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(54) Title: INTERCOOLED COOLED COOLING INTEGRATED AIR CYCLE MACHINE

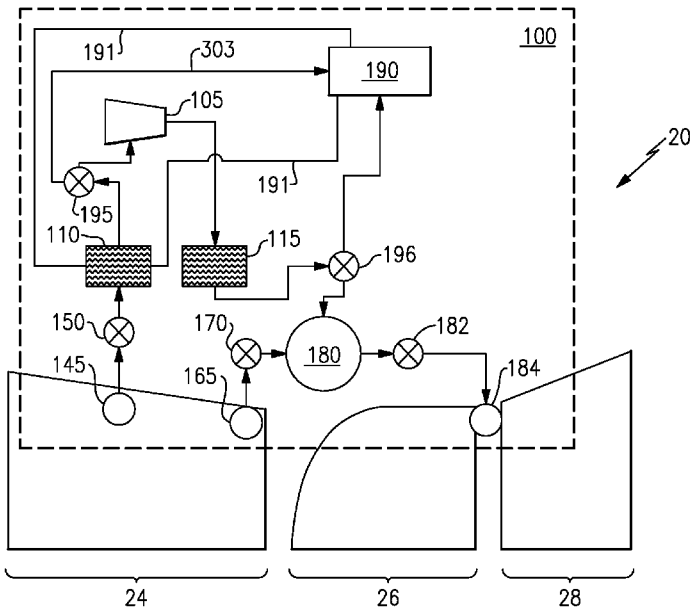


FIG.2

(57) Abstract: A first cooling stage is fluidly coupled to a bleed port of a compressor to receive and cool bleed air with the air stream to produce a cool bleed air. A cooling pump receives and increase a pressure of the cool bleed air to produce a pressurized cool bleed air. A second cooling stage is fluidly coupled to the pump to receive and cool the pressurized cool bleed air to produce an intercooled cooling air. A is valve downstream of the first cooling stage, the valve selectively delivering air into a mixing chamber where it is mixed with air from a tap that is compressed to a higher pressure than the air from the bleed port, and the valve also selectively supplying air from the first cooling stage to a use on an aircraft associated with the gas turbine engine. A method is also disclosed.

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INTERCOOLED COOLED COOLING INTEGRATED AIR CYCLE MACHINE

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application is a continuation-in-part of United States Patent Application No. 15/346,206, filed November 8, 2016.

BACKGROUND

[0002] This present disclosure relates to a gas turbine engine, and more particularly to improvements in providing cooling air from a compressor section to a turbine section in a gas turbine engine.

[0003] Gas turbine engines are known and typically include a fan delivering air into a bypass duct as propulsion air. Further, the fan delivers air into a compressor section where it is compressed. The compressed air passes into a combustion section where it is mixed with fuel and ignited. Products of this combustion pass downstream over turbine rotors driving them to rotate.

[0004] It is known to provide cooling air from the compressor to the turbine section to lower the operating temperatures in the turbine section and improve overall engine operation. Typically, air from the high compressor discharge has been tapped, passed through a heat exchanger, which may sit in the bypass duct and then delivered into the turbine section. The air from the downstream most end of the compressor section is at elevated temperatures.

[0005] Running the operating temperatures in the turbine section at high temperatures provides efficiency gains in the gas turbine engine; however, the high temperatures are exceeding material limits and are driving the need for improved cooling air. That is, conventional cooling air methods fail to provide cooling air at sufficient pressure to be introduced to the highest pressure places of the gas turbine engine and at cool enough temperature to reduce key component temperatures.

SUMMARY

[0006] In a featured embodiment, an intercooled cooling system for a gas turbine engine includes a plurality of cooling stages in fluid communication with an air

stream utilized by the plurality of cooling stages for cooling. A first cooling stage of the plurality of cooling stages is fluidly coupled to a bleed port of a compressor of the gas turbine engine to receive and cool bleed air with the air stream to produce a cool bleed air. A cooling pump is fluidly coupled to the first cooling stage to receive and increase a pressure of the cool bleed air to produce a pressurized cool bleed air. A second cooling stage of the plurality of cooling stages is fluidly coupled to the pump to receive and cool the pressurized cool bleed air to produce an intercooled cooling air. A is valve downstream of the first cooling stage, the valve selectively delivering air into a mixing chamber where it is mixed with air from a tap that is compressed to a higher pressure than the air from the bleed port, and the valve also selectively supplying air from the first cooling stage to a use on an aircraft associated with the gas turbine engine.

[0007] In another embodiment according to the previous embodiment, the use comprises a turbine configured to receive and extract work.

[0008] In another embodiment according to any of the previous embodiments, the use is an environmental control system for an associated aircraft.

[0009] In another embodiment according to any of the previous embodiments, the cooling pump is driven within a range of a desired speed.

[0010] In another embodiment according to any of the previous embodiments, the cooling pump is driven by an electric motor.

[0011] In another embodiment according to any of the previous embodiments, the electric motor is provided with a control to maintain the speed of the cooling pump within a predetermined distance from the desired speed.

[0012] In another embodiment according to any of the previous embodiments, a clutch selectively opens to stop drive of the cooling pump.

[0013] In another embodiment according to any of the previous embodiments, the cooling compressor is driven by a tower shaft from an associated gas turbine engine, and a control ensures the cooling compressor speed is within the predetermined distance.

[0014] In another embodiment according to any of the previous embodiments, the valve associated with the second cooling stage is provided with temperature protection.

[0015] In another embodiment according to any of the previous embodiments, the temperature protection includes at least one of a remote actuator or temperature shielding.

[0016] In another embodiment according to any of the previous embodiments, a selection valve is positioned in the first cooling stage and downstream of a heat exchanger in the first the cooling stage, and upstream of the cooling pump and the selection valve selectively delivering air around the cooling pump and to the use.

[0017] In another featured embodiment, a method of operating an intercooled cooling air system includes the steps of tapping air from a lower pressure location, and passing the air through a first heat exchanger, and then to a cooling pump, the cooling pump raising the pressure of the tapped air, and selectively delivering the tapped air to a turbine section, ensuring the speed of the cooling pump is within a predetermined distance of the desired speed.

