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(54) **Plasma actuation systems to produce swirling flows**

(57) The present application provides a plasma actuation system (100) for a turbo-machinery device (105). The plasma actuation system (100) may include an end wall (60), a number of end wall actuators (110) positioned

about the end wall (60), and a blade (50) positioned adjacent to the end wall (60). The end wall actuators (110) are oriented to produce a swirling flow (250) between the end wall (60) and the blade (50).

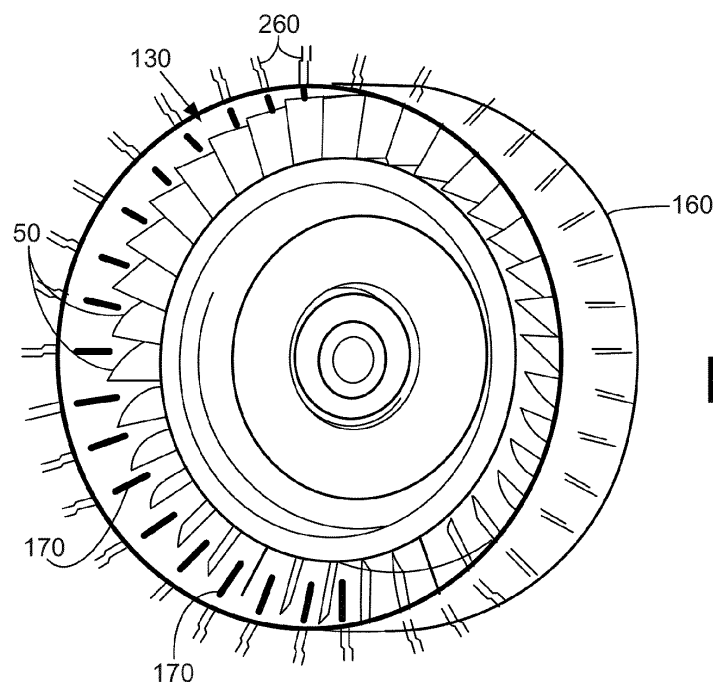


Fig. 7

EP 2 481 889 A2

Description

TECHNICAL FIELD

[0001] The present application relates generally to gas turbine engines and more particularly relates to plasma actuation systems that produce swirling flows at the end walls of turbo-machinery and the like so as to reduce to end wall blockages and losses therein.

BACKGROUND OF THE INVENTION

[0002] Aerodynamic instabilities such as rotating stall and surge impose fundamental limits on the stability of compressors. Rotating stall may occur as the mass flow through the compressor is decreased at a certain speed. Stall cells may be created and may rotate around the circumference of the compressor as opposed to moving in the axial flow direction. Such stall cells may reduce substantially the efficiency of the compressor and also may increase the structural load on the airfoils in the localized region. Compressor surge may result in the reversal of the flow through the compressor and the expulsion of the previously compressed air. Compressor surge may result when the compressor does not have the capacity to absorb momentary disturbances. Recovery from compressor surge typically involves a complete restart of the engine.

[0003] Compressors thus are generally designed with a safety margin or a stall margin against rotating stall and the like. Current compressor designs, however, may increase the tip clearance to blade height ratio and thus may result in a significant decrease in the stall margin. Known approaches to stall margin improvement, however, such as casing treatments, oscillating inlet guide vanes, rotor tip injections, and the like, may have an impact on the efficiency of the compressor and may result in significant penalties in terms of weight or the use of "expensive" high pressure air from downstream stages.

[0004] For a turbine, the clearance gap between the end walls and the blades may be a significant source of typical aerodynamic losses. The clearance flows also interact strongly with other secondary flows present in the blade passage. As a result, losses due to clearance flows may account for nearly a third of the total losses of the turbine.

[0005] There is thus a desire for improved compressor designs and/or flow control systems so as to provide a robust stall margin even with the use of smaller blade heights. By avoiding known aerodynamic instabilities such as those described above, compressor designs may have increased safety throughout a mission, increased tolerance for stage mismatch during transient operations, and the opportunity to match stages at maximum efficiency so as to reduce the fuel burn there-through while maintaining high efficiency. Likewise, there is strong need to develop flow control devices that can mitigate losses due to clearance flows in a turbine.

SUMMARY OF THE INVENTION

[0006] The present application provides a plasma actuation system for a turbo-machinery device. The plasma actuation system may include an end wall, a number of end wall actuators positioned about the end wall, and a blade positioned adjacent to the end wall. The end wall actuators are oriented to produce a swirling flow between the end wall and the blade.

