March 19, 1968 J. D. ROM 3,373,930

FAN STRUCTURE

Filed April 29, 1966 2 Sheets-Sheet 1

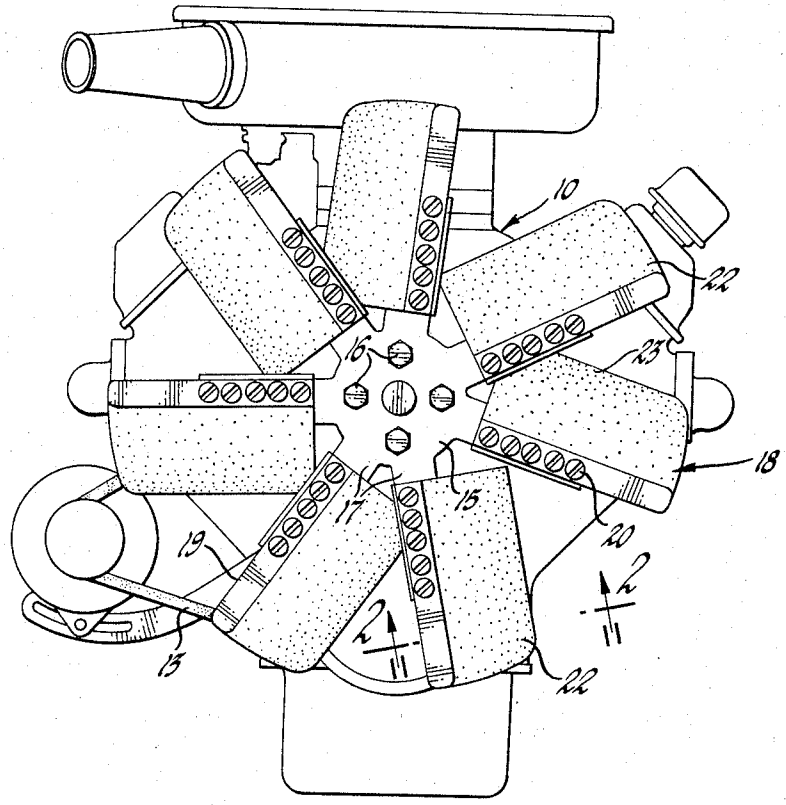

Fig. 1

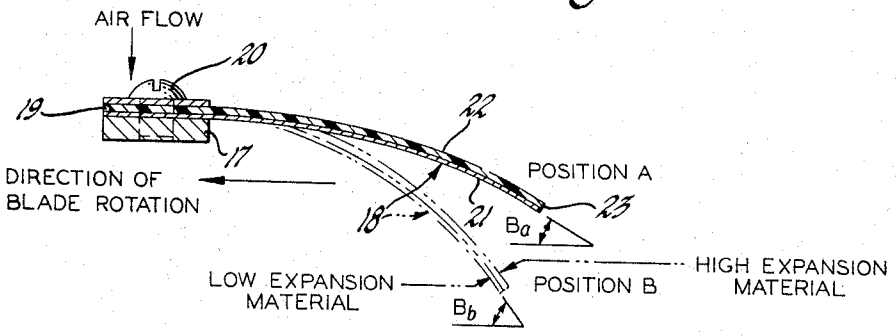

Fig. 2

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FAN STRUCTURE

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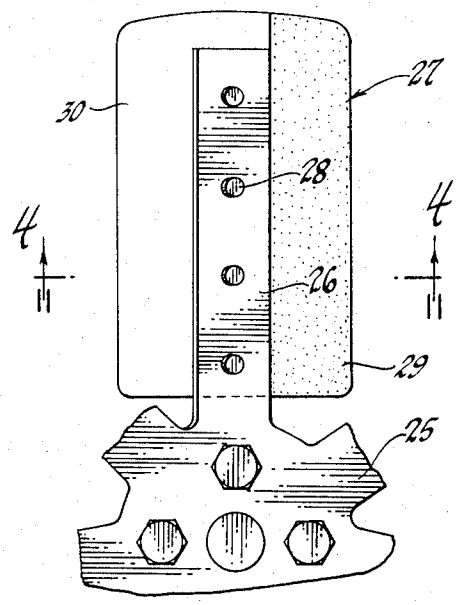

