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# (54) Turbine engine airfoil with wrapped leading edge cooling passage

Turbinenschaufel mit umfassendem Vorderkantenkühlkanal

Aube de turbine dotée d'un passage encerclé pour refroidissement de bord d'attaque

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## Description

### BACKGROUND

**[0001]** This disclosure relates to a cooling passage for an airfoil.

**[0002]** Turbine blades are utilized in gas turbine engines. As known, a turbine blade typically includes a platform having a root on one side and an airfoil extending from the platform opposite the root. The root is secured to a turbine rotor. Cooling circuits are formed within the airfoil to circulate cooling fluid, such as air. Typically, multiple relatively large cooling channels extend radially from the root toward a tip of the airfoil. Air flows through the channels and cools the airfoil, which is relatively hot during operation of the gas turbine engine.

**[0003]** Some advanced cooling designs use one or more radial cooling passages that extend from the root toward the tip near a leading edge of the airfoil. Typically, the cooling passages are arranged between the cooling channels and an exterior surface of the airfoil. The cooling passages provide extremely high convective cooling.

**[0004]** Cooling the leading edge of the airfoil can be difficult due to the high external heat loads and effective mixing at the leading edge due to fluid stagnation. Prior art leading edge cooling arrangements typically include two cooling approaches. First, internal impingement cooling is used, which produces high internal heat transfer rates. Second, showerhead film cooling is used to create a film on the external surface of the airfoil. Relatively large amounts of cooling flow are required, which tends to exit the airfoil at relatively cool temperatures. The heat that the cooling flow absorbs is relatively small since the cooling flow travels along short paths within the airfoil, resulting in cooling inefficiencies.

**[0005]** One arrangement that has been suggested to convectively cool the leading edge is a cooling passage wrapped at the leading edge. This wrapped leading edge cooling passage is formed by a refractory metal core that is secured to another core. The cores are placed in a mold, and a superalloy is cast into the mold about the cores to form the airfoil. The cores are removed from the cast airfoil to provide the cooling passages. However, in some applications, the wrapped leading edge cooling passage does not provide the amount of desired cooling to the leading edge.

**[0006]** What is needed is a leading edge cooling arrangement that provides desired cooling of the airfoil.

**[0007]** A turbine engine airfoil having multiple cooling passages formed in the leading edge of the airfoil is disclosed in EP-A-1467064.

### SUMMARY

**[0008]** A turbine engine airfoil in accordance with the invention is set forth in claim 1.

**[0009]** In one example, the second cooling passage extends radially, and the first cooling passage wraps around a portion of the second cooling passage from a pressure side to a suction side between the second cooling passage and the exterior surface. In the example, the first portion is arranged between the pressure and suction sides.

**[0010]** The invention also provides a method of manufacturing an airfoil, as set forth in claim 8.

**[0011]** These and other features of the disclosure can be best understood from the following specification and drawings, the following of which is a brief description.

### BRIEF DESCRIPTION OF THE DRAWINGS

**[0012]**

Figure 1 is a schematic view of a gas turbine engine incorporating an airfoil.

Figure 2 is a perspective view of the airfoil, which falls outside the scope of the invention, having the cooling passage.

Figure 3A is a cross-sectional view of a portion of the airfoil shown in Figure 2 and taken along 3A-3A.

Figure 3B is a perspective view of a core that provides the wrapped leading edge cooling passage shown in Figure 3A.

Figure 3C is a cross-sectional view of the airfoil shown in Figure 3A with the core removed from the airfoil and a trench formed in the leading edge.

Figure 4A is a partial cross-sectional view of another airfoil leading edge with another example core of an airfoil which falls outside the scope of the invention.

Figure 4B is a perspective view of the core shown in Figure 4A.

Figure 5A is a partial cross-sectional view of yet an airfoil leading edge with yet another example core of an airfoil in accordance with the invention.

Figure 5B is a perspective view of the core shown in Figure 5A.

Figure 5C is a front elevational view of the leading edge shown in Figure 5A.

Figure 6A is a partial cross-sectional view of another airfoil leading edge with still another example core of an airfoil in accordance with the invention.

Figure 6B is a front elevational view of the leading edge shown in Figure 6A.

Figure 6C is a perspective view of a portion of the core shown in Figure 6A.

### DETAILED DESCRIPTION

**[0013]** Figure 1 schematically illustrates a gas turbine engine 10 that includes a fan 14, a compressor section 16, a combustion section 18 and a turbine section 11, which are disposed about a central axis 12. As known in the art, air compressed in the compressor section 16 is mixed with fuel that is burned in combustion section 18 and expanded in the turbine section 11. The turbine section 11 includes, for example, rotors 13 and 15 that, in

response to expansion of the burned fuel, rotate, which drives the compressor section 16 and fan 14.

