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(54) **System and method for adaptive impingement cooling**

(57) An adaptive cooling structure comprises a mounting support 44, a liner 42, and a spacer 66. The mounting support 44 has a coolant aperture 62 for directing cooling air A_C through the support 44. The liner 42 has a first surface 52 facing away from the mounting support 44 and a second surface 54 facing towards the support 44. The liner 42 is coupled to the mounting support 44, and the spacer 66 is positioned between the support 44 and the liner 42. The positioning of the spacer 66 creates a chamber 70 between the mounting support 44 and the liner 42, thus allowing the cooling air A_C to impinge on the second surface 54 of the liner 42. The liner wall 48 is configured to deflect away from the mounting support 44 to expand the chamber 70, thus allowing the cooling air A_C to further impinge on the second surface 54 of the liner 42.

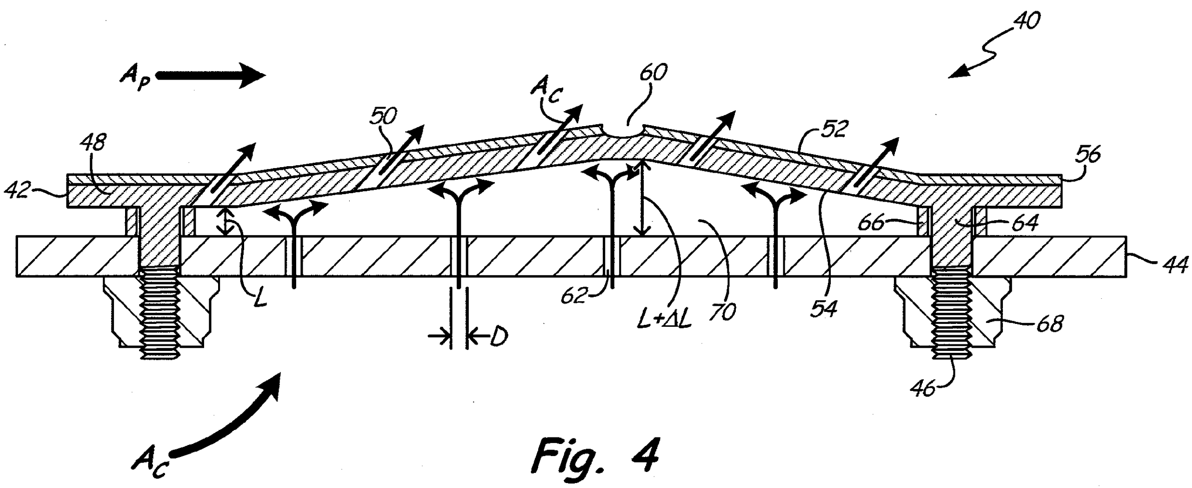

Fig. 4

EP 2 541 147 A2

Description

BACKGROUND

[0001] The present invention relates to cooling systems, and in particular, to a system and method for adaptive impingement cooling for use in hot environments such as those found in gas turbine engines.

[0002] Gas turbine engines operate according to a continuous Brayton cycle where a pressurized air and fuel mixture is ignited in a combustor to produce a flowing stream of hot gas. The air is compressed, used for combustion, expands through a turbine, and finally exits the engine. Some gas turbine engines also include an augmentation system downstream of the turbine, where fuel is also introduced and ignited to increase thrust. Most often, the temperature of the primary air is higher than the melting temperatures of the materials that form the combustor, turbine, and augmentation system components. As a result, adequate cooling is integral to the function of gas turbine engines.

[0003] It is common to combine the benefits of both impingement cooling and film cooling in gas turbine engines. This combination of impingement and film cooling is particularly useful in parts such as combustors and augmentation systems where local hot spots develop. Current practice is to design impingement cooling structures neglecting the deformation that occurs in local hot spots as the temperature in the hot spots increases. As a result, impingement cooling effectiveness decreases as the deformation develops, causing hot spots to become even hotter. Cooling effectiveness should be the highest at local hot spots.

