US 20190390603A1

(19) **United States**

(12) **Patent Application Publication**

Snyder

(10) **Pub. No.: US 2019/0390603 A1**

(43) **Pub. Date: Dec. 26, 2019**

(54) SYSTEMS AND METHODS FOR COOLING ELECTRONICS AND ELECTRICAL MACHINERY IN A HYBRID ELECTRIC AIRCRAFT

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(21) Appl. No.: **16/015,904**

(22) Filed: **Jun. 22, 2018**

Publication Classification

(51) **Int. Cl.**

F02C 7/18	(2006.01)
F28D 15/02	(2006.01)
H05K 7/20	(2006.01)

(52) **U.S. Cl.**

CPC ***F02C 7/185*** (2013.01); ***F28D 15/025*** (2013.01); ***H05K 7/20327*** (2013.01); ***H05K 7/203*** (2013.01); *F05D 2260/232* (2013.01); ***H05K 7/20318*** (2013.01); ***H05K 7/20381*** (2013.01); *F05D 2220/323* (2013.01); ***H05K 7/20309*** (2013.01)

(57) ABSTRACT

Systems and methods for cooling electrical components disposed in a jet engine. An example system includes an evaporation chamber configured to contain the electrical components in contact with a coolant liquid. The coolant vapor formed during the heat transfer from the electrical components to the coolant liquid flows to a condenser assembly having a fuel-cooled condenser and an air-cooled condenser. The air-cooled condenser cools the coolant vapor to condensation using either fan stream air or engine bleed air from the intermediate pressure compressor or the high pressure compressor. An air cycle machine cools the engine bleed air. A controller may be used to select a coolant source for condensing the coolant vapor based on operating conditions of the aircraft. Spent air from the air-cooled condenser may be recycled back to the engine for engine cooling, added thrust, oil sump buffering, oil or fuel cooling, or blade tip clearance control.