**[0014]** The turbine section 11 includes alternating rows of blades 20 and static airfoils or vanes 19. It should be understood that Figure 1 is for illustrative purposes only and is in no way intended as a limitation on this disclosure or its application.

**[0015]** An example blade 20 is shown in Figure 2. The blade 20 includes a platform 32 supported by a root 36, which is secured to a rotor. An airfoil 34, which falls outside the scope of the invention, extends radially outwardly from the platform 32 opposite the root 36. While the airfoil 34 is disclosed as being part of a turbine blade 20, it should be understood that the disclosed airfoil can also be used as a vane.

**[0016]** The airfoil 34 includes an exterior surface 57 extending in a chord-wise direction C from a leading edge 38 to a trailing edge 40. The airfoil 34 extends between pressure and suction sides 42, 44 in a airfoil thickness direction T, which is generally perpendicular to the chord-wise direction C. The airfoil 34 extends from the platform 32 in a radial direction R to an end portion or tip 33. A cooling trench 48 is provided on the leading edge 38 to create a cooling film on the exterior surface 57. In the examples, the trench 48 is arranged in proximity to a stagnation line on the leading edge 38, which is an area in which there is little or no fluid flow over the leading edge.

**[0017]** Figure 3A schematically illustrates an airfoil molding process in which a mold 94 having mold halves 94A, 94B provides a mold contour that defines the exterior surface 57 of the airfoil 34. In one example, cores 82, which may be ceramic, are arranged within the mold 94 to provide the cooling channels 50, 52, 54 (Figure 3C). Referring to Figure 3C, multiple, relatively large radial cooling channels 50, 52, 54 are provided internally within the airfoil 34 to deliver airflow for cooling the airfoil. The cooling channels 50, 52, 54 typically provide cooling air from the root 36 of the blade 20.

**[0018]** Current advanced cooling designs incorporate supplemental cooling passages arranged between the exterior surface 57 and one or more of the cooling channels 50, 52, 54. With continuing reference to Figure 3A, the airfoil 34 includes a first cooling passage 56 arranged near the leading edge 38. The first cooling passage 56 is in fluid communication with the cooling channel 50, in the example shown. One or more core structures 68 (Figures 3A and 3B), such as refractory metal cores, are arranged within the mold 94 and connected to the other cores 82. The core structure 68, which is generally C-shaped, provides the first cooling passage 56 in the example disclosed. In one example, the core structure 68 (shown in Figure 3B) is stamped from a flat sheet of refractory metal material. The core structure 68 is then bent or shaped to a desired contour. The ceramic core and/or refractory metal cores are removed from the airfoil 34 after the casting process by chemical or other means.

**[0019]** A core assembly can be provided in which a portion of the core structure 68 is received in a recess of the other core 82, as shown in Figure 3A. In this manner, the resultant first cooling passage 56 provided by the core structure 68 is in fluid communication with the cooling channel 50 subsequent to the airfoil casting process.

**[0020]** The core structure 68 includes a first portion 72 and a second portion. In the example shown in Figures 3A-3C, the second portion includes multiple, radially spaced first and second sets of arcuate legs 74, 76 that wrap around a portion of the cooling channel 50. The shape of the legs 74, 76 generally mirror the exterior surface 57 of the leading edge 38. The first and second sets of legs 74, 76 are secured to the other core 82. One set of legs 74 is arranged on the pressure side 42 and the other set of legs 76 is arranged on the suction side 44. In the example shown in Figures 3A-3C, the first portion 72 does not extend to the exterior surface 57. The trench 48 is formed by a chemical or mechanical machining process, for example, to fluidly connect the first portion 72 to the leading edge 38. Cooling fluid is provided from the first cooling channel 50 through the first cooling passage 56 to provide a cooling film on the leading edge 38 via the trench 48.

**[0021]** Referring to Figures 4A and 4B, a core structure 168 for a further airfoil which falls outside the scope of the invention is shown that provides the trench 48 during the casting process. The first portion 172 extends beyond the exterior surface and into the mold 94 where the first portion 172 is held by a core retention feature 96, which is provided by a notch in the mold 94, for example. Thus, when the core structure 168 is removed from the airfoil 134, a trench will be provided at the leading edge 138. The legs 174, 176 are at an angle or transverse laterally to the first portion 172. The example core structure 168 provides first and second sets of legs 174, 176 on opposite sides and in radially spaced, alternating relationship from one another. The first portion 172 extends in a direction opposite the other core 82.

**[0022]** In embodiments of the invention, the first cooling passage is provided by multiple separate networks of passageways, as illustrated in Figures 5A and 5B. The networks of passageways are formed with multiple core structures 86, 88 having first portions 272, 273 that are discrete from one another. One of the cores structures 86 is arranged on the suction side 44 and the other core structure 88 is arranged on the pressure side 42. The legs 274, 276 are only fluidly connected to one another through the cooling channel 50. The first portions 272, 273 extend beyond the exterior surface 57 in the leading edge 238 and are configured to provide laterally spaced trenches 248 on the airfoil 234, as shown in Figure 5C. The trenches 248 may be laterally and radially staggered.

