

[54] **ROTARY, TUBULAR IMPELLER**
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[52] U.S. Cl. **416/84, 416/230**

[51] Int. Cl. **B64c 27/46**

[58] Field of Search..... 416/229, 226, 230, 416/233, 241 A, 224, 84, 88

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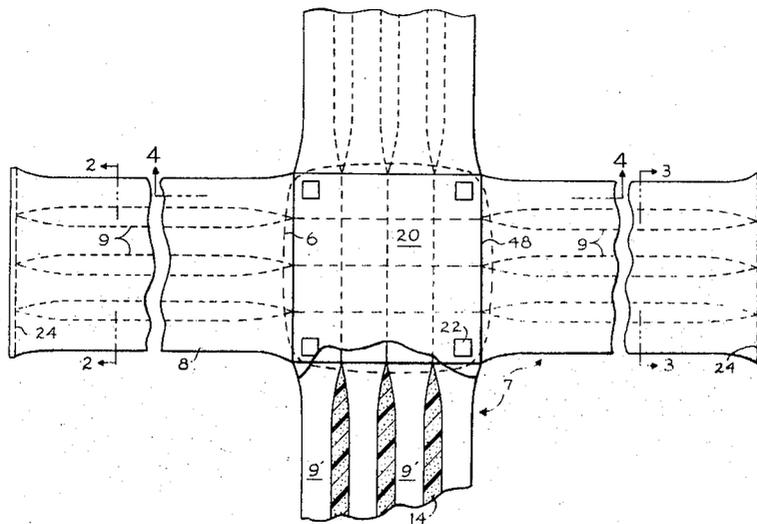
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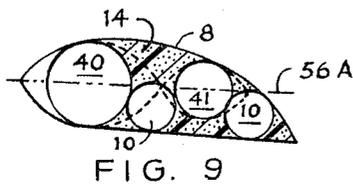
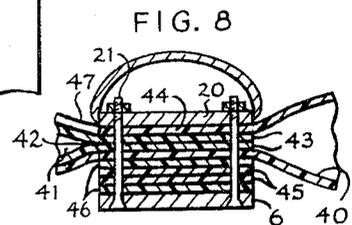
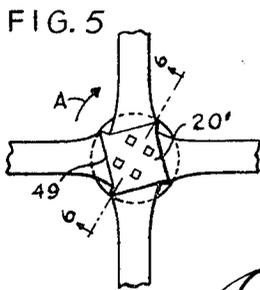
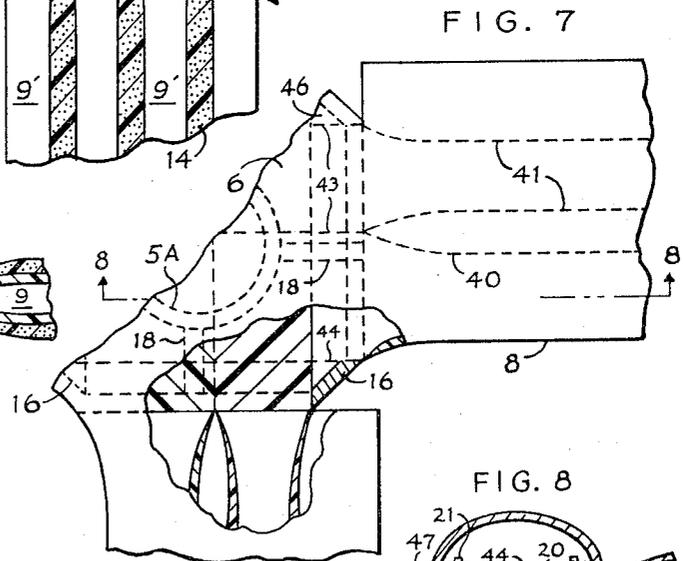
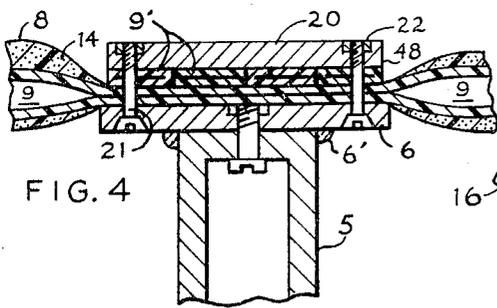
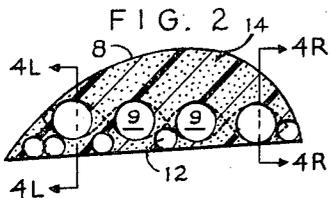
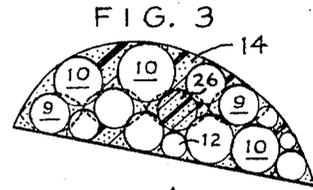
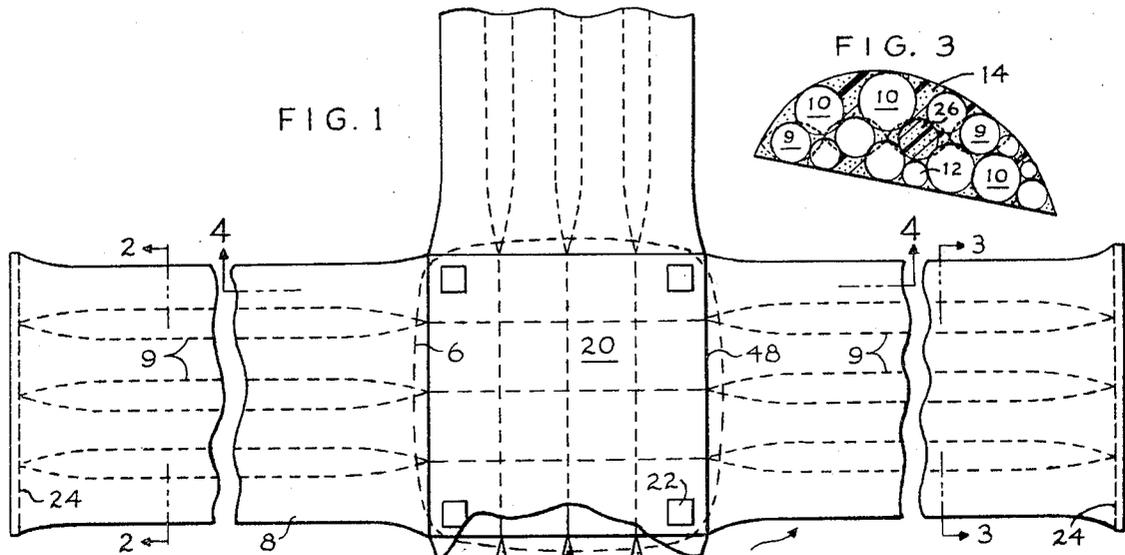
Primary Examiner—Everette A. Powell, Jr.

