(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 3 502 419 A1

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
26.06.2019 Bulletin 2019/26

(51) Int Cl.:
F01D 5/18 *(2006.01)*

(21) Application number: **18207552.3**

(22) Date of filing: **21.11.2018**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
KH MA MD TN

(30) Priority: **21.12.2017 GB 201721533**

(71) Applicant: **Rolls-Royce plc**
London SW1E 6AT (GB)

(72) Inventor: **Melia, Thomas**
Derby, Derbyshire DE24 8BJ (GB)

(74) Representative: **Rolls-Royce plc**
Intellectual Property Dept SinA-48
PO Box 31
Derby DE24 8BJ (GB)

(54) AEROFOIL WITH COOLING ARRANGEMENT

(57) An aerofoil comprises: a wall (43,44,45) comprising an external surface (43), and an internal surface (42) defining a cavity (41) for receiving a cooling fluid in use; a first trench (60a) formed in the external surface, and a second trench (60b) formed in the external surface; a first passageway (62a) extending from a first passageway inlet (64a) in the cavity to a first passageway outlet (66a) in the first trench, and a second passageway (62b) extending from a second passageway inlet (64b) in the cavity to a second passageway outlet (66b) in the second trench; wherein the first passageway and second passageway intersect within the wall.

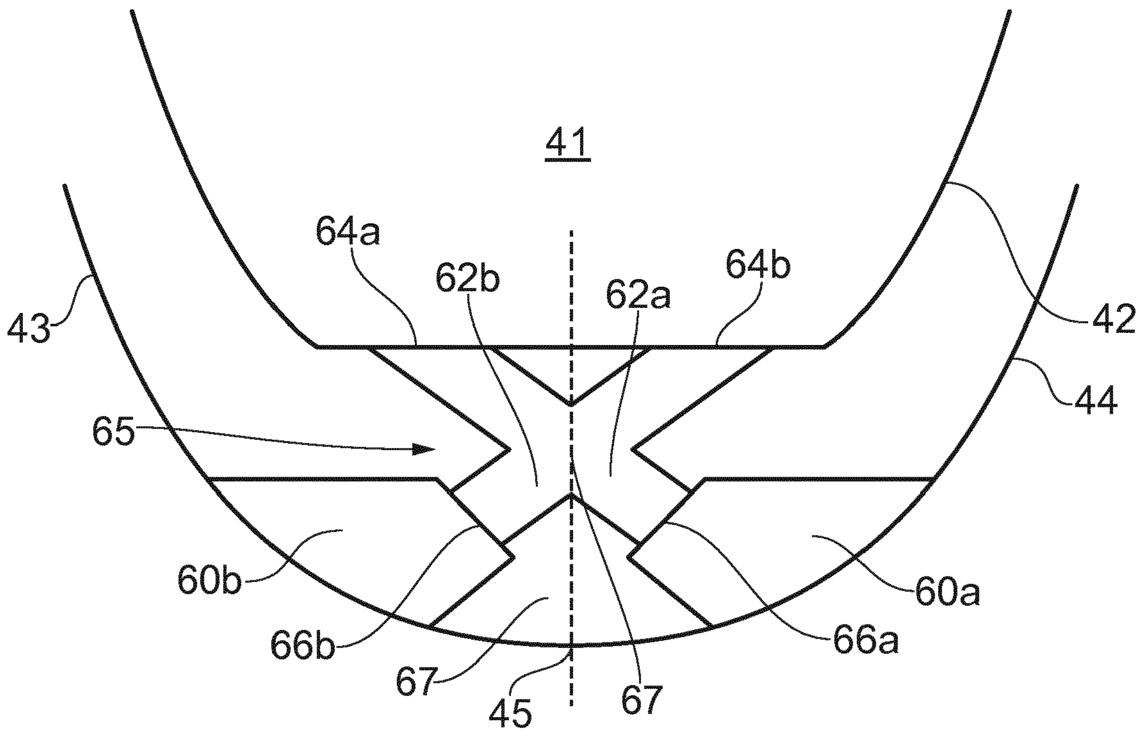


FIG. 6a

EP 3 502 419 A1

Description

Field

[0001] The present disclosure relates to an aerofoil. In particular, the present disclosure relates to an aerofoil comprising an aerofoil cooling arrangement, for use in a gas turbine engine.

Background

[0002] In the field of gas turbine engines, there is a drive for enhanced efficiency and performance. It is common to introduce steps to increase internal combustion temperatures, due to combustion being increasingly efficient at higher temperatures. However, safe operating temperatures of materials used in the hottest regions, such as the combustor and the turbine sections, place temperature constraints on uppermost operating temperatures. Thus, blades are commonly cooled to allow operation in environments above yield or melting temperatures of their constituent materials, whilst ensuring blade metal temperatures themselves remain below such temperature limits. In particular, high pressure turbine blades are commonly cooled using cooling air, bled from the compressor, that is significantly cooler then the main stream gas flow. Typically this air is used, in internal passages, to convectively cool the body of the blade, before being ejected on to the aerofoil surface to form a film of cool air. Such films prevent the hot main stream gas flow from overheating the aerofoil surface. To improve film cooling performance, particularly in the presences of a pressure gradient, it is known to shape, and orientate cooling holes in a particularly advantageous cooling direction.

[0003] With developing cooling hole technology, there are issues which limit the effectiveness of cooling holes in environments containing high levels of inorganic debris, which subsequently enters the main gas flow. Such environments may include, for example, a sandy- or desert-like region, or a volcanically active region, where inorganic material may be retained within the local atmosphere. In particular, shaped hole exits are prone to either restriction or blockage due to the build-up of main stream gas debris on the aerofoil surface and cooling hole exit. This reduces film performance and component life due to ineffective cooling of the turbine blade. This problem may be exacerbated by coatings, such as Thermal Barrier Coating (TBC), congregating around or within the hole during manufacture. This may reduce coolant flow rate, or a separate the film, further reducing film cooling effectiveness.

[0004] To provide restriction or blockage resistance, it is known to provide a cooling trench in a surface of the turbine blade. Thus, the cooling holes exit into the trench, so that main stream gas debris washes over the trench without interacting with the cooling hole exits. However, the application of such trenches results in the need for local wall thickening to incorporate cooling holes into the blade. This may create a local temperature increase within the thickened region for a given configuration of cooling holes, which may limit component life due to ineffective cooling. Thus, it is an object of the invention to provide an aerofoil comprising a cooling arrangement which provides either or both of a reduced susceptibility to blockage and improved cooling.

Statements

[0005] According to a first aspect there is provided an aerofoil, the aerofoil comprising a wall comprising an external surface, and an internal surface defining a cavity for receiving a cooling fluid in use. The aerofoil further comprises a first trench formed in the external surface, and a second trench formed in the external surface; a first passageway extending from a first passageway inlet in the cavity to a first passageway outlet in the first trench, and a second passageway extending from a second passageway inlet in the cavity to a second passageway outlet in the second trench. The first passageway and second passageway intersect within the wall.

[0006] The arrangement may allow respective passageways to break out into the bottom of a trench rather than the surface of the aerofoil. This may also allow the first passageway to be provided at a first angle, and the second passageway to be provided at a second angle. Such angling of the respective first and second passageways may provide the respective passageways with a downstream trajectory of a cooling fluid. Such a downstream trajectory may allow the flow vectors of the cooling fluid to at least partially match the flow vectors of the gas stream. This may aid in minimising losses and provide additional stabilisation of the resultant cooling film. Thus, the cooling film may be additionally stable and effective. Additionally, the arrangement may provide improved tolerance to either or both of restriction and blockage of the respective passageways due to debris accumulating in, or adjacent to, the respective passageway outlets. This may be achieved through the specific orientation of either or both of the passageways and configuration of the trench.

[0007] In conjunction with the first and second trenches, the configuration of the first and second passageways may provide additional internal surface area within the passageways over which to transfer heat between the walls of the respective passageways and the cooling fluid. The first passageway and second passageway intersect at an intersection point within the wall. The intersection point may be located between the first passageway inlet and the first passageway outlet, and between the second passageway inlet and second first passageway outlet. Through intersection of the first and second passageways, the arrangement may provide additional turbulation, in use, of the cooling fluid downstream of the intersection point. Such additional turbulation may provide the effect of resetting the thermal boundary layer within the respective first and second passageways at the point of intersection. Such resetting may provide an additional cooling effect by removing stagnant or slow moving flow close to the wall, so providing an increased thermal gradient in this location. This may drive higher heat transfer following the point of intersection. Such intersection of the cooling passageways may also provide additional turbulation of cooling fluid flowing into the first and second trenches if the length of the passageway following the intersection is not sufficient to fully re-establish the boundary layer. Such turbulation may also cause an increase in thermal gradient at the passageway outlet in a similar manner to that described above. By providing the first and second passageway with additional surface area for a given wall thickness and a means to restart the thermal boundary layer, the cooling effect may be improved without altering respective flow rates of cooling fluid flowing through the respective passages.

[0008] The first trench may be formed in the external surface at a first trench location. The second trench may be formed in the external surface at a second trench location. Thus, the first trench location and the second trench location may be located either side of a stagnation point. The stagnation point may be the leading edge of the aerofoil. The first trench may be configured to provide a cooling film over a first gas washed surface. The second trench may be configured to provide a cooling film over a second gas washed surface, which is distinct from the second gas washed surface. The first gas washed surface may be separated from the second gas washed surface by one or more of the stagnation point, stagnation point region, leading edge, or leading edge region. The leading edge may be cooled by conductive heat transfer between walls of the internal cavity or the respective passageways and the cooling fluid. In some examples, the first and second trenches may comprise either or both of two or more first, and two or more second passageways. Each of the respective first and second passageways may be spaced in the spanwise direction. In some examples, each of the first and second passageways spaced in the spanwise direction may form discrete pairs of passageways. The spanwise spacing between each pair may be equal. The spanwise spacing between each pair may be disparate.

[0009] The first trench location and the second trench location may be located adjacent the stagnation point. Thus, the portion of the aerofoil cooled by conductive heat transfer between walls of the respective passageways and the cooling fluid may be minimised. The external surface area of the aerofoil cooled by heat transfer between the external surface and the cooling film may be maximised. In locating the first and second trench adjacent the leading edge, the respective first and second trench locations may be located either side of, and adjacent to, an intended stagnation point. Thus, the first and second trench location may extend in a spanwise direction. The first and second trench location may be located at a respective first and second chordwise location in the external surface.

[0010] The wall may comprise a thickened region, adjacent the first and second location, comprising a wall thickness which is greater than the wall thickness at a pressure or suction surface of the aerofoil. Thus, the single thickened region may comprise the first trench location and the second trench location. Furthermore, the single thickened region may comprise the first passageway and second passageway. In further examples, a first and second thickened region of the respective first and second locations may be distinct. Thus, each thickened region may comprise a first trench location or a second trench location.

[0011] The first passageway may comprise a first longitudinal axis. The second passageway may comprise a second longitudinal axis. The first and second longitudinal axes may extend over a substantial portion of the respective first and second passageways. The first and second passageway may be substantially straight over an entire axial length of the passageways. Thus, first and second longitudinal axes may extend through both the passageway inlets in the cavity and the passageway outlets in the trench. Alternatively, the passageways may comprise one or more curved or angled portions, wherein the longitudinal axes extends over only a portion of the passageways, and through the passageway outlets only. Thus, the first and second passageways may be at least substantially straight. Alternatively, the first and second passageways may be at least substantially curved.

[0012] The first longitudinal axis and the second longitudinal axis may define a dihedral angle. The dihedral angle may be the internal angle between the first longitudinal axis and the second longitudinal axis, downstream of the intersection point, the dihedral angle may be between about 5 to about 170 degrees. The dihedral angle may be between about 10 to about 140 degrees. The dihedral angle may be between about 15 to about 110 degrees. The dihedral angle may be between about 20 to about 90 degrees. The dihedral angle may be between about 25 to about 70 degrees.

[0013] The first longitudinal axis and the second longitudinal axis may extend in a chordwise direction. The first longitudinal axis and the second longitudinal axis may be located at a first and second spanwise location in the external surface. The first longitudinal axis and the second longitudinal axis may extend in a chordwise direction at or from the respective first and second spanwise locations. The first longitudinal axis and the second longitudinal axis may extend along a single plane. The plane may be a chordwise plane substantially perpendicular to the spanwise direction of the first trench and the second trench.

