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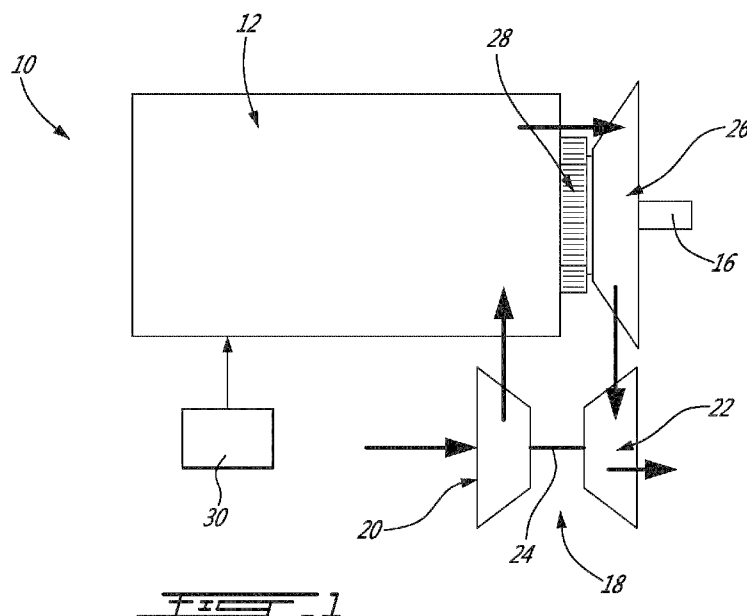
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(54) Title: COMPOUND CYCLE ENGINE



(57) Abstract: A compound cycle engine having at least one rotary unit defining an internal combustion engine, a first stage turbine in proximity of each unit, and a turbocharger is discussed. The exhaust port of each rotary unit is in fluid communication with the flowpath of the first stage turbine upstream of its rotor. The rotors of the first stage turbine and of each rotary unit drive a common load. The outlet of the compressor of the turbocharger is in fluid communication with the inlet port of each rotary unit, and the inlet of the second stage turbine of the turbocharger is in fluid communication with the flowpath of the first stage turbine downstream of its rotor. The first stage turbine has a lower reaction ratio than that of the second stage turbine. A method of compounding at least one rotary engine is also discussed.

COMPOUND CYCLE ENGINE

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims priority from U.S. application No. 14/740,869 filed June 16, 2015, which is a continuation-in-part of U.S. application No. 13/554,517 filed July 20, 2012, the entire contents of which are incorporated by reference herein.

TECHNICAL FIELD

[0002] The application relates generally to compound cycle engines and, more particularly, to such compound cycle engines including one or more rotary combustion engine(s).

BACKGROUND OF THE ART

[0003] Some compound cycle engines include a rotary engine turbocharged and compounded by a turbine located downstream of the turbocharger turbine. However, known compounded rotary engine arrangements typically have limited available power for turbo compounding and/or limited performances, for example on start-up before the turbocharger is running.

SUMMARY

[0004] In one aspect, there is provided a compound cycle engine comprising: at least one rotary unit each defining an internal combustion engine including an engine rotor sealingly and rotationally received within a respective housing, each housing defining an inlet port and an exhaust port; a first stage turbine in proximity of the at least one rotary unit, the first stage turbine including a flowpath and a turbine rotor having a circumferential array of blades extending across the flowpath, the turbine rotor of the first stage turbine and the engine rotor of each of the at least one rotary unit being in driving engagement with a common shaft; and a turbocharger including a compressor and a second stage turbine in driving engagement with one another; wherein: an outlet of the compressor is in fluid communication with the inlet port of each housing; the exhaust port of each housing is in fluid communication with a first portion of the flowpath of the first stage turbine, the first portion of the flowpath being located upstream of the circumferential array of blades of the first stage turbine; an inlet of the second stage

turbine is in fluid communication with a second portion of the flowpath of the first stage turbine, the second portion of the flowpath being located downstream of the circumferential array of blades of the first stage turbine; and the first stage turbine has a lower reaction ratio than that of the second stage turbine.

[0005] In another aspect, there is provided a compound cycle engine comprising: at least one rotary engine each having an engine rotor sealingly and rotationally received within a respective housing having an inlet port and an exhaust port, the engine rotor of each of the at least one rotary engine being drivingly engaged to a common shaft; a first stage turbine in proximity of the at least one rotary engine and having a turbine rotor drivingly engaged to the common shaft; a respective exhaust pipe providing fluid communication between each exhaust port and an inlet of the first stage turbine; a turbocharger including a compressor and a second stage turbine drivingly engaged to one another; an inlet duct providing fluid communication between an outlet of the compressor and the inlet port of each of the at least one rotary engine; and a turbine pipe providing fluid communication between an outlet of the first stage turbine and an inlet of the second stage turbine; wherein the first stage turbine has a lower reaction ratio than that of the second stage turbine.

[0006] In a further aspect, there is provided a method of compounding at least one rotary engine, the method comprising: drivingly engaging a second stage turbine and a compressor in a turbocharger; defining a fluid communication between an outlet of the compressor and an inlet port of each of the at least one rotary engine; defining a fluid communication between an exhaust port of each of the at least one rotary engine and an inlet of a first stage turbine, including directing the fluid communication onto blades of a turbine rotor of the first stage turbine, the first stage turbine having a lower reaction ratio than that of the second stage turbine; defining a fluid communication between an outlet of the first stage turbine and an inlet of the second stage turbine of the turbocharger; and drivingly engaging an engine rotor of each rotary engine and the rotor of the first stage turbine to a common shaft.

DESCRIPTION OF THE DRAWINGS

[0007] Reference is now made to the accompanying figures in which:

[0008] Fig. 1 is a block diagram of a compound cycle engine according to a particular embodiment;

[0009] Fig. 2 is a cross-sectional view of a Wankel engine which can be used in a compound cycle engine such as shown in Fig. 1, according to a particular embodiment;

[0010] Fig. 3 is a schematic representation of the compound cycle engine of Fig. 1 according to a particular embodiment;

[0011] Fig. 4 is a schematic tridimensional view of a compound cycle engine such as shown in Fig. 3 according to a particular embodiment; and

[0012] Fig. 5 is a block diagram of a compound cycle engine according to another embodiment.

