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(54) **CLEARANCE CONTROL ARRANGEMENT AND CORRESPONDING GAS TURBINE ENGINE**

(57) A clearance control arrangement (26) for a rotor (28), the arrangement comprising a rotor and a casing (32) radially outside the rotor. An annular array of segment assemblies (33) mounted to the casing and radially spaced from the rotor by a clearance (42). Each segment assembly comprising a heat transfer cavity (48) radially

adjacent to the casing. A birdmouth cavity (66) towards the rear of the segment assembly. A bypass hole (68) configured to deliver air to the birdmouth cavity to reduce the amount of air which leaks from the heat transfer cavity to the birdmouth cavity. A corresponding gas turbine engine is also provided.

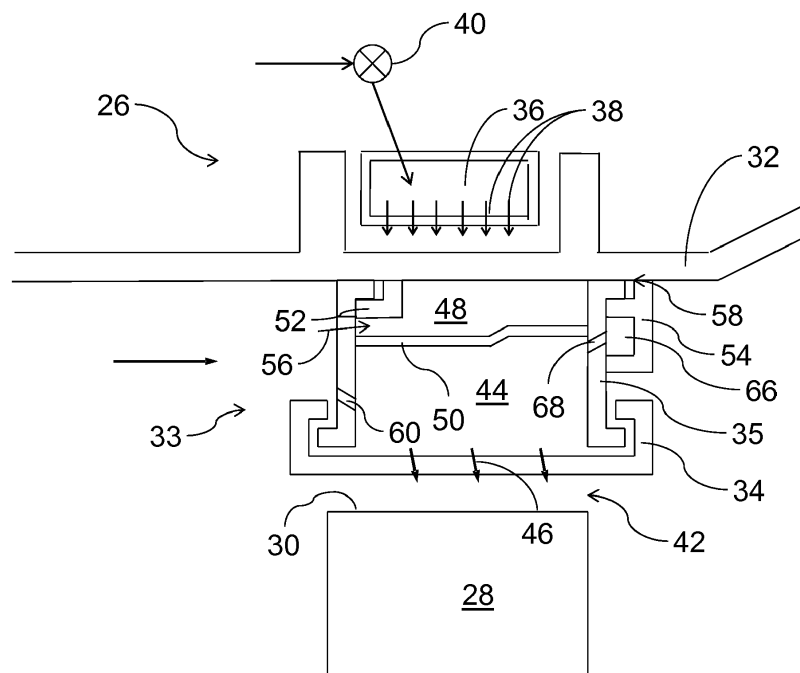


Figure 2

Description

[0001] The present disclosure concerns a clearance control arrangement for a rotor. It finds utility for a rotor stage of a gas turbine engine.

[0002] A gas turbine engine rotor stage typically has a rotor with a casing radially outside it. Mounted radially inside the casing is an array of segments. There is a small clearance between the segments and the tips of the rotor blades. Cooling air may be directed into the segment assemblies and directed towards the rotor blades to cool the segment. Cool air may also be impinged on the outside of the casing to change the rate at which it expands or contracts thermally to maintain the clearance at a preferred level.

[0003] According to a first aspect there is provided a clearance control arrangement for a rotor, the arrangement comprising:

- a rotor;
- a casing radially outside the rotor;
- an annular array of segment assemblies mounted to the casing and radially spaced from the rotor by a clearance; each segment assembly comprising:
 - a heat transfer cavity radially adjacent to the casing;
 - a birdmouth cavity towards the rear of the segment assembly; and
 - a bypass hole configured to deliver air to the birdmouth cavity to reduce the amount of air which leaks from the heat transfer cavity to the birdmouth cavity.

[0004] Advantageously the birdmouth cavity is independently fed by the bypass hole so that leakage from the heat transfer cavity is reduced. Advantageously the mass flow into the heat transfer cavity can therefore be reduced to a level which is suitable for its primary purpose of controlling the clearance.

[0005] The arrangement may further comprise a birdmouth seal defined at the radially outer extent of a rear segment carrier. Advantageously the pressure differential across the birdmouth seal can be reduced by supplying air to it through the bypass hole.

[0006] The birdmouth cavity may be downstream of the birdmouth seal. The arrangement may further comprise a rear hook which supports the rear segment carrier. The birdmouth cavity may be formed between the rear hook and the rear segment carrier. The birdmouth cavity may be formed at an extant junction between the rear hook and the rear segment carrier, for example by providing a radius or chamfer on one or both components. Alternatively the birdmouth cavity may be formed by providing an additional flange on the rear hook or rear segment carrier to form a new cavity.

[0007] Alternatively the birdmouth cavity may be upstream of the birdmouth seal. The birdmouth cavity may

be separated from the heat transfer cavity by a rib. The rib may extend towards the casing. Advantageously the pressure differential across the rib may be substantially equalised so no applied sealing is required. Advantageously the birdmouth cavity is contained within the space envelope of the segment assembly.

[0008] The arrangement may further comprise a segment cooling cavity at the radially inner extent of the segment assembly. The segment cooling cavity may supply air into the clearance. The bypass hole may be configured to receive air from the segment cooling cavity. Advantageously the bypass hole is supplied from a substantially unmetered cavity.

[0009] The arrangement may further comprise a supply cavity radially between the heat transfer cavity and the segment cooling cavity. The bypass hole may be configured to receive air from the supply cavity. Advantageously the birdmouth cavity is supplied by air which is independent of that used for the segment cooling or for affecting the temperature of the casing via the heat transfer cavity.

[0010] The arrangement may comprise an array of bypass holes. The bypass holes may be regularly spaced or irregularly spaced in the circumferential direction.

There may be one bypass hole in each segment assembly. Alternatively there may be more than one bypass hole in each segment assembly. In a further alternative there may be one bypass hole in one or more of the segment assemblies and more than one bypass hole in one or more others of the segment assemblies.

[0011] The arrangement may further comprise a first supply hole configured to allow ingress of air to the heat transfer cavity. There may be an array of first supply holes. The array may extend in the radial and/or circumferential directions.

[0012] The arrangement may further comprise a front hook which supports a front segment carrier. The front hook may be configured to allow ingress of air to the heat transfer cavity. The front hook may be intermittent in the circumferential direction. Alternatively it may include one or more slots, holes or apertures.

[0013] The arrangement may comprise an array of controlled entry holes configured to allow ingress of air to the heat transfer cavity. The controlled entry holes may be supplied from the segment cooling cavity or the supply cavity. Alternatively they may be supplied from outside, upstream of, the segment assembly.

[0014] The segment assembly may include cooling air delivery holes through its radially inner wall. The cooling air delivery holes may be supplied from the segment cooling cavity. The cooling air delivery holes may be angled or positioned to preferentially cool portions of the rotor blade tip across the clearance.

[0015] According to a second aspect there is provided a gas turbine engine comprising an arrangement as described.

[0016] 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.