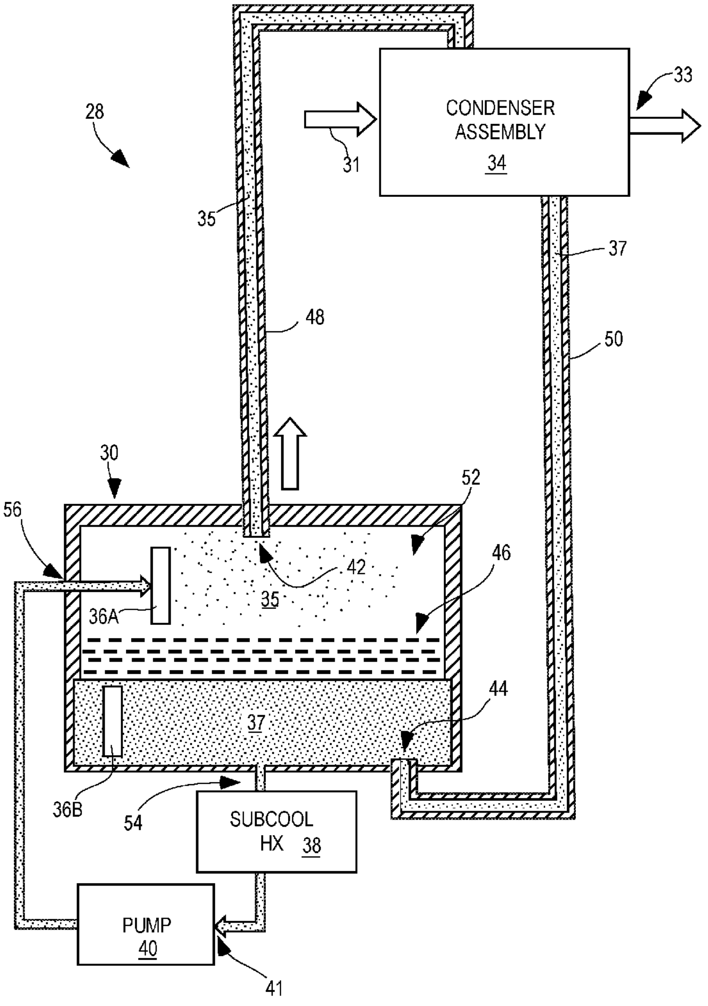


FIG. 1

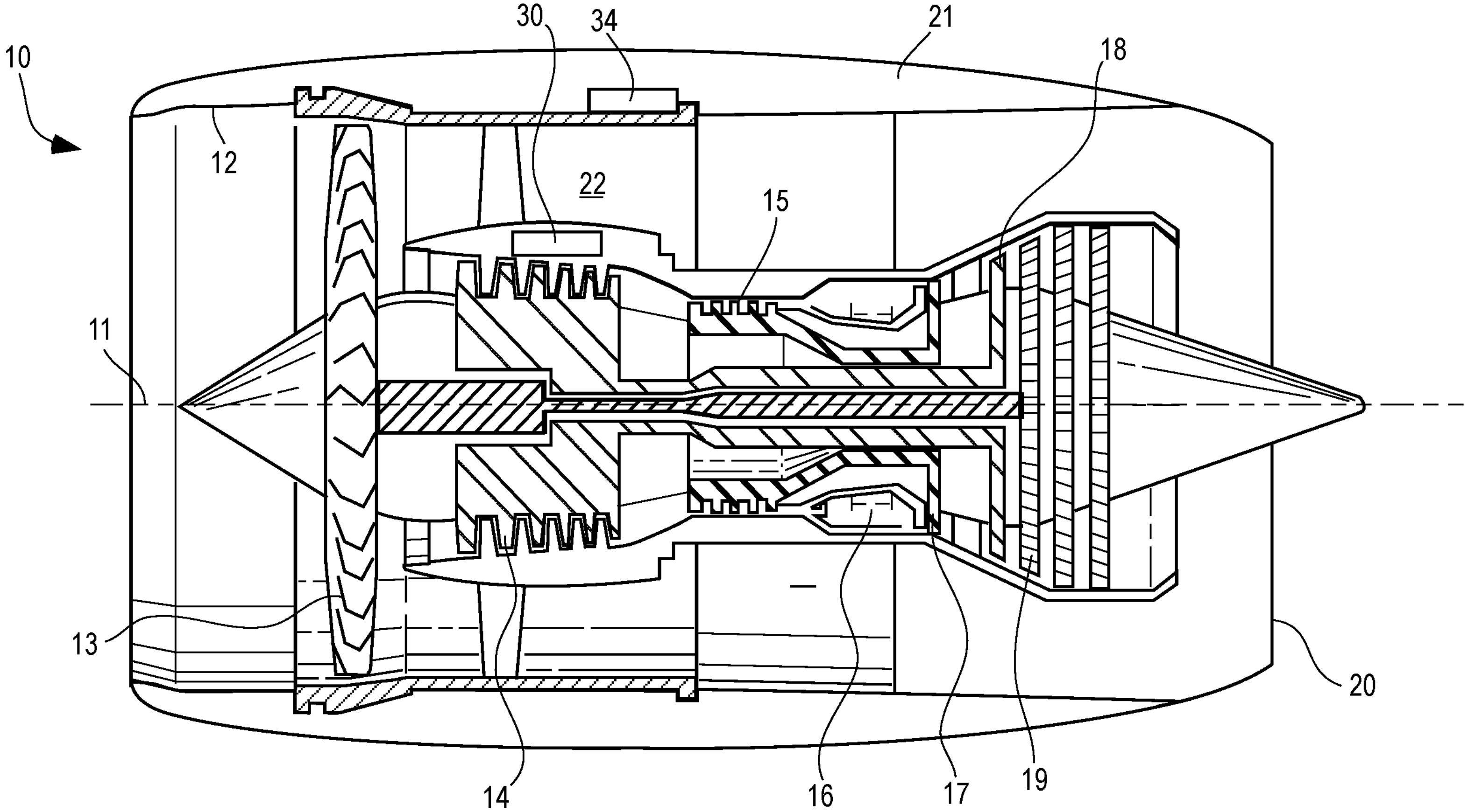


FIG. 2

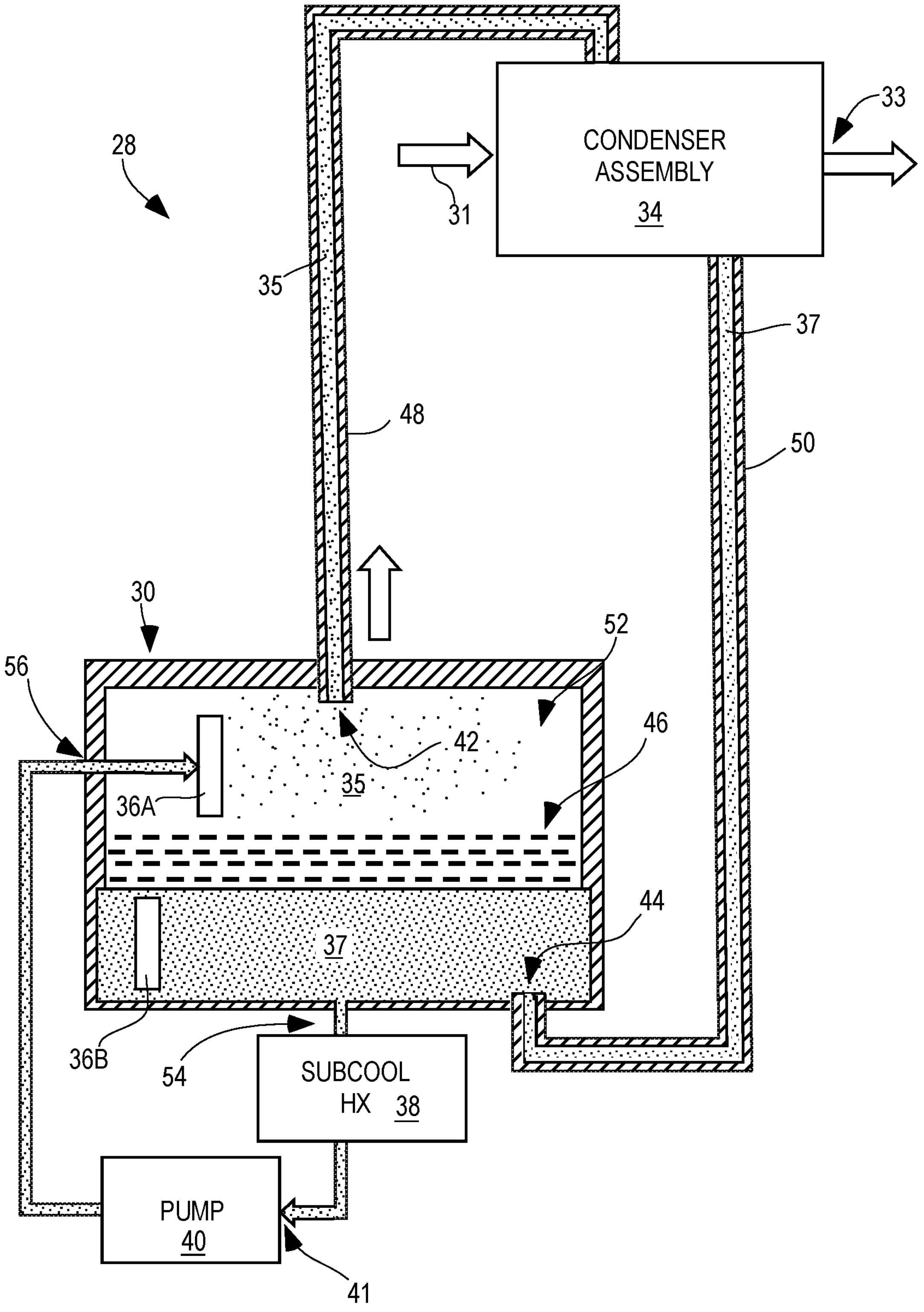

CONDENSER ASSEMBLY 34
33
28
31
35
37
48
50
30
52
56
42
46
35
36A
37
44
36B
54
SUBCOOL HX 38
PUMP 40
41

FIG. 3

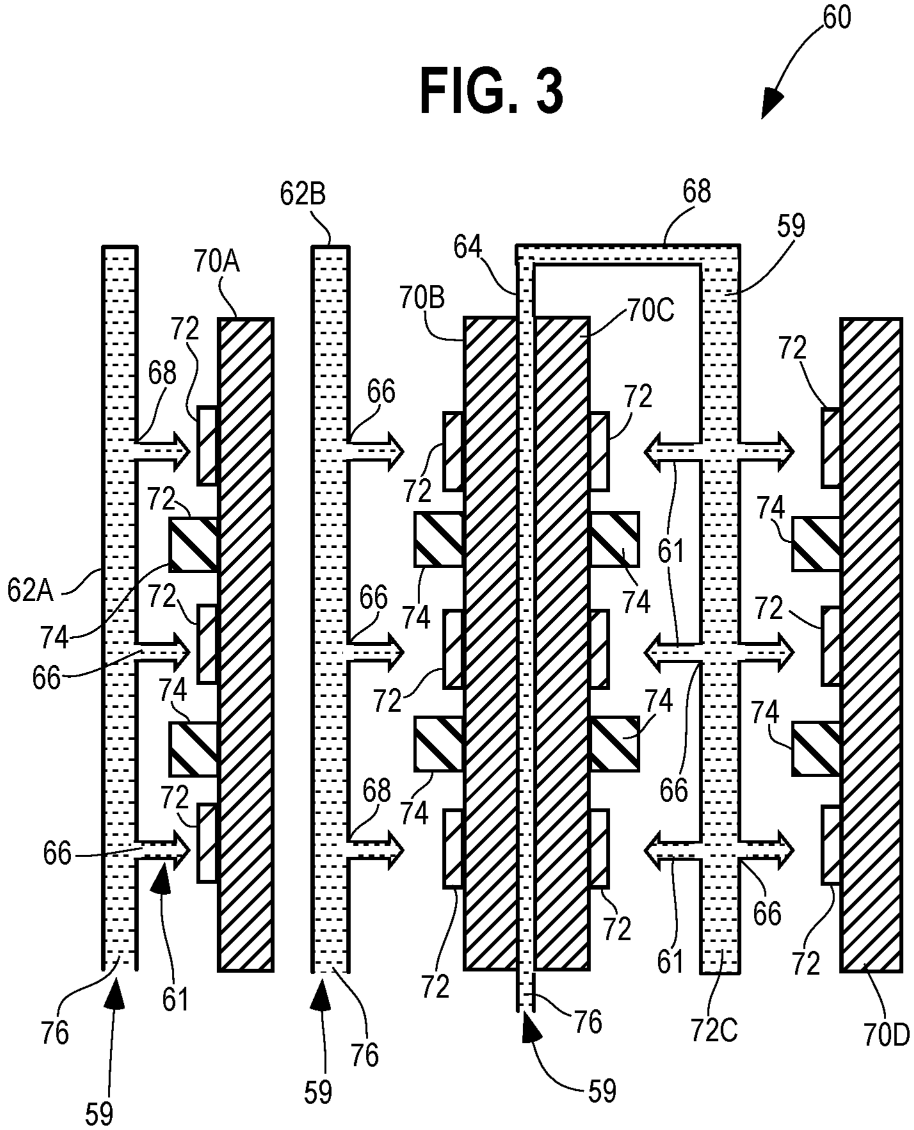

