LOW ENERGY ELECTRIC AIR CYCLE WITH PORTAL SHROUD CABIN AIR COMPRESSOR

Inventors: Henry M. Claeys, Lomita, CA (US); Katherine Clarke, Hermosa Beach, CA (US); David G. Elpern, Los Angeles, CA (US)

Correspondence Address:
HONEYWELL INTERNATIONAL INC.
101 COLUMBIA ROAD
P O BOX 2245
MORRISTOWN, NJ 07962-2245 (US)

Filed: Jul. 29, 2005

Related U.S. Application Data

Provisional application No. 60/604,610, filed on Aug. 25, 2004.

Publication Classification

Int. Cl. F25D 9/00 (2006.01)
U.S. Cl. ........................................... 62/401; 62/402

ABSTRACT

An environmental control system for an aircraft cabin includes a plurality of electrically-driven ported shroud cabin air compressors, each cabin air compressor compressing ram air received from the aircraft exterior, a heat exchange circuit comprising a primary heat exchanger receiving airflow from at least one of the cabin air compressors, and the secondary heat exchanger supplying airflow to the aircraft cabin, and an air cycle machine comprising a compressor adapted to receive airflow from the primary heat exchanger and supply compressed air to the secondary heat exchanger. The environmental control system may further comprise an air recirculation system, having an aft recirculation fan adapted to receive a portion of recirculation air from the aircraft cabin, and a recirculation heat exchanger, disposed in the heat exchange circuit in series with the primary and secondary heat exchangers, and adapted to receive airflow from the aft recirculation fan.
FIG. 1
LOW ENERGY ELECTRIC AIR CYCLE WITH PORTAL SHROUD CABIN AIR COMPRESSOR

CROSS-REFERENCES TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application No. 60/604,610 filed Aug. 25, 2004.

TECHNICAL FIELD

[0002] The present invention relates to environmental control systems for various aircrafts. More particularly, the present invention relates to electrically-driven air cycle systems that regulate the temperature of at least the aircraft fuselage.

BACKGROUND

[0003] Passenger aircrafts are typically equipped with an environmental control system, including an air cycle conditioning system for cooling the aircrew cabins, and other aircraft locations and components. One class of air cycle conditioning systems that are widely used in aircraft to provide cooled air takes advantage of a supply of pressurized air that is bled from an aircraft engine, known as bleed air. Other electrically-driven environmental control systems generally operate by receiving fresh ram air from inlets that are located in at least one favorable position near the aircraft’s forward belly fairing leading edge. The fresh ram air is supplied to at least one electric motor-driven air compressor that raises the air pressure to, for example, the desired air pressure for the aircrew cabins. From the at least one air compressor, the air is supplied to an ozone converter. Because air compression creates heat, the air is then supplied to an air conditioning pack in which the air is cooled and then transported to the aircraft fuselage. At least one recirculation system is also provided to recycle air from the fuselage back to the at least one air compressor. The recirculation system may be used at both high and low altitudes, but is particularly useful when the aircraft is flying at high altitudes where the pressure for the ram air is relatively low.

[0004] The numerous applications and components in a typical environmental control system, including the ram air cycle, the recirculation cycle, heat exchangers, condensers, reheaters, water extractors, and an air cycle machine, can require large amounts of energy to operate. Further, the large number of components in a typical environmental control system tends to be heavy and complex. Hence, there is a continuing need for simplification of environmental control systems for various aircrafts, including a reduction in the number of components, programming, and circuitry. There is also a need for environmental control systems that can be operated with minimized power consumption and weight.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] FIG. 1 is a flow chart illustrating the top-level architecture of an environmental control system for an aircraft in which the present invention may be incorporated;

[0006] FIG. 2 is a flow chart illustrating an air cycle pack for an aircraft according to an embodiment of the present invention;

[0007] FIG. 3 is a graph illustrating operational relationships between corrected compressor flow and a compressor pressure ratio in prior art air cycle systems and vapor cycle systems for an aircraft; and

[0008] FIG. 4 is a cross sectional elevation view of a ported shroud air compressor that is incorporated in the air cycle pack of FIG. 2 according to an embodiment of the present invention.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

[0012] The following detailed description of the invention is merely exemplary in nature and is not intended to limit the invention or the application and uses of the invention. Furthermore, there is no intention to be bound by any theory presented in the preceding background of the invention or the following detailed description of the invention.

