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Pearson et al.

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[54] **ROTOR BLADES FOR FLUID FLOW MACHINES**

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[30] **Foreign Application Priority Data**

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[52] **U.S. Cl.** **416/92**; 416/192; 416/193

[51] **Int. Cl.** **F01d 5/18**

[58] **Field of Search** 416/190, 191, 193, 221, 416/92, 97, 192; 415/172

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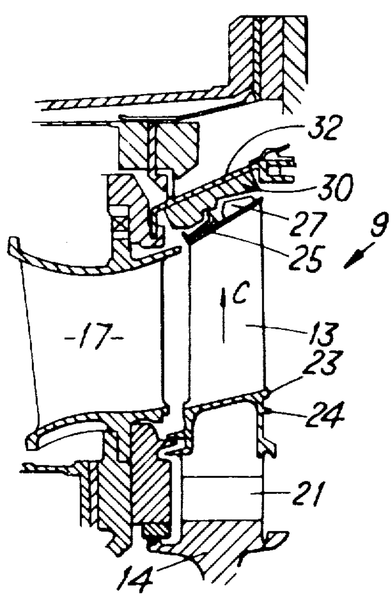
Attorney, Agent, or Firm—Cushman, Darby & Cushman

[57] **ABSTRACT**

This invention has the object of improving the efficiency of fluid flow machines generally, and particularly the specific fuel consumption of gas turbine engines. The invention comprises a fluid-flow deflector member for a rotor blade, which projects outwardly from the radially outer end of the blade into the region of leakage fluid flow in the clearance between the machine casing and the blade. The fluid-deflector member has a fluid-deflecting surface which is oriented generally transversely of the direction of blade rotation and which faces the upstream direction. An exchange of momentum occurs between the flow of leakage fluid and the deflector surface, and the deflector member thus transmits a force to the blade acting in the direction of blade rotation. If desired, the deflector member can also be positioned to extract momentum from blade cooling fluid ejected from the radially outer end of the blade, thus further augmenting rotor torque and increasing machine efficiency.

11 Claims, 8 Drawing Figures



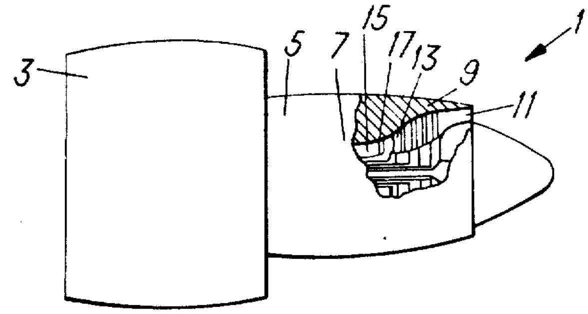


Fig. 1.

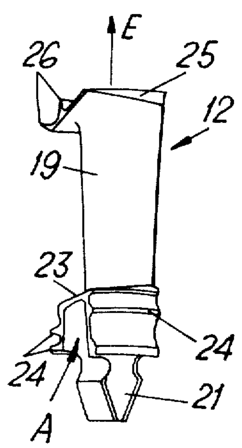


Fig. 2.
PRIOR ART

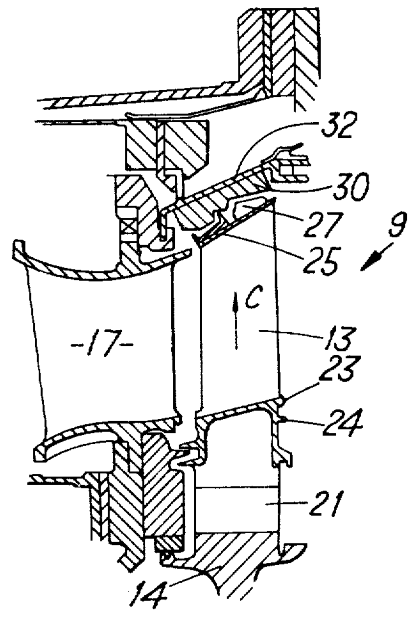


Fig. 3.