[0017] Embodiments will now be described by way of example only, with reference to the Figures, in which:

Figure 1 is a sectional side view of a gas turbine engine;

Figure 2 is a schematic illustration of a clearance control arrangement;

Figure 3 to Figure 9 are a schematic illustration of other clearance control arrangements;

[0018] With reference to Figure 1, a gas turbine engine is generally indicated at 10, having a principal and rotational axis 11. The engine 10 comprises, in axial flow series, an air intake 12, a propulsive fan 13, an intermediate pressure compressor 14, a high-pressure compressor 15, combustion equipment 16, a high-pressure turbine 17, an intermediate pressure turbine 18, a low-pressure turbine 19 and an exhaust nozzle 20. A nacelle 21 generally surrounds the engine 10 and defines both the intake 12 and the exhaust nozzle 20.

[0019] The gas turbine engine 10 works in the conventional manner so that air entering the intake 12 is accelerated by the fan 13 to produce two air flows: a first air flow into the intermediate pressure compressor 14 and a second air flow which passes through a bypass duct 22 to provide propulsive thrust. The intermediate pressure compressor 14 compresses the air flow directed into it before delivering that air to the high pressure compressor 15 where further compression takes place.

[0020] The compressed air exhausted from the high-pressure compressor 15 is directed into the combustion equipment 16 where it is mixed with fuel and the mixture combusted. The resultant hot combustion products then expand through, and thereby drive the high, intermediate and low-pressure turbines 17, 18, 19 before being exhausted through the nozzle 20 to provide additional propulsive thrust. The high 17, intermediate 18 and low 19 pressure turbines drive respectively the high pressure compressor 15, intermediate pressure compressor 14 and fan 13, each by suitable interconnecting shaft.

[0021] Other gas turbine engines to which the present disclosure may be applied may have alternative configurations. By way of example such engines may have an alternative number of interconnecting shafts (e.g. two) and/or an alternative number of compressors and/or turbines. Further the engine may comprise a gearbox provided in the drive train from a turbine to a compressor and/or fan.

[0022] Figure 2 shows a clearance control arrangement 26. The clearance control arrangement 26 includes a rotor blade 28 which is one of an annular array of rotor blades 28. The rotor blades 28 may form any one of the rotor stages of the intermediate pressure compressor 14,

high pressure compressor 15, high pressure turbine 17, intermediate pressure turbine 18 or low pressure turbine 19. Each rotor blade 28 includes a tip 30 at its radially outer end. The tip 30 may be parallel to the engine axis 11 or may be angled, curved or another more complex shape as known to the skilled reader. The tip 30 may include fences, shrouds or other features.

[0023] The clearance control arrangement 26 also includes a casing 32 which is annular and is arranged radially outside the rotor blades 28. The casing 32 may extend axially parallel to the engine axis 11 or may have a conical shape or other more complex shape. Typically the shape of the casing 32 radially outside the rotor blades 28 approximately matches the shape inscribed by the rotor blade tips 30.

[0024] A plurality of segments 34 are mounted radially inside the casing 32. The segments 34 form an annular array. There may be the same number of segments 34 as there are rotor blades 28, or there may be more segments 34 or fewer segments 34. Each segment 34 extends circumferentially so that the radially inner surfaces of all the segments 34 form a substantially continuous fluid-washed surface over which working fluid of the gas turbine engine 10 flows as it passes between and over the tips 30 of the rotor blades 28.

[0025] The segments 34 are each mounted to a segment carrier 35. The segment 34 and segment carrier 35 together are referred to as the segment assembly 33. Alternatively the segments 34 may be integrally formed with or coupled to the segment carrier 35 so that the segment assembly 33 forms a single part.

[0026] Radially outside the casing 32 there may be one or more cool air chambers 36 having an array of cooling holes 38 through its radially inner surface. The cool air chamber 36 is selectively filled with cool air, for example by opening or closing a valve 40. The cool air is delivered from the cool air chamber 36 through the cooling holes 38 to impinge against the casing 32 in the axial vicinity of the rotor blades 28. The cool air acts to retard the thermal growth of the casing 32 and therefore causes the radial clearance 42 between the rotor tips 30 and the segments 34 to be held small.

[0027] Each segment assembly 33 includes a number of cavities and chambers. At the radially inner extent of the segment assembly 33 may be a segment cooling cavity 44. The segment cooling cavity 44 includes cooling air delivery holes 46 through its radially inner wall, which is formed by the segment 34. The holes 46 form an array arranged in any suitable pattern in order to cool the segment 34. They may also form vortices or other fluid forms to aerodynamically reduce the clearance 42 perceived by the working fluid.

[0028] Each segment assembly 33 includes a heat transfer cavity 48 at the radially outer extent of the segment assembly 33, radially proximal the casing 32. The inner extent of the heat transfer cavity 48 may be defined by a plate 50. The outer extent is defined by the casing 32. The upstream extent is defined by the front segment

carrier 35 and front hook 52. The downstream extent is defined by the rear segment carrier 35 and rear hook 54. The front hook 52 is configured to support the front segment carrier 35 whilst the rear hook 54 is configured to support the rear segment carrier 35. The front hook 52 may be a fully annular ring or may be intermittent in the circumferential direction. The rear hook 54 is a fully annular ring.

[0029] The heat transfer cavity 48 may be supplied with air through the intermittent gaps in the front hook 52. Alternatively there may be a first supply hole or array of first supply holes 56 which allows air ingress to the heat transfer cavity 48. The first supply hole 56 may be provided through the front segment carrier 35 in some arrangements. Additionally or alternatively the heat transfer cavity 48 may be supplied with air via controlled entry holes 64 through the plate 50, as shown in Figure 4.

[0030] The heat transfer cavity 48 may be supplied with relatively hot air from a chamber upstream of the segment assemblies 33 and radially inside the casing 32, or from some other source. Alternatively relatively cool air may be supplied from a chamber upstream of the segment assemblies 33, for example air which has been pre-cooled through a heat exchanger or similar. The air supplied to the heat transfer cavity 48 acts to control the heat transfer coefficient across the casing 32. Advantageously the air impinged on the casing 32 from the heat transfer cavity 48 may be hotter than the casing 32 itself and so may heat up the casing 32, at least in the axial vicinity of the rotor blades 28. For engine transients, where the rotor disc grows thermally more quickly than the casing 32 would otherwise expand, such impingement heating can maintain the size of the clearance 42, and therefore prevent the clearance 42 reducing to levels where the blade tips 30 may rub the radially inner surface of the segments 34 causing permanent damage, by heating the casing 32 at a similar rate to the thermal growth of the rotor disc. The amount of air needed to be delivered to the heat transfer cavity 48 in order to control the clearance 42 is small. Alternatively the air supplied through the controlled entry holes 64 may reduce the heat transfer across the casing 32.

[0031] There is a birdmouth seal 58 at the rear of the heat transfer cavity 48. The birdmouth seal 58 may be formed between the radially outer end of the rear segment carrier 35 and the casing 32. Alternatively it may be formed between an axially extending portion of the rear hook 54 and the rear segment carrier 35. Alternatively the birdmouth seal 58 may be between a different portion of the rear hook 54 and the rear segment carrier 35. Air from the heat transfer cavity 48 leaks through the birdmouth seal 58 to an area axially downstream of the segment assembly 33. The leakage through the birdmouth seal 58 is governed by the pressure differential across it, which is generally large. This means that the mass flow pulled from the heat transfer cavity 48 across the birdmouth seal 58 to the downstream area is large and may become the governing factor for the amount of

air supplied to the heat transfer cavity 48 in known segment assemblies 33.

