making the leading region uniformly thick, the trailing region uniformly thin and the intermediate region of increasing thickness as it progresses between the trailing region and the leading region. The reverse twist feature is obtained by having the pitch at the tip of each blade greater than the pitch at its root.

28 Claims, 11 Drawing Figures

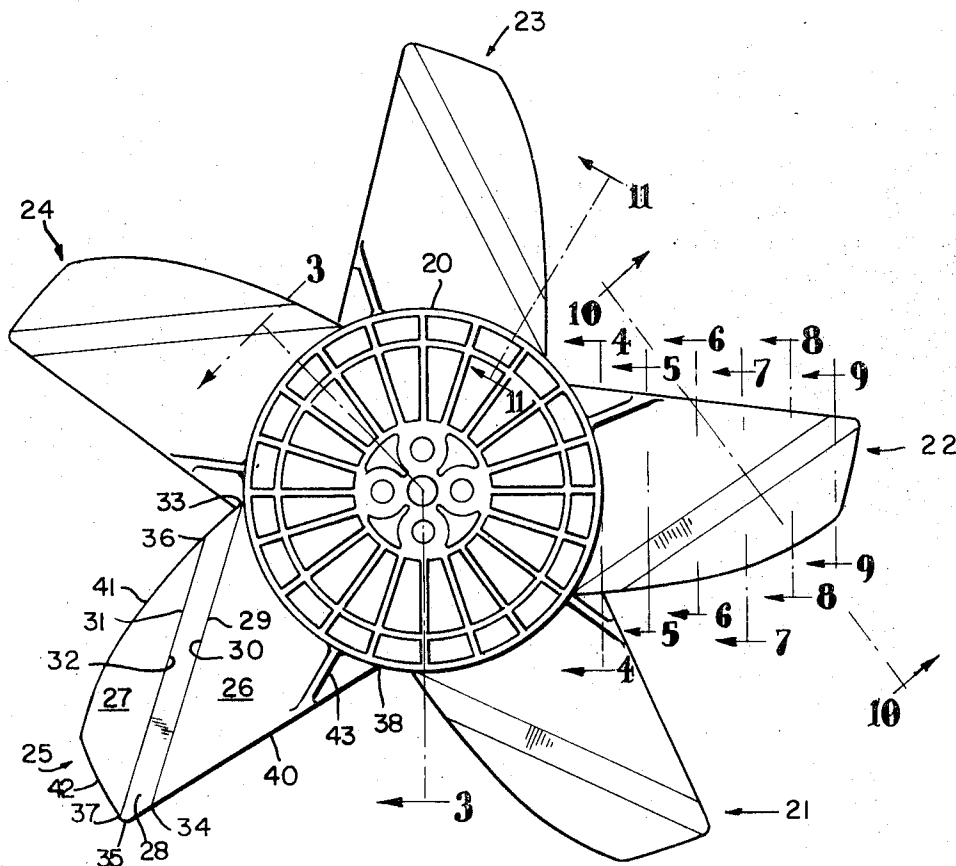


Fig. 1

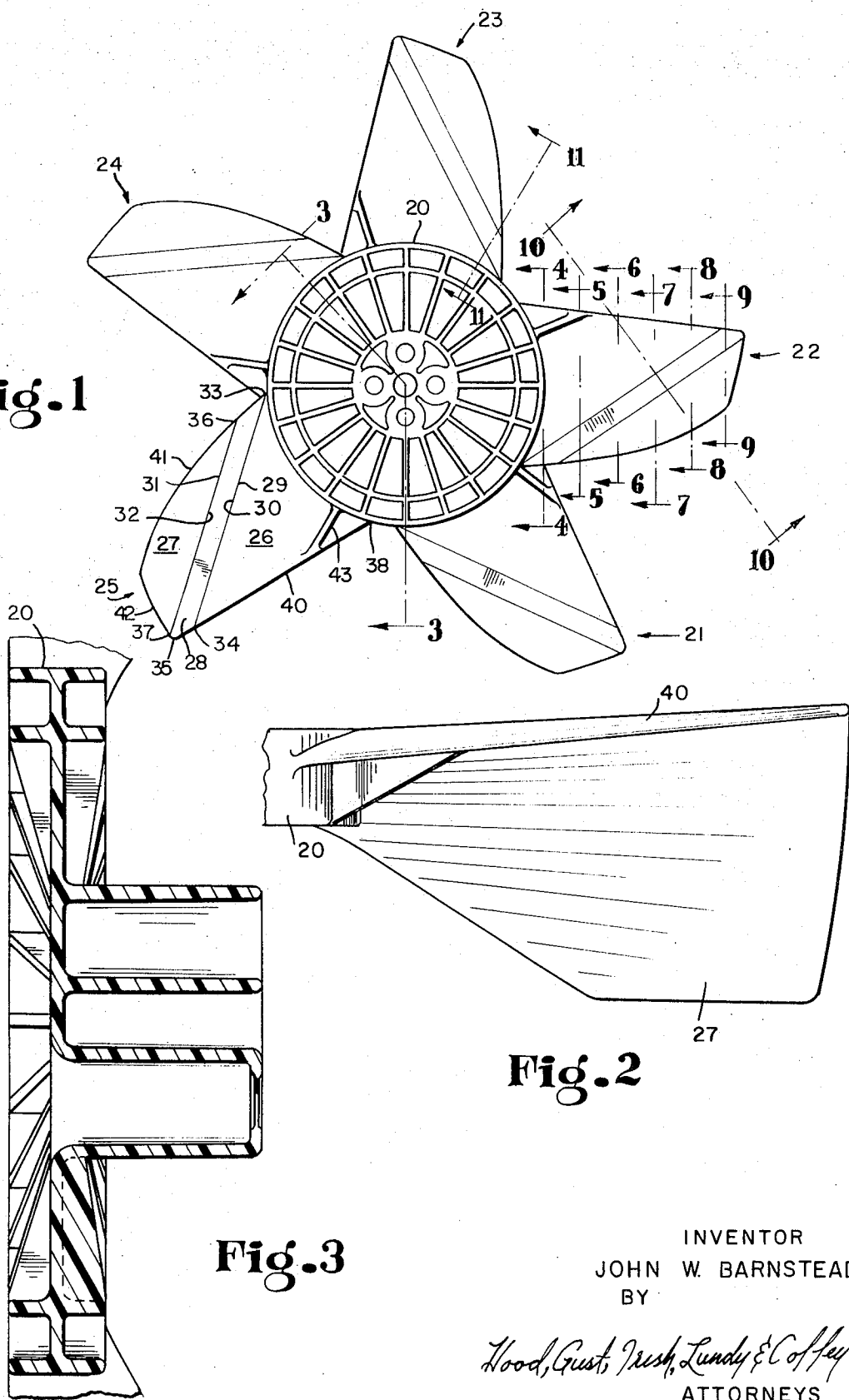


Fig. 2

Fig. 3

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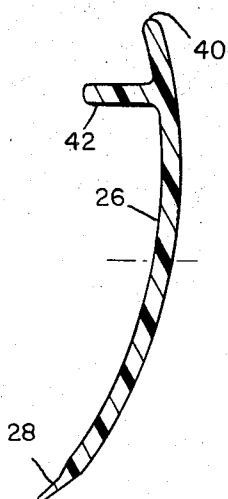


