US 20070023577A1

(19) United States

(12) Patent Application Publication (10) Pub. No.: US 2007/0023577 A1

Jones (43) Pub. Date: Feb. 1, 2007

(54) INCREASING THE PERFORMANCE OF AIRCRAFT ON-BOARD INERT GAS GENERATING SYSTEMS BY TURBOCHARGING

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(21) Appl. No.: **10/802,968**

(22) Filed: **Mar. 16, 2004**

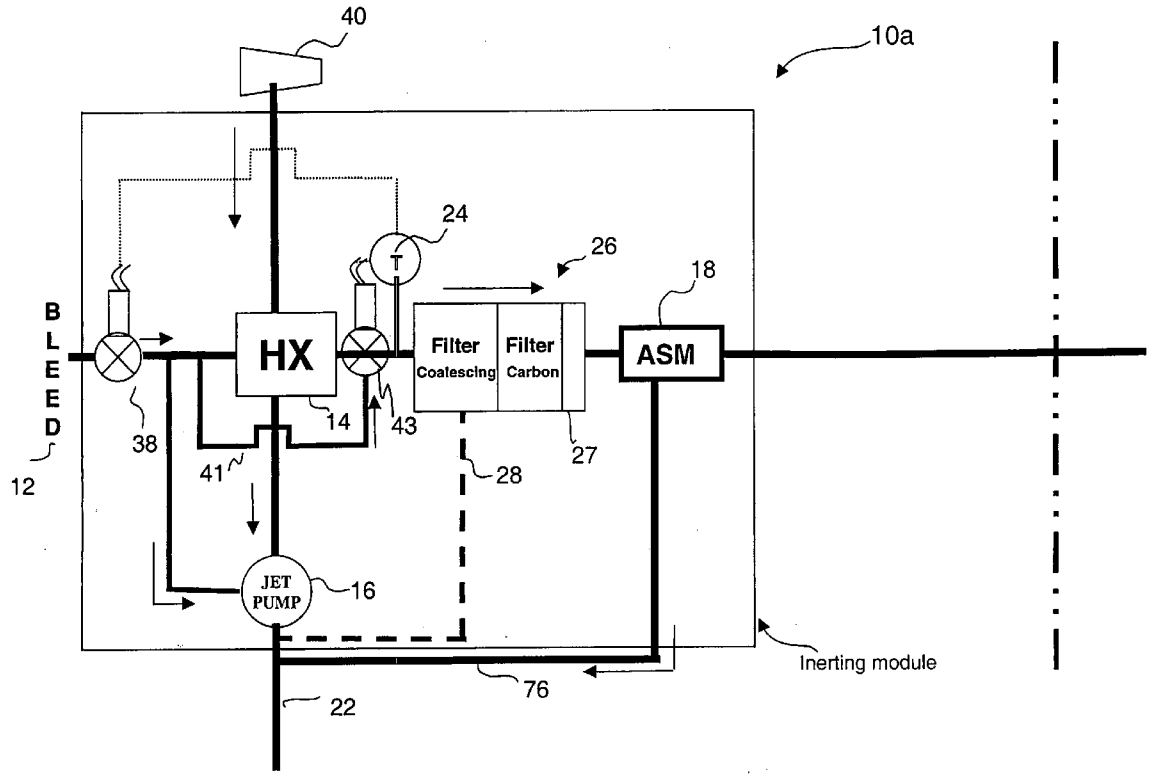
Publication Classification

(51) **Int. Cl.**
B64D 37/02 (2006.01)

(52) **U.S. Cl.** ..... **244/135 R**

(57) **ABSTRACT**

A modular, on-board, inert gas generating system for aircraft is disclosed in which main components such as a heat exchanger, filter, air separation module, and turbocharger are provided in a modular unit sized to provide a variable flow of nitrogen-enriched air to the aircraft spaces to be inerted. For different inert gas requirements, for example in larger aircraft, multiple modular units may be provided without redesigning the basic system. A method for inerting fuel tanks, cargo holds and other void spaces using the modular approach and turbocharged engine bleed air is also disclosed.