[0007] The present application further provides a method of reducing a blockage and losses about an end wall and a blade tip of a turbo-machinery device. The method may include the steps of actuating a number of end wall actuators, generating circumferential and/or intermediate momentum in a flow therethrough, and creating a swirling flow near the end wall and the blade tip so as to reduce the blockage and losses thereabout.

[0008] The present application further provides a plasma actuation system for a turbo-machinery device. The plasma actuation system may include an end wall with a number of circumferential momentum end wall actuators and/or a number of intermediate momentum end wall actuators and a blade with a number of circumferential momentum blade actuators and/or a number of intermediate momentum end wall actuators, the intermediate momentum end wall actuators, the circumferential momentum blade actuators, and the intermediate momentum blade actuators are oriented to produce a swirling flow between the end wall and the blade.

[0009] These and other features and improvements of the present application will become apparent to one of ordinary skill in the art upon review of the following detailed description when taken in conjunction with the several drawings and the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010]

Fig. 1 is a schematic view of a known gas turbine engine.

Fig. 2 is a partial cross-sectional view of a turbo-machinery device showing a blade tip and an end wall with a flow path therethrough.

Fig. 3 is a schematic view of a portion of a turbo-machinery device with a plasma actuation system as may be described herein.

Fig. 4 is a schematic view of a dielectric barrier discharge plasma actuator as may be used in the plasma actuation system of Fig. 3.

Fig. 5 a perspective view of a turbo-machinery device with a portion of the plasma actuation system of Fig. 3.

Fig. 6 is a schematic view of the plasma actuation system of Fig. 3 with the direction of the plasma force shown.

Fig. 7 a perspective view of a turbo-machinery device with a portion of the plasma actuation system of Fig. 3.

Fig. 8 is a schematic view of the plasma actuation system of Fig. 3 with the direction of the plasma force shown.

Fig. 9 is a schematic view of the plasma actuation system of Fig. 3 with the direction of the plasma force shown.

Fig. 10 a perspective view of a turbo-machinery device with a portion of the plasma actuation system of Fig. 3.

DETAILED DESCRIPTION

[0011] Referring now to the drawings, in which like numerals refer to like elements throughout the several views, Fig. 1 shows a schematic view of a rotary machine such as gas turbine engine 10. The gas turbine engine 10 may include a compressor 15. The compressor 15 compresses an incoming flow of air 20. The compressor 15 delivers the compressed flow of air 20 to a combustor 25. The combustor 25 mixes the compressed flow of air 20 with a compressed flow of fuel 30 and ignites the mixture to create a flow of combustion gases 35. Although only a single combustor 25 is shown, the gas turbine engine 10 may include any number of combustors 25. The flow of combustion gases 35 is delivered in turn to a turbine 40. The flow of combustion gases 35 drives the turbine 40 so as to produce mechanical work. The mechanical work produced in the turbine 40 drives the compressor 15 and also may drive an external load 45 such as an electrical generator and the like.

[0012] The gas turbine engine 10 may be one of any number of different gas turbine engines offered by General Electric Company of Schenectady, New York and the like. The gas turbine engine 10 may have other configurations and may use other types of components. Other types of gas turbine engines also may be used herein. Multiple gas turbine engines 10, other types of turbines, and other types of power generation and propulsion equipment also may be used herein together. Other types of rotary machines also may be used herein.

[0013] Generally described, the compressor 15 and the turbine 40 include a number of circumferentially spaced blades 50 positioned on a shaft 55 for rotation therewith. The blades 50 may be positioned within an end wall 60. The end wall 60 may be a casing or any type of other type of structure. A tip clearance space 65 may exist between the end wall 60 and a tip 70 of the blade 50. The blades 50 may rotate while the end wall 60 is

stationary. Likewise, the blade 50 may be in the form of a stationary stator and the end wall 60 may be positioned on a rotating shaft thereabout.

[0014] As is shown in Fig. 2, a tip clearance flow 75 may be driven therethrough by a pressure difference across the blade 50 (blade loading). The interaction of the clearance flow 75 with an incoming main flow 80 creates a region of low-speed fluid and high losses. These large clearance flow losses allow an interface 85 to be formed therein. The interface 85 may be defined as a region of high entropy gradient. The low-speed fluid region enclosed by the interface 85 thus acts as a blockage 90 to the main flow 80 and increases the blade loading near the tip 70. Increases in this blockage 90 may be a precursor to stall events such as those described above.

