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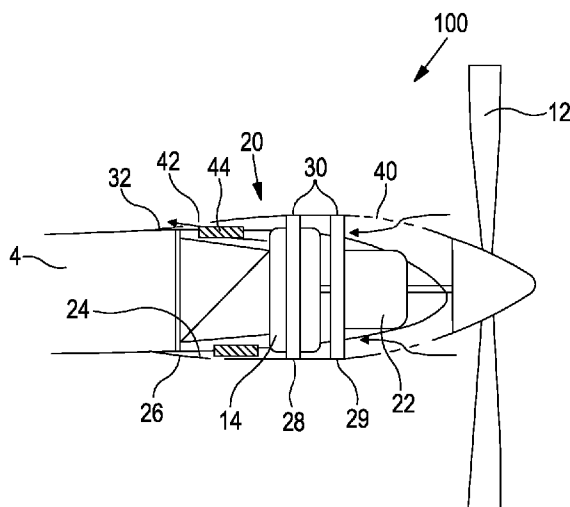


FIG. 2

(57) Abstract: A thermal management system is provided for managing the temperature of one or more components in an aircraft nacelle. The thermal management system comprises a nacelle having a profile and one or more electric components having an outer profile, the outer profile of the electric components being shaped to be conformal with the profile of the nacelle. The electric components comprise an electric motor and/or power electronics.



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SYSTEMS AND METHODS FOR AIRCRAFT

The present invention relates to systems and methods for aircraft. In particular, the present invention relates to systems such as thermal management systems, and associated methods.

5 BACKGROUND

An aircraft flight includes the following phases: taxiing to the runway; takeoff (which includes the takeoff roll); climb; cruise; descent; final approach; and landing (which includes the landing roll). In the taxiing phase, the aircraft moves to the runway under its own power. The aircraft is positioned on the runway ready for the takeoff roll. In takeoff, thrust from the aircraft propellers or jet engines
10 accelerate the aircraft up to speed during a takeoff roll, and once a suitable speed is achieved the nose of the aircraft is raised to increase lift from the wings and effect take off. In the climb phase, the aircraft climbs to cruise altitude and the aircraft speed is gradually increased. In cruise, the aircraft flies at a required altitude and, typically, at a constant speed. In the descent phase, the aircraft altitude is reduced by increasing drag. In the final approach, the aircraft is aligned with the runway before
15 landing. In the landing phase, the aircraft lands on the runway and performs the landing roll, in which the aircraft is decelerated.

Hybrid and electric aircraft have been proposed, to make one or more phases of aircraft flight, or general management, more efficient. Hybrid and electric aircraft are driven at least in part by electric components, including electric motors and power electronics. In such aircraft, it is beneficial to
20 monitor and maintain component health during operation, which may involve managing and monitoring the component temperature. Electric motors and power electronics typically require cooling. It is, however, advantageous not to use large amounts of energy providing cooling to such components. This is because power from batteries or other energy accumulators in electric aircraft will need to be diverted to power cooling systems, which could otherwise be used to propel the aircraft.

25 In addition, perhaps more generally, there is a drive to reduce pollution and other negative environmental impacts of aircraft and the aerospace industry as a whole.

“ Turnaround time” is the time between landing and a subsequent takeoff, wherein the aircraft is not in operation. Turnaround time is increased by components which are above a suitable temperature for subsequent takeoff and must be cooled before the aircraft can be allowed to take off. Hybrid and
30 electric aircraft are powered at least in part by batteries. Refuelling such aircraft involves charging batteries. This conventionally takes place on the ground, which also increases turnaround time. Decreasing turnaround time is a high priority for airlines.

It is an object of the present invention to provide improved systems for aircraft and/or to address one or more of the problems discussed above, or discussed elsewhere, or to at least provide
35 alternative systems.

SUMMARY OF THE INVENTION

According to the present invention there is provided a thermal management system, and associated method, as set forth in the appended claims. Other features of the invention will be apparent from the dependent claims, and the description which follows.

40 According to a first aspect of the present invention there is provided a thermal management system for managing the temperature of one or more components in an aircraft nacelle, the thermal

management system comprising a nacelle having a profile and one or more electric components having an outer profile, the outer profile of the electric components being shaped to be conformal with the profile of the nacelle.

5 A related aspect might relate to a method of thermal management of one or more components in an aircraft nacelle.

The electric components may comprise an electric motor and/or power electronics. The nacelle may have an inner profile and an outer profile. The outer profile of the electric components may be shaped to be conformal with the inner or outer profile of the nacelle. The outer profile of the electric components and the nacelle profile may be substantially contiguous. The outer profile of the electric components may be proximal to the inner profile of the nacelle. The electric components may be in contact with the nacelle.

15 The thermal management system may further comprise thermally conductive interface members for interfacing between the electric components and the nacelle, the interface members defining a thermally conductive path such that, when the components are in use, heat produced by the components is conducted away from the components along the conductive path toward the nacelle.

The interface members may substantially surround the components to form the nacelle. The interface members may be integrally formed with parts of the electric components. The interface members and parts of the electric components may be integrally formed by 3D printing or casting. Heat produced by the electric components may be conducted away from the components along the conductive path toward a temperature regulating region which comprises an external airflow.

20 According to a second aspect of the present invention there is provided a nacelle comprising a thermal management system according to the first aspect.

The nacelle may be comprised in an aircraft wing. The nacelle may be mounted to the aircraft by pylons.

25 According to a third aspect of the present invention there is provided an aircraft comprising a thermal management system or a nacelle as claimed in the first or second aspects.

According to a fourth aspect of the present invention there is provided a thermal management system for managing the temperature of one or more components in an aircraft nacelle, the thermal management system comprising: an inlet opening into the nacelle, an outlet opening out of the nacelle, a gas flow path extending between the inlet and outlet and at least proximal to the components to manage the component temperature, and a flow control system for selectively controlling a mass flow along the gas flow path.

30 The flow control system may be operable to control the mass flow along the gas flow path as a function of the component temperature. The flow control system may be operable to control the mass flow leaving the outlet to mitigate the aerodynamic interference caused by the presence of the nacelle.

The flow control system may comprise a transducer assembly provided in the flow path. The transducer assembly may be arranged to convert energy of the gas flow into electrical energy. The transducer assembly may comprise a turbine.

40 The thermal management system may be arranged to direct external airflow flowing past the nacelle into the inlet. The inlet may comprise a filter to reduce ingress of particulates into the system. The inlet may comprise a louvre to reduce ingress of particulates into the system.