Fig. 4

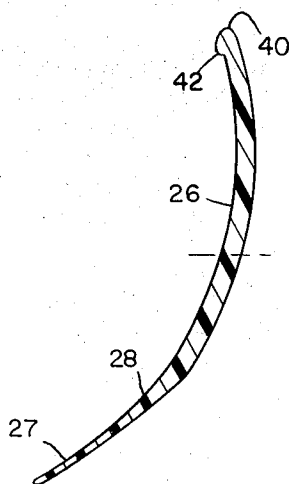


Fig. 5

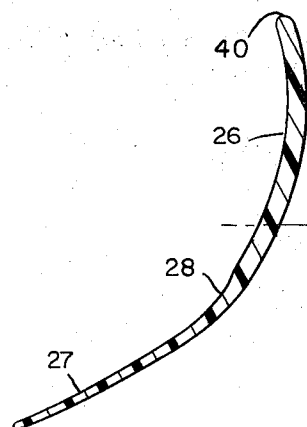


Fig. 6

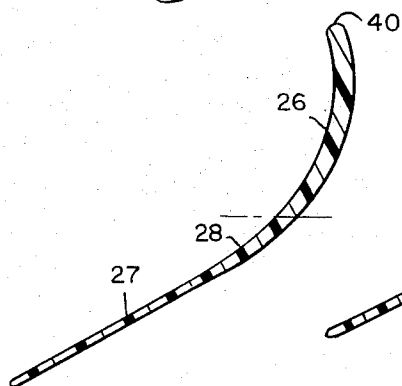


Fig. 7

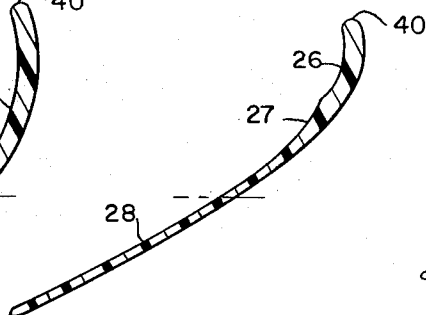


Fig. 8

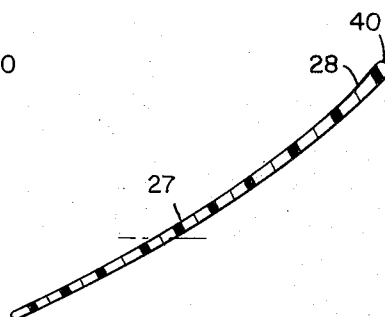


Fig. 9

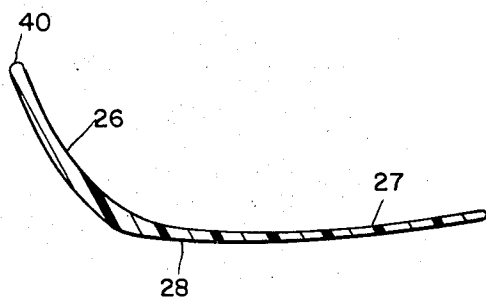


Fig. 10

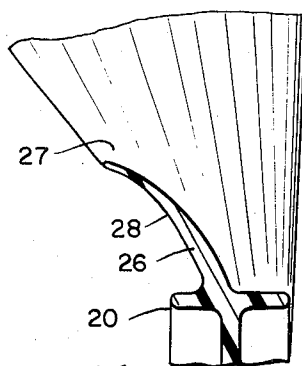


Fig. 11

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FLEXIBLE FAN

The present invention relates to a fan primarily intended to draw air through the radiator associated with an engine for driving an automotive vehicle. In today's luxury automobiles, wherein the engine must drive a heavy vehicle with great agility and must also drive numerous accessories even, sometimes for long periods, when the vehicle is stationary, great quantities of flowing air are required properly to cool the engine. Thus, the fan which is conventionally associated with the radiator in such a vehicle must be of high capacity even at idling speeds and therefore must be of such character as to demand a significant proportion of the torque developed by the engine. It has long been recognized that, as vehicle speed increases, much of the required air flow will be produced by the very movement of the vehicle through the atmosphere so that the demand upon the fan to produce air movement may be reduced until, at very high vehicle speeds, the requirements upon the fan are very significantly decreased. Thus, it is apparent that it would be desirable, as vehicle speed (and thus engine and fan speed) increases, to reduce the fan capacity and thus reduce the torque demand of the fan. Various expedients to that end have been tried; but, so far as I am advised, all previous efforts in that direction have been significantly less than successful or too expensive.

The primary object of the present invention, then, is to provide a fan of such character that, as its rotational speed increases, the pitch of its blades, and therefore its air-moving capacity, will be progressively reduced, whereby its torque demand upon the driving engine will be correspondingly reduced.

A further object of the invention is to provide a fan consisting of a hub with a plurality of substantially identical blades of reverse-twist formation, each blade having a stiff leading region and a resiliently flexible trailing region, the leading region tapering from the root of the blade toward its tip and the trailing region flaring from the blade root to its tip. Still another object is to provide such a fan in which the leading region of each blade is formed as a portion of a cone whose base is near the blade root and whose apex is near the blade tip, while the trailing region is formed as a portion of a cylinder whose axis is parallel with the region of emergence between the leading region and the trailing region.

Still further objects of the invention will appear as the description proceeds.

To the accomplishment of the above and related objects, my invention may be embodied in the form illustrated in the accompanying drawings, attention being called to the fact, however, that the drawings are illustrative only, and that change may be made in the specific construction illustrated and described, so long as the scope of the appended claims is not violated.