**[0023]** Another arrangement of multiple networks of passageways is shown in Figures 6A-6C. The first cooling passage is provided by two networks of passageways created by core structures 186a, 186b, 188a, 188b provided on each of the pressure and suction sides 42, 44 of airfoil 334. The core structures 186a, 186b, 188a, 188b

respectively provide discrete first portions 273a, 273b, 272a, 272b that create trenches 348 in leading edge 338, shown in Figure 6B.

**[0024]** Although example embodiments have been disclosed, a worker of ordinary skill in this art would recognize that certain modifications would come within the scope of the claims. For that reason, the following claims should be studied to determine their true scope and content.

## Claims

**1.** A turbine engine airfoil (34) comprising:

an airfoil structure including an exterior surface (57) providing a leading edge (38), multiple radially extending first cooling passages near the leading edge (38), each including a first portion and second portions, the first portion extending to the exterior surface (57) and forming a radially extending trench (248;348) in the leading edge (38), the second portions in fluid communication with a second cooling passage (50) being radially spaced arcuate legs, the radially extending trenches (248; 348) of the multiple first cooling passages being laterally spaced.

**2.** The turbine engine airfoil according to claim 1, wherein the second cooling passage (50) extends radially and the first cooling passage wraps around a portion of the second cooling passage (50) from a pressure side to a suction side between the second cooling passage and the exterior surface (57), the first portion arranged between the pressure and suction sides.

**3.** The turbine engine airfoil according to claim 2, wherein the first cooling passage is generally C-shaped.

**4.** The turbine engine airfoil according to claim 1, wherein one of the multiple of first cooling passages is located on the pressure side and another of the passages is located on the suction side, each of the second portions of the first cooling passages fluidly connected to the second portions of other of the multiple of first cooling passages only through the second cooling passage (50).

**5.** The turbine engine airfoil according to claim 4, wherein at least two first passages are arranged on at least one of the pressure and suction sides.

**6.** The turbine engine airfoil according to claim 5, wherein the radially spaced arcuate legs, are arranged in alternating relationship with one another.

**7.** The turbine engine airfoil according to any preceding claim, wherein the laterally spaced trenches (248) are also radially spaced.

**8.** A method of manufacturing an airfoil with internal cooling passages, the method comprising the steps of:

providing a multiple of first cores (186a,186b,188a,188b) each having a first, radially extending portion (272,273;272a,272b,273a,273b) and multiple generally arcuate second portions (274,276) extending generally chord-wise from the first portion (272,273;272a,272b,273a,273b), said second portions being arcuate shaped legs radially spaced from one another;
arranging the first cores (186a,186b,188a,188b) in a mold (94) at a location corresponding to a leading edge (38) of an airfoil to be formed by the mold (94), the mold (94) providing an airfoil contour such that the first radially extending portions (272,273;272a,272b,273a,273b) are laterally spaced from one another;
arranging a second core (82) radially within the mold (94), the second core (82) supporting the second portions (274,276) of the first cores (186a,186b,188a,188b),; and
depositing casting material into the mold (94) with the first portions (272,273;272a,272b,273a,273b) extending into the mold (94) beyond the airfoil contour and the second portions (274,276) surrounded by the casting material, the first portions (272,273;272a,272b,273a,273b) corresponding to multiple laterally spaced and radially extending trenches (48) in the leading edge (38).

**9.** The method according to claim 8, comprising the step of retaining the first portions (272,273;272a,272b,273a,273b) in the mold (94) in a core retention feature, the first portion (272,273;272a,272b,273a,273b) outside of the casting material.

**10.** The method according to claim 8 or 9, wherein the first cores (186a,186b,188a,188b) include at least one core member, the at least one core member (168) wrapping around the leading edge (38) generally mirroring the airfoil contour between sides, which correspond to pressure and suction sides of the airfoil.

**11.** The method according to any of claims 8 to 10, wherein the second core (82) is a ceramic core and the first cores (186a,186b,188a,188b) are refractory metal cores, the first and second cores (186a,186b,188a,188b,82) secured to one another.

**12.** The method according to any of claims 8 to 11, wherein the first cores (186a,186b,188a,188b) are provided by stamping a core structure including a desired shape from a refractory metallic material and bending the first cores (86,88;186a,186b,188a,188b) to provide a desired contour.

