A Description and Analysis of the FAA Onboard Oxygen Analysis System

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16. Abstract

The Federal Aviation Administration (FAA) is planning a series of ground and flight tests with Airbus to prove the concept of a simplified fuel tank inerting system, which has been developed by the FAA. The FAA has also developed an onboard oxygen analysis system to measure the oxygen concentration in the aircraft fuel tank during the testing. To help ensure smooth integration and the safety of the testing, the FAA has documented the system description, interfaces, operation, and has performed a failure mode effects criticality analysis. This analysis attempts to identify the failure modes of each system component and assess the effects of these failures on the component, system, and aircraft. The analysis also applies a hazard category to each hazard as well as some hazard probability when it was deemed necessary by the author. Hazard controls are also listed.

All relevant system information has been summarized to allow for the system to be properly integrated into the proposed flight test aircraft. The results of the analysis indicated that most failure modes had no effect on the aircraft or other secondary systems. The few hazards with potential aircraft effects have significant controls in place to reduce the likelihood of the hazard and mitigate any potential hazard exposure.

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BACKGROUND

The Federal Aviation Administration (FAA) is planning a series of ground and flight tests with Airbus to prove the concept of a simplified fuel tank inerting system developed by the FAA. To determine the effectiveness of the inerting system, the oxygen concentration will be measured at eight locations in the fuel tank, utilizing two 4-channel sample trains with in-line oxygen analyzers. The onboard oxygen analysis system (OBOAS) design is based on sound principals and engineering practices. This system is essentially the same system employed on previous flight tests with the Boeing Company to examine the concept of ground-based inerting. To allow for the smooth installation and operation of the system on the Airbus flight test aircraft, it is critical to document how the system works, how to interface with the system, and how to operate the system. It is also critical to document known failure modes of the OBOAS to better allow the owner/operator of the flight test aircraft to assess the risk of installing and operating the system on the aircraft. This report documents how the OBOAS operates, details the system interfaces, explains system operation, and gives a system-level failure mode effects criticality analysis (FMECA).

FMECA is a tool used to gage the reliability of a system. It can be structured to a safety outcome and used by a stakeholder, alone or with other analysis, to assess risk [1]. This type of analysis entails listing all components of a system with all known failure modes of that component (i.e., valve fails to open, or meter indicates incorrectly) with any known failure causes. With each failure mode, the effects of the hazard are listed for the component, the analyzed system, and the aircraft. In addition to failure effects, the hazard criticality is also assessed for each failure in terms of the hazard severity and probability. Hazard severity is generally assessed by categories (i.e., Cat 1-Catastrophic or Cat 2-Critcial), which are defined for each analysis. Hazard probability is based upon the best reliability data available from the component manufacturers. The analysis will also list hazard controls. Controls are mechanisms, physical or otherwise, that are in place in the system to prevent or mitigate the hazard. Any hazard comments are also listed in the analysis.

SYSTEM DESCRIPTION

SYSTEM OVERVIEW.

The OBOAS consists of a regulated sample train with flow through in-line oxygen sensors and ancillary equipment, comprised of two identical four-channel systems. Each four-channel system was self-contained in a standard 19-inch half rack designed to meet the airworthiness requirements of Title 14 Code of Federal Regulations (CFR) Part 25. Each system has four independent sample trains that can draw an ullage sample from four different locations in the fuel tank, regulate the sample pressure, expose the sample to the oxygen sensor, and redeposit the sample back into the fuel tank. Each oxygen sensor has a companion analyzer mounted on the same 19-inch rack. Also mounted on each rack was a four-channel inlet pressure controller and a single-outlet pressure controller electronic unit. These electronic units support the five pressure regulator/controllers in each four-channel system.

The system has the option of sampling from a calibration port, which could be supplied with air or a calibration gas of choice, and bypassing the tank return, thereby not contaminating the ullage space with the calibration gas. Each sample train channel has two selectable inputs to allow each channel to sample from two different locations. Each analyzer has a 4 to 20-mA output and a 0 to 10-volt output. The pressure regulator/controller electronic units also have a scaled voltage output to read unit-regulated pressure. These signals will be passed to the aircraft data acquisition system (DAS) for collection with other test data to assist in OBOAS data/health management. Figure 1 shows a block diagram illustrating the primary components of the measurement system, with the sample flow path, signal, and power flow highlighted. The numbered components are listed in appendix A with the name and model of the part, the manufacturer, and the part number. For completeness, a wiring diagram is given in appendix B.

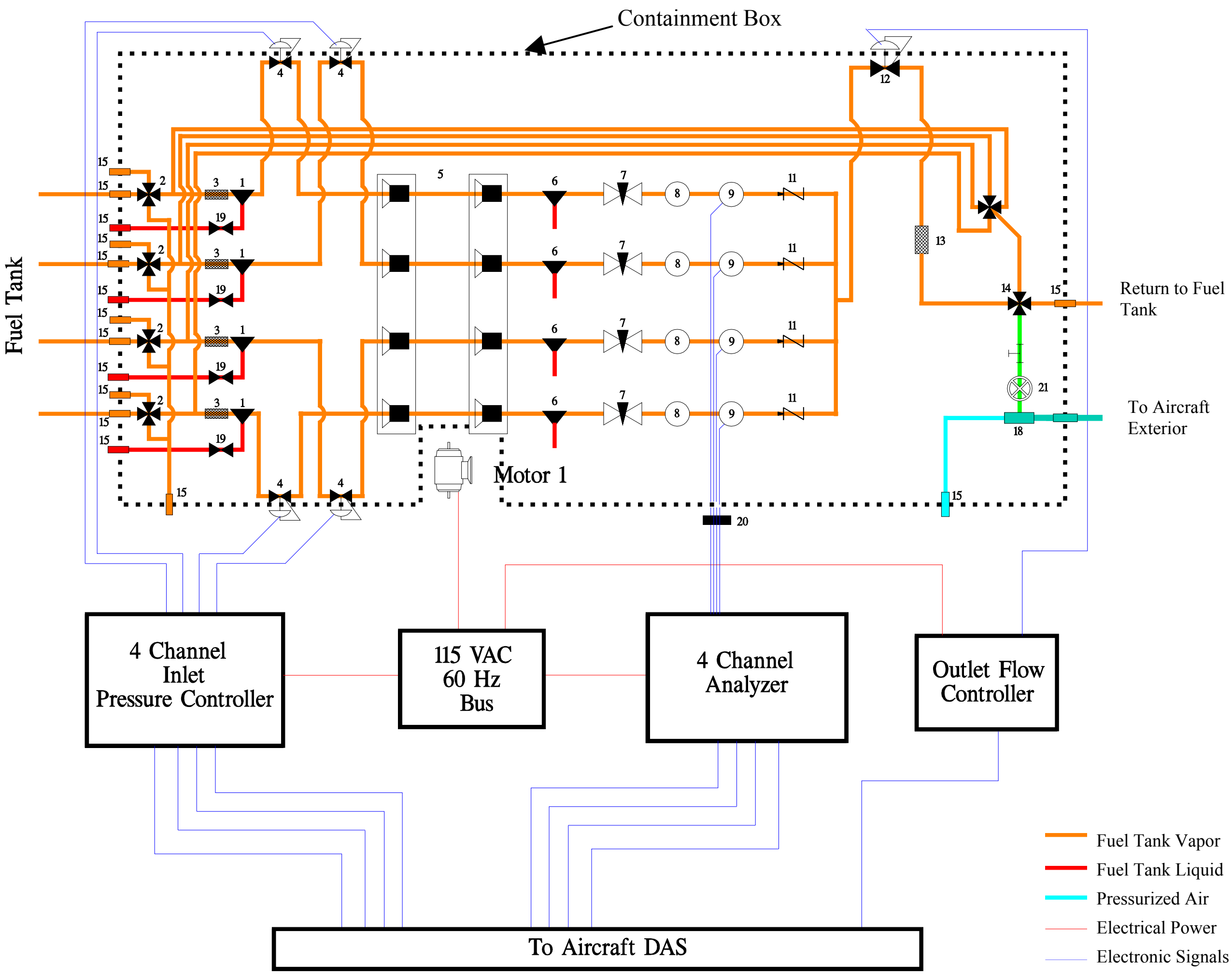


FIGURE 1. SYSTEM BLOCK DIAGRAM

SAMPLE TRAIN FLOW.

