

Fig. 1

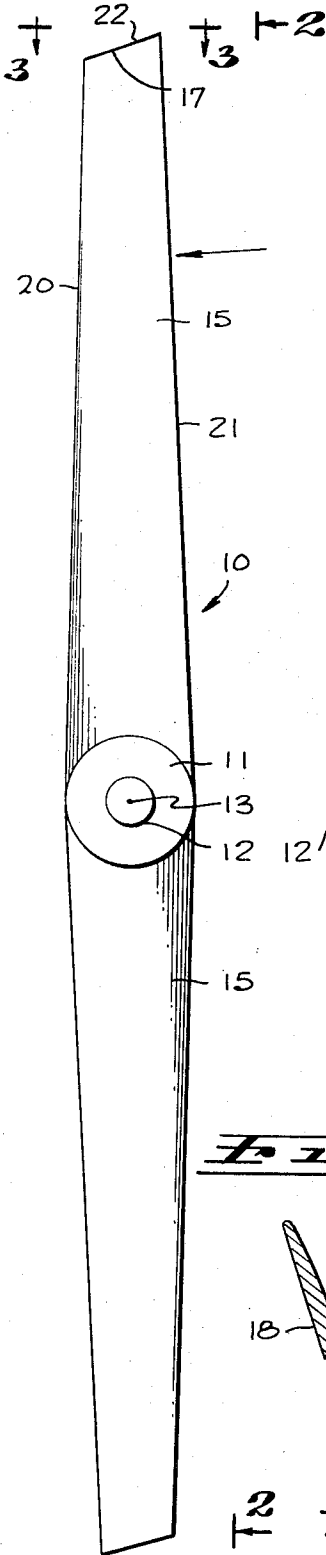


Fig. 2

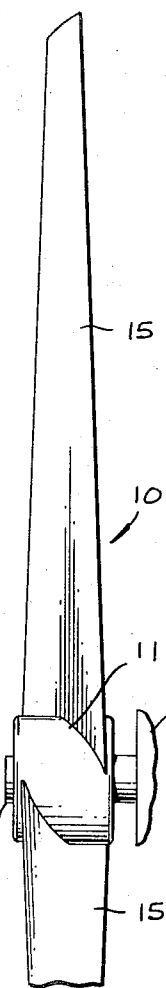


Fig. 6

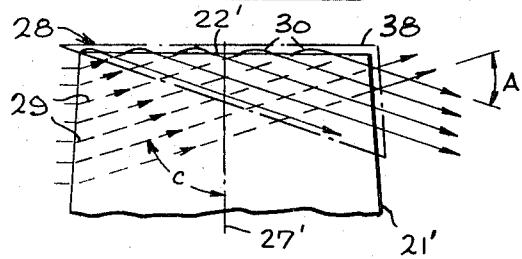


Fig. 3

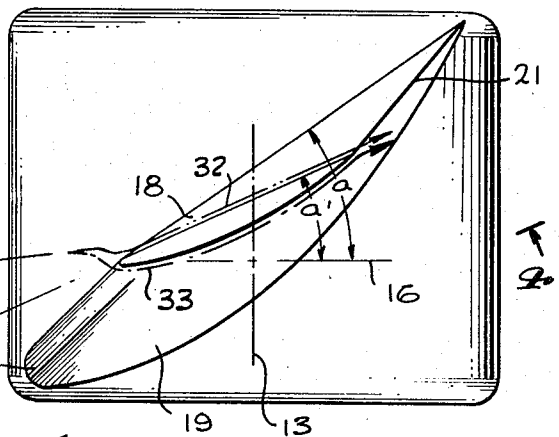


Fig. 4

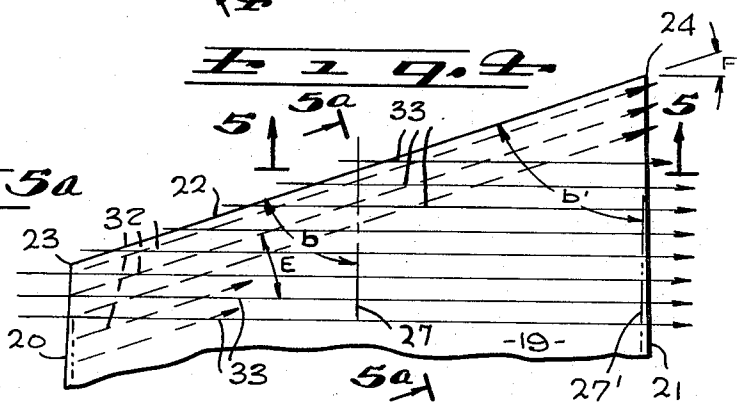


Fig. 5a



Fig. 5

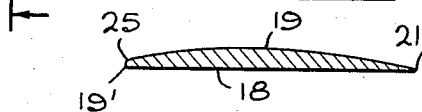
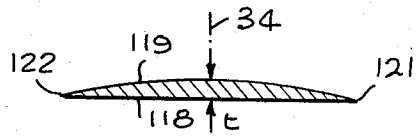


Fig. 7



PROPELLER HAVING ANGULARLY DISPOSED TIP

CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation-in-part of my co-pending application Ser. No. 159,184 filed July 2, 1971 on "Propeller Having Angularly Disposed Tip" now abandoned.

BACKGROUND OF THE INVENTION

This invention relates generally to improved airplane propeller structures, especially designed to attain increased efficiency and more silent operation as compared with conventional propellers currently in use.

As a conventional aircraft propeller moves through the air, a very substantial drag occurs at the tip of the propeller blade, resulting in an ineffective waste of power, and development of a noticeable tip noise produced by the turbulence accompanying the waste of energy. I have found that this inefficiency and unwanted tip noise are caused by a "spilling over" of some of the air from the back side of the propeller, past the tip of the blade, and to the front side of the propeller, in a manner destroying the forward 'lift' on a substantial portion of the tip area thus affected. When the tip is of the conventional square cut type, that is a type in which the edge of the tip extends directly perpendicular to a radial line extending outwardly from the axis of the propeller, the wasted portion of the tip constitutes a triangular region of substantial area. Since the horsepower derivable from different portions of a propeller blade increases rapidly as the blade advances outwardly toward its tip and in fact increases in proportion to a curve of the fourth power, any loss of effective area at the tip of the blade is of extreme importance from an efficiency standpoint.

SUMMARY OF THE INVENTION

A propeller constructed in accordance with the present invention is designed to substantially completely eliminate the above discussed spillage or flow of air from the high pressure back side of a propeller to its lower pressure forward side, to thereby avoid the mentioned loss of power and efficiency, and even more importantly for many installations, to eliminate tip noise and render the blade silent in operation. This result is achieved by special formation of the tip of the blade so that its outer edge gradually advances radially outwardly as it advances circularly from the leading edge to the trailing edge of the blade. The angle of outward advancement of the tip edge corresponds exactly to the outward