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Palmer

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(54) **LIGHTER-THAN-AIR AIRCRAFT AND RELATED METHODS FOR POWERING THE SAME**

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(73) Assignee: **Harris Corporation**, Melbourne, FL (US)

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(51) **Int. Cl.**
B64B 1/08 (2006.01)
(52) **U.S. Cl.** **244/30**
(58) **Field of Classification Search** 244/30, 244/31, 24, 96, 97, 61, 125, 126, 128
See application file for complete search history.

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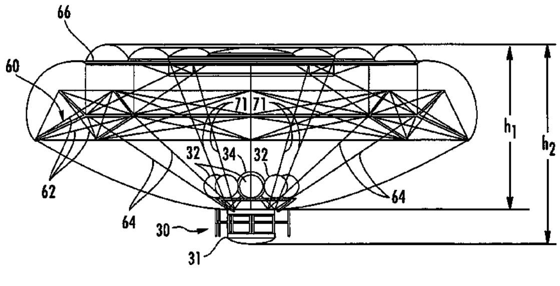
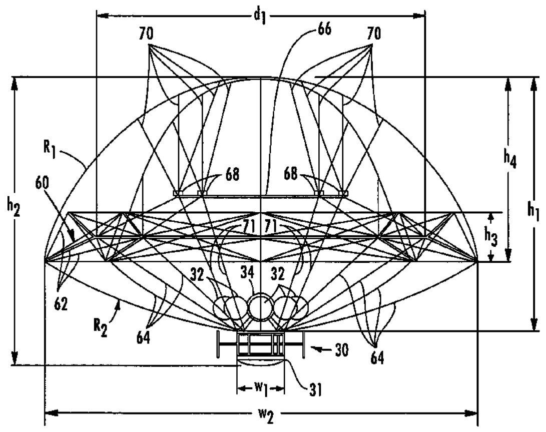
(74) *Attorney, Agent, or Firm*—Allen Dyer Doppelt Milbrath & Gilchrist

(57) **ABSTRACT**

A lighter-than-air aircraft includes a gas envelope for containing a buoyant gas, and a solar panel is carried by a predetermined portion of the gas envelope. A solar sensor is used for determining a direction of the sun. A propulsion system carried by the gas envelope orients the gas envelope so that the solar panel is oriented in the direction of the sun based upon the solar sensor. A navigation controller cooperates with the propulsion system to move the lighter-than-air aircraft along a desired flight path while the solar panel is oriented in the direction of the sun.

