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(54) Titre : CLAPET DE PURGE VARIABLE DE MOTEUR A TURBINE A GAZ POUR EXTRACTION DE GLACE
 (54) Title: GAS TURBINE ENGINE VARIABLE BLEED VALVE FOR ICE EXTRACTION

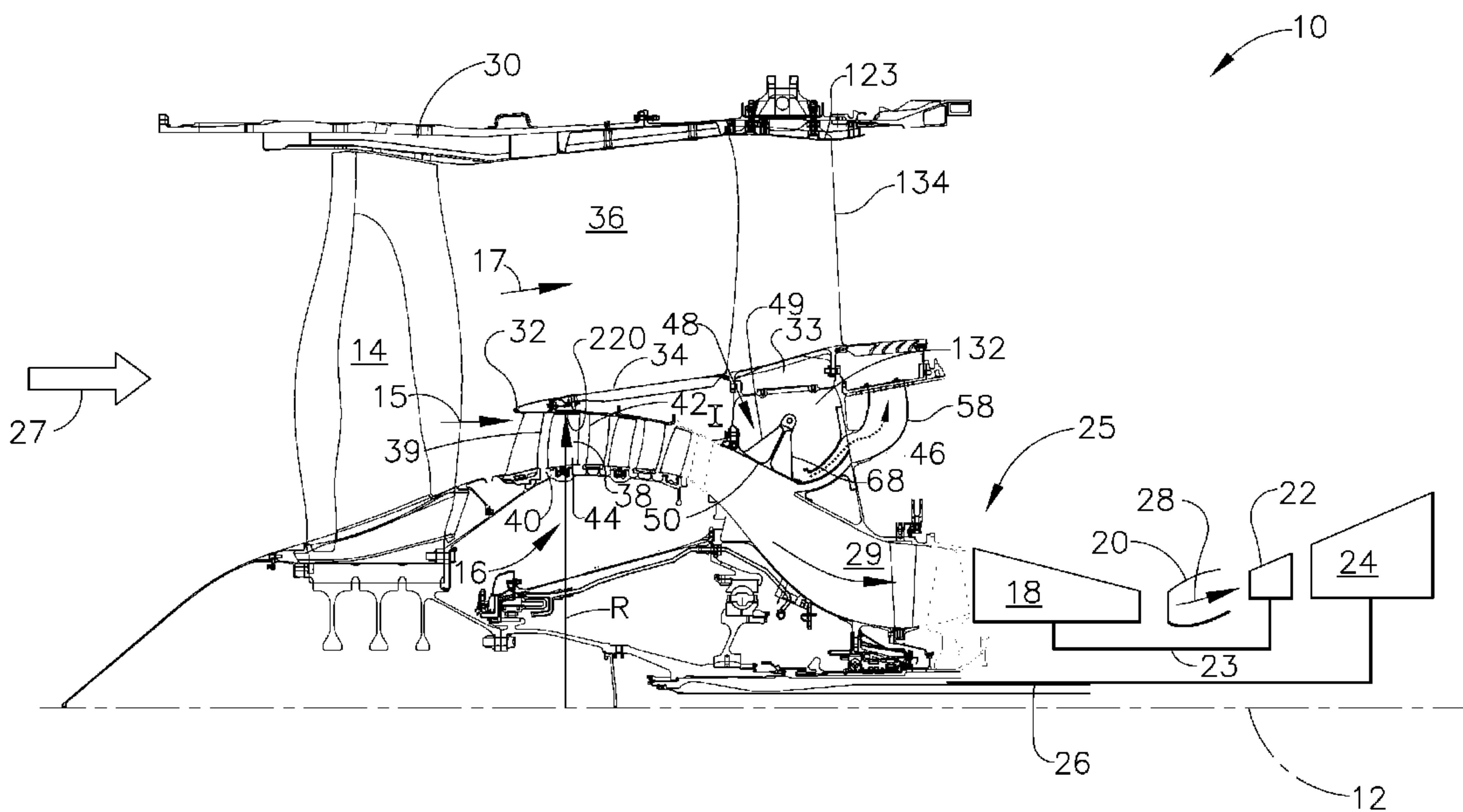


FIG. 1

(57) **Abrégé/Abstract:**

A variable bleed valve (49) includes a variable bleed valve door (50) disposed in a bleed inlet (47) in transition duct (29) and rotatable about an axis (160) at or near a forward end (53) of door (50). Valve (49) is operable to open and close a bleed slot (170) open to a booster bleed flowpath (46) located outwardly of transition duct (29) and having an airflow restrictor (88). Airflow restrictor (88) may be variable such as a flapper valve (92). Booster bleed flowpath (46) may pass through a bifurcated bleed duct (64) including an inner passage (60) radially bound by spaced apart inner and middle bleed walls (70, 72) and an outer passage (62) radially bound by middle bleed wall (72) and an outer bleed wall (74). Airflow restrictor (88) may include an outlet area (AO) smaller than an inlet area (AI) of inner passage (60). Door (50) seals against middle bleed wall (72) to open inner passage (60) and against outer bleed wall (74) to open both passages (60, 62).

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(54) Title: GAS TURBINE ENGINE VARIABLE BLEED VALVE FOR ICE EXTRACTION

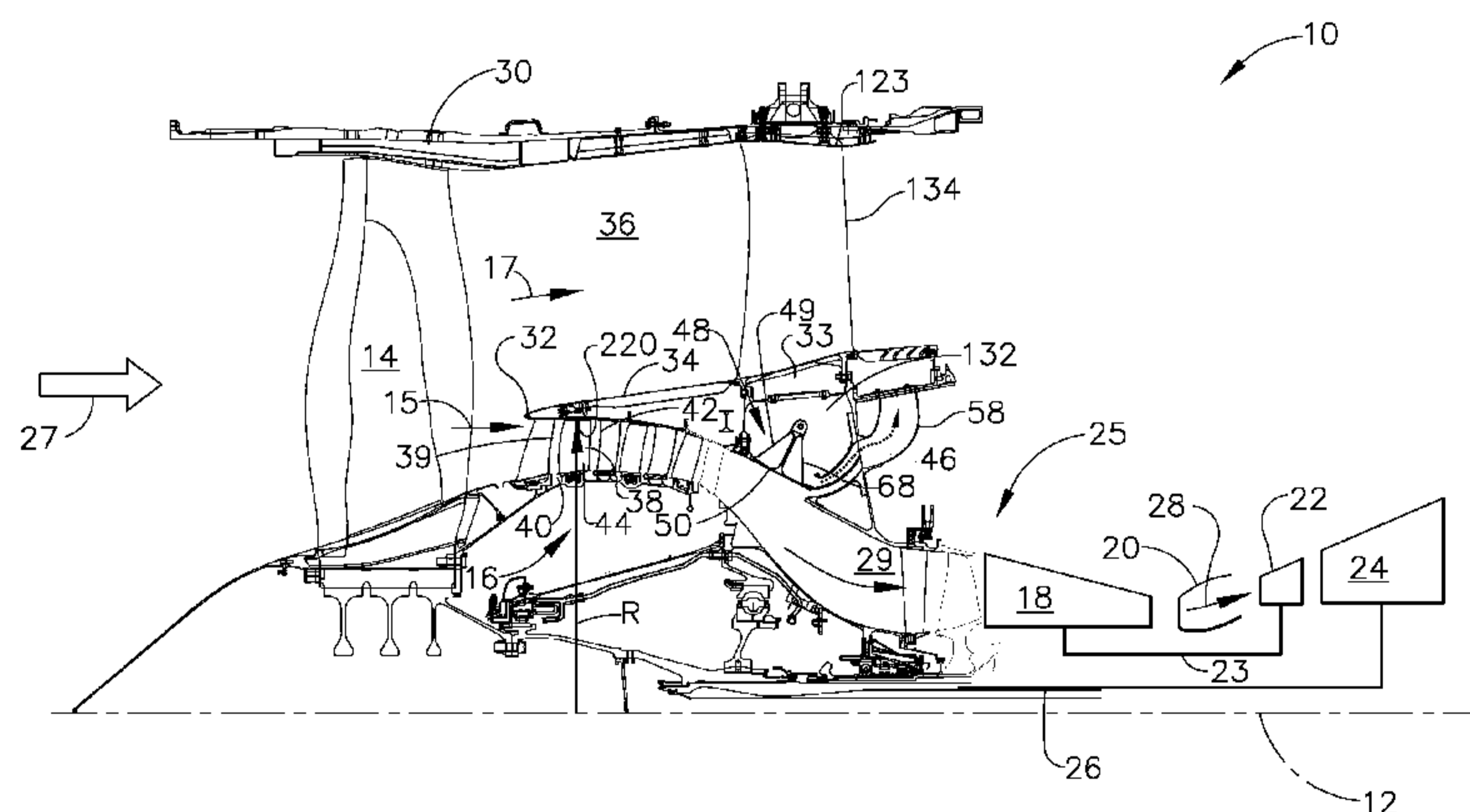


FIG. 1

(57) Abstract: A variable bleed valve (49) includes a variable bleed valve door (50) disposed in a bleed inlet (47) in transition duct (29) and rotatable about an axis (160) at or near a forward end (53) of door (50). Valve (49) is operable to open and close a bleed slot (170) open to a booster bleed flowpath (46) located outwardly of transition duct (29) and having an airflow restrictor (88). Airflow restrictor (88) may be variable such as a flapper valve (92). Booster bleed flowpath (46) may pass through a bifurcated bleed duct (64) including an inner passage (60) radially bound by spaced apart inner and middle bleed walls (70, 72) and an outer passage (62) radially bound by middle bleed wall (72) and an outer bleed wall (74). Airflow restrictor (88) may include an outlet area (AO) smaller than an inlet area (AI) of inner passage (60). Door (50) seals against middle bleed wall (72) to open inner passage (60) and against outer bleed wall (74) to open both passages (60, 62).

WO 2014/066210 A1 

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GAS TURBINE ENGINE VARIABLE BLEED VALVE FOR ICE EXTRACTION

BACKGROUND OF THE INVENTION

5 FIELD OF THE INVENTION

The invention relates to gas turbine engine variable bleed valves and, more particularly, to such valves used to prevent surge and remove ice from duct between booster and core engine compressor.

10 DESCRIPTION OF RELATED ART

It is well known in the gas turbine engine field to provide variable bleed valves (VBVs), typically, doors that open to provide a bleed flowpath to bleed off compressed air between the booster and core engine compressor of gas turbine engines. The air is often bled from what is referred to as a gooseneck flowpath between the booster and core engine compressor. Aircraft fan jet gas turbine engines and marine and industrial derivatives of such engines have employed various forms of curved flowpaths and VBV bleed doors that are retracted into the flowpath casing so as to form an entrance to a bleed duct that bleeds booster or low pressure compressor discharge airflow to draw particles out of the flowpath in a manner such as that disclosed in U.S. Patent No. 4,463,552 entitled "Combined Surge Bleed and Dust Removal System for a Fan-Jet Engine" by Monhardt et al.

Because the bleed flow abruptly curves away from the direction of the compressor flow, it is very difficult to hold larger particles in the bleed flow because of their momentum. This problem is common to aircraft, marine, and ground based gas turbine engines. Turbofan jet engines, such as the General Electric CF6 and GE90 series of engines, have in series relationship a fan, a booster, and a core engine compressor, whereby a portion of the air passing through the fan is ducted to the booster and then the core engine compressor. In order to match the inlet airflow of the core engine compressor to its flight operational requirements and to prevent booster stall, a booster variable bleed valve (VBV) is provided in the form of a booster bleed duct having an inlet between the booster and the core engine compressor and an outlet to the fan duct.

