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**(54) HYBRID GAS TURBINE ENGINE SYSTEM POWERED WARM-UP**

HYBRIDGASTURBINENTRIEBWERKSSYSTEM MIT UNTERSTÜTZTER AUFWÄRMUNG  
RÉCHAUFFEMENT ALIMENTÉ DE SYSTÈME DE MOTEUR À TURBINE À GAZ HYBRIDE

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(56) References cited:  
**EP-A1- 2 006 496 EP-A2- 2 452 878**  
**US-A1- 2007 101 721 US-A1- 2018 002 025**

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## Description

### BACKGROUND

**[0001]** The subject matter disclosed herein generally relates to engine systems and, more particularly, to a method and apparatus for hybrid gas turbine engine system powered warm-up.

**[0002]** Conventional gas turbine engines are typically operated at an idle power level during taxiing from a gate to a runway and can remain at idle power for a substantial period of time before takeoff, which consumes a quantity of fuel prior to flight. Hybrid electric aircraft use electricity to provide a portion of the power needed for aircraft propulsion by converting electricity into a propulsive force. A hybrid electric aircraft can use an electric drive to support taxiing operations on a runway and prevent fuel burn typical of conventional gas turbine engine idling.

**[0003]** US 2018/002025 discloses an aircraft including a parallel hybrid gas turbine electric propulsion system.

**[0004]** US 2007/101721 discloses a method and system for taxiing an aircraft having at least one gas turbine engine.

### BRIEF DESCRIPTION

**[0005]** According to one embodiment, a hybrid gas turbine engine system of a hybrid electric aircraft is provided. The hybrid gas turbine engine system includes a gas turbine engine, an electric motor operable to perform an electric taxiing of the hybrid electric aircraft, and a controller. The controller is operable to prevent fuel flow to the gas turbine engine during at least a portion of the electric taxiing and monitor for a powered warm-up request during the electric taxiing. A powered warm-up state of the gas turbine engine is initiated based on detecting the powered warm-up request. The powered warm-up state adds heat to one or more components of the gas turbine engine prior to transitioning to a takeoff power state. The gas turbine engine transitions from the powered warm-up state to the takeoff power state after reaching a target temperature of the one or more components in the powered warm-up state, wherein: the powered warm-up state includes enabling one or more electric heaters, and/or wherein the controller is configured to command a combination of vane positions and power setting of the gas turbine engine that reduces a compressor efficiency of the gas turbine engine to increase temperature at or below idle thrust in the powered warm-up state.

**[0006]** The system may include where the gas turbine engine includes a low speed spool and a high speed spool.

**[0007]** The system may include where the controller is configured to motor the high speed spool in reverse to urge heat in a reverse flow direction in the powered warm-up state.

**[0008]** The system may include where the controller is

configured to motor the high speed spool with a sub-idle fuel flow in the powered warm-up state.

**[0009]** The system may include a generator operably coupled to the low speed spool of the gas turbine engine, and the controller may be configured to operate the gas turbine engine with a higher engine power setting above idle to drive rotation of the generator and produce idle thrust during after the electric taxiing.

**[0010]** The system may include where the generator is a motor-generator and the controller is configured to operate the generator in a generator mode to charge a battery system and in a motor mode to provide supplemental rotation force to the gas turbine engine.

**[0011]** The system may include where the generator is configured to provide power for motoring the high speed spool and/or charging a battery system.

**[0012]** According to another embodiment, a propulsion system for a hybrid electric aircraft includes a gas turbine engine with a low speed spool, a high speed spool, and a combustor. The propulsion system also includes an electric motor operably coupled to the high speed spool and a controller. The controller is operable to prevent fuel flow to the combustor of the gas turbine engine during at least a portion of an electric taxiing of the hybrid electric aircraft and monitor for a powered warm-up request during the electric taxiing. A powered warm-up state of the gas turbine engine is initiated based on detecting the powered warm-up request. The powered warm-up state adds heat to one or more components of the gas turbine engine prior to transitioning to a takeoff power state. The gas turbine engine transitions from the powered warm-up state to the takeoff power state after reaching a target temperature of the one or more components in the powered warm-up state.

**[0013]** According to another embodiment, a method of providing a powered warm-up for a gas turbine engine of a hybrid electric aircraft includes preventing fuel flow to the gas turbine engine during at least a portion of an electric taxiing of the hybrid electric aircraft and monitoring for a powered warm-up request during the electric taxiing. A powered warm-up state of the gas turbine engine is initiated based on detecting the powered warm-up request. The powered warm-up state adds heat to one or more components of the gas turbine engine prior to transitioning to a takeoff power state. The gas turbine engine transitions from the powered warm-up state to the takeoff power state after reaching a target temperature of the one or more components in the powered warm-up state wherein: the powered warm-up state comprises enabling one or more electric heaters; and/or the method comprises commanding a combination of vane positions and power setting of the gas turbine engine that reduces a compressor efficiency of the gas turbine engine to increase temperature at or below idle thrust in the powered warm-up state.

**[0014]** A technical effect of the apparatus, systems and methods is achieved by providing a powered warm-up state for a hybrid gas turbine engine system during elec-

tric taxiing as described herein.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0015]** The following descriptions should not be considered limiting in any way. With reference to the accompanying drawings, like elements are numbered alike:

FIG. 1 is a partial cross-sectional illustration of a gas turbine engine, in accordance with an embodiment of the disclosure;

FIG. 2 is a schematic diagram of a hybrid gas turbine engine system, in accordance with an embodiment of the disclosure;

FIG. 3 is a schematic diagram of a hybrid gas turbine engine system, in accordance with an embodiment of the disclosure;

FIG. 4 is a temperature plot, in accordance with an embodiment of the disclosure;

FIG. 5 is a fuel flow plot, in accordance with an embodiment of the disclosure; and

FIG. 6 is a flow chart illustrating a method, in accordance with an embodiment of the disclosure.

## DETAILED DESCRIPTION

**[0016]** A detailed description of one or more embodiments of the disclosed apparatus and method are presented herein by way of exemplification and not limitation with reference to the Figures.

**[0017]** FIG. 1 schematically illustrates a gas turbine engine 20. The gas turbine engine 20 is disclosed herein as a two-spool turbofan that generally incorporates a fan section 22, a compressor section 24, a combustor section 26 and a turbine section 28. The fan section 22 drives air along a bypass flow path B in a bypass duct, while the compressor section 24 drives air along a core flow path C for compression and communication into the combustor section 26 then expansion through the turbine section 28. Although depicted as a two-spool turbofan gas turbine engine in the disclosed non-limiting embodiment, it should be understood that the concepts described herein are not limited to use with two-spool turbofans as the teachings may be applied to other types of turbine engines including three-spool architectures.

**[0018]** The exemplary engine 20 generally includes a low speed spool 30 and a high speed spool 32 mounted for rotation about an engine central longitudinal axis A relative to an engine static structure 36 via several bearing systems 38. It should be understood that various bearing systems 38 at various locations may alternatively or additionally be provided, and the location of bearing systems 38 may be varied as appropriate to the applica-

tion.

**[0019]** The low speed spool 30 generally includes an inner shaft 40 that interconnects a fan 42, a low pressure compressor 44 and a low pressure turbine 46. The inner shaft 40 is connected to the fan 42 through a speed change mechanism, which in exemplary gas turbine engine 20 is illustrated as a geared architecture 48 to drive the fan 42 at a lower speed than the low speed spool 30. The high speed spool 32 includes an outer shaft 50 that interconnects a high pressure compressor 52 and high pressure turbine 54. A combustor 56 is arranged in exemplary gas turbine 20 between the high pressure compressor 52 and the high pressure turbine 54. An engine static structure 36 is arranged generally between the high pressure turbine 54 and the low pressure turbine 46. The engine static structure 36 further supports bearing systems 38 in the turbine section 28. The inner shaft 40 and the outer shaft 50 are concentric and rotate via bearing systems 38 about the engine central longitudinal axis A which is collinear with their longitudinal axes.

**[0020]** The core airflow is compressed by the low pressure compressor 44 then the high pressure compressor 52, mixed and burned with fuel in the combustor 56, then expanded over the high pressure turbine 54 and low pressure turbine 46. The turbines 46, 54 rotationally drive the respective low speed spool 30 and high speed spool 32 in response to the expansion. It will be appreciated that each of the positions of the fan section 22, compressor section 24, combustor section 26, turbine section 28, and fan drive gear system 48 may be varied. For example, gear system 48 may be located aft of combustor section 26 or even aft of turbine section 28, and fan section 22 may be positioned forward or aft of the location of gear system 48.