DETAILED DESCRIPTION

[0013] Referring now to Fig. 1, a compound cycle engine 10 is schematically shown. The compound cycle engine 10 includes one or more rotary units 12, each unit 12 being defined by a rotary internal combustion engine having a rotor sealingly engaged in a respective housing. The rotary unit(s) 12 drive a common load. In the embodiment shown, the common load includes an output shaft 16 which may be for example connected to a propeller through a reduction gearbox (not shown) and to which the rotor of each unit 12 is engaged.

[0014] The compound cycle engine 10 also includes a turbocharger 18, formed by a compressor 20 and a second stage turbine 22 which are drivingly interconnected by a shaft 24. In a particular embodiment, the second stage turbine 22 is a pressure turbine, also known as a reaction turbine. The compressor 20 and the second stage turbine 22 may each be a single-stage device or a multiple-stage device with a single shaft or split on multiple independent shafts in parallel or in series, and may be a centrifugal or axial device. In the embodiment shown, the shaft 24 of the turbocharger 18 rotates independently of the common load. The compressor 20 of the turbocharger 18 compresses the air before it enters the unit(s) 12.

[0015] The rotary unit(s) 12 form the core of the compound cycle engine 10 and each provide an exhaust flow in the form of exhaust pulses. The exhaust flow from the unit(s) 12 is supplied to a compound or first stage turbine 26 in fluid communication therewith,

also driving the common load. The first stage turbine 26 is a velocity type turbine, also known as an impulse type turbine, and could be an axial, radial or mixed flow turbine.

[0016] A pure impulse turbine works by changing the direction of the flow without accelerating the flow inside the rotor; the fluid is deflected without a significant pressure drop in the blade passages. The blades of the pure impulse turbine are designed such that in a transverse plane perpendicular to the direction of flow, the area defined between the blades is the same at the leading edges of the blades and at the trailing edges of the blade: the flow area of the turbine is constant, and the blades are usually symmetrical about the plane of the rotating disc. The work of the pure impulse turbine is due only to the change of direction in the flow through the turbine blades. Each blade of the pure impulse turbine thus forms a bucket pushed by the exhaust flow. Typical pure impulse turbines include steam and hydraulic turbines.

[0017] In contrast, a reaction turbine accelerates the flow inside the rotor but needs a static pressure drop across the rotor to enable this flow acceleration. The blades of the reaction turbine are designed such that in a transverse plane perpendicular to the direction of flow, the area defined between the blades is larger at the leading edges of the blades than at the trailing edges of the blade: the flow area of the turbine reduces along the direction of flow, and the blades are usually not symmetrical about the plane of the rotating disc. The work of the pure reaction turbine is due mostly to the acceleration of the flow through the turbine blades.

[0018] Most aeronautical turbines are not “pure impulse” or “pure reaction”, but rather operate following a mix of these two opposite but complementary principles – i.e. there is a pressure drop across the blades, there is some reduction of flow area of the turbine blades along the direction of flow, and the speed of rotation of the turbine is due to both the acceleration and the change of direction of the flow. The degree of reaction of a turbine can be determined using the temperature-based reaction ratio (equation 1) or the pressure-based reaction ratio (equation 2), which are typically close to one another in value for a same turbine:

$$(1) \text{Reaction}(T) = \frac{(t_{s3} - t_{s5})}{(t_{s0} - t_{s5})}$$

$$(2) \text{Reaction}(P) = \frac{(P_{s3} - P_{s5})}{(P_{s0} - P_{s5})}$$

where T is temperature and P is pressure, s refers to a static port, and the numbers refers to the location the temperature or pressure is measured: 0 for the inlet of the turbine vane (stator), 3 for the inlet of the turbine blade (rotor) and 5 for the exit of the turbine blade (rotor); and where a pure impulse turbine would have a ratio of 0 (0%) and a pure reaction turbine would have a ratio of 1 (100%).

[0019] Aeronautical turbines referred to as impulse turbines typically have a reaction ratio of 0.25 (25% reaction) or lower, although other values are also possible.

[0020] In a particular embodiment, the first stage turbine 26 is configured to take benefit of the kinetic energy of the pulsating flow exiting the core engine(s) 12 while stabilizing the flow, and the second stage turbine 22 is configured to extract energy from the remaining pressure in the flow. Accordingly, the first stage turbine 26 has a lower reaction ratio (i.e. lower value) than that of the second stage turbine 22.

[0021] The rotor of the first stage turbine 26 is rotated by the forces exerted on the blades by the impingement against them of the exhaust pulses. As such, the kinetic energy provided by each exhaust pulse is used to drive the rotor of the first stage turbine 26 while imposing minimum back pressure on the rotary unit(s) 12.

[0022] In a particular embodiment, the second stage turbine 22 has a reaction ratio higher than 0.25; in another particular embodiment, the second stage turbine 22 has a reaction ratio higher than 0.3; in another particular embodiment, the second stage turbine 22 has a reaction ratio of about 0.5; in another particular embodiment, the second stage turbine 22 has a reaction ratio higher than 0.5.

[0023] In a particular embodiment, the first stage turbine 26 has a reaction ratio of at most 0.2; in another particular embodiment, the first stage turbine 26 has a reaction ratio of at most 0.15; in another particular embodiment, the first stage turbine 26 has a reaction ratio of at most 0.1; in another particular embodiment, the first stage turbine 26 has a reaction ratio of at most 0.05.

[0024] It is understood that any of the above-mentioned reaction ratios for the second stage turbine 22 can be combined with any of the above-mentioned reaction ratios for the first stage turbine 26 and that these ratios can be pressure-based or temperature-based. Other values are also possible.

[0025] The first stage turbine 26 is connected to the output shaft 16 through an appropriate type of transmission 28, for example a planetary, star, offset or angular gear system. The outlet of the first stage turbine 26 is in fluid communication with an inlet of the second stage turbine 22. Energy is extracted from the exhaust gas exiting the first stage turbine 26 by the second stage turbine 22 to drive the compressor 20 via the connecting shaft 24.

[0026] Although not shown, the air may optionally circulate through an intercooler between the compressor 20 and the unit(s) 12, and the compound cycle engine 10 also includes a cooling system, including for example a circulation system for a coolant (e.g. water-ethylene, oil, air) to cool the housing of each unit 12, an oil coolant for the internal mechanical parts of the unit(s) 12, one or more coolant heat exchangers, etc.