Opening and closing of the booster bleed duct is conventionally provided by a circumferentially disposed plurality of pivotal doors that retract into the engine structure or casing and are operated by a single unison ring powered by one or more fuel powered actuators. Bellcrank linkages operably connect the retracting pivotal bleed doors to the unison ring. An

example of such a stall prevention system using a retracting pivotal door, as compared to a sliding door or valve in the Monhardt patent, is disclosed in U.S. Patent No. 3,638,428 entitled "Bypass Valve Mechanism" by Shipley et al. and assigned to the same assignee as the present invention and incorporated herein by reference. The operation of the VBV is scheduled by the engine controller, either a mechanical or digital electronic type may be used.

The problem associated with conventional bleed valve ducts and valve doors is that larger particles and amounts of particles such as ice are often not drawn into the bleed duct. It is desirable to have an engine that provides the ability to remove large amounts of ice from the compressor airflow and as well as efficiently bleed air between the booster and the core engine compressor. Thus, it is highly desirable to remove ice from the gooseneck flowpath without removing core airflow or minimizing the amount of core airflow that is removed.

On the other hand, higher bypass ratio engines have smaller core flow and larger bullet-nose frontal area. This means more ice, hail, or water gets through the compressor into the combustor resulting in higher water content for the air. These two fundamental phenomena combine to cause substantial increase of water-to-air ratio in the combustor resulting in such aircraft engines being more susceptible to engine flame out problem in rain or hail storms. The higher bypass ratio engines, having the large frontal area, also result in increased ice accretion on the booster inlet and booster stages during idle operation within an icing environment. This results in increased ice shed during the acceleration, including sheds at or near maximum power operation. It also increases the risk of compressor stall due to the ice sheds and more particularly to high speed rotor ice sheds, which historically has been an issue on two-shaft large engines, and will continue to be an issue on future large engines.

Modern high bypass ratio engines incorporate higher pressure core compressors and lower pressure boosters and, thus, produce less pressure difference between the booster exit and the fan bypass duct. This increases the difficulty of bleeding sufficient amounts of air from downstream of the booster to the fan bypass duct for protecting boosters from stall. The booster stall margin is controlled by opening the VBV doors to dump some of the booster flow overboard so as to control the booster operating line to a point below its stall line.

Thus, it is highly desirable to have a variable bleed valve and system for high bypass ratio engines incorporate higher pressure core compressors and lower pressure boosters bleed sufficient amounts of air from downstream of the booster for protecting boosters from stall. It is also highly desirable to have a variable bleed valve and system for such high bypass ratio engines able to prevent ice sheds and more particularly high speed rotor ice sheds from causing compressor stall or flame quenching in the combustor.

SUMMARY OF THE INVENTION

5 A gas turbine engine variable bleed apparatus (48) includes a variable bleed valve (49) including a variable bleed valve door (50) disposed in a bleed inlet (47) in a transition duct (29) and forward and aft lips (51, 52) located at upstream or forward and downstream or aft ends (53, 54) of the door (50). The door (50) is pivotable or rotatable about an axis (160) at or near the forward end (53) of the door (50), the variable bleed valve (49) operable to open and close a bleed slot (170) open to a booster bleed flowpath (46) located radially outwardly of the transition duct (29). The bleed slot (170) extends generally radially outwardly from an outer annular wall (67) of the transition duct (29) at the bleed inlet (47) to the aft lip (52) of the VBV door (50) and an airflow restrictor (88) is disposed in the booster bleed flowpath (46). The airflow restrictor (88) may be a variable airflow restrictor (90) such as a flapper valve (92).

10 The transition duct (29) may have a transition duct conical angle (A1) with respect to an engine centerline (12), a booster outer shroud (222) upstream and adjacent the transition duct (29), the booster outer shroud (222) having a booster conical angle (A2) with respect to an engine centerline (12), and the transition duct conical angle (A1) being greater than the booster conical angle (A2).

15 The booster bleed flowpath (46) may extend through a bifurcated bleed duct (64) including inner and outer passages (60, 62), radially spaced apart inner and middle bleed walls (70, 72) radially bounding the inner passage (60), and the middle bleed wall (72) and an outer bleed wall (74) radially spaced apart from the middle bleed wall (72) and radially bounding the outer passage (62). The airflow restrictor (88) may be located at an inner passage exit (80) of the inner passage (60) and include an outlet area (AO) of the inner passage (60) at the inner passage exit (80) larger than an inlet area (AI) of the inner passage (60).

20 The door (50) may be operable to cooperate with and substantially seal the aft lip (52) at the aft end (54) of the door (50) against the middle bleed wall (72) to fully open the inner passage (60) and to cooperate with and substantially seal the aft lip (52) against the outer bleed wall (74) to fully open the inner and outer passages (60, 62).

25 The booster bleed flowpath (46) may also extend through a bleed duct (66) that is not bifurcated and is radially bounded by radially spaced apart and curved inner and outer bleed walls (70, 74) that are curved radially inwardly. The bleed duct (66) extends downstream or aft from a bleed duct inlet (77) to a bleed duct outlet (78) and a variable airflow restrictor (90) is operably located at the bleed duct outlet (78).

30 The booster bleed flowpath (46) may also extend through the booster bleed flowpath (46)

downstream or aft from the VBV door (50) with no bleed duct and the booster bleed flowpath (46) radially inwardly bounded by a radially inwardly curved inner bleed wall (70). The airflow restrictor (88) is a variable airflow restrictor (90). The variable airflow restrictor (90) may be a flapper valve (92) which may be operably linked to a radially outer end (128) of the door (50).

5 A method of operating the variable bleed valve (49) includes rotating a variable bleed valve door (50) of a gas turbine engine variable bleed valve (49) disposed in a bleed inlet (47) in a transition duct (29) about an axis (160) at or near the forward end (53) of the door (50) to open and close a bleed slot (170) at an inlet (77) of a bifurcated bleed duct (64). The bleed slot (170) extending generally radially outwardly from the transition duct (29) to an aft lip (52) at an aft
10 end (54) of the door (50).

The method may further include opening and closing inner and outer passages (60, 62) of the bifurcated bleed duct (64) wherein radially spaced apart inner and middle bleed walls (70, 72) radially bound the inner passage (60) and the middle bleed wall (72) and an outer bleed wall (74) radially spaced apart from the middle bleed wall (72) radially bound the outer passage (62).

15 Fully opening the inner passage (60) by rotating the door (50) about the axis (160) to substantially seal the aft end (54) against the middle bleed wall (72) and fully opening both the inner and outer passages (60, 62) by rotating the door (50) about the axis (160) to substantially seal the aft end (54) against the outer bleed wall (74).

20 The method may further include fully opening the inner passage (60) and partially to fully opening the outer passage (62) by rotating the door (50) about the axis (160) to move the aft lip (52) between the middle and outer bleed walls (72, 74) to modulate bleed air (19) from the core airflow (15) in the transition duct (29) for booster operating line control.

25 Another method of operating a gas turbine engine variable bleed valve (49) including a variable bleed valve door (50) disposed in a bleed inlet (47) in a transition duct (29) and rotatably attached to a hub frame (129) includes rotating the door (50) about an axis (160) at or near the forward end (53) of the door (50) to open and close a bleed slot (170) open to a booster bleed flowpath (46) disposed through the hub frame (129) and simultaneously opening or closing a variable airflow restrictor (90) disposed in the booster bleed flowpath (46), and operating the valve and the restrictor to bleed core airflow (15) and/or extract ice in the transition duct (29).

30 BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing aspects and other features of the invention are explained in the following description, taken in connection with the accompanying drawings where:

FIG. 1 is a longitudinal part sectional and part diagrammatical view illustration of an

exemplary embodiment of an aircraft turbofan gas turbine engine with a variable bleed valve (VBV) in a transition duct between a booster and a high pressure compressor that turns core airflow exiting out of the booster.

FIG. 2 is an enlarged part sectional and part diagrammatical view illustration of a door of the valve in a closed position in the engine illustrated in FIG. 1.

FIG. 3 is a sectional view illustration of the valve in a partially open position and the door illustrated in FIG. 2 in a first outwardly rotated position with respect to a transition duct in the engine.

FIG. 4 is a sectional view illustration of the valve in a fully open position and the door illustrated in FIG. 2 in a second outwardly rotated position with respect to a transition duct in the engine.

FIG. 5 is a sectional view illustration of an alternative door having a curved inner surface and deeper valve scoop than the door illustrated in FIG. 2.

FIG. 6 is a sectional view illustration of the door illustrated in FIG. 5 in a first outwardly rotated position with respect to a transition duct in the engine.

FIG. 7 is a sectional view illustration of the door illustrated in FIG. 5 in a second outwardly rotated position with respect to a transition duct in the engine.

FIG. 8 is a sectional and diagrammatical view illustration of an alternative valve with a non-bifurcated bleed duct and variable airflow restrictor in a hub frame in the engine illustrated in FIG. 1.

FIG. 9 is a sectional and diagrammatical view illustration of another alternative valve with a variable airflow restrictor and no bleed duct in the hub frame for use in the engine illustrated in FIG. 1.

DETAILED DESCRIPTION OF THE INVENTION

Illustrated in FIG. 1 is an exemplary aircraft turbofan gas turbine engine 10 circumscribed about an engine centerline 12 and suitably designed to be mounted to a wing or fuselage of an aircraft. The engine 10 includes, in downstream serial flow communication, a fan 14, a booster 16, a high pressure compressor 18, a combustor 20, a high pressure turbine (HPT) 22, and a low pressure turbine (LPT) 24. A core engine 25 includes the HPT or high pressure turbine 22 joined by a high pressure drive shaft 23 to the high pressure compressor 18 and the combustor 20. The LPT or low pressure turbine 24 is joined by a low pressure drive shaft 26 to both the fan 14 and the booster 16.

There are high bypass aircraft gas turbine engines such as some built by Rolls Royce that

have more than two compressors and turbines. Rolls Royce, for example, has a three spool engine with three compressors each of which is driven by a different turbine. Thus, the VBV valve and door disclosed herein may be incorporated between two compressors and is not limited to being only between a low pressure compressor such as the booster illustrated herein and a high pressure compressor.

In typical operation, air 27 is pressurized by the fan 14 and produces an inner or core airflow 15 channeled through the booster 16 which further pressurizes the core airflow 15. The pressurized air is then flowed to the high pressure compressor 18 which further pressurizes the air. The pressurized air is mixed with fuel in the combustor 20 for generating hot combustion gases 28 that flow downstream, in turn, through the HPT 22 and the LPT 24.

A flow splitter 34 surrounding the booster 16 immediately behind the fan 14 includes a sharp leading edge 32 which splits the fan air 27 pressurized by the fan 14 into a radially inner stream (core airflow 15) channeled through the booster 16 and a radially outer stream or bypass airflow 17 is channeled through a bypass duct 36 spaced radially outwardly from the booster 16.

A fan casing 30 surrounding the fan 14 and the bypass duct 36 is supported by an annular fan frame 33 circumscribed about the engine centerline 12. The booster 16 includes alternating annular rows 44 of booster blades and vanes 38, 42 extending radially outwardly and inwardly across a booster flowpath 39 in a booster duct 40. The annular row of booster blades 38 are suitably joined to the fan 14. The booster 16 is located forward of the fan frame 33 and radially inboard of the flow splitter 34.

The fan frame 33 includes an annular outer frame casing 123, a fan hub frame 129, and a plurality of circumferentially spaced apart duct struts 134 extending therebetween. The duct struts 134 are airfoil shaped since bypass air passes between the adjacent ones thereof. A transition duct 29 also referred to as a gooseneck is located at a radially inner end 136 of the fan hub frame 129 and is axially disposed between and in fluid communication with the booster 16 and the high pressure compressor 18 of the core engine 25. Bleed exhaust ducts 58 lead away from the fan hub frame 129 to the bypass duct 36.