[0014] The first longitudinal axis may intersect a first tangent of the external surface at the first location at a first angle. The second longitudinal axis may intersect a second tangent of the external surface at the second location at a first angle. Thus, the respective first angles provide the first passageway with a downstream trajectory relative to the first tangent, and the second passageway with a downstream trajectory relative to the second tangent. In some examples, the respective first angles may be equal. In further examples, the respective first angles may be disparate. The first angle may define an angle between the respective first and second longitudinal axes of the first and second passageways, and a portion of the respective first and second tangents at the first and second locations. The first angle may be an interior angle at the intersection between the respective longitudinal axes of the first and second passageways, and the respective tangents of the external surface. Thus, the first angles may extend downstream of, and between the respective longitudinal axes and the tangents of the external surface. The first angle may be an open angle, i.e. where the first angle is at least 90 degrees. In some examples, the first angles may be between about 90 and about 165 degrees. The first angles may be between about 93 and about 150 degrees. The first angles may be between about 95 and about 140 degrees.

[0015] The first and second trenches may comprise respective laidback second sidewalls downstream of the respective passageway outlets. Thus, the term laidback means that the respective second sidewalls are at a greater angle, relative to the respective tangents, than the respective longitudinal axes. The laidback second sidewalls may reduce either or both of mixing losses and turbulent flow downstream of the respective trenches, by expanding or diffusing the flow before it enters the gas stream. Thus, the laidback sidewalls may provide improved mixing of the cooling fluid with the main stream fluid flow. Improved flow, or mixing, of the cooling fluid on the surface of the aerofoil, via the laidback sidewalls, may provide both an increasingly stable and effective cooling film. Thus, the arrangement may provide a reduction in the amount of cooling fluid used, and hence improved component efficiency, and increased component life. Such improvements may result in enhanced engine performance, reduced operating costs, and increased efficiency.

[0016] A tangent of the second sidewall of the first trench may intersect the first tangent of the external surface at the first location at a second angle. A tangent of the second sidewall of the second trench may intersect the second tangent of the external surface at the second location at a second angle. Thus, the respective second sidewalls provide the second sidewalls with a downstream trajectory relative to the respective first and second tangents. The respective second angles may greater than the respective first angles, relative to the respective first and second tangents. The second angles may define an angle between the tangents of the respective second sidewalls, and a portion of the respective tangents of the external surface at the first and second locations. The second angles may be an interior angle at the intersection between respective tangents of the respective second sidewalls, and the respective tangents of the external surface. Thus, the second angles may extend downstream of, and between the respective tangents of the second sidewalls, and the tangents of the external surface. The second angle may be an open angle, i.e. where the second angle is at least 90 degrees. In some examples, the second angles may be between about 90 and about 175 degrees. The second angles may be between about 94 and about 160 degrees. The second angles may be between about 96 and about 150 degrees.

[0017] In further examples, the first angles and second angles may be measured relative any one or more of a different reference plane, tangent, axis or feature. However, in all examples, the second angles provide the laidback sidewall with an increasingly downstream trajectory relative to the respective first angles. In some examples, the second angles may be greater than the first angles by between about 0 and about 60 degrees. In some examples, the second angles may be greater than the first angles by between about 0.5 and about 60 degrees. In some examples, the second angles may be greater than the first angles by between about 1 and about 40 degrees [narrow]. The second angles may be greater than the first angles by between about 5 and about 20 degrees. The laidback sidewalls may be aft of the passageway exits. Furthermore, at least a portion of the laidback sidewalls may be aft of the respective longitudinal axes of the respective passageways.

[0018] The first and second passageways may comprise both a first major axis and a first minor axis adjacent the respective passageway inlets, and both a second major axis and a second minor axis adjacent the respective passageway outlets. The second major axes adjacent the respective passageway outlets may be greater than the first major axes adjacent the respective passageway inlets. The respective passageways may terminate in a divergent profile adjacent the respective passageway outlets. Each of the first minor axis, second major axis, first major axis and second minor axis may comprise a respective length. Thus, the respective first and second passageways may diverge, or increase from a first major axis either or both of adjacent the respective passageway inlets and downstream of the intersection point, to a second major axis adjacent the respective passageway outlets. The divergence may occur over the entire length of the first and second passageways. Alternatively, the divergence may occur over only a portion of the first and second passageways. Thus, the first and second passageways may diverge immediately adjacent the respective passageway outlets. Thus, the reduced velocity of the cooling fluid may act to provide enhanced film cooling onto the external surface of the aerofoil. In some examples, the first major axes may be between about 0.1mm and about 3mm. The first major axes may be between about 0.2mm and about 2mm. The first major axes may be between about 0.2mm and about 1mm. In some examples, the second major axes may be between about 0.1mm and about 3mm. The second major axes may be between about 0.2mm and about 2mm. The second major axes may be between about 0.2mm and about 1 mm.

[0019] Additionally or alternatively, the respective passageways may diverge, or increase from a first minor axis either or both of adjacent the respective passageway inlets and downstream of the intersection point, to a second minor axis adjacent the respective passageway outlets. The second minor axes may be greater than the first minor axes. Such divergence may occur over the entire length of the passageways. Alternatively, the passageways may not diverge, or increase from the first minor axis. The respective second minor axes may be equal to the respective first minor axes. In some examples, the first minor axes may be between about 0.1mm and about 3mm. The first minor axes may be between about 0.2mm and about 2mm. The first minor axes may be between about 0.2mm and about 1mm. In some examples, the second minor axes may be between about 0.1mm and about 3mm. The second minor axes may be between about 0.2mm and about 2mm. The second minor axes may be between about 0.2mm and about 1mm.

[0020] The passageways may terminate in a two dimensional divergent profile adjacent the respective passageway outlets. The two dimensional divergent profiles may diverge along the first and second longitudinal axes. Thus, the passageways may diverge along the first and second longitudinal axes in a further dimension. The further dimension may be the x axis. The further dimension may be the y axis. The further dimension may be the z axis. In some examples, the second major axis of the passageway outlets may be greater than the first major axes of the passageway inlets. Thus, the respective second minor axes of the passageway outlets may be approximately equal to the respective first minor axes of the passageway inlets. Alternatively, the respective second minor axes of the passageway outlets may be greater than the respective first minor axes of the passageway inlets. Thus, the respective second major axes of the passageway outlets may be approximately equal to the respective first major axes of the passageway inlets. The respective second minor axes of the passageway outlets may be less than the respective first minor axes of the passageway inlets. Alternatively, the respective second major axes of the passageway outlets may be less than the respective first major axes of the passageway inlets. The two dimensional divergent profiles may be in the form of a fan. The two dimensional divergent profiles may be in the form of a slot. The cross-sectional profiles may be perpendicular to the respective longitudinal axes.

[0021] The passageways may terminate in a three dimensional divergent profile adjacent the first and second passageway outlets. The three dimensional divergent profiles may diverge along the respective first and second longitudinal axes. Thus, the passageways may diverge along the respective longitudinal axes in two or more further dimensions. The two further dimensions may be two or more of the x, y and z axes. In this way, the respective second major axes of the passageway outlets may be greater than the respective first major axes of the passageway inlets. The respective second minor axes of the passageways outlets may be greater than the respective first minor axes of the passageway inlets. The three dimensional divergent profiles may be in the form of a cone. The three dimensional divergent profiles may be in the form of a fan. The cross-sectional profiles may be perpendicular to the respective longitudinal axes.

[0022] The passageway outlets may terminate in the cross-sectional profile of an ellipse. In further examples, the passageway outlets may terminate in the cross-sectional profile of a circle. In further examples, the passageway outlets may terminate in the cross-sectional profile of a slot. In further examples, the passageway outlets may terminate in the cross-sectional profile of a regular polygon. The passageway outlets may terminate in the cross-sectional profile of an irregular polygon. The passageway outlets may terminate in the cross-sectional profile of a rectangle. The passageway outlets may terminate in the cross-sectional profile of an oval. The oval may comprise two parallel sides.

[0023] The first and second trenches may comprise a trench depth which may be equal to or less than the respective second major axes. The respective trench depths may be equal to or less than the respective first major axes. The trench depths may be between about 0.1 and about 3 times the respective first major axes. The trench depths may be between about 0.3 and about 2 times respective first major axes. The trench depths may be between about 0.5 and about 1.5 times the respective first major axes. The respective trench depths may represent a distance between the first tangent of the external surface at the respective first or second locations, and parallel tangents of the bottom of the first and second respective trenches. Thus, the bottom of the trenches may represent the deepest point within the respective trenches, relative to the external surface. The bottom of the trench may be a single location within a curved bottom surface, or may be a planar portion as part of a bottom wall.

[0024] One or more of the respective first side walls and the respective second side walls may comprise a planar portion. Thus, one or more of the first side wall, and the second side wall may comprise a least a portion which is linear, or flat. Additionally or alternatively, one or more of the respective first side walls, and the respective second side walls may comprise a curved portion. Thus, one or more of the first side wall, and the second side may be curvilinear, or curved. Thus, the respective first side wall and second side walls may merge to form an arcuate profile. Trenches may comprise three or more sides. Thus, one or more of the first trench and the second trench may comprise three or more faces within the trench. One or more of the faces may be the planar portion as part of the bottom wall. According to further examples, the trench may further comprise two or more bottom walls. Thus, in further examples, one or more of the first side wall, second side wall, and bottom wall may merge to form an arcuate profile. Additionally or alternatively, respective trenches may comprise two or more sides. Thus, one or more of the first trench and the second trench may comprise two or more distinct faces within the trench.

[0025] The first and second trenches may comprise a trench width which is equal to or greater than the respective second major axes. The first and second trenches may comprise a trench width which is equal to or greater than the respective first major axes. The trench width may be between about 0.3 and about 3 times the first major axis. The trench width may be between about 0.5 and about 2 times the first major axis. The trench width may be between about 0.8 and about 1.5 times the first major axis.

[0026] According to a second aspect, there is provided a gas turbine engine comprising, except where mutually exclusive, an aerofoil comprising any one or more features previously described. According to a third aspect, there is provided a geared turbo fan comprising, except where mutually exclusive, an aerofoil comprising any one or more features previously described. In some examples, the aerofoil may be a turbine blade. In further examples, the aerofoil may be a vane.

[0027] The skilled person will appreciate that except where mutually exclusive, a feature described in relation to any one of the above aspects may be applied mutatis mutandis to any other aspect. Furthermore except where mutually exclusive any feature described herein may be applied to any aspect and/or combined with any other feature described herein.

Brief Description

[0028] Embodiments will now be described by way of example only, with reference to the Figures, in which:

- **Fig.1** is a sectional side view of a gas turbine engine;
- **Fig.2** is an expanded sectional view of a gearbox and compression section;
- **Fig.3** is a sectional frontal view of the gearbox;
- **Fig.4** is a plan view of an aerofoil known within the art;
- **Fig.5** is a plan perspective view of an aerofoil comprising a cooling arrangement;
- **Fig.6a** is a wire frame perspective of the cooling hole arrangement of Fig.5;
- **Fig.6b** is a wire frame perspective of the cooling hole arrangement of Fig.6a;
- **Fig.6c** is a wire frame perspective of the cooling hole arrangement of Fig.6a;
- **Fig.6d** is an exploded perspective of the cooling hole arrangement shown in Fig.6a;
- **Fig.7a** is a perspective view of the aerofoil of Fig.5, along with section A-A';
- **Fig.7b** is a first sectional view of section A-A';
- **Fig.7c** is a second sectional view of section A-A';
- **Fig.8a** is a perspective view of the aerofoil of Fig.5, along with section B-B";
- **Fig.8b** is a first sectional view of section B-B"; and,
- **Fig.8c** is a second sectional view of section B-B", according to examples of the present disclosure.

Specific Description

[0029] Fig.1 illustrates a gas turbine engine 110 having a principal rotational axis 109. The engine 10 comprises an air intake 112 and a propulsive fan 123 that generates two airflows A and B. The gas turbine engine 100 comprises a core engine 111 having, in axial flow A, a low pressure compressor 14, a high-pressure compressor 115, combustion equipment 116, a high-pressure turbine 117, a low pressure turbine 119 and a core exhaust nozzle 120. A nacelle 121 surrounds the gas turbine engine 110 and defines, in axial flow B, a bypass duct 122 and a bypass exhaust nozzle 118. The fan 123 is attached to and driven by the low pressure turbine 119 via shaft 126 and epicyclic gearbox 130.