[0015] Fig. 3 shows one example of a plasma actuation system 100 as may be described herein. The plasma actuation system 100 may be used with a turbo-machinery device 105 such as the compressor 25 and/or the turbine 40. The plasma actuation system 100 may include a number of end wall actuators 110 positioned about the end wall 60. The end wall actuators 110, in turn, may include a number of axial momentum end wall actuators 120, a number of circumferential momentum end wall actuators 130, and a number of intermediate momentum end wall actuators 135. Moreover, one or more of the blades 50 also may have a number of blade actuators 140 positioned thereabout. The blade actuators 140 may include one or more axial momentum blade actuators 150, one or more circumferential momentum blade actuators 160, and one or more intermediate momentum blade actuators. Other types of plasma actuators 110 may be used herein in other orientations and in other locations. Not all of the actuators 110 must be used in any given application. Any number of plasma actuators 110 may be used herein.

[0016] Fig. 4 shows an example of dielectric barrier discharge plasma actuator 170 as may be used as any of the actuators described above. The actuator 170 may include a conductive or a non-conductive substrate 180. A dielectric layer 190 may be positioned thereon. A first thin conductive layer 200 may be deposited on the non-conductive substrate 180 with the dielectric layer 190 on top. If the substrate 180 is conductive, the substrate itself acts as the first thin conductive layer 200. A second thin conductive layer 210 then may be disposed on the dielectric layer 190. The conductive layers 200, 210 may be connected to a power source 220 and a wave-form controller 230. The wave form controller 230 may be configured to control an input voltage level and pulsing, variable or AC voltage frequency, duty cycle and shape, and the like. Other types of actuators 170 also may be used herein such as single dielectric barrier discharge actuators, surface corona discharge actuators, and the like. Other components and other configurations may be used herein.

[0017] In use, an air flow located above the dielectric layer 190 and between the conductive layers 200, 210

may be ionized in a desired fashion to create a region of a discharge plasma 240. The actuator 170 thus may be oriented to impart momentum to a flow therethrough via the discharge plasma 240. In this example, multiple actuators 170 in different orientations may be used to create a swirling flow 250 from the tip clearance flow 75 and the incoming flow 80 with momentum injection as will be described in more detail below.

[0018] Fig. 5 shows an example of the axial momentum end wall actuator 120. As is shown, the actuators 120 may be positioned about the end wall 60 and face the blades 50 about the tip clearance space 65. A number of electrodes 260 may be in communication with each actuator 120. Each actuator 120 may extend the length of several blades 50. Fig. 6 shows the plasma 240 with the arrows 270 indicating the direction of the plasma force extending perpendicularly to a direction 280 of the blade rotation so as to increase the axial momentum of the flow therethrough.

[0019] Fig. 7 shows an example of the circumferential momentum end wall actuators 130. Likewise, the actuators 130 may be positioned about the end wall 60. In this example, one or more actuators 130 may be used for each blade 50. Fig. 8 shows the plasma 240 with the arrows 270 indicating the direction of the plasma force running parallel and in the same direction 280 as the blade direction. Fig. 9 shows the force of the plasma 240 running parallel but opposite of the direction 280 of the blade rotation (counter-swirl). Either direction acts to alter the circumferential momentum of the flow therethrough.

[0020] Likewise, the intermediate momentum end wall actuators 135 may generate the plasma 240 with force extending in any desired direction between axial and circumferential. The intermediate momentum end wall actuators 135 may alter the intermediate momentum of the flow therethrough.

[0021] Fig. 10 shows an example of the blade actuators 140. In this example, a number of axial momentum blade actuators 150, a number of the circumferential momentum blade actuators 160, and a number of intermediate momentum blade actuators 165 may be used at the tip 70. The arrows 270 show the different directions of the force of the plasma 240 so as to alter axial, circumferential, and/or intermediate momentum to the flow therethrough. Any number of the actuators 150, 160, 165 may be used on a given blade 50 in any orientation. Other components and configurations also may be used herein.

[0022] The combination of the different actuators 170 within the plasma actuation system 100 thus may be used to generate the swirling flows 250 about the tip 70 and the end wall 60 so as to reduce the blockage 90 and other losses near the tip 70. Specifically, the actuators 170 alter the axial, the circumferential momentum, and/or the intermediate momentum of the flows therethrough to create the swirling flow 250. Hence, the plasma actuation system 100 may inject an optimal combination of axial, circumferential, and/or intermediate momentum into the tip gap flows. Energizing the clearance flow by injection

of momentum in optimal directions and locations thus reduces the losses and blockage introduced by the interaction of the clearance flow with the main flow.