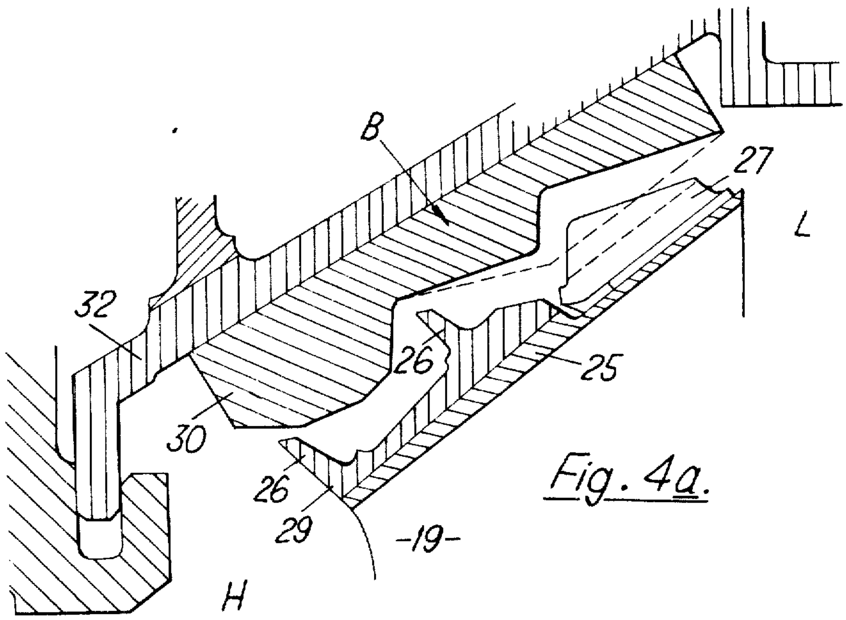


Fig. 4a.

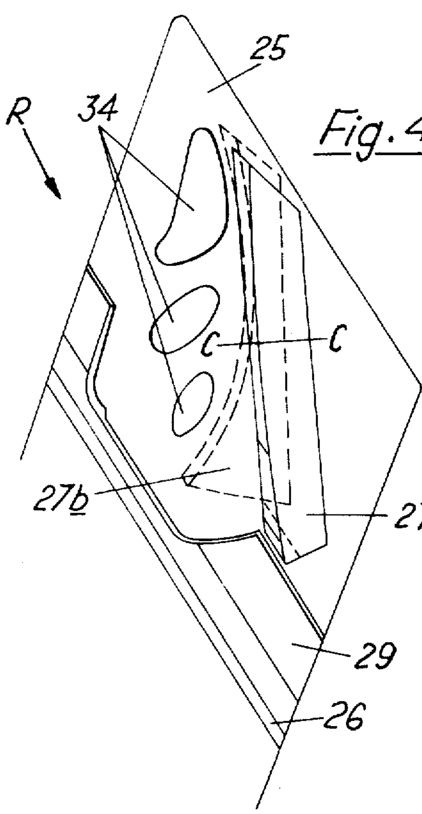


Fig. 4b.

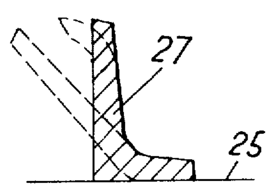


Fig. 4c.

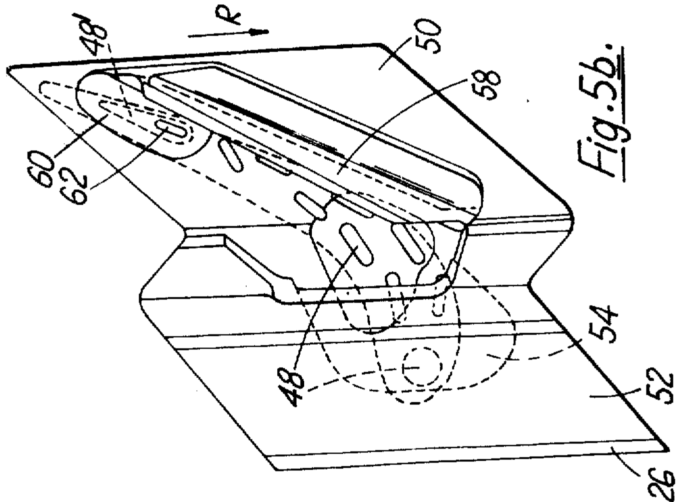


Fig.5b.