Each individual sample train consists of a complex, regulated flow path, with ancillary equipment designed to expose each oxygen sensor to the required constant sample conditions.

The sample is drafted from the fuel tank via a previously installed sample line. The sample enters the OBOAS through a selector valve, which allows selection of the input connector, system exposure to the calibration gas, or channel shutoff. The sample passes through a flash arrestor and a fluid trap that contains a float shutoff valve. The sample passes through an active pressure regulator/controller, which actively controls the inlet sample pressure to a vacuum pressure below the lowest expected atmospheric pressure in the fuel tank (around 2.9 psia). The sample is pumped to a pressure just above ambient sea level pressure (14.7 psia) in two stages with a diaphragm pump. The sample passes through a coalescing filter and a needle valve, where the initial flow conditions are set before each test, and through a flow meter that gives the sample flow rate. The sample passes through the oxygen sensor and through a check valve. The four sample trains in each system are ganged to a single outlet where they pass through the outlet pressure controller, another flash arrestor, and through a bypass valve back to the fuel tank. This bypass valve allows the sample to be sent to an outflow valve instead of back into the fuel tank or be redirected into any single-channel input. This feature was developed to allow the systems own pump pressure to free a stuck float valve during a test while having virtually no impact on the other three channels' data. The outlet pressure controller actively controls the outlet flow pressure back to the tank to give a sample pressure just above sea level, keeping a constant pressure between the diaphragm pump and the outlet controller.

SYSTEM SAFETY FEATURES.

Each four-channel sample train is contained in an onboard ullage sampling system (OBUSS) box that minimizes exposure of the operator and crew to hazardous vapors in the event of a leak in the sample train. The sampling lines are constructed of PFA tubing with Swagelok® connections. The OBUSS contains an air-supplied ejector that requires a minimum of 3 SCFM of compressed air at 40 psi or greater. This ejector maintains constant negative pressure on the inlet, drafting a volume of air from the inside of the OBUSS, to purge the box to prevent buildup of any hazardous vapors. This also prevents the escape of hazardous vapors from the OBUSS into the aircraft cabin. The ejector inlet is plumbed through a flow indictor that allows the operator to determine if purge flow is functional at any point in time. Each sample train has a fluid trap/float shutoff valve and a coalescing filter. These prevent fuel, fuel vapor, condensation, and water vapor from contaminating the sample train or damaging the in-line oxygen sensor. Each four-channel system has one 8-head diaphragm pump (two heads per channel), which supplies the displacement required to move the sample through the sample train at all fuel tank altitudes and temperatures. All electrical components indigenous to the OBUSS are mounted exterior to the containment box. This allows for the separation of potentially hazardous vapors in the containment box with a potential arc or spark from a faulty electrical circuit.

SYSTEM INTERFACE

POWER REQUIREMENTS.

The OBOAS consists of several laboratory instruments used to perform the function described in the previous section. This equipment is powered by standard North American household power, consisting of 115 Vac at 60 Hz. To allow for operation on an aircraft, each four-channel OBOAS uses a 3.5-kVA power frequency converter. Each converter accepts 115 Vac at 400 Hz (standard aircraft ac power) and creates the appropriate power. Each converter will require a

115 Vac three-phase power connection with a total capability of 30 amps. Each phase leg is capable of 13 amps. It is possible to provide only 25 amps of total power to the converter, provided the circuit breaker has overshoot capability to allow for a brief surge in power to start the system motor. The minimum overshoot capability needed to start the system is approximately 40 amps for 0.5 second. This number is based on preliminary laboratory testing and will be validated during ground testing. Appendix C gives the power required for all equipment for a single, four-channel OBOAS.

PHYSICAL INTERFACE.

Four primary interfaces exist between the OBOAS and the aircraft: the rack mounting to the aircraft, the gas sample and additional supply plumbing connections to the OBOAS interface panel, the aircraft power connections to the converters, and the signal connections to the aircraft DAS.

RACK MOUNTING. Each OBOAS is mounted in an industry standard flight test (14 CFR Part 25 certifiable data) 19″ instrumentation rack that is approximately 48″ tall (see figure 2). Two OBOASs mount together in a dual-rack configuration to a single 0.040″ thick aluminum plate with four large pieces of 1″ aluminum angle attached with fasteners to both the plate and racks. This aluminum plate mounts on a track-mating fixture designed to integrate with standard large commercial transport seat tracks for the purpose of attaching instrumentation racks into flight test aircraft. No engineering data is available for specification of the track-mating fixture. The aluminum plate attaches with pinch plates at the front and back of the plate that is held down with 3/8″ aircraft-quality bolts.

FIGURE 2. PHOTO OF OBOAS 1 AND 2 MOUNTED IN TWO 19″ FLIGHT TEST RACKS

PLUMBING CONNECTIONS. The gas sample lines integrate with the OBOAS via the rear interface panel on the sample system (OBUSS), shown in figure 3. Each channel has two inputs (A and B), which correspond to the input selector on the front panel of the OBOAS. Each sample tube mates to the interface panel via a 1/4″ female Swagelok® fitting. The sample return line also interfaces on the same panel with a 1/4″ female Swagelok® fitting.

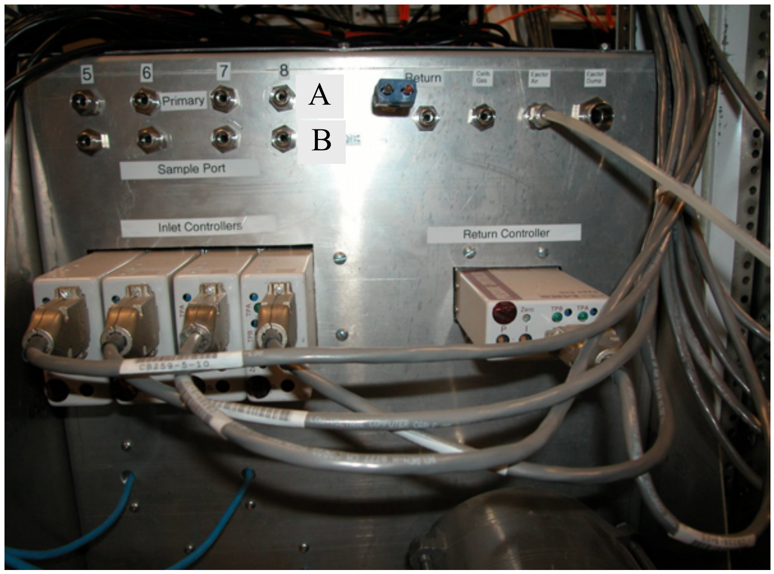


FIGURE 3. REAR INTERFACE PANEL ON OBUSS

A calibration gas can be plumbed to the system via the rear interface panel. This allows for calibration/validation of the system after system warmup and before the start of testing. The calibration gas tube mates to the interface panel via a 1/4″ female Swagelok® fitting. The pressure of the calibration gas source should be set to below 10 psig to ensure proper operation of the inlet pressure regulators during calibration. A nominal 5 psig supply pressure regulator setting is recommended for the calibration gas supply.

