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(54) Title: UNDUCTED THRUST PRODUCING SYSTEM ARCHITECTURE

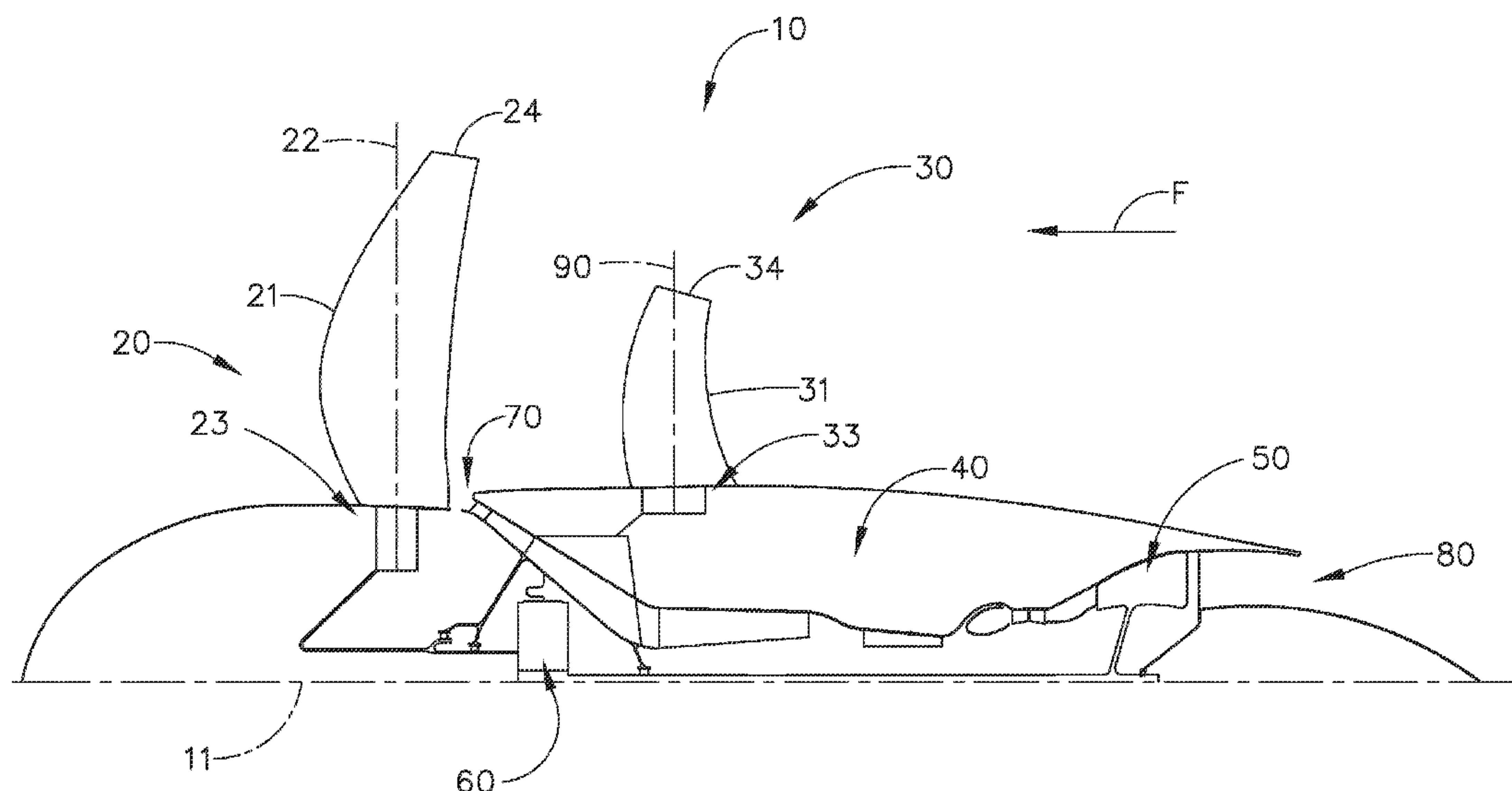


FIG. 1

(57) **Abrégé/Abstract:**

An unducted thrust producing system has a rotating element with an axis of rotation and a stationary element. The rotating element includes a plurality of blades, and the stationary element has a plurality of vanes configured to impart a change in tangential velocity of the working fluid opposite to that imparted by the rotating element acted upon by the rotating element. The system includes an inlet forward of the rotating element and the stationary element.

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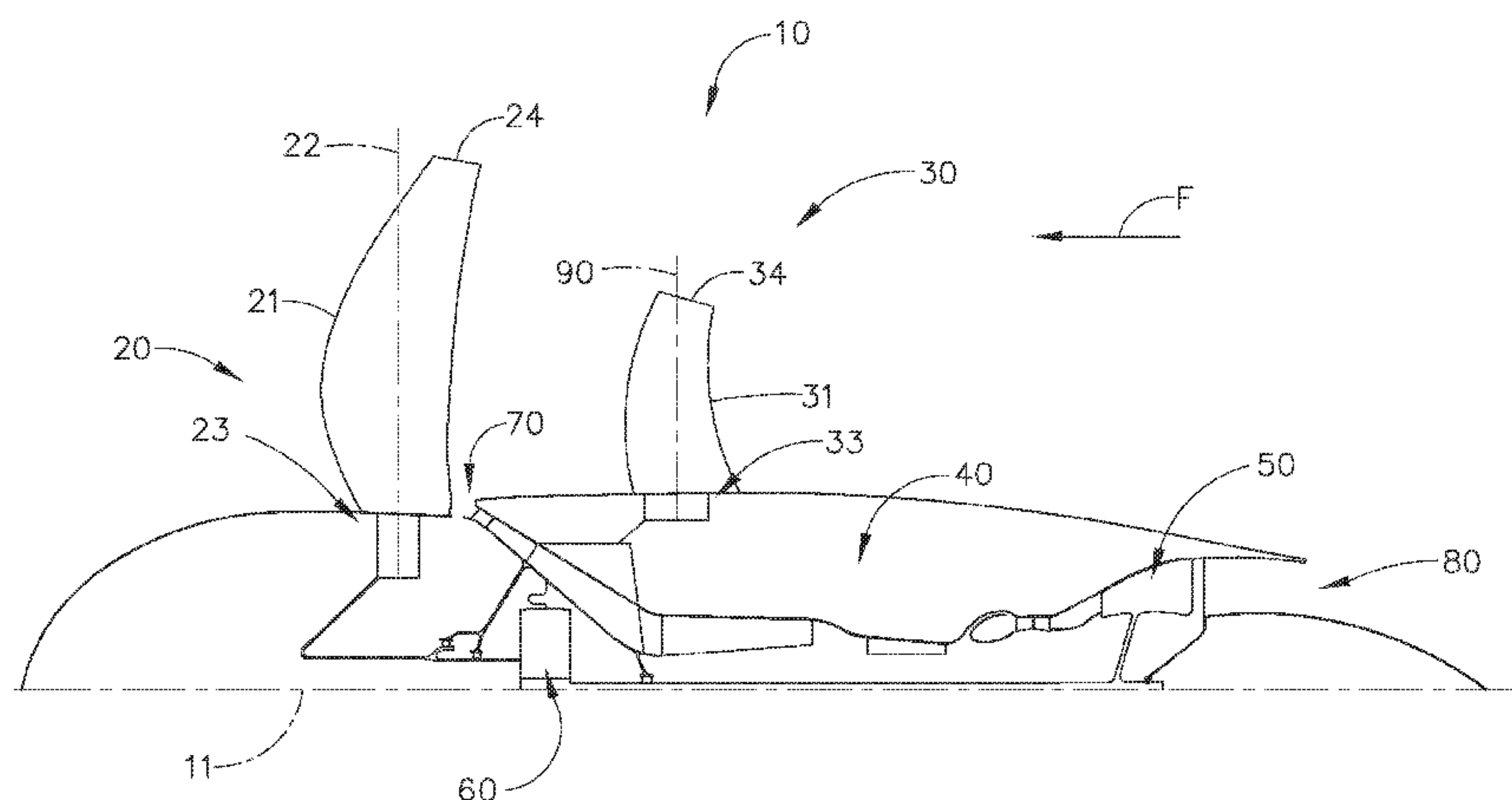


FIG. 1

(57) Abstract: An unducted thrust producing system has a rotating element with an axis of rotation and a stationary element. The rotating element includes a plurality of blades, and the stationary element has a plurality of vanes configured to impart a change in tangential velocity of the working fluid opposite to that imparted by the rotating element acted upon by the rotating element. The system includes an inlet forward of the rotating element and the stationary element.



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UNDUCTED THRUST PRODUCING SYSTEM ARCHITECTURE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is related to PCT/US13/XXXXX, Attorney docket no. 264668-2, titled “UNDUCTED THRUST PRODUCING SYSTEM” filed on October 23, 2013, and PCT/US13/XXXXX, Attorney docket no. 265517-2, titled “VANE ASSEMBLY FOR AN UNDUCTED THRUST PRODUCING SYSTEM” filed on October 23, 2013.

BACKGROUND OF THE INVENTION

[0002] The technology described herein relates to an unducted thrust producing system, particularly architectures for such systems. The technology is of particular benefit when applied to “open rotor” gas turbine engines.

[0003] Gas turbine engines employing an open rotor design architecture are known. A turbofan engine operates on the principle that a central gas turbine core drives a bypass fan, the fan being located at a radial location between a nacelle of the engine and the engine core. An open rotor engine instead operates on the principle of having the bypass fan located outside of the engine nacelle. This permits the use of larger fan blades able to act upon a larger volume of air than for a turbofan engine, and thereby improves propulsive efficiency over conventional engine designs.

[0004] Optimum performance has been found with an open rotor design having a fan provided by two contra-rotating rotor assemblies, each rotor assembly carrying an array of airfoil blades located outside the engine nacelle. As used herein, “contra-rotational relationship” means that the blades of the first and second rotor assemblies are arranged to rotate in opposing directions to each other. Typically the blades of the first and second rotor assemblies are arranged to rotate about a common axis in opposing directions, and are axially spaced apart along that axis. For example, the respective blades of the first rotor assembly and second rotor assembly may be co-axially mounted and spaced apart, with the blades of the first rotor assembly configured to rotate clockwise about the axis and the blades of the second rotor assembly configured to rotate counter-clockwise about the axis (or vice versa). In

appearance, the fan blades of an open rotor engine resemble the propeller blades of a conventional turboprop engine.

