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Aircraft comprising a control unit to run at least one of rotational apparatus or control apparatus based on temperature

Abstract

Freezing of an electrical component of a VTOL rotor is prevented. The aircraft **100** includes a fuselage **12**, a VTOL rotor **20** including one or more blades **23** that is supported on the boom **18** to be spaced apart from the fuselage for generating thrust in a vertical direction during take-off and landing, a motor **21** that is stored in the boom and is configured to cause the one or more blades to rotate, and an inverter **22** for controlling the motor, a detection unit **80** configured to detect a temperature of at least one apparatus of the motor or the inverter, and a control unit **99** configured to run the at least one apparatus based on a thrust request for a plurality of VTOL rotors and a detection result of the temperature.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS

(1) The contents of the following Japanese patent application(s) are incorporated herein by reference: NO. 2021-215050 filed in JP on Dec. 28, 2021

BACKGROUND

1. Technical Field

(2) The present invention relates to an aircraft and a method.

2. Related Art

(3) Conventionally, a vertical take-off and landing type aircraft (also called a vertical take-off and landing aircraft or simply an aircraft) is known which performs take-off and landing by elevating and lowering in a vertical direction with rotors for vertical take-off and landing (VTOL) arranged on the right side and the left side of the fuselage, and flies in a horizontal direction with a cruising rotor arranged on the back portion of the fuselage. Here, in Patent Document 1, it is described that a chamber for storing a rotor element and a heating apparatus for heating the chamber is provided in order to prevent freezing of the rotor element of the VTOL rotor due to low temperature during winter or low temperature accompanied by cruising altitude. However, addition of the heating

apparatus is required and a backup for a case where the heating apparatus experiences a failure.
Patent Document 1: U.S. Patent Application Publication No. 2020/0031478

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) FIG. **1** illustrates a configuration of an aircraft according to the present embodiment in a top view.

(2) FIG. **2**A illustrates an internal configuration of a boom.

(3) FIG. **2**B illustrates a configuration of a radiator in a front view.

(4) FIG. **2**C illustrates the configuration of the radiator in a side view.

(5) FIG. **2**D illustrates a circuit configuration of a cooling system.

(6) FIG. **3** illustrates a configuration of a control system for a heat generation unit for causing heat generation of the electrical components of a VTOL rotor and a cooling system for cooling thereof.

(7) FIG. **4** illustrates a flow of a heat generation and cooling method of the electrical components of the VTOL rotor.

(8) FIG. **5** illustrates another flow of a heat generation and cooling method of the electrical components of the VTOL rotor.

DESCRIPTION OF EXEMPLARY EMBODIMENTS

(9) Hereinafter, the present invention will be described through embodiments of the invention, but the following embodiments do not limit the invention according to the claims. In addition, not all combinations of features described in the embodiments are essential to the solution of the invention.

(10) FIG. **1** illustrates a configuration of an aircraft **100** according to the present embodiment in a top view. The aircraft **100** includes a rotor having an electric motor as its driving source, is a vertical take-off and landing aircraft that performs take-off and landing in a vertical direction by using rotors for vertical take-off and landing (VTOL) to generate thrust, as well as flies in a horizontal direction by using a cruising rotor (also called a cruise rotor) to generate thrust, and is a hybrid aircraft that is capable of operating an electric motor with electric power supplied from each of a battery and a motor generator while charging the battery with the motor generator. The aircraft **100** according to the present embodiment is configured to allow prevention of freezing of the electrical components of the VTOL rotor, in particular, without adding a heating apparatus, and includes a fuselage **12**, a front wing **14**, a rear wing **16**, two booms **18**, eight VTOL rotors **20**, two cruising rotors **29**, a cooling system **60**, a detection unit **80**, a heat generation unit **90**, and a control unit **99**.

(11) The fuselage **12** is a structure body for providing space for crews and passengers to board and to load cargo or the like, and for storing apparatuses such as the battery or the motor generator (neither are shown). The fuselage **12** is symmetric relative to a central axis L, and has a shape that extends in a front-back direction that is parallel to the central axis L and is thin in the left-right direction that is orthogonal to the central axis L in the horizontal plane. Here, the direction parallel to the central axis L is defined as the front-back direction, in which the left side of the drawing and the right side of the drawing are respectively the front (F) and back (B), and the direction orthogonal to the central axis L in the horizontal plane is defined as the width direction (or the left-right direction), in which the upper side of the drawing and the lower side of the drawing are respectively the right (R) and left (L). In addition, the vertical direction is orthogonal to each of these front-back direction and the width direction, in which the upward and downward in the vertical direction are also respectively referred to as upper (U) and lower (L). The fuselage **12** has a front end with a round curvature in a top view, and a rear end parallel to the width direction that is tapered to some extent relative to the barrel portion.