[0032] Air may be supplied to the segment cooling cavity 44 via a second supply hole or array of second supply holes 60. There may also be a metering hole or array of metering holes 62, shown in Figure 3, which deliver air from the heat transfer cavity 48 to the segment cooling cavity 44. The metering hole 62 can be sized to control the amount of air drawn into and through the heat transfer cavity 48 for rotor tip clearance purposes.

[0033] The clearance control arrangement 26 includes a birdmouth cavity 66. The birdmouth cavity 66 is situated towards the rear of the segment assembly 33. The birdmouth cavity 66 may be upstream or downstream of the birdmouth seal 58 as will be described. The birdmouth cavity 66 is supplied with air through a bypass hole or an array of bypass holes 68. The bypass holes 68 deliver air to the birdmouth cavity 66 in order to reduce the pressure differential across the birdmouth seal 58. Consequently the leakage mass flow from the heat transfer cavity 48 reduces and so the amount of air drawn into the heat transfer cavity 48 also reduces.

[0034] In a first aspect of the clearance control arrangement 26, as shown in Figure 2, the birdmouth cavity 66 is formed downstream of the birdmouth seal 58, between the rear hook 54 and the rear segment carrier 35. The rear hook 54 is shaped to have two axially extending portions with a radially extending wall joining their downstream ends. The axially extending portion which is closer to the casing 32 forms the hook which supports the rear segment carrier 35. The other axially extending portion of the rear hook 54 closes the birdmouth cavity 66. The bypass hole 68 is arranged to supply air from the segment cooling cavity 44 to the birdmouth cavity 66.

[0035] Advantageously the bypass hole 68 supplies the air which then leaks past the inner axially extending portion. Advantageously the birdmouth cavity 66 is pressurised enough to reduce the pressure differential, and thus leakage across, the birdmouth seal 58. The birdmouth cavity 66 may be sufficiently pressurised so that there is substantially no pressure differential, and consequently no air flow, across the birdmouth seal 58.

[0036] Optionally the segment assembly 33 may include a supply cavity 70 radially between the heat transfer cavity 48 and the segment cooling cavity 44, as shown in Figure 5. The radially outer extent of the supply cavity 70 may be defined by the plate 50 and the radially inner extent may be defined by a second plate 72. The supply cavity 70 may receive air through the second supply hole 60. It may be supplied with relatively hot air from a chamber upstream of the segment assemblies 33 and radially inside the casing 32, or from some other source. Alternatively relatively cool air may be supplied from a chamber upstream of the segment assemblies 33, for example air which has been pre-cooled through a heat exchanger or similar.

[0037] The supply chamber 70 may deliver air to the segment cooling cavity 44 through a delivery hole or array

of delivery holes 74 in the second plate 72. The supply cavity 70 may also be the source for the air which is delivered to the heat transfer cavity 48 through the optional controlled entry holes 64. The bypass hole 68 may receive air from the supply cavity 70 for delivery to the birdmouth cavity 66.

[0038] Advantageously the pressure in the birdmouth cavity 66 may be high enough to set the leakage across the birdmouth seal 58 to zero, or close to zero. This is because the flow supplied to the birdmouth cavity 66 does not affect the pressure of the flow in the segment cooling cavity 44. Advantageously the tip clearance 42 is wholly controlled by sized holes and not by leakage flows.

[0039] In a second aspect of the segment assembly 33, shown in Figure 6 and Figure 7, the birdmouth cavity 66 is again formed between the rear hook 54 and the rear segment carrier 35. However, unlike in the first aspect the rear hook 54 only includes one axially extending portion. The rear hook 54 includes a chamfer, radius or other cut away on the radially outer surface of the axially extending portion which leaves a space adjacent to the rear segment carrier 35 to form the birdmouth cavity 66. Thus in the second aspect the birdmouth cavity 66 is smaller than in the first aspect. Nevertheless it is sufficiently large to be pressurised and therefore to reduce the pressure differential across the birdmouth seal 58 so that the leakage mass flow is reduced.

[0040] Advantageously existing segment assemblies 33 may be adapted to provide the birdmouth cavity 66 of the second aspect by machining away a part of the rear hook 54 and drilling the bypass hole 68. Thus the benefit of the birdmouth cavity 66 can be realised via a modification of existing hardware.

[0041] The birdmouth cavity 66 is again fed with air through the bypass hole 68. The bypass hole 68 may be supplied from the segment cooling cavity 44, Figure 6, or from the supply cavity 70, Figure 7. The bypass hole 68 may be wholly within the rear segment carrier 35 or may partially pass through the plate 50.

[0042] In the second aspect the plate 50 may include the metering hole 62 and/or may include the controlled entry holes 64. Alternatively the heat transfer cavity 48 may be supplied solely by the first supply hole 56 either through the intermittent gaps in the front hook 52 or through the front segment carrier 35.

[0043] A third aspect is shown in Figure 8 and Figure 9. Each includes the optional controlled entry holes 64 which may alternatively be omitted. In the third aspect the rear hook 54 does not include a chamfer, radius or cut away. Instead the birdmouth cavity 66 is provided upstream of the birdmouth seal 58. A radially extending rib 76 is provided to truncate the heat transfer cavity 48 in the axial direction. The rib 76 may be mounted to or integrally formed with the plate 50 and extends towards the casing 32. The radially outer end of the rib 76 is close to, but not attached to, the casing 32 and does not require any applied sealing. The pressure across the rib 76 is balanced by supplying air from the segment cooling cavity

44 to the birdmouth cavity 66 via the bypass hole 68. Because the pressure is balanced there is little or no leakage of air from the heat transfer cavity 48 into the birdmouth cavity 66. The metering hole 62 may therefore be beneficial to maintain flow through the heat transfer cavity 48. Furthermore the leakage across the birdmouth seal 58 downstream of the birdmouth cavity 66 is supplied by the birdmouth cavity 66, which itself is supplied from the segment cooling cavity 44. The bypass hole 68 may have approximately twice the flow area of the metering hole 62. Thus any variation in the amount of flow in the heat transfer cavity 48 will be approximately one third of the variation in the amount of flow across the birdmouth seal 58. This compares favourably with known arrangements where the variation of flow in the heat transfer cavity 48 matched the variation in flow across the birdmouth seal 58.

[0044] Figure 9 is similar to Figure 8 but includes the optional supply cavity 70. The bypass hole 68 is illustrated to be configured to receive air from the segment cooling cavity 44. However, it may alternatively be supplied from the supply cavity 70. In this alternative the bypass hole 68 and metering hole 62 may be mutually offset circumferentially.

[0045] Advantageously the birdmouth cavity 66 supplied by the bypass hole 68 allows the air flow requirement for the heat transfer across the casing 32, in the heat transfer cavity 48, to be independent of the leakage across the birdmouth seal 58. Advantageously the mass flow to be delivered into the heat transfer cavity 48 can be reduced relative to known arrangements without a separately supplied birdmouth cavity 66. This improves the transient rotor tip clearance control.

