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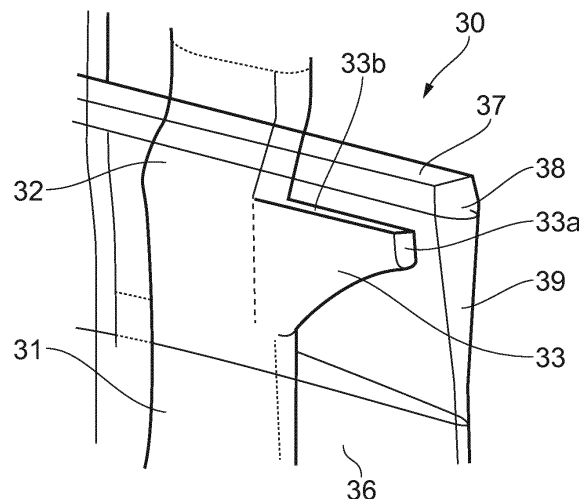
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(54) ROTOR BLADE

(57) A blade comprises a root portion and an elongate portion extending from the root portion to a tip, the elongate portion having an aerofoil-shaped cross section. The aerofoil has a leading edge (53), a trailing edge (54), a suction side (51) and a pressure side (52). The tip includes a squealer defining a gutter (57) at the tip wherein the squealer comprises a wall (56) extending from the trailing edge (54) along the entirety of a first of the suction side (51) and pressure side (52), around the leading edge (53) and partly along a second of the suction side (51) and pressure side (52) leaving a gap between the trailing edge (54) and an end of the wall (56b) on the second side. A main trailing edge cooling channel (58a) extends within the elongate portion in a direction from root to tip adjacent the trailing edge (54) and exits into the gutter (57). The main trailing edge cooling channel (58a) includes a bend just downstream of the exit such that the exit is displaced from a camber line (C-C) of the blade elongated portion towards the second side.

**FIG. 3****EP 3 301 262 A1**

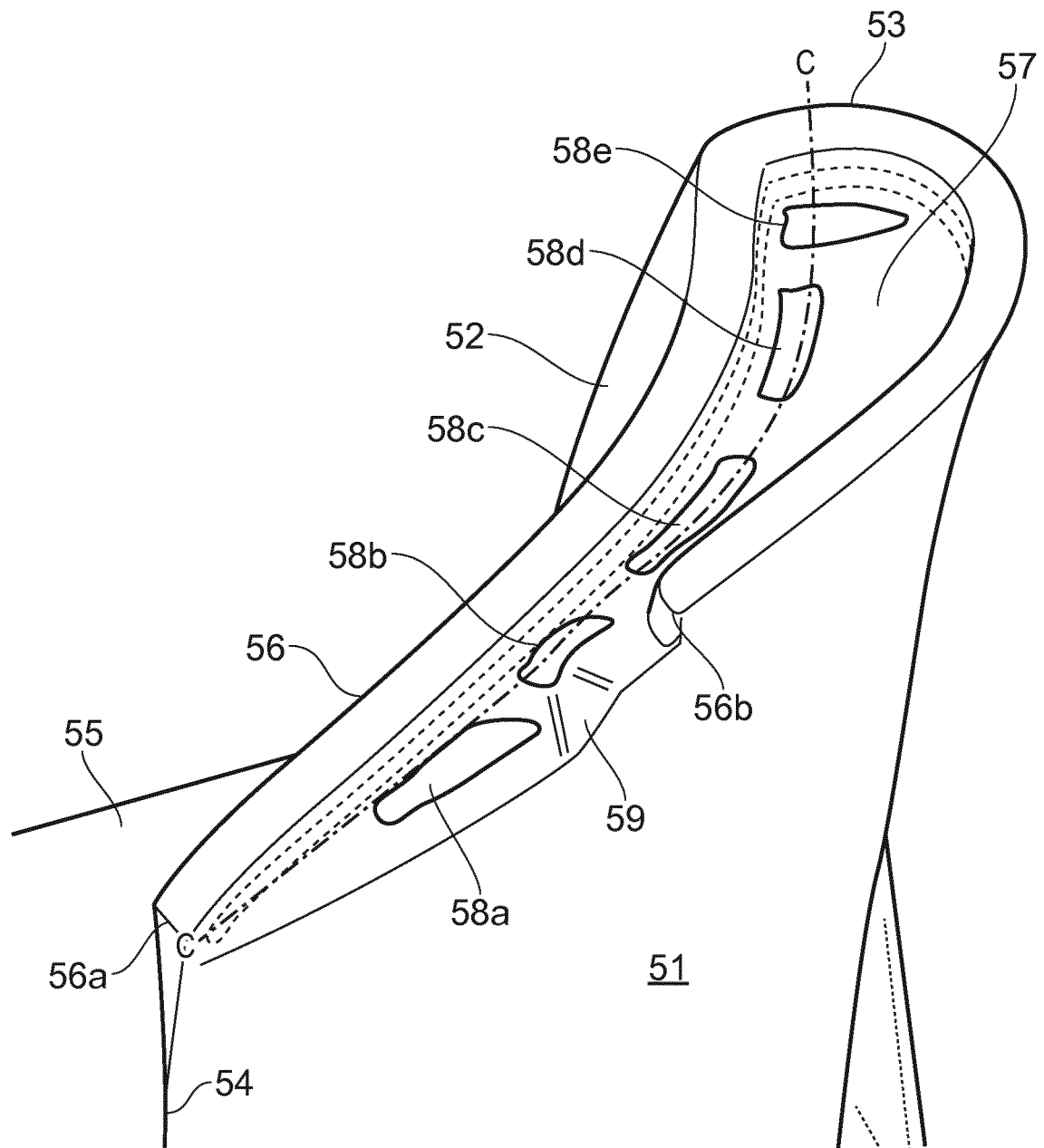


FIG. 5

Description

[0001] The present disclosure relates to shroudless turbine blades having squealer tips. More particularly the invention relates to the arrangement of internal cooling channels in this region of the blade and the geometry of squealer tips which accommodate the cooling channels.