(12) The front wing **14** is a wing body provided to extend laterally from the fuselage **12**, and configured to generate lift during cruise, that is, by moving forward, which functions as a canard of the aircraft **100**. The front wing **14** has a V-shape with two wing bodies respectively extending from the center portion to the front-left direction and the front-right direction, and is fixed on the upper portion of the front side of the barrel portion of the fuselage **12** at the center portion with the opening of the V-shaping facing toward the front. The front wing **14** includes an elevator **14***a* arranged on rear edge in each of the two wing bodies.
(13) The rear wing **16** is a wing body provided to extend laterally from the fuselage **12**, and configured to generate lift during cruise, that is, by moving forward, which functions as a swept-back wing configured to reduce air resistance. The rear wing **16** has a V-shape with two wing bodies respectively extending from the center portion to the rear-left direction and the rear-right direction, and is fixed on the upper portion of the rear end of the fuselage **12** at the center portion with the opening of the V-shaping facing toward the back via a pylon **32**. The rear wing **16** includes an elevon **16***a* arranged on the rear edge in each of the two wing bodies, and a vertical tail **16***b* arranged on a wing end.
(14) Here, the wing area of the rear wing **16** is greater than that of the front wing **14**, and the wing width of the rear wing **16** is wider than that of the front wing. In this manner, the lift generated by the rear wing **16** by moving forward is greater than the lift generated by the front wing **14**, and the rear wing **16** functions as the main wing of the aircraft **100**. Note that, the wing areas, the lengths or the like of the front wing **14** and the rear wing **16** may be defined based on the balance of the lift generated by each wing, the center of gravity, the posture of the aircraft body during cruise, and the like.
(15) The two booms **18** are structure bodies that are supported by the front wing **14** and the rear wing **16** to be spaced apart from the fuselage **12** to the left and to the right, respectively, and functions to support or store each units in the configuration of the VTOL rotor **20** and the cooling system **60** described below. The two booms **18** each have a cylindrical shape extending in a front-back direction in a top view and wing-shaped cross section with the upper side having a round curvature and the lower side tapered in a front view, and are paired to be arranged symmetrically with respect to the fuselage **12** (that is, the central axis L). Note that, the two booms **18** may be formed to extend in the front-back direction and have an arch-shape curvature in the width direction. The two booms **18** have their front side end portions positioned forward of the front wing **14** to be supported by the ends of the front wing **14** at the front side barrel portion (between the two VTOL rotors **20***a*, **20***b* on the front side), and have their rear side end portions positioned behind the rear wing **16** to be supported by the rear wing **16** at the rear side barrel portion (between the two VTOL rotors **20***c*, **20***d* on the rear side).
(16) FIG. **2**A illustrates an internal configuration of the boom **18**. The boom **18** includes a skin **18***a*, a rib **18***b*, and a spar **18***c*. The skin **18***a* is a member that constitutes the surface of the boom **18**, and is molded into a cylindrical shape having a wing-shaped cross section and extending in the front-back direction. The skin **18***a* rises high above where the VTOL rotor **20** is arranged and spreads in the left-right direction to form a space **18***d*, and rises to some extent above where the cooling system **60** is arranged and spreads in the left-right direction to form a space **18***e*. Note that, the skin **18***a* is molded to include an inlet **70***a* for taking in airflow and an outlet **70***b* for discharging airflow respectively on the upper side and the lower side of the location where the cooling system **60** is arranged. In addition, a shutter **70***a*.sub.0 for closing the inlet **70***a* may be included. The rib **18***b* is a wing-shaped plate member, and is arranged in a plurality of locations in the front-back direction to retain the skin **18***a* from the inside. Note that, the spaces **18***d*, **18***e* within the boom **18** are partitioned by the rib **18***b*. The spar **18***c* is a bar member that extends in the front-back direction, and constitutes a backbone for supporting the rib **18***b* and other members.
(17) The eight VTOL rotors **20** (**20***a* to **20***d*) are rotors that are supported by the two booms **18** to generate thrust in the vertical direction during take-off and landing. Four VTOL rotors **20***a* to **20***d*

among the eight VTOL rotors **20** are supported at a substantially equal interval by the boom **18** on the left-hand side, and the remaining four VTOL rotors **20***a* to **20***d* are supported at a substantially equal interval by the boom **18** on the right-hand side. Here, the VTOL rotor **20***a* is arranged frontmost, the two VTOL rotors **20***b*, **20***c* are arranged to be front and back, respectively, between the front wing **14** and the rear wing **16**, and the VTOL rotor **20***d* is arranged last. Among the VTOL rotors **20***a* to **20***d* on the left-hand side and the four VTOL rotors **20***a* to **20***d* n the right-hand side, each two VTOL rotors **20***a* to **20***d* which are located at the same position relative to the front-back direction form a pair, and are controlled to rotate in reverse directions from each other. Unless stated otherwise, each of the eight VTOL rotors **20***a* to **20***d* is referred to simply as the VTOL rotor **20**.
(18) The VTOL rotor **20** includes one or more blades **23**, a motor **21**, an inverter **22**, a variable pitch mechanism **24**, and an ECU **25**. Note that, the motor **21** and the inverter **22** are also called the electrical components.
(19) The one or more blades **23** are supported on the boom **18** as illustrated in FIG. **2**A, and are vane-shaped members that generate thrust in the vertical direction by rotation thereof. In the present embodiment, the number of the blades **23** is two, but it may be any number including one or three or more. The one or more blades **23** are supported at a position higher than the front wing **14** and the rear wing **16**. Note that, in FIG. **1**, the plane of rotation of the one or more blades **23** of each VTOL rotor **20** is illustrated by using two-dotted lines.
(20) The motor (an example of a rotational apparatus) **21** is an electric motor that includes a rotational axis **21***a* toward the up-down direction and causes the blade **23** fixed to the motor **21** to rotate via a transmission (not shown) for converting the rotation number of the rotational axis **21***a*. The motor **21** is supported by the spar **18***c* via a support member to be accommodated in the space **18***d* of the boom **18**.
(21) The inverter (an example of the control apparatus) **22** is an apparatus that receives DC power supply from the battery via a high-voltage system (also called a power distribution system (PDS)), and converts DC power to AC power by driving (turning on and off) the switching device according to a driving signal received from the ECU **25** described below to supply the same to the motor **21**, and is supported below the motor **21** by the spar **18***c*. The inverter **22** can control the rotational torque and the rotation speed of the motor **21** respectively by increasing and decreasing the amplitude and frequency of the AC power.
(22) The variable pitch mechanism **24** is a mechanism for changing the angle (that is, the pitch) with respect to the plane of rotation of each of the one or more blades **23**. The variable pitch mechanism **24** includes an actuator **24***a* that causes the base end of the one or more blades **23** to rotate. The thrust generated by rotation of the one or more blades **23** of the VTOL rotor **20** can be controlled by receiving a low-voltage DC power from the battery via a low-voltage system (also called a low-voltage system (LVS)), and then running the actuator **24***a* to adjust the pitch of the one or more blades **23**, for example, enhance the thrust by increasing the pitch and reducing the thrust by decreasing the pitch.
(23) The ECU (electronic control unit) **25** is an apparatus that is run by receiving a low-voltage DC power from the battery via a low-voltage system, which controls the operation of the inverter **22** by sending a driving signal thereto, and modulates the amplitude and frequency of the AC power. The ECU **25** is implemented by a microcontroller, as an example.
(24) The two cruising rotors **29** are rotors that are supported by the rear end of the fuselage **12** to generate thrust during cruise. The cruising rotors **29** are arranged side by side on the left and right to the central axis L in a cylindrical duct **54** fixed to the rear end of the fuselage **12**, and have one or more blades that are supported in the duct **54** to generate a forward thrust by rotation thereof, motors that have rotational axes toward the front-back direction, via which the one or more blades fixed to the end are caused to rotate, and inverters that receive DC power supply from the battery and converts it to AC power to supply it to the motor (neither are shown). The inverter can control