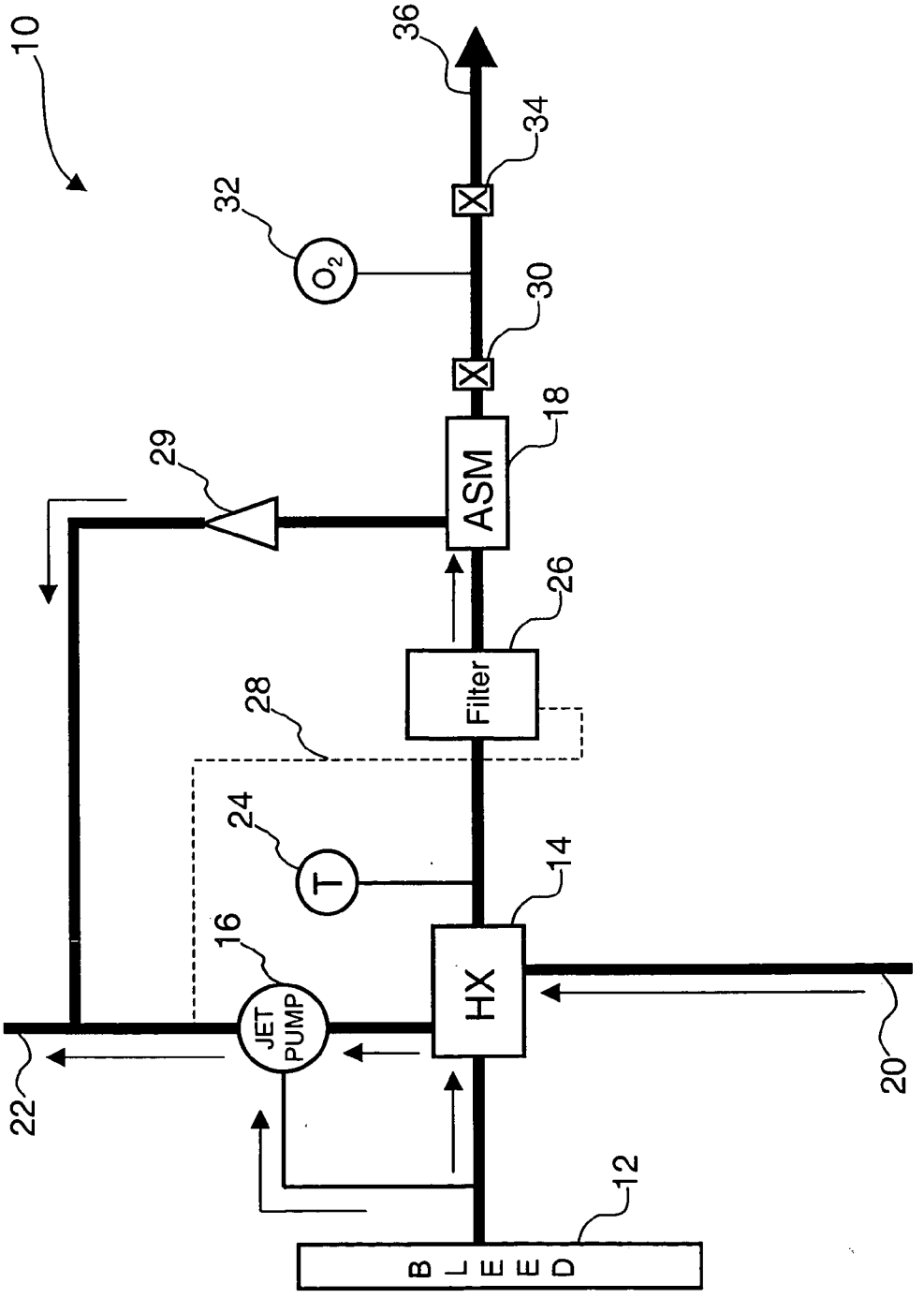

10
36
34
32
O_2
30
18
ASM
29
26
Filter
28
24
T
14
16
HX
JET PUMP
22
20
12
BLEED

Fig. 1

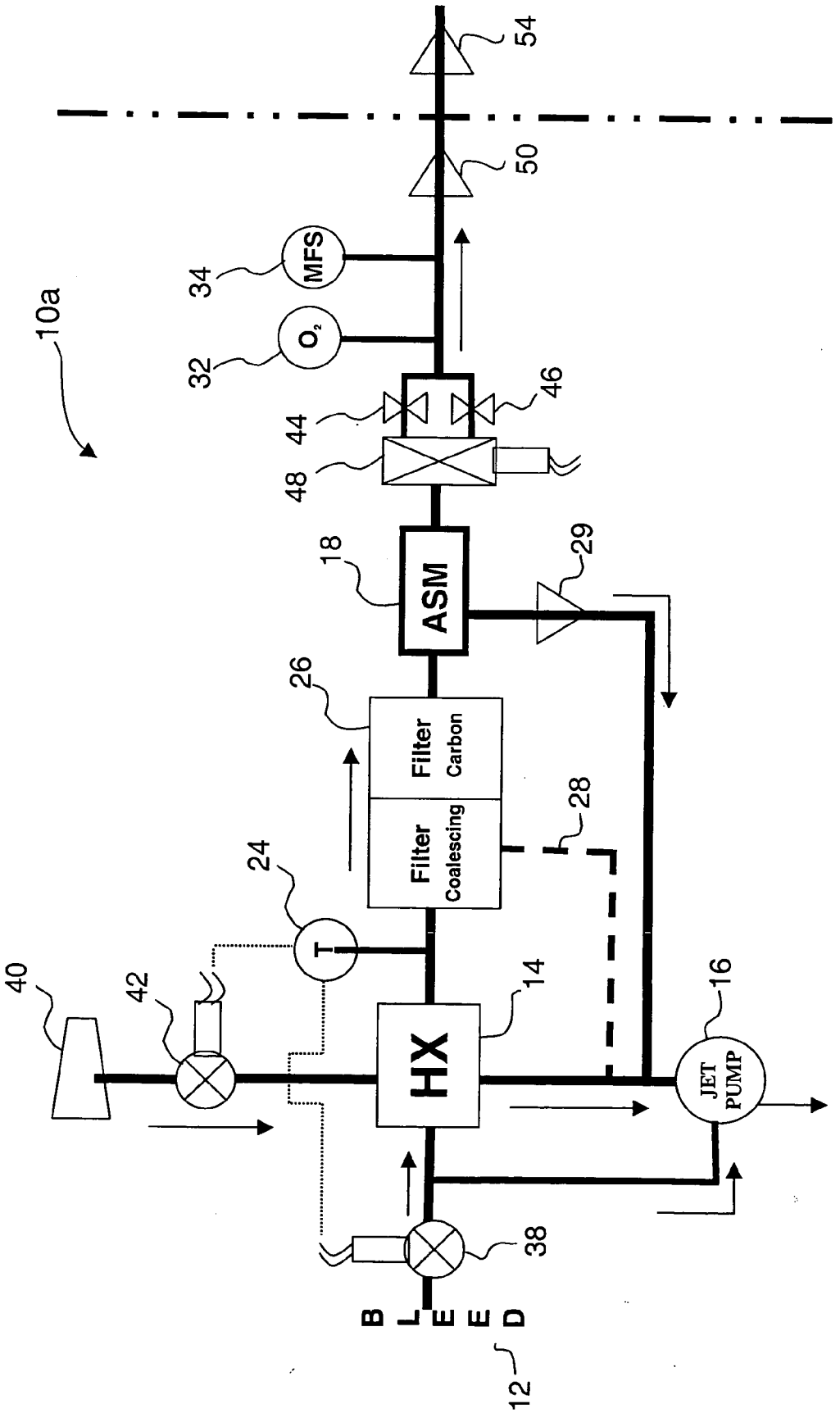

10a
54
50
34
MFS
32
O2
46
44
48
18
ASM
29
26
Filter Carbon
Filter Coalescing
28
24
T
40
42
14
HX
16
JET PUMP
38
BLEED
12

Fig. 2

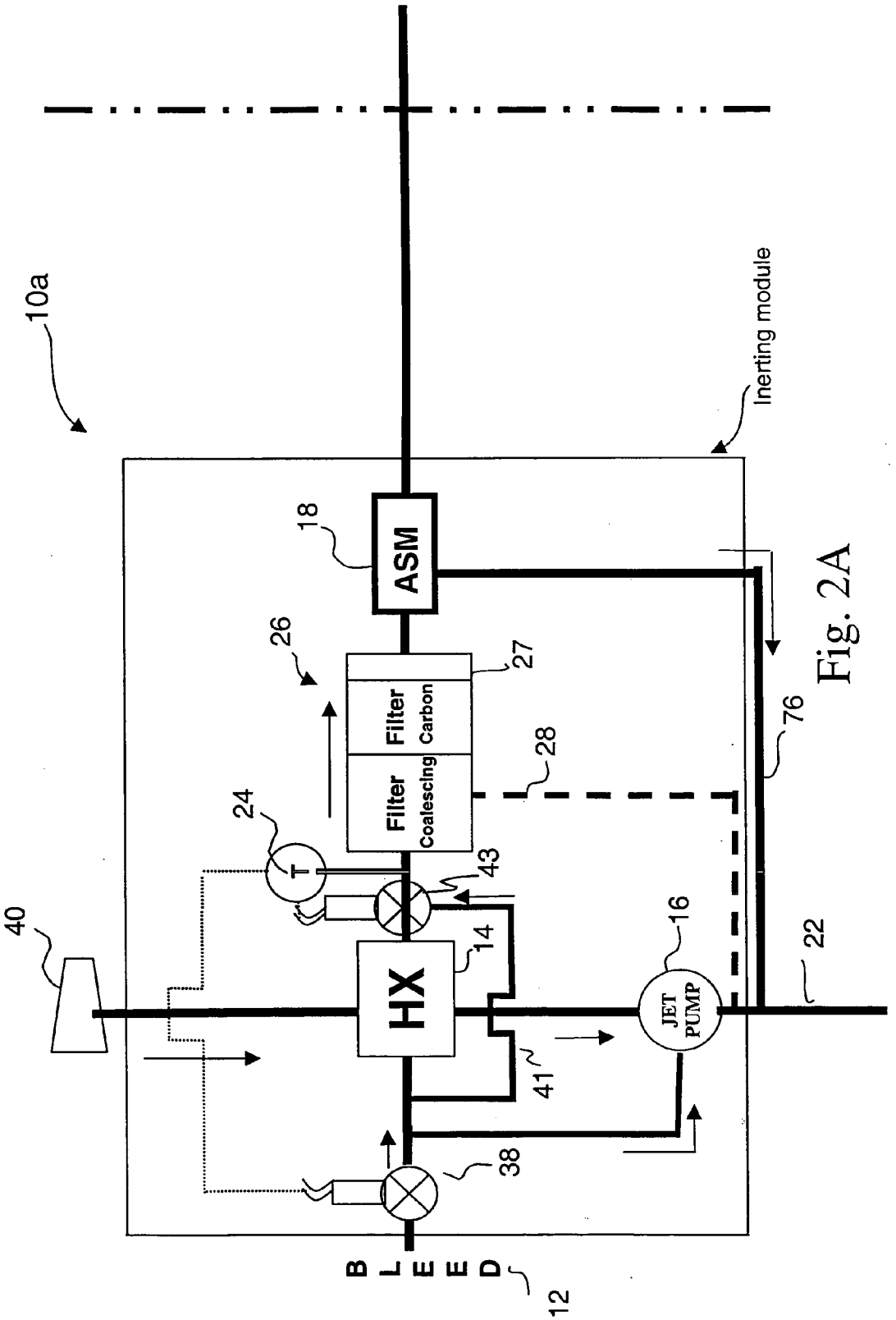

10a
Inerting module
18
ASM
26
27
Filter Carbon
Filter Coalescing
28
76
24
T
43
40
16
14
HX
JET PUMP
22
41
38
B L E E D
12