angularity at which I have discovered pressurized air normally flows along the back side of the propeller when the propeller is in operation under a heavy load, and more specifically is at a critical angle of 71.5 degrees with respect to a line drawn directly radially outwardly from the axis of the propeller and intersecting the tip edge. As a result of this angularity, the air at the back side of the propeller is effectively prevented from flowing forwardly past the tip to the front side of the blade.

The discussed outer tip edge of the blade, besides having this outward angularity, also has the usual pitch angularity, with respect to a plane disposed transversely of the rotary axis of the propeller, and the pro-

peller has a twist as it advances radially outwardly. The two angularities and the twist together result in an overall airplane propeller structure which is far superior, from both an efficiency and noise standpoint, to all prior propellers of which I am aware.

BRIEF DESCRIPTION OF THE DRAWING

The above and other features and objects of the invention will be better understood from the following detailed description of the typical embodiments illustrated in the accompanying drawing, in which:

FIG. 1 is a front view of an aircraft propeller constructed in accordance with the invention;

FIG. 2 is a side view of the propeller, taken on line 2—2 of FIG. 1;

FIG. 3 is a greatly enlarged view of the propeller taken of line 3—3 of FIG. 2, and showing it as it appears looking directly radially inwardly toward the axis of the propeller from a location beyond its tip;

FIG. 4 is a view of the tip taken on line 4—4 of FIG. 3, which line is parallel to the plane in which the tip portion of the blade lies;

FIGS. 5 and 5a are sections taken on lines 5—5 and 5a—5a respectively of FIG. 4;

FIG. 6 is a view similar to FIG. 4, but showing a conventional square cut tip, and the unwanted inefficient air turbulence which occurs at the tip of such a blade; and

FIG. 7 is a view similar to FIG. 5 but showing a variational blade tip cross section.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring first to FIG. 1, I have shown at 10 a propeller embodying the invention which is to be utilized for propelling an airplane forwardly in flight, and which has a central hub portion 11 adapted to be mounted on and be driven by a shaft 12 which turns about a generally horizontal axis 13. In FIG. 2, the aircraft engine which turns the propeller is represented diagrammatically at 14. The propeller is typically illustrated as one of fixed pitch, though it will be understood that the novelty of the invention may of course be applied to a variable pitch propeller. Further, the propeller may have more than the typically illustrated two blade 15.