the rotation speed of the motor.
(25) The cooling system (an example of the cooling apparatus) **60** is a system for cooling the motor **21** and the inverter **22** (which are called electrical components) that constitutes the VTOL rotor **20** in a liquid cooling manner by using the radiator **61** arranged within the boom **18**. Although, in the present embodiment, one cooling system **60** is provided for one VTOL rotor **20**, making a total of eight cooling systems **60**, it is not limited thereto, and one cooling system **60** may be provided for a plurality of (for example, two) VTOL rotors **20**. The cooling system **60** includes a radiator **61**, a pump **62**, a coolant fluid tank **63**, tubes **64**, **65**, and a temperature sensor **66**. Note that, water can be used as the coolant fluid.
(26) FIG. **2**B and FIG. **2**C illustrate configurations of the radiator **61** in a front view and a side view, respectively. The radiator **61** is a heat exchanger for cooling the coolant fluid to cool the motor **21** and the inverter **22**. Note that, the radiator **61** is supported between two ribs **18***b* by using the support member **61***f*, and is stored within the boom **18**. The radiator **61** includes a plurality of tubes **61***a* for causing the coolant fluid to flow upward and downward, a plurality of fins **61***b* fixed to each of the plurality of tubes **61***a* to increase the surface area that the airflow contacts, an upper tank **61***c* for sending the coolant fluid to the plurality of tubes **61***a*, a lower tank **61***d* for receiving the coolant fluid from the plurality of tubes **61***a*, and two fans **61***e* for sending the airflow to the plurality of fins **61***b*.
(27) The plurality of tubes **61***a* are arranged in a horizontal direction, assembled in a rectangular shape in the front view with the plurality of fins **61***b*, and constitutes the radiator main body with the upper tank **61***c* fixed on the upper side thereof and the lower tank **61***d* fixed on the lower side thereof. Operation of the pump **62** described below causes the coolant fluid having been heated by circling through the motor **21** and the inverter **22** to be fed to the upper tank **61***c* via the tube **64**, to be cooled by flowing downward through each of the plurality of tubes **61***a* and sent to the lower tank **61***d*, and to be sent to the motor **21** and the inverter **22** via the tube **65**. At this time, the two fans **61***e* operate to take in the airflow from the inlet **70***a* provided on the upper side of the boom **18** and to feed the airflow from one side (right-hand side in FIG. **2**C) of the radiator main body so as to contact the plurality of fins **61***b*, thereby causing heat exchange between the airflow and the radiator main body. The heated airflow is leaked from the other side (left-hand side in FIG. **2**C) of the radiator main body, and discharged from the outlet **70***b* provided on the lower side of the boom **18**.
(28) The pump **62** is connected to the radiator **61** via the tube **65**, and receives the coolant fluid that is cooled therefrom, and feeds the same to the motor **21** and the inverter **22**. In accordance with this, the coolant fluid having been heated through the motor **21** and the inverter **22** is fed to the radiator **61** via the tube **64**.
(29) The coolant fluid tank **63** is a container for storing the coolant fluid. For example, in a case where there is a shortage of the coolant fluid, the coolant fluid is sent from the coolant fluid tank **63** to the cooling circuit to supplement the coolant fluid.
(30) The tubes **64**, **65** are members for transporting the coolant fluid, and connects the radiator **61** and the pump **62** to the motor **21** and the inverter **22** to constitute a cooling circuit through which the coolant fluid circles.
(31) The temperature sensor **66** (see FIG. **3**) is a sensor for detecting a temperature of the coolant fluid that flows through the tubes **64**, **65** and/or the pump **62**. Any type of temperature sensors can be employed as the temperature sensor **66**, such as a temperature resistor (thermistor), a thermocouple, for example, as long as the temperature of the coolant fluid and/or the pump **62** when the cooling system **60** (radiator **61**) is running and when it is stopped can be detected within a temperature range (for example, −70 to 100° C.). Detecting the temperature of the coolant fluid and/or the pump **62** by using the temperature sensor **66** enables the heat generation unit **90** described below to be run to cause heat generation of the electrical components of the VTOL rotor **20** when the coolant fluid is at a low temperature, thereby heating the coolant fluid to prevent

freezing thereof.

(32) FIG. **2**D illustrates a circuit configuration of a cooling system. The upper tank **61***c* of the radiator **61** is connected to the motor **21** and the inverter **22** by the tube **64**. The lower tank **61***d* of the radiator **61** is connected to the motor **21** and the inverter **22** via the pump **62** by the tube **65**. The coolant fluid tank **63** is connected to the tube **65**. The operation of the pump **62** causes the coolant fluid heated in the motor **21** and the inverter **22** to be sent to the radiator **61** via the tube **64**, and the coolant fluid cooled at the radiator **61** is sent to the motor **21** and the inverter **22** via the tube **65**.

(33) Note that, in the cooling circuit provided by the cooling system **60**, the motor **21** and the inverter **22** are connected in series downstream of the pump **62**, but they may alternatively be connected in parallel. In addition, other electrical components may be connected to the motor **21** and the inverter **22** in series or in parallel.

(34) Note that, a cooling system having a configuration similar to that of the cooling system **60** may be provided to cool the electrical components of the cruising rotor **29**.

(35) The detection unit **80** is a unit for detecting the temperature of electrical components of the eight VTOL rotors **20** (**20***a* to **20***d*), an includes, in particular, the temperature sensors **81**, **82** provided at each of the motors **21** and the inverters **22** of the eight VTOL rotors **20**. Any type of temperature sensors can be employed as the temperature sensor **81**, **82**, such as a temperature resistor (thermistor), a thermocouple, for example, as long as the temperature when the motor **21** and the inverter **22** are running and when they are stopped can be detected within a temperature range (for example, −70 to 300° C.).