Referring to FIGS. 1 and 2, a bleed inlet 47, an opening, is disposed in an outer annular wall 67 of a transition duct 29 between booster 16 and the high pressure compressor 18. In the exemplary embodiments of the transition duct 29 illustrated in FIGS. 2-4 and 8-9, the outer annular wall 67 is an outer conical wall 68 and in the exemplary embodiments of the transition duct 29 illustrated in FIGS. 5-7, the outer annular wall 67 is curved. A variable bleed apparatus 48 is used to bleed the core airflow 15 between booster 16 and the high pressure compressor 18 to prevent the booster 16 from stalling under certain engine operating conditions.

The variable bleed apparatus 48 includes a variable bleed valve 49 (VBV) with a variable bleed valve door 50 disposed in the bleed inlet 47. The VBV door 50 is illustrated in FIG. 2 in a closed position completely closing the bleed inlet 47. The VBV door 50 is operable to open a bleed slot 170 open to a booster bleed flowpath 46 located radially outwardly of the transition duct 29 and extending from the VBV door 50 through the fan hub frame 129 through the bleed exhaust ducts 58 to the bypass duct 36. The bleed slot 170 extends radially from the outer conical wall 68 of the transition duct 29 at the bleed inlet 47 to the aft lip 52 of VBV door 50.

The VBV door 50 includes forward and aft lips 51, 52 located at upstream or forward and downstream or aft ends 53, 54 of the door 50. The VBV door 50 is used to bleed air and extract ice from the booster and the transition duct 29 before it reaches the high pressure compressor 18 where it can cause stall conditions, airflow instability conditions, and quench the flame or combustion in the combustor 20. A circumferentially disposed plurality of booster bleed flowpaths 46 indicated by the arrows and dotted line labeled 46 extend from the VBV door 50 in the fan hub frame 129 through the bleed exhaust ducts 58 to the bypass duct 36.

Referring back to FIG. 2, the VBV door 50 is pivotable or rotatable about an axis 160 which is exemplified by a hinge axis 160. The VBV door 50 is actuated by actuators (not shown) that forwardly and aftwardly axially translate and rotate radially unison ring 102 with respect to engine centerline 12. It is well known to operate or rotate VBV doors open and close using actuators, unison rings, and bellcranks for positioning the doors. One example of this may be found in United States Patent No. 3,638,428 to Shipley, et al., February 1, 1972, entitled "BYPASS VALVE MECHANISM".

The VBV door 50 is hinged to the fan hub frame 129 of the fan frame 33 near a forward end 53 of the VBV door 50. A door hinge 82 rotatably connects or hinges the VBV door 50 to the fan hub frame 129. A linkage 55 includes forward and aft links 110, 112 linked to forward and aft bellcrank arms 120, 122 of a bellcrank 114. The forward link 110 operably links the unison ring 102 to the forward bellcrank arm 120. The aft link 112 operably links the aft bellcrank arm 122 to an outer clevis 124 of an outer ball joint 126 on a radially outer end 128 of the VBV door 50. The bellcrank 114 pivots about a bellcrank axis 116 which is fixed with respect to the fan hub frame 129. This opens and closes the VBV door 50.

The exemplary embodiment of the variable bleed valve 49 includes a variable flow bifurcated bleed duct 64 radially adjacent inner and outer passages 60, 62 inside the fan hub frame 129 leading to the bleed exhaust duct 58. Radially spaced apart inner and middle bleed walls 70, 72 radially bound the inner passage 60. The middle bleed wall 72 and a radially outer bleed wall 74 radially spaced apart from the middle bleed wall 72 radially bound the outer

5 passage 62. The exemplary embodiment of the radially spaced apart inner, middle, and outer bleed walls 70, 72, 74 are curved radially inwardly. A forward lip 75 along a forward edge of the inner passage 60 and an edge of the outer conical wall 68 of the transition duct 29 meet along the bleed inlet 47 to provide a scoop 84 to enhance ice extraction. When the variable bleed valve 49 and the VBV door 50 are opened or in an open position, a bleed slot 170 at a bleed duct inlet 77 to the bifurcated bleed duct 64 is opened allowing bleed air 19 from the core airflow 15 to flow into the inner passage 60 or both the inner and outer passages 60, 62.

10 The variable bleed valve 49 is designed to be operated with the VBV door 50 in a fully closed or in a closed position as illustrated in FIG. 2 and in first and second or partial and full open positions as illustrated in FIGS. 3 and 4 respectively. The VBV door 50 may be rotated to any position between the fully closed position and the full open position as illustrated in FIGS. 3 and 4 respectively. The VBV door 50 in the fully closed position when the aft lip 52 at the aft end 54 of the VBV door 50 seals against the inner bleed wall 70 and seals the bleed inlet 47.

15 The aft lip 52 at the aft end 54 of the VBV door 50 cooperates with the middle and outer bleed walls 72, 74 to open the inner and outer passages 60, 62 to the transition duct 29 and the core airflow 15 through the bleed inlet 47. The VBV door 50 is rotated to cooperate with and substantially seal the aft lip 52 at the aft end 54 of the VBV door 50 against the middle bleed wall 72 to open the inner passage 60. The VBV door 50 is rotated to cooperate with and substantially seal the aft lip 52 at the aft end 54 of the door 50 against the outer bleed wall 74 to open both the inner and outer passages 60, 62.

20 The inner and outer passages 60, 62 are sized and shaped to minimize the impact on core airflow 15 and cycle operation such as by sizing an effective flow area A of the inner passage 60. This can be done by reducing either the circumferential width of this inner passage 60 or a passage radial height H at an inner passage exit 80. This provides an outlet area AO smaller than an inlet area AI of the inner passage 60 and the outlet area AO serves as an airflow restrictor 88 in the booster bleed flowpath 46 at the inner passage exit 80 of the inner passage 60. This aft end area of the inner passage 60 is sized so that the airflow through this passage is limited and is an amount acceptable for exhaust gas temperature (EGT) considerations. Seals 242 on the aft lip 52 at the downstream or aft end 54 of the door 50 and along side edges 86 of the VBV door minimize airflow losses and negative cycle impacts when the VBV door is in an open position.

30 The exemplary embodiment of the variable bleed valve 49 includes one or more hinge pins 76 rotatably disposed through linearly aligned coaxial hinge holes 100 in clevis lugs 98 of the hinge 82 attached to the VBV door 50 and the fan hub frame 129. The VBV door 50 is

rotatably connected to the fan hub frame 129. The hinge axis 160 passes through the one or more hinge pins 76 and about which the VBV door 50 is rotatable. The VBV door 50 is thus operable to rotate outwardly of and away from the transition duct 29 about the hinge axis 160 at or near the forward end 53 of the VBV door 50.

5 The exemplary embodiment of the variable bleed valve 49 is operated with the VBV door 50 fully closed or in the closed position as illustrated in FIG. 2 for high speed performance operation with no bleed air 19 removed from the core airflow 15 and no ice removed from the transition duct 29. The VBV door 50 may be rotated to the partially open first position as illustrated in FIG. 3 with the VBV door 50 cooperating with and substantially sealing the aft lip
10 52 at the aft end 54 of the VBV door 50 against the middle bleed wall 72 to open the inner passage 60. This first position is designed primarily for high speed and high power engine operation with ice, water, dust, and dirt extraction from the transition duct 29. Little bleed air 19 is removed from the core airflow 15 at this engine operating condition and variable bleed valve setting.

15 The VBV door 50 may be rotated to the fully open second position as illustrated in FIG. 4 with the VBV door 50 cooperating with and substantially sealing the aft lip 52 at the aft end 54 of the VBV door 50 against the outer bleed wall 74 to open both the inner and outer passages 60, 62. This second fully open position is designed primarily for low speed engine operation and also provides ice, water, dust, and dirt extraction from the transition duct 29. This is typically
20 done at idle and part power engine operation to pass the maximum required airflow for booster operating line control. The VBV door 50 can also be rotated between the first and second open positions to modulate the bleed air 19 from the core airflow 15 for booster operating line control. The modulation includes rotating the VBV door 50 so the aft lip 52 at the aft end 54 of the VBV door 50 moves between the middle and outer bleed walls 72, 74 to vary or modulate the bleed air
25 19 flowing through the outer passages 62. This fully opens the inner passage 60 and varies the amount the outer passage 62 is open.

Referring to FIGS. 1 and 2, ice and other particle removal is enhanced by further turning the core airflow 15 radially inwardly towards the engine centerline 12 and the high pressure compressor 18 in the transition duct 29 after it exists a booster outlet 228 leading to the
30 transition duct 29. Also, a booster outer flowpath 220 has a relatively high radius R, as measured from the engine centerline 12, over the last few stages of the booster 16. This flow turning is accomplished by the outer conical wall 68 of the transition duct 29 having a transition duct conical angle A1, with respect to the engine centerline 12, greater than a booster conical angle A2 of a booster outer shroud 222. The booster outer shroud 222 surrounds outer ends 224

of booster outlet guide vanes 226 (OGV) at the booster outlet 228.

Core airflow 15 exiting the booster 16 flows linearly on a path that is tangent to the outer flowpath of the booster outlet 228 which is generally the same as the booster outer shroud 222. In an ice shed, the ice particles follow this same path or trajectory with most of the ice being located in the outer portion of the flowpath. Conventionally, the flow direction set by the outer flowpath of the booster outlet 228 is parallel to the VBV door 50. Having the transition duct conical angle A1 greater than the booster conical angle A2 by about 10 degrees or more is more conducive for extracting shed ice at high speed, while minimizing the amount of airflow bleed from the booster discharge and thereby minimizing the exhaust gas temperature (EGT) and other cycle effects.

The core airflow 15 in the booster and transition duct stays attached to the wall, and turns down into the compressor because of its difference in conical angles. However, ice particles have too much mass and inertia to make this turn, and they continue on their straight trajectory out of booster. They then collide with the outer wall of the transition duct and slide along it until the flowpath turns again going into the HPC. When the aft slot is opened up at the aft end of the VBV door, the ice in the outer flowpath either collides with and slides along the bottom of the VBV door into the fan hub frame, or continues on its straight trajectory out of the booster and into the fan hub frame through the bleed slot 170. This will result in the particles being centrifuged outward and more readily extracted. In addition, the blade and vane designs may be changed to introduce more outward push to ice by an increased dihedral blade shape.

Illustrated in FIGS. 5-7 is an alternative embodiment of the variable bleed valve 49 with an alternative transition duct 29 and alternative VBV door 50. Instead of a purely conical outer wall in the transition duct 29 between booster 16 and the high pressure compressor 18, there is a bowed or curved outer annular wall 140 of the transition duct 29. The VBV door 50 includes a substantial portion of the outer annular wall 140. The outer annular wall 140 of the transition duct 29 include a radially inwardly axially curved surface 142 that curves radially inwardly towards the engine centerline 12 such that the VBV door 50 protrudes into the transition duct 29 and further turns the core airflow 15 radially inwardly in the transition duct 29. The curved outer annular wall 140 has a tangent 143 at the bleed inlet 47 adjacent the aft end 54 of the VBV door 50. The tangent 143 has a transition duct annular wall angle A3 the with respect to the engine centerline 12. The annular wall angle A3 is greater than the booster conical angle A2 of the booster outer shroud 222.