[0002] In a gas turbine engine, a compressor is arranged to compress air for delivery to a combustor. The combustor mixes the compressed air with fuel and ignites the mixture. Gas products of this combustion are directed at a turbine blade assembly causing rotation of the blades and the production of power from the turbine assembly. Combustion temperatures may exceed 1400°C and typical configurations expose the turbine blade assemblies to these high temperatures. Turbine blades are made of materials capable of withstanding such high temperatures and often contain cooling systems for prolonging the life of the blades, reducing the likelihood of failure as a result of exposure to these excessive temperatures.

[0003] A turbine blade has a root portion at one end and an elongated portion of aerofoil shaped cross section extending from the root portion. In a turbine blade assembly, the root portion is coupled to a platform, typically a radially outer surface of a circumferential wall of a rotor disc. The elongated portion extends radially outwardly and terminates in a tip. The aerofoil shaped cross section has a leading edge and a trailing edge joined by a suction side and a pressure side.

[0004] Efforts are continually being made to improve efficiency in gas turbine engines. It is known that a significant factor in reducing efficiency of the turbine assembly is attributable to the leakage of the combustion gas products over the tips of the turbine blades through a small gap between the tips of the blade assembly and a surrounding circumferential housing. It is believed such losses could account for 30% or more of total losses in the turbine assembly. As well as reduced efficiency, consequences include reduced life of turbine components due to high thermal stresses in this region.

[0005] It is known to provide turbine blade tips with seals to reduce this gap. Such tip seals are referred to as squealer tips and these are typically machined into a cast turbine blade. A squealer tip is formed as a wall extending around a substantial portion of the aerofoil at the blade tip defining a gutter within. Cooling air which has passed through the elongate portion of the blade may be expelled into this gutter and dispersed into the main gas stream.

[0006] For aerodynamic efficiency, it is desirable to minimise the thickness of a blade at its trailing edge. However, thinner sections of blade are more susceptible to the extreme temperatures and are at risk of deformation and damage a consequence of which may be reduced engine efficiency and potential failure of the component. Thus, the trailing edge of the blade must be well cooled.

[0007] In known blades having squealer tips, a main trailing edge cooling channel is provided in the elongated

portion of the blade and extends from root to tip of the blade. Multiple smaller diameter cooling channels (typically including effusion cooling channels) extend from the main trailing edge channel through the squealer wall in the region of the trailing edge and through the elongate portion to the thinnest parts of the trailing edge. Typically a gallery channel is provided just beneath the gutter surface of the squealer and extends from the main trailing edge cooling channel towards an apogee of the trailing edge. Effusion cooling channels extend through the squealer wall to the gallery channel. The main trailing edge cooling channel is typically integrally cast into the blade. The gallery channel and effusion cooling channels may be added in a subsequent machining step. The gallery channel is typically machined from the apogee of the trailing edge and its end at the apogee subsequently plugged or welded closed to encourage maximum flow to the effusion cooling channels.

[0008] An example of a prior art arrangement is shown in Figure 1. The figure shows the tip of a blade from a plan view, pressure side view and trailing edge end view. As can be seen, the tip has an aerofoil shaped cross section with a leading edge 1, a trailing edge 2, a suction side 3 and a pressure side 4. A squealer comprises a squealer wall 5 which extends from the trailing edge 2 along the suction side 3, around leading edge 1 and along the pressure side 4 returning to the trailing edge 2. The wall defines a gutter 6. Main cooling channels extend along the elongated portion of the blade and exit into the gutter 6. The main cooling channels include a main trailing edge cooling channel 7. A gallery channel 8 is drilled into the trailing edge 2 from the apogee 9 of the trailing edge 2. A first plurality of effusion cooling channels 10 extend from the gallery channel 8 and through the squealer wall 5. As can be seen, in the region of the tip, the apogee 9 of the trailing edge 2 is flared 12 and enlarged to accommodate the drilling of the gallery channel 8. A second plurality of effusion cooling channels 11 extends from the main trailing edge cooling channel into the thinnest region of the trailing edge exiting on the pressure side 4 adjacent the apogee 9 of the trailing edge 2.

[0009] The large overhang 12 of the squealer results in a larger wetted area and hence increased heat flux into the tip during engine operation. This increases the cooling requirement for this region. Other disadvantages of the arrangement include sub-optimal aerodynamic performance at the trailing edge resulting in efficiency losses and a weight penalty.

[0010] The present disclosure seeks to provide an improved cooling arrangement and associated squealer tip design which contributes to the mitigation of the problems identified above.

[0011] In accordance with the present disclosure there is provided a blade comprising a root portion and an elongate portion extending from the root portion to a tip, the elongate portion having an aerofoil-shaped cross section having a leading edge, a trailing edge, a suction side and pressure side, the tip including a squealer defining a gut-

ter at the tip wherein the squealer comprises a wall extending from the trailing edge along the entirety of a first of the suction side and pressure side, around the leading edge and partly along a second of the suction side and pressure side leaving a gap between the trailing edge and an end of the wall on the second side, a main trailing edge cooling channel extending within the elongate portion in a direction from root to tip adjacent the trailing edge and exiting into the gutter, wherein the main trailing edge cooling channel includes a bend just upstream of the exit such that the exit is displaced from a camber line of the blade elongated portion towards the gap on the second side.

[0012] In some embodiments the first side is the pressure side. In other embodiments the first side is the suction side. The end of the squealer wall on the second side may be curved.

[0013] In some embodiments, the gutter in the region of the trailing edge is inclined from the first side towards the second side whereby to maintain a surface which is substantially orthogonal to the walls of the main trailing edge cooling channel where they meet the gutter surface.

[0014] The depth of the squealer wall may vary from a first depth at the leading edge to a second and greater depth at the trailing edge. The width of the squealer wall may reduce from a maximum width at a first end of the squealer wall to a minimum width at a second end of the squealer wall. Optionally, the squealer wall may be locally thinned or thickened to accommodate internal passages within the wall or to satisfy manufacturing requirements.

[0015] The squealer wall may include a locally extended portion adjacent the trailing edge on the first side, the extended portion extending in a widthwise direction with respect to the squealer wall and away from the gutter. The extended portion may accommodate a gallery channel and associated effusion cooling channels for cooling the trailing edge at the tip.

