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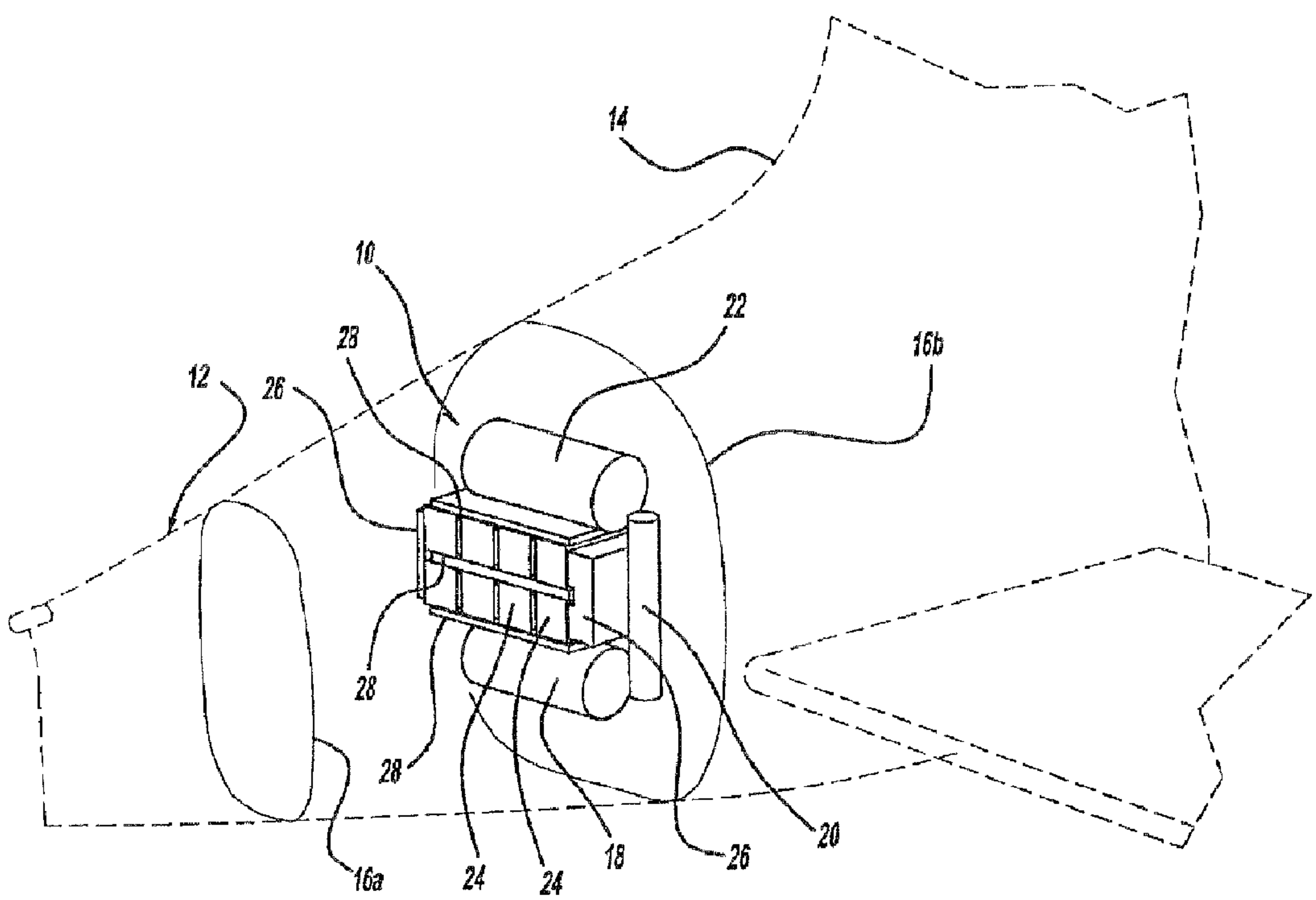
(54) Title: SOLID OXIDE FUEL CELL AS AUXILLIARY POWER SOURCE INSTALLATION IN TRANSPORT AIRCRAFT



(57) Abrégé/Abstract:
An auxiliary power unit (APU) for an aircraft utilizing solid oxide fuel cells for providing electrical power. The solid oxide electrolytes of the fuel cells allow for reformed fuel to provide a catalyst for oxygen migration. The auxiliary power unit, utilizing solid oxide fuel cells, can also power systems of the aircraft to produce water for use on the aircraft. Waste exhaust energy may be captured from the APU by a power recovery turbine which drives a compressor to provide aircraft cabin air under increased pressure to the fuel cell, thereby increasing system efficiency. The APU may provide all of the electricity to the aircraft allowing for more efficient aircraft engine design and a decrease in aircraft engine size. Furthermore, the fuel cell APU can reduce airport ramp noise and exhaust emissions.

SOLID OXIDE FUEL CELL AS AUXILIARY POWER SOURCE INSTALLATION IN TRANSPORT AIRCRAFT

ABSTRACT OF THE DISCLOSURE

[0045] An auxiliary power unit (APU) for an aircraft utilizing solid oxide fuel cells for providing electrical power. The solid oxide electrolytes of the fuel cells allow for reformed fuel to provide a catalyst for oxygen migration. The auxiliary power unit, utilizing solid oxide fuel cells, can also power systems of the aircraft to produce water for use on the aircraft. Waste exhaust energy may be captured from the APU by a power recovery turbine which drives a compressor to provide aircraft cabin air under increased pressure to the fuel cell, thereby increasing system efficiency. The APU may provide all of the electricity to the aircraft allowing for more efficient aircraft engine design and a decrease in aircraft engine size. Furthermore, the fuel cell APU can reduce airport ramp noise and exhaust emissions.

SOLID OXIDE FUEL CELL AS AUXILIARY POWER SOURCE INSTALLATION IN TRANSPORT AIRCRAFT

FIELD OF THE INVENTION

The present invention relates to an auxiliary power unit for an aircraft, and particularly relates to an auxiliary power unit utilizing fuel cells for an aircraft.

BACKGROUND OF THE INVENTION

It is generally known in the art to provide electricity for different functions of an aircraft such as environmental controls or systems and avionics. In addition, other electrical equipment or outlets on the aircraft, such as power outlets for passengers' use or electrical controls for controlling the aircraft, require electricity. Most often, the electricity for these systems is provided from the engines of the aircraft. The engines of the aircraft power generators which create electricity for use in these and other subsystems on the aircraft.

It is also known to provide an auxiliary power unit to provide electricity for use on an aircraft. The auxiliary power unit (APU) provides electricity in addition to, or supplementary to, the power produced by the engine generators. Generally, the APUs use gas turbine engines, similar to those of the engine, although smaller. An APU turbine is, therefore, limited in efficiency and creates gaseous emissions similar to the engines. The emissions of the APU at the airport are relatively high when compared to the engines. In addition, the APU reduces the overall fuel efficiency of the aircraft by converting jet fuel to electricity through internal combustion. Turbine APUs also reduce fuel efficiency of the aircraft.

Turbine APUs also create high levels of noise exterior to the aircraft. This requires ground crew to use extra hearing protection even when the engines of the aircraft are not running. This is generally because the turbine APUs are run at the airport to power aircraft systems prior to take off.