[0027] The fuel injector(s) of each unit 12, which in a particular embodiment are common rail fuel injectors, communicate with a source 30 of Heavy fuel (e.g. diesel, kerosene (jet fuel), equivalent biofuel), and deliver the heavy fuel into the unit(s) 12 such that the combustion chamber is stratified with a rich fuel-air mixture near the ignition source and a leaner mixture elsewhere.

[0028] In a particular embodiment each unit 12 is a Wankel engine. Referring to Fig. 2, an exemplary embodiment of a Wankel engine is shown; it is understood that the configuration of the unit(s) 12 used in the compound cycle engine 10, e.g. placement of ports, number and placement of seals, etc., may vary from that of the embodiment shown; each unit 12 may be defined by a rotary engine other than a Wankel engine.

[0029] As shown in Fig. 2, in a particular embodiment, each unit 12 comprises a housing 32 defining a rotor cavity with a profile defining two lobes, which is preferably an epitrochoid. A rotor 34 is received within the rotor cavity. The rotor defines three circumferentially-spaced apex portions 36, and a generally triangular profile with outwardly arched sides. The apex portions 36 are in sealing engagement with the inner

surface of a peripheral wall 38 of the housing 32 to form three working chambers 40 between the rotor 34 and the housing 32.

[0030] The rotor 34 is engaged to an eccentric portion 42 of the output shaft 16 to perform orbital revolutions within the stator cavity. The output shaft 16 performs three rotations for each orbital revolution of the rotor 34. The geometrical axis 44 of the rotor 34 is offset from and parallel to the axis 46 of the housing 32. During each orbital revolution, each chamber 40 varies in volume and moves around the stator cavity to undergo the four phases of intake, compression, expansion and exhaust.

[0031] An intake port 48 is provided through the peripheral wall 38 for admitting compressed air into one of the working chambers 40. An exhaust port 50 is also provided through the peripheral wall 38 for discharge of the exhaust gases from the working chambers 40. Passages 52 for a spark plug or other ignition mechanism, as well as for one or more fuel injectors (not shown) are also provided through the peripheral wall 38. Alternately, the intake port 48, the exhaust port 50 and/or the passages 52 may be provided through an end or side wall 54 of the housing.

[0032] For efficient operation the working chambers 40 are sealed, for example by spring-loaded apex seals 56 extending from the rotor 34 to engage the peripheral wall 38, and spring-loaded face or gas seals 58 and end or corner seals 60 extending from the rotor 34 to engage the end walls 54. The rotor 34 also includes at least one spring-loaded oil seal ring 62 biased against the end wall 54 around the bearing for the rotor 34 on the shaft eccentric portion 42.

[0033] Each Wankel engine provides an exhaust flow in the form of a relatively long exhaust pulse; for example, in a particular embodiment, each Wankel engine has one explosion per 360° of rotation of the output shaft, with the exhaust port remaining open for about 270° of that rotation, thus providing for a pulse duty cycle of about 75%. By contrast, a piston of a reciprocating 4-stroke piston engine typically has one explosion per 720° of rotation of the output shaft with the exhaust port remaining open for about 180° of that rotation, thus providing a pulse duty cycle of 25%. In a particular embodiment, the relatively long exhaust pulse of the Wankel engine may facilitate driving of the first stage turbine 26.

[0034] The pressure ratios across a compound cycle engine with one or more rotary engines or units can be defined by:

$$P_C = P_R P_{PT} P_{TT}$$

where P_C is the pressure ratio for the turbocharger compressor, P_R is the inlet to outlet pressure ratio of the rotary engines, P_{PT} is the pressure ratio for the compound turbine, and P_{TT} is the pressure ratio for the turbocharger turbine.

[0035] The inventors have found that in prior art compound engines including one or more rotary engines where the compound turbine is a pressure turbine located downstream of the turbocharger turbine, and where each rotary engine has equal volumetric expansion and compression ratios, the relatively high volumetric compression ratio of the rotary engine(s) typically results in a relatively low possible pressure ratio for the compressor of the turbocharger (P_C), as limited by the peak pressure capability of the rotary engine(s). As such, the pressure ratio across the turbines ($P_{PT}P_{TT}$) is limited, which limits the power available for the compound turbine.

[0036] In some compound engines, such as shown in U.S. 7,775,044 issued August 17, 2010 and incorporated by reference herein, the volumetric compression ratio of each rotary engine is smaller than its expansion ratio. The lower volumetric compression ratio typically results in a larger possible pressure ratio for the compressor of the turbocharger (P_C), which in turn increases the pressure ratio across the turbines ($P_{PT}P_{TT}$). However, the lower volumetric compression ratio usually leads to an inlet to outlet pressure ratio of the rotary engine(s) which is reduced P_R , which may increase back pressure and thermal loads on the rotary engine(s) because of the increased difficulty in purging the exhaust gases. Such a configuration also generally provides for a low compression on the rotary engine on start-up before the turbocharger is running, which may limit performances of the compound cycle engine.

[0037] By contrast, in at least some embodiments of the compound cycle engine 10, the pressure ratio P_{PT} across the first stage turbine 26 is close to or about 1 since it is a velocity or impulse turbine. As such, a same pressure ratio for the compressor P_C (to comply with the peak pressure capability) and a same inlet to outlet pressure ratio of the rotary unit(s) P_R (to minimize backpressure and thermal loading on each rotary unit) allow for the pressure ratio P_{TT} available for the turbine 22 of the turbocharger 18 to be

greater than with a compound cycle engine in which the compound turbine is a pressure turbine, i.e. with a pressure ratio P_{PT} greater than 1 and greater than that of the first stage turbine 26 of the compound cycle engine 10. Thus, the use of a velocity or impulse turbine as the first stage turbine 26 may allow for an increase of the power available to the turbo compounding.

[0038] In addition, the volumetric compression ratio of the rotary unit(s) 12 does not need to be reduced to achieve this increase in power available for the turbine 22 of the turbocharger 18. As such, in a particular embodiment, the volumetric efficiency of each rotary unit may be maximized and its thermal loads minimized, and the performances of the compound cycle engine 10 at start-up are not compromised by the increase of available power.

