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(54) **COOLING OF AN ELECTRONIC DEVICE IN AN AIRCRAFT BY CASE-BY-CASE SINGLE-PHASE OR TWO-PHASE COOLING**

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(57) **ABSTRACT**

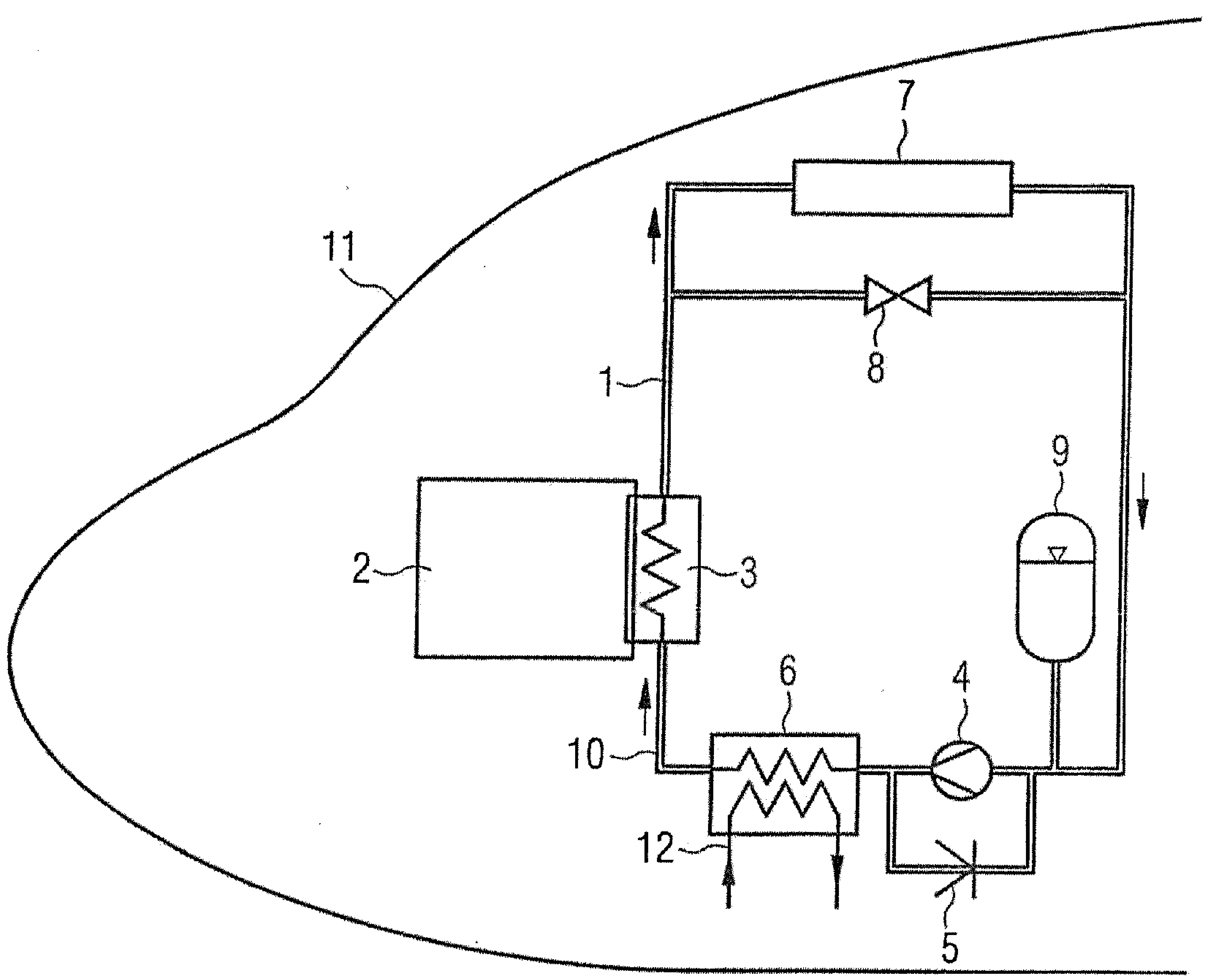
Cooling of an electronic device in an aircraft by case-by-case single-phase or two-phase cooling