Therefore, it would be desirable to provide an APU which does not create additional noise and discomfort to the passengers or ground crew. In addition, it is desired to provide an efficient and clean source of electricity. It is also desired to use an APU that provides nearly all of the electricity required on an aircraft. Aircraft engines may be reduced in size and increased in efficiency by removing the need for the engines to provide compressed air and electricity to the aircraft.

SUMMARY OF THE INVENTION

The present invention relates to an auxiliary power unit (APU) for an aircraft. The auxiliary power unit, utilizing solid oxide fuel cells, creates electricity through the migration of oxygen ions. In particular, the solid oxide electrolytes of the fuel cells provide for reformed fuel to cause oxygen migration across the electrolyte. The auxiliary power unit, utilizing solid oxide fuel cells, can power systems of the aircraft and produce water for use in the aircraft. Furthermore, the auxiliary power unit can provide all of the electricity to the aircraft allowing for more efficient aircraft engine design and a decrease in aircraft engine size.

A first preferred embodiment of the present invention provides an aircraft comprising a fuselage, wherein the fuselage comprises a cabin defining a volume of air including oxygen, and an engine for powering the aircraft in flight. A fuel supply provides fuel to the engine. Electronic components are arranged in the aircraft to control a plurality of functions of the aircraft. A power unit, comprising a fuel cell, including a solid electrolyte provides a first source of electricity for the electronic components. The fuel supply supplies the fuel to the power unit so that the power unit produces electricity.

A second preferred embodiment of the present invention provides an auxiliary power unit for an aircraft. The auxiliary power unit comprises a solid oxide fuel cell including a solid oxide electrolyte. A fuel supply supplies fuel to the auxiliary power unit. A fuel reformer reforms the fuel from the fuel supply to constituent elements comprising carbon monoxide and molecular hydrogen for use in the solid oxide fuel cell. An air supply system provides an oxidizer, wherein oxidizer is oxygen to the solid oxide fuel cell. A turbine powered by the solid oxide fuel cell is adapted to provide power to the oxygen supply system. The solid oxide fuel cell is adapted to allow the transport of oxygen ions from the oxygen supply system to combine with the reformed fuel to produce electricity.

The present invention also provides for a method of providing power to an aircraft. The method involves providing a solid oxide fuel cell comprising a solid oxide electrolyte, providing a fuel to the solid oxide fuel cell, and providing an oxidizer to the solid oxide fuel cell. Electricity is produced by passing the oxidizer through the solid oxide electrolyte. The method also involves powering a reclamation system with thermal energy from the solid oxide fuel cell to provide the oxidizer to the solid oxide fuel cell.

In accordance with one aspect of the invention, there is provided a method for providing auxiliary power in an aircraft. The method involves producing reformed fuel from fuel used to power engines of the aircraft and compressed air from a cabin of the aircraft. The method further involves causing a fuel cell to facilitate a chemical reaction in which oxygen and the reformed fuel is converted into electrical energy and excess heat, and coupling the electrical energy to at least one electrical system of the aircraft. The method also involves driving a turbine with the excess heat, and compressing air from the cabin of the aircraft using a compressor driven by the turbine, to produce the compressed air used for producing the reformed fuel.

The fuel cell may produce an exhaust, and the method may further involve separating water from the exhaust to enable the water to be used onboard the aircraft.

The method may involve powering a water separator using the turbine.

The method may involve supplying oxygen to the fuel cell.

Supplying oxygen may involve supplying at least one of compressed cabin air and reformed water to the fuel cell.

Producing reformed fuel may involve producing reformed fuel that includes excess fuel sufficient to resist corrosion in electrodes of the fuel cell.

Producing reformed fuel may involve producing reformed fuel that includes about **2** to about **3** percent excess fuel.

The method may further involve pressurizing the fuel cell.

Pressurizing may involve pressurizing the fuel cell with the compressed air.

Pressurizing may involve pressurizing the fuel cell to a pressure of between about **20** pounds per square inch and about **30** pounds per square inch.

The method may further involve preheating at least one of the fuel used to power engines of the aircraft, the compressed air and the oxygen.

In accordance with another aspect of the invention, there is provided an auxiliary power apparatus for an aircraft. The apparatus includes a processor system operably configured to produce reformed fuel from fuel used to power engines of the aircraft and compressed air from a cabin of the aircraft. The apparatus further includes a fuel cell operable to facilitate a chemical reaction in which oxygen and the reformed fuel is converted into electrical energy and excess heat. The apparatus also includes means for coupling the electrical energy to at least one electrical system of the aircraft. The apparatus further includes a turbine driven by the excess heat, and a compressor driven by the turbine for compressing air from the cabin of the aircraft to produce the compressed air for use by the processor system.

The fuel cell may produce an exhaust, and may further include a water separator operably configured to separate water from the exhaust to enable the water to be used on the aircraft.

The water separator may be powered by the turbine.

The apparatus may further include a pressure vessel. The processor system and the fuel cell may be enclosed in the pressure vessel.

The fuel cell may include a solid oxide fuel cell.

The apparatus may further include an oxygen source for supplying oxygen to the fuel cell.

The oxygen source may include at least one of compressed cabin air and reformed water.

The fuel cell may include electrodes, and the processor may be operably configured to produce reformed fuel that includes excess fuel sufficient to resist corrosion in the electrodes.

The processor system may be operably configured to produce reformed fuel that includes about **2** to about **3** percent excess fuel.

The processor system may include an air preheat system operably configured to preheat at least one of the fuel used to power engines of the aircraft, the compressed air and the oxygen.

In accordance with another aspect of the invention, there is provided an apparatus for providing auxiliary power in an aircraft. The apparatus includes means for producing reformed fuel from fuel used to power engines of the aircraft and compressed air from a cabin of the aircraft. The apparatus further includes a fuel cell operably configured to facilitate a chemical reaction in which oxygen and the reformed fuel is converted into electrical energy and excess heat. The apparatus also includes means for coupling the electrical energy to at least one electrical system of the aircraft, and a turbine driven by the excess heat. The apparatus further includes means driven by the turbine for compressing air from the cabin of the aircraft, to produce the compressed air used for producing for the reformed fuel.

Further areas of applicability of the present invention will become apparent from the detailed description provided hereinafter. It should be understood that the detailed description and specific examples, while indicating the preferred embodiment of the invention, are intended for purposes of illustration only and are not intended to limit the scope of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will become more fully understood from the detailed description and the accompanying drawings, wherein:

Figure **1** is a schematic view of an auxiliary power unit according to the present invention placed in the tail section of an aircraft;

Figure **2** is a diagrammatic view of an auxiliary power unit placed in an aircraft including electrical transmission lines to various aircraft portions;

Figure **3** is a schematic view of a simplified auxiliary power unit including fuel stacks according to a first embodiment of the present invention; and

Figure **4** is detailed schematic view of an auxiliary power unit as illustrated in Figure **3**.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The following description of the preferred embodiment(s) is merely exemplary in nature and is in no way intended to limit the invention, its application, or uses. Although the following description describes solid oxide fuel cells, it is understood that this is merely exemplary of fuel cell types which may be used as auxiliary power units in aircraft.