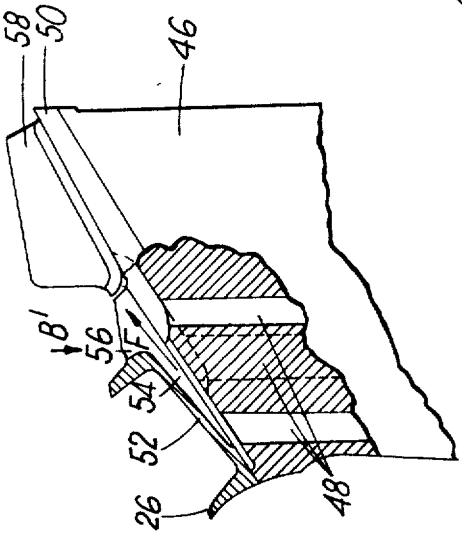


Fig.5a.

ROTOR BLADES FOR FLUID FLOW MACHINES

This invention relates to means whereby the efficiency of fluid flow machines may be increased. In particular, the invention provides means whereby flow through and past shrouded turbine blades of a gas turbine engine may be more efficiently utilised.

Turbine blades in many modern gas turbines have flange portions at their radially outward ends which cooperate with those of other blades which are circumferentially and axially spaced from them to define, or partially define, a radially outer wall of the annular gas duct through which the major portion of the combustion gases flow towards the exhaust nozzle. These flange portions are normally referred to as forming the "shroud" of the blade, and where the term "shroud" is used in this specification it will carry the above meaning.

In modern gas turbine engines utilising high temperatures of combustion, large quantities of relatively cool air may be passed through passages or the like in at least the first stage turbine blades of the turbine in order to keep the aerofoil walls of the blades at temperatures compatible with required blade strength and integrity. Prior to the present invention it has often been the case that cooling air has been allowed merely to issue radially outwards from the end of the blade and flow over the radially outer surface of the shroud. This is wasteful when one considers that work has been done in pressurising the cooling air to force it through the blades, and that therefore it posesses momentum due to its velocity as it passes out of the blade.

It is thus one object of the present invention to provide means whereby the cooling air may be utilised after it has emerged from the radially outward end of the blade such that at least some of the momentum of the cooling air is transferred to the blade thereby producing a force on the blade acting in the direction of blade rotation.

It will be seen that the efficiency of the turbine will be increased relative to a turbine having blades which do not have such means because the additional force acting in the direction of blade rotation will allow lower fuel consumption to be achieved for a given speed of rotation.

It is also a characteristic of shrouded gas turbine rotors that leakage flow of gases occurs between high and low pressure sides of the shroud via the space between the radially outer surface of the shroud and the wall of the fluid flow duct containing it. Where the term "leakage flow" is used in this specification, it will carry the above meaning. This leakage flow reduces the efficiency of the turbine, and it is therefore an object of this invention to utilise said flow so that at least some of the momentum of said flow will be transferred to the shroud in such a way as to produce forces on the rotor acting in the direction of rotation.

According to the present invention an axial flow turbine rotor blade having a shroud at its radially outer end has fluid flow deflecting means comprising at least one fluid-deflecting surface projecting from the radially outer end of said shroud into the region of leakage fluid flow over the radially outer end of said shroud, characterised in that said fluid-deflecting surface over at least the greater part of its length is oriented transversely of, but not normal to, the direction of rotation of said blade, such that said deflecting means transmits a force to said blade acting in the direction of rotation of said blade to assist the rotation thereof, said force resulting from an exchange of momentum between said leakage fluid flow and said fluid-deflecting surface.