**Patentansprüche**

**1.** Turbinenschaufel (34), umfassend:

eine Schaufelstruktur, die eine Außenfläche (57) beinhaltet, die eine Vorderkante (38) bereitstellt, mehrere sich radial erstreckende erste Kühlkanäle in der Nähe der Vorderkante (38), von denen jeder einen ersten Abschnitt und zweite Abschnitte beinhaltet, wobei sich der erste Abschnitt zur Außenfläche (57) hin erstreckt und einen sich radial erstreckenden Graben (248; 348) in der Vorderkante (38) bildet und die zweiten Abschnitte in Fluidkommunikation mit einem zweiten Kühlkanal (50) stehen und radial beabstandete gebogene Beine sind, wobei die sich radial erstreckenden Gräben (248; 348) der mehreren ersten Kühlkanäle seitlich beabstandet sind.

**2.** Turbinenschaufel nach Anspruch 1, wobei der zweite Kühlkanal (50) sich radial erstreckt und der erste Kühlkanal um einen Abschnitt des zweiten Kühlkanals (50) von einer Druckseite bis zu einer Ansaugseite zwischen dem zweiten Kühlkanal und der Außenfläche (57) herum verläuft, wobei der erste Abschnitt zwischen der Druck- und der Ansaugseite angeordnet ist.

**3.** Turbinenschaufel nach Anspruch 2, wobei der erste Kühlkanal im Wesentlichen C-förmig ist.

**4.** Turbinenschaufel nach Anspruch 1, wobei sich einer der mehreren ersten Kühlkanäle auf der Druckseite befindet und sich ein anderer der Kanäle auf der Ansaugseite befindet, wobei jeder der zweiten Abschnitte des ersten Kühlkanals ausschließlich durch den zweiten Kühlkanal (50) mit den zweiten Abschnitten anderer der mehreren ersten Kühlkanäle fluidverbunden ist.

**5.** Turbinenschaufel nach Anspruch 4, wobei mindestens zwei erste Kanäle auf mindestens einer der Druck- und der Ansaugseite angeordnet sind.

**6.** Turbinenschaufel nach Anspruch 5, wobei die radial beabstandeten gebogenen Beine in einer alternierenden Beziehung zueinander angeordnet sind.

**7.** Turbinenschaufel nach einem der vorhergehenden Ansprüche, wobei die seitlich beabstandeten Gräben (248) zudem radial beabstandet sind.

**8.** Verfahren zum Herstellen einer Schaufel mit internen Kühlkanälen, wobei das Verfahren die folgenden Schritte umfasst:

Bereitstellen mehrerer erster Kerne (186a, 186b, 188a, 188b), von denen jeder einen ersten, sich radial erstreckenden Abschnitt (272, 273; 272a, 272b, 273a, 273b) und mehrere im Wesentlichen gebogene zweite Abschnitte (274, 276), die sich im Wesentlichen in Sehnenrichtung aus dem ersten Abschnitt (272, 273; 272a, 272b, 273a, 273b) heraus erstrecken, aufweist, wobei die zweiten Abschnitte radial zueinander beabstandete bogenförmige Beine sind;
Anordnen der ersten Kerne (186a, 186b, 188a, 188b) in einer Gussform (94) an einer Stelle, die einer Vorderkante (38) einer Schaufel, die durch die Gussform (94) gebildet werden soll, entspricht, wobei die Gussform (94) eine derartige Schaufelkontur bereitstellt, dass die ersten sich radial erstreckenden Abschnitte (272, 273; 272a, 272b, 273a, 273b) seitlich voneinander beabstandet sind;
Anordnen eines zweiten Kerns (82) radial in der Gussform (94), wobei der zweite Kern (82) die zweiten Abschnitte (274, 276) der ersten Kerne (186a, 186b, 188a, 188b) stützt; und
Aufbringen von Gussmaterial in die Gussform (94), wobei die ersten Abschnitte (272, 273; 272a, 272b, 273a, 273b), die sich über die Schaufelkontur hinaus in die Gussform (94) hinein erstrecken, und die zweiten Abschnitte (274, 276) von dem Gussmaterial umgeben sind, wobei die ersten Abschnitte (272, 273; 272a, 272b, 273a, 273b) mehreren seitlich beabstandeten und sich radial erstreckenden Gräben (48) in der Vorderkante (38) entsprechen.

**9.** Verfahren nach Anspruch 8, umfassend den Schritt des Haltens der ersten Abschnitte (272, 273; 272a, 272b, 273a, 273b) in der Gussform (94) in einer Kernrückhaltefunktion, wobei sich der erste Abschnitt (272, 273; 272a, 272b, 273a, 273b) außerhalb des Gussmaterials befindet.

**10.** Verfahren nach Anspruch 8 oder 9, wobei die ersten Kerne (186a, 186b, 188a, 188b) mindestens ein Kernstück beinhalten, wobei das mindestens eine Kernstück (168) um die Vorderkante (38) verläuft und dabei die Schaufelkontur zwischen Seiten, die der Druck- und der Ansaugseite der Schaufel entsprechen, spiegelt.