With reference to Figure **1**, an auxiliary power unit **10** for an aircraft **12** is shown. The auxiliary power unit (APU) **10** utilizes fuel cells and is generally included in a tail section **14** of the aircraft **12**. More particularly, the APU **10** is generally placed within an envelope defined by a first cross-sectional area **16**a and a second cross-sectional area **16**b within the tail section **14**.

The APU **10**, utilizing fuel cells, generally includes a water sump **18**, a recirculation plenum **20** and a heat exchanger complex **22**. These surround a fuel cell stack **24** which is abutted by air manifolds **26** and intermingled with fuel manifolds **28**. These portions generally define the APU **10** and will be discussed in greater detail herein.

With continuing reference to Figure **1** and further reference to Figure **2**, the APU **10** is placed within the aircraft **12** to provide auxiliary power to the aircraft **12** and its electronic components. As discussed above, the APU **10** is generally placed within a tail section **14** of the aircraft **12**. The APU **10** provides electricity to either charge a battery **30** or to power various electronic components through a direct current (DC) power unit **32**. Alternatively, the APU **10** output may be converted to an alternating current (AC) with an AC converter **34**. The electricity is transmitted to electrical components through transmission lines **35**. The electronic components include an electric starter **36** for an engine **38** to assist in initial start-up. Other electronic components include avionics such as those to control the wing flaps **40**. Power can also be routed to gear lift motors **48** to power a gear lift **50** to raise and lower a landing gear **51**. Also electricity can be routed to environmental control systems **52** to power the environmental systems, such as air conditioning and air recirculation subsystems. Therefore, the APU **10** can provide power to all subsystems of the aircraft **12** which require electricity through the electrical transmission lines **35**, while unneeded power is stored in the battery **30** until it is required.

If the APU **10** is not intended to provide all of the power needed for the aircraft **12**, then a generator **42** is implemented and powered by the engines **38**. Power can then be diverted from the generator **42** and controlled by AC regulator **44**, or DC power can be provided with a DC unit **46**. It will be understood that the starter **36** and the generator **42** may be the same component depending upon whether the single component is driving or being driven by the engine **38**. It will also be understood that the APU **10** can be designed in such a way as to provide all electrical power necessary for powering all the electrical subsystems on the aircraft **12**. With the appropriate APU **10**, generators **42**, which use part of the power provided by the engines **38** to create additional electricity, may not be necessary for normal flight.

With reference to Figure **3**, the APU **10** preferably includes planar solid oxide fuel cell stacks (SOFC) **24**. Although described in greater detail below, the SOFCs **24** utilize a hydrocarbon fuel and oxygen to produce electricity. The SOFCs **24** are completely solid state with no moving mechanical parts and do not require pure hydrogen to produce electricity, as do some other fuel cell technologies. The electricity can be communicated directly as DC power or converted to AC with the AC converter **34**, alternatively electricity can be stored in the battery **30**. A voltage stepper may also be provided to regulate the electricity produced by the APU **10**. An integrated fuel processor and air preheat system (processor system) **56** is provided to first process and reform a fuel from a fuel supply **58** which is pumped to the processor system **56** with a fuel pump **59**, and preheat air before they enter the SOFCs **24**.

Because the APU **10** is not **100%** efficient, excess heat is produced from energy which is not converted into electricity. The SOFCs **24** also operate optimally only under pressure higher than ambient. This excess energy is provided through waste energy line **60** to a turbine **62**. The turbine **62** powers a compressor **64** to compress air from the cabin **66** to provide compressed air to the processor system **56**. It is understood that air contains oxygen; therefore the compressor also supplies oxygen to the processor system and the SOFC **24**. After fuel from the fuel supply **58** and air from the cabin **66** is compressed, the reformed fuel is provided to the SOFCs **24** through a reformed fuel line **68** while the air is provided through a compressed air line **70**. An SOFC system controller **72** controls the operation of the APU **10**. In particular, the SOFC system controller **72** can control the amount of fuel or air being provided to the SOFC **24** so that an efficient production of energy is created.

The turbine **62**, powered by the waste energy through the waste energy line **60**, can also power other systems. In particular, the turbine **10** can power a water separator **74**. Exhaust from the APU **10** is provided to the water separator **74** through an exhaust line **76**. The exhaust from the APU **10** includes combustion materials from the SOFC **24**, which is essentially combustion products from the hydrocarbon fuel and the cabin air, which are essentially carbon dioxide and water. Therefore, the water separator **74** can separate the water to provide it to a water container **78**. Therefore, even though the APU **10** may not be **100%** efficient in producing electricity, a greater operational or overall efficiency can be achieved by using the excess heat energy and exhaust from the APU **10** to power the turbine **62** to separate water from the exhaust, which may be used on the aircraft **12**.

With reference to Figure **4**, the APU **10** is shown in greater detail. The APU **10** may be enclosed in a pressure vessel **79**. The pressure vessel **79** encloses at least the SOFCs **24** and the processor system **56**. Among other things, the pressure vessel **79** decreases the chance of gas leakage due to pressure differentials during operation. In addition, the pressure vessel **79** reduces the mechanical strength requirements of both the SOFC **24** and the processor system **56** for installation into an aircraft **12**.

The SOFC **24** includes a plurality of a planar solid oxide fuel cell **80**, nevertheless only one is illustrated for clarity. Although only planar solid oxide fuel cells **80** are described herein, it will be understood the SOFC **24** may be in any appropriate arrangement. Each fuel cell **80** may be surrounded by a barrier **82** which is impermeable to the oxidizer and fuel which are provided to the fuel cell **80**. This creates discrete fuel cells **80** which may be placed in series.

Each fuel cell **80** also includes a solid oxide layer **90** with a reformed fuel layer **92** adjacent the solid oxide layer **90** and an oxidizer layer **94** adjacent the solid oxide layer **90**, but opposite the reformed fuel layer **92**. The solid oxide layer **90** provides a physical barrier between the reformed fuel layer **92** and the oxidizer layer **94**. The solid oxide layer **90** also performs the function of an electrolyte in the fuel cell **80**. In addition, a first electrode **96**, which is generally porous, is disposed adjacent one side of the solid oxide layer **90**, for example in the fuel layer **92**. A second electrode **98**, also generally porous, is disposed adjacent a second side of the solid oxide layer **90**, for example in the oxidizer layer **94**. Generally, the first and second electrodes **96** and **98** are porous and span the space between the barrier **82** and the solid oxide layer **90**. In this way the oxidizer layer **94** and the fuel layer **92** flow through the respective electrodes **96** and **98**.

The solid oxide layer **90** may be any appropriate solid electrolyte such as a metal oxide. One exemplary material is zirconium oxide that has been doped with a rare earth metal. Exemplary rare earth metals include yttrium, scandium, or cerium. Other exemplary metal oxides also include calcium oxide. It is preferred to have the dopant comprise between about **5**% and about **20**% by weight of the solid oxide layer **90**. It will be understood, however, that any appropriate solid oxide may be used in the SOFC **24**.

It will be understood that the SOFC **24** may contain any number of solid oxide layers **90** and a limited number is illustrated simply for clarity. A plurality of the fuel cells **80** are placed adjacent one another to form the SOFC **24**. It will also be understood that the configuration of the SOFC **24** may compromise any appropriate configuration to provide the APU **10**.