The purge air line is also connected to the OBUSS via the rear interface panel. The line mates to the interface panel via a 1/4″ female Swagelok® fitting. The purging ejector requires air supplied at 40 psig, giving an ejector inlet flow of 3 CFM. This inspires 3 CFM of purge air out of the sample system containment box, giving a total purge air dump flow of 6 CFM per OBOAS. The OBUSS should be purged while the sample pump is running. The ejector supply air may be shutoff above altitudes of approximately 25,000 feet, where the purge air dump will supply sufficient vacuum pressure to purge the box adequately. The purge air dump line mates to the system rear interface of each OBUSS with a 1/2″ female Swagelok® fitting. This fitting can be mated to an appropriate mating fixture in a dummy window to allow the OBUSS to vent the exterior of the aircraft.

Note all references to the 1/4″ or 1/2″ female Swagelok® fittings refer to the Swagelok Company compression fittings that accept 1/4″ or 1/2″ outer diameter tubing.

POWER CONNECTIONS. Aircraft power is supplied to each OBOAS by supplying three-phase 115 Vac power to the accompanying power frequency converter. An MS3106F18-11S cannon plug with five large solder-on pins, each capable of carrying 13 amps of 115 Vac power, was used to apply power to the converter. Table 1 gives the connector pin designations.

TABLE 1. FREQUENCY CONVERTER POWER CONNECTOR PIN DESIGNATION TABLE

Pin Label	Description
1	115 Vac 400 Hz, phase A
2	115 Vac 400 Hz, phase B
3	115 Vac 400 Hz, phase C
4	Neutral

SIGNAL CONNECTIONS. The signals from the OBOAS oxygen analyzers are supplied to aircraft DAS through a cannon plug with mating connector type MS3126F14-19S. In addition, the output from the pressure regulator electronic units can also be collected by the DAS to monitor system health and data quality. This also mates with the aircraft DAS through the same type of mating connector. The pin designations for those connectors are given in appendix D.

SIGNAL CHARACTERISTICS.

All OBOAS signals are linear voltage outputs corresponding to the instrument range.

The oxygen analyzers have a 0 to 10-volt output that corresponds to 0 to 25 percent oxygen. This gives a slope of 2.5% oxygen/volt with an intercept of 0. For the 100% oxygen analyzer being used to measure the system permeate gas, the 0 to 10-volt output corresponds to 0 to 100 percent oxygen giving a slope of 10% oxygen/volt with an intercept of 0.

The inlet pressure controllers have a 0 to 1-volt output that corresponds to 0 to 500 torr. This gives a slope of 0.5 torr/mvolt with an intercept of 0. For the outlet pressure controllers being used, the 0 to 1-volt output corresponds to 0 to 1000 torr, giving a slope of 1 torr/mvolt with an intercept of 0.

INSTRUMENT SETTINGS.

Each oxygen analyzer has been set to have a fixed-scale output, as described in the signal characteristics section. To obtain these signal characteristics, the analyzer output range must be set to “HI” and the analysis range must be set to 0% to 25% oxygen. This is achieved by selecting both the “Set High Range” and the “Set Low Range” buttons simultaneously and using the arrows to select HI. To correctly set the high and low range, select the Set High Range or Set Low Range button and use the up and down arrows to set the low range to 0 and the high range to 25.

The pressure regulator settings have been set to achieve maximum system efficiency for the proposed flight testing pressure range. These settings call for all channel inlet pressures to be set to 150 torr and the outlet pressure regulator for each OBOAS to be set to 840 torr. The inlet pressure for each channel is changed by selecting the correct channel from the channel display selector switch on the inlet pressure controller power supply, and then using the adjustment screw corresponding to that channel to change the pressure, which will be indicated on the readout panel. Note: You must hold the Set Pt. switch in the up position while turning the adjustment screw to observe the change in inlet pressure setting. To adjust the outlet pressure regulator setting, simply turn the Set Pt. knob on the front panel of the outlet pressure regulator power supply to indicate the desired pressure in torr. Figure 4 shows the inlet and outlet pressure controller power supplies.

FIGURE 4. INLET AND OUTLET PRESSURE CONTROLLER POWER SUPPLIES

SYSTEM OPERATION

The OBOAS is designed to run with no human interaction. The system will arrive at the test facility with all instruments set to the correct values for the proposed flight test scenario. These values will be validated during ground testing, and initial flight testing if necessary, to ensure valid, accurate data throughout the flight test program. The primary function of the system is to measure the oxygen concentration of the gas it is sampling. This is accomplished by turning the system on, allowing the system to warmup, and then calibrating the system. The system can then be used to measure the oxygen concentration in the fuel tank.

To turn the system on, all electronics must be on and all pressure regulators must be on and set to the flow position. Be sure the input selector is set to the auxiliary input port and sample return selector is set for sample dump. To start a single OBOAS, simply turn on the switch corresponding to the correct OBOAS motor. Check to ensure that all sample train pressures are being regulated to the desired value.

To calibrate the system, wait 2 hours for the system to adequately warmup and stabilize. Allow the system to sample from the open port (cabin air) and wait for the reading to stabilize. Select range from the oxygen analyzer and adjust the display to read 20.9. To validate the calibration, attach a calibration gas to the calibration port on the rear interface of the OBUSS. Select calibration from the input selector valve and be sure the sample return selector valve is set sample dump. Allow the system to stabilize and check to be sure that the measured value is consistent with the ticket on the calibration gas bottle. All readings are considered valid if within ±0.1 percent oxygen. It has been observed in the lab that readings of oxygen concentration in air can differ by 0.2-0.3 percent oxygen from the expected value of 20.9 with no adverse effect on the system accuracy.

To measure the oxygen concentration in the fuel tank, simply select the primary sample port on the input selector valve and turn the return selector valve to return to tank. If the power to the OBOAS converters should be removed for any reason during warmup, calibration, or testing (kill switch), the system pumps must be taken off-line before power is applied again. After system electrical power is restored, the pumps can be turned on and the system can continue to operate after an adequate stabilization period.

The system has the capability to dislodge a stuck fuel tank sample line float valve by back purging the input of the clogged sample line in question with the system outflow. This is accomplished by turning both the input selector and pressure controller off corresponding to the stuck float valve and selecting that channel number on the back purge selector valve. Next, select sample line purge on the sample return selector for a short period of time to ensure pressurization of the sample line. Return the sample return selector to the original position. Turn the selector valve to the primary sample port and turn on the channel regulator. The channel sample flow should return to normal.

