Dec. 11, 1945. H. F. HAGEN 2,390,879

PROPELLER FAN

Filed Sept. 21, 1940 3 Sheets-Sheet 1

Fig. 1.

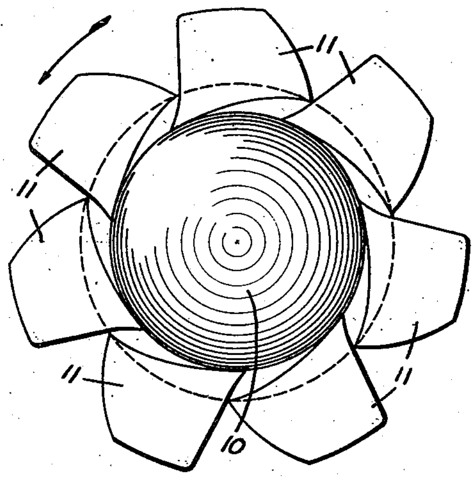


Fig. 2.

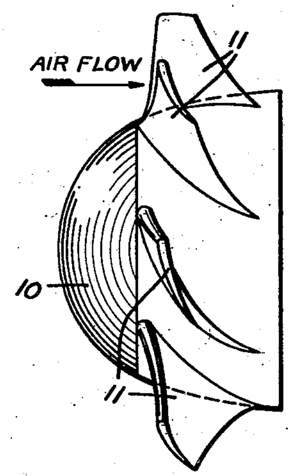
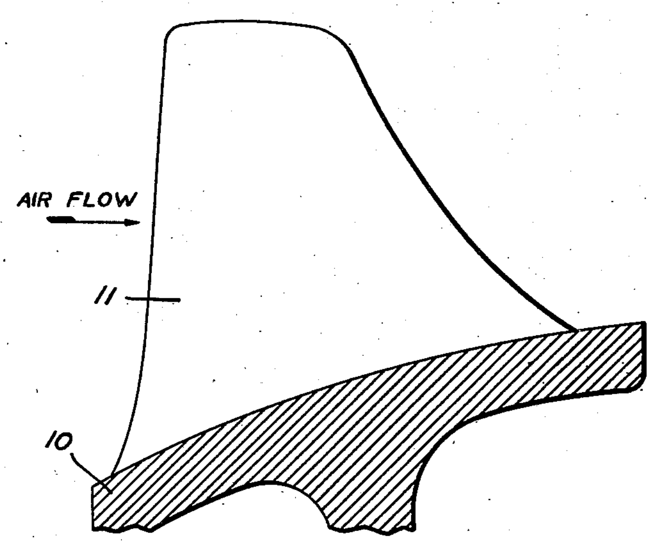


Fig. 3.



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PROPELLER FAN

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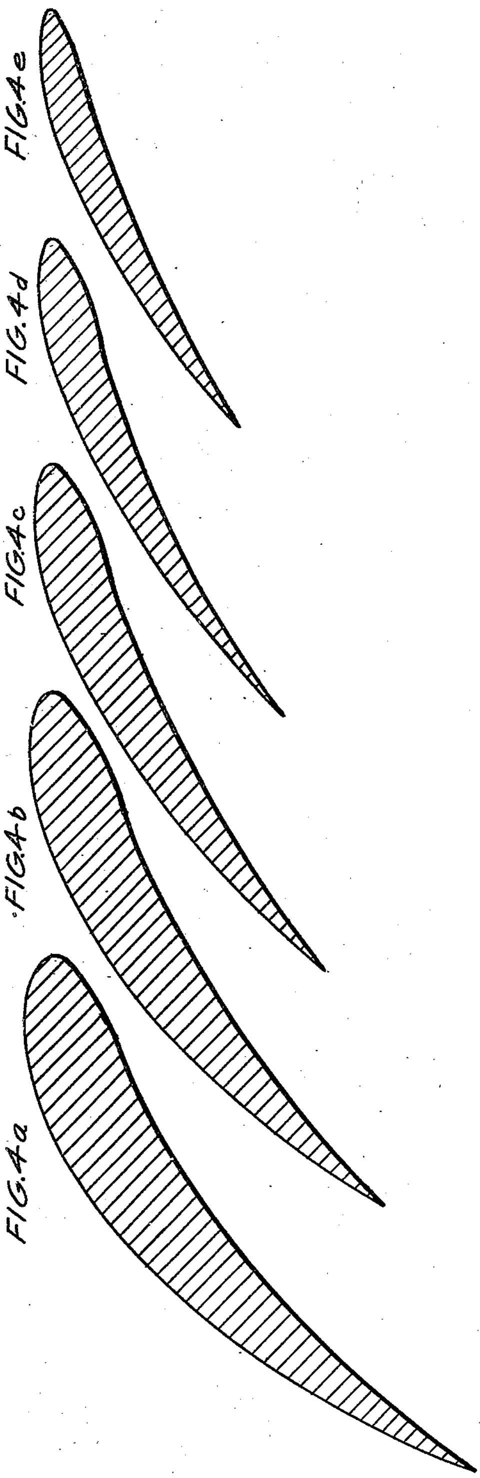