[0030] The gas turbine engine 110 works in a conventional manner with air in the core airflow A being accelerated and compressed by the low pressure compressor 14 and directed into the high pressure compressor 115 where further compression takes place. The compressed air exhausted from the high pressure compressor 115 is directed into the combustion equipment 116 where it is mixed with fuel and the mixture is combusted. The resultant hot combustion products then expand through, and thereby drive the high pressure and low pressure turbines 117, 119 before being exhausted through the nozzle 120 to provide some propulsive thrust. The high pressure turbine 117 drives the high pressure compressor 115 by a suitable interconnecting shaft. The fan 123 generally provides the majority of the propulsive thrust. The epicyclic gearbox 130 is a reduction gearbox.

[0031] A known mechanical arrangement for a geared fan gas turbine engine 110 is shown in Fig.2. The low pressure turbine 119 drives the shaft 126, which is coupled to a sun wheel, or sun gear, 128 of the epicyclic gear arrangement 130. Radially outwardly of the sun gear 128 and intermeshing therewith, in a conventional manner, is a plurality of planet gears 132 that are coupled together by a planet carrier 134. The planet carrier134 constrains the planet gears 132 to precess around the sun gear 128 in synchronicity whilst enabling each planet gear 132 to rotate about its own axis. The planet carrier 134 is coupled via linkages 136 to the fan 123 in order to drive its rotation about the engine axis 19. Radially outwardly of the planet gears 132 and intermeshing therewith is an annulus or ring gear 138 that is coupled, via linkages 140, to a stationary supporting structure 124.

[0032] The epicyclic gearbox 130 is of the planetary type, in that the planet carrier 134 rotates about the sun gear 128 and is coupled to an output shaft via linkages 136. In other applications the gearbox 130 may be a differential gearbox in which the ring gear 138 also rotates in the opposite sense and is coupled to a different output shaft via linkages 140. An epicyclic gearbox 130 must be lubricated, by oil or another fluid. However, the oil becomes heated by being worked during operation of the epicyclic gearbox 130. Furthermore, the oil may accumulate particulate debris from the components of the epicyclic gearbox 130 which may cause seizing or other problems. It is therefore necessary to eject the oil efficiently from the epicyclic gearbox 130 to allow its replacement by spraying in fresh, cool oil. Ejection of the oil, particularly when it is collected for cleaning before being returned to the reservoir from which fresh oil is supplied, is referred to as oil scavenge.

[0033] A typical arrangement of the epicyclic gearbox is shown in Fig.3. Each of the sun gear 128, planet gears 132 and ring gear 138 comprise teeth about their periphery to intermesh with the other gears. However, for clarity only exemplary portions of the teeth are illustrated in Fig.3. There are four planet gears 132 illustrated, although it will be apparent to the skilled reader that more or fewer planet gears 132 may be provided within the scope of the claimed invention. Practical applications of a planetary epicyclic gearbox 130 generally comprise at least three planet gears 132.

[0034] Additionally or alternatively the gearbox may drive additional and/or alternative components (e.g. the intermediate pressure compressor and/or a booster compressor, propeller (aero or hydro), or electrical generator). Additionally or alternatively such engines may have an alternative number of compressors and/or turbines and/or an alternative number of interconnecting shafts.

[0035] Unless otherwise stated, the terms "axial" or "axially" refer to the principal and rotational axis 109, describing a dimension along a longitudinal axis of the gas turbine engine 10. The terms "aft" or "downstream", unless otherwise stated, refers to a direction towards either or both of the rear and outlet of the gas turbine engine 10 relative to the principal and rotational axis 109. The terms "forward" or "upstream", unless otherwise stated, refers to a direction towards either or both of the front and inlet of the gas turbine engine 10 relative to the principal and rotational axis 109, or refer to a component being relatively closer to the inlet of the gas turbine engine 10 as compared to a further component.

[0036] Unless otherwise stated, the terms "radial" or "radially" refer to a dimension extending between the principal and rotational axis 109 and an outwardly displaced circumference therefrom. The terms "proximal" or "proximally," unless otherwise stated, refers to a direction towards the principal and rotational axis 109, or a component being relatively closer to the principal and rotational axis 109 as compared to a further component. The use of the terms "distal" or "distally," unless otherwise stated, refers to a direction towards the outwardly displaced circumference, or a component being relatively closer to the outwardly displaced circumference as compared to a further component. Directional references (i.e., radial, axial, proximal, distal, upper, lower, upward, downward, left, right, lateral, front, back, top, bottom, above, below, vertical, horizontal, clockwise, counterclockwise, upstream, downstream, aft, etc.) are to aid the reader's understanding of the arrangement and are, unless otherwise stated, not intended to limit the position, orientation, or use. Connection references (i.e., attached, coupled, connected, and joined) are to be construed broadly and can include intermediate members and relative movement between elements unless otherwise stated. Connection references are, unless otherwise stated, not intended to infer that two elements are directly connected to, or in fixed relation to each other. Furthermore, the exemplary drawings are for purposes of illustration only and the dimensions, positions, order and relative sizes reflected in the drawings may vary.

[0037] Fig.4 illustrates a cross-sectional plan perspective of a known aerofoil 20. The known aerofoil 20 is a high pressure turbine blade forming part of the high pressure turbine 117 assembly. The aerofoil 20 comprises a cavity 21 defined by one or more internal surfaces 22. The aerofoil 20 comprises a suction surface 23 and a pressure surface 24. The suction surface 23, pressure surface 24, leading edge 25 and the trailing edge 26 extend between a root and a tip. The aerofoil 20 also comprises a camber line 31, which represents the mean camber extending between the leading edge 25 and the trailing edge 26. The external surface of the aerofoil 20, being that of one or more of the suction surface 23, pressure surface 24, and leading edge 25, is also shown to comprise a normal axis 32 extending in a direction perpendicular to a tangent 33 of the external surface. The normal direction 32 is shown, for example, to extend perpendicularly relative to the pressure surface 24, but may extend perpendicularly relative to any such further external surface.

[0038] The aerofoil 20 comprises a leading edge 25, and a trailing edge 26 which is aft, or downstream, of leading edge 25. The leading edge is defined, in use, by a stagnation point, the stagnation point being a region of the aerofoil 20 when incident flow splits in order to flow over either the pressure surface or the suction surface of the aerofoil 20. Thus, the leading edge 25 is the portion of the aerofoil which first meets the gas flow 27. In some examples, the leading edge 25 may represent a region of the external surface which is substantially perpendicular to the gas flow direction 27. In some examples, the leading edge 25 may represent a region of the external surface which is immediately adjacent to the area substantially perpendicular to the gas flow direction 27. In some examples, the trailing edge 26 may represent a region of the external surface where the pressure surface 24 meets the suction surface 23. In some examples, the trailing edge 26 may represent a region of the external surface, aft of the leading edge 25, where the fluid flow separated by the leading edge 25 rejoins. The trailing edge 26 is aft of the leading edge 25, so being spaced from the leading edge 25 in a chordwise direction 29. The distance between the leading edge 25 and the trailing edge 26 may be expressed as a chord length which extends along a chord line 30 between the leading edge 25 and the trailing edge 26. The chord length is the distance between the trailing edge 26 and the point on the leading edge 25 where the chord intersects the leading edge 25. The distance between the leading edge 25 and the trailing edge 26 may be expressed as a length which extends in a chordwise direction 29. The aerofoil 20 is shown to be at angled at a particular angle of attack 28, which extends parallel to the gas flow direction 27, and which may vary according to requirements. In some examples, the angle of attack may be measured relative to the chord line 30. In further examples, the angle of attack may be measured relative to the chordwise direction 29.

[0039] Fig.5 shows an example of an aerofoil 40 comprising a cooling arrangement. The aerofoil 40 shown is a high pressure turbine blade, forming part of the high 17 pressure turbine assembly. In further examples, the aerofoil 40 may be a turbine, vane, or compressor blade for use in a defined stage of the aforementioned subassemblies, or a further aerofoil for use in a gas turbine engine 10. The aerofoil 40 comprises a wall comprising an external surface. The wall may be any one of a suction surface 43, a pressure surface 44, a leading edge 45 and a trailing edge 46 spaced from the leading edge 45, in a chordwise direction 49 along a chord line 50. The aerofoil 40 comprises a cavity 41 defined by an internal surface 42. The cavity 41 is configured to receive a cooling fluid, in use. The suction surface 43, pressure surface 44, leading edge 45 and the trailing edge 46 extend between a root 57 and a tip 58. The tip 58 is spaced from the root 57 in a spanwise direction 59. The spanwise direction 59 extends from the root 57 towards the tip 58. In some examples, the spanwise direction 59 extends perpendicularly from the root 57 towards the tip 58.

[0040] A first trench 60a and a second trench 60b are formed in the external surface, comprising a longitudinal length. The first trench 60a is formed in the pressure surface 44 of the aerofoil 40 at a first location 51a, measured along the chord line 50a relative to the leading edge 45. The second trench 60b is formed in the suction surface 43 of the aerofoil 40 at a second location 51b, measured along the chord line 50a relative to the leading edge 45. The chord length is traditionally measured over a chord line at a specific spanwise location, and can vary in length with radius. The chord length is defined as minimum distance from the leading edge to the trailing edge at a specified spanwise height. In Fig.5, the chord length is measured over a chord line 50a at the root 57 of the aerofoil. Additionally or alternatively, the chord length may be measured over a chord line 50b at the tip 58 of the aerofoil. In further examples, the aerofoil 40 may comprise a number of further chord lines at various distances in the spanwise direction 59 measured relative to the root 57, on either or both of the suction surface 43 and the pressure surface 44. Such chord lines may include a chord line measured at, for example, the median location of the aerofoil 40. The chord lengths of the further chord lines may vary according to the degree of curvature and the particular shape of the respective aerofoil 40. Thus, the chordwise location of the first and second trenches 60a,60b may be expressed as a percentage value of the chord length. Thus, the first and second trenches 60a,60b are shown to extend in the spanwise direction 59 at respective first and second chordwise locations 51a,51b. The respective first and second trenches 60a,60b may extend from and to particular percentages of the chord length over a range of spanwise distances measured relative to the root 57.

[0041] The first and second trenches 60a,60b are separated by the leading edge 45, defined, in use, by the designed stagnation point. The respective first and second trenches 60a,60b extend between an area spaced from the root 57 and an area spaced from the tip 58. The trench 60 is orientated in a spanwise direction 59 and follows the curvature of the external surface within which it is formed. In some examples, the trench 60 is of a constant depth over the longitudinal length of the trench 60. In further examples, the trench 60 may be of variable depth over the longitudinal length of the trench 60.

[0042] Fig.6a illustrates a cross-section of the aerofoil 40 shown in Fig.5. In particular, Fig.6a shows the first trench 60a, and a first passageway 62a extending from a first passageway inlet 64a in the cavity 41, to a first passageway outlet 66a in the first trench 60a. Fig.6a also shows the second trench 60b, and a second passageway 62b extending from a second passageway inlet 64b in the cavity 41, to a second passageway outlet 66b in the second trench 60b. The first trench 60a and second trench 60b are formed in the leading edge region, i.e. the respective regions immediately adjacent the leading edge. In further examples, the first trench 60a may be formed in the pressure surface 44, downstream of the leading edge 45. The second trench 60b may be formed in the suction surface 43 downstream of the leading edge 45. In order to accommodate both the first and second trenches 60a,60b, and the respective passageways 62a,62b, the wall of the aerofoil in the region surrounding the trenches is thickened, providing a thickened region 65. The thickened region 65 is shown adjacent the first trench 60a at the first location 51a, and the second trench 60b at the second location 51b. The thickened region 65 comprises a wall thickness which is greater than the wall thickness at a pressure or suction surface of the aerofoil. The aerofoil 40 may comprise a single thickened region 65 accommodating the first passageway 62a, first trench 60a, second passageway 62b, and second trench 60b. In further examples, the aerofoil 40 may comprise may comprise two or more thickened regions, each located at a respective trench location 51a,51b.

