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(54) ELECTRIC PROPULSION SYSTEMS

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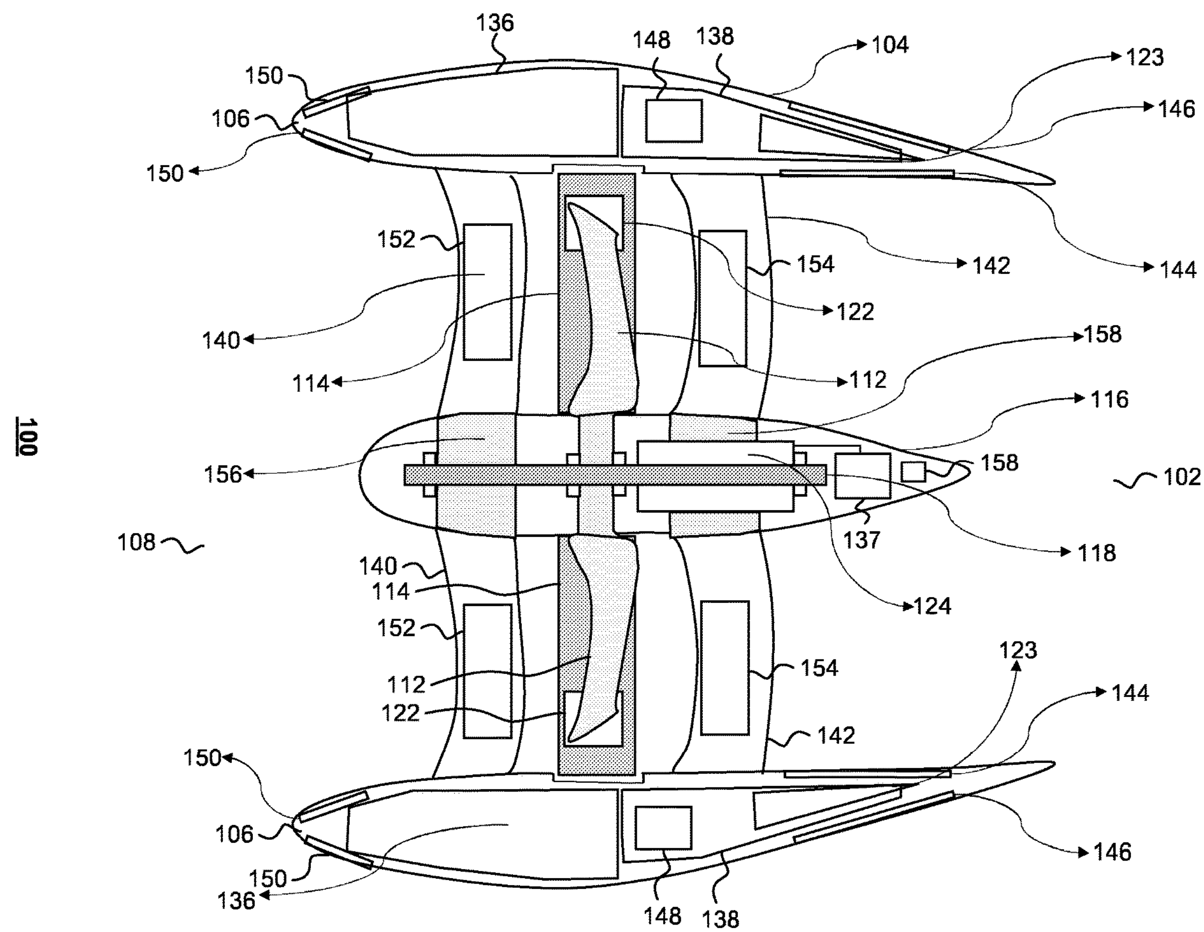
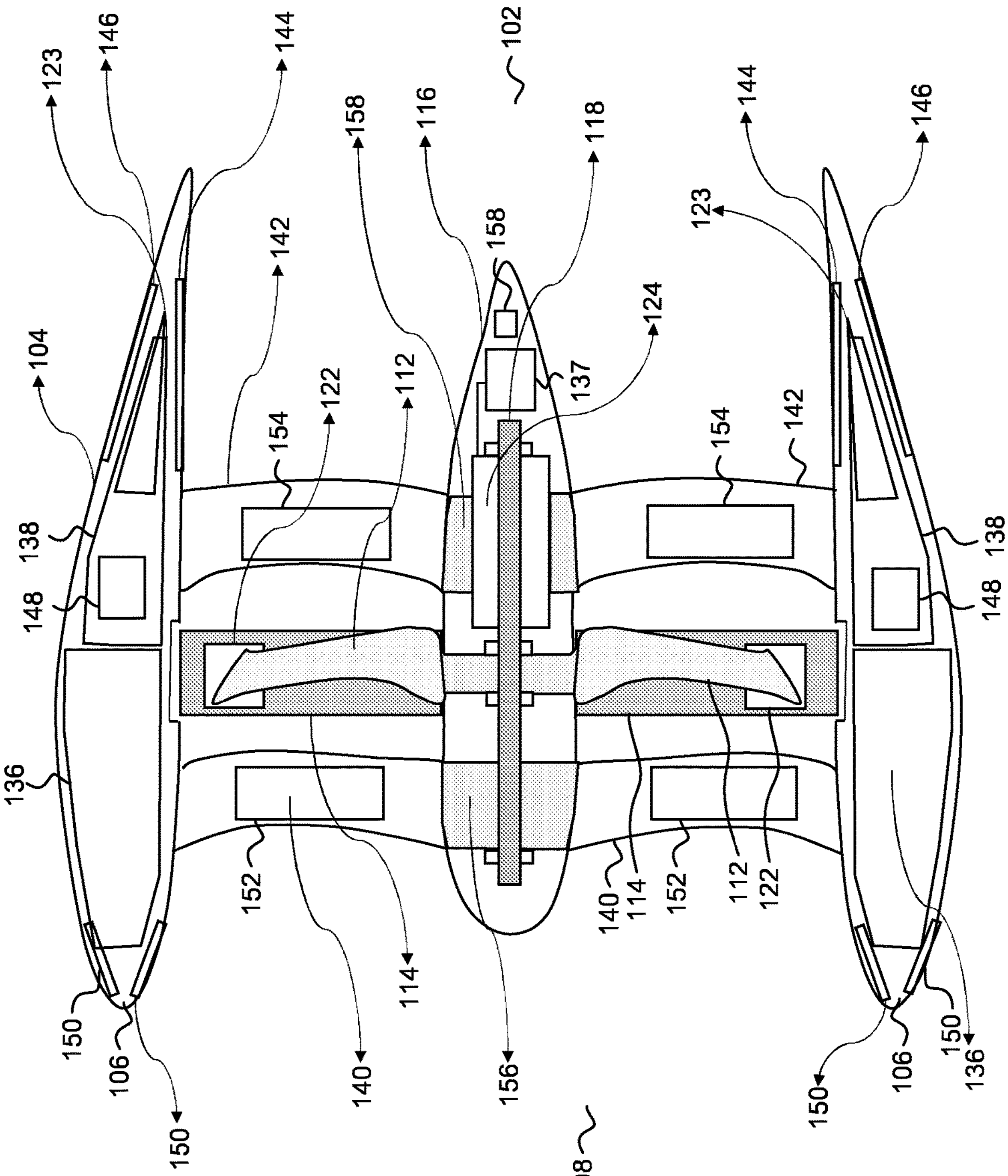
(57) ABSTRACT

Examples provide electric propulsion systems; such a system comprising: a. a nacelle comprising an aerodynamic annular housing defining an internal annular volume and defining an inner duct, b. at least one fan stage comprising a fan bearing a plurality of aerodynamic surfaces/blades to generate thrust mounted within a fan shroud, and c. a powertrain comprising at least one electric motor to drive the fan shroud and at least one electrical power source to power the electric motor; and d, wherein i. the fan shroud is disposed within the inner duct, ii. at least part of the powertrain is disposed within the internal annular volume, iii. the at least one electric motor is disposed within the central hub and iv. the hub-to-tip ratio is between 0.1 and 0.4, preferably, between 0.2 and 0.3.