FIG.4e

FIG.4d

FIG.4c

FIG.4b

FIG.4a

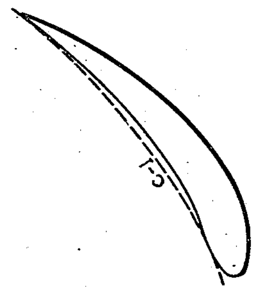

Fig.6.

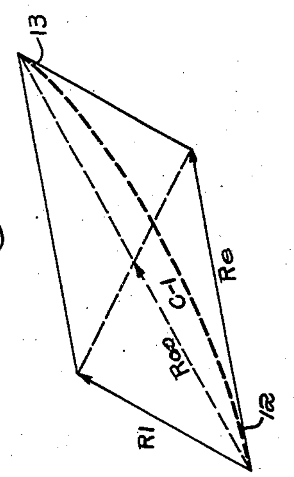

Fig.5.

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PROPELLER FAN

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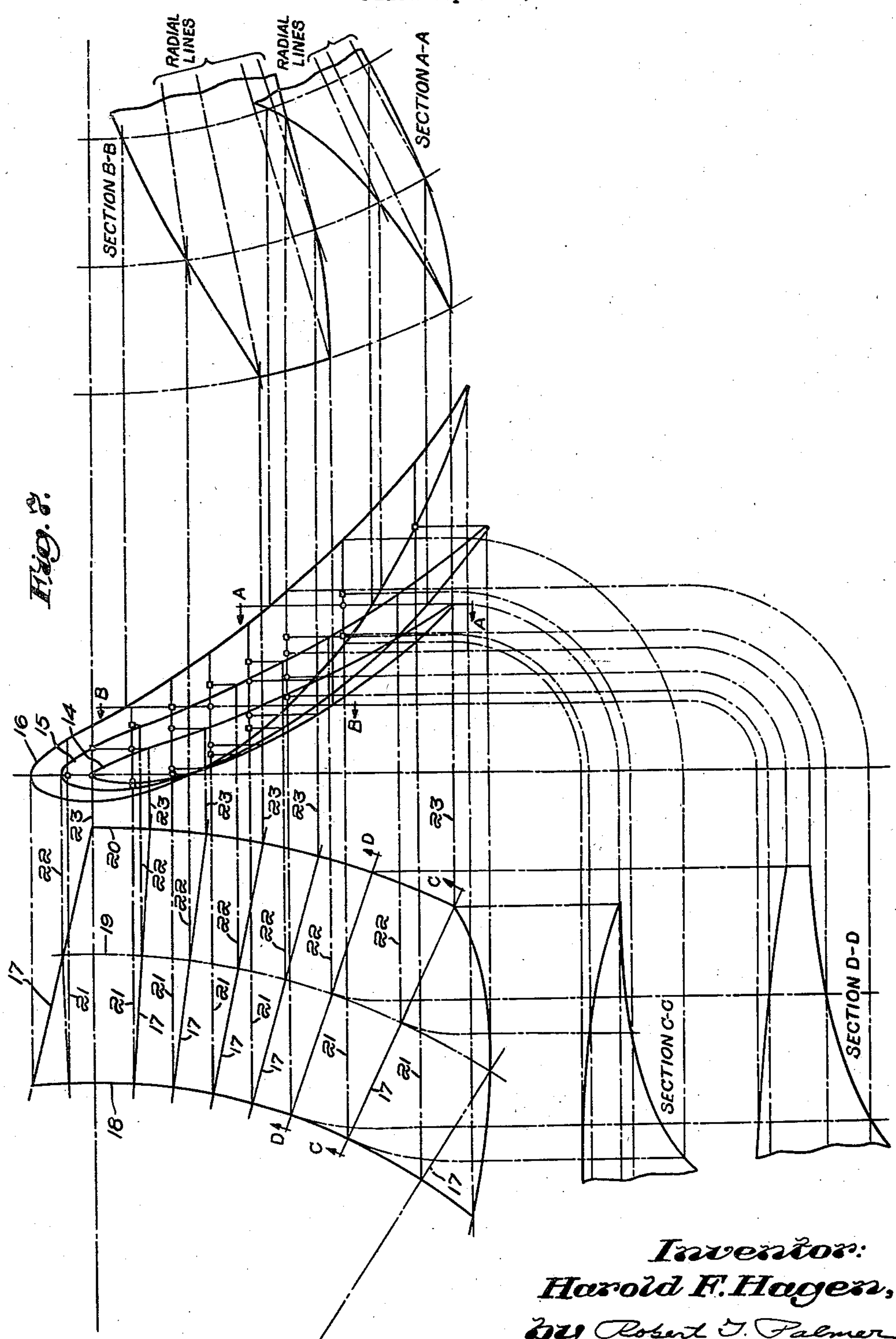