[0039] Also, the use of a velocity or impulse turbine as the first stage turbine 26 eliminates the need for the large volume exhaust collector typically required between the rotary engine(s) and a pressure first stage turbine. This allows for the compound turbine 26 to be located upstream of the turbocharger turbine 22 instead of downstream thereof.

[0040] In a particular embodiment which may be particularly but not exclusively suitable for low altitude, each rotary unit 12 is a Wankel engine with a volumetric compression ratio of from 6:1 to 8:1. The power recovery of the first stage turbine 26 may be maximized by having the exhaust gas temperatures at the material limit, and as such is suitable for such relatively low volumetric compression ratios, which may help increase the power density of the Wankel engine and may also improve combustion at high speed and of heavy fuel.

[0041] Referring to Figs. 3-4, a compound cycle engine 10 according to a particular embodiment is schematically shown. In this embodiment, two rotary units 12 in the form of Wankel engines are included, with the two eccentric portions 42 of the output shaft 16 being angularly offset at 180° from one another for balancing of the compound cycle engine 10. Fuel injectors 49 (Fig. 4), which may be common rail fuel injectors, communicate with each unit 12. In other embodiments, more or less rotary engines may be provided.

[0042] The rotor blades 64 of the first stage turbine 26 extend across an annular flowpath 66. In the embodiment shown, the rotor of the first stage turbine 26 is an axial rotor and the flowpath 66 extends axially. A respective exhaust pipe 68 extends from the exhaust port 50 (see also Fig. 2) of each unit 12 to a portion of the flowpath 66 located upstream of the rotor blades 64, as shown in Fig. 3. The exhaust pipes 68 extend independently from one another, and their length are minimized to maximize use of the exhaust pulse kinetic energy to drive the first stage turbine 26. The flowpath 66 and/or the outlet of each exhaust pipe 68 are shaped to direct the exhaust pulses onto the blades 64 to allow the exhaust pulses to drive rotation of the rotor of the first stage turbine 26. As can be seen more clearly from Fig. 4, each exhaust pipe 68 communicates with the flowpath 66 at a different location around the circumference of the first stage turbine 26.

[0043] A pipe 70 extends from an outlet of the compressor 20, and splits into two inlet pipes 72, each connected to the intake port 48 (see also Fig. 2) of the respective rotary unit 12. In this embodiment, the compressor 20 includes a single radial impeller 74. Alternately, the compressor 20 may include one or more rotors, with radial, axial or mixed flow blades.

[0044] In the embodiment shown, the transmission 28 of the first stage turbine 26 includes a sun gear 76 attached on the shaft of the rotor of the first stage turbine 26, and an array of planet gears 78 meshed with the sun gear 76. The planet gears 78 are mounted on a rotating carrier which is drivingly engaged to the output shaft 16. The planet gears 78 are meshed with a stationary ring gear 79. In another embodiment, the planet gears 78 are mounted on a stationary carrier, and are meshed with a ring gear drivingly engaged to the output shaft 16. The speed reduction ratio of the transmission 28 may be selected to optimize operation of the first stage turbine 26 and of the rotary units 12.

[0045] A turbine pipe 80 extends from a portion of the flowpath 66 downstream of the rotor blades 64 (as shown in Fig. 3) to the inlet of the second stage turbine 22 such as to circulate the exhaust flow from the first stage turbine 26 to the second stage turbine 22. In this embodiment, the second stage turbine 22 includes a single radial impeller 82. Alternately, the second stage turbine 22 may include one or more rotors, with radial, axial or mixed flow blades.

[0046] The turbocharger shaft 24 extends along a different axis than that of the output shaft 16. In the particular embodiment shown in Fig. 4, the turbocharger shaft 24 extends transverse to the output shaft 16. The turbocharger shaft 24 may additionally be connected to a different load than that of the output shaft 16, through a gearbox if necessary.

[0047] Referring to Fig. 5, a compound cycle engine 110 according to another embodiment is schematically shown, where elements similar to those of the previously described compound cycle engine 10 are identified by the same reference numerals and will not be further described therein. In this embodiment, the turbocharger 118 is defined coaxially with the output shaft 16. The compressor 120 is connected to the output shaft 16 through an appropriate type of transmission 128, for example a planetary or star gear system. The second stage turbine 122 of the turbocharger 118 is connected to the first stage turbine 26 to rotate together therewith, or else connected to the output shaft 16 through an appropriate type of transmission (not shown).

[0048] In another embodiment which is not shown, the turbocharger and rotary unit(s) are coaxial, but the output shaft and turbocharger shaft rotate independently from one another, for example with the output shaft being hollow and surrounding the turbocharger shaft which extends therethrough.

[0049] Although not shown, in all embodiments, variable geometry elements such as inlet guide vanes, blow-off valves, waste gates, variable turbine nozzles, etc. may be used to obtain desired system operability.

[0050] Although not shown, the first stage turbine 26 may be mounted in an offset manner rather than co-axially with the rotary units 12. The first stage turbine 26 may be drivingly engaged to the output shaft through an angular, for example perpendicular, transmission system, for example including a gearbox and a tower shaft.

[0051] The above description is meant to be exemplary only, and one skilled in the art will recognize that changes may be made to the embodiments described without departing from the scope of the invention disclosed. Modifications which fall within the scope of the present invention will be apparent to those skilled in the art, in light of a review of this disclosure, and such modifications are intended to fall within the appended claims.

CLAIMS:

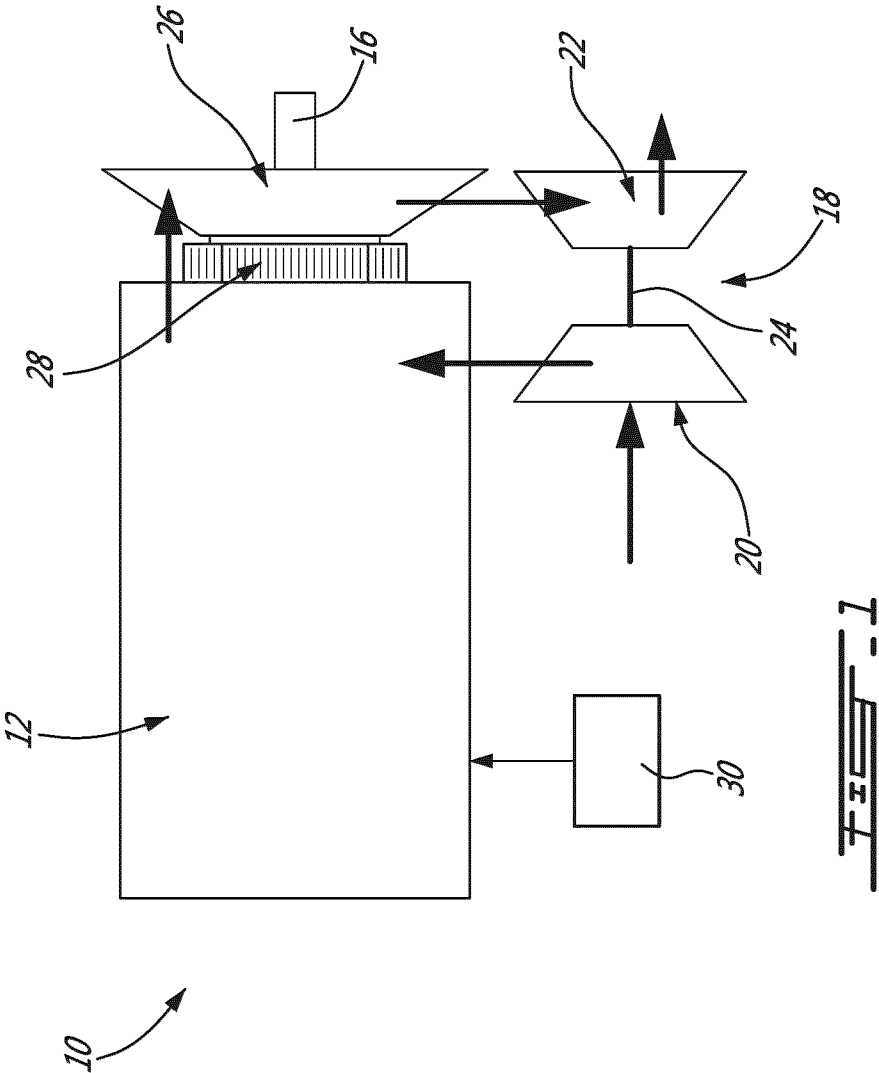
1. A compound cycle engine comprising:
 - at least one rotary unit each defining an internal combustion engine including an engine rotor sealingly and rotationally received within a respective housing, each housing defining an inlet port and an exhaust port;
 - a first stage turbine in proximity of the at least one rotary unit, the first stage turbine including a flowpath and a turbine rotor having a circumferential array of blades extending across the flowpath, the turbine rotor of the first stage turbine and the engine rotor of each of the at least one rotary unit being in driving engagement with a common shaft; and
 - a turbocharger including a compressor and a second stage turbine in driving engagement with one another; wherein:
 - an outlet of the compressor is in fluid communication with the inlet port of each housing;
 - the exhaust port of each housing is in fluid communication with a first portion of the flowpath of the first stage turbine, the first portion of the flowpath being located upstream of the circumferential array of blades of the first stage turbine;
 - an inlet of the second stage turbine is in fluid communication with a second portion of the flowpath of the first stage turbine, the second portion of the flowpath being located downstream of the circumferential array of blades of the first stage turbine; and
 - the first stage turbine has a lower reaction ratio than that of the second stage turbine.
2. The compound cycle engine as defined in claim 1, wherein the reaction ratio of the first stage turbine is a pressure-based reaction ratio having a value of at most 0.25.
3. The compound cycle engine as defined in claim 1, wherein the reaction ratio of the first stage turbine is a pressure-based reaction ratio having a value of at

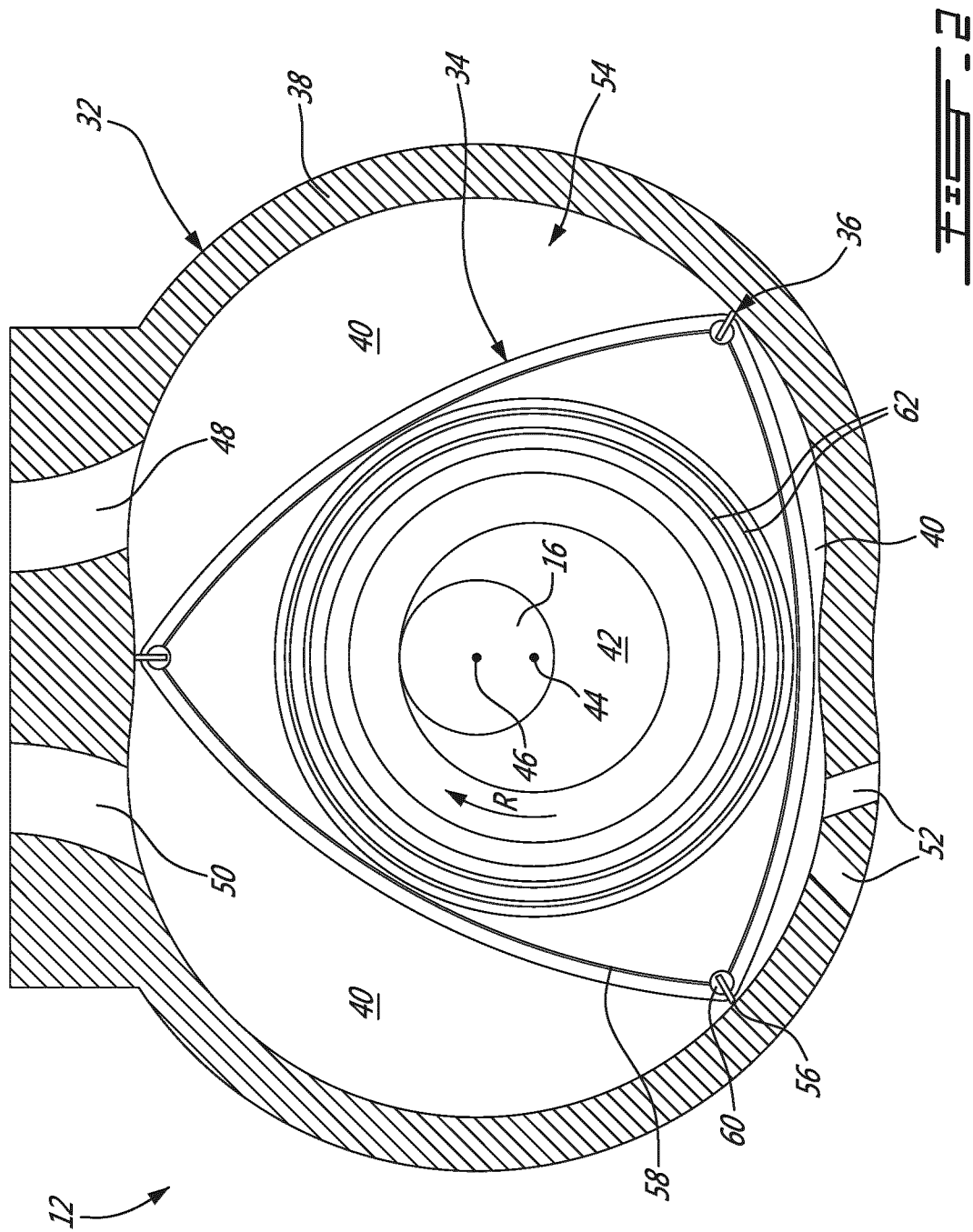
- most 0.1 and the second stage turbine has a pressure-based reaction ratio having a value of at least 0.25.
4. The compound cycle engine as defined in claim 1, wherein the reaction ratio of the first stage turbine is a pressure-based reaction ratio having a value of at most 0.1 and the second stage turbine has a pressure-based reaction ratio having a value of at least 0.25.
 5. The compound cycle engine as defined in claim 1, wherein each of the at least one rotary unit is a Wankel engine.
 6. The compound cycle engine as defined in claim 1, wherein the flowpath of the first stage turbine is an axial flowpath.
 7. The compound cycle engine as defined in claim 1, wherein the compressor and the second stage turbine are in driving engagement with one another through a turbocharger shaft rotatable independently of the common shaft.
 8. The compound cycle engine as defined in claim 1, wherein the compressor and the second stage turbine are in driving engagement with the common shaft.
 9. The compound cycle engine as defined in claim 1, wherein the compressor and the second stage turbine are in driving engagement with one another through a turbocharger shaft, and wherein the common shaft is an output shaft having a different axis than that of the turbocharger shaft, the compressor and the second stage turbine each including at least one radial impeller.
 10. The compound cycle engine as defined in claim 1, wherein the common shaft is an output shaft connected to the engine rotor of each of the at least one rotary unit, the first stage turbine being drivingly engaged to the output shaft through a transmission.
 11. The compound cycle engine as defined in claim 1, further comprising common rail fuel injectors for each of the at least one rotary unit, and a heavy fuel source in communication with the fuel injectors