[0043] The first passageway 62a and the second passageway 62b intersect at an intersection point 67 within the wall of the aerofoil 40. In the example shown, the intersection point 67 is located in line with, and aft of the leading edge 45 per se. Hence, the first passageway 62a and the second passageway 62b are configured within the wall in the same plane, which is at an equivalent offset in the spanwise direction 59 from the root 57. In some examples, the first passageway 62a and the second passageway 62b may be orientated towards the tip 58. In some examples, the first passageway 62a and the second passageway 62b may be orientated towards the root 57. In alternative examples, the first passageway 62a and the second passageway 62b may be configured within the wall in dissimilar planes, relative to the spanwise direction 59. For example, the first passageway 62a may be orientated towards the tip 58, and the second passageway 62b may be orientated towards the root 57, or vice-versa. In all examples however, the first passageway 62a and the second passageway 62b are configured to intersect at the intersection point 67. In further examples, the intersection point 67 may be in line with a camber line, or a gas flow direction. In further examples, the intersection point may be adjacent to, or laterally displaced from the camber line, or the gas flow direction. It will also be appreciated that in further examples, there may be a plurality of first passageways 62a and a plurality of second passageways 62b. Thus, there may be a plurality of intersection points 67 in each intersecting trench arrangement. Thus, it will also be appreciated that there may be a plurality of intersecting trench arrangements spaced in the spanwise direction 59.

[0044] Fig.6b shows an exploded view of the first trench 60a shown in Fig.5. The first passageway 62a extends downstream from the intersection point 67 to a first passageway outlet 66a in the first trench 60a. The aerofoil 40 is shown to comprise a plurality of such first passageways 62a. The first passageways 62a are shown to be spaced in the spanwise direction 59 along the first trench 60a. Furthermore, the first trench 60a may comprise either a single or a plurality of first passageways 62a, according to requirements.

[0045] Fig.6c shows an exploded view of the second trench 60b shown in Fig.5 and 6a. The second passageway 62b extends downstream from the intersection point 67 to a second pasageway outlet 66b in the second trench 60b. The aerofoil 40 is shown to comprise a plurality of such second passageways 62b. Each second passageway 62b is shown to be spaced in the spanwise direction 59 along the second trench 60b. Furthermore, the second trench 60b may comprise either a single or a plurality of second passageways 62b, according to requirements.

[0046] Fig.6d shows an enlarged view of the first trench 60a, previously shown in Fig.6b. It will be appreciated that the features described herewith, in relation to Fig.6d, apply equally to the second passageway 62b, second trench 60b, second passageway inlet 64b, second passageway outlet 66b, and their respectively associated features, shown in Figs.6a and 6c, mutatis mutandis. Fig.6d shows the direction of flow of an incident working fluid 73, flowing over pressure surface 44 of the aerofoil 40 in a direction of flow. Fig.6d also shows a flow of cooling fluid 70, from the cavity 41, flowing along a first longitudinal passageway axis 72a before exiting the first passageway 62a into the first trench 60a. It will however be appreciated that, regarding the second trench 60b, the flow of cooling fluid 70 flows along a second longitudinal passageway axis 72b before exiting the first passageway 62a into the second trench 60b. In the example shown, first and second sidewalls 74,76 merge to form an arcuate, or curvilinear profile. In further examples, the first and second sidewalls 74,76 may be parallel or angled relative to one another. In some examples, such as shown in Fig.6d, the second sidewall 76 is downstream of the first passageway outlet 66a, and laidback relative to the first passageway axis 72a.

[0047] The first passageway axis 72a extends along the first passageway 62a from the first passageway inlet 64a, past the intersection point 67, and to the first passageway outlet 66a. Fig.6d also shows that, downstream of the intersection point 67, the first passageway 62a comprises both a first major axis 78a and a first minor axis 80a adjacent the intersection point 67, and both a second major axis 78b and a second minor axis 80b adjacent the first passageway outlet 66a. Thus, it will be appreciated that the first major axis 78a and a first minor axis 80a immediately downstream of the intersection point 67is equal to the first major axis 78a and a first minor axis 80a at the first passageway inlet 64a.

[0048] The respective major axes 78a,78b represent the largest diameter across a cross-section of the respective passageways 62a,62b at a given position along the respective passageway axes 72a,72b. The major axes may be perpendicular to the longitudinal passageway axes 72a,72b. In some examples, the largest diameter across the passageways 62a,62b are provided across the divergent profile at the location of the respective passageway outlets 66a,66b into the respective first and second trenches 60a,60b. Thus, the second major axis 78b may be indicative of the direction of divergence. The first major axis 78a represents a diameter across the respective passageways 62a,62b in a direction parallel to the second major axis 78b. Thus, the first major axis 78a represents a diameter across the respective passageways 62a,62b, prior to divergence. According to examples, the first major axis 78a represents a diameter across the respective passageways 62a,62b at the respective passageway inlets 64a,64b. In the example shown in Fig.6d, the major axes 78a,78b are shown to extend in a longitudinal direction relative to the first trench 60a. In some examples, the major axes 78a,78b may extend in a spanwise direction. In further examples, the major axes 78a,78b may extend in a chordwise direction.

[0049] The respective minor axes 80a,80b represent the smallest diameter across a cross-section of the respective passageways 62a,62b at a given position along the respective passageway axes 72a,72b. The minor axis may be perpendicular to the longitudinal passageway axes 72a,72b. In some examples, the smallest diameter across the passageways 62a,62b is perpendicular to the largest diameter across the divergent profile at the location of the respective passageway outlets 66a,66b into the respective first and second trenches 60a,60b. Thus, the second minor axis 80b may be perpendicular to either or both of the second major axis 78b, or the direction of divergence. According to examples, the first minor axis 80a represents a diameter across the respective passageways 62a,62b, in a direction parallel to the second major axis 80b. According to examples, the first minor axis 80a represents a diameter across the respective passageways 62a,62b, prior to divergence. Additionally or alternatively, the first minor axis 80a represents a diameter across the respective passageways 62a,62b at the respective passageway inlets 64a,64b. In the example shown in Fig.6d, the minor axes 80a,80b are shown to extend in a transverse direction relative to the first trench 60a. In some examples, the minor axes 80a,80b may extend in a chordwise direction. In further examples, the minor axes 80a,80b may extend in a spanwise direction.

[0050] In some examples, the first major axis 78a and second major axis 78b extend along a chordwise plane. In further examples, the first major axis 78a and second major axis 78b extend along different planes. In either example, either or both of the respective passageways 62a,62b and respective passageway axes 72a,72b may twist or vary. Such twisting may promote a vortical flow of cooling fluid flowing within either or both of the respective passageways 62a,62b. Referring again to Fig.6d, the second major axis 78b adjacent the respective passageway outlets 66a,66b, is greater than the first major axis 78a, shown downstream of the intersection point 67. Thus, the respective passageways 62a,62b diverge along the longitudinal passageway axes 72a,72b from the first major axis 78a towards the second major axis 78b. The respective passageways 62a,62b terminate in a divergent profile adjacent the respective passageway outlets 66a,66b. The divergent profile may diverge in at least two dimensions. Thus, the respective passageway outlets 66a,66b may have a cross-sectional shape of, for example, any one of an elongate slot, oval, regular polygon, irregular polygon, or any further shape according to requirements.

[0051] In some examples, the second minor axis 80b may be substantially equal to the first minor axis 80a. In some examples, the first major axis 80a may equal the first minor axis 78a. Thus, the respective passageways 62a,62b may not diverge along the longitudinal passageway axes 72a,72b. In further examples, the divergent profile may diverge in three dimensions. In yet further examples, the first minor axis 78a may be greater than the second minor axis 78b.

[0052] Figs.7a-7c show projections of the aerofoil 40 shown in Fig.5. In addition, Fig.7a shows a cross section through both the aerofoil 40 and the first trench 60a between points A-A'. Cross-section A-A' provides a chordwise cross-section of the aerofoil 40 taken at the midpoint of the span. Fig.7b shows a cross-sectional perspective of the aerofoil 40 and an example of the first trench 60a, of the type described in Figs.5-6d, between points A-A'. It will be appreciated that the features described herewith, in relation to Figs.7a-8c, apply equally to the second passageway 62b, second trench 60b, second passageway inlet 64b, second passageway outlet 66b, and their respectively associated features, shown and described in relation to Figs.6a and 6c, mutatis mutandis.

[0053] Figs.7b and 7c show the first passageway 62a extending along the first longitudinal passageway axis 72a, to the first passageway outlet 66a in the first trench 60. Normal axes $52a_1$,$52a_2$ (not shown) extend perpendicularly relative to the external surface at a first and second location 51a,51b. The first passageway axis 72a is shown to be canted, at a first angle $84a_1$, from the normal axis $52a_1$, which extends in a direction perpendicular to a first chordwise tangent 82a of the external surface, so that the first passageway axis 72a is directed downstream, in a chordwise direction. The first chordwise tangent 82a at the first location 51a intersects the first passageway axis 72a at the first angle $84a_1$, which provides the first passageway 62a with a downstream trajectory relative to the normal axis $52a_1$.

[0054] The first angle $84a_1$,$84a_2$ (not shown) defines an angle between the respective first and second passageway axes 72a,72b, and a portion of respective first chordwise tangent 82a of the external surface, at the first and second locations 51 a,51 b. The first angle $84a_1$,$84a_2$ is ordinarily taken to be an interior angle at the intersection between the respective longitudinal axes 72a,72b of the first and second passageways 62a,62b, and the respective first chordwise tangent 82a. Thus, the first angle $84a_1$,$84a_2$ ordinarily extends downstream of, and between the respective longitudinal axes 72a,72b and respective first chordwise tangents 82a. The first angle $84a_1$,$84a_2$ is at least 90 degrees. Thus, the first angle $84a_1$,$84a_2$ provides the respective passageway axes 72a,72b with a downstream trajectory relative to the respective normal axes $52a_1$,$52a_2$. The first angle $84a_1$,$84a_2$ is a first chordwise angle. It will be appreciated that further constructions of the first angle $84a_1$,$84a_2$ are possible and within the scope of the current disclosure.

[0055] The first trench 60a is shown to comprise a first sidewall 74, a second sidewall 76, and a trench bottom surface 75. In some examples, trench 60 may contain one or more first sidewalls 74, one or more second sidewalls 76, and optionally one or more bottom surfaces 75. The bottom of the trench describes a location of the trench having the greatest depth relative to the external surface at the first location 51a. The bottom surface 75 may be a planar section of constant depth. Alternatively, the bottom surface 75 may be a planar section of varying depth. The bottom surface 75 may be a non-planar section of varying depth relative to the external surface at the first location 51a. The bottom of the trench 60 may comprise a linear surface. Alternatively, the bottom of the trench 60 may not comprise a bottom surface, i.e., the first sidewall 74 may abut, or merge, into the second sidewall 76.

[0056] The first trench 60a comprises a trench depth 91 which is equal to or less than the second major axis 78b. The trench depth 91 represents a distance between the tangent of the external surface at the first location

51a, and a parallel tangent of the bottom of the trench 60. In some examples, the trench depth 91 may be equal to or less than the second major axis 78b. In further examples, the trench depth 91 may be equal to or less than the first major axis 78a. The first trench 60a further comprises a trench width 93 which is equal to or greater than the second major axis 78b. In some examples, the trench width 93 represents a distance between the first sidewall 74 and the second sidewall 76. In some examples, the trench width 93 may be equal to or greater than the second major axis 78b, or alternatively, equal to or greater than the first major axis 78a.

[0057] In Fig.7c, the first passageway axis 72a of the first trench 60a is angled, relative to the first chordwise tangent 82a at the first location 51a, at a greater angle than in the example of Fig.7b. Thus, the first passageway axis 72a is increasingly angled in the chordwise direction 49 (i.e. towards the trailing edge 46) relative to the trench shown in Fig.7b. The first angle $84a_1$,$84a_2$ may vary according to, for example, one or more of the spanwise or chordwise position of the first trench 60a, the position of the first passageway 62a in the first trench 60a, or cooling requirements, according to predetermined conditions.