In the drawings:

FIG. 1 is a front elevation of a fan constructed in accordance with the present invention;

FIG. 2 is an elevation, drawn to an enlarged scale and looking head-on into the leading edge and face of a blade, a fragment of the hub being shown;

FIG. 3 is a longitudinal section taken on the line 3—3 of FIG. 1 and looking in the direction of the arrows; and

FIGS. 4 to 11 are enlarged sectional views taken on the correspondingly identified section lines of FIG. 1.

Referring more particularly to the drawings, it will be seen that in the illustrated embodiment of the invention a hub 20 is provided with five substantially identical blades radiating in asymmetrical peripherally spaced positions from said hub. The asymmetrical spacing of the blades is intended to reduce the noise level of the fan at high speeds. In some cases, it may be advisable not to have all blades identical, especially for noise and resonance detuning purposes. The optimum arrangement illustrated is such that any point on the blade 22 is spaced 58° from a corresponding point on the blade 21, the blade 23 is spaced 83° from the blade 22, the blade 24 is spaced 68° from the blade 23, the blade 25 is spaced 68° from the blade 24, and the blade 21 is spaced 83° from the blade 25.

Since the blades are identical in the illustrative embodiment, only one will be described in detail. Thus, each blade comprises a stiff leading region 26 of uniform thickness, a resiliently flexible trailing region 27 of uniform thickness significantly less than that of the region 26 and an intermediate region 28 whose leading edge 29 is equal in thickness to, and merges with, the trailing edge 30 of the region 26 and whose trailing edge 31 is equal in thickness to, and merges with, the leading edge 32 of the trailing region 27. The leading edge 29 of the intermediate region 28 is rectilinear and extends from a point 33 at which the trailing edge of the root of the blade meets the periphery of the hub 20 to a point 34 on the leading edge of the blade adjacent the extreme tip 35 of the blade. The trailing edge 31 of the intermediate region 28 is likewise rectilinear and extends, in parallelism with the edge 29, from a point 36 on the trailing edge of the blade to a point 37 adjacent the tip 35, the points 34 and 37 being disposed on opposite sides of the tip 35. Any longitudinal section through the region 28 will be rectangle, while any transverse section therethrough will be generally arcuate because it is a continuation of the cylindrically formed trailing region as will be discussed hereinafter.

The stiff leading region 26 of each blade is formed as a portion of a cone having its base adjacent the hub 20 and its apex adjacent the point 34. In the optimum embodiment of the invention illustrated, the cone base is circular and lies in a plane which cuts the periphery of the hub 20 at the points 33 and 38 and is perpendicular to the hub radius which substantially bisects the blade root. The center of the circular cone base lies in the said radius. The axis of the cone is inclined forwardly in the direction of rotation of the fan so that the apex of the cone lies at the point 34. The reference cone is, therefore, an oblique cone or a skew cone.

The flexible, trailing region 29 is formed as a portion of a right cylinder whose axis is parallel with the trailing edge 29 of the leading region 26. The intermediate region 28 is formed as a continuation of that cylinder portion, and its leading edge 29 meets the trailing edge 30 of the leading region 26 tangentially. That is, a plane which is tangent to the cylindrical surface of the region 28 at the leading edge 29 of that region is also tangent to the conical surface of the region 26 at the trailing edge 30 of said leading region.

The leading edge 40 of the blade is a generally straight line which inclines rearwardly away from the direction of rotation of the fan as it progresses from its root point 38 to its tip 35. The trailing edge 41 of the blade includes a generally straight line 41a (FIG. 2) which inclines forwardly toward the direction of rota-

tion of the fan as it progresses from its root point 33 to an intermediate point 41b from which it inclines generally parallel to a plane perpendicular to the axis of rotation as indicated by portion 41c. The distal end 42 of the blade is generally arcuately formed about the axis of rotation of the fan in the flexed condition of the fan.

As is to be seen in FIG. 1, the trailing edges of certain of the blades, near their roots, overlap small portions of the root regions of the leading edges of adjacent blades. Particularly in such instances, the overlapped portions of the blades may be cut away; and a bracing rib 43 may be provided on the forward face of the blade near the edge of such cut away portion. This is one of the reasons why the blades may not be identical.