[57] **ABSTRACT**

A helicopter, autogyro, windmill or other impeller, comprising blades, optionally resilient or substantially rigid, each having: a tip free of attachment to other blades and urged into extended position by centrifugal force; and blade-strengthening tubular members containing gaseous material, imbedded in foam plastic. Each tubular member may be: an elongated flat-ended tube or can; or a row of end-joined tubes or cans. The gaseous material may be: helium, air or other gas (preferably strongly pressurized); gas-cell-containing foam plastic; or other, gas-containing material. The preferably hinged form of the impeller comprises at least one aligned pair of blades (two pairs being shown), each pair comprising inflated tubes extending from one end of the blades to the other end, having walls of: thin ductile or resilient metal (preferably lead), optionally coated with rubber-impregnated fabric or with rubber or other resilient plastic; plastic-coated fabric; resilient plastic; glass; or the like. Each tube has flattened and sealed ends and a flattened middle portion clamped by a plate to the impeller shaft, providing flexible, integral hinges at this middle portion permitting tilting of the blades, balancing centrifugal and aerodynamic forces on each side of the rotary shaft. The flat-ended tubes are preferably flanked by blade-stiffening tubular members - preferably rows of metal cans, end-joined by preferably resilient plastic. When the tubular members are of plastic or glass they optionally may be blow-molded or centrifugally molded.

27 Claims, 19 Drawing Figures





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FIG. 10

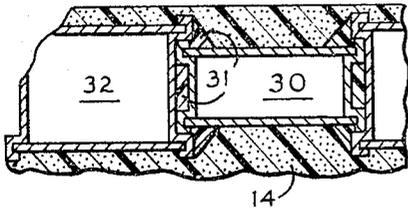


FIG. 11

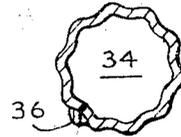
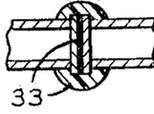


FIG. 12

FIG. 13

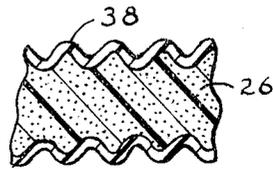
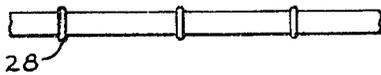


FIG. 14

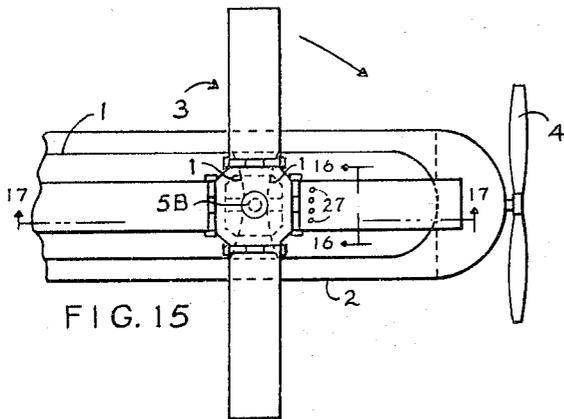


FIG. 15

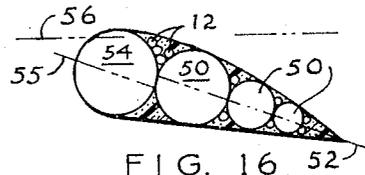


FIG. 16

FIG. 17

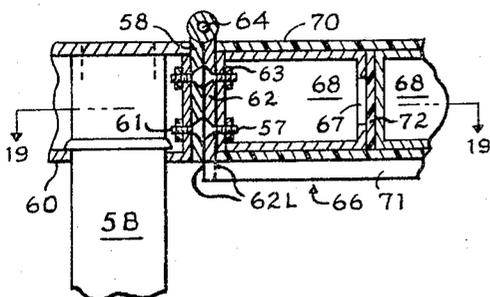


FIG. 19

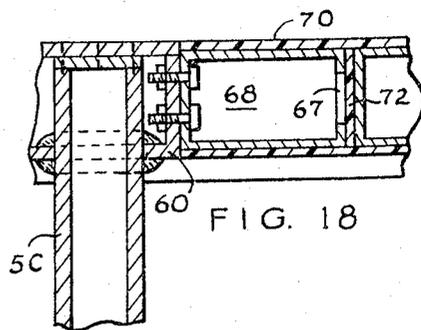
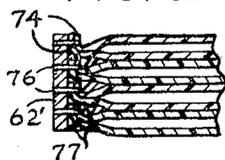


FIG. 18

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ROTARY, TUBULAR IMPELLER

This application is a continuation-in-part of prior, co-pending application Ser. No. 822,199, filed on May 6, 1969 (U.S. Pat. No. 3,559,923), comprising parts that were divided from that application.

Excepting slight drawing changes, FIGS. 7, 8, 9, 11, 16, 17 and 19 are, respectively, practically the same as FIGS. 12, 13, 14, 6, 2, 11 and 15 of application Ser. No. 822,199; FIG. 15 is the same as the forward, impeller part of FIG. 1 of the prior application; and FIGS. 10 and 18 are somewhat similar to FIGS. 8 and 11 of the former application.

