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Auxier

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[54] **TURBINE BLADE WITH INCREASED FILM COOLING**

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[52] **U.S. Cl.** **416/97**

[51] **Int. Cl.** **B63h 1/14**

[58] **Field of Search** 416/90, 97, 233, 95, 231

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[57] **ABSTRACT**

An air-cooled turbine blade having a plurality of serially spaced cavities therein is provided with cooling air inlets at its base. One of the inlets directs a cooling flow into a cavity proximate the trailing edge of the blade for cooling the blade surfaces defining this cavity. From this cavity, the flow is directed in serpentine fashion into a second cavity remote from the trailing edge for cooling the surfaces defining this latter cavity. The cooling flow is then directed in a film from the second cavity onto the outer surface of the blade for cooling the latter.

7 Claims, 5 Drawing Figures

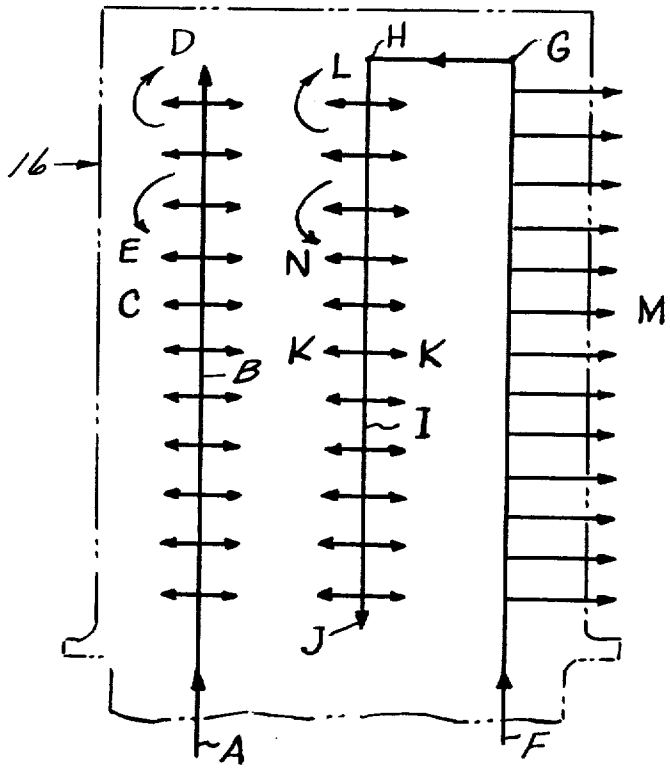


Fig 1

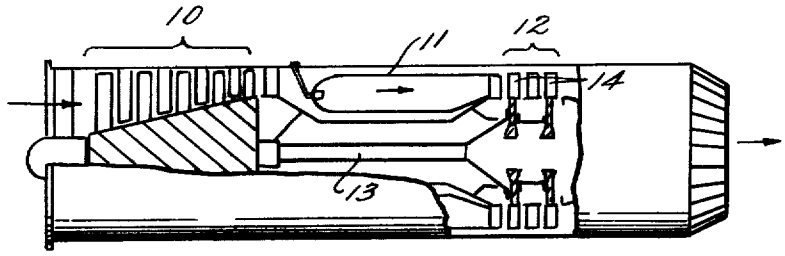


Fig 2

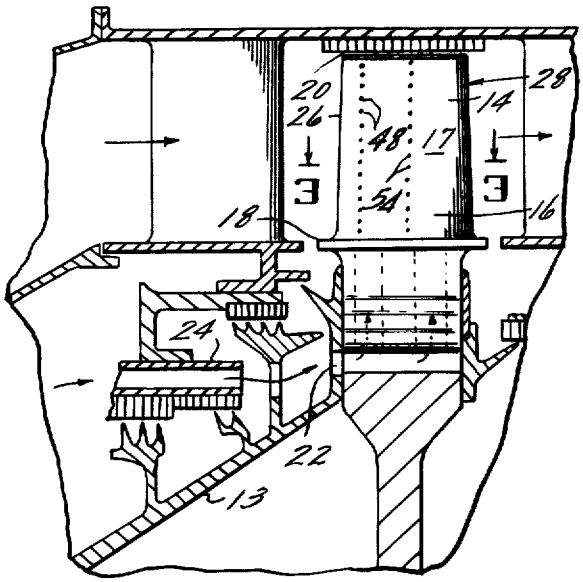


Fig 4

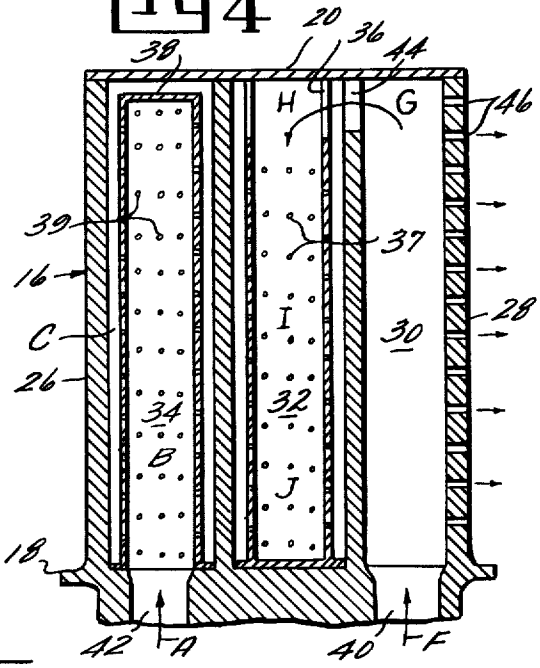


Fig 3

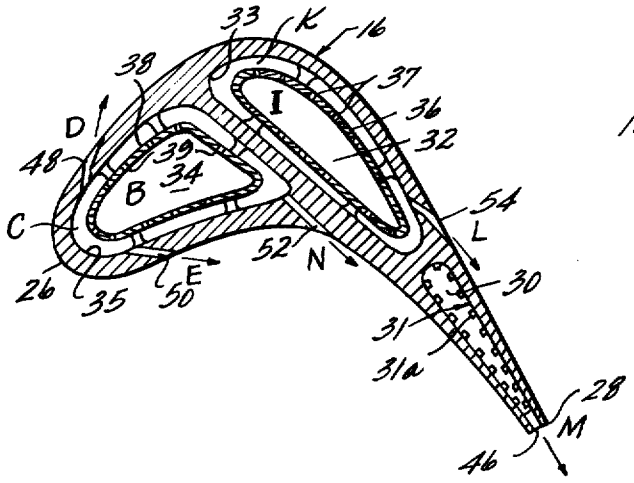
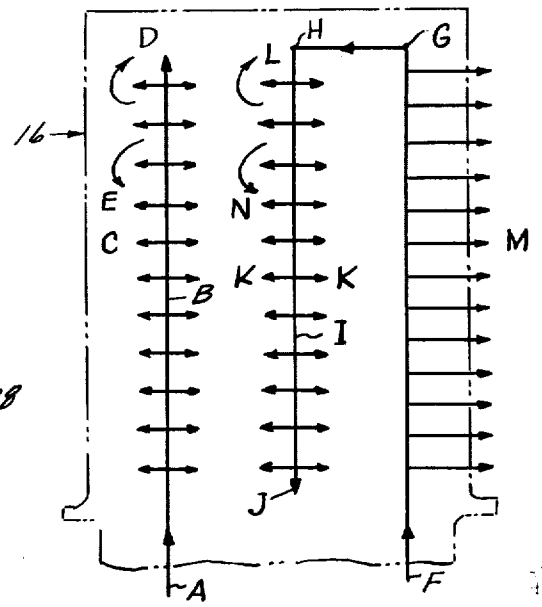


Fig 5



TURBINE BLADE WITH INCREASED FILM COOLING

The invention herein described was made in the course of or under a contract, or a subcontract thereunder, with the United States Department of the Air Force.

BACKGROUND OF THE INVENTION

This invention relates to blades for use in turbomachinery and, more particularly, to air-cooled blades of the aforesaid variety.

In turbomachinery, a flow of pressurized working fluid is directed onto a plurality of turbine blades mounted upon rotatable discs for imparting momentum thereto, whereby the kinetic energy of the fluid flow may be transformed into torque. In a number of applications of turbomachine concepts, and particularly with respect to turbojet engines, the working fluid flow is heated to extremely high temperatures, and travels at extremely high velocities. As a result, it has become requisite to discover ways in which to maintain the performance and reliability of turbine blades subjected to such a working environment.

Improvements in metal alloys provided early solutions to the contemporaneous problems of mechanical strength and heat resistance of turbine blades. However, increased demands for performance and ever larger power outputs have mandated blade design variations in addition to improvements in material compositions. Objectives of the design variations have been to provide means for passing cooling fluids to or through portions of the blades subjected to particular heating while reinforcing the structure of turbine blades in the areas of particular mechanical stress.