[0005] The use of contra-rotating rotor assemblies provides technical challenges in transmitting power from the power turbine to drive the blades of the respective two rotor assemblies in opposing directions.

[0006] It would be desirable to provide an open rotor propulsion system utilizing a single rotating propeller assembly analogous to a traditional bypass fan which reduces the complexity of the design, yet yields a level of propulsive efficiency comparable to contra-rotating propulsion designs with a significant weight and length reduction.

BRIEF DESCRIPTION OF THE INVENTION

[0007] An unducted thrust producing system has a rotating element with an axis of rotation and a stationary element. The rotating element includes a plurality of blades, and the stationary element has a plurality of vanes configured to impart a change in tangential velocity of the working fluid opposite to that imparted by the rotating element acted upon by the rotating element. The system includes an inlet forward of the rotating element and the stationary element.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate one or more embodiments and, together with the description, explain these embodiments. In the drawings:

[0009] FIGURE 1 is a cross-sectional schematic illustration of an exemplary embodiment of an unducted thrust producing system;

[0010] FIGURE 2 is an illustration of an alternative embodiment of an exemplary vane assembly for an unducted thrust producing system;

[0011] FIGURE 3 is a partial cross-sectional schematic illustration of an exemplary embodiment of an unducted thrust producing system depicting an exemplary compound gearbox configuration;

[0012] FIGURE 4 is a partial cross-sectional schematic illustration of an exemplary embodiment of an unducted thrust producing system depicting another exemplary gearbox configuration;

[0013] FIGURE 5 is a cross-sectional schematic illustration of another exemplary embodiment of an unducted thrust producing system;

[0014] FIGURE 6 is a cross-sectional schematic illustration of another exemplary embodiment of an unducted thrust producing system;

[0015] FIGURE 7 is a cross-sectional schematic illustration of another exemplary embodiment of an unducted thrust producing system;

[0016] FIGURE 8 is a cross-sectional schematic illustration of another exemplary embodiment of an unducted thrust producing system;

[0017] FIGURE 9 is a cross-sectional schematic illustration of another exemplary embodiment of an unducted thrust producing system;

[0018] FIGURE 10 is a cross-sectional schematic illustration of another exemplary embodiment of an unducted thrust producing system;

[0019] FIGURE 11 is a cross-sectional schematic illustration of another exemplary embodiment of an unducted thrust producing system;

[0020] FIGURE 12 is a cross-sectional schematic illustration of another exemplary embodiment of an unducted thrust producing system;

[0021] FIGURE 13 is a cross-sectional schematic illustration of another exemplary embodiment of an unducted thrust producing system;

[0022] FIGURE 14 is a cross-sectional schematic illustration of another exemplary embodiment of an unducted thrust producing system; and

[0023] FIGURE 15 is a cross-sectional schematic illustration taken along lines 15-15 of FIGURE 14 illustrating the inlet configuration of the unducted thrust producing system of FIGURE 14.

DETAILED DESCRIPTION OF THE INVENTION

[0024] In all of the Figures which follow, like reference numerals are utilized to refer to like elements throughout the various embodiments depicted in the Figures.

[0025] Figure 1 shows an elevational cross-sectional view of an exemplary embodiment of an unducted thrust producing system 10. As is seen from Figure 1, the unducted thrust producing system 10 takes the form of an open rotor propulsion system and has a rotating element 20 depicted as a propeller assembly which includes an array of airfoil blades 21 around a central longitudinal axis 11 of the unducted thrust producing system 10. Blades 21 are arranged in typically equally spaced relation around the centreline 11, and each blade 21 has a root 23 and a tip 24 and a span defined therebetween. Unducted thrust producing system 10 includes a gas turbine engine having a gas generator 40 and a low pressure turbine 50. Left- or right-handed engine configurations can be achieved by mirroring the airfoils of 21, 31, and 50. As an alternative, an optional reversing gearbox 55 (located in or behind the low pressure turbine 50 as shown in Figures 3 and 4 or combined or associated with power gearbox 60 as shown in Figure 3) permits a common gas generator and low pressure turbine to be used to rotate the fan blades either clockwise or counterclockwise, i.e., to provide either left- or right-handed configurations, as desired, such as to provide a pair of oppositely-rotating engine assemblies as may be desired for certain aircraft installations. Unducted thrust producing system 10 in the embodiment shown in Figure 1 also includes an integral drive (power gearbox) 60 which may include a gearset for decreasing the rotational speed of the propeller assembly relative to the low pressure turbine 50.

[0026] Unducted thrust producing system 10 also includes in the exemplary embodiment a non-rotating stationary element 30 which includes an array of vanes 31 also disposed around central axis 11, and each blade 31 has a root 33 and a tip 34 and a span defined therebetween. These vanes may be arranged such that they are not all equidistant from the rotating assembly, and may optionally include an annular shroud or duct 100 distally from axis 11 (as shown in Figure 2) or may be unshrouded. These vanes are mounted to a stationary frame and do not rotate relative to the central axis 11, but may include a mechanism for adjusting their orientation relative to their axis 90 and/or relative to the blades 21. For reference purposes, Figure 1 also depicts a Forward direction denoted with arrow F, which in turn defines the forward and aft portions of the system. As shown in Figure 1, the rotating element 20 is located forward of the gas generator 40 in a “puller” configuration, and the exhaust 80 is located aft of the stationary element 30.

[0027] In addition to the noise reduction benefit, the duct 100 shown in Figure 2 provides a benefit for vibratory response and structural integrity of the stationary vanes 31 by coupling them into an assembly forming an annular ring or one or more circumferential sectors, i.e., segments forming portions of an annular ring linking two or more vanes 31 such as pairs forming doublets. The duct 100 may allow the pitch of the vanes to be varied as desired.

[0028] A significant, perhaps even dominant, portion of the noise generated by the disclosed fan concept is associated with the interaction between wakes and turbulent flow generated by the upstream blade-row and its acceleration and impingement on the downstream blade-row surfaces. By introducing a partial duct acting as a shroud over the stationary vanes, the noise generated at the vane surface can be shielded to effectively create a shadow zone in the far field thereby reducing overall annoyance. As the duct is increased in axial length, the efficiency of acoustic radiation through the duct is further affected by the phenomenon of acoustic cut-off, which can be employed, as it is for conventional aircraft engines, to limit the sound radiating into the far-field. Furthermore, the introduction of the shroud allows for the opportunity to integrate acoustic treatment as it is currently done for conventional aircraft engines to attenuate sound as it reflects or otherwise interacts with the liner. By introducing

acoustically treated surfaces on both the interior side of the shroud and the hub surfaces upstream and downstream of the stationary vanes, multiple reflections of acoustic waves emanating from the stationary vanes can be substantially attenuated.

[0029] In operation, the rotating blades 21 are driven by the low pressure turbine via gearbox 60 such that they rotate around the axis 11 and generate thrust to propel the unducted thrust producing system 10, and hence an aircraft to which it is associated, in the forward direction F.

[0030] It may be desirable that either or both of the sets of blades 21 and 31 incorporate a pitch change mechanism such that the blades can be rotated with respect to an axis of pitch rotation either independently or in conjunction with one another. Such pitch change can be utilized to vary thrust and/or swirl effects under various operating conditions, including to provide a thrust reversing feature which may be useful in certain operating conditions such as upon landing an aircraft.

[0031] Blades 31 are sized, shaped, and configured to impart a counteracting swirl to the fluid so that in a downstream direction aft of both rows of blades the fluid has a greatly reduced degree of swirl, which translates to an increased level of induced efficiency. Blades 31 may have a shorter span than blades 21, as shown in Figure 1, for example, 50% of the span of blades 21, or may have longer span or the same span as blades 21 as desired. Vanes 31 may be attached to an aircraft structure associated with the propulsion system, as shown in Figure 1, or another aircraft structure such as a wing, pylon, or fuselage. Vanes 31 of the stationary element may be fewer or greater in number than, or the same in number as, the number of blades 21 of the rotating element and typically greater than two, or greater than four, in number.

[0032] In the embodiment shown in Figure 1, an annular 360 degree inlet 70 is located between the fan blade assembly 20 and the fixed or stationary blade assembly 30, and provides a path for incoming atmospheric air to enter the gas generator 40 radially inwardly of the stationary element 30. Such a location may be advantageous for a variety of reasons, including management of icing performance as well as protecting the inlet 70 from various objects and materials as may be encountered in operation.

[0033] Figure 5 illustrates another exemplary embodiment of a gas turbine engine 10, differing from the embodiment of Figure 1 in the location of the inlet 71 forward of both the rotating element 20 and the stationary element 30 and radially inwardly of the rotating element 20.

[0034] Figures 1 and 5 both illustrate what may be termed a “puller” configuration where the thrust-generating rotating element 20 is located forward of the gas generator 40. Figure 6 on the other hand illustrates what may be termed a “pusher” configuration embodiment where the gas generator 40 is located forward of the rotating element 20. As with the embodiment of Figure 5, the inlet 71 is located forward of both the rotating element 20 and the stationary element 30 and radially inwardly of the rotating element 20. The exhaust 80 is located inwardly of and aft of both the rotating element 20 and the stationary element 30. The system depicted in Figure 6 also illustrates a configuration in which the stationary element 30 is located forward of the rotating element 20.

[0035] The selection of “puller” or “pusher” configurations may be made in concert with the selection of mounting orientations with respect to the airframe of the intended aircraft application, and some may be structurally or operationally advantageous depending upon whether the mounting location and orientation are wing-mounted, fuselage-mounted, or tail-mounted configurations.

[0036] Figures 7 and 8 illustrate “pusher” embodiments similar to Figure 6 but wherein the exhaust 80 is located between the stationary element 30 and the rotating element 20. While in both of these embodiments the rotating element 20 is located aft of the stationary element 30, Figures 7 and 8 differ from one another in that the rotating element 20 of Figure 7 incorporates comparatively longer blades than the embodiment of Figure 8, such that the root 23 of the blades of Figure 7 is recessed below the airstream trailing aft from the stationary element 30 and the exhaust from the gas generator 40 is directed toward the leading edges of the rotating element 20. In the embodiment of Figure 8, the rotating element 20 is more nearly comparable in length to the stationary element 30 and the exhaust 80 is directed more radially outwardly between the rotating element 20 and the stationary element 30.