[0013] Turning now to the figures, FIG. 1 is a flow chart illustrating the top-level architecture of an exemplary environmental control system 100 for an aircrew cabin or other area in an aircraft fuselage 30. The illustrated system 100 includes four electrically-driven cabin air compressors 10a-10d, each receiving fresh ram air from inlets that are located in at least one favorable position near the aircraft’s forward...
The air compressors 10a–10d raise the ram air pressure to a level that is slightly above the desired aircraft cabin pressure. The compressed air then passes through check valves 12a–12d, and through one of two ozone converters 14a, 14b. If air conditioning is not necessary, bypass valves 15a, 15b are opened and the compressed air is supplied directly to the aircraft fuselage 30 from the ozone converters 14a, 14b. Since some air temperature control is typically required, the air is normally supplied to one of two air conditioning packs 20a, 20b, which then transfer the air to an air distribution system 26 that delivers the air about the aircraft fuselage 30.

The air conditioning packs 20a, 20b may receive about 50% fresh air from the cabin air compressors 10a–10d, and about 50% recirculation air from the aircraft fuselage 30, although these percentages vary according to a range of factors including the aircraft velocity and altitude. Air that is recirculated to the air conditioning packs 20a, 20b from the aircraft fuselage 30 passes through valves 22a, 22b and regulators 24a, 24b. The environmental control system 100 thus uses a relatively cool air supply compared to the conventional system in which a supply of hot pressurized air is bled from an aircraft engine, known as bleed air. In fact, the environmental control system 100 of the present invention entirely eliminates the conventional engine air bleed system.

Turning now to FIG. 2, details pertaining to an air conditioning pack 20 are illustrated, it being understood that the illustrated air conditioning pack 20 may represent either of the air conditioning packs 20a, 20b depicted in FIG. 1. The air conditioning pack includes the components to the right of the ozone converter 14a, and to the left of the vertical discontinuous line 58 in FIG. 2, the components and flow paths to the right of the discontinuous line 58 being directed into or disposed inside the aircraft fuselage.

As previously mentioned, the air conditioning pack 20 receives two air sources, namely, fresh ram air and recirculation air. First, fresh ram air is supplied to the air conditioning pack 20 from the compressors 10a, 10b powered by motors 11a, 11b. The ozone converter 14a removes all or most of the ozone from the compressed ram air, specifically at high altitudes where ozone is included in the air at relatively high concentrations.

The compressed ram air passes through a primary heat exchanger 32 that is disposed in a ram air heat exchanger circuit 56. The ram air heat exchanger circuit 56 has ambient ram air passing therethrough, which cools compressed air in the primary heat exchanger 32, a secondary heat exchanger 34, and an air recirculation heat exchanger 36 that are located in the circuit 56. The ram air heat exchanger circuit 56 receives air drawn through a ram scoop during aircraft flight, and is driven by an electric fan 54 when the aircraft is stationary. In the preferred embodiment illustrated in FIG. 2, the electric fan 54 is disposed downstream of the heat exchangers 32, 34, 36 so the heat from the fan 54 is directed overboard rather than into the heat exchangers 32, 34, 36. A portion of the air entering the ram air heat exchanger circuit 56 is diverted upstream of the primary heat exchanger for use as trim air by the cabin temperature control system. Because the ambient ram air in the circuit 56 is cooler than the air passing through the heat exchangers 32, 34, 36, the ambient ram air serves as a heat sink before the air is expelled using the electric fan 54.

After the compressed ram air passes through the primary heat exchanger 32, the air is supplied to a bootstrap air cycle machine, referring specifically to a compressor 40 and turbine 42 that either share the same rotating axis or are otherwise powered and rotated together. The compressor 40 further pressurizes and heats the ram air. The compressed air is then supplied to the secondary heat exchanger 34, causing the compressed air to cool. During normal operation, an altitude valve 60 is closed, causing the air to pass through a re-heater 44 and a condenser 46, and then through a water extractor 48, which substantially dries the air. From the water extractor 48, the air is again heated in the re-heater 44, and then the hot and dry air is supplied to the turbine 42. The turbine 42 forwards the air to the condenser 46, which cools the air further and supplies the air to the aircrew cabinets in the aircraft fuselage 30. At high altitudes, the altitude valve 60, and also a compressor bypass check valve 62 is opened, causing air from the secondary and primary heat exchangers 34, 32, respectively, to bypass the bootstrap air cycle machine and revert to the ram air heat exchanger circuit 56 for cooling. This bypass mode of operation minimizes the supply pressure to the air conditioning pack 20 and reduces the required input power to the cabin air compressors 10a–10d. At low elevations, a recirculation heat exchanger bypass valve 64 is opened, allowing the recirculation air from an aft recirculation fan 52 to bypass the recirculation heat exchanger 36.