The turbine rotor blades may be fluid-cooled such that in operation they discharge cooling fluid from one or more apertures in the radially outer surface of said shroud at the end of the blade, the fluid-flow deflecting surface being positioned to deflect said cooling fluid in addition to the leakage air, thereby to exchange momentum with said cooling fluid to produce a force on said deflecting means acting in the direction of blade rotation to assist therewith.

In another embodiment of the invention, one or more the cooling fluid-discharging apertures in the radially outer surface of the shroud may be covered by a hollow cap member which is adapted to deflect said cooling fluid through one or more apertures in said cap in a direction substantially opposite to the direction of rotation of said shroud to assist therewith, the fluid deflecting surface of said fluid deflecting means being situated on the radially outer side of said hollow cap member to deflect the leakage fluid flow.

In an alternative arrangement the hollow cap member is adapted to deflect the cooling fluid through one or more apertures in said cap member onto the fluid flow deflecting surface, which in this case is situated downstream of the cap member.

The rotor blade may be either shrouded or unshrouded at its radially outer end, and in the case of an unshrouded blade, it is preferred that the fluid flow deflecting surface is the concave face of a lip which extends along the convex side of the aerofoil at the radially outer end thereof and which projects therefrom into the region of fluid flow over the blade tip.

The axial flow turbine is preferably part of a gas turbine engine, the rotor blade being a gas turbine rotor blade. The cooling fluid is preferably air, but may be water, steam, or a mixture of water or steam with air.

The fluid flow deflecting means may be formed as a separate component and thereafter brazed, welded or otherwise fixed to the shroud. Alternatively, it may be formed as an integral part of the blade shroud or may form part of or be attached to a cap-like component which in turn may be fixed to the shroud. Said cap-like component may also incorporate flange-like members adapted to produce a seal between said component and the wall of the fluid flow duct.

If the deflection means is formed as a separate component, it preferably comprises the fluid-deflecting portion and a base-portion by which said deflecting portion is fixed to the shroud or to the cap-like component, but if said deflection means is formed integrally with said shroud or said cap-like component, said deflection means may comprise only said fluid deflecting portion.

Specific embodiments of the invention will now be described by way of example only and with reference to the accompanying drawings in which

FIG. 1 is a diagrammatic representation of a gas turbine engine which may incorporate the present invention.

FIG. 2 is a perspective view of a first-stage turbine blade which does not incorporate the present invention.

FIG. 3 shows a blade according to the invention as it could be situated in an engine according to FIG. 1.

FIG. 4*a* is an enlarged scrap view of the blade shroud as shown in FIG. 3.

FIG. 4*b* is a view of the shroud as seen on arrow B in FIG. 4*a*, and

FIG. 4*c* is a representation of the view on section C—C in FIG. 4*b*.

FIG. 5*a* is a partly sectioned side elevation of the tip of a shrouded turbine blade showing a further embodiment of the invention.

FIG. 5*b* is a view of the top of the turbine blade shroud portion as seen from the direction of arrow B'.

Referring to FIGS. 1 and 3, a ducted fan gas turbine engine 1 comprises a fan section 3, compressor section 5, combustion apparatus 7, turbine section 9 and exhaust section 11, these all being arranged in flow series with respect to each other.

As illustrated in FIG. 1, the turbine 9 comprises several stages, the first stage of which may include the turbine blade indicated by reference numeral 13 as shown in FIG. 3. This blade 13 receives combustion products from annular combustion chamber 15 via a plurality of nozzle guide vanes 17 as it rotates about the axis of the engine.

As is best seen from FIG. 2, a typical turbine blade 12 of the prior art comprises an aerofoil-shaped portion 19, a root-portion 21 whereby the blade is retained in a turbine disc such as that shown in FIG. 3 by the reference numeral 14, a platform portion 23 with sealing flanges 24, and a shroud portion 25 having sealing flanges 26.