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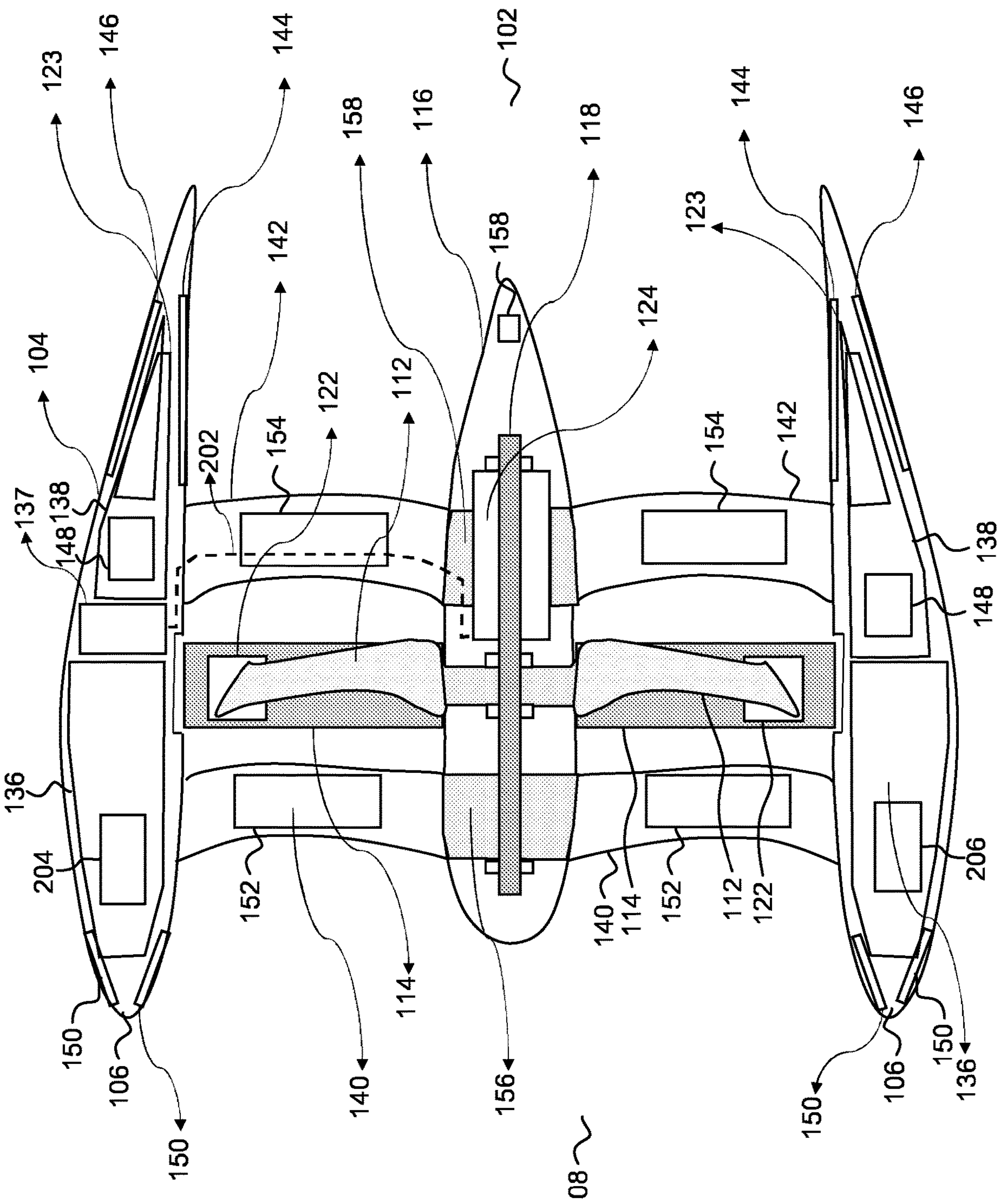
100

FIG 1



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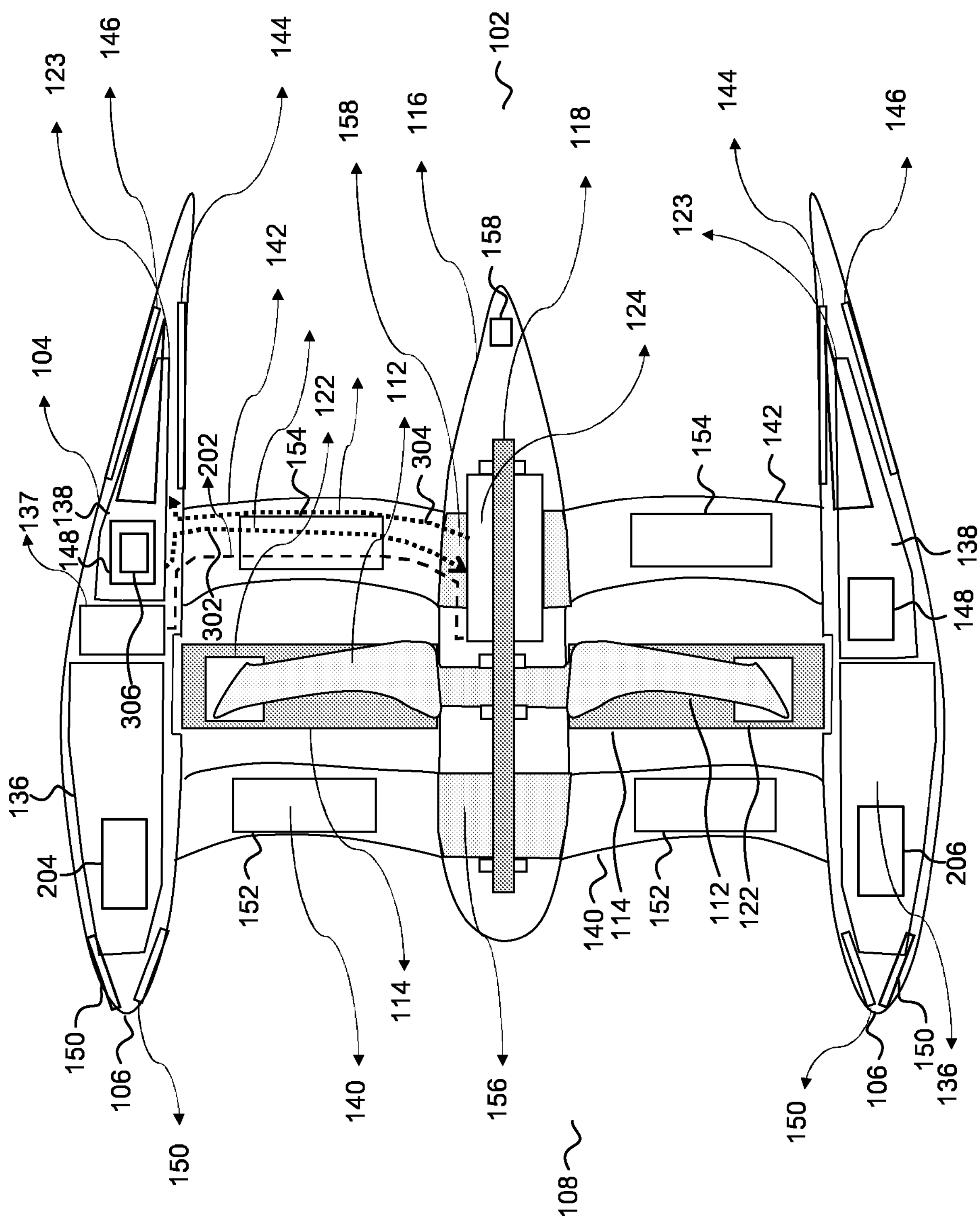
200

