March 15, 1966 H. WATTS ETAL 3,240,468

TRANSPIRATION COOLED BLADES FOR TURBINES, COMPRESSORS, AND THE LIKE

Filed Dec. 28, 1964 4 Sheets-Sheet 1

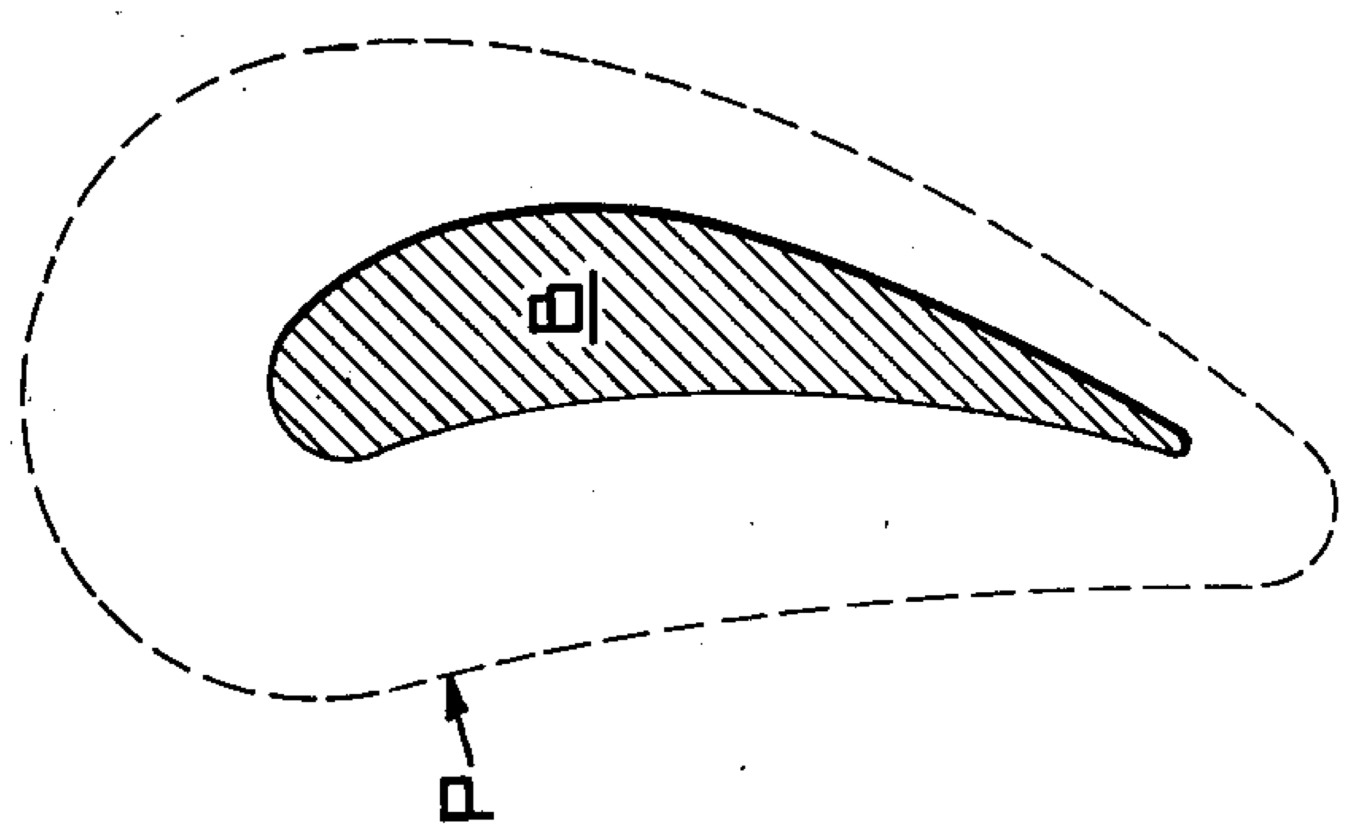

FIG. 2

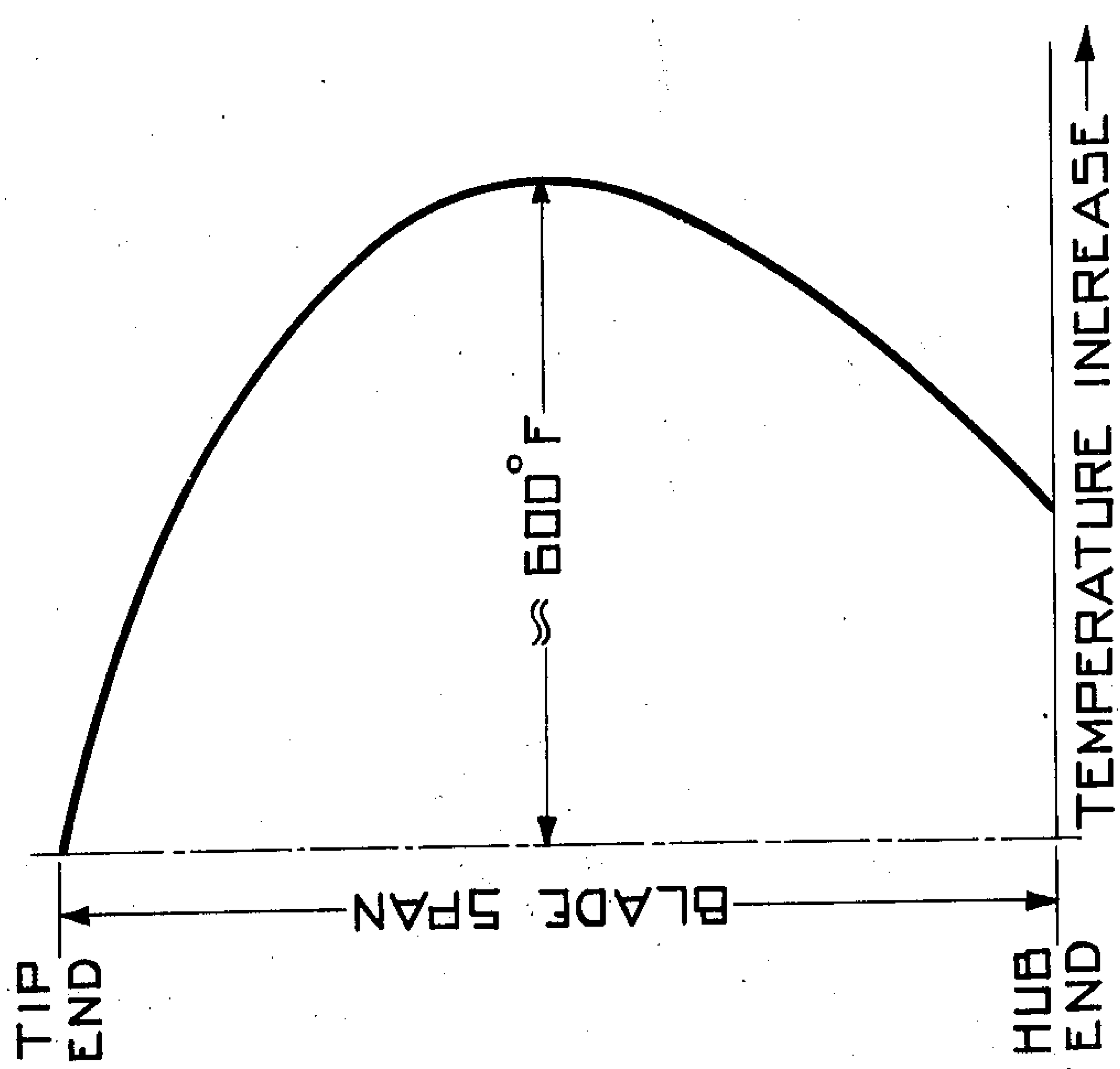

FIG. 1

INVENTORS
HARGUS WATTS
ANGELO DE FEO
BY Raymond P. Wallace
AGENT

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Filed Dec. 28, 1964 4 Sheets-Sheet 2