Appendix E gives a detailed list for the above-mentioned system operational procedures.

FAILURE MODE EFFECTS CRITICALITY ANALYSIS

The FMECA was performed for the system as defined in the system diagram (see figure 1). The FMECA identifies all critical components of the system and attempts to identify all failure modes associated with the operation or incorrect operation of each component during normal system operation. All listed component, system, and aircraft effects are based on worst credible case scenario, as seen by the analyst. It is important to note that aircraft effects are based on the author’s aviation knowledge and engineering experience but only the aircraft operator/end user can truly assess and quantify the ultimate aircraft effect. Failure modes are listed, with hazard data compiled, in appendix F.

For time’s sake, the FMECA only considers the in-flight phase of operation with a near-full center wing tank because it was deemed most safety critical. If an identified failure mode has a worse-case hazard category or probability during other phases of operation (i.e., parked/ground taxi), it will be noted in the analysis comments, and due to the limited time and scope of the analysis, failure mode causes will be given in general terms.

A tertiary analysis was performed to determine the equivalent level of safety an oxygen analysis system would need to measure the oxygen concentration of an inert gas generator during a flight test. Appendix G addresses this question.

HAZARD SEVERITY.

Table 2 lists the hazard category definitions used for the analysis. These are based on standard categories developed for system safety analysis in Mil-Std 882C. When a hazard has multiple possible scenarios with a different possible resulting severity, the worst credible case severity (with I being the worst) is used as the hazard severity regardless of the assessed probability.

All hazard data given is for the single failure listed, in terms of the analyzed system.

TABLE 2. TABLE OF HAZARD SEVERITY DEFINITIONS

Code	Hazard Category	Description
I	Catastrophic	Results in failure of the system or death or critical injury to operator or nearby personnel
II	Critical	Results in major system damage or degraded system operation/severe injury to operator or nearby personnel
III	Marginal	Results in minor system damage or undesirable system operation/minor injury to operator or nearby personnel
IV	Negligible	Results in negligible system damage or injury to operator or nearby personnel

HAZARD PROBABILITY.

Probabilities will be assigned to specific hazards identified by the end user. These will be hazards with potentially critical or catastrophic effects on the aircraft. Individual hazard probabilities will be assessed as deemed necessary with the best engineering and reliability data available.

HAZARD STATUS.

The following definitions apply to hazard status categories

- Open—Hazard needs to be addressed by end user immediately
- Monitor—Hazard needs further review by end user before testing
- Closed—Hazard requires no further review

Only hazards with potentially critical or catastrophic effects on the aircraft will be left in monitor or open status. All other hazards will be closed. Any hazards with an open or monitor status should be closed, by consensus, at the test readiness review.

CONCLUSIONS AND RECOMMENDATIONS

All hazards have been controlled to the satisfaction of the system developer/operator. All hazards having significant potential aircraft effects have adequate controls in place to ensure safety of operation, given the limited exposure of the measurement system to the flight test environment.

REFERENCES

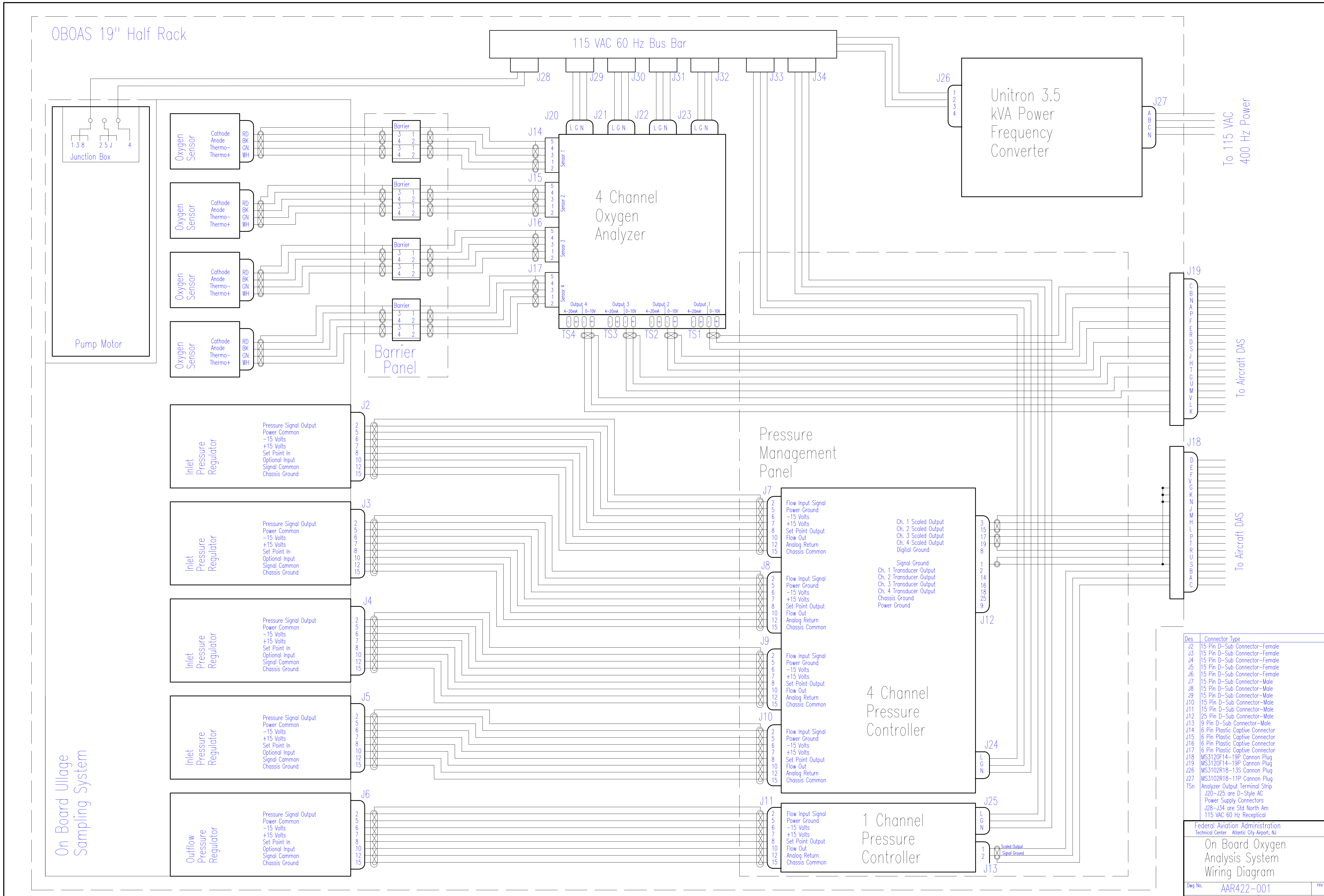
1. Roland, Harold E. and Moriarty, Brian, “System Safety Engineering and Management,” Wiley Press, 1990.