60
62B
68
59
64
70A
70B
70C
72
68
66
72
72
72
72
74
74
62A
74
72
66
72
72
74
66
74
66
74
74
74
74
72
72
68
74
66
66
72
72
61
66
76
61
72
61
72
72C
70D
76
76
76
59
59
59

FIG. 4

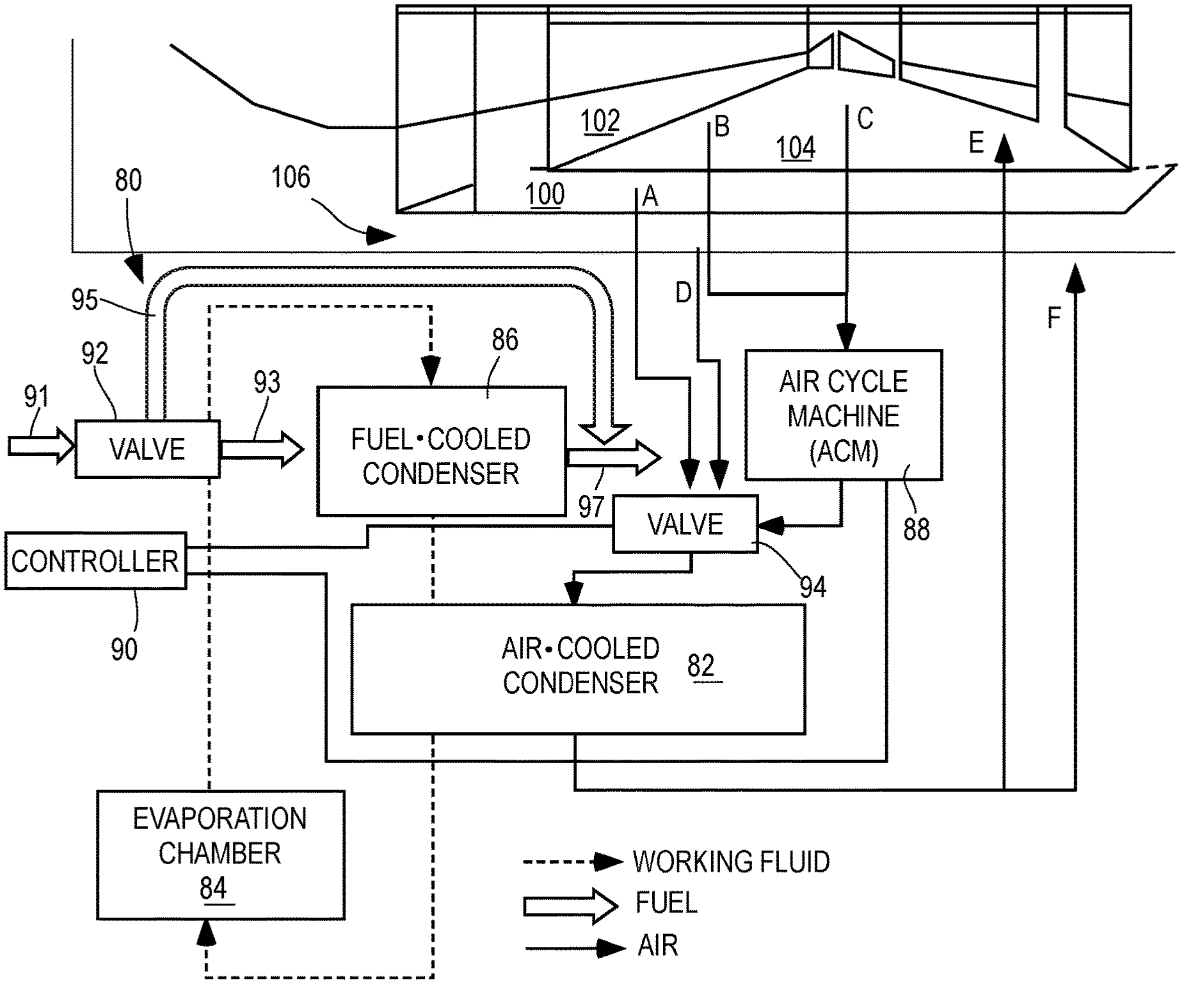
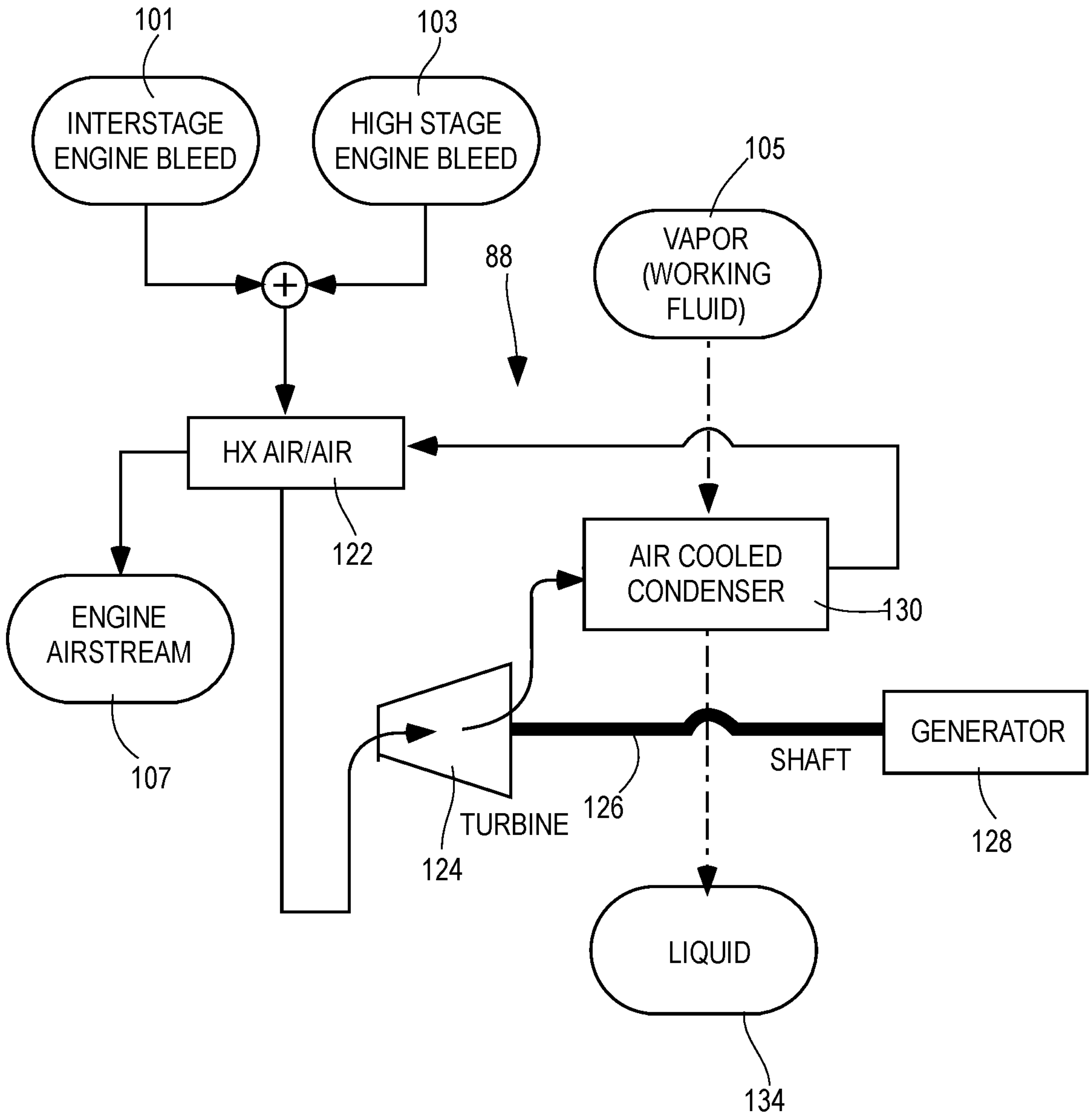