17 Claims, 10 Drawing Sheets





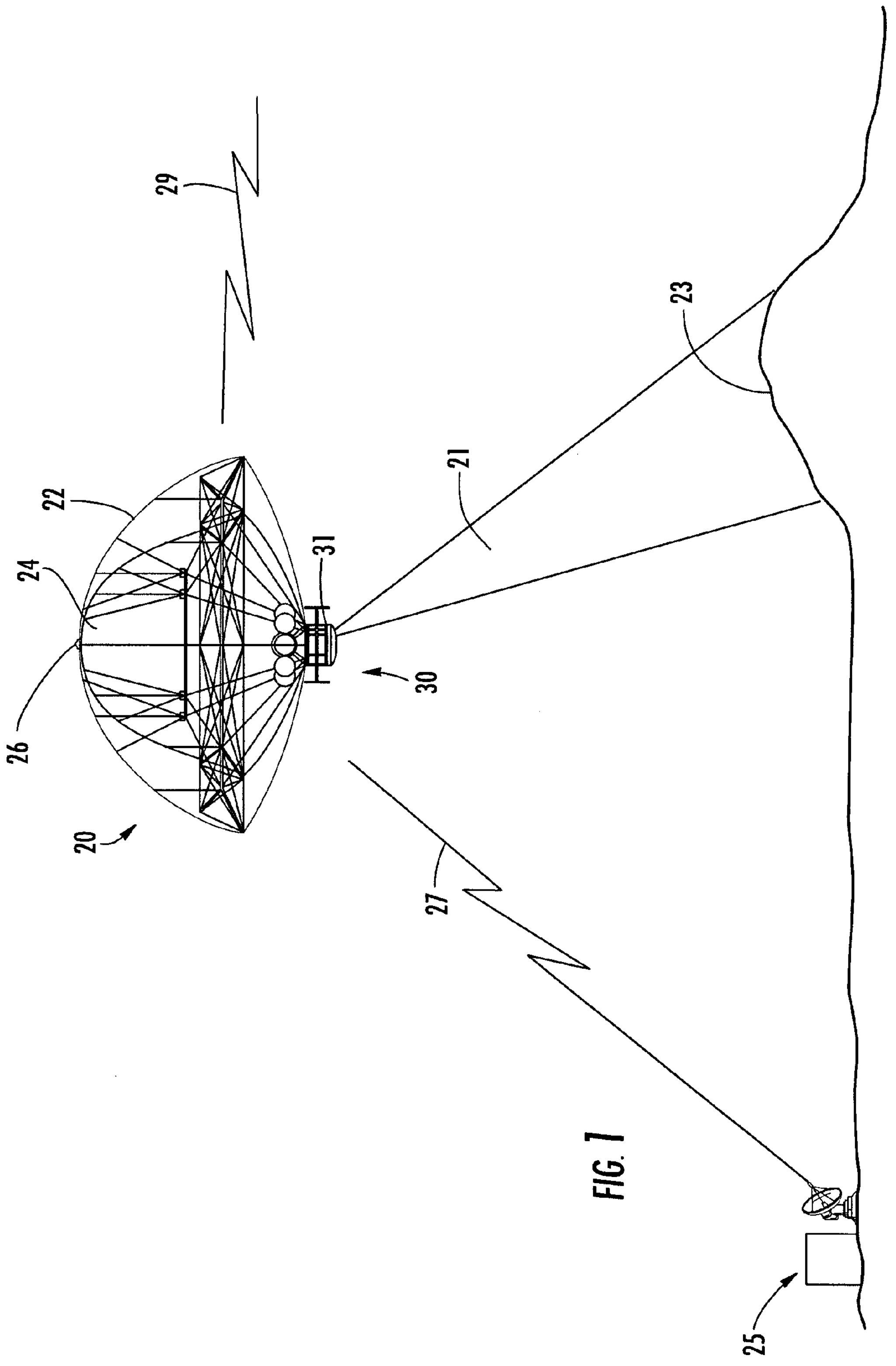


FIG. 1

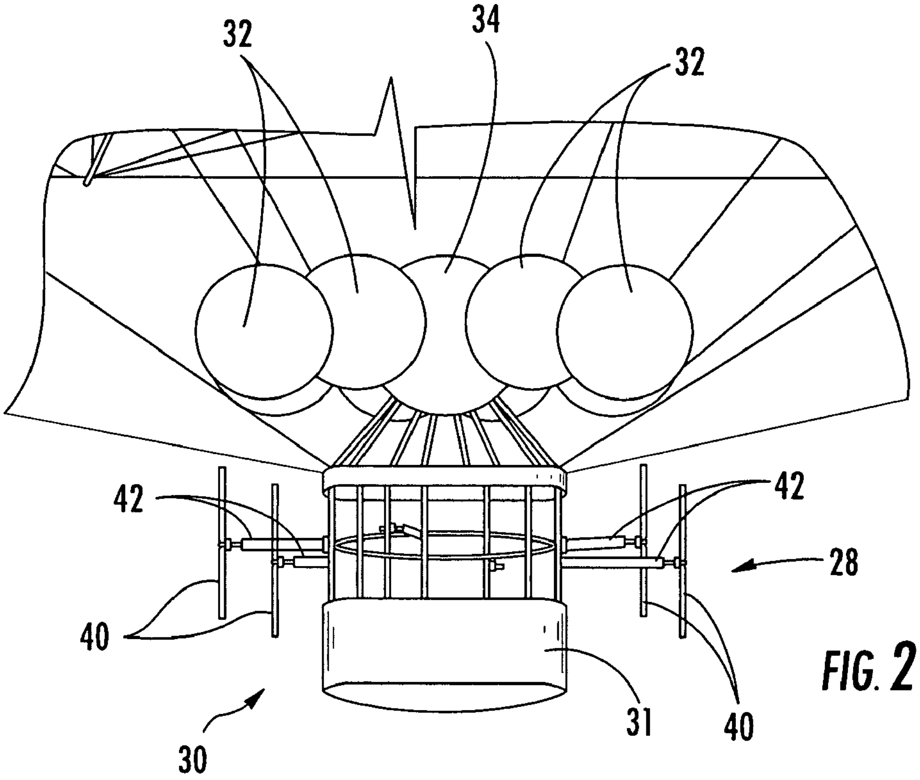


FIG. 2

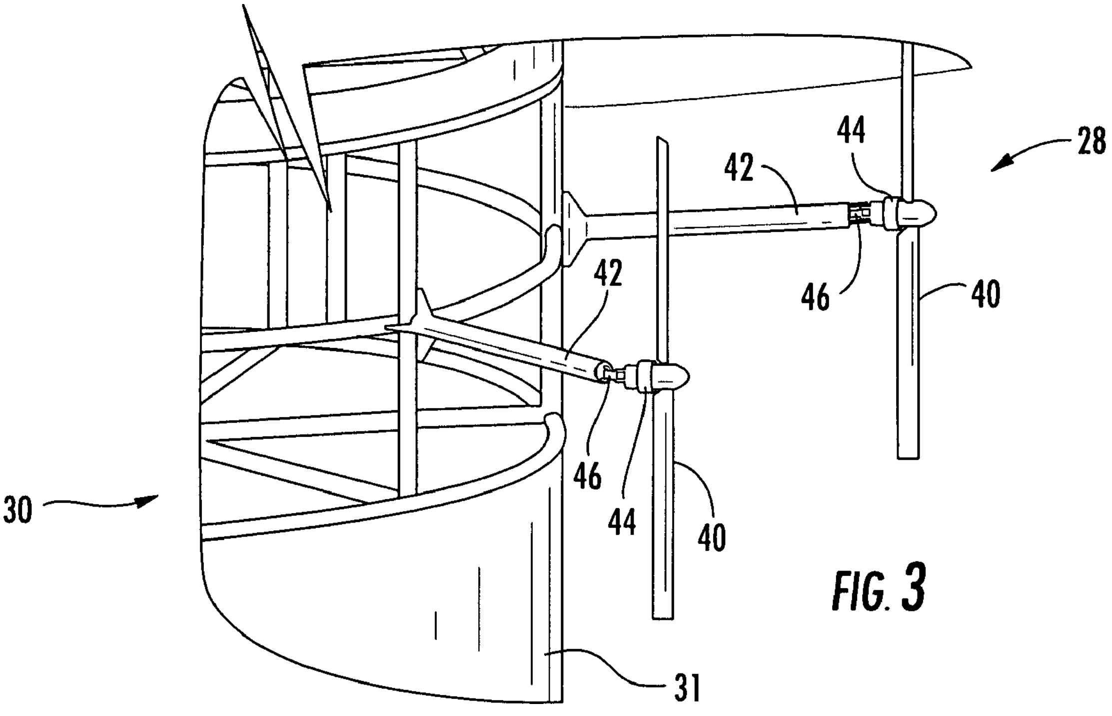


FIG. 3

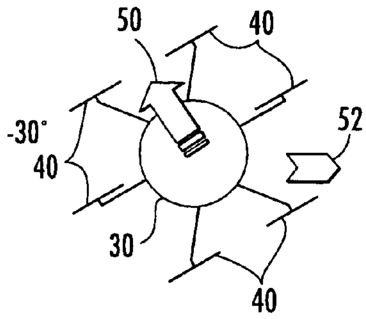


FIG. 4a

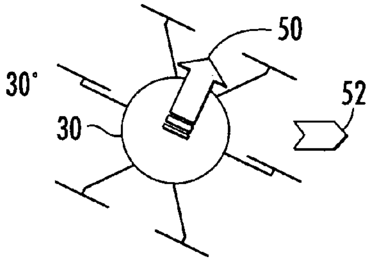


FIG. 4b

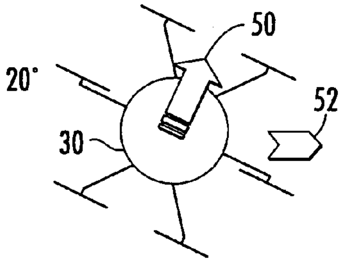


FIG. 4c

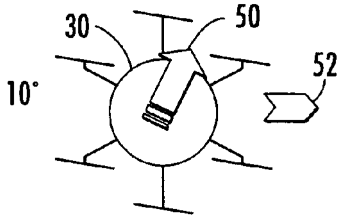


FIG. 4d

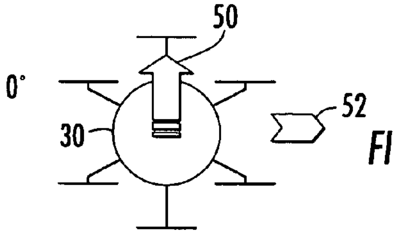


FIG. 4e

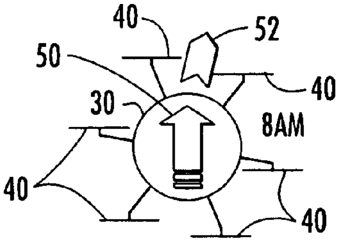


FIG. 5a

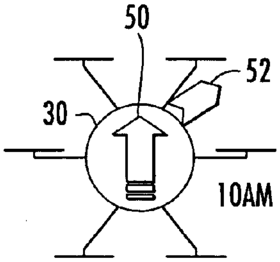


FIG. 5b

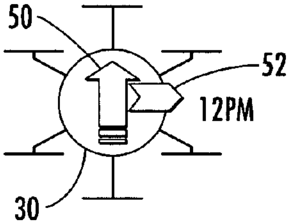


FIG. 5c

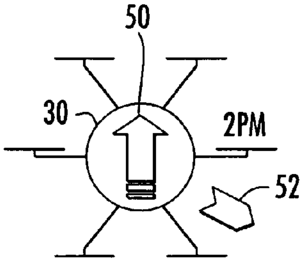


FIG. 5d

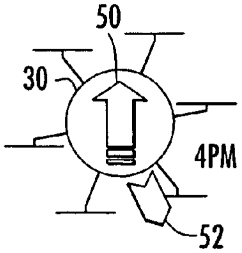


FIG. 5e

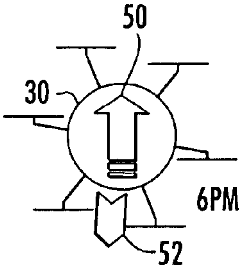


FIG. 5f

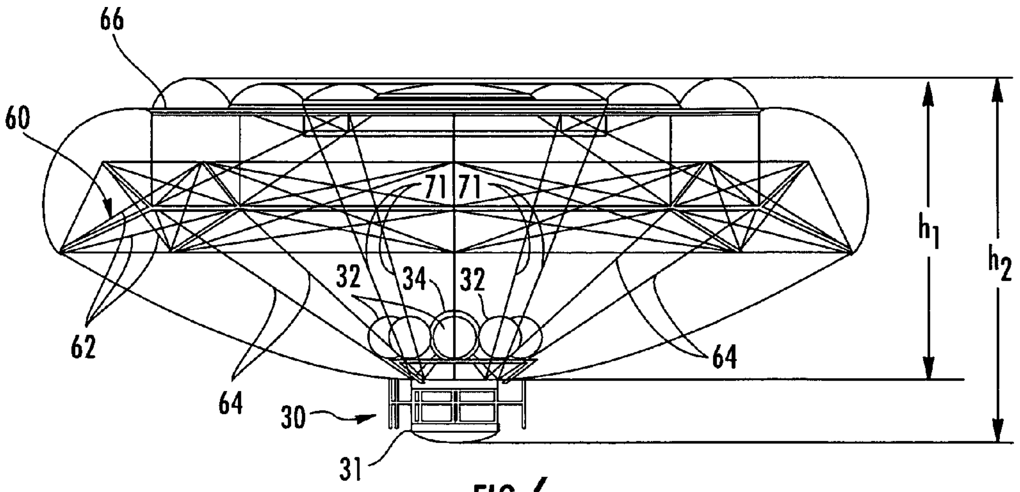
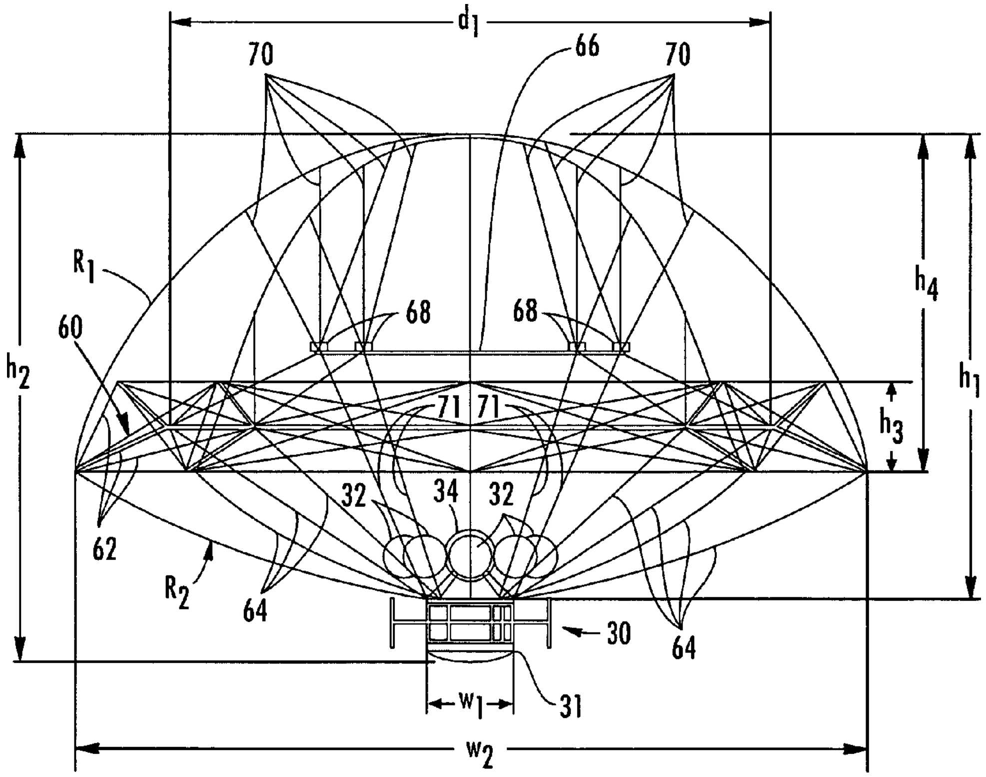

66
60
71
71
32
34
32
62
64
64
30
31
h1
h2

FIG. 6


d1
70
66
70
R1
60
68
68
h2
h4
h1
h3
71
71
32
34
32
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R2
64
30
64
w1
31
w2