[0046] Advantageously, deterioration through life, variation between turbine stages of a gas turbine engine 10 and variation between the turbines of different gas turbine engines 10 can be better accommodated since the segment assembly 33 is less sensitive to changes or differences in the birdmouth leakage. That is, if the birdmouth seal 58 deteriorates through life or is less effective (within its defined tolerance limits) the flow across the birdmouth seal 58 will be larger than intended. However, the required increase in air flow will be predominantly or wholly sourced from the segment cooling cavity 44 or supply cavity 70 and not from the heat transfer cavity 48 so the effect on the tip clearance control is minimal.

[0047] The clearance control arrangement 26 finds particular utility for a rotor in a gas turbine engine 10. Such a gas turbine engine 10 may be used to power an aircraft or a marine vessel. The arrangement 26 may be used on one or more than one rotor stage. For example it may be used for a rotor stage of the high pressure turbine 17, the intermediate pressure turbine 18 or the low pressure turbine 19. It may be used on each of several rotor stages of one of the turbines 17, 18, 19 whether the stages are consecutive or separated by other rotor stages. The arrangement 26 may also be used for rotor stages of the compressors, 14, 15.

[0048] It will be understood that the invention is not limited to the embodiments above-described and various modifications and improvements can be made without departing from the concepts described herein. Except where mutually exclusive, any of the features may be employed separately or in combination with any other features and the disclosure extends to and includes all combinations and sub-combinations of one or more features described herein.

Claims

1. A clearance control arrangement (26) for a rotor (28), the arrangement (26) comprising:
 - a rotor (28);
 - a casing (32) radially outside the rotor (28);
 - an annular array of segment assemblies (33) mounted to the casing (32) and radially spaced from the rotor (28) by a clearance (42); each segment assembly (33) comprising:
 - a heat transfer cavity (48) radially adjacent to the casing (32);
 - a birdmouth cavity (66) towards the rear of the segment assembly (33);
 - a bypass hole (68) configured to deliver air to the birdmouth cavity (66) to reduce the amount of air which leaks from the heat transfer cavity (48) to the birdmouth cavity (66); and
 - a birdmouth seal (58) defined at the radially outer extent of a rear segment carrier (35).
2. An arrangement (26) as claimed in claim 1 wherein the birdmouth cavity (66) is downstream of the birdmouth seal (58).
3. An arrangement (26) as claimed in claim 2 further comprising a rear hook (54) which supports the rear segment carrier (35), the birdmouth cavity (66) formed between the rear hook (54) and the rear segment carrier (35).
4. An arrangement (26) as claimed in claim 1 wherein the birdmouth cavity (66) is upstream of the birdmouth seal (58).
5. An arrangement (26) as claimed in claim 4 wherein the birdmouth cavity (66) is separated from the heat transfer cavity (48) by a rib (76).
6. An arrangement (26) as claimed in any preceding claim further comprising a segment cooling cavity (44) at the radially inner extent of the segment assembly (33).
7. An arrangement (26) as claimed in claim 6 wherein the bypass hole (68) is configured to receive air from the segment cooling cavity (44).
8. An arrangement (26) as claimed in claim 6 or claim 7 further comprising a supply cavity (70) radially between the heat transfer cavity (48) and the segment cooling cavity (44).
9. An arrangement (26) as claimed in claim 8 wherein the bypass hole (68) is configured to receive air from the supply cavity (70).
10. An arrangement (26) as claimed in any preceding claim comprising an array of bypass holes (68).
11. An arrangement (26) as claimed in any preceding claim further comprising a first supply hole (56) configured to allow ingress of air to the heat transfer cavity (48).
12. An arrangement (26) as claimed in any preceding claim further comprising a front hook (52) which supports a front segment carrier (35), the front hook (52) configured to allow ingress of air to the heat transfer cavity (48).
13. An arrangement (26) as claimed in any preceding claim further comprising an array of controlled entry holes (64) configured to allow ingress of air to the heat transfer cavity (48).
14. An arrangement (26) as claimed in any preceding claim wherein the segment assembly (33) includes cooling air delivery holes (46) through its radially inner wall.
15. A gas turbine engine (10) comprising an arrangement (26) as claimed in any preceding claim.