[0016] The gutter may be shallower adjacent the leading edge than it is at the trailing edge. Variation in gutter depth may be achieved by providing an inclined surface to the tip within the gutter. Alternatively, variation in gutter depth is achieved by varying the height of the wall of the squealer between the trailing edge and the leading edge. Gutter depth may vary gradually along an incline, alternatively or in addition, gutter depth may vary due to one or more steps within the gutter. The gallery channel may be shaped to follow variations in the depth of the gutter. For example, the gallery channel may include a stepped section to accommodate a step in the gutter.

[0017] A gallery channel may be integrally cast into the blade using an adapted core which defines both the main trailing edge cooling channel and has an extension defining the gallery channel.

[0018] The gallery channel may be provided in a shape which minimises flow restriction in the gallery channel. For example the gallery channel is conically tapered from its open end to its closed end. In more complex embodiments, the cross sectional shape of the gallery channel

may be varied in a manner designed to tune coolant flow to suit cooling requirements in different regions of the blade tip and squealer. For example, the gallery channel is shaped to encourage optimum flow rates to the film cooling holes in accordance with cooling requirements at the exits of the film cooling holes. For example, to control the impact of aerodynamics in a known operational environment in which the blade is to be used, the gallery may be configured to bias cooling towards one of the suction side and pressure side.

[0019] The film cooling channels may comprise effusion cooling channels. Axes of the effusion cooling channels may be inclined to a surface of the squealer wall. The effusion cooling channels may have a varying cross section, for example the effusion cooling channels may include a fanned portion adjacent the exit to a squealer wall surface. Film cooling channels may be introduced after a blade has been cast. For example, the film cooling channels may be drilled using an EDM process.

[0020] The blade may be configured for use in a gas turbine engine, for example the blade may be configured for use in a compressor section or turbine section of a gas turbine engine. One useful application of the design of the invention is in blades of a high pressure turbine stage in a gas turbine engine.

[0021] For the purposes of exemplification, some embodiments of the invention will now be described with reference to the accompanying Figures in which;

Figure 1 shows a blade tip having a squealer and cooling channel arrangement as is known from the prior art;

Figure 2 shows a core for defining a main trailing edge cooling channel in a blade in accordance with the invention;

Figure 3 shows the core of Figure 2 positioned with respect to a surface of a blade made in accordance with the invention;

Figure 4 shows an alternative core positioned with respect to a surface of a blade made in accordance with the invention;

Figure 5 shows a view from the tip of a blade manufactured in accordance with the invention;

Figure 6 shows an embodiment of a squealer arrangement of a blade in accordance with the invention;

Figure 7 shows an alternative embodiment of a squealer arrangement of a blade in accordance with the invention;

Figure 8 shows an example of a gas turbine engine into which blades in accordance with the invention

may usefully be incorporated.

[0022] Figure 1 has already been described above.

[0023] Figure 2 shows a core suited to defining a main trailing edge cooling channel in an embodiment of a blade in accordance with the invention. The core 20 has a main trailing edge cooling channel section 21 which is elongate and proportioned to extend in a root to tip direction within a mould which defines the elongate portion of a blade to be cast in the mould. Towards the tip end, the main trailing edge cooling channel section 21 has an inclined portion 22 as compared to the remainder of the main trailing edge cooling channel section 21. Within a mould, the main trailing edge cooling channel section 21 sits substantially in alignment with a camber line of the blade mould. The inclined portion 22 results in an exit of the main trailing edge cooling channel section 21 being positioned to one side of the camber line. Depending on requirements, the incline could be towards the pressure surface side or the suction surface side of the blade. The core further includes a gallery channel portion 23. The gallery channel portion 23 extends in a leading edge to trailing edge direction within the blade mould. The gallery channel portion 23 has a substantially flat upper wall 24 which defines a wall of the gallery channel in a blade which is substantially in parallel with a surface of a gutter in the tip of the blade. A lower surface 25 of the gallery channel 23 is curved to form a spout shaped gallery channel portion 23.

[0024] Figure 3 shows a wireframe view of the core of Figure 2 arranged behind a pressure surface side 36 of a blade 30 in accordance with the invention. The main trailing edge cooling channel core 31, 32 has an elongate section 31 and inclined section 32. The elongate section 31 extends in a root to tip direction through the blade 30 passing through a camber line of the blade. The inclined section 32 tilts the channel away from the camber line and towards a suction surface side (not shown) of the blade 30. A spout shaped gallery channel portion 33 extends from the elongate section 31 towards an apogee 39 of the trailing edge of the blade 30. A closed end of the gallery channel portion 33a sits behind the apogee 39. A top surface 33b of the gallery channel portion 33 is planar and extends in parallel with a surface of a gutter 38 which is bordered by a squealer wall 37. The gallery channel portion 33 extends beneath the surface of the gutter 38. The inclined portion 32 exits into the gutter 38 towards the suction surface side of the camber line.

[0025] Figure 4 shows a wireframe view of an alternative core arranged behind a pressure surface side 46 of a blade 40 in accordance with the invention. The main trailing edge cooling channel core 41, 42 has an elongate section 41 and inclined section 42. The elongate section 41 extends in a root to tip direction through the blade 40 passing through a camber line of the blade. The inclined section 42 tilts the channel away from the camber line and towards a suction surface side (not shown) of the blade 40 and exits through gutter 48 at a position to the suction surface side of the camber line. In this arrange-

ment, there is no gallery channel section to the core. A gallery channel may be added after casting by drilling from the apogee 49 side through to the elongate section 41. In such a case the end of the gallery channel at the apogee 49 may be plugged or welded to close the gallery channel.

[0026] Figure 5 shows the tip end of a blade having an aerofoil-shaped cross section. The blade has a suction side 51 and a pressure side 52 which meet to form a leading edge 53 and a trailing edge 54. The elongate portion of the blade terminating in the tip extends from a root portion 55. Around a perimeter of the tip is provided a squealer wall 56 which extends from a first end 56a at the trailing edge 54 to a second end 56b midway along the suction side 51 leaving a gap along the remainder of the suction side 51 to the trailing edge 54.