The one or more components may be comprised in an aircraft propulsion system. The aircraft propulsion system may comprise a plurality of propellers. The one or more components may comprise an electric motor and/or power electronics.

5 According to a fifth aspect of the present invention there is provided a nacelle comprising a thermal management system according to the fourth aspect. The nacelle may be comprised in an aircraft wing.

According to a sixth aspect of the present invention there is provided an aircraft comprising a thermal management system or a nacelle according to the fourth or fifth aspect.

10 According to a seventh aspect of the present invention there is provided a method of thermal management of one or more components in an aircraft nacelle, the method comprising the steps of: providing a thermal management system comprising an inlet opening into the nacelle, an outlet opening out of the nacelle, a gas flow path extending between the inlet and outlet and at least proximal to the components; and controlling a mass flow along the gas flow path to control the temperature of the components.

15 According to an eighth aspect of the present invention there is provided a thermal management system for managing the temperature of one or more components in an aircraft nacelle, the thermal management system comprising: an airflow generator provided within the nacelle, the airflow generator configured to generate an airflow past components within the nacelle.

20 The one or more components may be comprised in an aircraft propulsion system. The one or more components may comprise an electric motor and/or power electronics. The airflow generator may comprise a fan. The thermal management system may comprise a rotatable drive shaft and the airflow generator may be fixed to the drive shaft.

The drive shaft may be comprised in an aircraft propulsion system. The drive shaft may be a drive shaft for a propeller. The airflow generator may compress the airflow.

25 The thermal management system may comprise an inlet opening into the nacelle, an outlet opening out of the nacelle, a gas flow path extending between the inlet and outlet. In use, the airflow generator may draw gas into the nacelle from outside of the nacelle. The gas flow path may pass through the airflow generator, and the airflow generator may be operable to control the mass flow along the gas flow path.

30 According to a ninth aspect of the present invention there is provided a nacelle comprising a thermal management system according to the eighth aspect.

The nacelle may be comprised in an aircraft wing.

According to a tenth aspect of the present invention there is provided an aircraft comprising a thermal management system or a nacelle according to the eighth or ninth aspects.

35 According to an eleventh aspect of the present invention there is provided a method of thermal management of one or more components in an aircraft nacelle, the method comprising the steps of: providing a thermal management system comprising an airflow generator provided within the nacelle; and generating an airflow within the nacelle to control the temperature of the one or more components in the nacelle.

40 According to a twelfth aspect of the present invention there is provided a thermal management system for managing the temperature of one or more components in an aircraft nacelle, the thermal

management system comprising: a rotatable hub of an aircraft propulsion system, the hub comprising an aperture for facilitating airflow into the nacelle via the aperture.

The hub may comprise a hub duct extending through the hub and the aperture may open into the duct. The aircraft propulsion system may comprise one or more propellers and the hub is a propeller
5 hub.

The thermal management system may further comprise a fairing provided over the hub, the fairing comprising an aperture for facilitating airflow through the rotatable hub aperture via the fairing aperture. The fairing may comprise a fairing duct extending through the fairing and the aperture opens into the duct.

10 The thermal management system may comprise an airflow generator for drawing air into the nacelle through the hub aperture. The fairing duct may comprise channels which, when the fairing is rotated, draws air into the nacelle. The rotating channels may increase the pressure of the airflow. The fairing may be 3D printed and/or cast with the channels integrally formed.

15 The thermal management system may comprise an outlet opening out of the nacelle, a gas flow path extending between the and outlet. The one or more components may comprise an electric motor and/or power electronics.

According to a thirteenth aspect of the present invention there is provided a nacelle comprising a thermal management system according to the twelfth aspect.

The nacelle may be comprised in an aircraft wing.

20 According to a fourteenth aspect of the present invention there is provided an aircraft comprising a thermal management system or a nacelle according to the eleventh or twelfth aspects.

According to a fifteenth aspect of the present invention there is provided a method of thermal management of one or more components in an aircraft nacelle, the method comprising the steps of: providing a thermal management system comprising a rotatable hub of an aircraft propulsion system,
25 the rotatable hub comprising an aperture for facilitating airflow into the nacelle via the aperture; and generating an airflow within the nacelle via the aperture to control the temperature of the one or more components in the nacelle.

Although some exemplary embodiments of the present invention are shown and described, it will be appreciated by those skilled in the art that various changes and modifications might be made
30 without departing from the scope of the invention, as defined in the appended claims.

Additionally, it will be appreciated that the various aspects and embodiments are closely related in terms of concept and technical implementation, and as a result various features of those aspects and embodiments are clearly combinable with one another, and/or may replace one another, unless such combination or replacement would be understood by the skilled person reading this
35 disclosure to be mutually exclusive.

BRIEF DESCRIPTION OF THE DRAWINGS

For a better understanding of the invention, and to show how embodiments of the same may be carried into effect, reference will now be made, by way of example only, to the accompanying diagrammatic drawings in which:

40 Figure 1 shows an aircraft according to an embodiment of the present invention;

Figure 2 shows an aircraft nacelle comprising a thermal management system according to an embodiment of the present invention;

Figure 3 shows a general thermal management system according to an embodiment of the present invention;

5 Figure 4 shows a general thermal management system according to an embodiment of the present invention;

Figure 5 shows general methodology principles associated with a thermal management system according to an embodiment of the present invention;

10 Figure 6 shows an aircraft nacelle comprising a thermal management system according to an embodiment of the present invention;

Figure 7 shows a general thermal management system according to an embodiment of the present invention;

Figure 8 shows general methodology principles associated with a thermal management system according to an embodiment of the present invention;

15 Figure 9 shows an aircraft nacelle comprising a thermal management system according to an embodiment of the present invention;

Figure 10 shows a general thermal management system according to an embodiment of the present invention; and

20 Figure 11 shows general methodology principles associated with a thermal management system according to an embodiment of the present invention;

DETAILED DESCRIPTION

Referring to Figure 1, an aircraft 1 comprises a fuselage 2, wings 4, an empennage or tail assembly 6 and landing gear comprising wheels 8. The aircraft further comprises a propulsion system comprising an air propulsion system 10. The air propulsion system 10 comprises propellers 12 and air propulsion system motors 14 arranged to drive the propellers 12. The air propulsion system 10 is connected to a power supply 16 comprising an energy accumulator, which in this exemplary embodiment, comprises a battery 18. The battery 18 is configured to supply power to the air propulsion system motors 14. The aircraft is therefore an electric, or at least hybrid, aircraft.