Members of one variety of blades resulting from the application of these criteria have included a plurality of radially extending cavities serially spaced between the leading and trailing edges of the blades. The cavities perform the function of directing a flow of cooling fluid through the interior of the turbine blades in order to cool respective portions thereof. Cross ribs extending between adjacent cavities serve to increase the strength of the blades in the directions of stress to which the blades are subjected. In blades of this variety, it has been the conventional practice to provide cooling air inlets to the cavities which open through the base or tip of each blade to passages in the disc upon which the blades are mounted or to a plenum surrounding the disc. The cooling flow is passed from these inlets through the cavities and eventually is dumped out of the cavities through exits into the environment thereof for expulsion with the working fluid.

In modern, high-powered turbomachinery, overall operating efficiency suffers when turbine blades are cooled by the inefficient application of large amounts of cooling air to the individual blades, since the work required to provide cooling air negates a similar amount of output available from the engine. Consequently, blades using minimum quantities of cooling fluid are desirable. Thus, it has become increasingly important to make full cooling use of the cooling fluid passed through each blade.

Variation of the flow path of the cooling fluid through the blades has been suggested, whereby an increased portion of the available cooling power of the fluid is utilized. A common approach has been to direct

a given cooling flow in a serpentine path serially through a number of adjacent cavities prior to the expulsion thereof. It has been further suggested in the prior art to pass a flow of cooling fluid in this serpentine fashion from the trailing edge cavity to one or more serially adjacent cavities before expelling the cooling fluid from apertures near the blade base, tip end and/or trailing edge. While the serpentine path of the fluid increases the utilization of available cooling power, the dumping of the used fluid from the tip, base end or trailing edge of the blade fails to comprehend further use to which the cooling fluid might be put, namely utilization of the fluid's film cooling potential. This potential has in the past been utilized with respect to cooling flow introduced into leading edge cavities. But the film cooling potential remaining in trailing edge cooling flow upon completion of its serpentine flow path has not been appreciated.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide an air-cooled turbine blade having a plurality of internal cavities therein with means for further utilizing the cooling potential of a flow of cooling air subsequent to the utilization of this air for the cooling of the blade surfaces defining the internal cavities.

It is a further object of the present invention to accomplish this increased use of cooling potential by directing the flow of cooling air from an internal cavity onto the outer blade surface in a cooling film.

It is a more particular object of the present invention to perform the directing of the cooling air as a film onto the outer blade surface after completion by the air of a serpentine flow path through serially adjacent internal cavities originating with the trailing edge cavity.

The present invention seeks to more fully utilize the cooling power of the quantity of cooling fluid supplied to turbine blade trailing edge cavities by expelling particular portions of that fluid (which otherwise would be dumped into the gas stream) in a film onto the outer surface of the blade. In order to accomplish this, the present invention provides a number of exit apertures communicating the outer blade surface to the interior of a particular blade cavity. This cavity is the one which the cooling flow reaches upon completion of a predetermined flow path through the blade. The apertures are arranged in a manner appropriate to the formation of a cooling film upon the blade's outer surface. The resulting fluid film serves to convectively remove heat from this surface as well as to form a barrier against direct impingement upon the blade by the hot working fluid. As a result, the external blade surface temperature remains lower, so that less cooling air need be provided. Consequently, the overall efficiency of the engine is enhanced.

Further objects of the present invention will become apparent from the detailed description of a preferred embodiment contained hereinafter as illustrated by the following figures wherein:

FIG. 1 is a section view of a typical turbojet engine showing the essential elements thereof;

FIG. 2 is a partial section view of the turbojet engine of FIG. 1 showing the turbine arrangement in greater detail;

FIG. 3 is a section view of the blade of FIG. 2 taken along lines 3—3;

FIG. 4 is a half-section view of the turbine blade of the present invention; and

FIG. 5 is a schematic diagram of the flowpath of cooling air within the turbine blade of FIG. 2.

DESCRIPTION OF A PREFERRED EMBODIMENT

The following description amplifies the particular embodiment of the present invention depicted in the accompanying drawings. One skilled in the art might easily recognize numerous changes which may be made in the structure of this embodiment without departing from the spirit of the present invention.