[0027] The wall 56 defines a gutter 57 in the tip. As can be seen a plurality of cooling channels 58a, 58b, 58c, 58d, 58e exit the elongate portion of the blade in the gutter 57. Exits to cooling channels 58b, 58c, 58d and 58e sit along a camber line C-C of the blade. Cooling channel 58a is the main trailing edge cooling channel which includes the inclined portion as discussed in accordance with the invention. As can be seen, this channel 58a has an exit which is positioned towards the suction side 51 of the camber line C-C. In a subsequent manufacturing step, the cooling channels 58a, 58b, 58c, 58d and 58e may be blocked at the blade tip by weld caps, each weld cap having a small diameter hole through it (typically 0.5mm) to allow egress of dust from the internal passages. Film cooling channels may be provided through the suction side and/or pressure side walls to connect with the channels. Capping at the tip encourages greater flow to these film cooling channels.

[0028] The gutter 57 includes a step 59 which results in the gutter 57 being deeper towards the trailing edge 54 end of the gutter than the leading edge 53 end of the gutter 57 and also provides an incline from the suction side towards the pressure side. This incline is selected to ensure that the surface of the gutter 57 around the exit of channel 58a is approximately orthogonal to walls of the channel 58a at the exit.

[0029] The second end 56b of the squealer wall 56 is gently curved to discourage turbulent flow of cooling air which exits into the gutter 57 from the channels 58a-58e and flows towards the trailing edge 54 to join a main flow of hot air delivered from the combustor to generate work from a turbine assembly of which the blade forms a part.

[0030] Figure 6 shows the tip end of a blade in accordance with invention. As can be seen, the blade has a suction side 61, a pressure side 62, a leading edge 63 and a trailing edge 64. A squealer wall 66 extends from a first end 66a along the pressure side 62, around the leading edge 63 and part way along the suction side 61 to a second end 66b. The second end 66b is smoothly curved. The wall 66 defines a gutter 67 which has a first depth d_1 at the trailing edge 64 and a second depth d_2 at the leading edge 63. The first depth d_1 is greater than

the second depth d_2 . This is achieved by an incline on the gutter 67 surface from the leading edge 63 to the trailing edge 64. The wall has a first width w_1 adjacent the trailing edge 64 on the pressure side 62 and a second width w_2 adjacent second end 66b on the suction side 61. The first width w_1 is greater than the second width w_2 and smoothly varies from suction side to the pressure side. In other embodiments, the variation may be reversed with width w_2 being greater than width w_1 , the wall 66 being generally thinner along the pressure side. The first width w_1 is increased by the inclusion of an extension 68 adjacent the first end 66a which extends from the trailing edge 64 a short distance along the pressure side 62.

[0031] In the embodiment of Figure 7, in contrast to the embodiments of Figures 1 and 2, the squealer wall 76 extends from a first end 76a at the trailing edge 74 entirely along the suction side 71, around the leading edge 73 and terminates at a second end 76b part way along the pressure side 72. The wall defines a gutter 77 which may include a gradual incline (not shown) from the leading edge 73 to the trailing edge 74. The wall has an extension 78 on the suction side 71 adjacent the trailing edge which serves to increase the wall width w_1 at this location such that it is wider than a wall width w_2 near the second end 76b on the pressure side 72.

[0032] With reference to Figure 8, a gas turbine engine is generally indicated at 600, having a principal and rotational axis 611. The engine 600 comprises, in axial flow series, an air intake 612, a propulsive fan 613, a high-pressure compressor 614, combustion equipment 615, a high-pressure turbine 616, a low-pressure turbine 617 and an exhaust nozzle 618. A nacelle 620 generally surrounds the engine 600 and defines the intake 612.

[0033] The gas turbine engine 600 works in the conventional manner so that air entering the intake 612 is accelerated by the fan 613 to produce two air flows: a first air flow into the high-pressure compressor 614 and a second air flow which passes through a bypass duct 621 to provide propulsive thrust. The high-pressure compressor 614 compresses the air flow directed into it before delivering that air to the combustion equipment 615.

[0034] In the combustion equipment 615 the air flow is mixed with fuel and the mixture combusted. The resultant hot combustion products then expand through, and thereby drive the high and low-pressure turbines 616, 617 before being exhausted through the nozzle 618 to provide additional propulsive thrust. The high 616 and low 617 pressure turbines drive respectively the high pressure compressor 614 and the fan 613, each by suitable interconnecting shaft.

[0035] For example the blades of the high and low pressure turbines 616, 617 may be configured in accordance with blades of the invention described herein.

[0036] Other gas turbine engines to which the present disclosure may be applied may have alternative configurations. By way of example such engines may have an alternative number of interconnecting shafts (e.g. three) and/or an alternative number of compressors and/or tur-

bines. Further the engine may comprise a gearbox provided in the drive train from a turbine to a compressor and/or fan.

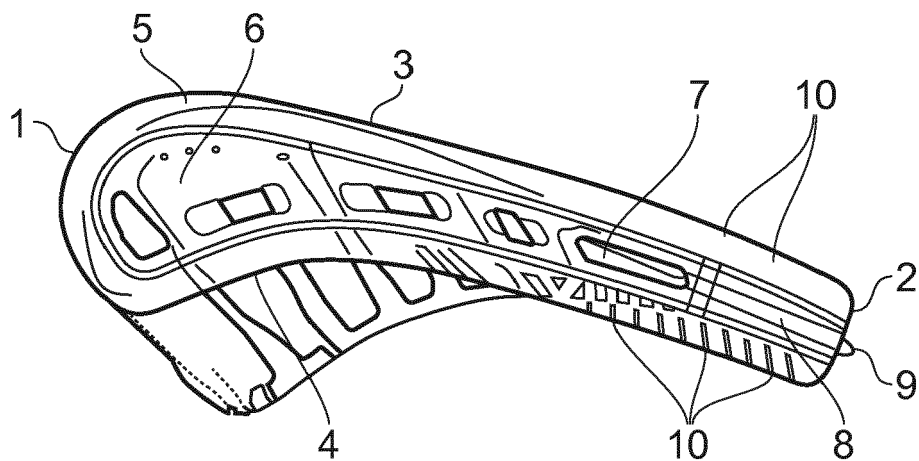
[0037] It will be understood that the invention is not limited to the embodiments above-described and various modifications and improvements can be made without departing from the concepts described herein and claimed in the appended claims. Except where mutually exclusive, any of the features may be employed separately or in combination with any other features and the disclosure extends to and includes all combinations and sub-combinations of one or more features described herein.

