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Meginnis [45] **Oct. 17, 1972**

[54] TRANSPIRATION COOLING

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[73] Assignee: **General Motors Corporation**, Detroit, Mich.

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[52] **U.S. Cl.** **416/96,** 416/231
[51] **Int. Cl.** **F01d 5/18**
[58] **Field of Search**............416/90, 96, 97, 229, 231

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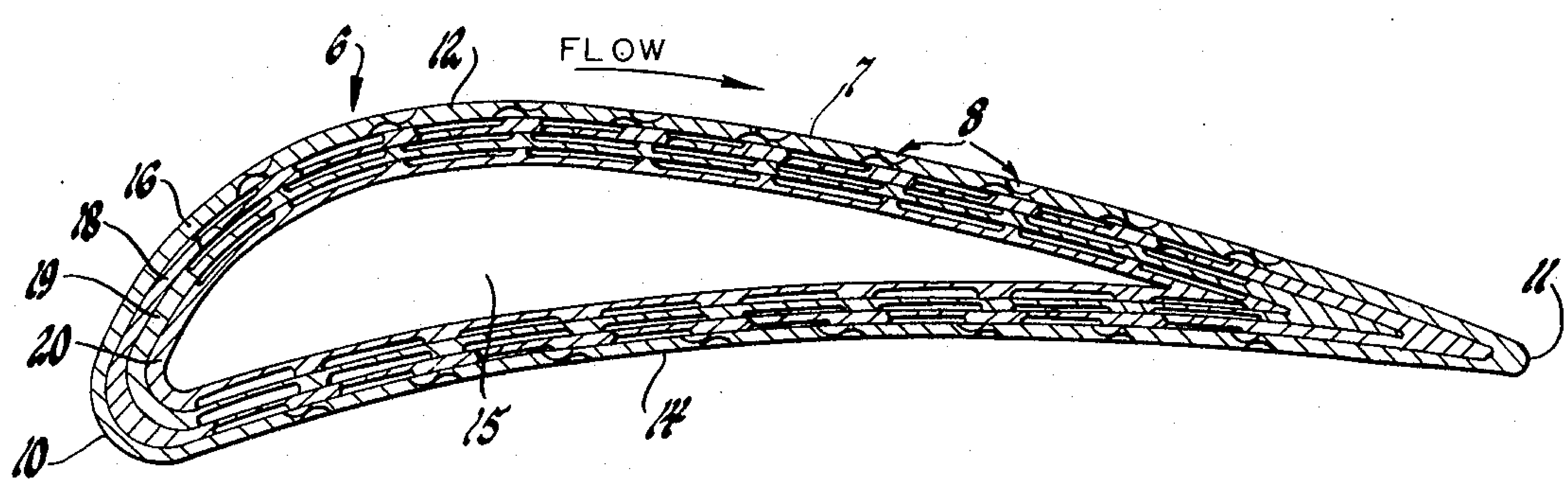
[57] **ABSTRACT**

An airfoil such as a vane or blade intended to be cooled by transpiration of air from the interior to the exterior of the blade has an outer layer in which pores for the cooling air are defined by pits extending in from the outer and inner faces of the layer and intersecting at the bottoms of the pits, the pits being offset to provide a hole from which flow tends to proceed at an acute angle to the face. To decrease the angle between the discharge of gas and the surface of the airfoil, a control sheet underlying the outer layer has holes to supply air to the pits in the inner surface of the outer layer which are offset with respect to the pits. In one form the outer layer is composed of two laminations each having holes entirely through the laminations which are then bonded together with the holes offset to provide the general type of structure defined by the offset intersecting pits in a single sheet or lamination.