[0018] In another embodiment according to the previous embodiment, the cooling pump is driven by an electric motor.

[0019] In another embodiment according to any of the previous embodiments, the electric motor is provided with a control to maintain the speed of the cooling pump within a predetermined distance from the desired speed.

[0020] In another embodiment according to any of the previous embodiments, a clutch is opened to selectively stop drive of the cooling pump.

[0021] In another featured embodiment an intercooled cooling air system for a gas turbine engine includes a plurality of cooling stages in fluid communication with an air stream utilized by the plurality of cooling stages for cooling, and a means to cool the tapped air. A valve is downstream of the first cooling stage for selectively delivering the tapped air into a mixing chamber, and where it is mixed with air at a higher pressure than the tapped air, and means for also selectively supplying air from the mixing chamber to cool a turbine and for supplying tapped air to a use on an aircraft associated with the gas turbine engine.

[0022] In another embodiment according to the previous embodiment, the use is an environmental control system for the associated aircraft.

[0023] In another embodiment according to any of the previous embodiments, the use is a turbine to extract energy from the cool bleed air.

[0024] In another embodiment according to any of the previous embodiments, the means to increase a pressure of the cool bleed air includes a control for maintaining a speed of the means.

[0025] In another embodiment according to any of the previous embodiments, the control includes a clutch.

[0026] These and other features may be best understood from the following drawings and specification.

BRIEF DESCRIPTION OF THE DRAWINGS

[0027] The following descriptions should not be considered limiting in any way. With reference to the accompanying drawings, like elements are numbered alike:

[0028] FIG. 1 schematically shows an embodiment of a gas turbine engine.

[0029] FIG. 2 is an intercooled cooled cooling air system in accordance with an embodiment; and

[0030] FIG. 3 is an intercooled cooled cooling air system with an integrated air cycle machine in accordance with another embodiment.

[0031] FIG. 4 shows a flowchart.

DETAILED DESCRIPTION

[0032] 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.

[0033] 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. Alternative engines might include an augmenter section (not shown) among other systems or features. 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.

[0034] 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 application.

[0035] 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.

[0036] 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.

[0037] 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.

[0038] 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 (10,688 meters). The flight condition of 0.8 Mach and 35,000 ft. (10,688 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 lbm 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 [(Tram °R)/(518.7 °R)]0.5. 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).

[0039] Turning now to FIG. 2, an intercooled cooled cooling air system 100 is provided in accordance with an embodiment. In general, the intercooled cooled cooling air system 100 comprises a staged cooling arrangement coupled to an air cycle machine. The stages cooling arrangement can comprise one or more heat exchangers for each stage. In operation, bleed air from a first compressor is put through a first stage of the

staged cooling arrangement (e.g., a first heat exchanger or set of heat exchangers). The flow is collected and run through a second compressor to pump it up. The discharge of the second compressor is then run through a second stage of the staged cooling arrangement (e.g., a second heat exchanger or set of heat exchangers) before being delivered as intercooled cooled cooling air. The air cycle machine can selectively receive a percentage or portion of the cooling air from the staged cooling arrangement (e.g., bleed air running through the inter-cooled loop). The air cycle machine can utilize the received cooling air to provide pneumatic power to an accessory with a byproduct being cool/cold air.

[0040] The intercooled cooled cooling air system 100 is in fluid communication with bleed air of a gas turbine engine 20, which is illustrated schematically in FIG. 2. A non-limiting gas turbine engine 20 is described and illustrated in FIG. 1. Components of the gas turbine engine 20 that are similar to the gas turbine engine 20 of FIG. 1 have been reused for ease of explanation, by using the same identifiers, and are not re-introduced. As shown in FIG. 2, components of the environmental control system 100 comprise a pump 105 and at least one heat exchanger as the staged cooling arrangement. In one non-limiting embodiment, the at least one heat exchanger may comprise a first heat exchanger 110 (a first cooling stage) and a second heat exchanger 115 (a second cooling stage). Components of the system 100 may also comprise a first port 145, a valve 150, a second port 165, a valve 170, a demarcation or mixing chamber 180, a valve 182, a port 184, an air cycle machine 190, a valve 195, and a valve 196.

[0041] As shown in FIG. 2, the pump 105, the first heat exchanger 110, and the second heat exchanger 115 are in fluid communication with bleed air of the gas turbine engine 20. Bleed air (e.g., a first bleed air flow) can be extracted from a first port 145 of the compressor section 24 of the gas turbine engine 20, as regulated by a valve 150. Bleed air (e.g., a second bleed air flow) can also be extracted from a second port 165 of the compressor section 24 of the gas turbine engine 20, as regulated by a valve 170. These portions can be mixed, as noted by demarcation 180, before being sent through a valve 182 to a third port 184 of the turbine section 28 of the gas turbine engine 20. Further, the air cycle machine 190 is in fluid communication with outputs of the first heat exchanger 110 and the second heat exchanger 115, as respectively regulated by the valve 195 and the valve 196.

[0042] As can be appreciated, tap 165 may be downstream of the last stage of the compressor section 24 and tap 145 is at a lower pressure location. Further, while the air is shown being delivered radially inwardly at point 184, it should be understood that air may move radially inwardly upstream of the combustor 26, passed radially through passages within the combustor module 26 that pass uncombusted air to the turbine and be delivered to the turbine section 28. The air may be injected into the turbine rotor assembly through a tangential on-board injector (TOBI).

[0043] A heat exchanger (e.g., the first heat exchanger 110 and a second heat exchanger 115) is a device built for efficient heat transfer from one medium to another. Examples of heat exchangers include circular, double pipe, shell and tube, plate, plate and shell, adiabatic wheel, plate fin, pillow plate, and fluid heat exchangers.