FIG. 7

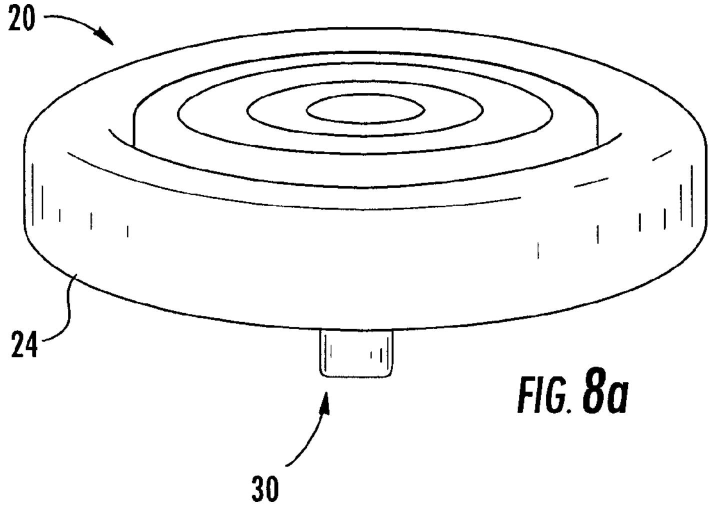


FIG. 8a

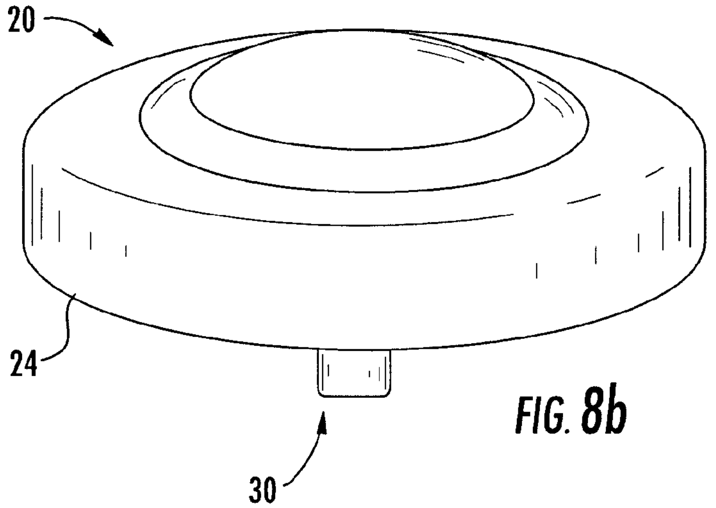


FIG. 8b

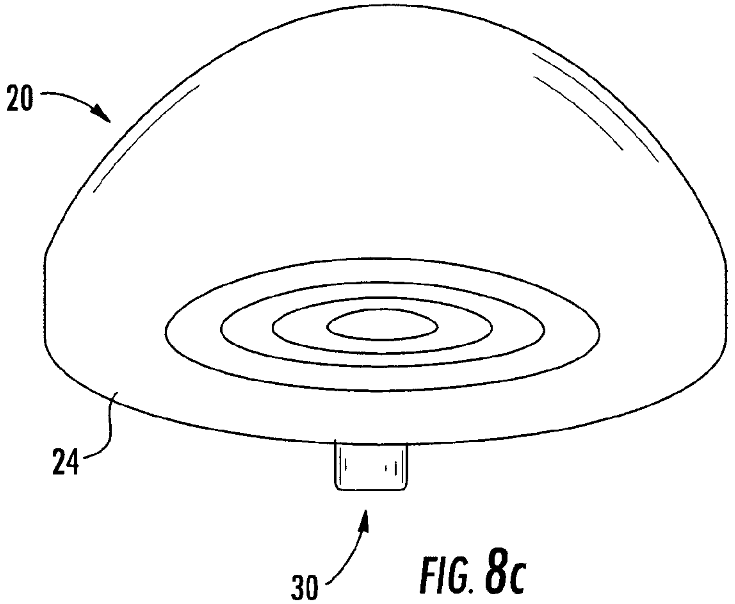


FIG. 8c

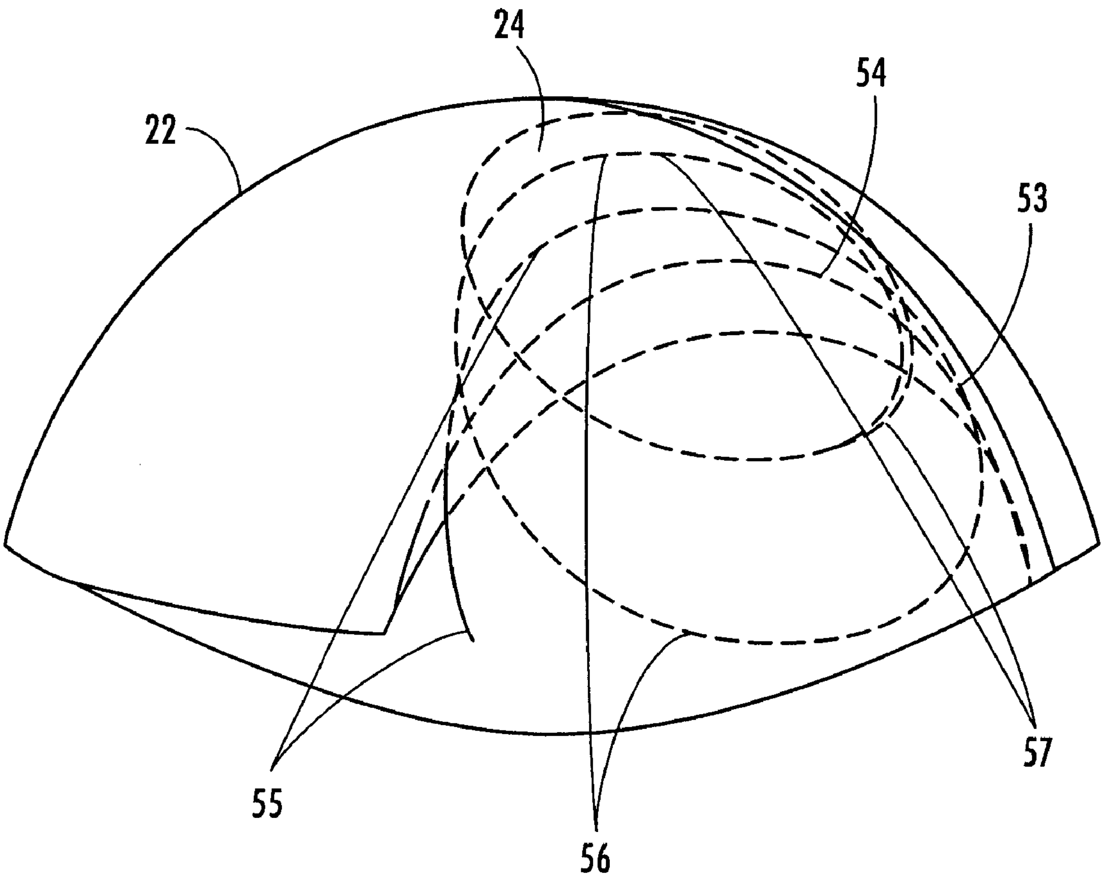


FIG. 9

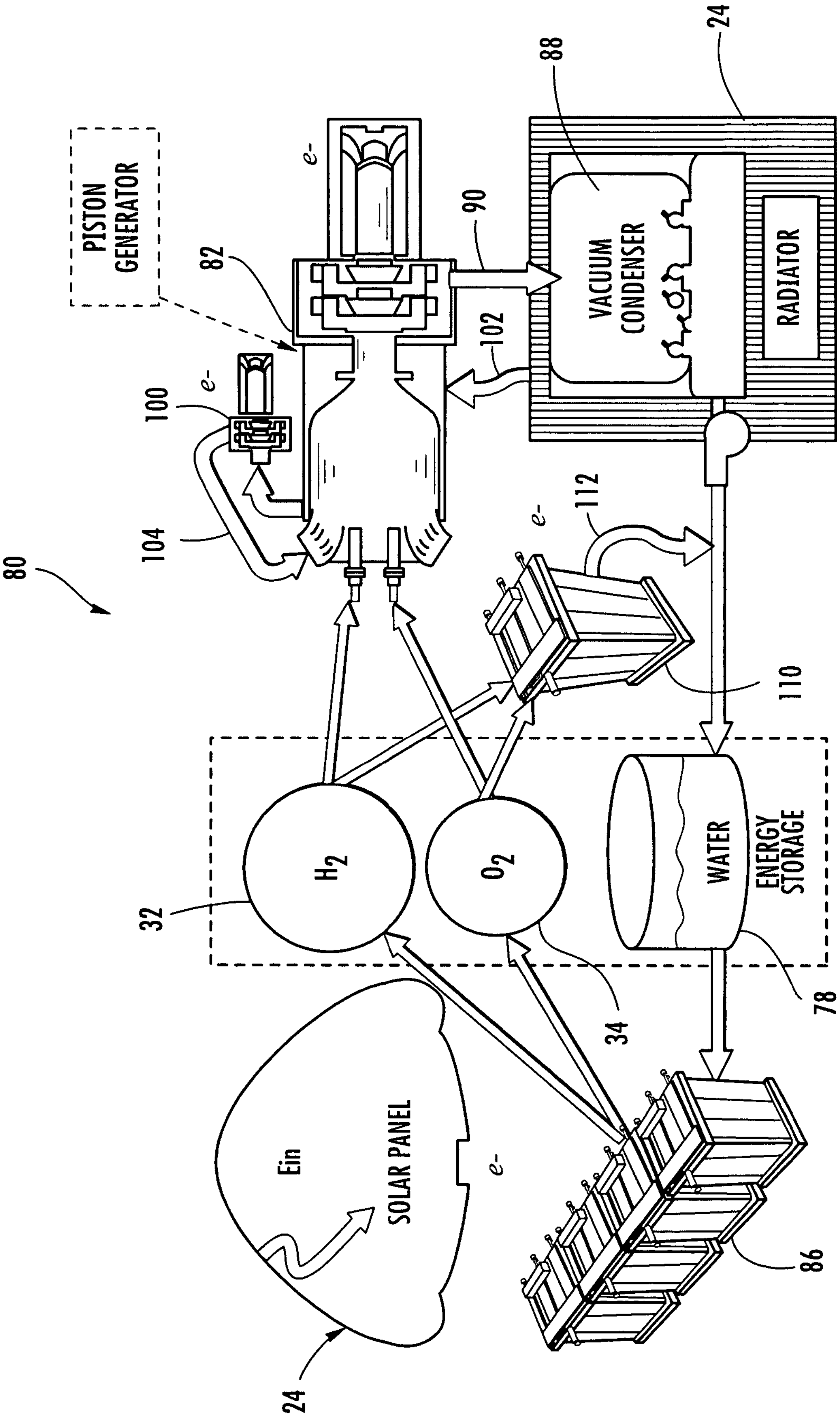

80
PISTON GENERATOR
82
e-
90
88
24
100
e-
104
102
VACUUM CONDENSER
RADIATOR
112
e-
110
32
H_2
O_2
34
WATER
ENERGY STORAGE
78
Ein
SOLAR PANEL
e-
86
24