102
B
C
104
E
100
A
80
106
95
D
F
92
86
91
93
VALVE
FUEL•COOLED CONDENSER
AIR CYCLE MACHINE (ACM)
97
VALVE
88
CONTROLLER
94
90
AIR•COOLED CONDENSER 82
EVAPORATION CHAMBER 84
WORKING FLUID
FUEL
AIR

FIG. 5


101
INTERSTAGE ENGINE BLEED
103
HIGH STAGE ENGINE BLEED
105
VAPOR (WORKING FLUID)
88
HX AIR/AIR
122
AIR COOLED CONDENSER
130
ENGINE AIRSTREAM
107
TURBINE
124
126
SHAFT
GENERATOR
128
LIQUID
134

SYSTEMS AND METHODS FOR COOLING ELECTRONICS AND ELECTRICAL MACHINERY IN A HYBRID ELECTRIC AIRCRAFT

FIELD OF DISCLOSURE

[0001] The present invention relates to systems and methods for cooling electrical components, and more particularly, for cooling electrical components in a gas turbine engine.

BACKGROUND

[0002] Hybrid electric aerospace vehicles are being developed to power-assist a gas turbine engine using an electric drive. One problem such a combination of technologies raises is keeping the electrical systems cool. Electrical systems operating in a hybrid aerospace vehicle generate relatively large heat loads at very low temperatures relative to conventional gas turbine engine heat load temperatures. The types of components in electrical systems that may be subject to such high heat loads include power electronics, electric machines (generators, motors), and batteries. Each type of component has its cooling requirements and may be cooled using similar cooling systems and methods. Power electronic devices may have the most susceptibility in terms of the tolerance of such components to heat.

[0003] Historically, electrical components have been cooled with water based or oil based coolants that rely on sensible heat storage. The components may be mounted on a printed circuit board or other substrate, which may then be mounted to contact a cooled container of the water or oil. The cooled container would then absorb the heat generated by the components on the circuit board. In some solutions, a two-phased loop may be used in which the container contacting the electrical components may contain a coolant liquid that vaporizes upon absorbing the heat from the components. The vapor may be passed to a condenser, which may comprise a heat exchanger, to condense the vapor back to the cooling liquid. The cooling liquid is then passed back to the cooled container.

[0004] The condenser may typically be implemented as a heat sink for the coolant to reject its heat, which may be cooled using a cooling fluid, to effect condensation of the vaporized coolant. One difficulty in implementing condensers in an aerospace vehicle is in securing a sufficiently cool source of cooling fluid for the heat sink. One source may be the fan stream air flowing from the fan in the gas turbine engine. Another source may be the engine fuel, where the engine includes a flow path for the fuel to the heat sink before being fed to the combustors. Another source may be ambient air permitted to flow into the engine casing through a duct.

[0005] The options for cooling the vaporized coolant may be adequate, however, their cooling effectiveness depends on operating conditions. Fan air flow provides the best cooling effect at altitude where the air is much cooler. During take-off however, the fan air flow is typically too hot to provide much of a cooling effect. Cooling with a fuel flow is best during take-off when the fuel flow rate is high. At cruising speeds, the fuel flow rate drops and may not provide sufficient cooling. Ambient air, like fan air flow, is cool at higher altitude, but may be used during takeoff.

[0006] Some solutions use a combination of cooling sources controlled using valves to enable shutting off a source of cooling depending on operating conditions. However, solutions for cooling electronics will likely be implemented on the outer portion of the engine typically just inside the engine nacelle, due to the large size of the electrical system and its cooling system. In hybrid engines, it may be preferred to mount the electronics inboard of the fan stream of the engine; however, the electronics may be subject to more extreme heat.