FIG 2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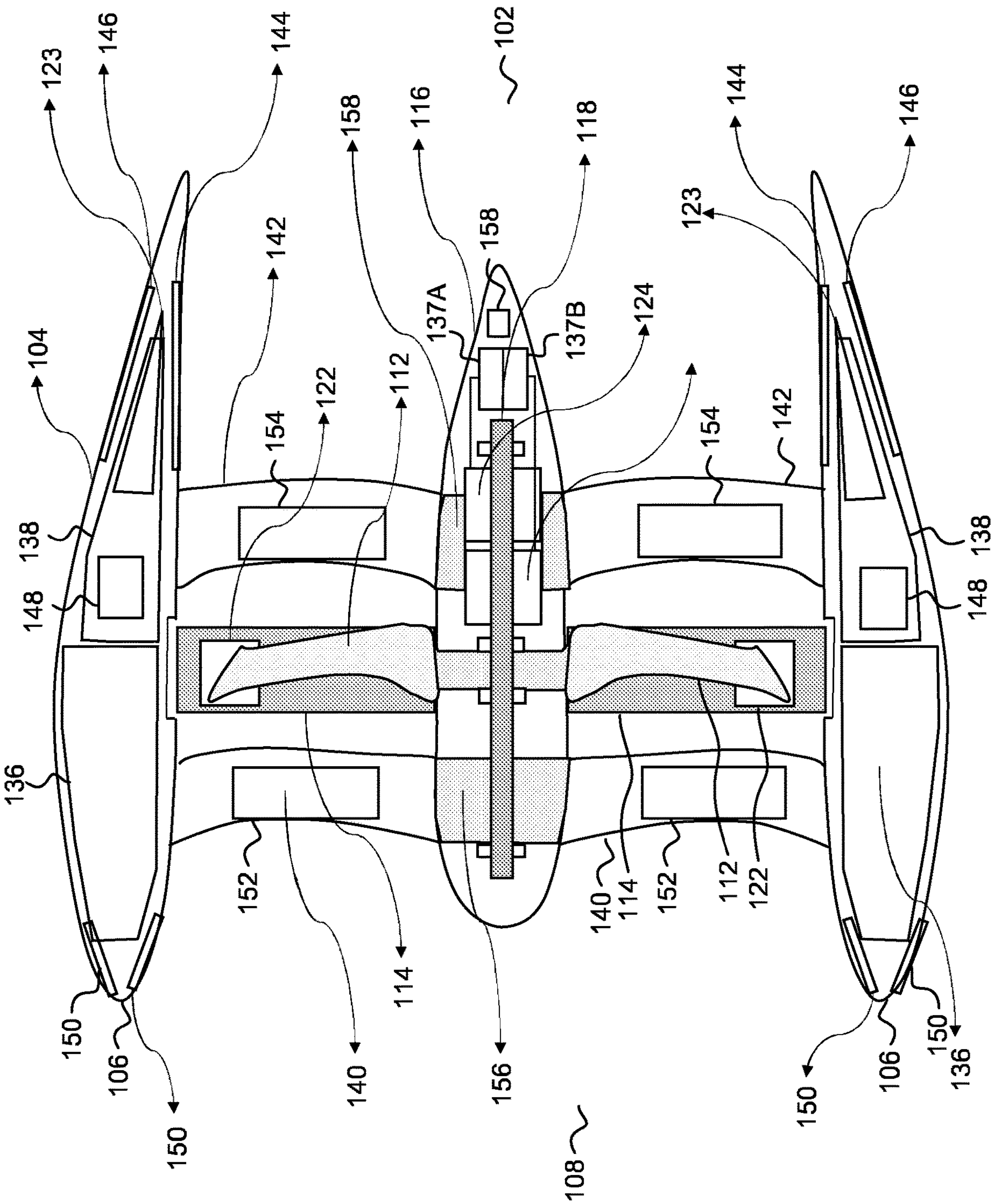
300

FIG 3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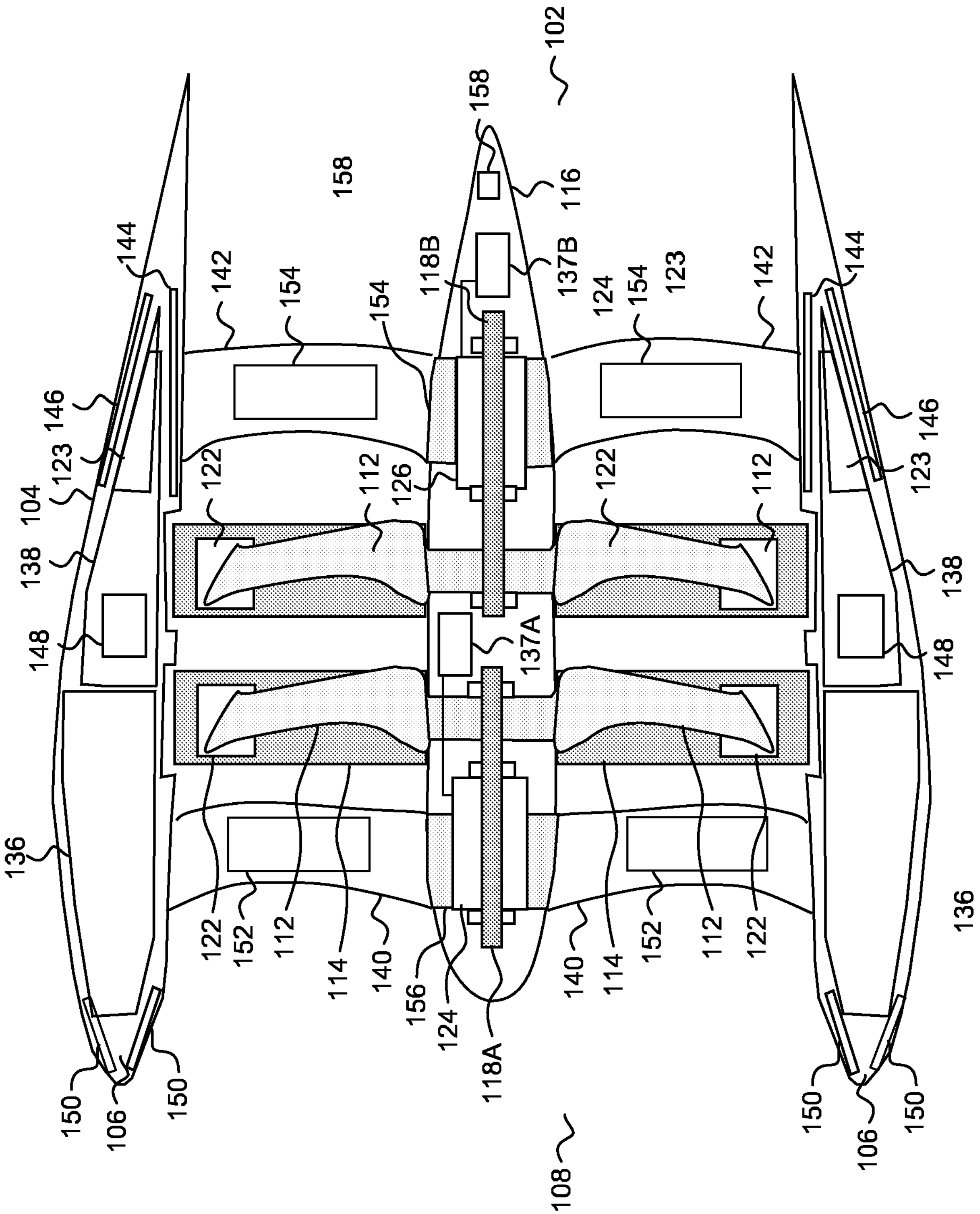
400

FIG 4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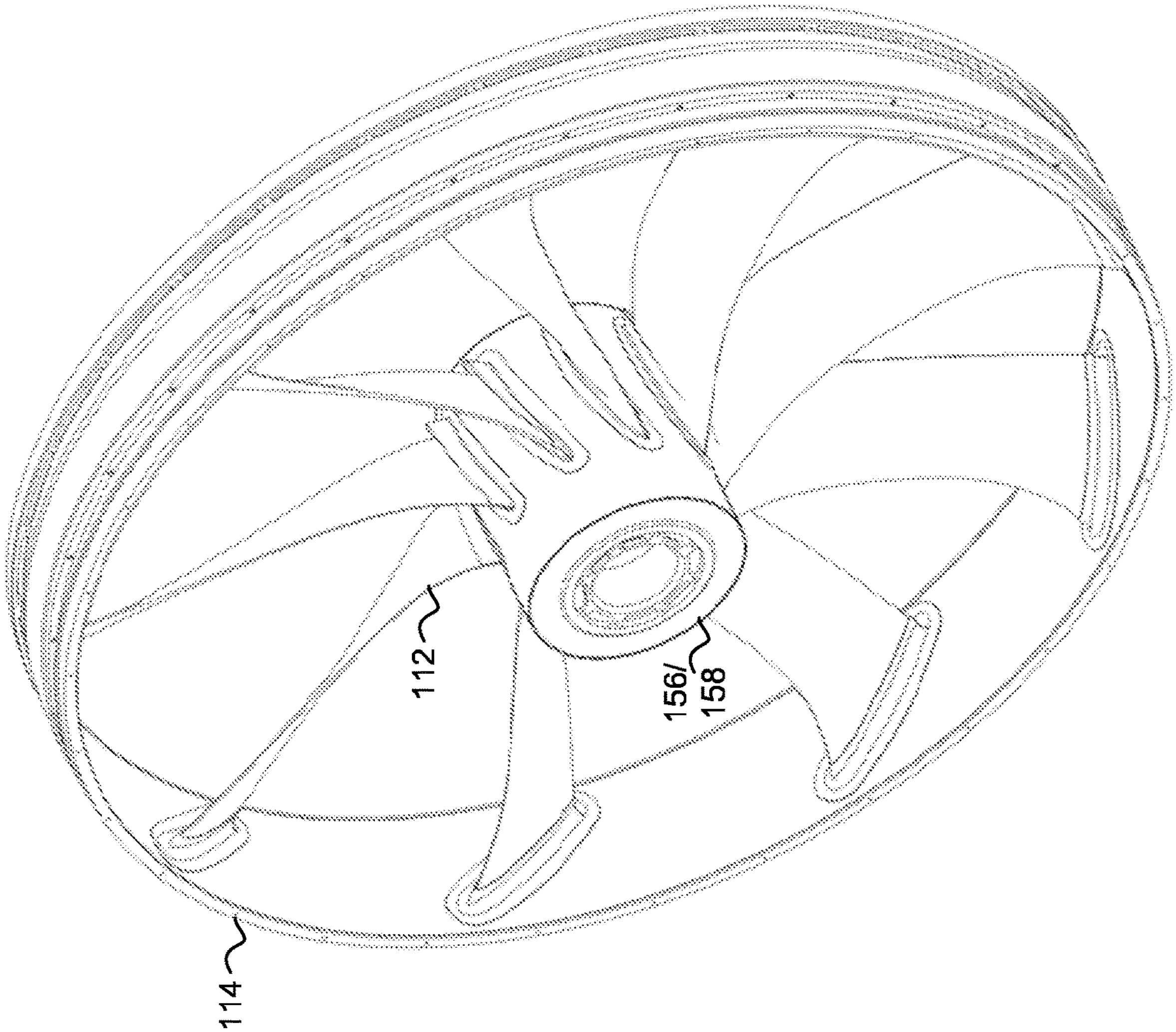
108