SUMMARY

[0004] An adaptive cooling structure comprises a mounting support, a liner, and a spacer. The mounting support has a coolant aperture for directing cooling air through the support. The liner has a first surface facing away from the mounting support and a second surface facing towards the support. The liner is coupled to the mounting support, and the spacer is positioned between the support and the liner. The positioning of the spacer creates a chamber between the mounting support and the liner, thus allowing the cooling air to impinge on the second surface of the liner. The liner wall is configured to deflect away from the mounting support to expand the chamber, thus allowing the cooling air to further impinge on the second surface of the liner.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] FIG. 1 is a simplified cross-sectional view of an embodiment of a gas turbine engine which employs the adaptive impingement cooling system and method of the present invention.

[0006] FIG. 2 is a partial isometric view of an embodiment of the adaptive cooling structure of the present invention.

[0007] FIG. 3 is a cross-sectional view of the embodiment of the adaptive cooling structure in FIG. 2 at a non-hot spot location.

[0008] FIG. 4 is a cross-sectional view of the embodiment of the adaptive cooling structure in FIG. 2 at a hot spot location.

[0009] FIG. 5 is a graph showing preferred ranges of impingement effectiveness for designing the adaptive cooling structure of the present invention.

DETAILED DESCRIPTION

[0010] FIG. 1 is a simplified cross-sectional view of mixed flow turbofan engine 10 which can employ the adaptive impingement cooling system and method of the present invention. Turbofan engine 10 includes augmentation system 12, fan duct 14, drive fan 16, low pressure compressor 18, high pressure compressor 20, combustor 22, high pressure turbine 24, low pressure turbine 26, and exhaust nozzle 28. Drive fan 16 and low pressure compressor 18 are driven by low pressure turbine 26 with shaft 30. High pressure compressor 20 is driven by high pressure turbine 24 with shaft 32. High pressure compressor 20, combustor 22, high pressure turbine 24 and shaft 32 comprise the core of turbofan engine 10. Augmentation system 12 includes augmenter duct 34 and augmenter liner 36.

[0011] Ambient air $A_{Ambient}$ enters turbofan engine 10 at inlet 38 through drive fan 16. Drive fan 16 is rotated by low pressure turbine 26 to accelerate $A_{Ambient}$ thereby producing a major portion of the thrust output of turbofan engine 10. Accelerated $A_{Ambieni}$ is divided into two streams of air: primary air A_P and secondary air As. Secondary air As, also known as bypass air, passes into fan duct 14 where it passes on to augmentation system 12. Primary air A_P, also known as hot air, is a stream of air that is directed first into low pressure compressor 18 and then into high pressure compressor 20. Pressurized primary air Ap is then passed into combustor 22 where it is mixed with a fuel supply and ignited to produce the high energy gases used to turn high pressure turbine 24 and low pressure turbine 26. Combusted primary air A_P and secondary air A_S are passed through augmentor duct 34 and into augmentation system 12 where a secondary combustion process can be carried out. Augmentation liner 36 prevents heat damage to augmentation system 12 and turbofan engine 10. Exhausted air A_{Ex} exits turbofan engine 10 through exhaust nozzle 28. The adaptive cooling structure of the present invention can be used in combustor 22 or augmentation system 12.

[0012] Referring now to FIG. 2, adaptive cooling structure 40, such as augmentation liner 36 in augmentation system 12 or a heat shield in combustor 22 (FIG. 1), is exposed directly to hot air A_p. Adaptive cooling structure 40 includes liner 42 and mounting support 44. Liner 42 is affixed to mounting support 44 by fastening means 46 such as threaded studs, bolts, rivets, welds, or other suitable fastening means. Liner 42 includes liner wall 48 with one or more film apertures 50. Liner wall 48 has first surface 52 facing away from the mounting support 44 and second surface 54 facing towards mounting support 44. Liner wall 48 may be made from a high temperature, cast, forged or sheet material such as nickel or cobalt for example. First surface 52 may also include one or more layers of thermal barrier coating (TBC) 56, such as a metallic or ceramic material, for improved insulation from hot air A_p. Thermal gradient lines 58 depict the temperature differential across first surface 52 and indicate that hot spot location 60 is present in the area of liner 42. Spallation of TBC layer 56 is also indicative of the presence of hot spot location 60. Mounting support 44 includes one or more coolant apertures 62.

