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# Oxigraf O2N2 Oxygen Analyzer for

# On-Board Inert Gas Generation System (OBIGGS) validation

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# Table of Contents



# Table of Figures

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## 1.0 Introduction:

This proposal describes the Oxigraf O2N2 Oxygen Analyzer for On-Board Inert Gas Generation System (OBIGGS) validation. An OBIGGS is now mandatory for many civilian and military aircraft to prevent the buildup of explosive conditions in fuel tanks by generating Nitrogen Enriched Air (NEA) to lower the oxygen content in the fuel tank headspace or ullage. The Oxigraf oxygen analyzer characterizes the performance of an OBIGGS system over the flight profile of takeoff, climb, cruise, and descent by measuring the oxygen concentration at multiple sites in the fuel tanks every 16 seconds. The O2N2 analyzer is a specialized instrument evolved from Oxigraf oxygen analyzers commonly used for medical, scientific, and industrial process and safety applications. The patented laser diode absorption spectroscopy technology employed by Oxigraf is a natural fit for analyzing oxygen concentrations in a Jet-A fuel-air mixture as only light comes in contact with the gas sample, and the gas sample is maintained at a low temperature. The sensor responds in milliseconds, has no cross sensitivity to other gases, corrects automatically for changes in temperature and pressure, measures quickly over a wide dynamic range, and is insensitive to vibration. The O2N2 system utilizes features to mitigate risks of escape of the sample gas, such as monitored nitrogen purging of the electronics enclosure. The O2N2 Analyzer along with associated valves, regulators, purge and calibration gas supplies, fuel tank sample kits, and a laptop computer with the system control and data logging software comprise the complete OBIGGS Validation System that will be described herein. Oxigraf has delivered O2N2 systems to airframe and integrators both in the USA and internationally including Boeing Commercial Airplanes, Westland Helicopters, Parker Aerospace, EATON Aerospace, Mitsubishi, Airbus, Sukhoi and Boeing Integrated Defense Systems.

## 1.1 Oxigraf History/Background:

Oxigraf was founded in 1990 and has developed oxygen analysis instruments based on laser diode absorption spectroscopy technology described in eight patents assigned to Oxigraf. Unique hardware and firmware technology controls the laser diode and gas sample temperatures, scans and integrates the oxygen absorption, removes laser noise, measures the gas sample pressure, and computes the oxygen concentration. Oxigraf expertise relates to the design, assembly, burn-in, and test of laser diode, optical, gas sensor, and gas sampling assemblies. The Oxigraf team includes specialists in opto-electronic engineering, mechanical engineering, manufacturing, and quality control. The team is led by Bruce W. McCaul, Ph.D., who has sixteen years of prior experience as CEO in two companies manufacturing laser spectroscopy systems, medical lasers, infrared detectors, and noble gas arc lamps.

Oxigraf manufactures a complete line of laser diode sensors and instruments for the medical, analytical, industrial and process control industries. Laboratory table-top and industrial wall-mount NEMA rated enclosures are available. Industrial applications may require sample conditioning to remove water, side-stream sampling for fast system response, and dual channel sampling for redundant monitoring for inert gas safety applications. Company highlights include:

- The Model O2 received clearance for marketing for human use by the FDA under the 510K process and CE medical device qualification in 1998.
- Oxigraf has performed two Phase I and one Phase II SBIR contracts for the U.S. Air Force and NASA.
- Oxigraf has been certified to quality management system to the US FDA 21 CFR Part 820 Quality system, the European medical quality system standard EN ISO 13485, the international quality systems standard ISO 9001, and the European Medical Device Directive 93/42/EEC. This quality system covers the design, production, installation, and servicing of Oxigraf sensors.
- Oxigraf performed manufacturing and quality engineering services for the ORCA Diagnostic, Inc cardiopulmonary stress test analyzer leading to UL, CSA, and CE approvals in 2000. The ORCA analyzer incorporates an X1004 Oxigraf sensor. Since 2002, Oxigraf has been the exclusive distributor for the ORCA system.
- Oxigraf delivers the O2N2 OBIGGS test and evaluation system to Boeing Commercial Aircraft for the 777 aircraft in 2006 and for the 787 in 2007. O2N2 systems also delivered to Westland Helicopter in 2007, Airbus in 2008, Sukhoi in 2009, Mitsubishi in 2012, and Parker Aerospace and EATON Aerospace in 2012.