The present invention is of an aircraft lifting propeller (or other impeller usable in transport craft or windmills) that is nearly wreckage-proof. It is made in view of the need to reduce the complexity, expense and noise of present-day helicopters, and is especially intended for use in helicopters or autogyros. The autogyro, invented by de la Cierva and developed in the late 1920's and 1930's, is a simpler and cheaper-to-build machine than the currently-known helicopter. Its defect of heavy drag per pound of load can be alleviated by use of the light-weight body construction and balloon means presented by this inventor in the said application Ser. No. 822,199 and in others of his applications and patents. Such use makes possible an efficient small-diameter autogyro impeller having little drag but sufficient lifting force to lift a slightly heavier than air craft off the land or water. A balloon means aiding in attaining such lightness is shown for instance in FIG. 15 at 1; preferably it is larger than here illustrated — having sufficient buoyancy to lift a substantial portion of the weight of the light-weight-framed, load-carrying body 2 from a stationary position. The impeller 3 may be of an autogyro but preferably it, as well as each of the impellers of FIGS. 1 to 9, is a lifting propeller of a light-weight helicopter, optionally rotated by an auxiliary electric or fluid motor or gas turbine, and optionally in combination with a traction propeller, 4.

Some objects of this invention are to provide: (1) a light-weight but strong propeller assembly having a shaft and blades hinged with respect to the shaft, comprising tubular members containing gaseous material and plastic surrounding the tubular members; (2) such an impeller having a pair of aligned blades, each comprising a plurality of juxtaposed, inflated, resilient tubular members extending from end to end of the pair, having integrally hinged central portions that are flattened and clamped by an element on an end of the shaft; (3) an impeller as in object (1), having an aligned pair of blades, each comprising a plurality of juxtaposed, inflated, resilient tubular members, extending from a flattened and sealed, central-hub, hinged portion to a flattened and sealed free end, unattached to other structure; (4) an impeller as in object (1) in which the tubular members comprise a plurality of cans; (5) an impeller as in object (4) in which the cans have corrugated walls; and (6) an impeller as in object (4) in which the tubular members comprise rows of end-joined cans.

Other objects of the invention will be apparent in the following specification and claims and the accompanying drawings.

In these drawings:

FIG. 1 is a plan view of one form of the invented impeller, partly broken away to expose its internal structure along a plane normal to the impeller's axis;

FIG. 2 is a sectional view from the plane indicated by the arrows 2—2 of FIG. 1;

FIG. 3 is a sectional view from the plane 3—3 of FIG. 1, showing one of the optional types of airfoil body material;

FIG. 4 is a sectional view from the plane 4—4 of FIG. 1, showing another of the optional types of airfoil body material;

FIG. 5 is a plan view on a scale reduced from that of FIG. 1 of an impeller of the general type of FIGS. 1 to 4, in which the integral hinges of each aligned pair of the blades are not at the right angle to the axis of the blades;

FIG. 6 is a sectional detail view, from a plane comparable to that indicated at 6—6 in FIG. 5, of the clamping plate used to flatten the middle parts of the blades;

FIG. 7 is a plan view, partly broken away and partly in section from a plane normal to the axis of the propeller, showing a second form of the impeller;

FIG. 8 is a detail view, in section from a plane comparable to that indicated by the arrows 8—8 of FIG. 7, showing an optional form of the hub and assembled set of impeller blades, comprising a curved spinner disk in advance of the blades, and not having the optional bracing bars 18;

FIG. 9 is a view in section from a plane normal to the axis of an aligned pair of the blades of FIGS. 7 and 8;

FIG. 10 is a detail sectional view of a row of end-joined cans from a plane parallel to the axis of a blade that comprises rows of cans as tubular members;

FIG. 11 is a detail sectional view of an alternative type of row of cans;

FIGS. 12 and 14 are detail sectional views of tubular members comprising corrugated cans or tubes;

FIG. 13 is a detail plan view, partly broken away, of another form of corrugated tubular member;

FIG. 15 is a plan view, partly broken away, of a third form of the invented tubular impeller, having metallic hinges;

FIG. 16 is a sectional view from the plane 16—16 of FIG. 15;

FIG. 17 is a detail view, in section from the plane indicated by the lines 17—17 of FIG. 15, showing an optional type of the hinges and blades;

FIG. 18 is a sectional view similar to FIG. 17, showing a tubular impeller that does not have metallic or flattened-tube hinges; and

FIG. 19 is a detail view in section from a plane comparable to that indicated by the arrows 19—19 of FIG. 17, on a reduced scale, showing one form of joint between flattened-end tubular members and hinge plates of the type of FIG. 17 or hub portions of the type of FIG. 18.

With reference to the drawings, the invented impeller basically comprises: a rotary shaft 5, 5A, 5B, 5C, an optional but preferable hub (the hub plate 6 in FIGS. 1 and 4; 6-16-18 in FIG. 7; 60 in FIGS. 17 and 18); blades (7 in FIG. 1, 66 in FIG. 17); aerodynamically-shaped airfoil skins — optionally the outer surfaces of the airfoil body material, or rubber or epoxy coating, or other envelopes of molded, dense, resilient plastic, or fabric impregnated with rubber or other flexible plastic (8 in FIGS. 1 to 4 and 7, 70 in FIGS. 17 and 18); tubular members of thin metal, plastic, fabric-and-plastic, glass, or the like (9, 9', 10 and 12 in FIGS. 1 to 4; 40 and 41 in FIGS. 7 to 9; 68 in FIGS. 17 and 18; and in FIG. 19); gaseous material in the tubular members;

and airfoil-body material between the tubular members and skin, preferably surrounding all or nearly all of the tubular elements in each blade (14 in FIGS. 1 to 4, 9 and 10).