[0013] Coolant apertures 62 in mounting support 44 direct cooling air A_C, such as pressurized air bled from compressor 18 or 20 (FIG. 1), to second surface 54 of liner 42. Coolant apertures 62 are perpendicular to the flow of hot air A_p. In an alternative embodiment, coolant apertures 62 can be angled to the flow. Cooling air A_C provides cooling to reduce the operating temperature of mounting support 44 as it flows through coolant apertures 62. Cooling air A_C exits coolant apertures 62, flows between mounting support 44 and liner wall 48, impinging on second surface 54. Cooling air A_C exits liner 42 through film apertures 50 in liner wall 48, and provides film cooling of first surface 52. In an alternative embodiment, liner 42 is porous instead of having film apertures 50, and cooling air A_C exits liner 42 through the pores.

[0014] The present invention combines the benefits of both impingement cooling and film cooling and is particularly useful in parts such as combustor 22 and augmentation system 12 (FIG.1) where local hot spots develop. When liner wall 48 of adaptive cooling structure 40 is exposed to hot air A_p, hot spot location 60 causes liner wall 48 to deflect away from mounting support 44 (as seen in FIG. 4). Impingement cooling has parameters which when engineered can provide an increased impingement rate upon deflection of liner wall 48. Thus, the present invention configures these parameters to accommodate such deflections as ignoring these parameters results in a less efficient cooling structure.

[0015] FIG. 3 is a cross-sectional view of adaptive cooling structure 40 taken at a non-hot spot location along line 3-3 of FIG. 2. Liner 42 of adaptive cooling structure 40 includes mounting post 64. Mounting post 64 with fastening means 46 is surrounded by spacer 66 and extends from second surface 54 of liner wall 48 through mounting support 44. Nut 68 secures mounting post 64 to mounting support 44 via fastening means (threads) 46. Spacer 66, such as a washer or other suitable spacer, creates chamber 70 between mounting support 44 and liner 42 for impingement cooling. Chamber 70 has distance L between mounting support 44 and liner 42. Coolant apertures 62 have a circular cross section with diameter D. In other embodiments, coolant apertures 62 can have a non-circular cross section with effective diameter D.

[0016] Adaptive cooling structure 40 is directly exposed to hot air A_P. Cooling air A_C flows through coolant apertures 62 and enters chamber 70, impinging on second surface 54. Cooling air A_C exits first surface 52 through film apertures 50 in liner wall 48, forming a film. Film apertures 50 have a circular cross section, but can have a non-circular cross section or can be flared. Film apertures 50 are angled with the flow of hot air A_P. In alternative embodiments, film apertures 50 can be at another angle or can be perpendicular to the flow. The location of coolant apertures 62 is staggered in relation to film apertures 50. In alternative embodiments, the location of coolant apertures 62 can be aligned with film apertures 50 or completely independent of the location of film apertures 50.

[0017] In impingement cooling a ratio L/D of distance L to diameter D of approximately three provides a preferred impingement heat transfer coefficient. When hot spot location 60 causes liner wall 48 to deflect away from mounting support 44 (as seen in FIG. 4), distance L increases and ratio L/D increases as a result. Thus, the present invention is designed to accommodate the deformation by configuring adaptive cooling structure 40 with a ratio L/D lower than three. For adaptive cooling structure 40, employing both impingement cooling and film cooling, the preferred as-fabricated ratio L/D is in the range between approximately two and three, and more specifically 2.5. The configuration of the present invention thus results in increased impingement cooling effectiveness upon deformation in the hot spot, where it is most needed.

[0018] FIG. 4 is a cross-sectional view of adaptive cooling structure 40 taken at a hot spot location along line 4-4 of FIG. 2. Liner wall 48 is deflected away from mounting support 44 due to extreme heat caused by hot spot location 60. Hot spot location 60 is exacerbated by an area of spalled TBC layer 56. The deflection of liner wall 48 expanded chamber 70, increasing distance L to $L+\Delta L$ at hot spot location 60 and in turn increasing ratio L/D of distance L to diameter D of coolant apertures 62.

[0019] Cooling air A_C flows through coolant apertures 62 and enters chamber 70, impinging on second surface 54. Cooling air A_C exits first surface 52 through film apertures 50 in liner wall 48, forming a film. Impingement effectiveness is increased at hot spot location 60 as a result of the deflection of liner 48 away from mounting support 44. As discussed in relation to FIG. 3, the fabrication of adaptive cooling structure 40 with a ratio L/D lower than the preferred ratio of three provides for increased impingement effectiveness when the deflection of liner wall 48 at hot spot location 60 increases distance L to $L+\Delta L$. Thus, the preferred increased ratio L/D resulting from the deflection of liner wall 48 is between three and 3.5, which results in a preferred impingement heat transfer coefficient. In alternative embodiments, the increased ratio L/D ratio can be between approximately one and four or between two and four.