Claims

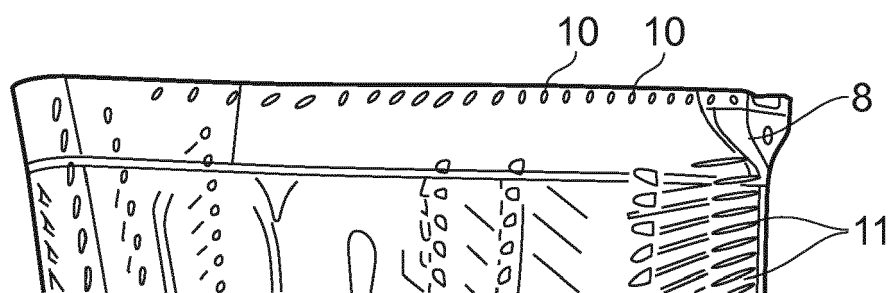
1. A blade comprising a root portion and an elongate portion extending from the root portion to a tip, the elongate portion having an aerofoil-shaped cross section having a leading edge (53), a trailing edge (54), a suction side (51) and a pressure side (52), the tip including a squealer defining a gutter (57) at the tip wherein the squealer comprises a wall (56) extending from the trailing edge (54) along the entirety of a first of the suction side (51) and pressure side (52), around the leading edge (53) and partly along a second of the suction side (51) and pressure side (52) leaving a gap between the trailing edge (54) and an end of the wall (56b) on the second side, a main trailing edge cooling channel (58a) extending within the elongate portion in a direction from root to tip adjacent the trailing edge (54) and exiting into the gutter (57), wherein the main trailing edge cooling channel (58a) includes a bend just upstream of the exit such that the exit is displaced from a camber line (C-C) of the blade elongated portion towards the second side.
2. A blade as claimed in claim 1 wherein the first side is the pressure side (52) and the main trailing edge cooling channel (58a) bends towards the suction side (51).
3. A blade as claimed in claim 1 wherein the first side is the suction side (51) and the main trailing edge cooling channel (58a) bends towards the pressure side (52).
4. A blade as claimed in any preceding claim wherein the gutter (57) is shallower adjacent the leading edge (53) than it is at the trailing edge (54).
5. A blade as claimed in any preceding claim wherein the gutter (57) in the region of the trailing edge (54) is inclined from the first side (51, 52) towards the second side (51, 52) whereby to maintain a surface which is substantially orthogonal to the walls of the

main trailing edge cooling channel (58a) where they meet the gutter (57).

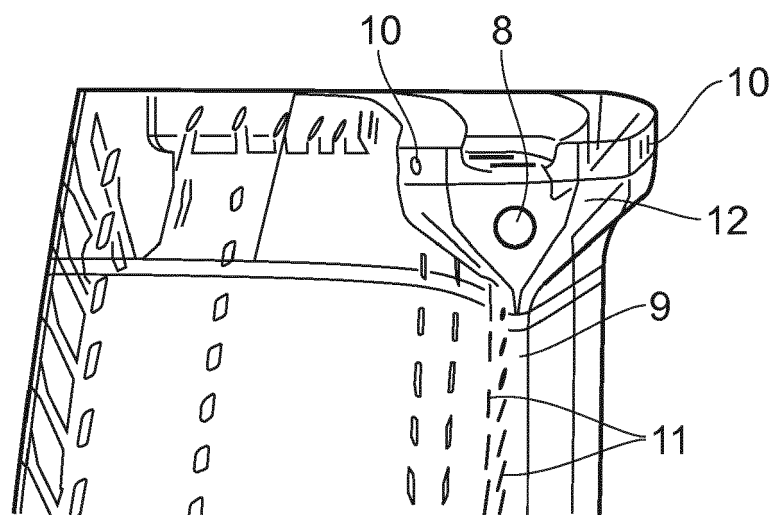
6. A blade as claimed in any preceding claim further comprising a gallery channel integrally cast into the blade (30) using an adapted core which defines both the main trailing edge cooling channel (31, 32) and has an extension defining the gallery channel (33). 5
7. A blade as claimed in claim 5 wherein the gallery channel is provided in a shape which minimises flow restriction in the gallery channel. 10
8. A blade as claimed claim 5 or 6 wherein the gallery channel is spout shaped having a larger diameter at an open end where it intersects the main trailing edge cooling channel and a smaller diameter at a closed end (33a) which sits just behind an apogee (39) of the trailing edge. 15
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9. A blade as claimed in any of claims 5 to 8 wherein a tip facing surface (24) of the gallery channel is profiled to complement and extend in parallel with the surface of the gutter (38) in the trailing edge region. 25
10. A blade as claimed in any of claims 5 to 9 wherein the gallery channel is shaped to follow variations in the depth of the gutter.
11. A blade as claimed in any of claims 5 to 10 further comprising an array of film cooling channels extending from the gallery channel (33) and through the squealer wall (37). 30
12. A blade as claimed in any preceding claim wherein the depth of the squealer wall varies from a first depth at the leading edge to a second and greater depth at the trailing edge. 35
13. A blade as claimed in any preceding claim wherein the width of the squealer wall is variable. 40
14. A blade as claimed in claim 13 wherein the width of the squealer wall (56) reduces from a maximum width at a first end (56a) of the squealer wall to a minimum width at a second end (56b) of the squealer wall. 45
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15. A blade as claimed in any preceding claim wherein the squealer wall includes a locally extended portion adjacent the trailing edge on the first side, the extended portion extending in a widthwise direction with respect to the squealer wall and away from the gutter. 55
16. A blade as claimed in any preceding claim configured for use in a gas turbine engine.