11 Claims, 6 Drawing Figures



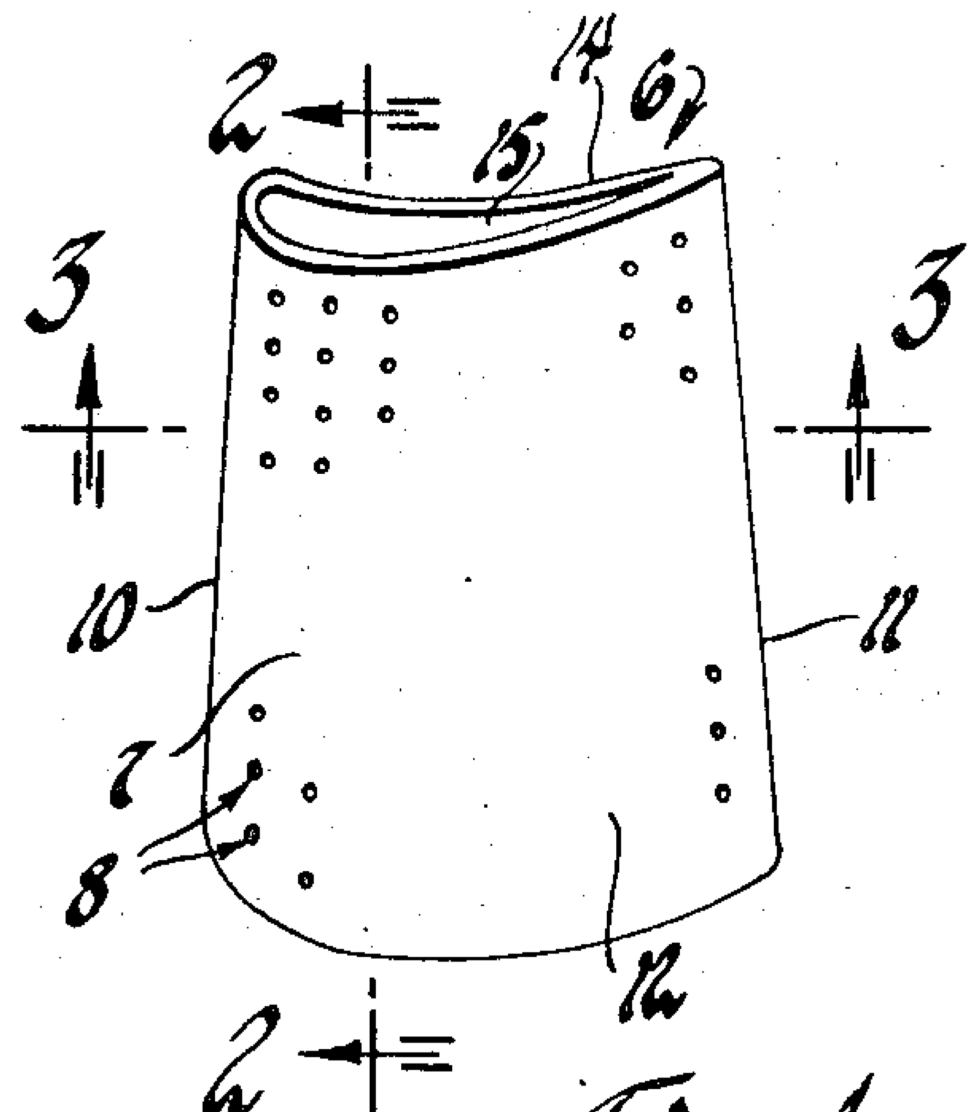


Fig. 1

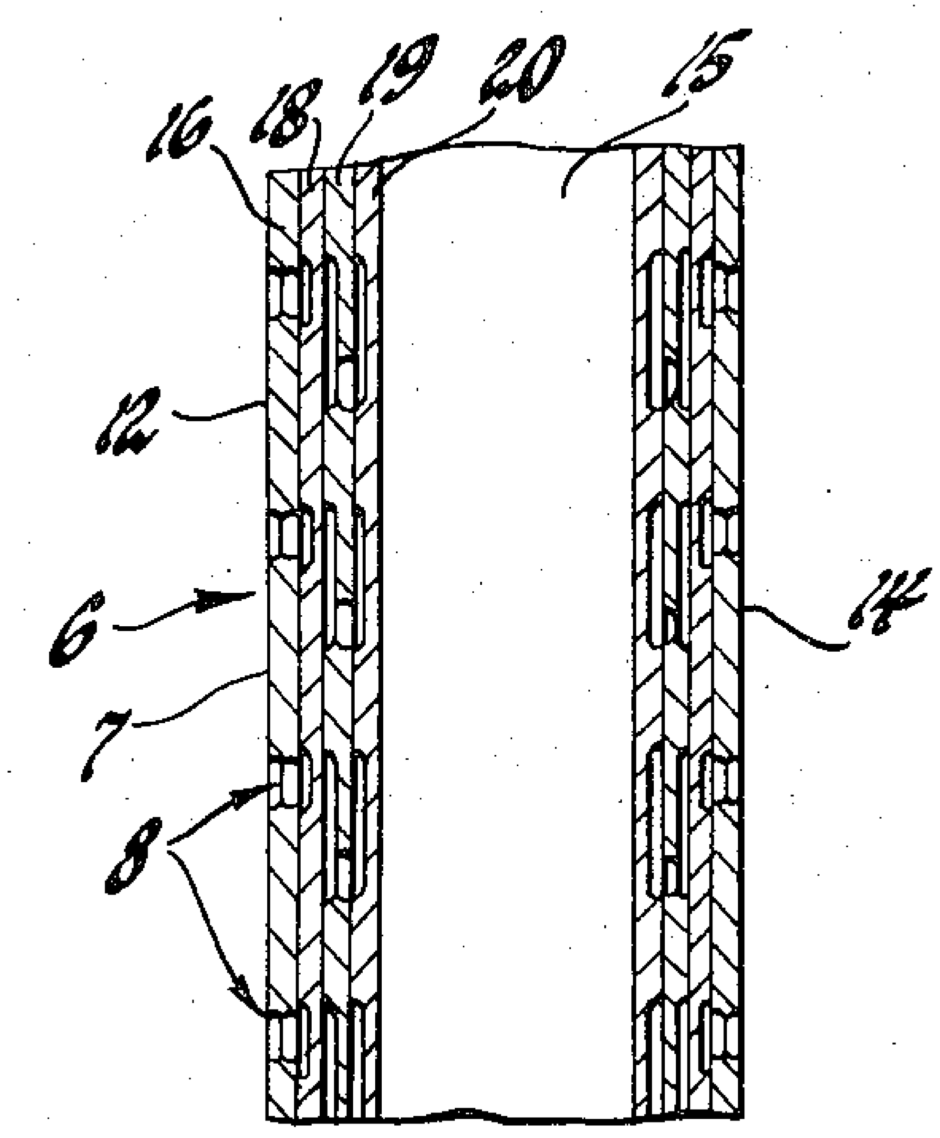


Fig. 2

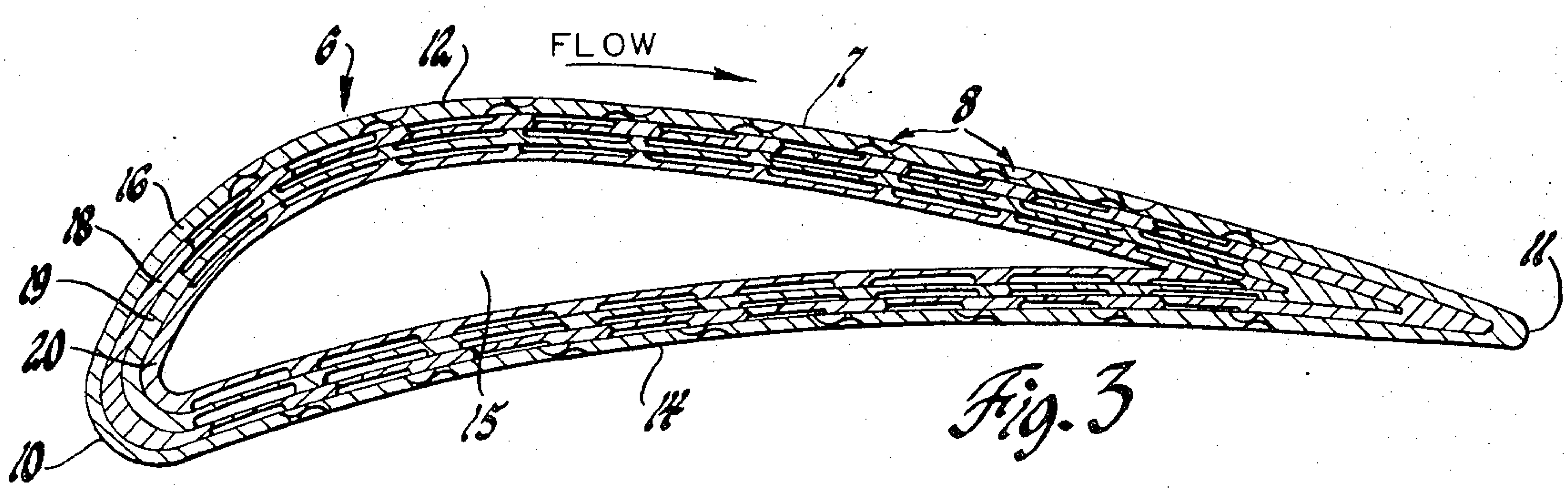


Fig. 3

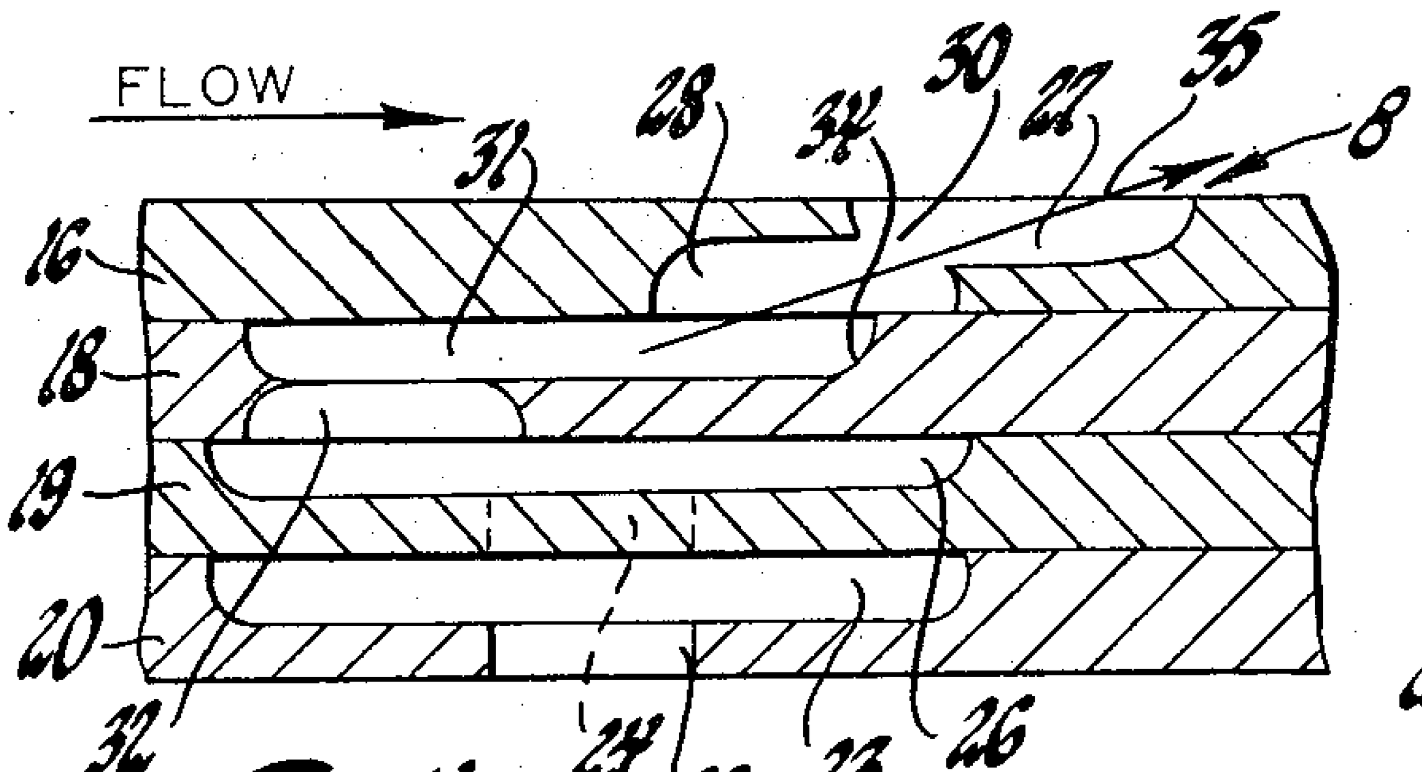


Fig. 4

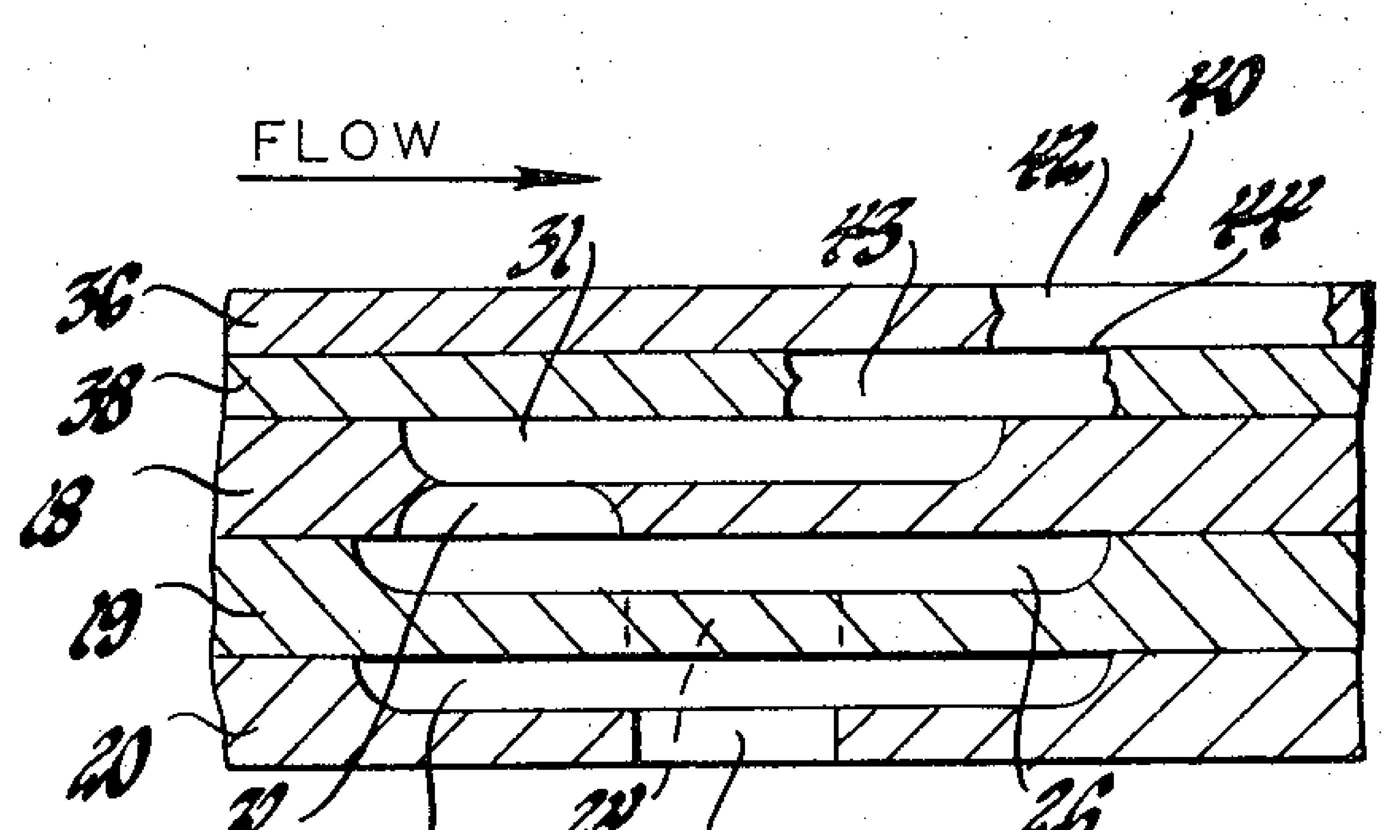


Fig. 5

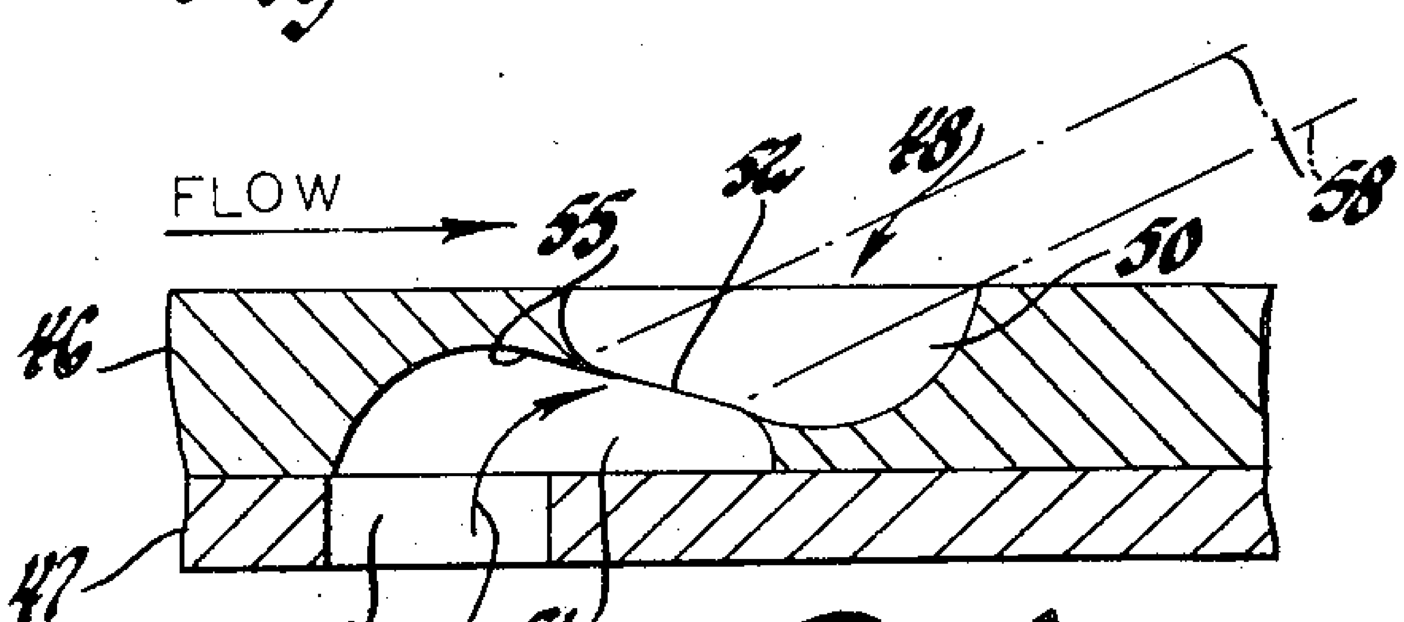


Fig. 6

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TRANSPIRATION COOLING

The invention herein described was made in the course of work under a contract or subcontract thereunder with the Department of Defense.

DESCRIPTION

My invention relates to improvements in turbine vanes and blades and other such devices which are protected from high temperature gas by discharge of a cooling gas through numerous pores distributed over the surface of the vane or the like. This mode of cooling is referred to as transpiration cooling.