## 1.2 The Oxigraf Aircraft OBIGGS Validation System:

The aircraft OBIGGS validation system is comprised of several rack mount Oxigraf O2N2 oxygen analyzers mounted in a rugged rack system along with associated manual sampling valves, calibration and purge gases, regulators, and a laptop computer with control and display software. A fuel sampling kit is also provided which includes five (5) fuel tank float valves and associated Teflon tubing for sampling and gas return lines. The number of O2N2 analyzers depends on the number of sample points in the fuel tank system to be monitored, with each O2N2 analyzer having four (4) sample channels. These items together make a complete system and a typical system rack mount analyzer system is shown in the figure 1 for reference. A process schematic of this system is shown in Figure 2. The process schematic shows the O2N2 analyzer in relation to the float valves in the fuel tanks, the purge and calibration gasses and flows, and the control and data system. Communications to the control and data system are through RS-232/485 links and an ARINC-429 interface is provided to communicate with customer furnished data monitoring and recording systems. The individual components comprising this system are described in the following paragraphs of the proposal.

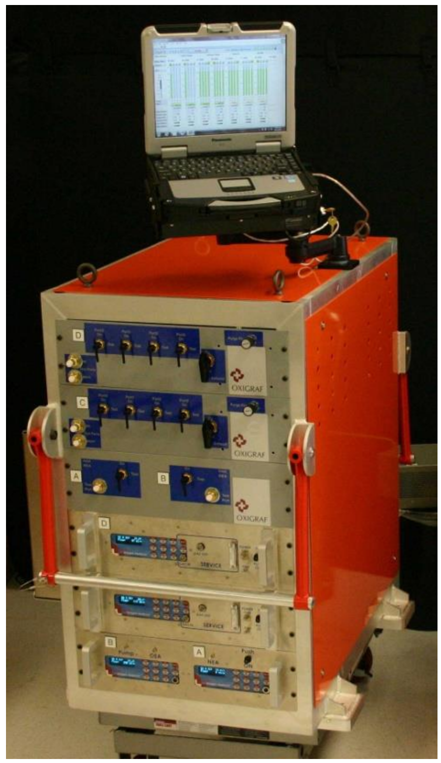

**Figure 1: 18U OBIGGS Validation System**

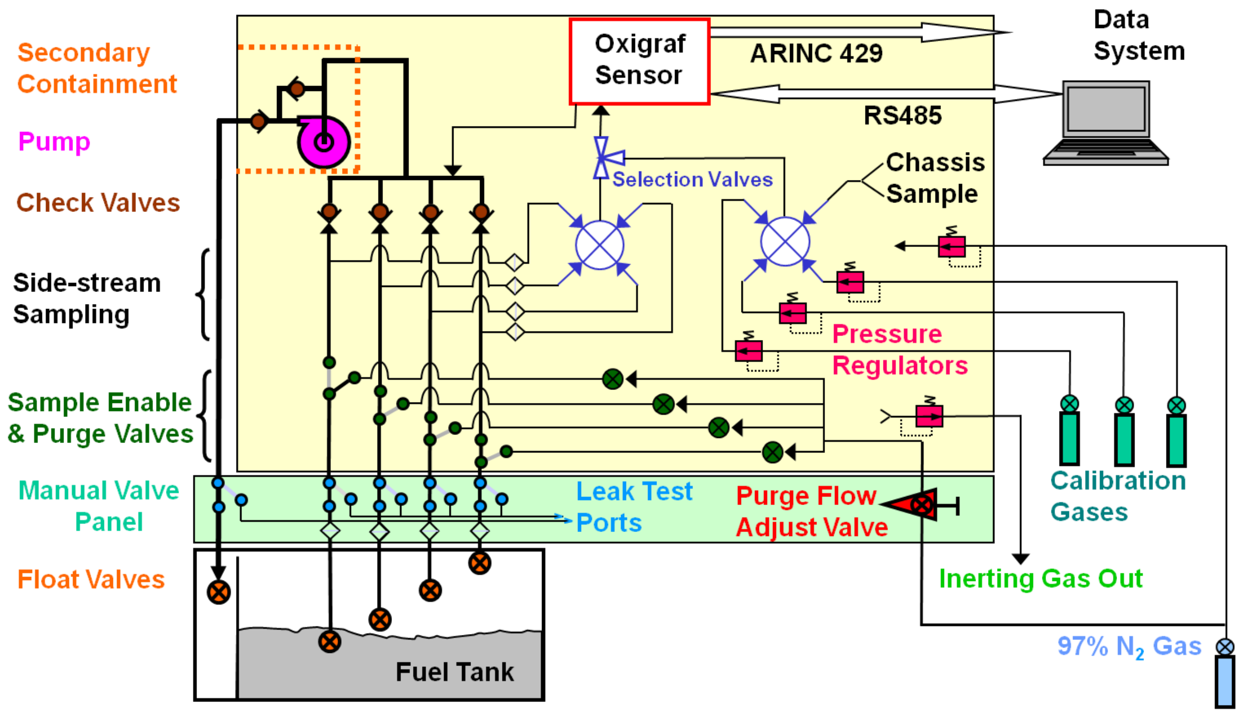


Figure 2: O2N2 Process Schematic

## 2.0 The O2N2 and O2NEA/OEA Oxygen Analyzer:

The Oxigraf model O2N2 oxygen analyzer is a 3U height rack mount instrument design to analyze oxygen content in fuel air mixture sample lines and includes internally a four (4) channel gas sampling system, auto-calibration system, vacuum florescent display (VFD), keypad, RS-485 link with ModBus communications protocol, and ARINC-429 interface. The O2N2 is shown in the rendering in figure 3 below:

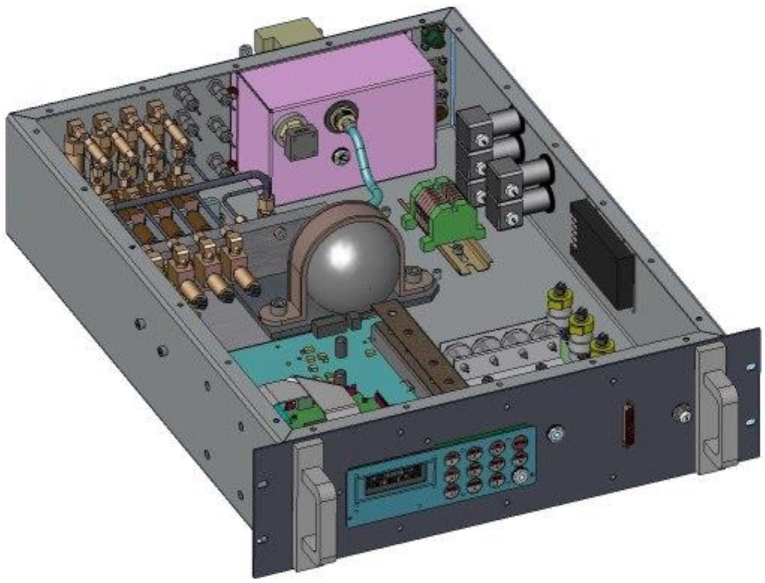

Figure 3: 02N2 Oxygen Analyzer

## 2.1 Theory of operation:

The Oxigraf oxygen sensor uses laser diode absorption technology to measure oxygen concentration in the gas sample. A laser diode produces light in the visible spectrum at 760 nanometers, which is absorbed by oxygen. To analyze oxygen the laser beam is focused through the sample gas onto a detector. Oxygen concentration is inversely proportional to the amount of light reaching the detector. An analysis is made every 10 ms, with the analyzer automatically zeroing at each measurement interval by electronically tuning the laser to oxygen non-absorption wavelengths. The absorption and line width measurements are used in an Oxigraf proprietary algorithm to compute O2 concentration independent of pressure or foreign gas composition.

The O2N2 measures and displays the oxygen concentration in a gas sample drawn through the instrument. A high-volume pump continuously pumps the four input gas streams through pressure reducing check valves to the exhaust port. The analyzer samples each of these streams to measure sequentially the oxygen concentration of the four input channels. This scheme reduces the measurement time latency since all four channels are pumped continuously, allowing the use of a fast response input multiplexer with short sample lines. The transit time of the sample from the fuel tank to the analyzer may be 30 to 60 seconds, a latency which is a constant and can be corrected to the real-time flight profile. The multiplexer looks at each of the four channels for 4 seconds resulting in a complete measurement of every site in 16 seconds.

Calibration gas inputs, one midpoint check gas input, and a chassis ambient sample input are also provided. Two-point auto-calibration and timed scanning of the check gas can be set up to allow unattended calibration and verification of the analyzer. Automatic detection of sample line blockage and initiation of high-pressure purging can also be enabled.

Measured oxygen concentration in percent volume fraction is displayed on a front panel alphanumeric VFD display. Two lines of 16 characters show numeric data and the parameter units or other annunciation. The instrument mode is controlled via a front panel keypad array. Eight keys select the mode (O2, Setup, Test, Cal 1, Cal 2, Flow, Alarms, and Help) while the other keys facilitate selection and modification of parameters.

Analyzer data is also available at a serial RS232 port in Oxigraf format, a serial RS485 port in ModBus format, and an ARINC-429 output port. Either the RS-232 or RS-485 port can be used to control the analyzer as well as transmit data. The ARINC-429 interface only has transmission capability, with the report rate and base label set via the keypad or through ModBus interface.

The analyzer is packaged in a rack-mounted enclosure with all gas and electrical connections on the back panel. Gas lines are connected via 1/8-inch OD compression fittings. Circular connectors provide the physical interface for 24Volts DC power, RS-232/RS-485 serial data, and the ARINC-429 output. The analyzer power is switched by a circuit breaker on the front panel along with a switch for the pump.