Fig. 2A

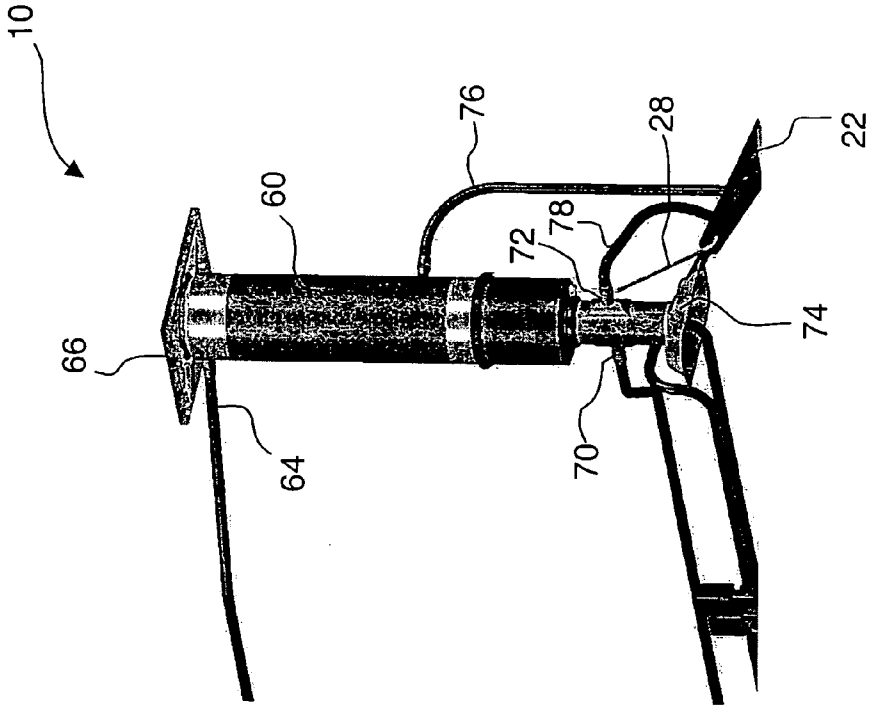


Fig. 4

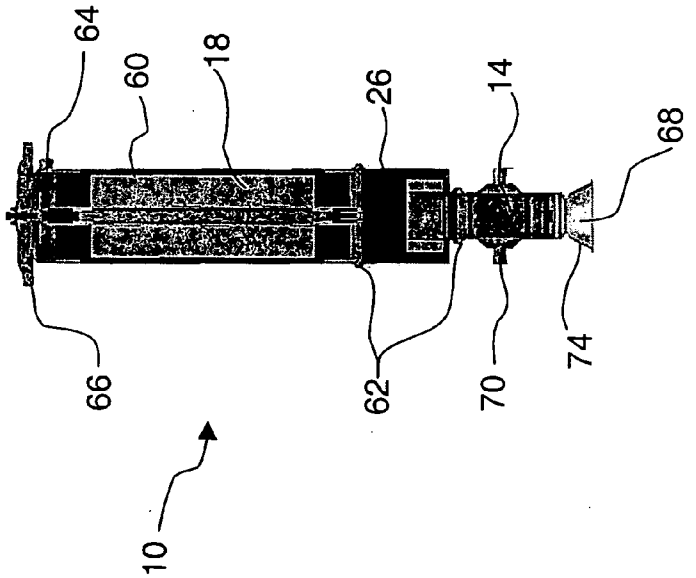


Fig. 3

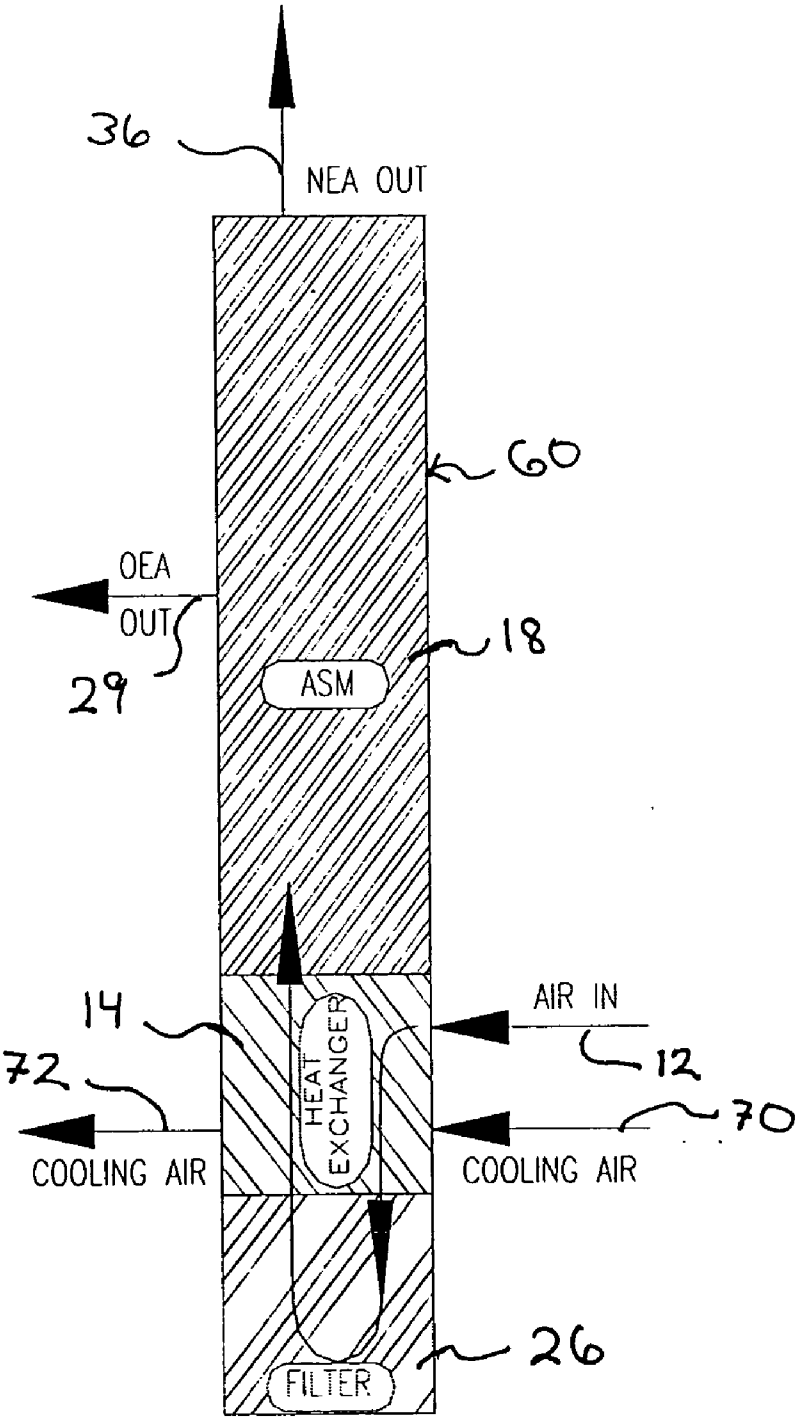

36
NEA OUT
60
OEA
OUT
29
18
ASM
14
AIR IN
12
72
HEAT EXCHANGER
70
COOLING AIR
COOLING AIR
26
FILTER

FIG. 3A

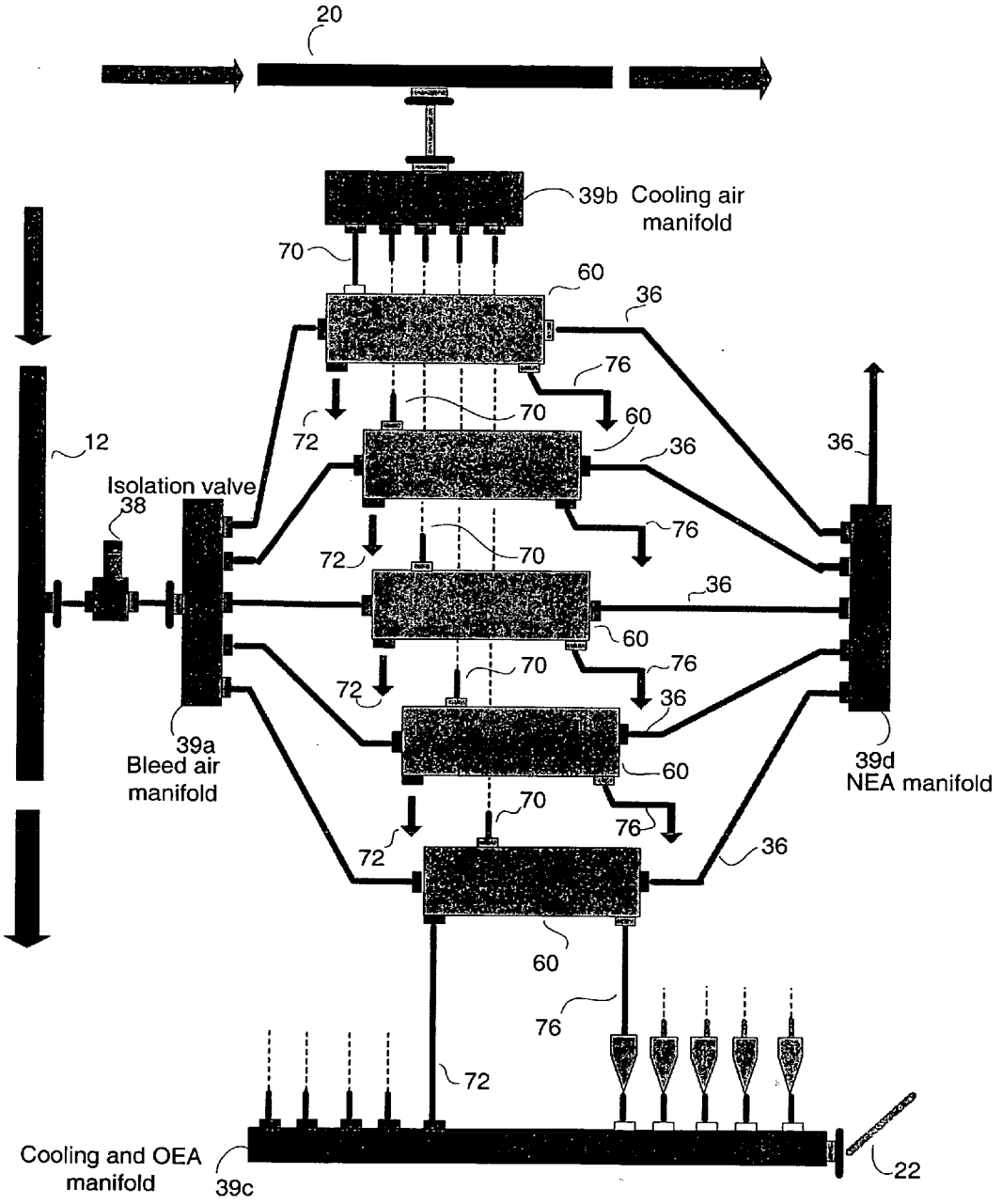

20
39b Cooling air manifold
70
60
36
76