The following four briefly described forms of the invention are illustrated in the drawings: (1) The species of FIGS. 1 to 6 (considered with FIGS. 10 to 14) comprises four elongated, inflated tubes (9) of flexible material, each of which is flattened at the hub between tube-clamping hub plates 6 and 20 (or 20'), forming a long-lasting integral hinge between aligned, integrally-joined blade tubes. These integral tubes, which extend thru the hub part from one blade tip to the tip of the opposite blade, thus are hinge tubes. Their walls are of strong and highly ductile or resilient material — preferably ductile metal (for example, lead) — preferably thin lead, sheathed in strong fabric. They are preferably so highly pressurized with air or other gas or pressurized foam plastic that they yield (safely) only under such a major shock as would break or badly damage a presently common type autogyro or other impeller blade. This invention form comprises auxiliary, plastic-enveloped, blade stiffening and strengthening tubular members (10 or 12) which stop short of the hub and thus do not interfere with hinging of the flexible, flattened-tube hinges. Their main purpose is to fill out and strengtheningly form the major portion of each airfoil blade, with a minimum of weight. Being preferably stiffly flexible (for example, of bamboo or rubber-jointed cans), in major shock they safely follow the movements of their connected impeller-hinge tubes 9. In FIG. 5, the flat, integral-tube hinges of the tubes 9 are exemplified as optionally at oblique angles to the axis of each pair of aligned blades. (2) The invention species of FIGS. 7 and 8 differs from the above species (1) in having, in each blade: only two inflated flat-hinge-providing tubes (40 and 41), having unequal diameters and tube-flattened, hub-clamped hinge parts that are not integral with opposite tubes; and in having blade-stiffening, light-weight, tubular filler members 10 (FIG. 9) that are arranged differently from the filler elements 10 and 12 of FIGS. 1 to 6. (3) In the invention form of FIG. 19 (considered with FIGS. 15, 16 and 2), each blade has a plurality of stiffly-flexible, light-weight, strength-providing, flat-ended, inflated tubes of different diameters. These blade tubes are similar to the hinge tubes of FIGS. 1 to 9 except that they are not integral with blade tubes on opposite sides of the hub. They are hinged to the hub by the pivot-bearing type of hinge shown at 62' and 62 in FIGS. 19 and 17 and in FIG. 15. (4) The invention species of FIGS. 17 and 18 (considered with FIGS. 15, 16 and 9 and optionally with FIGS. 10 to 14) comprises blades having rows of cans that are joined at their ends by preferably resilient plastic, and are optionally connected to the hub by the hinge of FIG. 17 or the joint of FIG. 18. In each of the currently preferred forms of the invention (shown in FIGS. 1 to 9) the rotor blades are stiffly resilient because of the inflated ductile or resilient tubes 9 and the preferably resilient auxiliary tubular members 10 and 12 — which preferably comprise cans end-connected by resilient plastic (31 or 33); but the blade roots comprise tube-flattened, hub-plate-clamped portions of the strong tubular material that are very flexible, permitting the blades to automatically pivot with respect to the rotor's axis, thus balancing the two sides of the rotor under varying conditions of blade attack. In an

autogyro or helicopter that is underway, for example, the stiffly resilient blades automatically flap up and down during each rotation. And in the form of the invention shown in FIGS. 19 and 15, the closely compacted connections of the tubes of each blade to its rigid hinge plate 62' are sufficiently strong and flexible to counteract tendency of the blade to break off the hinge at its root.

Although the impeller hub of FIGS. 1 to 8 may be an integral part of the rotary shaft, it is preferably a separate element, welded, bolted or otherwise fixed to the shaft. This hub is shown in FIGS. 1, 4 and 8 as comprising a thick, metal plate 6, welded at 6' to the shaft 5 and preferably bolted to the shaft with a bolt or bolts as in FIG. 4. The edge of this plate is preferably arcuate; its curves are shown in FIG. 1 as having a plurality of centers of curvature; but optionally it may be circular. In FIG. 7 the hub is indicated as comprising: a metal plate, preferably of steel, fixed to the shaft (like 6); four metal projections 16, jutting upward or outward (toward the flattened-tube, impeller-support plies that are housed between the projections), these projections being of the proper height (extension from the hub plate 6) to allow the clamping plate 20 to be bolt-drawn against them and also sufficiently drawn against the flexible flattened-tube portions to clamp them tightly and sealingly between the plates 16 and 20; and four optional, hub-bracing bars, 18, that are welded to the shaft and to the shaftward surface of the hub plate.

A plurality of relatively-small-diameter hinge-providing tubular elements are indicated as the main impeller-blade-supporting tubes in FIGS. 1 to 8. In FIGS. 1 to 4 four such tubular elements are shown in each blade. Each aligned pair of these elements are the blade portions of an integral, tubular member which extends from the tip of one blade over the hub and to the tip of the opposite blade. Sectional FIG. 4 illustrated one integral tubular member at 9—9 and four other integral tubular members having tube-flattened hinge portions at 9' that are orthogonally arranged relative to the member 9, as well as to the three other members 9 that are not shown in FIG. 4 but are indicated in FIGS. 1 to 3. The middle portions of all the tubular members 9 and 9' are tightly and flatly held on the hub plate 6 by clamping means which, as shown, is in the form of a plate, 20, screwed tightly down on the middle tubular-member portions and the hub by means of the bolts 21 and nuts 22.

As shown in FIG. 4, these tubular-member middle portions are tightly-pressed tube folds, and the orthogonal arrangement of the members is such that the middle folds of 9' fit over the middle folds of 9. But optionally the middle portions of 9' may be slit sufficiently at their sides for the four middle folds of 9 to fit between the slit-formed plies of 9; and in this event all the axes of the blade-supporting tubular members 9 and 9' are in the same plane — instead of in slightly spaced planes as in FIG. 4.

In addition to its hub-attached, flat, flexible, hinge-providing fold or pair of slit plies, each of these hinge-providing, blade-supporting tubular members comprises: an arcuate-in-cross-section middle-blade part, containing gaseous material; and a pair of flattened-tube, blade-tip portions, 24, each of which comprises flattened-tube end edges that are permanently sealed together by bonding material (for example, vulcanized

rubber, epoxy putty or other plastic glue, brazing, welding or solder).

The wall material of these members is of a type that will stand frequent and long-repeated flexing, especially at the integral, hubward hinges, without fracture or other disruption. This material optionally may be: cloth or metal fabric, impregnated and coated with resilient rubber or other flexible plastic; dense, strong, resilient plastic; thin sheet metal that is very ductile or resilient (for example, thin copper or aluminum sheet, thin spring steel or phosphor-bronze or very thin lead), preferably covered with a flexible coating (for instance, rubberized fabric or resilient plastic). The inventor currently prefers a sealed, thin-lead inner tube, permanently inflated, sheathed in a closely-fitting envelope of strong, flexible fabric. Thin lead has numerous critical advantages in such tubes, for it may be flexed indefinitely — a multitude of times — without gas-losing fracture, without necessity of subsequent re-inflation, and easily welded by simple application of heat.