[0007] One solution for cooling electronics on a jet engine allows for a liquid coolant to contact the components in an evaporator tank. The coolant is vaporized and allowed to flow to the condensers to condense the vapor back to a liquid. One problem with this solution on an aerospace vehicle is the liquid does not remain settled in contact with the components. The movement of the jet engine causes the solution to splash and stir in the tank leaving the component without contact with the liquid for periods of time during the flight. The components may be left uncooled for sufficient time to overheat.

SUMMARY

[0008] In view of the above, devices, systems and methods are provided to cool electrical components that generate a substantial amount of heat in a gas turbine engine. In one aspect, a system for cooling an electrical component in a gas turbine engine comprises an evaporation chamber configured to contain the electrical component and a cooling liquid in contact with the electrical component. The evaporation chamber includes a liquid input port and a vapor output port. The cooling liquid evaporates while cooling the electrical component and emits a coolant vapor via the vapor output port. The evaporation chamber receives condensed coolant liquid via the liquid input port. A condenser assembly is configured to receive the coolant vapor from the vapor output port of the evaporation chamber and to effect condensation of the coolant vapor using a cooling air flow. An air cycle machine is configured to cool engine bleed air to provide the cooling air flow to the condenser assembly.

[0009] In another aspect, a method is provided for cooling an electrical component disposed in an engine core of a gas turbine engine for an aircraft. An example method includes cooling a flow of engine bleed air at an air cycle machine. A coolant vapor is cooled at an air-cooled condenser using the cooled engine bleed air when the aircraft is preparing for take-off. The coolant vapor at the air-cooled condenser is cooled using a fan stream air flow when the aircraft has reached an altitude where the fan stream air flow enables cooling. An air/air valve is controlled to use the fan stream air flow to condense the coolant vapor at the air-cooled condenser or to use engine bleed air according to the aircraft operating conditions. A condensed coolant vapor flows from the air-cooled condenser to an evaporation chamber disposed in an engine core section of the gas turbine engine as a coolant liquid. The coolant liquid contacts the electrical component contained in the evaporation chamber to cool the electrical component. Coolant vapor is formed by absorption of heat from the electrical component into the cooling liquid coming from the air-cooled condenser.

[0010] Some examples of devices, systems, and methods for cooling electrical components in a gas turbine engine are outlined above rather broadly in order that the detailed description thereof may be better understood, and in order that the present contribution to the art may be better appreciated. Additional example implementations of the devices, systems, and methods are described below and will form the subject matter of the claims appended hereto. In this respect, before explaining at least one example of the devices, systems, and methods in detail, it is to be understood that the devices, systems, and methods are not limited in their application to the details of construction or to the arrangements of the components set forth in the following description or illustrated in the drawings. Other example implementations of the devices, systems, and methods may be developed, practiced and carried out in various ways. Also, it is to be understood that the phraseology and terminology employed herein are for the purpose of the description and should not be regarded as limiting.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG. **1** is a side view of an example of a gas turbine engine containing a system for cooling electrical components in a core region of the jet engine.

[0012] FIG. **2** is a schematic diagram illustrating operation of an example system for cooling electrical components.

[0013] FIG. **3** is a schematic diagram of an example implementation of an evaporation chamber containing electrical components being cooled by contact with a liquid coolant.

[0014] FIG. **4** is a schematic diagram illustrating operation of a system for condensing a coolant vapor to a coolant liquid for cooling electrical components.

[0015] FIG. **5** is a block diagram illustrating operation of an example of a condensing system using an air cycling machine.

DETAILED DESCRIPTION

[0016] Disclosed herein are systems and methods for cooling electrical components in a hybrid turbine engine. With reference to FIG. **1**, a gas turbine engine is generally indicated at **10**, having a principal and rotational axis **11**. The engine **10** comprises, in axial flow series, an air intake **12**, a propulsive fan **13**, an intermediate pressure compressor **14**, a high pressure compressor **15**, combustion equipment **16**, a high pressure turbine **17**, an intermediate pressure turbine **18**, a low pressure turbine **19** and an exhaust nozzle **20**. A nacelle **21** generally surrounds the engine **10** and defines both the intake **12** and the exhaust nozzle **20**. The engine **10** includes a cooling system for cooling an electrical component, the cooling system comprising an evaporation chamber **30** and a condenser assembly **34**. The electrical component may be a printed circuit board, an assembly of printed circuit boards, and one or more discrete electrical devices such as for example, power electronic devices configured for attachment as standalone components including insulated gate bipolar junction transistors (IGBT), MOSFETs, silicon-controlled rectifiers (SCR), and other similar devices. The electrical component may also include electrical machinery, such as electric motors, generators, batteries, and other electrical machines. In some example implementations, the evaporation chamber **30** may be configured for one type of electrical component, such as printed circuit boards and assemblies, and another evaporation chamber **30** may be added to contain other types of electrical components, such as an electric motor and/or generator or battery.

[0017] During operation, air entering the intake **12** is accelerated by the fan **13** to produce two air flows: a first air flow into the intermediate pressure compressor **14** and a second air flow which passes through a bypass duct **22** to provide propulsive thrust. The intermediate pressure compressor **14** compresses the air flow directed into it before delivering that air to the high pressure compressor **15** where further compression takes place. As shown in in FIG. **1** the evaporation chamber **30** may be disposed inboard of the fan stream between the first air flow and the second air flow. In the example shown in FIG. **1**, the evaporation chamber **30** is disposed in an enclosure containing the intermediate pressure compressor **14**. The condenser assembly **34** may be disposed inside the nacelle **21** as depicted in FIG. **1**, or in any suitable part of the engine **10** from which the condenser assembly **34** can draw from heatsinking sources as described in more detail below with reference to FIG. **4**.

[0018] The compressed air exhausted from the high pressure compressor **15** is directed into the combustion equipment **16** where it is mixed with fuel and the mixture combusted. The resultant hot combustion products then expand through, and thereby drive the high, intermediate and low pressure turbines **17**, **18**, **19** before being exhausted through the nozzle **20** to provide additional propulsive thrust. The high **17**, intermediate **18** and low **19** pressure turbines drive respectively the high pressure compressor **15**, intermediate pressure compressor **14** and fan **13**, each by suitable interconnecting shaft.

[0019] Other gas turbine engines to which the present disclosure may be applied may have alternative configurations. By way of example such engines may have an alternative number of interconnecting shafts (e.g. two) and/or an alternative number of compressors and/or turbines. Further the engine may comprise a gearbox provided in the drive train from a turbine to a compressor and/or fan.