72
12
Isolation valve
38
39a
Bleed air
manifold
39d
NEA manifold
Cooling and OEA
manifold
39c
22

Fig. 3B

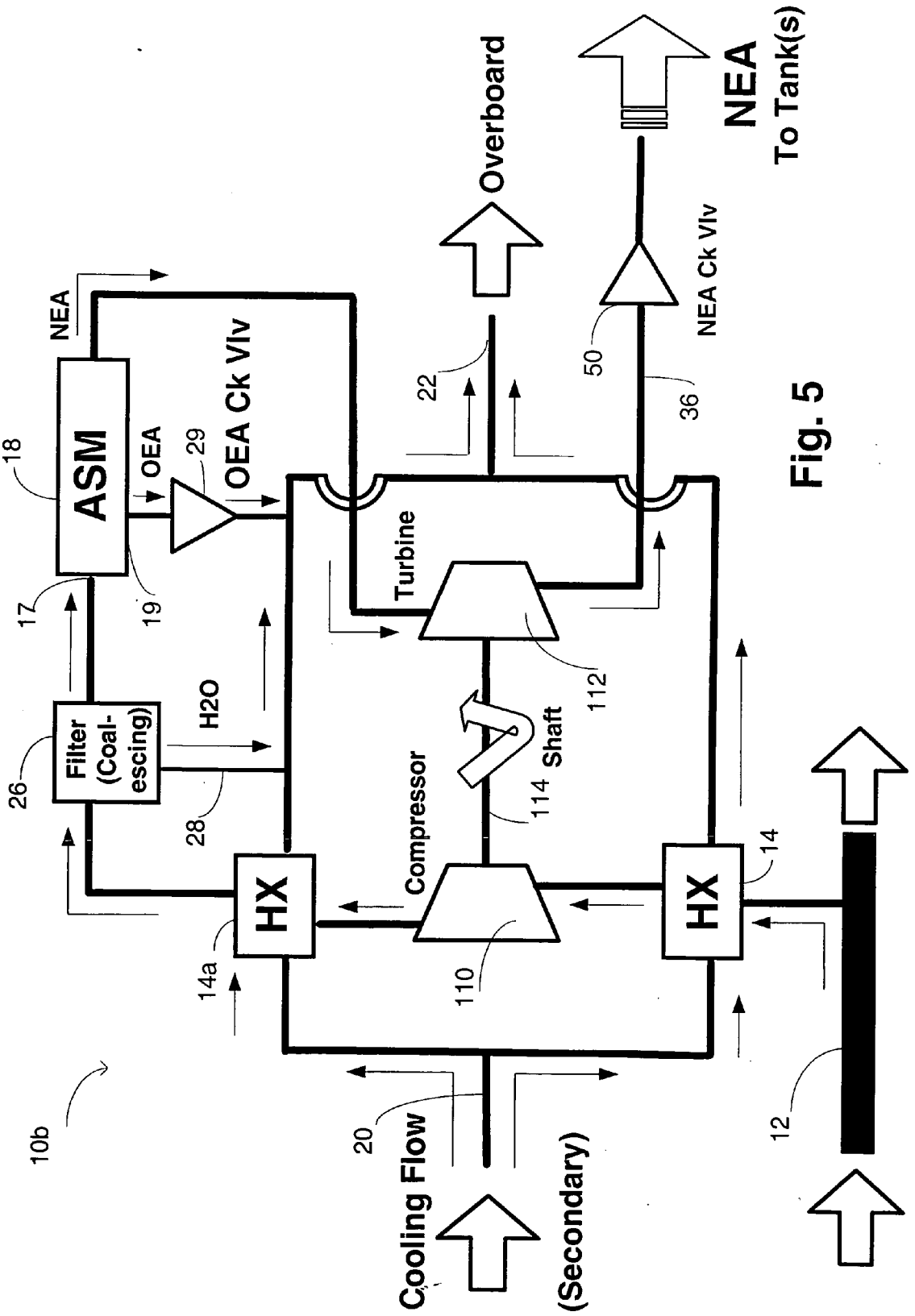

10b
Cooling Flow (Secondary)
20
HX
14a
HX
14
12
Compressor
110
Turbine
112
Shaft
114
Filter (Coal-escing)
26
28
H2O
ASM
18
17
19
NEA
OEA
29
OEA Ck Vlv
22
Overboard
50
NEA Ck Vlv
36
NEA
To Tank(s)