[0058] In Figs.7b and 7c, the second sidewall 76 is laidback from the first longitudinal passageway axis 72 at an increased second angle $88a_1$ relative to the first chordwise tangent 82a. The second angle $88a_1$, $88a_2$ (not shown) defines an angle between the tangent 86 of the respective second sidewalls 76, and a portion of the first chordwise tangent 82a of the external surfaces at the respective first and second locations 51 a,51 b. The second angle $88a_1$,$88a_2$ is ordinarily taken to be an interior angle at the intersection between respective tangents of the respective laidback second sidewalls 76, and the respective tangents 82a,82b of the external surface. Thus, the second angles $88a_1$,$88a_2$ ordinarily extend downstream of, and between the respective tangents of the respective second sidewalls 76, and the tangents 82a,82b of the external surface. Thus, the respective second sidewalls 76 are both downstream of the passageway outlets 66a,66b, and at a second angle $88a_1$,$88a_2$ relative to the respective first chordwise tangents 82a,82b, which are greater than the first angle $84a_1$,$84a_2$. Thus, the second angle $88a_1$,$88a_2$ provides the respective second sidewalls 76 with an increased downstream trajectory relative to both the first chordwise tangent 82a,82b and the first and second passageway axes 72a,72b. It will be appreciated that further constructions of the second angle are possible and may be considered within the scope of the current disclosure. Thus, the second angle may be an open angle. By an open angle, it is meant that the second angle is at least 90 degrees.

[0059] Fig.8a-c show projections of the aerofoil 40 previously shown in Figs.5 and 7a-7c. In addition, Fig.8a shows a cross section through both the aerofoil 40 and the first trench 60a between points B-B'. Cross-section B-B' provides a spanwise cross-section B-B' of the aerofoil 40 at the first position 51a. Fig.8b shows a cross-sectional perspective of the aerofoil 40 and an example of the first trench 60a, of the type described in Figs.5a-7c, between points B-B'. It will be appreciated that the features described herewith, in relation to Figs.8a-8c, apply equally to the second passageway 62b, second trench 60b, second passageway inlet 64b, second passageway outlet 66b, and their respectively associated features, shown and described in relation to Figs.6a and 6c, mutatis mutandis.

[0060] Figs.8b and 8c show the first passageway 62a extending along the first longitudinal passageway axis 72a to the first passageway outlet 66a in the first trench 60a. Normal axes $52b_1$,$52b_2$ (not shown) extend perpendicularly relative to the external surface 44 at the first and second locations 51a,51 b. The first passageway axis 72a is shown to be canted, at a first spanwise angle $84b_1$, from the normal axis $52b_1$, which extends in a direction perpendicular to a first spanwise tangent 83a of the external surface, such that the first passageway axis 72a is directed towards the tip 58. In alternative examples, the first passageway axis 72a is directed towards the root 57. The first spanwise tangent 83a at the first location 51a intersects the first passageway axis 72a at the first spanwise angle $84b_1$, which provides the first passageway 62a with a spanwise trajectory relative to the normal axis $52b_1$.

[0061] In Fig.8c, the first passageway axis 72a of the first trench 60a is angled, relative to the first spanwise tangent 83a at the first location 51a, at a greater angle than in the example of Fig.8b. Thus, the first passageway axis 72a is increasingly angled in the spanwise direction 59 (i.e. towards the tip 58), relative to the trench shown in Fig.8b. The first spanwise angle $84b_1$ may vary according to, for example, one or more of the spanwise or chordwise position of the first trench 60a, the position of the first passageway 62a in the first trench 60a, or cooling requirements, according to predetermined conditions.

[0062] The first spanwise angle $84b_1$,$84b_2$ (not shown) defines an angle between the respective first and second passageway axes 72a,72b, and a portion of respective first and second spanwise tangents 83a,83b of the external surface, at the first and second location 51a,51 b. The first spanwise angle $84b_1$, $84b_2$ is ordinarily taken to be an interior angle at the intersection between the respective longitudinal axes of the first and second passageways 72a,72b, and the respective spanwise tangents 83a,83b. Thus, the first spanwise angle $84b_1$,$84b_2$ ordinarily extends downstream of, and between the respective longitudinal axes 72a,72b and spanwise tangents 83a,83b. The first angle $84a_1$, $84a_2$ is at least 90 degrees. Thus, the first angle $84a_1$, $84a_2$ provides the respective passageway axes 72a,72b with a spanwise trajectory relative to the respective normal axes 51a,51 b. The first spanwise angle $84b_1$, $84b_2$ is a first spanwise angle. It will be appreciated that further constructions of the first spanwise angle $84b_1$,$84b_2$ are possible and within the scope of the current disclosure.

[0063] In Fig.8b and Fig.8c, the second sidewall 76 is laidback from the longitudinal passageway axis 72 at an increased second spanwise angle $88b_1$ relative to the second spanwise tangent 83. The second spanwise angle $88b_1$, $88b_2$ (not shown) defines an angle between the tangent of the respective second sidewalls 76, and a portion of the respective second spanwise tangents 83 of the external surfaces at the respective first and second locations 51a,51 b. The second spanwise angle $88b_1$,$88b_2$ is ordinarily taken to be an interior angle at the intersection between respective tangents of the respective second sidewalls 76, and the respective tangents 83 of the external surface. Thus, the second spanwise angles $88b_1$,$88b_2$ ordinarily extend spanwise of, and between the respective tangents of the second sidewalls, and the second spanwise tangents 83. Thus, the respective second sidewalls 76 are downstream of, and displaced in the spanwise direction from the passageway outlets 66a,66b, at second angles $88a_1$,$88a_2$ relative to the second spanwise tangents 83, which are greater than the first angles $84a_1$,$84a_2$. Thus, the second spanwise angle $88b_1$,$88b_2$ provides the respective second sidewall 76 with an increased downstream trajectory relative to both the spanwise tangent 83 and the first and second passageway axes 72a,72b. It will be appreciated that further constructions of the second spanwise angle are possible and may be considered within the scope of the current disclosure. Thus, the second spanwise angle may be an open angle. By an open angle, it is meant that the second angle is at least 90 degrees.

[0064] In further examples, the trench arrangements described in Figs.5-8c may be located at further chordwise locations on the surface of the aerofoil 40. For examples, the first trench 60a, the second trench 60b, and the respective passageways 62a,62b, may be located on the pressure surface 44. Additionally or alternatively, the first trench 60a and the second trench, and the respective passageways 62a,62b, 60b may be located on the suction surface 43. Thus, in some examples, it will be appreciated that the first trench 60a and the second trench 60b may not be separated by the stagnation point, or adjacent the leading edge 45. However, the remaining features described in relation to Figs.5-8c may be employed separately or in combination with the features relating to the presently described example.

[0065] As shown in Figs.5-8c, two or more trenches 60a,60b are provided within an aerofoil 40. The aerofoil is suitable for use in a gas turbine engine 10. In some examples, the aerofoil 40 may be a turbine blade. In further examples, the aerofoil 40 may be a vane. The aerofoil 40 may be a cast article. The aerofoil 40 may be an investment cast article. The aerofoil 40 may be of single-piece construction. Thus, the aerofoil 40 may be a unitary body and the respective trenches 60a,60b may be formed into a surface of the unitary body. One or more of respective passageways 62a,62b, divergent profiles, or trenches 60a,60b may be formed in the aerofoil 40 via a mechanical machining process. Alternatively, one or more of respective passageways 62a,62b, divergent profiles, or trenches 60a,60b may be formed in the aerofoil 40 via a non-traditional machining process. The non-traditional machining process may be one or more of a chemical machining process, an electro-discharge machining process, a laser-based machining process, or an electron beam machining process. Additionally or alternatively, one or more of respective passageways 62a,62b, divergent profiles, or trenches 60a,60b may be formed in the aerofoil 40 during manufacture of the aerofoil 40. Thus, the aerofoil 40 may be constructed by an additive manufacturing method such as, for example, 3-D printing, direct laser deposition, or selective laser sintering. Alternatively, any further machining or manufacturing process capable of repeatable, high-accuracy material addition or removal may be employed in either or both of the machining or manufacture of each respective trench 60a,60b or respective passageway 62a,62b.

[0066] In some examples, the cooling fluid is air. In some examples, the cooling fluid is an air mixture. In some examples, the cooling fluid may comprise a liquid. In further examples, the aerofoil 40 may comprise nickel. The aerofoil 40 may be a nickel alloy. The aerofoil 40 may be a nickel-based superalloy. The aerofoil 40 may be a cobalt-based superalloy. The aerofoil 40 may be an iron-based superalloy. In further examples, the aerofoil 40 may comprise titanium. The aerofoil 40 may be a titanium alloy. The aerofoil 40 may be a titanium-alumnide. The aerofoil 40 may be a ceramic matrix composite. The aerofoil 40 may be a metal matrix composite.

[0067] It will be understood that the invention is not limited to the embodiments above-described and various modifications can be made without departing from the concepts described herein. 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. An aerofoil (40), comprising:

a wall (43,44,45,46) comprising an external surface, and an internal surface (42) defining a cavity (41) for receiving a cooling fluid in use;
a first trench (60a) formed in the external surface, and a second trench (60b) formed in the external surface;
a first passageway (62a) extending from a first passageway inlet (64a) in the cavity to a first passageway outlet (66a) in the first trench, and a second passageway (62b) extending from a second passageway inlet (64b) in the cavity to a second passageway outlet (66b) in the second trench;
wherein the first passageway and second pas-

sageway intersect within the wall.

2. The aerofoil as claimed in Claim 1, wherein the first trench is formed in the external surface at a first trench location (51a), and the second trench is formed in the external surface at a second trench location (51b), wherein the first trench location and the second trench location are located either side of a stagnation point.

3. The aerofoil as claimed in Claim 2, wherein the first trench location and the second trench location are located adjacent the stagnation point.

4. The aerofoil as claimed in Claim 2 or Claim 3, wherein the wall comprises a thickened region (65) adjacent the first and second location, comprising a wall thickness which is greater than the wall thickness at a pressure or suction surface (44,43) of the aerofoil.

5. The aerofoil as claimed in any preceding Claim, wherein the first passageway comprises a first longitudinal axis (72a), and the second passageway comprises a second longitudinal axis (72b).

6. The aerofoil as claimed in Claim 5, wherein the first longitudinal axis and the second longitudinal axis extend in a chordwise direction.

7. The aerofoil as claimed in Claim 5 or Claim 6, wherein the first longitudinal axis intersects a first tangent (82a) of the external surface at the first location, and the second longitudinal axis intersects a second tangent (82b) of the external surface at the second location at respective first angles ($84a_1$,$84a_2$), to provide the first passageway with a downstream trajectory relative to the first tangent, and the second passageway with a downstream trajectory relative to the second tangent.

8. The aerofoil as claimed in any preceding Claim, wherein the first and second trenches comprise respective laidback second sidewalls (76) downstream of the respective passageway outlets.

9. The aerofoil as claimed in Claim 8, wherein a tangent (86) of the second sidewall of the first trench intersects the first tangent of the external surface at the first location, and a tangent of the second sidewall of the second trench intersects the second tangent of the external surface at the second location at respective second angles ($88a_1$,$88a_2$), to provide the respective second sidewalls with a downstream trajectory relative to the respective first and second tangents.

10. The aerofoil as claimed in any one of Claims 7 to 9, wherein the respective second angles are greater than the respective first angles, relative to the respective first and second tangents.

11. The aerofoil as claimed in any preceding Claim, wherein the first and second passageways comprise both a first major axis (78a) and a first minor axis (80a) adjacent the respective passageway inlets, and both a second major axis (78b) and a second minor axis (80b) adjacent the respective passageway outlets, wherein the second major axes adjacent the respective passageway outlets are greater than the first major axes adjacent the respective passageway inlets.

12. The aerofoil as claimed in Claim 11, wherein the first and second passageways terminate in a divergent profile adjacent the respective passageway outlets.

13. The aerofoil as claimed in any preceding Claim, wherein the first and second trenches comprise a trench depth (91) which is equal to or less than the respective second major axes.

14. The aerofoil as claimed in any preceding Claim, wherein the first and second trenches comprise a trench width (93) which is equal to or greater than the respective second major axes.