12. A compound cycle engine comprising:
- at least one rotary engine each having an engine rotor sealingly and rotationally received within a respective housing having an inlet port and an exhaust port, the engine rotor of each of the at least one rotary engine being drivingly engaged to a common shaft;
 - a first stage turbine in proximity of the at least one rotary engine and having a turbine rotor drivingly engaged to the common shaft;
 - a respective exhaust pipe providing fluid communication between each exhaust port and an inlet of the first stage turbine;
 - a turbocharger including a compressor and a second stage turbine drivingly engaged to one another;
 - an inlet duct providing fluid communication between an outlet of the compressor and the inlet port of each of the at least one rotary engine;
 - and
 - a turbine pipe providing fluid communication between an outlet of the first stage turbine and an inlet of the second stage turbine;
- wherein the first stage turbine has a lower reaction ratio than that of the second stage turbine.
13. The compound cycle engine as defined in claim 12, wherein the reaction ratio of the first stage turbine is a pressure-based reaction ratio having a value of at most 0.25.
14. The compound cycle engine as defined in claim 12, wherein the reaction ratio of the first stage turbine is a pressure-based reaction ratio having a value of at most 0.1 and the second stage turbine has a pressure-based reaction ratio having a value of at least 0.25.
15. The compound cycle engine as defined in claim 12, wherein the reaction ratio of the first stage turbine is a pressure-based reaction ratio having a value of at most 0.1 and the second stage turbine has a pressure-based reaction ratio having a value of at least 0.25.

16. The compound cycle engine as defined in claim 12, wherein the compressor and the second stage turbine are in driving engagement with one another through a turbocharger shaft rotatable independently of the common shaft.
17. The compound cycle engine as defined in claim 12, wherein the compressor and the second stage turbine are in driving engagement with the common shaft.
18. The compound cycle engine as defined in claim 12, wherein the turbine rotor of the first stage turbine is an axial rotor.
19. The compound cycle engine as defined in claim 12, wherein each of the at least one rotary engine is a Wankel engine.
20. The compound cycle engine as defined in claim 12, further comprising common rail fuel injectors for each of the at least one rotary engine, and a heavy fuel source in communication with the fuel injectors.
21. A method of compounding at least one rotary engine, the method comprising:
 - drivingly engaging a second stage turbine and a compressor in a turbocharger;
 - defining a fluid communication between an outlet of the compressor and an inlet port of each of the at least one rotary engine;
 - defining a fluid communication between an exhaust port of each of the at least one rotary engine and an inlet of a first stage turbine, including directing the fluid communication onto blades of a turbine rotor of the first stage turbine, the first stage turbine having a lower reaction ratio than that of the second stage turbine;
 - defining a fluid communication between an outlet of the first stage turbine and an inlet of the second stage turbine of the turbocharger; and
 - drivingly engaging an engine rotor of each rotary engine and the rotor of the first stage turbine to a common shaft.

22. The method as defined in claim 21, further comprising providing fluid communication between a source of heavy fuel and each of the at least one rotary engine.