APPENDIX A—PARTS LIST

Entry Number	Part Name	Manufacturer	Part Number
1	1/4″ NPT female Drain Trap (21.66 cubic in.)	Spirax Sarco, Inc.	FA-150
2	1/4″ Calibration Selector Valve	Swagelok Inc.	---------
3	1/4″ NPT female Flash Arrestor (Inlet)	Matheson	6104
4	1/4″ Tube Absolute Pressure Controller (inlet)	MKS Instruments, Inc.	640A52TS1V32V
	Pressure Controller Power Supply/Readout	MKS Instruments, Inc.	246C
5	3/8″ NPT female 8 Head Pump	Air Dimensions Inc.	01780TS
6	1/4″ NPT female Coalescing Filter	Parker Filtration	14RL/08UK
7	Needle Valve	Swagelok Inc.	---------
8	1/4″ NPT female 0.5-5.0 SCFH Flowmeter	Dwyer Instruments	RMB-49
9	1/4″ Inlet SS Sensor Housing	Teledyne Analytical, Inc.	Cell Block Assy
10*	Model 3290 Oxygen Analyzer	Teledyne Analytical, Inc.	M64643
11	Check Valve		
12	1/4″ Tube Absolute Pressure Controller (outlet)	MKS Instruments, Inc.	640A13TS1V42V
	Pressure Controller Power Supply/Readout	MKS Instruments, Inc.	247D
13	1/4″ NPT female Flash Arrestor (Outlet)	Matheson	6104
14	1/4″ Bypass Selector Valve	Swagelok Inc.	---------
15	Swagelok® Bulkhead Connection	Generic	
16*	1/4″ Nylon 11 Tubing	McMaster-Carr	5548k44
17*	1/4″ 316 SS Tubing	McMaster-Carr	89785k23
18	Sonic Venturi Ejector (0.060″ orifice)	Fox Valve Corp.	61121060
19	Fluid Drain	Swagelok Inc.	---------
20	760 ae Shunt Diode Safety Barrier	MTL	
21*	RF-2500 Flow Indicator	GEMS Sensor	155480
22*	Cannon Plug	Generic	
23*	Power Chord	Generic	
24*	Wire Harness	Generic	

*Items not labeled in figure 1.

APPENDIX B—ONBOARD OXYGEN ANALYSIS SYSTEM WIRING DIAGRAM


OBOAS 19" Half Rack
115 VAC 60 Hz Bus Bar
J28 J29 J30 J31 J32 J33 J34
J26
Unitron 3.5 kVA Power Frequency Converter
J27
To 115 VAC 400 Hz Power
Junction Box
Pump Motor
Oxygen Sensor
Cathode
Anode
Thermo-
Thermo+
RD BK GN WH
Barrier
Barrier Panel
J14 J15 J16 J17 J20 J21 J22 J23
4 Channel Oxygen Analyzer
TS1 TS2 TS3 TS4
J19
To Aircraft DAS
J18
To Aircraft DAS
Inlet Pressure Regulator
Outflow Pressure Regulator
Pressure Signal Output
Power Common
-15 Volts
+15 Volts
Set Point In
Optional Input
Signal Common
Chassis Ground
J2 J3 J4 J5 J6
Pressure Management Panel
J7 J8 J9 J10 J11 J12 J13 J24 J25
Flow Input Signal
Power Ground
-15 Volts
+15 Volts
Set Point Output
Flow Out
Analog Return
Chassis Common
Ch. 1 Scaled Output
Ch. 2 Scaled Output
Ch. 3 Scaled Output
Ch. 4 Scaled Output
Digital Ground
Signal Ground
Ch. 1 Transducer Output
Ch. 2 Transducer Output
Ch. 3 Transducer Output
Ch. 4 Transducer Output
Chassis Ground
Power Ground
4 Channel Pressure Controller
1 Channel Pressure Controller
Scaled Output
Signal Ground
On Board Ullage Sampling System
Des Connector Type
J2 15 Pin D-Sub Connector-Female
J3 15 Pin D-Sub Connector-Female
J4 15 Pin D-Sub Connector-Female
J5 15 Pin D-Sub Connector-Female
J6 15 Pin D-Sub Connector-Female
J7 15 Pin D-Sub Connector-Male
J8 15 Pin D-Sub Connector-Male
J9 15 Pin D-Sub Connector-Male
J10 15 Pin D-Sub Connector-Male
J11 15 Pin D-Sub Connector-Male
J12 25 Pin D-Sub Connector-Male
J13 9 Pin D-Sub Connector-Male
J14 6 Pin Plastic Captive Connector
J15 6 Pin Plastic Captive Connector
J16 6 Pin Plastic Captive Connector
J17 6 Pin Plastic Captive Connector
J18 MS3120F14-19P Cannon Plug
J19 MS3120F14-19P Cannon Plug
J26 MS3102R18-13S Cannon Plug
J27 MS3102R18-11P Cannon Plug
TSn Analyzer Output Terminal Strip
J20-J25 are D-Style AC Power Supply Connectors
J28-J34 are Std North Am 115 VAC 60 Hz Receptical
Federal Aviation Administration
Technical Center Atlantic City Airport, NJ
On Board Oxygen Analysis System Wiring Diagram
Dwg No. AAR422-001
rev F
Sheet 1 of 1

APPENDIX C—POWER REQUIREMENTS FOR ONBOARD OXYGEN ANALYSIS SYSTEM

Item	Power
Pump Motor	12.0 amps
4-Channel Pressure Controller Unit	0.65 amp
Single-Channel Pressure Controller Unit	0.61 amp
4-Channel Oxygen Analyzer (4 @ 0.3 amp)	1.2 amps

Total =	14.5 amps
Two 4-Channel Systems Require 2 * 14.5 amps -	29.0 amps

- <u>Pump Motors (2) – CL5009A Baldor Motor</u>

  HP: 1
  RPM: 3450
  Voltage: 115 Vac
  Amps: 12
  Hertz: 60
  Phase: 1

  Thermal Protection: Auto
  Class I, Group D
  Class II, Group F & G, T4
  U.L. & C.S.A.

- <u>Oxygen Analyzers (8) - Teledyne Model 3290</u>

  Power Requirements:
    Voltage: 115 Vac
    Frequency: 60 Hz
    Amps: 0.3 amp
  Signal output: 0-10 Vdc

- <u>Inlet Pressure Controller Read Out (2) - Model 247D</u>

  Power Requirements for the 247D unit are:
    Voltage: 115 Vac
    Hertz: 60
    19 VA (with no pressure controllers attached)
    10 VA for each pressure controller attached (4)
    Additional 15VA for start-up
    Total VA = 19+40+15 = 74 VA
    Current = 0.6435 amp
  Signal output: 0-1Vdc (for all 4 channels)

- <u>Outlet Pressure Controller Read Out (2) - Model 246C</u>

  Power Requirements for the 246C unit are:
    Voltage: 115 Vac
    Hertz: 60
    70 VA (maximum)
    Current = 0.6087 amps
  Signal output: 0-1Vdc

APPENDIX D—SIGNAL CONNECTOR PIN DESIGNATIONS

Oxygen Analyzer Connector

Analyzer	Channel Description	Pin
Oxygen Signal Channel # 1	- Signal Voltage	A
	+ Signal Voltage	B
	Shield	C
Oxygen Signal Channel # 2	- Signal Voltage	D
	+ Signal Voltage	E
	Shield	F
Oxygen Signal Channel # 3	- Signal Voltage	G
	+ Signal Voltage	H
	Shield	J
Oxygen Signal Channel # 4	- Signal Voltage	K
	+ Signal Voltage	L
	Shield	M
	OPEN	N
	OPEN	P
	OPEN	R
	OPEN	S
	OPEN	T
	OPEN	U
	OPEN	V