500

FIG 5



600

FIG 6

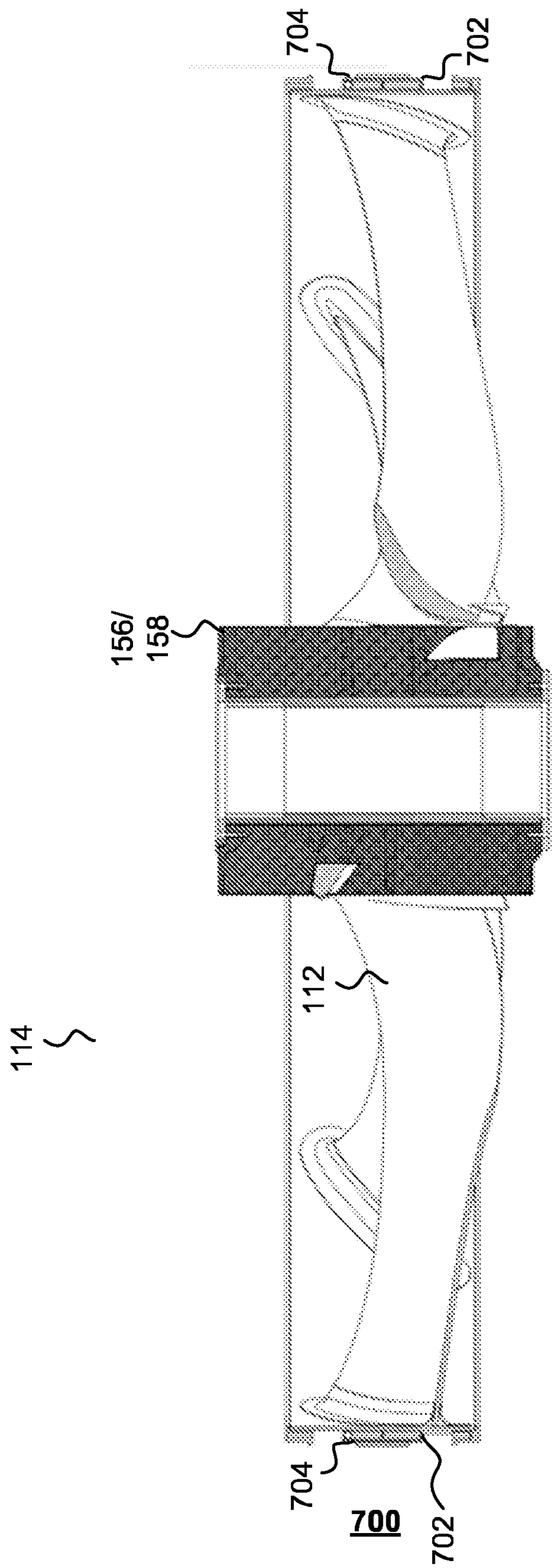
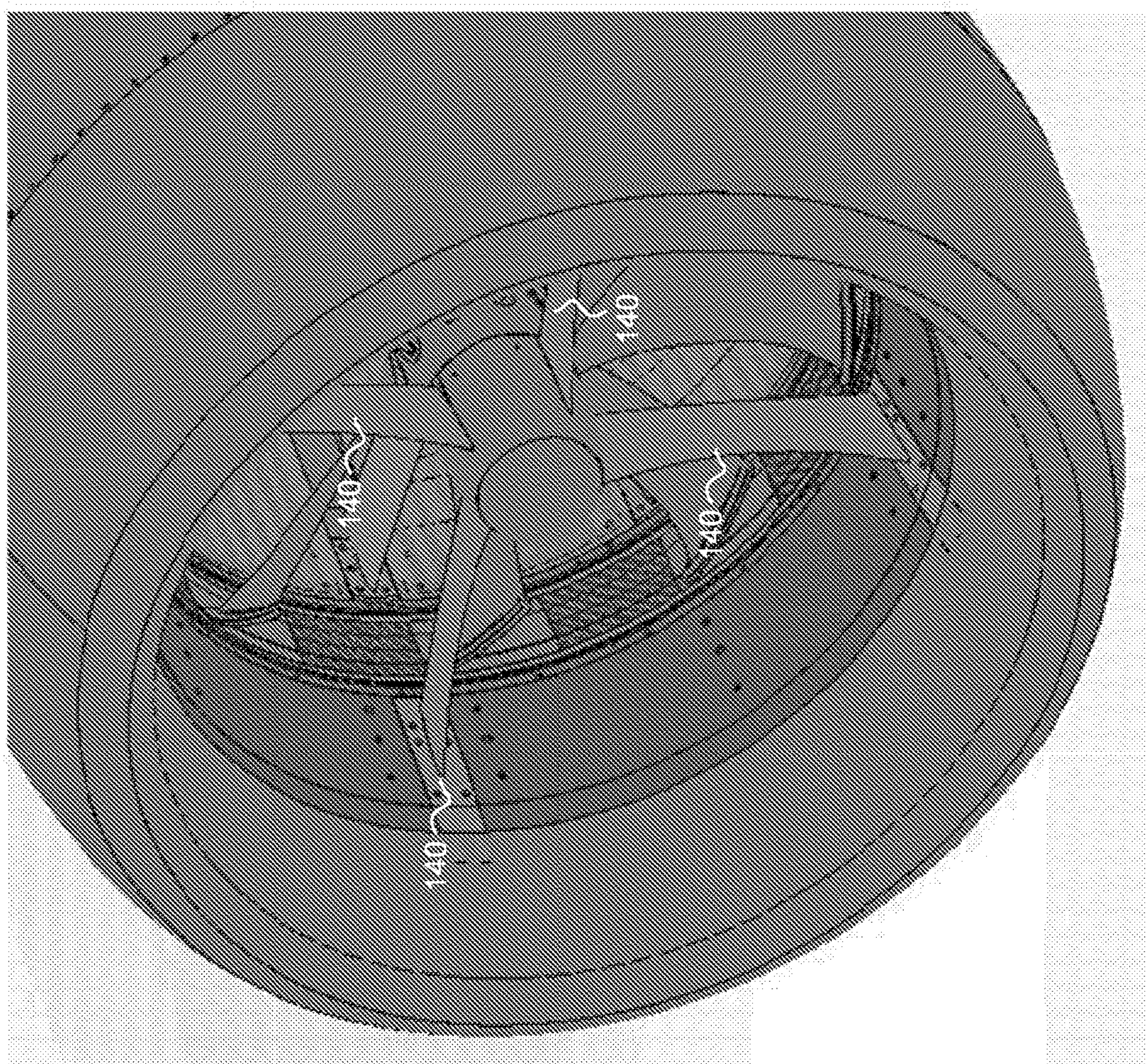
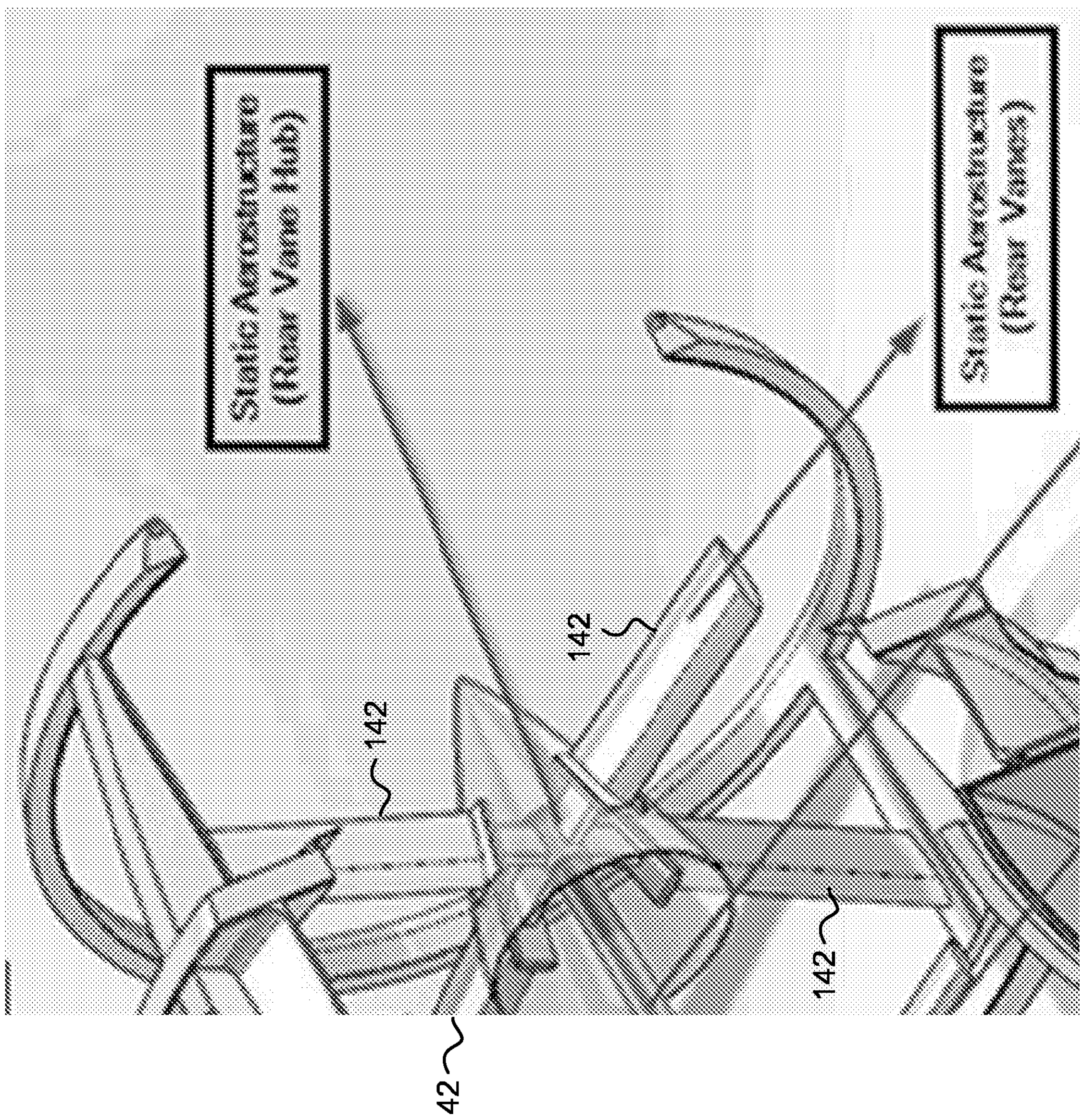