Cooling air is supplied to the blade at A, passes up through the aerofoil portion 19 by means of a passage or passages (not shown) and is expelled at E from holes (not shown, but similar to holes 34 in FIG. 4*b*) in the shroud 25.

FIG. 3 includes a blade 13, which is generally similar to blade 12 but which is modified according to the present invention. Those parts which correspond to parts already identified in connection with FIGS. 1 and 2 are numbered identically, and will require no further description. As before, cooling air passes up the inside of the blade in the direction indicated by the arrow C and exhausts from the radially outer side of the shroud 25.

In some modern gas turbines, high mass flows of cooling air are used because of the high temperature of the combustion gases which impinge upon the blade. In the blade according to FIG. 2, the residual energy of this high mass flow was wasted because the air left the shroud in a radial direction and then merely flowed out over the shroud surface, "sandwiched" between the shroud and the turbine duct wall. However, in FIG. 3, a fin or fence-like member 27 is brazed or otherwise fixed onto the radially outer side of the shroud 25 in order to intercept the cooling air as it flows out over the shroud in the restricted space between the shroud and the duct wall, and hence to produce a momentum interchange between the cooling air and blade.

The shape and position of the member 27 as shown more clearly in FIGS. 4*a*, *b* and *c*.

FIG. 4*a* is an enlarged section view of the shroud 25 and adjacent parts shown in FIG. 3. It will be seen that the shroud 25 has two pieces fixed thereto, these being a cap 29 having sealing flanges 26, and the member 27. Sealing flanges 26 operate in conjunction with seal lining 30 which is attached to the inner casing 32. The purpose of flanges 26 and lining 30 is to reduce the leakage flow of air and combustion gases from the high pressure area H to the lower pressure area L via the clearance between blade shroud 25 and duct wall 32; obviously, the greater the proportion of gases which pass over the aerofoil surface 19 and hence exchange momentum with the blade, then the greater the efficiency of the turbine will be. Lining 30 is abradable so that the flanges will cut channels for themselves as the clearances vary according to engine operating conditions. In spite of these precautions, however, a leakage flow occurs, and another function of the fence is to intercept leakage gases as they flow over the shroud and thereby transfer some of their momentum to the blade in the direction of rotation.

The position of the member 27 on the shroud 25 in relation to the cooling air exit holes 34 and the cap 29 is shown in FIG. 4*b*, which is a plan view of part of the shroud 25 as seen when looking along arrow B is FIG. 4*a*. The direction of rotation of the blade is indicated by arrow R, and it will be noticed that the fin or fence (as shown by the unbroken lines) is in the form of a straight strip which is fixed to the shroud 25 in a position flanking the holes 34 and transverse of the direction of rotation. If a cross-section of the fence is taken on line C—C, the view in FIG. 4*c* is obtained, and it will be seen that the section is substantially L-shaped as shown by the unbroken lines. The base of the L may be secured to the shroud by brazing or welding.

Returning to FIG. 4*a*, member 27 as shown by the unbroken lines has a fence-portion of variable height along its length relative to the shroud surface. The fence portion approximates a triangular shape, the apex of the triangle being situated such that the greatest fence area is presented to the region of greatest combined cooling air and leakage gas flow. Abradable seal-lining 30 conforms approximately to the shape of the fence portion but is obviously spaced therefrom as shown.

Alternative embodiments of the invention are shown in FIGS. 4*a*, *b* and *c* means of broken lines. In FIG. 4*a*, the member 27 is modified to have a fence portion of constant height over the major portion of its length, as shown by the broken line. As a result, the profile of the seal lining 30 is also modified to that shown by the corresponding broken line. Such a profile would be used for ease of manufacture and/or in cases where the combined fluid flow across the shroud is substantially constant all along the shroud width.

Another alternative embodiment is shown by the broken lines in FIG. 4*b*, where reference numeral 27*b* indicates a member in which the fence portion when seen in plan view is arcuately disposed alongside the cooling air holes in contrast to the previously described member 27 shown by unbroken lines, which is linearly so disposed. The arcuately formed embodiment may be more efficient in collecting the cooling air as it spills over the shroud.