The reformed fuel is reformed in the processor system **56** to break the fuel into substantially carbon monoxide, H_2, or hydrogen atoms which are components of hydrocarbon fuels. Although the processor system **56** is described herein using steam, it will be understood that other reformation systems may be used. For example, an auto thermal, thermal decomposition, or partial oxidation techniques may also be used to reform the fuel for the APU **10**. The constituents of the reformed fuel are the fuel for the SOFC **24** and are present in the fuel layer **92**. The oxidizer layer **94** includes air from the cabin **66** that has been compressed to concentrate the oxygen present in air in the cabin **66**. The oxygen in the air is the oxidizer in oxidizer layer **94**. It will be understood, however, that another oxidizer or oxygen from a different source may be used in oxidizer layer **94**. The solid oxide layer **90** allows the oxygen ions present in the oxidizer layer **94** to transport through the solid oxide layer **90** to combine with the fuel in the fuel layer **92**. The migration of oxygen ions across the solid oxide layer **90** produces, by creating an electrical potential, electricity. The potential is created between the two electrodes **96**, **98** in the fuel cell **80**. In the fuel layer **92** the oxygen combines with carbon monoxide, H_+, or H_2 to form CO_2 and H_2O.

The heat exchanger complex **22**, in the processor system **56**, may further include a first heat exchanger **22**a and a second heat exchanger **22**b. A recirculation plenum **20** is also diagrammatically shown to illustrate the capability of the APU **10** to reuse resources such as water or air. The water sump **18** provides water to the system. Water provided in the water sump **18** may either come from the water supply **78**, from the water separator **74**, or from an onboard water supply. A jet pump **100** pumps water from the water sump **18** into the processor system **56**. The first heat exchanger **22**a heats the water and jet fuel to bring them up to the temperature necessary to vaporize the liquid mixture into gaseous form. The second heat exchanger **22**b further heats the steam and jet fuel mixture before entry into the mixing plenum **104**. The mixing plenum **104** allows for a remix of the steam and jet fuel mixture from the first heat exchanger **22**a to the second heat exchanger **22**b ensuring that a proper mix has been accomplished before entry into the steam reformer **102**. This helps to prevent fuel coking at too high of a temperature and to ensure that enough steam is produced to prevent fuel coking.

The steam reformer **102** breaks the fuel into simpler molecular components to provide the proper components to the SOFCs **24**. A preheater **106** provides additional energy to the steam reformer **102** and to the second heat exchanger **22**b to ensure that the water is converted to steam for use in the steam reformer **102**. Additionally, fuel and air may be transferred between the recirculation plenum **20** and the preheater **106** to allow for an initial heat up of the SOFCs **24** for initial start-up.

After the fuel has been reformed in the steam reformer **102** it travels through a reformed fuel line **108** to be fed into the SOFCs **24**. A valve **110** controls the flow of reformed fuel through the reformed fuel line **108** and air through an air line **112**. The valve **110** is controlled by the SOFC system controller **72** to create the proper mix of fuel and air in the SOFC **24** to ensure the most efficient power production.

The SOFCs **24** work most efficiently when they are between about **600** ^{o}C. and **1000** ^{o}C (about **1112** ^{o}F and about **1832** ^{o}F). Therefore, if the SOFCs **24** have cooled due to not being operated or because of a cool environment, they are most efficient after being first heated. The preheater **106** assists in heating the SOFCs **24** to ensure that they reach the optimal operating temperature quickly. Fuel is supplied to the preheater **106** from the fuel supply **58** to be used to heat the water for use in the steam reformer **102**. Therefore, the fuel and oxygen may also be heated before entering the SOFC **24**.

Though any appropriate configuration may be used to provide the fuel cell **80** of the APU **10**, the solid oxide fuel cells **80** are preferred for aircraft because fuel cells **80** do not require pure hydrogen for proper operation. In particular, the reformed jet fuel from the jet fuel supply **58**, which is already provided on an aircraft **12**, can be used to provide the hydrogen and carbon monoxide to cause the migration of oxygen ions across the solid oxide layer **90**. Generally, preferred are carbon monoxide and atomic hydrogen, but molecular hydrogen is also usable. Therefore, rather than requiring the inclusion of another fuel source, particularly a highly explosive hydrogen fuel source, reformed jet fuel can be used to power the SOFCs **24**. Furthermore, the APU **10** allows for the recirculation and re-use of cabin air from the cabin **66** to provide the oxygen for the SOFCs **24**. Again, rather than providing a pure oxygen source, compressed air from the cabin **66** or reformed water may be used to provide the oxygen source for the SOFCs **24**.

Furthermore, the turbine **62** of the APU **10** is part of a reclamation system. The reclamation system allows for the reuse of waste thermal energy produced by the APU **10** to power a turbine to reform exhaust produced by the APU **10**. The turbine **62** powers the compressor **64** to convert the exhaust into usable water. In particular, the exhaust of the APU **10** using SOFCs **24** generally consists substantially only of H_2O and CO_2. Therefore, the H_2O may be separated, with the water separator **74** and stored in the water container **78**, to provide water for use in the aircraft **12**. Furthermore, the water can be used for other uses in the aircraft **12** such as general humidity control in the environment control systems **52** and other gray water uses.

An SOFC **24** is theoretically approximately **45-55**% efficient. Due to certain inefficiencies and other physical constraints, however, the APU **10** is generally approximately **30-40**% efficient. It is this waste thermal energy which provides the energy required to power the turbine **62** to power the compressor **64**. The turbine **62** is an expansion turbine which uses hot gases to expand through turbine blades to spin the blades. This provides kinetic energy for things such as powering the compressor **64**.

It will be understood that varying configurations of the APU **10** can be used to provide different amounts of electricity to aircraft **12**. Therefore, the aircraft **12**, where the APU **10** only provides a portion of the electricity to the aircraft **12**, especially when the aircraft **12** is on the ground, can be provided. When the APU **10** is provided in the aircraft **12**, especially when the aircraft **12** is in flight, the engines **38** may power a generator **42** to provide electricity necessary for the aircraft **12**. During this time, the APU **10** can charge the battery **30** to provide additional power for later use.

The APU **10** can also be designed to provide all the electricity at all times so that the engines **38** never need to provide electricity to the aircraft **12**. In this way, the engines **38** can be decreased in size and increased in efficiency since they will not need to power generators **42** to provide electricity. Therefore, the overall efficiency of the components of the aircraft **12** can be increased by using the APU **10** to provide all the electricity necessary to power the electrical subsystems of the aircraft **12**.

It will also be understood that the foregoing description of the preferred embodiments is merely exemplary. For example, the processor system **56** could be integrated further into the SOFCs **24**. Therefore, rather than having separate components separated physically from the SOFCs **24**, the processor system **56** can be designed so that it is interspersed with the SOFCs **24**. Furthermore, the size or number of SOFCs **24** can be augmented depending upon the amount of electricity required for a particular application.

The mixture of the fuel in the SOFC **24** may include between about **2-3%** excess fuel to resist corrosion of the electrodes **96** and **98**. In addition, the SOFC **24** is preferably pressurized to a pressure between about **20** and about **30** psi to increase efficiency of the SOFCs **24**. The air from the cabin **66**, which is compressed by the compressor **64**, may both pressurize and cool the

SOFCs **24**. Generally, the greatest electrical density is formed on the SOFC **24** when the pressure is between about **20** psi and about **30** psi. Therefore, not only does the air provided by the compressor provide oxygen to the oxidizer layer **94**, it also cools the SOFCs **24** by pulling air through the heat exchangers **97**, **98**. This air can also be used to pressurize the SOFCs **24** to increase the electrical density of the SOFCs **24**.