[0020] As noted above, the electrical component or components in the cooling system evaporation chamber is cooled in order to enable operation within the extreme heat that may develop in the engine **10** as well as to remove the heat generated by the electrical component or components. In an example implementation, the cooling system comprises the evaporation chamber **30** and the condenser assembly **34**. The evaporation chamber **30** contains the electrical component, or components, and a cooling agent in the form of a cooling liquid. The cooling liquid evaporates during the exchange of heat with the electrical component, turning into a coolant vapor. The coolant vapor flows to the condenser assembly, which effects condensation back to the liquid phase. Coolant liquid is then permitted to flow back to the evaporation chamber.

[0021] In an example implementation, the condenser assembly **34** includes a fuel-cooled condenser and an air-cooled condenser. The coolant vapor may flow through either, or both, the fuel-cooled condenser or the air-cooled condenser. The air-cooled condenser may include multiple and switchable coolant sources that may be used to condense the coolant vapor. The coolant sources for the air-cooled condenser include a fan stream air flow, an ambient air flow (or ram air flow), an engine bleed from the high-pressure compressor **15**, and an engine bleed from the intermediate-pressure compressor **14**. The fan stream air flow may be permitted to flow to the air-cooled condenser by a fan stream flow path extending from the bypass duct **22** to the condenser assembly. The ambient air flow may be received at the condenser assembly in the space between the nacelle **21** and a casing surrounding the bypass duct **22**. The engine bleed air from the intermediate-pressure compressor **14** and the high-pressure compressor **15** may be pre-cooled using an air cycle machine as described in more detail below with reference to FIGS. **4** and **5**.

[0022] In an example implementation, a controller may provide program control over the selection of a coolant source for condensing the coolant vapor. The controller may receive inputs from temperature sensors, altitude sensors, air flow sensors, or any other sensors strategically placed to enable the controller to determine the best coolant source to use to condense the coolant vapor. The controller may switch the state of valves to enable or disable a selected coolant source.

[0023] In an example implementation, the air-cooled condenser is configured to recycle spent air, which is air that has been used to cool coolant vapor to condensation, by conducting the spent air in a useful way. If the spent air comes from having used fan air flow for condensing the coolant vapor, the spent air may be returned to a lower pressure region of the fan stream or passed through a separate nozzle to produce some engine thrust. If the spent air comes from having used engine bleed air, the spent air may still have sufficient pressure to be returned to the engine to be used as buffer air for bearing sumps or for cooling in some portion of the engine, such as turbine tip clearance control or the oil system or even possibly the fuel.

[0024] FIG. **2** is a schematic diagram illustrating operation of an example system **28** for cooling electrical components **36**A and **36**B. The cooling system **28** includes an evaporation chamber **30** and a condenser assembly **34**. The evaporation chamber **30** contains the electronic components **36**A and **36**B and a liquid coolant **37** such that the liquid coolant **37** is in contact with the electrical components **36**A and **36**B. The cooling of the electrical components **36**A and **36**B causes the liquid coolant **37** to vaporize into a coolant vapor **35**. The evaporation chamber **30** includes a coolant vapor output port **42** to enable the coolant vapor **35** to flow through a first fluid conduit **48** to the condenser assembly **34**. The condenser assembly **34** uses a condensing fluid **31**, which is colder than the coolant vapor **35**, to condense the coolant vapor **35** back to the coolant liquid **37**. The condenser assembly **34** outputs a spent condensing fluid **33** to either fuel the engine if the cooling fluid is cooling fuel, or to provide a useful function if the condensing fluid is a cooling air. The coolant liquid **37** from the condenser assembly **34** flows through a second fluid conduit **50** back to a liquid input port **44** on the evaporation chamber **32**.

[0025] In an example implementation, the coolant liquid **37** may include any suitable refrigerant, such as R134a, R245fa, Fluorinert and Novec (available from 3M™), or other suitable refrigerant fluids that have a liquid/vapor transition in the temperature range of the system being cooled. In the example in FIG. **2**, the system being cooled includes the electrical components **36**A and **36**B, which in some example implementations may operate in the range of about 100 to 200 degrees C. The electrical components **36** may include power electronics boards **36**A and **36**B embedded inside of the evaporation chamber **30**, which is preferably hermetically sealed. The evaporation chamber **30** may be evacuated before adding the working fluid. The power electronics boards **36**A and **36**B may include components that contain power devices, such as MOSFETS or IGBTs or other similar components such as capacitors and inductors.

[0026] As noted above, the coolant liquid **37** cools the electrical components **36**A and **36**B by contact. The coolant liquid **37** may be in contact with the electrical components **36**A and **36**B in one of two ways. FIG. **2** shows a first way in which the coolant liquid **37** exits the evaporation chamber **30** via liquid output port **54** and pumped back into the evaporation chamber **30** at liquid input port **56**. The coolant liquid **37** is then directed to liquid input port **56** to cool the first electrical component **36**A by direct impingement. The coolant liquid **37** may be sub-cooled by a sub-cooling heat exchanger **38** to ensure that the pump **40** receives the coolant in liquid form and not vapor form thereby preventing cavitation of the pump **40**. The subcooling can also improve the critical heat flux of the coolant **37**, when cooling electrical component **36**A. The cooling of the first electrical component **36**A by direct impingement enables constant cooling in the event of aircraft maneuvers or aircraft buffeting from turbulence.

[0027] FIG. **2** also shows the electrical component **36**B cooled by submerging the electrical component **36**B in the coolant liquid **37**. By containing the electrical components **36** in the evaporation chamber **32**, the electrical systems may be able to operate at higher voltages since the coolant fluid in the evaporation chamber **32** prevents electrical discharges.

[0028] It is noted that the evaporation chamber **30** may take any suitable shape to form a container having at least one wall **52** (e.g. for a cylindrical or spherical container). The evaporation chamber **30** in FIG. **2** includes a baffle structure **46** attached to the wall **52** or walls of the evaporation chamber **30**. The baffle structure **46** provides a mechanism for resisting fluid redistribution in the evaporation chamber **30** during aircraft maneuvers or during aircraft buffeting from atmospheric turbulence. The resistance to the fluid redistribution helps maintain the second electrical component **36**B submerged in the coolant liquid **37** and also to maintain liquid at the pump inlet **54**.

[0029] FIG. **3** is a schematic diagram of an example implementation of an evaporation chamber with a direct impingement cooling system **60** containing electrical components **70**A, **70**B, **70**C, and **70**D being cooled by direct impingement with a coolant liquid **59** entering a fluid conduit **62**A, **62**B, and **62**C. The electrical components **70**A, **70**B, **70**C, and **70**D may be mounted in the evaporation chamber **30** (in FIG. **2**) to receive the coolant liquid by direct impingement. The first printed circuit board **70**A is mounted opposite a first fluid conduit **62**A having liquid openings **66**. The coolant liquid **59** enters an opening at one end of the first fluid conduit **62**A. The opposite end of the first fluid conduit **62**A is closed to allow the formation of liquid jets **61** aimed to contact the first printed circuit board **70**A. In an example implementation, the liquid jets **61** may be aligned with high heat-generating devices **72**, such as MOSFETs, IGBTs, etc. to maximize the cooling effect directly on the components on the printed circuit board **60**A that run hottest. Other devices **74** may be cooled by residual splashing of the coolant liquid.