**[0021]** The engine 20 in one example is a high-bypass geared aircraft engine. In a further example, the engine 20 bypass ratio is greater than about six (6), with an example embodiment being greater than about ten (10), the geared architecture 48 is an epicyclic gear train, such as a planetary gear system or other gear system, with a gear reduction ratio of greater than about 2.3 and the low pressure turbine 46 has a pressure ratio that is greater than about five. In one disclosed embodiment, the engine 20 bypass ratio is greater than about ten (10:1), the fan diameter is significantly larger than that of the low pressure compressor 44, and the low pressure turbine 46 has a pressure ratio that is greater than about five 5:1. Low pressure turbine 46 pressure ratio is pressure measured prior to inlet of low pressure turbine 46 as related to the pressure at the outlet of the low pressure turbine 46 prior to an exhaust nozzle. The geared architecture 48 may be an epicycle gear train, such as a planetary gear system or other gear system, with a gear reduction ratio of greater than about 2.3:1. It should be understood, however, that the above parameters are only exemplary of one embodiment of a geared architecture engine and that the present disclosure is applicable to other gas turbine engines including direct drive turbofans.

**[0022]** A significant amount of thrust is provided by the bypass flow B due to the high bypass ratio. The fan section 22 of the engine 20 is designed for a particular flight condition—typically cruise at about 0.8 Mach and about 35,000 feet (10,668 meters). The flight condition of 0.8 Mach and 35,000 ft (10,668 meters), with the engine at its best fuel consumption—also known as "bucket cruise Thrust Specific Fuel Consumption ('TSFC')"—is the industry standard parameter of lbf of fuel being burned divided by lbf of thrust the engine produces at that minimum point. "Low fan pressure ratio" is the pressure ratio across the fan blade alone, without a Fan Exit Guide Vane ("FEGV") system. The low fan pressure ratio as disclosed herein according to one non-limiting embodiment is less than about 1.45. "Low corrected fan tip speed" is the actual fan tip speed in ft/sec divided by an industry standard temperature correction of  $[(T_{\text{ram}} - T_{\text{ref}})/(518.7 - T_{\text{ref}})]^{0.5}$ , (where  $T = K \times 9/5$ ). The "Low corrected fan tip speed" as disclosed herein according to one non-limiting embodiment is less than about 1150 ft/second (350.5 m/sec).

**[0023]** While the example of FIG. 1 illustrates one example of the gas turbine engine 20, it will be understood that any number of spools, inclusion or omission of the gear system 48, and/or other elements and subsystems are contemplated. Further, rotor systems described herein can be used in a variety of applications and need not be limited to gas turbine engines for aircraft applications. For example, rotor systems can be included in power generation systems, which may be ground-based as a fixed position or mobile system, and other such applications.

**[0024]** FIG. 2 illustrates a hybrid gas turbine engine system 201 including a rotor system 202 that includes at least one compressor section 204 and at least one turbine section 208 operably coupled to a shaft 206 as part of a hybrid electric aircraft 200. The rotor system 202 can be a spool of the gas turbine engine 20 of FIG. 1, such as the low speed spool 30 or the high speed spool 32. For example, when embodied as the low speed spool 30, the at least one compressor section 204 can be equivalent to the low pressure compressor 44, the shaft 206 can be equivalent to the inner shaft 40, and the at least one turbine section 208 can be equivalent to the low pressure turbine 46 of FIG. 1. When embodied as the high speed spool 32, the at least one compressor section 204 can be equivalent to the high pressure compressor 52, the shaft 206 can be equivalent to the outer shaft 50, and the at least one turbine section 208 can be equivalent to the high pressure turbine 54 of FIG. 1.

**[0025]** In the example of FIG. 2, an electric power system 210 is operably coupled to the rotor system 202. The electric power system 210 includes a motor-generator 212 operably coupled to the shaft 206. The motor-generator 212 can be configured as an electric motor or a generator depending upon an operational mode or system configuration. In the example of FIG. 2, a geared interface 230 operably couples the motor-generator 212

to the shaft 206. The geared interface 230 can include, for instance, an auxiliary gear 233 coupled to an auxiliary shaft 235 driven by the motor-generator 212. The geared interface 230 can also include a rotor gear 237 coupled to the shaft 206. The auxiliary gear 233 and the rotor gear 237 can each be beveled gears. The auxiliary shaft 235 can be a tower shaft. A disconnect 240, such as a clutch, can be positioned between the motor-generator 212 and a portion of the shaft 206 such that the motor-generator 212 can be selectively engaged and disengaged to rotate with rotation of the shaft 206. In alternate embodiments, the motor-generator 212 is operably coupled to the shaft 206 absent the geared interface 230 (e.g., direct coupling).

**[0026]** The electric power system 210 also includes converter electronics 214 operable to condition current to/from the motor-generator 212. In some embodiments, the motor-generator 212 is configured in a generator mode to charge a battery system 250 and in a motor mode to provide supplemental rotation force to the rotor system 202 of gas turbine engine 20 of FIG. 1. The motor-generator 212 can include conventional motor and generator components, such as a rotor and stator, including a plurality of windings and/or permanent magnets. The converter electronics 214 can also include conventional current control electronics, such as filters, switching components, rectifiers, inverters, voltage converters, and the like. The motor-generator 212 can perform as a variable frequency generator in a generator mode due to speed fluctuations of rotation of the shaft 206, which may be primarily driven by the at least one turbine section 208. Alternatively, a frequency normalizing component can interface with the motor-generator 212 to produce a constant frequency output (e.g., through the converter electronics 214 or as a mechanical interface between the motor-generator 212 and the shaft 206). In some embodiments, the motor-generator 212 may be operable as a starter motor to partially or completely power rotation of the shaft 206 in a starting mode of operation (e.g., to start the gas turbine engine 20 of FIG. 1) and/or can provide supplemental power to the shaft 206 during various flight phases of the hybrid electric aircraft 200. Other uses and functions for the motor-generator 212 are contemplated.

**[0027]** The converter electronics 214 can control charging of the battery system 250 responsive to a controller 216. The controller 216 can enable a flow of a charging current from the motor-generator 212 or a power input 252 to charge the battery system 250 as regulated and conditioned through the converter electronics 214. The power input 252 can be an external input, such as power received through a plug interface while the hybrid electric aircraft 200 is on the ground at a ground-based power source, e.g., at a gate or service location. In some embodiments, the converter electronics 214 may receive electric current from an auxiliary power input 254 to provide a supplemental or alternative power source for charging the battery system 250. For instance, the auxiliary power input 254 may receive electric current

from an auxiliary power unit (not depicted) or another instance of the gas turbine engine 20 on the hybrid electric aircraft 200. The charge stored in the battery system 250 can provide an electric current for a propulsion system use 256, which may include powering one or more electric motors of the hybrid electric aircraft 200 during various operational states and/or providing power to the motor-generator 212 when operating in a motor mode, for instance, to assist in driving rotation of shaft 206. The propulsion system use 256 can be part of the gas turbine engine 20 that includes the rotor system 202 or another aircraft system, such as another instance of the gas turbine engine 20 on the hybrid electric aircraft 200. Further, the propulsion system use 256 can include powering one or more electric heaters 262, 264, for instance, during a powered warm-up state of the gas turbine engine 20. One or more electric heaters 262 can warm an oil tank 260 to add heat to lubricating oil, for instance, to transfer heat to other components of the gas turbine engine 20 and/or alter viscosity of the lubricating oil. One or more electric heaters 264 can heat a portion of the compressor section 204, such as a rear portion of the high pressure compressor 52 of FIG. 1.

**[0028]** In embodiments, the controller 216 of the electric power system 210 can monitor one or more rotor system sensors 218 while the rotor system 202 is rotating. The rotor system sensors 218 can be any type or combination of sensors operable to measure aspects of the motion of the rotor system 202. For example, the rotor system sensors 218 can include one or more accelerometers, speed sensors, torque sensors, and the like. The rotor system sensors 218 can be existing sensors used for controlling the gas turbine engine 20. The controller 216 can control a charging of the battery system 250, for instance, by selecting the source of electric current received through the converter electronics 214. Data collected from the rotor system sensors 218 can be used to determine an operational status of a gas turbine engine 20 of FIG. 2. Alternatively, the operational status of a gas turbine engine 20 can be received as a signal or message from an alternate source, such as an engine system or aircraft communication bus. The controller 216 may also control other system aspects, such as controlling operation of the gas turbine engine 20 of FIG. 1. For example, the controller 216 can be integrally formed or otherwise in communication with a full authority digital engine control (FADEC) of the gas turbine engine 20. The rotor system sensors 218 need not be directly coupled to the controller 216, as sensor data or sensor-derived data can be observed or determined by another control (e.g., a FADEC) and provided to the controller 216. In embodiments, the controller 216 can include a processing system 220, a memory system 222, and an input/output interface 224. The processing system 220 can include any type or combination of central processing unit (CPU), including one or more of: a microprocessor, a digital signal processor (DSP), a microcontroller, an application specific integrated circuit (ASIC), a field programmable gate

array (FPGA), or the like. The memory system 222 can store data and instructions that are executed by the processing system 220. In embodiments, the memory system 222 may include random access memory (RAM), read only memory (ROM), or other electronic, optical, magnetic, or any other computer readable medium onto which is stored data and algorithms in a non-transitory form. The input/output interface 224 is configured to collect sensor data from the one or more rotor system sensors 218 and interface with the converter electronics 214 and/or other systems (not depicted).