It will also be understood that the solid oxide layers **90** may be formed from any appropriate material such as those that are doped with calcium oxide and scandium oxide. The solid oxide layer **90** provides the electrolyte that ions of oxygen may transfer through. The solid oxide layer **90** also separates the reformed fuel layer **92** from the oxidizer layer **94**. Therefore, the oxygen ions must cross through the solid oxide layer **90**, thereby creating a charge differential and the flow of electricity. Although the SOFC **24** has been described herein, it will be understood that various other fuel cells may be used. Generally, a fuel cell causes the migration of an oxidizer, such as oxygen ions, across an electrolyte to produce electricity. Other possible fuel cells include PEM fuel cells, which require hydrogen ions as the fuel source alone and carbon must be scrubbed from the fuel before entering the fuel layer **92**.

The APU **10** of the present invention thus provides an efficient and quiet source of electricity to the aircraft **12**. In particular, the APU **10** is entirely solid state. Therefore, the APU **10** will not produce any vibrations or noise to disturb the passengers in the cabin **66**. Additionally, the APU **10**, using SOFCs **24**, is theoretically approximately between about **30** and about **60** percent efficient. Even though physical and mechanical constraints presently provide APUs **10** which are generally between about **30** and about **40** percent efficient. Turbines are generally between about **20** and about **30** percent efficient. Therefore, the APU **10**, according to the present invention, provides electricity to the aircraft **12** at an increased efficiency of between about **10** and about **20** percent. This increases overall fuel efficiency of the aircraft **12** and provides a cleaner source of electricity to the aircraft **1**

The APU **10** also assists in decreasing undesirable emissions such as nitrous oxide emissions. Because nitrous oxides are generally produced at elevated temperatures, generally above **1500** °C, substantial amounts of nitrous oxides are not produced in the APU **10**. This is because the SOFC **24** operates at a temperature generally below about **1400** °C. Therefore, nitrous oxide emissions are substantially eliminated and much below the emissions of gas turbine power units.

The description of the invention is merely exemplary in nature and, thus, variations that do not depart from the gist of the invention are intended to be within the scope of the invention. Such variations are not to be regarded as a departure from the spirit and scope of the invention.

THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. A method for providing auxiliary power in an aircraft, the method comprising:

   producing reformed fuel from fuel used to power engines of the aircraft and compressed air from a cabin of the aircraft;

   causing a fuel cell to facilitate a chemical reaction in which oxygen and said reformed fuel is converted into electrical energy and excess heat;

   coupling said electrical energy to at least one electrical system of the aircraft;

   driving a turbine with said excess heat; and

   compressing air from the cabin of the aircraft using a compressor driven by said turbine, to produce said compressed air used for producing said reformed fuel.

2. The method of claim 1 wherein said fuel cell produces an exhaust and further comprising separating water from said exhaust, to enable said water to be used onboard the aircraft.

3. The method of claim 2 further comprising powering a water separator using said turbine.

4. The method of any one of claims 1 to 3 further comprising supplying oxygen to said fuel cell.

5. The method of claim **6** wherein supplying said oxygen comprises supplying at least one of compressed cabin air and reformed water to said fuel cell.

6. The method of any one of claims **1** to **5** wherein producing reformed fuel comprises producing reformed fuel that includes excess fuel sufficient to resist corrosion in electrodes of said fuel cell.

7. The method of claim **6** wherein producing reformed fuel comprises producing reformed fuel that includes about **2** to about **3** percent excess fuel.

8. The method of any one of claims **1** to **7** further comprising pressurizing said fuel cell.

9. The method of claim **8** wherein pressurizing comprises pressurizing said fuel cell with said compressed air.

10. The method of claim **9** wherein pressurizing comprises pressurizing said fuel cell to a pressure of between about **20** pounds per square inch and about **30** pounds per square inch.

11. The method of any one of claims **1** to **10** further comprising preheating at least one of said fuel used to power engines of said aircraft, said compressed air and said oxygen.

12. An auxiliary power apparatus for an aircraft, the apparatus comprising:

a processor system operably configured to produce reformed fuel from fuel used to power engines of the aircraft and compressed air from a cabin of the aircraft;

a fuel cell operable to facilitate a chemical reaction in which oxygen and said reformed fuel is converted into electrical energy and excess heat;

means for coupling said electrical energy to at least one electrical system of the aircraft;

a turbine driven by said excess heat; and

a compressor driven by said turbine, for compressing air from the cabin of the aircraft to produce said compressed air for use by said processor system.

13. The apparatus of claim **12** wherein said fuel cell produces an exhaust and further comprising a water separator operably configured to separate water from said exhaust, to enable said water to be used on the aircraft.

14. The apparatus of claim **13** wherein said water separator is powered by said turbine.

15. The apparatus of any one of claims **12** to **14** further comprising a pressure vessel and wherein said processor system and said fuel cell are enclosed in said pressure vessel.

16. The apparatus of any of claims **12** to **15** wherein said fuel cell includes a solid oxide fuel cell.

17. The apparatus of any one of claims **12** to **16** further comprising an oxygen source for supplying oxygen to said fuel cell.

18. The apparatus of claim **17** wherein said oxygen source comprises at least one of compressed cabin air and reformed water.

19. The apparatus of any one of claims **12** to **18** wherein said fuel cell comprises electrodes and wherein said processor is operably configured to produce reformed fuel that includes excess fuel sufficient to resist corrosion in said electrodes.

20. The apparatus of claim **19** wherein said processor is operably configured to produce reformed fuel that includes about **2** to about **3** percent excess fuel.

21. The apparatus of any one of claims **12** to **20** further comprising means for pressurizing said fuel cell.

22. The apparatus of claim **21** wherein said means for pressurizing comprises said compressed air.

23. The apparatus of claim **21** wherein said means for compressing is operably configured to produce compressed air operable to pressurize said fuel cell to a pressure of between about **20** pounds per square inch and about **30** pounds per square inch.

24. The apparatus of any one of claims **12** to **23** wherein said processor comprises an air preheat system operably configured to preheat at least one of said fuel used to power engines of the aircraft, said compressed air and said oxygen.

25. An apparatus for providing auxiliary power in an aircraft, the apparatus comprising:

means for producing reformed fuel from fuel used to power engines of the aircraft and compressed air from a cabin of the aircraft;

a fuel cell operably configured to facilitate a chemical reaction in which oxygen and said reformed fuel is converted into electrical energy and excess heat;

means for coupling said electrical energy to at least one electrical system of the aircraft;

a turbine driven by said excess heat; and

means driven by said turbine for compressing air from the cabin of the aircraft, to produce said compressed air used for producing for said reformed fuel.

26. The apparatus of claim **25** wherein said fuel cell produces an exhaust and further comprising means for separating water from said exhaust, to enable said water to be used onboard the aircraft.

27. The apparatus of claim **26** wherein said means for separating water from said exhaust comprises a water separator driven by said turbine.