Fig. 3

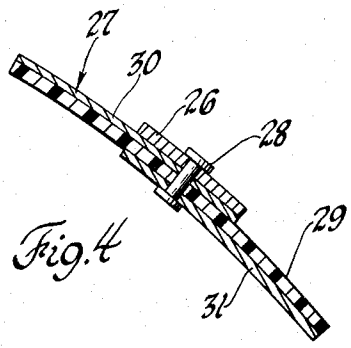

Fig. 4

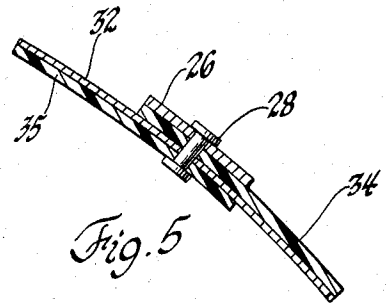

Fig. 5

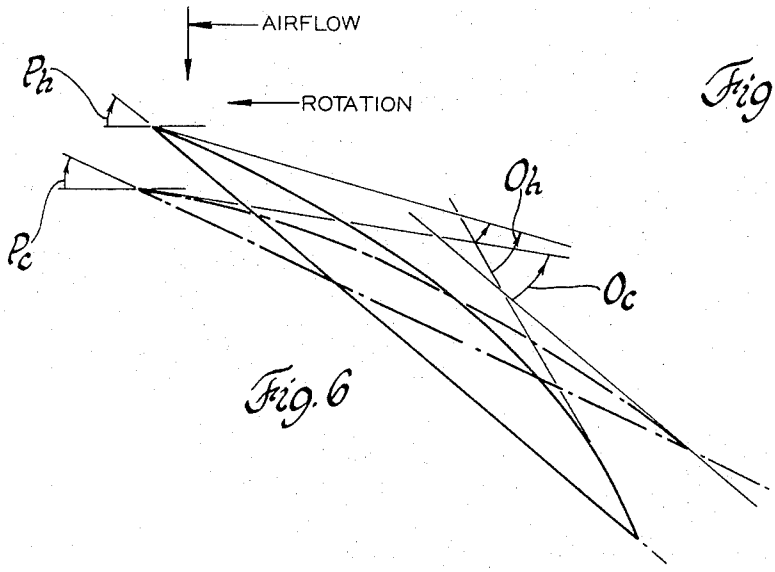

Fig. 6

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FAN STRUCTURE

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5 Claims. (Cl. 230—270)

ABSTRACT OF THE DISCLOSURE

This invention relates to a speed and temperature-responsive fan having fan blades supported upon support arms extending outwardly from a fan hub and wherein the blades are spaced from the hub by the support arms. The blades are forward of a composite assembly of coextensive sheets of plastic and sheet steel bonded together by a thermosetting adhesive to provide a unitary blade structure responsive to rise of temperature to cause the blades to bend about the longitudinal blade axis to increase air displaced at any given speed of rotation and wherein the blades are responsive to increase in speed of rotation to decrease the air displaced at any given blade temperature upon increase in speed of rotation of the blade. The quantity of air displaced per revolution is a function of both fan blade temperature and speed which increases with temperature rise and decreases with increase of fan speed.

This invention relates to fans and more particularly to an improved fan wherein the fan blades per se are made temperature responsive so as to increase the fan blade pitch and camber in response to rise of fan blade temperature and to decrease fan blade pitch and camber upon a drop of a fan blade temperature. Variable pitch fans have heretofore been proposed whereby the fan pitch may be varied in response to temperature variation. Such structures have generally been expensive to manufacture, requiring separate temperature-responsive power elements and mechanical means operated by the power element for changing blade pitch. In the present invention the fan blades are made up of a laminated assembly of two layers or sheets of material bonded to each other. The blades are shaped about their longitudinal axis to provide convex and concave surfaces. The layer or sheet located on the convex side of each blade comprises material having a relatively high coefficient of thermal expansion while the layer or sheet which is positioned on the concave side of the blade has a relatively low coefficient of thermal expansion. As the blade temperature increases, the curvature of the blade cross section increases due to the different coefficients of expansion of the two dissimilar materials comprising the blade assembly.

The fan is particularly useful for cooling vehicle engines. The fan is illustrated for use as an engine cooling fan in the accompanying drawings in which:

FIGURE 1 is a front elevational view of an engine having a fan constructed in accordance with the principles of this invention associated therewith;

FIGURE 2 is a sectional view of one of the fan blades taken along the line 2—2 of FIGURE 1 and illustrating two different fan blade positions,

FIGURE 3 is a front elevational view of a modified fan structure and fan blade mounting,

FIGURE 4 is a sectional view taken along the line 3—3 of FIGURE 3, and

FIGURE 5 is a sectional view through a further modified fan blade assembly.

