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(71) Applicant: **UNITED TECHNOLOGIES CORPORATION** [US/US]; One Financial Plaza, Hartford, CT 06101 (US).

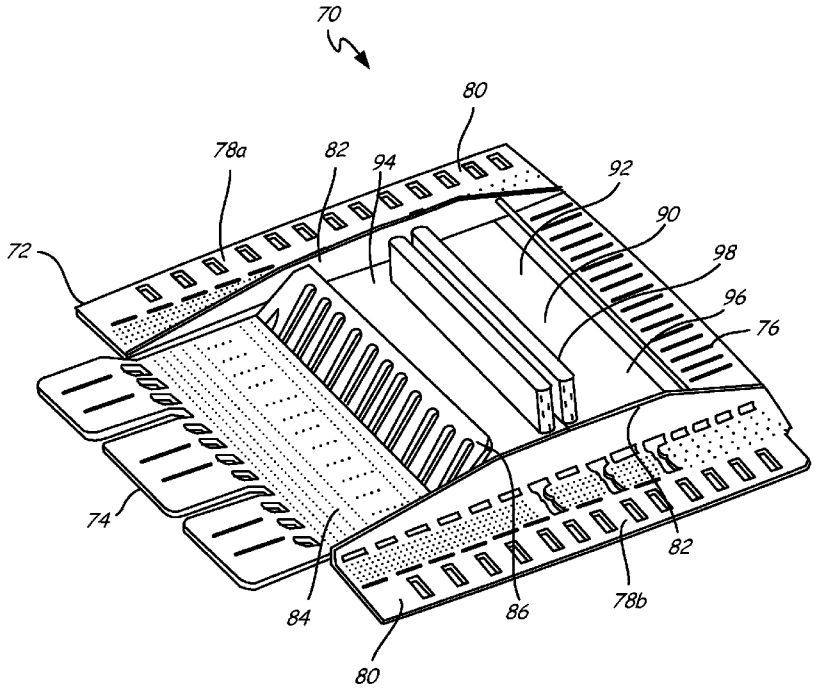
(72) Inventors: **THOLEN, Susan, M.**; 2 Kimball Lane, Kennebunk, ME 04043 (US). **MONGILLO, Dominic,J.**; 167 Four Mile Road, West Hartford, CT 06107 (US). **LUTJEN, Paul, M.**; 129 Whitten Hills Road, Kennebunkport, ME 04046 (US). **KNAPP, James, N.**; 7 Berube Lane, Sanford, ME 04073 (US). **ROSS, Virginia, L.**; 4301 Hillcrest Drive, Madison, WI 53705 (US). **EARL, Jonathan, J.**; 342 Perry Oliver Road, Wells, ME 04090 (US). **HUDSON, Eric, A.**; 331 Burlington Road, Harwinton, CT 06791 (US).

(74) Agents: **BERGMAN, Larrin** et al.; 312 South Third Street, Minneapolis, MN 55415-1028 (US).

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(54) Title: BLADE OUTER AIR SEAL HYBRID CASTING CORE



(57) Abstract: A hybrid sacrificial core for forming an impingement space and an internal cooling passageway network separate from the impingement space of a part may comprise a ceramic core having a first surface portion for forming the impingement space, and a refractory metal core that forms a plurality of passages of the internal cooling passageway network.

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BLADE OUTER AIR SEAL HYBRID CASTING CORE

STATEMENT OF GOVERNMENT INTEREST

This invention was made with government support under F33615-03-D-2354-0009 awarded by The United States Air Force. The government has certain rights in the invention.

BACKGROUND

The invention relates to gas turbine engines. More particularly, the invention relates to casting of cooled shrouds or blade outer air seals (BOAS).

BOAS segments may be internally cooled by bleed air. For example, there may be an array of cooling passageways within the BOAS. Cooling air may be fed into the passageways from the outboard (OD) side of the BOAS (e.g., via one or more inlet ports). The cooling air may exit through the outlet ports.

The BOAS segments may be cast via an investment casting process. In an exemplary casting process, a casting core is used to form the passageway legs and other features. The core has legs corresponding to the passageway legs that extend between portions of the core. The core may be placed in a die. Wax may be molded in the die over the core legs to form a pattern. The pattern may be shelled (e.g., a stuccoing process to form a ceramic shell). The wax may be removed from the shell. Metal may be cast in the shell over the core. The shell and core may be destructively removed. After core removal, the core legs leave the passageway legs in the casting. The as-cast passageway legs are open at both circumferential ends of the raw BOAS casting. At least some of the end openings are closed via plug welding, braze pins, welded-on coverplate or other means. Air inlets to the passageway legs may be drilled from the OD side of the casting.

SUMMARY

In one embodiment, a hybrid sacrificial core for forming an impingement space and an internal cooling passageway network separate from the impingement space of a part may comprise a ceramic core having a first surface portion for forming the impingement space, and a refractory metal core that forms a plurality of passages of the internal cooling passageway network.

In another embodiment, the method comprises fabricating a refractory metal core to define a plurality of passages of an internal cooling passageway network, fabricating a ceramic core to define an impingement cavity, molding a sacrificial

material over the refractory metal core and ceramic c

and casting a component containing the hybrid core.

In yet another embodiment, a sacrificial core forms a cooling network in a part that includes a network of closed cooling passages and an open channel on at least one face that contains at least one terminating aperture for at least one cooling passage. The core comprises a refractory metal core with a plurality of extensions connected together to form the cooling passages, and a protrusion connected to at least one of the extensions to form the channel.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a cross-sectional view of a turbine section of a gas turbine engine.

FIG. 2 is a top perspective view of a BOAS.

FIG. 3 is a bottom perspective view of the BOAS.

FIG. 4 is a cross-sectional view of the BOAS.

FIG. 5 is a perspective view of a hybrid casting core for the BOAS.

FIG. 6 is a perspective view of the BOAS with an enlarged view of one side.