The curved surface 142 substantially reaches its max height MH at the aft end 54 of the door 50. The curved surface 142 continues axially aft and narrows in surface height along the

outer annular wall 140 from the bleed inlet 47 adjacent the aft end 54 of the VBV door 50 until the curved surface height is 0 at an axially aft end of the curved surface 142. The surface may be circular or parabolic, or elliptical or otherwise curved. A forward lip 75 along a forward edge of the inner passage 60 and an edge of the outer conical wall 68 of the transition duct 29 meet along the bleed inlet 47 to provide a scoop 84 to enhance ice extraction. This scoop is deeper and extends further into the transition duct 29 than in the embodiment illustrated in FIG. 2 and further enhances ice extraction.

The variable bleed valve 49 is designed to be operated with the VBV door 50 in a fully closed or in a closed position as illustrated in FIG. 5 and in first and second or partial and full open positions as illustrated in FIGS. 6 and 7 respectively. The VBV door 50 may be rotated to any position between the fully closed position and the full open position as illustrated in FIGS. 6 and 7 respectively. Seals 242 on the aft lip 52 at the downstream aft end 54 of the door 50 are designed to engage and seal against the inner, middle, and outer bleed walls 70, 72, 74. Side door seals (not shown) along side edges 86 of the VBV door 50 engage and seal against hub struts 132 in the hub frame 129. These seals minimize airflow losses and negative cycle impacts when the VBV door is in an open position.

Illustrated in FIG. 8 is an alternative variable bleed valve 49 with a non-bifurcated bleed duct 66 and a variable airflow restrictor 90 in the booster bleed flowpath 46. The bleed duct 66 is bounded by radially spaced apart and curved inner and outer bleed walls 70, 74 that are curved radially inwardly. The bleed duct 66 extends downstream or aft from a bleed duct inlet 77 to a bleed duct outlet 78. The variable airflow restrictor 90 is illustrated as a flapper valve 92 operably located at the duct outlet 78. The inwardly and outwardly opening flapper valve 92 is operably linked to the bellcrank 114 for actuation (opening and closing) by a valve link 94 between the flapper valve 92 and the radially outer end 128 of the VBV door 50. The variable airflow restrictor 90 and in particular the flapper valve 92 may be opened and closed in a controlled scheduled and proportional manner using appropriate linkage between the bellcrank and these restrictors.

Illustrated in FIG. 9 is another alternative variable bleed valve 49 with no bleed duct and a variable airflow restrictor 90 in the booster bleed flowpath 46. The booster bleed flowpath 46 extends downstream or aft from the VBV door 50 through the fan hub frame 129 where it is bounded radially inwardly by an inner bleed wall 70 that is curved radially inwardly. The variable airflow restrictor 90 is illustrated as a flapper valve 92 operably located at an exhaust duct inlet 59 to the bleed exhaust duct 58. The bleed exhaust duct 58 is illustrated herein as mounted on the fan hub frame 129. The inwardly and outwardly opening flapper valve 92 is

operably linked to the bellcrank 114 for actuation (opening and closing) by a valve link 94 between the flapper valve 92 and the radially outer end 128 of the VBV door 50. The variable airflow restrictor 90 and in particular the flapper valve 92 may be opened and closed in a controlled scheduled and proportional manner using appropriate linkage between the bellcrank and these restrictors.

The present invention has been described in an illustrative manner. It is to be understood that the terminology which has been used is intended to be in the nature of words of description rather than of limitation. While there have been described herein, what are considered to be preferred and exemplary embodiments of the present invention, other modifications of the invention shall be apparent to those skilled in the art from the teachings herein and, it is, therefore, desired to be secured in the appended claims all such modifications as fall within the true spirit and scope of the invention.

Accordingly, what is desired to be secured by Letters Patent of the United States is the invention as defined and differentiated in the following claims:

CLAIMS:

What is claimed is:

- 5 1. A gas turbine engine variable bleed apparatus (48) comprising:
a variable bleed valve (49) including a variable bleed valve door (50) disposed in a bleed inlet (47) in a transition duct (29),
forward and aft lips (51, 52) located at upstream or forward and downstream or aft ends (53, 54) of the door (50),
10 the door (50) pivotable or rotatable about an axis (160) at or near the forward end (53) of the door (50),
the variable bleed valve (49) operable to open and close a bleed slot (170) open to a booster bleed flowpath (46) located radially outwardly of the transition duct (29),
the bleed slot (170) extending generally radially outwardly from an outer annular wall (67) of the transition duct (29) at the bleed inlet (47) to the aft lip (52) of the VBV door (50), and
15 an airflow restrictor (88) in the booster bleed flowpath (46).
2. The gas turbine engine variable bleed apparatus (48) as claimed in Claim 1 further comprising:
20 the booster bleed flowpath (46) extending through a bifurcated bleed duct (64),
the bifurcated bleed duct (64) including inner and outer passages (60, 62),
radially spaced apart inner and middle bleed walls (70, 72) radially bounding the inner passage (60), and
the middle bleed wall (72) and an outer bleed wall (74) radially spaced apart from the
25 middle bleed wall (72) radially bounding the outer passage (62).
3. The gas turbine engine variable bleed apparatus (48) as claimed in Claim 2 further comprising the airflow restrictor (88) located at an inner passage exit (80) of the inner passage (60) and the airflow restrictor (88) including an outlet area (AO) of the inner passage (60) at the
30 inner passage exit (80) larger than an inlet area (AI) of the inner passage (60).
4. The gas turbine engine variable bleed apparatus (48) as claimed in Claim 3 further comprising the door (50) being operable to cooperate with and substantially seal the aft lip (52) at the aft end (54) of the door (50) against the middle bleed wall (72) to fully open the inner

passage (60) and the door (50) being operable to cooperate with and substantially seal the aft lip (52) against the outer bleed wall (74) to fully open the inner and outer passages (60, 62).

5. The gas turbine engine variable bleed apparatus (48) as claimed in Claim 1 further comprising:

the transition duct (29) having a transition duct conical angle (A1) with respect to an engine centerline (12),

a booster outer shroud (222) upstream and adjacent the transition duct (29),

the booster outer shroud (222) having a booster conical angle (A2) with respect to an engine centerline (12), and

the transition duct conical angle (A1) being greater than the booster conical angle (A2).

6. The gas turbine engine variable bleed apparatus (48) as claimed in Claim 5 further comprising:

the booster bleed flowpath (46) extending through a bifurcated bleed duct (64),

the bifurcated bleed duct (64) including inner and outer passages (60, 62),

radially spaced apart inner and middle bleed walls (70, 72) radially bounding the inner passage (60), and

the middle bleed wall (72) and an outer bleed wall (74) radially spaced apart from the middle bleed wall (72) radially bounding the outer passage (62).

7. The gas turbine engine variable bleed apparatus (48) as claimed in Claim 6 further comprising the airflow restrictor (88) located at an inner passage exit (80) of the inner passage (60) and the airflow restrictor (88) including an outlet area (AO) of the inner passage (60) at the inner passage exit (80) larger than an inlet area (AI) of the inner passage (60).

8. The gas turbine engine variable bleed apparatus (48) as claimed in Claim 7 further comprising the door (50) being operable to cooperate with and substantially seal the aft end (54) against the middle bleed wall (72) and fully open the inner passage (60) and the door (50) being operable to cooperate with and substantially seal the aft end (54) against the outer bleed wall (74) to fully open the inner and outer passages (60, 62).

9. The gas turbine engine variable bleed apparatus (48) as claimed in Claim 1 further comprising the airflow restrictor (88) being a variable airflow restrictor (90).

10. The gas turbine engine variable bleed apparatus (48) as claimed in Claim 9 further comprising:

the transition duct (29) having a transition duct conical angle (A1) with respect to an engine centerline (12),

a booster outer shroud (222) upstream and adjacent the transition duct (29),

the booster outer shroud (222) having a booster conical angle (A2) with respect to an engine centerline (12), and

the transition duct conical angle (A1) being greater than the booster conical angle (A2).

11. The gas turbine engine variable bleed apparatus (48) as claimed in Claim 10 further comprising:

the booster bleed flowpath (46) extending through a bleed duct (66),

the bleed duct (66) radially bounded by radially spaced apart and curved inner and outer bleed walls (70, 74) that are curved radially inwardly,

the bleed duct (66) extending downstream or aft from a bleed duct inlet (77) to a bleed duct outlet (78), and

the variable airflow restrictor (90) operably located at the duct outlet (78).

12. The gas turbine engine variable bleed apparatus (48) as claimed in Claim 11 further comprising the variable airflow restrictor (90) being a flapper valve (92).

13. The gas turbine engine variable bleed apparatus (48) as claimed in Claim 12 further comprising the flapper valve (92) operably linked to a radially outer end (128) of the door (50).

14. The gas turbine engine variable bleed apparatus (48) as claimed in Claim 10 further comprising:

the booster bleed flowpath (46) extending downstream or aft from the VBV door (50),

the booster bleed flowpath (46) radially inwardly bounded by a radially inwardly curved inner bleed wall (70), and

the airflow restrictor (88) being a variable airflow restrictor (90).

15. The gas turbine engine variable bleed apparatus (48) as claimed in Claim 14 further comprising the variable airflow restrictor (90) being a flapper valve (92).

16. The gas turbine engine variable bleed apparatus (48) as claimed in Claim 1 further comprising:

the outer annular wall (67) being a curved outer annular wall (140),

5 the door (50) including a substantial portion of the outer annular wall (140),

a booster outer shroud (222) upstream and adjacent the transition duct (29),

the booster outer shroud (222) having a booster conical angle (A2) with respect to an engine centerline (12), and

10 a tangent (143) to the curved outer annular wall (140) at the bleed inlet (47) adjacent the aft end (54) of the VBV door (50) having a transition duct annular wall angle (A3) with respect to the engine centerline (12) greater than the booster conical angle (A2).

17. The gas turbine engine variable bleed apparatus (48) as claimed in Claim 16 further comprising the airflow restrictor (88) being a variable airflow restrictor (90).

18. The gas turbine engine variable bleed apparatus (48) as claimed in Claim 16 further comprising:

the bifurcated bleed duct (64) including inner and outer passages (60, 62),

15 radially spaced apart inner and middle bleed walls (70, 72) radially bounding the inner passage (60), and

20 the middle bleed wall (72) and an outer bleed wall (74) radially spaced apart from the middle bleed wall (72) radially bounding the outer passage (62).

19. The gas turbine engine variable bleed apparatus (48) as claimed in Claim 18 further comprising the airflow restrictor (88) at an inner passage exit (80) of the inner passage (60) and including an outlet area (AO) of the inner passage (60) at the inner passage exit (80) smaller than an inlet area (AI) of the inner passage (60).

20. The gas turbine engine variable bleed apparatus (48) as claimed in Claim 19 further comprising the door (50) being operable to cooperate with and substantially seal the aft end (54) against the middle bleed wall (72) and fully open the inner passage (60) and the door (50) being operable to cooperate with and substantially seal the aft end (54) against the outer bleed wall (74) to fully open the inner and outer passages (60, 62).

21. The gas turbine engine variable bleed apparatus (48) as claimed in Claim 17 further comprising:

the booster bleed flowpath (46) extending through a bleed duct (66),

the bleed duct (66) radially bounded by radially spaced apart and curved inner and outer bleed walls (70, 74) that are curved radially inwardly,

the bleed duct (66) extending downstream or aft from a bleed duct inlet (77) to a bleed duct outlet (78), and

the variable airflow restrictor (90) operably located at the duct outlet (78).

22. The gas turbine engine variable bleed apparatus (48) as claimed in Claim 21 further comprising the variable airflow restrictor (90) being a flapper valve (92).

23. The gas turbine engine variable bleed apparatus (48) as claimed in Claim 22 further comprising the flapper valve (92) operably linked to a radially outer end (128) of the door (50).