(36) The heat generation unit **90** is a unit for controlling the electrical components of the VTOL rotor **20** to generate heat. In the present embodiment, in particular, the electrical components can be caused to generate heat when over-cooled, to prevent freezing thereof. In addition, freezing of the coolant fluid of the radiator **61** can also be prevented. The heat generation unit **90** can be configured to include the ECU **25** and the variable pitch mechanism **24** described above.

(37) By being controlled by the control unit **99** described below to send a driving signal to the inverter **22**, the ECU **25** increases and decreases the rotation number of the motor **21** by increasing and decreasing the frequency of the AC power applied to a three-phase coil of the motor **21**, and increases and decreases the rotational torque of the motor **21** by increasing and decreasing the amplitude (that is, the voltage amplitude) of the AC power applied to the three-phase coil of the motor **21**. By running the motor **21** with increased and decreased power (which is equal to the product of the rotation number and the rotational torque) by one or both of the above, it is possible to generate an amount of heat that corresponds to the power of the motor **21**.

(38) In addition, the ECU **25** is controlled by the control unit **99** described below to cause the inverter **22** to generate heat by increasing the current amount that flows through the switching device of the inverter **22** to increase power loss. Note that, the current amount that flows through the switching device may be directly controlled by the control unit **99**. Alternatively or additionally, the ECU **25** controls driving timing of the switching device, and modulates the phase of the AC power applied to the three-phase coil of the motor **21** to lower the DC and AC power conversion efficiency, thereby causing power loss of the inverter **22** to increase and to cause heat generation thereof. Here, the power conversion efficiency can be increased by setting the phase difference between UVW phases to 120 degrees, and can be lowered by offsetting the phase difference of at least one phase among the UVW phases with respect to the other phases from 120 degrees.

(39) The variable pitch mechanism **24** is controlled by the control unit **99** described below to drive the actuator **24***a* such that required thrust can be achieved by the VTOL rotor **20**, that is, by rotation of the one or more blades **23** and adjusts the pitches thereof when the rotation number of the motor **21** is increased or decreased by the ECU **25**. For example, when the thrust generated by the VTOL rotor **20** exceeds the required thrust (thrust request) due to increase in the rotation number to cause the motor **21** to generate heat during cruise, the pitch of the one or more blades **23** is reduced (to be closer to the plane of rotation) by the variable pitch mechanism **24**, thereby suppressing the thrust.

In addition, when the thrust generated by the VTOL rotor **20** does not meet the thrust request even with increase in the rotation number of the motor **21**, or when the thrust generated by the VTOL rotor **20** is below the thrust request due to increase in the thrust request to cause the aircraft **100** to ascend, the pitch of the one or more blades **23** is increased (to be away from the plane of rotation) by the variable pitch mechanism **24**, thereby increasing the thrust. As such, the pitch of the blade **23** is optimized with respect to the rotation number of the motor such that the thrust generated by the VTOL rotor **20** satisfies the thrust request.
(40) FIG. **3** illustrates a configuration of a control system for the heat generation unit **90** for causing the electrical components of a VTOL rotor **20** to generate heat and a cooling system **60** for cooling the electrical components of a VTOL rotor **20**. Note that, although only one VTOL rotor **20** representing the eight VTOL rotors **20** and one cooling system **60** provided for that VTOL rotor **20** are illustrated for convenience, the control unit **99** performs control similarly for the other VTOL rotors **20** and the cooling systems **60** provided therefor.
(41) The control unit **99** is a unit for controlling running of the motors **21** and the inverters **22** of the eight VTOL rotors **20** and the cooling system **60** (the radiator **61**), and can be implemented by a computer apparatus that achieves a control function by activating a control program. The control unit **99** includes an interface **99***a* such as a control stick, thrust lever, or the like for receiving operational signals by a pilot of the aircraft **100**, such as a signal related to steering of the aircraft, a thrust request for the VTOL rotor **20**, a thrust request for the cruising rotor **29**, for example.
(42) The control unit **99** runs the motor **21** and/or the inverter **22** via the ECU **25** to cause heat generation thereof, based on the thrust request for the VTOL rotor **20** inputted via the interface **99***a* and a detection result of the temperature of the motor **21** and the inverter **22** detected by the detection unit **80**. In addition, the control unit **99** may further stop the cooling system **60** based on the detection result of the temperature of the motor **21** and the inverter **22** detected by the detection unit **80**, and stop cooling of the motor **21** and the inverter **22**. Here, the control unit **99** may stop the radiator **61** or the pump **62** included in the cooling system **60** or both, or may stop the cooling function by closing, with the shutter **70***a*.sub.0, the inlet **70***a* provided on the upper side of the boom **18** for introducing airflow to the radiator **61**. In this manner, over-cooling of the motor **21** and the inverter **22** can be prevented.
(43) Note that, the control unit **99** may operate by switching the heat generation unit **90** and the cooling system **60** during vertical take-off and landing and during cruise. For example, the cooling system **60** may be run when running the VTOL rotor **20**, and the motor **21** and the inverter **22** of the VTOL rotor **20** may be run via the heat generation unit **90** to cause heat generation thereof when the cruising rotor **29** is running, such as during cruise.
(44) FIG. **4** illustrates a flow S**100** of a heat generation and cooling method of the electrical components of the VTOL rotor **20**. Although this flow describes heat generation and cooling of electrical components of one VTOL rotor **20** representing the eight VTOL rotors **20**, heat generation and cooling of the electrical components of the other VTOL rotors **20** can be performed similarly.
(45) At step S**12**, the control unit **99** receives a thrust request for the VTOL rotor **20** from the pilot of the aircraft **100** via the interface **99***a*.
(46) At step S**14**, the control unit **99** determines whether the thrust generated by the VTOL rotor **20** is lower than the thrust request received at step S**12**. The thrust of the VTOL rotor **20** can be decided by the rotation number and the pitch of the one or more blades **23**. When the thrust of the VTOL rotor **20** is smaller than the thrust request, the flow proceeds to step S**16**, and when it is larger, the flow proceeds to step S**32**.
(47) Note that, instead of determining based on the thrust of the VTOL rotor **20**, the flow may be branched based on determining which of the VTOL rotor **20** and the cruising rotor **29** to run. For example, in a case where the VTOL rotor **20** is fully run, such as during vertical take-off and landing, the flow may proceed to step S**16** to run the cooling system **60**, and in a case where the

cruising rotor **29** is run and the VTOL rotor **20** is stopped or not fully run, such as during cruise, the flow may proceed to step S**32** to temporarily run the motor **21** and the inverter **22** to cause heat generation thereof.