**[0029]** The controller 216 is operable to determine when to charge the battery system 250 and when to use the battery system 250. During powered warm-up state, the motor-generator 212 can charge the battery system 250 while putting an increased load on the rotor system 202 of the gas turbine engine 20 to more rapidly add heat. Upon transitioning to the takeoff power state, charging can be halted to reduce loading on the gas turbine engine 20. In some embodiments, the motor-generator 212 can transition to a motor mode during takeoff to provide supplemental rotational force to the shaft 206. Further, supplemental or replacement current can be provided for battery charging or to supply other electric loads through the auxiliary power input 254. Alternate transition points and operational states to support powered warm-up state are contemplated. Powered warm-up state adds heat to one or more components of the gas turbine engine 20 prior to transitioning to a takeoff power state, as depicted in the example plot 400 of FIG. 4.

**[0030]** As illustrated in FIG. 4, a conventional idle state gradually increases temperature over time as a conventional idle state temperature 402 from ambient 406 through a target temperature 408 and beyond. The target temperature 408 indicates a desired temperature level to enhance efficiency and operational performance of the gas turbine engine 20 prior to takeoff. In embodiments, while electric taxiing is performed at an electric taxiing temperature 404, fuel flow to combustor 207 (e.g., combustor 56 of FIG. 1) may be blocked/prevented, keeping the gas turbine engine 20 at or near ambient 406. Upon initiation of a powered warm-up state (e.g., based on detecting a powered warm-up request), heating of the gas turbine engine 20 can occur at a faster rate as a powered warm-up state temperature 405 than the conventional idle state temperature 402. After reaching the target temperature 408, the gas turbine engine 20 can transition from the powered warm-up state to a takeoff power state.

**[0031]** There can also be differences in fuel flow between a conventional idle state and a powered warm-up state. For example, as depicted in the example plot 500 of FIG. 5, a conventional idle fuel flow 502 may rise early and hold steady for a substantial period of time during idle. An electric taxiing fuel flow 504 may be at or near zero during electric taxiing until transitioning to a powered warmup state (e.g., after completion of electric taxiing) where a powered warmup fuel flow 505 rises above the conventional idle fuel flow 502. However, the total fuel

consumption in the combination of electric taxiing and the powered warmup fuel flow 505 may be less than the total fuel consumption of the conventional idle fuel flow 502.

**[0032]** FIG. 3 is a schematic diagram of a hybrid gas turbine engine system 301 as part of a hybrid electric aircraft 300 according to an embodiment. The hybrid gas turbine engine system 301 includes a first rotor system 302A and a second rotor system 302B, which may be an embodiment of the gas turbine engine 20 of FIG. 1. For instance, the first rotor system 302A can be the low speed spool 30 of the gas turbine engine 20, and the second rotor system 302B can be the high speed spool 32 of the gas turbine engine 20. The first rotor system 302A can include a first compressor section 204A and a first turbine section 208A operably coupled to a first shaft 206A. The second rotor system 302B can include a second compressor section 204B and a second turbine section 208B operably coupled to a second shaft 206B, where the second shaft 206B is concentrically arranged with respect to the first shaft 206A. With respect to the gas turbine engine 20 of FIG. 1, the first compressor section 204A can be equivalent to the low pressure compressor 44, the first shaft 206A can be equivalent to the inner shaft 40, and the first turbine section 208A can be equivalent to the low pressure turbine 46 of FIG. 1. Similarly, the second compressor section 204B can be equivalent to the high pressure compressor 52, the second shaft 206B can be equivalent to the outer shaft 50, and the second turbine section 208B can be equivalent to the high pressure turbine 54 of FIG. 1.

**[0033]** In the example of FIG. 3, an electric power system 310 includes a motor-generator 212 operably coupled to converter electronics 214 and an electric motor 312 driven by drive electronics 314. A first set of one or more rotor system sensors 218A may be associated with the first rotor system 302A, and a second set of one or more rotor system sensors 218B may be associated with the second rotor system 302B. The converter electronics 214 can control charging of the battery system 250 and conditioning current to/from the motor-generator 212 responsive to a controller 216 that may receive sensor data from the first set of one or more rotor system sensors 218A and the second set of one or more rotor system sensors 218B. The controller 216 may control the electric motor 312 through the drive electronics 314 responsive to sensor data from the first set of one or more rotor system sensors 218A and/or the second set of one or more rotor system sensors 218B. In other embodiments, the controller 216 is further subdivided as two or more separate controls, for instance, where a separate instance of the controller 216 is provided for each of the motor-generator 212 and the electric motor 312. The motor-generator 212 (when operated in a motor mode) and the electric motor 312 can be independently controlled to each supply a supplemental motive force to the respective shafts 206A, 206B, where fuel combustion in the combustor 207 can provide a primary motive force for

the first rotor system 302A as the low speed spool 30 and for the second rotor system 302B as the high speed spool 32. In some embodiments, the motor-generator 212 and the electric motor 312 can each be configured in either a generator mode or a motor mode.

**[0034]** The motor-generator 212 can be operably coupled to the first shaft 206A using a direct coupling, while the electric motor 312 can be operably coupled to the second shaft 206B using a geared interface 330. A first disconnect 240A, such as a clutch, can be positioned between the motor-generator 212 and a portion of the first shaft 206A, and a second disconnect 240B can be positioned between the electric motor 312 and a portion of the second shaft 206B. The geared interface 330 can include, for instance, a motor gear 333 coupled to a motor shaft 335 driven by the electric motor 312 and a rotor gear 337 coupled to the second shaft 206B. While the example of FIG. 3 depicts the electric power system 310 with the motor-generator 212 and electric motor 312 in different coupling configurations, it will be understood that both of the motor-generator 212 and electric motor 312 can be directly or indirectly coupled to corresponding first and second shafts 206A, 206B. For instance, the motor-generator 212 may be indirectly coupled through a tower shaft to the first shaft 206A, while the electric motor 312 is directly coupled to the second shaft 206B. Further, the coupling locations of the motor-generator 212 and electric motor 312 to the first and second shafts 206A, 206B can vary, and the coupling locations depicted in FIG. 3 are merely one example.

**[0035]** In the example of FIG. 3, the propulsion system use 256 can be to provide electrical power to the electric motor 312, power one or more electric heaters 262, 264, provide electrical power to the motor-generator 212 when operating in a motor mode, and/or other uses. In embodiments, the controller 216 may disable or provide limited current to the electric motor 312 while the battery system 250 is being charged by one or more of the motor-generator 212, the power input 252, and/or the auxiliary power input 254. Electric current produced by the motor-generator 212 above a level needed to charge the battery system 250 may be provided to other on-board uses.

**[0036]** Referring now to FIG. 6 with continued reference to FIGS. 1-5, FIG. 6 is a flow chart illustrating a method 600 for hybrid gas turbine engine system powered warm-up, in accordance with an embodiment. The method 600 may be performed, for example, by the systems 210, 310 of FIGS. 2 and 3. For purposes of explanation, the method 600 is described primarily with respect to the system 210 of FIG. 2; however, it will be understood that the method 600 can be performed on other configurations, such as the system 310 of FIG. 3 as well as other configurations (not depicted).

**[0037]** At block 602, the controller 216 can prevent fuel flow to the combustor 56 of the gas turbine engine 20 during at least a portion of electric taxiing of the hybrid electric aircraft 200, 300. At block 604, the controller 216 can monitor for a powered warm-up request during the

electric taxiing. A powered warm-up state request can be received as a message, for instance, a pilot initiated command. At block 606, the controller 216 can initiate a powered warm-up state of the gas turbine engine 20 based on detecting the powered warm-up request, where the powered warm-up state adds heat to one or more components of the gas turbine engine 20 prior to transitioning to a takeoff power state. Adding of heat is not limited to the use of electric heaters 262, 264 but can include any means of adding heat to one or more components of the gas turbine engine 20, such as starting combustion and operating the gas turbine engine 20 above a nominal idle fuel flow rate after electric taxiing, for example. At block 608, the controller 216 can transition the gas turbine engine 20 from the powered warm-up state to the takeoff power state after reaching a target temperature 408 of the one or more components in the powered warm-up state. Engine spool rotational speed, throttle commands, and other inputs received at the controller 216 can be used to determine the operational status of the gas turbine engine 20.

**[0038]** An electric motor, such as motor-generator 212 or electric motor 312, can be used to drive rotation of the gas turbine engine 20 as part of electric taxiing. Alternatively, electric taxiing can include the use of an electric motor to push, pull, or drive ground wheel rotation of the hybrid electric aircraft 200, 300 while on the ground.

**[0039]** In embodiments, the powered warm-up state can include enabling one or more electric heaters 262, 264. Further, in powered warm-up state, the high speed spool 32 can be motored in reverse to urge heat in a reverse flow direction as compared to normal engine operation. The powered warm-up state can include motorizing the high speed spool 32 with a sub-idle fuel flow. Further, the gas turbine engine 20 can be operated with a higher engine power setting above idle to drive rotation of a motor-generator 212 operably coupled to the low speed spool 30 and produce idle thrust after the electric taxiing. As a further option for powered warm-up state, the controller 216 can command a combination of vane positions and power setting of the gas turbine engine 20 that reduces a compressor efficiency of the gas turbine engine 20 to increase temperature at or below idle thrust.