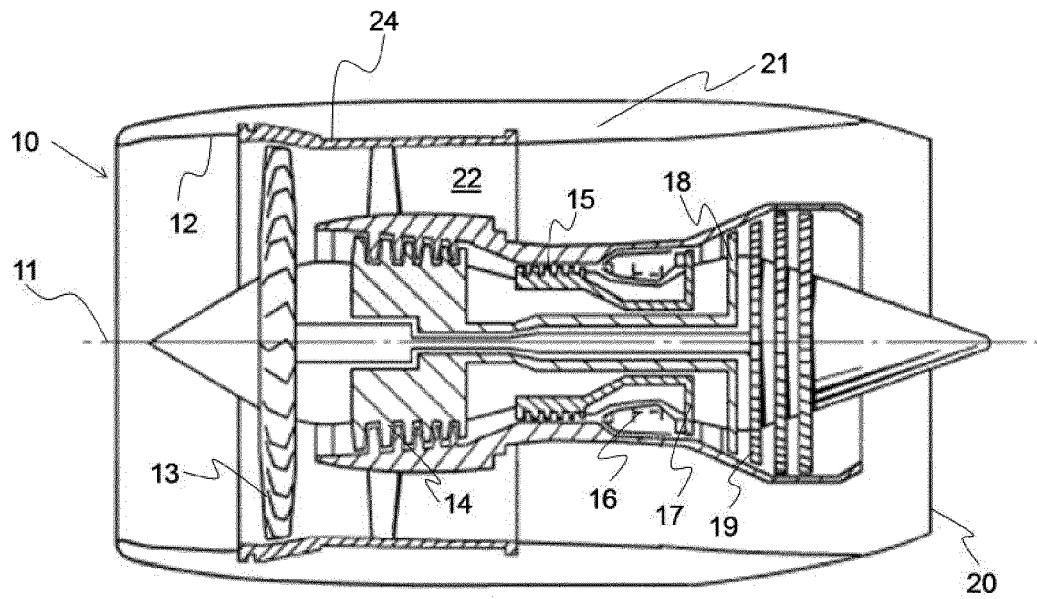


Figure 1

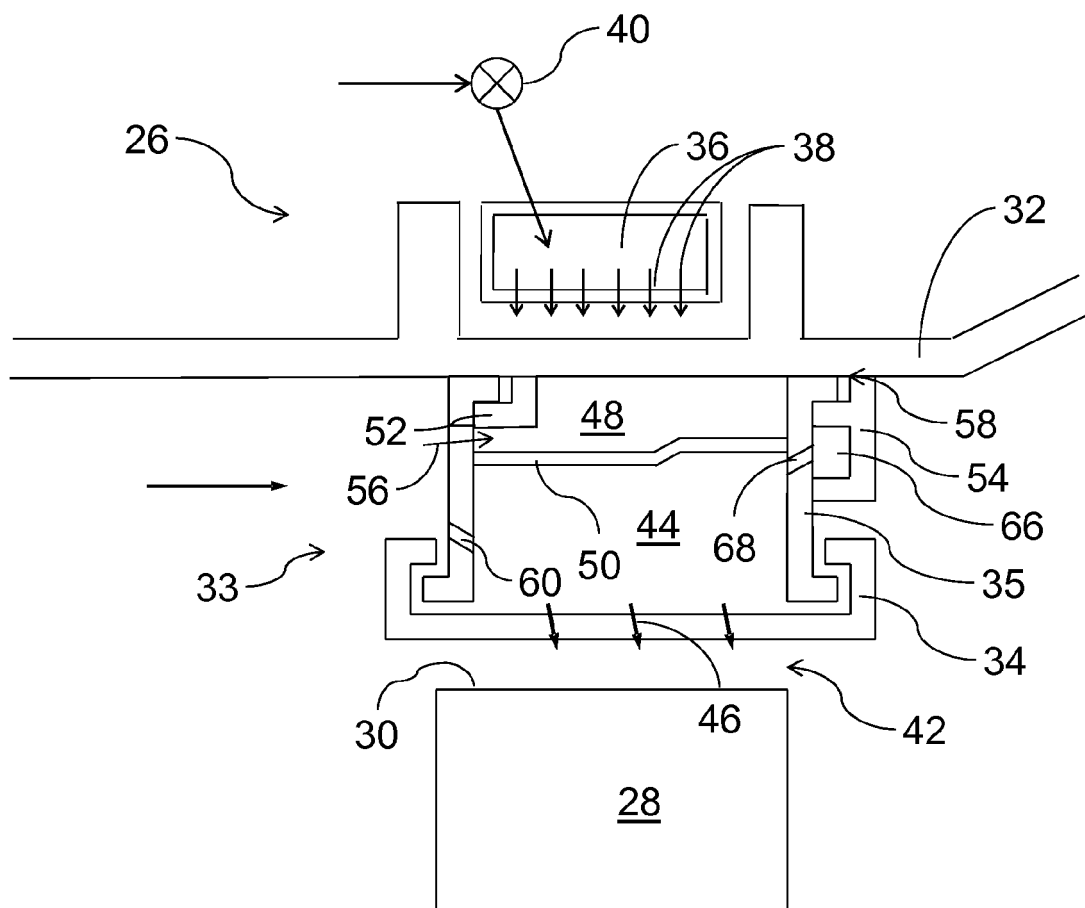


Figure 2

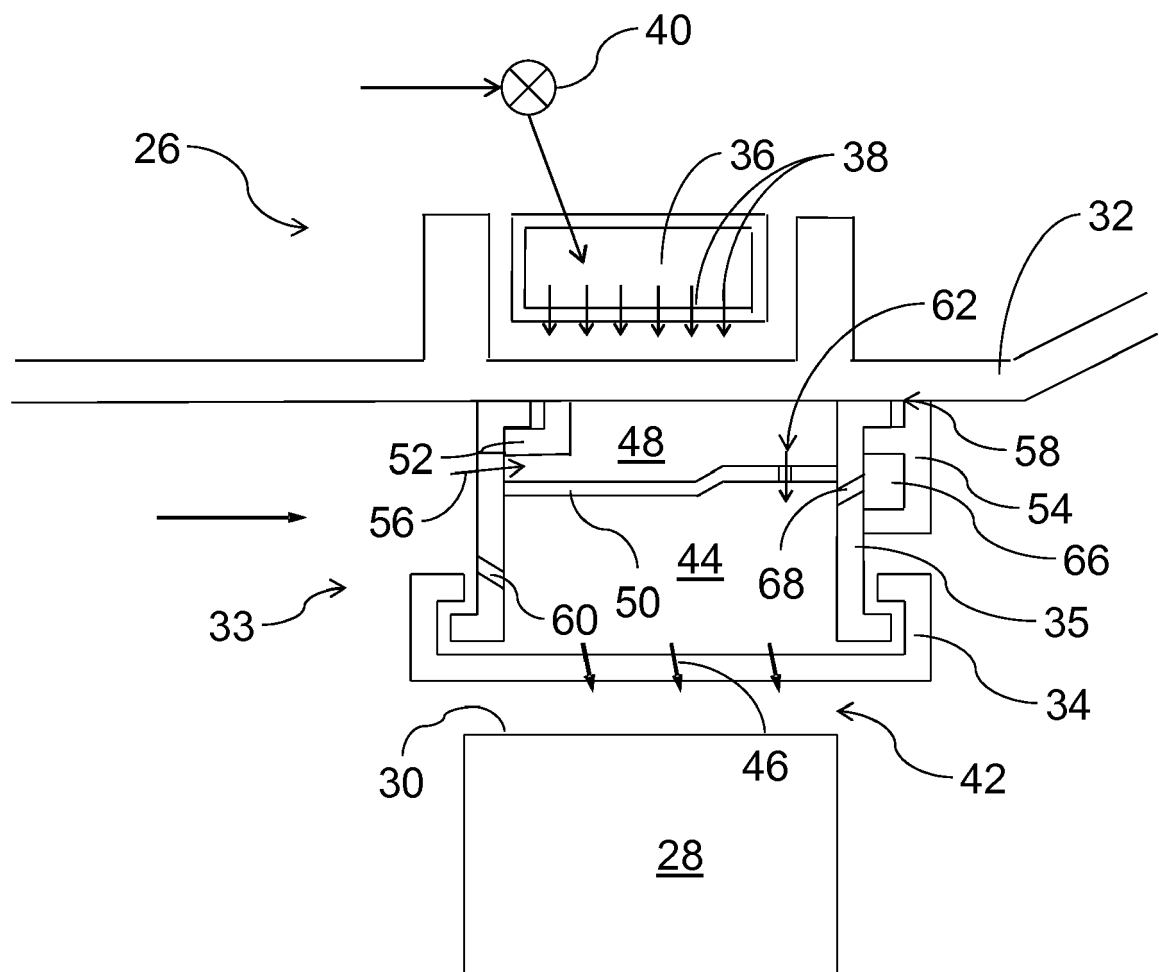


Figure 3

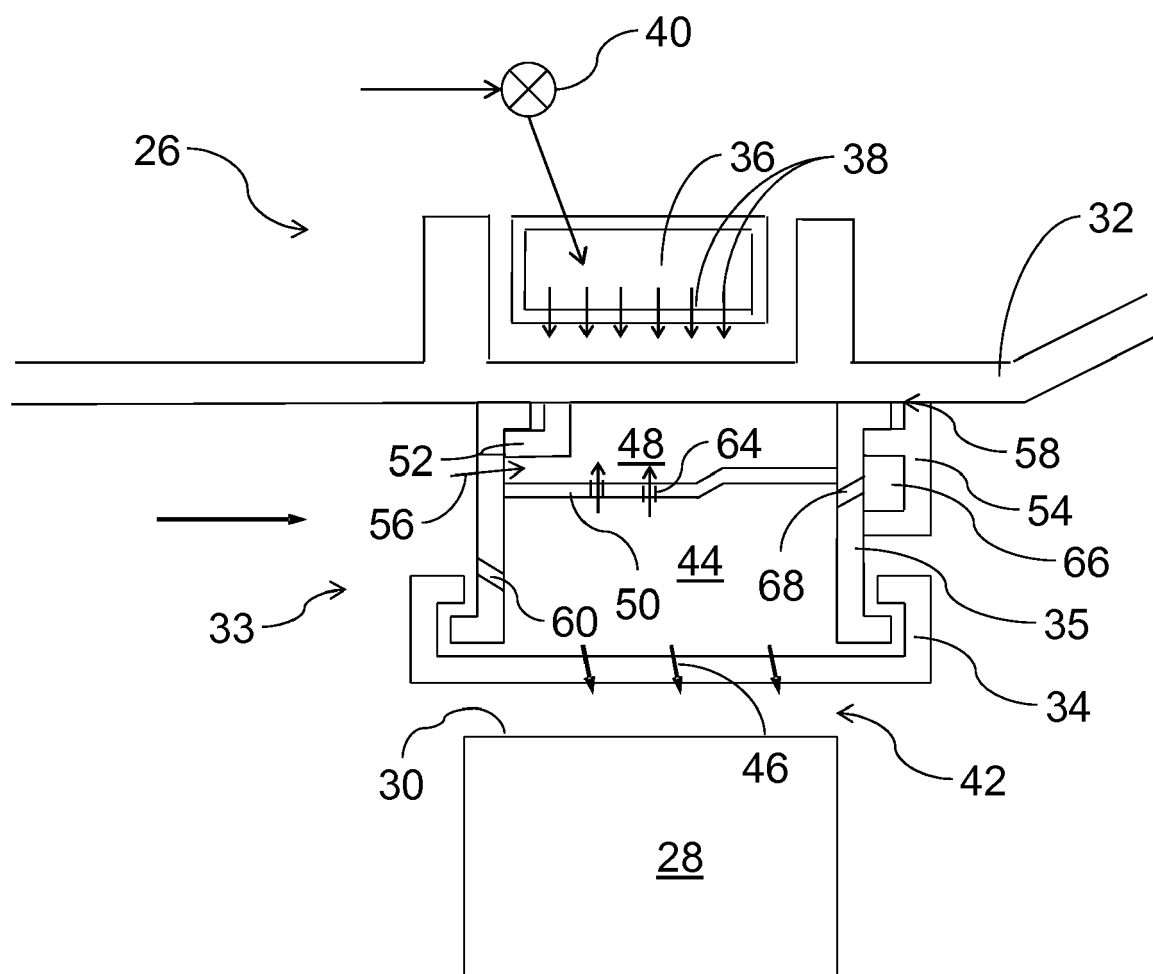


Figure 4

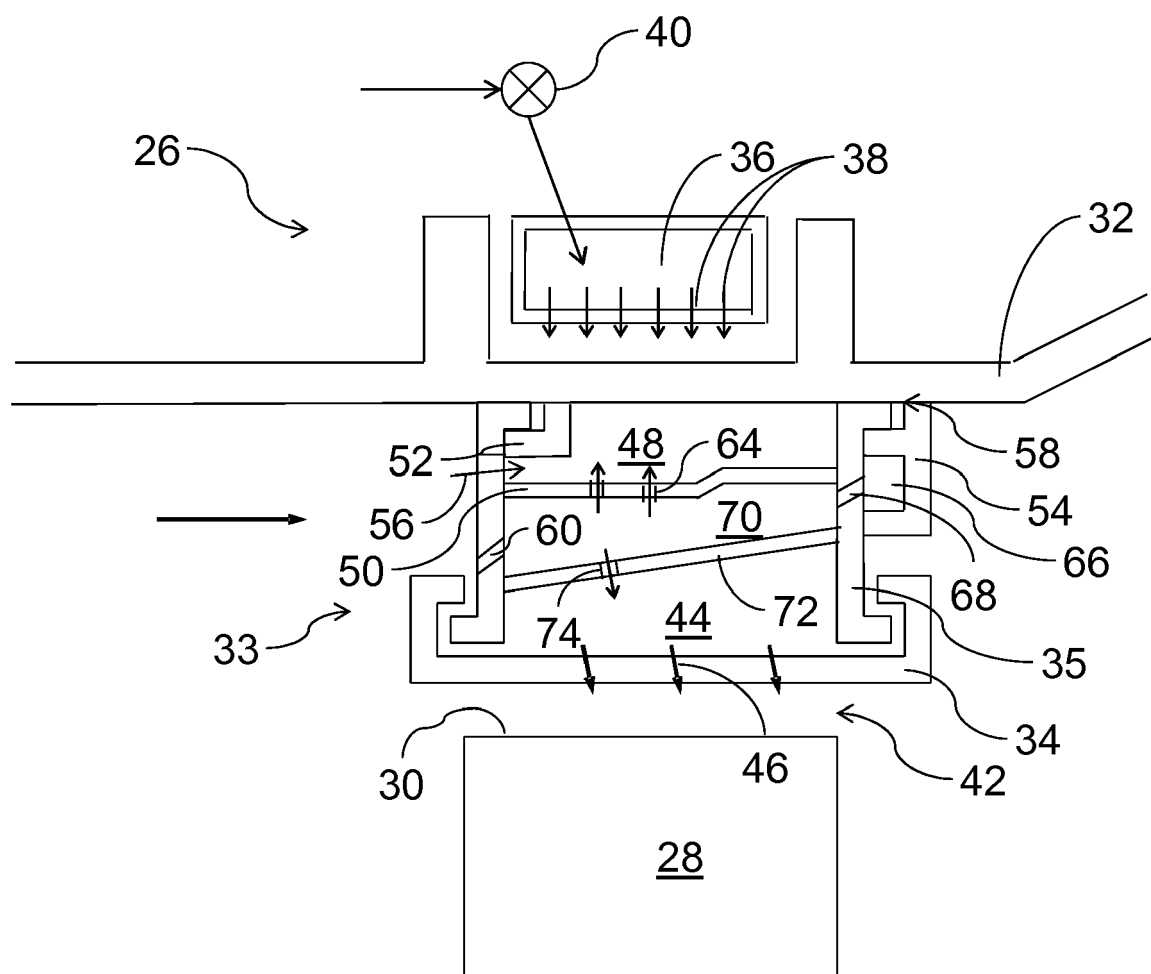


Figure 5