DETAILED DESCRIPTION

Referring to FIG. 1, a section of a gas turbine engine 10 includes a blade outer air seal 12 (hereinafter "BOAS") disposed between a plurality of circumferentially disposed rotor blades 14 of a rotor stage 16 and an annular outer engine case 18 (hereinafter "engine case"). In one embodiment, the BOAS 12 includes a plurality of circumferentially extending segments and is adapted to limit air leakage between blade tips 20 and the engine case 18 that are evenly spaced about an engine centerline C/L.

FIG. 2 is a top perspective view of BOAS 12, and FIG. 3 is a bottom perspective view of the BOAS 12. FIG. 4 is a cross-section of BOAS 12. BOAS 12 has a main body portion 22 having a leading/upstream/forward end 24 and a trailing/downstream/aft end 26. The body has first and second circumferential ends or matefaces 28 and 30. The body has an ID face 32 and an OD face 34. To mount BOAS 12 to environmental structure of gas turbine engine 10 (FIG. 1), BOAS 12 has a plurality of mounting hooks including forward mounting hooks 42 having a forwardly-projecting distal portion recessed aft of the forward end 24, and aft hooks 44. Cooling air enters center cavity via aperture 63 on OD face 34 between forward mounting hooks 42 and aft hooks 44 and exits center cavity via aperture 62 on ID face 32.

A circumferential ring array of a plurality of BOAS 12 may encircle an associated blade stage of gas turbine engine 10. The assembled ID faces 32 thus locally

bound an outboard extreme of the core flowpath 1

BOAS 12 may have features for interlocking the array. Exemplary features include finger and shiplap joints.

BOAS 12 is air-cooled. Bleed air may be directed to a chamber (FIG. 1) immediately outboard of the face 34. The bleed air may be directed through ports 51, 52, 54, 56 that create internal cooling passageway network 60. The exemplary network includes a plurality of passages from the interior chamber of BOAS 12 to a plurality of outlets. Exemplary outlets may include outlets along the circumferential ends 28 and 30. In the exemplary BOAS 12, some outlets are ports 54 are formed along the first circumferential end 28 and some outlets are ports 50 formed along the second circumferential end 30. As is discussed in further detail below, adjacent ports may be interconnected by interconnecting passageways.

In operation, exits from the ID face 32 are fed by passages from internal cooling passageway network 60. In addition, apertures 62 extend from central cavity to ID face 32, and apertures 63 feed central cavity with bleed air from OD face 34. In some embodiments, center cavity may contain an impingement plate 65 to regulate or meter the flow of bleed air from the chamber above. Internal cooling passageway network 60 provides convection cooling of the perimeter of BOAS 12. Apertures 62 allow for film cooling of ID face 32 of BOAS 12.

BOAS 12 is a cast engine component. The casting system includes the base shape formed from a metal or metal alloy such as a nickel based superalloy. FIG. 5 is a perspective view of a hybrid casting core 70 for BOAS 12. Hybrid casting core is comprised of refractory metal core (hereinafter "RMC") 72 and ceramic core 90. RMC core 72 may be formed by any suitable metallic material known in the art.

RMC 72 contains leading edge core 74, trailing edge core 76, and side cores 78a and 78b. In one embodiment, side cores 78a and 78b are mirror images of one another, while in other embodiments (such as the one illustrated) the cores contain different geometries to focus the convection cooling of BOAS 12 based on the geometry of BOAS 12. Side cores 78a and 78b contain axial portions 80 and radial portions 82. Radial portions 82 contain angled legs that allow for the formation of passages that extend through BOAS 12 to connect airflow to the generally axial outlet ports 50 and 54. In some embodiments, axial portion 80 is utilized to create a recessed channel 58 in matefaces 28 and 30 (see FIG. 6). Casting channel 58 rather than machining the same structure desensitizes flow through adjacent passages and apertures to machining burrs.

The design also simplifies the casting process thro
produces channel 58 without additional concerns of a fully enclosed passage.

Similar to the construction of side cores 78a and 78b, leading edge core 74 contains both flat axial portions 84 and radial angled portions 86. The angles between the axial portion 84 and radial portions 86 may vary, and typically are designed to be either 45°, 60°, or 90° with respect to one another. Leading edge core 74, trailing edge core 76, and side cores 78a and 78b may be separate and distinct parts, or in alternate embodiments may be joined into three, two, or a single core through fabrication techniques commonly used in the art, such as welding or brazing.

Ceramic core 90 may be comprised of two separate core pieces 92 and 94, with each part being a mirror copy of the other, or in another embodiment, the same geometry with one piece rotated 180 degrees from the other. Thus, although formed as two individual parts, only a single pattern is required for construction of the core which saves time and controls cost of the finished component incorporating the parts. Core pieces 92 and 94 each contain an axial portion Ceramic core 90 is utilized to create central cavity in BOAS 12. Upon the part being cast, apertures 62 and 63 are formed, such as by laser drilling or electro-discharge machining.

RMC 72 may be bonded to ceramic core 90, such as by adhesives. The exemplary ceramic adhesive may initially be formed of a slurry comprising ceramic powder and organic or inorganic binders. With a binder combination, the organic binder(s) (e.g., acrylics, epoxies, plastics, and the like) could allow for improved room temperature strength of a joint while the inorganic binder(s) (e.g., colloidal silica and the like) may convert to ceramic(s) at a moderate temperature (e.g., 500C). Adhesives may be used to secure RMCs to pre-formed green cores or may be used to secure RMCs to fired ceramic cores. Adhesive may be used in combination with further mechanical interlocking features.

An exemplary RMC 72 may easily be formed from sheetstock. RMCs with various features may be cast or machined, or assembled from multiple sheet pieces or folded from a single sheet piece. Exemplary RMC materials are refractory alloys of Mo, Nb, Ta, and W. These are commercially available in standard shapes, such as sheets, which can be cut as needed to form cores using processes such as laser cutting, shearing, piercing and photo etching. The cut shapes can be deformed by bending and twisting. The standard shapes can be corrugated or dimpled to produce passages which

induce turbulent airflow. Holes can be punched into vanes in passageways.