FIG. 10

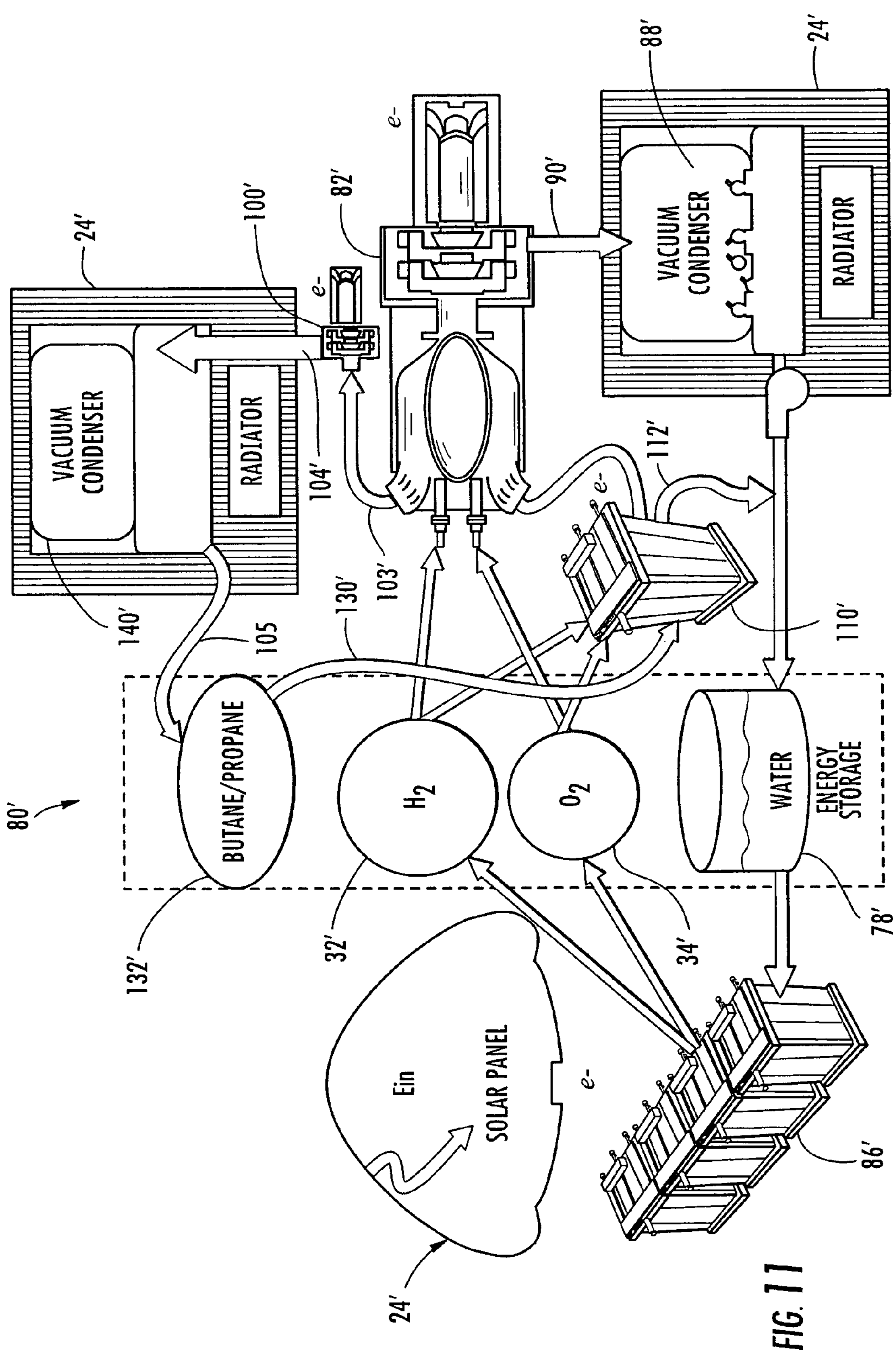
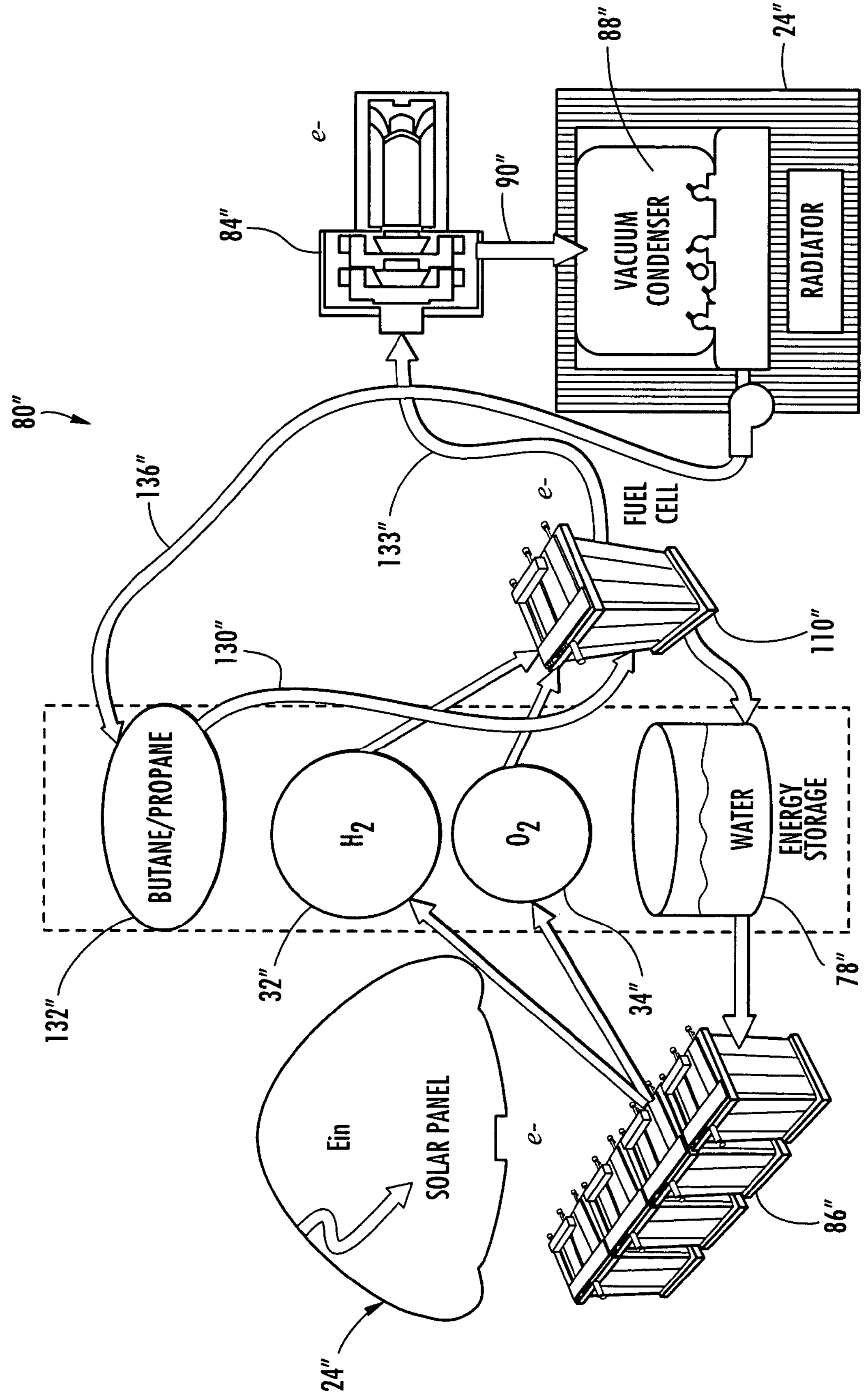

80'
24'
VACUUM CONDENSER
RADIATOR
140'
105
100'
e-
104'
103'
82'
e-
90'
88'
24'
VACUUM CONDENSER
RADIATOR
112'
e-
130'
110'
BUTANE/PROPANE
H_2
O_2
WATER
ENERGY STORAGE
132'
32'
34'
78'
Ein
SOLAR PANEL
e-
86'
24'

FIG. 11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84"
e-
90"
88"
24"
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RADIATOR
136"
133"
e-
FUEL CELL
130"
110"
BUTANE/PROPANE
H2
O2
WATER
ENERGY STORAGE
132"
32"
34"
78"
Ein
SOLAR PANEL
e-
86"
24"

FIG. 12

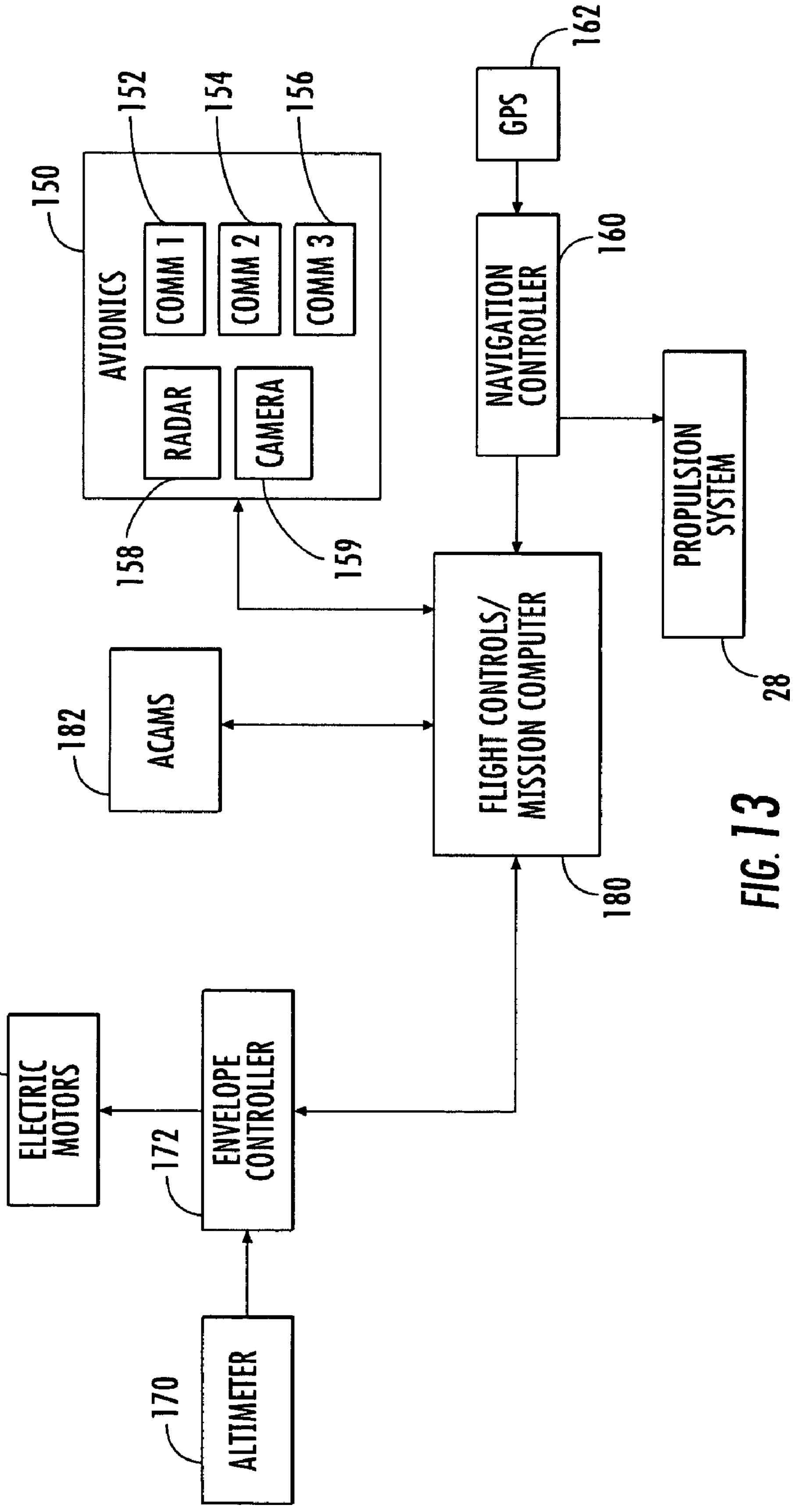
150
AVIONICS
152
COMM 1
154
COMM 2
156
COMM 3
RADAR
158
CAMERA
159
162
GPS
160
NAVIGATION CONTROLLER
PROPULSION SYSTEM
28
182
ACAMS
FLIGHT CONTROLS/ MISSION COMPUTER
180
68
ELECTRIC MOTORS
172
ENVELOPE CONTROLLER
170
ALTIMETER