30 In this exemplary embodiment the air propulsion system 10 comprises four propellers 12. Nevertheless, it will be appreciated by the person skilled in the art that the air propulsion system 10 may comprise any suitable number of propellers 12 and associated air propulsion system motors 14. For example, the air propulsion system 10 may comprise one, two, three, four, five or six propellers 12. It is highly advantageous for propellers 12 to be positioned such that the force produced by the air propulsion system 10 is substantially symmetric either side of the aircraft fuselage 2.

35 Referring to Figure 2, each air propulsion system motor 14 is housed, or received, in a nacelle 20. Power electronics 22 relating to each motor 14 is also housed in the nacelle 20 alongside the motor 14. Whilst the power electronics 22 can alternatively be housed elsewhere in the aircraft 1, it is advantageous to house them alongside the motor 14 in the nacelle 20 so that the temperature of the power electronics 22 and motor can be managed using thermal management systems provided for both
40 components, as will be described in greater detail below.

A nacelle is perhaps typically understood to relate to or be a streamlined casing (or pod) on the outside of an aircraft, especially one housing an aircraft engine or motor, or other (e.g. propulsion system) components. However, a nacelle is alternatively or additionally described or defined as a housing, or streamlined casing, for an aircraft, in general, especially one housing an aircraft engine or motor, or other (e.g. propulsion system) components. That is, a nacelle does not need to be 'outside' of an aircraft or separate to an aircraft fuselage. For example, a nacelle may be located in a nose of an aircraft, in a tail of an aircraft, or in a wing, tail or fin of an aircraft. For example, a nacelle may be integral to the main body or fuselage of an aircraft, such as in the tail assembly or nose cone, and hold or house propulsion components, motors, power supplies, electronics, or other equipment on an aircraft including motors and power electronics (i.e. electronic components, or components in general associated with management or propulsion of the aircraft).

A thermal management system 100 is devised for managing the temperature of components housed, or received, in the nacelle 20. The thermal management system 100 functions to manage the temperature of components in dependence upon the ambient temperature external to the aircraft 1. Such a construction is advantageous as it may eliminate the need for additional thermal management systems for the aircraft motors 14 and power electronics 22. Moreover, a cooling flow of air will be constantly present during flight, or motion in general, thus allowing the motors 14 to be cooled in a manner which does not require additional energy input. In exemplary embodiments, the thermal management system 100 is a cooling system for cooling one or more components in an aircraft nacelle 20.

Depending on ambient temperatures, the thermal management might involve heating of components, for example when ambient temperatures are higher than temperatures in the nacelle, or temperate of components in the nacelle.

Each nacelle 20 has an inner profile and an outer profile defined by inner surfaces 24 and outer surfaces 26 of the nacelle 20. Each air propulsion system motor 14 and power electronics unit 22 has an outer profile defined by outer surfaces 28 of the motor 14 and outer surfaces 29 of the power electronics unit 22. In the thermal management system 100, the outer profile, or outer surfaces 28, of each motor 14 is shaped to be conformal with the outer profile, or outer surface 26 of its respective nacelle 20. The outer profile, or outer surfaces 29, of each power electronics unit 22 is shaped to be conformal with the outer profile, or outer surface 26, of its respective nacelle 20. In another exemplary embodiment, the outer profile, or outer surfaces 28, of each motor 14 is shaped to be conformal with the inner profile, or inner surface 24 of its respective nacelle 20. The outer profile, or outer surfaces 29, of each power electronics unit 22 is shaped to be conformal with the inner profile, or inner surface 24, of its respective nacelle 20.

As explained below, conformal means, in general, that the two respective components take the same general shape. The components might be in contact, or close proximity, or contiguous, sufficient for thermal transfer to be effective.

A conformal motor 14 and power electronics unit 22 is advantageous as it not only reduces the spatial footprint of the nacelle 20, thus improving aerodynamics, but also ensures that the motor 14 and power electronics unit 22 are close to, or at, or even forming, a surface of the nacelle 20, thus improving transfer of heat from the motor 14 and electronics unit 22 to the surrounding air. A thermal management system 100 can therefore be provided wherein the motor 14 and power electronics unit 22

are exposed to an external flow of air. An additional advantage is that the close fitting of motor 14, power electronics unit 22 and nacelle 20 facilitates easier access to the motor 14 for maintenance and inspection.

The exterior profile of the nacelle 20 is defined by the nacelle outer mould line 26. In an exemplary embodiment, the outer profile, or exterior surface 28, of each motor 14 is shaped to be conformal with the exterior surface 26 of its respective nacelle 20, such that the outer profiles are contiguous, and the nacelle 20 has a continuous outer skin. This may also be described as the motor 14 being at least partially at the nacelle outer surface 26, or forming that surface. Such a construction is advantageous as part of the motor 14 is directly in contact with ambient airflow around the nacelle 20. In another exemplary embodiment, the outer profile of each motor 14 is shaped to be conformal with an interior profile of the nacelle 20 to ensure that the motor 14 is proximal to the nacelle 20 which substantially surrounds the motor 14. That is, the outer profile of each motor 14 closely follows the interior profile of the nacelle 20. Benefits are obtained by the motor 14 being proximal to, or closely following, the nacelle 20 in that conductive transfer of heat is improved. In another exemplary embodiment, the outer profile of each motor 14 is shaped to ensure that the motor 14 is in contact with the nacelle 20, at least at the points wherein significant heat is generated. The points of contact facilitate the conduction of heat.

In this exemplary embodiment, the outer profile of each motor 14 is defined by thermally conductive interface members 30 which are 3D printed manifolds extending from various parts of the motor 14. Interface members 30 also extend from various parts of the power electronics 22. The interface members 30 are thus integrally formed with the motor 14 and power electronics 22. The interface members 30 substantially surround the motor 14 and power electronics 22. Whilst 3D printed manifolds are comprised in this exemplary embodiment, casting could also be used to manufacture integrally formed components and interface members 30.

The interface members 30 are conformal with the exterior surface 26 of the nacelle 20, such that the interface members 30 are contiguous with the exterior profile of the nacelle 20, thereby forming part of the nacelle outer mould line 26. The interface members 30 therefore provide a thermally conductive path from the motor 14 to an external airflow around the nacelle 20. When the motor 14 is in use, the heat produced by the motor 14 is conducted away from the motor 14 along the conductive path. The external shape of the motor 14 is therefore adapted to form the external skin of the nacelle 20. The interface members 30 facilitate a weight saving, as well as a cooling benefit, as a separate nacelle 20 (or nacelle region or portion) need not be provided in addition to the interface members 30 to form a conductive path between the motor 14 and nacelle 20. That is, in an exemplary embodiment, the motor 14, in effect, is the nacelle 20.