**11.** Verfahren nach einem der Ansprüche 8 bis 10, wobei der zweite Kern (82) ein Keramikkern ist und die ersten Kerne (186a, 186b, 188a, 188b) hochschmelzende Metallkerne sind, wobei die ersten und die zweiten Kernstücke (186a, 186b, 188a, 188b, 82) aneinander befestigt sind.

**12.** Verfahren nach einem der Ansprüche 8 bis 11, wobei die ersten Kerne (186a, 186b, 188a, 188b) durch Stanzen einer Kernstruktur, einschließlich einer gewünschten Form, aus einem hochschmelzenden metallischen Material und Biegen der ersten Kernstücke (86, 88; 186a, 186b, 188a, 188b), um eine gewünschte Kontur bereitzustellen, bereitgestellt werden.

**Revendications**

**1.** Aube de turbine (34) comprenant :

une structure d'aube incluant une surface extérieure (57) fournissant un bord d'attaque (38), de multiples premiers passages pour refroidissement s'étendant radialement près du bord d'attaque (38), comprenant chacun une première partie et des secondes parties, la première partie s'étendant vers la surface extérieure (57) et formant une tranchée s'étendant radialement (248 ; 348) dans le bord d'attaque (38), les secondes parties étant en communication fluidique avec un second passage pour refroidissement (50) étant des pattes arquées espacées radialement, les tranchées s'étendant radialement (248 ; 348) des multiples premiers passages pour refroidissement étant espacées latéralement.

**2.** Aube de turbine selon la revendication 1, dans laquelle le second passage pour refroidissement (50) s'étend radialement et le premier passage pour refroidissement encercle une partie du second passage pour refroidissement (50) d'un côté pression à un côté aspiration entre le second passage pour refroidissement et la surface extérieure (57), la première partie étant disposée entre les côtés pression et aspiration.

**3.** Aube de turbine selon la revendication 2, dans laquelle le premier passage pour refroidissement est généralement en forme de C.

**4.** Aube de turbine selon la revendication 1, dans laquelle l'un des multiples premiers passages pour refroidissement est situé du côté pression et un autre des passages est situé du côté aspiration, chacune des secondes parties des premiers passages pour refroidissement étant reliée de manière fluidique aux secondes parties de l'autre des multiples premiers passages pour refroidissement seulement à travers le second passage pour refroidissement (50).

**5.** Aube de turbine selon la revendication 4, dans laquelle au moins deux premiers passages sont disposés sur au moins l'un des côtés pression et aspiration.

**6.** Aube de turbine selon la revendication 5, dans laquelle les pattes arquées espacées radialement sont disposées en relation alternée les unes avec les autres.

**7.** Aube de turbine selon une quelconque revendication précédente, dans laquelle les tranchées espacées latéralement (248) sont également espacées radialement.

**8.** Procédé de fabrication d'une aube dotée de passages pour refroidissement internes, le procédé comprenant les étapes de :

fourniture de multiples premiers noyaux (186a, 186b, 188a, 188b) ayant chacun une première partie s'étendant radialement (272, 273 ; 272a, 272b, 273a, 273b) et de multiples secondes parties généralement arquées (274, 276) s'étendant généralement dans le sens de la corde à partir de la première partie (272, 273 ; 272a, 272b, 273a, 273b), lesdites secondes parties étant des pattes de forme arquée espacées radialement les unes des autres ;
disposition des premiers noyaux (186a, 186b, 188a, 188b) dans un moule (94) à un emplacement correspondant à un bord d'attaque (38) d'une aube devant être formée par le moule (94), le moule (94) fournissant un contour d'aube de sorte que les premières parties s'étendant radialement (272, 273 ; 272a, 272b, 273a, 273b) sont espacées latéralement les unes des autres ;
disposition d'un second noyau (82) radialement à l'intérieur du moule (94), le second noyau (82) supportant les secondes parties (274, 276) des premiers noyaux (186a, 186b, 188a, 188b) ; et
dépôt du matériau de moulage dans le moule (94) avec les premières parties (272, 273 ; 272a, 272b, 273a, 273b) s'étendant dans le moule (94) au-delà du contour d'aube et les secondes parties (274, 276) encerclées par le matériau de moulage, les premières parties (272, 273 ; 272a, 272b, 273a, 273b) correspondant à de multiples tranchées espacées latéralement et s'étendant radialement (48) dans le bord d'attaque (38).

**9.** Procédé selon la revendication 8, comprenant l'éta-

pe de retenue des premières parties (272, 273 ; 272a, 272b, 273a, 273b) dans le moule (94) dans une caractéristique de retenue de noyau, la première partie (272, 273 ; 272a, 272b, 273a, 273b) étant à l'extérieur du matériau de moulage.