A forward recirculation fan 50 mixes some recirculation air from the aircraft fuselage 30 into the fresh air supplied from the air conditioning pack 20 before the fresh air reaches the aircrew cabinets. However, a majority of the recirculation air is transferred back to the air conditioning pack 20 using the aft recirculation fan 52, which supplies the recirculation air to the recirculation heat exchanger 36 for cooling. The cooled recirculation air leaves the recirculation heat exchanger 36 and is then mixed with the fresh air being supplied to the aircraft fuselage 30. Thus, the air conditioning pack 20 delivers a dry, subfreezing supply of air to the air conditioning system with a significant portion of the ventilation air entering the aircrew cabins being recirculation air.

In the embodiment illustrated in FIG. 2, the recirculation heat exchanger circuit 36 is located with the primary and secondary heat exchangers 32, 34 in the ram air heat exchanger circuit 56. Additional heat exchangers may also be located in a series arrangement with the primary, secondary, and recirculation heat exchangers 32, 34, 36. For example, motor cooling heat exchangers for the cabin air compressor motors may be located in the ram air heat exchanger circuit 56. Also, a power electronics chiller, which is a liquid-to-air heat exchanger, can be located in the ram air heat exchanger. In an alternate embodiment, the motor cooling heat exchangers and the power electronics
chiller are disposed in series in a separate, parallel ram circuit that is powered by a separate electric fan.

[0022] In a preferred environmental control system 100, the compressors 10a-10d are ported shroud compressors. One example of a suitable ported shroud compressor is illustrated in FIG. 4, although various other designs may also be incorporated. The compressor 10 includes a housing 162 with an outer wall 164 defining an inlet 166. The inlet 166 includes an outer portion 167 and an inner portion 168. The compressor housing 162 also defines an outlet 186. Within the outer wall 164 is a shroud 170 that is defined by an inner compressor wall 172 having an inner surface 174 and an outer surface 176. In one embodiment, the outer wall 164 defined by the housing 162 is circular, and the shroud is defined by the circular inner compressor wall 172 concentric to the outer wall 164.

[0023] A compressor wheel 180 is rotatably mounted within the shroud 170. In one embodiment, the compressor wheel 180 includes a plurality of vanes or blades 182. The compressor wheel 180 is located so the shroud inner surface 174 is adjacent to the compressor wheel blades 182. The wheel 180 is coupled to a shaft 184. As the compressor wheel turns, air is drawn into the compressor 10 through the inlet 166, through the blades or vanes 182 of the compressor wheel 180, and then forced out through the outlet 186.

[0024] The shroud inner wall 172 defines a central channel 188. An annular channel 190 is defined between the outer surface 176 of the shroud inner wall 172 and an inner surface of the housing wall 164. The central channel 188 and the annular channel 190 form the inlet inner portion 168. At least one port 192 extends through the shroud inner wall 172, allowing communication between the annular channel 190 and the compressor wheel blades or vanes 182. In one embodiment, the at least one port 192 comprises a series of apertures through the shroud inner wall 172. However, slots or other methods of allowing flow through the shroud inner wall 172 may also be incorporated.

[0025] Ram air enters the ported shroud compressor 10 through the inlet outer portion 167. The air then passes through the central channel 188, into the compressor wheel 180, and is forced to the outlet 186. A surge condition may exist at low altitudes, in which the volume of air entering the compressor exceeds the compressor requirements. In order to avoid a surge condition, air also bleeds from the compressor wheel 180 through the at least one port 192 and flows through the annular channel 190 back to the inlet outer portion 167 where the air re-enters the central channel 188. This bypass action allows the compressor to reach an equilibrium state.

[0026] A choke condition may exist at high elevations, in which the compressor's requirements exceed the volume of air entering the compressor. In order to avoid a choke condition, air enters the compressor 10 through the inlet outer portion 167, where a portion passes through the central channel 188 and into the compressor wheel 180, and another portion bleeds through the annular channel 190 and directly into the compressor wheel blades or vanes 182 through the at least one port 192, with both portions then forced to the outlet 186. This inward flow bypass action allows greater airflow into the compressor wheel 180.

[0027] Referring to the graph of FIG. 3, the data represented by line 80 denote an operation range in which conditions are optimal, meaning that the compressor 10 is neither at risk of a choke condition or a surge condition. The data represent a relationship between a compressor pressure ratio, with values for such on the Y-axis, and a corrected flow per compressor, with values for such on the X-axis. If the compressor pressure ratio for a given flow rate is to the left of line 80, there is a risk of a surge condition since the air exceeds the requirements of the compressor 10. As seen by the data set for a conventional air conditioning pock that includes electric compressors, the data set represented by line 90, at a high altitude of 43 kft the conventional air conditioning pock operates well within optimal range. However, for low aircraft velocities at which the airflow per compressor approaches 1 lb/s, there is a risk of a surge condition.