In an exemplary embodiment, an exterior surface 32 at the rear of the nacelle 20 is comprised (i.e. located) in the aircraft wing 4. The exterior surface 28 of each air propulsion system motor 14 is shaped to be conformal (e.g. contiguous) with the profile of the wing in the region of the exterior surface 32 at the rear of the nacelle 20. The conformal, or matching, shape of the outer profile of the motors 14 and wings 4 reduces drag and provides cooling due to airflow over the wings 4, and by extension, the nacelles 20. In another exemplary embodiment, the nacelles are mounted to the aircraft by pylons extending below the wings, or from the fuselage 2 or tail assembly 6.

In Figure 3, a general thermal management system 100 according to an embodiment of the present invention is shown. The thermal management system 100 is for managing the temperature of one or more components in an aircraft nacelle 20. The thermal management system 100 comprises a nacelle 20 having a profile and one or more electric components 14, 22 having an outer profile, the outer profile of the electric components 14, 22 being shaped to be conformal with the profile of the nacelle 20.

Referring back to Figure 2, the thermal management system 100 comprises an inlet 40, opening into internal volume of the nacelle 20, and an outlet 42. In an exemplary embodiment, the inlet 40 and outlet 42 are of the type developed by the National Advisory Committee for Aeronautics (NACA). A gas flow path extends between the inlet 40 and outlet 42 through the nacelle and passes over and around the motor 14 and power electronics 22 housed within the nacelle 20. In this example the inlet 40 is shaped to provide an axisymmetric flow, which ensures that shear forces are not applied to the nacelle 20. For example, inlets 40 and/or outlets 42 might be distributed evenly or uniformly, or symmetrically, about the nacelle 20. Additionally, or alternatively, the inlet 40 can be shaped to provide cooling to specific components, or to maximise the positive pressure at the inlet 40. The inlet 40 and outlet 42 are arranged to reduce ingress of particulates into the nacelle 20. The inlet 40 and outlet 42 are positioned on an upper surface of the nacelle 20. The inlet 40 comprises a louvre filter to reduce ingress of particulates into nacelle 20. The outlet 42 might have similar functionality. The inlet 40 also comprises a recirculation system for improved protection from freezing and ice build-up, which is typically an electric recirculation system, but may be a gas recirculation system. The motor 14 and power electronics 22 are provided with temperature sensors. The motor 14 and power electronics 22 are provided downstream in the gas flow path, so that the gas (e.g. air) can flow through the inlet 40 and over or around the motor 14 and power electronics 22, before leaving the nacelle 20 via outlet 42. Such a thermal management system is advantageous in ensuring the motor and power electronics provided in the nacelle do not overheat.

A flow control system 44 is built into the outlet 42. The flow control system 44 is operable to selectively control a mass flow along the gas flow path. In an exemplary embodiment, the flow control system 44 comprises an autonomous aperture control to throttle the mass flow to achieve a desired motor and/or power electronics temperature. Opening the aperture allows a greater mass flow through the nacelle 20, thus cooling the components therein. Conversely, closing the aperture reduces mass flow through the nacelle 20, allows the components housed therein to heat. Such “throttling” of the air flow allows the system to ensure that component temperature is always optimum. In a related example, such a flow control system could also, or alternatively, be located at the inlet 40.

In this example, the flow control system 44 comprises turbines comprising turbine motors. The turbines are provided in addition to, or in place of, the autonomous aperture control. The turbines rotate creating suction through the nacelle 20, which draws air through the nacelle 20 at a greater rate. The rate of airflow through the nacelle 20 is thus a function of the rotational velocity of the turbines. By increasing the rate of airflow, the motor 14 and power electronics 22 can be cooled more rapidly, and by decreasing the rate of airflow, they can be cooled less rapidly, the temperature maintained, or the components 14, 22 allowed to heat. The temperature of the components 14, 22 is monitored, and an appropriate load (e.g. electrical or mechanical) is placed on the turbine motors to increase or decrease

the rotational velocity of the turbines, to thereby increase or decrease the rate of airflow through the nacelle 20 as necessary or desired. The turbine motors are, in this example, connected to a battery, such that a greater motor load produces an increased rate of battery charging and a reduced motor load produces a reduced rate of battery charging. Energy recovery is thus facilitated. Whilst in this exemplary embodiment Li-Ion batteries are employed, supercapacitors and flywheels are also a feasible alternative energy accumulators or energy storage means.

Exhaust air from the outlet 42 opening out of the nacelle 20 is ejected upwardly out of the nacelle 20 onto the wing upper surface. The aerodynamic interference caused by the presence of the nacelle 20 can thus be controlled or offset, using the air that emerges from the nacelle outlet 42. The low pressure on the upper surface of the wing 4 will augment the flow rate and provide the maximum pressure difference to induce airflow through the nacelle 20. At low aircraft forward speed, induced flow over the wing is used to relieve flow separations around and behind the nacelle. At high aircraft forward speed, induced flow over the wing can be managed by shaping of the nacelle, such as conformal shaping.

In Figure 4, a general thermal management system 110 according to an embodiment of the present invention is shown. The Figures are used to describe different general thermal management system and methods, but it will be appreciated that these might relate to the same or closely related system or method. Different reference numerals have been used, simply to denote different general functions.

The thermal management system 110 is for managing the temperature of one or more components 14, 22 in an aircraft nacelle 20. The thermal management system comprises an inlet 40 opening into the nacelle 20, an outlet 42 opening out of the nacelle 20, a gas flow path extending between the inlet 40 and outlet 42 and at least proximal to the components to manage the component temperature, and a flow control system 44 for selectively controlling a mass flow along the gas flow path.

In Figure 5, general methodology principles associated with a thermal management system 110 according to an embodiment of the present invention are shown. Step 46 comprises providing a thermal management system comprising an inlet 40 opening into the nacelle 20, an outlet 42 opening out of the nacelle 20, a gas flow path extending between the inlet 40 and outlet 42 and at least proximal to the components 14, 22. Step 48 comprises controlling a mass flow along the gas flow path to control the temperature of the components 14, 22.