24. The gas turbine engine variable bleed apparatus (48) as claimed in Claim 17 further comprising the booster bleed flowpath (46) extending downstream or aft from the VBV door (50) and the booster bleed flowpath (46) radially inwardly bounded by a radially inwardly curved inner bleed wall (70).

25. The gas turbine engine variable bleed apparatus (48) as claimed in Claim 24 further comprising the variable airflow restrictor (90) being a flapper valve (92).

26. The gas turbine engine variable bleed apparatus (48) as claimed in Claim 25 further comprising the flapper valve (92) operably linked to a radially outer end (128) of the door (50).

27. An aircraft gas turbine engine (10) comprising:

in downstream serial flow communication a fan (14), a booster (16), and a high pressure compressor (18) circumscribed about an engine centerline (12);

a bypass duct (36) spaced radially outwardly from the booster (16);

an annular fan frame (33) supporting a fan casing (30) surrounding the fan (14) and the bypass duct (36);

the fan frame (33) including an annular outer frame casing (123), a fan hub frame (129), and a plurality of circumferentially spaced apart duct struts (134) extending therebetween;

a transition duct (29) located at a radially inner end (136) of the fan hub frame (129) and axially disposed between and in fluid communication with the booster (16) and the high pressure compressor (18);

bleed exhaust ducts (58) extending from the fan hub frame (129) to the bypass duct (36);

5 at least one variable bleed valve (49) including a variable bleed valve door (50) disposed in a bleed inlet (47) in the transition duct (29);

forward and aft lips (51, 52) located at upstream or forward and downstream or aft ends (53, 54) of the door (50);

10 the door (50) hinged to the fan hub frame (129) and pivotable or rotatable about an axis (160) at or near the forward end (53) of the door (50);

the variable bleed valve (49) operable to open and close a bleed slot (170) open to a booster bleed flowpath (46) extending from bleed slot (170) through one of the bleed exhaust ducts (58) to the bypass duct (36);

15 the bleed slot (170) extending generally radially outwardly from an outer conical wall (68) of the transition duct (29) at the bleed inlet (47) to the aft lip (52) of the VBV door (50); and an airflow restrictor (88) in the booster bleed flowpath (46).

28. The aircraft gas turbine engine (10) as claimed in Claim 27 further comprising:

the booster bleed flowpath (46) extending through a bifurcated bleed duct (64),

20 the bifurcated bleed duct (64) extending downstream through the fan hub frame (129) from the aft lip (52) of the door (50) to one of the bleed exhaust ducts (58),

the bifurcated bleed duct (64) including inner and outer passages (60, 62),

radially spaced apart inner and middle bleed walls (70, 72) radially bounding the inner passage (60), and

25 the middle bleed wall (72) and an outer bleed wall (74) radially spaced apart from the middle bleed wall (72) radially bounding the outer passage (62).

29. The aircraft gas turbine engine (10) as claimed in Claim 28 further comprising the airflow restrictor (88) located at an inner passage exit (80) of the inner passage (60) and the
30 airflow restrictor (88) including an outlet area (AO) of the inner passage (60) at the inner passage exit (80) larger than an inlet area (AI) of the inner passage (60).

30. The aircraft gas turbine engine (10) as claimed in Claim 29 further comprising the door (50) being operable to cooperate with and substantially seal the aft end (54) against the middle

bleed wall (72) and fully open the inner passage (60) and the door (50) being operable to cooperate with and substantially seal the aft end (54) against the outer bleed wall (74) to fully open the inner and outer passages (60, 62).

5 31. The aircraft gas turbine engine (10) as claimed in Claim 27 further comprising:
the transition duct (29) having a transition duct conical angle (A1) with respect to an
engine centerline (12),
a booster outer shroud (222) upstream and adjacent the transition duct (29),
the booster outer shroud (222) having a booster conical angle (A2) with respect to an
10 engine centerline (12), and
the transition duct conical angle (A1) being greater than the booster conical angle (A2).

32. The aircraft gas turbine engine (10) as claimed in Claim 31 further comprising:
a bifurcated bleed duct (64) extending downstream through the fan hub frame (129) from
15 the door (50) to one of the bleed exhaust ducts (58),
the bifurcated bleed duct (64) including inner and outer passages (60, 62),
radially spaced apart inner and middle bleed walls (70, 72) radially bounding the inner
passage (60), and
the middle bleed wall (72) and an outer bleed wall (74) radially spaced apart from the
20 middle bleed wall (72) radially bounding the outer passage (62).

33. The aircraft gas turbine engine (10) as claimed in Claim 32 further comprising the
airflow restrictor (88) located at an inner passage exit (80) of the inner passage (60) and the
airflow restrictor (88) including an outlet area (AO) of the inner passage (60) at the inner
25 passage exit (80) larger than an inlet area (AI) of the inner passage (60).

34. The aircraft gas turbine engine (10) as claimed in Claim 33 further comprising the door
(50) being operable to cooperate with and substantially seal the aft end (54) against the middle
bleed wall (72) and fully open the inner passage (60) and the door (50) being operable to
30 cooperate with and substantially seal the aft end (54) against the outer bleed wall (74) to fully
open the inner and outer passages (60, 62).

35. The gas turbine engine variable bleed apparatus (48) as claimed in Claim 27 further
comprising:

the booster bleed flowpath (46) extending through a bleed duct (66),
the bleed duct (66) radially bounded by radially spaced apart and curved inner and outer
bleed walls (70, 74) that are curved radially inwardly,
the bleed duct (66) extending downstream or aft from a bleed duct inlet (77) to a bleed
5 duct outlet (78), and
the variable airflow restrictor (90) operably located at the duct outlet (78).

36. The gas turbine engine variable bleed apparatus (48) as claimed in Claim 35 further
comprising the variable airflow restrictor (90) being a flapper valve (92).

10 37. The gas turbine engine variable bleed apparatus (48) as claimed in Claim 36 further
comprising the flapper valve (92) operably linked to a radially outer end (128) of the door (50).

15 38. The gas turbine engine variable bleed apparatus (48) as claimed in Claim 27 further
comprising the booster bleed flowpath (46) extending downstream or aft from the VBV door
(50) and the booster bleed flowpath (46) radially inwardly bounded by a radially inwardly
curved inner bleed wall (70).

20 39. The gas turbine engine variable bleed apparatus (48) as claimed in Claim 38 further
comprising the variable airflow restrictor (90) being a flapper valve (92).

25 40. The aircraft gas turbine engine (10) as claimed in Claim 27 further comprising:
the outer annular wall (67) being a curved outer annular wall (140),
the door (50) including a substantial portion of the outer annular wall (140),
a booster outer shroud (222) upstream and adjacent the transition duct (29),
the booster outer shroud (222) having a booster conical angle (A2) with respect to an
engine centerline (12), and
a tangent (143) to the curved outer annular wall (140) at the bleed inlet (47) adjacent the
aft end (54) of the VBV door (50) having a transition duct annular wall angle (A3) with respect
30 to the engine centerline (12) greater than the booster conical angle (A2).

41. The aircraft gas turbine engine (10) as claimed in Claim 40 further comprising the
airflow restrictor (88) being a variable airflow restrictor (90).

42. The aircraft gas turbine engine (10) as claimed in Claim 40 further comprising:
the bifurcated bleed duct (64) including inner and outer passages (60, 62),
radially spaced apart inner and middle bleed walls (70, 72) radially bounding the inner
passage (60), and

5 the middle bleed wall (72) and an outer bleed wall (74) radially spaced apart from the
middle bleed wall (72) radially bounding the outer passage (62).

43. The aircraft gas turbine engine (10) as claimed in Claim 42 further comprising the
airflow restrictor (88) at an inner passage exit (80) of the inner passage (60) and including an
10 outlet area (AO) of the inner passage (60) at the inner passage exit (80) smaller than an inlet area
(AI) of the inner passage (60).

44. The aircraft gas turbine engine (10) as claimed in Claim 43 further comprising the door
(50) being operable to cooperate with and substantially seal the aft end (54) against the middle
15 bleed wall (72) and fully open the inner passage (60) and the door (50) being operable to
cooperate with and substantially seal the aft end (54) against the outer bleed wall (74) to fully
open the inner and outer passages (60, 62).

45. The aircraft gas turbine engine (10) as claimed in Claim 41 further comprising:
20 the booster bleed flowpath (46) extending through a bleed duct (66),
the bleed duct (66) radially bounded by radially spaced apart and curved inner and outer
bleed walls (70, 74) that are curved radially inwardly,
the bleed duct (66) extending downstream or aft from a bleed duct inlet (77) to a bleed
duct outlet (78), and

25 the variable airflow restrictor (90) operably located at the duct outlet (78).

46. The aircraft gas turbine engine (10) as claimed in Claim 45 further comprising the
variable airflow restrictor (90) being a flapper valve (92).

30 47. The aircraft gas turbine engine (10) as claimed in Claim 46 further comprising the flapper
valve (92) operably linked to a radially outer end (128) of the door (50).

48. The aircraft gas turbine engine (10) as claimed in Claim 41 further comprising the
booster bleed flowpath (46) extending downstream or aft from the VBV door (50) and the

booster bleed flowpath (46) radially inwardly bounded by a radially inwardly curved inner bleed wall (70).

49. The aircraft gas turbine engine (10) as claimed in Claim 50 further comprising the
5 variable airflow restrictor (90) being a flapper valve (92).

50. The aircraft gas turbine engine (10) as claimed in Claim 49 further comprising the flapper
valve (92) operably linked to a radially outer end (128) of the door (50).

10 51. A method of operating a gas turbine engine variable bleed valve (49) including a variable
bleed valve door (50) disposed in a bleed inlet (47) in a transition duct (29), the method
comprising rotating the door (50) about an axis (160) at or near the forward end (53) of the door
(50) to open and close a bleed slot (170) at an inlet (77) of a bifurcated bleed duct (64), the bleed
slot (170) extending generally radially outwardly from the transition duct (29) to an aft lip (52)
15 at an aft end (54) of the door (50).

52. The method as claimed in Claim 51 further comprising:
opening and closing inner and outer passages (60, 62) of the bifurcated bleed duct (64),
wherein radially spaced apart inner and middle bleed walls (70, 72) radially bound the
20 inner passage (60) and the middle bleed wall (72) and an outer bleed wall (74) radially spaced
apart from the middle bleed wall (72) radially bound the outer passage (62),
fully opening the inner passage (60) by rotating the door (50) about the axis (160) to
substantially seal the aft end (54) against the middle bleed wall (72), and
fully opening both the inner and outer passages (60, 62) by rotating the door (50) about
25 the axis (160) to substantially seal the aft end (54) against the outer bleed wall (74).

53. The method as claimed in Claim 51 further comprising:
opening and closing inner and outer passages (60, 62) of the bifurcated bleed duct (64),
wherein radially spaced apart inner and middle bleed walls (70, 72) radially bound the
30 inner passage (60) and the middle bleed wall (72) and an outer bleed wall (74) radially spaced
apart from the middle bleed wall (72) radially bound the outer passage (62), and
fully opening the inner passage (60) and partially to fully opening the outer passage (22)
by rotating the door (50) about the axis (160) to move the aft lip (52) between the middle and
outer bleed walls (72, 74) to modulate bleed air (19) from the core airflow (15) in the transition

duct (29) for booster operating line control.

54. A method of operating a gas turbine engine variable bleed valve (49) including a variable bleed valve door (50) disposed in a bleed inlet (47) in a transition duct (29) and rotatably attached to a hub frame (129), the method comprising:

rotating the door (50) about an axis (160) at or near the forward end (53) of the door (50) to open and close a bleed slot (170) a booster bleed flowpath (46) disposed through the hub frame (129),

simultaneously opening or closing a variable airflow restrictor (90) disposed in the booster bleed flowpath (46), and

operating the valve and the restrictor to bleed core airflow (15) and/or extract ice in the transition duct (29).