[0044] The pump 105 (along with the compressor section 24) is a mechanical device built to raise a pressure of a gaseous medium. The compressor section 24, particularly, receives a medium (e.g., fresh atmospheric air) that flows through the compressor, which brings the medium to higher pressure. The pump 105 can raise the pressure of air bled from the compressor section 24. Examples of pumps and compressors include turbines, impellers, centrifugal compressors, diagonal or mixed-flow compressors, axial-flow impellers, reciprocating devices, ionic liquid piston devices, rotary screw compressors, rotary vane compressors, scroll compressors, diaphragm compressors, air bubble compressors, etc. Further, the pump 105 can be driven by a motor or a medium or by a shaft and gearbox connected to one main engine's shafts a non-limiting embodiment, the pump 105 can be an impeller.

[0045] The combustor section 26 can comprise a diffuser case surrounding the combustor and a combustor to enable combustion of the medium. The combustor is a component or area of the gas turbine engine 20 where combustion takes place. Combustion comprises when energy is added to a medium received from the compressor section 24, which is at the higher pressure, by spraying fuel into the medium and igniting the fuel (so the combustion generates a high-temperature flow of the medium). The diffuser is a component that slows the medium from the compressor section 24 (e.g., the high speed, highly compressed air) to a velocity optimal for combustion. The combustion module in every engine has spaces not involved in the

combustion process where the air at port 184 can be forced to flow to the turbine or to the rearmost section of the compressor module 24.

[0046] The turbine section 28 extracts energy from a medium flow. For example, the turbine of the turbine section 28 is a rotary mechanical device that expands a medium received from the diffuser and combustor of the combustor section 26 down to an exhaust pressure to produce thrust.

[0047] Bleed ports are apertures that allow for a medium to be bled from the compressor section 24 (i.e., a compressor stage of the gas turbine engine 20, upstream of the combustor section 26) and may be located anywhere along the compressor section 24 (e.g., anywhere along the low pressure compressor 44 and the high pressure compressor 52 of FIG. 1). A temperature, a humidity, and a pressure of a bleed medium, also referred to as bleed air, varies depending upon a compressor stage and a revolutions per minute of the gas turbine engine 20. In a non-limiting embodiment, a plurality of bleed ports are represented by the first port 145 and the second port 165. The first port 145 can be a low pressure bleed port that is located towards an intake side of the compressor (e.g., the low pressure compressor 44) of the compressor section 24, where the pressure of the air is at or near atmospheric pressure. The second port 165 can be a high pressure bleed port that is located towards an exhaust side of the compressor (e.g., the high pressure compressor 52) of the compressor section 24, where the pressure of the air is at or near combustion pressure. The first port 145 can also be located at a mid-compressor bleed location, where the pressure of the air is between atmospheric pressure and combustion pressure. In contrast to the first port 145 and the second port 165, the third port 184 is an aperture that allows for a medium to be supplied to the gas turbine engine 20. In a non-limiting embodiment, the third port 184 is shown as being located at or near an intake of the turbine section 28 (downstream of the combustor section 26).

[0048] The valves 150, 170, 182, 195, and 196 are devices that regulate, direct, and/or control a flow of a medium by opening, closing, or partially obstructing various passageways within the tubes, pipes, etc. of the intercooled cooled cooling air system 100. Valves 150, 170, 182, 195, and 196 can be operated by actuators, such that flow rates of the medium in any portion of the intercooled cooled cooling air system 100 can be regulated to a desired value. Examples of valves 150, 170, 182, 195, and 196 include

a flow regulation device or a mass flow valve. In a non-limiting embodiment, the valve 195 and the valve 196 can be operated by a control system coupled to the intercooled cooled cooling air system 100 to selectively regulate percentages or portions of bleed air flowing to the air cycle machine 190 (by controlling the actuators that manage the operations of the valve 195 and the valve 196). In another non-limiting embodiment, the valve 150 can be a shut off or modulated valve and can require a check; the valve 195 can divert flow after a first cooling stage as a cooling source or direct cool air supply; the valve 196 can split flow between air cycle machine or some other bleed demand; the valve 170 can modulate uncooled "mixing" bleed to cooled cooling air; and the valve 182 can control cooled cooling air flow or direct where the flow is going.

[0049] The control of the array of valves presented can be such at a hot day takeoff condition is to the turbine from valve 150, the heat exchanger 110, then to the compressor 105, then to the heat exchanger 115, then to valve 196 and the mixing chamber 180, then to the turbine at 184. While this flow path in in operation and the engine is at this high power the air from the compressor at 165 is too hot for use in the turbine without potentially causing damage to the turbine blades and to the turbine disks and other components. At the same time, cabin cooling from the air cycle machine may be necessary for cooling, but not in an amount that would entail fuselage pressurization. Therefore, at this same time and engine condition some flow also might pass from valve 195 to line 303 and the air cycle machine 190.

[0050] As the aircraft climbs away from the runway, power is reduced and the intercooling of turbine air will no longer be necessary in light of the coatings and materials used in the turbine, so the flow described in paragraph 44 from bleed port 145 to port 184 can be eliminated. Further, the flow needed by the turbine to pressurize areas surrounding disks can be from the port labeled 165 and pass to the valve 170 and the mixing chamber 180 and to the turbine at 184 without extra cooling, At the same time the aircraft will have climbed to an altitude where cooling by the air cycle machine 190 and the pressurization function of 190 require more flow, so the valve 196 will be closed to the mixing chamber 180 and the flow from port 145 will all be direct to 190 via lines 303 or via valve 196. The line or lines chosen depends on the fight condition meaning the temperature and pressure in each line and the temperature required by the

air cycle machine for pressure requirements, or temperature requirements, or simply for the most efficient use of air or energy within the air cycle machine.

[0051] A mixing point is a location within the intercooled cooled cooling air system 100 where multiple medium and/or multiple medium flows are combined. In a non-limiting embodiment, the demarcation 180 marks a mixing point between the first bleed air flow and the second bleed air flow.