**[0040]** The term "about" is intended to include the degree of error associated with measurement of the particular quantity based upon the equipment available at the time of filing the application.

**[0041]** The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the present disclosure. As used herein, the singular forms "a", "an" and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms "comprises" and/or "comprising," when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, oper-

ations, element components, and/or groups thereof. The invention is defined by the appended claims.

## 5 Claims

1. A hybrid gas turbine engine system (201; 301) of a hybrid electric aircraft (200; 300), the hybrid gas turbine engine system comprising:

a gas turbine engine (20);  
an electric motor (312) operable to perform an electric taxiing of the hybrid electric aircraft; and  
a controller (216) operable to:

prevent fuel flow to the gas turbine engine (20) during at least a portion of the electric taxiing;

monitor for a powered warm-up request during the electric taxiing;

initiate a powered warm-up state (405) of the gas turbine engine (20) based on detecting the powered warm-up request, wherein the powered warm-up state adds heat to one or more components of the gas turbine engine prior to transitioning to a takeoff power state; and

transition the gas turbine engine (20) from the powered warm-up state to the takeoff power state after reaching a target temperature (408) of the one or more components in the powered warm-up state;

**characterised in that**

the powered warm-up state (405) comprises enabling one or more electric heaters (262, 264), and/or

the controller is configured to command a combination of vane positions and power setting of the gas turbine engine (20) that reduces a compressor efficiency of the gas turbine engine to increase temperature at or below idle thrust in the powered warm-up state (405).

2. The hybrid gas turbine engine system of claim 1, wherein the gas turbine engine (20) comprises a low speed spool (30) and a high speed spool (32).
3. The hybrid gas turbine engine system of claim 2, wherein the controller is configured to motor the high speed spool (32) in reverse to urge heat in a reverse flow direction in the powered warm-up state (405).
4. The hybrid gas turbine engine system of claim 2, wherein the controller is configured to motor the high speed spool (32) with a sub-idle fuel flow in the powered warm-up state (405).

5. The hybrid gas turbine engine system of claim 2, further comprising:  
a generator (212) operably coupled to the low speed spool (30) of the gas turbine engine (20), and the controller is configured to operate the gas turbine engine (20) with a higher engine power setting above idle to drive rotation of the generator (212) and produce idle thrust after the electric taxiing.

6. The hybrid gas turbine engine system of claim 5, wherein the generator (212) is a motor-generator wherein the controller is configured to operate the generator in a generator mode to charge a battery system (250) and in a motor mode to provide supplemental rotation force to the gas turbine engine (20); and/or wherein the generator (212) is configured to provide power for motoring the high speed spool (32) and/or charging a battery system (250).

7. A propulsion system for a hybrid electric aircraft (200; 300), the propulsion system comprising:

a hybrid gas turbine engine system (201; 301) of any preceding claim, the gas turbine engine (20) comprising a low speed spool (30), a high speed spool (32), and a combustor (56; 207); the electric motor (312) being operably coupled to the high speed spool; and the controller (216) being operable to prevent fuel flow to the combustor (56; 207) of the gas turbine engine during at least a portion of an electric taxiing of the hybrid electric aircraft.

8. A method of providing a powered warm-up for a gas turbine engine (20) of a hybrid electric aircraft (200; 300), the method comprising:

preventing (602) fuel flow to the gas turbine engine during at least a portion of an electric taxiing of the hybrid electric aircraft;  
monitoring (604) for a powered warm-up request during the electric taxiing;  
initiating (606) a powered warm-up state (405) of the gas turbine engine (20) based on detecting the powered warm-up request, wherein the powered warm-up state adds heat to one or more components of the gas turbine engine (20) prior to transitioning to a takeoff power state; and  
transitioning (608) the gas turbine engine (20) from the powered warm-up state to the takeoff power state after reaching a target temperature (408) of the one or more components in the powered warm-up state;

**characterised in that**

the powered warm-up state (405) comprises enabling one or more electric heaters (262, 264), and/or the method comprises commanding a combina-

tion of vane positions and power setting of the gas turbine engine (20) that reduces a compressor efficiency of the gas turbine engine to increase temperature at or below idle thrust in the powered warm-up state.

9. The method of claim 8, wherein the gas turbine engine comprises a low speed spool (30) and a high speed spool (32), and further comprising: motoring the high speed spool (32) in reverse to urge heat in a reverse flow direction in the powered warm-up state.

10. The method of claim 8, wherein the gas turbine engine (20) comprises a low speed spool (30) and a high speed spool (32), and further comprising: motoring the high speed spool (32) with a sub-idle fuel flow in the powered warm-up state.

11. The method of claim 8, wherein the gas turbine engine comprises a low speed spool (30) and a high speed spool (32), and further comprising: operating the gas turbine engine (20) with a higher engine power setting above idle to drive rotation of a generator (212) operably coupled to the low speed spool (30) and produce idle thrust after the electric taxiing, wherein the generator (212) is a motor-generator operable in a generator mode to charge a battery system (250) and/or provide power for motoring the high speed spool (32), and the generator (212) is operable in a motor mode to provide supplemental rotation force to the gas turbine engine.

**Patentansprüche**

1. Hybridgasturbinentriebwerkssystem (201; 301) eines hybrid-elektrischen Luftfahrzeugs (200; 300), wobei das Hybridgasturbinentriebwerkssystem Folgendes umfasst:

ein Gasturbinentriebwerk (20);  
einen Elektromotor (312), der betrieben werden kann, um ein elektrisches Rollen des hybrid-elektrischen Luftfahrzeugs durchzuführen; und  
eine Steuerung (216), die betrieben werden kann, um:

Kraftstoffdurchsatz zum Gasturbinentriebwerk (20) während mindestens eines Abschnitts des elektrischen Rollens zu verhindern;  
eine unterstützte Aufwärmanforderung während des elektrischen Rollens zu überwachen;  
einen unterstützten Aufwärmzustand (405) des Gasturbinentriebwerks (20) basierend auf der Erkennung der unterstützten Auf-



wärmanforderung zu initiieren, wobei der unterstützte Aufwärmzustand einer oder mehreren Komponenten des Gasturbinen-  
triebwerks vor dem Übergang in einen  
Startleistungszustand Wärme zuführt; und  
das Gasturbinen-  
triebwerk (20) von dem unter-  
stützten Aufwärmzustand in den Start-  
leistungszustand übergehen zu lassen,  
nachdem eine Zieltemperatur (408) der ei-  
nen oder mehreren Komponenten in dem  
unterstützten Aufwärmzustand erreicht ist;

**dadurch gekennzeichnet, dass**

der unterstützte Aufwärmzustand (405) die Ak-  
tivierung einer oder mehrerer elektrischer Heiz-  
vorrichtungen (262, 264) umfasst, und/oder  
die Steuerung dazu konfiguriert ist, eine Kom-  
bination von Leitschaukelpositionen und Lei-  
stungseinstellung des Gasturbinen-  
triebwerks (20) zu steuern, die eine Verdichtereffizienz des  
Gasturbinen-  
triebwerks reduziert, um die Tem-  
peratur bei oder unter dem Leerlaufschub in  
dem unterstützten Aufwärmzustand (405) zu er-  
höhen.

2. Hybridgasturbinen-  
triebwerkssystem nach Anspruch  
1, wobei das Gasturbinen-  
triebwerk (20) eine Spule  
(30) mit einer niedrigen Geschwindigkeit und eine  
Spule (32) mit einer hohen Geschwindigkeit um-  
fasst.
3. Hybridgasturbinen-  
triebwerkssystem nach Anspruch  
2, wobei die Steuerung dazu konfiguriert ist, die Spu-  
le (32) mit einer hohen Geschwindigkeit umgekehrt  
anzutreiben, um Wärme in einer umgekehrten Strö-  
mungsrichtung in den unterstützten Aufwärmzu-  
stand (405) zu drängen.
4. Hybridgasturbinen-  
triebwerkssystem nach Anspruch  
2, wobei die Steuerung dazu konfiguriert ist, die Spu-  
le (32) mit einer hohen Geschwindigkeit mit einem  
Kraftstoffdurchsatz im Leerlauf in dem unterstützten  
Aufwärmzustand (405) anzutreiben.
5. Hybridgasturbinen-  
triebwerkssystem nach Anspruch  
2, ferner umfassend:  
einen Generator (212), der mit der Spule (30) mit  
einer niedrigen Geschwindigkeit des Gasturbinen-  
triebwerks (20) wirkverbunden ist, und wobei die  
Steuerung dazu konfiguriert ist, das Gasturbinen-  
triebwerk (20) mit einer höheren Triebwerkslei-  
stungseinstellung über dem Leerlauf zum Antreiben  
der Drehung des Generators (212) und Erzeugen  
von Leerlaufschub nach dem elektrischen Rollen zu  
betreiben.
6. Hybridgasturbinen-  
triebwerkssystem nach Anspruch  
5, wobei der Generator (212) ein Motorgenerator ist,

wobei die Steuerung dazu konfiguriert ist, den Ge-  
nerator in einem Generatormodus zum Laden eines  
Batteriesystems (250) und in einem Motormodus  
zum Bereitstellen einer zusätzlichen Drehkraft an  
das Gasturbinen-  
triebwerk (20) zu betreiben;  
und/oder wobei der Generator (212) dazu konfigu-  
riert ist, eine Leistung für den Antrieb der Spule (32)  
mit einer hohen Geschwindigkeit und/oder für die  
Ladung eines Batteriesystems (250) bereitzustellen.