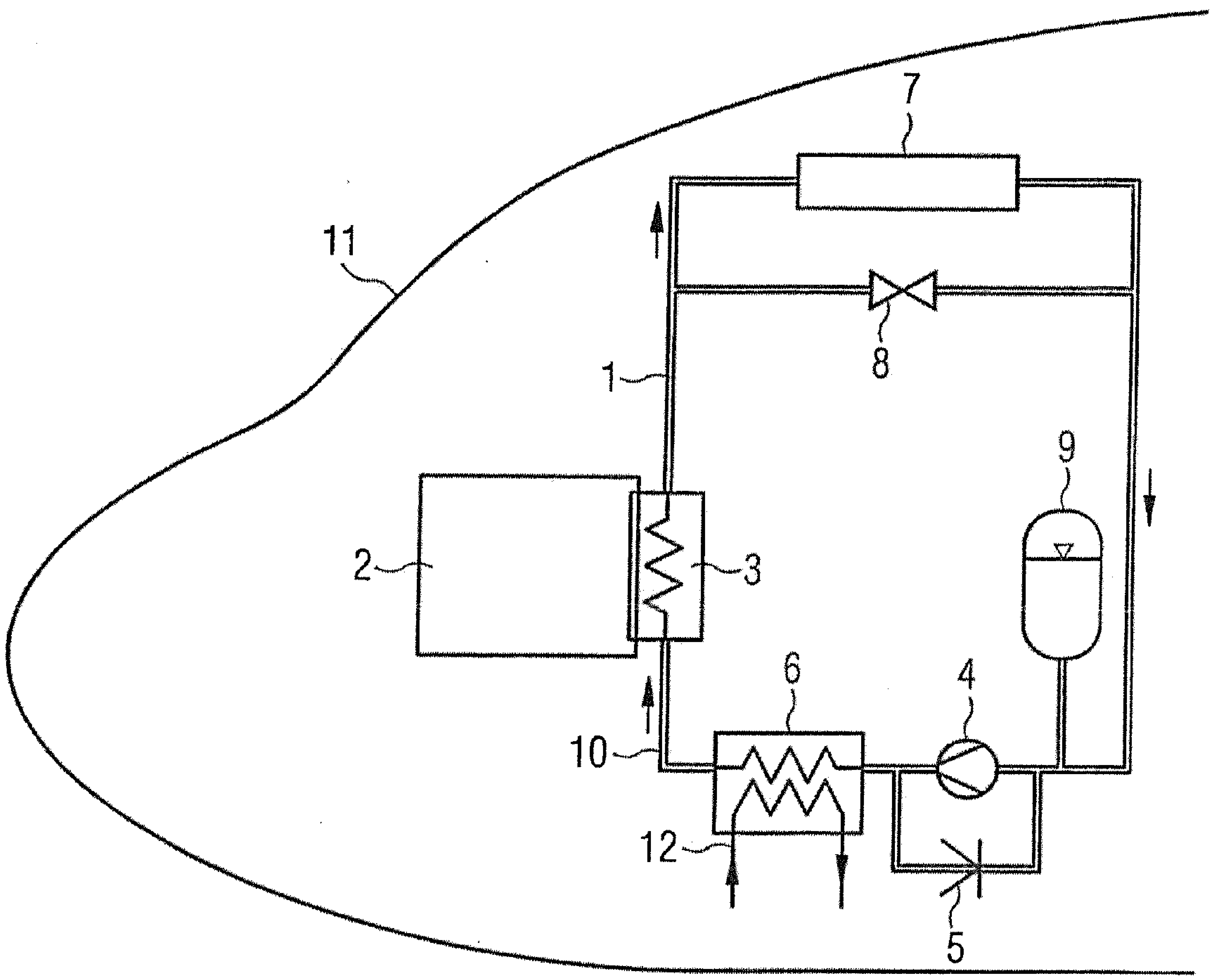
There is proposed a method for cooling an electronic device in an aircraft (**11**), comprising the following steps:

circulating a coolant in a cooling circuit,

cooling the electronic device (**2**) by means of the coolant, and

in an aircraft outer-shell heat exchanger, emitting the heat taken up by the coolant. The coolant evaporates, at least partially, during the cooling of the electronic device (**2**), and condenses in the aircraft outer-shell heat exchanger (**7**). The coolant circulates in the coolant circuit by natural convection.