(48) At step S**16**, the control unit **99** controls the ECU **25** to increase power of the motor **21** by increasing the rotation number and/or the rotational torque of the motor **21**. In this manner, the rotation number of the one or more blades **23** is increased.

(49) At step S**18**, the control unit **99** controls the thrust generated by rotation of the one or more blades **23** by controlling the actuator **24***a* via the variable pitch mechanism **24** to adjust the pitch of the one or more blades **23**. For example, in a case where the thrust of the VTOL rotor **20** is larger than the thrust request, the thrust is suppressed by reducing the pitch (to be closer to the plane of rotation) of the one or more blades **23** by the variable pitch mechanism **24**. In a case where the thrust of the VTOL rotor **20** is smaller than the thrust request, the thrust is enhanced by increasing the pitch (to be away from the plane of rotation) of the one or more blades **23** by the variable pitch mechanism **24**.

(50) At step S**20**, the control unit **99** detects the temperature (rotor temperature of the electrical components of the VTOL rotor **20** by the detection unit **80**, and determines whether the detected rotor temperature is higher than a predetermined reference temperature. The temperature of either one of the motor **21** and the inverter **22** may be given as the rotor temperature, or the higher one of those temperatures may be given as the rotor temperature.

(51) When the rotor temperature is high, the flow proceeds to step S**22** to run the cooling system **60**. Note that, the control unit **99** may increase the cooling efficiency of the radiator **61** by increasing the running amount of the pump **62** of the cooling system **60** to increase the flow capacity of the coolant fluid of the radiator **61** or to increase the rotation number of the fan **61***e*. In this manner, the electrical components of the VTOL rotor **20** are cooled. After running the cooling system **60**, the flow returns to step S**12**.

(52) When the rotor temperature is low, the flow proceeds to step S**24** to stop the cooling system **60**. Here, the control unit **99** may stop the radiator **61** or the pump **62** included in the cooling system **60** or both, or may stop the cooling function by closing, with the shutter **70***a*.sub.0, the inlet **70***a* provided on the upper side of the boom **18** for introducing airflow to the radiator **61**. In addition, the cooling efficiency of the radiator **61** may be lowered by decreasing the running amount of the pump **62** of the cooling system **60** to reduce the flow capacity of the coolant fluid of the radiator **61** or to reduce the rotation number of the fan **61***e*. After stopping the cooling system **60**, the flow returns to step S**12**.

(53) Note that, in a case where the rotor temperature is as low as nearly the lower limit of the operation guarantee temperature of the electrical components of the VTOL rotor **20**, heat retention of the electrical components of the VTOL rotor **20** may be attempted by running the pump **62** while stopping the fan **61***e* of the cooling system **60** or closing the inlet **70***a* with the shutter **70***a*.sub.0 to stop the cooling function.

(54) At step S**32**, the control unit **99** detects the temperature (rotor temperature) of the electrical components of the VTOL rotor **20** by the detection unit **80**, and determines whether the detected rotor temperature is higher than a predetermined reference temperature. The temperature of either one of the motor **21** and the inverter **22** may be given as the rotor temperature, or the higher one of those temperatures may be given as the rotor temperature.

(55) When the rotor temperature is high, the flow proceeds to step S**34** to run the cooling system **60**. Similarly to step S**22**, the control unit **99** may increase the cooling efficiency of the radiator **61** by increasing the running amount of the pump **62** of the cooling system **60** to increase the flow capacity of the coolant fluid of the radiator **61** or to increase the rotation number of the fan **61***e*. In this manner, the electrical components of the VTOL rotor **20** are cooled. After running the cooling system **60**, the flow proceeds to step S**38**.

(56) When the rotor temperature is low, the flow proceeds to step S**36** to stop the cooling system