[0052] The air cycle machine 190 is a mechanical device that includes components for performing thermodynamic work on the medium (e.g., extracts or works on the medium by raising and/or lowering pressure and by raising and/or lowering temperature). Examples of the air cycle machine 190 include a two-wheel, a three-wheel machine, a four wheel-machine, etc. where the wheels are compressors for raising the pressure and temperature of the air and further wheels are turbines for expanding the air to cause it to cool down.

[0053] The intercooled cooled cooling air system 100 comprises improvements in providing cooling air from the compressor section 24 to the turbine section 28 in the gas turbine engine 20. Embodiments of these improvements include a cooling-pumping-cooling operation, pumping-cooling-cooling operation, and cooling-cooling-pumping operation. An example the cooling-pumping-cooling operation of the intercooled cooled cooling air system 100 will now be described.

[0054] In the case where an operating temperature in the turbine section 26 the gas turbine engine 20 is at a high temperature (at or exceeding material limits), air can be bled from the first port 145 by the value 150, operated by an actuator, of the intercooled cooled cooling air system 100. This air can be referred to as bleed air (e.g., a first bleed air flow). Further, air can be bled from the second port 165 by the value 170, operated by an actuator, of the intercooled cooled cooling air system 100. This air can also be referred to as bleed air (e.g., a second bleed air flow). In the example cooling-pumping-cooling operation, the bleed air that is described as being extracted from the first port 145 at the low pressure portion of the compressor section 24 to produce low pressure bleed air, and the air that is extracted from the second port 145 at the high pressure portion of the compressor section 24 can be high pressure bleed air. Note that the pressure of the air is generally the same at an exhaust of the compressor

section 24 and at an intake of the turbine section 28 because there is a minimal amount of pressure loss when going through the combustor section 26.

[0055] The low pressure bleed air from the first port 145 can be supplied to the staged cooling arrangement of the intercooled cooled cooling air system 100. As shown in FIG. 2, the low pressure bleed air passes through the first heat exchanger 110, where it is cooled to produce cool low pressure bleed air (cooling). The cool low pressure bleed air is then supplied to the pump 105, which pressurizes the cool low pressure bleed air to produce cool high pressure bleed air (pumping). The cool low pressure bleed air can also be supplied to the air cycle machine 190 (via vale 195), which can receive any percentage or portion of the cool low pressure bleed air. In an embodiment, an inlet of the air cycle machine 190 can be in fluid communication with bleed air that is upstream of the pump 105 and downstream of the first heat exchanger 210. As shown in FIG. 2, the inlet can be represented as the valve 195, which selectively regulate the bleed air to the air cycle machine 190.

[0056] Next, the cool high pressure bleed air passes through the second heat exchanger 115, where it is further cooled to produce the cooled cool high pressure bleed air (cooling). The cool high pressure bleed air can also be supplied to the air cycle machine 190 (via valve 196), which can receive any percentage or portion of the cool high pressure bleed air. The cooled cool high pressure bleed air from the staged cooling arrangement can then be mixed at the demarcation point 180 with the high pressure bleed air from the second port 165 to produce intercooled cooled cooling air. In an embodiment, an inlet of the air cycle machine 190 can be in fluid communication with bleed air that is upstream of the demarcation 180 and downstream of the second heat exchanger 210. As shown in FIG. 2, the inlet can be represented as the valve 196, which selectively regulate the bleed air to the air cycle machine 190.

[0057] The air cycle machine 190 can utilize the received cool low pressure bleed air and/or cool high pressure bleed air respectively received from the exhausts of the first heat exchanger 110 and the second heat exchanger 115 to provide pneumatic power to an accessory. By providing the pneumatic power, the air cycle machine 190 can also produce byproduct of cool/cold air. The air cycle machine 190 is one example of a device that can received cool low pressure bleed air and/or cool high pressure bleed air and is not intended to be limiting.

[0058] Note that the act of cooling by the first heat exchanger 110 can cause a pressure drop on the bleed air. In this way, the first heat exchanger 110 can be configured to offset a performance of the pump 105. Further, the pump 105 can be configured to pressurize the air to at, slightly above, or considerably above the pressure at the exhaust of the compressor section 24 to compensate for an original low pressure at the first port 145 and/or for the pressure drop across the staged cooling arrangement. Furthermore, the second heat exchanger can be configured to cool the air exhausted from the pump 105 back down.

[0059] A line 191 is shown which may deliver spray water from the air cycle machine 190 back into an intake line at the heat exchanger 110 to provide additional cooling.

[0060] A clutch 300 is shown between the gear box 220 and cooling compressor 105. In addition, a control 302 is shown. It should also be noted that gear box 220 could be replaced by an electric motor or a hydraulic motor.

[0061] Valve durability and reliability at the locations listed is a challenge. These locations might benefit from poppet valves with piston sliding materials such as carbon or ceramic matrix composites. Actuators may be used that are remote from the hot valve body and/or the actuators may have their own cooling enclosure with the cooling air brought from a cooler part of the engine or its subsystems. Valve 182 is optional, particularly if the mixing chamber is within the engine casing.

[0062] FIG. 3 is an intercooled cooled cooling air system 200 in accordance with another embodiment. In general, the intercooled cooled cooling air system 200 comprises a staged cooling arrangement located in a bypass duct of the gas turbine engine 20. Components of the intercooled cooled cooling air system 100 and the gas turbine engine 20 that are similar to the intercooled cooled cooling air system 200 have been reused for ease of explanation, by using the same identifiers, and are not re-introduced. Components of the environmental control system 200 comprise a first heat exchanger 210, a second heat exchanger 215, a gearbox 220, a tower shaft 225, and a fan section 22 comprising a plurality of fans. In a non-limiting embodiment, the fan section 22 comprises a first fan 230, a second fan 235, and a third fan 240. Components of the environmental control system 200 also comprise one or more bypass streams encased by ducts. In an embodiment and as shown in FIG. 3, a main bypass stream 265

and a secondary bypass stream 275 are isolated within first and second bypass ducts of the gas turbine engine 20 (by a first duct wall 276 and a second duct wall 277). A third bypass stream 285 can be located in a third bypass duct external to the second bypass duct, but within a casing of the gas turbine engine 20 (e.g., located in an outer duct that bypasses the fan section 22). The intercooled cooled cooling air system 200 is also integrated with a pump 290 and an electric generator 291.