FIG. 13

LIGHTER-THAN-AIR AIRCRAFT AND RELATED METHODS FOR POWERING THE SAME

FIELD OF THE INVENTION

The present invention relates to the field of lighter-than-air aircraft, and in particular, to a lighter-than-air aircraft capable of remaining in the air at high altitudes for extended periods of time.

BACKGROUND OF THE INVENTION

High altitude, long-duration solar powered aircraft have been proposed for both commercial and military applications. For example, lighter-than-air aircraft have been proposed for cellular telephone applications. Military applications also include telecommunication applications as well as providing surveillance.

There is a domain in the upper stratosphere at 60,000 feet where it is ideal to position a lighter-than-air aircraft. This altitude allows on-board sensors to see over the horizon at least 350 miles in any direction. In most such applications, long duration station keeping is essential. Consequently, the issue is not in getting an aircraft to 60,000 feet, but in maintaining power so that the on-board sensors and electronics are continuously powered for extended periods of time, which may be from a few weeks to several months to even longer.

Electrical energy generated using solar cells or photovoltaic cells are typically used to power lighter-than-air aircraft. For example, U.S. Patent Application No. 2002/0005457 discloses a lighter-than-air aircraft powered with flexible solar cells integrated within the material covering the aircraft. Although the energy provided by solar cells is adequate to power lighter-than-air aircraft while in the sunlight, the challenge is to repeatedly get through the night. To keep a large lighter-than-air aircraft in a general location at 60,000 feet requires a significant amount of power. The solar panels not only need to take in enough solar energy to power the aircraft during the day, but also needs to take in additional power to be stored in batteries so that it can be used during the night.

In addition, extra power is needed to maintain position due to the upper winds or air currents at 60,000 feet, and for maintaining direction of the solar panels toward the sun as the direction of the sun changes throughout the day. This puts a bigger demand on the ability to store power for use during the night. One approach is to place more solar panels on the aircraft for collecting and storing the additional power, but this results in an increase of the weight of the aircraft. The greater the weight, the greater the volume of lift gas required, which increases the amount of material necessary to contain the lift gas. These increases in weight and volume impose additional power requirements.

As an alternative to placing more solar panels on the aircraft, one approach is to maintain an optimum position of the solar cells in relationship to the sun. For example, most all spacecraft are solar powered. In such spacecraft, the solar panels are rotatable so that an optimum angle can be maintained between the solar panels and the sun. However, these systems are not particularly advantageous on a lighter-than-air aircraft. In U.S. Pat. No. 6,371,409, solar panels mounted on an outer surface of a lighter-than-air aircraft are movable over a portion of the surface thereof to adjust for changes in the direction of the sun, or if maintained in a stationary position, for the inclination of the sun throughout the day.

Another approach to providing the power needed throughout the night is to use fuel cells. For example, the power requirements for the high altitude airship (HAA) as designed by Lockheed Martin Corp. are met by a combination of solar cells, fuel cells and batteries, wherein the fuel cells provide electrical power during the night. The fuel cells receive the gaseous elements of hydrogen and oxygen for generating electrical power.

SUMMARY OF THE INVENTION

In view of the foregoing background, it is therefore an object of the present invention to increase the efficiency at which energy is collected, stored and converted to power so that a lighter-than-air aircraft can remain aloft at high altitudes for extended periods of time without having to return to ground for refueling.

This and other objects, features, and advantages in accordance with the present invention are provided by a lighter-than-air aircraft comprising a gas envelope for containing a buoyant gas, at least one solar panel carried by a predetermined portion of the gas envelope, and at least one solar sensor for determining a direction of the sun.

A propulsion system carried by the gas envelope orients the gas envelope so that the solar panel is oriented in the direction of the sun based upon the solar sensor. The lighter-than-air aircraft may further comprise a navigation controller cooperating with the propulsion system to move the lighter-than-air aircraft along a desired flight path while the solar panel is oriented in the direction of the sun. Pointing the solar panel in the direction of the sun independent of the desired flight path increases the efficiency at which solar energy is collected.

The lighter-than-air aircraft is capable of high-altitude station keeping within altitude and perimeter boundaries for extended periods of time. The lighter-than-air aircraft is intended to operate at an altitude of about 60,000 to 80,000 feet in the stratosphere, where it is ideal to sit, look, listen and provide surveillance and communications from a strategic perspective. This altitude allows on-board sensors to see over the horizon at least 350 miles in any direction.

Since the propulsion system orients the gas envelope so that the solar panel is oriented in the direction of the sun based upon the solar sensor, this allows the solar panel to be constantly pointing toward the sun. With the performance of the solar panel being optimized, extra solar panels do not need to be carried by the gas envelope. This advantageously reduces the overall weight and cost of the lighter-than-air aircraft.

The gas envelope may be substantially symmetrical about a vertical axis and may comprise an upper portion having a partial spheroidal shape. The solar panel may be carried by a predetermined segment of the partial spheroid. As a result of the symmetry of the gas envelope, the solar panel may be placed on any side thereof and still be optimized for collecting solar energy when facing the direction of the sun. In contrast, the direct front or rear of a traditional blimp has little or no solar exposure since the blimp does not have symmetry about its vertical axis.

The propulsion system may comprise an electrical propulsion system. The lighter-than-air aircraft may further comprise a closed loop fuel cell carried by the gas envelope for powering the electrical propulsion system when the solar panel is not generating sufficient electricity, and having its fuel regenerated by the solar panel from its exhaust when the solar panel is generating sufficient electricity. The closed loop fuel cell advantageously increases the efficiency at which fuel is stored and converted to power so that the lighter-than-air aircraft can remain aloft at high altitudes for extended periods of time without having to return to ground for refueling.

The lighter-than-air aircraft may further comprise a support structure within the gas envelope. The support structure moves the gas envelope from a retracted position to an expanded position as the buoyant gas expands due to an increase in altitude of the lighter-than-air aircraft. A gondola may also be carried by the gas envelope, and as the gas envelope moves from the retracted position to the expanded position, the gondola may be lowered from the gas envelope as the later expands.

In the retracted position, the gas envelope and gondola have less drag because of its "flat top," and because the gondola is pulled closer to the gas envelope. This results in the gas envelope and gondola having a reduced cross section, which helps to reduce the effects of winds at the lower altitudes. Another advantage of the "flat top" design is that it allows for a significant reduction in the height of the facility constructing the lighter-than-air aircraft. Once the lighter-than-aircraft reaches its desired altitude near or above 60,000 feet, the gas envelope is fully expanded.

The propulsion system may comprise a plurality of spaced apart propellers extending outwardly from the gondola. A respective electric motor may drive each of the propellers. The propulsion system may further comprise a respective gimbal coupled to each of the propellers.

Another aspect of the present invention is directed to a method for operating a lighter-than-air aircraft comprising a gas envelope for containing a buoyant gas, at least one solar panel carried by a predetermined portion of the gas envelope, at least one solar sensor, and a propulsion system carried by the gas envelope. The method comprises determining a direction of the sun based upon the at least one solar sensor, and using the propulsion system for orienting the gas envelope so that the at least one solar panel is oriented in the direction of the sun.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective view of a lighter-than-air aircraft at high altitude providing surveillance and communications about a desired location on earth in accordance with the present invention.

FIG. **2** is an enlarged perspective view of the underside of the lighter-than-air aircraft as shown in FIG. **1** illustrating in greater detail the gondola and fuel storage holders.

FIG. **3** is an enlarged view of the gondola as shown in FIG. **2** illustrating in greater detail the propulsion system for the lighter-than-air aircraft.

FIGS. **4***a*-**4***e* illustrate various positions of the propulsion system resulting in a navigation vector that varies while the solar panel is continuously pointed in the direction of the sun for the lighter-than-air aircraft in accordance with the present invention.

FIGS. **5***a*-**5***f* illustrate various positions of the propulsion system resulting in a navigation vector that remains constant while the position of the solar panel varies for tracking the sun during the day for the lighter-than-air aircraft in accordance with the present invention.

FIG. **6** is a cross-sectional side view of the lighter-than-air aircraft illustrating the support structure within the gas envelope wherein the upper portion of the gas envelope is in a retracted position in accordance with the present invention.

FIG. **7** is a cross-sectional side view of the lighter-than-air aircraft illustrating the support structure within the gas envelope wherein the upper portion of the gas envelope is in an expanded position in accordance with the present invention.