## 2.2 Model O2N2 Specifications:

The performance specifications are valid under the following conditions:

| | |
|---|---|
| Ambient temperature | 5 to 40° C (40 to 105° F) operating; -20 to 60° C (-2 to 140° F) storage |
| Cell pressure | 1.06 to 19.2 PSIA (73 to 1324 mb) (54 to 993 mm Hg) |
| Warm-up for full accuracy | 10 minutes |
| Fuel Tank Altitude | 0 – 44,000 feet. (Cabin altitude: 0 – 15,000 feet). |
| Humidity | 0 to 95%, non-condensing (at 40° C or lower) |

Performance Specifications

| | |
|---|---|
| Range: | 3 to 21% Oxygen |
| Resolution: | 0.1% |
| Stability (24 hrs): | +- 0.5% |
| Linearity: | +-0.2% |
| Cross-sensitivity: | +-0.2%, and gas mixture |
| Sensor Response time: | 1s @350 ml/min flow and electronic filter setting 6 |

| | |
|---|---|
| Multiplexer cycle time | 16 seconds for four channels. |
| Latency of sample | 10 to 60 seconds depending on length of sampling line. |
| Alarms (4): | Oxygen A, Oxygen B, Low Flow, System Check |
| Digital Output: | ARINC-429, RS-232, RS-485 |

Electrical Specifications

| | |
|---|---|
| DC power supply | 28 VDC, 3.3 A |

Mechanical Specifications

| | |
|---|---|
| Sample Inlet Fittings: | SwageLok 1/8" Tube, Stainless Steel (4X) |
| Sample Return Fitting: | SwageLok ¼" Tube, Stainless Steel |
| Weight | 39 lb. (18 Kg) |

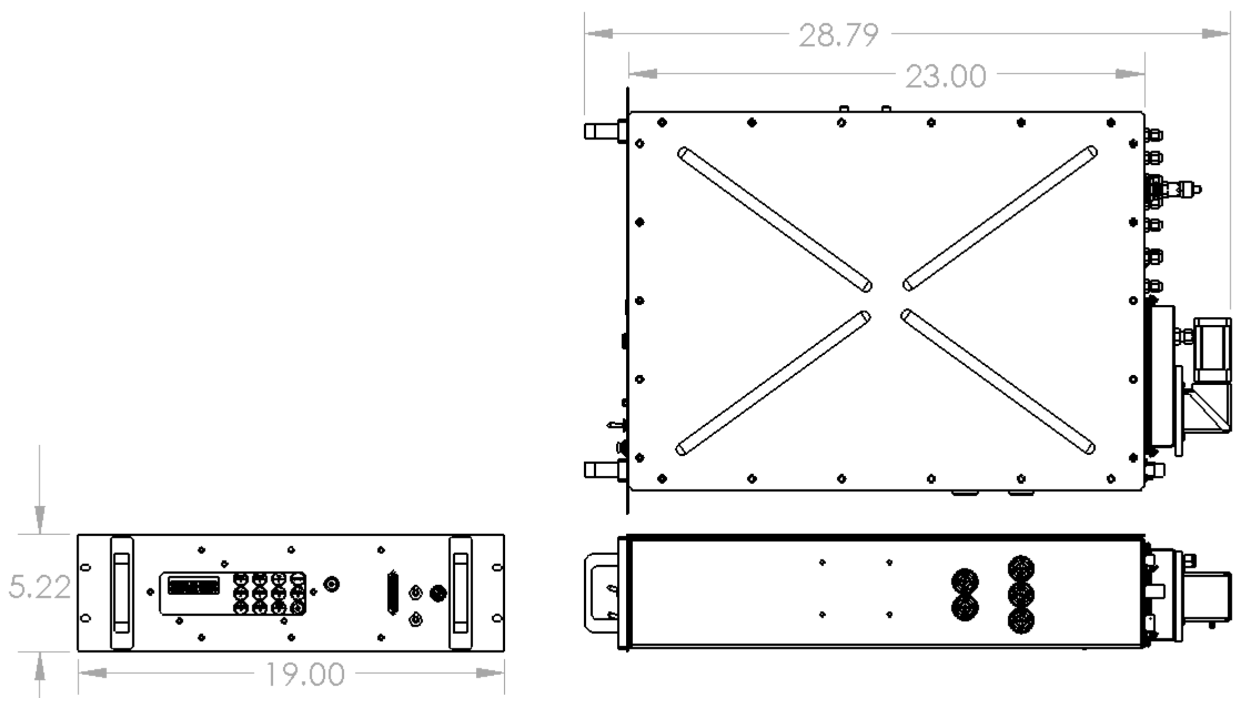


**Figure 4: O2N2 Mechanical Dimensions**

## 2.3 O2NEA/OEA Analyzer

The Oxigraf O2NEA/OEA analyzer is based on the O2N2 analyzer but integrates two Oxigraf oxygen sensors into a single gas sampling system, autocalibration system, vacuum fluorescent alphanumeric displays (VFD), keypads, RS485 link with Modbus communication protocol, and ARINC 429 interface.