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COOLING OF AN ELECTRONIC DEVICE IN AN AIRCRAFT BY CASE-BY-CASE SINGLE-PHASE OR TWO-PHASE COOLING

[0001] The invention relates to the cooling of an electronic device in an aircraft by means of a coolant that, during normal operation, is in the single-phase, liquid phase and, in the case of a malfunction, can have both the gaseous and the liquid phase.

[0002] In the case of an aircraft of the prior art, an electronic device is cooled by means of air. If the aircraft is on the ground, air is taken from the cabin for the purpose of cooling the electronic device, and returned to the cabin. This requires fans, which cause a considerable noise load. Further, the waste heat drawn into the cabin results in unwanted heating of the cabin.

[0003] In the case of a cooling device of the prior art, air circulates between the electronic device and an aircraft outer-shell heat exchanger during the flight. Since air can take up only relatively small quantities of heat, large quantities of air, large heat-exchanger surfaces, and air ducts of large cross-section are required. The weight and the space requirement of the cooling device and electronic device are increased as a result. This results in problems during installation in an aircraft. Both the supplying of air to the electronic device and the removal of air from the electronic device require a respective fan. The fans have a comparatively high electric power consumption, this resulting in an increased kerosene consumption on the ground and during the flight. Further, the fans cause vibrations and noise. In the case of a breakdown of one of the fans, the electronic device has to be switched off, since there is a risk of malfunction in the case of an excessively high operating temperature. Since certain functions are no longer available when the electronic device has been switched off, the safety of the aircraft can be impaired.

[0004] JP 2001-010595 proposes the cooling of an electronic device through the use of three cascaded cooling circuits. In the first cooling circuit, coolant circulates through an aircraft outer-shell heat exchanger and a condenser of a second cooling circuit. The second cooling circuit generates cold by compressing, condensing and evaporating. The evaporator of the second cooling circuits cools a heat exchanger of a third cooling circuit, which cools the electronic device. All three cooling circuits have a forced convection, by means of a respective pump device. In the case of a failure of one of the three pump devices that ensure the forced convection, the electronic device can no longer be operated, and the safety of the aircraft is impaired.

[0005] It is an object of the invention to provide a more reliable cooling of an electronic device in an aircraft.

[0006] In the case of a method, according to the invention, for cooling an electronic device in an aircraft, coolant circulates in a coolant circuit. The electronic device is cooled by means of the coolant and, in an aircraft outer-shell heat exchanger, the heat taken up by the coolant is emitted to the environment. The coolant can evaporate, at least partially, during the cooling of the electronic device and condense in the aircraft outer-shell heat exchanger. The coolant circulates in the coolant circuit by natural convection. The invention has the advantage that no pump device is required to ensure forced convection. This increases the reliability and safety of the aircraft. Further, the mass of the aircraft is reduced, which reduces the kerosene consumption. Further, there is no need for a refrigerating machine or ventilators, or for air shafts of large cross-section. As a result, the mass and the space requirement of a cooling device for the electronic device is reduced, and the integration into an aircraft is simplified.

[0007] During normal operation, the coolant can be permanently in a liquid phase, and circulate in the coolant circuit by forced convection. In the case of a malfunction, the coolant evaporates, at least partially, during the cooling of the electronic device, and condenses in the aircraft outer-shell heat exchanger, as previously described. In the case of a malfunction, the coolant circulates in the coolant circuit by natural convection. The malfunction can be, for example, the failure of a pump device for ensuring the forced convection.

[0008] The malfunction can also be an increased demand for cooling capacity. In this case, a forced convection can also be provided in addition.