28. The apparatus of any one of claims **25** to **27** further comprising means for supplying oxygen to said fuel cell.

29. The apparatus of claim **28** wherein said means for supplying said oxygen comprises means for supplying at least one of compressed cabin air and reformed water to said fuel cell.

30. The apparatus of any one of claims **25** to **29** wherein said fuel cell comprises electrodes and wherein said means for producing reformed fuel is operably configured to produce reformed fuel that includes excess fuel sufficient to resist corrosion in said electrodes.

31. The apparatus of claim **30** wherein said means for producing reformed fuel is operably configured to produce reformed fuel that includes about **2** to about **3** percent excess fuel.

32. The apparatus of any one of claims **25** to **31** further comprising means for pressurizing said fuel cell.

33. The apparatus of claim **32** wherein said means for pressurizing said fuel cell comprises means for pressurizing said fuel cell using said compressed air.

34. The apparatus of claim **33** wherein said means for pressurizing is operably configured to pressurize said fuel cell to a pressure of between about **20** pounds per square inch and about **30** pounds per square inch.

35. The apparatus of any one of claims **25** to **34** further comprising means for preheating at least one of said fuel used to power engines of the aircraft, said compressed air and said oxygen.

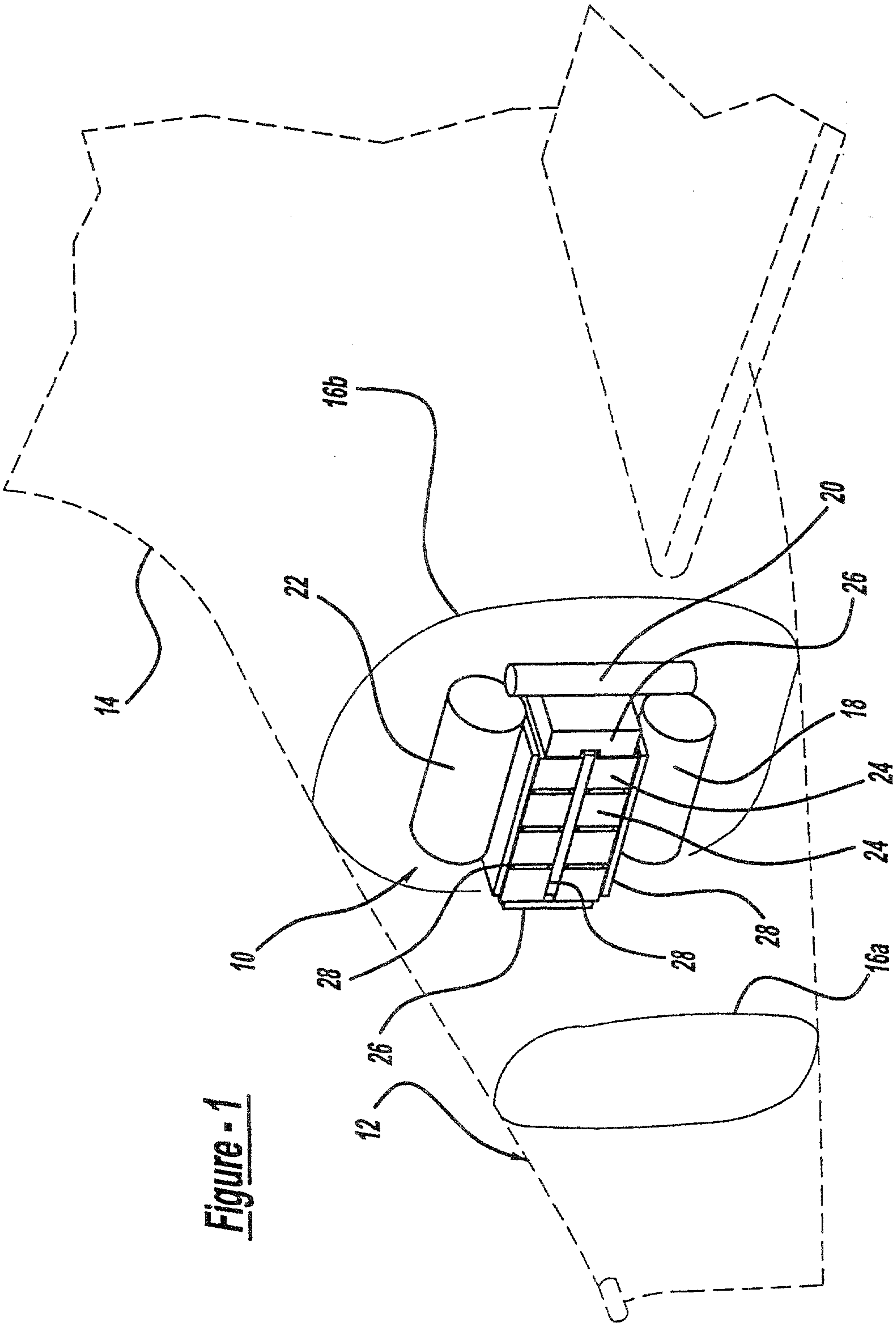
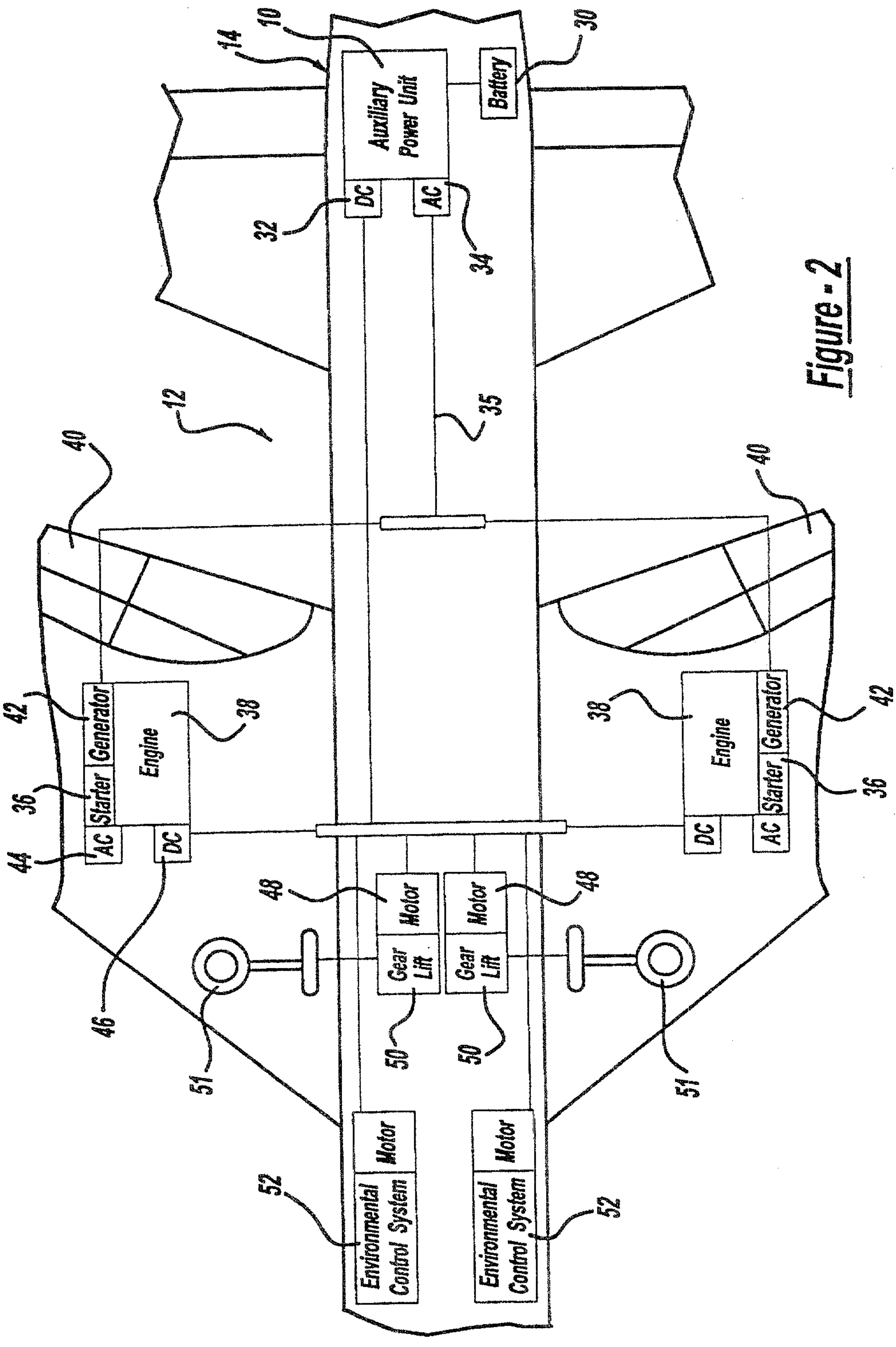