Referring to Figure 6, an airflow generator 50 is provided in the nacelle 20. The airflow generator 50 is positioned forward of the motor 14 and power electronics in the nacelle 20. The airflow generator 50 is configured to generate an airflow past components within the nacelle 20. In this exemplary embodiment, the airflow generator 50 is positioned forward of the components and is therefore configured to provide an airflow past the components, the airflow being toward a rear of the nacelle 20. Nevertheless, it will be appreciated that the airflow generator 50 could be positioned rearward of the components, and therefore configured to draw airflow past the components from a different position.

The airflow generator 50 comprises a fan 52 operably connected to the rotating drive shaft 54 of the motor 14. The drive shaft 54 extends through the central hub of the fan 52 such that the fan 52 and drive shaft 54 are coaxial, and the fan 52 is fixed to the drive shaft 54 such that rotation of the

drive shaft 54 induces equivalent rotation of the fan 52. In other words, the airflow generator 50 is directly driven by the drive shaft 54. This means that there is synergy, in that driving of the propellers 12 will cause heating of the motor 14, but such driving also causes rotate of fan 52, which serves to cool the motor 12. The inlets and outlets of the previous embodiment may be useful for facilitating such an airflow, or an improved airflow.

In an exemplary embodiment, the thermal management system 110 comprises an airflow generator 50, an inlet 40 opening into the nacelle 20 and an outlet 42 opening out of the nacelle 20 defining a gas flow path, as described above. The airflow generator 50 is positioned upstream of the motor 14 and power electronics 22 in the gas flow path. Operation of the airflow generator 50 creates a region of lower pressure within the nacelle 20, which draws air through the inlet 40 into the nacelle 20 from outside the nacelle 20. In an exemplary embodiment, the airflow generator 50 comprises a radial compressor operably connected to the drive shaft 54. Cooling of the motor 14 and power electronics 22 is critical to performance, and such a system can induce improved air flow through the nacelle when compared with a simpler inlet/outlet, or “ram air”, system. Rotational velocity of the airflow generator 50 is controllable to control the mass flow of air through the nacelle 20.

In one example, the airflow generator could take the form of an internal surface (that is, facing into the nacelle) of a hub for the propeller, such that a dedicated, separate component (e.g. a fan) is not required. The internal surface could be shaped or textured to provide or drive such air flow.

In Figure 7, a general thermal management system 120 according to an embodiment of the present invention is shown. The thermal management system 100 is for managing the temperature of one or more components 14, 22 in an aircraft nacelle. The thermal management system 100 comprises an airflow generator 50 provided within the nacelle 20, the airflow generator 50 configured to provide an airflow past components 14, 22 within the nacelle 20.

In Figure 8, general methodology principles associated with a thermal management system 120 according to an embodiment of the present invention are shown. Step 56 comprises providing a thermal management system comprising an airflow generator provided within the nacelle. Step 58 comprises generating an airflow within the nacelle to control the temperature of the one or more components in the nacelle.

Referring to Figure 9, the air propulsion system 6 comprises propellers 12 and air propulsion system motors 14 arranged to drive the propellers 12. The propellers 12 are connected to the motors 14 via a drive shaft 54 and the central hub 60 of the propeller 12 is fixed to the drive shaft 54 such that rotation of the drive shaft 54 induces propeller rotation. A substantially conical fairing 62, or nose cone, is provided over the hub 60. The fairing tip is the foremost point of the propeller/nacelle construction. Thus, in flight, it experiences maximum positive pressure or “stagnation pressure”.

The fairing 62 and hub 60 comprise apertures 64 for facilitating airflow into the nacelle 20 via the apertures 64. The apertures 64 open into flow paths through the hub 60 and fairing 62. The hub 60 comprises an inlet opening into a hub duct defining a flow path formed within the hub, and an outlet opening out of the duct into the nacelle 20. The fairing 62 comprises an inlet opening into a fairing duct defining a flow path formed within the fairing 62, and an outlet opening out of the duct into the hub aperture. The fairing 62 is 3D printed to form a fairing 62 that is hollow and comprises airflow channels 66 integrally formed within the ducting. The channels 66 allow high pressure air to flow

through the fairing 62, around the bearings of the hub 60, and into the nacelle 20 to provide a cooling airflow. In an exemplary embodiment, and as alluded to above, the internal channels 66, or ducting, is shaped to form an axial compressor. The fairing 62 is fixed over the propeller hub 60 and rotation of the fairing energises the airflow. Whilst in this exemplary embodiment the fairing 62 is 3D printed, it could be cast to form the fairing comprising integrally formed airflow channels 66.

It is notable that such a construction enables cooling air flow into the nacelle 20 even when the aircraft 1 is not in flight, or in motion. During a taxiing phase of flight, the aircraft 1 is often required to wait until space becomes available on the runway for takeoff. The aircraft 1 sits with the propellers 12 rotating, but the brakes applied such that the aircraft 1 has no forward velocity. By the provision of a propeller fairing 62 comprises channels 66 for drawing air into the nacelle, rotation of the propellers 12 creates a cooling airflow through the nacelle 20 even when the aircraft 1 has no forward velocity.

Whilst in this exemplary embodiment both the fairing 62 and hub 60 comprise apertures 64, it will be appreciated by the person skilled in the art that a fairing 62 need not be provided, and the hub 60 may be shaped, or comprise integrally formed and appropriately shaped manifolds, to form a hub 60 with a conical frontward portion.

In Figure 10, a general thermal management system 130 according to an embodiment of the present invention is shown. The thermal management system 130 is for managing the temperature of one or more components 14, 22 in an aircraft nacelle 20. The thermal management system comprises a rotatable hub 60 of an aircraft propulsion system 6, the hub 60 comprising an aperture 64 for facilitating airflow into the nacelle 20 via the aperture 64.

In Figure 11, general methodology principles associated with a thermal management system 130 according to an embodiment of the present invention are shown. Step 68 comprises providing a thermal management system comprising a rotatable hub of an aircraft propulsion system, the rotatable hub comprising an aperture for facilitating airflow into the nacelle 20 via the aperture 64. Step 70 comprises generating an airflow within the nacelle via the aperture to control the temperature of the one or more components in the nacelle. This could be via general airflow, airflow due to movement of the aircraft, or driven airflow (e.g. using an airflow generator).