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Patented Dec. 11, 1945

UNITED STATES PATENT OFFICE

2,390,879

PROPELLER FAN

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Application September 21, 1940, Serial No. 357,767

4 Claims. (Cl. 170—159)

This invention relates to propeller fans and has as its object the improvement in performance of such fans.

Propeller fans operating at relatively low speeds and providing relatively low pressures have been used. Where high pressures involving high rotative speeds have been desired, it has been the practice to utilize centrifugal fans.

This invention provides a propeller fan which provides the desired high pressures and which has a performance exceeding that of centrifugal fans which it has replaced for duties requiring high pressures and involving high rotative speeds.

Pressure, speed, space and perhaps other considerations have required that relatively small diameter propeller fans with a relatively large number of blades be used. For example, seven blades may be used. Previous design data, for such fans has been at fault due to the treatment of the blades as individual air foils performing as in a wind tunnel and as a result failing to understand the correct, curved flow of air past the blade elements, and as a consequence failing to understand that the chords of greater length could be used with closely spaced propeller blades without interference, than has been appreciated before.

This invention provides a propeller fan with improved performance in the delivery of high pressures, and utilizing a relatively large number of relatively small diameter blades.

A feature of this invention resides in the use of blade elements having a greater camber than has been proposed in the past.

Another feature of this invention resides in the use of blade elements having longer chords than have been proposed in the past.

Another feature of the invention resides in the use of blade elements having cambers and chords which increase from minimum at the blade tips to maximum at the hub.

Another feature of the invention resides in providing blades having air foil sections, the chord angles of which decrease from the hub to the tip at such a rate that outer sections are out of plan view alignment with inner sections and yet which are so shaped and arranged that the contour of each outer section is contained within the enveloping contour formed by radial line generatrices enveloping the contour of each inner blade section having a smaller radius, the contour of the inner blade section being a directrix. This results in no outer elements of the blades falling outside of radial lines extending through underlying inner elements. With such construction, the centrifugal stresses are at a minimum, a consideration which is important due to the high rotational speeds involved.

The purpose of a fan is to provide energy to initiate the flow of air and to add to each unit volume of air a net increase in energy sufficient to compensate for pressure losses. Where no initial spin is given the air entering the fan, an expression for the addition of energy to each unit volume of air may be written:

$$\Delta E = \omega\rho Wnr$$

where:

ω=the angular velocity of blade.
ρ=the mass per unit volume.
Wn=the rotative velocity of the air.
r=the blade radius.

In the propeller type fan under discussion, the flow of air is substantially axial without radial divergence. Since it is desired to add equal amounts of energy to each particle of air, the expression Wnr must remain constant across the section of air and at each radius. This is equivalent to saying that the product of the spin component of the air and the radius at which the spin is measured, is constant at each radius directly behind the fan. This product multiplied by $2\pi = 2\pi Wnr$ is called Γ and represents the circulation of the air stream leaving the blades and is equal to the sum of the circulations γ of the individual blades.

Knowing the pressure desired Wnr can be calculated from the formula

$$P = \rho\omega Wnr$$

where P=pressure increase desired, and from which the value of Wnr may be substituted in the formula

$$\Gamma = 2\pi Wnr \text{ or } \Gamma = \frac{2\pi P}{\rho\omega}$$

for calculating the circulation at different radii. It is also known that

$$\gamma = \frac{\Gamma}{Z} = \frac{C_L R\infty b}{2}$$

where

C_L=the lift coefficient
$R\infty$=the average relative air velocity past blade, and
b=the length of chord,
Z=number of blades.

This formula may be changed to read

$$C_L b = \frac{2\gamma}{R\infty} \text{ or } b = \frac{2\gamma}{R\infty C_L}$$

With the value for the circulation substituted in this formula; the lift coefficient determined from the selected air foil and the angle of attack, and the value of $R\infty$ determined from the vector diagrams of air flow, the proper chord for each blade element at different radii may be calculated.