[0037] Figures 9, 10, and 11 depict other exemplary “pusher” configuration embodiments wherein the rotating element 20 is located forward of the stationary element 30, but both elements are aft of the gas generator 40. In the embodiment of Figure 9, the exhaust 80 is located aft of both the rotating element 20 and the stationary element 30. In the embodiment of Figure 10, the exhaust 80 is located forward of both the rotating element 20 and the stationary element 30. Finally, in the embodiment of Figure 11, the exhaust 80 is located between the rotating element 20 and the stationary element 30.

[0038] Figures 12 and 13 show different arrangements of the gas generator 40, the low pressure turbine 50 and the rotating element 20. In Figure 12, the rotating element 20 and the booster 300 are driven by the low pressure turbine 50 directly coupled with the booster 300 and connected to the rotating element 20 via the speed reduction device 60. The high pressure compressor 301 is driven directly by the high pressure turbine 302. In Figure 13 the rotating element 20 is driven by the low pressure turbine 50 via the speed reduction device 60, the booster 303 is driven directly by the intermediate pressure turbine 306, and the high pressure compressor 304 is driven by the high pressure turbine 305.

[0039] Figure 15 is a cross-sectional schematic illustration taken along lines 15-15 of Figure 14 illustrating the inlet configuration of the unducted thrust producing system of Figure 14 as a non-axisymmetric, non-annular inlet. In the configuration shown, the inlet 70 takes the form of a pair of radially-opposed inlets 72 each feeding into the core.

[0040] The gas turbine or internal combustion engine used as a power source may employ an inter-cooling element in the compression process. Similarly, the gas turbine engine may employ a recuperation device downstream of the power turbine.

[0041] In various embodiments, the source of power to drive the rotating element 20 may be a gas turbine engine fuelled by jet fuel or liquid natural gas, an electric motor, an internal combustion engine, or any other suitable source of torque and power and may be located in proximity to the rotating element 20 or may be remotely

located with a suitably configured transmission such as a distributed power module system.

[0042] In addition to configurations suited for use with a conventional aircraft platform intended for horizontal flight, the technology described herein could also be employed for helicopter and tilt rotor applications and other lifting devices, as well as hovering devices.

[0043] It may be desirable to utilize the technologies described herein in combination with those described in commonly-assigned, co-pending applications [] and [].

[0044] The foregoing description of the embodiments of the invention is provided for illustrative purposes only and is not intended to limit the scope of the invention as defined in the appended claims.

[0045] This application is related to PCT/US13/XXXXX, Attorney docket no. 264668-2, titled “UNDUCTED THRUST PRODUCING SYSTEM” filed on October 23, 2013, and PCT/US13/XXXXX, Attorney docket no. 265517-2, titled “VANE ASSEMBLY FOR AN UNDUCTED THRUST PRODUCING SYSTEM” filed on October 23, 2013, the entire contents of which is incorporated herein by reference.

CLAIMS

What Is Claimed Is:

1. An unducted thrust producing system, said thrust producing system comprising a rotating element, a stationary element, and an inlet forward of the rotating element and the stationary element.
2. The thrust producing system of Claim 1, wherein said rotating element has an axis of rotation and a plurality of blades and said stationary element has a plurality of vanes configured to impart a change in tangential velocity of the air opposite to that imparted by said rotating element.
3. The thrust producing system of Claim 2, wherein at least one of said vanes include a shroud distally from said axis.
4. The thrust producing system of Claim 1, wherein at least one of said vanes is attached to an aircraft structure.
5. The thrust producing system of Claim 1, wherein said stationary element includes more than two vanes.
6. The thrust producing system of Claim 5, wherein said stationary element includes more than four vanes.
7. The thrust producing system of Claim 1, wherein said unducted thrust producing system is a tilt rotor system.
8. The thrust producing system of Claim 1, wherein said unducted thrust producing system is a helicopter lift system.
9. The thrust producing system of Claim 1, wherein said rotating element is driven via a torque producing device.
10. The thrust producing system of Claim 9, wherein said torque producing device is selected from the group consisting of electric motors, gas turbines,

gear drive systems, hydraulic motors, and combinations thereof.

11. The thrust producing system of Claim 1, wherein said unducted thrust producing system is a propeller system.
12. The thrust producing system of Claim 1, wherein said unducted thrust producing system is an open rotor system.
13. An unducted thrust producing system, said thrust producing system comprising a rotating element, a stationary element, and an inlet between said rotating element and said stationary element, wherein said inlet passes radially inward of said stationary element.
14. The thrust producing system of Claim 13, wherein said rotating element has an axis of rotation and a plurality of blades and said stationary element has a plurality of vanes configured to impart a change in tangential velocity of the air opposite to that imparted by said rotating element.
15. The thrust producing system of Claim 14, wherein at least one of said vanes include a shroud distally from said axis.
16. The thrust producing system of Claim 13, wherein at least one of said vanes is attached to an aircraft structure.
17. The thrust producing system of Claim 13, wherein said stationary element includes more than two vanes.
18. The thrust producing system of Claim 17, wherein said stationary element includes more than four vanes.
19. The thrust producing system of Claim 13, wherein said unducted thrust producing system is a tilt rotor system.
20. The thrust producing system of Claim 13, wherein said unducted thrust producing system is a helicopter lift system.

21. The thrust producing system of Claim 13, wherein said rotating element is driven via a torque producing device.
22. The thrust producing system of Claim 21, wherein said torque producing device is selected from the group consisting of electric motors, gas turbines, gear drive systems, hydraulic motors, and combinations thereof.
23. The thrust producing system of Claim 13, wherein said unducted thrust producing system is a propeller system.
24. The thrust producing system of Claim 13, wherein said unducted thrust producing system is an open rotor system.
25. An unducted thrust producing system, said thrust producing system comprising a rotating element, a stationary element, and a nonannular inlet aft of both elements.
26. The thrust producing system of Claim 25, wherein said rotating element has an axis of rotation and a plurality of blades and said stationary element has a plurality of vanes configured to impart a change in tangential velocity of the air opposite to that imparted by said rotating element.
27. An unducted thrust producing system, said thrust producing system comprising a rotating element and a stationary element, wherein said rotating element is driven via a speed reduction device located forward of both rotating and stationary elements.
28. An unducted thrust producing system, said thrust producing system comprising a rotating element and a stationary element having a trailing edge, wherein said rotating element is driven via a speed reduction device located between said rotating element and said trailing edge.
29. An unducted thrust producing system, said thrust producing system comprising a rotating element, a stationary element, and an exhaust forward of said rotating and stationary elements.

30. An unducted thrust producing system, said thrust producing system comprising a rotating element, a stationary element, and an exhaust between said rotating element and said stationary element.
31. An unducted thrust producing system, said thrust producing system comprising a rotating element, a stationary element, and an exhaust aft of said rotating element and said stationary element.
32. An unducted thrust producing system, said thrust producing system comprising a plurality of rotating and stationary elements, wherein at least one rotating element rotates in an opposite direction to at least one other rotating element, and wherein the span of said stationary elements are at least 25% the span of said rotating elements.
33. An unducted thrust producing system, said thrust producing system comprising a rotating element, a stationary element, and a gas turbine engine comprising a core, a booster, and a low pressure turbine, wherein said rotating element and said booster are driven by said low pressure turbine directly coupled with said booster and connected to said rotating element via said speed reduction device.
34. An unducted thrust producing system, said thrust producing system comprising a rotating element, a stationary element, and a gas turbine engine comprising a core, said core having an intermediate pressure turbine and a booster, wherein said rotating element is driven by said low pressure turbine via a speed reduction device, and wherein said booster is driven via said intermediate pressure turbine directly coupled with said booster.