My invention is particularly adapted to transpiration cooled vanes and blades of the general sort described in prior patent applications, of common ownership with this application, as follows: Bratkovich and Meginnis, Ser. No. 526,207 for Laminated Porous Metal, filed Feb. 9, 1966 U.S. Pat. No. 3,584,972; Emmerson, Ser. No. 691,834 for Turbine Cooling, filed Dec. 19, 1967; Helms, Ser. No. 707,556 for Turbine Blade, filed Feb. 23, 1968; and Meginnis, Ser. No. 742,900 for Turbine Blade, filed July 5, 1968 U.S. Pat. No. 3,619,082.

These applications describe turbine vanes or blades having laminated walls, the outermost layer of which has pores which are machined in the surface of the layer by a process such as photoetching to provide numerous outlets for cooling air or other gas from the interior of the vanes or blades. Vanes, blades, or other structures to be protected from hot gas by transpiration cooling will be referred to hereafter in this specification as "vanes" for conciseness.

It has been found that the discharge of the cooling air from the surface of the vane has some adverse effect upon the efficiency of the turbine or other aerodynamic machine. This appears to be due to some interference between the cooling air coming out substantially perpendicularly from the vane surface and the motive fluid or other gas flowing substantially tangentially to the surface.

I have conceived a modification of the configuration of the passages from which the cooling air is discharged adjacent the outer surface of the vane such that this interference may be substantially reduced and the efficiency of the turbomachinery correspondingly enhanced.

In the preferred embodiments of my invention, this is accomplished by offsetting the pores in the vane facing or outer layer and the adjacent layer or layers so that the gas discharged from the pores is directed largely downstream with respect to the motive fluid flow past the vane.

The principal objects of my invention are to improve the efficiency and temperature tolerance of high temperature turbomachinery; to improve the efficiency of transpiration cooled vanes, blades, and other elements of engines; and to provide a simple and effective means for discharging transpiration cooling air from a vane in a direction largely conforming to the flow past the vane rather than directly transverse to such flow.