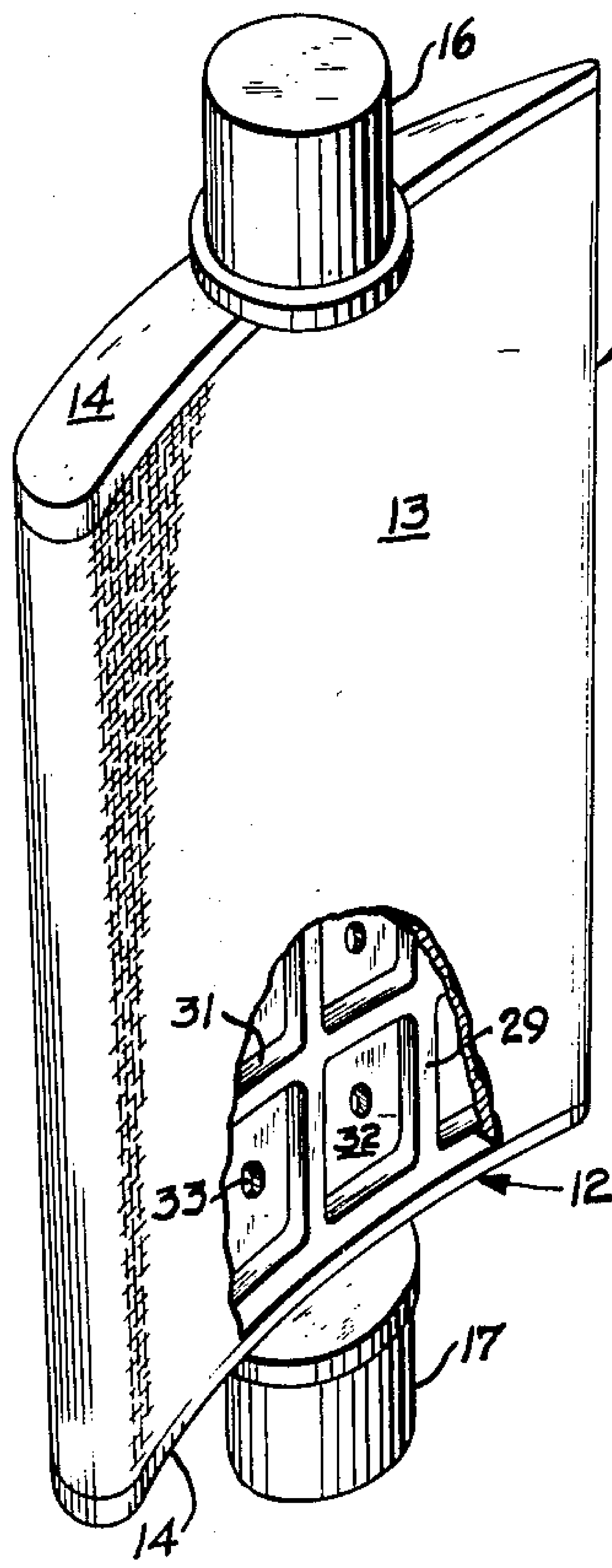

FIG. 3

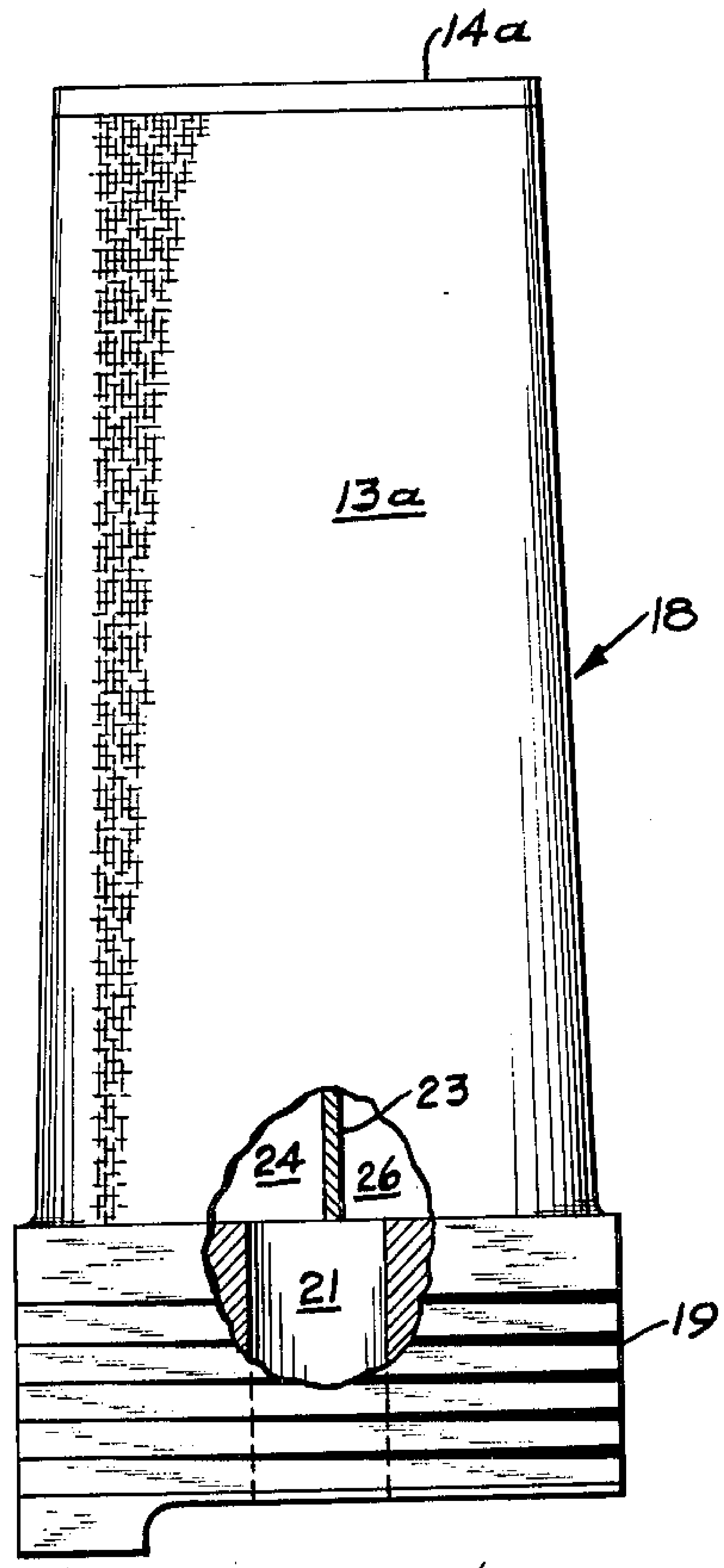

FIG. 4

INVENTORS
HARGUS WATTS
ANGELO DE FEO
BY Raymond P. Wallace

AGENT

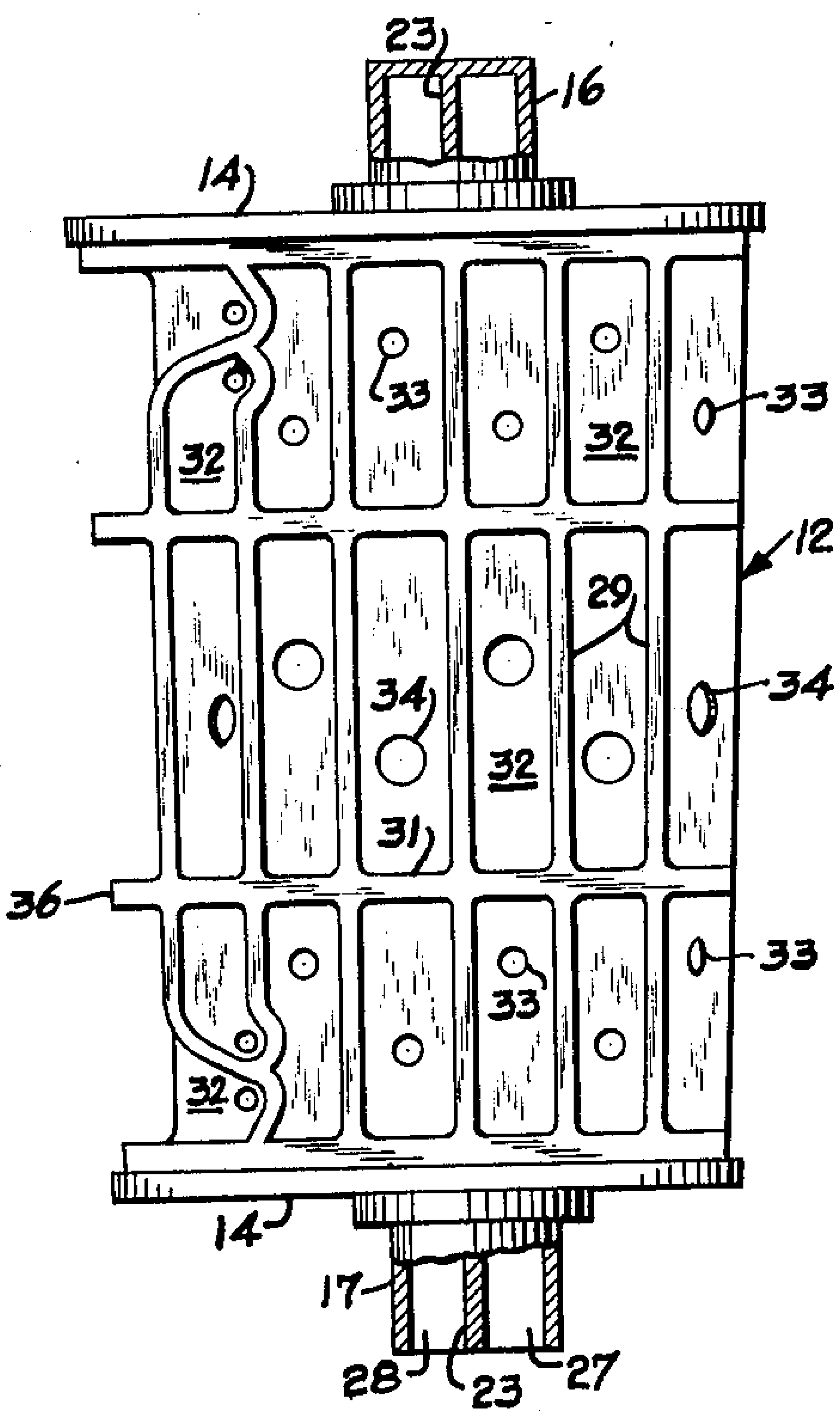