PLAN VIEW



SIDE VIEW



END VIEW

FIG. 1

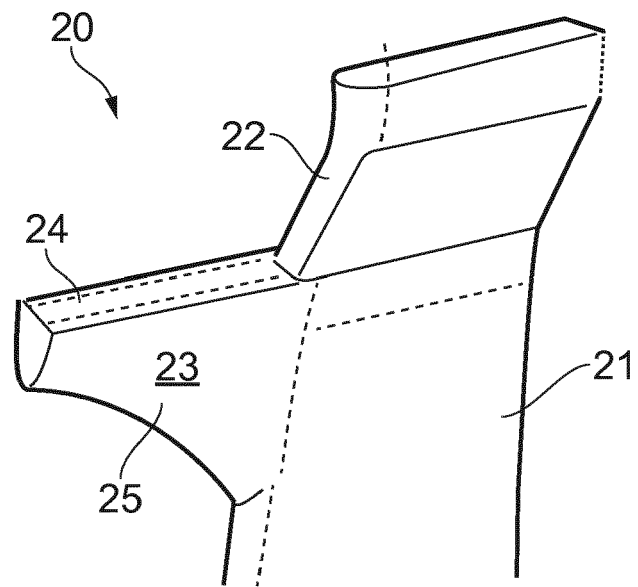


FIG. 2

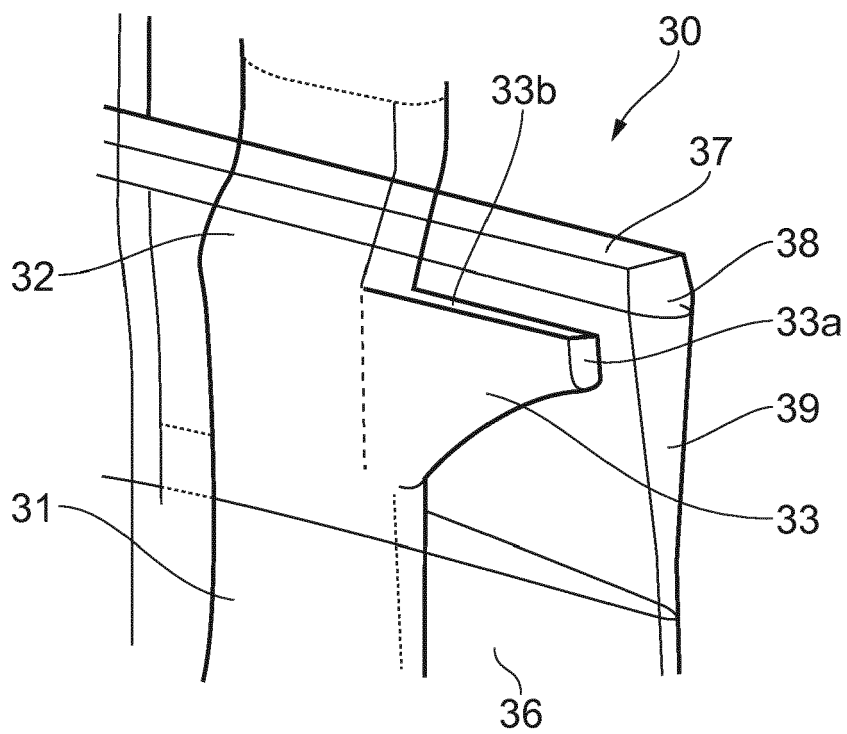


FIG. 3

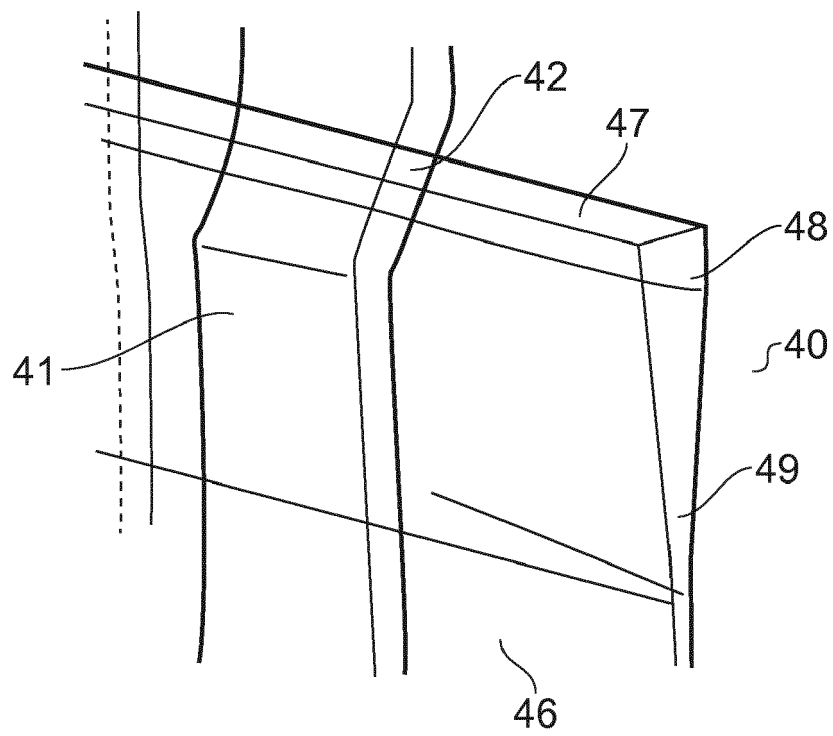


FIG. 4

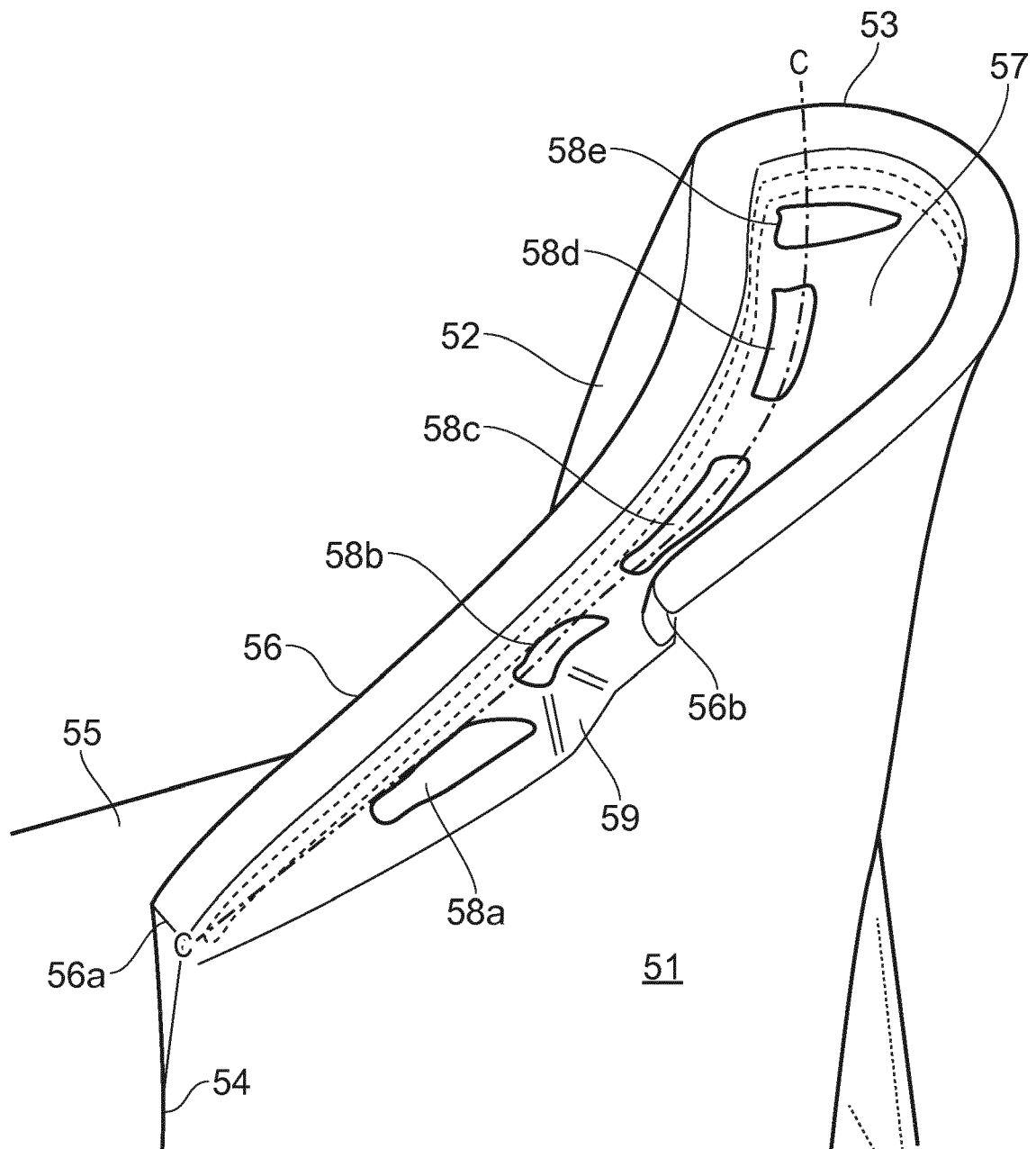


FIG. 5

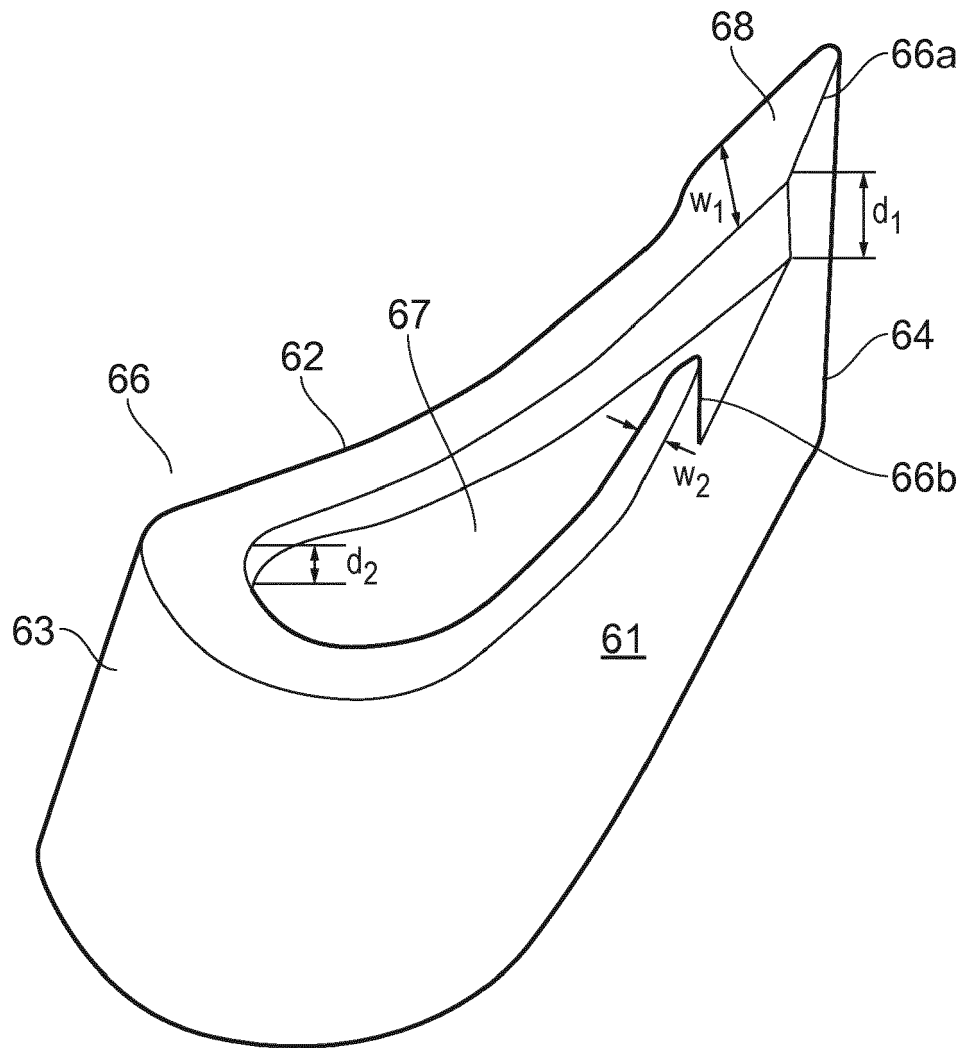


FIG. 6

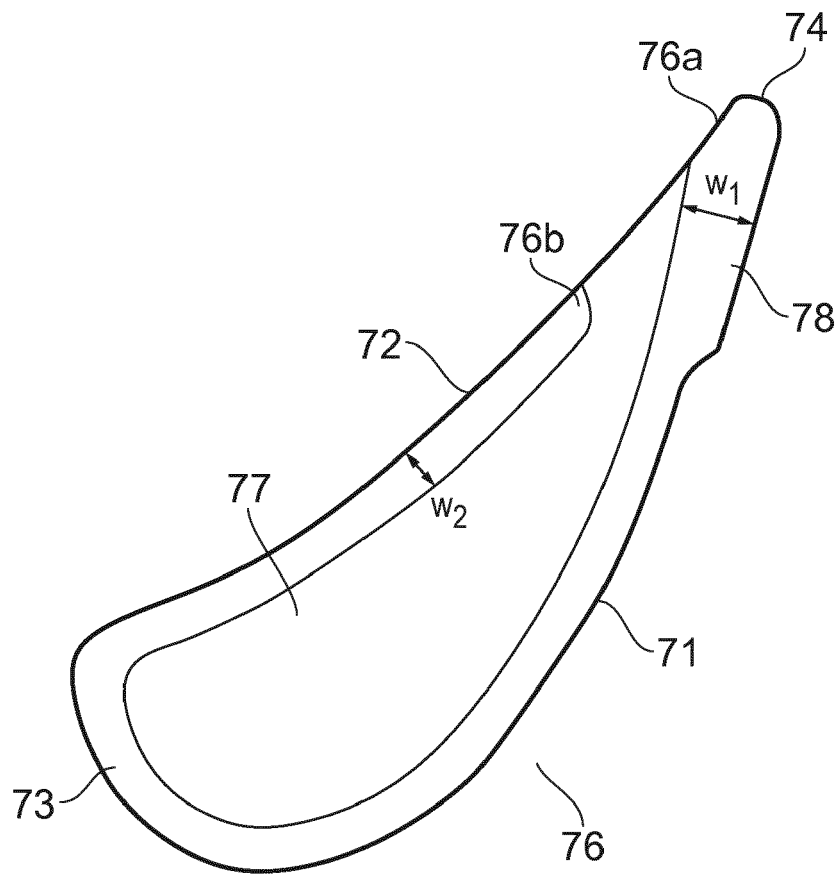


FIG. 7