[0063] As shown in FIG. 3, the first heat exchanger 210 and the second heat exchanger 215 are aligned in the secondary bypass stream 275 to enable the stream to act as the heat sink for the blead air flow from the first port 145. Within the secondary bypass stream 275, the first heat exchanger 210 is upstream of the second heat exchanger 215. Alternative embodiments include collectively aligning the first heat exchanger 210 and the second heat exchanger 215 in the main bypass stream 265, collectively aligning the first heat exchanger 210 and the second heat exchanger 215 in the third bypass stream 285, collectively aligning the first heat exchanger 210 and the second heat exchanger 215 on the first duct wall 276 (e.g., to enable a combination of streams the main bypass stream 265 and the secondary bypass stream 275), and collectively aligning the first heat exchanger 210 and the second heat exchanger 215 on the second duct wall 277 (e.g., to enable a combination of streams the secondary bypass stream 275 and the third bypass stream 285). Alternative embodiments also include separately aligning the first heat exchanger 210 and the second heat exchanger 215 in different streams 275, 285, and 295 and/or on different duct walls 276 and 277. Further, embodiments can include utilizing one or more sources for a heat sink, such as bleed air, fluid cooling, air cycle machine cooling, etc., in lieu of or in addition to the streams described herein.

[0064] The pump 290 can selectively receive cool low pressure bleed air and/or cool high pressure bleed air respectively received from the exhausts of the first heat exchanger 110 and the second heat exchanger 115 regardless of their location. In a non-limiting embodiment, the pump 290 can be a turbine. Selective regulation can be implemented by operations of the valve 195 and the valve 196, which can operate in response to operating conditions of the gas turbine engine 20 and/or other systems (e.g., an electric heater powered by the generator 291 requires more power, and therefore a higher percentage or portion of bleed air is supplied by the valve 195 and/or valve 196

to generate that power). Embodiments of selective regulation include the pump 290 receiving bleed air from only the valve 195; the pump 290 receiving bleed air from only the valve 196; the turbine 290 receiving bleed air from both the valve 195 and the valve 196; the turbine 290 receiving proportional bleed air from the valve 195 and the valve 196; etc.

[0065] The turbine 290 can extract work from the cool low pressure bleed air and/or the cool high pressure bleed air to provide pneumatic power to the generator 291. By providing the pneumatic power to the generator 291, the generator 291 can produce electricity to power one or more applications (see dash-arrow pointing to dashed-circle A). Examples of application include electricity to provide heat to diffuser (e.g., electric heater); providing thermo-electricity to an auxiliary system; electricity to provide shaft power (e.g., gearbox generator, motor drive, pump, etc.); electricity to provide aircraft power (e.g., aircraft system); etc. The work extracted by the pump produces byproduct of cool/cold air that can be a cooling sink for one or more applications elsewhere in the gas turbine engine 20 or aircraft (see dash-arrow pointing to dashed-circle B). In an embodiment, the one or more applications include providing the cooling sink to an environmental control system of an aircraft.

[0066] Also, as shown in FIG. 3, the gear box 220 can, in turn, be powered by tower shaft 225, which can in turn be powered by the high or low speed spools to drive the pump 105 (e.g., cause the pump to compress bleed air received from the first heat exchanger 210). In another non-limiting embodiment, the gear box 220 can be representative of an electric motor that powers the pump 105.

[0067] It is desirable to maintain the speed of the cooling compressor 105 constant, or within a narrow range. As such, FIG. 4 shows a method flowchart. The speed of the compressor 105 is compared to a desired speed at step 400. The control 302 moves the speed of the compressor 105 back towards the desired speed should it differ by more than a predetermined amount at step 402. Control 302 may be programmed to achieve this method. Control 302 may be part of a FADEC, as an example.

[0068] The programming of control 302 may be relatively simple should an electric motor be utilized as the motor for the cooling compressor 105. Further, when airflow through the cooling compressor 105 is not needed, the clutch 300 may open. In

such cases, the selection valve 195 may divert all air around the cooling compressor 106 and into a line 303 leading directly to the air cycle machine (see FIG. 2) or the turbine 290 (see FIG. 3).

[0069] The control 302 might also be operable to change various aspects of the operation of the compressor 105 to maintain the speed within the narrow band should a variable input speed, such as from the accessory gear box 220, be utilized.

[0070] It would be desirable that the compressor 106 be shut down either by stopping its motor or opening the clutch, prior to the valve 195 closing flow to the compressor.

[0071] With regard to the mixing chamber 180, the flow from tap 165 and the use of the mixing chamber 180, allows the size of the tap 145 to be reduced by overcooling this tapped air and then mixing it with hotter air from the tap 165. Desirably, the tap 165 should only be shutoff under certain conditions, such as if the flow to 184 is to the high pressure compressor alone, and not to the turbine, where disc rim cavities and blade shower head cooling requires pressure above backflow from the gas path at all times. Also, if there is substantial base flow to the turbine from the high pressure compressor discharge, say along an inner compressor case wall, then the flow to 184 can be shut down or reduced, but desirably while still maintaining backflow margin in the turbine.

[0072] Returning to FIG. 3, a sensor 306 is shown at the location 108. This could be a pressure or temperature measurement, or both. The controller for the engine should desirably have logic that determines the severity of a failure in the system and identifies an appropriate response. Maintenance flags and recommendations for in-flight shutdown, power reduction recommended, etc. may be utilized.

[0073] Further, many of the several valves located in the system desirably have position feedback capability and/or temperature measurements for identifying potential concerns. Again, the control should be programmed to isolate and identify faults.

[0074] Technical effect and benefits of an intercooled cooled cooling air system include producing a cold heat sink and/or cool flow from direct cooling, where a two heat exchanger configuration further provides variable options for the pressure and temperature of the cooling technical effect and benefits of an intercooled cooled cooling

air system include producing a variable speed, variable power off-take to be used on an accessory like generator.