FIG 7



800

FIG 8


Static Aerostructure
(Rear Vane Hub)
Static Aerostructure
(Rear Vanes)
142
142
142
142

900

FIG 9

ELECTRIC PROPULSION SYSTEMS

BACKGROUND

[0001] There is an increasing drive to reduce carbon emissions to combat global warming. Part of that drive involves improving the efficiency of existing gas turbine engines and internal combustion engines of, for example, aircraft. Alternative propulsion technologies are also being investigated such as, for example, electric propulsion systems. Ground vehicles that use electric motors are well-established. However, aircraft that use electric motors to drive aerodynamic surfaces are less well established and face a number of technical challenges such as the relatively low energy density of electrical energy sources, lower power densities of batteries and inherent inefficiencies such as thermal management systems, power losses and other inefficiencies.

BRIEF INTRODUCTION OF THE DRAWINGS

[0002] Examples will be described with reference to the accompanying drawings in which

[0003] FIG. **1** shows an electric propulsion system according to a first example;

[0004] FIG. **2** illustrates an electric propulsion system according to a second example;

[0005] FIG. **3** depicts an electric propulsion system according to a third example;

[0006] FIG. **4** shows an electric propulsion system according to a fourth example;

[0007] FIG. **5** illustrates an electric propulsion system according to a fifth example;

[0008] FIG. **6** depicts a fan shroud according to examples;

[0009] FIG. **7** shows a sectional view of the fan shroud of FIG. **6**;

[0010] FIG. **8** illustrates inlet guide vanes according to examples; and

[0011] FIG. **9** depicts outlet guide vanes according to examples.

DETAILED DESCRIPTION

[0012] Referring to FIG. **1** there is shown a view **100** of an electric propulsion system **102**. The electric propulsion system can be for an aircraft. The electric propulsion system **102** comprises a nacelle **104**. The nacelle **104** comprises an aerodynamic annular housing. The annular housing defines an internal annular volume **106**. The annular housing also defines an inner duct indicated generally as **108**. The inner duct is external to the housing and forms an airflow path through which air passes. The electric propulsion system **102** comprises at least one fan stage **110**. The fan stage has a plurality of aerodynamic surfaces or blades **112** for generating thrust. The blades **112** are mounted to an annular fan shroud **114**. The fan shroud **114** is mounted on a central hub **116** so that the fan comprising the blades **112** can rotate about a central shaft **118**. Each of the blades **112** is mounted to the fan shroud **114** via a respective fixture **122**. Using a fan shroud can reduce noise generation that is otherwise associated with open tip blades. The noise reduction can be realised, at least in part, using sound absorbing materials to form the nacelle housing. Further noise reductions can be realised by profiling a profiled trailing edge geometry to the nacelle **104**. The profiled trailing edge bears features such as, for example, a Helmholtz Resonator muffler **123**, that reduce aero-electric noise associated with operating the propulsion system **102**. The Helmholtz Resonator muffler **123** is arranged to suppress large amplitude and mid to low frequency pressure fluctuations such as, for example, mechanical vibratory noise of aerodynamic bodies immersed in a propulsive medium and buffeting noise arising at an engine intake.

[0013] The electric propulsion system **102** comprises a powertrain having at least one electric motor to drive the fan stage **110** via the fan shroud **114**. Other than the electric motor, the powertrain is, at least partly, housed within the inner annular volume **106**. Housed within the inner annular volume **106** is at least one electrical power source to power the at least one electric motor. In the example illustrated, a single electric motor **124** is provided. A electric motor **124** comprises a set of stator coils (not shown) that are arranged to cooperate with a set of rotor magnets (not shown). The fan shroud is driven by the electric motor **124** . . . . The nacelle **104**, as well as producing thrust, acts as structural housing for the powertrain. The nacelle **104** also functions as a safety shroud that protects the vehicle against blade failure.

[0014] The internal volume **106** of the nacelle **104** houses part of the powertrain for driving the fan stage **110**. Examples can be realised in which the powertrain comprises at least one or more than one of: at least one electric motor, at least one electrical power source to power the at least one electric motor, an engine control unit, at least one inverter, a power distribution system, a thermal management system, a fuel cell, taken jointly and severally in any and all permutations. While the electric motor **124** is housed in the central hub **116**, other parts of the powertrain are housed within the interior annual volume **106** defined by the nacelle **104**.

[0015] In the example depicted, the powertrain comprises at least one electrical power source **136**. The at least one electrical power source **136** can comprise an energy storage system. The energy storage system can comprise at least one battery. The at least one electrical power source **136** is housed within the internal volume **106** of the nacelle **104**. The at least one electrical power source **136** is arranged to supply power to one or more inverters **137** for driving the electric motor **124**. Alternatively, the one or more inverters **137** can be housed within the interior volume **106** of the nacelle **104** with the drive signals being coupled to the electric motor **124** via cabling.

[0016] The nacelle **104** comprises a further internal volume **138**. The further internal volume **138** is arranged to accommodate system, a fire protection system, a de-icing system, taken jointly and severally in any and all permutations.