[0020] FIG. 5 is a graph of ratio L/D versus impingement effectiveness H including preferred impingement effectiveness range 72. If as-fabricated adaptive cooling structure 40 has ratio L/D in range 74, less than approximately three, the deflection of liner wall 48 in hot spot location 60 will increase the impingement effectiveness to range 72. If as-fabricated adaptive cooling structure 40 were to have ratio L/D equal to or greater than three, the deflection of liner wall 48 in hot spot location 60 would result in decreased impingement effectiveness range 76. Thus, the present invention is specifically designed so the deflection of liner wall 48 results in ratio L/D in preferred impingement effectiveness range 72. Impingement effectiveness range 72 can have L/D of between one and four, between two and four, or between 2.5 and 3.5. As discussed in relation to FIG. 3, the preferred as-fabricated range 74 has ratio L/D of between approximately two and three, but can be anything less than three. In one embodiment, decreased impingement effectiveness range 76 has ratio L/D of anything above four.

[0021] 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 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 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 structure for adaptive cooling (40) comprising:

a mounting support (44) having a coolant aperture (62) for directing cooling air (A_C) through the mounting support;
a liner (42) coupled to the mounting support, including a wall (48) having a first surface (52) facing away from the mounting support and a second surface (54) facing toward the mounting support; and
a spacer (66) positioned between the mounting support and the liner, the spacer creating a chamber (70) between the mounting support and the liner, thus allowing the cooling air to impinge on the second surface of the liner;

wherein the liner wall is configured to deflect away from the mounting support when exposed to hot air, to expand the chamber, thus allowing the cooling air to further impinge on the second surface of the liner.

2. The structure of claim 1, wherein the spacer positions the liner a distance away from the mounting support to provide impingement cooling at a first rate, and wherein the liner is configured to deflect an amount to increase the distance such that impingement cooling is provided at a second, greater rate.

3. The structure of claim 1 or 2, wherein the liner permits the cooling air to pass through and exit the first surface, forming a film; and/or
wherein the coolant aperture has a diameter D, the chamber has a distance L between the liner and the support that is less than three times the value of D, and the liner wall deflects away from the mounting support when exposed to hot air, increasing L to approximately three times the value of D.

4. The structure of claim 1, 2 or 3, wherein a mounting post (64) with a threaded stud (46) extends from the second surface of the liner wall and through the support, the mounting post is surrounded by a washer acting as the spacer between the support and the liner, and a nut (68) secures the mounting post to the support.

5. The structure of any preceding claim, wherein the first surface is a hot surface with a hot spot location (60), and the hot spot location causes the liner wall to deflect away from the mounting support.

6. The structure of any preceding claim, wherein the liner is an impingement film cooled panel acting as a heat shield in a gas turbine combustor (22), or wherein the liner is an impingement film cooled liner in a gas turbine augmenter (12).

7. A method of adaptively cooling a liner (42) coupled to a support (44) with a spacer (66) positioned between the liner and the support, the method comprising:

introducing cooling air (A_C) into a coolant aperture (62) in the support;
directing the cooling air into a chamber (70) between the support and the liner and
impinging the cooling air against the liner at a first rate;
deflecting the liner away from the mounting support,
expanding the chamber; and
directing the cooling air into the chamber and further impinging the cooling air against the liner at a second rate.

8. The method of claim 7, wherein the spacer positions the liner a distance away from the mounting support to provide impingement cooling at the first rate, and wherein the liner is configured to deflect an amount to increase the distance such that impingement cooling is provided at the second rate, wherein the second rate is preferably greater than the first rate.

9. The method of claim 7 or 8, wherein the coolant aperture has a diameter D, the chamber has a distance L between the liner and support that is less than three times the value of D, and the deflecting step causes the liner to deflect away from the mounting support, increasing L to between approximately one to four times the value of D.

10. The method of any of claims 7 to 9, wherein the deflecting step causes the liner to deflect away from the mounting support, increasing a distance L between the liner and support to between approximately two to four times the value of a diameter D of the coolant aperture, preferably to between approximately 2.5 to 3.5 times the value of D, and more preferably to approximately three times the value of D.