Fig. 5

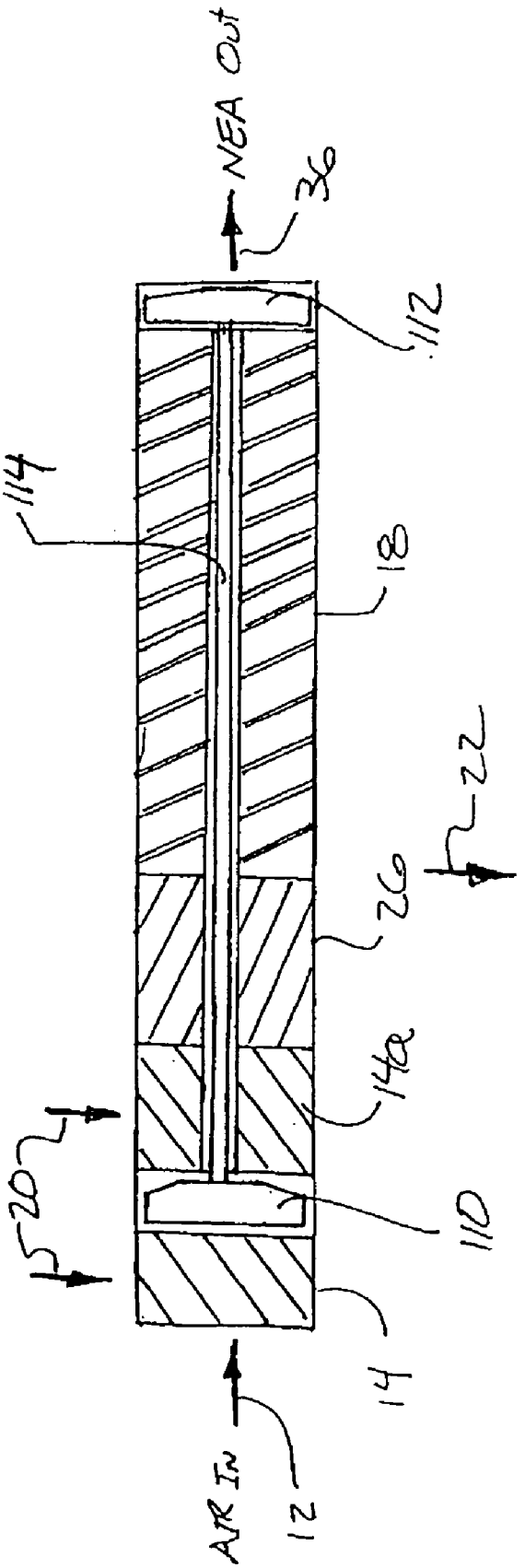


FIG. 6

INCREASING THE PERFORMANCE OF AIRCRAFT ON-BOARD INERT GAS GENERATING SYSTEMS BY TURBOCHARGING

[0001] This application claims priority pursuant to 35 U.S.C. §120 to U.S. application Ser. No. 10/308,973, filed Dec. 3, 2002, which application is based on U.S. Provisional Patent Application Ser. No. 60/416,177, filed Oct. 4, 2002, and to U.S. application Ser. No. 10/308,971, filed Dec. 3, 2002, which application is based on U.S. Provisional Application No. 60/392,909, filed Jun. 28, 2002, the specifications of which are incorporated herein by reference in their entireties

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] This invention relates to a method and apparatus for improving aircraft safety. More specifically, it relates to an apparatus and method for preventing combustion in aircraft fuel tanks and cargo spaces by supplying inert gas using turbocharged engine bleed air.

[0004] 2. Description of the Related Art

[0005] Military aircraft have used On-board Inert Gas Generating Systems (OBIGGS) for some years to protect against fuel tank explosions due to undesired phenomena, such as penetration from small arms fire. Military aircraft are not the only aircraft that would benefit from OBIGGS. For example, investigations into the cause of recent air disasters have concluded that unknown sources may be responsible for fuel tank ignition and explosion. Subsequently, OBIGGS has been evaluated as a way to protect commercial aircraft against such fuel tank explosions started by unknown ignition sources.

[0006] OBIGGS protects against fuel tank explosions by replacing the potentially explosive fuel/air mixture above the fuel in the tanks (the ullage) with an inert gas (usually nitrogen—N_2). The nitrogen is generated by separating oxygen from local, ambient air and pumping the inert product into the tanks.

[0007] In previous applications, OBIGGS has proved relatively unreliable, heavy, and costly for both initial acquisition and operation in aircraft. Furthermore, military aircraft systems often have the strict requirements that derive from military flight profiles that include high-rate descent from high-altitude flight. Applications of OBIGGS to commercial aircraft would benefit by considering the fact that a typical flight profile for the commercial application has a less demanding requirement for the system because commercial aircraft do not operate at the same flight profiles of military aircraft.

[0008] Thus, there is a need for a gas generation and inerting system that minimizes the quantity and complexity of sub-components (particularly moving parts). The system should also consider a typical commercial aircraft flight profile and take advantage of the reduced descent rates (compared to military aircraft).

SUMMARY OF THE INVENTION

[0009] The present invention provides an apparatus and method for reducing the possibility of combustion in aircraft fuel tanks by replacing air in the ullage of the fuel tank with an inert gas that has been separated from the engine bleed air. The apparatus includes an air separation module, a filter, a heat exchanger, and a rotary compressor and turbine (or "turbocharger"). In this invention, the turbine is powered by a flow of nitrogen-enriched air from the air separation module and drives the compressor through a shaft and the compressor creates an increased engine bleed air pressure for the air separation module. In one preferred embodiment, a single housing contains at least the air separation module, filter, heat exchanger, and turbocharger. The air separation module can be mounted in a center-section of the housing, may be a canister-type design, may include a replaceable cartridge, and may be a hollow-fibre permeable membrane configuration.

[0010] The method of the present invention includes displacing the atmosphere in the ullage of a fuel tank with a non-combustible gas. In one embodiment, the method comprises compressing engine bleed air and subsequently supplying it to an air separation module that generates a non-combustible nitrogen-enriched air. This method also includes providing at least one modular unit capable of producing a flow of nitrogen-enriched air at a predetermined flow rate and oxygen purity level; sizing the modular unit based on compressed engine bleed air; grouping a number of the modular units sufficient to meet the aircraft's inert gas requirement with a combination of said predetermined flow rates. Preferably, the introduction of high-purity non-combustible gas occurs during take-off and level flight of an airplane and introduction of the lower-purity gas occurs during descent of the airplane.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0011] The foregoing and other aspects and advantages of the present invention will be better understood from the following detailed description when read in conjunction with the drawings, in which:

[0012] FIG. **1** is a schematic view of one embodiment of a modular on-board inert gas generating system according to the present invention;

[0013] FIG. **2** is a schematic view of an alternative embodiment of the invention;

[0014] FIG. **2**A is a schematic view of an alternative embodiment of the invention based on the embodiment in FIG. **2**;

[0015] FIG. **3** is a cross-sectional view of a modular system according to the invention;

[0016] FIG. **3**A is a cross-sectional view of another modular system according to the invention;

[0017] FIG. **3**B is a schematic view of a modular system employing multiple modules according to the invention;

[0018] FIG. **4** is a perspective view of an embodiment of the invention;

[0019] FIG. **5** is a schematic view of an additional alternative embodiment of the invention; and

[0020] FIG. **6** is a cross-sectional view of an alternative embodiment of the invention of FIG. **5**.

[0021] Like numerals refer to similar elements throughout the several drawings.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0022] As illustrated in FIG. **1**, system **10** according to one embodiment of the invention uses aircraft engine bleed air **12** that is supplied under conditions of elevated temperature and elevated pressure to generate gas for inerting aircraft fuel tanks. It will be appreciated by persons skilled in the art that the present invention is equally useful for inerting cargo holds and other void spaces. Engine bleed air is typically supplied from taps in the turbine section of the aircraft engines at temperatures in the range of 300° F.-400° F. and at pressures in the range of 10-45 psig depending on turbine rotation speed. It is typically used as a utility source of pressurized air on board aircraft. System **10** operates whenever bleed air is available and, thus, avoids the use of compressors or complex control valves.

[0023] Bleed air **12** is introduced at one end of system **10** and nitrogen-enriched air (NEA) is produced from the other end. Bleed air **12** flows under pressure and temperature to heat exchanger **14**. A branch passage taps off a small portion of the pressurized bleed air to power jet pump **16**. For efficient operation, depending on size, air separation module (ASM) **18** requires input air temperature in the range of less than 200° F. Heat exchanger **14** is therefore used to control the temperature of the engine bleed air fed into ASM **18**. Secondary cooling flow **20** is provided to heat exchanger **14** for this purpose. Jet pump **16** may be utilized to provide the cooling flow, which is vented overboard at outlet **22**. If desired, temperature sensor **24** may be positioned down stream of the heat exchanger to monitor output temperature and control secondary flow **20**, and/or jet pump **16** based on the monitored temperature.

[0024] The pressurized air flow from heat exchanger **14** enters filter **26**. Filter **26** may comprise multiple filters, such as a coalescing filter to remove particulate contaminants and moisture, and a carbon filter for removing hydrocarbons. Filter drainpipe **28** drains removed moisture and directs it overboard at outlet **22**.