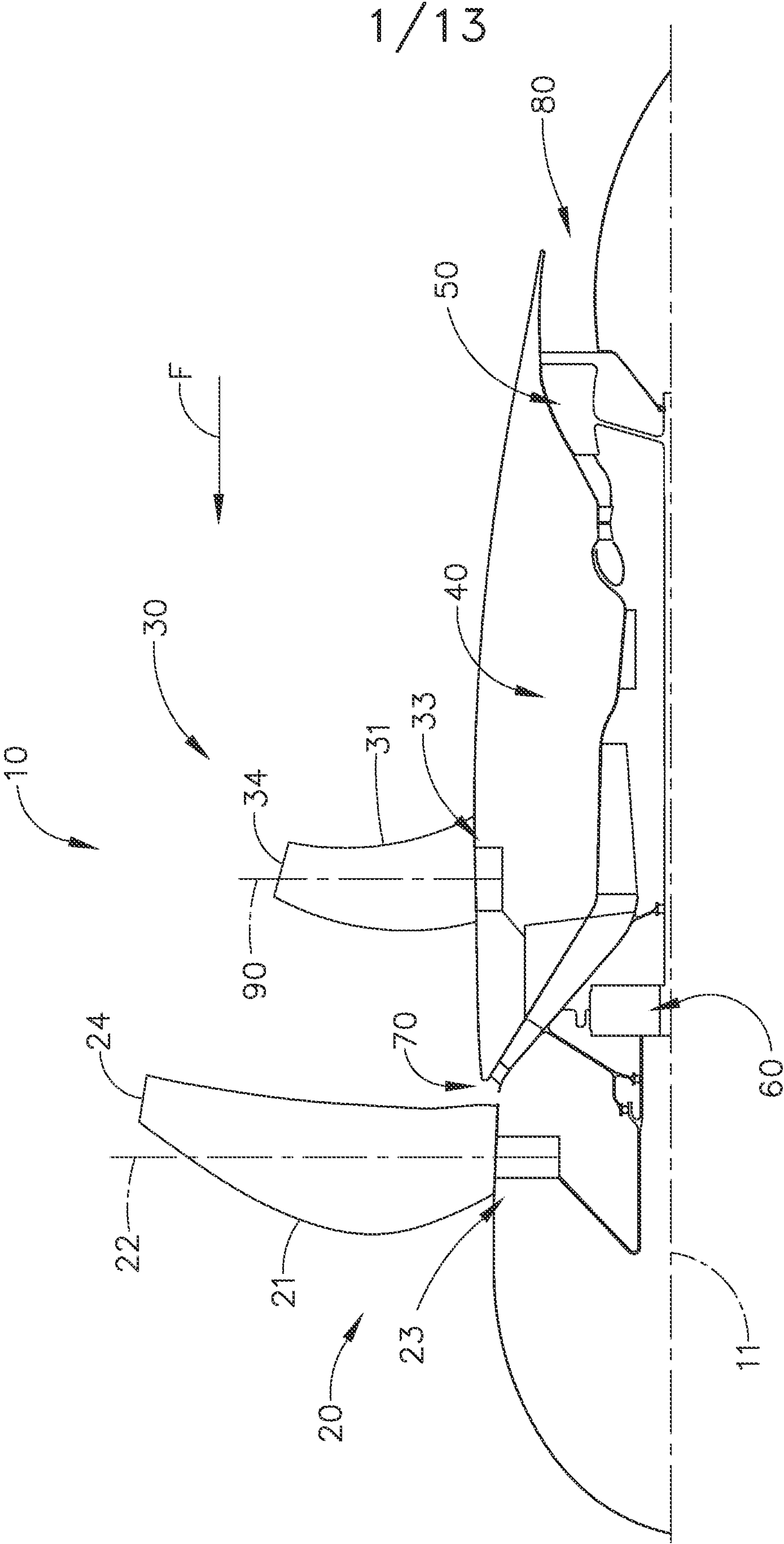


FIG. 1

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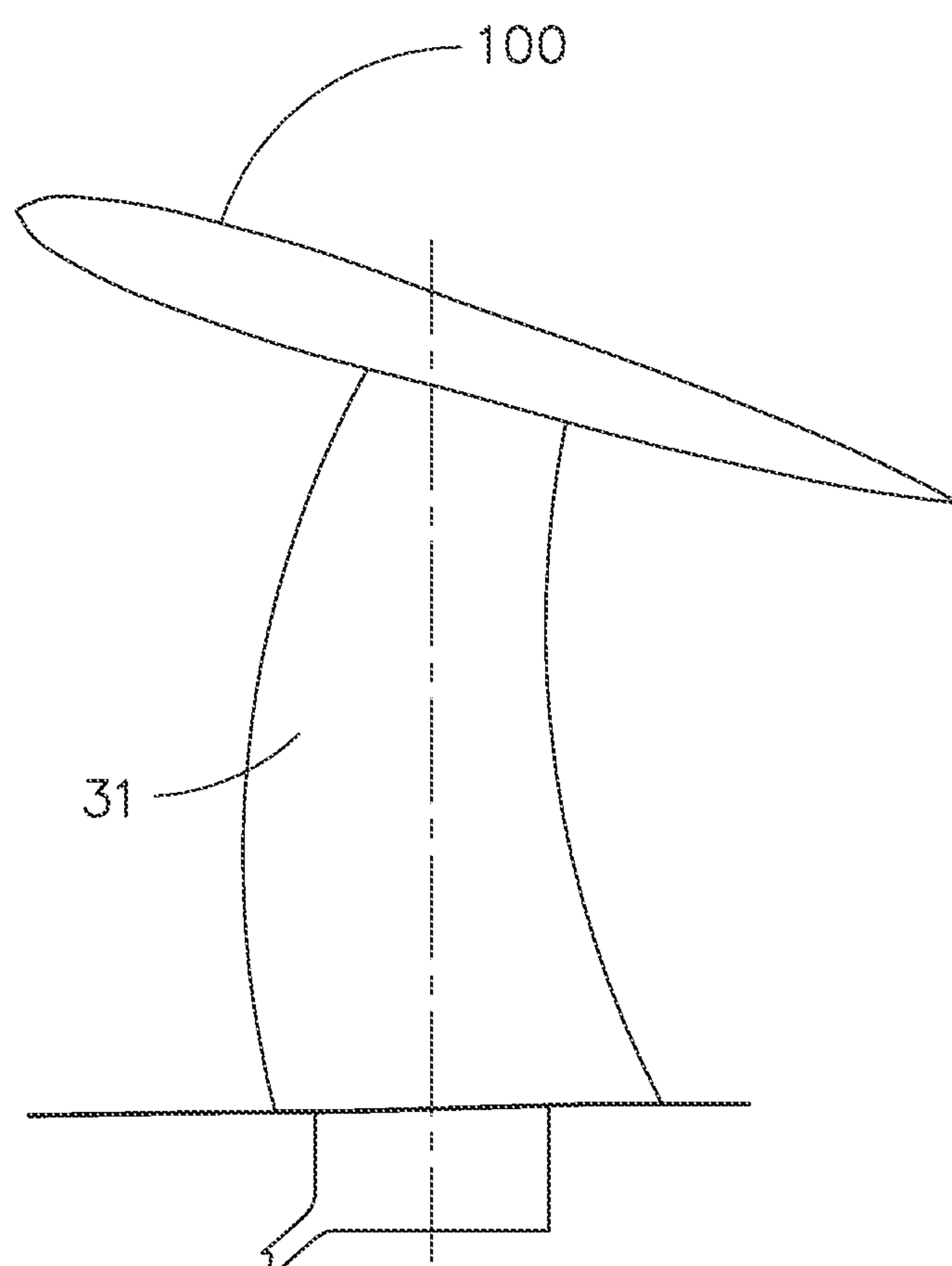


FIG. 2

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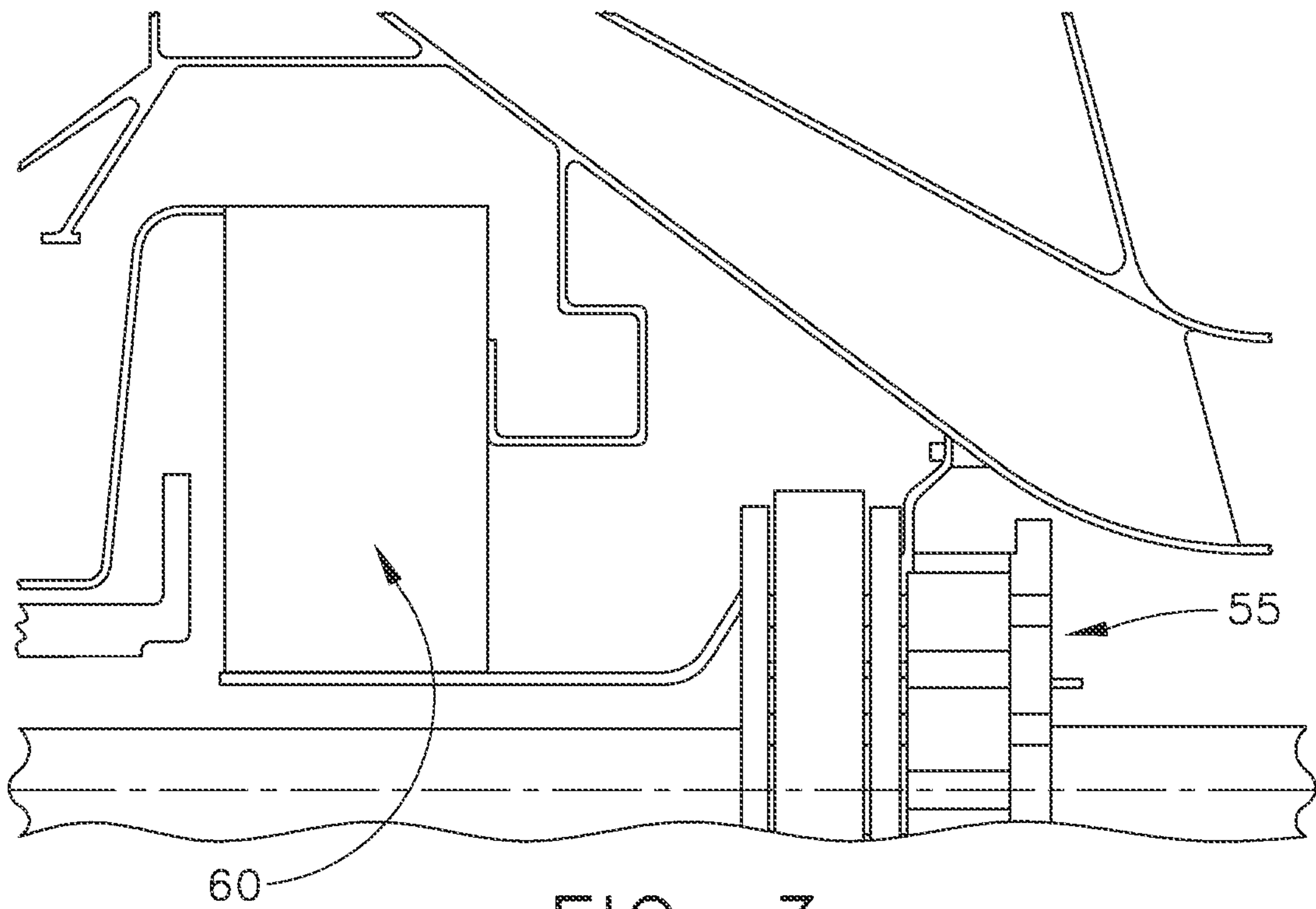