In summary, we provide systems for managing the temperature of components, in particular electric components, provided in aircraft nacelles. Such systems facilitate cooling, both whilst the aircraft is in flight, or stationary. Exemplary embodiments of these systems are energy efficient and require little or no electrical power to operate. Other exemplary embodiments facilitate energy recovery whilst also providing cooling. Accurate control of component temperature is facilitated by the provision of flow control systems, airflow generation within the nacelle and propeller hub and fairing design. Finally, the systems can be provided in new aircraft or can be retrofitted in existing aircraft to provide improved performance during the various stages of aircraft flight.

At least some of the example embodiments described herein may be constructed, partially or wholly, using dedicated special-purpose hardware. Terms such as 'component', 'module' or 'unit' used herein may include, but are not limited to, a hardware device, such as circuitry in the form of discrete or integrated components, a Field Programmable Gate Array (FPGA) or Application Specific Integrated Circuit (ASIC), which performs certain tasks or provides the associated functionality. In some embodiments, the described elements may be configured to reside on a tangible, persistent, addressable

storage medium and may be configured to execute on one or more processors. These functional elements may in some embodiments include, by way of example, components, such as software components, object-oriented software components, class components and task components, processes, functions, attributes, procedures, subroutines, segments of program code, drivers, firmware, microcode, circuitry, data, databases, data structures, tables, arrays, and variables. Although the example
5 embodiments have been described with reference to the components, modules and units discussed herein, such functional elements may be combined into fewer elements or separated into additional elements. Various combinations of optional features have been described herein, and it will be appreciated that described features may be combined in any suitable combination. In particular, the
10 features of any one example embodiment may be combined with features of any other embodiment, as appropriate, except where such combinations are mutually exclusive. Throughout this specification, the term “comprising” or “comprises” means including the component(s) specified but not to the exclusion of the presence of others.

Although a few preferred embodiments have been shown and described, it will be appreciated
15 by those skilled in the art that various changes and modifications might be made without departing from the scope of the invention, as defined in the appended claims.

Attention is directed to all papers and documents which are filed concurrently with or previous
to this specification in connection with this application and which are open to public inspection with
this specification, and the contents of all such papers and documents are incorporated herein by
20 reference.

All of the features disclosed in this specification (including any accompanying claims, abstract
and drawings), and/or all of the steps of any method or process so disclosed, may be combined in any
combination, except combinations where at least some of such features and/or steps are mutually
exclusive.

Each feature disclosed in this specification (including any accompanying claims, abstract and
25 drawings) may be replaced by alternative features serving the same, equivalent or similar purpose, unless expressly stated otherwise. Thus, unless expressly stated otherwise, each feature disclosed is one example only of a generic series of equivalent or similar features.

The invention is not restricted to the details of the foregoing embodiment(s). The invention
30 extends to any novel one, or any novel combination, of the features disclosed in this specification (including any accompanying claims, abstract and drawings), or to any novel one, or any novel combination, of the steps of any method or process so disclosed. The invention and above-described features, elements and systems may be adopted or deployed in other transportation and vehicular systems, aerial or otherwise, such as in manned or unmanned drones.

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CLAIMS

1. A thermal management system for managing the temperature of one or more components in an aircraft nacelle, the thermal management system comprising a nacelle having a profile and one or more electric components having an outer profile, the outer profile of the electric components being shaped to be conformal with the profile of the nacelle.
2. A thermal management system as claimed in claim 1 wherein the electric components comprise an electric motor and/or power electronics.
3. A thermal management system as claimed in either of claims 1 or 2 wherein the nacelle has an inner profile and an outer profile, and the outer profile of the electric components is shaped to be conformal with the inner or outer profile of the nacelle.
4. A thermal management system as claimed in claim 3 wherein the outer profile of the electric components is proximal to the inner profile of the nacelle.
5. A thermal management system as claimed in any preceding claim wherein the outer profile of the electric components and the nacelle profile are substantially contiguous.
6. A thermal management system as claimed in any preceding claim wherein the electric components are in contact with the nacelle.
7. A thermal management system as claimed in any preceding claim wherein the thermal management system further comprises thermally conductive interface members for interfacing between the electric components and the nacelle, the interface members defining a thermally conductive path such that, when the components are in use, heat produced by the components is conducted away from the components along the conductive path toward the nacelle.
8. A thermal management system as claimed in claim 7 wherein the interface members substantially surround the components to form the nacelle.
9. A thermal management system as claimed in either of claims 7 or 8 wherein the interface members are integrally formed with parts of the electric components.
10. A thermal management system as claimed in any of claims 7 to 9 wherein the interface members and parts of the electric components are integrally formed by 3D printing or casting.
11. A thermal management system as claimed in any of claims 7 to 10 wherein heat produced by the electric components is conducted away from the components along the conductive path toward a temperature regulating region which comprises an external airflow.

12. A nacelle comprising a thermal management system as claimed in any preceding claim.
13. A nacelle as claimed in claim 12 wherein the nacelle is comprised in an aircraft wing.
- 5
14. A nacelle as claimed in either of claims 12 or 13 wherein the nacelle is mounted to the aircraft by pylons.
15. An aircraft comprising a thermal management system or a nacelle as claimed in any preceding
- 10 claim.