60. Similarly to step S**24**, the control unit **99** may stop the radiator **61** or the pump **62** included in the cooling system **60** or both, or may stop the cooling function by closing, with the shutter **70***a*.sub.0, the inlet **70***a* provided on the upper side of the boom **18** for introducing airflow to the radiator **61**. In addition, the cooling efficiency of the radiator **61** may be lowered by decreasing the running amount of the pump **62** of the cooling system **60** to reduce the flow capacity of the coolant fluid of the radiator **61** or to reduce the rotation number of the fan **61***e*. In this manner, over-cooling of the motor **21** and the inverter **22** can be prevented. After stopping the cooling system **60**, the flow proceeds to step S**38**.
(57) Note that, in a case where the rotor temperature is as low as nearly the lower limit of the operation guarantee temperature of the electrical components of the VTOL rotor **20**, heat retention of the electrical components of the VTOL rotor **20** may be attempted by running the pump **62** while stopping the fan **61***e* of the cooling system **60** or closing the inlet **70***a* with the shutter **70***a*.sub.0 to stop the cooling function.
(58) At step S**38**, the control unit **99** detects the temperature (motor temperature) of the motor **21** of the VTOL rotor **20** by the detection unit **80**, and determines whether the detected motor temperature is higher than a predetermined reference temperature. When the motor temperature is low, the flow proceeds to step S**40**, and when the motor temperature is high, the flow proceeds to step S**42**.
(59) At step S**40**, the control unit **99** enhances the power of the motor **21**. Here, the control unit **99** enhances the frequency of the AC power applied to the three-phase coil of the motor **21** to increase the rotation number of the motor **21** by sending a driving signal from the ECU **25** to the inverter **22**. In addition, the control unit **99** increases the amplitude (that is, the voltage amplitude) of the AC power applied to the three-phase coil of the motor **21** to increase the rotational torque of the motor **21**. An amount of heat corresponding to the power of the motor **21** is generated by running the motor **21** with increased power (which is equal to the product of the rotation number and the rotational torque) by one or both of the above. After running the motor **21**, the flow proceeds to step S**44**.
(60) At step S**42**, the control unit **99** decreases the power of the motor **21**. Here, the control unit **99** decreases the frequency of the AC power applied to the three-phase coil of the motor **21** to decrease the rotation number of the motor **21** by sending a driving signal from the ECU **25** to the inverter **22**. In addition, the control unit **99** reduces the amplitude (that is, the voltage amplitude) of the AC power applied to the three-phase coil of the motor **21** to reduce the rotational torque of the motor **21**. The amount of heat generation of the motor **21** is suppressed by running the motor **21** with decreased power (which is equal to the product of the rotation number and the rotational torque) by one or both of the above. After running the motor **21**, the flow proceeds to step S**44**.
(61) At step S**44**, the control unit **99** controls the thrust generated by rotation of the one or more blades **23** by controlling the actuator **24***a* via the variable pitch mechanism **24** to adjust the pitch of the one or more blades **23**. For example, in a case where the thrust of the VTOL rotor **20** becomes larger than the thrust request due to enhancing of the rotation number of the motor **21** at step S**40**, the thrust is suppressed by reducing the pitch (to be closer to the plane of rotation) of the one or more blades **23** by the variable pitch mechanism **24**. In a case where the thrust of the VTOL rotor **20** becomes smaller than the thrust request due to decreasing of the rotation number of the motor **21** at step S**42**, for example, the thrust is enhanced by increasing the pitch (to be away from the plane of rotation) of the one or more blades **23** by the variable pitch mechanism **24**.
(62) Note that, the motor **21** may be run by increasing the pitch of the blade **23** in order to reducing the rotation number of the motor **21** and increase the rotational torque to reduce the noise of the VTOL rotor **20**. In order to lower the motor temperature in such a case, heat generation may be suppressed by enhancing the running efficiency of the motor **21** while maintaining the thrust by decreasing the rotation number of the motor **21** at step S**42** and increasing the pitch of the blade **23** at S**44**. In addition, in order to increase the temperature of the motor, the amount of heat generation

of the motor may be increased by lowering the running efficiency of the motor **21** by increasing the rotation number of the motor **21** at step S**40** and reducing the pitch of the blade **23** at step S**44**.
(63) At step S**46**, the control unit **99** detects the temperature (inverter temperature) of the inverter **22** of the VTOL rotor **20** by the detection unit **80**, and determines whether the detected inverter temperature is higher than a predetermined reference temperature. When the inverter temperature is low, the flow proceeds to step S**48**, and when the motor temperature is high, the flow proceeds to step S**52**.
(64) At step S**48**, the control unit **99** increases the power loss (inverter loss) of the inverter **22**. Here, the control unit **99** causes the inverter **22** to generate heat by increasing the current amount flowing through the switching device of the inverter **22** to increase power loss of the inverter **22**.
(65) At step S**50**, the control unit **99** lowers the power conversion efficiency of the inverter **22**. Here, the control unit **99** modulates the phase of the AC power applied to the three-phase coil of the motor **21** to lower DC and AC power conversion efficiency by controlling driving timing of the switching device of the inverter **22** via the ECU **25**, thereby increasing power loss of the inverter **22** to increase the amount of heat generation.
(66) Note that, only one of step S**48** or step S**50** may be performed.
(67) At step S**52**, the control unit **99** decreases the power loss (inverter loss) of the inverter **22**. Here, the control unit **99** suppresses heat generation of the inverter **22** by decreasing the current amount flowing through the switching device of the inverter **22** to decrease power loss of the inverter **22**.
(68) At step S**54**, the control unit **99** increases the power conversion efficiency of the inverter **22**. Here, the control unit **99** modulates the phase of the AC power applied to the three-phase coil of the motor **21** to increase DC and AC power conversion efficiency by controlling driving timing of the switching device of the inverter **22** via the ECU **25**, thereby suppressing power loss of the inverter **22** to suppress the amount of heat generation.
(69) Note that, only one of step S**52** or step S**54** may be performed.
(70) Further, the control unit **99** detects the temperature of the coolant fluid of the radiator **61** and/or the pump **62** by the temperature sensor **66**, and when the detected temperature is lower than a predetermined reference temperature, may run the heat generation unit **90**, that is, increase the power of the motor **21** similarly to step S**40** and/or increase the inverter loss similarly to step S**48** to cause heat generation thereof and to heat the coolant fluid. In this manner, freezing of the coolant fluid can be prevented.
(71) Once steps S**46** to S**52** has ended, the flow returns to step S**12**.
(72) As described above, a thrust request for the VTOL rotor **20** is received and the temperature of the motor **21** and the inverter **22** of the VTOL rotor **20** stored within the boom **18** is detected, and by running the motor **21** and the inverter **22** based on the thrust request and the detection result of the temperature to cause heat generation, freezing thereof can be prevented without using a heating apparatus.
(73) FIG. **5** illustrates another flow S**110** of a heat generation and cooling method of the electrical components of the VTOL rotor **20**. Although this flow describes heat generation and cooling of electrical components of one VTOL rotor **20** representing the eight VTOL rotors **20**, heat generation and cooling of the electrical components of the other VTOL rotors **20** can be performed similarly. Steps S**12** to S**24** in this flow is similar to those in the flow S**100** described above. At step S**14**, when the control unit **99** determines that the thrust generated by the VTOL rotor **20** is not lower than the thrust request received at step S**12**, the flow proceeds to step S**62**.
(74) At step S**62**, the control unit **99** detects the temperature of the electrical components of the VTOL rotor **20** (the temperature of the motor **21** and/or the inverter **22**) by the detection unit **80**, detects the temperature of the coolant fluid of the radiator **61** and/or the pump **62** by the temperature sensor **66**, and determines whether the detected temperature of at least one of the motor **21** or the like (referred to as the rotor temperature) is lower than a predetermined reference