[0009] This embodiment has the advantage that the cooling capacity, and therefore the temperature of the electronic device, can be controlled by controlling the forced convection. For example, the forced convection can be controlled in such a way that the air surrounding the electronic device is permanently at a temperature above the dew point, and the temperature of the electronic device is below a failure temperature. Even in the case of a breakdown of the forced convection, the cooling of the electronic device can be ensured. Consequently, in the case of a breakdown of the forced convection, the electronic device can continue to be operated, as a result of which the safety of the aircraft is increased.

[0010] During normal operation, the coolant is in the single-phase, liquid phase. In the case of a malfunction, the coolant has a two-phase behaviour. The coolant can acquire both the liquid and the gaseous phase in the case of a malfunction.

[0011] The coolant can be bypassed past the aircraft outer-shell heat exchanger, at least partially, if the temperature in the aircraft outer-shell heat exchanger exceeds a first threshold value. The coolant can be cooled case-by-case in an additional heat exchanger, which is cooled by a further cooling system. This can be necessary if the aircraft is on the ground and/or the external temperature is relatively high. In this case, the aircraft outer-shell heat exchanger is unable to cool the coolant. The further cooling system can be a liquid cooling system, or a cooling system that cools by compressing, condensing and evaporating. The first threshold value can be selected in such a way that the coolant, upon entering the electronic device, has a temperature by which it can be ensured that the temperature of the electronic device is safely below the breakdown temperature. The first threshold value can also correspond to the actual temperature of the coolant emerging from the cooling heat exchanger. If the temperature of the aircraft outer-shell heat exchanger is lower than the actual temperature of the coolant emerging from the cooling heat exchanger, the coolant flows through the aircraft outer-shell heat exchanger and is at least partially cooled. If the temperature of the aircraft outer-shell heat exchanger is higher than the actual temperature of the coolant emerging from the cooling heat exchanger, the coolant does not flow through the aircraft outer-shell heat exchanger, and therefore cannot become heated in the aircraft outer-shell heat exchanger.

[0012] The coolant can be bypassed past the aircraft outer-shell heat exchanger, at least partially, if the temperature in the aircraft outer-shell heat exchanger and/or of the coolant falls below a corresponding second threshold value in each case. If the aircraft is at great altitude, the external temperature can acquire very low values. Owing to the coolant being bypassed past the aircraft outer-shell heat exchanger, at least partially, it can be ensured that the temperature of the air surrounding the electronic device is always above the dew point. As a result, condensation of water in and/or on the electronic device is prevented, which increases the reliability and service life of the electronic device. Consequently, the second threshold value can be selected such that the temperature of the air surrounding the electronic device is always above the dew point.

[0013] The invention also relates to an aircraft cooling device, comprising a cooling heat exchanger adapted to cool an electronic device by means of a coolant, and an aircraft outer-shell heat exchanger adapted to cool the coolant, wherein the cooling heat exchanger and the aircraft outer-shell heat exchanger are arranged in a closed coolant circuit. The coolant can evaporate, at least partially, in the cooling heat exchanger during the cooling of the electronic device and condense in the aircraft outer-shell heat exchanger. The coolant circulates in the coolant circuit by natural convection. The coolant Galden, for example, which is a perfluorinated polyether distributed by Solvay Solexis, can be used as a coolant. Further, propylene glycol solutions, also referred to by the abbreviation PGW, can also be used as a coolant. This cooling device operates by natural convection and consequently does not require a pump device, so resulting in a compact and fail-safe aircraft cooling device. To ensure the natural convection, the line between the cooling heat exchanger and the aircraft outer-shell heat exchanger can be dimensioned with a larger diameter. The coolant functions as a two-phase coolant, since it can exist in both the gaseous and the liquid state.

[0014] The aircraft cooling device can have a pump device, which, during normal operation, circulates coolant in the coolant circuit. The aircraft cooling device can be adapted such that, during normal operation, the liquid coolant is permanently in a liquid phase and, because of the pump, circulates in the coolant circuit by forced convection. In the case of a malfunction, the coolant evaporates, at least partially, in the cooling heat exchanger during the cooling of the electronic device and condenses in the aircraft outer-shell heat exchanger. In the case of a malfunction, the coolant circulates in the coolant circuit by natural convection. As mentioned previously, in the case of this embodiment it is particularly easy to ensure that the temperature of the air surrounding the electronic device is permanently above the dew point, as a result of which the reliability and service life of the electronic device, and thereby the safety and reliability of the aircraft, are increased.