The nature of my invention and its advantages will be clear to those skilled in the art from the succeeding detailed description of preferred embodiments of the invention and the accompanying drawings thereof.

FIG. 1 is an axonometric view of a hollow laminated porous airfoil.

FIG. 2 is a partial sectional view of the same taken on the plane indicated by the line 2—2 in FIG. 1.

FIG. 3 is a transverse sectional view of the same taken on the plane indicated by the line 3—3 in FIG. 1.

FIG. 4 is a greatly enlarged fragmentary sectional view illustrating one form of the invention.

FIG. 5 is a similar view illustrating a second form of the invention.

FIG. 6 is a similar view illustrating a third form of the invention.

Referring first to FIG. 1, this illustrates a hollow tubular member 6 which may be a turbine vane airfoil or the airfoil portion of a turbine blade or might represent some other structure in a high temperature machine such as a turbine. The airfoil 6 has a formed outer wall 7 perforated by numerous small closely spaced pores 8. This structure as so far described may be similar to those described in the above-mentioned patent applications. Referring also to FIGS. 2 and 3, the vane airfoil illustrated has a leading edge at 10, a trailing edge at 11, a convex face 12, and a concave face 14, although, of course, the structure might have other configurations than the specific one described. The vane defines an interior chamber 15 to which air for cooling may be supplied by any suitable structure.

As illustrated in FIGS. 2, 3, and 4, the vane wall is defined by four layers or laminae, these being respectively, from the outside of the blade to the inside, an outside or discharge layer 16, a control layer 18, a layer 19, and an innermost layer 20. The thickness of these layers may be considered as exaggerated for clarity, depending upon the overall size of the airfoil. Generally as described in the above-mentioned patent applications, each of these layers is formed with holes through the layers and with elevations on the surface which serve to provide spaces between the layers for conduction of the cooling gas, all the layers being bonded together so that a structure of overall controlled porosity is provided with a multiplicity of paths for flow of the cooling air from the interior of the vane to the large number of distributed pores 8 on the surface.

The general nature of such a structure may be apprehended from consideration of FIG. 4 in which the cooling air may flow through a hole 22 in layer 20 into a space 23 from which it flows through a hole 24 offset from hole 22 into a space 26 between layers 19 and 18 from which it flows through pores which have been developed in accordance with the present invention in layers 18 and 16, flowing out at the outlet 8 as indicated in FIGS. 3 and 4. So far as the present invention is concerned, sheets or layers 19 and 20 serve only as means to support the outer layers 16 and 18 and to distribute the cooling air to them and, so far as the present invention is concerned, their presence is nonessential.

Referring now to FIG. 4 for a detailed description of one embodiment of the invention, it will be understood that the gas flow past the air foil is in the direction indicated by the legend FLOW and arrow in FIGS. 4, 5, and 6. In order to give a sense of scale to the discussion of the succeeding figures, it may be mentioned that the sheets 16, 18, 19 and 20 in FIG. 4, in the preferred embodiment of the invention, are about 0.010 inch thick are diffusion bonded together to provide a blade wall having a thickness of about 0.040 inch. The surface relief and the holes through the layers are provided by a chemical machining process such as photoetching in the preferred mode of manufacture of the blade wall.

For each pore **8** the layer **16** has etched into its exterior surface a pit **27** and into its interior surface a pit **28**, these each extending slightly more than half way through the thickness of the sheet and intersecting to define a passage **30** for the cooling air to flow to the exterior of the vane. In the form illustrated in FIG. **4**, the overlap between the two pores is something like one-third of their total width providing a more or less elliptical passage **30** about 0.006 to 0.008 of an inch in minor diameter. Air is supplied to each pit **28** from a feed hole or groove **31** in the outer surface of layer **18** which in turn is supplied by a hole **32** extending from the inner surface of this layer in register with a part of the space **26**. Hole **32** connects to the feed hole **31** at a point substantially offset from pit **28**. It will also be noted that the feed hole **31** terminates at **34** so that, in general the portion of pit **28** which underlies the passage **30** is cut off from the direct supply of air; or, to put it otherwise, the discharge from the hole **31** into pit **28** is offset from the center of pit **28** in the same direction that pit **28** is offset from pit **27**. This fact tends to increase the angle of discharge of the cooling air with respect to the direction normal to the surface. Also, since the cooling air must flow substantially parallel to the inner surface of layer **16** to reach the point of discharge into pit **28**, it arrives at this point with a velocity substantially parallel to the surface of the sheet and is then deflected slightly outwardly, generally as indicated by the arrow **35** in FIG. **4**. It will be understood that the mode of supply of air to each of the pores **8** may be the same. It has been found that the arrangement illustrated in FIG. **4** results in a lower angle between the direction of flow of the gas and the surface of the sheet than a construction in which the direction of flow is determined primarily by the configuration of the offset pits in sheet **16** only. Also, it has been found easier to control accurately the magnitude and general configuration of the pores **8** where the passage such as **30** is determined primarily by an intersection between the bottoms of the pits rather than by an intersection between the side walls of pits as in a copending application of Thomas H. Mayeda Ser. No. 879,094 for Cooled Airfoil filed Nov. 24, 1969.