FIG-5

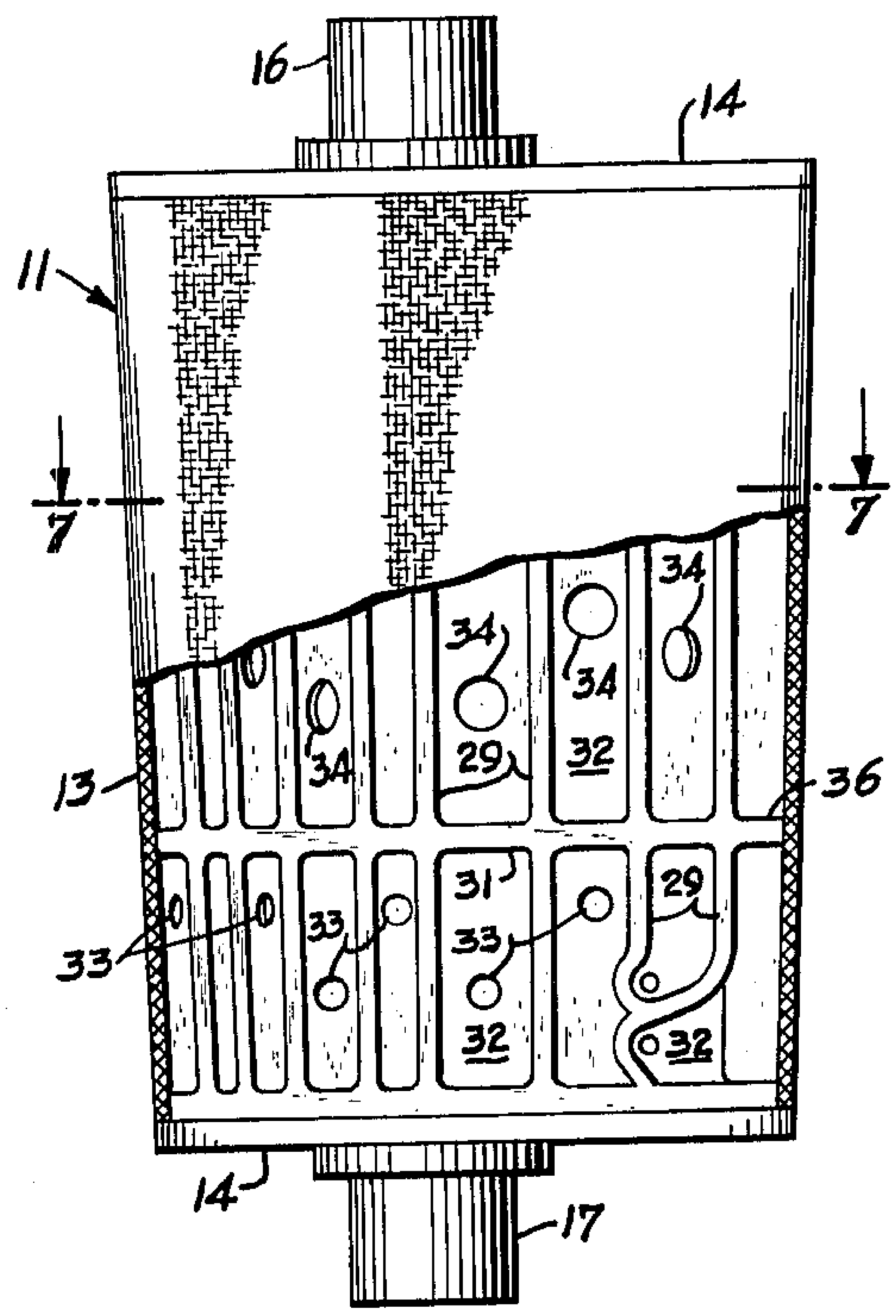

FIG-6

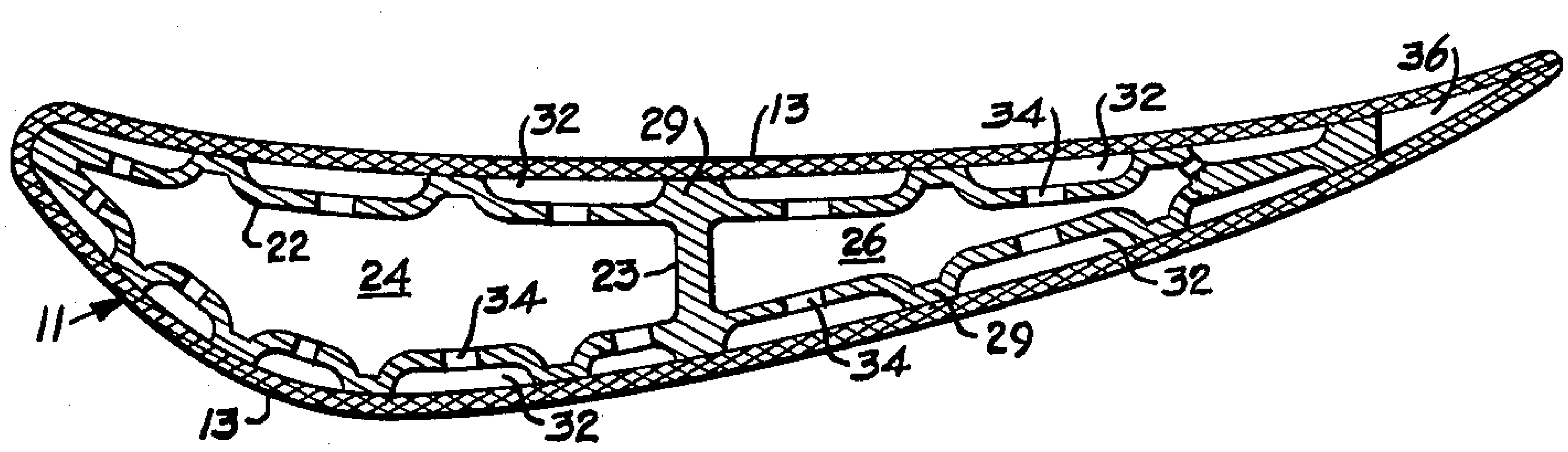

FIG-7

INVENTORS
HARGUS WATTS
ANGELO DE FEO
BY *Raymond P. Wallace*

AGENT