7. Antriebssystem für ein hybrid-elektrisches Luftfahr-  
zeug (200; 300), wobei das Antriebssystem Folgen-  
des umfasst:

ein Hybridgasturbinen-  
triebwerkssystem (201;  
301) nach einem der vorhergehenden Ansprü-  
che, wobei das Gasturbinen-  
triebwerk (20) eine  
Spule (30) mit einer niedrigen Geschwindigkeit,  
eine Spule (32) mit einer hohen Geschwindig-  
keit und eine Brennkammer (56; 207) umfasst;  
wobei der Elektromotor (312) mit der Spule mit  
einer hohen Geschwindigkeit wirkverbunden ist;  
und

wobei die Steuerung (216) betrieben werden  
kann, um einen Kraftstoffdurchsatz zu der  
Brennkammer (56; 207) des Gasturbinen-  
triebwerks während mindestens eines Abschnitts  
von einem elektrischen Rollen des hybrid-elek-  
trischen Luftfahrzeugs zu verhindern.

8. Verfahren zur Bereitstellung einer unterstützten Auf-  
wärmung für ein Gasturbinen-  
triebwerk (20) eines hy-  
brid-elektrischen Luftfahrzeugs (200; 300), wobei  
das Verfahren Folgendes umfasst:

Verhindern (602) eines Kraftstoffdurchsatzes zu  
dem Gasturbinen-  
triebwerk während mindes-  
tens eines Abschnitts eines elektrischen Rollens  
des hybrid-elektrischen Luftfahrzeugs;

Überwachen (604) einer unterstützten Aufwär-  
manforderung während des elektrischen Rol-  
lens;

Initiieren (606) eines unterstützten Aufwärmzu-  
stands (405) des Gasturbinen-  
triebwerks (20)  
basierend auf der Erkennung der unterstützten  
Aufwärmanforderung, wobei der unterstützte  
Aufwärmzustand einer oder mehreren Kompo-  
nenten des Gasturbinen-  
triebwerks (20) vor dem  
Übergang in einen Startleistungszustand Wär-  
me zuführt; und

Übergehenlassen (608) des Gasturbinen-  
triebwerks (20) von dem unterstützten Aufwärmzu-  
stand in den Startleistungszustand nach dem  
Erreichen einer Zieltemperatur (408) der einen  
oder mehreren Komponenten in dem unterstütz-  
ten Aufwärmzustand;

**dadurch gekennzeichnet, dass**

der unterstützte Aufwärmzustand (405) die Ak-

tivierung einer oder mehrerer elektrischer Heizvorrichtungen (262, 264) umfasst, und/oder das Verfahren die Steuerung einer Kombination von Leitschaukelpositionen und Leistungseinstellung des Gasturbinentriebwerks (20) umfasst, die eine Verdichtereffizienz des Gasturbinentriebwerks reduziert, um die Temperatur bei oder unter dem Leerlaufschub in dem unterstützten Aufwärmzustand zu erhöhen.

9. Verfahren nach Anspruch 8, wobei das Gasturbinentriebwerk eine Spule (30) mit einer niedrigen Geschwindigkeit und eine Spule (32) mit einer hohen Geschwindigkeit umfasst, und ferner umfassend: umgekehrtes Antreiben der Spule (32) mit einer hohen Geschwindigkeit, um Wärme in einer umgekehrten Strömungsrichtung in den unterstützten Aufwärmzustand zu drängen.
10. Verfahren nach Anspruch 8, wobei das Gasturbinentriebwerk (20) eine Spule (30) mit einer niedrigen Geschwindigkeit und eine Spule (32) mit einer hohen Geschwindigkeit umfasst, und ferner umfassend: Antreiben der Spule (32) mit einer hohen Geschwindigkeit mit einem Kraftstoffdurchsatz im Leerlauf in dem unterstützten Aufwärmzustand.
11. Verfahren nach Anspruch 8, wobei das Gasturbinentriebwerk eine Spule (30) mit einer niedrigen Geschwindigkeit und eine Spule (32) mit einer hohen Geschwindigkeit umfasst, und ferner umfassend: Betreiben des Gasturbinentriebwerks (20) mit einer höheren Triebwerksleistungseinstellung über dem Leerlauf, um die Drehung eines Generators (212) anzutreiben, der mit der Spule (30) mit einer niedrigen Geschwindigkeit wirkverbunden ist, und um einen Leerlaufschub nach dem elektrischen Rollen zu erzeugen, wobei der Generator (212) ein Motorgenerator ist, der in einem Generatormodus zum Laden eines Batteriesystems (250) und/oder Bereitstellen einer Leistung für den Antrieb der Spule (32) mit einer hohen Geschwindigkeit betrieben werden kann, und wobei der Generator (212) in einem Motormodus zum Bereitstellen einer zusätzlichen Drehkraft an das Gasturbinentriebwerk betrieben werden kann.

## Revendications

1. Système de moteur à turbine à gaz hybride (201 ; 301) d'un aéronef électrique hybride (200 ; 300), le système de moteur à turbine à gaz hybride comprenant :  
  
un moteur à turbine à gaz (20) ;  
un moteur électrique (312) pouvant fonctionner pour effectuer un roulage électrique de l'aéronef

électrique hybride ; et  
un dispositif de commande (216) pouvant fonctionner pour :

empêcher l'écoulement de carburant vers le moteur à turbine à gaz (20) pendant au moins une partie du roulage électrique ;  
surveiller une demande de réchauffement alimenté pendant le roulage électrique ;  
initier un état de réchauffement alimenté (405) du moteur à turbine à gaz (20) sur la base de la détection de la demande de réchauffement alimenté, dans lequel l'état de réchauffement alimenté ajoute de la chaleur à un ou plusieurs composants du moteur à turbine à gaz avant la transition à un état de puissance de décollage ; et  
faire passer le moteur à turbine à gaz (20) de l'état de réchauffement alimenté à l'état de puissance de décollage après avoir atteint une température cible (408) des un ou plusieurs composants dans l'état de réchauffement alimenté ;

## caractérisé en ce que

l'état de réchauffement alimenté (405) comprend l'activation d'un ou de plusieurs radiateurs électriques (262, 264), et/ou  
le dispositif de commande est configuré pour commander une combinaison de positions d'aubes et de réglage de puissance du moteur à turbine à gaz (20) qui réduit l'efficacité d'un compresseur du moteur à turbine à gaz pour augmenter la température à ou au-dessous de la poussée de ralenti dans l'état de réchauffement alimenté (405).

2. Système de moteur à turbine à gaz hybride selon la revendication 1, dans lequel le moteur à turbine à gaz (20) comprend une bobine faible vitesse (30) et une bobine haute vitesse (32).
3. Système de moteur à turbine à gaz hybride selon la revendication 2, dans lequel le dispositif de commande est configuré pour motoriser la bobine haute vitesse (32) en sens inverse afin de pousser la chaleur dans une direction d'écoulement inverse dans l'état de réchauffement alimenté (405) .
4. Système de moteur à turbine à gaz hybride selon la revendication 2, dans lequel le dispositif de commande est configuré pour motoriser la bobine haute vitesse (32) avec un écoulement de carburant au régime inférieur au ralenti dans l'état de réchauffement alimenté (405).
5. Système de moteur à turbine à gaz hybride selon la revendication 2, comprenant en outre :