temperature. When the rotor temperature is high, the flow proceeds to step S**64** to run the cooling system **60**. Details are similar to step S**22** described above. After running the cooling system **60**, the flow returns to step S**12**. When the rotor temperature is low, the flow proceeds to step S**66**.
(75) At step S**66**, the cooling function of the cooling system **60** is stopped. Here, the control unit **99** runs the pump **62** to retain heat of the electrical components of the VTOL rotor **20** while stopping the cooling function by stopping the fan **61***e* of the cooling system **60** and/or closing the inlet **70***a* with the shutter **70***a*.sub.0.
(76) At step S**68**, again, the control unit **99** detects the rotor temperature, and determines whether this is lower than the predetermined reference temperature. When the rotor temperature is high, it is determined that heat of the electrical component VTOL rotor **20** has been retained by step S**66**, and the flow returns to step S**12**. When the rotor temperature is still low, the flow proceeds to step S**70**.
(77) At step S**70**, the control unit **99** controls driving timing of the switching device of the inverter **22** via the ECU **25** to send DC power to the motor **21** via the inverter **22**, thereby increasing power loss of the motor **21** and the inverter **22** and causing heat generation thereof without causing the motor **21** to rotate. Note that, the control unit **99** can adjust power loss of the motor **21** and the inverter **22**, that is, the amount of heat generation by increasing and decreasing the current amount of the DC power.
(78) At step S**72**, again, the control unit **99** detects the rotor temperature, determines whether the temperature of the motor **21**, coolant fluid of the radiator **61**, and/or the pump **62** (referred to as the motor **61** or the like) is still lower than the predetermined reference temperature inspite of the temperature of the inverter **22** becoming high. When the temperature of the motor **61** or the like is high, it is determined that heat of the electrical component VTOL rotor **20** has been retained by step S**68**, and the flow returns to step S**12**. When the temperature of the motor **61** or the like is still low, the flow proceeds to step S**74**.
(79) At step S**74**, the control unit **99** suppresses the thrust by controlling the actuator **24***a* via the variable pitch mechanism **24** to reduce the pitch of the one or more blades **23** (to be closer to the plane of rotation), and controls driving timing of the switching device of the inverter **22** via the ECU **25** to send the AC power to the motor **21**, thereby causing the motor **21** to rotate. In this manner, heat generation of the inverter **21** is mitigated and the motor **21** is caused to generate heat. Once step S**74** has ended, the flow returns to step S**12**.
(80) Note that, at step S**68**, a different process may be performed by setting a plurality of reference temperatures. For example, the flow proceeds to step S**70** in a case where the rotor temperature is lower than a first reference temperature which is relatively high, and increases the power loss of the motor **21** and the inverter **22** to cause heat generation thereof without causing the motor **21** to rotate. The flow skips steps S**70** to S**72** and proceeds to step S**74** in a case where the rotor temperature is lower than a second reference temperature which is relatively low, and increases the power loss of the motor **21** and the inverter **22** to cause heat generation thereof while causing the motor **21** to rotate. In this manner, freezing protection can be swiftly performed in a case where the rotor temperature is extremely low (for example, −10 to 0° C.) due to freezing rain or fog.
(81) As described above, a thrust request for the VTOL rotor **20** is received and the temperature of the motor **21** and the inverter **22** of the VTOL rotor **20** stored within the boom **18** is detected, and by running the motor **21** and the inverter **22** based on the thrust request and the detection result of the temperature to cause heat generation, freezing thereof can be prevented without using a heating apparatus.
(82) The aircraft **100** according to the present embodiment includes a fuselage **12**, a VTOL rotor **20** including one or more blades **23** that is supported on the boom **18** to be spaced apart from the fuselage **12** for generating thrust during take-off and landing, a motor **21** that is stored in the boom **18** and is configured to cause the one or more blades **23** to rotate, and an inverter **22** for controlling the motor **21**, a detection unit **80** configured to detect a temperature of at least one apparatus of the motor **21** or the inverter **22**, and a control unit **99** configured to run the at least one apparatus based

on a thrust request for a plurality of VTOL rotors **20** and a detection result of the temperature. Accordingly, by detecting a temperature of at least one apparatus of the motor **21** or the inverter **22** stored within the boom **18** that is spaced apart from the fuselage **12** by the detection unit **80** and running the at least one apparatus to cause heat generation thereof based on the thrust request for the VTOL rotor **20** and a detection result of the temperature by the control unit **99**, freezing thereof can be prevented without using a heating apparatus.
(83) The heat generation method of electrical components of the VTOL rotor **20** according to the present embodiment includes receiving a thrust request for a VTOL rotor **20** including one or more blades **23** that is supported on the boom **18** to be spaced apart from the fuselage **12** for generating thrust during take-off and landing, a motor **21** that is stored in the boom **18** and is configured to cause the one or more blades **23** to rotate, and an inverter **22** for controlling the motor **21**, detecting a temperature of at least one apparatus of the motor **21** or the inverter **22**, and running the at least one apparatus based on a thrust request and a detection result of the temperature. Accordingly, by receiving a thrust request for the VTOL rotor **20**, detecting a temperature of at least one apparatus of the motor **21** or the inverter **22** stored within the boom **18** that is spaced apart from the fuselage **12** and running the at least one apparatus to cause heat generation thereof based on the thrust request and a detection result of the temperature, freezing thereof can be prevented without using a heating apparatus.
(84) While the embodiments of the present invention have been described, the technical scope of the invention is not limited to the above described embodiments. It is apparent to persons skilled in the art that various alterations and improvements can be added to the above-described embodiments. It is also apparent from the scope of the claims that the embodiments added with such alterations or improvements can be included in the technical scope of the invention.
(85) The operations, procedures, steps, and stages of each process performed by an apparatus, system, program, and method shown in the claims, embodiments, or diagrams can be performed in any order as long as the order is not indicated by “prior to,” “before,” or the like and as long as the output from a previous process is not used in a later process. Even if the process flow is described using phrases such as “first” or “next” in the claims, embodiments, or diagrams, it does not necessarily mean that the process must be performed in this order.