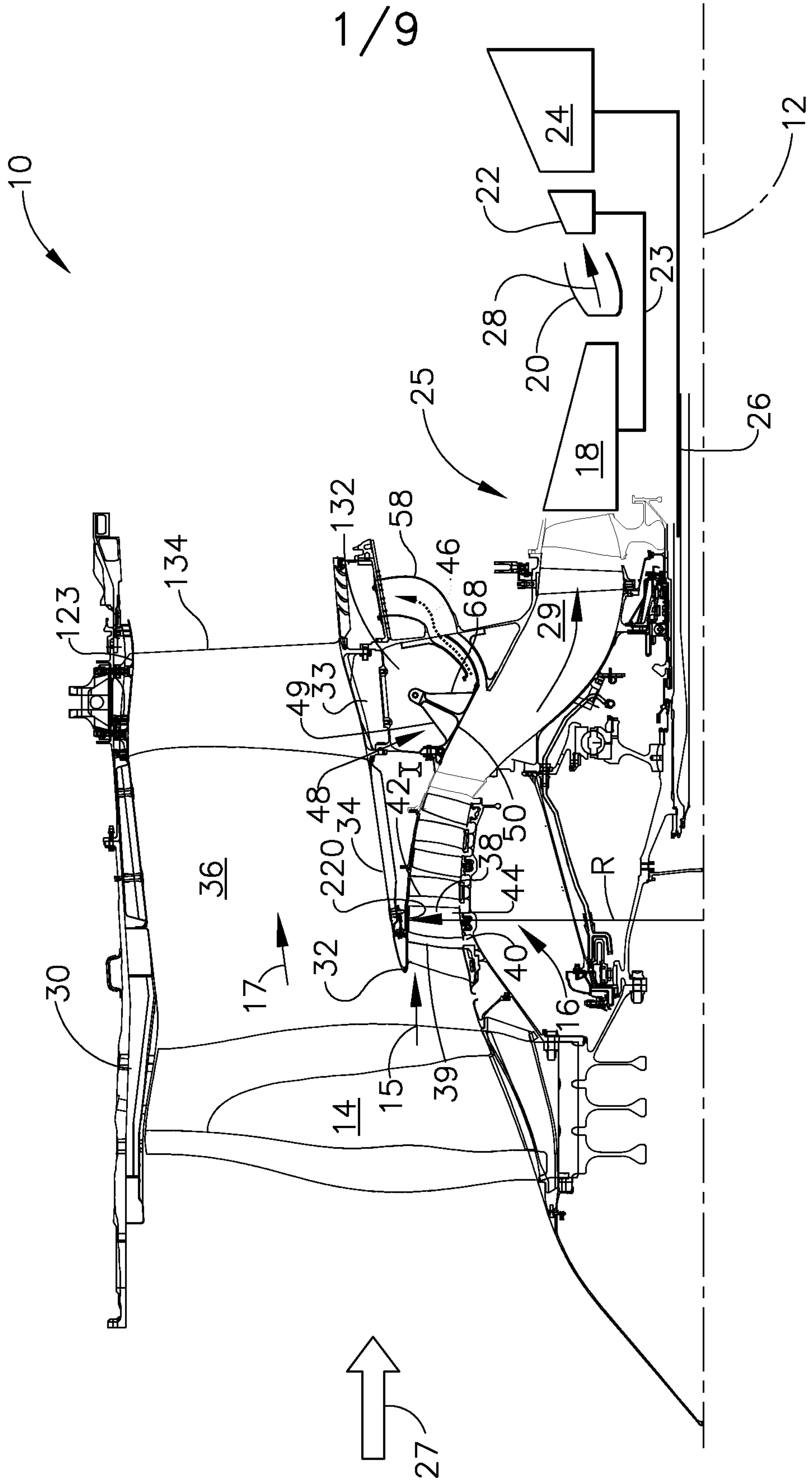


FIG. 1

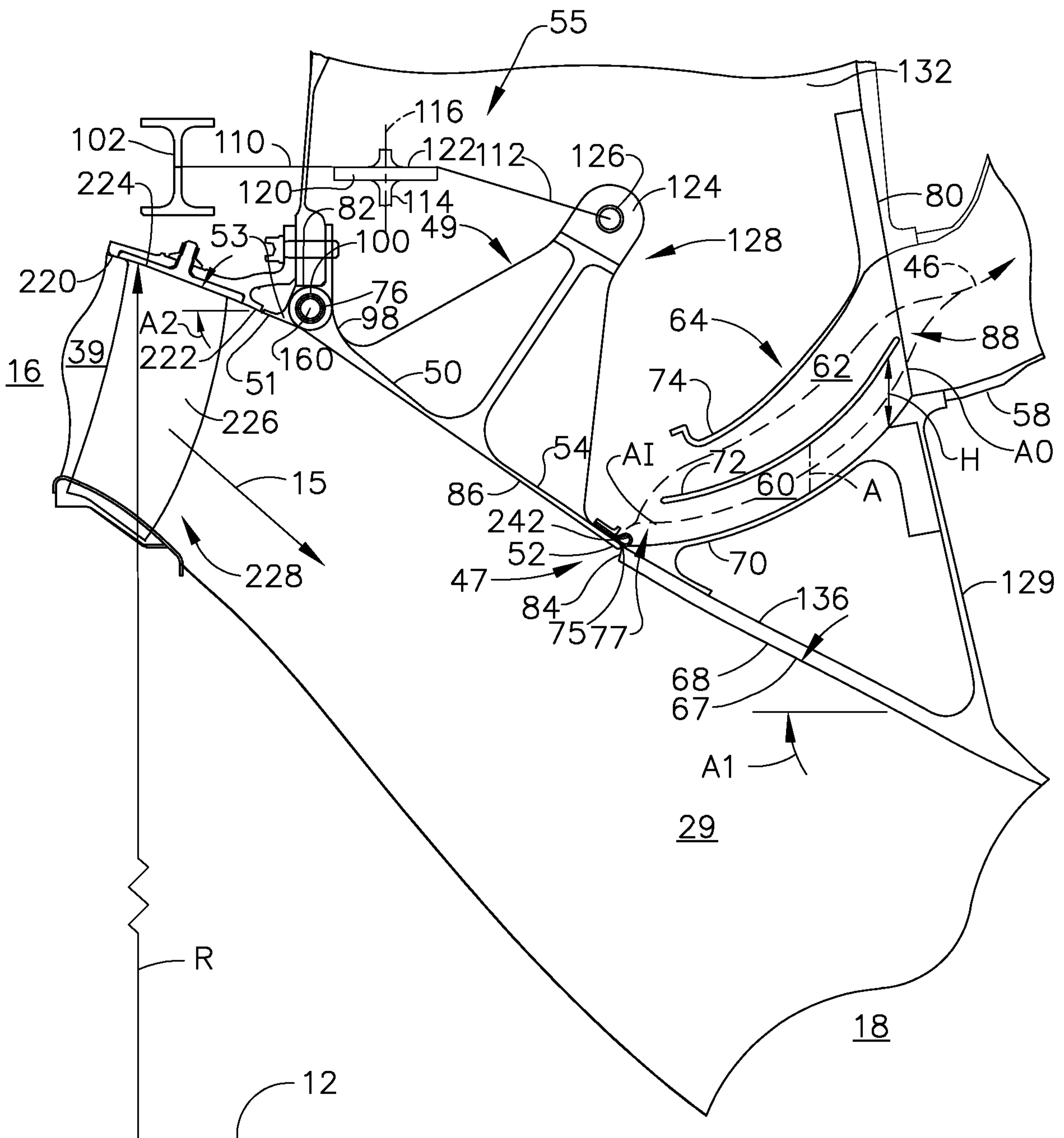


FIG. 2

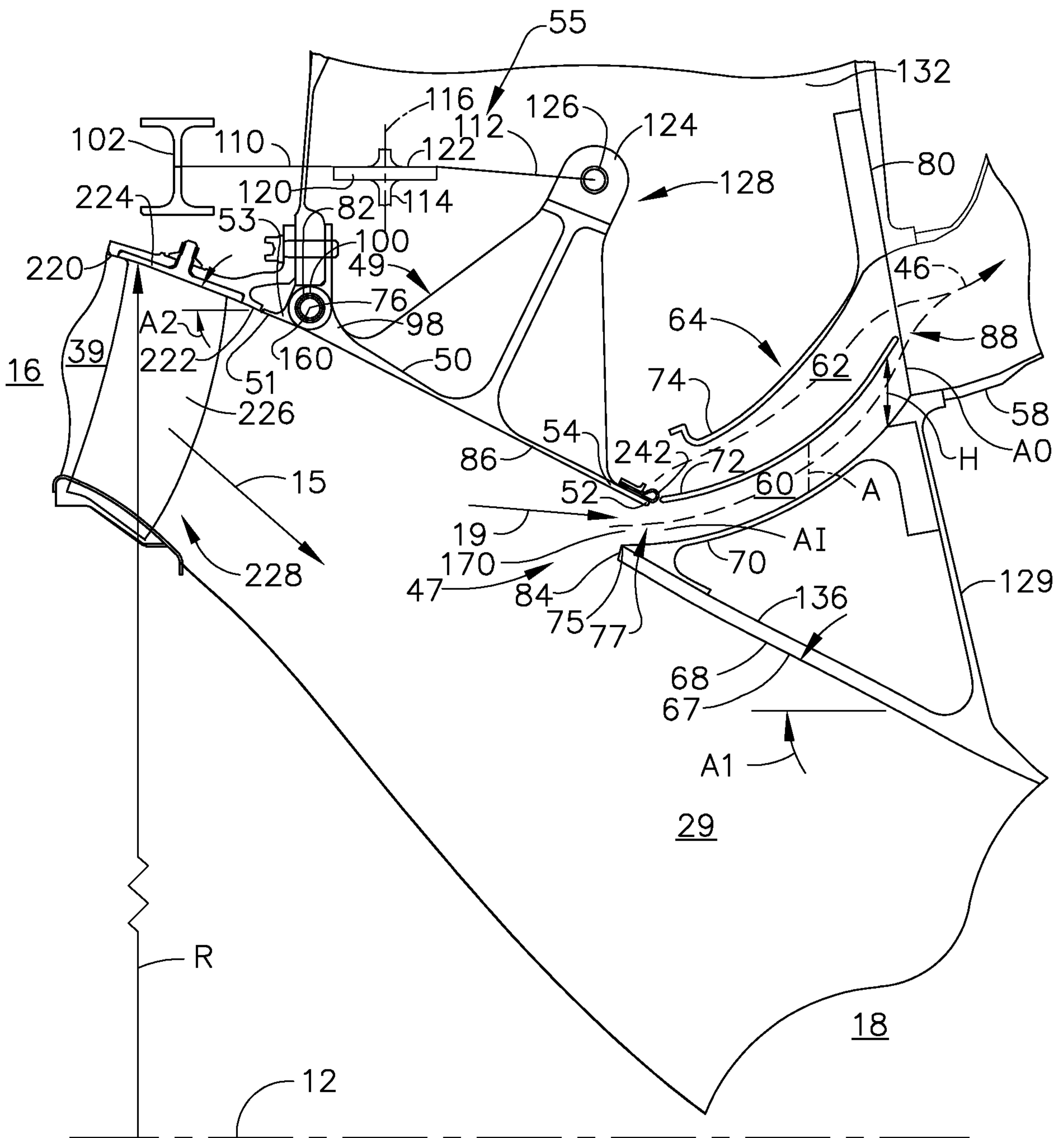


FIG. 3