Figure - 1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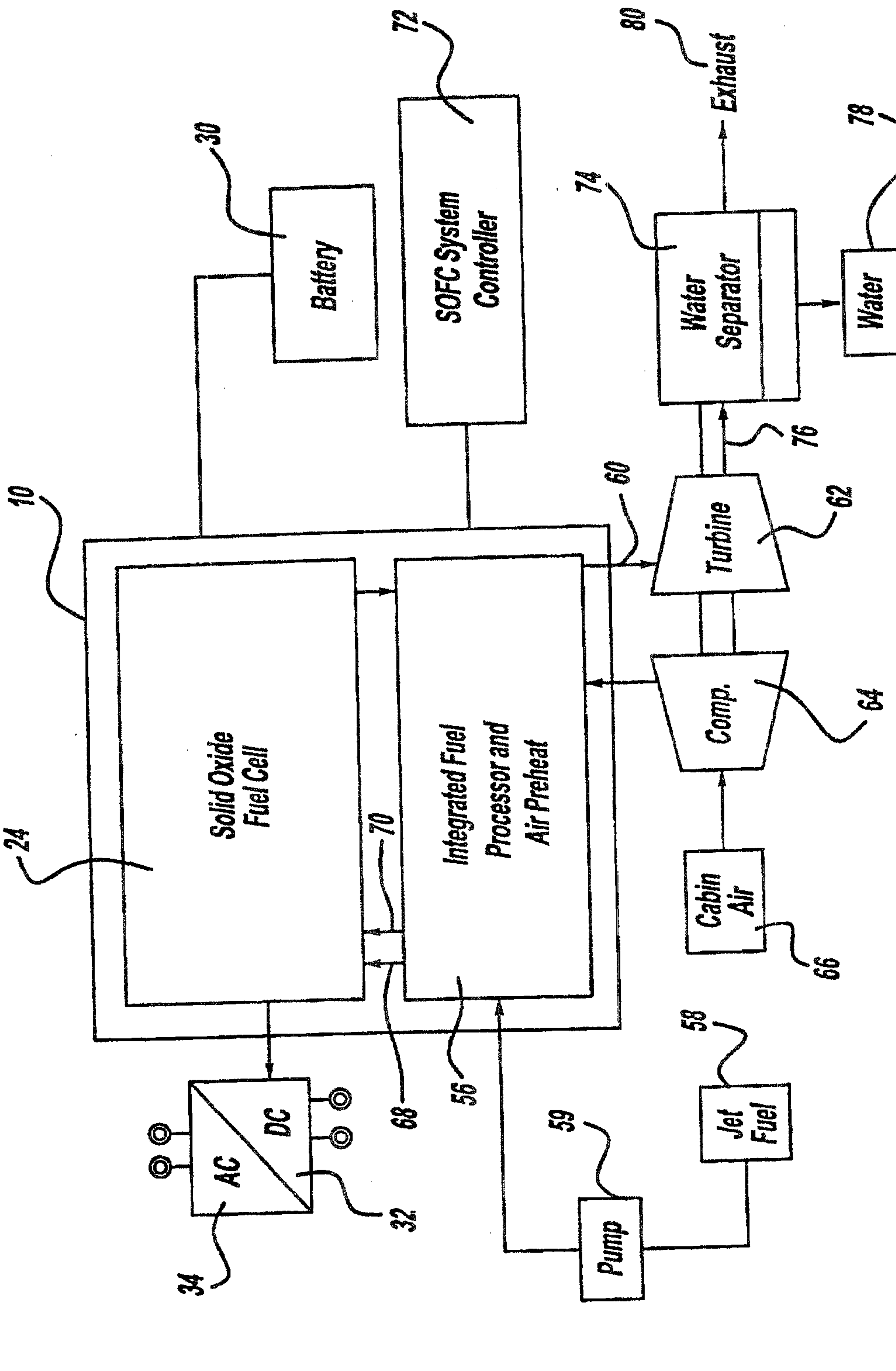
14
Auxiliary Power Unit
Battery
30
DC
32
AC
34
35
12
40
40
Generator
42
Starter
36
Engine
38
AC
44
DC
46
Engine
38
Generator
42
Starter
36
DC
AC
Motor
48
Motor
48
Gear Lift
50
Gear Lift
50
51
51
Environmental Control System
Motor
52
Environmental Control System
Motor
52