[0015] The aircraft cooling device can further have an aircraft outer-shell heat-exchanger bypass valve, which is adapted to bypass the coolant past the aircraft outer-shell heat exchanger, at least partially, if the temperature in the aircraft outer-shell heat exchanger exceeds a first threshold value. The aircraft cooling device can have an additional heat exchanger, which is cooled case-by-case by an additional cooling system, the additional heat exchanger being adapted such that the coolant of the coolant circuit is cooled in the additional heat exchanger if the additional heat exchanger is cooled by the additional cooling system. As mentioned previously, the external temperature can have high values, for example, if the aircraft is on the ground. In this case, the aircraft outer-shell heat exchanger might possibly no longer cool the coolant to such an extent that the temperature of the electronic device is always below the breakdown temperature. In this case, the coolant is cooled partially or completely by an additional heat exchanger, which is cooled by the additional cooling system. The additional cooling system can be a liquid cooling system, for example a so-called cold bus, or have a cycle of compression, condensing and evaporation. The first threshold value can be selected such that it is ensured that the coolant, upon entering the cooling heat exchanger, has a temperature by which it can be ensured that the temperature of the electronic device is always below the breakdown temperature. The aircraft outer-shell heat-exchanger bypass valve can also be opened if the temperature of the aircraft outer-shell heat exchanger is higher than the actual temperature of the coolant emerging from the cooling heat exchanger.

[0016] The aircraft outer-shell heat-exchanger bypass valve can be realized to bypass the coolant past the aircraft outer-shell heat exchanger, at least partially, if the temperature in the aircraft outer-shell heat exchanger and/or of the coolant falls below a corresponding second threshold value in each case. It can thereby be ensured that the temperature of the air surrounding the electronic device is always above the dew point, so increasing the reliability and service life of the electronic device, and thereby the safety of the aircraft. Consequently, the second threshold value can be selected such that the air surrounding the electronic device has a temperature that is above the dew point. It is understood that, instead of an aircraft outer-shell heat-exchanger bypass valve having two threshold values, it is possible to provide two aircraft outer-shell heat-exchanger bypass valves, each of which responds to one threshold value.

[0017] The aircraft cooling device can have a pump-device bypass valve, which is adapted to bypass the coolant past the pump device in the case of a malfunction of the pump device. The pump-device bypass valve can be connected parallel to the pump device. The pump-device bypass valve can have a spring, which opens the valve in the case of a preset pressure difference.

[0018] The coolant can be adapted such that, in the case of a malfunction, it evaporates in the cooling heat exchanger at a temperature above the dew point of the air surrounding the electronic device. The aircraft cooling device can be adapted such that, in the case of a malfunction, the electronic device, because of the evaporating of the coolant in the cooling heat exchanger, has a temperature below the breakdown temperature of the electronic device.

[0019] The pump device can be arranged, in the direction of flow of the coolant, after the aircraft outer-shell heat exchanger and before the additional heat exchanger. The cooling heat exchanger is located after the additional heat exchanger in the direction of flow of the coolant. There can be a reservoir for equalizing a thermal expansion of the coolant and/or for replenishing coolant in the case of a leakage.

[0020] The invention also relates to a redundant aircraft electronics cooling system having a plurality of the previously described aircraft cooling devices, wherein the plurality of aircraft cooling devices are adapted to cool the same electronic device. As a result, a particularly fail-safe cooling of the electronic device is achieved, such that the safety of the aircraft is further increased.

[0021] The invention is now explained with reference to the appended FIGURE, which is a schematic representation of an aircraft cooling device according to the invention.