Each of the tubular members 9 and 9', as well as each of the other tubular members shown in FIGS. 5 to 18, contains gaseous material — preferably helium, air or other gas — preferably under high pressure (for example, in the range of ten to thirty pounds per square inch); but optionally this gaseous material may be gas-cell-containing foam plastic, preferably of the known pressurized type, as indicated in FIGS. 3 and 14 at 26. When the gaseous material is pressurized gas it optionally may be forced into the tubular elements either thru a small, permanently sealable, gas-inlet tube or a gas-inlet valve. When the wall material of the tubular elements is permeable to gas (for example, of fabric and rubber) the gas preferably is intermittently supplied thru gas-inlet valves, indicated in FIG. 15 at 27.

The airfoil-body material that is between the skin 8 and the tubular members 9 and 9' comprises: plastic (preferably foam plastic, optionally resilient or substantially rigid, the liquid materials of which optionally may contain known fire-proofing chemicals); and optionally and preferably other, blade-strengthening tubular members 10 and/or 12 are imbedded in this airfoil-body plastic. The members 12 may be elongated or short metal cans, but preferably each is an elongated, hollow, corrugated, gas-containing element of the type shown in FIG. 13 — of bamboo or of mold-formed, dense plastic that has annular corrugation ridges, 28. The tubular members 10 also may be of such bamboo or plastic (of diameters larger than 12); but preferably these are of any of the types shown in FIGS. 10 to 12, 14 and 16 to 19.

Each of these members 10 may be a single, elongated can of thin metal or strong, dense plastic, extending nearly the full length of a blade (optionally with flattened and sealed ends of the above-described type or with disk-like ends); or, as shown in FIGS. 10, 11, 17 and 18, each member 10 may be an end-joined row of cans, which may be of thin steel or aluminum or dense plastic. In any event, each member contains gaseous material of the above-described type (gas, preferably pressurized, or foam plastic). FIG. 10 shows end-joined cans of different diameters, with the end caps of cans of smaller diameter (30) being fixed by bonding material, 31, of the above-described type (optionally resilient rubber) within the recessed end caps of larger-diameter cans, 32. FIG. 11 shows similarly bonded-together cans; here the can-end caps are not indented;

but they are fastened together by bonding material 33 that is similar to 31. FIG. 12 shows a can, 34, having corrugated walls comprising elongated corrugation ridges and grooves. This tubular element, which may be an integrally elongated tubular member, or a shorter can in a row of end-joined cans, may be of aluminum-alloy sheet of the type commonly sold as corrugated roofing (but preferably of thinner metal), made by bending the sheet around a mandrel and joining its edges by the welding or other bonding material, 36. The annularly corrugated tube 38 of FIG. 14 is of cast material, preferably of dense, strong, molded plastic. Any of these tubular elements optionally may be made of blow-molded plastic.

The type of impeller shown in FIG. 7, somewhat similar to that of FIG. 1, may have two or three blades; but as shown it has four. It comprises integral-hinge, blade-supporting, different-in-diameter, tubular members 40 and 41, of materials and construction very similar to those of the tubes 9 and 9' of FIGS. 1 to 4; but the tubular members 40 and 41 are exemplified as not integrally extending from one blade tip across the hub to an opposite blade tip. Instead, each has: a flattened-tube blade-tip portion, like the bands of material 24 of FIG. 1; an arcuate middle-of-the-blade portion; and a flattened-tube hubward portion that extends across the hub plate 6 and ends in a line substantially coextensive with an edge of the hub plate. As above described, the overlapping flattened-tube portions, compositely sheathed by the preferable fabric-and-resilient-plastic airfoil skin, are tightly clamped between plates 6 and 20.

The flattened-tube portions are formed, at each end of the tubular member, by flattening and thoroughly, sealingly bonding together the two contiguous flat plies, so that the middle part of the tube, preferably containing highly pressurized gas (but optionally instead containing gas-cell-containing foam plastic — preferably pressurized) remains arcuate in cross section, and from a point spaced from each flat end of the tubular member, toward each flat part, the curved tubular walls arcuately flare outward on two sides and arcuately flare inward on two other, orthogonally located sides.

This inventor has discovered the following valuable inventive principles in such flat-ended tubular elements: (1) They may be of thin, dense, impermeable-to-gas material that is prone to damage by wrinkling, and yet be easily, strongly and permanently inflated without wrinkling by lighter-than-air gas. For instance, this material may be very thin lead, copper, steel or other very thin metal or dense, permanently-wrinkleable plastic. Previously such inflation required the expensive and time-consuming formation of a vacuum before inflation with helium or the like, and this vacuum tried to flatten but badly wrinkled the dense material of an ordinary tube that was circular-in-cross-section throughout its length. But in accordance with this invention the tubular members may originally be made of two equal, flat, rectangular, optionally integral and folded parts of dense sheet material, welded, brazed or otherwise sealed at all edges, and thru gas-passage holes or small, sealable inlet tubes the helium is forced between the flat plies, forcing the mid-tube portion into a smoothly arcuate contour that smoothly tapers to each flat end. The width of the flattened-tube ends is equal to the original width of the rectangular

parts — and is substantially equal to 1.57 times the circumference of the cross-sectional circle of the arcuate middle portion when the tubular member is sufficiently long for this portion to taper from the flat ends thru oblong cross sections to such a circle; and the length of each taper has been roughly, empirically determined to be over $2\frac{1}{2}$ times such diameter. (2) When the band of the two bonded flat-end portions is sufficiently extensive along the tube's axis, attachment bolts of the type shown in FIG. 4 (at 21) or in FIG. 8 may be passed thru holes in the flat, sealed portions.