[0028] Some conventional ways to correct this condition include turning off one or more of the compressors 10a-10d at low velocity or when the aircraft is not moving, thereby increasing the airflow per compressor and shifting the line 80 to the right. However, automating a power shut-off requires additional programming and circuitry, and can consequently be inefficient in terms of cost and complexity. Other conventional ways to correct this condition include installing a more complex variable diffuser compressor as part of the bootstrap air cycle machine. However, a variable diffuser compressor is costly as it requires its own actuation mechanism, and includes a large number of moving components that introduce the possibility for compressor leakage and increased maintenance.

[0029] Utilizing the ported shroud air compressor 10 to receive the ram air for the environmental control system 100 overcomes the problems of operating with a risk of a surge or choke condition by enabling operation within at least a 10% to 15% margin between line 80 and line 90 in FIG. 3 by effectively shifting the line 80 to the left in the low pressure, low flow region.

[0030] Thus, the previously-described environmental control system 100 provides a low energy consumption cycle that minimizes the expenditure of power and reduces the weight of the overall system. While the invention has been described with reference to a preferred embodiment, 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 invention. In addition, many modifications may be made to adapt to a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the appended claims.

We claim:
1. An environmental control system for an aircraft cabin, comprising:
a plurality of electrically-driven cabin air compressors, each cabin air compressor compressing ram air received from the aircraft exterior;
a heat exchange circuit comprising a primary heat exchanger and a secondary heat exchanger in series, the primary heat exchanger adapted to receive airflow from
at least one of the cabin air compressors, and the secondary heat exchanger adapted to supply airflow to the aircraft cabin; and

an air cycle machine comprising a compressor, adapted to receive airflow from the primary heat exchanger and supply compressed air to the secondary heat exchanger,

wherein at least one of the cabin compressors comprises:

a housing having an air inlet, and an air outlet in communication with the primary heat exchanger, the air inlet defining an outer circular wall, an inner circular shroud wall having at least one port extending therethrough, a central channel, and an annular channel disposed concentrically around the central channel and in communication with the central channel by way of the at least one port extending through the inner circular shroud wall, and

a compressor wheel having a plurality of vanes, the wheel being interposed between the inlet and the outlet, and disposed in the central channel.

2. The environmental control system according to claim 1, wherein the air cycle machine compressor further comprises:

a shaft that is rotatably coupled to the air cycle machine compressor; and

a turbine that is rotatably coupled to the shaft, the turbine being adapted to receive airflow from the secondary heat exchanger and supply airflow to the aircraft cabin.

3. The environmental control system according to claim 2, further comprising:

a reheater disposed upstream with respect to the turbine and adapted to receive airflow from the secondary heat exchanger;

a condenser disposed upstream with respect to the turbine, and adapted to receive reheated air from the reheater; and

a water extractor disposed upstream with respect to the turbine, and adapted to receive condensed air from the condenser and to supply airflow to the turbine.

4. The environmental control system according to claim 3, wherein the reheater is further adapted to receive airflow from the water extractor and to supply airflow to the turbine.

5. The environmental control system according to claim 3, wherein the condenser is further adapted to receive airflow from the turbine and to supply airflow to the aircraft cabin.

6. The environmental control system according to claim 1, further comprising:

an air recirculation system, comprising:

a forward recirculation fan adapted to supply a portion of recirculation air from the aircraft cabin to the airflow supplied from the secondary heat exchanger to the aircraft cabin.

7. The environmental control system according to claim 1, further comprising:

an air recirculation system, comprising:

an aft recirculation fan adapted to receive a portion of recirculation air from the aircraft cabin;

a recirculation heat exchanger, disposed in the heat exchange circuit in series with the primary and secondary heat exchangers, and adapted to receive airflow from the aft recirculation fan.

8. The environmental control system according to claim 7, wherein the recirculation heat exchanger is further adapted to supply airflow from the aft recirculation fan to the airflow supplied from the secondary heat exchanger to the aircraft cabin.

9. The environmental control system according to claim 1, wherein the heat exchange circuit has ambient ram air passing therethrough, which cools air in at least the primary and secondary heat exchangers.

10. The environmental control system according to claim 1, wherein the heat exchange circuit receives external air drawn during aircraft flight.

11. The environmental control system according to claim 1, wherein the heat exchange circuit is driven by an electric fan disposed downstream from the primary and secondary heat exchangers.

12. The environmental control system according to claim 1, comprising two pairs of the cabin air compressors, and a pair of the air cycle machines, each pair of cabin air compressors providing airflow to one air cycle machine.