**10.** Procédé selon la revendication 8 ou 9, dans lequel les premiers noyaux (186a, 186b, 188a, 188b) comprennent au moins un élément de noyau, l'au moins un élément de noyau (168) encerclant le bord d'attaque (38) reflétant généralement le contour d'aube entre des côtés, qui correspondent aux côtés pression et aspiration de l'aube.

**11.** Procédé selon l'une quelconque des revendications 8 à 10, dans lequel le second noyau (82) est un noyau céramique et les premiers noyaux (186a, 186b, 188a, 188b) sont des noyaux métalliques réfractaires, les premier et second noyaux (186a, 186b, 188a, 188b, 82) étant fixés l'un à l'autre.

**12.** Procédé selon l'une quelconque des revendications 8 à 11, dans lequel les premiers noyaux (186a, 186b, 188a, 188b) sont obtenus par estampage d'une structure de noyau comprenant une forme souhaitée à partir d'un matériau métallique réfractaire et par pliage des premiers noyaux (86, 88 ; 186a, 186b, 188a, 188b) pour fournir un contour souhaité.

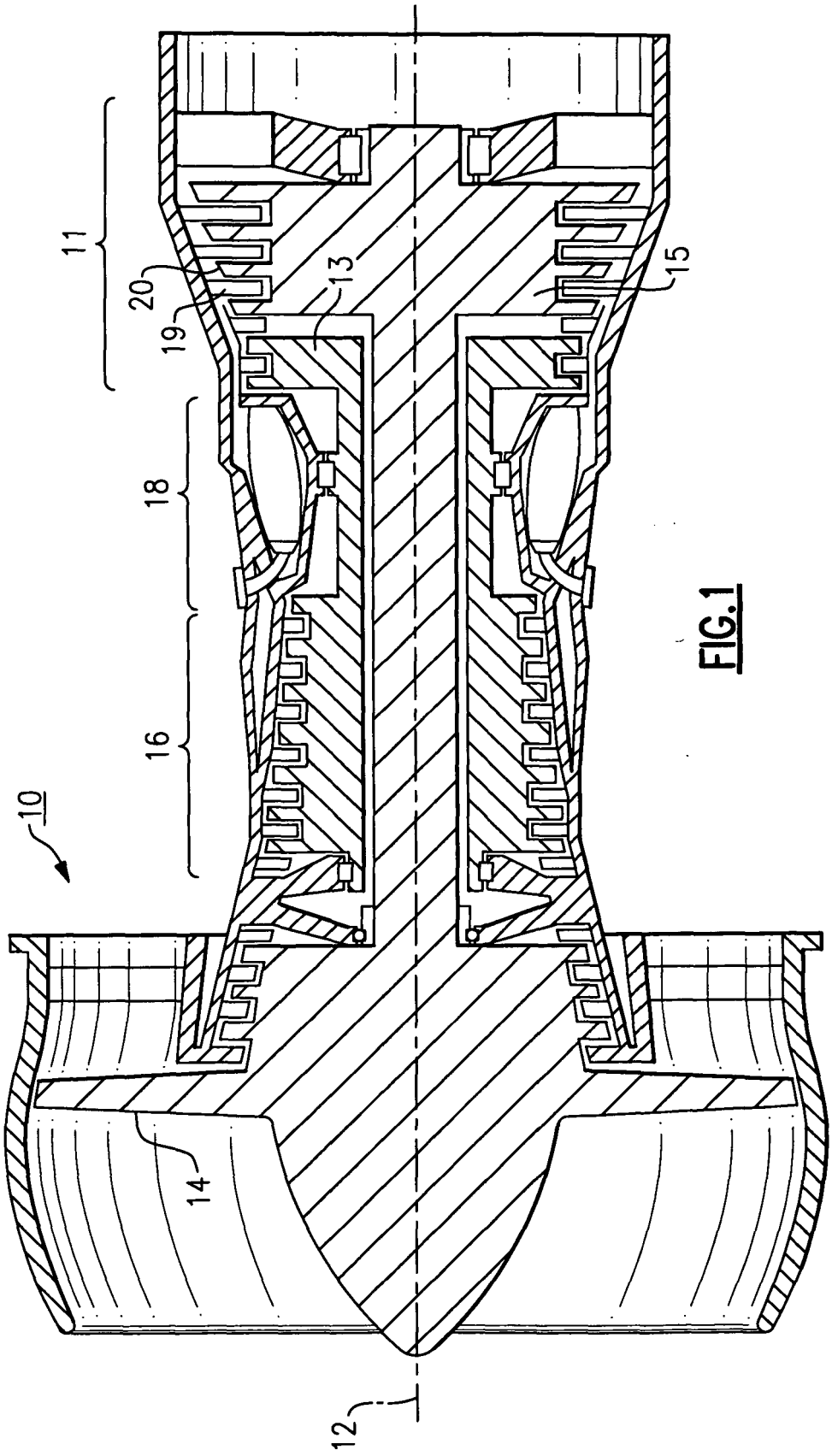



FIG.1

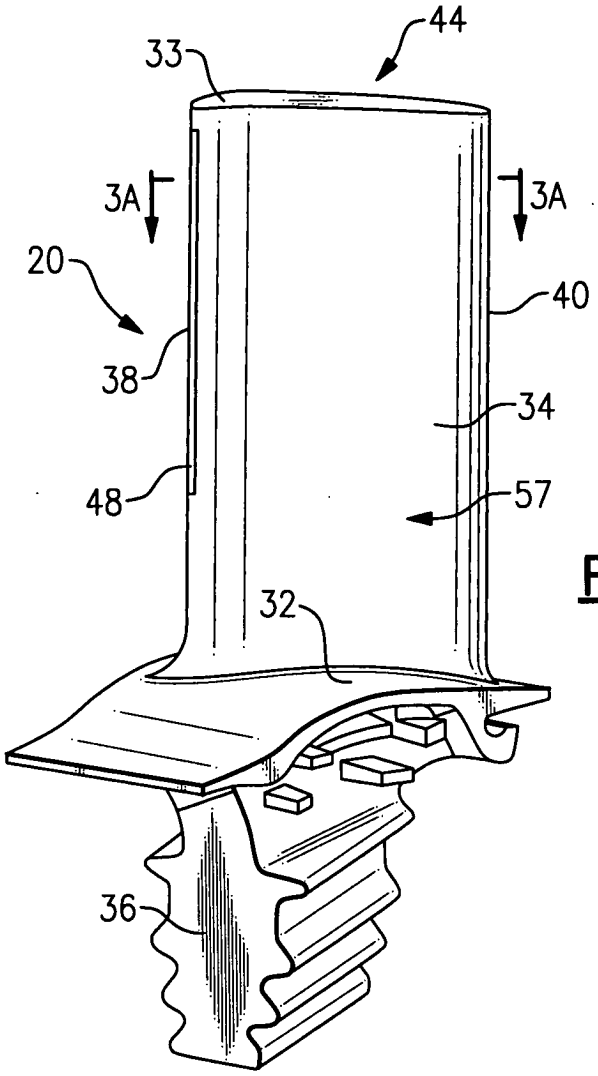
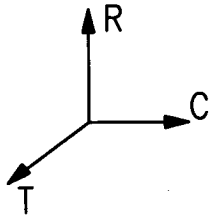