FIG. **5** illustrates a modification of the structure of FIG. **4**, the basic difference being that the outside or discharge layer corresponding to layer **16** in FIG. **4** is, in the structure of FIG. **5**, a layer made up of two laminae **36** and **38** bonded together in proper registry and bonded to the layer **18**. In this case, the pores **40** corresponding to pores **8** of FIG. **4** are defined by a first pore section **42** in the lamina **36** and a second pore section **43** in the lamina **38**, these being offset so that the overall effect is a pore inclined to the direction normal to the surface of the airfoil, the discharge passage **44** being defined by the area of overlap between these two pore sections. As illustrated, the pores are etched in from both faces of the laminae, but this is not necessary.

The arrangement for supplying cooling air to the pore section **43** through holes **32** and feed hole **31** remains as previously described. The point of the structure of FIG. **5** as compared to that of FIG. **4** is that it is easier to control the pores and particularly control precise overlap between them if the pores are made in two similar sheets which are then bonded together with the proper shift in registry of these pores to provide a structure as illustrated in FIG. **5**. The area of the passage **44** is not as sensitive to minor variations in the speed or duration of the etching operation as the passage **30** in FIG. **4**.

FIG. **6** illustrates a somewhat different approach to the provision of the air discharge pores and feed holes. In this form, there is a discharge layer **46** defining the exterior surface of the cooled body and a control layer **47**. There may, if desired, be additional layers such as layers **19** and **20** illustrated in the other figures. The pore **48** through layer **46** comprises an outer pit **50** and an inner pit **51**, these, as illustrated, being offset by an amount about one-half of the width of the pits so that the overlap is about half the diameter of each pit. As before, the pits extend slightly more than half way through the layer **46** which may be, for example, 0.010 inch thick and their intersection defines passage **52** corresponding to passages **30** and **44** previously described. In the structure of FIG. **6**, there is a difference in the arrangement of the feed hole which is indicated at **54**. As previously, the feed hole is offset so as in general to be beyond or principally beyond the periphery of the pit **50**. However, it does not have the extension parallel to the surface of the sheet but is simply a small hole going directly through the layer **47**. In this form of the structure, the impingement of the cooling air against the bottom surface **55** of the pit **51** is depended upon to divert the air to a direction roughly parallel to the surface of the layer **46** as indicated by the arrow **56**. The result is a discharge of the air generally in the path indicated by the two parallel lines **58**.

It has been found by experiment that very low discharge angles of the cooling air with respect to the outer surface of the airfoil may be obtained with the structure described herein. Angles as low as 10° are quite feasible. This improves the adherence of the transpiration cooling air to the outer surface of the airfoil and minimizes any interference with the flow of the exterior of hot gas over the surface of the airfoil.

The detailed description of the preferred embodiment of the invention for the purpose of explaining the principles thereof is not to be considered as limiting or restricting the invention, as many modifications may be made by the exercise of skill in the art.

I claim:

1. A wall structure adapted to have a gas flow over the exterior surface of the wall in a particular direction and having a porous wall for transpiration cooling of the structure by a cooling gas discharged from the inner side of the wall through pores in the wall to the exterior thereof characterized by an outside layer having an array of pores extending through the said layer; each pore being defined by two intersecting pits extending into the exterior and interior faces of the layer, respectively, each pit only partially overlapping the other, the pit extending into the interior face being offset upstream, with reference to the direction of flow over the surface, with respect to the pit extending into the exterior face, the opening defined by the intersection between the said pits being substantially entirely in the bottom of each pit and having an axis directed at an angle of less than 30° to the normal to the faces of the layer.

2. A wall structure adapted to have a gas flow over the exterior surface of the wall in a particular direction and having a porous wall for transpiration cooling of the structure by a cooling gas discharged from the inner side of the wall through pores in the wall to the exterior thereof characterized by an outside layer having an array of pores extending through the said layer; the outside layer comprising two laminae abutting and bonded together, an outer and an inner lamina; each pore being defined by two intersecting pits extending through the outer and inner laminae, respectively, each pit only partially overlapping the other, the pit extending through the inner lamina being offset upstream, with reference to the direction of flow over the surface, with respect to the pit extending through the outer lamina, the opening defined by the intersection between the said pits being in the bottom of each pit and having an axis directed substantially normal to the faces of the layer.

3. A hollow airfoil adapted to have a gas flow over the exterior surface of the airfoil in a particular direction and having a porous wall for transpiration cooling of the airfoil by a cooling gas discharged from the interior of the wall through pores in the wall to the exterior thereof characterized by an outside layer having an array of pores extending through the said layer; each pore being defined by two intersecting pits extending into the exterior and interior faces of the layer, respectively, each pit only partially overlapping the other, the pit extending into the interior face being offset upstream, with reference to the direction of flow over the surface, with respect to the pit extending into the exterior face, the opening defined by the intersection between the said pits being substantially entirely in the bottom of each pit and having an axis directed at an angle of less than 30° to the normal to the faces of the layer.