15. A gas turbine engine comprising an aerofoil as claimed in any preceding claim.

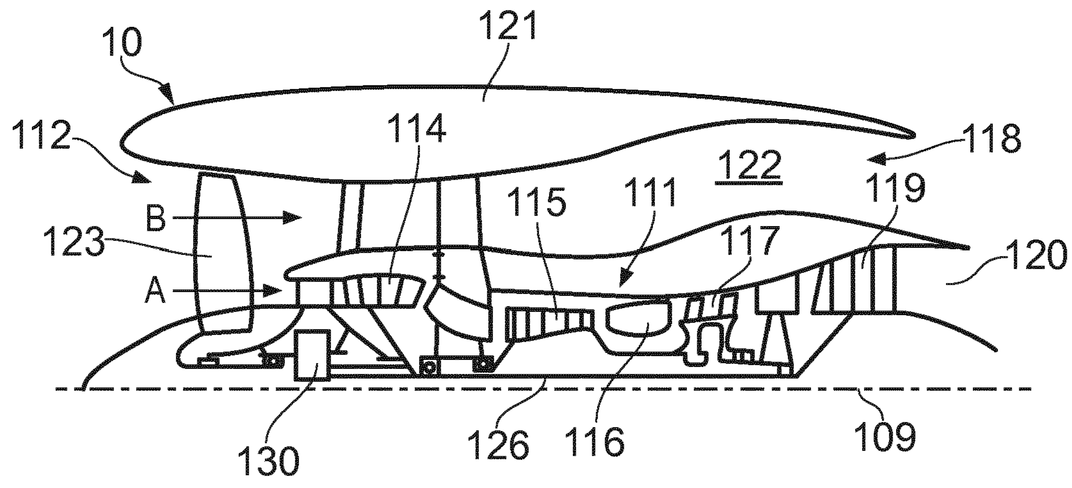

10
121
112
114
118
122
B
115
111
119
123
117
120
A
130
126
116
109

FIG. 1

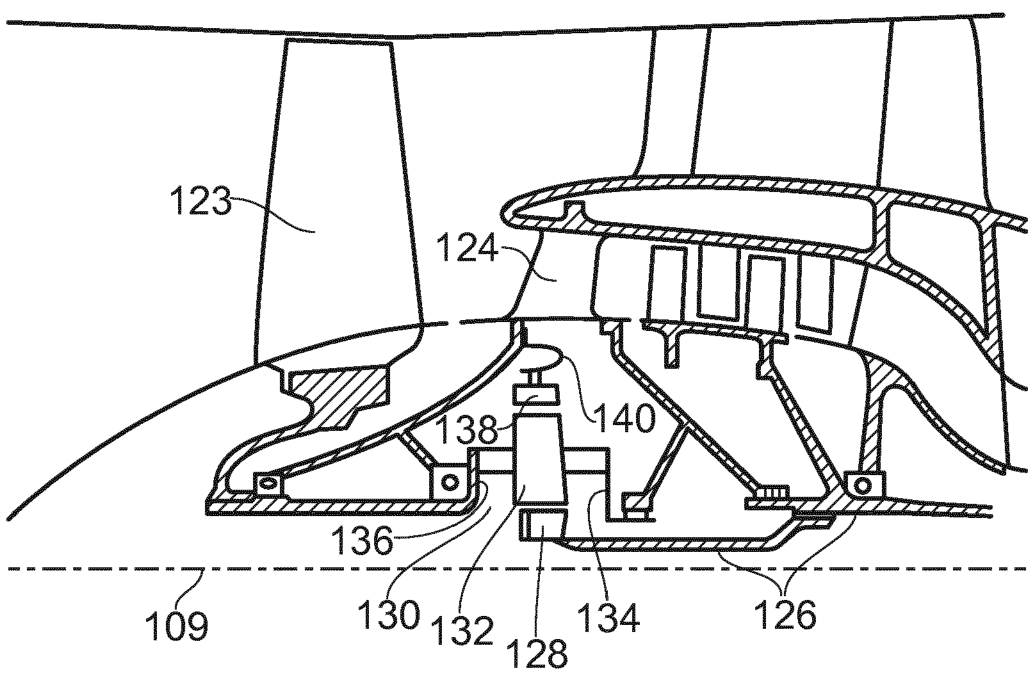

123
124
140
138
136
109
130
132
128
134
126

FIG. 2

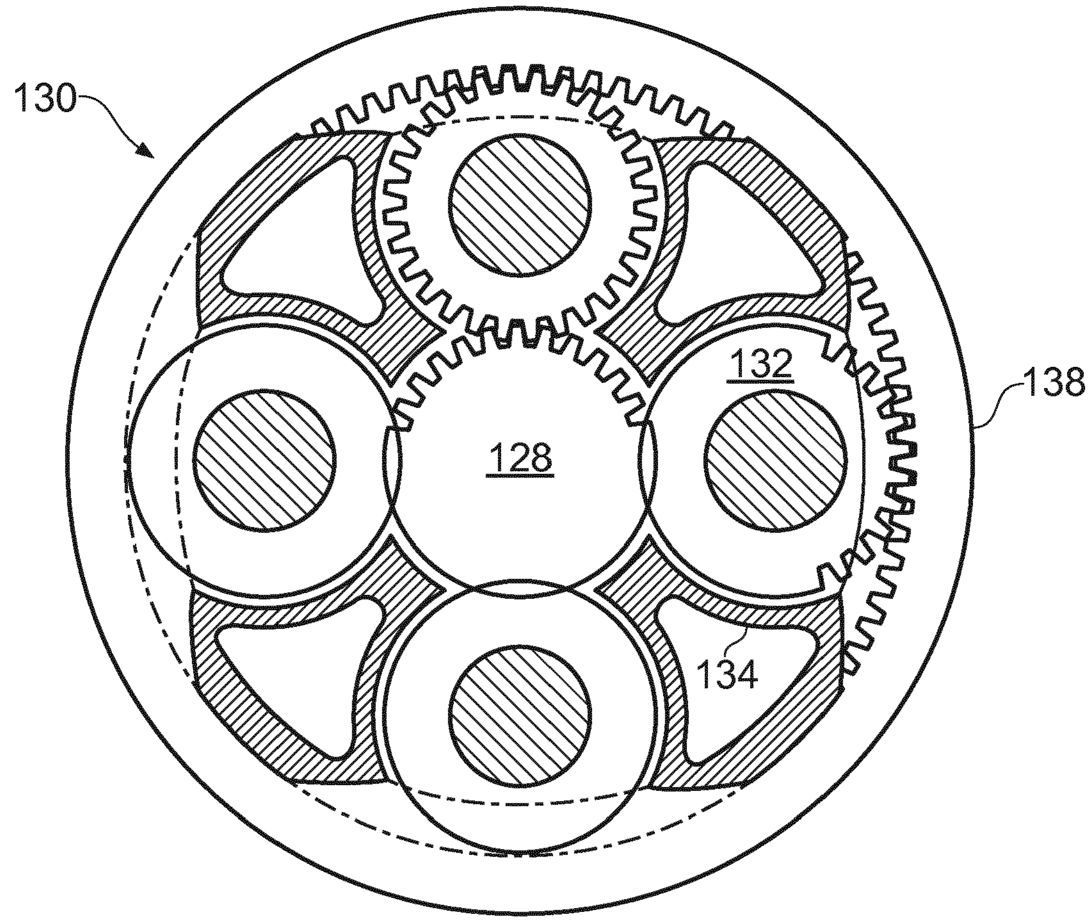


FIG. 3

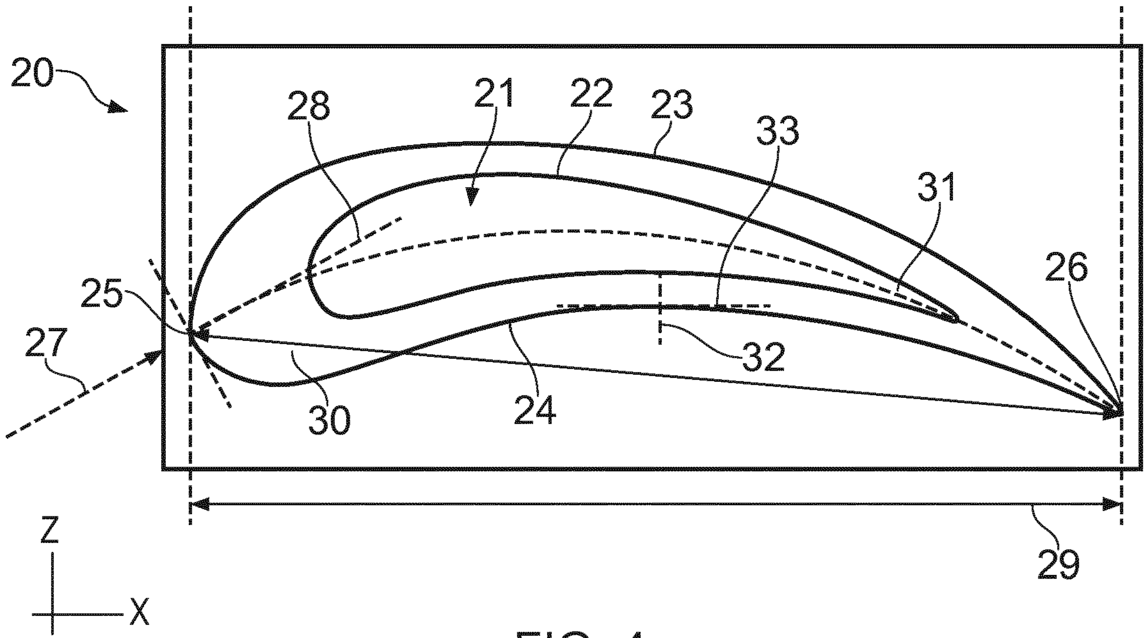

20
21
22
23
28
33
31
26
25
27
30
24
32
29
Z
X

FIG. 4

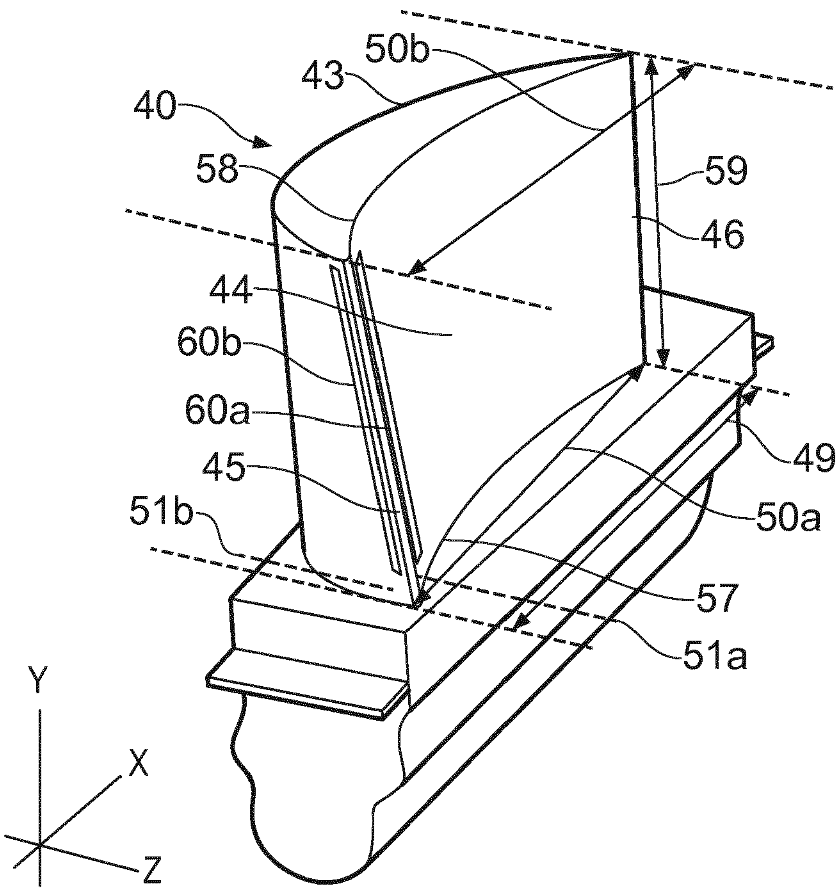

40
43
50b
58
59
46
44
60b
60a
45
51b
49
50a
57
51a
Y
X
Z

FIG. 5

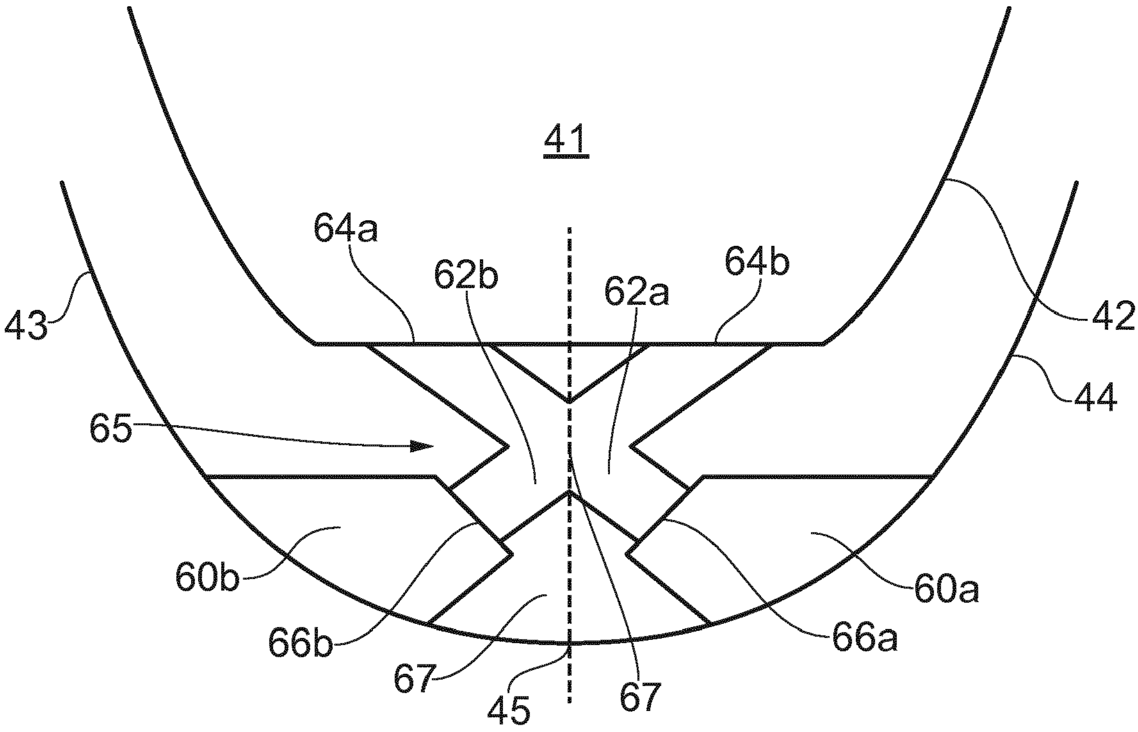

41
64a
62b
62a
64b
43
42
44
65
60b
60a
66b
66a
67
45
67

FIG. 6a

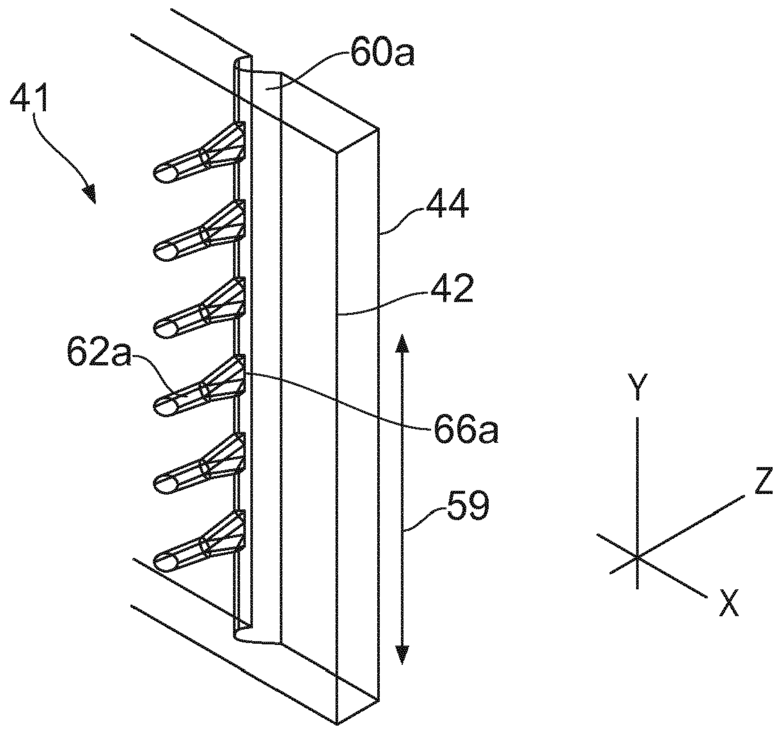

60a
41
44
42
62a
66a
59
Y
Z
X

FIG. 6b

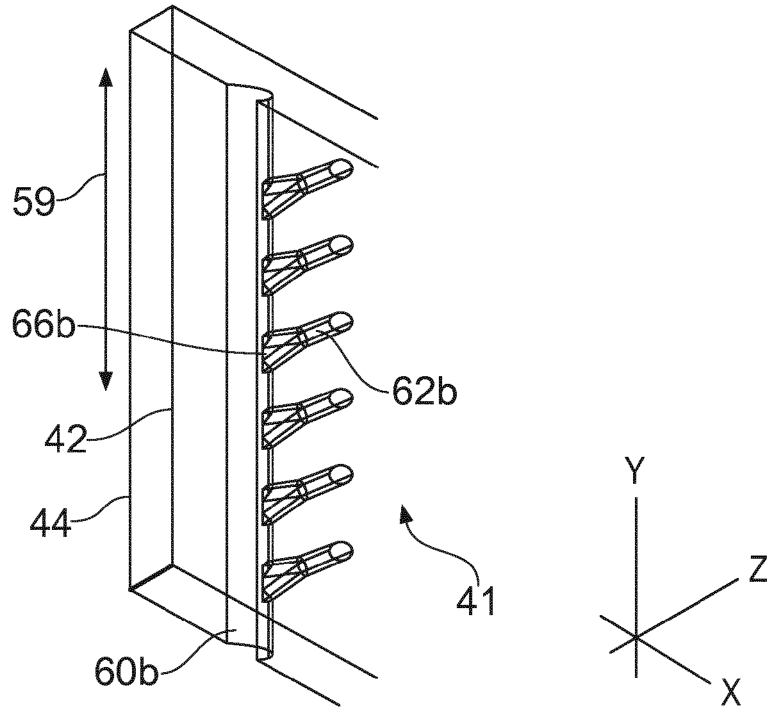

59
66b
62b
42
44
41
60b
Y
Z
X

FIG. 6c

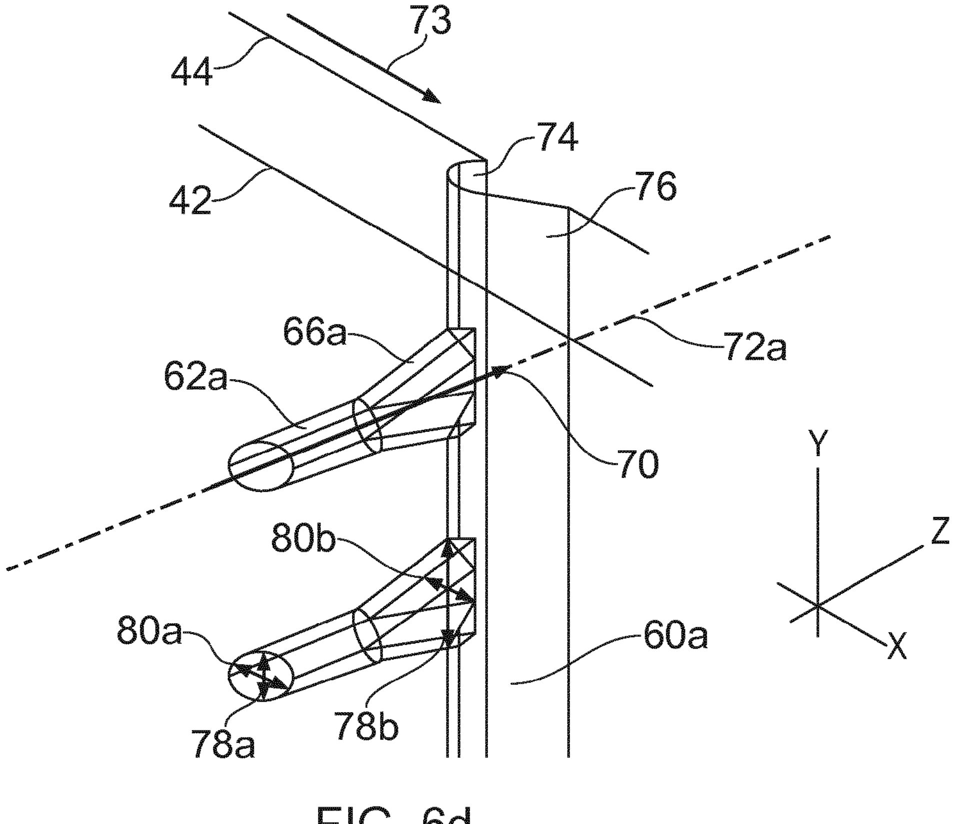

73
44
74
76
42
72a
66a
62a
70
80b
80a
60a
78a
78b
Y
Z
X

FIG. 6d

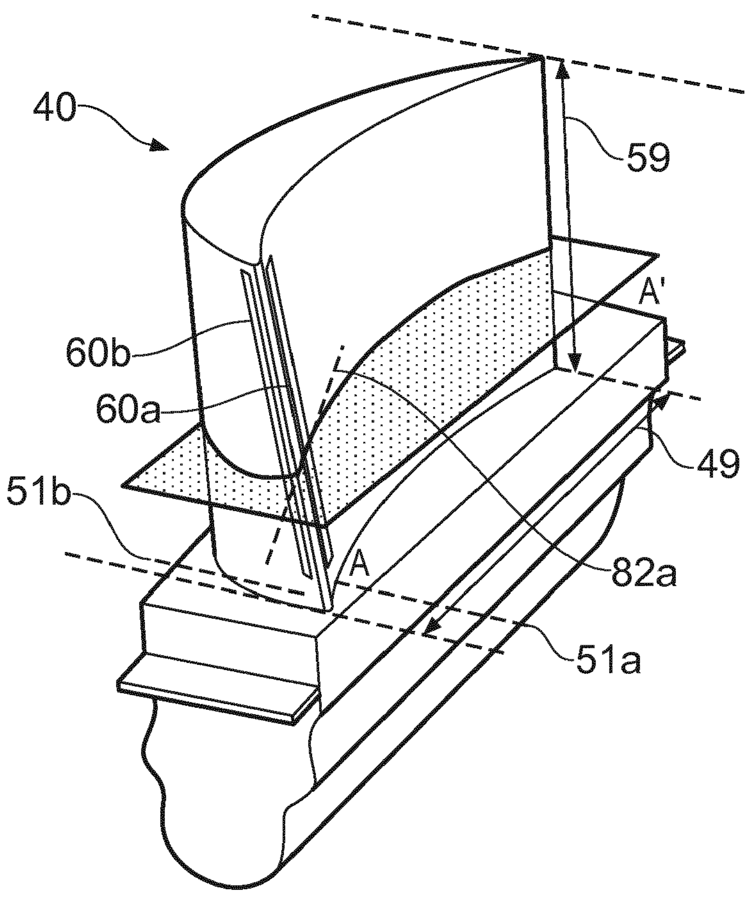

40
59
A'
60b
60a
49
51b
A
82a
51a

FIG. 7a

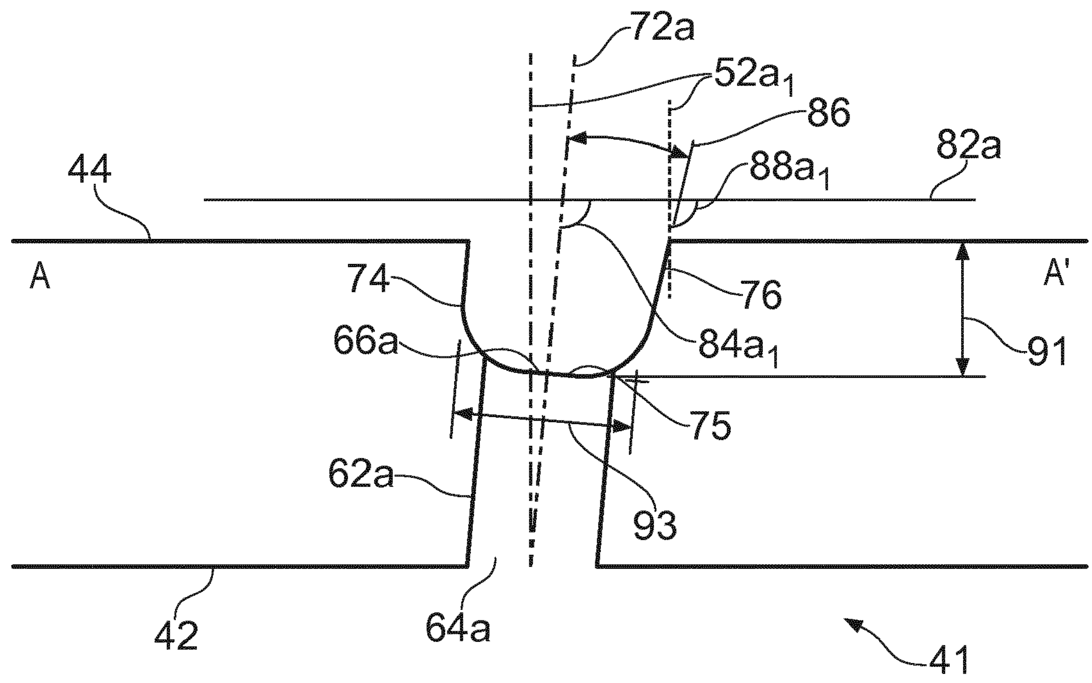