[0025] After leaving filter **26**, the conditioned air enters ASM **18**. Preferably ASM **18** provides a total flow in the range of approximately 2-4 lbs./min., with a pressure drop of a few psig. Depending on aircraft requirements or other system limitations, other sizes of ASM may be selected. Using conventional hollow-fiber technology, ASM **18** separates the air into oxygen-enriched air (OEA) and nitrogen-enriched air (NEA). In a preferred embodiment, the ASM provides nitrogen-enriched air at flow rates between about 0.5 lbs./min. up to about 2 lbs./min. At the lower flow rates a greater nitrogen purity can be achieved, with oxygen making up only about one percent by volume of the nitrogen-enriched air. At higher flow rates the oxygen content of the nitrogen-enriched air is typically about nine to ten percent by volume. Oxygen-enriched air is piped from ASM **18** overboard through outlet **22**. Check valve **29** is provided in the overboard OEA line to prevent back-flow. Nitrogen-enriched air produced by ASM **18** is directed to the fuel tank and/or cargo hold. Orifice **30** is preferably provided downstream of ASM **18** to control the flow rate through the ASM. If desired, a stepped or variable orifice may be provided to control flow rate as described in greater detail below. Optional oxygen sensor **32** may be configured to provide signals representing oxygen content of the NEA and may be utilized for orifice control. Another optional sensor that may be provided is mass air flow sensor **34**. This may be an automotive-style hot wire mass-flow sensor. System outlet **36** directs the NEA to the fuel tank ullage and optionally to aircraft cargo hold as desired.

[0026] In an alternative embodiment illustrated in FIG. **2**, engine bleed air first passes through an isolation valve **38**. Isolation valve **38** permits system **10***a* to be isolated from the bleed air and, if desired, may be controlled by signals from temperature sensor **24**. In this embodiment secondary cooling air is provided by an NACA scoop **40**. A ram air scoop may also be used to provide secondary cooling air. Secondary cooling air passes through temperature modulation valve **42**, which also may be controlled by temperature sensor **24**. Alternatively, temperature control of the primary bleed air flow may be achieved through a modulated by-pass flow arrangement (described in detail with reference to FIG. **2**A). Secondary cooling air obtained from scoop **40** typically will have a temperature ranging from about −60° F. to 110° F. or greater, depending on the environmental conditions experienced by the aircraft. The secondary air flow again passes through heat exchanger **14**, optionally assisted by jet pump **16**. Operation of filter **26** and ASM **18** is essentially as described above. In this exemplary embodiment, an orifice is provided with two steps or as a stepped choke valve. For example, a first orifice **44** presents an opening of a first size and second orifice **46** presents an opening of a second size. The orifice seen by the NEA flow is determined by orifice selector **48**, which may be a solenoid actuated valve, or other flow control device. The orifice selector is utilized to control the flow rate as described below. NEA exiting the system optionally passes through a first check valve **50**, after which it is directed through the fuel tank or cargo hold bulkhead **52**. A second check valve **54** may be provided before the NEA is injected into the fuel tank or cargo hold.

[0027] The embodiments of the present invention as described above take advantage of characteristics of ASM **18** to produce higher purity NEA (lower O_2 content) when flow is restricted. Flow may be restricted using down stream orifices or back pressure. In the embodiments utilizing the variable orifices, preferably two different restrictions are used. Other numbers might be used if warranted by system performance and requirements. A high restriction provides low flow and high purity, and a low restriction provides a higher flow and low purity. These embodiments rely on existing aircraft vent systems to provide normal tank inward and outward venting while mixing the NEA in the tank ullage or cargo hold space. A high NEA outlet purity combined with a longer flow time will result in an ullage gas with a higher NEA purity. During the climb and cruise portion of a flight, the high purity (low flow) NEA is delivered to the fuel tank. This stores a high nitrogen concentration gas in the fuel tank ullage. During the descent portion of the flight, in which more air vents into the fuel tank as altitude decreases, the orifice is set to provide a lower restriction and higher flow, thus producing a lower purity NEA but at greater volume. Because high purity NEA is already stored in the fuel tank ullage, however, air forced in through tank vents during descent simply serves to decrease the nitrogen purity. When supplemented by the high flow low purity NEA provided during descent, the ullage main-

tains a nitrogen purity sufficient to maintain the inert condition. Given the typical commercial flight profile, although the nitrogen level decreases during aircraft descent, with an appropriately sized system the nitrogen levels can be maintained at an inert level through aircraft landing.

[0028] In further alternative embodiments, the system of the present invention may be designed to eliminate components such as sensors, variable orifices and the jet pump, thereby further simplifying the system and increasing reliability. In one embodiment, orifices **44** and **46**, and selector valve **48** are eliminated by sizing the system to meet extreme operating conditions at all times. This may be accomplished by sizing the system to provide sufficient NEA during climb and cruise operation, so that the oxygen level in the ullage remains at below a critical level during descent and landing. Typically, the critical oxygen level will be less than about 10%-14% oxygen, more particularly less than about 12% oxygen. For example, if a system using the multiple orifices as described above were sized to provide NEA at 0.5 lbs/min with 1% oxygen curing climb and cruise, in eliminating the orifices the system may be sized to provide NEA continuously with about 2% oxygen at a slightly higher flow rate. Factors considered include fuel tank size and aircraft flight profile. The system is then designed to, in effect, store high purity NEA in the fuel tank ullage so that upon inflow of air during descent the critical oxygen level is not exceeded before aircraft operation ceases after landing.

[0029] In another embodiment, jet pump **16** may be eliminated by sizing the system to rely only on ram air from scoop **40** for secondary cooling flow. This has the advantage of further simplifying the system by removing another component with moving parts. This advantage must be balanced with the need for additional ground service equipment to provide cooling for testing and maintenance when the aircraft is not in flight.

[0030] Another variation involves the removal of temperature sensor **24** and temperature modulation valve **42**, or primary bypass flow control if this is the solution used. In this embodiment, a maximum hot temperature is assumed based on the expected operating conditions. In typical commercial flight profiles in most parts of the United States this would be about 200° F. ASM **18** is then sized to provide the required purity of NEA based on an input temperature at the assumed maximum.

[0031] With the system sized to produce a minimum known NEA flow and purity, additional sensors such as oxygen sensor **32** and mass flow sensor **34** also may be eliminated. These alternatives for reducing system complexity may be employed alone or in any combination. Exact sizing of the system in the various alternatives described will depend upon the inerting needs and flight profile of the particular aircraft in which the system is to be mounted. A person of ordinary skill in the art will be able to match the system to the aircraft inerting needs based on the disclosure contained herein.

[0032] In FIG. **2**A, an alternative embodiment of the invention uses primary heat exchanger bypass flow control to control the temperature of the air entering the ASM inlet. Bypass valve **43** controls the air flow going into heat exchanger **14**. Bypass valve **43** modulates incrementally between being closed and directing all the air flow through heat exchanger **14** and being open, and allowing the unrestricted bypass of heat exchanger **14**. The air flow allowed to bypasss heat exchanger **14** follows bypass conduit **41** to the air conduit upstream of temperature sensor **24** and filter **26**. Temperature sensor **24** is, therefore positioned to determine the temperature of the air entering filter **26** and ASM **18**. That temperature is used to direct bypass valve **43** to open and allow an appropriate amount of air to flow around heat exchanger **14** so that the temperature of the air entering filter **26** and ASM **18** is within a desired temperature range. Bypass valve **43** is preferably a phase-change direct acting mechanical sensor and flow control valve. Temperature modulation valve **42** (FIG. **1**) and the corresponding control capability are added for additional temperature control if desired.

[0033] As also shown in FIG. **2**A, filter **26** may include three sections. As previously described, filter **26** may contain a coalescing and solid containment HEPA filter section, for removing particles and water, and a carbon filter section for hydrocarbon removal. In this embodiment, the filter also includes an additional HEPA filter **27**, similar to the first filter section, to prevent carbon filter bits from flaking off the previous filter section and traveling to ASM **18**. Subcomponents downstream of ASM **18** may be eliminated as shown in FIG. **2**A to reduce cost and complexity. In this embodiment the OEA outlet **76** exits the module to combine with the cooling air flow downstream of the jet pump **16**. The filter drainpipe **28** also merges with the cooling air flow downstream of the jet pump **16**, but does so within the modular assembly. The embodiments shown in FIG. **2**A are otherwise as described with reference to FIG. **2**.