Pressure Regulator Connector

Analyzer	Channel Description	Pin
1-4 Return Pressure	- Signal Voltage	A
	+ Signal Voltage	B
	Shield	C
	OPEN	D
	OPEN	E
	OPEN	F
Inlet Pressure Channel #1	- Signal Voltage	G
	+ Signal Voltage	H
	Shield	J
Inlet Pressure Channel #2	- Signal Voltage	K
	+ Signal Voltage	L
	Shield	M
Inlet Pressure Channel #3	- Signal Voltage	N
	+ Signal Voltage	P
	Shield	R
Inlet Pressure Channel #4	- Signal Voltage	S
	+ Signal Voltage	T
	Shield	U
	OPEN	V

APPENDIX E—ONBOARD OXYGEN ANALYSIS SYSTEM OPERATIONAL PROCEDURES

OBOAS START-UP PROCEDURES

1. Ensure Power Transfer Switches (4) on rear of OBOAS are set to OFF
2. Ensure all instrumentation units are OFF
3. Ensure Unitron's #1/#2 are set to OFF
4. Perform visual inspection of all electrical connectors for proper security
5. Provide Aircraft Power to Unitron's #1/#2 (115 Vac/400 Hz/3 Phase)
6. Turn both Unitron's ON
7. WAIT—Ensure Green LED's are ON
8. Power up instrumentation using switch #4
9. Turn ON all instrumentation units
10. Set all pressure controllers to ON
11. Set all pressure controllers to FLOW
12. Verify inlet controllers (four-channel power supply) are set to 150 torr
13. Verify return controllers (single channel) are set to 840 torr or lowest controllable pressure
14. Ensure all float drain valves are closed (rear of OBOAS)
15. Pressurize ejectors on both OBOAS units
16. Verify ejector flow indicator is rotating
17. Set inlet selector valves to Sample Port B—Cabin Air
18. Set Return selector valves to Sample Dump
19. Start-up #1 OBOAS pump (switch #1) by selecting a Unitron
20. Start-up #2 OBOAS pump (switch #2) by selecting a Unitron
21. Allow 2 hours to warmup units

OBOAS CALIBRATION PROCEDURES

1. Allow system to sample cabin air (Sample Port B) until the reading stabilizes
2. Press SPAN once on each oxygen analyzer
3. Using the arrow keys, adjust the displays to read the proper oxygen concentration (20.9)
4. Ensure calibration/validation gas bottle is open and pressure regulator is set below 10 psig
5. Ensure calibration/validation gas sample line is connected to OBOAS
6. Set inlet selector valves to CAL
7. Allow all analyzers to stabilize. Validate the analyzers read the value given on the ticket on the calibration gas bottle.
8. Return the inlet selector valves to B
9. Verify the analyzers stabilize around 20.9

OBOAS FUEL TANK SAMPLING PROCEDURES

1. Set inlet selector valves to A—Sample line from center wing fuel tank
2. Set Return selector valves to Return to Tank

OBOAS SAMPLE LINE PURGING PROCEDURES

1. Secure the line to be purged by turning OFF the inlet pressure controller
2. Set the purge selector valve to the proper sample line
3. Set the return selector valve to Sample Line Purge
4. Allow time for the purge, then set the return selector valve to Return to Tank
5. Return the inlet pressure controller to the ON position
6. Verify flow is resumed or repeat as needed

OBOAS SECURING PROCEDURES

1. Set inlet selector valves to Sample Port B—Cabin Air
2. Set return selector valves to Sample Dump
3. Allow adequate time to sample from cabin air prior to shutdown
4. Shutdown #2 OBOAS pump—Switch #2 to OFF
5. Shutdown #1 OBOAS pump—Switch #1 to OFF
6. Set inlet selector valves to OFF
7. Set return selector valves to OFF
8. Turn off pressurized air source for the ejectors
9. Set all pressure controllers to OFF

10. Turn OFF all instrumentation units
11. Secure instrumentation—Set switch #4 to OFF
12. Turn both Unitron's OFF
13. Secure aircraft power to Unitron's #1 and #2 (115 Vac/400 Hz/3 Phase)
14. Inspect for liquid in all float drain valves then close (rear of OBOAS)

APPENDIX F—FAILURE MODE EFFECTS CRITICALITY ANALYSIS HAZARD LISTING FOR ONBOARD OXYGEN ANALYSIS SYSTEM

ID	Component	Failure Mode	Failure Cause	Component Effect	System Effect	Aircraft Effect*	Hazard Cat.	Hazard Prob.	Status	Controls	Comments
1a	Fluid trap float valve	Float valve stuck open	Bent or broken float arm, severe aircraft attitude	Float valve does not block the passage of fuel into the system	Single channel fills with fuel, contaminates pump and pressure controllers, damages sensors	Corrupted return sample line	II	N/A	Closed	Operator monitors system for fuel contamination	
1b		Float valve stuck closed	Stuck switch mechanism	Gas sample cannot pass through trap	Single channel fails to operate, loss of data	No effect	II	N/A	Closed	Operator checks system for correct operation prior to test	
2a	Input selector valve	Blocked	Sample line contamination	Gas sample cannot pass through valve	Single channel fails to operate, loss of data	No effect	II	N/A	Closed	Lines have traps, filters, and flash arrestors	
2b		Stuck	Mechanical failure	Operator cannot select calibration or off in flight	Change/no effect	No effect	IV	N/A	Closed		
2c		Indicator indicates incorrectly	Mechanical failure	Indicator indicates sample when it is off or on calibration line	System would sample from cabin, calibration line, or be off instead of tank	No effect	II	N/A	Closed	Obvious failure mode to user; highly reliable hardware	
3a	Inlet flame arrestor	Fails closed	Accidentally tripped due to vibration, impact	Arrestor blocked	Single channel blocked closed, loss of data	No effect	II	N/A	Closed		
3b		Fails open	Mechanical failure	Arrestor will not trip in the event of an inline detonation	No effect	No effect	IV	N/A	Closed	Unlikely flame front will propagate “up stream” back to tank; down stream flame arrestor; ignition sources and ullage sample have been separated; reliable, proven effective part	
4a	Inlet pressure regulator	Fails full open	Mechanical failure Logic control failure	Regulator/controller allows pressure on pump inlet to rise to atmospheric	Single channel fails to maintain correct sample pressure; degraded data; increased pump work/heat rejection	No effect	III	N/A	Closed		
4b		Fails full closed	Mechanical failure Logic control failure	Regulator/controller shuts off flow	Single channel fails to operate; loss of data	No effect	II	N/A	Closed		
4c		Fails to regulate correctly	Logic control failure	Regulator/controller fails to regulate pressure within acceptable limits, oscillates, or spikes	Single channel fails to maintain correct sample pressure; degraded data accuracy; increased pump work/heat rejection; pressure surge/swings damage sensor	No effect	II	N/A	Closed		
4d		Regulator electrical case short	Electrical failure, EMI	Regulator electronics arcs/sparks; possible deflagration internal to regulator; possible failure of regulator valving/casing	Single channel failure, loss of data; possible loss of ancillary equipment, rack damage, secondary aircraft damage	Possible release of flammable vapors; and/or small-scale deflagration fire/smoke, ancillary damage, release of noxious fumes	II		Monitor	Operator monitors for correct operation; internal fusing of controller unit; external power circuit breakers; hand-held fire extinguishers on aircraft	