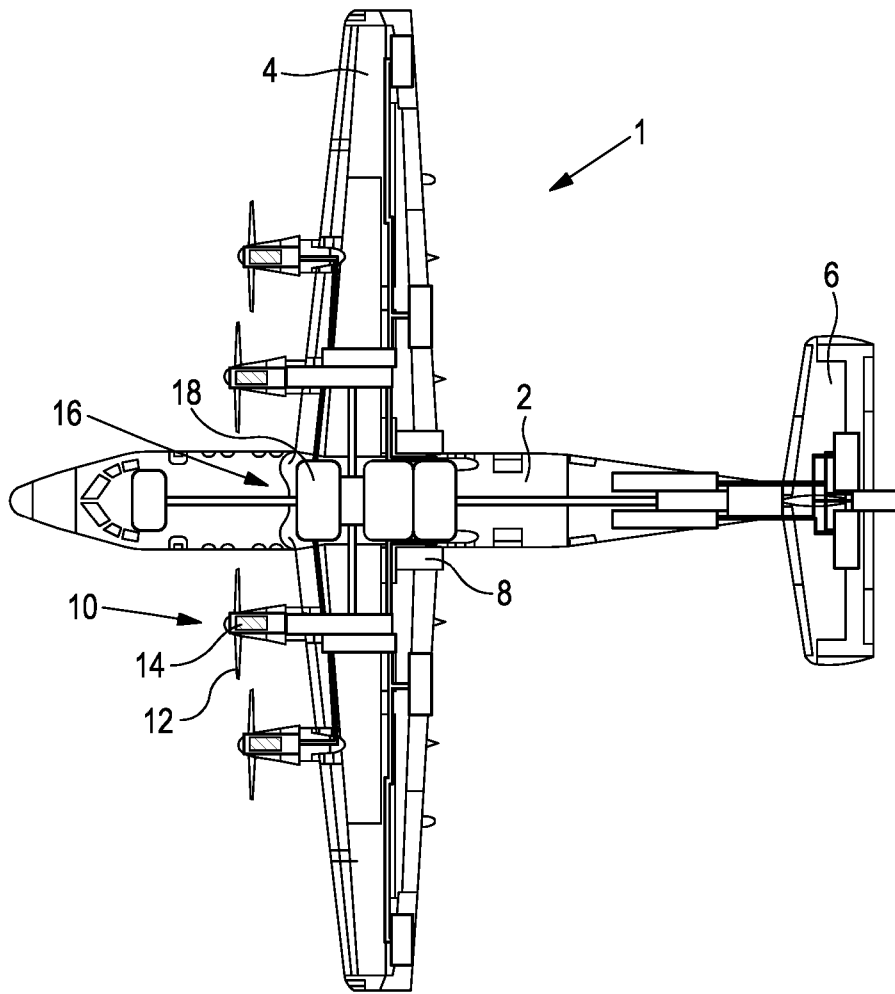


FIG. 1

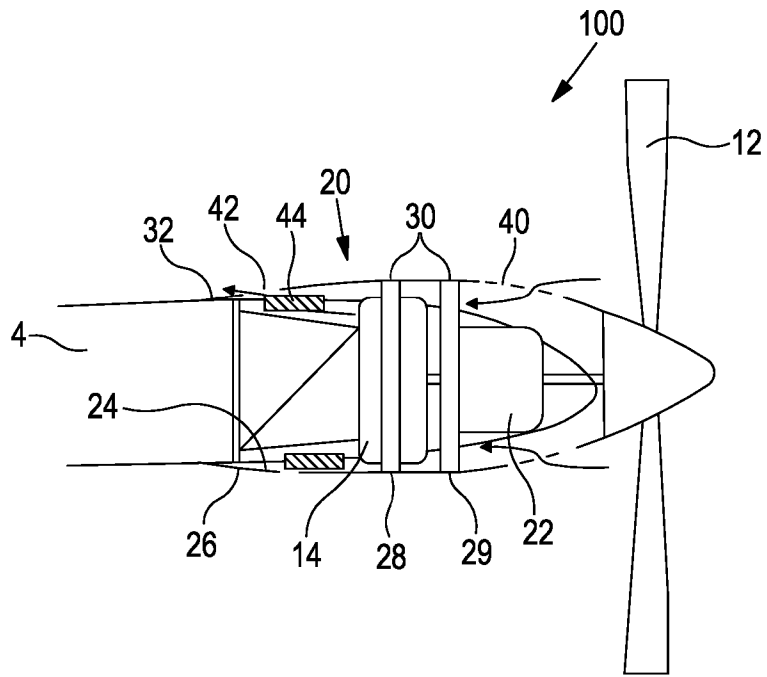


FIG. 2

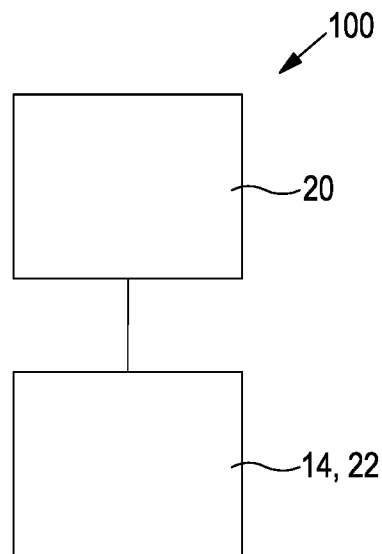


FIG. 3

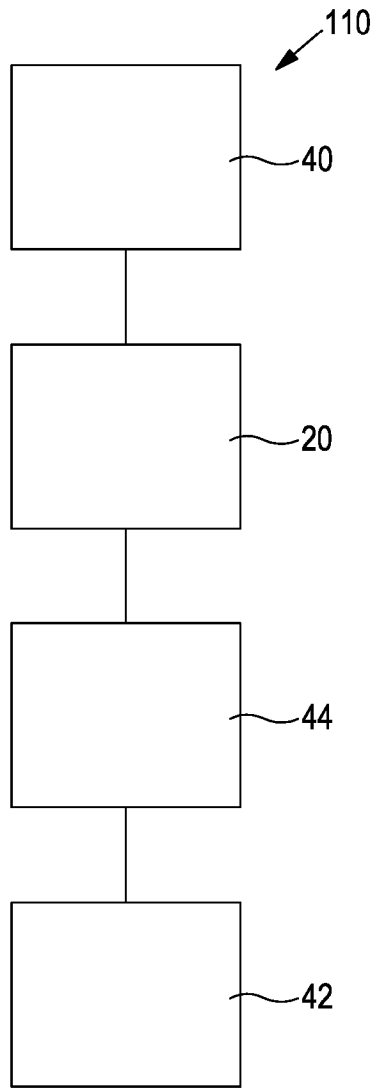


FIG. 4

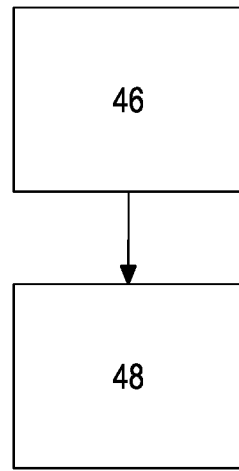


FIG. 5

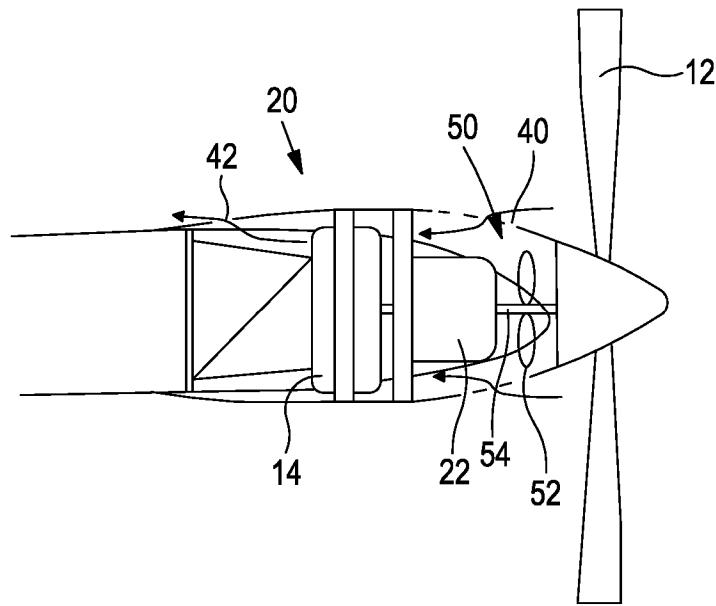