[0023] The location of the actuators 170 may be chosen based on a specific turbo-machinery design so as to reduce the blockage 90 and losses in and about the tip/end wall region. The actuators 170 also may be excited at different forcing frequencies so as to minimize the losses and blockages introduced in and about the tip/end wall region. For example, the blade passing frequencies and variations thereon may be used. The actuators 170 also have the relatively fast response time so as to enable active feedback control. Multiple actuators 170 may be used in series to augment the force imparted to the flow 250.

[0024] The appropriate injection of momentum by the actuators 170 may energize end wall boundary layers so as to minimize end wall boundary layer separation, reduce blade loading at the tip, and minimize blockage and losses. The swirling flows 250 produced by the actuators 170 thus may improve the aerodynamic performance stability characteristics of the overall turbo-machinery device 105. Such increased stability may lead to increased safety throughout the mission, increased tolerances for stage mismatch during part speed operation and transients, and an opportunity to match stages at the compressor maximum efficiency point so as to reduce fuel burn. Moreover, the actuators 170 do not use the "expensive" compressed air from upstream stages. Reduction in tip clearance flows also may lead to reduced fuel burn,

[0025] It should be apparent that the foregoing relates only to certain embodiments of the present application and that numerous changes and modifications may be made herein by one of ordinary skill in the art without departing from the scope of the invention as defined by the following claims and the equivalents thereof.

Claims

1. A plasma actuation system (100) for a turbo-machinery device (105), comprising:

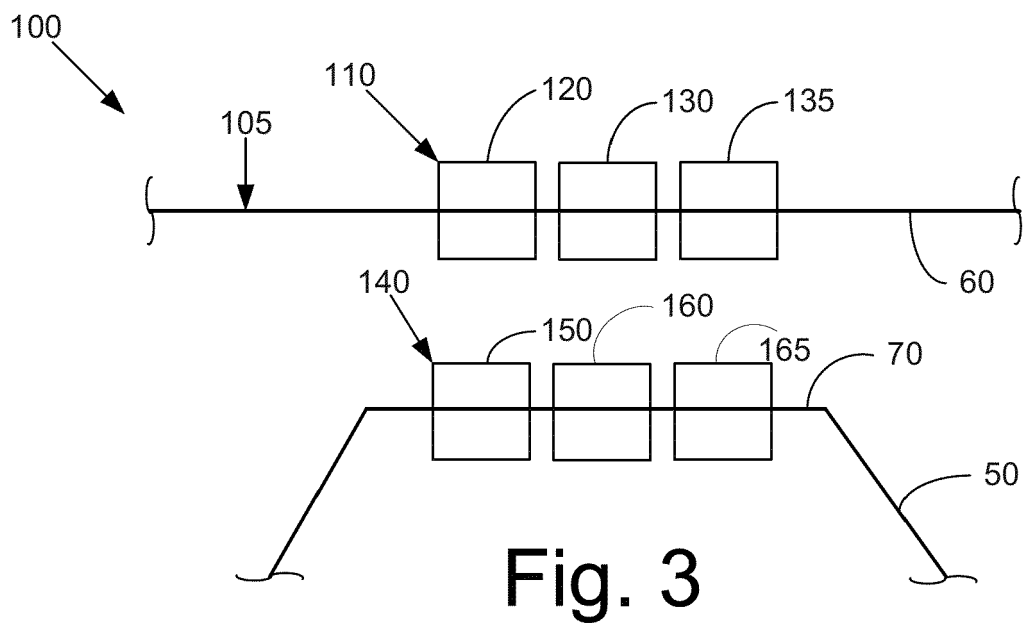
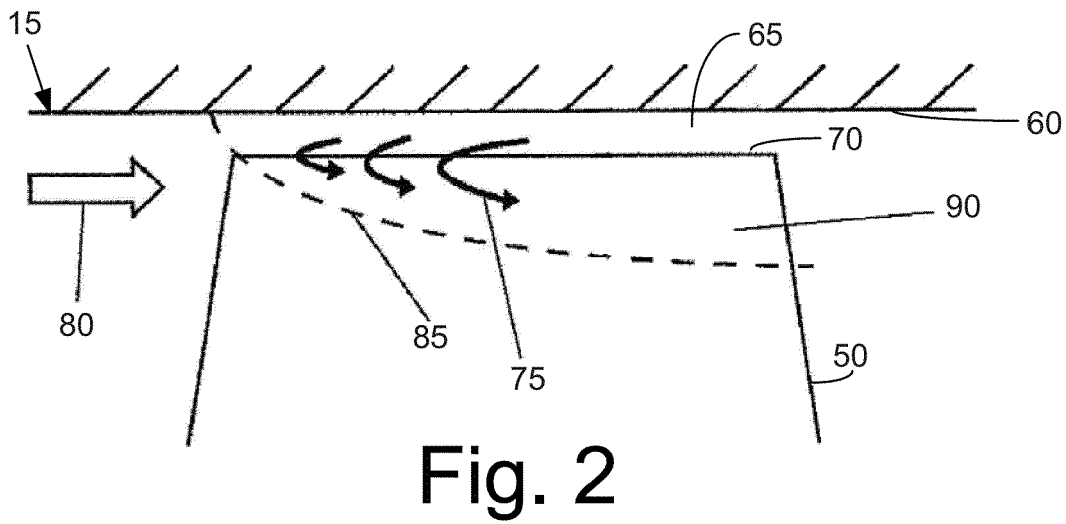
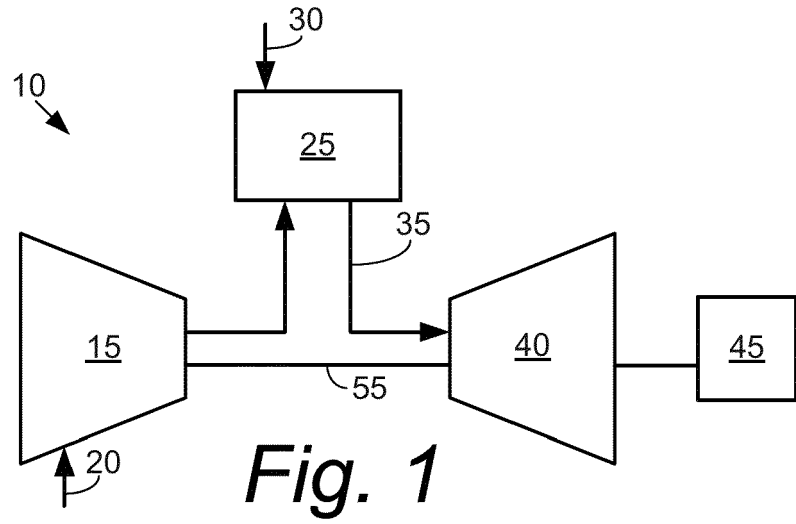
an end wall (60);
a plurality of end wall actuators (110) positioned about the end wall (60); and
a blade (50) positioned adjacent to the end wall (60);