[0017] The central hub **116** is coupled to the nacelle **104** via a number of load transfer members. Examples can be realised in which the number of load transfer members comprises a set of fore, or inlet, guide vanes **140**. Examples can be realised additionally, or alternatively, in which the load transfer members comprise a set of aft, or exit, guide vanes **142**, which are described below with reference to figures. The load transfer members are arranged to transfer thrust generated by the blades **112** to the rest of the electric propulsion system **102** and, ultimately, to a vehicle bearing such a propulsion system. The exit guide vanes can be used as control surfaces to enable the thrust to be vectored, which can be used to manoeuvre an associated vehicle such as an aircraft.

[0018] The aft portion of the nacelle **104** comprises at least one heat exchanger. In the example shown the aft portion of the nacelle **104** comprises sets of heat exchangers. A first set of heat exchangers **144** is disposed on an inward facing surface of the nacelle housing. The first set of heat exchangers **144** is arranged to couple heat from the powertrain to the air contained within the inner duct **104**. Coupling heat from the powertrain to the air within the inner duct **108** causes that air to expand and, therefore, to contribute to generating thrust. The aft portion of the nacelle comprises a further set of heat exchangers **146**. The further set of heat exchangers **146** is arranged to couple heat from the powertrain and vent it to atmosphere in order to manage the thermal conditions within the powertrain.

[0019] Any and all examples can be realised in which the heat exchangers **144** have surface features that suppress noise associated any boundary layer of the downstream flow within the inner duct. The surface features can comprise undulations on the inwardly directed surfaces of the heater exchangers **114**. Examples can be realised in which the undulations present a ribbed texture surface or airflow interface. The undulations can comprise microscale structures, such as, for example, dentils, arranged to create longitudinal grooves. The size and pitch of these grooves is a function of an expected local velocity and density of the medium flowing through the nacelle. Any or each of the examples described herein can be realised comprising such microstructures in the range of 100 to 300 μm in depth and 30 to 40 μm in width. Examples presenting such a textured or profiled surface realise boundary layer noise attenuation as well as local skin friction reduction. Examples can be realised in which such attenuation follows without incurring a specific heat exchange penalty.

[0020] A thermal management system **148** is provided to manage the thermal conditions associated with the powertrain. A common thermal management system is used to manage the thermal conditions associated with each element, or at least with selectable elements, of the powertrain. The thermal management system **148** uses liquid coolant, such as, for example, a dielectric fluid to transfer heat away from any such elements of the powertrain and to direct that heat to at least one, or both, of the first **144** and second **146** sets of heat exchangers. Having a common thermal management system **148** supports collecting or harvesting heat from one or more than one component of the electric propulsion system, in particular, the powertrain such as, for example, one or more than one of: any motor or motors, any battery or batteries, any power electronics such as any inverter or inverters taken jointly and severally in any and all permutations, which saves weight and complexity.

[0021] The thermal management system **148** can also direct heat generated by the powertrain to a set of heaters, or to at least one set of heaters. For example, the thermal management system **148** can direct heat generated by the powertrain to de-icing heaters **150** associated with the leading edge of a fore section of the nacelle **104**. The de-icing heaters **150** are arranged to de-ice the nacelle. Examples can also be realised in which the thermal management system **148** can couple heat to at least one, or both, of the load transfer members **140** and/or **142**, or the blades **112**. The thermal management system **148** can couple heat from the powertrain to heaters or heat exchangers **152** and/or **154** in the inlet **140** and exit **142** guide vanes. Furthermore, the thermal management system **148** can couple heat from the powertrain to the central hub **116** via a respective heater or respective heat exchanger **158**.

[0022] An effective way of realising lightweight motors for a given power is to increase the revolutions per minute and to reduce the torque since electric motors are sized according to torque. To introduce electric redundancy into the electric propulsion system **102**, examples can be realised in the electric motor **124** is capable of spinning at a high RPM, that is, that are capable of spinning above a threshold level RPM. Examples can be realised in which the threshold level RPM would be a speed above 2,000 RPM and below 60,000 RPM. Examples can be realised in which the motors are arranged to generate fan speeds of between 2,000 and 3,000 RPM. It can be appreciated that electric motor **124** is used to drive the central shaft **118** carrying the fan shroud **114**. Aerodynamic efficiency is realised by ensuring that the single fan stage **110** operates at RPMs of above 2000.

[0023] As indicated above the interior volume **106** of the nacelle **104** can comprise a powertrain having a fuel cell, that is, can comprise a fuel cell powertrain. Several advantages follow from including a fuel cell powertrain in the interior of the nacelle **104**. For example, electrical cabling within an aircraft needed by the propulsion system can be reduced thereby leaving space for hydrogen storage and distribution systems. Furthermore plug and play propulsion, that is, electricity generation to thrust generation in a propulsor, supports quick replacement of the powertrain that, in turn, can reduce aircraft downtime for operators.

[0024] It can be appreciated that the load transfer members **140** and **142** are coupled to respective structures **156** and **158** for transferring load from the rotor fan stage **114** to the inlet guide vanes **140** and exit guide vanes **142**. The respective structures can comprises a central hub or boss **156**, **158**.

[0025] It will be appreciated that the motor, inverter and battery share at least one of: power management, thermal management, structural housing, and protection equipment, taken jointly and severally in any and all permutations, thereby leading to weight and efficiency gains. Furthermore, as the motors are direct drive, the rotational speeds are relatively low. Normally low rotational speeds require a high torque and heavy electric motor because, in traditional systems, the motor has to have a large radius.

[0026] Referring to FIG. **2**, there is shown a view **200** of an example of the electric propulsion system **102**.

[0027] Reference numerals common to FIGS. **1** and **2** refer to the same elements.

[0028] The electric propulsion system **102** houses the inverter **137** within interior volume **106** of the nacelle **104**. Accordingly, cabling **202** is provided to couple the drive signals output by the inverter **137** to the electric motor **124**.

[0029] The example of the electric propulsion system **102** depicted in FIG. **2** can also comprise one or more than one fuel cell. In the example depicted, two fuel cells **204** and **206** are illustrated. Although the example shown illustrates two fuel cells **204** and **206**, examples are not limited to such an arrangement. Examples can be realised in which multiple fuel cells are positioned within the annular space **106** defined by the nacelle housing **104**. Examples can be realised in which a single fuel cell is provided that has an annular shape. Alternatively, or additionally, the one or more than one fuel cell **204** and **206** can comprise annular segments circumferentially disposed within the interior annular space defined by the nacelle **104**.

[0030] There are several advantages to including a fuel cell in the inner volume **106** of the nacelle **104** such as, for example, increasing payload volume in the aircraft. Furthermore, all electrical cabling in the aircraft needed by the propulsion system can be reduced since the distance between the fuel cell and any electric motors is reduced, which leaves space within the aircraft for fuel storage for the fuel to power the fuel cell such as hydrogen storage and hydrogen distribution systems.

[0031] Referring to FIG. **3**, there is shown a view **300** of an electric propulsion system **102** according to an example. Reference numerals common to FIG. **3** and any preceding figure refer to the same elements.

[0032] The thermal management system **148** comprises flow **302** and return **304** pipes for carrying a coolant from a coolant reservoir **306** to the electric motor **124**. Examples can be realised in which the coolant is a dielectric coolant. The coolant is arranged to carry heat away from the electric motor **124**. Additionally, in examples in which the inverter **137** is also in the central hub **116**, the coolant can carry heat away from the inverter **137**. The heater can be directed to any of the heat exchangers and/or heaters.

[0033] Referring to FIG. **4**, there is shown a view **400** of an example of the electric propulsion system **102**. Reference numerals common to FIG. **4** and any preceding figure refer to the same element.

[0034] The electric propulsion system **102** comprises first **124** and second **126** electric motors. The first and second **124** and **126** electric motors have respective first **137**A and second **137**B inverters. The motors **124** and **126** are axially aligned along the length of the central shaft **118**. The motors **124** and **126** are operably independently of one another to drive the central shaft **118** and, in turn, drive the fan shroud **114**. The motors **124** and **126** are also operable simultaneously.

[0035] As with the example describe above with reference to FIG. **3**, the example electric propulsion system **102** can comprise the coolant flow **302** and return **304** and the coolant reservoir **306**. Furthermore, the example electric propulsion system **102** have the one or more inverters **137**A and **137**B in the interior volume **106** of the nacelle **104** as opposed to the inverters **137**A and **137**B being positioned within the central hub **116**.