Refractory metals are generally prone to oxidize at elevated temperatures and are also somewhat soluble in molten superalloys. Accordingly, the RMCs may advantageously have a protective coating to prevent oxidation and erosion by molten metal. These may include coatings of one or more thin continuous adherent ceramic layers. Suitable coating materials include silica, alumina, zirconia, chromia, mullite and hafnia. Preferably, the coefficient of thermal expansion (CTE) of the refractory metal and the coating are similar. Coatings may be applied by CVD, PVD, electrophoresis, and sol gel techniques. Individual layers may typically be 0.1 to 1 mil thick. Metallic layers of Pt, other noble metals, Cr, and Al may be applied to the RMCs for oxidation protection, in combination with a ceramic coating for protection from molten metal erosion.

Refractory metal alloys and intermetallics such as Mo alloys and MoSi2, respectively, which form protective SiO2 layers may also be used for RMCs. Such materials are expected to allow good adherence of a non-reactive oxide such as alumina. Silica, though an oxide, is very reactive in the presence of nickel based alloys and is advantageously coated with a thin layer of other non-reactive oxide. However, by the same token, silica readily diffusion bonds with other oxides such as alumina forming mullite.

After the casting process is complete, the shell and core assembly are removed. The shell is external and can be removed by mechanical means to break the ceramic away from the casting, followed as necessary by chemical means usually involving immersion in a caustic solution to remove to core assembly. Typically, ceramic cores are removed using caustic solutions, often under conditions of elevated temperatures and pressures in an autoclave. The same caustic solution core removal techniques may be employed to remove the present ceramic cores. The RMCs may be removed from superalloy castings by acid treatments. For example, to remove Mo cores from a nickel superalloy, one may use an exemplary 40 parts HNO_3, 30 parts H_2SO_4, with balance H_2O at temperatures of 60–100° C. For refractory metal cores of relatively large cross-sectional dimensions thermal oxidation can be used to remove Mo which forms a volatile oxide. In Mo cores of small cross-sections, thermal oxidation may be less effective.

Hybrid casting core 70 allows for an exempla

Other methods are possible, including a variety of prior art methods and yet-developed methods. Hybrid casting core 70 assembly is overmolded with an easily sacrificed material such as a natural or synthetic wax (e.g., via placing the assembly in a mold and molding the wax around it). There may be multiple such assemblies involved in a given mold.

The overmolded hybrid core assembly (or group of assemblies) forms a casting pattern with an exterior shape largely corresponding to the exterior shape of the part to be cast. The pattern may then be assembled to a shelling fixture (e.g., via wax welding between end plates of the fixture). The pattern may then be shelled (e.g., via one or more stages of slurry dipping, slurry spraying, or the like). After the shell is built up, it may be dried. The drying provides the shell with at least sufficient strength or other physical integrity properties to permit subsequent processing. For example, the shell containing the invested core assembly may be disassembled fully or partially from the shelling fixture and then transferred to a dewaxer (e.g., a steam autoclave). In the dewaxer, a steam dewax process removes a major portion of the wax leaving the core assembly secured within the shell. The shell and core assembly will largely form the ultimate mold. However, the dewax process typically leaves a wax or byproduct hydrocarbon residue on the shell interior and core assembly.

After the dewax, the shell is transferred to a furnace (e.g., containing air or other oxidizing atmosphere) in which it is heated to strengthen the shell and remove any remaining wax residue (e.g., by vaporization) and/or converting hydrocarbon residue to carbon. Oxygen in the atmosphere reacts with the carbon to form carbon dioxide. Removal of the carbon is advantageous to reduce or eliminate the formation of detrimental carbides in the metal casting. Removing carbon offers the additional advantage of reducing the potential for clogging the vacuum pumps used in subsequent stages of operation.

The mold may be removed from the atmospheric furnace, allowed to cool, and inspected. The mold may be transferred to a casting furnace (e.g., placed atop a chill plate in the furnace). The casting furnace may be pumped down to vacuum or charged with a non-oxidizing atmosphere (e.g., inert gas) to prevent oxidation of the casting alloy. The casting furnace is heated to preheat the mold. This preheating serves two purposes: to further harden and strengthen the shell; and to preheat the shell for the

introduction of molten alloy to prevent thermal shoc
the alloy.

After preheating and while still under vacuum conditions, the molten alloy is poured into the mold and the mold is allowed to cool to solidify the alloy (e.g., after withdrawal from the furnace hot zone). After solidification, the vacuum may be broken and the chilled mold removed from the casting furnace. The shell may be removed in a deshelling process (e.g., mechanical breaking of the shell).

The core assembly is removed in a decoring process to leave a cast article (e.g., a metallic precursor of the ultimate part). The cast article may be machined, chemically and/or thermally treated and coated to form the ultimate part. Some or all of any machining or chemical or thermal treatment may be performed before the decoring.

The design of BOAS 12 may involve providing increased cooling to the BOAS. In an exemplary design situation, shifting of the inlets provides the resulting flows with shorter flowpath length than the length (circumferential) of the baseline passageway. In some situations the baseline passages may have been flow-limited due to the pressure loss from the friction along the relatively larger flowpath length. The ratio of pressures just before to just after the outlet determines the flow rate (and thus the cooling capability). For example, a broader design of the engine may increase BOAS 12 heat load and thus increase cooling requirements. Thus, reducing the pressure drop by shortening the flowpath length may provide such increased cooling. RMC core 72 provides an alternative to circumferentially shortening the BOAS (which shortening leads to more segments per engine and thus more cost and leakage) or further complicating the passageway configuration. Alternatively, the design may increase the BOAS circumferential length and decrease part count/cost and air loss.