wherein the plurality of end wall actuators (110) are oriented to produce a swirling flow (250) between the end wall (60) and the blade (50).

2. The plasma actuation system (100) of claim 1, wherein the plurality of end wall actuators (110) comprises a plurality of circumferential momentum end wall actuators (130).

3. The plasma actuation system (100) of claim 2, wherein one or more of the plurality of circumferential momentum end wall actuators (130) are positioned about the blade (50). 5
4. The plasma actuation system (100) of any preceding claim, wherein the plurality of end wall actuators (110) comprises a plurality of intermediate momentum end wall actuators (135). 10
5. The plasma actuation system (100) of any preceding claim, further comprising a plurality of blade actuators (140) positioned on the blade (50).
6. The plasma actuation system (100) of claim 5, wherein the plurality of blade actuators (140) comprises a plurality of circumferential momentum blade actuators (160). 15
7. The plasma actuation system (100) of either of claim 5 or 6, wherein the plurality of blade actuators (140) comprises a plurality of intermediate momentum blade actuators (165). 20
8. The plasma actuation system (100) of any of claims 5 to 7, wherein the plurality of blade actuators (140) are positioned about a tip (70) of the blade (50). 25
9. The plasma actuation system (100) of claim 5, wherein the plurality of end wall actuators (110) and the plurality of blade actuators (140) comprise a plurality of axial momentum actuators (120, 150). 30
10. The plasma actuation system (100) of claim 5, wherein the plurality of end wall actuators (110) and the plurality of blade actuators (140) comprise a plurality of dielectric barrier discharge plasma actuators (170). 35
11. The plasma actuation system (100) of claim 10, wherein each of the plurality of dielectric barrier discharge plasma actuators (170) comprises a pair of conductive layers (200, 210) to produce a plasma flow (240) therebetween. 40
12. The plasma actuation system (100) of any preceding claim, wherein the turbo-machinery device (105) comprises a compressor (15). 45
13. The plasma actuation system (100) of any preceding claim, wherein the turbo-machinery device (105) comprises a turbine (40). 50
14. A method of reducing a blockage and losses (90) about an end wall (60) and a blade tip (70) of a turbo-machinery device (105), comprising: 55
 - generating circumferential and/or intermediate momentum in a flow (75, 80) therethrough; and
 - creating a swirling flow (250) near the end wall (60) and the blade tip (70) so as to reduce the blockage and losses (90) thereabout.
15. The method of claim 14, further comprising the step of actuating a plurality of blade actuators (140) generating circumferential and/or intermediate momentum in the flow (75, 80) therethrough.