When the flattened-end tubes of any of the illustrated propeller forms are of water-hose-like or rubber-tire-like materials, permeable to gas, they are provided with the gas-inlet valves 27, like those of rubber tires, thru which they may be repeatedly inflated with helium, air or other gas - preferably to high pressure, for example of ten to thirty pounds per square inch. Examples of such permeable materials comprise various types of rubber-coated fabric (fiberglass, nylon or other cloth, or fine-wire mesh of spring steel, copper, aluminum alloy, or the like).

As illustrated in FIG. 8, the flared wall portions of a smaller tubular element 41 are flattened to the same plane at 42, and the similar flared wall portions of the opposite larger, propeller-leading-edge tube 40 would taper to the same plane if, as is optional, the flattened portions of the two tubular elements stopped and met at the line thru the axis of the hub plate 6 (and thru the axis of the impeller shaft that later in the manufacture is welded to plate 6). But as shown the bonded flattened portions 43 of the trailing-edge tube 41 extend thru and are strongly glued to the overlying flattened portions 44 (folded and slit at the folded edges) of the leading-edge tube 40. The similar overlapping and glued-together four flat plies of the pair of blade tubular elements that are orthogonally arranged with respect to tubes 40 and 41 are shown at 45 (plies of the smaller trailing-edge tube that have been widened by overlying and tube-strengthening bands of glued or welded fabric) and 46 (overlying flat plies of the larger tube). The leading-edge tube 40 of the left-hand set of tubes in FIG. 8 (not shown in section) is illustrated at 47. The smaller right-hand tube whose flattened ends are glued within those of tubular-member ends 47 is not seen in FIG. 8; but in FIG. 7 two such orthogonally arranged pairs are shown.

The hinge line between the hub and the flexible, blade-root, tube-flattened portions (and of the hubward flexible-skin element that envelops them) is determined by bordering edges of the clamping plate (20 or 20'). In FIGS. 1 and 4 this plate is square and these bordering edges (48) are normal to the axes of the blades. In FIGS. 5 and 6 the plate 20' is shaped to provide straight portions 49 of its border, each of which is in a plane making an oblique angle with the axis of its adjacent blade. When the blade is in a vertical-axis impeller, is rotating in the direction of the arrow A, and momentarily moving against fluid current, this oblique angle permits it to decrease its angle of attack relative to the fluid current; and thus, against centrifugal force, it balances the thrust of the blade that is opposite to its. The border of the plate 20' comprises edges that are angled to the edge portions 49. Both of the plates 20 and 20' are preferably streamlined, with thin edges all around, as at 49A.

Instead of integrally flexible hinges for the tubular blades, metallic, pintle-comprising hinges, such as are indicated in FIGS. 15, 17 and 19, may be utilized. In FIGS. 15 and 16: the tubular members 50 are bisected by a common plane 52 that in a lifting propeller is inclined to the horizontal; the tubular member 54 is bisected by the inclined plane 55; but the axis of the hinge pintle is not thus inclined. Instead it is horizontal, and is in or nearly in the horizontal plane indicated by the line 56 — or in arrangement as in FIG. 9 the plane indicated at 56A. This line also indicates the top edge of the hinge plate 62 (or 62') that is fastened to ends of the cans 50 and 54 by the bolts 57. Each of these tubular members 50 and 54 may be a single can (optionally having either disk-like or flattened-tube ends) extending from points at or near the hub to points at or near the blade tip; or each member may be an end-connected row of shorter cans of the type shown in FIG. 17.

The blade hinges illustrated in FIGS. 15, 17 and 19 may be of aluminum alloy, stainless steel or other strong metal. As shown in FIGS. 17 and 19, each of these hinges has: a plate 58, securely fixed to the metal hub 60 by bolts or rivets 61; another plate, 62 (62' in FIG. 19), that is pivoted with respect to 58, fixed to can-end caps by the bolts 57 and nuts 63, and, as indicated at 62L, extends from the pintle to the thrust surface of the blade; and the hinge pintle 64, forming part of the pivot bearing of the hinge. The plate 62 is securely fastened to the skin and tubular members of the propeller blade (or vane), 66, which may have any of the forms to tubular members shown in FIGS. 9 to 19. When they have disk-like hubward ends, the hinge-attachment bolts 57 may be either fixed to each can end-cap before this cap is bonded to the can cylinder; or they may be placed thru holes 67 after the end-cap is thus bonded. In this latter event the bolt heads preferably are located inside the can.

As indicated in FIGS. 9 and 16, the blade comprises a plurality of juxtaposed rows of tubular members; and as illustrated in FIG. 17, each tubular member comprises a row of end-joined tubular cans 68 of the same diameter. The varying diameters of the rows (50 and 54 in FIG. 16) are preferably calculated to fit closely within the aerodynamically streamlined plastic skin 70. As indicated in FIG. 17 at 71, the lower surface of this skin 70 is coextensive with the lower edge of the hinge plate 61-62L. When relatively short, disk-ended cans of the type of 68 are used, they preferably are of the general type (of thin sheet steel, aluminum or aluminum alloy) currently made by can-manufacturing companies and commonly used for holding food, liquids or other materials. Optionally the tubular containers may be filled with foamed plastic, which may be of the closed-gas-cell type; but preferably they contain sealed gas (for example, air, helium, nitrogen, ammonia, or hydrogen mixed with a small amount of combustion-inhibiting gas). This gas may be under pressure well above that of the atmosphere, placed in the can thru an opening (or openings) in it, and then the opening is sealed, preferably around a valve, stopper or other closure, with the aid of brazing, welding, solder, or epoxy putty or glue. The cans may be of the type commonly made with soldered end caps, or, like paint cans, with lids that snap into a recess; but such recess-filling lids are preferably epoxy-glued, welded or soldered around their annular edges.

As indicated in FIG. 17, a layer of plastic or the like, 72, preferably stiffly resilient, is placed between adjacent ends of the cans. This optionally may be plastic set from liquid materials poured in place, or an annular disk of sheet rubber that is glued to one or both of the can ends.