[0075] 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. For example, "about" can include a range of ± 8% or 5%, or 2% of a given value.

[0076] 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, operations, element components, and/or groups thereof.

[0077] While the present disclosure has been described with reference to an exemplary embodiment or embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the present disclosure. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the present disclosure without departing from the essential scope thereof. Therefore, it is intended that the present disclosure not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this present disclosure, but that the present disclosure will include all embodiments falling within the scope of the claims.

CLAIMS

1. An intercooled cooling system for a gas turbine engine, the intercooled cooling system comprising:

a plurality of cooling stages in fluid communication with an air stream utilized by the plurality of cooling stages for cooling,

wherein a first cooling stage of the plurality of cooling stages is fluidly coupled to a bleed port of a compressor of the gas turbine engine to receive and cool bleed air with the air stream to produce a cool bleed air;

a cooling pump fluidly coupled to the first cooling stage to receive and increase a pressure of the cool bleed air to produce a pressurized cool bleed air,

wherein a second cooling stage of the plurality of cooling stages is fluidly coupled to the pump to receive and cool the pressurized cool bleed air to produce an intercooled cooling air;

a valve downstream of said first cooling stage, said valve selectively delivering air into a mixing chamber where it is mixed with air from a tap that is compressed to a higher pressure than the air from said bleed port, and said valve also selectively supplying air from said first cooling stage to a use on an aircraft associated with the gas turbine engine.

2. The intercooled cooled cooling air system of claim 1, wherein the use comprises a turbine configured to receive and extract work.

3. The intercooled cooled cooling air system of claim 2, wherein the use is an environmental control system for an associated aircraft.

4. The intercooled cooling air system of claim 1, wherein said cooling pump is driven within a range of a desired speed.

5. The intercooled cooling air system of claim 4, wherein said cooling pump is driven by an electric motor.

6. The intercooled cooling air system of claim 5, wherein said electric motor is provided with a control to maintain the speed of said cooling pump within a predetermined distance from said desired speed.

7. The intercooled cooling air system of claim 4, wherein a clutch selectively opens to stop drive of said cooling pump.

8. The intercooled cooling air system of claim 4, wherein said cooling compressor is driven by a tower shaft from an associated gas turbine engine, and a control ensures said cooling compressor speed is within said predetermined distance.

9. The intercooled cooling air system of claim 1, wherein said valve associated with said second cooling stage is provided with temperature protection.

10. The intercooled cooling air system of claim 9, wherein said temperature protection includes at least one of a remote actuator or temperature shielding.

11. The intercooled cooling air system of claim 1, wherein a selection valve is positioned in said first cooling stage and downstream of a heat exchanger in said first said cooling stage, and upstream of said cooling pump and said selection valve selectively delivering air around said cooling pump and to said use.

12. A method of operating an intercooled cooling air system comprising the steps of:

tapping air from a lower pressure location, and passing said air through a first heat exchanger, and then to a cooling pump, said cooling pump raising the pressure of said tapped air, and selectively delivering said tapped air to a turbine section; and

ensuring the speed of said cooling pump is within a predetermined distance of the desired speed.

13. The method of claim 12, including the step of driving said cooling pump by an electric motor.

14. The method of claim 13, wherein said electric motor is provided with a control to maintain the speed of said cooling pump within a predetermined distance from said desired speed.

15. The method of claim 12, wherein opening a clutch to selectively stop drive of said cooling pump.

16. An intercooled cooling air system for a gas turbine engine, the intercooled cooling system comprising:

a plurality of cooling stages in fluid communication with an air stream utilized by the plurality of cooling stages for cooling,

means to cool the tapped air; and

a valve downstream of said first cooling stage for selectively delivering the tapped air into a mixing chamber, and where it is mixed with air at a higher pressure than said tapped air, and means for also selectively supplying air from said mixing chamber to cool a turbine and for supplying tapped air to a use on an aircraft associated with the gas turbine engine.

17. The intercooled cooling air system of claim 16, wherein said use is an environmental control system for the associated aircraft.

18. The intercooled cooling air system of claim 16, where said use is a turbine to extract energy from the cool bleed air.

19. The intercooled cooling air system of claim 16, wherein said means to increase a pressure of the cool bleed air includes a control for maintaining a speed of said means.