actuating a plurality of end wall actuators (110);



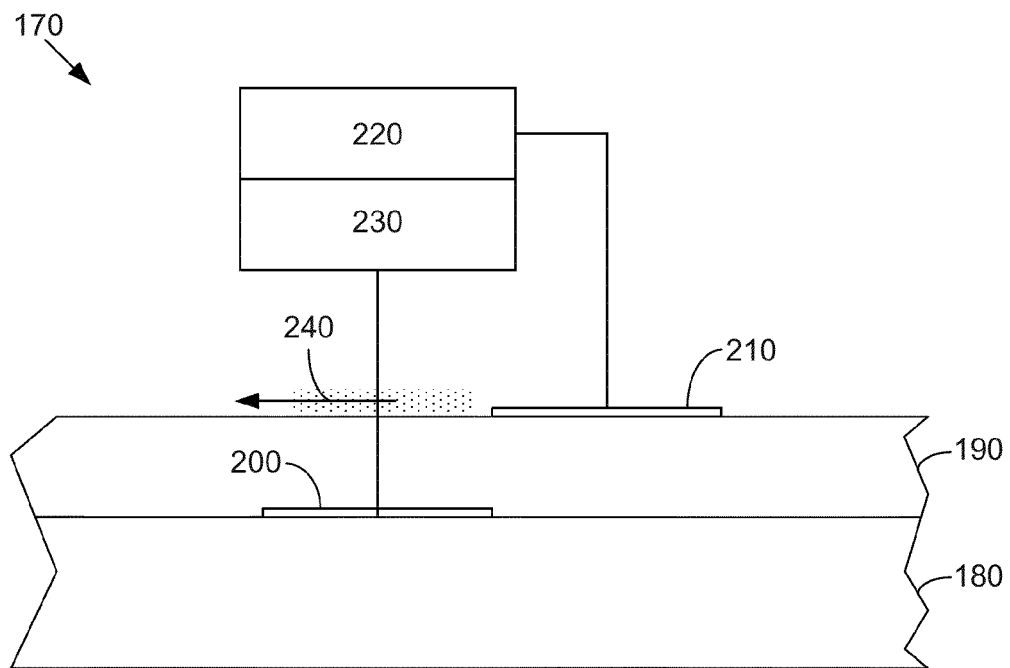


Fig. 4

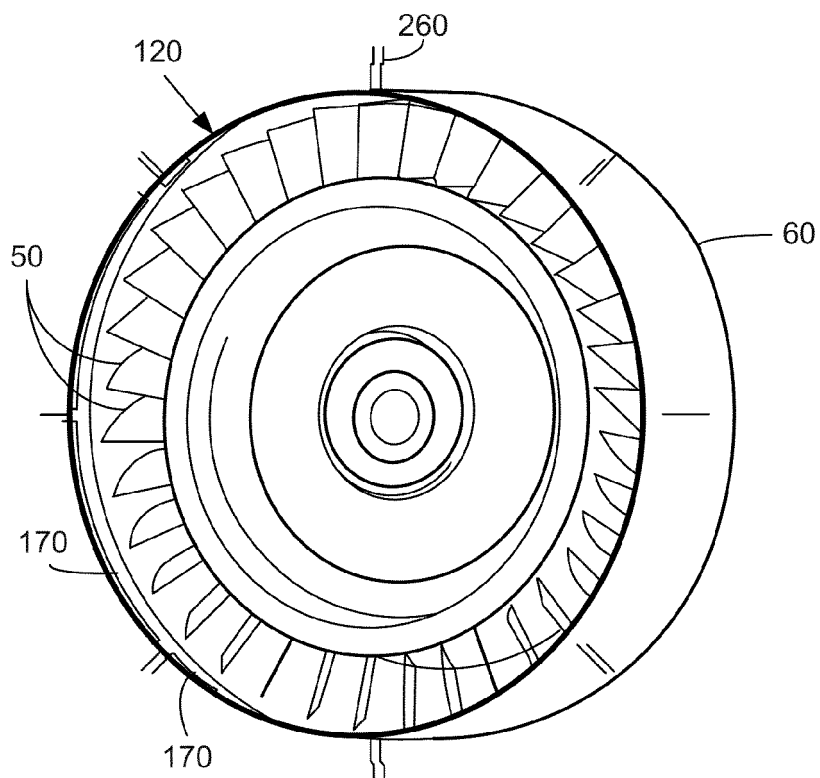
