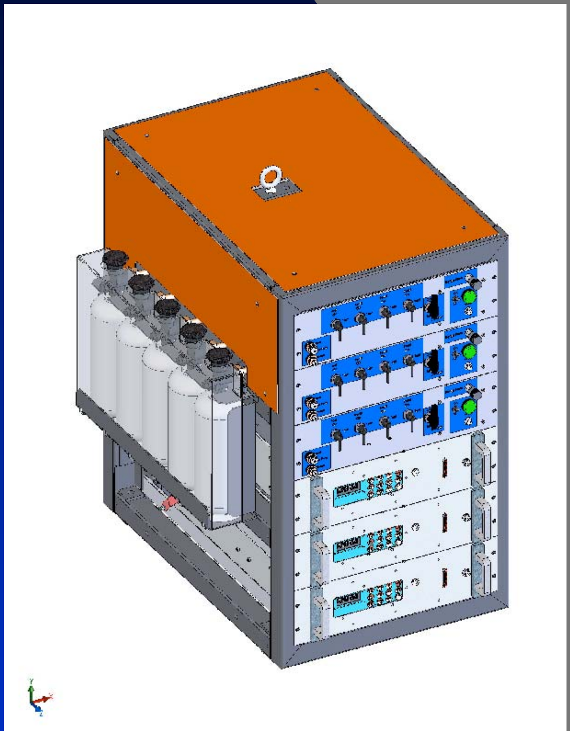
Verification of Airliner Fuel Tank Inerting



- Sampling 8 to 28 points simultaneously
- Tunable diode laser oxygen analyzer samples 4 channels sequentially
- New data every 15 seconds
- Sampling latency 60 seconds
- Pressure correction over flight profile to 40,000’
- Auto calibration checks during flight
- Risk mitigation for measurement hazards

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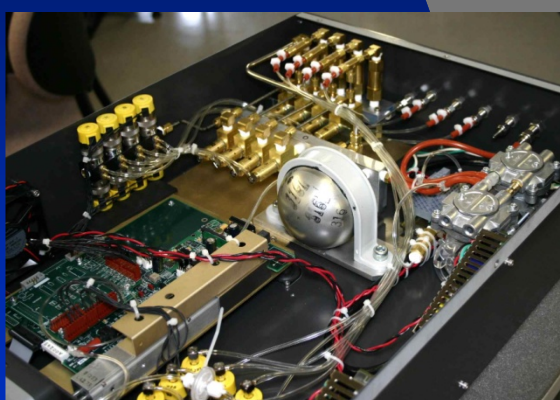
Why tunable diode laser oxygen sensors for inert gas monitoring?



- Zirconia sensors at 700 C would ignite flammable mixtures
- Electrochemical sensors are often poisoned by chemical vapors and are slow responding
- Paramagnetic sensors are motion sensitive
- Reliability: 500,000 hours

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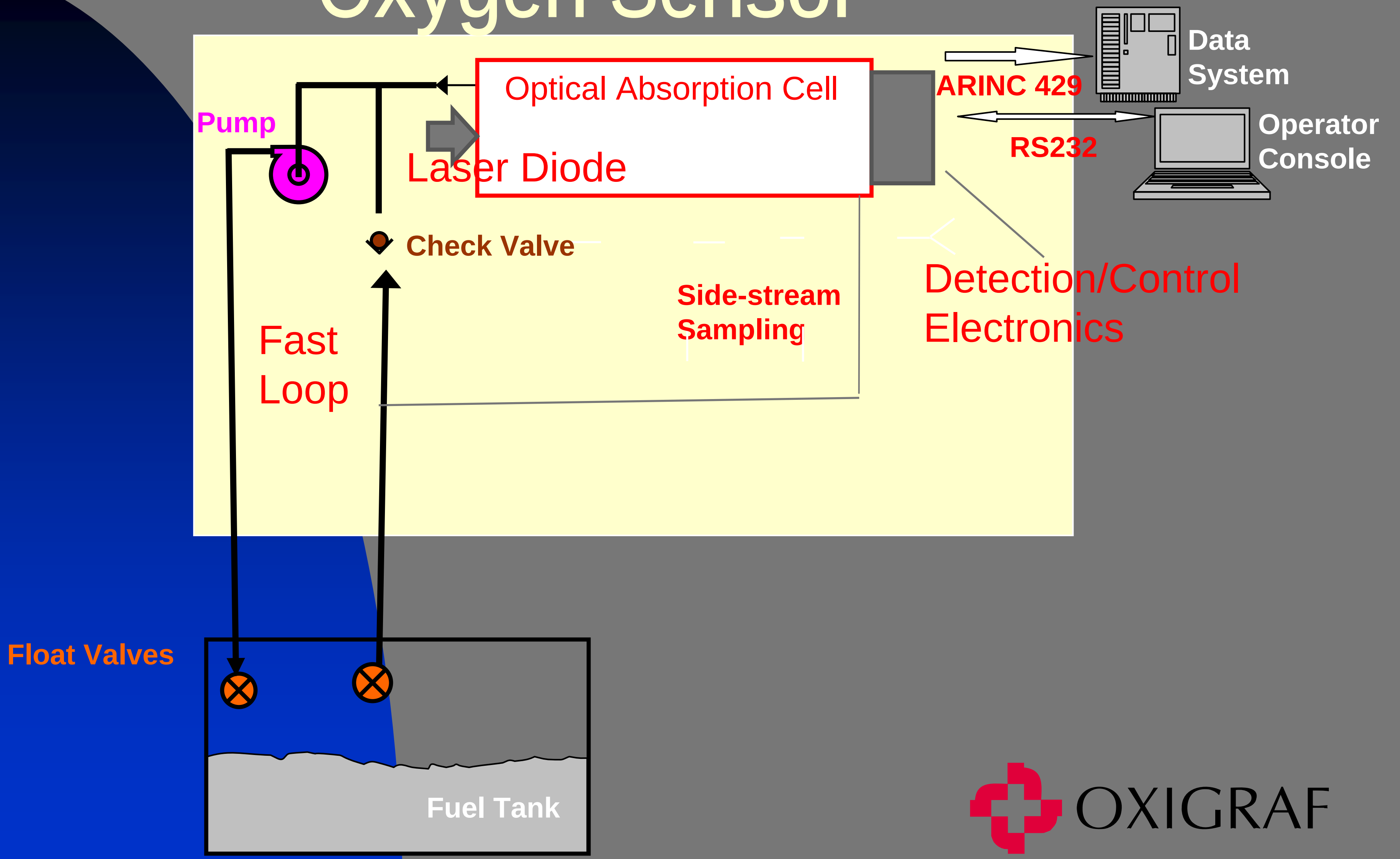
Tunable Diode Laser Oxygen Sensor