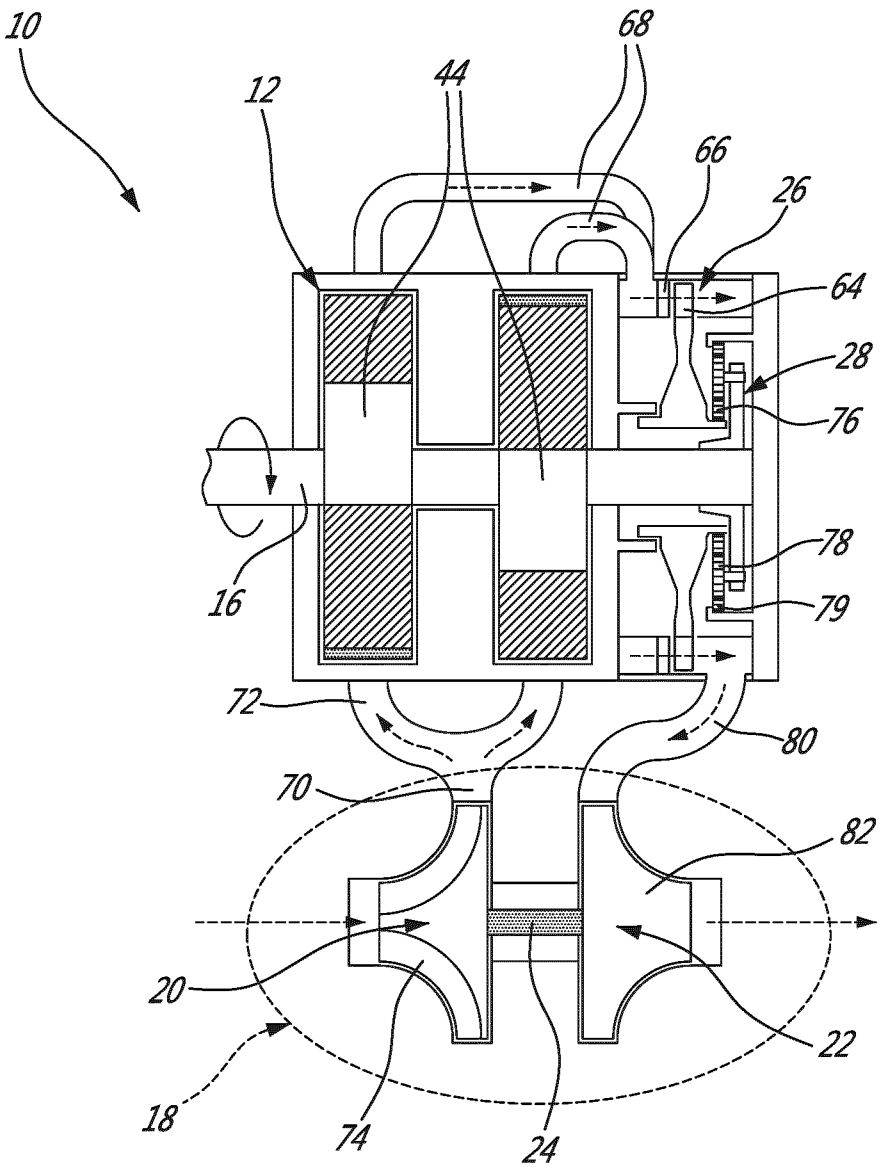
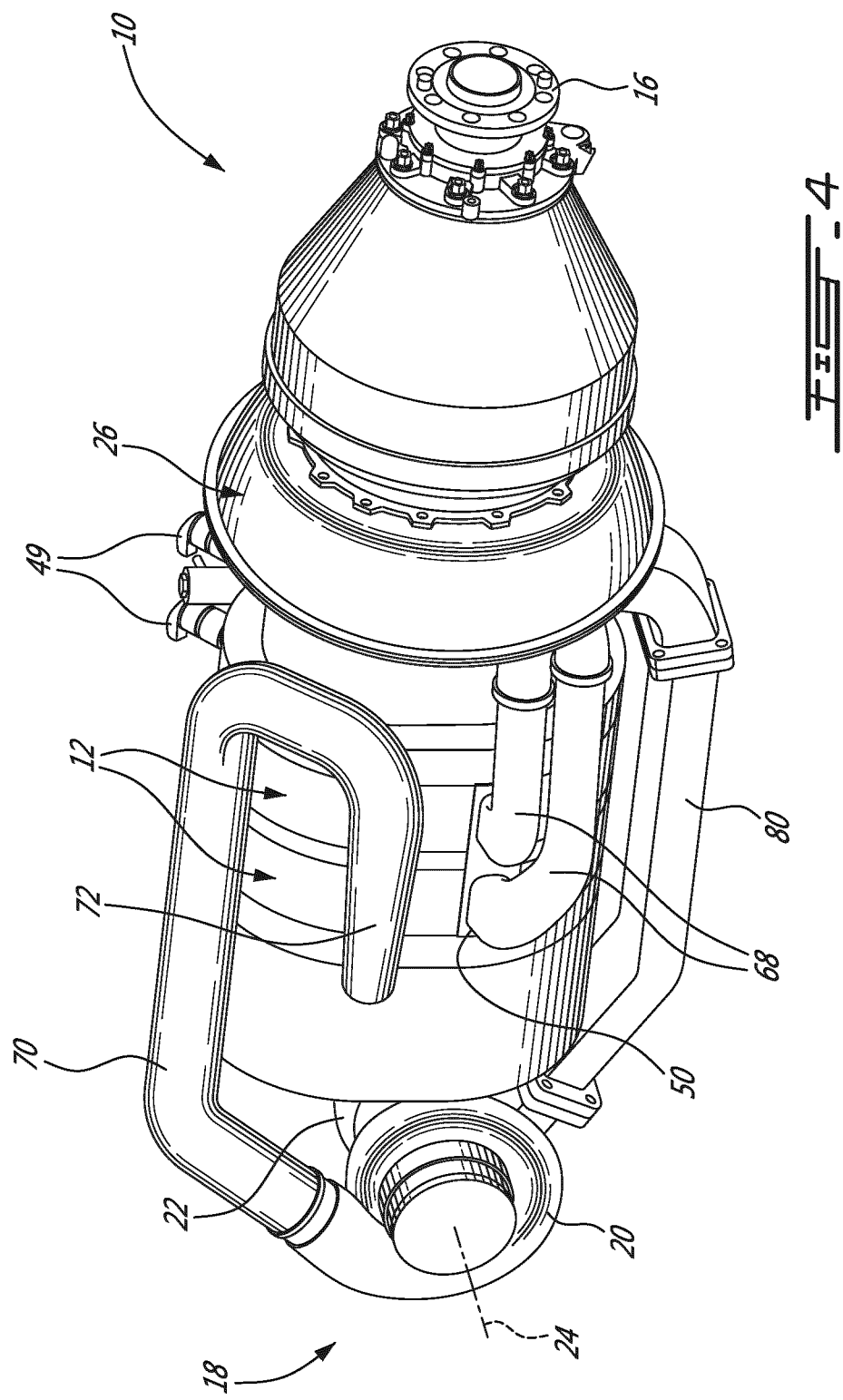
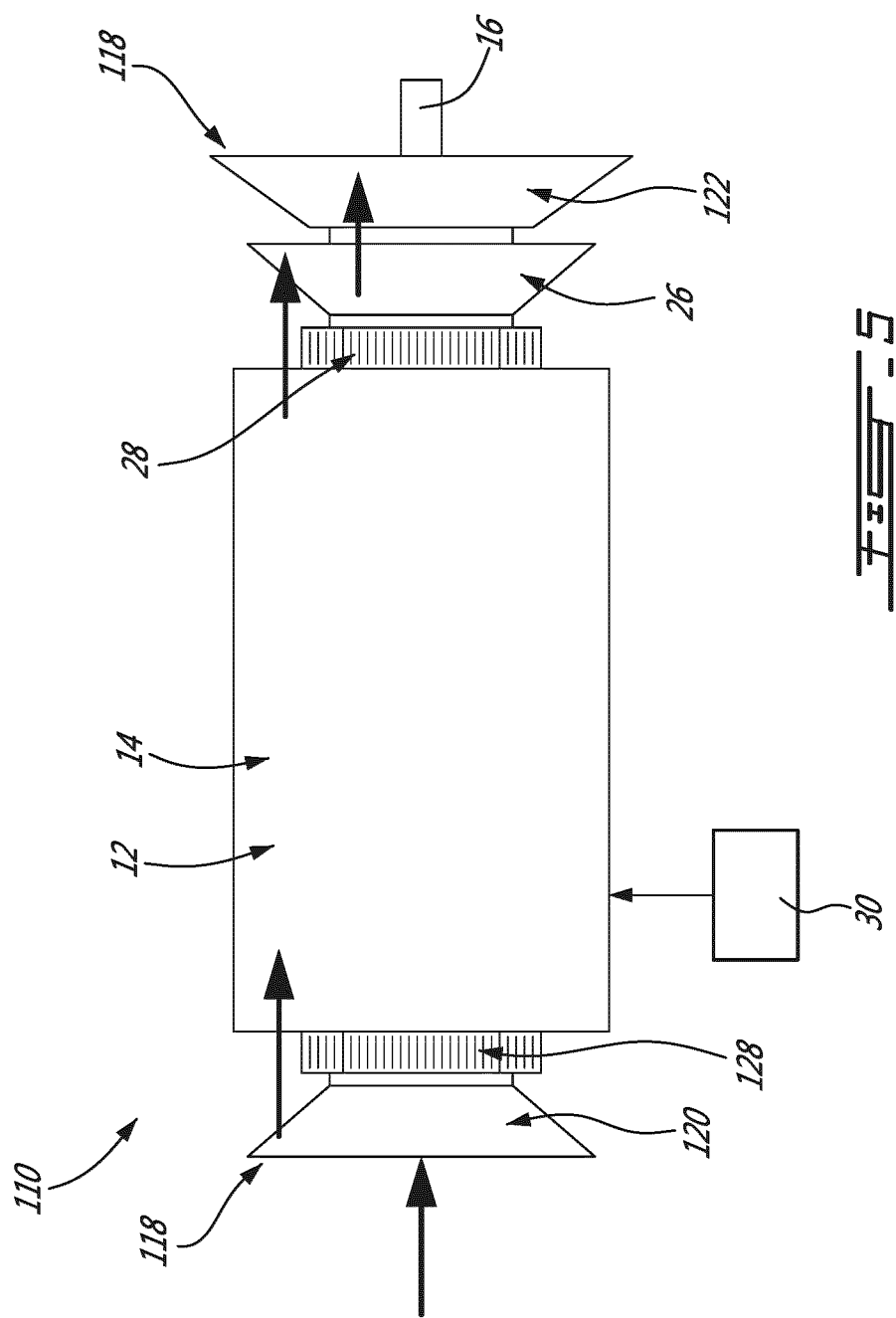