March 15, 1966 H. WATTS ETAL 3,240,468

TRANSPIRATION COOLED BLADES FOR TURBINES, COMPRESSORS, AND THE LIKE

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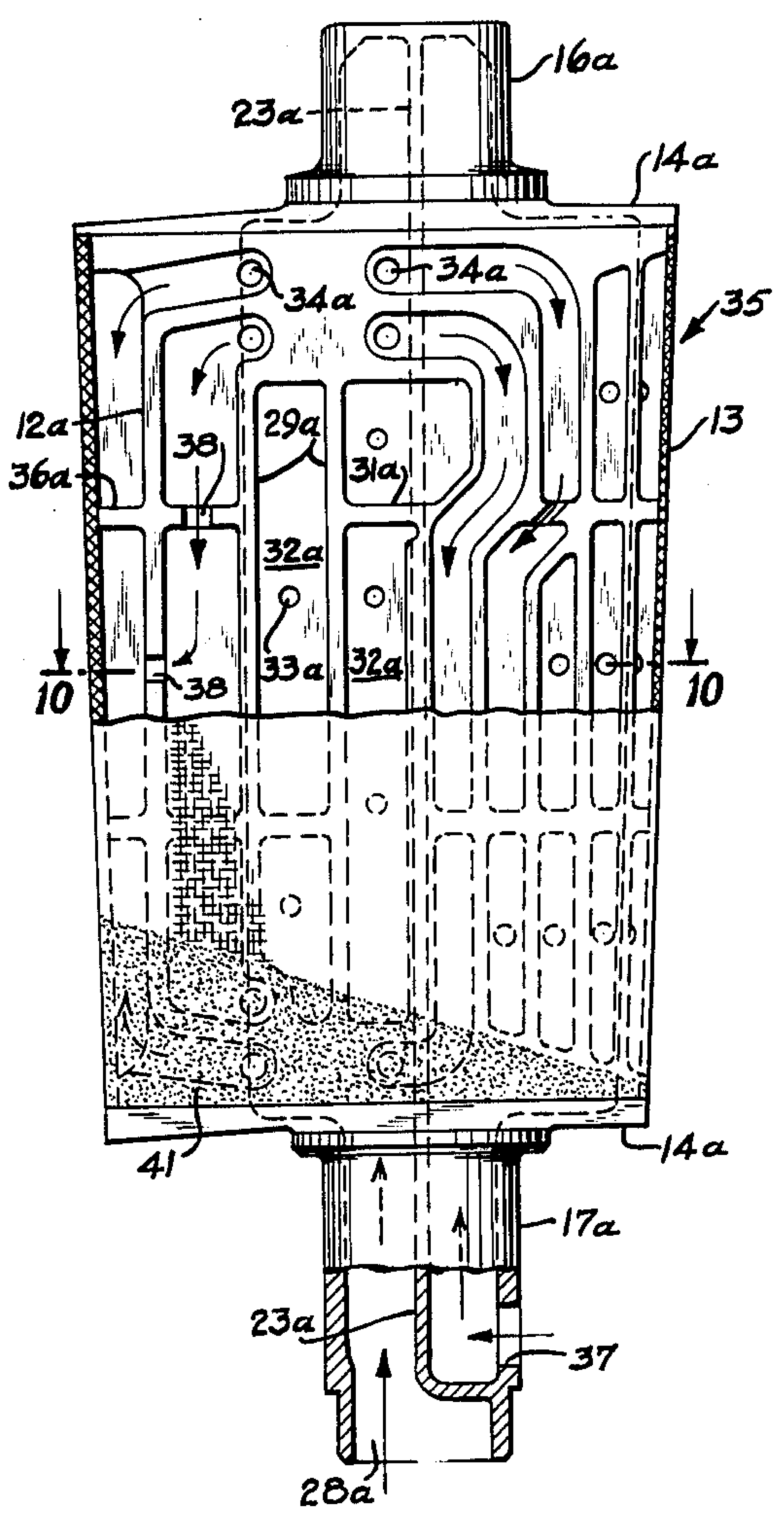