FIGURE 6 is a schematic diagram illustrating the relationship of blade pitch angle and blade camber characteristics with change of blade temperature.

With the development of engines of relatively large horsepower and the adoption of multiple engine driven accessories such as power steering pumps, air conditioning compressors, air compressors for power steering and for engine air injection for engine smog emission control, for example, the problem of adequate engine cooling, particularly at engine idle operation at high ambient temperatures, has become critical. The present fan with its flexible and temperature-responsive blades assures adequate cooling under conditions of maximum cooling demand and at the same time varies the air flow according to the cooling system requirements so as to minimize fan noise and reduce parasitic power consumption as the cooling requirements become reduced. The fan particularly reduces its power consumption and noise as the fan speed increases as compared to conventional fixed blade fans.

The embodiment of FIGURES 1 and 2 is both temperature and speed responsive and is preferred for installation in automobiles, busses, and vehicles wherein the maximum cooling requirements frequently occur at relatively low engine speed. The embodiments of FIGURES 3 through 5 is designed to be temperature responsive and is preferred for installation in vehicles wherein maximum air flow is required at relatively high engine speeds such as trucks and tractors.

Referring to the drawings, the numeral **10** generally represents one end of an internal combustion engine for driving a vehicle. A conventional fan hub (not shown) driven by a fan belt **13** may have a fan blade spider **15** bolted thereto by bolts **16** for rotation therewith.

A series of fan blade support arms **17** extend radially outwardly from spider **15** and may be equally spaced from each other or spaced at random spacing with respect to each other. Fan blades **18** at their leading edge **19** are secured to arms **17** by rivets **20** or by other means. Fan blades **18** comprise an assembly of two thin laminated sheets **21** and **22** of dissimilar materials having substantially different thermal coefficients of expansion. The sheets are bonded to each other and have a circular-arc cross section as best shown in FIGURE 2. Sheet **21**, positioned on the concave side of the blade has a relatively low coefficient of thermal expansion while sheet **22**, located on the convex side of the blade has a relatively high coefficient of thermal expansion.

The performance of the fan for a given speed of rotation varies with change in temperature because the blades change both pitch and camber with changes in temperature. The blade sheets which are bonded together expand at different rates to effect an arc-shaped profile. The blades **18** are fastened to arms **17** at the leading edge **19** of the blades such that a deflection of the trailing edge **23** will change both pitch and camber. The term "pitch" or pitch angle herein is defined as the angle which a chord line passing through the leading and trailing edge of a fan blade makes with the plane of rotation of the fan. The term "camber" or camber angle is the change in the tangent from the leading to the trailing edge of the blade.

In designing a satisfactory fan of the type disclosed, a number of variables are involved from which proper selections must be made. These include the two different materials used in the blade construction, their respective thicknesses, and the blade radius of curvature at the bonding temperature. The primary criterion for selecting the materials and their respective thickness was maximum change in curvature for a given temperature change. Selection of the blade radius of curvature at the bonding temperature was a matter of relating absolute curvature and temperature in an optimum manner.

In designing a bi-material blade providing proper desirable deflection characteristics, the two most important factors affecting the radius of curvature, other than the degree of temperature change, are the difference in the

thermal expansion coefficients of the two materials and the total thickness of the blade. The curvature of the blade for a given temperature is directly proportional to the former and inversely proportional to the latter. To provide a fan having satisfactory performance characteristics and commercial acceptability it is necessary to form the fan blades of two materials having properties consistent with a high thermal deflection rate, adequate mechanical strength, and which are economical. The best existing commercial bi-metallic strips were found to have comparatively small deflection rates. Materials having relatively high thermal expansion coefficients generally are structurally weak. It has been found however that certain commercial plastics have a favorable and acceptable set of properties which is a compromise between these materials having very high expansion coefficients and low strengths, and those of metals which have relatively low expansion coefficients and high strengths. One such commercially available plastic having satisfactory strength and expansion coefficient is an acetal resin plastic commonly known as Delrin. A second plastic material having satisfactory characteristics is nylon. A comparison of the properties of the acetal resin plastic and nylon is as follows:

	Delrin	Nylon-6
Thermal expansion coefficient (per ° F.)	4.5×10^{-5}	5.5×10^{-5}
Modulus of elasticity at 70° F. (p.s.i.)	4×10^{5}	2.5×10^{5}
Flexural modulus at 70° F. (p.s.i.)	4×10^{5}	1.8×10^{6}

Delrin is preferred over nylon because of its relatively high fatigue and creep resistance, excellent low temperature strength, negligible water absorption and excellent resistance to organic solvents.