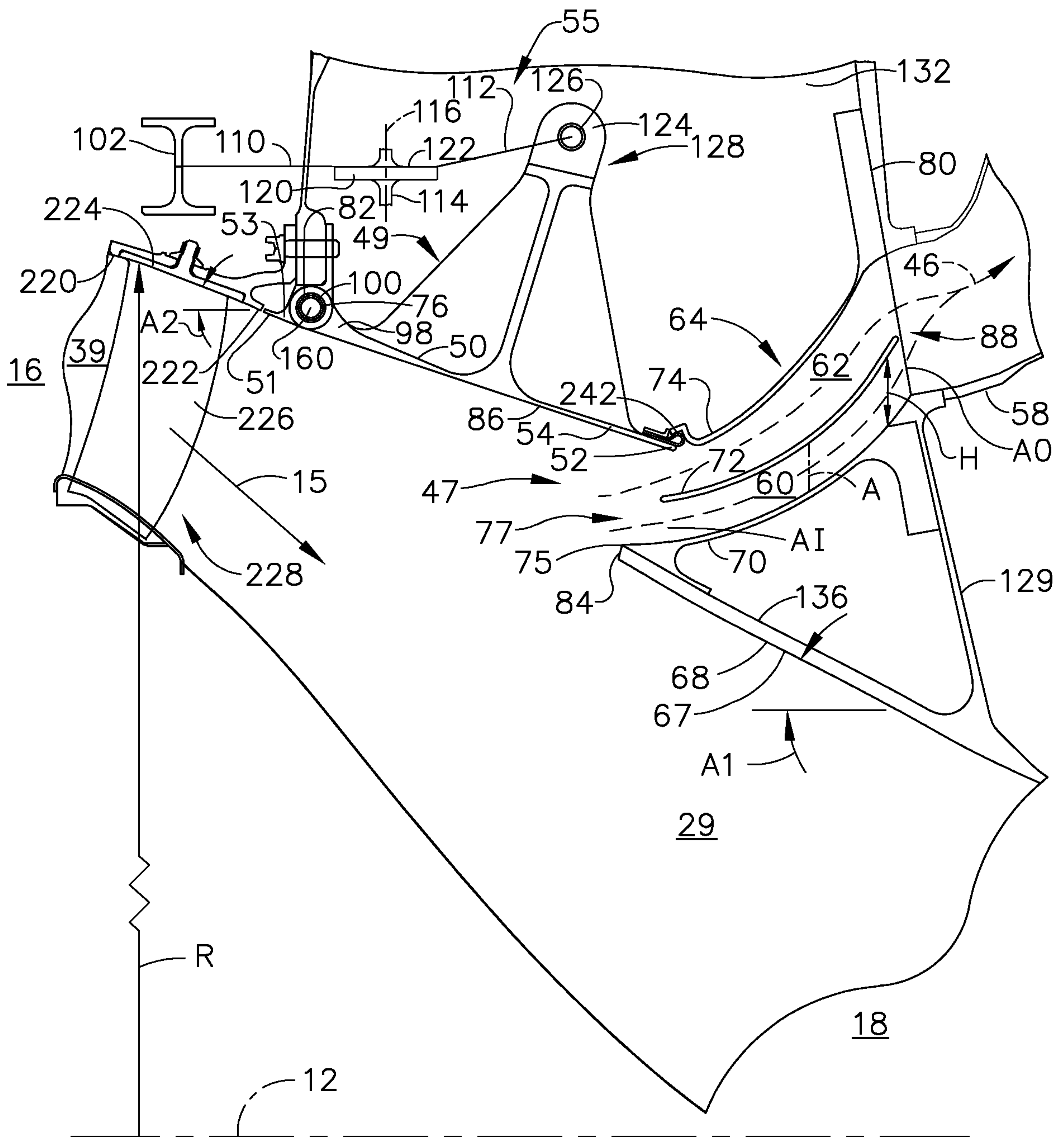


FIG. 4

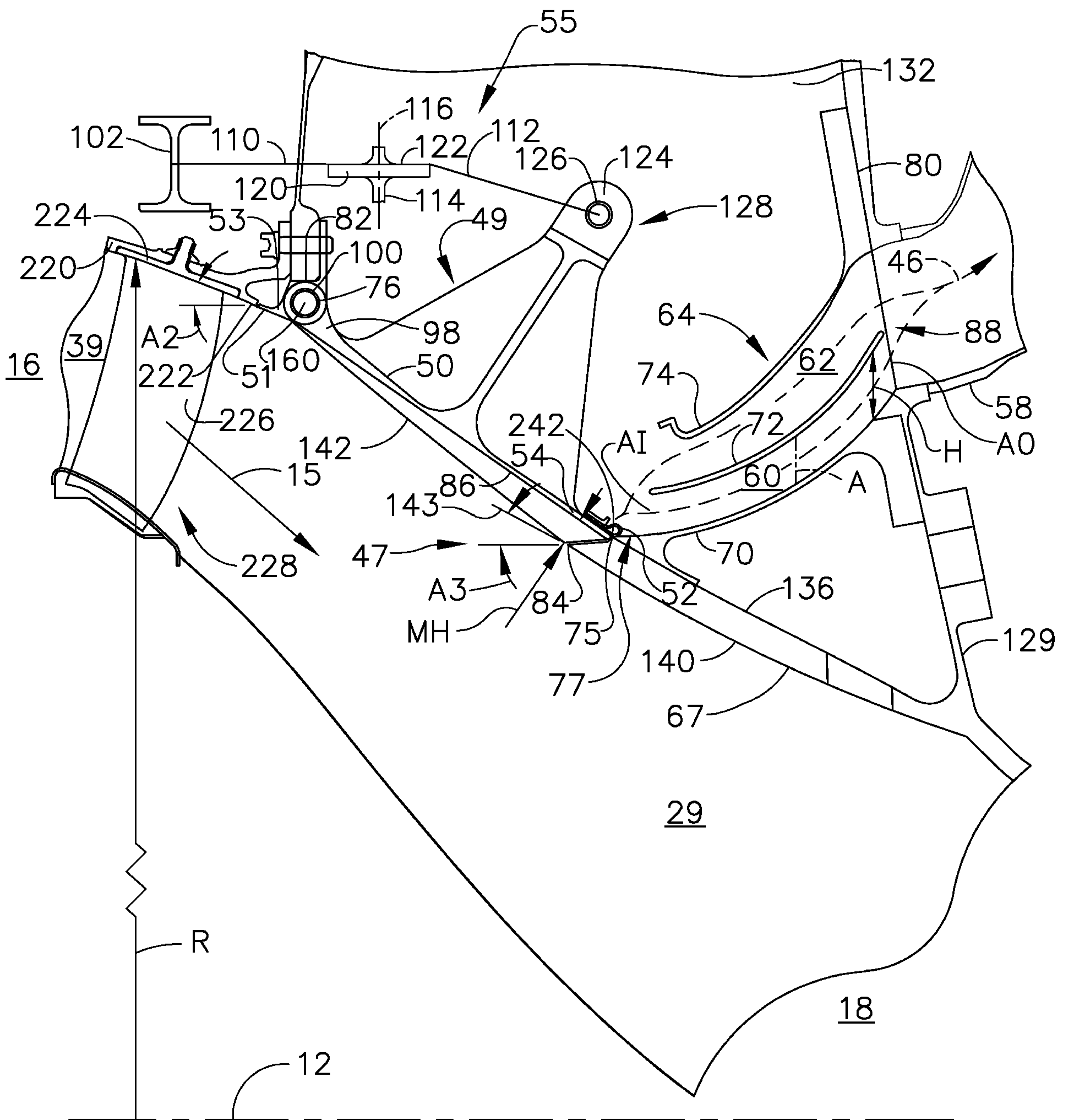


FIG. 5

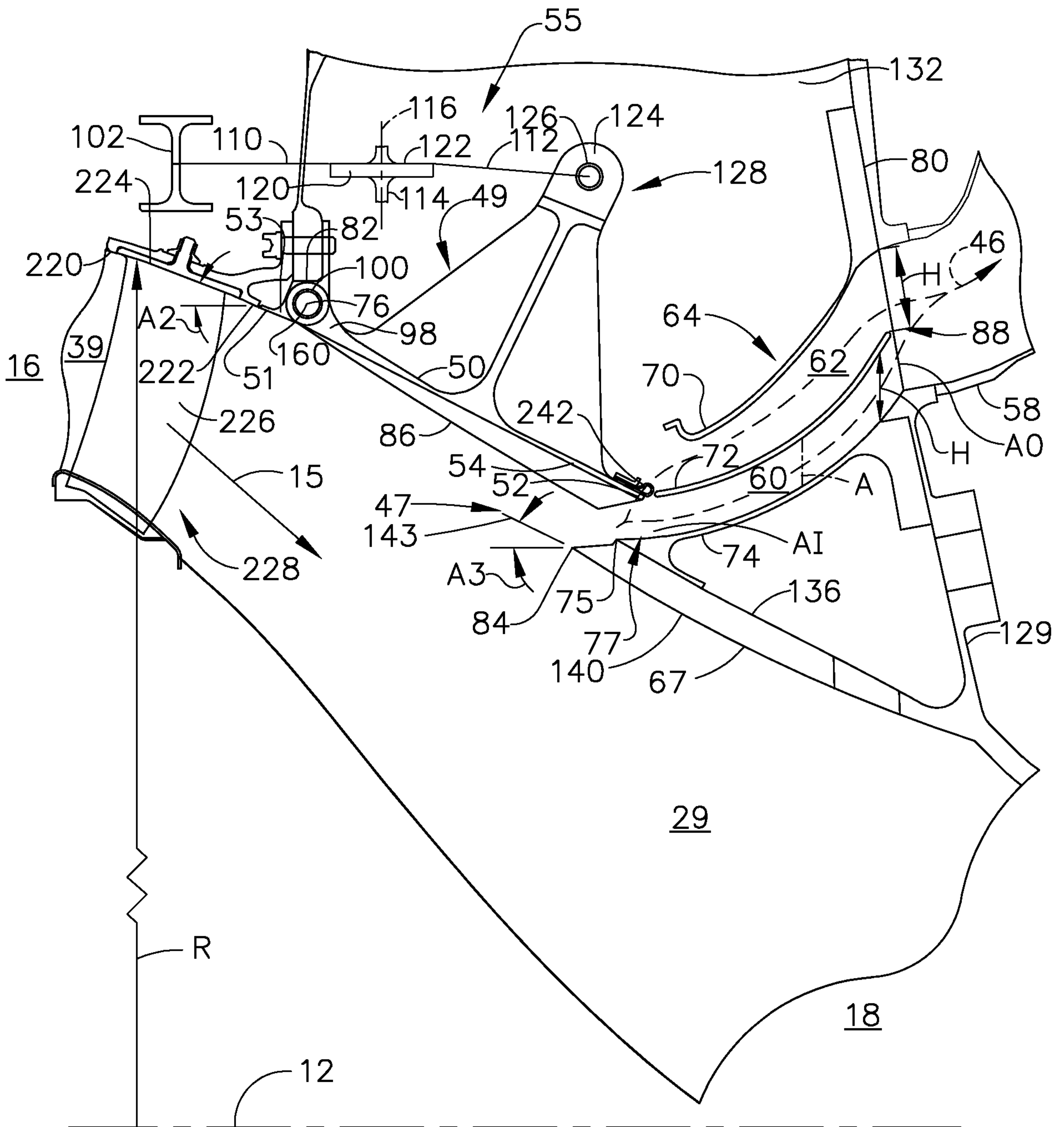


FIG. 6