FIGS. **8***a*-**8***c* are perspective views of the gas envelope changing from a retracted position to an expanded position as the altitude of the lighter-than-air aircraft increases in accordance with the present invention.

FIG. **9** is a perspective view of the gas envelope illustrating various angles of solar incidence for the solar panel in accordance with the present invention.

FIG. **10** is a block diagram of a closed loop combustion generator for generating electricity for the lighter-than-air aircraft in accordance with the present invention.

FIG. **11** is a block diagram of another embodiment of the closed loop combustion generator as shown in FIG. **11**.

FIG. **12** is a block diagram of a closed loop fuel cell for generating electricity for the lighter-than-air aircraft in accordance with the present invention.

FIG. **13** is a block diagram illustrating the on-board electronics carried by the lighter-than-air aircraft in accordance with the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout, and prime, and double prime notations are used to indicate similar elements in alternative embodiments.

Referring initially to FIGS. **1**-**3**, the lighter-than-air aircraft **20** is capable of high-altitude station keeping within altitude and perimeter boundaries for extended periods of time. The illustrated lighter-than-air aircraft **20** is in the upper stratosphere at 60,000 to 80,000 feet, for example, where it is ideal to sit, look, listen and provide surveillance and communications from a strategic perspective. This altitude allows on-board sensors to see at least 350 miles in any direction. For example, the lighter-than-air aircraft **20** may provide surveillance **21** about a location of interest **23** on the surface of the earth, and provide this information to a command and control center **25** via a communications link **27**, as illustrated in FIG. **1**. The lighter-than-air aircraft **20** may also provide over the horizon surveillance or communications **29**.

The lighter-than-air aircraft **20** is unmanned, and communications **27** is provided with the ground based command and control center **25**. Communications **27** may be directly between the command and control center **25** and the lighter-than-air aircraft **20**. Alternatively, communications **27**, **29** may be provided via a relay satellite or other airborne platform.

The lighter-than-air aircraft **20** comprises a gas envelope **22** containing a buoyant gas, and at least one solar panel **24** is carried by a predetermined portion of the gas envelope. The at least one solar panel may be one large solar panel, or may be a solar array comprising a plurality of smaller solar panels. For purposes of discussion, the at least one solar panel **24** will simply be referred to as the solar panel. The solar panel **24** may be integrated into the skin of the gas envelope **22**, or may be separate from the skin, as readily appreciated by those skilled in the art. The buoyant gas, for example, may be helium, hydrogen or combinations thereof, or other combinations of lighter-than-air gasses.

At least one solar sensor **26** determines a direction of the sun based upon the incident light rays received from the sun. The solar sensor **26** may be separate from the solar panel **24**, as illustrated. Alternatively, the solar sensor **26** may be integrated within the solar panel **24** for determining the direction of the sun based upon the incident light rays. The illustrated solar sensor **26** is located on top of the gas envelope **22**. In another embodiment, a plurality of solar sensors **24** are spaced around the gas envelope **22**.

A propulsion system **28** orients the gas envelope **22** so that the solar panel **24** is oriented in the direction of the sun based upon the solar sensor **26**. This advantageously allows the solar panel **24** to be constantly pointing toward the sun. Since the performance of the solar panel **24** is optimized, extra solar panels do not need to be carried by the gas envelope **22**, which reduces the overall weight, complexity and cost of the lighter-than-air aircraft **20**.

A gondola **30** is carried by the gas envelope **22**. As will be discussed in greater detail below, power conversion, management functions and the propulsion system **28** are an integral part of the gondola **30**. Many of these items are carried by the payload bay **31** of the gondola **30**. In particular, the payload bay **31** carries the electronics, communications and/or surveillance equipment. Fuel storage is above the gondola **30** and is enclosed by the gas envelope **22**. The fuel storage includes hydrogen and oxygen fuel holders **32**, **34** for respectively storing the gaseous elements of hydrogen and oxygen to be used for powering the propulsion system **28**. The water that is broken down into hydrogen and oxygen gases is carried in the gondola **30**.

The propulsion system **28** comprises a plurality of spaced apart propellers **40** extending from the gondola **30**. Each propeller **40** can be independently driven, or the propellers can all be driven together. In the illustrated embodiment of the propulsion system **28**, six booms **42** are attached to the gondola **30** for supporting six independent drives **44**, i.e., six electric motors. Each boom **42** thus supports a respective electric motor **44** for driving the propeller **40** coupled thereto. The actual number of motors/propellers can vary depending on their size and the size of the lighter-than-air aircraft **20**.

Each electric motor **44** is also coupled to a dual axis gimbal **46**. The dual axis gimbals **46** advantageously allow the propellers **40** to be positioned so that the lighter-than-air aircraft **20** can move in any direction, similar to a helicopter. An advantage of the propulsion system **28** is that the lighter-than-air aircraft **20** can move in any direction while the solar panel **24** is continuously being pointed in the direction of the sun. In other words, the navigation vector of the lighter-than-air aircraft **20** can vary while the sun vector associated with the angle of the solar panel **24** pointed in the direction of the sun remains constant toward the sun.

An example of the solar panel **24** being continuously pointed toward the sun while the navigation vector changes is illustrated in FIGS. **4***a*-**4***e*. The navigation vector **50** represents the direction and motion of the lighter-than-air aircraft **20**. Even if the lighter-than-air aircraft **20** is not moving, the navigation vector **50** may vary to compensate for wind direction and speed. In FIG. **4***a*, the propellers **40** are rotated so that the navigation vector **50** is at −30 degrees while the sun vector **52** is at 90 degrees. The sun vector **52** represents the direction the solar panel **24** is pointing.

If the navigation vector **50** changes to 30 degree, the propellers **40** carried by the gondola **30** are rotated accordingly while the sun vector **52** remains constant at 90 degrees, as illustrated in FIG. **4***b*. The same concept applies when the navigation vector **50** changes to 20, 10 and 0 degrees, as illustrated in FIGS. **4***c*, **4***d* and **4***e*.

An example of the navigation vector **50** being constant while the sun vector **52** changes is illustrated in FIGS. **5***a*-**5***f*. With the lighter-than-air aircraft **20** holding a fixed position, the gas envelop **22** needs to rotate as the sun rises and sets during the day so that the solar panel **24** remains constantly pointed toward the direction of the sun.

At 8 am, for example, the sun vector **52** is at 10 degrees, as illustrated in FIG. **5***a*. At 10 am, the sun vector **52** is at 45 degrees, but this requires the propellers **40** that are carried by the gondola **30** to be rotated so that the solar panel **24** follows the direction of the sun while the navigation vector **50** remains constant, as illustrated in FIG. **5***b*. The process is repeated throughout the day as the sun changes position, as illustrated in FIGS. **5***c*-**5***f*.

In the illustrated lighter-than-air aircraft **20**, the gas envelope **22** and the gondola **30** are fixed. That is, when the gas envelope **22** rotates, so does the gondola **30**. This embodiment requires the motors **44** to operate in a sequence with a step-wise re-clocking of the propellers **40** when they have been rotated as far as they can rotate for maintaining a constant pointing of the solar panel **24** toward the direction of the sun. For example, when a first motor in the sequence of motors reaches its maximum allowable gimbal rotation, it simply slows and rotates approximately 180 degrees and becomes the last motor in the sequence of motors. The sequence of the motors continues to change as necessary based upon the desired navigation and/or solar vector. Also, the thrust direction of each re-clocked propeller **40** is reversed.

In another embodiment, the gas envelope **22** and the gondola **30** rotate independently from one another, much like a turret on a tank. The gondola **30** may rotate as necessary to maintain a desired flight path vector while the solar panel **24** remains in the direction of the sun.

Referring now to FIGS. **6** and **7**, the gas envelope **22** comprises a support structure for moving THE gas envelope from a retracted position (FIG. **6**) to an expanded position (FIG. **7**). The support structure comprises a hoop-truss member **60** having a ring shape. The hoop-truss member **60** is derived from hoop antennas that are deployed in space, as readily appreciated by those skilled in the art. The hoop-truss member **60** includes a number of compressive members and stabilizing tension cords **62** for providing the necessary support. Other internal design structures are acceptable as readily appreciate by those skilled in the art, such as a radial rib structure, for example.

The gondola **30** is attached to the hoop-truss member **60** via attachments **64**, and to a control member **66** via attachments **71**. The control member **66** is above the hoop-truss member **60**. Fuel storage holders for the applicable gases are above the gondola **30**, and are enclosed by the gas envelope **22**. The fuel storage holders as noted above include hydrogen and oxygen fuel holders **32**, **34** for respectively storing the gaseous elements of hydrogen and oxygen to be used for powering the propulsion system **28** during the night.

The control member **66** enables volumetric control of the upper portion of the gas envelope **22** during ascent and decent. As the buoyant gas expands or contracts as a function of the altitude, the volume of the gas envelope **22** changes accordingly. Although not shown in the figures, a perimeter stabilized inflatable structure, in concert with the more stable rigid members **60** and **66**, may also be used to provide support of the desired contour of the gas envelope **22**. An approach of using radial members within the cord structure allows the creation of a substantially circular shape.

Volumetric control of the gas envelope **22** may be performed manually or automatically. Small electric motors **68** are positioned around the control member **66**, and retract or release tie-downs **70** attached to the upper surface of the gas envelope **22**, and tie-downs **71** attached to the gondola **30**. The electric motors **68** are not limited to being located around the control member **66**. They may be located around the hoop-truss member **60**, for example. The gondola **30** carries an altimeter **72** for determining the altitude of the lighter-than-air aircraft **20**, and provides the altitude to an envelope controller **74** or measurement of barometric pressure/relative pressure.

The altimeter **72** and the controller **74**, as well as other on-board electronics and sensors, will be discussed in greater detail when reference is made to FIG. **13**. The envelope controller **74** operates the small electric motors **68** so that the tension cords or tie-downs **70**, **71** are either retracted or released based upon the altitude. This feature of the present invention advantageously allows for the expansion of the buoyant gas as the lighter-than-air aircraft **20** traverses the atmosphere to the desired station keeping altitude.

The desired altitude of the lighter-than-air aircraft **20** is preferably in the stratosphere, which corresponds to an altitude of 60,000 feet or higher. Of course, the lighter-than-air aircraft **20** may operate at lower altitudes depending on its intended purpose.