The range of thermal expansion coefficients of metals is relatively small. Accordingly, from the standpoint of mechanical strength and economy, low carbon, high temper sheet steel was selected as the best material having a low expansion coefficient.

In addition to having blades that are thermally sensitive, it is advantageous that the blades be flexible so that the blade pitch decreases as the fan speed increases as a result of centrifugal forces acting on the blades. This arrangement reduces fan noise during fan speed acceleration and at relatively high fan speeds. The blades herein described are both temperature sensitive and flexible. Minimum blade thickness contributes to both of these properties. However, a blade that is too thin will be nonresponsive to temperature change at relatively high fan speed because it will be unable to develop sufficient thermal deflection force to overcome the component of centrifugal force which uncambers the blade. A blade having satisfactory performance characteristics throughout its normal operating speed range of rotation from minimum to maximum was made up of bonded plastic and steel sheets of respective thicknesses of .035 inch and .010 inch.

Blade camber radius at the bonding temperature is another design variable which was necessary to determine. This radius must be of such value that the proper range of radii are obtained in the cooling system operating temperature range for optimum fan performance. With too little camber the required fan performance woud not be obtained and, with too much camber, extensive stall would occur resulting in poor performance and a high noise level.

The two sheets are bonded together by a rapid curing structural adhesive which is cured for five minutes at 250° F. under sufficient pressure to obtain full contact at the bonding surface. Curing time may be reduced by raising the temperature. For example, curing time may be one minute at 300° F. Using a blade camber radius of 2.25 inches during bonding resulted in a finished blade having satisfactory performance characteristics.

The fan herein described is of simple and economical construction and is responsive to rise of temperature to increase air flow per revolution and responsive to increase in centrifugal force to decrease air flow per revolution.

For a given fan speed the volume flow rate increases with increase in temperature due to the action of the bi-material blades which increase the blade camber and pitch with rise of air temperature. At engine idle condition of operation and a fan air temperature of 160° F., which is within range of temperature of current cooling systems at engine idle operation the improved fan herein, by actual test, pumped 24% more airflow than a production fan of the same size and having conventional fan blades of fixed geometry which at a temperature of 80° F., both fans pumped the same airflow. In addition the noise level of the improved fan herein, particularly for speeds above 1000 r.p.m. was lower than the standard production fan primarily because of its flexible blades which reduce the blade pitch and camber with increase in speed. At fan speeds of 3400 r.p.m. the difference in noise level between the production fixed blade geometry fan and the improved fan herein was 6db, which is a significant difference in noise level. The present fan is advantageous during cold weather vehicle operation. As the temperature decreases, the fan performance decreases. Consequently, the engine being cooled can more quickly warm up to more rapidly provide passenger compartment heating. In addition, when operating after initial engine warm-up, but at low ambient temperatures, the fan will pump less air than a conventional fan and maintain at a higher engine compartment temperature level for improved engine operation.

In FIGURE 2, two different fan blade positions are illustrated. The composite blade assembly includes the plastic surface **22** having a relatively high thermal expansion coefficient and the sheet metal surface **21** having a relatively low thermal expansion coefficient bonded to each other. The sheet **22** is thicker than sheet **21**. Position A represents the normal blade temperature at relatively cool temperature. As the fan blade temperature increases, the curvature of the blade cross section increases, and the blade moves about support arm **17** from position A to position B. Blade trailing edge **23** moves from position A to position B. As shown, the blade leaving angle B_a increases with rise of blade temperature from a minimum to a maximum B_b in position B, and the pressure rise and air flow produced by the fan, at a given fan speed of rotation in a given air flow system, will increase with rise of fan blade temperature.

Referring to FIGURE 3 there is shown a modified fan assembly including a fan hub **25** having a fan blade support arm **26** having a fan blade **27** mounted to the arm **26** at approximately mid-chord of the blade by means of rivets **28**. Shifting the mounting location of the blade from the blade leading edge as shown in FIGURES 1 and 2 to the blade mid-chord as shown in FIGURE 3 reduces the blade trailing edge deflection due to centrifugal forces for any given speed of rotation to less than one-tenth of that for leading blade edge mounting as a result of reduced bending moments about mounting arm **26** and reduced blade beam length.