The impeller blade of FIG. 19 is also optionally resilient or substantially rigid; but it is preferably stiffly resilient. In this form the blades, having flattened-tube ends, are similar to those of FIGS. 7 and 8 in optional wall materials, general method of construction and the gaseous material they contain. But in FIG. 19 the flattened hubward ends of the tubular members and the enveloping airfoil skin are shown as extending along upright planes — instead of in the horizontal arrangement of such flattened ends in FIGS. 7 and 8. At the root of each blade the flattened and sealed end of each of the tubular members is formed (bent, pressed or deformed to the side) in a right angle to the axis of the tube. When it is made of thin resilient metal its flat hubward end is annealed before it is thus shaped; and when the tube comprises thermoplastic material its hubward end is sufficiently heated to plasticize it just before that end is formed into the hinge-attaching, tube-bracing angle.

The flange or brace 74 thus formed is securely fastened to the hinge plate 62', which is similar to plate 62 of FIG. 17. Epoxy glue or putty is applied to the contiguous surfaces of the flanges 74 and plate 62', some of it penetrating holes 76 in the plate 62 and flanges 74 for extra holding power. And before this glue sets bolts of the general type of 57 in FIG. 17, having screwdriver kerfs like those in the heads of bolts 21 of FIG. 4, are extended thru the holes 76, and with a screwdriver in the exterior kerfs nuts like 63 of FIG. 17 are tightened. Preferably also dense, strong plastic, 77 — for example epoxy putty — is applied between the hubward flattened portions at the time of assembly of the tubular members and hinge plate.

The impeller blade of FIG. 18 is also optionally either resilient or substantially rigid. Except for its lack of a pintle-comprising hinge it is of the same type of construction as the propeller of FIG. 17. Its elements 72 optionally may be resilient or substantially rigid plastic (for example, rubber or epoxy), and optionally may be only between the cans of each row or a row-spanning, resilient or substantially rigid rib of one of the above-described types. When the blade is resilient (because of the resilient nature of 70 and 72), the impeller's resiliency may be increased by placing resilient elements similar to 72 between each blade root and the hub 60. The blade as a whole thus is optionally resilient, thus reducing damaging vibration and the possibility of breakage.

Each blade of FIG. 17 or FIG. 18 is completed by forming the optionally flexible skin 70 (of fabric-reinforced plastic, thin copper, resilient steel or other sheet metal) and placing plastic (preferably resilient foam plastic) between the skin and tubular members. The skin may be made by wrapping and flexible-cement-gluing textile or metallic fabric or mesh around the cans. Optionally this mesh may be of fine-wire spring steel, fine-wire copper network, aluminum mesh or cloth. Preferably it is impregnated and glued, by flexible, liquid-rubber cement (for example, Pliobond) to an outer sheet of resilient rubber before the composite skin is wrapped and glued to the cans and ribs. But

optionally the mesh may be first wrapped and flexibly glued to the cans and ribs, and then either sheet rubber is slightly stretched and flexibly-glued around the mesh or the blade frame is placed in a blade-shaping mold and liquid plastic materials (preferably mixed with fiberglass or other plastic-reinforcing elements) are poured into the mold, around the frame. These materials optionally may be the type which forms foamed plastic. This general method of molding may be used in formation of any of the blades of FIGS. 1 to 19.

If the blade in any of the forms of the invented impeller is not thus finished in a mold, its skin (optionally of reinforced plastic or of two forged parts of sheet metal that are brazed or otherwise edge-bonded around the tubular members) is drilled or punctured sufficiently to inject foamed-plastic liquids into the spaces around the tubular elements and within the skin; and then the skin is quickly sealed again to prevent loss of the foaming, gas-pressurized liquids. This way of providing airfoil-body plastic (optionally foamed plastic) is preferably utilized in finishing all the impeller blades of the disclosed forms of this invention; but when they are of the integral-hinge type of FIGS. 1 to 8 their skins are either: (1) entirely flexible — of strong, resilient or highly ductile material (for example, fabric, coated with resilient plastic, or thin resilient or very ductile metal); or (2) the skin of each blade proper is a composite of metal or plastic sheet enveloped by an overall flexible skin of the above type (which in the forms of FIGS. 1 to 8 extends across the hub and provides integrally flexible hinges). Each of the airfoil skins of this invention may be of one of the above two optional types of construction.

When the tubular members are of the type shown in FIG. 10 the foaming plastic materials easily pass from a single injection inlet to all spaces around the cans because of the differences in their diameters; and when the containers are of the type indicated in FIGS. 11, 17 and 18 the end caps in practice project slightly outward from the can cylinders and the foaming plastic also may be put in place thru one hole; but otherwise — unless the blade is finished in a mold — a plurality of inlet holes are advisable.

In the following claims, unless otherwise qualified: the term "tubular member" signifies a single, elongated can or tube of any cross-sectional shape or a plurality of end-connected cans or tubes; "can" means a tubular article of any cross-sectional shape, comprising a middle hollow portion; "tube" signifies an elongated hollow article of any cross-sectional shape; "tubular element" means a single tube or can distinct from other tubular articles or a single tubular unit in a tubular member as above defined; "gaseous material" means: any gas, gaseous mixture, gas-cell-containing foam plastic or yieldable material comprising fibers or other particles and air or other gas between the particles; "gas": any pure gas, or mixture of gases (for example, air, or hydrogen mixed with inert gas); "plastic": rubber or any other natural or synthetic plastic; "fabric": any fibrous or metallic cloth or mesh; and "skin" means: an exterior surface of material (for example of molded or cast material), an exterior coating, or an exterior sheath or envelope.

I claim:

1. A rotary impeller, comprising: a rotary shaft; blades connected to said shaft, each of which has a free end, unattached to other structure; and hinge means,

comprising blade-root-attachment means, connecting said blades to the shaft, permitting angular movement of each blade with respect to said shaft in balancing said impeller during its rotary interaction with a fluid current; in which:

each of the said blades comprises: an aerodynamically streamlined skin; within said skin, at least one elongated, sealed, inflated tube, having: curved wall structure, comprising dense, flexible material that is substantially impermeable to gas; a blade-root portion, adjacent to said blade-root-attachment means, that comprises a pair of substantially flattened tube parts, integral with a middle portion of said tube, each of said flattened parts being wider than an adjacent portion of the tube's middle part; means holding said substantially flattened tube parts together in strong junction; gaseous material under above-atmospheric pressure in said sealed tube; and plastic between said skin and tube; and

the said hinge means further comprises means strongly fastening said blade-root portions to said blade-attachment means, holding a substantially flat surface of each blade-root portion in substantially compressed relation to the blade-attachment means.