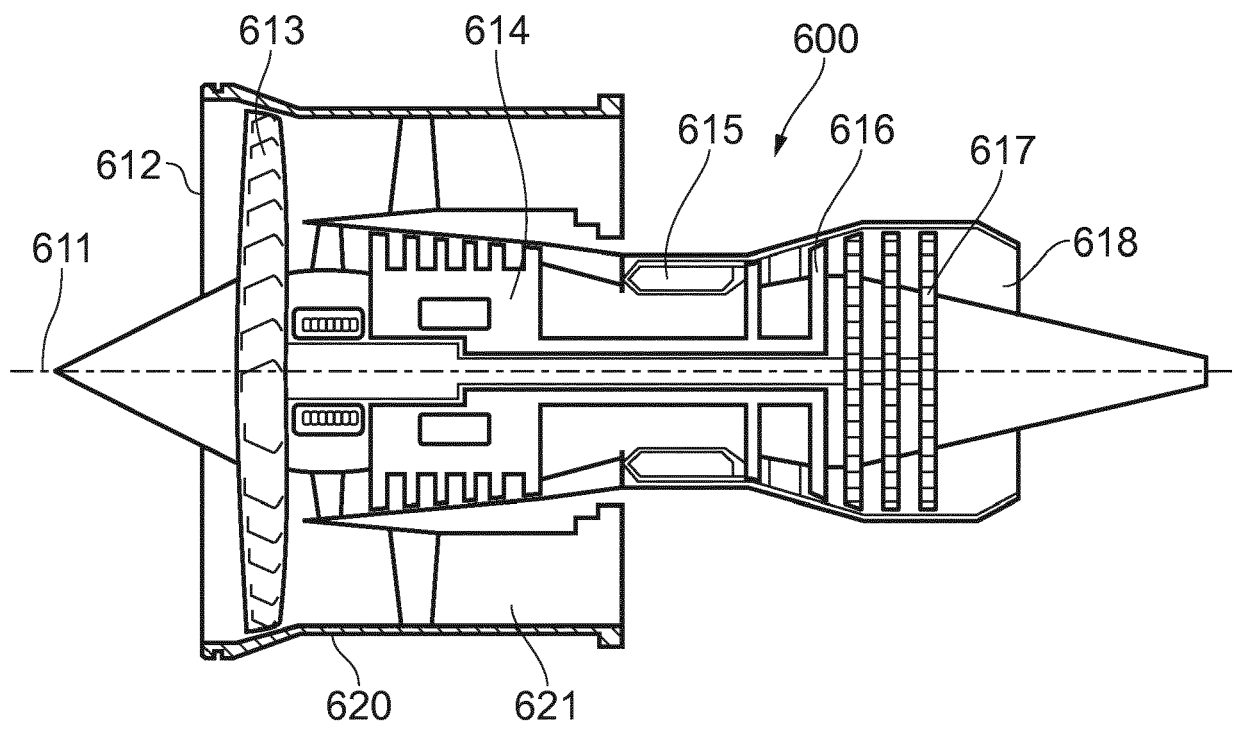


FIG. 8



EUROPEAN SEARCH REPORT

Application Number
EP 17 18 7258

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DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	US 8 435 004 B1 (LIANG GEORGE [US]) 7 May 2013 (2013-05-07) * figures 1,4,6 *	1-16	INV. F01D5/20
A	EP 3 064 713 A1 (GEN ELECTRIC [US]) 7 September 2016 (2016-09-07) * figure 3 *	1-16	
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			TECHNICAL FIELDS SEARCHED (IPC)
			F01D
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 7 February 2018	Examiner Raspo, Fabrice
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

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This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82