When the lighter-than-air aircraft **20** is in the lower atmosphere, the upper portion of the gas envelope **24** is retracted toward the control member **66**, and the gondola **30** is also retracted toward the control member as illustrated in FIG. **6**. This reduces the cross-sectional area of the gas envelope **24**, which results in a low profile, i.e., a reduced drag. The winds in the denser air of the lower atmosphere have a significant effect on large structures, such as the lighter-than-air aircraft **20**.

When the gas envelope **22** is fully collapsed, the height h_1 of the illustrated gas envelope is 80 feet, and the height h_2 including the gondola **30** is 97 feet. When the gas envelope **22** is fully expanded, as illustrated in FIG. **7**, these dimensions h_1, h_2 are respectively 96 feet, 148 feet. The width w_1 of the gondola **30** is 22 feet, and the overall width w_2 of the lighter-than-air aircraft **20** is 215 feet. The height h_3 of the hoop-truss member **60** is 24 feet, and the height h_4 between the hoop-truss member and the top of the gas envelope **22** is 91 feet. The radius r_1 of the upper portion of the gas envelope **22** when fully expanded is 118 feet, whereas the radius r_2 of the lower portion of the gas envelope is 272 feet. The inside diameter of the hoop-truss member **60** is 161 feet. These numbers are for illustrative purposes only, and the actual size of the lighter-than-air aircraft will vary depending on the intended application.

FIGS. **8***a*-**8***c* are perspective views of the gas envelope **22** changing from the retracted position to the expanded position as the altitude of the lighter-than-air aircraft **20** increases. In the retracted position, the gas envelope **22** has a low drag because of its "flat top" and because the gondola **30** is pulled or held closer position toward the gas envelope, as shown in FIG. **8***a*. Because of the reduced cross section, this helps to reduce the effects of winds at the lower altitudes. As the lighter-than-air aircraft **20** increases in altitude, the buoyant gas expands so that the volume of the gas envelope **22** increases and the gondola **30** is lowered away from the gas envelope, as shown in FIG. **8***b*. Once the lighter-than-aircraft **20** reaches its desired altitude near or above 60,000 feet, the gas envelope **22** is fully expanded and the gondola **30** is in its resting position, as shown in FIG. **8***c*.

Another advantage of the "flat top" design is that it allows for a significant reduction in the height of the facility constructing the lighter-than-air aircraft **20**. The lighter-than-air aircraft **20** may be constructed at the reduced height, and then moved outside for deployment.

The flexible material covering the hoop-truss member **60** and the control member **66** is preferably a high strength material. This material may be made from Kapton films, Tedlar, and Vectran, for example. The material may also comprise a polyester film, and may also be a combination of different materials. For example, Vectran may be used for the load bearing fabric. Tedlar and polyester film laminates may form the ultraviolet protection layer, and also function as a gas barrier. These materials have a high resistance to radiation and to cold temperatures.

An advantage of the present invention is that the gas envelope **22** may be constantly pointed in the direction of the sun. The gas envelope **22** is substantially symmetrical about its vertical axis and comprises an upper portion having a partial spheroidal shape. This shape advantageously provides for good solar incidence 360 degrees around the perimeter of the gas envelope **22**, and at low elevation angles.

The solar panel **24** is carried by a predetermined angular segment of the partial spheroid. Out of a total angular segment of 360 degrees, the predetermined angular segment is within a range of about 60 to 120 degrees, for example, with about 90 degrees being illustrated in the figures. In contrast, the direct front or rear of a blimp has little or no solar exposure due to its lack of symmetry about a vertical axis. As a result of the spheroidal shape of the gas envelope **22**, the solar panel **24** may be placed on any side thereof and still be optimized for collecting solar energy via the solar panel facing the direction of the sun. Since the effectiveness of the solar panel **24** is directly related to the incidence angle of the sunlight, it becomes very important to optimize these pointing angles.

Various example positions of the sun above the horizon and its footprint on the solar panel **24** are shown in FIG. **9**. For example, reference **53** represents the sun 0° above the horizon with a +/−40° view angle, reference **54** represents the sun 14° above the horizon with a +/−40° view angle, reference **55** represents the sun 28° above the horizon with a +/−35° view angle, reference **56** represents the sun 42° above the horizon with a +/−30° view angle, and reference **57** represents the sun 56° above the horizon with a +/−25° view angle. In addition, the solar panel **24** is plumbed back to the gondola **30** using reinforced channels within the solar surface and routing through portions of the inner support structure. The solar panel **24** thus has an efficient overall incident area when directed toward the sun. As a result of the additional weight of the solar panel **24** on one side of the gas envelope **22**, the gondola **30** should be slightly off center or internal elements should be adjusted to balance the center of gravity.

As an alternative embodiment resulting from the gas envelope **22** being symmetrical about its vertical axis, solar panels **24** may be placed all the way around so that it does not matter which direction the gas envelope is pointing. Consequently, the use of the solar sensor **26** is no longer necessary. This embodiment may be particularly attractive if the technology for solar panels allows for light weight solar panels, and the impact of placing them all the way around the gas envelope **22** is not too detrimental to the overall weight and performance of the lighter-than-air aircraft **20**.

Referring now to FIGS. **10**-**12**, various embodiments for generating electricity for the lighter-than-air aircraft **20** during the night cycle will now be discussed. It is worth noting that these different embodiments for generating electricity may also be used on other types of aircraft, including those that are heavier-than-air, as readily appreciated by those skilled in the art.

The sun is generally available for about 8 hours during the day in which extra electricity is generated beyond what is required for powering the lighter-than-air aircraft **20**. Availability of the sun is highly dependent on location of the lighter-than-air aircraft **20** relative to the equator and on the time of the year. This extra electricity is used for regenerating fuel, which is then used for generating electricity during the night cycle. There are an additional 1.5 hours in the morning and 1.5 hours in the evening where the sun provides enough solar energy for powering the lighter-than-air aircraft **20**, but does not generate any extra electricity. The night cycle is about 13 hours where there is effectively no sunlight available.

In the illustrated embodiment of the lighter-than-air aircraft **20**, it is estimated that about 750 W-hr/kg is required. However, current battery technology offers about 150 W-hr/kg storage potential. Consequently, these batteries are not efficient enough, per unit of weight, for them to be a good choice for powering the lighter-than-air aircraft **20** during the night.

In one embodiment, a closed loop combustion generating system **80** powers the propulsion system **28** when the solar panel **24** is not generating sufficient electricity (i.e., during the night), and has its fuel regenerated by the solar panel from its exhaust when the solar panel is generating sufficient electricity (i.e., during the day). The closed loop combustion generating system **80** comprises a combustion generator **82** for receiving the fuel, and for generating a pressurized gas based upon combustion of the fuel. The combustion generator **82** may comprise a turbine generator or a piston generator, for example, for generating electricity and producing exhaust **90** as a result thereof.

The closed loop combustion generating system **80** comprises a condenser **88** for condensing the exhaust **90** from the combustion generator **82** to a liquid. The condenser **88** takes advantage of the cold ambient night to remove heat from the exhaust. In the illustrated embodiment, the condenser **88** is carried by the gas envelope **22** adjacent the solar panel **24**. The condenser **88** is spread out adjacent the solar panel **24**, which acts as a radiator for removing heat, i.e., a large heat sink potential. With the ambient air being about −70° F. at 60,000 feet, and the heat sink potential being about 18 W/ft^2, the solar panel **24** can effectively function as a radiator. In another embodiment, the condenser **88** is carried by the gondola **30**, and air may be forced over the condenser to help condense the exhaust **90** to a liquid.

At least one converter **86** converts the liquid from the condenser **88** back into fuel when electricity is being input from the solar cell **24**, i.e., during the day. The fuel comprises hydrogen gas and oxygen gas so that the exhaust comprises water. The converter **86** comprises an electrolyzer for breaking the water down during the day into the hydrogen and oxygen gases, which are stored in respective fuel storage holders **32**, **34**. This fuel is then used during the night cycle for generating electricity. The water is stored in a water storage holder **78** in the gondola **30**. Insulation and mini-heaters are used to keep the water from freezing at the high operating altitudes of the lighter-than-air aircraft **20**.

If the water ever needs to be replenished while the lighter-than-air aircraft **20** is in flight, the aircraft may drop its altitude so that it is in the clouds. Once the lighter-than-air aircraft **20** is in the clouds, water may be collected, as readily appreciated by those skilled in the art. Along these same lines, if the buoyant gas in the gas envelope **22** needs to be replenished, then a portion of the hydrogen gas in the hydrogen gas storage holder **32** may be added to the gas envelope.

A fuel cell **110** may also be used for combining the hydrogen and oxygen gases for generating electricity. A by-product **112** of combining the hydrogen and oxygen gases in the fuel cell **110** is water **112**, which is routed to the water storage holder **78**.

The closed loop combustion generating system **80** may also includes a second generator **100** for generating electricity. A portion of the water **102** from the condenser **88** or a portion of the water **112** from the fuel cell **110** may be routed to the combustion generator **82**. The combustion generator **82** can reach temperatures of about 5800° F., and the heat generated by the combustion chamber is used to heat the water.

Once the water is heated to a pressurized gas, it is applied to the second generator **100**. The pressurized gas may drive a turbine, as illustrated, or a piston, for example, for generating electricity. The exhaust **104** exiting the second generator **100** is then combined with the hydrogen and oxygen gases within the combustion generator **82**. Effectively, this is a reheat stage that includes the addition of the new combustion gas products.

In another embodiment, the closed loop combustion generator **80'** is based upon the use of a vaporization fluid such as butane or propane for generating electricity, as shown in FIG. **11**. The elements having the same reference numerals as in FIG. **10** perform the same function and will not be discussed.

Liquid butane or propane **130'** is first routed from a supplemental fuel holder **132'** to the fuel cell **110'**. The fuel cell **110'** is about 50% efficient, which means the heat generated by the fuel cell when generating electricity may be used for heating the butane or propane. The butane or propane will also be referred to as a supplemental liquid **130'**.

In lieu of propane or butane, another liquid or gas having similar properties may be used as the supplemental liquid. These properties include low vapor pressure at temperatures between −30° F. and −70° F., and a much higher vapor pressure at temperatures between 110° F. and 180° F. For example, the supplemental liquid has gas properties of 0 psig vapor pressure at −60° F. (in the condenser **140'**), and between 150-200 psig at 110° F. (at the fuel cell **110'**). Propane or butane, for example, condenses to a liquid at about −60° F., which is the same temperature as the ambient atmosphere at 60,000 feet. Thermal removal rate is about 18 W/ft^2.