[0036] Referring to FIG. **5**, there is shown a view **500** of example of the electric propulsion system **102**. Reference numerals common to FIG. **5** and any of the preceding figures refer to the same elements.

[0037] The electric propulsion system **102** comprises first **124** and second **126** electric motors that are arranged to drive respective central shafts **118**A and **118**B housed within the central hub **116**. The electric motors **124** and **126** are arranged to drive respective fan shrouds **114**A and **114**B in response to drive signals from respective inverters **137**A and **137**B.

[0038] Although the inverters are indicated as being housed within the central hub **116**, examples are not limited thereto. Examples can be realised in which the inverters **137**A and **137**B are housed within the interior volume **106** of the nacelle **104**.

[0039] The fan shrouds **114**A and **114**B can be driven to provide contra-rotating fans.

[0040] Referring to FIG. **6**, there is shown a view **600** of the fan shroud **114** used in the examples described herein. The fan shroud **114** comprises a set of blades. In the example shown, the set of blades comprises nine blades **112**. The blades **112** are anchored at respective blade roots to a central hub or boss **156**, **158**. The fan shroud **114** depicted in FIG. **6** I san example of any and all of the fan shrouds described and/or claimed herein.

[0041] Referring to FIG. **7**, there is shown a view **700** of a section through the fan shroud **114** depicted in FIG. **6**. The shroud **114** has at least one set of the rotor magnets **702** disposed circumferentially around the outer surface **704** of the shroud **114**. The example depicted in FIG. **7** has two sets **702** and **704** of such circumferentially disposed rotor magnets that cooperate with respective sets of stator magnets in a twin motor topology. The sets **702** and **704** of rotor magnets **702** are examples of the above described rotor magnets.

[0042] Referring to FIG. **8**, there is shown a view **800** of an electric propulsion system such as any of the systems described herein more clearly depicting the set of inlet guide vanes. In the example shown, the set of inlet guide vanes comprises four inlet guide vanes **140**.

[0043] Referring to FIG. **9**, there is shown a view **900** of an electric propulsion system such as any of the systems described herein more clearly depicting the set of outlet or exit guide vanes. In the example shown, the set of outlet or exit guide vanes comprises four outlet or exit guide vanes **140**.

[0044] The electric propulsion systems can be used for all classes of aircraft and ground vehicles that use an electric motor(s) to drive aerodynamic surfaces that produce thrust, which includes all VTOL (vertical take-off and landing), CTOL (conventional take-off and landing), STOL (short take-off and landing), STOVL (short take-off and vertical landing) aircraft, hovercraft, airships, and transportation devices that produce thrust via an electric powertrain. The energy source on the aircraft might be maybe an electro-chemical battery, hydrogen driving a fuel cell or internal combustion engine generator, any carbon fuel driving a generator (gas turbine/internal combustion engine) or any other source. Examples of such aircraft include Volocopter™, Ehang™, Lilium™, Airbus Vahana™, Bell Nexus™, Eviation Alice™. The use of an electric propulsion enables many novel vehicle configurations with unique advantages that are not possible with traditional powertrains such as gas turbines and internal combustion engines. At the same time, there are several challenges with these classes of vehicles, such as low energy density of certain electrical energy sources (e.g. electro-chemical), heavy thermal management systems (low grade heat rejection), heavy cabling amongst others that are surmounted using the propulsion system according to the examples described herein.

[0045] Furthermore, many known electric powertrains for ducted propulsors for aircraft are distributed across the aircraft. The energy storage, typically a battery pack or fuel cell, is located in the fuselage or within the wing structures. Long cables then connect the battery packs to the inverters. The inverters, in turn, connect to the electric motor via cables and the motor then drives a propeller or a ducted fan to generate thrust. There are several inefficiencies these arrangement that are surmounted by the electric propulsion systems according to the examples described herein.

[0046] The weight of cabling can be between $\frac{1}{10}$th and $\frac{1}{5}$th the overall weight of the powertrain. Additionally, the cabling can cause up to 5-10% of overall power loss due to its internal resistance.

[0047] Still further, since each component of the powertrain is located independently of the other components, each requires its own housing structure, thermal management system and protection equipment. These can further increase overall powertrain weight to the point where the overall power density and energy density of the aircraft is very low. Again, the example electric propulsions systems described here surmount those technical challenges.

[0048] Additionally, the heat generated from each element of the powertrain, namely, any batteries, any motors, and inverters, is usually wasted into the ambient air. This loss can be up to 10-15% of overall power and can significantly affect overall powertrain performance. Again, the example electric propulsion systems described herein surmount that technical problem by harvesting heat from the powertrain to perform useful functions such as, for example, de-icing or increasing thrust.

[0049] All of the above problems result in low aircraft range and endurance. In a few electric aircraft classes such as eVTOLs, there is not enough power/energy available to get the aircraft of the ground when the requirement for reserve power is also considered.

[0050] The examples described herein can be realised so that an entire powertrain is embedded within a single unit, or are positioned close to one another, the cabling is reduced compared to a powertrain comprising more distributed components. Furthermore, the close proximity of the components of the powertrain allow at least one of: the mechanical housing, thermal management systems and protection equipment, taken jointly and severally in any and all permutations, to be shared, which leads to an overall weight reduction.

[0051] Example that use a battery or battery pack are the electrical energy source provide high power density (W/m3) but at low specific energy (J/kg) and energy density (W/m3). Since the battery or batter pack is located inside the inner volume **106** of the nacelle **104** itself, instead of a central fuselage, provides an aircraft level advantage and a safety advantage over systems where the energy source is located in the fuselage. The central fuselage space is freed up for at least one, or both, of more payload and fuel cell powertrains within the fuselage. Fuel cells powertrains offer high specific energy (J/kg) but at a low energy density (J/m3) and power density (W/m3). When both batteries and fuel cells are used together, they are competing for space in the fuselage volume, which leads to a compromised solution. By placing the battery packs in the electric propulsion system (away from the fuselage), and the fuel cell powertrains in the fuselage, the aircraft can take advantage of having both sources of energy and power achieving a higher overall power density and specific energy than a traditional powertrain where only one of the two energy sources are chosen. The safety advantage is that all of the battery packs are not located in one central location on the aircraft close to the passengers/cargo, rather they are distributed in respective electric propulsion systems around the aircraft. In case of a single failure of a pack, the damage cannot propagate to all other battery packs.

[0052] Any and all examples can be realised in which the at least one fan stage comprising a fan bearing a plurality of aerodynamic surfaces/blades to generate thrust comprises a single such fan stage bearing a plurality of aerodynamic surfaces/blades to generate thrust.

[0053] Using ducted fans is more efficient than open propellers of the same diameter at low speeds (typical of electric aircraft) due to thrust generation from the duct itself. Further, the duct of the examples described herein, in addition to producing thrust, acts as a structural housing for the powertrain including the heat exchangers. The duct also acts as a safety shroud that protects the aircraft and payload in case of blade failure.

[0054] The examples described herein find particular application in electric propulsion systems that have a particular range of hub to tip ratios. The example electric propulsion systems described herein have a range of hub to top ratios of 0.2 to 0.3.

[0055] In any and all examples described and/or claims herein, the combination of having an electrical power source in the inner volume of the nacelle, a motor in the central hub, a shrouded fan and a hub-to-tip ratio of between 0.1 to 0.4, preferably, 0.2 to 0.3, allows electric propulsion systems to be realised that have favourable performance across a range of parameters such as, for example, at least one, or both, of acoustic noise and high propulsion efficiency.