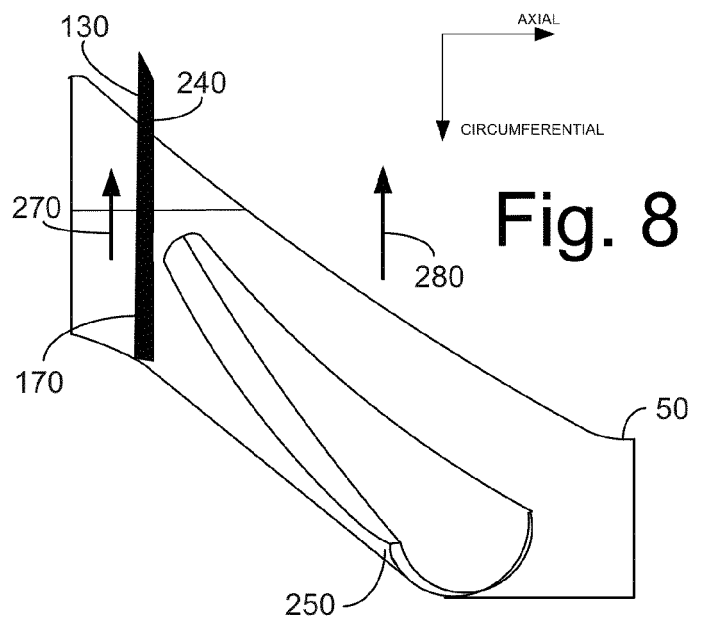
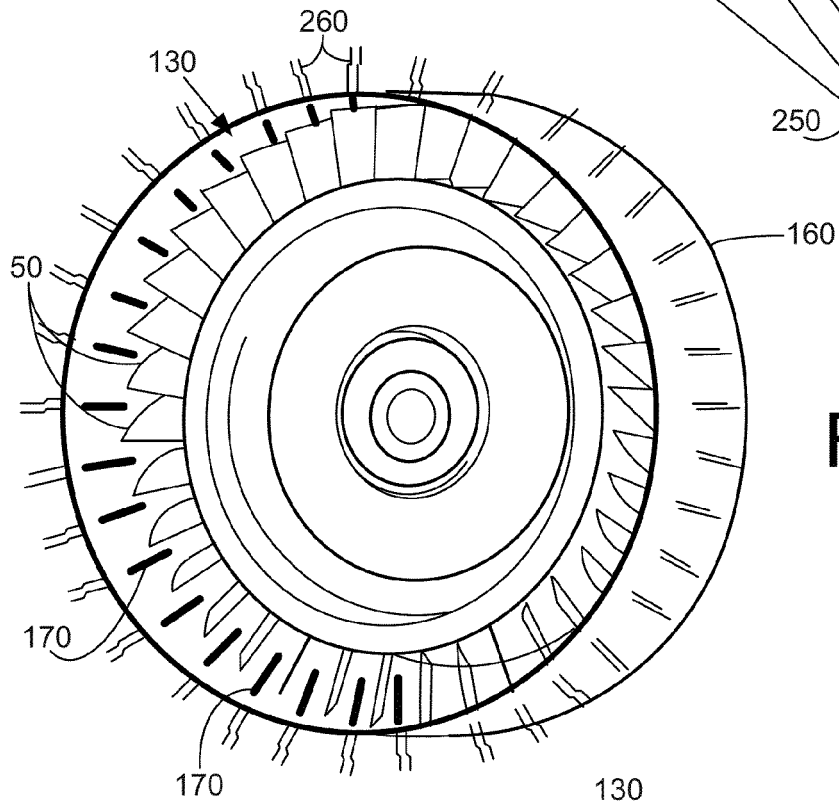
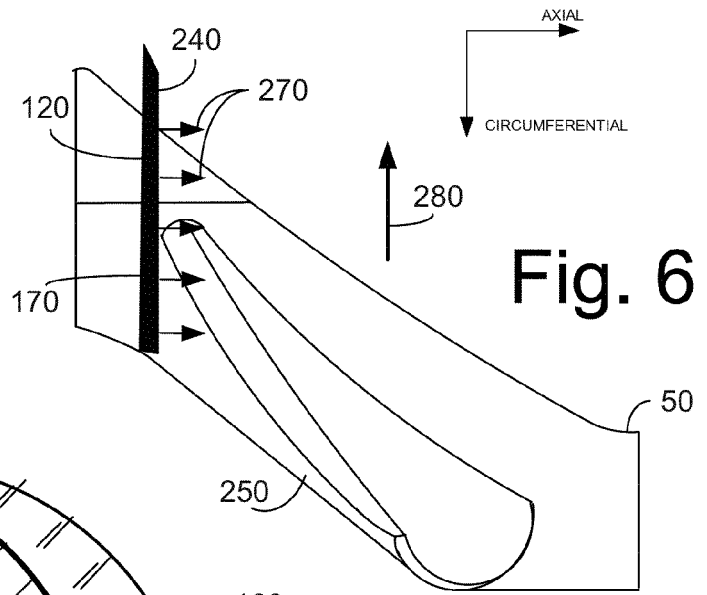