[0034] In a further preferred embodiment of the invention, system **10** is provided as a modular assembly as shown in FIGS. **3** and **4**. In one embodiment, components such as ASM **18**, filters **26** and heat exchanger **14** are provided within common housing **60**. Alternatively, housing **60** may encompass only the ASM and filters, with the heat exchanger mounted thereon to form a single modular unit. For example, band clamps **62** may be provided between ASM **18** and filter **26**, and filter **26** and heat exchanger **14** to secure the components together.

[0035] At the outlet side, NEA outlet port **64** communicates with the fuel tank ullage. An upper mounting bracket **66** may be provided for securing the unit in an aircraft cargo hold or other appropriate space. At the inlet side, inlet **68** receives engine bleed air **12** and directs it toward heat exchanger **14**. Secondary air inlet **70** provides a secondary cooling air flow and outlet **72** communicates with overboard outlet **22**. Lower mount **74** also may be provided for securing the unit. As shown in FIG. **4**, OEA outlet pipe **76**, secondary air flow pipe **78** and filter drainpipe **28** all lead to overboard outlet **22**. Oxygen and mass flow sensors may be provided as part of the modular unit, or separately provided, depending on space and installation requirements. Similarly, the orifice and associated control valve may be included in the modular system.

[0036] The single-housing design thus facilitates a simple, lightweight configuration that minimizes both acquisition and in-service costs by eliminating many of the sub-components of a typical military application. By eliminating sub-components the single-housing design will also minimize installation costs when compared to the current distributed component approach. The single-housing design

also improves reliability. In preferred embodiments, the filter is arranged to be an easily replaceable, disposable cartridge.

[0037] FIG. **3**A shows an additional preferred embodiment of a modular assembly with components contained within a housing **60**. In this embodiment, the arrangement of components ASM **18**, filter **26**, and heat exchanger **14** is changed so that heat exchanger **14** is between filter **26** and ASM **18**. This provides better access to filter **26** for maintenance purposes. FIGS. **1** and **2** still describe the function of this embodiment, with the internal plumbing of the various air flows configured to accommodate the component arrangement in FIG. **3**A.

[0038] Using the modular approach as described, a module may be designed to provide a particular, predetermined NEA flow rate (where a predetermined flow rate includes a predetermined range of flow rates) and multiple modules may be employed to meet higher flow rate requirements. For example, the individual module may be sized to meet the inerting requirements of a particular customer's smallest aircraft based on the size of the fuel tank, the time available to inert the tank, and the requirements for inerting the tank based on flight profiles. For larger aircraft of the same customer, instead of redesigning the module, multiple modules may be employed to meet the higher flow rate requirements. In this manner, inventory and maintenance costs are reduced because only one type of equipment is required to service an entire fleet of aircraft of different sizes.

[0039] FIG. **3**B shows a preferred embodiment of a modular assembly employing multiple modules. In this embodiment five housings **60** each contain an ASM **18**, heat exchanger **14**, and filter **26**, as depicted in FIG. **3**A. These housings are plumbed together in parallel. Bleed air **12** is provided to each heat exchanger **14** through a single isolation valve **38** and a manifold **39***a*. Similarly, manifold **39***b* provides cooling flow **20** to heat exchanger **14** and manifold **39***c* collects both the OEA and the post-heat exchanger cooling air flow and directs it overboard **22**. NEA is collected by manifold **39***d* and directed to system outlet **36** and the fuel tank ullage.

[0040] A further embodiment of the invention boosts system flow performance by tapping bleed air from the high-pressure segment of the aircraft's Air Cycle Machine (ACM). Aircraft environmental control systems often use an air compressor to increase bleed air pressure and temperature in the ACM. This can be used alone or in conjunction with a turbocharger to apply a significantly higher pressure to the ASM. The higher pressure increases the flow and/or purity performance of the ASM, resulting in a smaller and less costly ASM for equivalent system performance. Alternatively, for larger aircraft, fewer ASM's may be required using this embodiment, again resulting in reduced costs and reduced complexity.

[0041] In an additional alternative embodiment illustrated in FIG. **5**, system **10***b* performance is improved by boosting the pressure of the air supplied to ASM **18** using a rotary compressor **110** (a part of a "turbocharger"). For ASMs using hollow fiber membrane separators, higher supply air pressure at ASM inlet **17** (relative to the oxygen enriched air pressure at OEA port **19**) allows reducing the ASM size while retaining performance equivalent to an ASM with unboosted supply air pressure. This allows a smaller modular OBIGGS to supply the same predetermined NEA flow.

[0042] Producing higher inlet pressures at the ASM inlet usually requires the addition of a compressor, which must be powered by either an electric motor or other power source. Such power is both expensive to produce and difficult to provide for OBIGGS retrofit applications. In this embodiment of the invention, rotary compressor **110** is powered by a turbine **112** that uses the NEA flowing from ASM **18** as its energy source.

[0043] As in FIG. **1**, engine bleed air **12** and secondary cooling flow **20** pass directly to heat exchanger **14**. Secondary cooling flow **20**, provided by means of a ducted ambient air flow, again passes through heat exchanger **14**, but then passes directly overboard through overboard outlet **22**. Secondary cooling flow **20** is also directed to a heat exchanger **14***a*. Heat exchanger **14** cools engine bleed air **12** as it passes through. Compressor **110** compresses the cooled engine bleed air and heat exchanger **14***a* cools the now-compressed engine bleed air. Heat exchangers **14** and **14***a* are sized to ensure that the bleed air temperature within the compressor is kept relatively low (especially at its discharge) and that the temperature of the air supplied to ASM inlet **17** does not exceed optimum ASM operating limits. Heat exchangers **14** and **14***a* may be a bifurcated heat exchanger, or two separate heat exchangers, and may be separate or integral to the OBIGGS module. The operation of filter **26** and ASM **18** is essentially as described above.

[0044] The NEA produced by ASM **18** flows through turbine **112**, which is mounted on a common shaft **114** within compressor **110**. Flowing NEA through turbine **112** serves to reduce the NEA pressure and temperature before delivering NEA to the fuel tank ullage or other location. Flowing NEA through turbine **112** also yields the energy associated with the NEA pressure and flow to turbine **112** which, in turn, transfers the energy to compressor **110** through shaft **114**. A preferred embodiment of the invention using the turbocharger as described is shown in cross-section in FIG. **6**.

[0045] The size of ASM **18** may be reduced by operating the unit at a higher pressure than is available from bleed air **12**. Higher ASM operating pressure is achieved by using the energy in the NEA, associated with its pressure and flow, to further compress the air supplied to the ASM above that of the bleed air pressure. The higher operating pressure improves the performance of the ASM (and potentially its efficiency) due to its increased pressure gradient to the Oxygen Enriched Air (OEA) area. The higher ASM operating pressure is achieved without adding a compressor powered by some external additional means, thus reducing the overall size of the OBIGGS. In a further preferred embodiment, a second rotary compressor, coaxial to rotary compressor **110** and powered by OEA, provides additional power to further compress the engine bleed air.

[0046] In another preferred embodiment, for some flight profiles (such as when the descent portion is relatively steep) the turbocharger is fitted with a co-axial boost motor. This may be powered by electrical or other means, and allows the embodiment to provide additional NEA flow to the fuel tank or cargo area. This embodiment allows the option of obtaining both high flow and high purity NEA during conditions when tank purity could be reduced significantly, such as during the descent. And this embodiment achieves this while using a relatively small ASM, provided the additional power

is available. This embodiment may also be useful in military aircraft OBIGGS applications to provide increased system performance during some portions of the flight.

[0047] A further embodiment of the invention boosts system flow performance by tapping bleed air from the high-pressure segment of the aircraft's Air Cycle Machine (ACM). Aircraft environmental control systems often use an air compressor to increase bleed air pressure and temperature in the ACM. This can be used alone or in conjunction with a turbocharger to apply a significantly higher pressure to the ASM. The higher pressure increases the flow and/or purity performance of the ASM, resulting in a smaller and less costly ASM for equivalent system performance. Alternatively, for larger aircraft, fewer ASM's may be required using this embodiment, again resulting in reduced costs and reduced complexity.