[0030] The second printed circuit board **70**B is mounted with one side in contact with a cold plate **64**. The cold plate **64** is formed as a container having an opening **76** for receiving coolant liquid. The container shape may be any suitable shape configured to provide a maximum cooling effect for the printed circuit board **70**B. The container forming the cold plate **64** may include internal fins or mini/micro channels for enhancing heat transfer. The cold plate **64** may be disposed to cool the printed circuit boards

70B and **70**C mounted on opposite sides of the cold plate **64** as shown in FIG. **3**. The printed circuit board **70**B may be cooled on one side by the cold plate **64** and on the other side by a second fluid conduit **62**B with liquid openings **66** to produce liquid jets aimed at heat-generating devices **72** on the second printed circuit board **70**B. The cold plate **64** in FIG. **3** may include a fluid passage **68** to a third fluid conduit **62**C with liquid openings **66** aimed to direct liquid jets **61** at components **72** on the third printed circuit board **70**C, thereby providing a double-sided cooling of the third printed circuit board **70**C. The third fluid conduit **62**C may also include liquid openings **66** on an opposite side to cool the fourth printed circuit board **70**D.

[0031] The direct impingement cooling structure illustrated in FIG. **3** may be configured in any suitable way with more or fewer printed circuit boards **70** and with more or fewer fluid conduits **62** and cold plates **64**. The fluid conduits **62** may also differ in the number and types of jets **66**. The direct impingement cooling system **60** may be further combined in the evaporation chamber **30** with structure for mounting other components that need cooling, such as the submerged electrical component **36**B shown in FIG. **2**.

[0032] FIG. **4** is a schematic diagram illustrating operation of a system **80** for condensing a coolant vapor to a coolant liquid for cooling electrical components. FIG. **4** shows an evaporator chamber **84** forming the **2**-phase loop with a condenser assembly similar to the cooling system **28** in FIG. **2**. The condenser assembly in FIG. **4** includes a fuel-cooled condenser **86** and an air-cooled condenser **82**. The fuel-cooled condenser **86** receives a cooling fuel flow **93** as part of a fuel flow **97** used to power the engine. The fuel flow **97** may include fuel that has a portion recirculated back to the aircraft fuel tanks. The fuel-cooled condenser **86** is used to cool the coolant vapor to condensation. The cooling effect provided by the cooling fuel flow may be best during take-off or other operating conditions when the rate of fuel flow is greatest. A fuel valve **92** may be used to reduce or stop the fuel flow for cooling the coolant vapor to condensation when the fuel becomes too hot to provide a cooling effect. The fuel valve **92** may circulate all or part of the fuel flow at **91** to bypass the fuel-cooled condenser **86** at **95**. A controller **90** may be programmed to control the state of the fuel valve **92** based on a variety of engine operating conditions, such as for example, the fuel temperature, air temperature at various heatsinking sources described below, fuel flow rate, and other operating conditions.

[0033] The coolant vapor may also be cooled by the air-cooled condenser **82**, which may provide a cooling air flow from one or more selected sources. For example, the sources of cooling air may be a fan **100** air stream at A, an intermediate pressure compressor **102** engine bleed air at B, a high pressure compressor **104** engine bleed air at C, or an ambient air stream at D. The selection of either the fan air stream at A, the engine bleed air at B and/or at C, or the ambient air stream at D may be switched by an air valve **94**. The controller **90** may be programmed to control the valve **94** to select the air source that provides the best cooling given the operating conditions. For example, during take-off, the controller may control the air/air valve **78** to select an engine bleed at B and/or at C over the fan air stream at A since the fan air stream at A may not be sufficiently cool to provide a cooling effect to condensation. Alternatively, the controller may select the air valve **94** to disable both air sources in favor of using fuel-cooled condensation at the fuel-cooled condenser **86** during take-off. The controller **90** may then control the air valve **94** to select the fan air stream at A or ambient air flow at D over the engine bleed at B or at C at cruising speed and altitude when the fan stream air flow and/or the ambient air flow are cooler. The controller **90** may also disable the fuel-flow cooling during idle descent when the fuel heat sink is too low and the temperature of the fuel is too hot to provide sufficiently cool fuel to the coolant vapor.

[0034] The air-cooled condenser **82** may conduct spent air, or air used to cool the coolant vapor back into the engine in a useful manner. For example, the spent air may be used to cool the engine at E or to provide thrust at F.

[0035] The engine bleed air B or C may be pre-cooled by an air cycle machine (ACM) **88**. FIG. **5** is a block diagram illustrating operation of an example of a condensing system using an air cycling machine **88**. The ACM **88** in FIG. **5** may include a heat exchanger **122** that receives air from an air-cooled condenser **130**, which may operate as described above with reference to FIGS. **1** and **4**, to cool an intermediate stage engine bleed air at **101** or a high pressure engine bleed air at **103**. The intermediate stage engine bleed air at **101** is received from the intermediate pressure compressor **102** shown in FIG. **4**. The high pressure stage engine bleed air at **103** is received from the high pressure compressor **104** as shown in FIG. **4**. The cooled engine bleed air from **101** and/or **103** may exit the heat exchanger **122** into a turbine **124** and eventually into an engine airstream **107** (E or F) as described with reference to FIG. **4**) after its cooling function in the air-cooled condenser **130** is completed. The air flowing into the turbine **124** assists in operating a shaft **126**, which may be used to rotate a generator **128**. The generator **128** may be used to provide electrical power for other aircraft functions, such as lighting, control functions, and other functions in the cabin. FIG. **5** shows the turbine **124** providing cooling air at the air-cooled condenser **130** for cooling the coolant vapor to condensation as cooling liquid **134**. The work performed by the air flowing through the turbine **124** has a cooling effect for air flowing into the air-cooled condenser **130**, which remains sufficiently cool to provide a heat sink in the heat exchanger **122**.

[0036] The use of the terms "a" and "an" and "the" and similar references in the context of describing the invention (especially in the context of the following claims) are to be construed to cover both the singular and the plural, unless otherwise indicated herein or clearly contradicted by context. Recitation of ranges of values herein are merely intended to serve as a shorthand method of referring individually to each separate value falling within the range, unless otherwise indicated herein, and each separate value is incorporated into the specification as if it were individually recited herein. All methods described herein can be performed in any suitable order unless otherwise indicated herein or otherwise clearly contradicted by context. The use of any and all examples, or exemplary language (e.g., "such as") provided herein, is intended merely to better illuminate the disclosure and does not pose a limitation on the scope of the disclosure unless otherwise claimed. No language in the specification should be construed as indicating any non-claimed element as essential to the practice of the disclosure. Numerous modifications to the present disclosure will be apparent to those skilled in the art in view of the foregoing description. It should be understood that the illustrated embodiments are exemplary only, and should not be taken as limiting the scope of the disclosure.