It may be noted that the spin varies inversely with the blade radius, this requiring for practicability a chord which increases in length from a minimum at the tip to a maximum at the hub.

Heretofore, in propeller fan design, the air foils have been selected from published data such as given in the publications of the National Advisory Committee for Aeronautics and used without modification. Such design principles have been based upon the assumption that the flow of the air particles past the blade elements is in straight lines. I have determined that flow is in curved paths of relatively sharp curvature and have modified the selected air foils on this account, to have camber which is greater than used before for similar duties and which increases in degree of curvature from minimum at the blade tips to maximum at the hub. This feature will be described in more detail in connection with Figs. 5 and 6 of the drawings.

The invention will now be described with reference to the drawings, of which:

Fig. 1 is a view looking axially into the front of a propeller fan wheel embodying this invention;

Fig. 2 is an elevation view of the fan wheel of Fig. 1;

Fig. 3 is an enlarged profile view of one of the fan blades with a portion of the hub shown in section;

Figs. *4a*, *4b*, *4c*, *4d*, and *4e* are developments of sections taken along circular section lines at different radii. By development of the sections, it is meant that they appear as they would if the circular section lines referred to were straightened out to form straight, instead of curved, lines.

Fig. 5 is a vector diagram illustrating air velocities at the entrance and delivery edges of an airfoil blade element and the derivation of a curved center line for the blade element;

Fig. 6 is a view illustrating an air foil blade element formed by utilizing the curved center line derived as shown by Fig. 5 as a chord line, and

Fig. 7 is a projection drawing illustrating the relation of the profiles of different blade sections to each other and to radial lines from the shaft center extending through the profiles of sections of lesser radii.

As illustrated by Figs. 1 and 2, the relatively large hub 10 has mounted thereon the seven blades 11. The blades have such long chords at the hub that they overlap projected axial areas. As shown most clearly by Fig. 3, the blade elements extend substantially along radial lines in their entering portions, the increase in chord resulting from the extension of the elements having less radii, axially to the rear of the elements having greater radii. These features result in the desired provision of constant circulation and in the equal loading of all blade elements.

Fig. 5 illustrates resultant velocity vectors where

Rl=the velocity at the delivery edge of the blade element,

Re=the velocity at the entrance of the blade element,

R_∞=the mean relative velocity, and

c—l=the curved center line as derived from the velocity vectors for selecting an air foil profile.

The heavy dashed line *c—l* is derived by being drawn as a smooth curve tangent at 12 to the vector Re and at 13 to the vector opposite and parallel to the vector *Rl*.

An air foil having the desired characteristics is selected from the data published by the National Advisory Committee for Aeronautics, but instead of adopting this air foil and swinging it through the desired angle of attack as has been done in the past, the curved center line *c—l* is substituted for the chord or base line of the selected air foil and the air foil is given the increased camber required by the substituted curved chord line. This results in the air foil being given increased curvature at both the entrance and leaving edges and in its having a camber which is sharper in curvature than the camber of the selected air foil. Then when the desired angle of attack is calculated as usual, the air foil as a whole is rotated through this angle of attack. The flow line of course, increases its curvature towards the hub with the result that the camber of the air foil elements increases as the distance from the hub decreases. This feature results in greatly improved performance of the fan as indicated by increased efficiency and decreased noise.

Fig. 7 is a geometrical projection of cylindrical sections taken through a fan blade and shows how the contours of the blade elements having greater radii are contained within the envelope formed by radial line generatrices enveloping the contour of any inner blade element, and illustrates how, by projection, this may be determined.

The three air foil sections shown at the center of Fig. 7 are the cylindrical section 14 taken at the tip, the cylindrical section 15 taken at a point mid-way of the tip and hub, and the cylindrical section 16 taken at the hub. As shown by Fig. 7 the chord angles of the blade sections decrease as the distance of the sections from the hub increases, at such a rate that outer sections are not in plan view alignment with inner sections. It is desired that the contour of the mid-section 15 be contained within the envelope formed by radial line generatrices enveloping the contour of the hub section 16, and that the contour of the tip section 14 be contained within the radial line generatrices enveloping the contour of the mid-section 15. The radial line generatrices are lines spaced axially along the center line of the fan shaft and extending perpendicular thereto.

The radial lines 17 are drawn through the line 18 on the blade where the hub section is taken, through the line 19 where the mid-section is taken and to the line 20 at the tip. The lines 21 are horizontal lines of projection extending from the points of intersection of the hub section line 18 with the lines 17, through the blade sections 14, 15, and 16. The lines 22 are horizontal lines of projection extending from the points of intersection of the mid-section line 19 with the lines 17, through the blade sections. The lines 23 are horizontal lines of projection extending from the points of intersection of the tip line 20 with the lines 17, through the blade sections.