The fan is so designed that it may be integrally formed as a plastic molding. It is presently believed that an optimum material for such molding is a 40% long fiberglass filled nylon and one commercially available substance for such use is known as FIBERFIL G-13/40 Type 6, natural, offered by Fiberfil Division of Dart Industries, Evansville, Indiana 47717. Other materials of similar characteristics are believed to be equally available but may require some dimensional modifications.

Alternatively, the hub and the several blades may be separately molded and then assembled in any well-known manner. Still further, the fan may be fabricated from metal or other materials having suitable characteristics of stiffness and resilient flexibility. Whatever material is used, the relative thicknesses of these regions 26 and 27 will be so selected as to provide the desired stiffness for the region 26 and the desired resilient flexibility for the region 27.

In the one embodiment of the invention tested, the radius of the hub 20 is 3.75 inches. The radius of the cylinder upon which the region 27 is formed is 12.0 inches. The section line 4—4 is tangent to the hub periphery and in FIG. 4 the radius of curvature of the region 26 is 4.55 inches. The section line 5—5 is 4.75 inches from the center of the hub and the radius of curvature of the region 26 in FIG. 5 is 3.65 inches. The section line 6—6 is 5.75 inches from the center of the hub and the radius of curvature of the region 26 in FIG. 6 is 2.69 inches. The section line 7—7 is 6.75 inches from the center of the hub and the radius of curvature of the region 26 in FIG. 7 is 1.76 inches. The section line 8—8 is 7.75 inches from the center of the hub and the radius of curvature of the region 26 in FIG. 8 is 0.82 inches. The section line 9—9 is 8.62 inches from the center of the hub, it intersects the leading edge of the blade at the point 34 and therefore it does not cut the region 26. A line parallel with the section line 9—9 and including the extreme distal tip 35 of the blade is 9.25 inches from the center of the hub.

The perpendicular distance between the parallel rectilinear edges 29 and 31 of the intermediate region 28 is 0.5 inches.

The thickness of the region 26 is 0.15 inches, the thickness of the region 27 is 0.045 to 0.05 inches and, of course, the thickness of the region 28 increases from 0.045 — 0.05 inches at its edge 31 to 0.15 inches at its edge 29.

Under test and stroboscopic examination, it is found that plastic blades constructed as discussed maintain their equilibrium configuration illustrated in FIGS. 4 to 9 at velocities up to approximately 1,400 rpm. Thereafter, as speeds increase, the trailing blade region 27 begins to flex bodily substantially about the line 31 or in

the region of the line 31 until a velocity of approximately, for instance, 4,000 rpm is reached. Thereafter, as velocity continues to increase, the cylindrically curved trailing region 27 gradually begins to "unroll" until, at velocities above approximately 4,000 rpm, the trailing region becomes almost flat and provides a pitch of about 30° by sight measurement.

The pitch of each blade at its root is approximately 8°, while the pitch near the blade tip is approximately 56° when the blade is in equilibrium condition. As the blade trailing region is flexed under the influence of centrifugal force and the force of the air, obviously the tip pitch gradually decreases as mentioned above to about 30°.

It will be appreciated that each blade of the illustrated fan is basically a portion of a right cylinder of uniform thickness joined to a portion of a skew or oblique cone of uniform thickness with a tapered section (also cylindrically formed) joining the cylindrical and conical portions. The trailing region 27 is the portion of the cylinder and the leading region 26 is the portion of the cone with the intermediate region 28 being the above-referred to tapered section. The joining of a conical portion with a cylindrical portion in this manner produces a blade which is effective for the intended purpose and which is also relatively easy to manufacture using conventional manufacturing processes.

The tapered region 28 prevents a stress concentration at the change in thickness between the leading region 26 and trailing region 27. The region 28 facilitates the provision of gradual change in curvature of the blade surfaces. The cylindrically formed trailing region 27 and tapered region 28 minimize the resistance to bending because any section parallel to the tapered region 28 is of minimum section modulus. The conical leading region 26 provides a surface of high section modulus. The oblique conical region 26 which is formed about a conical axis inclined forwardly relative to the direction of rotation of the fan, causes a larger component of the radial centrifugal force to act on the flexible trailing region 27 which is particularly important in plastics because of their lower densities. That is, the forwardly inclining oblique cone permits the lines 29, 31 to incline forwardly by an angle greater than would be permitted by a right conical region 26.