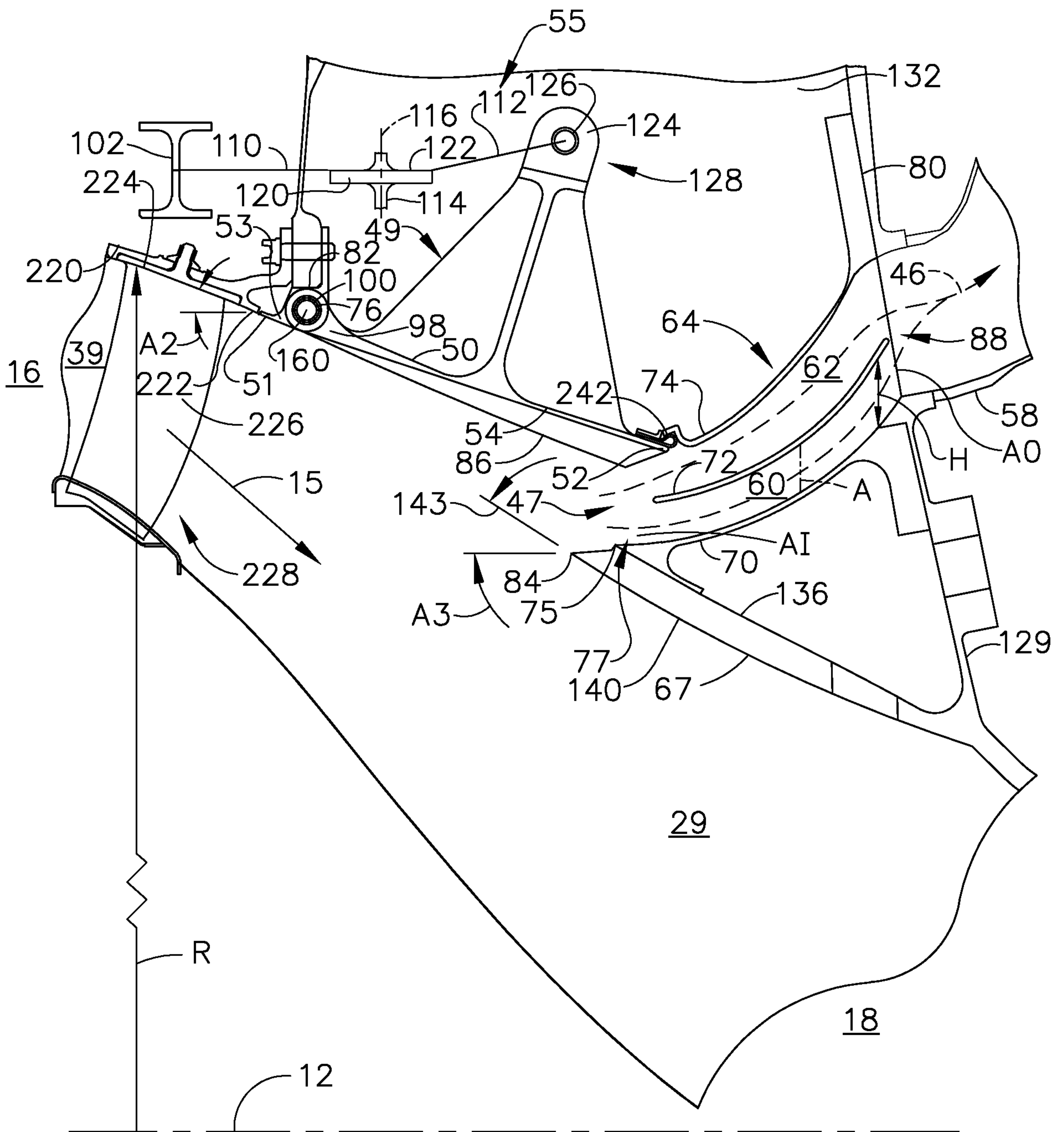


FIG. 7

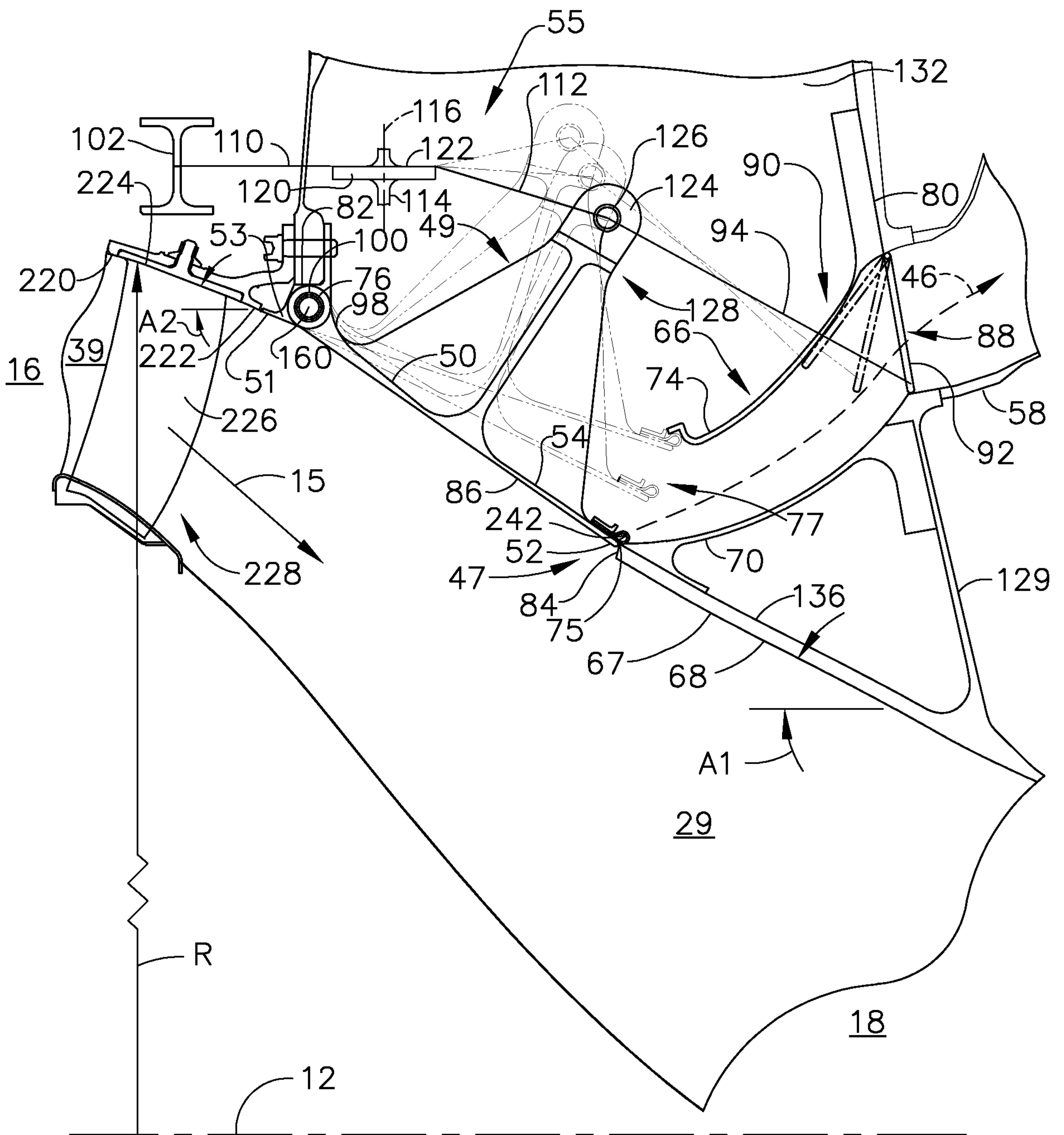


FIG. 8

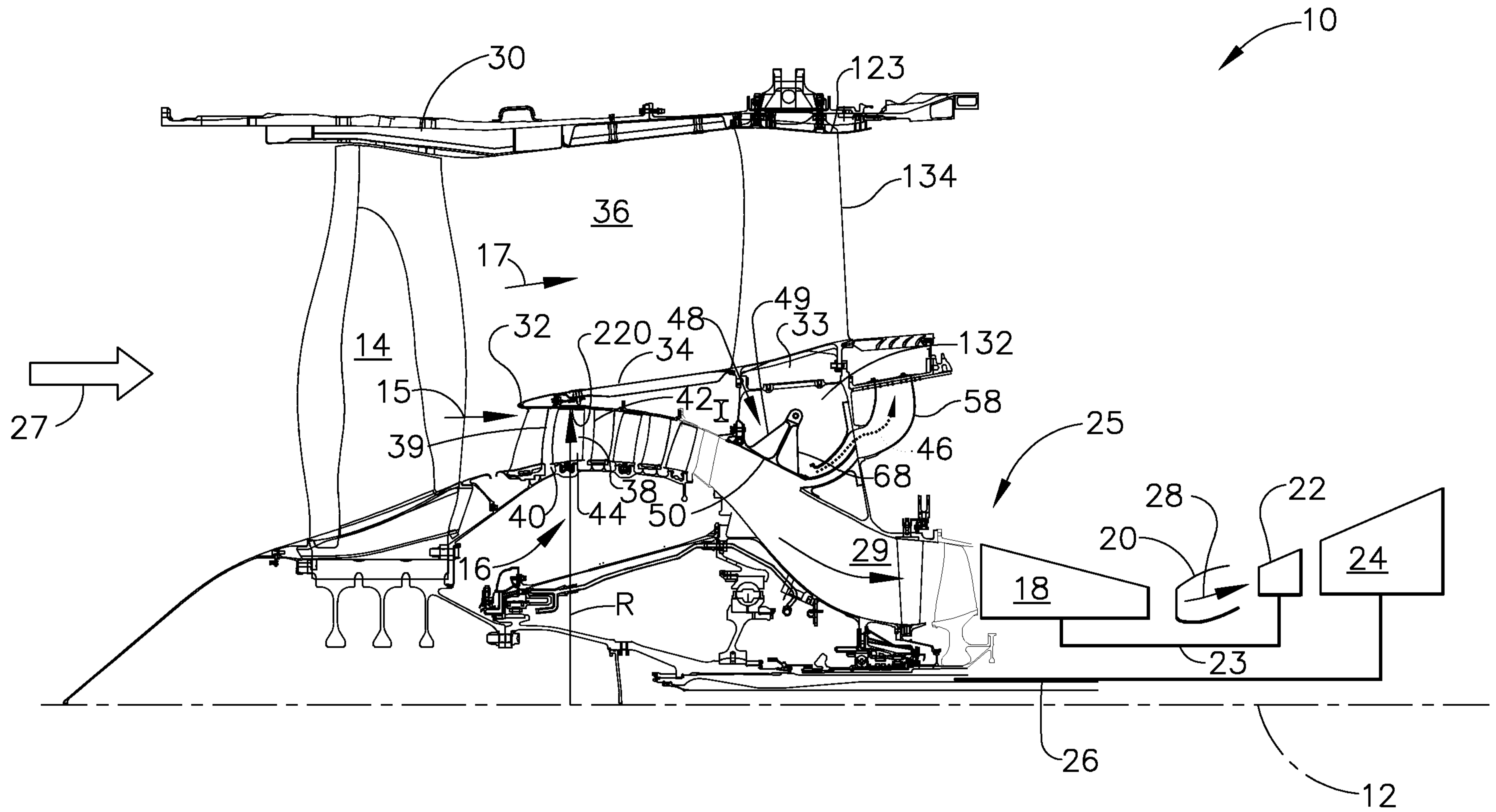


FIG. 1