What is claimed is:

1. A system for cooling an electrical component in association with a gas turbine engine, the system comprising:

an evaporation chamber configured to contain the electrical component and a cooling liquid in contact with the electrical component, the evaporation chamber comprising a liquid input port and a vapor output port, where the cooling liquid evaporating while cooling the electrical component emits a coolant vapor via the vapor output port and receives condensed coolant liquid via the liquid input port;

a condenser assembly configured to receive the coolant vapor from the vapor output port of the evaporation chamber and to effect condensation of the coolant vapor using a cooling air flow; and

an air cycle machine configured to receive an engine bleed air to use as the cooling air flow, the air cycle machine comprising a heat exchanger and a turbine to cool the engine bleed air before the engine bleed air flows to the condenser assembly.

2. The system of claim **1** where the evaporation chamber includes a liquid output port and a pumped liquid input port, the system comprising:

a coolant pump configured to receive liquid coolant from the liquid output port of the evaporation chamber, and to pump the liquid coolant to the pumped liquid input port of the evaporation chamber forming a plurality of liquid jets directed at portions of the electrical component.

3. The system of claim **2** further comprising:

a sub-cooling heat exchanger configured to further cool liquid coolant from the liquid output port and to flow subcooled liquid coolant to the coolant pump to prevent cavitation from insufficiently condensed coolant fluid and to improve heat transfer.

4. The system of claim **2** further comprising:

a cold plate in the coolant evaporator, where the cold plate comprises flow channels configured to effect a flow of liquid coolant from the coolant pump and into the evaporation chamber while at the same time providing cooling, wherein the cold plate is in contact with one side of the electrical component.

5. The system of claim **2** where the electrical component comprises a printed circuit board having high power devices and low power devices, the system further comprising:

a fluid conduit having a plurality of jet openings positioned on the fluid conduit to direct a liquid jet towards the printed circuit board.

6. The system of claim **5** where the evaporation chamber comprises:

a first component support configured to hold the printed circuit board in position to receive the liquid jet from the fluid conduit; and

a second component support configured to hold a second electric component immersed in the coolant liquid.

7. The system of claim **5** where the plurality of jet openings are positioned on the fluid conduit to direct the liquid jet towards the high power devices on the printed circuit board.

8. The system of claim **1** where the evaporation chamber comprises:

at least one wall forming a liquid containing portion of the evaporation chamber; and

a baffle extending parallel to a liquid surface of coolant liquid pooling in the evaporation chamber, where the baffle is mounted on the at least one wall to maintain cooling liquid below the baffle in the liquid containing portion.

9. The system of claim **1** where the engine bleed air includes an intermediate pressure compressor bleed.

10. The system of claim **1** where the engine bleed air includes a high pressure compressor bleed.

11. The system of claim **1** where the condenser assembly comprises a fuel-cooled condenser configured to cool the cooling vapor using a cooling fuel flow and an air-cooled condenser configured to cool the cooling vapor using the cooling air flow.

12. The system of claim **11** further comprising:

an air valve switchable between providing a first air flow path from a fan air stream and providing the engine bleed air cooled by the air cycle machine to the air-cooled condenser as the cooling air flow.

13. The system of claim **12** where the valve is configured to switch to provide an ambient air flow to the air-cooled condenser assembly.

14. The system of claim **12** further comprising a fuel valve switchable between providing the cooling fuel flow to the fuel-cooled condenser and bypassing the fuel-cooled condenser.

15. The system of claim **14** further comprising:

a controller configured to control the switching of the air valve and the fuel valve.

16. The system of claim **1** further comprising:

a spent air flow path for coolant air from the condenser assembly to either cool engine components or to provide thrust.

17. A method for cooling an electrical component disposed inboard of a fan stream of a gas turbine engine for an aircraft, the method comprising:

cooling an engine bleed air at an air cycle machine;

cooling a coolant vapor at an air-cooled condenser using the cooled engine bleed air when the aircraft is preparing for take-off;

cooling the coolant vapor at the air-cooled condenser using a fan stream air flow when the aircraft has reached an altitude where the fan stream air flow enables cooling;

controlling an air valve to permit the fan stream air flow to cool the coolant vapor at the air-cooled condenser while controlling the air valve to reduce cooling air flow from the engine bleed air according to the aircraft altitude;

flowing condensed coolant vapor from the air-cooled condenser to an evaporation chamber disposed inboard of the fan stream of the gas turbine engine as a coolant liquid to contact the electrical component contained in the evaporation chamber to cool the electrical component; and

flowing coolant vapor formed from the cooling of the electrical component by the cooling liquid to the air-cooled condenser.

18. The method of claim **17** further comprising:

cooling the coolant vapor at a fuel-cooled condenser using a cooling fuel flow;

flowing condensed vapor from the fuel-cooled condenser to the evaporation chamber; and

controlling a fuel valve to reduce the cooling fuel flow at the fuel-cooled condenser when the aircraft has reached an altitude where the fan stream air flow enables cooling of the coolant vapor.

19. The method of claim **17** further comprising:

flowing the coolant liquid from the evaporation chamber to a pump configured to pump the coolant liquid back to the evaporation chamber via a coolant liquid conduit forming a cold plate contacting a portion of the electrical component.

20. The method of claim **17** further comprising:

flowing the coolant liquid from the evaporation chamber to a pump configured to pump the coolant liquid back to the evaporation chamber via a coolant liquid conduit comprising at least one opening configured to form a liquid jet of coolant liquid directed to impinge on a portion of the electrical component.

21. The method of claim **17** where the electrical component is a printed circuit board comprising at least one high power device and at least one low power device, the method further comprising:

flowing the coolant liquid from the evaporation chamber to a pump configured to pump the coolant liquid back to the evaporation chamber via a coolant liquid conduit comprising at least one opening configured to form a plurality of liquid jets of coolant liquid directed to impinge on the at least one high power device on the printed circuit board.

22. The method of claim **17** further comprising:

supporting the electrical component in the evaporation chamber where the electrical component is immersed in the coolant liquid.

23. The method of claim **17** further comprising:

flowing cooling air flow from the condenser assembly as spent cooling air to either cool engine components or to provide thrust.

24. The method of claim **17** where the air valve is configured to select an ambient air flow, the step of controlling the air valve comprising:

switching the air valve to provide the ambient air flow to the air-cooled condenser assembly.

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