FIG. 3

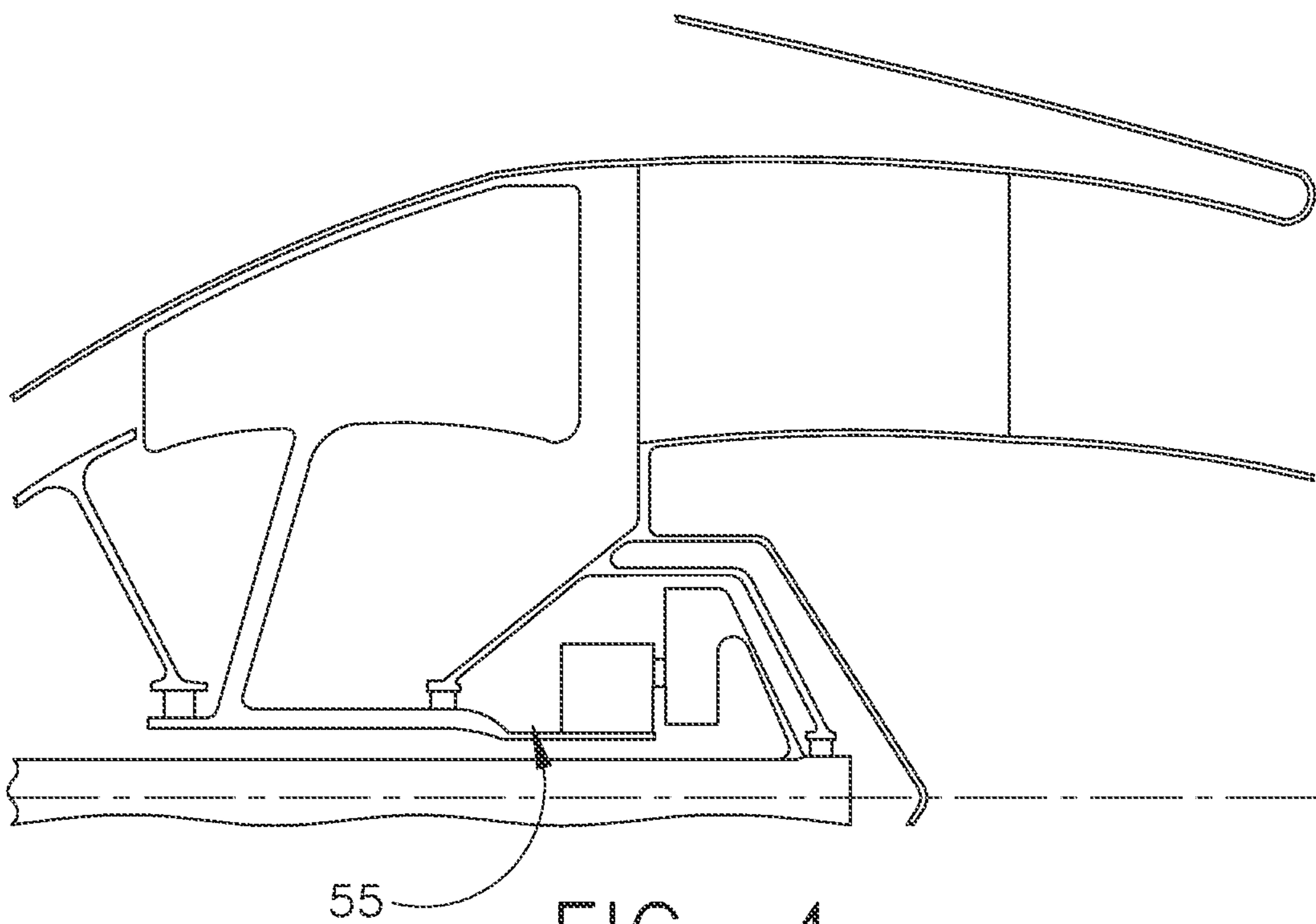


FIG. 4

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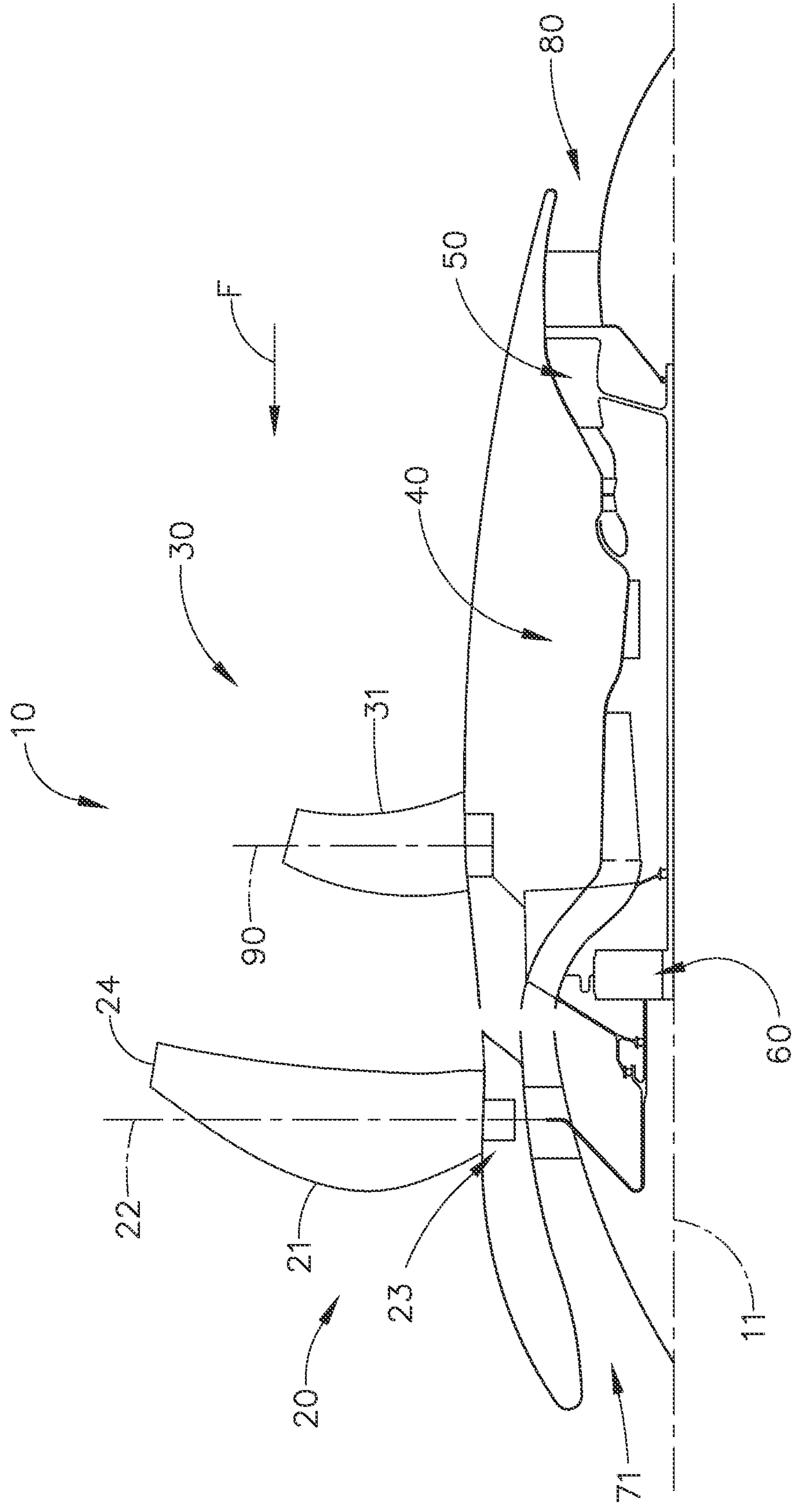
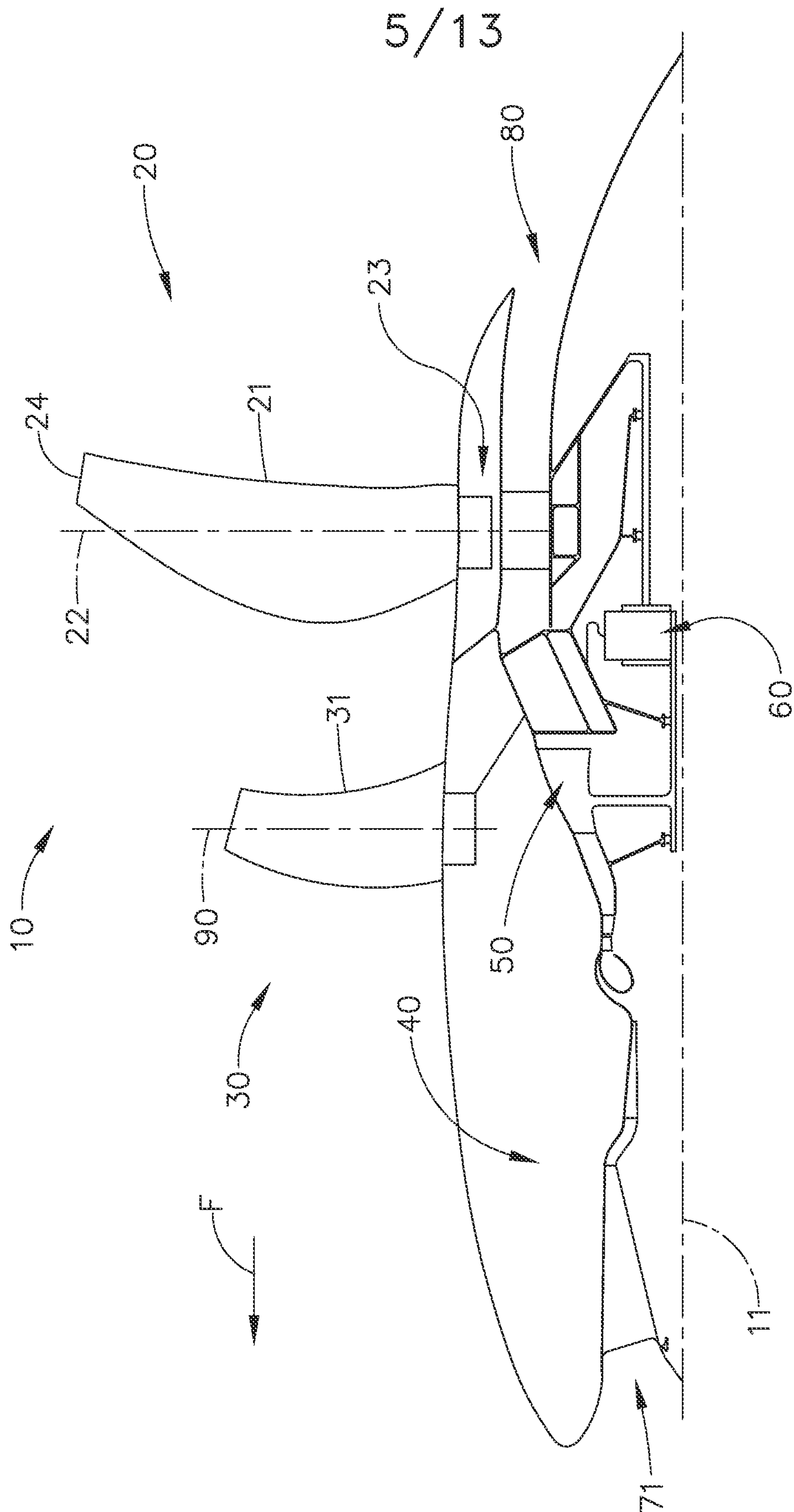
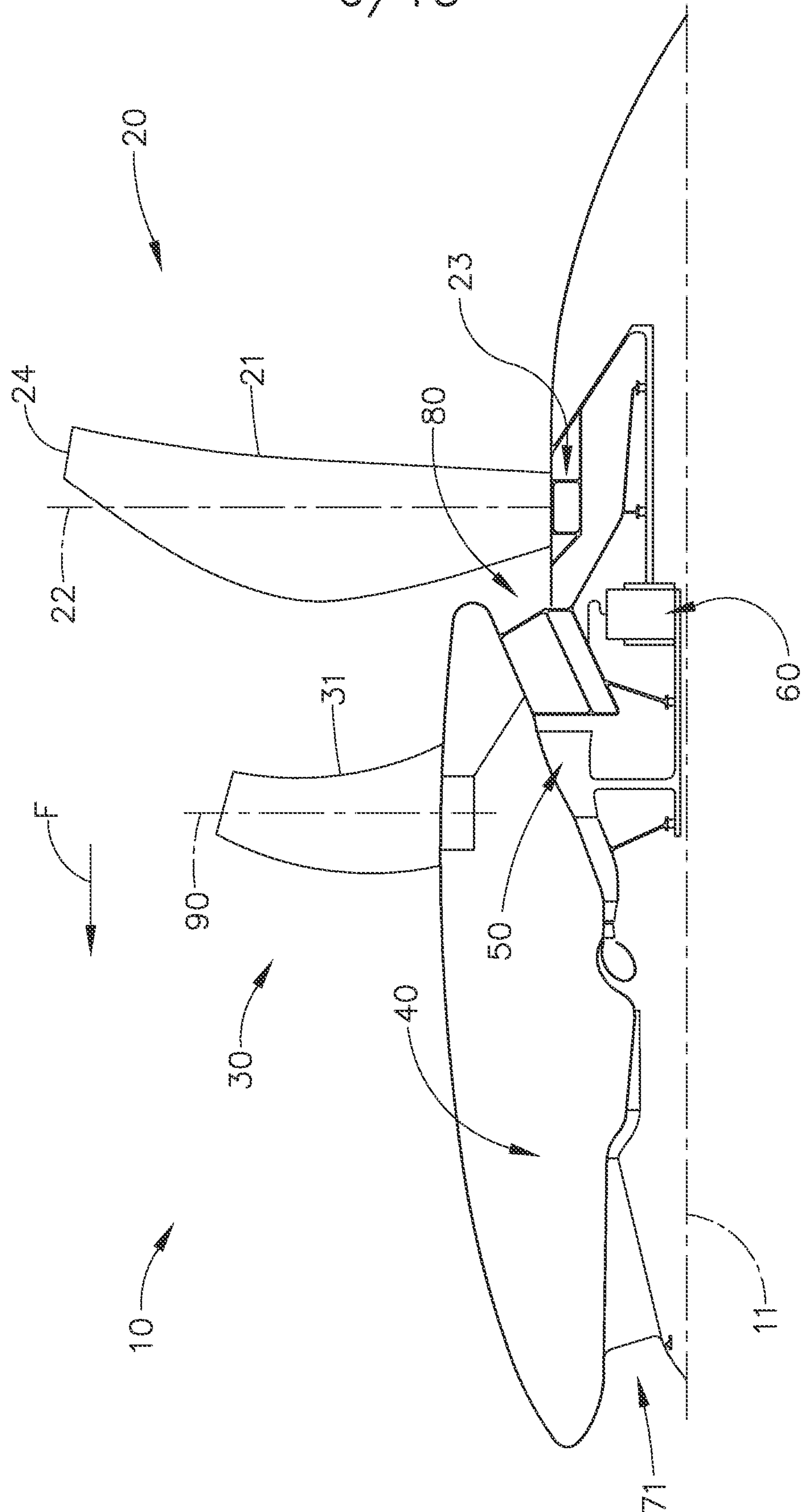