The illustrative fan is believed to unload by a combination of centrifugal and air forces. When the fan is run in what is referred to in the trade as a bursting pit, the blades are observed to flex. The bursting pit is substantially evacuated so that high speeds may be obtained with very low power. Thus, the observed flexing was due solely to the centrifugal component. Since the blades appear to flex significantly more in air, it can be assumed that air resistance plays a significant role in the flexing.

A metal fan constructed in accordance with the above description, with the exception that the trailing regions 27 of the blades are approximately 0.018 inches thick, was tested and the results obtained are shown in Tables I through III as follows:

TABLE I

Tests at 500 rpm varying the static pressure at the exhaust side of the fan

CFM *	STATIC PRESSURE **
1015	0.00 (Ambient)
900	0.01
705	0.02

635	0.03
550	0.04
465	0.06
465	0.12

TABLE II

Tests at 1250 rpm varying the static pressure at the exhaust side of the fan

CFM *	STATIC PRESSURE **
2780	0.00 (Ambient)
2685	0.02
2600	0.04
2600	0.06
2510	0.08
2465	0.10
2365	0.12
2330	0.14
2225	0.17
2120	0.21
1885	0.25
1710	0.30
1330	0.39
1245	0.61

TABLE III

Tests at 3900 rpm varying the static pressure at the exhaust side of the fan

CFM *	STATIC PRESSURE **
5370	0.00 (Ambient)
5270	0.08
4785	0.48
4410	0.80
4285	0.97
4205	1.20
4090	1.43
3880 ***	1.70 ***

* Cubic Feet per Minute corrected to standard conditions of 0.075 lbs. per cubic foot air density.

** Static pressure in inches of water.

*** Reading taken at 3880 rpm because of loading of the drive motor.

During the tests reported in Table I, the torque varied from 4 lb.-inches at ambient static pressure to 5 lb.-inches at 0.12 inches water static pressure; during the tests reported in Table II, the torque varied from 14 lb.-inches at ambient static pressure to 20 lb.-inches at 0.61 inches water static pressure; and during the tests reported in Table III, the torque varied from 40 lb.-inches at ambient static pressure to 47 lb.-inches at 1.70 inches water static pressure. From this data, it can be calculated that the horsepower requirements of the fan at the higher speeds (3,900 rpm) are much reduced over that which would have been required if the blades had not flexed or unloaded.

What is claimed is:

1. A fan comprising a hub and a plurality of blades radiating therefrom, each of said blades having a tip pitch significantly exceeding its root pitch and each of said blades including a stiff leading region formed as a portion of a cone having its base adjacent said hub and its apex disposed radially outwardly from said hub and a flexible generally cylindrically formed trailing region, the leading edge of said trailing region and the trailing edge of said leading region extending from an area adjacent the trailing edge of the blade root to an area adjacent the leading edge of the blade tip.

2. The fan of claim 1 in which said cone base is a circle located in a plane which is perpendicular to that radius of said hub which includes the center of said circle.

3. The fan of claim 2 in which said cone base is a circle located in a plane which cuts the periphery of said hub and is perpendicular to that radius of said hub which includes the center of said circle.

4. The fan of claim 2 in which the axis of said cone inclines forwardly to intersect the leading edge of said blade near said blade tip.

5. The fan of claim 3 in which the axis of said cone inclines forwardly to intersect the leading edge of said blade near said blade tip.

6. The fan of claim 1 in which the leading edge of said trailing region is rectilinear and said cylinder is a right cylinder whose axis is parallel with said leading edge of said trailing region.

7. The fan of claim 1 in which there are five identical blades peripherally spaced about said hub at successive angular intervals of 58°, 83°, 68°, 68° and 83°.

8. A fan comprising a hub and a plurality of blades radiating therefrom, each of said blades being formed to have a stiff leading region providing a leading edge and a trailing edge, a flexible trailing region having a thickness significantly less than that of said leading region and a leading edge, and an intermediate region flaring in thickness from its trailing edge, where it merges with the leading edge of said trailing region, to its leading edge, where it merges with the trailing edge of said leading region, said intermediate region extending forwardly from an area adjacent the trailing edge of the blade root to an area adjacent the leading edge of the blade tip, said leading edge of said intermediate region intersecting the leading edge of said leading region and said trailing edge of said intermediate region intersecting the distal end edge of the blade.