The Oxigraf sensor uses laser diode absorption technology to measure oxygen concentration in the gas sample. A laser diode produces light in the visible spectrum at 760 nanometers, which is absorbed by oxygen. To analyze oxygen the laser beam is focused through the sample gas onto a detector. Oxygen concentration is inversely proportional to the amount of light reaching the detector. An analysis is made every 10 ms, with the analyzer automatically zeroing at each measurement interval by electronically tuning the laser to oxygen non-absorption wavelength. The peak absorption measurement and line width measurement are used in an Oxigraf proprietary algorithm to compute O2 concentration independent pressure or foreign gas composition.

The OEA/NEA measures and displays the oxygen concentration in a gas sample that flows through the instrument. For the OEA, a high-volume pump continuously pumps the gas stream through a pressure reducing check valve, then through the O2 sensor, and on to the exhaust port. For the NEA, the other analyzer relies on the pressurized supply of NEA to produce flow through the system.

Calibration gas inputs, one midpoint check gas input, and a chassis ambient sample input are also provided. Two-point autocalibration and timed scanning of the check gas can be set up to allow unattended calibration and verification of the analyzers. Automatic detection of sample line blockage and initiation of high-pressure purging can also be enabled.

Measured oxygen concentration in percent volume fraction is displayed on a separate front panel alphanumeric VFD display for each analyzer. Two lines of 16 characters show numeric data and the parameter units or other annunciation. The instrument mode is controlled via a front panel keypad array. Eight keys select the mode (O2, Setup, Test, Cal 1, Cal 2, Flow, Alarms, and Help) while the other keys facilitate selection and modification of parameters.

Analyzer data is also available at a serial RS232 port in Oxigraf format, a serial RS485 port in Modbus format, and an ARINC 429 output port. Either the RS232 or RS485 port can be used to control the analyzer as well as transmit data. The ARINC 429 interface only has transmit capability, with the report rate and base label set via the keypad or Modbus.

The analyzer is packaged in a rack-mounted enclosure with all gas and electrical connections on the back panel. Sample gas inputs are connected via 1/8-inch OD compression fittings. The OEA outlet is ¼” OD.

Circular connectors provide the physical interface for 24 or 28 VDC power, RS232/RS485 serial data, and the ARINC 429 output. The analyzer and pump power is supplied through a circuit breaker on the front panel. The pump and analyzers each then have individual switches.

## 2.4 O2NEA/OEA Performance Conditions

The performance specifications are valid under the following conditions:

| | |
|---|---|
| Ambient temperature | 5 to 40° C (40 to 105° F) operating; -20 to 60° C (-2 to 140° F) storage |
| Cell pressure | 1.4 to 17.4 PSI (120 to 1200 mb) (100 to 900 mm Hg) (OEA) |
| Warm-up for full accuracy | 10 minutes |
| Altitude | 0 - 44000 feet (OEA) |
| Humidity | 0 to 95%, non-condensing (at 40° C or lower) |

Performance Specifications

| | |
|---|---|
| Range: | 3 to 40% (OEA), 0 to 21% (NEA) |
| Resolution: | 0.1% |
| Stability (24 hrs): | +- 1.0% |
| Linearity: | +-0.6% |
| Cross-sensitivity: | +-0.4%, and gas mixture (OEA) |
| Response time: | 1s @350 ml/min flow and electronic filter setting 6 |
| Alarms (4): | Oxygen A, Oxygen B, Low Flow, System Check |
| Digital Output: | ARINC 429 (2X), RS-232, RS-485 |

Electrical Specifications

| | |
|---|---|
| DC power supply | 28 VDC, 6.0 A |

Mechanical Specifications

| | |
|---|---|
| Sample Inlet Fittings: | SwageLok 1/8" Tube, Stainless Steel (2X) |

| | |
|---|---|
| Sample Return Fitting: | SwageLok 1/4" & 1/8" Tube, Stainless Steel |
| Weight | 40 lb.  (18 Kg) |