Claims

1. An aircraft comprising: a fuselage; a rotor including one or more blades that is supported on a support member spaced apart from the fuselage, for generating thrust in a vertical direction during take-off and landing, and a rotational apparatus stored in the support member for causing the one or more blades to rotate and a control apparatus configured to control the rotational apparatus; a detection unit configured to detect a temperature of at least one apparatus of the rotational apparatus or the control apparatus; and a control unit configured to run the at least one apparatus based on a thrust request for the rotor and a detection result of the temperature, wherein i) the detection unit is configured to detect the temperature of the rotational apparatus, and the control unit is configured to increase an amount of heat generation of the rotational apparatus by enhancing a power of the rotational apparatus or by lowering a running efficiency of the rotational apparatus when the detected temperature of the rotational apparatus is lower than a predetermined reference temperature, or ii) the detection unit is configured to detect the temperature of the control apparatus, and the control unit is configured to ii) increase an amount of heat generation of the control apparatus by increasing a power loss of the control apparatus when the detected temperature of the control apparatus is lower than a predetermined reference temperature.
2. The aircraft according to claim 1, wherein the control unit is configured to control at least one of a rotation number or rotational torque of the rotational apparatus.
3. The aircraft according to claim 2, wherein the rotor further includes an actuator configured to

adjust a pitch of the one or more blades, and the control unit is further configured to control thrust generated by rotation of the one or more blades by running the actuator to adjust a pitch of the one or more blades.
4. The aircraft according to claim 1, wherein the control unit is configured to control current amount that flows through a switching device of the control apparatus.
5. The aircraft according to claim 2, wherein the control unit is configured to control current amount that flows through a switching device of the control apparatus.
6. The aircraft according to claim 3, wherein the control unit is configured to control current amount that flows through a switching device of the control apparatus.
7. The aircraft according to claim 1, wherein the control unit is configured to control driving timing of a switching device of the control apparatus to adjust power conversion efficiency.
8. The aircraft according to claim 2, wherein the control unit is configured to control driving timing of a switching device of the control apparatus to adjust power conversion efficiency.
9. The aircraft according to claim 3, wherein the control unit is configured to control driving timing of a switching device of the control apparatus to adjust power conversion efficiency.
10. The aircraft according to claim 1, further comprising a cooling apparatus configured to cool the at least one apparatus, wherein the control unit is configured to stop the cooling apparatus based on a detection result by the detection unit.
11. The aircraft according to claim 2, further comprising a cooling apparatus configured to cool the at least one apparatus, wherein the control unit is configured to stop the cooling apparatus based on a detection result by the detection unit.
12. The aircraft according to claim 3, further comprising a cooling apparatus configured to cool the at least one apparatus, wherein the control unit is configured to stop the cooling apparatus based on a detection result by the detection unit.
13. The aircraft according to claim 10, wherein the control unit is configured to stop a radiator or a pump of the cooling apparatus.
14. The aircraft according to claim 10, wherein the control unit is configured to close an inlet for introducing airflow to a radiator of the cooling apparatus.
15. The aircraft according to claim 13, wherein the control unit is configured to close an inlet for introducing airflow to a radiator of the cooling apparatus.
16. The aircraft according to claim 1, further comprising: a cooling apparatus for cooling at least one apparatus of the rotational apparatus or the control apparatus; and a cruising rotor that is provided at a rear end of the fuselage, the cruising rotor including one or more blades for generating thrust during cruise, wherein the control unit is configured to run the cooling apparatus when the rotor is running, and to run at least one of the rotational apparatus or the control apparatus to cause heat generation thereof when the cruising rotor is running.
17. The aircraft according to claim 2, further comprising: a cooling apparatus for cooling at least one apparatus of the rotational apparatus or the control apparatus; and a cruising rotor that is provided at a rear end of the fuselage, the cruising rotor including one or more blades for generating thrust during cruise, wherein the control unit is configured to run the cooling apparatus when the rotor is running, and to run at least one of the rotational apparatus or the control apparatus to cause heat generation thereof when the cruising rotor is running.
18. The aircraft according to claim 1, further comprising a wing body that extends laterally from the fuselage, the wing body being configured to generate lift during cruise, wherein the support member is supported by the wing body to be spaced apart from the fuselage.
19. The aircraft according to claim 2, further comprising a wing body that extends laterally from the fuselage, the wing body being configured to generate lift during cruise, wherein the support member is supported by the wing body to be spaced apart from the fuselage.
20. A method comprising: receiving a thrust request for a rotor including one or more blades that is supported on a support member that is spaced apart from a fuselage, the one or more blades being

configured to generate thrust in a vertical direction during take-off and landing, and a rotational apparatus stored in the support member for causing rotation of the one or more blades and an a control apparatus for controlling the rotational apparatus; detecting a temperature of at least one apparatus of the rotational apparatus or the control apparatus; and running the at least one apparatus based on the thrust request and a detection result of the temperature, wherein i) the detecting the temperature includes detecting the temperature of the rotational apparatus, and the running the at least one apparatus includes increasing an amount of heat generation of the rotational apparatus by enhancing a power of the rotational apparatus or by lowering a running efficiency of the rotational apparatus when the detected temperature of the rotational apparatus is lower than a predetermined reference temperature, or ii) the detecting the temperature includes detecting the temperature of the control apparatus, and the running the at least one apparatus includes ii) increasing an amount of heat generation of the control apparatus by increasing a power loss of the control apparatus when the detected temperature of the control apparatus is lower than a predetermined reference temperature.

21. An aircraft comprising: a fuselage; a rotor including one or more blades that is supported on a support member spaced apart from the fuselage, for generating thrust in a vertical direction during take-off and landing, and a rotational apparatus stored in the support member for causing the one or more blades to rotate and a control apparatus configured to control the rotational apparatus; a detection unit configured to detect a temperature of the rotational apparatus and the control apparatus; and a control unit configured to i) increase an amount of heat generation of the rotational apparatus by enhancing a power of the rotational apparatus or by lowering a running efficiency of the rotational apparatus when the detected temperature of the rotational apparatus is lower than a predetermined reference temperature, and ii) increase an amount of heat generation of the control apparatus by increasing a power loss of the control apparatus when the detected temperature of the control apparatus is lower than a predetermined reference temperature.

22. The aircraft according to claim 1, wherein the control unit is configured to increase current amount that flows through a switching device of the control apparatus.

23. The aircraft according to claim 1, wherein the control unit is configured to control driving timing of a switching device of the control apparatus to lower power conversion efficiency.