[0022] An aircraft **11** has an electronic device **2**. The electronic device **2** can be located, for example, together with a plurality of electronic devices **2** in a switchgear cabinet (not shown). The electronic device **2** is thermally coupled to a cooling heat exchanger **3**. This thermal coupling can be effected by means of a gas, a liquid or a mechanical connection. The cooling heat exchanger **3** is connected to a supply line **10**, which supplies liquid coolant to the cooling heat exchanger **3**. The supplied coolant cools the electronic device **2** as a result of the previously described thermal coupling. During normal operation, the coolant enters the output line **1** as a liquid coolant, and is supplied as a liquid coolant to the aircraft outer-shell heat exchanger **7**. There the coolant undergoes cooling, in that heat is removed from it and output to the environment of the aircraft. The coolant emerging from the aircraft outer-shell heat exchanger **7** enters a pump device **4**, which supplies the coolant back to the cooling heat exchanger **3** via an additional heat exchanger **7** and the supply line **10**. The coolant therefore passes through a closed circuit.

[0023] During normal operation, i.e. if the pump device **4** is functional, the coolant is permanently in a closed circulation loop. The temperature of the coolant upon entering the cooling heat exchanger, and therefore the temperature of the electronic device, can be set particularly easily by setting the pump power. The temperature of the electronic device **2** is preferably to have such a value that the temperature of the air surrounding the electronic device **2** is always above the dew point. Further, the temperature of the electronic device **2** must be lower than the breakdown temperature.

[0024] As mentioned previously, there is an additional heat exchanger **6** in the cooling circuit. If the aircraft **11** is on the ground, the external temperature can be so high that the aircraft outer-shell heat exchanger **7** cannot remove any heat, or cannot remove sufficient heat, from the coolant. In this case, the coolant is cooled partially or completely in the additional heat exchanger **6**, and it cannot, at least partially, flow through the aircraft outer-shell heat exchanger **7**. The additional heat exchanger **6** can be cooled by means of a liquid cooling system, for example a so-called cold bus, or by means of a cooling system having a cycle of compression, condensing and evaporation. An additional coolant supply **12** is effected if the temperature of the external air and/or the temperature of the coolant after emergence from the aircraft outer-shell heat exchanger **7** is above a threshold value. Consequently, cooling of the electronic device **2** can also be ensured on the ground. In the case of a low external temperature, for example during flight, the cooling of the coolant is effected in the aircraft outer-shell heat exchanger **7**. In this case, the additional coolant supply **12** to the additional heat exchanger can be omitted. It is also possible to provide a bypass valve (not shown) parallel to the additional heat exchanger **6**, which bypass valve is opened if the temperature of the external air and/or the temperature of the coolant after emergence from the aircraft outer-shell heat exchanger **7** is below a threshold value that ensures that the coolant circulating in the cooling circuit effects sufficient cooling of the electronic device **2**. The coolant can flow through both the aircraft outer-shell heat exchanger **7** and the additional heat exchanger **6** if the aircraft outer-shell heat exchanger **7** is unable to cool the coolant to a predefined setpoint value.

[0025] Further, the cooling circuit includes a reservoir **9** for equalizing a change in volume of the coolant and/or for replenishing coolant in the case of a leakage. In the embodiment represented, the reservoir **9** is located after the aircraft outer-shell heat exchanger **7** and before the additional heat exchanger **6**, in the direction of flow of the coolant. However, the reservoir **9** can also be located after the aircraft outer-shell heat exchanger **6** and before the cooling heat exchanger **3**, in the direction of flow of the coolant.

[0026] In the embodiment represented, the pump device **4** is located between the aircraft outer-shell heat exchanger **7** and the additional heat exchanger **6**, in the direction of flow of the coolant. The pump device can also be located between the additional heat exchanger **6** and the cooling heat exchanger **3**. At least one aircraft outer-shell heat-exchanger bypass valve **8** is connected parallel to the aircraft outer-shell heat exchanger **7**. The aircraft outer-shell heat-exchanger bypass valve **8** opens if the external temperature is so high that the coolant can no longer by cooled by the aircraft outer-shell heat exchanger **7**. This prevents the coolant from being heated by the aircraft outer-shell heat exchanger **7**. Heating of the coolant in the aircraft outer-shell heat exchanger **7** is undesirable, because in this case the additional heat exchanger **6** has to discharge more heat to the additional cooling system, so increasing the kerosene consumption.