FIG. 8

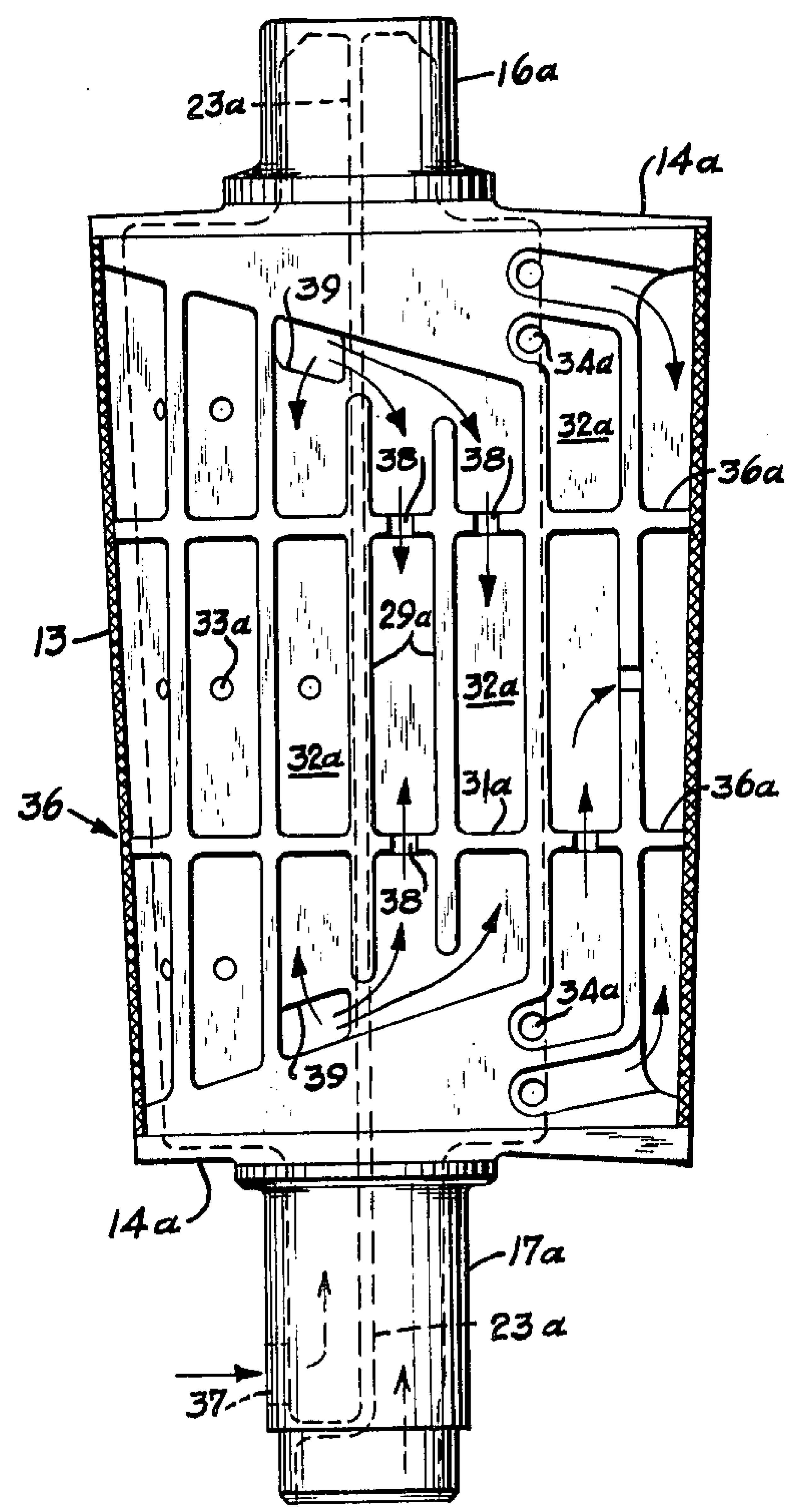

FIG. 9

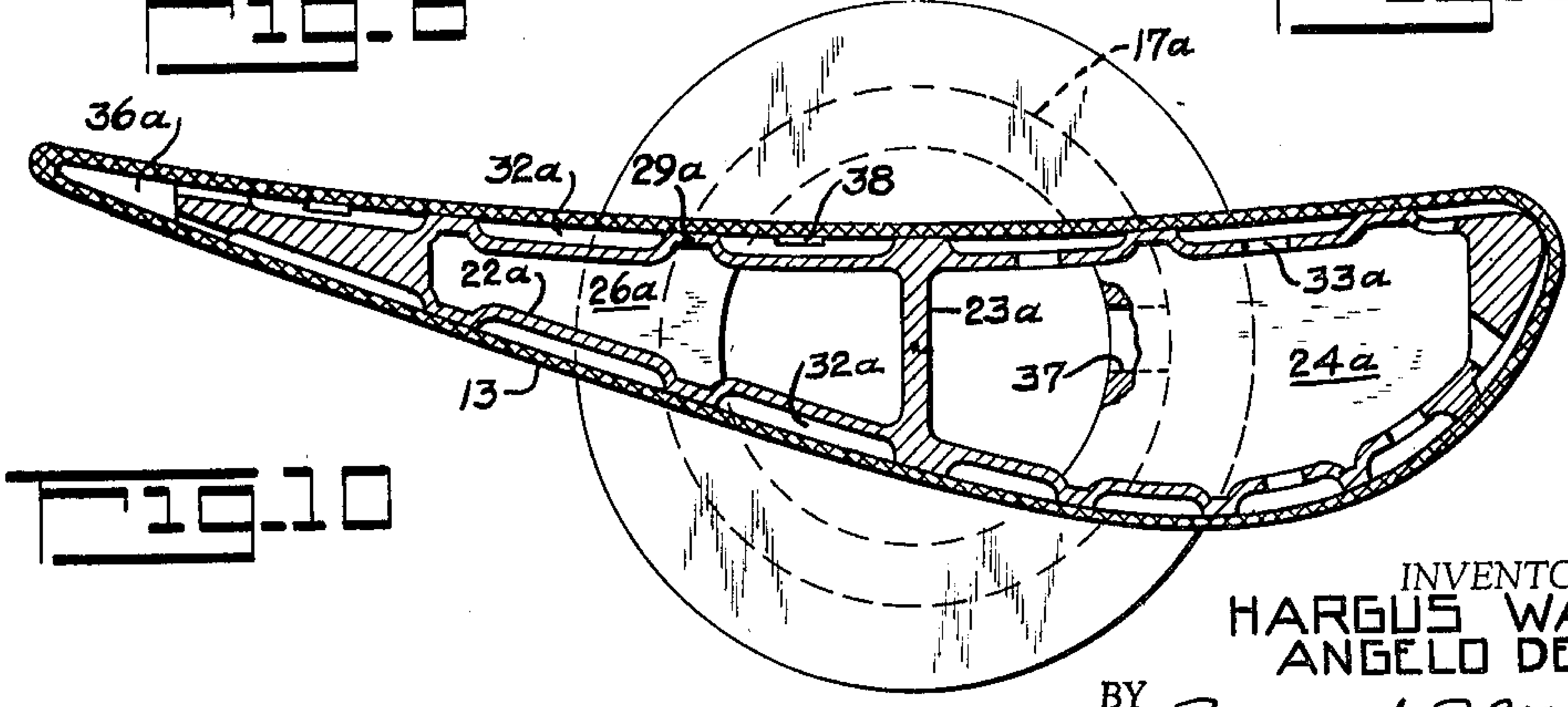

FIG. 10

INVENTORS
HARGUS WATTS
ANGELO DE FEO
BY Raymond P. Wallace
AGENT

United States Patent Office

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3,240,468

TRANSPIRATION COOLED BLADES FOR TURBINES, COMPRESSORS, AND THE LIKE

Hargus Watts, Hawthorne, and Angelo De Feo, Totowa Boro, N.J., assignors to Curtiss-Wright Corporation, a corporation of Delaware

Filed Dec. 28, 1964, Ser. No. 421,512
8 Claims. (Cl. 253—39.15)

This invention relates to hollow blades for turbines, compressors, and the like, and particularly to rotor and stator blades having a porous skin for transpiration cooling, with provision for channeling more or less coolant to various portions of the blade in relation to gas temperatures, pressures, and velocities prevailing in localized regions.