The turbojet engine depicted in FIG. 1 comprises the basic elements of typical machinery of this variety. A substantially cylindrical housing surrounds a compressor **10**, combustors **11**, and a turbine **12**, all disposed about rotatable shaft **13**. As is well known in the art, atmospheric air enters the machine from the left to be pressurized, heated and expelled to the right to provide usable thrust. More particularly, air enters from the left and is operated upon by the compressor **10** (in combination with the shape of the lead end of shaft **13**) to be pressurized and directed, in part, into combustors **11**. Heat energy is added to the air within the combustors by the burning of appropriate fuel supplied thereto. Working fluid, which is a combination of air and burned fuel, exits at the right end of the combustors and impinges the plurality of turbine blades **14** carried by a number of adjacent discs making up the turbine **12**. The impingement of the turbine blades **14** by the working fluid serves to drive the turbine in rotation, which rotation is imparted to shaft **13**. The rotation of shaft **13** is the motivating force for the operation of the compressor **10** at the forward end of the machine.

Turbine blades **14** must be extremely strong and heat resistant in order to withstand the force and heat of the impinging working fluid. The cooling system of the present invention, by which the blades **14** are protected from overheating, is depicted in FIGS. **2** through **5** and operates by making use of a portion of the air operated upon by compressor **10** but not directed into the combustors **11**.

FIG. **2** shows a typical turbine blade **14** and its cooperation with shaft **13** and elements of the cooling system which are elucidated hereinafter. Blade **14** includes a blade shell **16** in the shape of an airfoil, and a platform **18** adapted to cooperate with disc **19** by which the plurality of blades are supported. Blade shell **16** has an outer surface **17** and a plurality of inner cavities which will also be discussed hereinafter. At the blade tip (the blade end opposite platform **18**) is a closure **20** which separates the blade inner cavities from environmental atmosphere, and which may be integral with the blade shell **16** or a separate piece affixed thereto. The blade shell **16** further has a leading edge **26** and a trailing edge **28**.

In the embodiment of the invention disclosed in FIG. **2**, an aperture **22** in shaft **13** permits the passage therethrough of cooling air from a cooling air expander **24** cooperating with an appropriate plenum (not shown) for the delivery of cooling air to the blade. It is recognized that the present invention is equally applicable to blades which are designed to be cooled by the application of air provided through inlets located near the tip of the blade rather than near the platform or by internal turbine circuits that do not use a cooling air expander. The present embodiment is to serve only as an example and not be considered the only embodiment of the present invention.

The cross-sectional views of blade **14** depicted in FIGS. **3** and **4**, taken together with the schematic flow path of FIG. **5**, disclose the blade structure which directs the application of the cooling air fed to the blade platform **18** as described above. FIGS. **3** and **4** show that the turbine blade of the present embodiment of the invention incorporates first, second and third cavities labeled **30**, **32** and **34**, respectively, which are disposed serially adjacent to one another between leading edge **26** and trailing edge **28** of the blade shell **16**. The cavities are defined within the shell by inner shell surfaces **31**, **33** and **35**, respectively. The three cavities are of shape and size determined to be appropriate for the optimization of cooling efficiency and mechanical blade strength. Cavity **30** is disposed proximate trailing edge **28** of the blade, while cavity **32** is disposed remote from the trailing edge **28**. Cavity **34** is disposed proximate the leading edge of the blade.

Inserts **36** and **38** are disposed respectively within cavities **32** and **34**, and respectively bear pluralities of orifices **37** and **39** for the distribution of cooling air in an impinging flow against the inner surfaces of each respective cavity. The inner surfaces **31** of cavity **30** are provided with a plurality of protrusions **31a** appropriately positioned to enhance the turbulence of flow for minimum pressure drop. As defined by the state of the art, the impinging flow associated with cavities **32** and **34** and the turbulent flow associated with cavity **30** are superior in cooling characteristics to the flows which would occur within the cavities absent the provisions described.

The blade **14** of the present embodiment is provided with two inlets **40** and **42** for the entry of cooling fluid from passage **22** (see FIG. **2**). It is noted that the two inlets **40** and **42** service cavities **30** and **34**, respectively. Means for passing cooling fluid to cavity **32** includes a passage **44** between cavities **32** and **30** disposed in proximity to the tip of blade **14** and remote from inlet **40**. The two cavities **30** and **32** and passage **44** define a serpentine path for the cooling fluid entering inlet **40**.

The definition of appropriate exits for the cooling fluid, which exits combine with the foregoing blade structure to maximize the utilization of the cooling fluid, accomplishes the objects of the present invention. As in the prior art, a minor portion of the cooling fluid which has been introduced through trailing edge inlet **40** is exhausted through a plurality of exit apertures **46** provided at the trailing edge **28** of the blade shell **16**. As is also prevalent in the prior art, a portion of the air entering leading edge cavity **34** through inlet **42** is exhausted through three groups of exit apertures **48**, **50** and **52** positioned and adapted to direct the exiting fluid in a film across various portions of the outer surface of the blade shell **16**.