Yet two more embodiments are shown by the broken lines in FIG. 4*c*. As previously mentioned, the unbroken lines in FIG. 4*c* define a cross-section of the member 27 taken on section line C—C in FIG. 4*b*, in which the gas-intercepting surface of the member is disposed normal to the shroud surface. However, greater efficiency may be obtained by employing a fence-portion the top part of which is inclined (36) or curved (38) over towards the cooling air exit holes in the shroud. In this way, more efficient use of the air may be made before it spills over the top of the fence.

It should be realised that the unbroken lines in FIGS. **4***a*, *b* and *c* illustrate one basic embodiment seen in three different views, but that the broken lines in the same Figures respectively illustrate a further four separate embodiments drawn in for comparison with the corresponding view of the basic embodiment. However, features of all five embodiments may easily be brought together in any combination, and still further variations will be apparent to one skilled in the gas turbine art.

As yet another example, the present invention may be used in conjunction with the invention disclosed in our co-pending U.S. Patent application Ser. No. 406,388, in which a shroud cap, which could be similar to the one numbered **29** in FIG. **4** of the present application, extends over cooling air exit holes in the blade shroud and incorporates ducts or channels to deflect the cooling air which exits from these holes. In an embodiment of the invention of the co-pending application, the direction of discharge of cooling air from the cap is approximately tangential to the rotor and opposite to its direction of rotation. A deflector fence may in this case be situated on the top of the cap to intercept leakage air passing over the top of the cap.

An alternative way of using a deflector cap and fence in conjunction is shown in FIGS. **6***a* and *b* of the present specification. A blade **46** is provided with an array of cooling air channels **48** in both leading and trailing edges, and corresponding cooling air exit holes are provided in the radially outer side of the shroud **50.** A hollow shroud cap **52** (having sealing fins **26** as described with reference to FIG. **4**) is brazed or otherwise fixed in position over the holes. The cooling air enters the space **54** between the shroud surface and the cap and is exhausted from the cap in the direction of arrow F through the opening **56** at the downstream end.

The deflector **58** is essentially of the same form as that described in relation to the full lines of FIG. **4,** except that a blanking plate **60** with dust hole **62** is formed as an integral part of the deflector fence to cover the cooling air exit hole **48'** on the downstream edge of the shroud. This has the effect of stopping most of the air flow in the cooling air channel from escaping through the shroud, thus ensuring a plentiful supply of air for film-cooling of the trailing edge of the blade. The small dust-hole is provided for the purpose of expelling any small particles which would otherwise accumulate in the cooling air channel.

As can be seen from FIG. **5***a*, the direction F of discharge of cooling air from the cap is such as to direct the air onto the deflector fence, which also intercepts air issuing directly from uncapped cooling air holes, as well as some leakage gas. The provision of such a deflector cap, which collects cooling air exhausted from the upstream edge of the shroud and directs it towards the downstream edge to be intercepted by appropriately oriented deflector fence, effectively increases the fluid-collecting ability of the defelctor fence whilst preserving an efficient orientation on the shroud.

Expected gains in the efficiency of a modern gas turbine engine when fitted with deflector fences are worthwhile. For example, specific fuel consumption may be improved by an amount of the order of **1–2** percent.

What we claim is:

1. An axial flow turbine rotor blade having a shroud at its radially outer end and a fluid deflecting member projecting outwardly of the radially outer suface of said shroud into the region of leakage fluid flow between the high and low pressure sides of the shroud, said fluid deflecting member possessing a substantially fin-shaped fluid-deflecting surface which over at least the greater part of its area is oriented transversely of the direction of rotation of said blade, but not normal thereto, and faces towards both the high pressure side of the shroud and the trailing edge of the shroud, thereby to deflect at least a portion of said leakage flow and exchange momentum therewith, a force acting in the direction of blade rotation thereby being produced on said member to assist the rotation of said blade.