The propeller is driven in a counterclockwise direction as viewed in FIG. 1. Each of the blades 15 (both or all of which are identical) is disposed at a pitch angle (see FIG. 3) with respect to a plane 16 disposed directly transversely of the axis 13 of the propeller. The blade has a slight twist as it advances radially outwardly, so that the pitch angle decreases from the angle α of FIG. 3 at the innermost portion of the blade to the angle α' at its tip 17. Throughout this entire radial extent, the blade may have a conventional airfoil cross section, defined by a flat surface 18 at the back side of the blade and a slightly convexly curved forward surface 19 of the blade. These two surfaces 18 and 19 meet at an approximately radially extending leading edge 20 of the blade, and a second approximately radial trailing edge 21.

The radially outer tip 17 of each blade is defined by an outer tip edge 22, which meets the radially outer extremity of leading edge 20 of the blade at 23, and extends from that location to a point of juncture 24 with the outermost extremity of trailing edge 21. In advanc-

ing generally circularly from the location of leading edge 20 to trailing edge 21, the tip edge 22 also advances progressively radially outwardly, as seen clearly in FIGS. 1 and 4, so that in effect the blade becomes longer as it approaches trailing edge 21. Edge 22 may lie in the plane of the radially outermost portion of planar rear surface 18 of the blade, with the forward face 19 of the blade being curved or rounded as seen at 25 in FIGS. 5 and 5a to merge with planar surface 18 at edge 22. The discussed radially outward advancement of tip edge 22 in a direction away from axis 13 of the propeller continues throughout substantially the entire length of edge 22.

To describe the shape of outer tip edge 22 even more specifically, it is preferred that at each individual point along edge 22 that edge be disposed at a critical angle of 71.5° with respect to a line extending directly radially outwardly from axis 13 and intersecting that particular point on edge 22. For example, with respect to the approximately central portion of edge 22 which has been designated by the numeral 26 in FIG. 4, the mentioned radial line extending directly radially outwardly to that point from axis 11 is shown at 27, and the discussed critical angle between tip edge 22 and line 27 is designated by the letter b' . Similarly, for the previously mentioned point 24 at the juncture between edge 22 and trailing edge 21, the directly radial line passing through that point from axis 13 is represented at 27', and the critical angle at that location is designated b' . Both of angles b and b' , as well as all other corresponding angles at locations across substantially the entire length of edge 22, are the specified 71.5° .

It will be apparent that if the ideal angularity of the tip edge is maintained continuously along the entire length of edge 22, that edge will theoretically follow a very slightly curved arc between points 23 and 24. This theoretical arc, however, has so little curvature that it may be considered as a substantially straight line, and may in actual practice be formed as a completely straight line, without causing the discussed critical angularity to vary appreciably from the desired 71.5° . Any appreciable deviation from this 71.5° angularity results in a decrease in efficiency and an increase in noise at the propeller tip.

In order to bring out the reason for the angularly disposed outer tip edge 22 in FIGS. 1 to 5, I have illustrated at 28 in FIG. 6 the outer tip portion of a conventional square cut aircraft propeller, which may be considered as identical with the propeller of FIGS. 1 to 5 except that the outer tip edge 22' (corresponding to edge 22 of FIG. 4) is not disposed angularly, but rather is precisely perpendicular to a line 27' extending directly radially outwardly from the axis of the propeller. When a propeller of this FIG. 6 type is driven about its axis, say with the tip moving leftwardly in FIG. 6, it is found that as the tip moves through the air, the air which engages the back side of the tip (the surface corresponding to surface 18 of FIG. 3) progressively moves angularly radially outwardly as it passes over that rear surface. The angular path which this air follows is represented by the lines 29 in FIG. 6, which are disposed at an angle c with respect to the radial line 27'. Because of this angularly outward movement of the air relative to the engaged back side of the blade, some of the air which passes the leading edge of the blade reaches the outer tip edge 22' before it reaches the trailing edge 21', and as a result spills over the tip

edge 22', as indicated at 30, and flows forwardly to the front low pressure side of the blade in a manner destroying or reducing the front to rear pressure differential and therefore the forward thrust produced at that spillover location, and providing the elements of a vortex. The overall result is a loss of forward thrust over a triangular area of the tip portion of the blade as represented at 38 in FIG. 6. This reduces the efficiency of the blade and causes an undesirable noise at the tip.