An object of the invention is the provision of a novel hollow transpiration cooled blade such that high cooling efficiency of the blade is produced with reduction of thermal stresses and gradients over the surface of the blade, with consequent longer life at higher operating temperatures.

Another object is the provision of a blade having a hollow strut member covered by a permeable sheath, the hollow strut receiving coolant and distributing it in varying amounts to different portions of the sheath.

A further object of this invention is the provision of a blade having a porous skin mounted on a hollow strut, the strut having external lands projecting therefrom dividing the skin into discrete sections, with provision for feeding coolant to each section in proportion to local requirements.

Other objects and advantages will become apparent upon reading the following detailed description in connection with the annexed drawings, in which

FIG. 1 is a graph of a typical distribution of gas temperatures along the span of a turbine blade;

FIG. 2 is a graphic representation of a typical variation of gas pressure around a portion of a turbine blade;

FIG. 3 is a perspective view, partly broken away, of a stator blade according to the invention;

FIG. 4 is an elevation, partly broken away, of a rotor blade according to the invention;

FIG. 5 is an elevation of the concave side of a hollow blade strut;

FIG. 6 is an elevation, partly broken away, of the convex side of a transpiration cooled blade;

FIG. 7 is a cross-section on an enlarged scale taken along line 7—7 of FIG. 6;

FIG. 8 is an elevation, partly in cross-section, of the convex side of another embodiment of stator blade;

FIG. 9 is an elevation, with the skin in cross-section, of the concave side of the blade of FIG. 8; and

FIG. 10 is a cross-section taken on line **10—10** of FIG. 8.

It has been found that there is a considerable variation in both temperature and gas pressure across a turbine passage or a compressor passage, that is, between the radially inner or root ends of the blades and the radially outer or tip ends. In a general way, the temperature of the combustion gases driving a turbine wheel will be highest around the center of the turbine passage, in the region of the center of the distance between the root ends and the tip ends of the turbine blades. The temperature toward the root is somewhat lower than at the center, and the temperature at the tip is again lower than that at the root. The difference between the lowest temperature encountered in the passage and the highest may be very considerable. If the blades are uncooled they must be made of a material which will withstand the highest operating temperature encountered for long periods of time without structural damage. Since available ma-

terials for blade manufacture are limited, such a requirement limits the temperature at which the machine can be operated, with consequent limitation of the power output.

Cooled blades are known in the prior art. Some have been provided with internal passages for circulation of a coolant therethrough; however, the efficiency of such blades is restricted by the difficulty of providing sufficient flow, the impossibility of providing passages in thin sections such as the trailing edge, and the complexity of the apparatus required to handle the coolant.

Transpiration cooled blades are also known, wherein the blade has a permeable skin through which coolant may be bled from a hollow interior, discharging into the gas stream through the skin. In blades of the prior art cooled either by internal passages or by transpiration, although the average temperature of the blade may be considerably reduced, temperature gradients still exist along the span and across the chord and between the concave side and the convex side. Such blades can operate in an environment of higher average temperature than uncooled blades, but their operating life is limited by the stresses set up by the temperature gradients, which stresses eventually cause failure of the blade.

The present invention provides a transpiration cooled blade in which the total available coolant may be distributed unequally to various portions of the blade in accordance with local cooling requirements, with larger flows going to areas encountering higher temperatures or pressures, whereby the temperature of the blade during operation may be substantially equalized throughout, minimizing stresses and maintaining the whole blade at a safe operating temperature.

FIG. 1 shows a typical temperature distribution profile along the span of a turbine blade from the hub or root end to the tip. The lowest temperature encountered during operation is shown at the blade tip at the left side of the graph; the temperature rises rapidly from the tip to the middle section of the blade, then drops off somewhat toward the root, but with the root temperature still considerably higher than that at the tip. It is to be understood that FIG. 1 is illustrative only of a typical condition and specific parameters are not given, since they vary with the design of the engine and blades, the number of stages in the turbine, and the conditions of operation. However, blades of the present invention have operated successfully where the average combustion gas temperature in the turbine passage was approximately 3000° F. Also, though the temperature difference from the coolest region to the hottest of the span is shown typically in the illustration as being of the order of 600° F., such difference will vary with the factors mentioned above, and may on occasion be as much as 800° F.

Although not here illustrated, it is further to be understood that combustion gas pressure and velocity of gas flow vary along the blade span and across the chord, so that it may be necessary to provide more cooling flow in a region of high gas pressure or high velocity even though the gas temperature in such a region may not be greater than in a region of lower pressure or velocity. Blades of this invention may be designed to provide for such conditions.

In FIG. 2 there is shown a graphic representation of a typical variation of external gas pressure around a turbine blade in the region around the midsection, approximately halfway between the root and the tip. A cross-section of a blade B is shown schematically, surrounded by a curve P in dotted line, the varying distance of the curve P from the surface of the blade representing the variation in pounds per unit area of the external gas pressure surrounding the blade. Similar cross-sections taken at the root and at the tip would differ somewhat from the cross-section at the middle portion, as well as from each other. Again, FIG. 2 is to be understood as illustrative only of pressure variations which may occur, specific parameters depending on such factors as mentioned above in connection with temperature.

FIG. 3 shows an angularly adjustable stator blade **11** constructed according to the invention. Such a blade comprises a suitably formed hollow strut **12** (better shown in FIG. 5) covered by a sheathing **13** of porous material defining an airfoil shape or other shape suitable to the intended use of the blade. The strut is provided with a closure member **14** at each end which may be integral with the body of the strut or assembled to it by any convenient means. The blade is provided with a trunnion at each end for adjustable mounting; in the embodiment of FIG. 3 the top trunnion **16** is closed, whereas the lower trunnion **17** has passage means therethrough communicating with the hollow interior of the strut for introduction of coolant thereinto. The flow of the coolant through the blade structure will be more particularly described hereinafter.

The permeable sheathing **13** may be formed of powdered metal or ceramic pressed to the desired shape and dimensions and sintered, as is known in the art. However, particularly suitable materials are metal fabrics, composed of fine filaments compressed and sintered together. Such metal fabrics are known in the prior art, and in one form may comprise a plurality of layers of woven mesh, assembled in laminar form and rolled or otherwise compressed to the desired thickness and porosity, and sintered or brazed together. Another satisfactory porous metal fabric may be obtained by winding a plurality of layers of a continuous filament on a mandrel, rolling, and sintering.