4. A hollow airfoil adapted to have a gas flow over the exterior surface of the airfoil in a particular direction and having a porous wall for transpiration cooling of the airfoil by a cooling gas discharged from the interior of the wall through pores in the wall to the exterior thereof characterized by an outside layer having an array of pores extending through the said layer; each pore being defined by two intersecting pits extending into the exterior and interior faces of the layer, respectively, each pit only partially overlapping the other, the pit extending into the interior face being offset upstream, with reference to the direction of flow over the surface, with respect to the pit extending into the exterior face, the opening defined by the intersection between the said pits being in the bottom of each pit and having an axis directed substantially normal to the faces of the layer; the said outside layer comprising an outer lamina and an inner lamina, the said pits being within the respective laminae and overlapping at the interface between the laminae.

5. A structure adapted to have a gas flow over the exterior surface of the structure in a particular direction and having a porous exterior portion for transpiration cooling of the structure by a cooling gas discharged from the inner side of the structure through pores in the structure to the exterior thereof characterized by an array of pores extending through the exterior portion configured to direct the gas at an acute angle to the surface of the structure in a direction downstream relative to flow over the surface in normal operation, the said exterior portion comprising a discharge layer defining the exterior surface of the structure and a control layer immediately adjacent to and bonded to the discharge layer, the discharge layer having pores defined by intersecting pits extending into the layer from the opposite faces of the layer, each pit only partially overlapping the other, mutually offset in the direction of the said gas flow with the pit in the outer face downstream, and having an intersection at the bottoms of the pits, and the control layer defining a feed hole for each pore offset from the said intersection feeding into the pit in the adjacent face of the discharge layer so as to direct the flow into the pore toward the said intersection.

6. A structure as recited in claim 5 in which the discharge layer comprises an outer lamina defining the pits extending from the exterior face and an inner lamina defining the pits extending from the interior face of the layer.

7. A structure adapted to have a gas flow over the exterior surface of the structure in a particular direction and having a porous exterior portion for transpiration cooling of the structure by a cooling gas discharged from the inner side of the structure through pores in the structure to the exterior thereof characterized by an array of pores extending through the exterior portion configured to direct the gas at an acute angle to the surface of the structure in a direction downstream relative to flow over the surface in normal operation, the said exterior portion comprising a discharge layer defining the exterior surface of the structure and a control layer immediately adjacent to and bonded to the discharge layer, the discharge layer having pores defined by intersecting pits extending into the layer from the opposite faces of the layer, each pit only partially overlapping the other, mutually offset in the direction of the said gas flow with the pit in the outer face downstream, and having an intersection at the bottoms of the pits, and the control layer defining a feed hole for each pore offset from the said intersection feeding into the pit in the adjacent face of the discharge layer so as to direct the flow into the pore toward the said intersection, the feed hole being directed normal to the surface of the control layer so as to direct the cooling gas against the bottom of the pit in the inner face of the discharge layer for deflection by the surface bounding the pit in a direction toward the said intersection.

8. A structure adapted to have a gas flow over the exterior surface of the structure in a particular direction and having a porous exterior portion for transpiration cooling of the structure by a cooling gas discharged from the inner side of the structure through pores in the structure to the exterior thereof characterized by an array of pores extending through the exterior portion configured to direct the gas at an acute angle to the surface of the structure in a direction downstream relative to flow over the surface in normal operation, the said exterior portion comprising a discharge layer defining the exterior surface of the structure and a control layer immediately adjacent to and bonded to the discharge layer, the discharge layer having pores defined by intersecting pits extending into the layer from the opposite faces of the layer, each pit only partially overlapping the other, mutually offset in the direction of the said

gas flow with the pit in the outer face downstream, and having an intersection at the bottoms of the pits, and the control layer defining a feed hole for each pore offset from the said intersection feeding into the pit in the adjacent face of the discharge layer so as to direct the flow into the pore toward the said intersection, the feed hole being defined by a passage extending parallel to the surface of the said layers having a supply entrance to the said passage offset from the pit in the inner face of the discharge layer so as to direct the cooling gas into the said pore generally parallel to the surface of the said layers.

9. A structure as defined in claim **8** in which the discharge layer is a single lamina.

10. A structure as recited in claim **8** in which the discharge layer comprises two laminae bonded together.

11. A hollow airfoil adapted to have a gas flow over the exterior surface of the airfoil in a particular direction and having a porous exterior position for transpiration cooling of the airfoil by a cooling gas discharged from the interior of the airfoil through pores in the airfoil to the exterior thereof characterized by an array of pores extending through the exterior portion configured to direct the gas at an acute angle to the surface of the airfoil in a direction downstream relative to flow over the surface in normal operation, the exterior portion comprising a discharge layer defining the exterior surface of the airfoil and a control layer immediately adjacent to and bonded to the discharge layer, the discharge layer having pores defined by intersecting pits extending into the layer from the opposite faces of the layer, each pit only partially overlapping the other, mutually offset in the direction of the said gas flow with the pit in the outer face downstream, and having an intersection at the bottoms of the pits, and the control layer defining a feed hole for each pore offset from the said intersection feeding into the pit in the adjacent face of the discharge layer so as to direct the flow into the pore toward the said intersection.

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