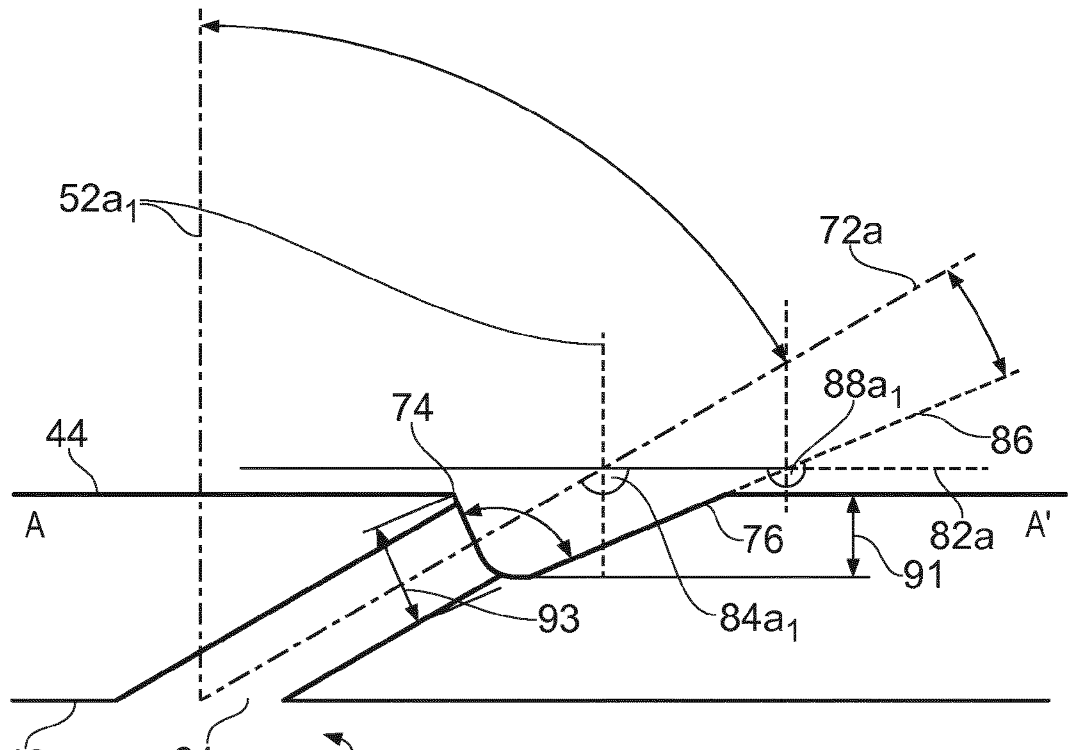
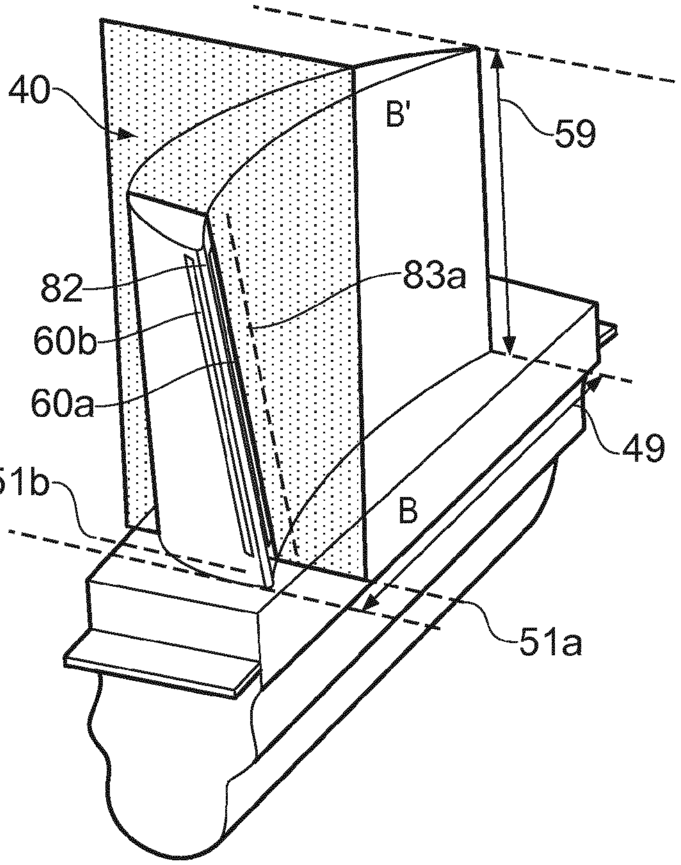

72a
52a1
86
82a
44
88a1
A
74
76
A'
66a
84a1
91
75
62a
93
42
64a
41

FIG. 7b



52a1
72a
88a1
86
74
44
A
76
82a
A'
91
93
84a1
42
64a
41

FIG. 7c



40
B'
59
82
83a
60b
60a
49
51b
B
51a

FIG. 8a

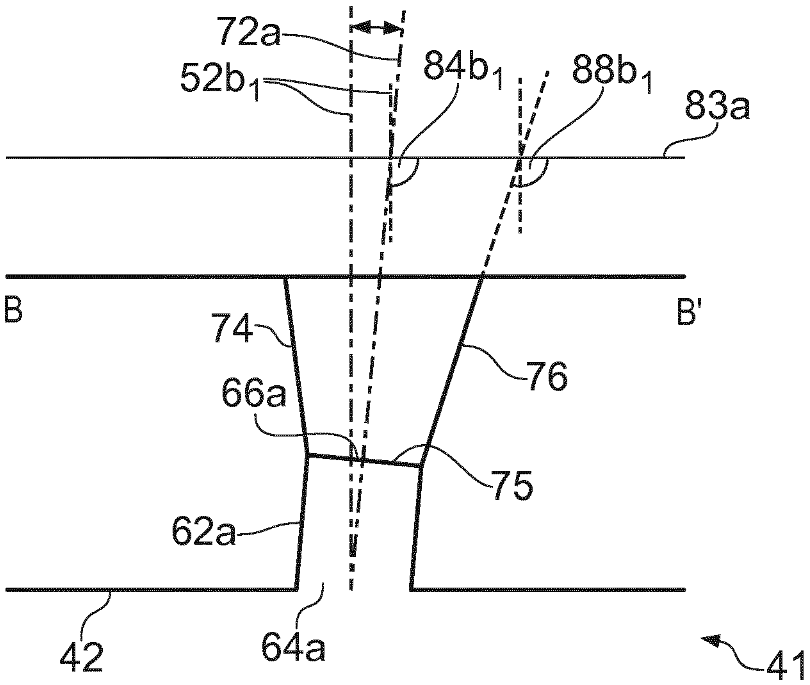

72a
52b1
84b1
88b1
83a
B
B'
74
76
66a
75
62a
42
64a
41

FIG. 8b

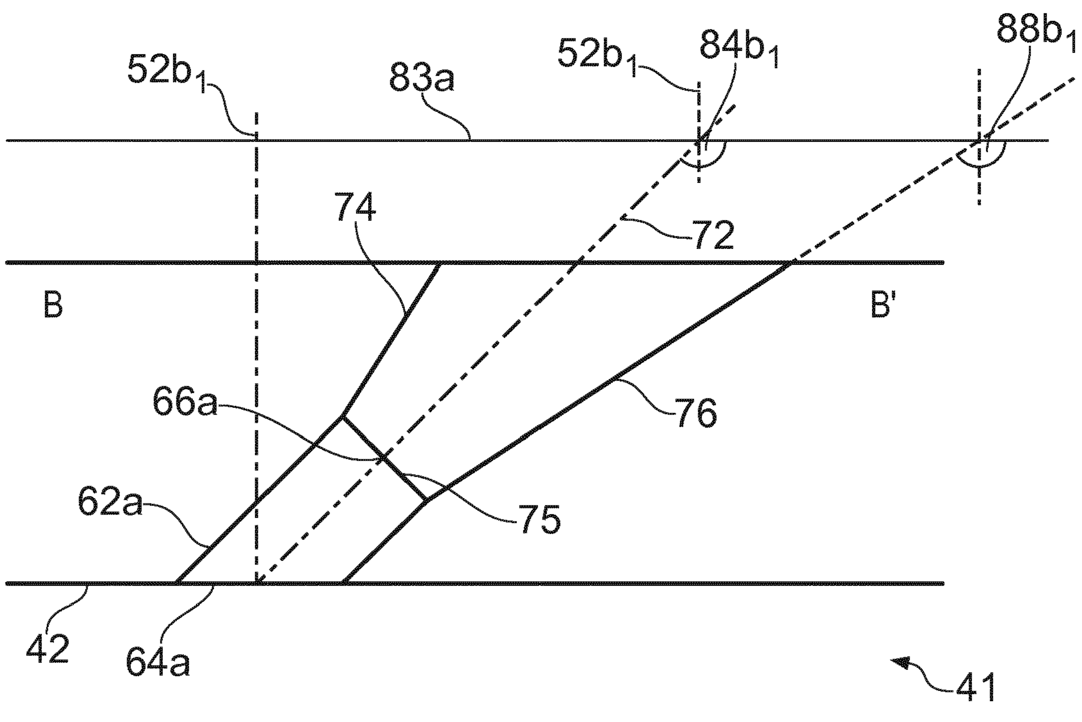

52b1
83a
52b1
84b1
88b1
74
72
B
B'
66a
76
62a
75
42
64a
41

FIG. 8c

Europäisches Patentamt
European Patent Office
Office européen des brevets

EUROPEAN SEARCH REPORT

Application Number
EP 18 20 7552

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
Y	US 2005/135932 A1 (DODD ALEC G [GB]) 23 June 2005 (2005-06-23) * paragraphs [0016] - [0018]; figures 1-3 *	1-15	INV. F01D5/18
Y	EP 2 154 333 A2 (UNITED TECHNOLOGIES CORP [US]) 17 February 2010 (2010-02-17) * paragraphs [0018] - [0035]; figures 1-6 *	1-15	
Y	EP 0 924 384 A2 (UNITED TECHNOLOGIES CORP [US]) 23 June 1999 (1999-06-23) * paragraphs [0011] - [0015]; figures 1-3 *	1-15	
A	US 5 419 681 A (LEE CHING-PANG [US]) 30 May 1995 (1995-05-30) * column 5, lines 19-23; figures 5,6 *	1-15	
A	EP 1 655 453 A1 (ROLLS ROYCE PLC [GB]) 10 May 2006 (2006-05-10) * figures 3c,7,8,9 *	1-15	TECHNICAL FIELDS SEARCHED (IPC) F01D

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	10 May 2019	Dreyer, Christoph

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

EPO FORM 1503 03.82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 18 20 7552

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

10-05-2019

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2005135932 A1	23-06-2005	GB 2401915 A	24-11-2004
		US 2005135932 A1	23-06-2005
EP 2154333 A2	17-02-2010	EP 2154333 A2	17-02-2010
		US 2010040478 A1	18-02-2010
EP 0924384 A2	23-06-1999	EP 0924384 A2	23-06-1999
		JP H11247611 A	14-09-1999
		KR 19990063131 A	26-07-1999
US 5419681 A	30-05-1995	NONE	
EP 1655453 A1	10-05-2006	EP 1655453 A1	10-05-2006
		US 2006099074 A1	11-05-2006

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82