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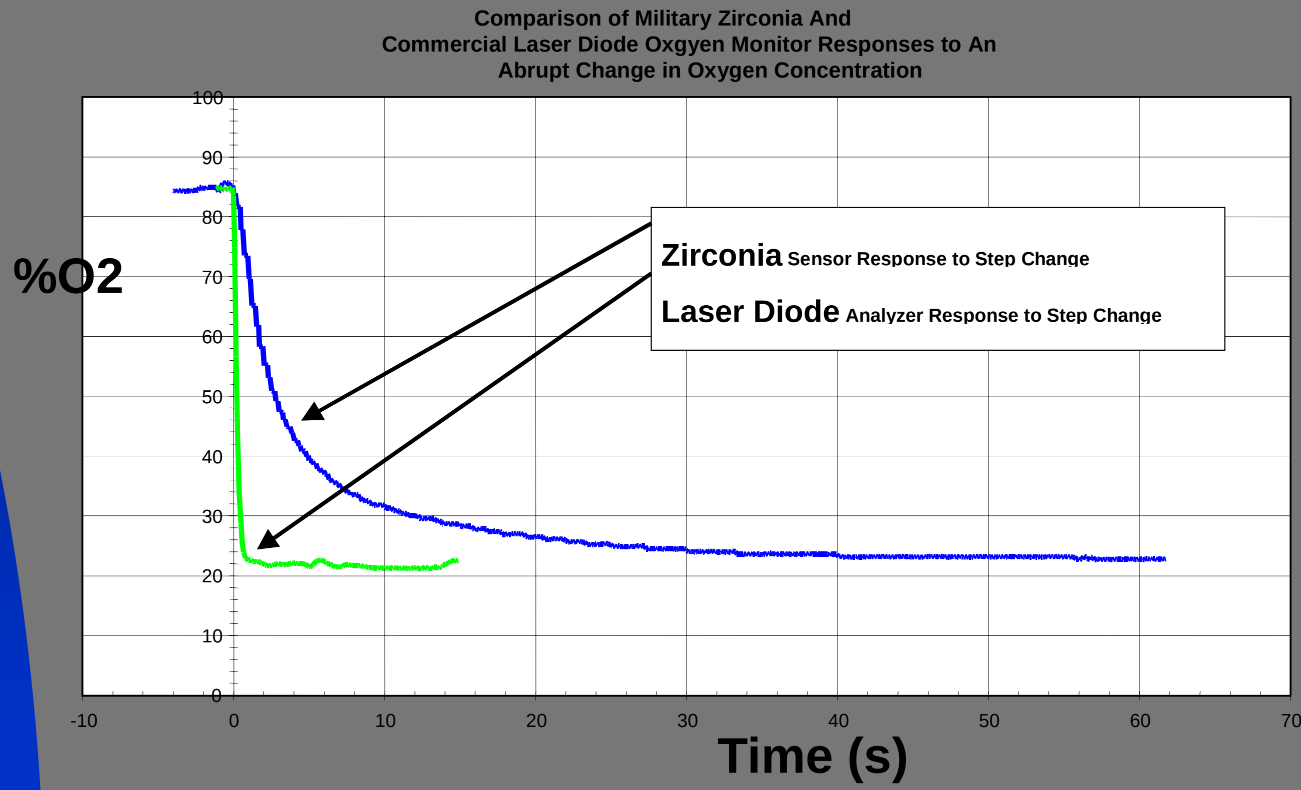
Zirconia vs Laser Diode Oxygen Sensor Time Response