- un générateur (212) couplé de manière opérationnelle à la bobine faible vitesse (30) du moteur à turbine à gaz (20), et le dispositif de commande est configuré pour faire fonctionner le moteur à turbine à gaz (20) avec un réglage de puissance de moteur plus élevé au-dessus du ralenti pour entraîner la rotation du générateur (212) et produire une poussée au ralenti après le roulage électrique.
- 5
6. Système de moteur à turbine à gaz hybride selon la revendication 5, dans lequel le générateur (212) est un générateur-moteur dans lequel le dispositif de commande est configuré pour faire fonctionner le générateur dans un mode générateur pour charger un système de batterie (250) et dans un mode moteur pour fournir une force de rotation supplémentaire au moteur à turbine à gaz (20) ; et/ou dans lequel le générateur (212) est configuré pour fournir de la puissance pour motoriser la bobine haute vitesse (32) et/ou charger un système de batterie (250) .
- 10
7. Système de propulsion pour un aéronef électrique hybride (200 ; 300), le système de propulsion comprenant :
- 15
- un système de moteur à turbine à gaz hybride (201 ; 301) selon une quelconque revendication précédente, le moteur à turbine à gaz (20) comprenant une bobine faible vitesse (30), une bobine haute vitesse (32) et une chambre de combustion (56 ; 207) ;
- 20
- le moteur électrique (312) étant couplé de manière opérationnelle à la bobine haute vitesse ; et
- le dispositif de commande (216) pouvant fonctionner pour empêcher l'écoulement de carburant vers la chambre de combustion (56 ; 207) du moteur à turbine à gaz pendant au moins une partie d'un roulage électrique de l'aéronef électrique hybride.
- 25
8. Procédé de fourniture d'un réchauffement alimenté pour un moteur à turbine à gaz (20) d'un aéronef électrique hybride (200 ; 300), le procédé comprenant :
- 30
- le fait d'empêcher (602) l'écoulement de carburant vers le moteur à turbine à gaz pendant au moins une partie d'un roulage électrique de l'aéronef électrique hybride ;
- 35
- la surveillance (604) d'une demande de réchauffement alimenté pendant le roulage électrique ; l'initiation (606) d'un état de réchauffement alimenté (405) du moteur à turbine à gaz (20) sur la base de la détection de la demande de réchauffement alimenté, dans lequel l'état de réchauffement alimenté ajoute de la chaleur à un
- 40
- ou plusieurs composants du moteur à turbine à gaz (20) avant la transition à un état de puissance de décollage ; et
- la transition (608) du moteur à turbine à gaz (20) de l'état de réchauffement alimenté à l'état de puissance de décollage après avoir atteint une température cible (408) des un ou plusieurs composants dans l'état de réchauffement alimenté ;
- 45
- caractérisé en ce que**
- l'état de réchauffement alimenté (405) comprend l'activation d'un ou de plusieurs radiateurs électriques (262, 264) et/ou
- le procédé comprend la commande d'une combinaison de positions d'aubes et de réglage de puissance du moteur à turbine à gaz (20) qui réduit l'efficacité d'un compresseur du moteur à turbine à gaz pour augmenter la température à ou au-dessous de la poussée de ralenti dans l'état de réchauffement alimenté.
- 50
9. Procédé selon la revendication 8, dans lequel le moteur à turbine à gaz comprend une bobine faible vitesse (30) et une bobine haute vitesse (32), et comprenant en outre :
- la motorisation de la bobine haute vitesse (32) en sens inverse afin de pousser la chaleur dans une direction d'écoulement inverse dans l'état de réchauffement alimenté.
- 55
10. Procédé selon la revendication 8, dans lequel le moteur à turbine à gaz (20) comprend une bobine faible vitesse (30) et une bobine haute vitesse (32), et comprenant en outre :
- la motorisation de la bobine haute vitesse (32) avec un écoulement de carburant au régime inférieur au ralenti dans l'état de réchauffement alimenté.
11. Procédé selon la revendication 8, dans lequel le moteur à turbine à gaz comprend une bobine faible vitesse (30) et une bobine haute vitesse (32), et comprenant en outre :
- le fonctionnement du moteur à turbine à gaz (20) avec un réglage de puissance de moteur plus élevé au-dessus du ralenti pour entraîner la rotation d'un générateur (212) couplé de manière opérationnelle à la bobine faible vitesse (30) et produire une poussée au ralenti après le roulage électrique, dans lequel le générateur (212) est un générateur-moteur pouvant fonctionner dans un mode générateur pour charger un système de batterie (250) et/ou fournir de la puissance pour motoriser la bobine haute vitesse (32), et le générateur (212) peut fonctionner dans un mode moteur pour fournir une force de rotation supplémentaire au moteur à turbine à gaz.