FIG.2



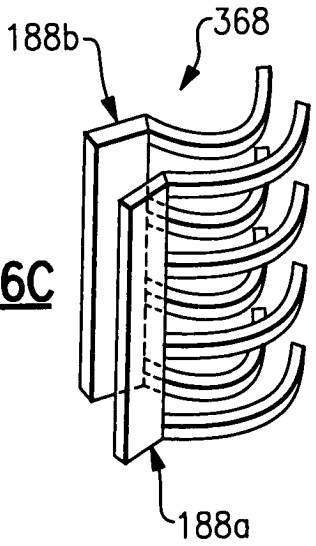




FIG.6C

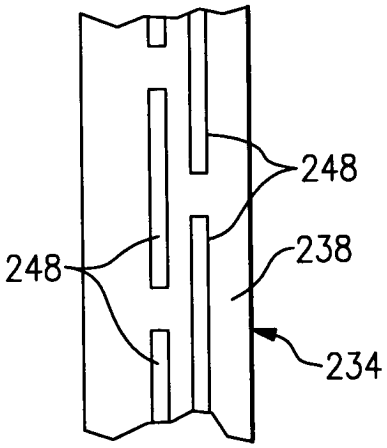



FIG.5C

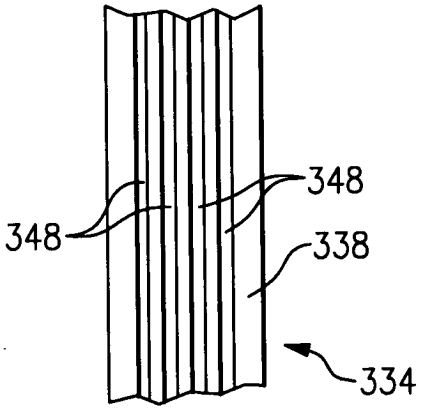



FIG.6B

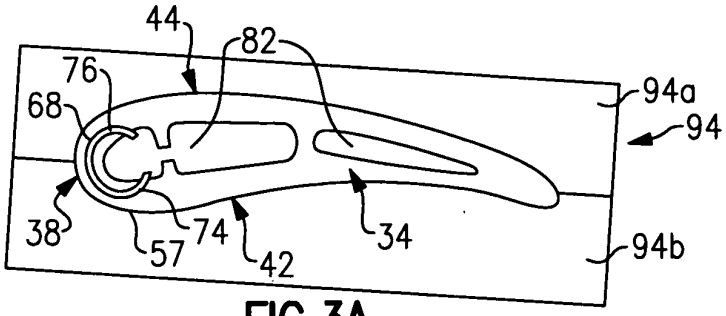



FIG.3A

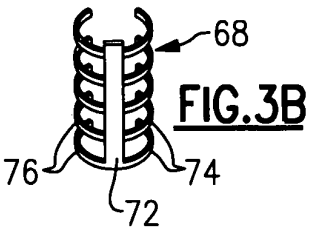



FIG.3B

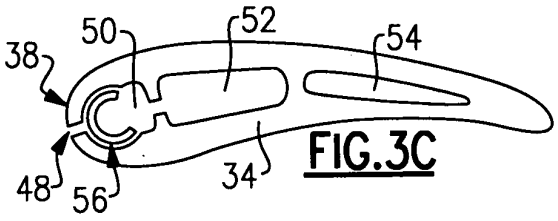



FIG.3C

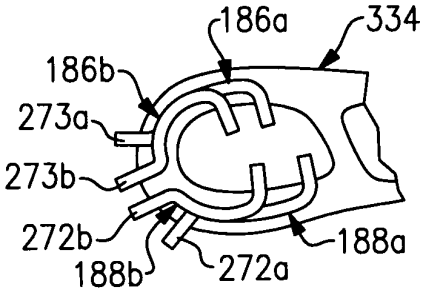



FIG.6A

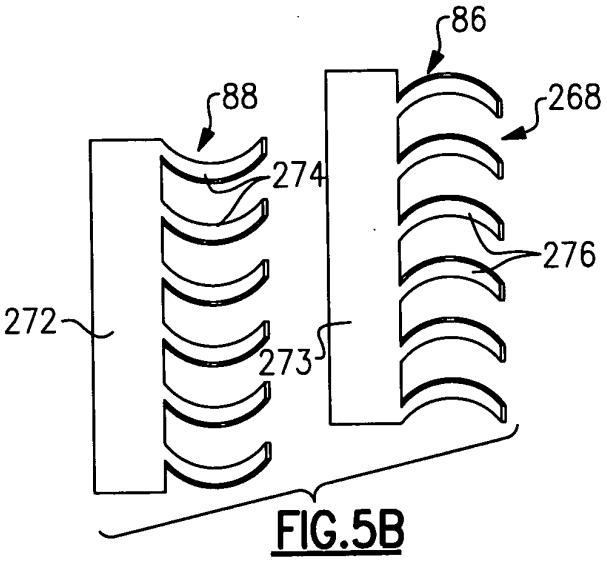



FIG.5B

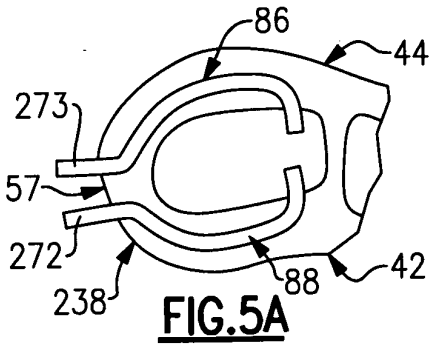



FIG.5A

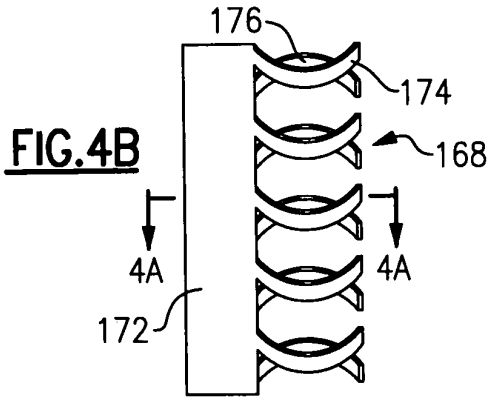



FIG.4B

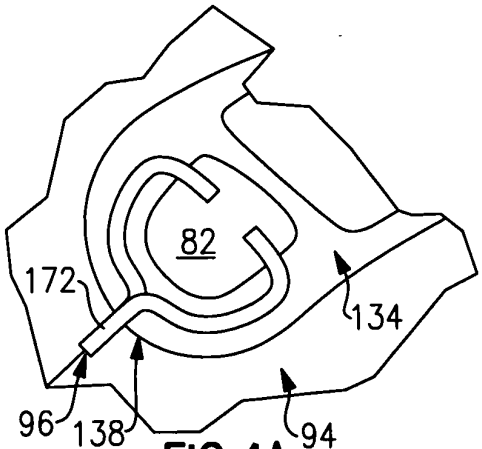



FIG.4A

## REFERENCES CITED IN THE DESCRIPTION

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### Patent documents cited in the description


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