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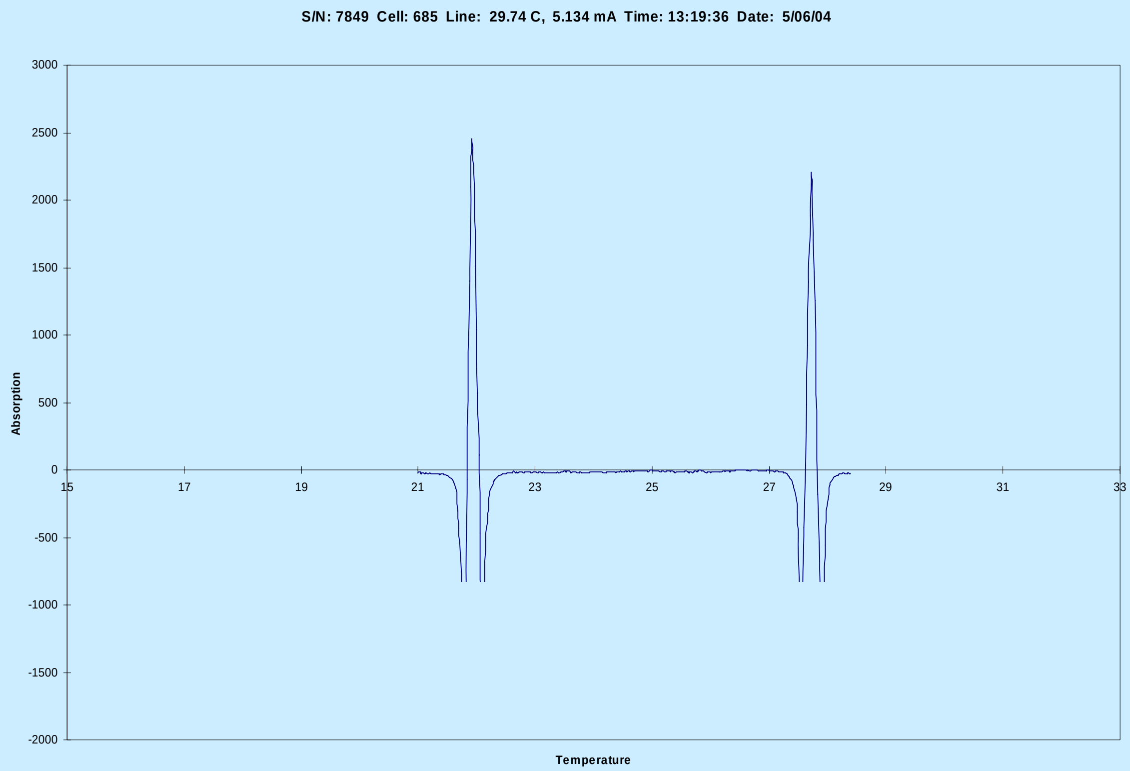
Scanning the Oxygen Absorption Lines



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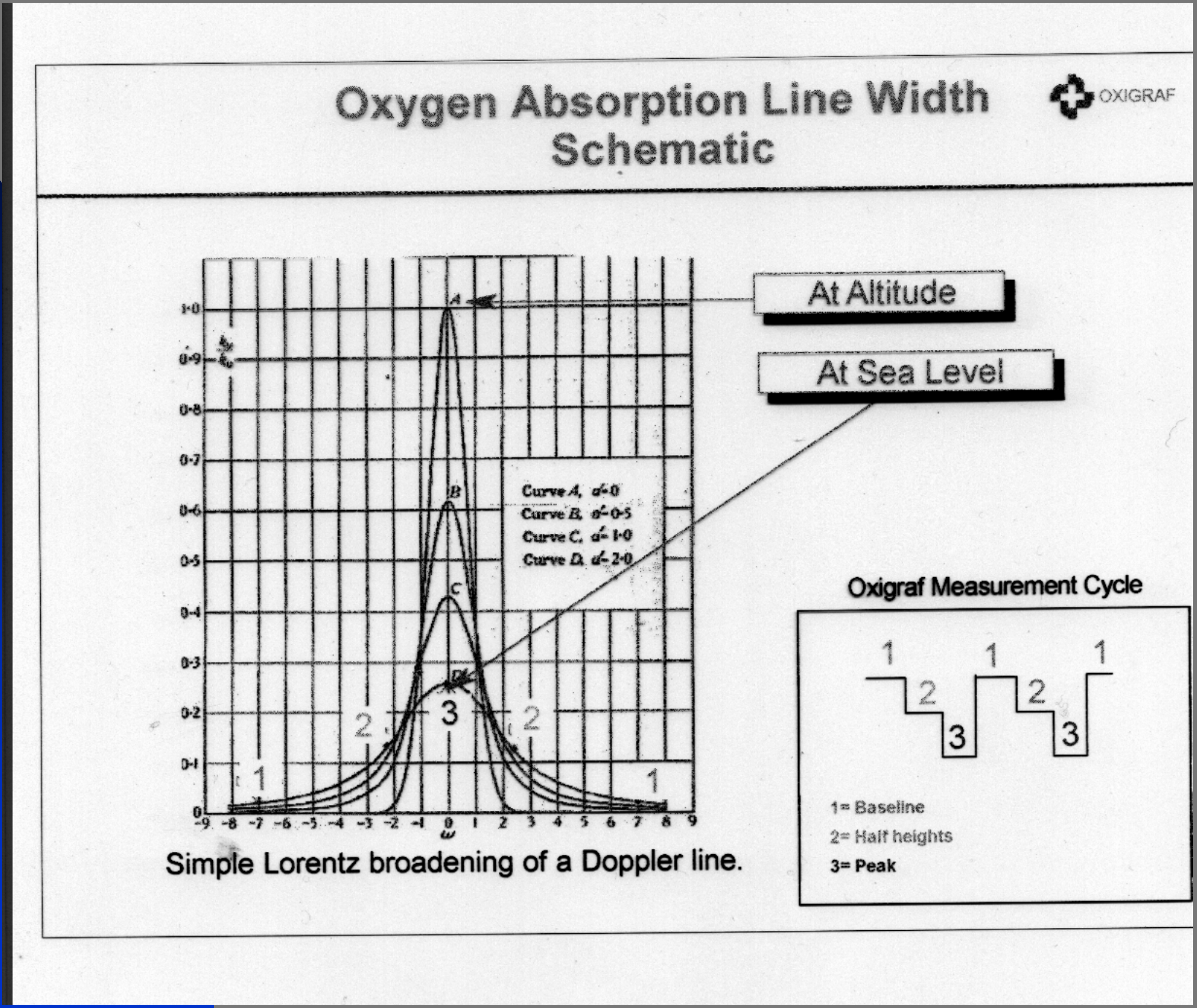
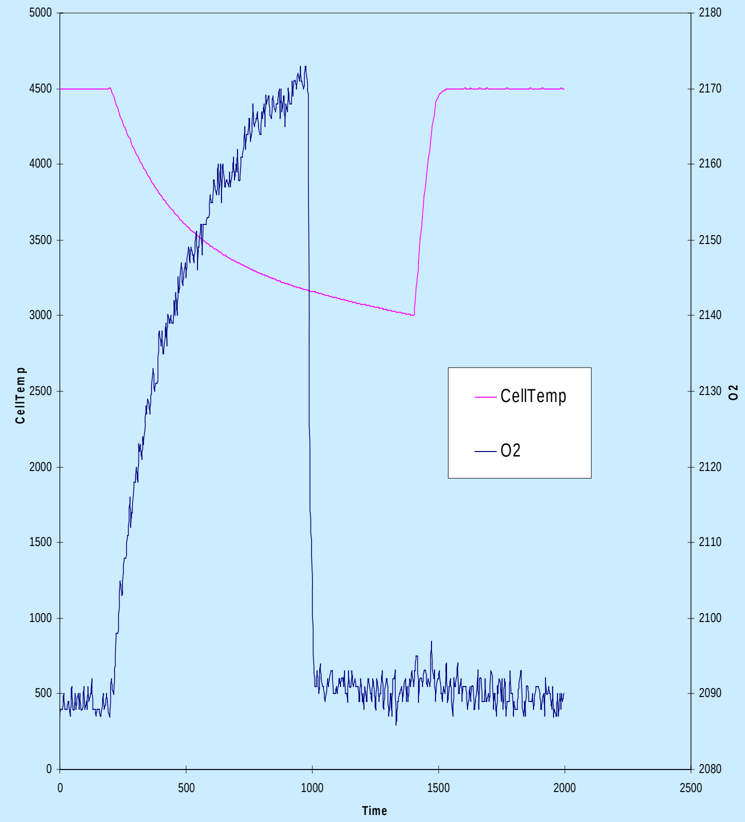
O2 Line Width