[0056] When integrating the powertrain into the duct, an approach would be to also locate the electric motor drive in the rim to realise the benefits of integrating at least one, or both, of any electric motors and inverters within the duct too so that those other aspects are close to the other aspects of the power train such as, for example, one or more than one of the following taken jointly and severally in any and all permutations: energy storage, thermal management systems and power management systems. A further motivation to use rim driven motors is that they provide gear free torque merging from multiple powertrains into a single stage. However, examples can be realised in which the at least one or more than one electric motor is incorporated into a central hub while other elements of the power train are housed within the duct, that is, within the internal volume of the nacelle, which can be advantageous in certain conditions, such as, for example, when at least one or more of the following, taken jointly and severally in any and all permutations, are required or realised: when more battery capacity needs to be integrated into the duct, when one or more than one fuel cell needs to be integrated into the duct or the power required from the one or more than one electric motor is small enough for the electric motor to be positioned inside the central hub while maintaining a hub-to-tip ratio of 0.2-0.3. Having the one or more than one electric motor in the hub is advantageous since reductions can be realised in terms of weight and drag penalties associates with at least one, or both of, a longer or thicker duct, that is, an increased diameter that increases the wetted area and drag. The foregoing is contrary to conventional approaches, since in ‘low power’ situations with electric motors for a given size of a ducted fan with an inner diameter, outer diameter and hub-to-tip ratio, an electric motor can sit in various locations to drive the fan stage. For example, referring to FIG. **1**, for a given size of a ducted fan, which can be set by dimensional constrains on an aircraft, to increase or improve aerodynamic efficiency, for example, balance is chosen between contributions to thrust from the fan blades versus cross-sectional area of air-flow through the duct versus motor size, and, hence, central hub size. For instance, examples can be realised that have a hub-to-tip ratio of 0.1-0.4, or, preferably. 0.2-0.3. Therefore, for a fixed nacelle size, if a certain thrust is sought, the associated power requirements from the electric motor or electric motors can be determined. If the thrust levels and power levels are low enough such that an electric motor can be sized to fit within the ideal hub-to-tip ratio of 0.2-0.3 then, for a given duct size, the electric motor or motors might be positioned in the central hub as shown by reference **124** in FIG. **1**. As the thrust and power requirement grows, the electric motor or electric motors get bigger that, in turn, requires more ancillaries for thermal management, for instance, which begins to require a larger hub-to-tip ratio of greater than 0.3 or greater than 0.4. The foregoing, at that transition point, presents significant challenges in the design of the electric ducted fan. Firstly, the higher hub-to-tip ratio mean that less area is available for air to pass through the duct, which increases the power requirement further as the reduced air has to be accelerated to high speeds to produce the same thrust. Secondly, it becomes increasingly challenging to remove heat from the electric motor **124** through air cooling alone and liquid cooling becomes essential. If, at this transition point or stage, a rim-driven motor is employed, the increased volume available in the duct can be used for the higher power requirement and the central hub can be reduced to the original hub-to-tip ratio of 0.2-0.3 for better aero-efficiency or examples can use a hub-less arrangement with a suitable rim bearing.

[0057] Additionally, when at least one or more than one electric motor is located in the central hub, a fan stage is, or fan stages are, driven from the fan blade root at the hub as opposed to the fan blade tip near the duct as with rim driven arrangements. With rim driven systems, the shroud of the shrouded fan blades is used to support the weight of the permanent magnet rotor elements. However, when driven from the hub, there is no longer a need to provide a shrouded fan blade because the permanent magnet rotor elements are supported at the fan blade root rather than the tip. Accordingly, central hub based electric motors use open tip unshrouded fan blades. Using a shroud comprising shrouded fan blades has one or more than one key advantage such as at least one or more of the following, taken jointly and severally in any and all permutations: better control of tip leakage that otherwise cause noise and efficiency losses, lower tip degradation problems and better fan blade retention leading to safer operations. The addition of the shroud is counter intuitive since it comes at the price of increased weight. However, the increased weight is offset by appropriate design of the fan blade and shroud composite structure. A schematic of the shrouded fan blades is shown in FIGS. **6** and **7**.

[0058] Accordingly, examples provide an electric propulsion system; the system comprising

[0059] a. a nacelle comprising an aerodynamic annular housing defining an internal annular volume and defining an inner duct,

[0060] b. at least one fan stage comprising a fan bearing a plurality of aerodynamic surfaces/blades to generate thrust mounted within a fan shroud, and

[0061] c. a powertrain comprising at least one electric motor to drive the fan shroud and at least one electrical power source to power the electric motor; and

[0062] d, wherein

[0063] i. the fan shroud is disposed within the inner duct,

[0064] ii. at least part of the powertrain is disposed within the internal annular volume,

[0065] iii. the at least one electric motor is disposed within the central hub, and

[0066] iv. the hub-to-tip ratio is between 0.1 and 0.4, preferably, between 0.2 and 0.3.

[0067] Examples can be realised according to the following clauses:

1. An electric propulsion system; the system comprising

a. a nacelle comprising an aerodynamic annular housing defining an internal annular volume and defining an inner duct,

b. at least one fan stage comprising a fan bearing a plurality of aerodynamic surfaces/blades to generate thrust mounted within a fan shroud, and

c. a powertrain comprising at least one electric motor to drive the fan shroud and at least one electrical power source to power the electric motor; and

d. wherein

i. the fan shroud is disposed within the inner duct,

ii. at least part of the powertrain is disposed within the internal annular volume,

iii. the at least one electric motor is disposed within a central hub and

iv. the hub-to-tip ratio is between 0.1 and 0.4, preferably, between 0.2 and 0.3.

2. The electric propulsion system of claim **1**, in which the powertrain comprises one or more than one or more than one of: an engine control unit, at least one inverter, or a power distribution system taken jointly and severally in any and all permutations.

3. The electric propulsion system of any preceding claim in which the at least one electrical power source comprises an energy storage system.

4. The electric propulsion system of claim **3**, in which the energy storage system comprises at least one battery.

5. The electric propulsion system of claim **4**, in which the at least one battery comprises at least a partially toroidal form factor adapted to fit within internal annular volume of the nacelle.

6. The electric propulsion system of any preceding claim, in which the at least one electrical power source comprises a fuel cell to generate electrical power to power the at least one electric motor.

7. The electric propulsion system of any preceding claim comprising a thermal management system disposed within the interior volume of the nacelle.

8. The electric propulsion system of claim **7**, in which the thermal management system comprises a heat collection system carrying a heat absorbing medium.

9. The electric propulsion system of claim **8**, in which the heat absorbing medium comprises a dielectric liquid.

10. The electric propulsion system of any of claims **7** to **9**, in which the heat collection system comprises a network carrying the heat absorbing medium; the network being common to multiple heat generating elements of powertrain.

11. The electric propulsion system of any of claims **7** to **10**, in which thermal management system comprises a heat redistribution network; the heat redistribution network being arranged to redistribute heat generated by the powertrain to selectable portions of the electric propulsion system.

12. The electric propulsion system of claim **11**, in which the heat redistribution network is arranged to redistribute heat generated by the powertrain to a heat exchanger arranged to vent heat into an aft portion of the inner duct for heating air within that inner duct.

13. The electric propulsion system of claim **12**, in which the heat exchanger comprises a profiled surface adapted to radiate the heat into the inner duct.

14. The electric propulsion system of any of claims **11** to **13**, in which the heat redistribution network is arranged to redistribute heat generated by the powertrain to at least one, or more than one, of a leading edge of a fore portion of the nacelle, a leading edge of the plurality of aerodynamic surface.

15. The electrical propulsion system of any of preceding claim, comprising at least two fan stages each comprising a respective fan bearing a plurality of aerodynamic surfaces/blades to generate thrust mounted within a respective fan shroud and in which the at least one electric motor comprises at least two central hub mounted electric motors arranged to drive said respective fan shrouds.

16. The electric propulsion system of claim **15**, in which each motor of the at least two central hub mounted electric motors are operable at least one, or both, of: independently and simultaneously.

17. The electric propulsion system of any of preceding claim, in which the at least one electric motor is arranged to drive the at least one fan stage at above a threshold revolutions per minute, RPM.

18. The electric propulsion system of claim **17**, in which the threshold RPM is 2000 RPM.

19. The electric propulsion system of any preceding claim, in which the or any fan shroud is arranged to influence at least one, or both, of: air flow associated with radially extremities of the aerodynamic surface/blades of the fan or noise generated by radially extremities of the aerodynamic surface/blades of the fan.

20. The electric propulsion system of claim **19**, in which the or any fan shroud comprises a plurality of fixtures for mounting the aerodynamic surfaces/blades to the fan shroud.

21. The electric propulsion system of any preceding claim, in which the at least one fan stage is rotatably mounted for rotation on the central hub.

22. The electric propulsion system of claim **21**, comprising a plurality of load transfer members to couple load generated in response to the thrust to load bearing members for coupling to an aircraft.

23. The electric propulsion system of claim **22**, in which the plurality of load transfer members comprises a set of inlet guide vanes shaped to influence airflow into the fan stage.

24. The electric propulsion system of either of claims **22** and **23**, in which the plurality of load transfer members comprises a set of exit guide vanes shaped to influence airflow through an aft portion of the nacelle.

25. The electric propulsion system of any of claims **21** to **24**, in which the central hub comprise a bearing system for carrying the at least one fan stage; the bearing system being rotatable about a central axially disposed shaft.

26. The electric propulsion system of any preceding claim, in which the nacelle comprises three section comprising a fore section, and aft section and a middle section; the fore section comprising a leading edge of the nacelle, middle section bearing the at least one fan stage and the aft section comprising a trailing edge or exhaust section of the nacelle.

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