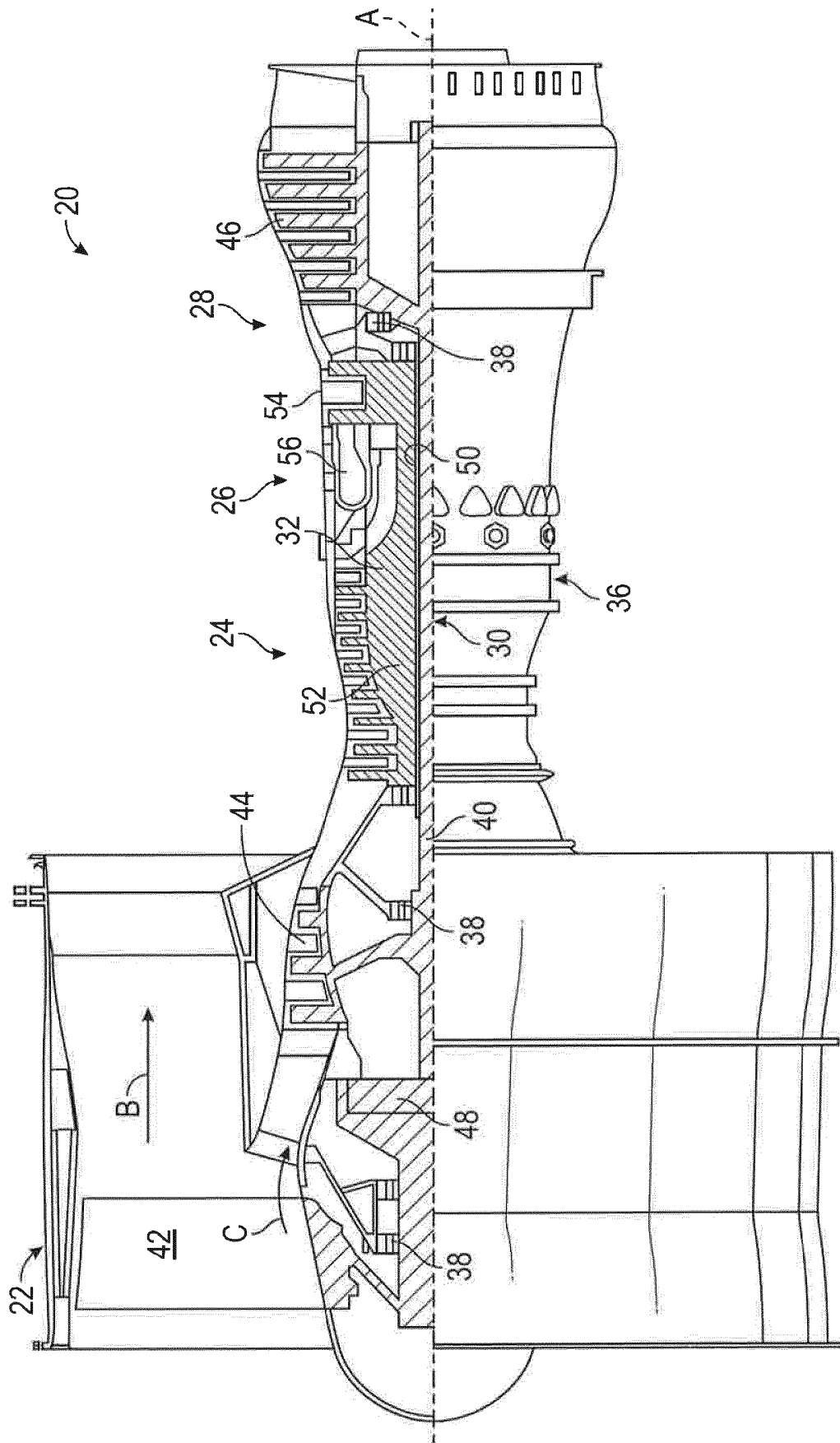


FIG. 1

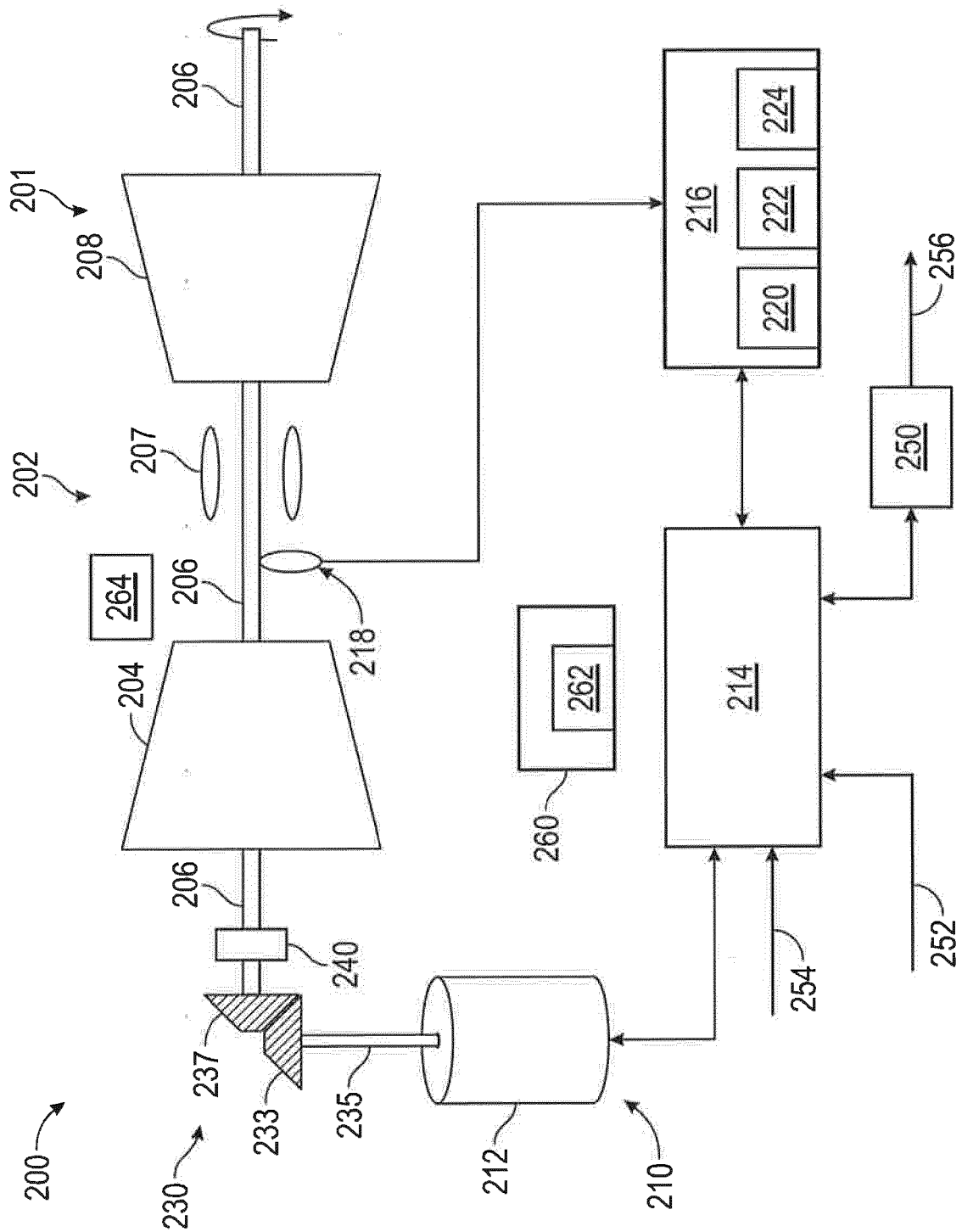


FIG. 2

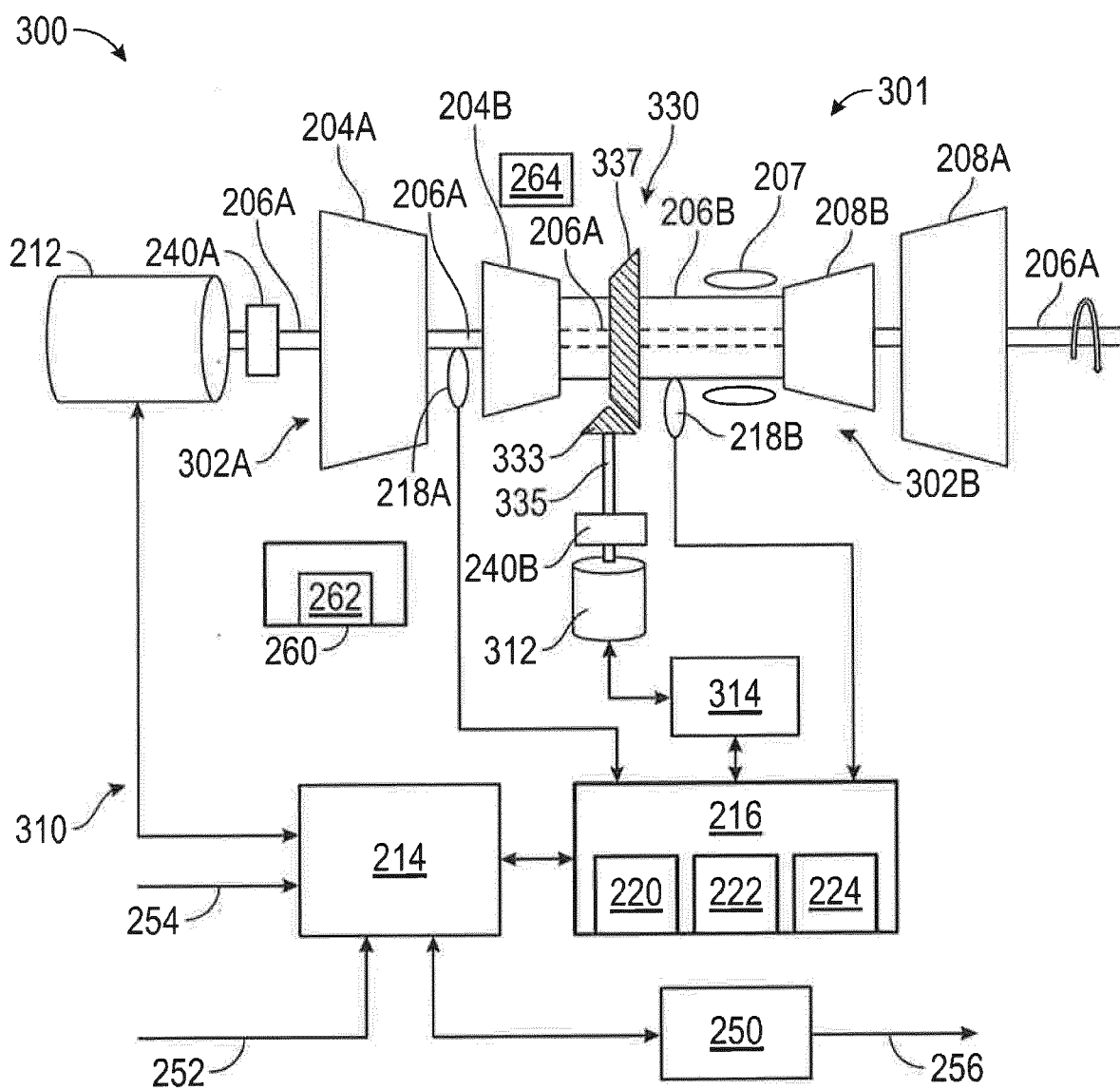


FIG. 3

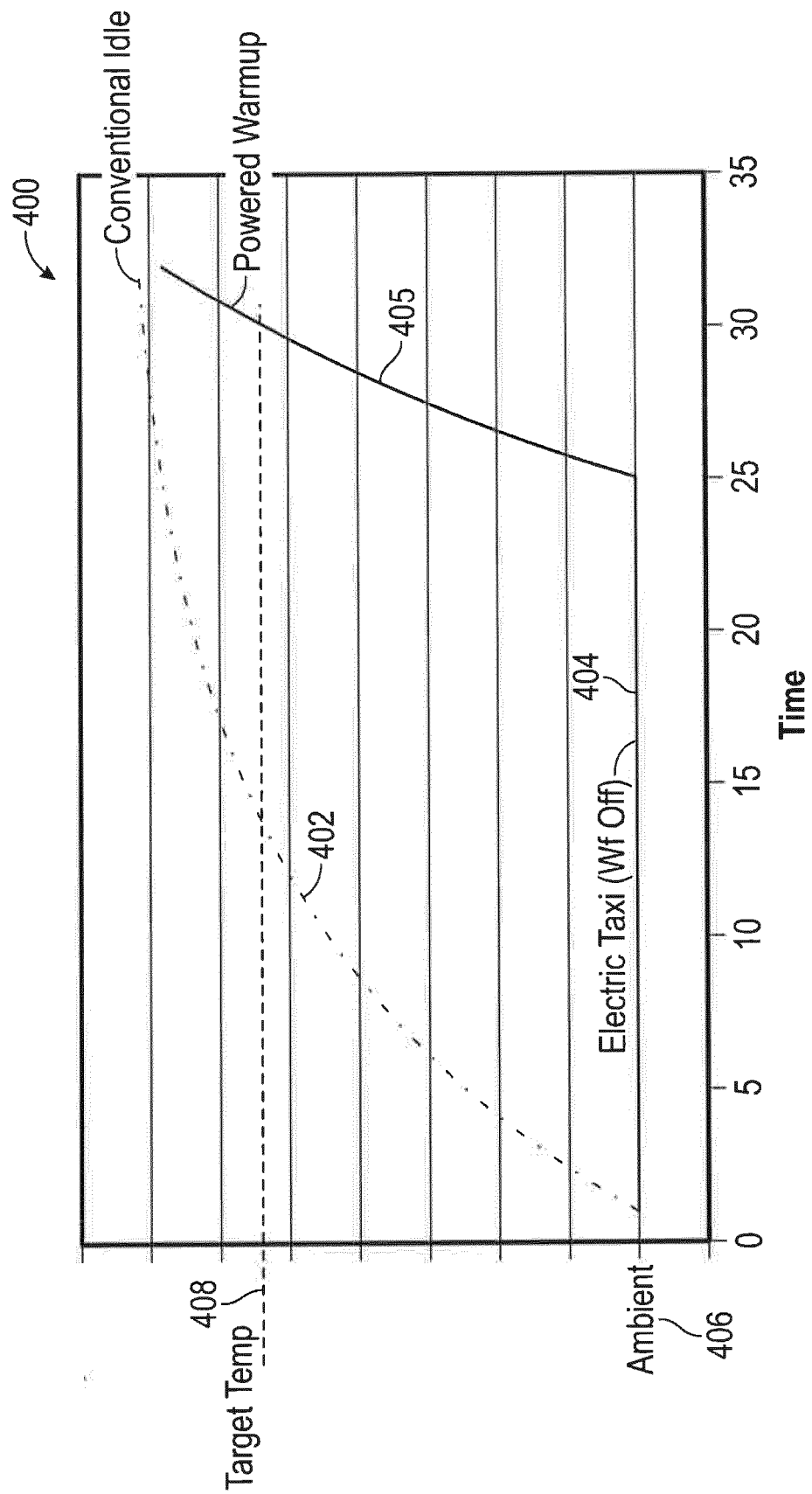


FIG. 4

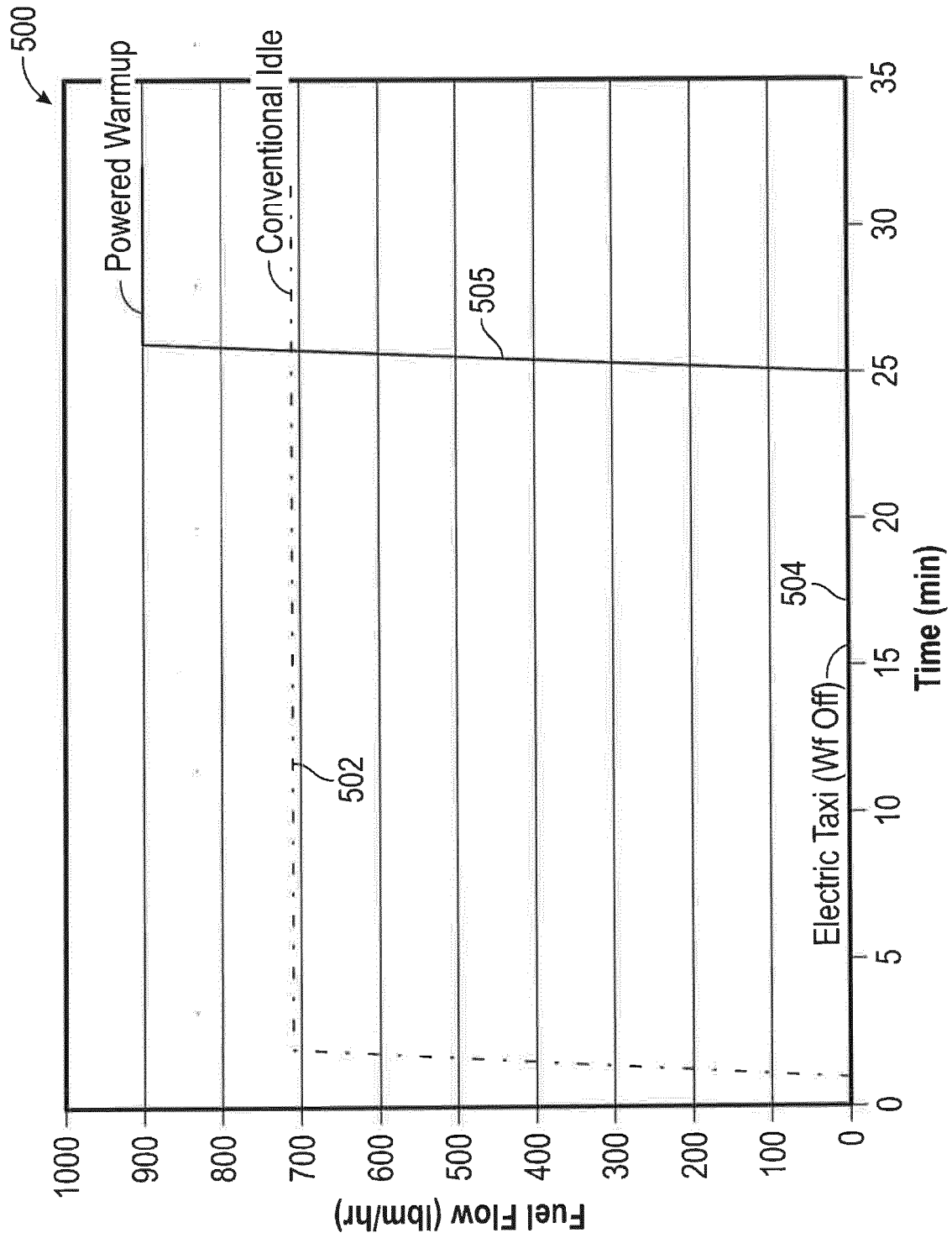