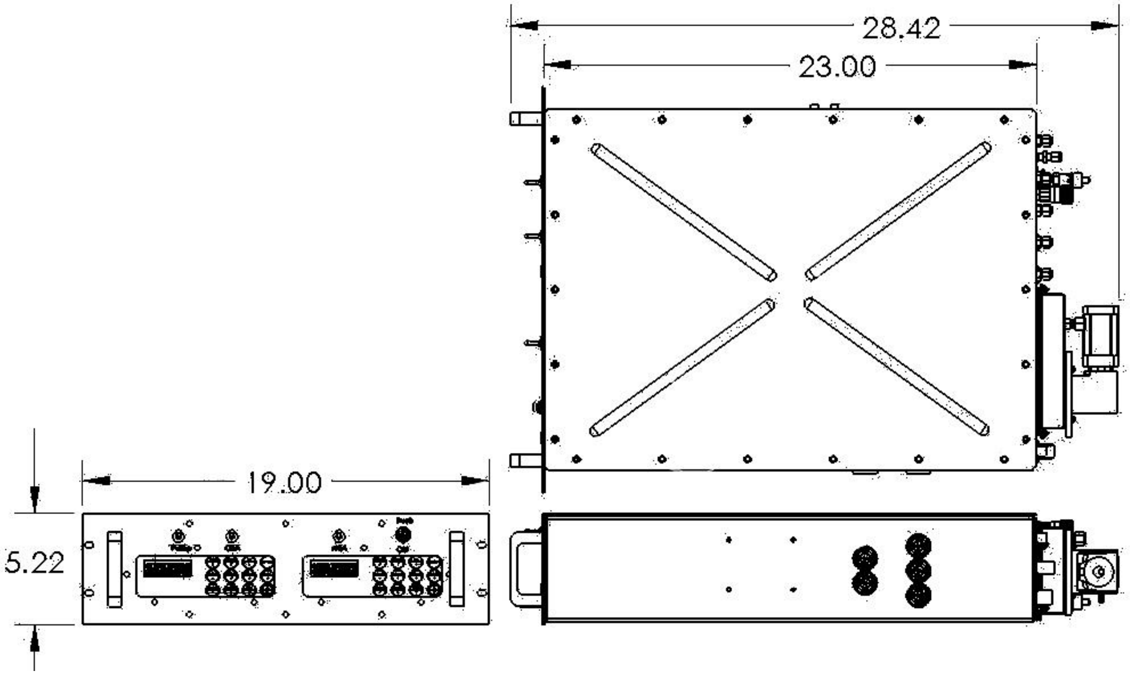


Figure 5: O2NEA/OEA Mechanical Dimensions

## 3.0 18U Chassis:

Oxigraf manufactures an 18U height rack-mount chassis for installation of the O2N2 analyzers, O2NEA/OEA analyzers, RA pressure regulators and calibration/purge gasses (now mounting on the top of the rack), and MV manual valve assemblies.  The 18U height chassis is shown below in Figure 1, with two (2) 02N2 oxygen analyzers for eight (8) fuel tank sample ports and a O2NEA/OEA analyzer for two (2) channels of NEA and OEA measurement. A drawing of the 18U chassis is included in the proposal, drawing number 07-0433, revision B3.  A stress analysis with 20 g lateral and longitudinal acceleration stresses applied shows acceptable deformation and was performed in lieu of crash testing.   Vibration tests have been carried out for the 12U chassis with a four (4) channel system installed to MIL SPEC standards for aircraft and helicopters.  Temperature, water drip, magnetic influence and other test data and/or analyses are available upon request and copies of these reports will be included in the program data package.

## 4.0 Model MV and MV NEA/OEA Manual Valve Assemblies:

The sampling valves in the Model O2N2 are solenoid piloted pneumatic valves under program control. The channel selection and sampling dwell times can be programmed from the laptop computer (and alternatively front the O2N2 front panel). Nevertheless, manual valve are provided to open/close individually the sample and return lines, and the manual valves provide a convenient tool for leak checking. The MV assembly also a needle valve for controlling the purge flow rate. The manual valve assembly mounts in the rack-mount chassis and provides convenient operator controls on the front panel. Two (2) Model MV manual valve assemblies and one (1) Model MV NEA/OEA is shown in figure 1 above and are the items labeled A, B, C and D in the chassis. The Model MV manual valve assembly handles four (4) sample channels and the MV NEA/OEA manual valve assembly handles the NEA and OEA sample lines.

## 5.0 Model RA Pressure Regulators and Gauges:

The Regulator Assembly accepts high pressure inputs from the calibration, verification, inerting, and pneumatic valve operating gas cylinders. The pressure is regulated to approximately 15 psig for the calibration and verification gases and to approximately 70 psi for the valve operating gas, which also provides the 2% chassis inerting gas. Gauges and valves provide operator convenience to monitor cylinder pressure and control delivery pressure. A sample regulator assembly is shown below in figure 6, and mounts to the rack-mount chassis.