There may be one or more of several advantages to using the exemplary RMC core 72 with ceramic core 90. The combination of microcircuit and impingement/film technologies allow for a greater use of design configurations to obtain proper cooling of the component. Impingement provided through ceramic core 90 with film cooling from aperture 62 control the thermal gradient of the component and provides adequate thermal mechanical fatigue life for BOAS 12. RMC 72 creates microcircuit passages, which are arranged at the perimeter of BOAS 12 to provide better cooling to those regions most susceptible to oxidation. Hybrid casting core 70 isolates the center region from secondary distress by mitigating the risk of burn through progressing from the edges.

Use of RMC core may avoid or reduce the nee
core 72 for internal cooling passageway network 60 relative to a ceramic core may permit the casting of finer passageways. Where the finer passageways are not needed, i.e., central cavity, ceramic core 90 may be utilized. For example, core thickness and passageway height may be reduced relative to those of a baseline ceramic core and its cast passageways by utilizing RMC core 72. Exemplary RMC thicknesses are typically 0.5-11.0 mm, and more narrowly, less than 1.25 mm. RMC core 72 may also readily be provided with features (e.g., stamped/embossed or laser etched recesses) for casting internal trip strips or other surface enhancements. Meanwhile, ceramic core 90 is cheaper to create, and the size and location of apertures 62 and 63 allow for the easy manufacturing of said apertures without the concerns associated with finer passageways, such as plugging with machining slurry during material removal, the complexity of machining convoluted passages, and obstacles related to the deburring process of small passages.

DISCUSSION OF POSSIBLE EMBODIMENTS

The following are non-exclusive descriptions of possible embodiments of the present invention.

A hybrid sacrificial core for forming an impingement space and an internal cooling passageway network separate from the impingement space of a part may comprise a ceramic core having a first surface portion for forming the impingement space, and a refractory metal core that forms a plurality of passages of the internal cooling passageway network.

The core of the preceding paragraph can optionally include, additionally and/or alternatively any one or more of the following features, configurations, and/or additional components:

the ceramic core is comprised of at least two distinct parts;

the two distinct parts are of the same geometry;

the refractory metal core is comprised of four distinct parts;

refractory metal cores may be mirror images of one another;

the refractory metal core is comprised of a leading edge core, a trailing edge core, and two side cores;

the four distinct parts are joined together;

at least one of the distinct parts contains an axial portion and a radial portion;

the four distinct parts are arranged at nine adjacent part, and a generally rectangular space is contained among the four distinct parts;

the ceramic core is placed in the generally rectangular space;

the ceramic core is attached to the refractory metal core.

A method comprises fabricating a refractory metal core to define a plurality of passages of an internal cooling passageway network, fabricating a ceramic core to define an impingement cavity, molding a sacrificial material over the refractory metal core and ceramic core to form a hybrid casting core, and casting a component containing the hybrid core.

The assembly of the preceding paragraph can optionally include, additionally and/or alternatively any one or more of the following features, configurations, steps, and/or additional components:

shelling the sacrificial material;

removing the shell;

the component being cast is a blade outer air seal;

drilling a plurality of apertures on an inner diameter face to the impingement cavity;

drilling a plurality of apertures on an outer diameter face to the impingement cavity;

the impingement cavity is centrally located within the component, and internal cooling passageway network is peripherally located within the component.

A sacrificial core forms a cooling network in a part that includes a network of closed cooling passages and an open channel on at least one face that contains at least one terminating aperture for at least one cooling passage. The core comprises a refractory metal core with a plurality of extensions connected together to form the cooling passages, and a protrusion connected to at least one of the extensions to form the channel.

The core of the preceding paragraph can optionally include, additionally and/or alternatively any one or more of the following features, configurations, and/or additional components:

the refractory metal core is comprised of four distinct parts, each distinct part containing a plurality of extensions;

the refractory metal core is comprised of a l
core, and two side cores, wherein at least one of the side cores contains the protrusion connected to at least one of the extensions;

the four distinct parts are joined together;

at least one of the distinct parts contains an axial portion and a radial portion.

While the invention has been described with reference to an exemplary embodiment(s), it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment(s) disclosed, but that the invention will include all embodiments falling within the scope of the appended claims.

CLAIMS:

1. A hybrid sacrificial core for forming an impingement space and an internal cooling passageway network separate from the impingement space of a part, the core comprising:

a ceramic core having a first surface portion for forming the impingement space; and

a refractory metal core that forms a plurality of passages of the internal cooling passageway network.

2. The sacrificial core of claim 1, wherein the ceramic core is comprised of at least two distinct parts.

3. The sacrificial core of claim 2, wherein the two distinct parts are of the same geometry.

4. The sacrificial core of claim 1, wherein the refractory metal core is comprised of four distinct parts.

5. The sacrificial core of claim 4, wherein the refractory metal core is comprised of a leading edge core, a trailing edge core, and two side cores.

6. The sacrificial core of claim 4 wherein the four distinct parts are joined together.

7. The sacrificial core of claim 4 wherein at least one of the distinct parts contains an axial portion and a radial portion.

8. The sacrificial core of claim 4, wherein the four distinct parts are arranged at ninety degrees with respect to each adjacent part, and wherein a generally rectangular space is contained among the four distinct parts.

9. The sacrificial core of claim 4, wherein at least two of the leading edge core, trailing edge core, and two side cores are mirror images of one another.

10. The sacrificial core of claim 1, wherein the ceramic core is attached to the refractory metal core.

11. A method comprising:

fabricating a refractory metal core to define a plurality of passages of an internal cooling passageway network;

fabricating a ceramic core to define an impingement cavity;

molding a sacrificial material over the refractory metal core and ceramic core to form a hybrid casting core; and

casting a component containing the hybrid core.

12. The method of claim 11 further comprising:

shelling the sacrificial material; and

removing the shell.

13. The method of claim 12 wherein the component being cast is a blade outer air seal.

14. The method of claim 13 further comprising:

drilling a plurality of apertures on an inner diameter face to the impingement cavity; and

drilling a plurality of apertures on an outer diameter face to the impingement cavity.