FIG. 5



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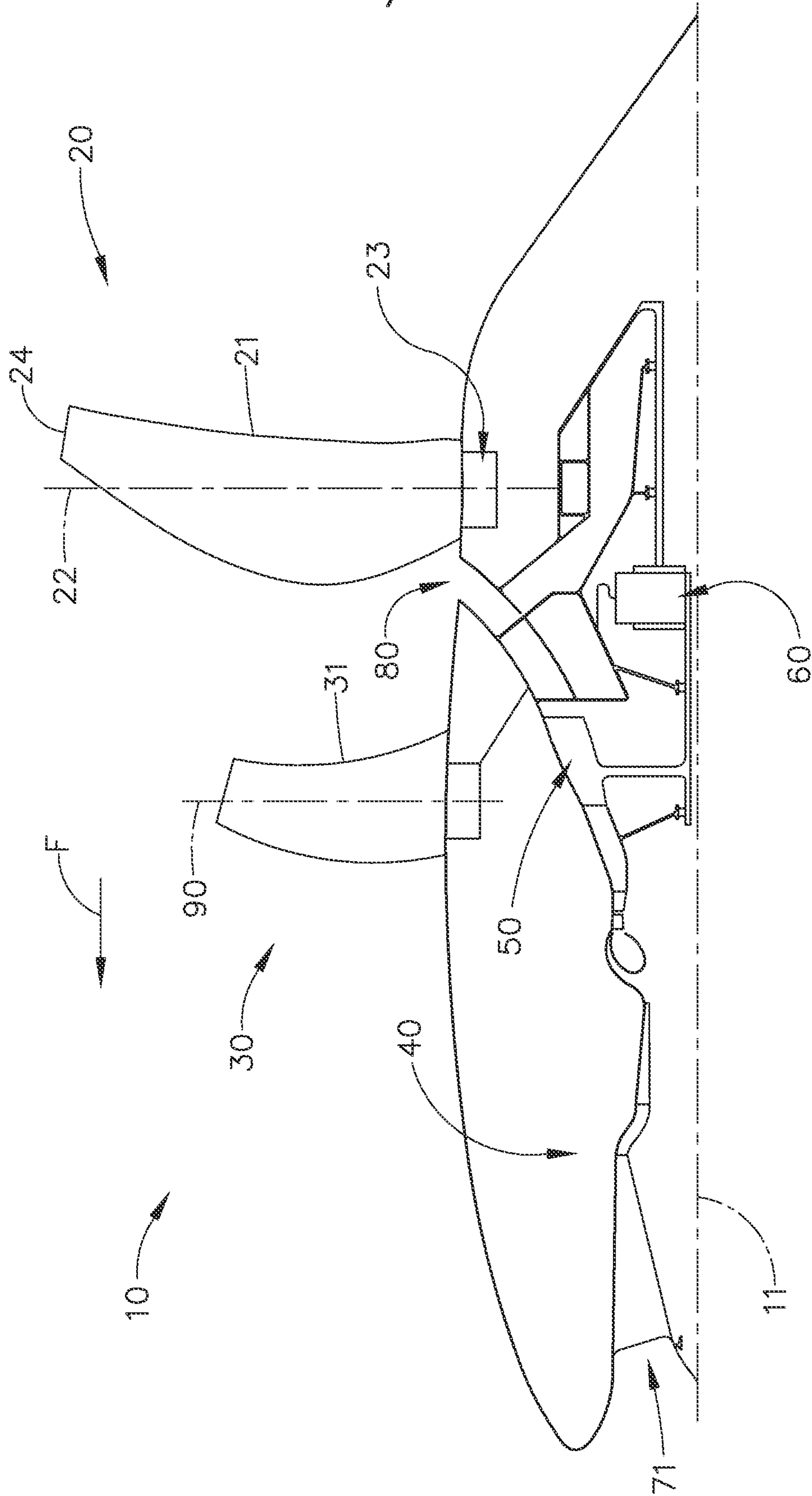