[0027] The aircraft outer-shell heat-exchanger bypass valve **8** can be opened if the external temperature value falls below a value that results in the coolant being cooled to such an extent that the air surrounding the electronic device **2** is below the dew point. In this case, one portion of the coolant flows through the aircraft outer-shell heat exchanger **7** and another portion flows through the aircraft outer-shell heat-exchanger bypass valve **8**. Through control of the opening or through modulation of the aircraft outer-shell heat-exchanger bypass valve **8**, it is possible to control the temperature of the coolant supplied to the cooling heat exchanger **3**, which is thermally coupled to the electronic device **2**.

[0028] In the embodiment represented, the aircraft outer-shell heat-exchanger bypass valve **8** can open completely upon a first threshold value being exceeded, for example if the external temperature is too high, and open at least partially or be modulated upon a falling below a second threshold value, for example if the external temperature is too low. It is also possible, however, to provide two aircraft outer-shell heat-exchanger bypass valves, which each respond to a threshold value. Such a design is considered as equivalent.

[0029] As mentioned previously, during normal operation, for example if the pump device **4** is functional, the coolant is permanently in the liquid phase. The pump device **4** operates only as a pump for liquid coolant. The pump device **4** does not operate as a compressor, and during normal operation, for example if the pump device **4** is functional and there is sufficient cooling power, condensing and evaporating does not occur.

[0030] In the case of a breakdown of the pump device **4**, the temperature of the coolant in the cooling heat exchanger **3** rises. As a result, the coolant in the cooling heat exchanger can evaporate. The evaporating process produces, on the one hand, a positive pressure in the direction of the aircraft outer-shell heat exchanger **7** and the pump device **4** and, on the other hand, a negative pressure in the direction of the supply line **10** and the additional heat exchanger **6**. As a result, a pressure difference emerges at the pump device **4**. This pressure difference causes a pump-device by-pass valve **5** to be opened. The pump-device bypass valve **5** preferably has only mechanical components, so increasing its reliability. Preferably, the release pressure of the pump-device bypass valve can be set through a spring.

[0031] This embodiment, in the case of a functional pump device, also enables coolant to flow through the pump-device bypass valve **8** and past the pump device **7** if coolant evaporates in the cooling heat exchanger **3**, for example because of an increased cooling load. In this operating case, also, the at least one aircraft outer-shell heat-exchanger bypass valve **8** can operate as described previously.

[0032] In the case of a failed pump device **4**, the coolant **3** evaporates in the cooling heat exchanger and condenses in the aircraft outer-shell heat exchanger **7**. For this purpose, it is expedient for the output line **1** to be dimensioned with a larger cross-section, in order that sufficient gaseous coolant can be conveyed from the cooling heat exchanger **3** to the aircraft outer-shell heat exchanger **7**.

[0033] In the case of breakdown of the pump device **4**, the coolant circulates through the cooling circuit by natural convection. As a result, cooling of the electronic device during flight can be ensured, such that the latter can continue to be operated, so increasing the reliability and safety of the aircraft.

[0034] It is possible to provide two or more aircraft cooling devices, of substantially identical construction, which cool the same electronic device. An additional redundancy is thereby created, which further increases the reliability and safety of the aircraft.

[0035] The aircraft cooling device according to the invention has the advantage that use of a liquid coolant reduces the required installation space. Further, there is no need for a refrigerating machine, as in the prior art. In contrast to a cooling system having a gaseous coolant, the aircraft cooling device according to the invention does not require fans and air ducts of large cross-section. Consequently, the mass of the cooling system and the electric power consumption can be reduced, which simplifies installation in an aircraft and reduces the kerosene requirement. Further, the liquid coolant has the advantage that the temperature differences in the electronic device are reduced in comparison with a conventional gaseous coolant.