20. The intercooled cooling air system of claim 16, wherein said control includes a clutch.

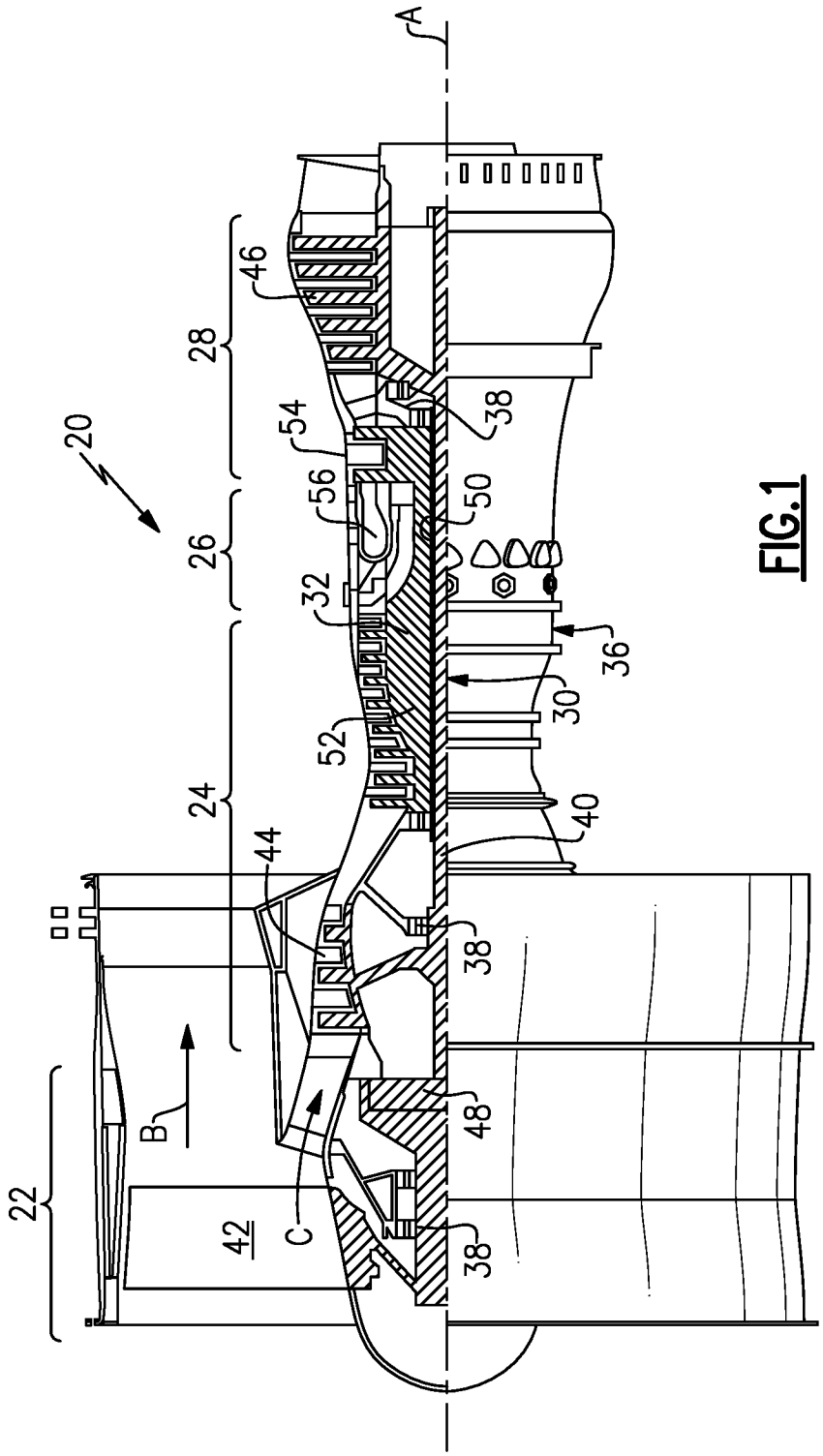


FIG.1

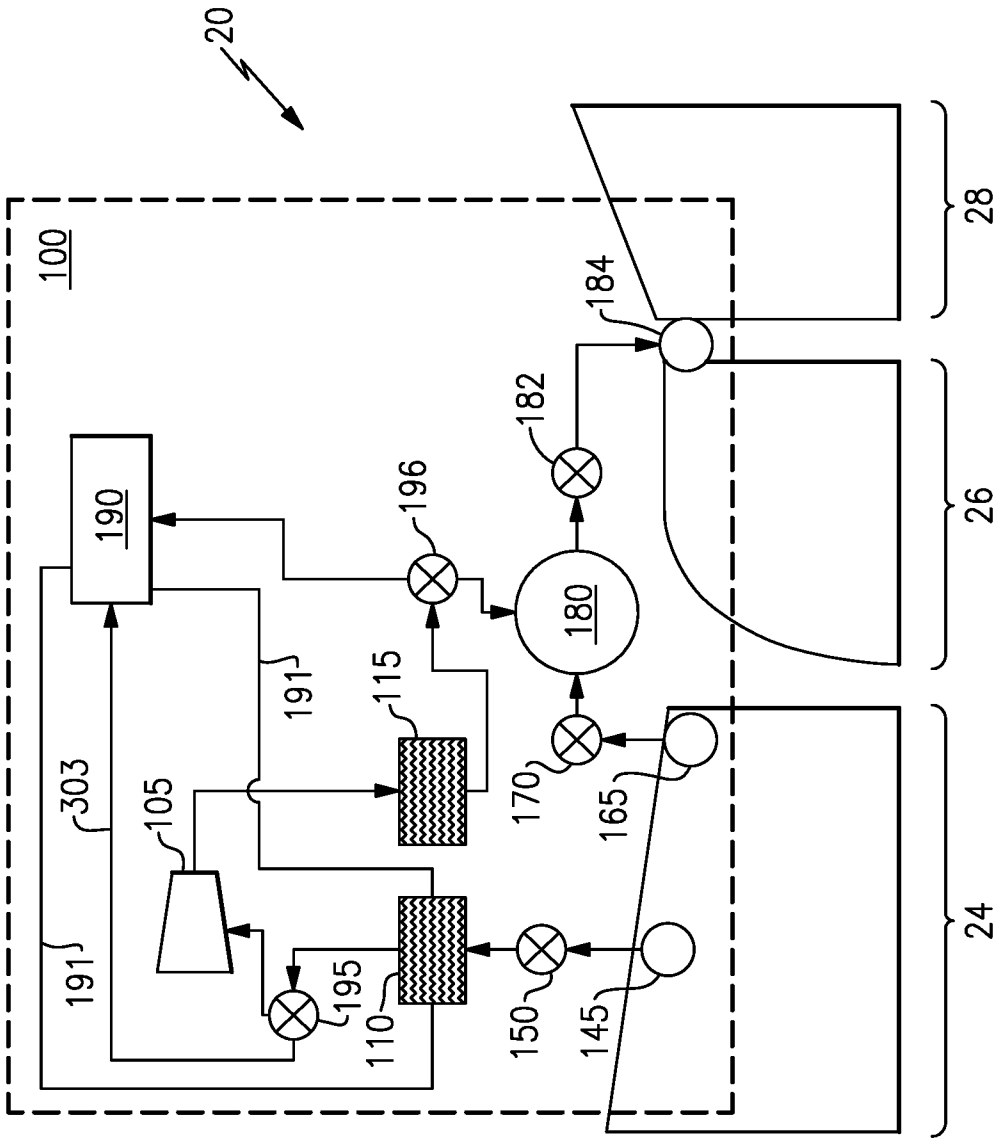

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100
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184
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303
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170
165
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150
145