FIG. 8

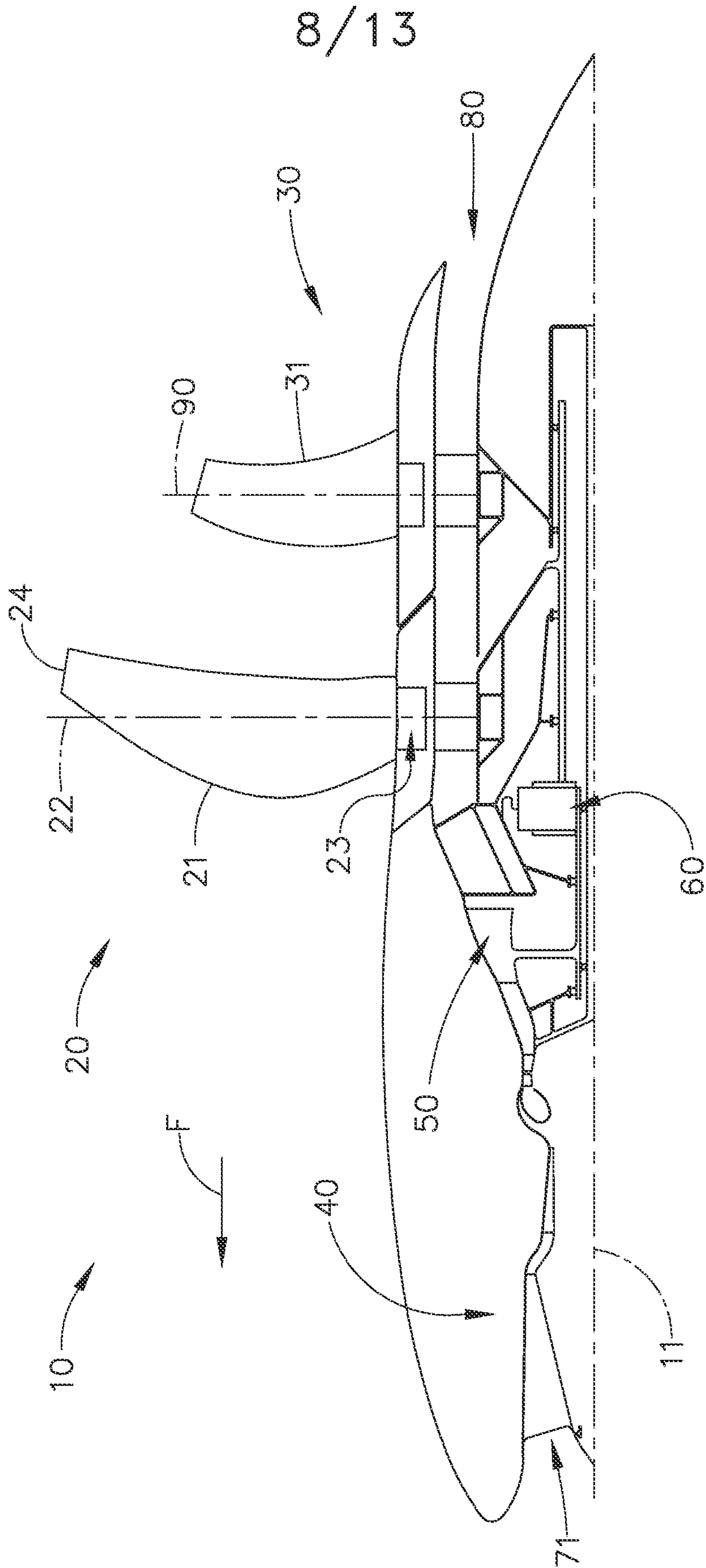


FIG. 9

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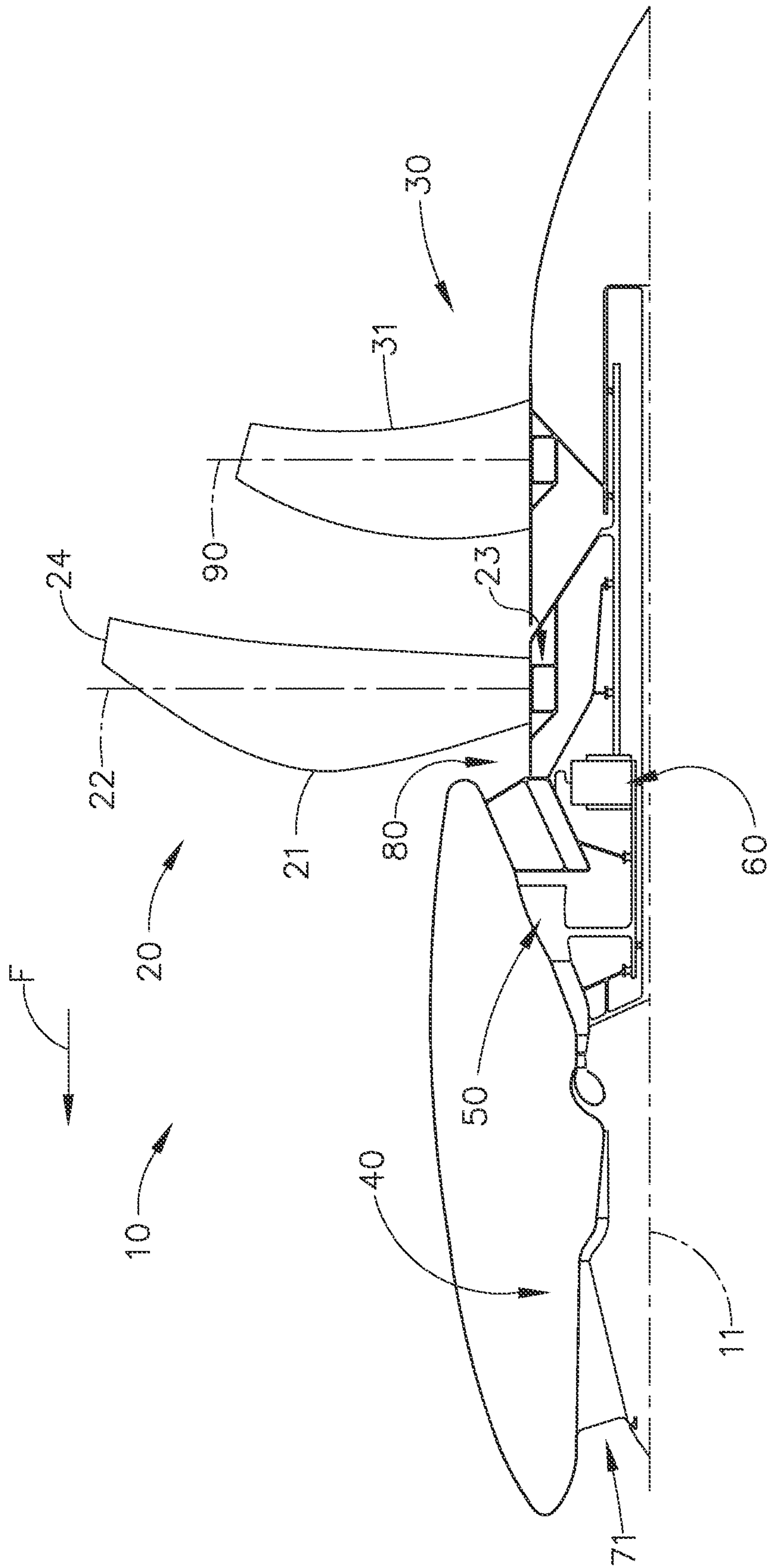


FIG. 10

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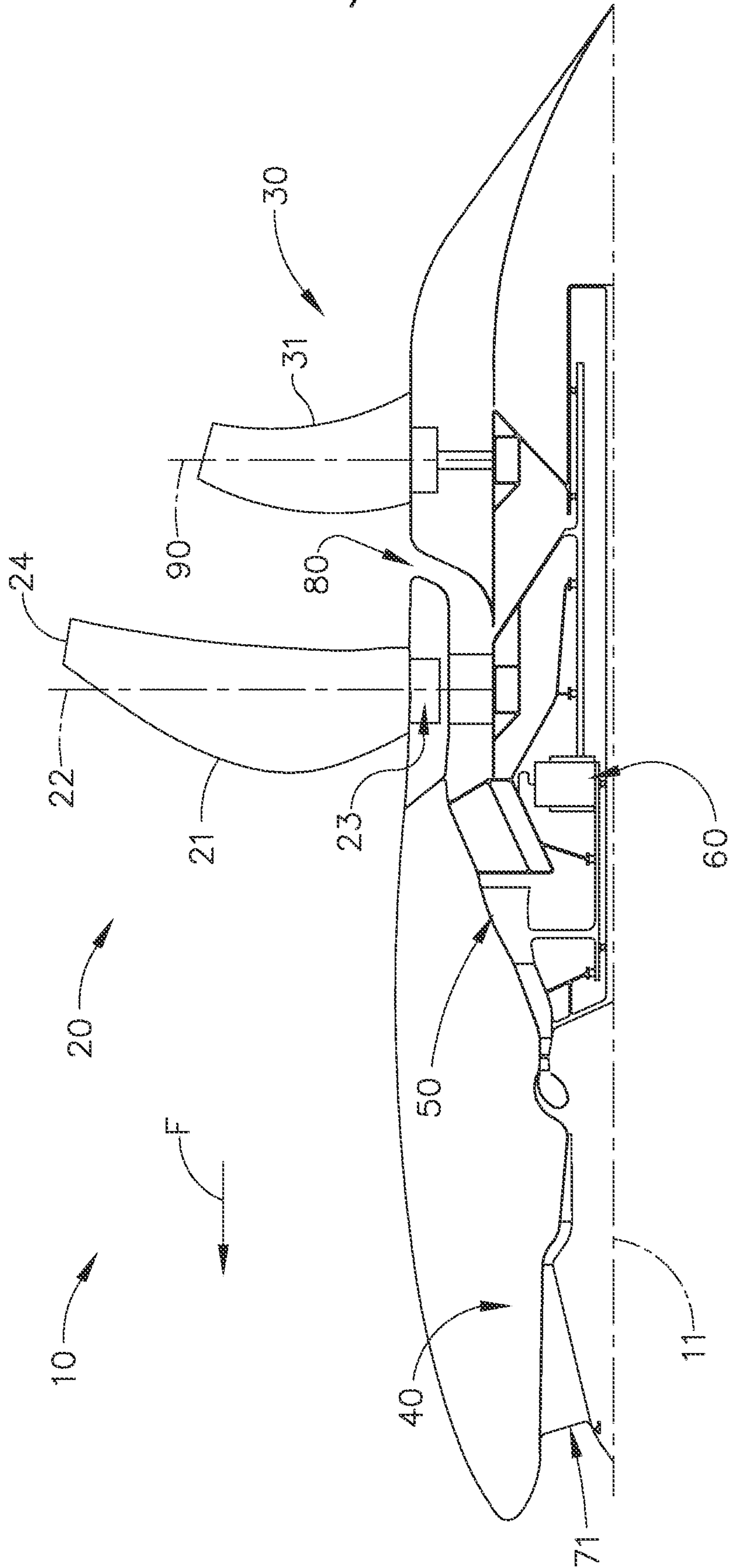