FIG. 6

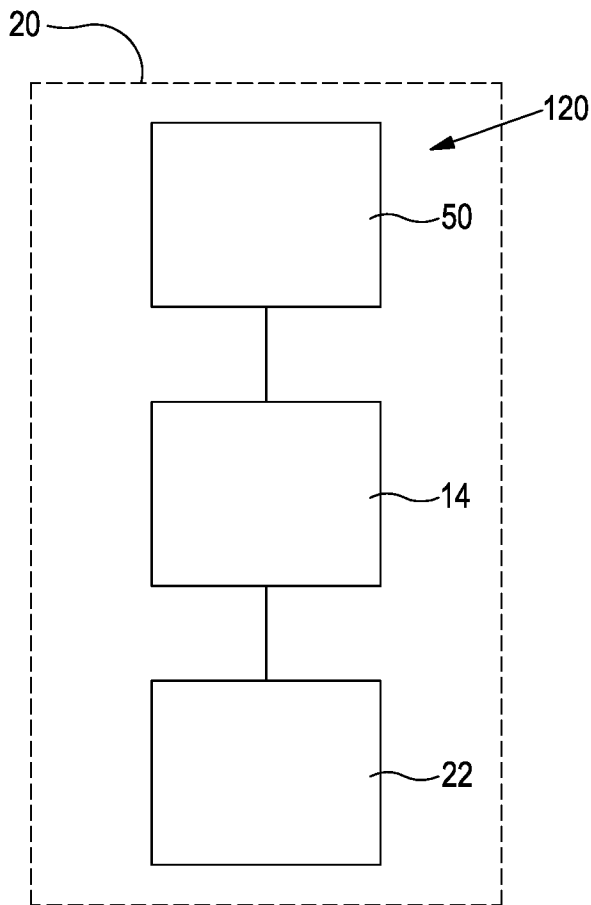


FIG. 7

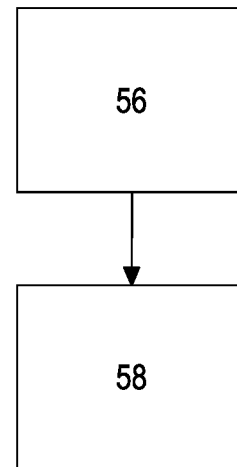


FIG. 8

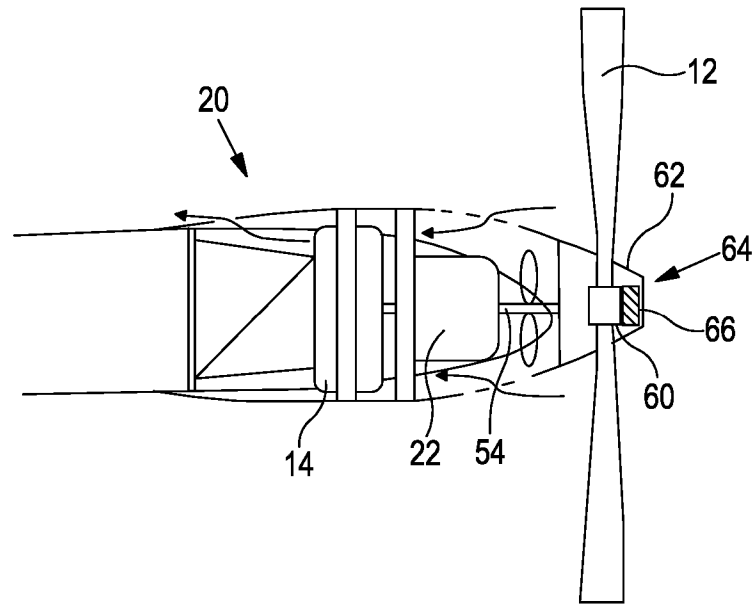


FIG. 9

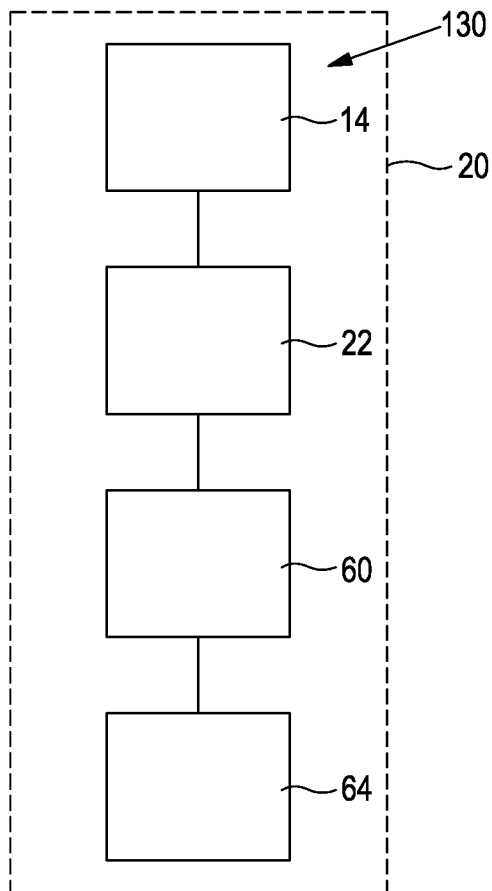


FIG. 10

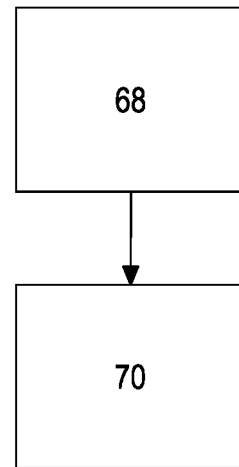


FIG. 11