Where the lines 22 intersect the profile of the mid-blade section 15, vertical lines are drawn to intersect the lines 21, the points of intersection being indicated on the drawings by the small squares. Where the lines 22 intersect the profile of the tip section 14, vertical lines are drawn to intersect the lines 21, the points of intersection being indicated on the drawings by the small circles.

It will be observed that except at the points corresponding to the ends of the blade sections there are two circles and two squares lying on each line 21. The circles on each line 21 are seen to lie between the squares in the same line and this shows, as is also shown by the sections A—A, B—B, C—C, and D—D that no outer section contour has any portion which lies outside the envelope formed by radial line generatrices enveloping the contour of any inner blade sections. The dash-dot lines drawn through sections A—A, B—B, C—C, and D—D are radial lines and illustrate that no outer portion of the contour of any section, taken in any plane, lies outside any radial line drawn through the contour of any inner section. This results in no elements being out of radial alignment with corresponding elements having smaller radii so that centrifugal strains are at a minimum.

The propeller may be operated at very high speeds without tendency for deformation due to centrifugal forces.

It should be understood that the contours of the outer blade sections do not naturally fall within the envelope generatrices described in the foregoing. This may only be determined by projection line drawings as described and usually it is necessary to change the physical proportions and arrangements of the selected profiles to cause them to fall within the requirements as outlined.

In the annexed claims "curved chord lines" are defined as: The datum lines from which the ordinates of the air foil section are measured.

While one embodiment has been described for the purpose of illustration, it should be understood that the invention is not limited to the exact arrangement disclosed as modifications thereof may be suggested by those skilled in the art without departure from the essence of the invention.

What is claimed is:

1. In a propeller fan, an airfoil air coacting element having a smoothly curved chord line formed tangent at the entrance edge of the element to the velocity vector *Re* and formed tangent at the delivery edge of the element to the vector equal to and forming the opposite vector to the vector *Rl* in the parallelogram of vectors including *Re* and *Rl* as adjacent sides, where

Re=the relative velocity between the air and the element at the entrance edge of the element, and

Rl=the relative velocity between the air and the element at the delivery edge of the element.

2. A propeller fan comprising a hub having a plurality of blades attached thereto, the elements of each of said blades having sections with chords, thicknesses, cambers, and chord angles, which increase from minimum at the tip to maximum at the hub, the elements of said blades having tapered air-foil sections with curved chord lines, the radii of curvature of said chord lines decreasing from maximum at the blade tips to minimum at the hub and being formed tangent at the entrance edges of the blade elements, to the velocity vectors *Re*, and being formed tangent at the delivery edges of the blade elements, to the vectors equal to, and forming the opposite vectors to vectors *Rl* in the parallelogram of vectors including *Re* and *Rl* as adjacent sides, where *Re*=the velocities at the entrance edges of the blade elements, and *Rl*=the velocities at the delivery edges of the blade element.

3. A propeller fan comprising a hub having a plurality of blades attached thereto, the elements of each of said blades having tapered air foil sections with chords, cambers and thicknesses which increase from minimum at the tip to maximum at the hub and the cambers and the chord angles of which decrease from a maximum at the hub to a minimum at the tip at such a rate that outer sections are out of plan view alignment with inner sections the contours of the blade sections being contained within the enveloping contours formed by radial line generatrices enveloping the contour of any inner blade section, said contour of said inner blade section being a directrix, said elements having curved chord lines, the radii of curvature of said chord lines decreasing from maximum at the blade tip to minimum at the hub and being formed tangent at the entrance edges of the blade elements, to the velocity vectors *Re* and being formed tangent at the delivery edges of the blade elements, to the vectors equal to, and forming the opposite vectors to the vectors *Rl* in the parallelograms of vectors including *Re* and *Rl* as adjacent sides, where

Re=the velocities at the entrance edges of the blade elements, and

Rl=the velocities at the delivery edges of the blade elements.

4. A propeller fan having a hub with a plurality of blades attached thereto, the elements of each of said blades having sections with chords, and thicknesses which increase from minimum at the tip to maximum at the hub and chambers and the chord angles of which decrease from a maximum at the hub to a minimum at the tip at such a rate that outer sections are out of plan view alignment with inner sections, the contours of the glade sections being contained within the enveloping contours formed by radial line generatrices enveloping the contour of any inner blade section, said contour of said inner blade section being a directrix.

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