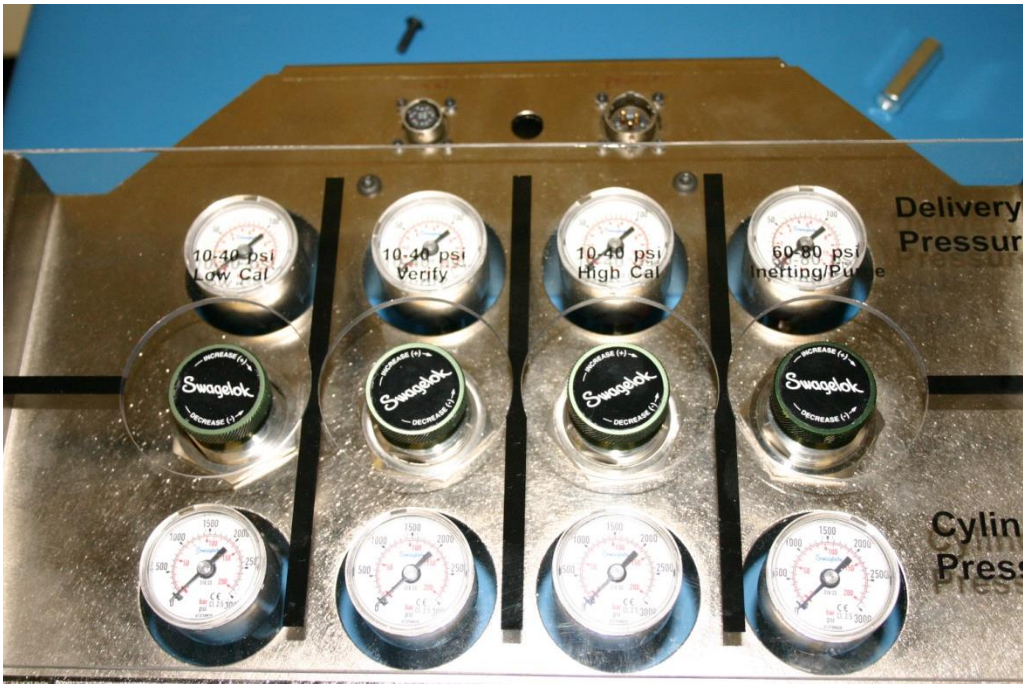


Figure 6: Regulator Assembly

## 6.0 Toughbook Laptop:

Oxigraf will incorporate a Panasonics Toughbook Laptop computer (Model CF-31) as part of the control and monitoring system to support Oxigraf OBIGGS Validation test systems. The Toughbook laptop will include the OxiFTE software described below installed on its hard-drive and provide operator control over the validation test system. The laptop will interface to the test rack (s) via ModBus interaface. The laptop is shown with the 18U chassis in Figure 1 above. The laptop is mounted to the top of the chassis and provided with a 28 VDC input MIL SPEC charging supply. The laptop requires approximately 4.0A of 28VDC power for operation and is powered from the main power connector on the rear of the rack.

## 7.0 OxiFTE Control Software:

Oxigraf OxiFTE software is designed to communicate exclusively with the Oxigraf O2N2 oxygen analyzer system.. The OxiFTE software uses the Modbus interface of the Model O2N2 Oxygen Analyzer to perform setup and monitor operations.

The OxiFTE software performs simultaneous monitoring on all of the analyzers in a system that are connected to the Modbus cable. The Modbus is connected to a USB-to-Modbus converter and the converter connects to a standard USB port on the rugged toughbook laptop.  A typical display generated by the OxiFTE software is shown in figure 7.  A copy of the OxiFTE software manual will be provided in the appendix of this proposal for review.