9. The fan of claim 8 in which each of said blades has a tip pitch significantly exceeding its root pitch.

10. A fan comprising a hub and a plurality of blades radiating therefrom, each of said blades being formed to have a stiff leading region, a flexible trailing region having a thickness significantly less than that of said leading region, and an intermediate region flaring in thickness from its trailing edge, where it merges with the leading edge of said trailing region, to its leading edge, where it merges with the trailing edge of said leading region, said intermediate region extending from an area adjacent the trailing edge of the blade root to an area adjacent the leading edge of the blade tip, said leading region being formed as a portion of a cone having its base adjacent said hub and its apex disposed radially outwardly from said hub, and said trailing region being formed as a portion of a cylinder whose axis is parallel to the leading edge of said trailing region.

11. The fan of claim 10 in which said intermediate region is formed as a continuation of such cylinder, the leading edge of said intermediate region and the trailing edge of said leading region meeting along a line lying in a plane which is tangential to such cylinder and such cone.

12. The fan of claim 11 in which each of said blades has a tip pitch significantly exceeding its root pitch.

13. The fan of claim 10 in which each of said blades has a tip pitch significantly exceeding its root pitch.

14. The fan of claim 11 in which said leading region and trailing region, respectively, have uniform thicknesses and every longitudinal section of said intermediate region is bounded by parallel straight lines lying, respectively, in the inner and outer surfaces of such cylinder.

15. The fan of claim 8 in which the leading and trailing edges of said intermediate region are parallel.

16. The fan of claim 14 in which the leading and trailing edges of said intermediate region are parallel.

17. The fan of claim 16 in which each of said blades has a tip pitch significantly exceeding its root pitch.

18. A molded plastic fan comprising a hub and a plurality of substantially identical blades radiating therefrom at non-uniform peripheral spacings, each of said blades having a tip pitch significantly exceeding its root pitch and each of said blades comprising a stiff leading region of uniform thickness and formed as a portion of a cone, a trailing region of uniform thickness significantly less than that of said leading region and formed as a portion of a right cylinder, and an intermediate region formed as a continuation of said cylinder and flaring in thickness from its rectilinear trailing edge, where it merges with the leading edge of said trailing region, to its rectilinear leading edge, where it tangentially meets the trailing edge of said leading region.

19. The fan of claim 18 in which said intermediate region extends from an area adjacent the trailing edge of the root of the blade to an area adjacent the leading edge of the tip of the blade.

20. The fan of claim 18 in which every longitudinal section of said intermediate region is bounded by parallel straight lines lying, respectively, in the inner and outer surfaces of such cylinder.

21. The fan of claim 19 in which said rectilinear edges of said intermediate region are parallel.

22. The fan of claim 21 in which the distal ends of said rectilinear edges are oppositely offset from the extreme tip of said blade.

23. A fan blade having a stiff leading region providing a leading edge, and a flexible trailing region merging in a generally rectilinear intermediate region extending forwardly from an area adjacent the trailing edge of the root of said blade to an area adjacent the leading edge of the tip of said blade, said intermediate region having a rectilinear leading edge intersecting the leading edge

of said leading region and a rectilinear trailing edge intersecting the distal end edge of said blade, and said blade having a tip pitch significantly exceeding its root pitch.

24. A fan blade having a stiff leading region and a flexible trailing region merging in a generally rectilinear region extending from an area adjacent the trailing edge of the root of said blade to an area adjacent the leading edge of the tip of said blade, said leading region being formed as a portion of a cone with its base near the root of said blade and its apex near the tip of said blade, and said trailing region being formed as a portion of a cylinder.

25. The fan blade of claim 24 in which said cylinder is a right cylinder with its axis parallel with said rectilinear region.

26. A molded plastic fan blade having a reverse twist whereby its pitch at its tip significantly exceeds its pitch at its root, said blade comprising a stiff leading region formed as a portion of a cone, a flexible trailing region having a thickness significantly less than that of said leading region and formed as a portion of a cylinder, and an intermediate region formed as a continuation of said cylinder and flaring in thickness from its rectilinear trailing edge, where it merges with the leading edge of said trailing region, to its rectilinear leading edge, where it tangentially meets the trailing edge of said leading region.

27. The blade of claim 26 in which said intermediate region extends from an area adjacent the trailing edge of the blade root to an area adjacent the leading edge of the blade tip.

28. The blade of claim 27 wherein said cylinder is a right cylinder whose axis is parallel with said rectilinear edges.

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