15. The method of claim 13 wherein the impingement cavity is centrally located within the component, and internal cooling passageway network is peripherally located within the component.

16. A sacrificial core that forms a cooling network in a part that includes a network of closed cooling passages and an open channel on at least one face that contains at least one terminating aperture for at least one cooling passage, the core comprising:

a refractory metal core comprising:

a plurality of extensions connected together to form the cooling passages;

a protrusion connected to at least one of the extensions to form the channel.

17. The sacrificial core of claim 16 wherein the refractory metal core is comprised of four distinct parts, each distinct part containing a plurality of extensions.

18. The sacrificial core of claim 17, wherein the refractory metal core is comprised of a leading edge core, a trailing edge core, and two side cores, wherein at least one of the side cores contains the protrusion connected to at least one of the extensions.

19. The sacrificial core of claim 17 wherein the four distinct parts are joined together.

20. The sacrificial core of claim 17 wherein at least one of the distinct parts contains an axial portion and a radial portion.

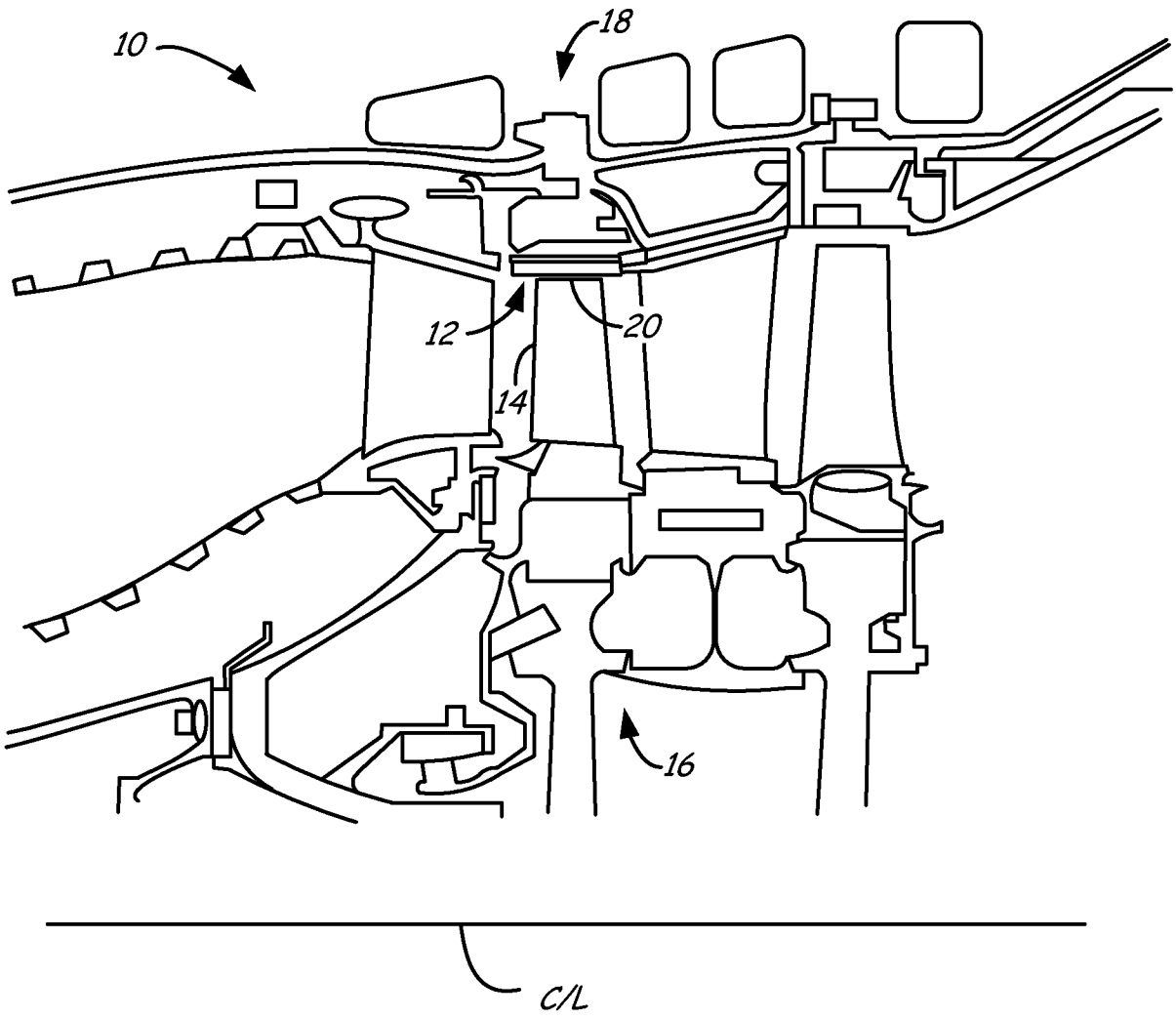


Fig. 1

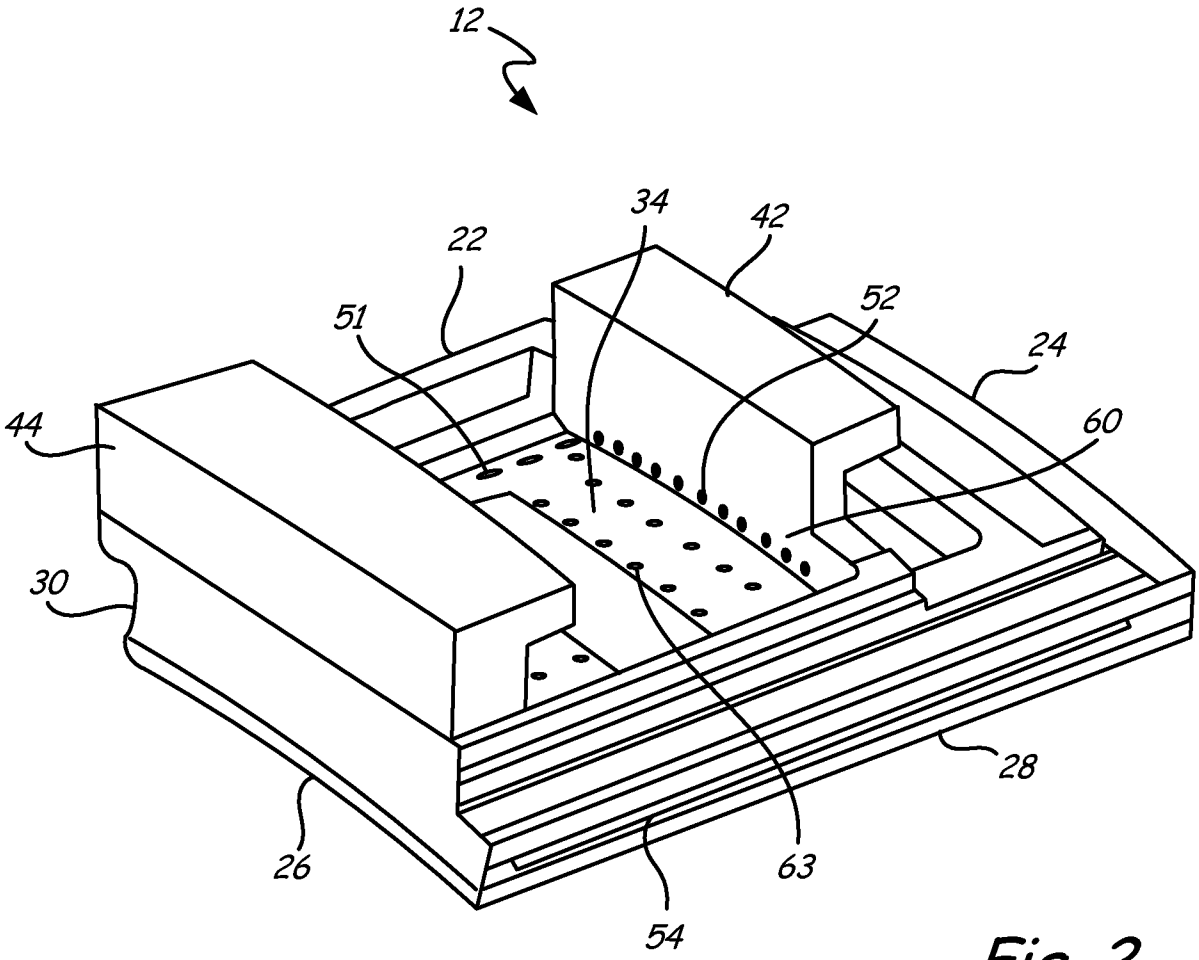


Fig. 2

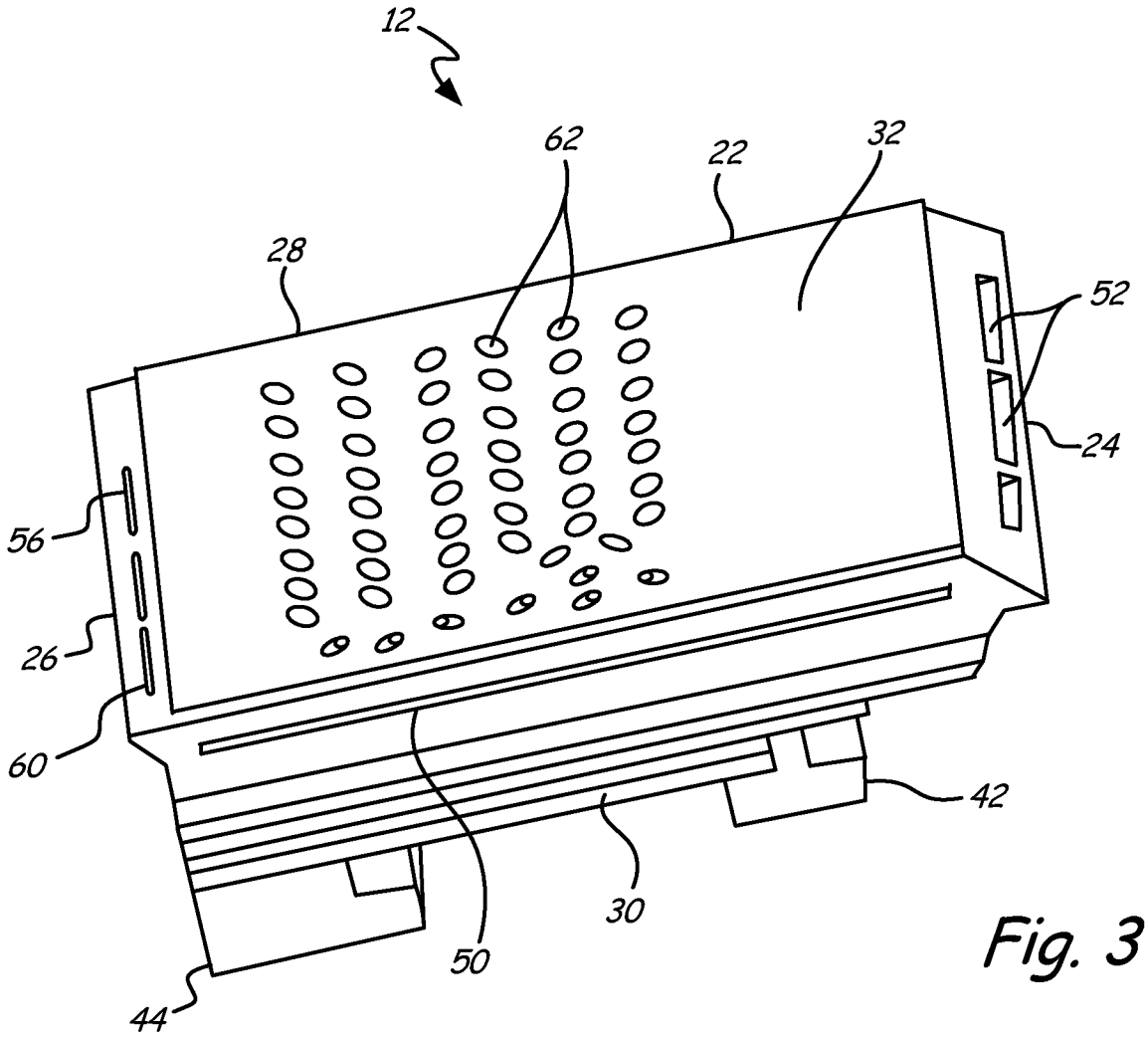


Fig. 3

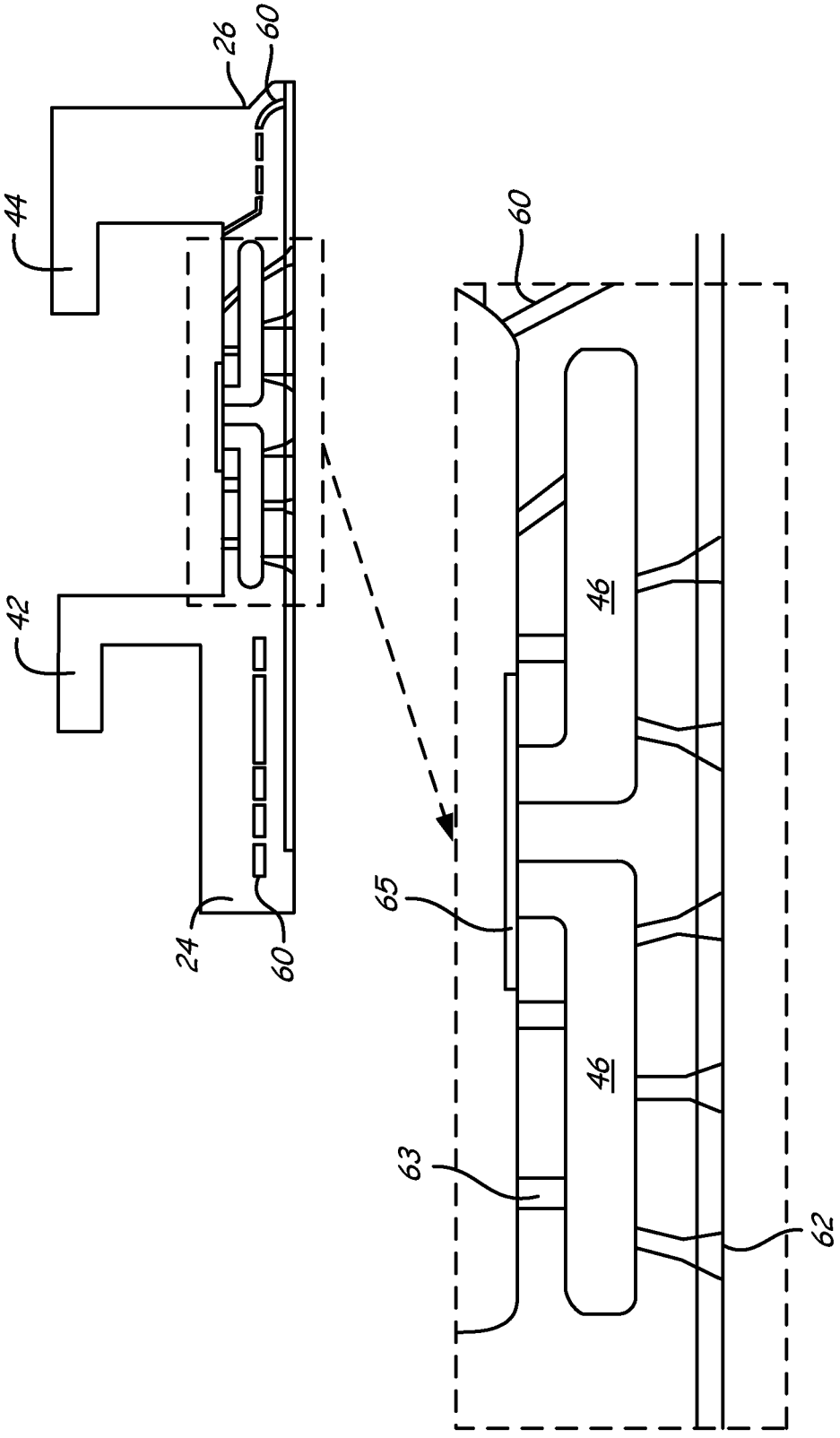


Fig. 4

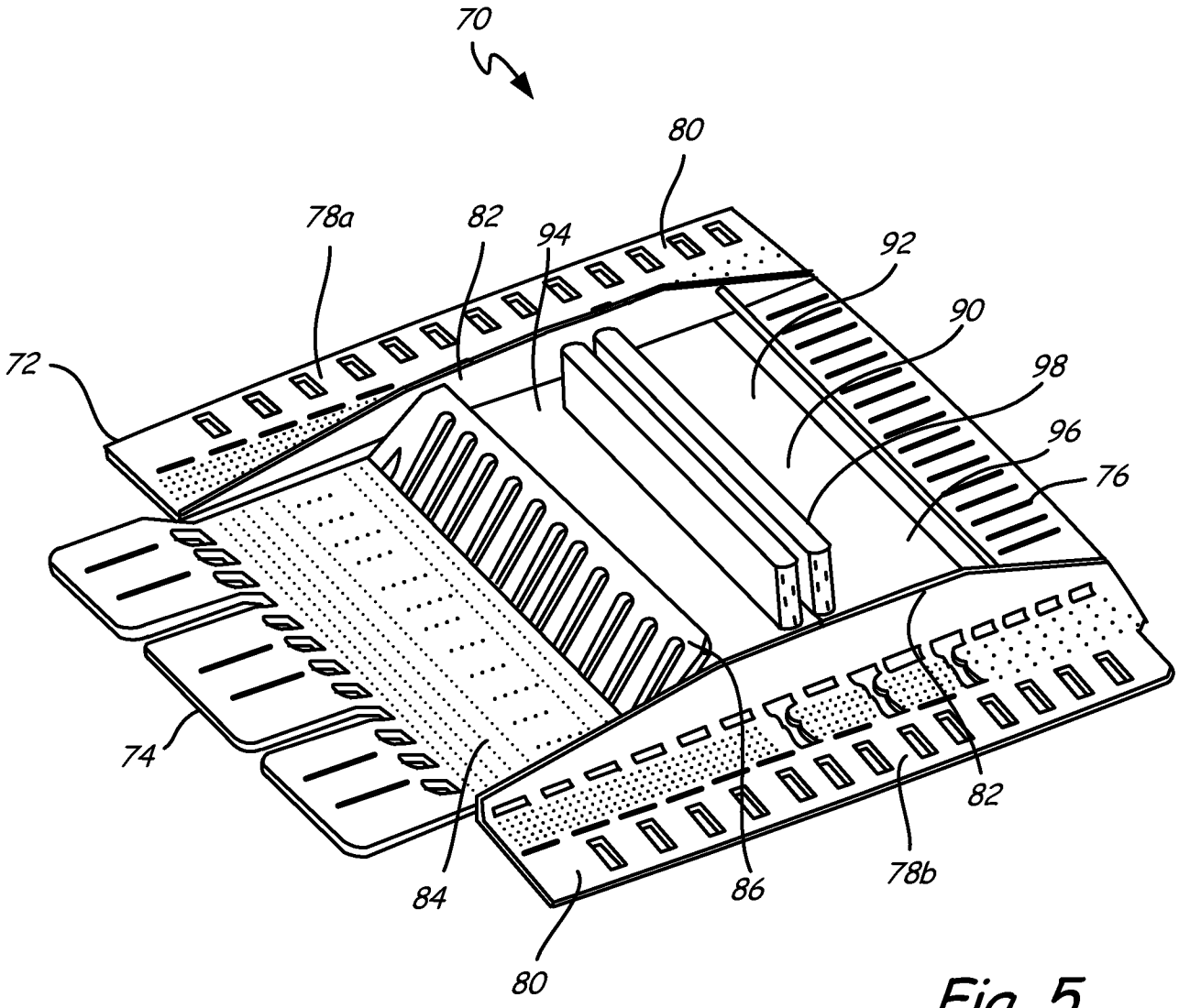


Fig. 5

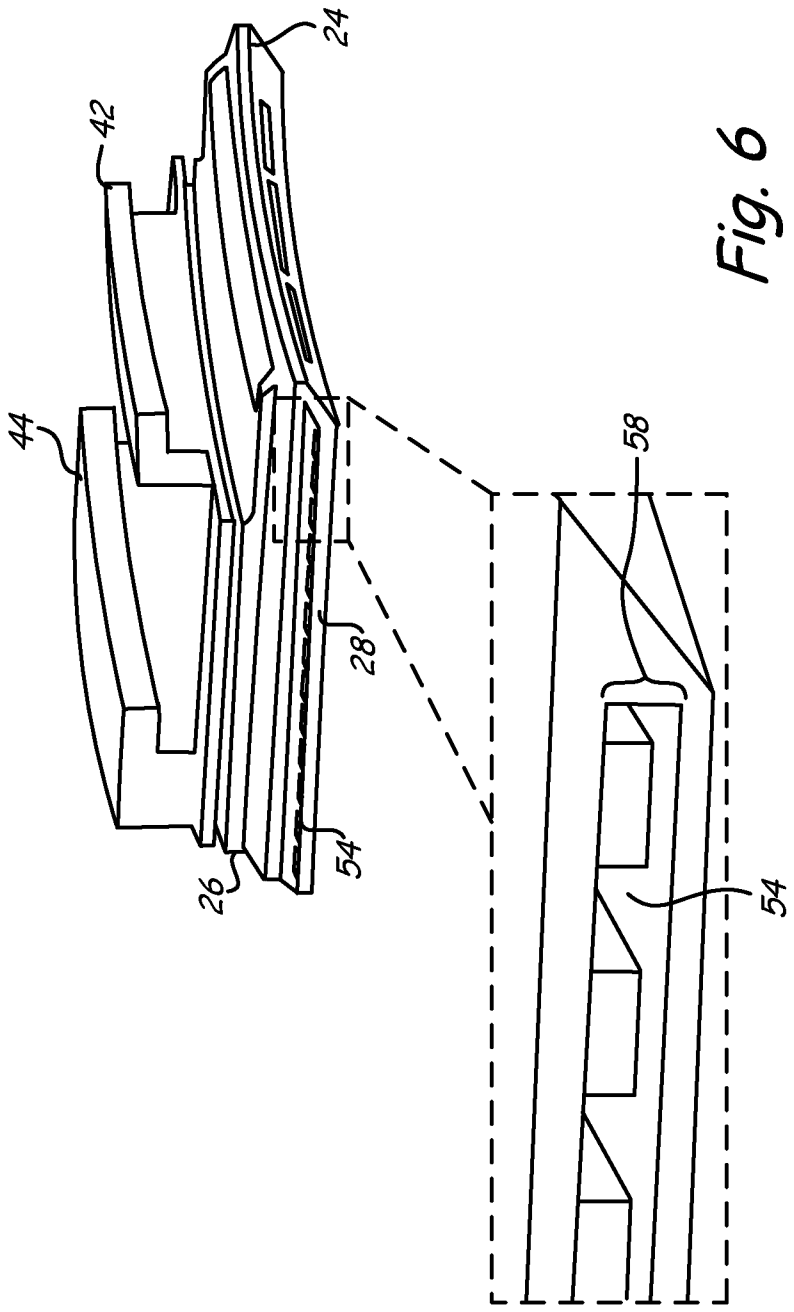


Fig. 6