Film cooling has been found to be useful to increase the use to which cooling air may be put, whose cooling potential has not been exhausted during application to the inner surfaces of the blade shell. If, after passing from the inlet **42** and through orifices **39** in insert **38** and against surfaces **35**, the air within cavity **34** remains at a temperature lower than that existing in the working fluid near the outer surfaces of the blade shell **16**, the passing of this air out of cavity **34** in a film across such outer surfaces would serve to cool them

and thus to make further use of the cooling flow. It is precisely to this film-cooling concept that the present invention is directed.

While the prior art has comprehended the use of exit film cooling to maximize the utilization of the cooling power of air fed into leading edge cavities, it has been common practice with respect to cooling flow fed into trailing edge cavities to dump the flow out of exit apertures at the tip, base or trailing edge of the blade after an internal serpentine path has been completed. Wherever the working fluid near the outer surfaces of the blade to which this latter flow might be directed is at a temperature higher than the exiting cooling flow, this practice constitutes a waste of cooling power.

The present invention thus provides a plurality of spaced exit apertures **54** through which the cooling fluid may be directed onto the outer surface of blade shell **16** downstream of apertures **54.** Apertures **54** are located substantially along a radial line between the ends of blade shell **16** and are configured appropriately for the formation of a cooling film upon the outer blade surface. The film thus formed serves as a barrier to protect the blade from the direct impingement of the hot working fluid. Further, the film serves to remove heat from the blade surface by convective heat flow. This added usage of the cooling power of the cooling fluid allows the turbine blade to be cooled to the same extent as previously, but with the expenditure of less cooling fluid. As described above, beneficial effects upon the overall efficiency of the turbomachine are thus achieved.

The operation of the cooling system of the present invention will now be described with the aid of the alphabetical designations of locations depicted in FIGS. **3** and **4** and represented schematically in FIG. **5.** Cooling air from the plenum is passed through air passage **22** of FIG. **2** to the platform **18** of blade **14** and into inlets **40** and **42** of FIG. **4.** That portion of the flow entering inlet **42** passes from point A below cavity **34** to point B within cavity **34** and into contact with insert **38.** The air is passed through orifices **39** and into the area represented by point C, which is defined by the insert **38** and inner surfaces **35** of the blade shell. The impingement of this air against surfaces **35** serves to cool these surfaces before the air is exhausted through exit apertures **48** and **50** to points D and E, respectively. The working fluid flowing past points D and E impinges the exiting cooling fluid and, due to the viscous forces therebetween, creates films to the downstream sides of each point which films serve to cool the external surfaces of the blade shell **16** until the films are separated therefrom by turbulence.

The second portion of cooling air flowing into the blade (through inlet **40**) passes from point F below the blade shell to point G proximate the blade tip closure **20.** Since the flow enters the blade at the trailing edge at its coolest temperature, a minimum portion of this fluid is forced out of cavity **30** through trailing edge exit apertures **46.** The predominant portion of the fluid passes through passage **44** from point G to point H within cavity **32.** This flow continues past point I within cavity **32** and to point J. While within cavity **30,** the cooling fluid acts in turbulent flow to cool surfaces **31.** Having passed into cavity **32,** the fluid is directed by orifices **37** of insert **36** into the area represented by point K and into impingement with surfaces **33** for the cooling thereof. Having progressed to this point and having been raised in temperature by contact with surfaces **31** and **33** of the blade shell, the cooling fluid remains at a temperature below the external surface temperature of the blade shell. Thus, the fluid still possesses usable cooling power. Accordingly, there are provided apertures **54** through which the fluid is subsequently passed to point L outside of the blade shell. The viscous forces of the passing working fluid act upon the exiting cooling fluid to create a cooling film downstream of exit orifices **54** upon the outer surface of the blade shell proximate trailing edge **28.** This film forms a barrier between the outer blade surface and the working fluid. The film also cools the blade surface by convective heat transfer. Consequently, the film serves to further cool the blade by increasing heat transfer to the cooling fluid after its exit from the blade.