FIG. 3





INTERNATIONAL SEARCH REPORT

International application No.

PCT/CA2016/050692

A. CLASSIFICATION OF SUBJECT MATTER IPC: F02B 53/14 (2006.01), B64D 41/00 (2006.01), F01C 1/22 (2006.01), F02B 33/40 (2006.01), F02B 37/02 (2006.01), F02B 41/10 (2006.01) According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) IPC: F02B 53/14 (2006.01), B64D 41/00 (2006.01), F01C 1/22 (2006.01), F02B 33/40 (2006.01), F02B 37/02 (2006.01), F02B 41/10 (2006.01) Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched IPC: B64D 33 (2006.01), B64D 41 (2006.01), F01C 01 (2006.01), F02B 37 (2006.01), F02B 33 (2006.01), F02B 53 (2006.01), F02B 55 (2006.01), F02B 57 (2006.01), F02B 59 (2006.01) Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used) Questel Orbit: FamPat Search terms: turbine, velocity, pressure, ratio, compound, engine, reaction, second, stage, turbo, charger, impulse, Wankel		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CA 2 821 497 A1 (BOLDUC, S. et al.), 20 January 2014 (20-01-2014) The whole document	1 to 22
A	US 2009 / 0 007 882 A1 (LENTS, C. E. et al.), 08 January 2009 (08-01-2009) The whole document	1
A	CA 2 516 720 A1 (CHEVREFILS, A. et al.), 02 September 2004 (02-09-2004) The whole document	1
A	SU 1 686 202 A1 (ROMANOV, V. et al.), 23 October 1991 (23-10-1991) The whole document	1
☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents: "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family	
Date of the actual completion of the international search 12 July 2016 (12-07-2016)		Date of mailing of the international search report 21 July 2016 (21-07-2016)
Name and mailing address of the ISA/CA Canadian Intellectual Property Office Place du Portage I, C114 - 1st Floor, Box PCT 50 Victoria Street Gatineau, Quebec K1A 0C9 Facsimile No.: 819-953-2476		Authorized officer Felix-Antoine Dandenault (819) 635-4801

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CA2016/050692

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