In the improved tip of FIG. 4, edge 22 is disposed at exactly the same angle (b, b' , etc.) as is followed by the air along paths 32 at the back side of the propeller (corresponding to paths 29 of FIG. 6), so that edge 22 actually parallels these paths of air movement, and the air at the back of the blade can never reach and spill over edge 22 before arriving at the trailing edge 21 of the blade. This prevents both the inefficiency and noise which occur in the FIG. 6 arrangement.

As indicated previously, for optimum results the angles b, b' , etc. in FIG. 4 should be 71.5° , which angularity I have found corresponds precisely to the angularity of air movement relative to the tip portion of the blade when working at maximum effort. To the extent that these angles b, b' , etc. may be more than the optimum 71.5° , some of the air will be permitted to spill forwardly over the outer edge 22 of the blade, and therefore some inefficiency and noise are developed. On the other side of the coin, to the extent that the angles b, b' , etc. are permitted to be less than the optimum 71.5° , a portion of the tip which would otherwise be effective in producing forward thrust has needlessly been removed, and in this way reduces efficiency for a propeller of given diameter.

It should also be noted that, while the pressurized air at the back side of the blade follows the angular outwardly advancing paths represented at 32 in FIG. 4, the lower pressure air at the front of the blade does not advance radially outwardly in this manner, but rather moves directly across the blade along paths such as those represented at 33 in FIG. 4, which paths are substantially perpendicular to the radial center line 27 of the blade (or more precisely are very slightly but imperceptibly curved and at each point normal to a radial line extending through that point). The angular tip edge 22 of the blade functions as a leading edge with respect to this air at the front of the blade, and for maximum efficiency the blade is given an airfoil section in each of the planes in which the air at the front of the blade moves. FIG. 5 is a section taken in one of these planes (normal to radial center line 27) and shows the airfoil section in that plane, consisting of a portion of that planar surface 18 at the back of the blade and a portion of the convexly curved surface 19 at the front of the blade. The leading portion 19' of this airfoil section is slightly rounded, as shown, while the trailing portion adjacent edge 21 may be essentially sharp. Without specifically illustrating the airfoil section in other planes, it will be understood that in all planes which are parallel to the plane of FIG. 5 and which intersect outer edge 22 the tip of the blade has a similar airfoil section of the general type illustrated in FIG. 5, to thus maximize the efficiency of the tip portion of the blade.

In the Figures, the outer tip edge 22 is illustrated as meeting the leading and trailing edges 20 and 21 in abrupt or sharp corners at 23 and 24 as viewed in FIG. 4. In actual practice, it will of course be understood

that these corners may be slightly rounded to facilitate handling of the blade without injury.

In FIG. 3, the direction of flight of the blade tip through the air (including the forward component of blade movement) is represented by the arrow 35. The lines 32 and 33 in this Figure represent certain of the paths of air flow 32 and 33 of FIG. 4, at the back and front sides respectively of the blade. The angle of attack of any particular portion of the blade in FIG. 3 with respect to the contacted air is designated as the angle D in FIG. 3, that is, the angle between arrow 35 and the plane 36 of rear face 18 of that particular portion of the blade. In a fluid, the maximum value which this angle of attack, angle D, can have before stalling is 18.5°. The angle of stall in fluids has a slope of 1 to 3, and therefore a tangent of 0.333, and hence is 18.5°. When the blade is operating at maximum effort, the blade will be disposed at this 18.5° angle of stall.

Relating this angle D of FIG. 3 to the showing of FIG. 4, angle E in FIG. 4 may be termed the angle of displacement, and represents the angle through which the air is deflected (in the FIG. 4 plane) when contacted by the rear face 18 of the blade. This angle of displacement E in FIG. 4 is always equal to the angle of attack D of FIG. 3, up to the maximum effort angle of attack of 18.5°, beyond which point stall conditions set in as indicated. Thus, the angle of displacement E in FIG. 4 is 18.5 degrees at maximum effort, and the optimum value for angle F in FIG. 4 is 18.5 degrees, the complement of the previously discussed critical 71.5° angle *b* by which the angularity of edge 22 has been defined at most points in this specification.