In this way, the present invention increases the utilization of the cooling power of a given quantity of cooling fluid by maximizing the contact with various turbine blade shell surfaces of that portion of the cooling fluid fed into trailing edge cavities. Were the fluid entering inlet **40** to be dumped into the passing working fluid from either the tip or base ends of the blade shell, no film would be created upon the outer surface of the blade by this fluid, and the remaining cooling power thereof would be wasted. By the application of the present invention to turbine blades, reductions in the amount of cooling fluid required to be fed to the rear or trailing edge blade cavities may be effected, with attendant increases in machine efficiency.

While the present invention has been described in conjunction with a preferred embodiment thereof, it is apparent that numerous variations in the application thereof may be made without departing from the spirit of the invention. For example, a turbine blade having a plurality of cavities in a number of larger than the three disclosed might be devised wherein cooling air fed to one of the cavities proximate the trailing edge is passed in a serpentine path through serially adjacent cavities and finally exhausted in a cooling film upon external blade surfaces. Another variation, which was discussed briefly above, might involve the application of cooling fluid through inlets located near the tip rather than the platform of the blade shell. Additionally, while the embodiment herein disclosed passes a cooling film over only one side of the outer surface of the blade shell, a plurality of apertures could easily be applied which would serve to communicate the other side of the shell to a trailing edge cavity for the passing of cooling fluid thereacross.

Other modifications of the described embodiment of the invention will occur to those skilled in the art within the scope of the present inventive concept without departing from the spirit thereof.

What is claimed as new and desired to be secured by Letters Patent of the United States is:

1. In a turbomachine, an air-cooled blade comprising:

a blade shell having an outer surface, first, second and third inner surfaces, and a leading edge and a trailing edge;

a first cavity in said shell proximate said trailing edge and formed by said first inner surface of said shell;

a second cavity in said shell remote from said trailing edge and formed by said second inner surface of said shell;

a third cavity in said shell proximate said leading edge and formed by said third inner surface of said shell;

means for introducing cooling air into said first cavity for cooling said first inner surface;

means for introducing cooling air into said third cavity for cooling said third inner surface;

a plurality of passageways formed through said trailing edge and communicating with said first cavity for efflux of a first portion of said first cavity cooling air therefrom;

means for directing the remainder of said first cavity cooling air from said first cavity into said second cavity for cooling said second inner surface; and

means for directing all of said cooling air delivered to said second cavity in a film from said second cavity onto said outer surface for cooling said outer surface.

2. The blade of claim **1** further comprising first and second blade ends and a pair of ribs located internally of said shell and extending between said first and second blade ends, wherein said means for introducing cooling air into said first cavity is disposed proximate said first blade end, and said means for directing said cooling air into said second cavity comprises an opening in one of said ribs disposed proximate said second blade end.

3. The blade of claim **1** further comprising a radially outward tip end and a radially inward platform wherein said means for directing said cooling air onto said outer surface comprises a plurality of spaced apertures providing communication between said second cavity and said outer surface, disposed between said tip end and said platform and substantially aligned along a radial line along said blade shell.

4. The blade of claim **3** further including a hollow impingement insert positioned within said second cavity, and said cooling air directing means directs said remainder of said cooling air initially to the interior of said insert.

5. The blade of claim **4** further including a second hollow impingement insert positioned within said third cavity.

6. An air-cooled blade for use in a turbomachine, said blade comprising:

a blade shell in the shape of an airfoil having a leading edge and a trailing edge and further having an outer surface and first, second and third inner surfaces and first and second ends;

a blade platform proximate the first end of said shell;

first, second and third serially spaced cavities defined respectively by said first, second and third inner surfaces of said shell and disposed respectively proximate said trailing edge, remote from said trailing edge, and proximate said leading edge;

a blade closure proximate the second end of said shell for separating said cavities from an environmental atmosphere;

means for introducing a first flow of cooling air through said platform into said first cavity for cooling said first inner surface;

a plurality of passageways formed through said trailing edge and communicating with said first cavity for efflux of a first portion of said first cavity cooling air therefrom,

means proximate said closure for directing the remainder of said first flow from said first cavity into said second cavity for cooling said second inner surface;

means for directing all of said first flow delivered to said second cavity in a film from said second cavity onto said outer surface for cooling said outer surface;

means for introducing a second flow of cooling air through said platform into said third cavity for cooling said third inner surface; and

means for directing said second flow in a film from said third cavity onto said outer surface for further cooling said outer surface.

7. The blade of claim **6** wherein said means for directing said first flow onto said outer surface comprises a plurality of spaced apertures substantially aligned along a radial line between said first and second ends of said blade shell.

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