* To be qualified by end user

ID	Component	Failure Mode	Failure Cause	Component Effect	System Effect	Aircraft Effect	Hazard Cat.	Hazard Prob.	Status	Controls	Comments
5a	Pump	Contained motor failure	Faulty rotating part, motor short	Pump stops	Complete sample train shutdown, all channels failed	No effect	I	N/A	Closed	Two redundant four-channel systems	
5b		Uncontained motor failure	Unbalanced high-output state, faulty rotating part	Pump stops	Complete sample train shutdown, all channels failed	Possible breach of pressure vessel/aircraft depressurization; possible in-flight breakup of fuselage	I	1.00E-06	Monitor	Motor meets ANSI standard for failure containment IAW explosion-proof specification	Tech Center excepts this limitation
5c		Pump head failure	Blown seal, diaphragm failure	Pump head stops moving air	Single channel fails to operate; loss of data	No effect	II	N/A	Closed		
5d		Bad head delta P	Diaphragm fouled or damaged	Pump fails to increase sample pressure adequately	Loss of pressure rise on single channel, degraded/bad data	No effect	III	N/A	Closed		
5e		Motor electrical case short	Electrical failure, EMI	Motor arcs/sparks, shorts into OBUSS	Possible failure of internal components, breach of sample train; possible deflagration, release of flammable vapors, failure of system, loss of data; possible loss of ancillary equipment, rack damage, secondary aircraft damage	Possible release of flammable vapors and/or small-scale deflagration fire/smoke, ancillary damage, release of noxious fumes	I	1.66E-05	Monitor	Motor bonded to rack via OBUSS; internal motor fusing; external power circuit breakers; hand-held fire extinguishers in cabin	
6a	Coalescing filter	Clogs	Fouled sample	Gas sample cannot pass through separator	Single channel fails to operate; loss of data	No effect	II	N/A	Closed		
6b		Fails to eliminate moisture	Mechanical failure	Separator fails to eliminate moisture	Failure of oxygen sensor; single channel fails to operate	No effect	II	N/A	Closed		
7a	Needle valve	Fails open	Mechanical failure	Valve cannot change flow rate of sample	Failure to regulate volume flow IAW calibration; degraded data, possible lost data	No effect	III	N/A	Closed		
7b		Fails closed	Mechanical failure	Gas sample cannot pass through valve	Single channel fails to operate; loss of data	No effect	II	N/A	Closed		
8a	Flow meter	Clogs	Fouled sample	Gas sample cannot pass through meter	Single channel fails to operate; loss of data	No effect	II	N/A	Closed		
8b		Indicates incorrectly	Mechanical failure	Incorrect or inconsistent sample flow rate	Single channel degraded data accuracy	No effect	III	N/A	Closed		
9a	Oxygen sensor	Output fails	Cell expires, electrical failure	Sensor has no electrical output	Single channel fails to operate; loss of data	No effect	II	N/A	Closed		
9b		Short to housing	Electrical failure	Sensor low-power shorts on case	Single channel fails to operate; loss of data	No effect	II	N/A	Closed	Low power on sensor, wiring done IAW sound practices	

ID	Component	Failure Mode	Failure Cause	Component Effect	System Effect	Aircraft Effect	Hazard Cat.	Hazard Prob.	Status	Controls	Comments
10a	Oxygen analyzer	Fails	Electrical failure	Analyzer has no output	Single channel output fails; loss of data	No effect	II	N/A	Closed		
10b		Indicates incorrectly	Electrical failure	Analyzer has incorrect output	Degraded or bad data	No effect	III	N/A	Closed		
10c		Analyzer case short	Electrical defect, EMI	Analyzer arcs/sparks; possible smoke/fire	Single channel failure, loss of data; possible loss of ancillary equipment, rack damage	Possible release of flammable vapors and/or small-scale deflagration fire/smoke, ancillary damage, release of noxious fumes	II	N/A	Closed	Operator monitors for correct operation; internal fusing of analyzer unit; external power circuit breakers; hand-held fire extinguishers in cabin	
10d		Analyzer case short energizes sensor	Electrical defect, EMI	Housing/sensor arcs/sparks; possible deflagration in housing, explosion, smoke/fire	Single channel failure, loss of data; possible loss of ancillary equipment, rack damage	Possible release of flammable vapors and/or small-scale deflagration, fire/smoke, ancillary damage, release of noxious fumes	II	1.00E-09	Monitor	Fusing/circuit breakers; intrinsically safe barriers between analyzer and sensor housing, hand-held fire extinguishers in cabin	
11a	Check valve	Stuck closed	Blocked, mechanical failure	Gas sample cannot pass through valve	Single channel fails to operate; loss of data	No effect	II	N/A	Closed		
11b		Fails open	Mechanical failure	Reverse flow in system will not be prevented	No effect	No effect	IV	N/A	Closed		
12a	Outlet pressure regulator	Fails full open	Mechanical failure Logic control failure	Regulator/controller allows pressure drop on pump outlet	All four channels fail to maintain correct sample pressure; incorrect data; possible damage to sensor	No effect	I	N/A	Closed		
12b		Fails full closed	Mechanical failure Logic control failure	Regulator/controller shuts off flow	All four channels fail to operate; loss of system data	No effect	I	N/A	Closed		
12c		Fails to regulate correctly	Logic control failure	Regulator/controller fails to regulate pressure within acceptable limits, oscillates, or spikes	All four channels fail to maintain correct sample pressure; bad data accuracy; increased pump work/heat rejection; pressure surges/swings damage sensor	Box could heat up, pose potential burn hazard	I	N/A	Closed		
12d		Regulator electrical case short	Electrical failure, EMI	Regulator electronics arcs/sparks; possible deflagration internal to regulator; possible failure of regulator valving/casing	All four channels fail, loss of all data; possible loss of ancillary equipment, rack damage, secondary aircraft damage	Possible release of flammable vapors and/or small-scale fire/smoke, release of noxious fumes	I		Monitor	Operator monitors for correct operation; internal fusing of controller unit; external power circuit breakers; hand-held fire extinguishers	
12e		Controller unit arcs/sparks	Electrical failure, EMI	Controller unit arcs/sparks; possible smoke/flames	All four channels fail, loss of all data; possible loss of ancillary equipment, rack damage, secondary aircraft damage	Possible small-scale fire, smoke, release of noxious fumes	I	N/A	Closed	Operator monitors for correct operation; internal fusing of controller unit; external power circuit breakers; hand-held fire extinguishers in cabin	