FIG. 11

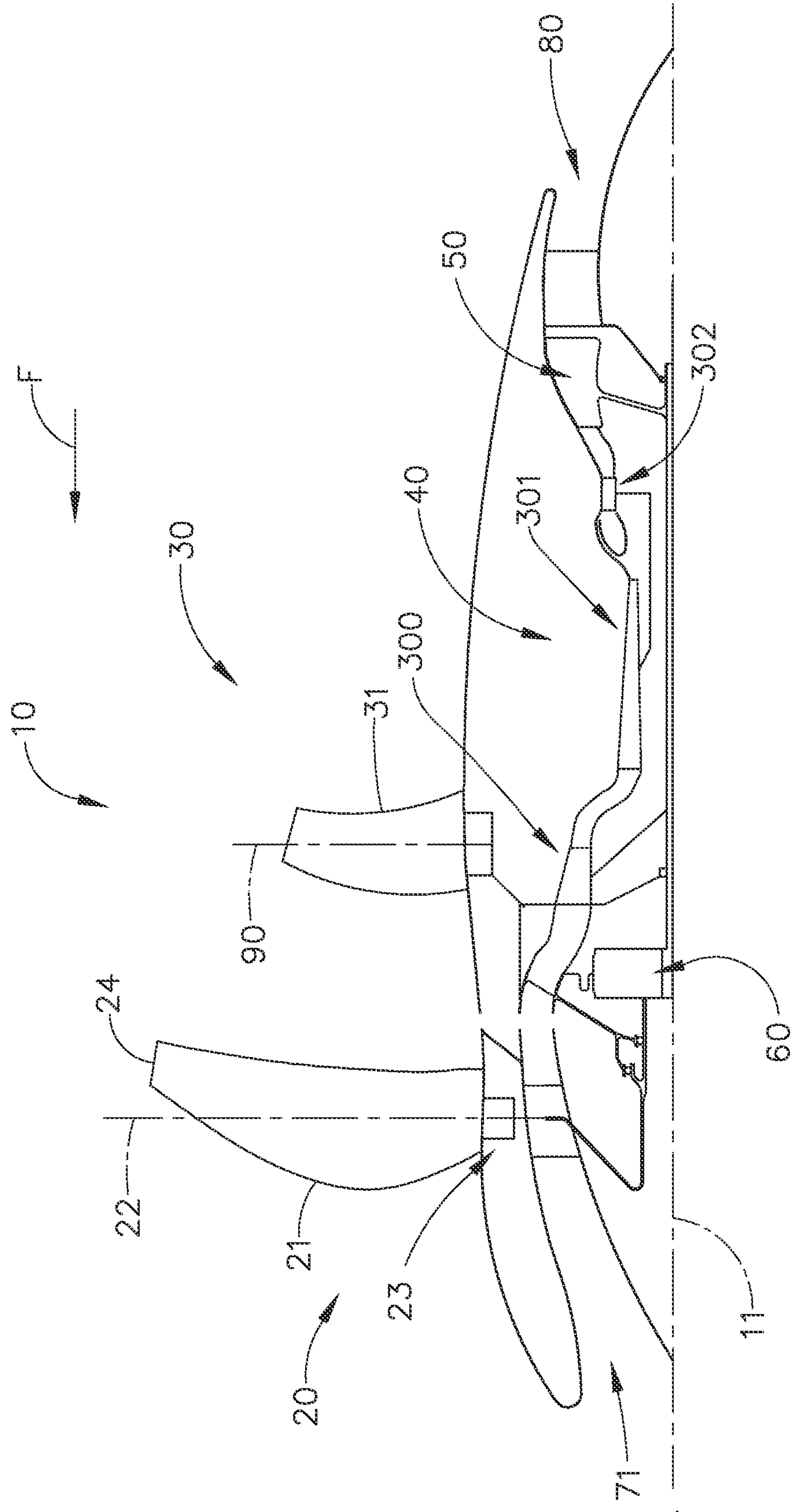


FIG. 12

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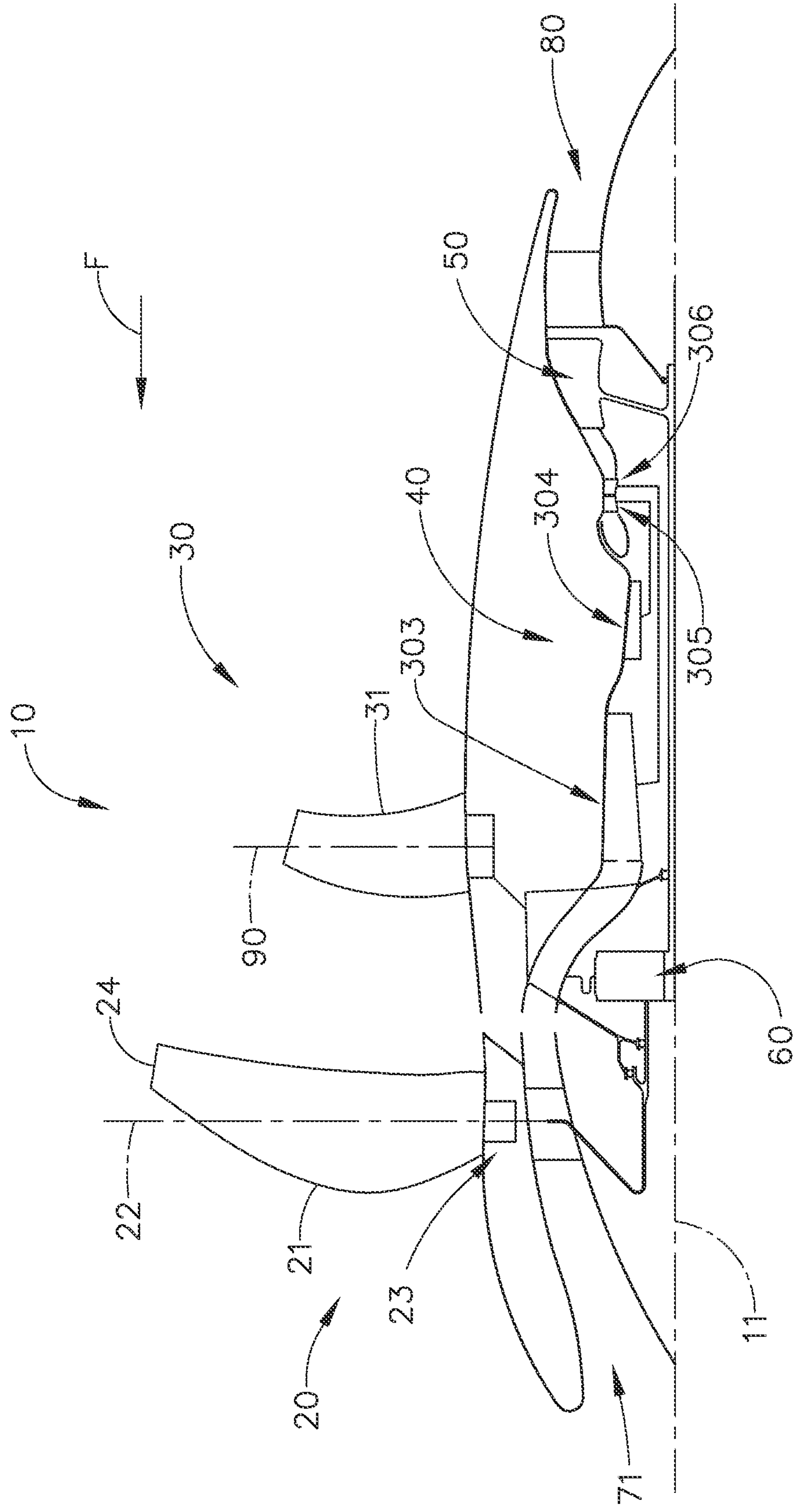


FIG. 13

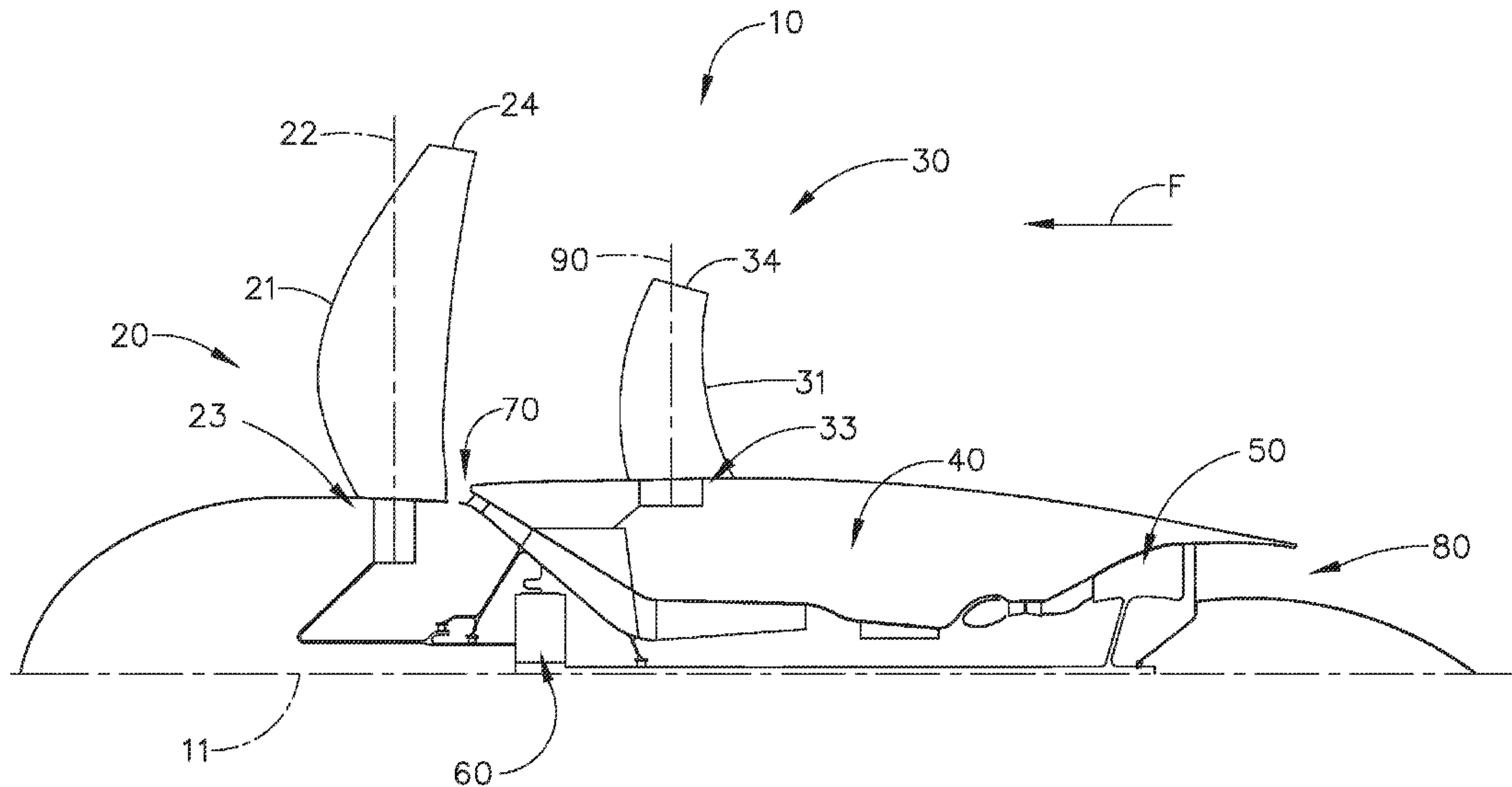


FIG. 1