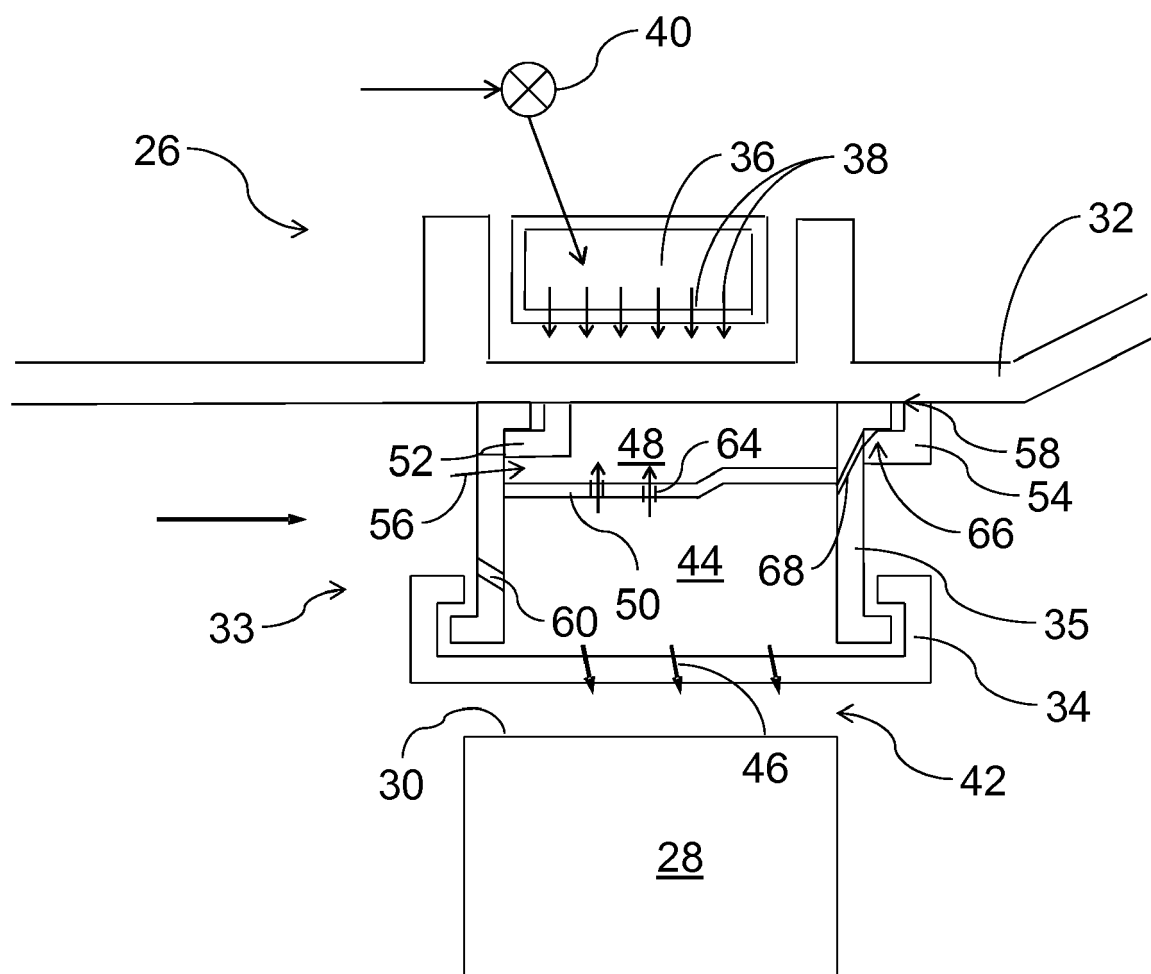


Figure 6

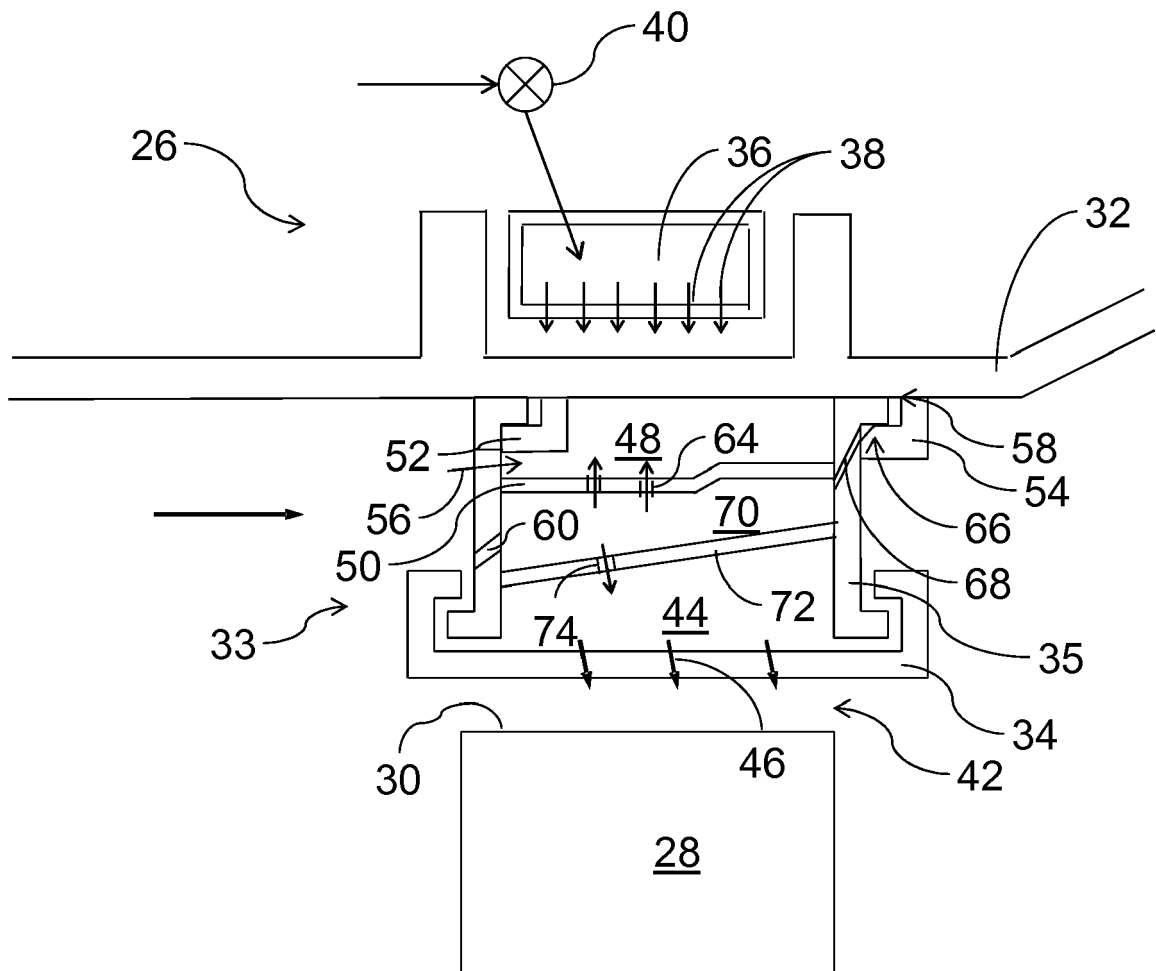


Figure 7

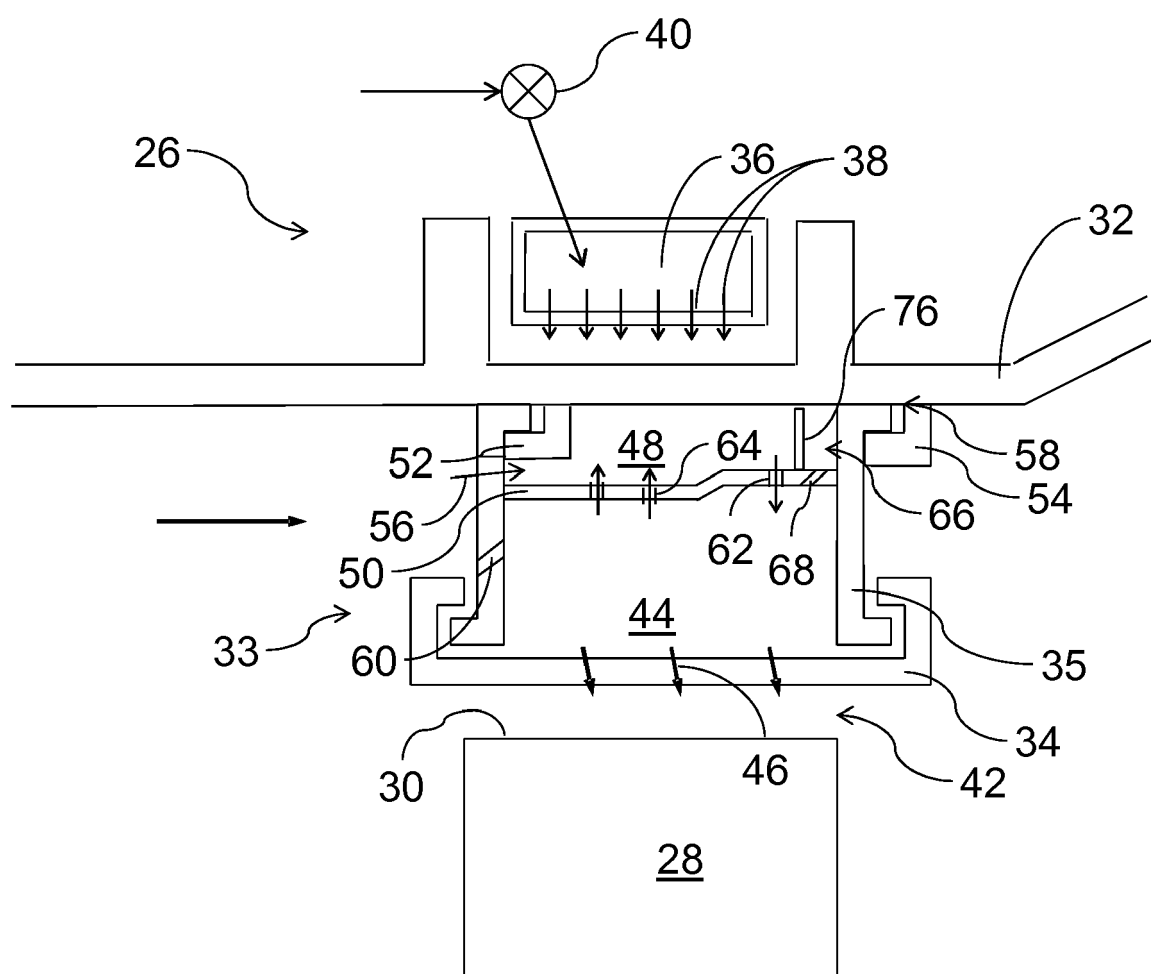


Figure 8

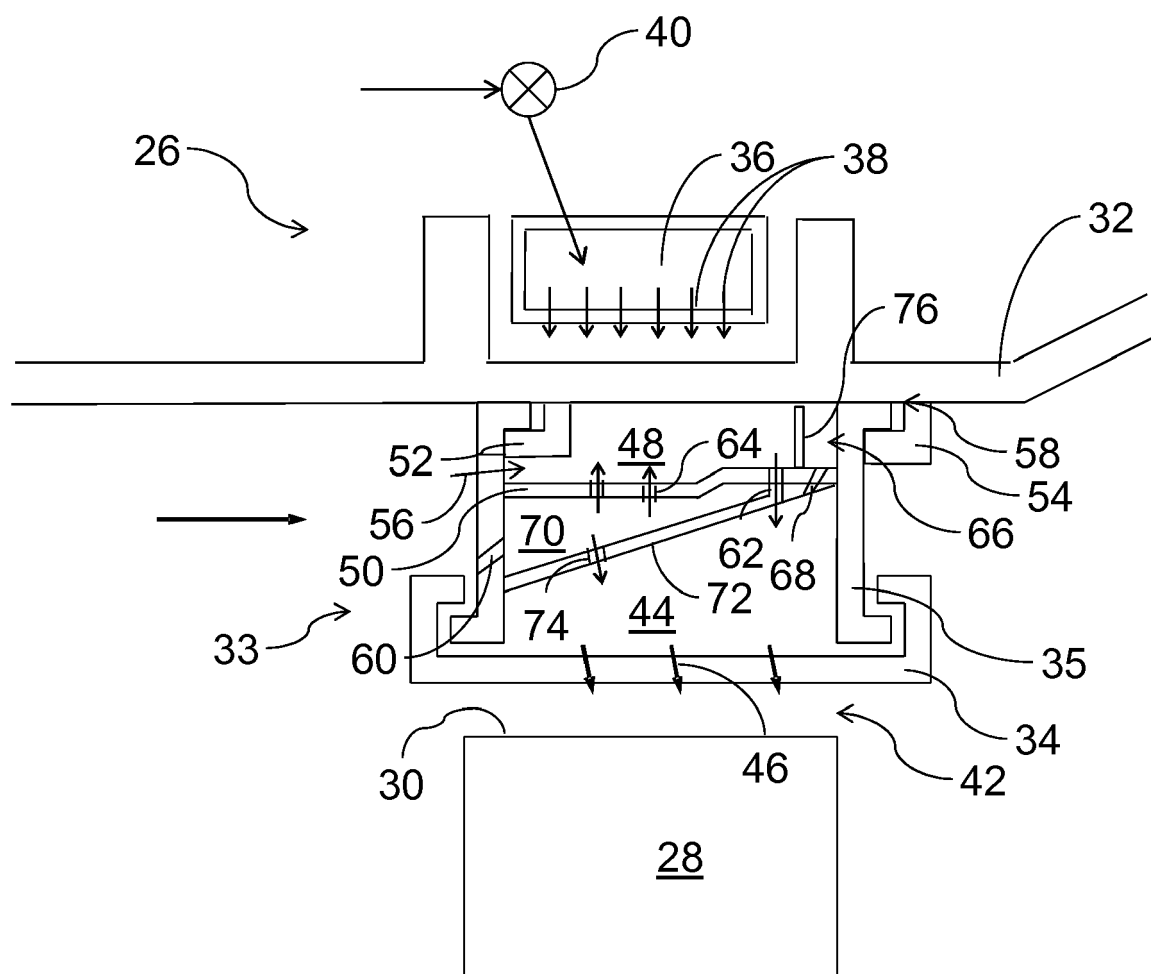


Figure 9



EUROPEAN SEARCH REPORT

Application Number
EP 18 17 1196

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DOCUMENTS CONSIDERED TO BE RELEVANT			
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			TECHNICAL FIELDS SEARCHED (IPC)
			F01D
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 25 September 2018	Examiner Lutoschkin, Eugen
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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**ANNEX TO THE EUROPEAN SEARCH REPORT
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EP 18 17 1196

5 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
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