The heat generated by the fuel cell **110'** is used to pre-heat the supplemental liquid **130'**. When the supplemental liquid **130'** is heated, it vaporizes at a much lower temperature. As it heats, the liquid butane or propane turns into a gas. The goal is to convert from liquid to vapor within the fuel cell **110'** which maximizes the effective heat transfer associated with the latent heat of vaporization. The gas is routed to the combustion generator **82'**. As the gas is heated even higher, it becomes more unstable and becomes a pressurized gas which increases the volume that is maintained near constant pressure.

The pressurized gas **103'** is used to drive a second generator **100'** for generating electricity. The exhaust **104'** from the second generator **100'** is routed to a second condenser **140'**. The condensed supplemental exhaust **105'** is routed to the supplemental liquid holder **132'**. In the illustrated embodiment, the second condenser **140'** is also carried by the gas envelope **22'** adjacent the solar panel **24'**. In another embodiment, the second condenser **140'** is carried by the gondola **30'**, and air may be forced over the condenser to help condense the gas to liquid form. The exhaust **104'** will be in the form of an expanded gas. The ambient temperature will cool the gas back to the supplemental liquid **130'** (a point of re-liquefaction/condensing). This process for the supplemental liquid **130'** does not occur naturally at or near the earth's surface, for instance, below 20,000 feet altitude.

In yet another embodiment of generating electricity during the night, a closed loop fuel cell **80"** is used, and the supplemental liquid **130"** is heated by the fuel cell **110"**. The supplemental liquid **130"** is heated until it becomes a pressurized gas

133". The pressurized gas **133"** is used to drive a generator **84"** for generating electricity. The generator **84"** is a turbine generator or a piston generator, for example.

The exhaust **90"** from the generator **84"** is routed to a condenser **88"**. The condensed supplemental exhaust **136"** is then routed to the supplemental liquid holder **132"**. As in the previous embodiments, the condenser **88"** is also carried by the gas envelope **22"** adjacent the solar panel **24"** so that it operates as a heat sink during the night. In another embodiment, the condenser **88"** is carried by the gondola **30"**, and air may be forced over the condenser to help condense the gas to liquid form.

Another advantage of this particular embodiment is that the system can be reversed during the day for generating electricity. That is, the supplemental liquid is heated by the solar panel **24** so that it becomes a pressurized gas for driving a generator for generating electricity, as readily appreciated by those skilled in the art. Further, the supplemental liquid is re-condensed in the gondola **30** by ambient air forced over a heat exchanger, as readily appreciated by those skilled in the art.

The on-board electronics carried by the lighter-than-air aircraft **20** will now be discussed with reference to FIG. **13**. The avionics **150** required to support the lighter-than-air aircraft includes a number of different type communications links. A first communications link **152** is a two-way, line-of-sight system capable of uploading commands for controlling the aircraft's **20** systems and payloads, and downloading the status of all on-board systems and mission payload data. This communications link may operate at the Ku-band and is capable of providing uplink rates of at least 200 kbps and downlink rates from 2 Mbps to 274 Mbps.

A second communications link **154** includes one or more satellite communication systems to be used for both vehicle and payload control and monitoring as well as transmission of payload data. A third communications link **156** includes VHF/UHF radios for providing a direct communications path to air traffic controllers. It also allows a remotely located "pilot" to communicate with a controller, thus providing a standard interface to the world. The avionics **150** also includes a radar **158** and a camera **159**.

The navigation controller **160** cooperates with the propulsion system **28** to move the lighter-than-air aircraft **20** along a desired flight path while the solar panel **24** is oriented in the direction of the sun. The navigation controller **160** receives information on the location of the lighter-than-air aircraft **20** from a GPS receiver **162**. An altimeter **170** provides altitude information to an envelope controller **172** for controlling the profile of the gas envelope **22** based upon the altitude. As discussed above, the gas envelope **22** may be in a retracted position at low altitudes, but as the altitude increases and the buoyant gas expands within the gas envelope, then the envelope controller **172** places the gas envelope in the expanded position.

Flight controls/mission computer **180** interfaces with the other electronic devices on-board for providing overall control of the lighter-than-air aircraft **20**. An aircraft condition analysis and management system (ACAMS) **182** is also carried by the lighter-than-air aircraft **20** for providing aircraft diagnostics.

Many modifications and other embodiments of the invention will come to the mind of one skilled in the art having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. In addition, other features relating to the lighter-than-air aircraft is disclosed in the copending patent application filed concurrently herewith and assigned to the assignee of the present invention and is entitled LIGHTER-THAN-AIR AIRCRAFT INCLUDING A CLOSED LOOP COMBUSTION GENERATING SYSTEM AND RELATED METHODS FOR POWERING THE SAME, Application Ser. No. 10/977,791, the entire the entire disclosure of which is incorporated herein in its entirety by reference. Therefore, it is understood that the invention is not to be limited to the specific embodiments disclosed, and that modifications and embodiments are intended to be included within the scope of the appended claims.

That which is claimed is:

1. A lighter-than-air aircraft comprising:

a gas envelope for containing a buoyant gas;

a support structure within said gas envelope for moving said gas envelope from a retracted position to an expanded position, said support structure comprising

a hoop-truss member,

a control member positioned above and coupled to said hoop-truss member, and

a first plurality of tie-downs between said control member and a portion of said gas envelope positioned above said control member, with a length of said first plurality of tie-downs being increased as said gas envelope moves from the retracted position to the expanded position;

at least one solar panel carried by a predetermined portion of said gas envelope;

at least one solar sensor for determining a direction of the sun; and

a propulsion system carried by said gas envelope for orienting said gas envelope so that said at least one solar panel is oriented in the direction of the sun based upon said at least one solar sensor to thereby increase solar energy collection efficiency.

2. A lighter-than-air aircraft according to claim **1** further comprising a navigation controller cooperating with said propulsion system to move the lighter-than-air aircraft along a desired flight path while said at least one solar panel is oriented in the direction of the sun.

3. A lighter-than-air aircraft according to claim **1** wherein said gas envelope is substantially symmetrical about a vertical axis and comprises an upper portion having a partial spheroidal shape; and wherein said at least one solar panel is carried by a predetermined segment of said partial spheroid.

4. A lighter-than-air aircraft according to claim **1** wherein said propulsion system comprises an electrical propulsion system; and further comprising at least one closed loop fuel cell carried by said gas envelope for powering said electrical propulsion system when said at least one solar panel is not generating sufficient electricity, and having its fuel regenerated by said at least one solar panel from its exhaust when said at least one solar panel is generating sufficient electricity.

5. A lighter-than-air aircraft according to claim **1** further comprising a gondola carried by said gas envelope; and wherein said support structure further comprises a second plurality of tie downs between said control member and said gondola, with a length of said second plurality of tie-downs being increased as said gas envelope moves from the retracted position to the expanded position.

6. A lighter-than-air aircraft according to claim **5** further comprising:

at least one electric motor controlling the length of said first and second plurality of tiedowns; and

an envelope controller connected to said at least one electric motor for control thereof based upon an altitude of the lighter-than-air aircraft.

7. A lighter-than-air aircraft according to claim **1** further comprising a gondola carried by said gas envelope; and wherein said propulsion system comprises:

a plurality of spaced apart propellers extending outwardly from said gondola; and

a respective electric motor for driving each of said propellers.

8. A lighter-than-air aircraft according to claim **7** wherein said propulsion system further comprises a respective gimbal coupled to each of said propellers.

9. A lighter-than-air aircraft according to claim **1** wherein the lighter-than-air aircraft is unmanned.

10. A lighter-than-air aircraft comprising:

a gas envelope for containing a buoyant gas and being symmetrical about a vertical axis;

a support structure within said gas envelope for moving said gas envelope from a retracted position to an expanded position, said support structure comprising a hoop-truss member,

a control member positioned above and coupled to said hoop-truss member, and

a first plurality of tie-downs between said control member and a portion of said gas envelope positioned above said control member, with a length of said first plurality of tie-downs being increased as said gas envelope moves from the retracted position to the expanded position;

at least one solar panel carried by a predetermined portion of said gas envelope;

at least one solar sensor for determining a direction of the sun; and

a propulsion system carried by said gas envelope for orienting said gas envelope so that said at least one solar panel is oriented in the direction of the sun based upon said at least one solar sensor to thereby increase solar energy collection efficiency.

11. A lighter-than-air aircraft according to claim **10** further comprising a navigation controller cooperating with said propulsion system to move the lighter-than-air aircraft along a desired flight path while said at least one solar panel is oriented in the direction of the sun.

12. A lighter-than-air aircraft according to claim **10** wherein said gas envelope comprises an upper portion having a partial spheroidal shape; and wherein said at least one solar panel is carried by a predetermined angular segment of said partial spheroid.

13. A lighter-than-air aircraft according to claim **10** wherein said propulsion system comprises an electrical propulsion system; and further comprising at least one closed loop fuel cell carried by said support structure for powering said electrical propulsion system when said at least one solar panel is not generating sufficient electricity, and having its fuel regenerated by said at least one solar panel from its exhaust when said at least one solar panel is generating sufficient electricity.

14. A lighter-than-air aircraft according to claim **10** further comprising a gondola carried by said gas envelope; and wherein said support structure further comprises a second plurality of tie downs between said control member and said gondola, with a length of said second plurality of tie-downs being increased as said gas envelope moves from the retracted position to the expanded position.

15. A lighter-than-air aircraft according to claim **14** further comprising:

at least one electric motor controlling the length of said first and second plurality of tie-downs; and

an envelope controller connected to said at least one electric motor for control thereof based upon the altitude of the lighter-than-air aircraft.

16. A lighter-than-air aircraft according to claim **10** further comprising a gondola carried by gas envelope; and wherein said propulsion system comprises:

a plurality of spaced apart propellers extending outwardly from said gondola; and

a respective electric motor for driving each of said propellers.

17. A lighter-than-air aircraft according to claim **16** wherein said propulsion system further comprises a respective gimbal coupled to each of said propellers.

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