As discussed previously, one reason for the loss of efficiency in the conventional FIG. 6 type of blade results from the loss of pressure differential between the front and back of the blade across the triangular area which has been designated 38 in FIG. 6. Another reason for loss of efficiency, however, results from the development of a vortex circularly behind trailing edge 21' of the blade, because the angle A between the air leaving the front and rear sides of the blade is in excess of 18.5 degrees. In FIG. 4, on the other hand, this angularity between the two streams of air is the angle E, which is 18.5° at maximum effort and will not develop a vortex.

FIG. 7 represents a variational form of the invention, and in particular shows the sectional configuration of this variational form in the plane in which FIG. 5 is taken. Except with respect to this blade cross section, the propeller of FIG. 7 may be considered as identical with that of FIGS. 1 to 5. For example, the tip edge 122 of the FIG. 7 blade is of course disposed at the same 71.5 degree critical angle as is edge 22 of FIG. 4, with respect to a radial line such as that shown at 27 in FIG. 4 (angle *b* in FIG. 4) and the blade has the same pitch angle, twist, and other structural features as in FIGS. 1 to 5, except for the illustrated difference in blade cross section. For most applications, the FIG. 7 contour has been found preferable to that of FIG. 5 for maximizing blade efficiency and minimizing air turbulence.

In FIG. 7, the airfoil section between the angular tip edge 122 (corresponding to edge 22 of FIG. 4) and the trailing edge 121 of the blade (corresponding to edge 21 of FIG. 4) is shaped as a fifty percent airfoil. Stated differently the plane 34 in which the airfoil section has its maximum thickness *t* between rear surface 118 and surface 119 is located half way between tip edge 122

and trailing edge 121. Further, the leading portion of this airfoil section, at edge 122, is much thinner than in FIG. 5, and in fact tapers to a substantially sharp edge at 122. Similarly, trailing edge 121 is substantially sharp. In thus using the term "sharp" in describing edges 121 and 122, I intend to indicate that these edges are as thin as is practical in a blade of this type, though it will of course be understood that a knife sharp condition should preferably be avoided in order to prevent injury to persons handling the propeller. Thus, the edges 121 and 122 may be rounded or curved at an extremely small radius, say for instance about 0.020 of an inch, with the edges then typically having an overall thickness of about 0.040 of an inch. The thickness of the FIG. 7 cross section increases only gradually as it approaches the central plane 34 from edge 122, and then preferably decreases at the same gradual rate between plane 34 and trailing edge 121, to thus be symmetrical with respect to plane 34. The rear face 118 as viewed in FIG. 7 follows a straight line in extending between edges 122 and 121, in correspondence with the similar rear face 18 of FIG. 5. Rear face 118 is therefore substantially planar, except with respect to the very slight curvature resulting from the gradual radial twist of the blade.

The variational form of blade whose cross section is represented in FIG. 7 has a sharp edged 50 percent airfoil section of the type illustrated in FIG. 7 in all planes parallel to the plane of FIG. 5 and perpendicular to radial line 27 of FIG. 4 (e.g. in planes containing the various lines 33 of FIG. 4). This is true of all such cross sections at any point throughout the entire radial extent of the blade, including sections near the tip of the blade which extend between any portion of tip edge 122 and the corresponding portion of trailing edge 121, and also similar sections extending between edges 122 and 121 at locations radially inwardly of the tip portion. All such cross sections have the same appearance and proportions as are represented in FIG. 7, though the actual length of the different cross sections will of course vary in accordance with the actual distance between the edges of the blade in the planes of the different sections.

It is found that this 50 percent airfoil of FIG. 7, with a sharp leading edge, maintains as nearly as possible constant acceleration of the air at the forward side of the blade, and coacts with the 71.5° angularity previously discussed in optimizing the operational characteristics of the blade.

While certain specific embodiments of the present invention have been disclosed as typical, the invention is of course not limited to these particular forms, but rather is applicable broadly to all such variations as fall within the scope of the appended claims.