FIG.2

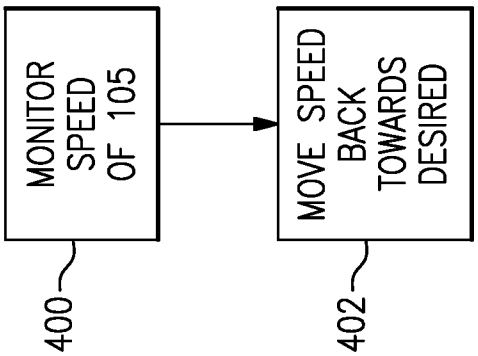

MONITOR SPEED OF 105
MOVE SPEED BACK TOWARDS DESIRED
400
402

FIG.4

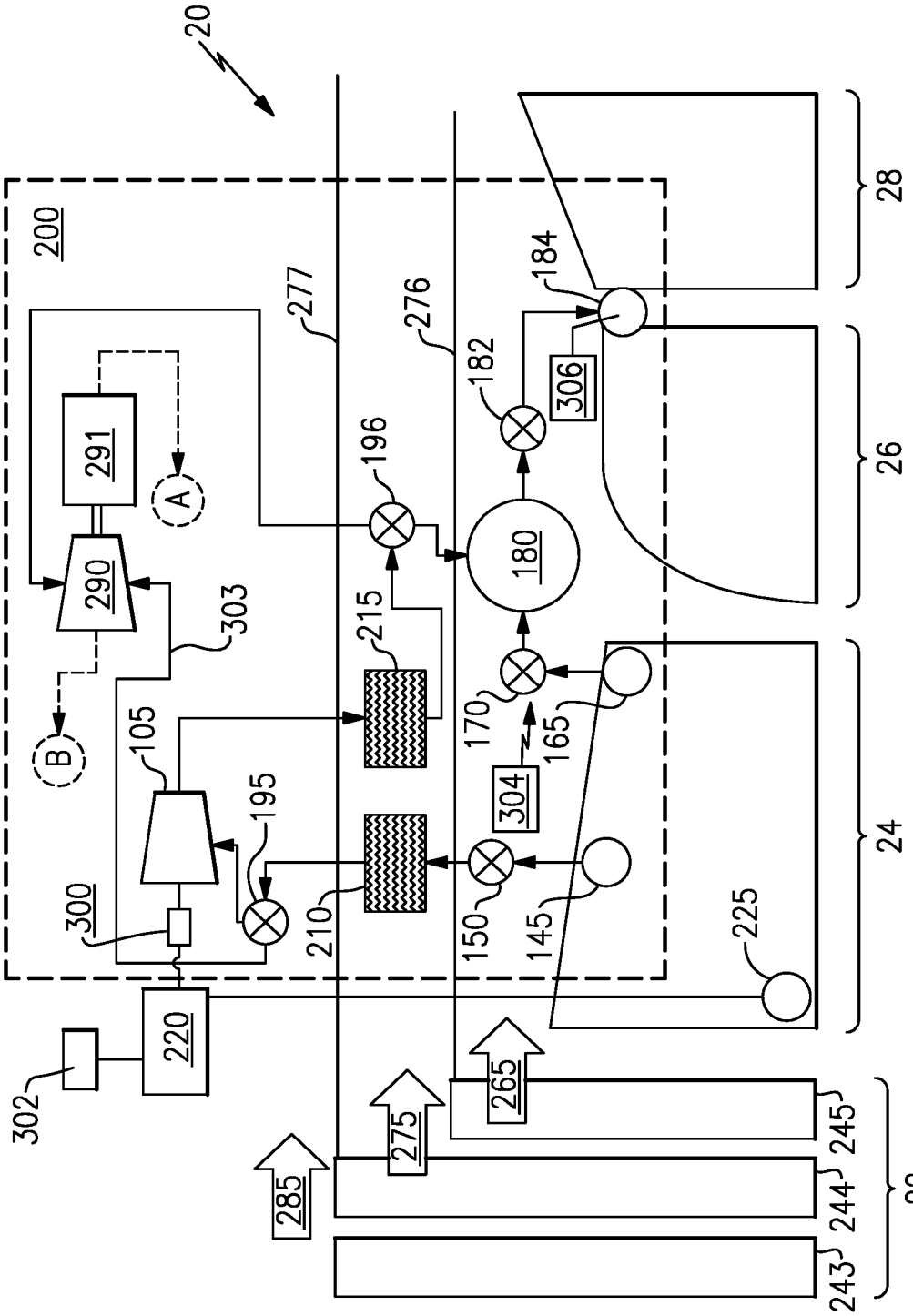

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FIG.3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2017/060587

A. CLASSIFICATION OF SUBJECT MATTER

F02C 7/18(2006.01)i, F02C 9/18(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F02C 7/18; F01D 25/12; F02B 29/04; F25B 9/06; F02D 41/00; F02C 7/143; F25B 49/04; F02C 9/18; F02C 1/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords:
intercooled cooling system, cooling stage, cooling pump, bleed air, valve, mixing chamber

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2016-0312711 A1 (UNITED TECHNOLOGIES CORPORATION) 27 October 2016 See paragraphs [0002], [0032]-[0060] and figures 1-6.	1-20
Y	US 2013-0283848 A1 (CAMERON INTERNATIONAL CORPORATION) 31 October 2013 See paragraphs [0027]-[0029] and figures 1-2.	1-20
A	EP 2767701 A1 (THE BOEING COMPANY) 20 August 2014 See paragraphs [0033]-[0037] and figure 3.	1-20
A	US 2007-0144176 A1 (JOSHI et al.) 28 June 2007 See paragraphs [0010]-[0028] and figures 1-2.	1-20
A	US 2016-0281604 A1 (GENERAL ELECTRIC COMPANY) 29 September 2016 See paragraphs [0013]-[0031] and figure 2.	1-20

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 February 2018 (19.02.2018)	**20 February 2018 (20.02.2018)**

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.
PCT/US2017/060587

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