Figure - 2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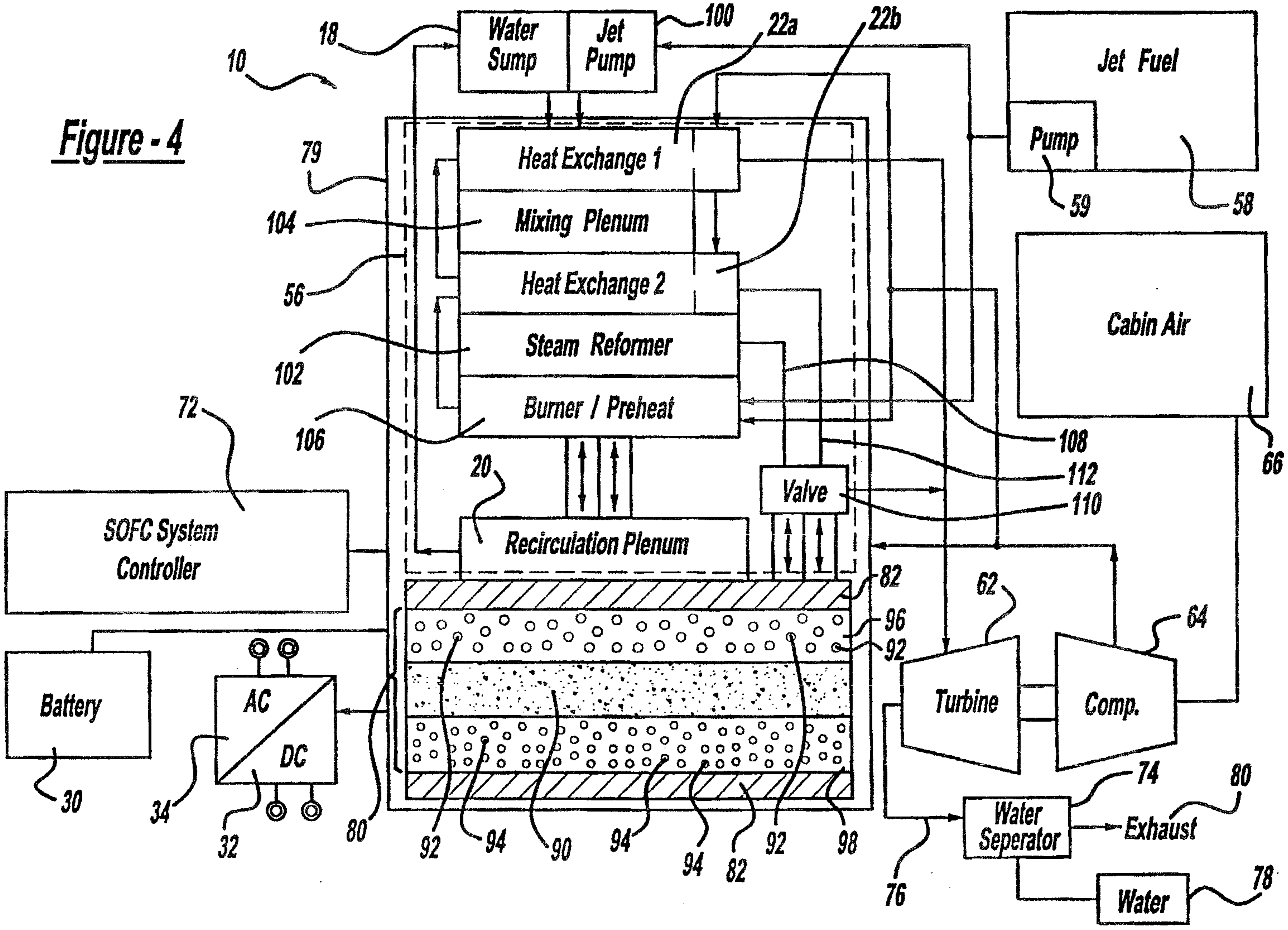
24
Solid Oxide Fuel Cell
70
Integrated Fuel Processor and Air Preheat
68
56
AC
DC
34
32
30
Battery
72
SOFC System Controller
60
Turbine
62
Comp.
64
Cabin Air
66
76
Water Separator
74
Exhaust
80
Water
78
Pump
59
Jet Fuel
58

Figure - 3

Figure - 4



10
18
Water Sump
Jet Pump
100
22a
22b
Jet Fuel
Pump
59
58
79
Heat Exchange 1
Mixing Plenum
104
56
Heat Exchange 2
Steam Reformer
102
Burner / Preheat
106
Cabin Air
66
108
112
110
72
20
Valve
SOFC System Controller
Recirculation Plenum
82
62
64
96
92
Battery
AC
DC
Turbine
Comp.
30
34
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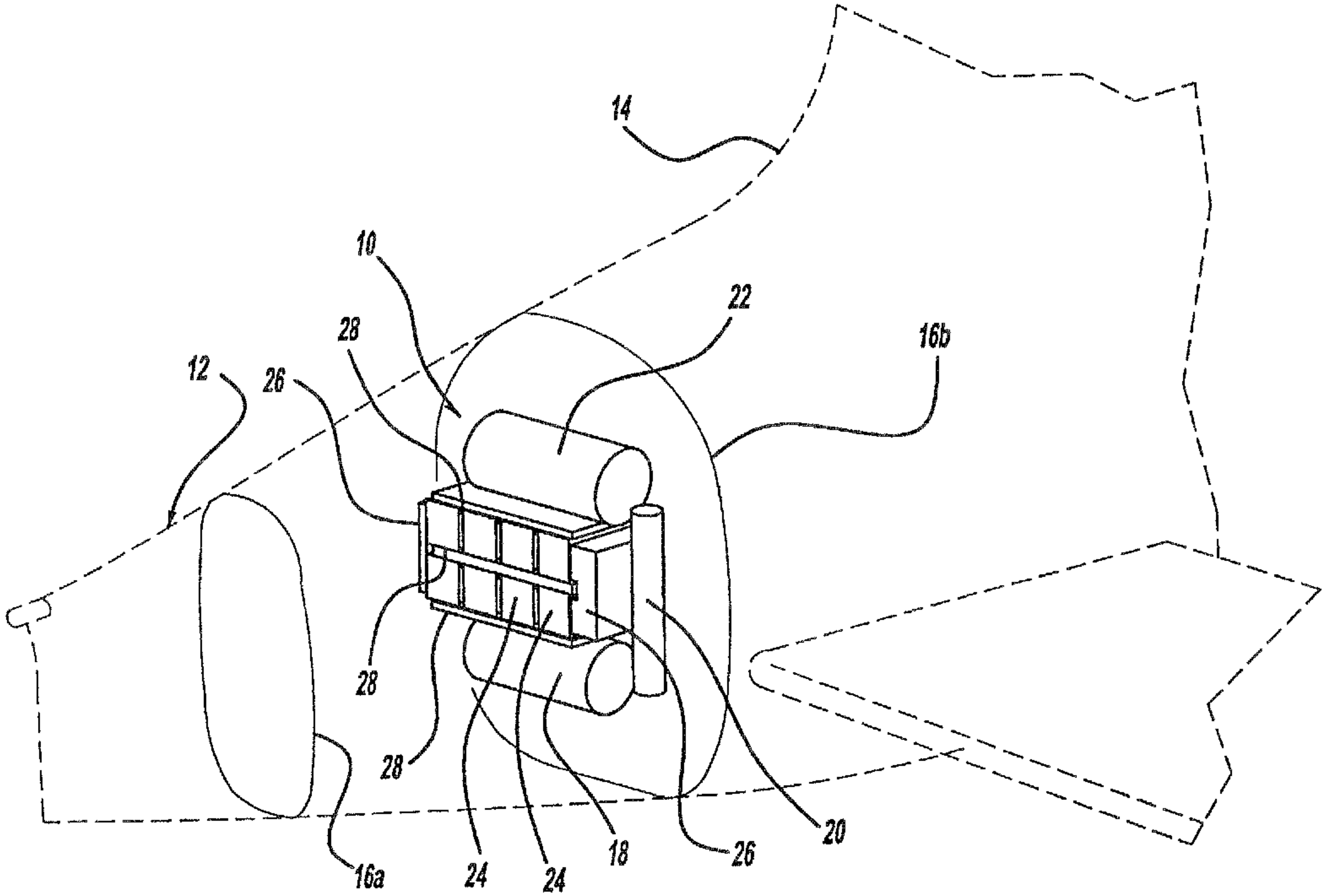
92
94
90
94
94
82
92
98
74
80
Water Seperator
Exhaust
76
Water
78


14
10
22
16b
28
12
26
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28
24
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18
26
20
16a