Simple Lorentz broadening of a Doppler line.

Temperature Correction



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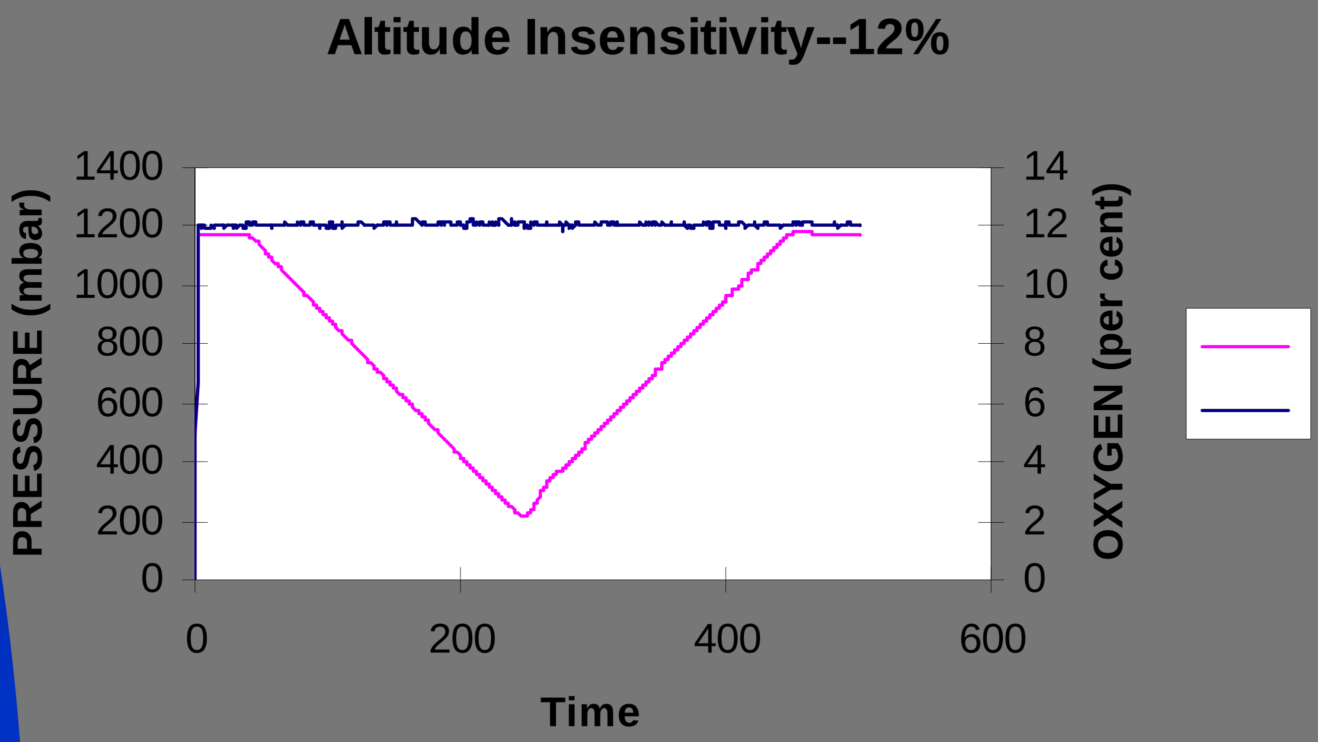
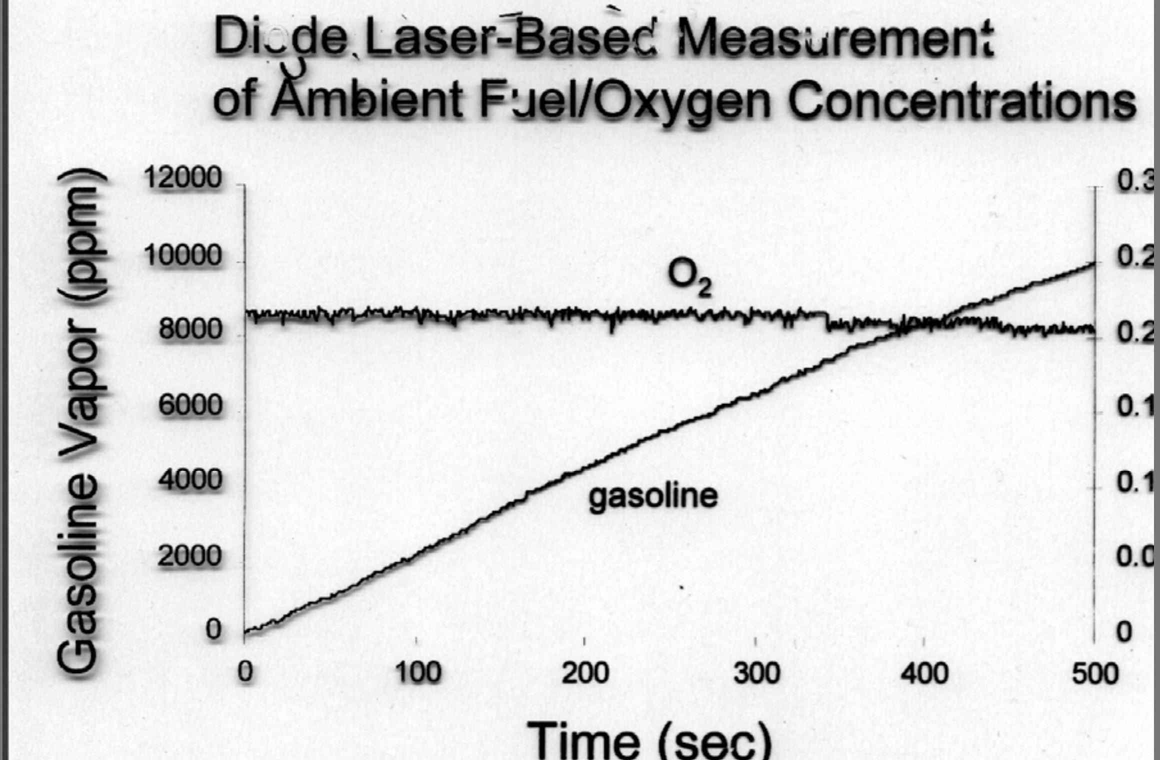
Pressure Correction: 12% Oxygen