11. The method of any of claims 7 to 10, wherein the coolant aperture has a diameter D, the chamber has a distance L between the liner and support that is between approximately two to three times the value of D, and the deflecting step causes the liner to deflect away from the mounting support, increasing L to between approximately two to four times the value of D.

12. The method of claim 11, wherein the deflecting step causes the liner to deflect away from the mounting support, increasing L to between approximately 2.5 to 3.5 times the value of D, preferably to approximately three times the value of D.

13. The method of any of claims 7 to 12, further comprising:

directing the cooling air to pass through the liner and exit a first surface (52),
forming a film.

14. The method of any of claims 7 to 13, wherein a hot spot location (60) on the liner causes the deflecting step.

15. The method of any of claims 7 to 14, wherein the liner is an impingement film cooled panel acting as a heat shield in a gas turbine combustor (22) or the liner is an impingement film cooled liner in a gas turbine augmenter (12), and in either case the liner is exposed directly to hot air.

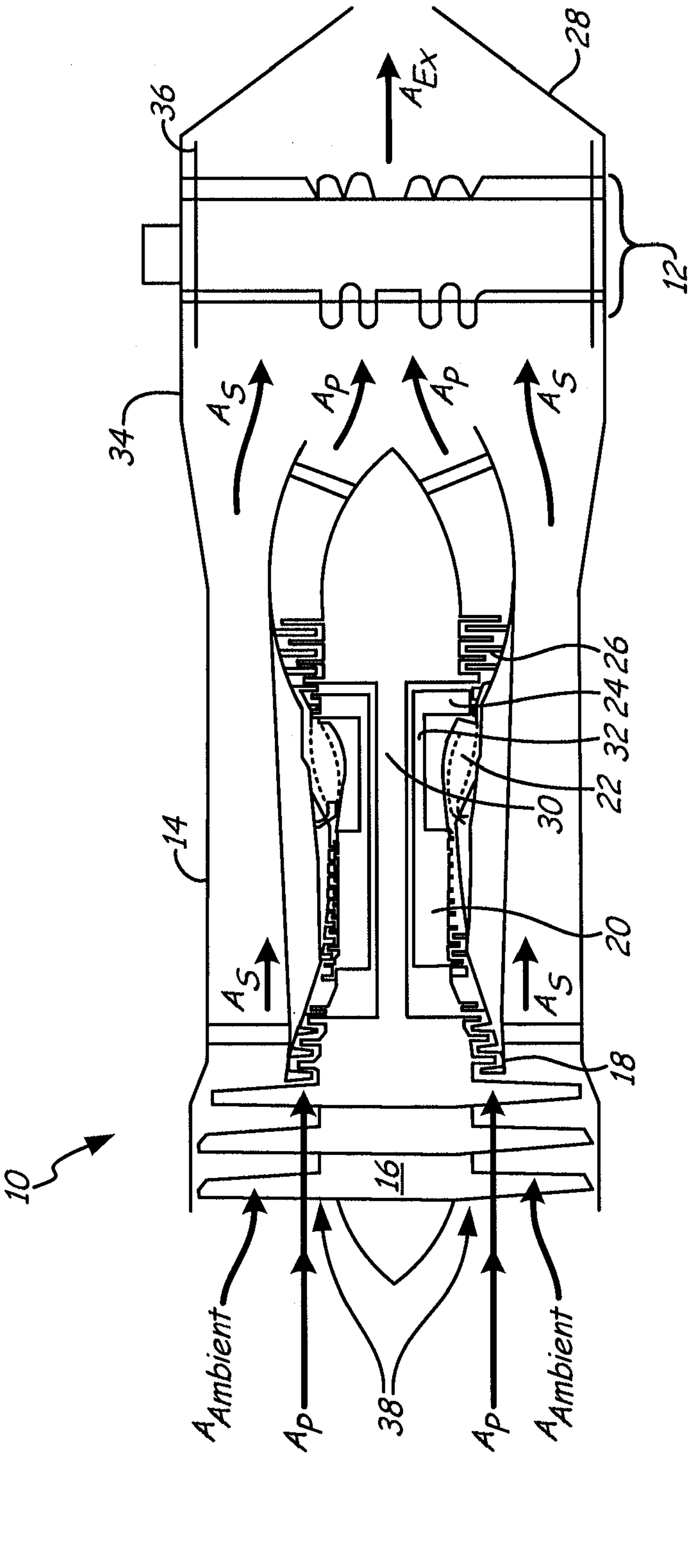

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Fig. 1

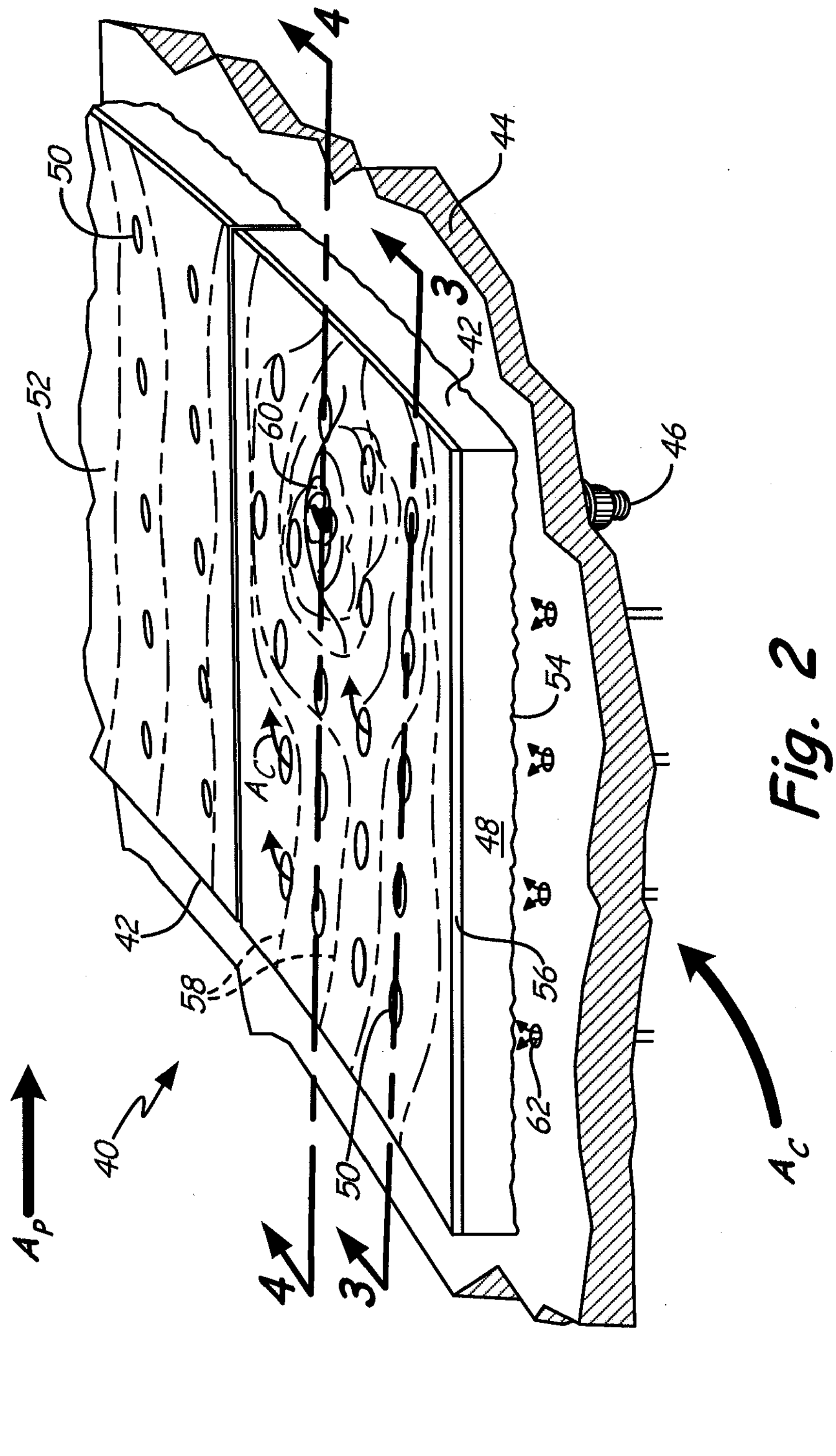

Fig. 2

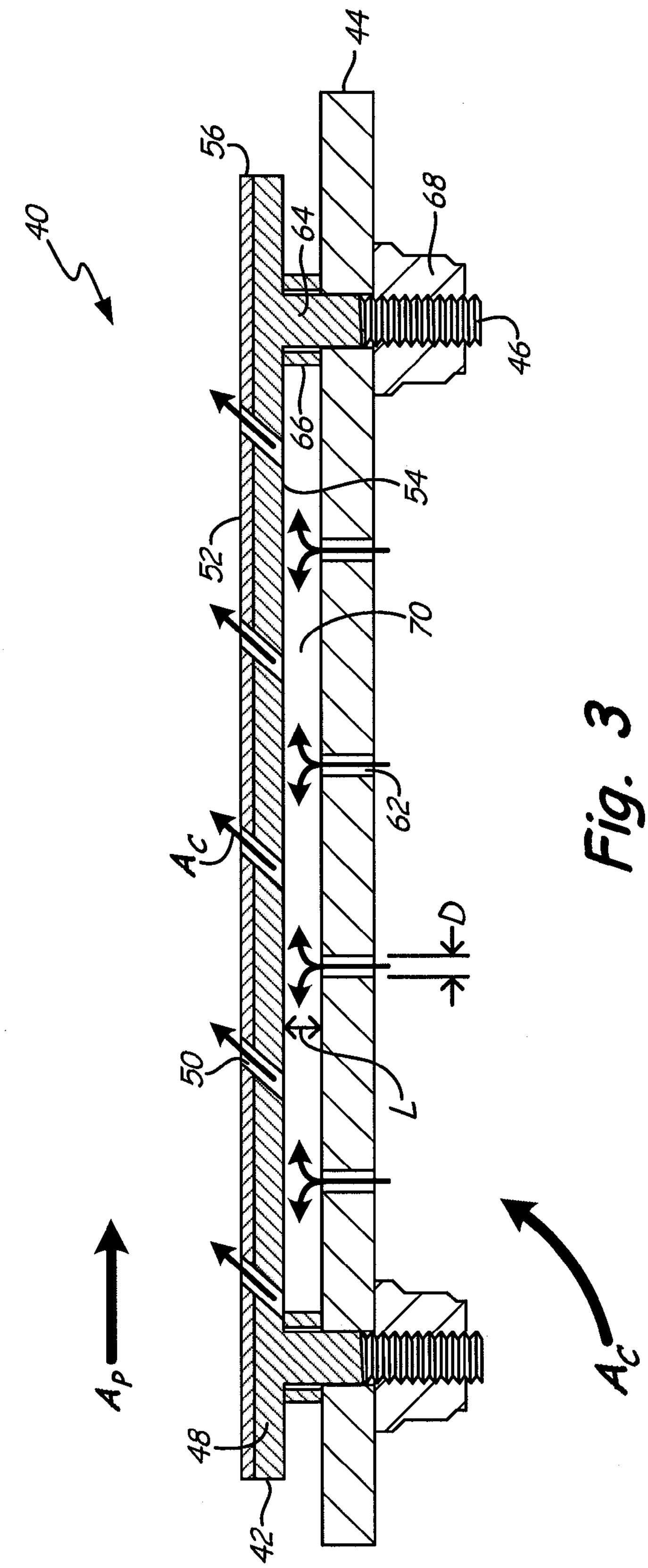

Fig. 3

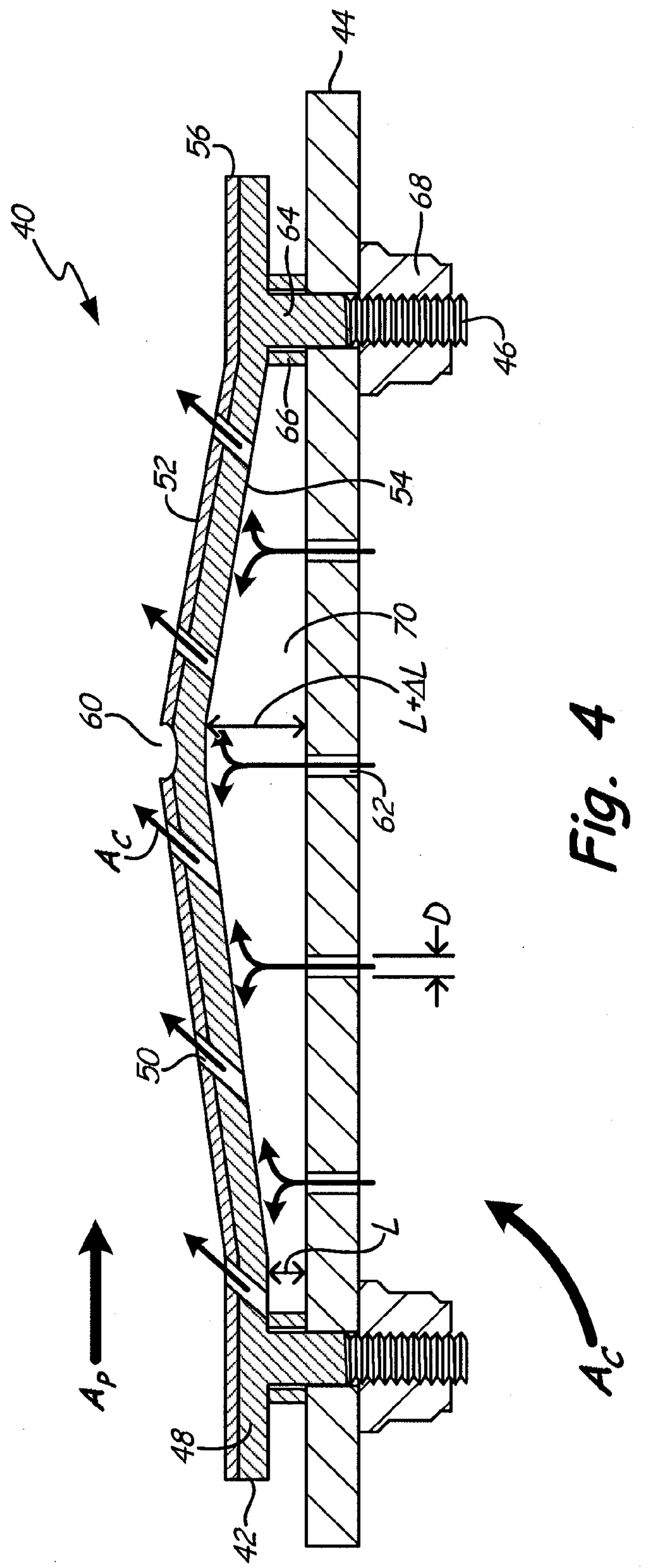

Fig. 4

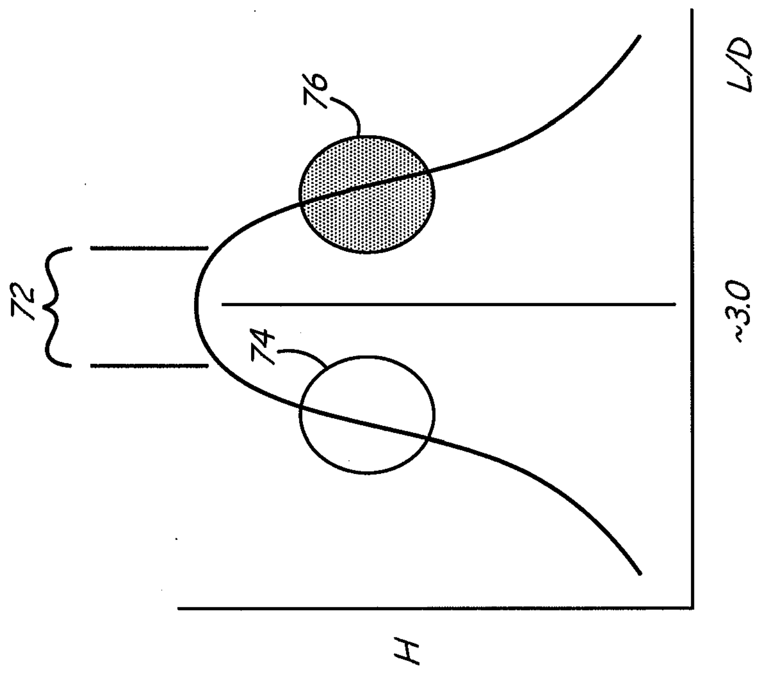

Fig. 5