In FIG. 4 there is shown a blade **18** constructed similarly to that of FIG. 3, but intended as a rotor blade. The strut is provided with a suitable means of attachment to a turbine or compressor rotor, such as the conventional fir-tree root **19** shown, the root having a passage **21** therethrough communicating with the hollow interior of the strut, which has a closure **14*a*** at the other end. The strut is covered by a sheath of porous material **13*a*** as in the previous embodiment.

A typical strut member **12** for a stator blade constructed according to the invention is shown in FIG. 5. A similar strut is used for rotor blades, with appropriate mounting means. The strut may be formed of metal, cermet, or ceramic as its intended use may require, but is preferably formed of an alloy suited to high temperature environments when it is contemplated for use in turbine blades, such alloys being well known for this purpose. When compressor blades are intended, the strut may be formed of a much lighter material, such as an aluminum or magnesium base alloy; although compressors do not attain the temperatures of turbines, it may still be desirable to cool the blades when they are formed of material having less heat resistance.

The strut **12** comprises a hollow shell with a transverse cross-section (shown in FIG. 7) of generally airfoil outline having walls **22**; the interior of the shell may be divided longitudinally by one or more septa **23** into separate chambers. A single septum **23** is shown, dividing the strut interior into a leading edge chamber portion **24** and a trailing edge chamber portion **26**. In the embodiment of FIG. 5 the septum **23** is shown extending into the hollow open-ended trunnion **17** and dividing the passage therethrough into a portion **27** communicating with inner chamber portion **24**, and a portion **28** communicating with chamber portion **26**, whereby cooling fluid may be supplied at different pressures to the leading chamber portion and the trailing chamber portion. In the embodiment of FIG. 4 the generally central septum **23** is shown positioned somewhat closer to the trailing edge and extending only to the internal orifice of passage **21** through root **19**, whereby the major portion of a coolant flow through the passage will enter the leading edge chamber **24**. It will be obvious that the septum may be positioned to direct the flow to either chamber portion in any desired proportion, and that with either embodiment there may be more than one such internal septum dividing the interior of the strut into a plurality of chamber portions, and further that such a septum may be disposed chordwise of the strut to provide separate chambers for the concave side and the convex side thereof.

The wall **22** of the strut has a plurality of generally longitudinal ribs or lands **29** and a plurality of generally transverse ribs or lands **31** projecting externally therefrom in a generally waffle-like pattern defining a plurality of recesses **32** in the surface of the strut. Ribs **29** and **31** may be straight and the recesses defined thereby rectangular, or other shapes may be employed. The external faces of the ribs are flat for attachment thereto of the porous sheathing **13**, which is brazed or welded along the ribs. The closures **14** or **14*a*** at the ends of the strut have a flange portion projecting the thickness of the sheathing used, so that the porous material may be also welded or brazed to the strut at the ends with a fair surface.

Recesses **32** are provided with apertures **33** and **34** through wall **22** to the hollow interior of the strut. Such a construction produces a blade jacketed with a permeable sheathing and having a plurality of discrete recesses disposed behind the sheathing, to which recesses cooling fluid may be distributed through the hollow blade in amounts required by the local conditions prevailing at a plurality of small areas of the surface of the blade. The amount of coolant reaching any given recess may be governed by the amount of coolant flow directed to various inner chamber portions, and/or by the size of the aperture communicating with the internal supply, and the recesses may be of various sizes in various portions of the blade, according as it may be necessary to differentiate the surface more precisely. In FIGS. 5 and 6 apertures **34** communicating with the recesses in the center portion of the blade span are shown larger than apertures **33** to the end recesses, since the center portion of the span is usually the hottest and requires more cooling. However, control may also be achieved by having a larger number of small recesses in hot portions, with the apertures the same size throughout, or a combination of both means may be used. Further, the apertures need not be round bores as shown, but may have any other convenient shape, such as slits. It is preferable to stagger the positioning of apertures across the chord of the blade, to prevent the stress concentration which would arise from having them in line.

At the trailing edge of the blade, where the strut becomes very thin in cross-section in order to bring the sheathing out to a relatively thin edge for smooth aerodynamic flow, it may not be possible to extend the inner strut chamber entirely out to the trailing edge. For this reason, as shown in FIGS. 5 and 6, the generally longitudinal ribs **29** may be forwardly curved at certain portions in order to provide at such portions apertures angled forwardly to establish communication between the inner chamber and the trailing edge recesses. The trailing edge of the strut may have one or more tapered projections **36** extending therefrom to which the trailing edge of the skin may be attached for stiffening and support, or the trailing edge of the strut may extend solidly along the span and be tapered to a relatively sharp edge.

The recesses **32** need not be generally rectangular as shown, but the ribs or lands may be so disposed as to define recesses of any other desired shape, such as round, hexagonal, or other convenient outline. Struts **12** may be fabricated by one of the various casting processes, or by machining, or by forging in parts which are subsequently welded together, or by any combination of such processes.

FIGS. 6 and 7 exemplify an embodiment in which more cooling is desired on the convex surface of the blade than on the concave, especially toward the leading edge. Hence, there are more longitudinal ribs **29** on the covex side defining more recesses, and toward the leading edge the longitudinal ribs are positioned closer together than toward the trailing edge, making a larger number of recesses in the convex side of the leading edge portion. A similar effect can be achieved by appropriate positioning of transverse ribs **31**.

The coolant for transpiration cooled turbine blades, whether stator or rotor blades, may be any suitable fluid, and in some cases it is fuel which bleeds through the blade sheathing and is burned in the turbine passage or downstream therefrom. More commonly the coolant is air which is bled from the compressor supply before it enters the combustion chamber. The copending application of Angelo De Feo and Ferdinand P. Sollinger for a Gas Turbine Engine, Serial No. 290,718, filed June 26, 1963 and assigned to the same assignee as the present application, shows an engine in which a portion of the compressor supply is bled off and fed to transpiration cooled stator and rotor blades in the turbine, with provision for adjusting the supply of cooling air to the stator blades whereby the leading edges may receive more air than the trailing edges.

When blades of the present invention are used in an engine such as that disclosed in application Serial No. 290,718, cooling air bled from the compressor enters the interior of the blade strut, either through the trnnnion **17** in the case of a stator blade or through the root **19** in the case of a rotor blade, and is distributed by the structure described above to the various recesses in amounts according to local needs, in accordance with the temperature, pressure, and gas velocity conditions prevailing at each portion of the blade. The air then passes through the permeable blade sheath and maintains it at substantially the same temperature throughout, thus avoiding the thermal stresses which would be set up in the blade if it were subject to the same temperature profile as that of the turbine passage, as indicated in FIG. 1. The cooling air passing through the skin of the blade forms a boundary layer around the blade, so that the hot combustion gases do not impinge directly on the skin. Although such a boundary layer is continually being eroded away by the combustion gases, it is also continually being replenished from the interior of the blade, so that an equilibrium is reached and turbine blades of this invention may be operated at higher ambient temperatures than has heretofore been possible.