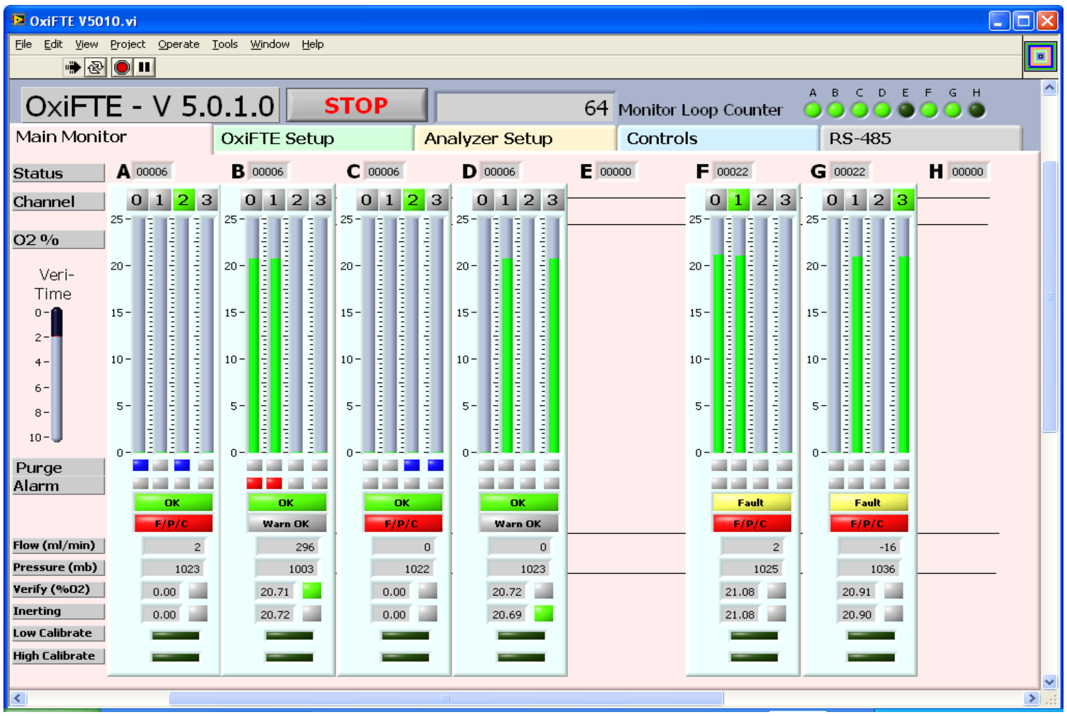


Figure 7: OxiFTE Main Monitor Window

## 8.0 Fuel Sampling Kit:

The fuel sampling kits consist of 50 meters of PTFA tubing for the four (4) sampling lines and one (1) return line needed for each analyzer.   Each line is provided with a float valve suitable for mounting in the fuel tank and a bulkhead fitting for the tank entry.   The tubing sizes are 3/16" OD for the sampling lines and ½" OD for the return line.   The sampling lines are recommended to be maintained of equal lengths to balance the sampling latency time of the four (4) channels to each analyzer.  A drawing of the sample float valve (P/N 07-0337) and return float valve (P/N 07-0319) are included in the appendix of the proposal.  A picture of the tubing and one each of the float valves is shown below in Figure 8.

**Figure 8: Fuel Sample Kit**

Oxigraf can supply two (2) fuel sample kits for installation in the G7000/8000 aircraft for the two (2) O2N2 analyzers in that system.  Oxigraf will also supply three (3) additional fuel sample kits for the E2 Program.

## 9.0 Oxigraf In-Line Liquid Stop-Valve

Oxigraf also proposes to incorporate an additional liquid stop valve on each fuel sample line at the 18U rack to prevent liquid ingestion into the analyzers in the event of a failure mode, such as a float valve failure, that would allow liquid to be drawn toward the analyzers.  The liquid stop valves are shown in the assembly in the following Figure 9 and would be mounted in groups of four (4) valves for each analyzer in the rack.  The liquid stop valves would work with the O2N2 purging system to open and allow clearance of fuel from the sample lines during a purge cycle.  A maximum total of twelve (12) stop valves would be incorporated into the 18U chassis.  The liquid stop valves would be additional layer of safety and system reliability.  These can be configured for either G7/8 or E2 system.

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Figure 8: Liquid stop valve assembly

## 10.0 G7000/8000 Proposed 10 channel O2N2 Configurations

Oxigraf proposes an OBIGGS validation system comprised of an 18U rack chassis with two (2) O2N2 analyzers, and single O2NEA/OEA analyzer , MV Assemblies, , RA Assembly and a Toughbook laptop computer along with fuel tank sampling kits and calibration and purge gasses.

Each O2N2 analyzer will sample from four (4) fuel tank probes and be controlled by a MV assembly in the rack for a total of eight (8) channels. The O2NEA/OEA analyzer and MV NEA/OEA assembly is used for the two (2) channels of NEA and OEA outputs. The RA assembly in the rack will interface with calibration and purge gasses contained in cylinders mounted on the top of the rack. The toughbook computer will mount on an arm and provide control of the system. A similar configuration is also shown in Figure 1 in this proposal.

Additionally, Oxigraf will support Intertechnique with design reviews, customer support, service, and user training to an agreed upon schedule and requirements. Any additional travel and other requirements can be quoted separately as described in the cost proposal.

## 11.0 E2 Proposed 12 Channel O2N2 Configurations

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Oxigraf proposes an OBIGGS validation system comprised of the 18U rack chassis previously supplied to the G7000/8000 system with the O2NEA/OEA analyzer and MV NEA/OEA assembly removed and replaced by a single spare O2N2 analyzer and MV valve assembly with changes to the tubing internal to the 18U chassis as necessary.  Oxigraf will have manufactured these items and install and test them in the 18U chassis during the G7000/8000 construction and removed these items and placed them in crates for customer storage and future re-assembly.  This system will be able to operate and analyzer a total of twelve (12) O2N2 sample channels and will only require additional calibration/purge gasses and necessary.  The electronics/software are common to the two systems.