2. An impeller as set forth in claim 1, in which: each of the said tubes comprises, adjacent to said free blade-end, a second pair of said substantially flattened tube parts and means holding said last-named tube parts together in strong, sealed junction.

3. An impeller as set forth in claim 1, in which said dense material comprises metal having ductility at least equal to that of copper.

4. An impeller as set forth in claim 3, in which said metal is lead.

5. An impeller as set forth in claim 1, in which said dense material comprises thin lead and a covering on the lead comprising fabric.

6. An impeller as set forth in claim 1, in which: said dense material comprises metal having ductility at least equal to that of copper; said gaseous material comprises gas under above-atmospheric pressure, permanently sealed in each of said tubes; and each of said tubes comprises a permanently sealed inflation-gas inlet.

7. An impeller as set forth in claim 1, in which said gaseous material is gas under pressure of at least 8 pounds per square inch, and each of said tubes extends from a point near said shaft to an outer end adjacent to the tip of its blade and, at said outer end, comprises: a second pair of substantially flattened tube parts, each of which is wider than an adjacent portion of the tube's middle part; and means holding said second pair of tube parts together in strong junction; whereby the said tube may be temporarily changed in shape under external major shock and thereafter may return to its former configuration.

8. An impeller as set forth in claim 1, in which the said hinge means comprises: a hub plate, fixed to an end of said rotary shaft; integral extensions of said pair of substantially flattened tube parts, lying on and fixed to said hub plate; a clamping plate, juxtaposed to said extensions on their side opposite to said hub plate; and in which the said blade-root-attachment means comprises rod-like clamping elements, tightly clamping together said clamping plate and tube-part extensions

and hub plate, whereby each of said blades may change its angle to the axis of said shaft by bending of said flexible material in the integral junction of said clamped extensions and blade-root portion.

9. An impeller as set forth in claim 1, comprising, in each blade, a plurality of juxtaposed tubes of the type of said elongated, inflated tube, in which the said hinge means comprises: a hinge plate; integral extensions of each of said pairs of substantially flattened tube parts, in contact with said hinge plate, each of said pairs being turned at said plate to form an angle to the axis of its associated tube that is in the neighborhood of 90°; the said blade-root-attachment means, comprising means securely fastening said extensions to said hinge plate; and a pivot bearing providing for hinging motion of each of said blades with respect to said shaft.

10. A rotary impeller, adapted to operate in a fluid, comprising: a rotary shaft; blades connected to said shaft, each of which has an airfoil-shaped contour and a free end that is unattached to other structure; and hinge means, connecting said blades to said shaft, permitting angular movement of each blade with respect to the shaft in balancing the centrifugal force and changing fluid-dynamic force on the blade during its rotation;

each of the said blades comprising a plurality of juxtaposed, sealed, inflated, elongated tubes, and each of the said tubes having: a curved wall structure of blade-strength-providing flexible material; substantially flat blade-root and blade-tip portions, each portion comprising a pair of integral, substantially flat tube parts, each of which is wider than an adjacent portion of the tube's middle part; means holding each pair of said substantially flat tube parts together in strong junction; gaseous material in each said sealed tube; tubular members, adjacent to said tubes, stiffening and strengthening said blade; and plastic on and between said tubes and blade-stiffening members, having outer surfaces conforming to said airfoil-shaped contour;

the said hinge means comprising: integral, hinge extensions of said substantially flat blade-root portions; and blade-root-clamping means, fixed to said shaft, comprising a clamping element on each side of said blade-root extensions and means forcing said elements and blade-root extensions into tightly clamped relationship, securing said blades to said shaft.

11. An impeller as set forth in claim 10, comprising at least one pair of said blades, in which: the said pair of blades are on opposite sides of the axis of said shaft; the said tubes are arranged in pairs, each of said pairs of tubes having integral wall and blade-root material, and integrally-joined blade-root extensions between said clamping elements.

12. An impeller as set forth in claim 10, in which said flexible material comprises metal having ductility at least equal to that of copper.

13. An impeller as set forth in claim 12, in which said metal is lead.

14. An impeller as set forth in claim 10, in which said gaseous material is gas.

15. An impeller as set forth in claim 14, in which said gas is under pressure above that of the atmosphere.

16. An impeller as set forth in claim 10, in which said gaseous material is gas-cell-containing foam plastic.

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17. An impeller as set forth in claim 10, in which said tubular members comprise metallic walls.

18. An impeller as set forth in claim 10, in which said tubular members comprise sealed cans.

19. An impeller as set forth in claim 18, in which each of said tubular members comprises a row of said cans in aligned, end-connected arrangement.

20. An impeller as set forth in claim 19, in which said row comprises cans of relatively smaller diameter, end-connected to cans of relatively larger diameter.

21. An impeller as set forth in claim 19, in which said cans are corrugated.

22. An impeller as set forth in claim 10, in which at least some of said tubular members comprise elongated blade-stiffening tubular elements, each of which has flattened-tube portions, one of said portions being adjacent to said shaft, and the other comprising a said free end.

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23. An impeller as set forth in claim 19, comprising bonding material connecting ends of end-connected pairs of the said cans.

24. An impeller as set forth in claim 10, in which the walls of said tubular members have corrugations whose ridges and grooves are substantially parallel to longitudinal axes of tubular members.

25. An impeller as set forth in claim 10, in which the said blade-stiffening tubular members comprise tubular elements having corrugations whose ridges and grooves extend around longitudinal axes of tubular members.

26. An impeller as set forth in claim 25, in which said tubular elements are of bamboo.

27. An impeller as set forth in claim 1, in which said skin comprises fabric and resilient plastic coating said fabric.

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