In certain applications, particularly truck operation, the condition at which engine cooling is most critical is high engine load, at or near 100% top engine speed, minimum vehicle speed, and high ambient air temperature. Since the critical cooling condition occurs at high engine speed and, therefore, high fan speed, fan performance should be high at this condition. Therefore the structural arrangement of FIGURES 1 and 2, which is desirable in a cooling fan for a passenger car application, in that it utilizes centrifugal force at increasing speed to reduce the fan performance and fan noise, is undesirable in a truck cooling system application. Consequently, for truck use in particular, the effect of centrifugal force is minimized such that control of the fan performance is essentially through thermal sensitivity alone rather than a combination of thermal sensitivity and centrifugal force.

As shown in FIGURES 3 and 4, the fan blade **27** is constructed of continuous sheet of plastic **29** extending

throughout the full length and width of the fan blade and having sheets of sheet metal **30** and **31** bonded thereto and disposed on opposite surfaces of the plastic. Each sheet metal sheet extends lengthwise the full length of the fan blade but only half way across the width such that rivets **28** extend through plastic sheet **29** and both sheets **30** and **31**.

In FIGURE 5 a sheet metal blade **32** extends through the full length and width of the fan blade and has two plastic sheets **34** and **35** bonded to opposite surfaces of the metal blade portion **32**. Plastic sheets **33** and **34** extend through the length of blade portion **32** but only approximately half way across the width of blade portion **32** to receive rivets **28**.

FIGURE 6 illustrates the temperature deflection characteristics obtained by the type of blade illustrated in FIGURES 3 through 6. It is clear that increase in blade temperature increases both the blade pitch angle P and blade camber angle θ, and thereby increases fan performance with increase in blade temperature. In FIGURE 6, P_c represents the blade pitch angle when the blade is relatively cold and P_h the blade pitch angle when the blade is relatively hot. By the same token θ_c represents blade camber of a relatively cold blade while θ_h illustrates the camber of a relatively hot blade.

I claim:

1. A fan of the type comprising a fan blade support spider including a rotatable hub having a plurality of spaced fan blade support arms extending outwardly from said hub, a fan blade spaced from said hub and supported on each of said arms, each fan blade being formed of an assembly of sheets of plastic material and sheet metal to form a unitary fan blade structure, said sheets of material being of substantially equal area and having adjacent surfaces adhesively bonded together throughout the complete area of said surfaces to form said unitary fan blade structure, the inner radial zone of said fan blade structure being spaced outwardly from said hub to provide an edge of said blade adapted for movement relative to said hub and support arm at the inner radial zone of said fan blade, said sheets of plastic material and sheet metal material having different coefficients of thermal expansion said fan blade structure being movable relative to said support arm and hub to increase the volume of air displaced by said fan blade per revolution of said hub at any given speed of rotation of said hub upon increase of temperature of said fan blade structure, said fan blade structure being movable relative to said support arm and hub to decrease the volume of air displaced per revolution of said hub at any given fan blade temperature in response to increase in speed of rotation of said hub.

2. A fan comprising a rotatable support spider, said spider including a hub and a fan blade support arm extruding outwardly from said hub, a fan blade supported on said support arm at substantially the fan blade midchord and extending axially outwardly from said arm at opposite sides of said arm, said fan blade being formed of a composite assembly of sheets of material bonded to each other and having different coefficients of thermal expansion, one of said sheets extending axially at opposite sides of said arm the full width of said blade, a second of said sheets being bonded to the surface of said one sheet at one side of said one sheet and extending axially from said arm at one side of said arm, a third of said sheets being bonded to said first sheet and extending axially from said arm at the opposite side of said arm from said second sheet.

3. A fan as set forth in claim **2** wherein the coefficient of expansion of said first sheet is different from the coefficient of expansion of said second and third sheets.

4. A fan as set forth in claim **2** wherein the coefficient of expansion of said first sheet is greater than the coefficient of expansion of said second and third sheets.

5. A fan as set forth in claim **2** wherein the coefficient of expansion of said first sheet is less than the coefficient of expansion of said second and third sheets.

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HENRY F. RADUAZO, *Primary Examiner.*