Fig. 5



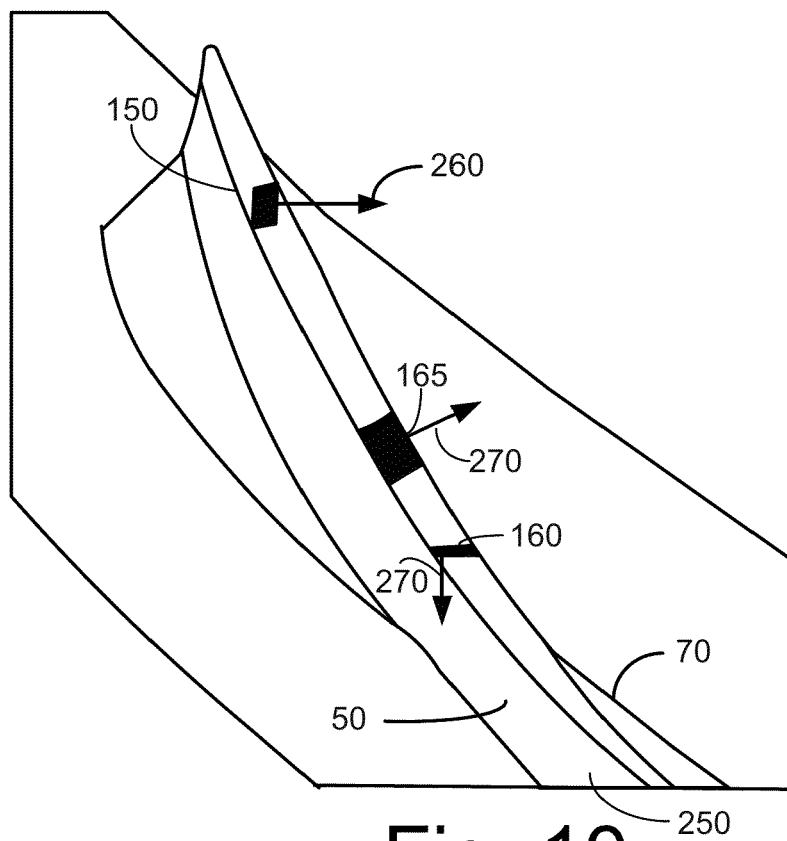
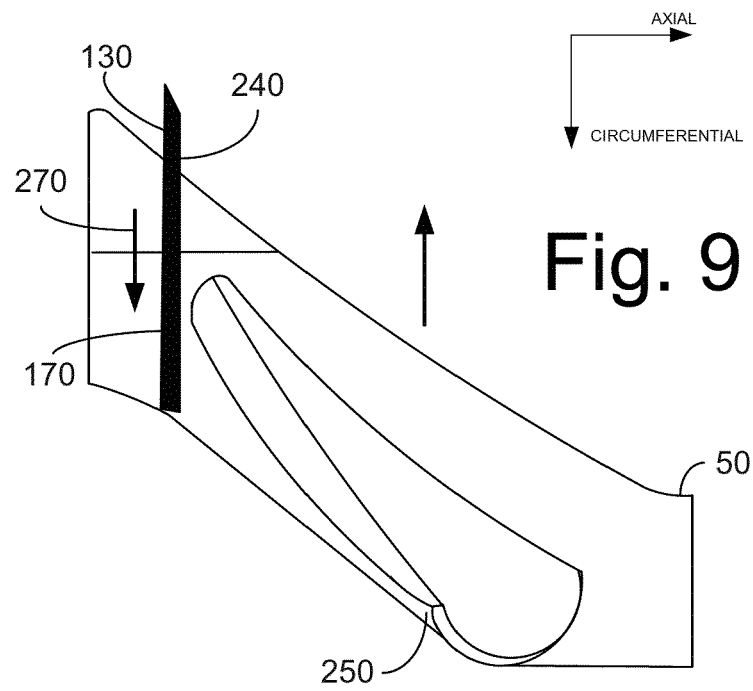


Fig. 10