In FIGS. 8–10 there is shown another embodiment of a stator blade **35**, having a different arrangement for distribution of the transpiration cooling medium. A hollow strut **12*a*** is provided, having a closed trunnion **16*a*** at the radially outermost end, an apertured trunnion **17*a*** for admission of cooling fluid at the radially inner end, and covered with a porous skin **13**. The interior of the strut shell is divided by a septum **23*a*** into a leading edge chamber portion **24*a*** and a trailing edge chamber portion **26*a***, as before, except that in this embodiment the septum does not extend entirely to the open bottom end of trunnion **17*a***, but near the bottom end the septum is extended horizontally forwardly (toward the leading edge of the blade) and joins the trunnion wall, blocking the forward half of the internal diameter of the trunnion. An aperture **37** is provided in the forward portion of the trunnion wall communicating with leading chamber portion **24*a***.

The strut is provided on its exterior surface with a plurality of projecting generally longitudinal ribs or lands **29*a*** and a plurality of generally transverse ribs **31*a***, defining a plurality of recesses **32*a*** in the surface of the strut. As in the previous embodiment, the lands may be curved as required to communicate with a desired inner chamber portion, and although the recesses **32*a*** are shown generally rectangular other shapes may be employed. Apertures **33*a*** and **34*a*** are provided at suitable locations through wall **22*a*** to the hollow interior of the strut. The trailing edge of the strut has tapered projections **36*a*** for stiffening and support of the porous sheath **13*a***, which elsewhere is attached to the lands **29*a*** and **31*a***.

In the embodiment of blade **35** it is not desired to feed the landing edge of the blade with coolant only from leading chamber portion **24*a*** and the trailing edge with coolant only from trailing chamber portion **26*a***. Instead, it is intended to feed some recesses which are closer to the chamber portion having the higher pressure coolant with coolant from the lower pressure chamber portion, and vice versa. For this reason, the ribs and recesses are curved as shown, the coolant paths being denoted by the arrows in FIGS. 8 and 9. For instance, in FIG. 8 which shows the convex side of the blade, the high pressure coolant, which may be air from the compressor, enters the trunnion **17*a*** through aperture **37** and supplies forward chamber portion **24*a***, and the lower pressure coolant enters the trunnion through aperture **28*a*** and supplies trailing chamber portion **26*a***. Nevertheless, as shown at the top of the figure, some of the recesses in the leading half of the blade are curved to communicate with chamber portion **26*a*** in the trailing half of the blade. Similar arrangements may be seen in FIG. 9, showing the concave side.

Some recesses which do not require high coolant flow have no aperture directly to the interior of the strut, but instead are fed from adjacent recesses, for which purpose there are provided slots **38** across either the longitudinal or the transverse ribs, providing communication between adjacent recesses otherwise separated by the ribs. Such slots result in a pronounced pressure drop in the coolant supplied to the ultimate recess, since the coolant is also bleeding through the skin of the first recess supplied. In some casese it may be desired to supply a plurality of recesses directly from a single aperture through wall **22*a***, as shown in FIG. 9, in which case larger apertures **39** are provided, having several times the area of other apertures, and communicating directly with a plurality of recesses.

In some normally cooler portions of the blade it may be unnecessary to have any transpiration cooling at all, and the porosity of the skin may be blocked or diminished in those portions. This is exemplified in FIG. 8, where a portion of the skin is shown masked at **41**. Such masking may be accomplished by making that portion of the skin of solid material, or by spraying with metal powder or other infiltrant which fills the pores. The strut under the masked portion may be apertured and the lands suitably contoured to lead a supply of coolant to recesses in unmasked portions.

The present blades may also be used as compressor blades when a lightweight material is desired which may be deleteriously affected by the compressor temperatures, which may be of the order of 800°–1000° F. For compressor use the coolant may be derived from a refrigerated fluid or other suitable source of coolant, which may be fuel.

Although the invention has been described above in a preferred embodiment, various alterations and modifications may be made by those skilled in the art without departing from the concept of the invention. It is intended to cover all such modifications in the appended claims.

What is claimed is:

1. A transpiration cooled blade for turbines, compressors, and the like, comprising in combination a hollow strut member having a peripheral wall of generally airfoil outline defining an inner chamber, said strut member being closed at one end and having coolant supply passage means at the other end communicating with said inner chamber for supplying coolant thereto, said strut member having a plurality of generally longitudinal lands on the outer surface of said peripheral wall extending between said ends and a plurality of generally transverse lands on said outer surface extending between said longitudinal lands, said generally longitudinal and generally transverse lands defining a plurality of generally rectangular discrete recesses in said surface in a generally honeycomb pattern, said peripheral wall having a plurality of passage means therethrough communicating between said inner chamber and at least some of said recesses for transmitting coolant from said chamber to said recesses, some of said peripheral wall passage means being of larger cross-section than others for transmitting more coolant, each of said peripheral wall passage means opening into a single discrete recess, and a peripherally continuous porous sheathing covering said recessed surface and attached to said lands.

2. A transpiration cooled blade as in claim 1, wherein said strut member has an imperforate internal septum extending from the end having coolant supply passage means to the closed end dividing said inner chamber into a leading edge portion and a trailing edge portion.

3. A transpiration cooled blade as in claim 1, wherein said recesses are of different sizes in various portions of said blade.

4. A transpiration cooled blade as in claim 1, wherein the concave side of said blade has a different number of recesses from the convex side.

5. A transpiration cooled blade as in claim 4, wherein the convex side of said blade has a larger number of recesses than the concave side.

6. A transpiration cooled blade as in claim 1, wherein the leading portion of said blade has a different number of recesses from the trailing portion.

7. A transpiration cooled blade as in claim 6, wherein said leading portion has a larger number of said recesses than the trailing portion.

8. A transpiration cooled blade for turbines, compressors, and the like, comprising in combination a hollow strut member having a peripheral wall of generally airfoil outline defining an inner chamber, said strut member being closed at one end and having coolant supply passage means at the other end communicating with said inner chamber for supplying coolant thereto, said strut member having an imperforate internal septum extending from one end of the other and dividing said inner chamber into a leading edge chamber portion and a trailing edge chamber portion and dividing said supply passage into a first passage portion communicating with said leading chamber portion and a second passage portion communicating with said trailing chamber portion for supplying coolant at different pressures to said chamber portions, said strut member having a plurality of generally longitudinal lands on the outer surface of said peripheral wall extending between said ends and a plurality of generally transverse lands on said outer surface extending between said longitudinal lands, said generally longitudinal and generally transverse lands defining a plurality of discrete recesses of various sizes in said surface in a generally honeycomb pattern, there being a larger number of said recesses in the leading portion of said strut member than in the trailing portion, said peripheral wall having a first plurality of apertures therethrough communicating between said leading chamber portion and at least some of said recesses and having a second plurality of apertures therethrough communicating between said trailing chamber portion and at least some other of said recesses, each of said apertures opening into a single discrete recess for transmitting coolant from the respective chamber portions to communicating recesses, some of said apertures being of larger cross-section than others for transmitting more coolant, and a porous sheath formed of metal mesh material covering said recessed surface and attached to said lands, whereby the amount of coolant transpiring through various portions of said sheath is governed by said differential pressures and by the positioning of said recesses and by the size of said apertures.

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SAMUEL LEVINE, *Primary Examiner.*

JULIUS E. WEST, *Examiner.*