2. An axial flow turbine rotor blade having a shroud at its radially outer end and a fluid deflecting member projecting outwardly of the radially outer surface of said shroud into the region of leakage fluid flow between the high and low pressure sides of the shroud, said fluid deflecting member possessing a substantially fin-shaped fluid-deflecting surface which over at least the greater part of its area is oriented transversely of the direction of rotation of said blade, but not normal thereto, and faces towards both the high pressure side of the shroud and the trailing edge of the shroud, thereby to deflect at least a portion of said leakage flow and exchange momentum therewith, said rotor blade being adapted to be fluid-cooled, the cooling fluid being discharged from one or more apertures in the radially outer side of said shroud, at least a portion of said cooling fluid being deflected by the fin-shaped member to exchange momentum therewith, a force acting in the direction of blade rotation being thereby produced on said fin-shaped member to assist the rotation of said blade.

3. An axial flow turbine rotor blade having a shroud at its radially outer end and a fluid deflecting member projecting outwardly of the radially outer surface of said shroud into the region of leakage fluid flow between the high and low pressure sides of the shroud, said fluid deflecting member possessing a substantially fin-shaped fluid-deflecting surface which over at least the greater part of its area is oriented transversely of the direction of rotation of said blade, but not normal thereto, and faces towards both the high pressure side of the shroud and the trailing edge of the shroud, to thereby deflect at least a portion of said leakage flow and exchange momentum therewith, said rotor blade being fluid-cooled, the cooling fluid being discharged from apertures in the radially outer side of said shroud, at least one of said apertures being covered by a hollow cap member which is adapted to deflect said cooling fluid through one or more further apertures in said cap in a direction substantially opposite to the direction of rotation of said blade to assist therewith, the fin-shaped member being on the radially outer surface of said cap and projecting outwardly therefrom, said leakage fluid and said cooling fluid generating a force acting in the direction of blade rotation to assist the rotation of said blade.

4. An axial flow turbine rotor blade having a shroud about its radially outer end and a fluid deflecting member projecting outwardly of the radially outer surface of said shroud into the region of leakage fluid flow between the high and low pressure sides of the shroud, said fluid deflecting member possessing a substantially fin-shaped fluid-deflecting surface which over at least the greater part of its area is oriented transversely of the direction of rotation of said blade, but not normal thereto, and faces towards both the high pressure side of the shroud and the trailing edge of the shroud, to thereby deflect at least a portion of said leakage flow and exchange momentum therewith, said turbine rotor blade being adapted to be fluid-cooled, the cooling fluid being discharged from apertures in the radially outer side of said shroud, at least one of said apertures being covered by a hollow cap member which is adapted to deflect said cooling fluid through at least one further aperture in said cap onto the fluid-flow deflecting surface of the fin-shaped member which projects outwardly from the radially outer surface of the shroud into the region of fluid-flow over said radially outer surface, a force being thereby produced which acts in the direction of blade rotation on said member to assist the rotation of said blade.

5. An axial flow turbine rotor blade according to claim **1** in which the fin-shaped member is of substantially triangular configuration and has its greatest height relative to the radially outer shroud surface at the position of greatest momentum of the flow of fluid over said surface.

6. An axial flow turbine rotor blade according to claim **1** in which the radially outer edge of said fin-shaped member is of substantially uniform height relative to the radially outer shroud surface.

7. An axial flow turbine rotor blade according to claim **1** in which the fluid-deflecting face of the fin-shaped member makes an acute angle with the radially outer shroud surface.

8. An axial flow turbine rotor blade according to claim **1** in which the radially outer free end of said fin-shaped member is of arcuate shape and overhangs the fluid-deflecting face of the fin-shaped member.

9. An axial flow turbine rotor blade according to claim **2** in which the fluid deflecting surface of the fin-shaped member is concave in the same sense as the blade aerofoil portion.

10. An axial flow turbine rotor blade according to claim **1**, said blade being a gas turbine engine turbine rotor blade.

11. An axial flow turbine rotor blade according to claim **2** in which the cooling fluid is air.

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