[0036] It is understood that a plurality of aircraft outer-shell heat-exchanger bypass valves **7**, which respond to the same temperature threshold value, can be provided in order to increase the reliability of the cooling system. It is also possible to provide a plurality of pump-device bypass valves **5**, such that the reliability of the aircraft cooling device is increased. It is also possible for each previously described component to be designed in a redundant manner, e.g. through parallel connection of two substantially identical components.

1-14. (canceled)

15. Method for cooling an electronic device in an aircraft, comprising the following steps:

circulating a coolant in a cooling circuit,

cooling the electronic device by means of the coolant, and,

in an aircraft outer-shell heat exchanger, emitting the heat taken up by the coolant, characterized in that, during normal operation, the coolant is permanently in a liquid phase and circulates in the coolant circuit by forced convection and, in the case of a malfunction and/or in the case of an increased cooling demand, the coolant evaporates, at least partially, during the cooling of the electronic device, condenses in the aircraft outer-shell heat exchanger, and circulates in the coolant circuit by natural convection.

16. Method according to claim **15**,

characterized in that the coolant is bypassed past the aircraft outer-shell heat exchanger, at least partially, if the temperature in the aircraft outer-shell heat exchanger exceeds a first threshold value.

17. Method according to claim **15**,

characterized in that the coolant is cooled case-by-case in an additional heat exchanger, which is cooled by an additional cooling system.

18. Method according to claim **15**,

characterized in that the coolant is bypassed past the aircraft outer-shell heat exchanger, at least partially, if the temperature in the aircraft outer-shell heat exchanger and/or the temperature of the coolant falls below a second threshold value.

19. Aircraft cooling device, comprising

a cooling heat exchanger adapted to cool an electronic device by means of a coolant, and

an aircraft outer-shell heat exchanger adapted to cool the coolant, wherein the cooling heat exchanger and the aircraft outer-shell heat exchanger are arranged in a closed coolant circuit,

characterized by a pump device, which, during normal operation, circulates coolant in the coolant circuit, wherein the aircraft cooling device is adapted and the coolant is selected such that, during normal operation, the liquid coolant is permanently in a liquid phase and, because of the pump device, circulates in the coolant circuit by forced convection and, in the case of a malfunction and/or in the case of an increased cooling demand, the coolant evaporates, at least partially, in the cooling heat exchanger during the cooling of the electronic device, condenses in the aircraft outer-shell heat exchanger, and circulates in the coolant circuit by natural convection.

20. Aircraft cooling device according to claim **19**,

characterized by at least one aircraft outer-shell heat-exchanger bypass valve, which is adapted to bypass the coolant past the aircraft outer-shell heat exchanger, at least partially, if the temperature in the aircraft outer-shell heat exchanger exceeds a first threshold value.

21. Aircraft cooling device according to claim **19**,

characterized by an additional heat exchanger, which is cooled case-by-case by an additional cooling system, wherein the additional heat exchanger is adapted such that the coolant of the coolant circuit is cooled in the additional heat exchanger if the additional heat exchanger is cooled by the additional cooling system.

22. Aircraft cooling device according to claim **19**,

characterized in that the at least one aircraft outer-shell heat-exchanger bypass valve is adapted to bypass the coolant past the aircraft outer-shell heat exchanger, at least partially, if the temperature in the aircraft outer-shell heat exchanger and/or the temperature of the coolant falls below a second threshold value.

23. Aircraft cooling device according to claim **19**,

characterized by a pump-device bypass valve, which is adapted to bypass the coolant past the pump device in the case of a malfunction of the pump device.

24. Aircraft cooling device according to claim **19**,

characterized in that the coolant is adapted such that, in the case of a malfunction, it evaporates in the cooling heat exchanger at a temperature above the dew point of the air surrounding the electronic device.

25. Aircraft cooling device according to claim **19**,

characterized in that the aircraft cooling device is adapted such that, because of the evaporating of the coolant in the cooling heat exchanger, a temperature below the break-down temperature of the electronic device prevails within the electronic device in the case of a malfunction.

26. Redundant aircraft electronics cooling system,

characterized by a plurality of aircraft cooling devices according to claim **19**, wherein the plurality of aircraft cooling devices is adapted to cool the same electronic device.

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