I claim:

1. A propeller which is to be power driven rotatively about a predetermined generally horizontal axis and in a predetermined direction to cause horizontal advancement of an airplane: said propeller having a blade projecting generally radially outwardly away from said axis and which has a leading edge, and a trailing edge, and a tip edge extending therebetween; said tip edge being disposed at a pitch angle with respect to a plane extending perpendicular to said axis of the propeller; said leading and trailing edges having outer portions at substantially their outermost ends which extend approximately radially with respect to said axis and which es-

sentially meet opposite ends of said tip edge; said tip edge being so shaped that, as it advances generally circularly from said approximately radial outer portion of the leading edge to said approximately radial outer portion of said trailing edge, the tip edge also advances progressively radially outwardly away from said axis, throughout essentially the entire circular distance between said approximately radial outer portions of said leading and trailing edges, and at an angle of 71.5° with respect to a line extending directly radially outwardly from said axis and intersecting the tip edge; said blade in extending between said tip edge and said trailing edge having an airfoil cross section in all planes perpendicular to a radial line and intersecting both the tip edge and trailing edge, which airfoil cross section is defined by a convexly curved forward face of the blade and a substantially flat rear face following a straight line between said tip edge and said trailing edge; said airfoil cross section, in all of said planes, tapering to thin substantially sharp shapes at both the tip edge and trailing edge of the blade.

2. A propeller which is to be power driven rotatively about a predetermined generally horizontal axis and in a predetermined direction to cause horizontal advancement of an airplane: said propeller having a blade projecting generally radially outwardly away from said axis and which has a leading edge, and a trailing edge, and a tip edge extending therebetween; said tip edge being disposed at a pitch angle with respect to a plane extending perpendicular to said axis of the propeller; said leading and trailing edges having outer portions at substantially their outermost ends which extend approximately radially with respect to said axis and which essentially meet opposite ends of said tip edge; said tip edge being so shaped that, as it advances generally circularly from said approximately radial outer portion of the leading edge to said approximately radial outer portion of said trailing edge, the tip edge also advances progressively radially outwardly away from said axis, throughout essentially the entire circular distance between said approximately radial outer portions of said leading and trailing edges, and at an angle of 71.5° with respect to a line extending directly radially outwardly from said axis and intersecting the tip edge; said blade in extending between said tip edge and said trailing edge having an airfoil cross section, in all planes perpendicular to a radial line and intersecting both the tip edge and trailing edge, which airfoil cross section is defined by a convexly curved forward face of the blade and a substantially flat rear face following a straight

line between said tip edge and said trailing edge; said airfoil cross section, in all of said planes, being a fifty percent airfoil cross section having its maximum thickness at a point midway between said tip edge and said trailing edge, and tapering to thin substantially sharp shapes at both the tip edge and trailing edge of the blade.

3. A propeller which is to be power driven rotatively about a predetermined generally horizontal axis and in a predetermined direction to cause horizontal advancement of an airplane: said propeller having a blade projecting generally radially outwardly away from said axis and which has a leading edge, and a trailing edge, and a tip edge extending therebetween; said tip edge being disposed at a pitch angle with respect to a plane extending perpendicular to said axis of the propeller; said leading and trailing edges having outer portions at substantially their outermost ends which extend approximately radially with respect to said axis and which essentially meet opposite ends of said tip edge; said tip edge being so shaped that, as it advances generally circularly from said approximately radial outer portion of the leading edge to said approximately radial outer portion of said trailing edge, the tip edge also advances progressively radially outwardly away from said axis, throughout essentially the entire circular distance between said approximately radial outer portions of said leading and trailing edges, and at an angle of 71.5° with respect to a line extending directly radially outwardly from said axis and intersecting the tip edge; said blade in extending between said tip edge and said trailing edge having an airfoil cross section, in all planes perpendicular to a radial line and intersecting both the tip edge and trailing edge, which airfoil cross section is defined by a convexly curved forward face of the blade and a substantially flat rear face following a straight line between said tip edge and said trailing edge; said airfoil cross section, in all of said planes, being a 50 percent airfoil cross section having its maximum thickness at a point midway between said tip edge and said trailing edge, and tapering to thin substantially sharp shapes at both the tip edge and trailing edge of the blade; said blade also having an airfoil cross section through at least a portion of its radial extent radially inwardly of said tip edge, in planes intersecting both said leading edge and said trailing edge, which airfoil cross section is defined by a convexly curved forward face and an essentially flat rear face following a straight line between said leading edge and said trailing edge.

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