Cross Sensitivity to Organic Vapors



imultaneous measurement of fuel/oxygen concentration (by volume) during isplacement of contents (dry air) of a 14 liter vessel by air saturated by gas apor at 294K and 1 atmosphere total pressure. Oxygen sensor courtesy f Oxigraf, Inc.

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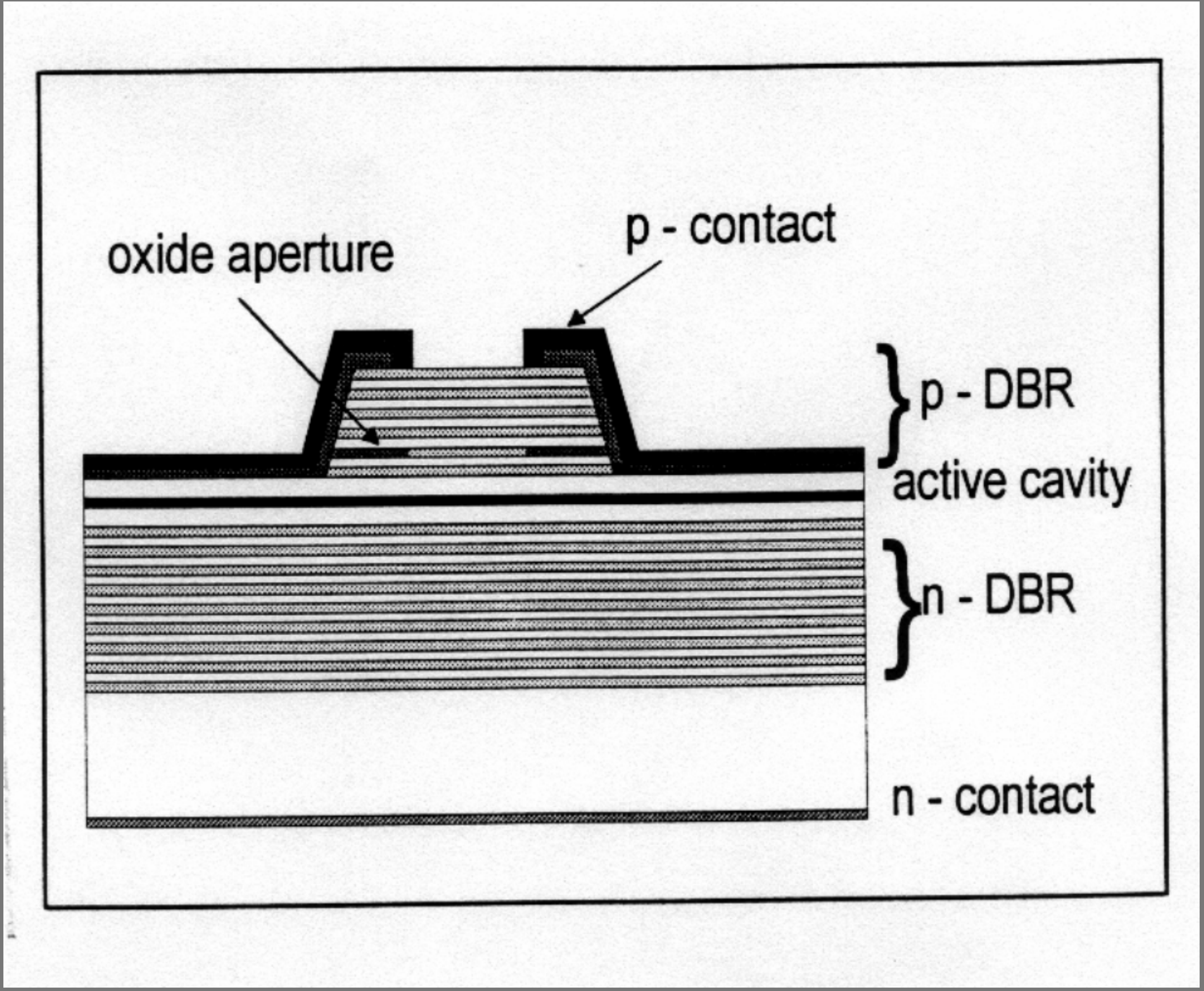
Reliability ....
VCSEL: Vertical Cavity Surface Emitting Laser