FIG. 5



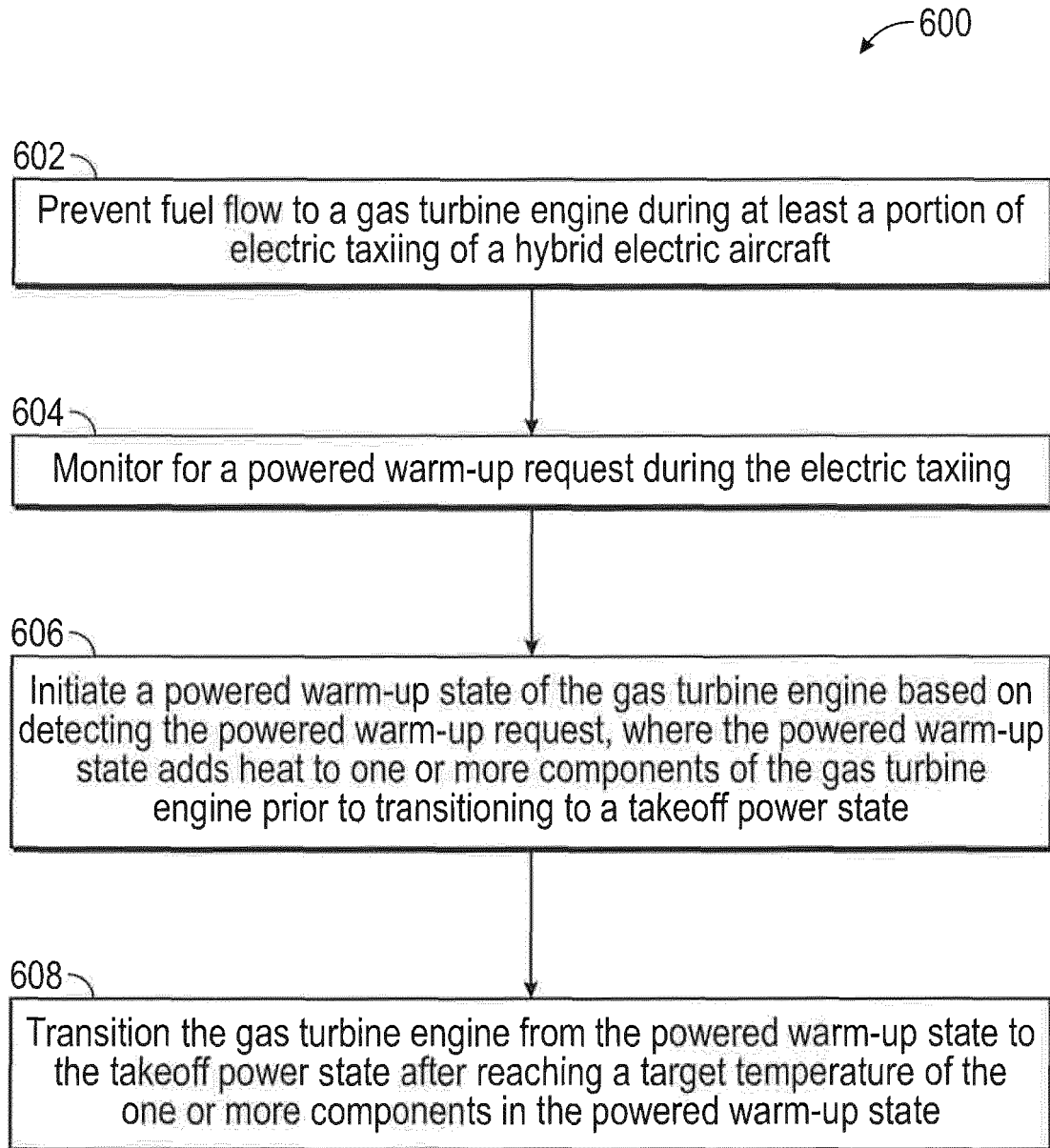


FIG. 6

**REFERENCES CITED IN THE DESCRIPTION**

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**Patent documents cited in the description**

- US 2018002025 A [0003]
- US 2007101721 A [0004]