[0048] The apparatus and method of the present invention provide a more satisfactory OBIGGS for a number of reasons. The modular approach to the design of the equipment reduces acquisition and installation costs. The cartridge-style filter with quick-release installation features, together with high OBIGGS reliability due to reduced complexity, also reduces operational costs. The methodology of increasing NEA purity in the tank ullage during cruise, together with increased flow/lower purity NEA injection during descent gives all of the benefits of a traditional OBIGGS system with a much smaller, lighter, less costly, more reliable system.

1. An inerting system, comprising:

at least one modular unit comprising a housing containing:

an air separation module configured to receive an air flow from a pressurized air source, said air separation module generating a flow of nitrogen-enriched air from said air flow;

a turbine communicating with said flow of nitrogen-enriched air and powered thereby; and

a compressor disposed in said air flow between the air separation module and said source and said compressor being rotated by said turbine to increase the pressure of said air flow to the air separation module.

2. The inerting system of claim 1, wherein the air separation module is sized to provide predetermined flow rate and purity level of the nitrogen-enriched air based on the increased air pressure.

3. The inerting system of claim 1, further comprising a filter disposed between the air separation module and pressurized air source.

4. The inerting system of claim 3, further comprising a first heat exchanger mounted in said modular unit in communication with said filter and configured to be connected to the compressor, thereby providing a temperature conditioned increased air pressure to the filter.

5. The inerting system of claim 4, further comprising a second heat exchanger mounted in said modular unit in communication with said compressor and configured to be connected to the source of pressurized air, thereby providing a temperature conditioned pressurized air to the compressor.

6. The inerting system of claim 4, further comprising:

a source of cooling air for said heat exchanger;

a temperature sensor configured to monitor a temperature of the temperature conditioned increased air pressure; and

a temperature modulation valve configured to control a flow of the cooling air based on said temperature.

7. The inerting system of claim 4, further comprising:

a source of cooling air for said heat exchanger;

a temperature sensor configured to monitor a temperature of the temperature conditioned increased air pressure; and

a jet pump configured to control a flow of the cooling air based on said temperature.

8. The inerting system of claim 5, wherein the first heat exchanger communicates with a source of cooling air for cooling the compressed air and the second heat exchanger communicates with the source of cooling air for cooling the pressurized air.

9. The inerting system of claim 8, wherein the first and second heat exchangers and air separation module are sized to meet the predetermined flow rate and purity level without a temperature sensor in the air flow through the system.

10. The inerting system of claim 8, wherein the cooling air is provided by a ram air source.

11. The inerting system of claim 8, wherein the cooling air is provided by an National Advisory Committee on Aeronautics (NACA) scoop.

12. The inerting system of claim 1, wherein the source of pressurized air comprises aircraft engine bleed air.

13. The inerting system of claim 12, wherein the system is mounted in an aircraft having a requirement for nitrogen-enriched air inerting gas, said system comprising a number of said modular units producing a combined flow rate sufficient to meet said requirement.

14. The inerting system of claim 13, wherein said air separation module in each modular unit is sized, in combination with all other modular units, to meet the predetermined flow rate and purity level based on the increased air pressure.

15. The inerting system of claim 13, further comprising a first heat exchanger mounted in said modular unit in communication with said filter and configured to be connected to the compressor, thereby providing a temperature conditioned increased air pressure to the filter.

16. The inerting system of claim 15, further comprising a second heat exchanger configured to receive the engine bleed air, said heat exchanger communicating with the compressor to provide a flow of temperature conditioned air thereto.

17. The inerting system of claim 16, wherein said first heat exchanger, said second heat exchanger, and said air separation module in each modular unit are sized, in combination with all other modular units, to meet the predetermined flow rate and purity level based on the increased air pressure.

18. A modular system for inerting spaces in aircraft, comprising at least one modular unit, wherein:

said at least one modular unit is configured and dimensioned to be mounted in the aircraft and to communicate with said space in a quantity sufficient in combination to meet a nitrogen-enriched flow requirement for inerting said space; and

each said modular unit comprises a separately housed and interchangeable unit containing:

an air separation module configured to be connected to an on-board source of air, said air separation module generating a flow of nitrogen-enriched air corresponding to a portion of said flow requirement;

a turbine disposed in said flow of nitrogen-enriched air; and

a compressor disposed to receive said engine bleed air and deliver it to the air separation module at an increased pressure, said compressor being driven by said turbine.

19. The modular system of claim 18, wherein said modular unit further comprises:

a filter configured to receive the compressed air; and

an air separation module communicating with the filter to produce said nitrogen-enriched air flow.

20. The modular system of claim 18, wherein said turbine and compressor form a part of the modular unit.

21. The modular system of claim 18, wherein said modular unit further comprises a first heat exchanger in communication with said filter and configured to be connected to the compressor, thereby providing a temperature conditioned compressed air to the filter.

22. The modular system of claim 21, wherein said heat exchanger is configured to communicate with a source of cooling air and wherein said modular unit further comprises:

a temperature sensor configured to monitor a temperature of the temperature conditioned compressed air; and

a temperature modulation valve configured to control a flow of the cooling air based on said temperature.

23. The modular system of claim 21, wherein said heat exchanger is configured to communicate with a source of cooling air and wherein said modular unit further comprises:

a temperature sensor configured to monitor a temperature of the temperature conditioned compressed air; and

a jet pump configured to control a flow of the cooling air based on said temperature.

24. The modular system of claim 21, wherein said modular unit further comprises a second heat exchanger configured to receive the air, said heat exchanger communicating with the compressor to provide a flow of temperature conditioned engine bleed air thereto.

25. The modular system of claim 24, wherein said first heat exchanger, said second heat exchanger, and said air separation module in each modular unit are sized, in combination with all other modular units, to meet the nitrogen-enriched flow requirement for inerting said space, based on the compressed air.

26. A method for inerting void spaces in aircraft, the aircraft having an inert gas requirement for said inerting, the method comprising:

connecting at least one modular unit comprising a separately housed and interchangeable unit containing a compressor, an air separation module, and a turbine to a source of air at a first pressure, said unit producing a flow of nitrogen-enriched air at a predetermined flow rate and oxygen purity level based on air input at a second, higher pressure;

compressing air from the source to said second higher pressure; and

directing the nitrogen-enriched air to the space to be inerted.

27. The method of claim 26, further comprising:

mounting in said aircraft a number of said modular units sufficient to meet the aircraft inert gas requirement with a combination of said predetermined flow rates; and

connecting an output of each of said modular units to the space to be inerted.

28. The method of claim 27, wherein the source of air is engine bleed air.

29. The method of claim 28, wherein each said modular unit comprises:

a filter configured to receive the engine bleed air, wherein said air separation module communicates with the filter to receive the engine bleed air and produce said nitrogen-enriched air flow; and wherein said compressor compresses the engine bleed air before the air separation module receives the engine bleed air.

30. The method of claim 29, wherein each said modular unit further comprises a first heat exchanger in said modular unit in communication with said filter and configured to be connected to the compressor, thereby providing a temperature conditioned compressed engine bleed air to the filter.

31. The method of claim 30, further comprising:

connecting said modular units to a source of cooling air for said heat exchanger;

monitoring a temperature of the temperature conditioned compressed engine bleed air; and

controlling a flow of the cooling air based on said temperature.

32. The method of claim 30, further comprising:

connecting said modular units to a source of cooling air for said heat exchanger;

monitoring a temperature of the temperature conditioned compressed engine bleed air; and

controlling a flow of the cooling air, using a jet pump, based on said temperature.

33. The method of claim 27, further comprising sizing the modular units to meet said aircraft inert gas requirement without sensing temperature of air flow through said units.

34. The method of claim 26, wherein said compressing comprises:

powering said turbine with said flow of nitrogen-enriched air; and

driving said compressor with said turbine to compress said air.

35. The method of claim 34, wherein said compressing further comprises driving the compressor with power from a motor co-axial to the turbine.

36. The method of claim 26, wherein said compressing comprises powering the turbine with bleed air from a high-pressure sector of an air cycle machine.

37. The method of claim 26, wherein the source of air is a high-pressure sector of an air cycle machine.

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