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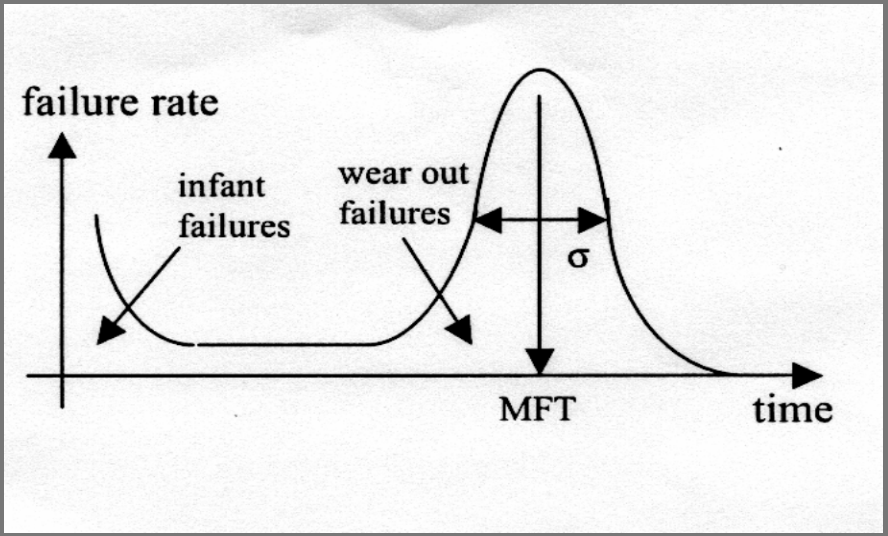
Laser Diode Reliability



Method: Stress groups of LDs at

- 75, 100, 125 C and
- 8, 12, and 16 mA.

Acceleration Model MFT~ I^{-n} exp(E/kT)

(Operate LDs at 30 C and 4 mA.)

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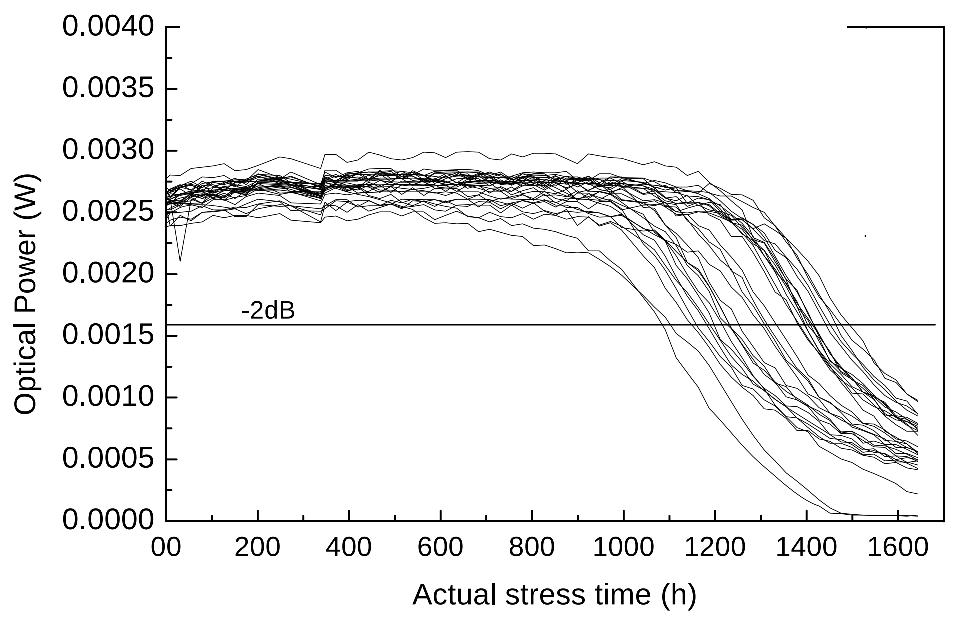
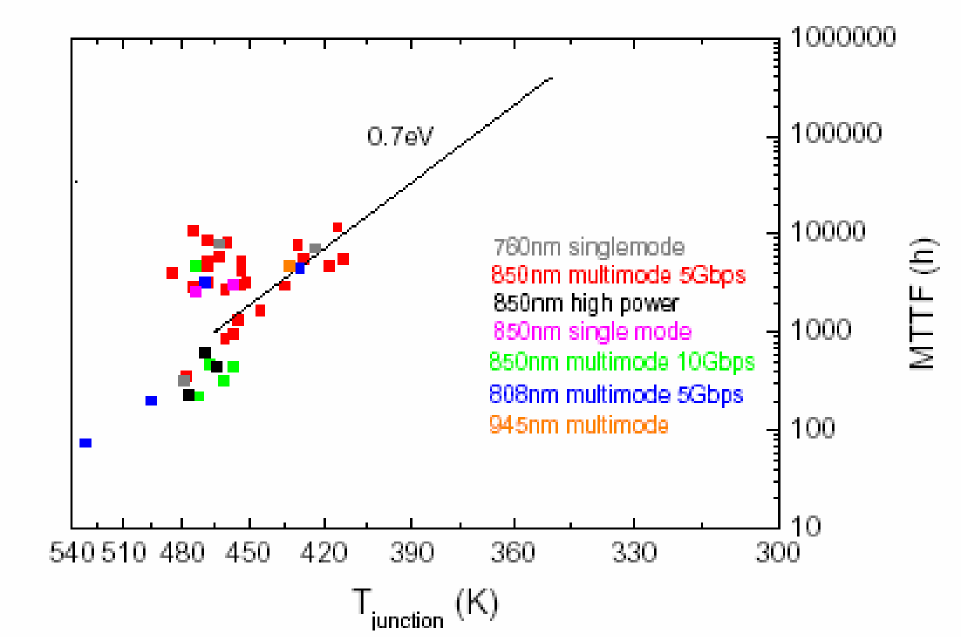
Reliability