ID	Component	Failure Mode	Failure Cause	Component Effect	System Effect	Aircraft Effect	Hazard Cat.	Hazard Prob.	Status	Controls	Comments
13a	Outlet flame arrestor	Fails closed	Clogged	Arrestor blocked	All four channels blocked closed; loss of all data	No effect	I	N/A	Closed	Gas sample desiccated and filtered	
13b		Fails open	Very powerful explosion within sample train	Arrestor will not arrest flame front in the event of an outflow line detonation	No effect	No effect	IV	N/A	Closed	Ignition sources and sample train separated	Failure mode borderline credible
14a	Bypass selector valve	Blocked	Sample line contamination	Gas sample cannot pass through valve	All four channels fails to operate; loss of data	No effect	I	N/A	Closed	Lines have traps, filters, and flash arrestors	
14b		Stuck	Mechanical failure	Operator cannot select outflow in tank in flight	No effect	No effect	IV	N/A	Closed		
14c		Indicator indicates incorrectly	Mechanical failure	Indicator indicates sample when it is off or on calibration line	Sample would be routed to outflow valve instead of tank; could bias data	No effect	III	N/A	Closed	Highly reliable hardware	
15a	Swagelok connection	Leaks	Vibration, incorrect connection, bad swage	<u>Positive Pressure Section</u>: Single-channel gas sample leaks into box	<u>Positive Pressure Section</u>: Single channel has bad sample volume IAW calibration procedures, possible degraded data quality/accuracy	<u>Positive Pressure Section</u>: Possible release of flammable vapors, release of noxious fumes	III	N/A	Closed	Box leak checked after assembly	
				<u>Negative Pressure Section</u>: Single-channel gas sample drafts box air into sample line	<u>Negative Pressure Section</u>: Single channel contaminated sample; bad data	<u>Negative Pressure Section</u>: No effect	II	N/A	Closed	Failure most likely noticed by operator; box leak checked after assembly	
16a	Nylon tubing	Cracks/leaks	Age/vibration/chaffing	<u>Positive Pressure Section</u>: Single-channel gas sample leaks into box	<u>Positive Pressure Section</u>: Single channel has bad sample volume IAW calibration procedures, possible degraded data quality/accuracy	<u>Positive Pressure Section</u>: Possible release of flammable vapors, release of noxious fumes	III	N/A	Closed		
				<u>Negative Pressure Section</u>: Single-channel gas sample drafts box air into sample line	<u>Negative Pressure Section</u>: Single channel contaminated sample; bad data	<u>Negative Pressure Section</u>: No effect	II	N/A	Closed	Failure most likely noticed by operator	
17a	Stainless steel tubing	Cracks/leaks	Vibration/bad bend	<u>Positive Pressure Section</u>: Single-channel gas sample leaks into box	<u>Positive Pressure Section</u>: Single channel has bad sample volume IAW calibration procedures, possible degraded data quality/ accuracy	<u>Positive Pressure Section</u>: Possible release of flammable vapors, release of noxious fumes	III	N/A	Closed		
				<u>Negative Pressure Section</u>: Single-channel gas sample drafts box air into sample line	<u>Negative Pressure Section</u>: Single channel contaminated sample; bad data	<u>Negative Pressure Section</u>: No effect	II	N/A	Closed	Failure most likely noticed by operator	
18a	Sonic ejector/ evacuator	Clogged	Contaminated supply line/ejector drafts particulate matter	Ejector fails to draft air from box	Ullage sampling system containment box fails to maintain a negative pressure	No effect	IV	N/A	Closed		

ID	Component	Failure Mode	Failure Cause	Component Effect	System Effect	Aircraft Effect	Hazard Cat.	Hazard Prob.	Status	Controls	Comments
19a	Fluid drain	Clogged	Mechanical failure	Fluid cannot be drained from trap or water separator	If not noticed by operator could cause separator or trap to fill with fluid; possible bad data or damages sensor/loss of single channel	No effect	II	N/A	Closed	Failure most likely noticed by operator in the form of bad data on one channel	
19b		Leaks	Mechanical failure	Fluid spills/leaks from component	No effect	Fluid spills/accumulates under instrumentation racks; possible noxious vapors	III	N/A	Closed	Fluid/smell most likely noticed by operator	
20a	Cannon plug	Pin-to-pin short	Bent pin, cracked or damaged insert	No effect	Possible signal failure; incorrect data, bad data on one channel	No effect	II	N/A	Closed	Pins installed IAW proper handling procedures	
20b		Case short	Bent pin, cracked or damaged insert	Damaged connector	Possible signal failure; incorrect data, bad data, noisy data on multiple channels	No effect	II	N/A	Closed	Cannon plug shorts are rare	
21a	Power chord	Internal short	Chaffed wire, faulty chord	Failed electrical path, wire overheats, possible smoke and fire	Failed primary equipment, loss of data on some or all channels; possible ancillary damage	Possible ancillary damage from smoke/fire; possible minor burns and/or noxious fumes	I	N/A	Closed	Chords tested and inspected prior to construction; power chords bundled and tied to prevent chaffing; circuit breakers in line to protect wire runs and equipment from overheating and fire; hand-held fire extinguisher in cabin	
21b		Short to aircraft/rack	Chaffed wire	Failed electrical path, wire overheats, possible smoke and fire	Failed primary equipment, loss of data on some or all channels; possible ancillary damage	Possible ancillary damage from smoke/fire; possible severe burns and/or noxious fumes	I	N/A	Closed	Chords tested and inspected prior to construction; power chords bundled and tied to prevent chaffing; circuit breakers in line to protect wire runs and equipment from overheating and fire; hand-held fire extinguisher in cabin	
22a	Wire harness	Wire short	Chaffed/cracked wire	Failed electrical path, possible wire overheat	Failed signal path, loss of data on some or all channels; possible equipment damage overheating	Possible ancillary damage from overheating	II	N/A	Closed	Aircraft-grade wire installed IAW sound practices inspected prior to construction, wires bundled and tied to prevent chaffing, low power signals and excitation on wires only	

APPENDIX G—DESCRIPTION AND ANALYSIS OF LAB-BASED OXYGEN ANALYSIS SYSTEM FOR USE WITH FLIGHT TEST INERT GAS GENERATOR

A tertiary analysis of a lab-based altitude oxygen analyzer was performed to determine what features would be required to provide an equivalent level of safety for measuring the oxygen concentration of the product and permeate oxygen concentration of an onboard inert gas generator (OBIGGs) during a flight test. It was determined that the OBIGGs has sufficient controls to prevent flammable vapors and liquids from being present during operation. This eliminates the need for a purged containment system with liquid traps and other related safety equipment. The only hazard analyzed with significant aircraft effects, which is not a direct result of flammable liquids or vapors at the sample location, is the uncontained failure of the pump motor (see appendix F, hazard 5b). This hazard can be controlled by using an explosion-proof pump that has a motor designed to contain fragments in the event of a failure. This would allow for an equivalent level of safety to the onboard oxygen analysis system (OBOAS) by using a laboratory altitude oxygen analyzer to measure the oxygen concentration from an OBIGGs during a flight test.

The two-channel laboratory oxygen analyzer developed by the Federal Aviation Administration has gas sample interfaces similar to OBOAS on the rear access panel as well as the sample return. It does not require purge air but does have a port for calibration, and the sample return has the option to bypass the sample or return it to the system. It has similar power requirements to the OBOAS, as it uses a four-headed pump (for two gas sample channels) that uses the same explosion-proof motor. This system must be rack-mounted in 14 vertical inches of a 19-inch instrumentation rack with adequate space beneath to mount the large pump. The system interfaces to the data acquisition system with the same two cannon plugs described in appendix D, with the output for oxygen signals 1 and 2, inlet pressures 1 and 2, and the return pressure all being on the same pins identified. All other pins on the connectors are open. The system is operated identically to the OBOAS.