- Accelerated Lifetime Testing @ 160°C ambient, laser current 7mA, junction temperature 182°C



- 1315 h MTTF @ 160°C calculated from TTF values
- Fitted to lognormal distribution
- Failure defined as 2 dB power drop
- Results in MTTF of 10^7h @ RT (extrapolated)
- > 3000h 85%RH/85°C certified

Aircraft Fuel Tank Explosions

- 13 Military Fuel Tank Explosions 1970 to 1993.
- 14 Commercial Airliner Fuel Tank Explosions 1959 to 2001.
- 3 Accidents, 231 Lives Lost, TWA Flight 800, 1996.
- NTSB 1996 Recommendations
- FAA Fuel Tank Inerting Initiatives, A320 and 747 Center Tanks
- FAA Certification Document Boeing 747 and other models, 2005

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Required Oxygen Limits for Inerting Aircraft Fuel Tanks

- Determine the Lower Oxygen Content (LOC) at altitudes ranging from 0 – 40 kft.
  - What is the O_2 concentration, below which ignition of the ullage fuel vapors will not occur?

Steve Summer
Project Engineer
Federal Aviation Administration
Fire Safety Branch
November 15 – 18, 2004

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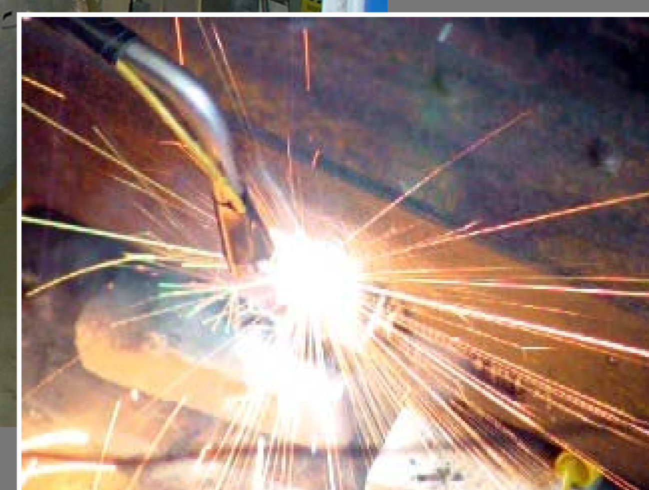
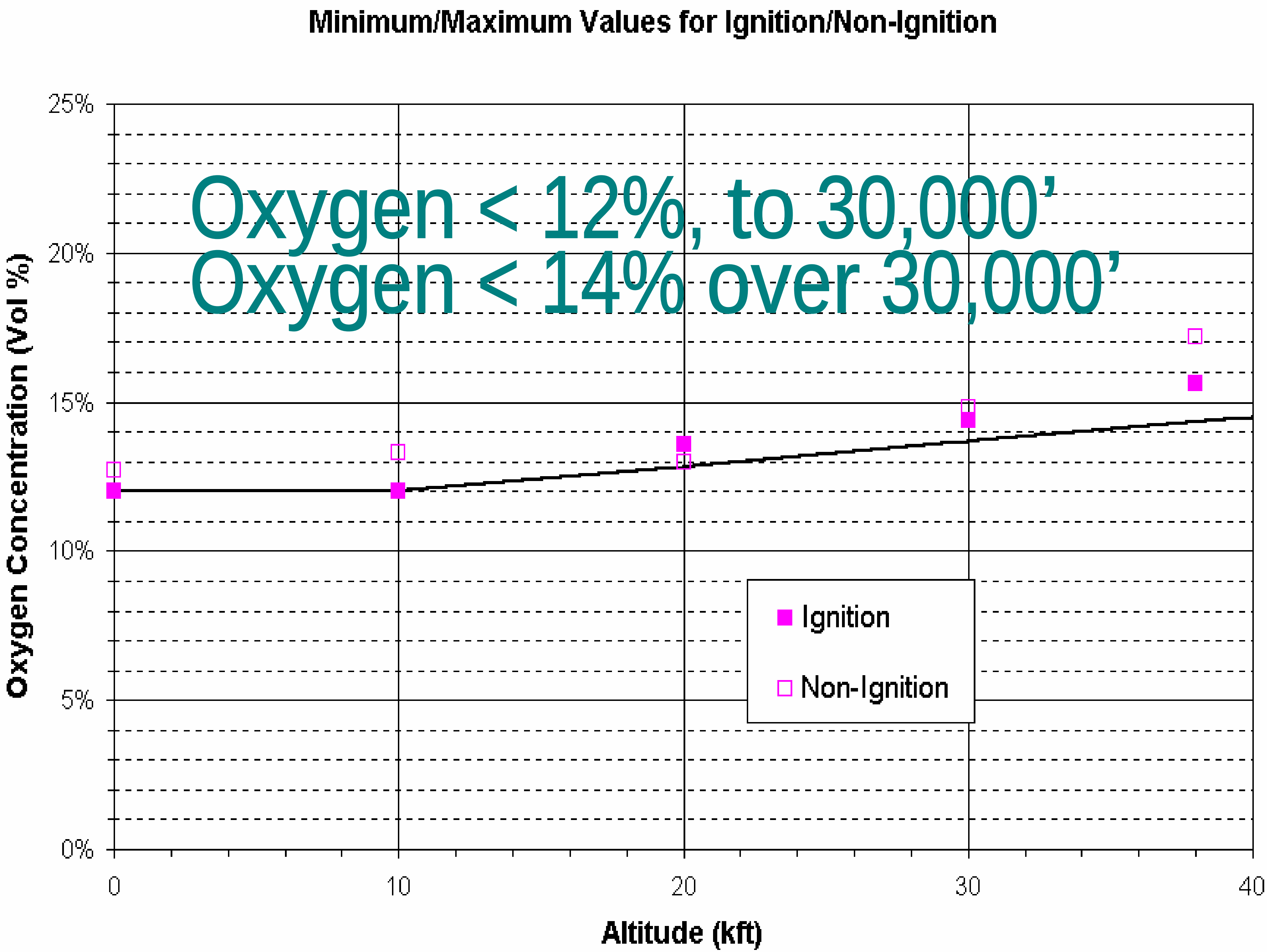
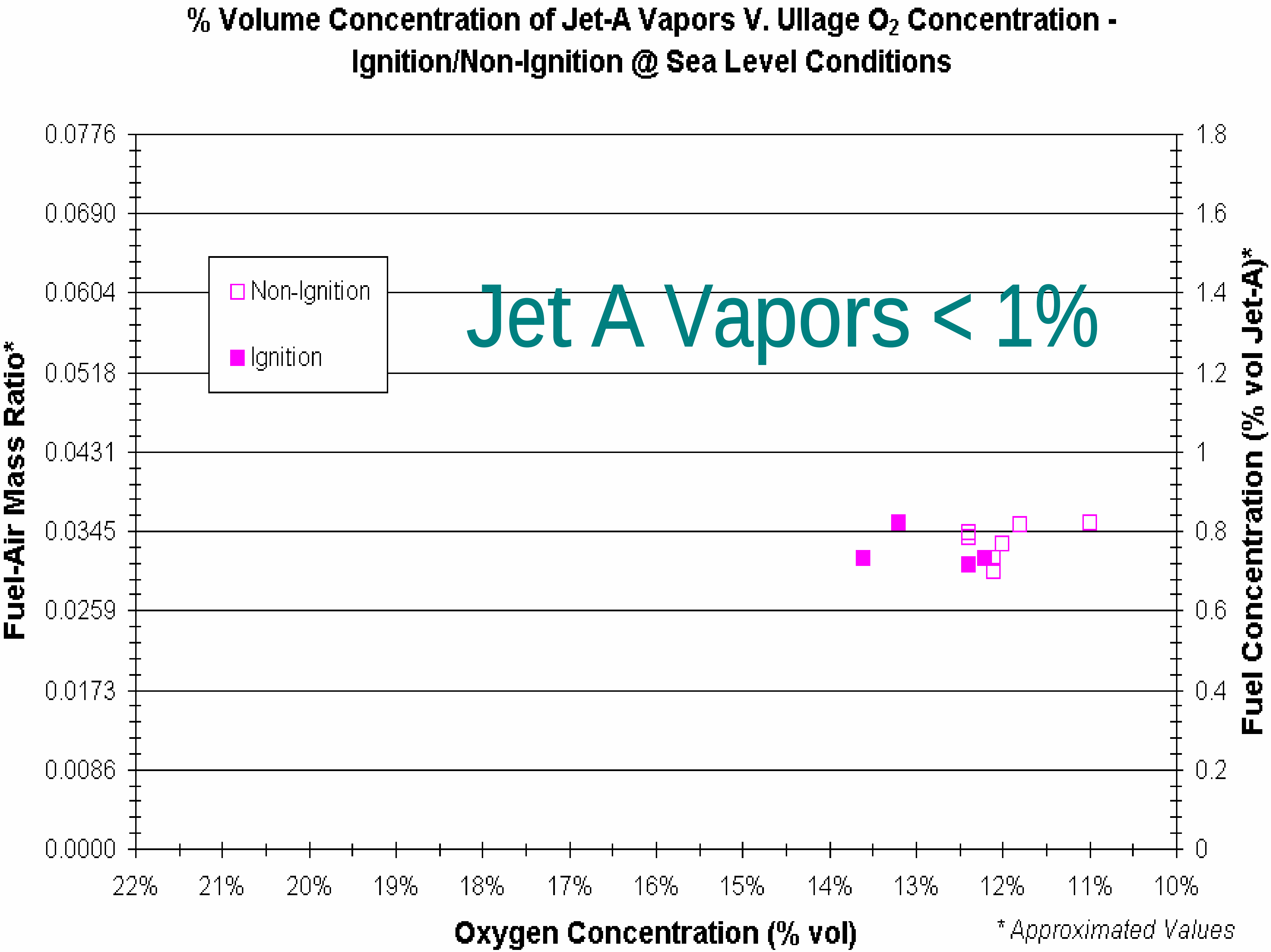
FAA Altitude/Spark Chamber

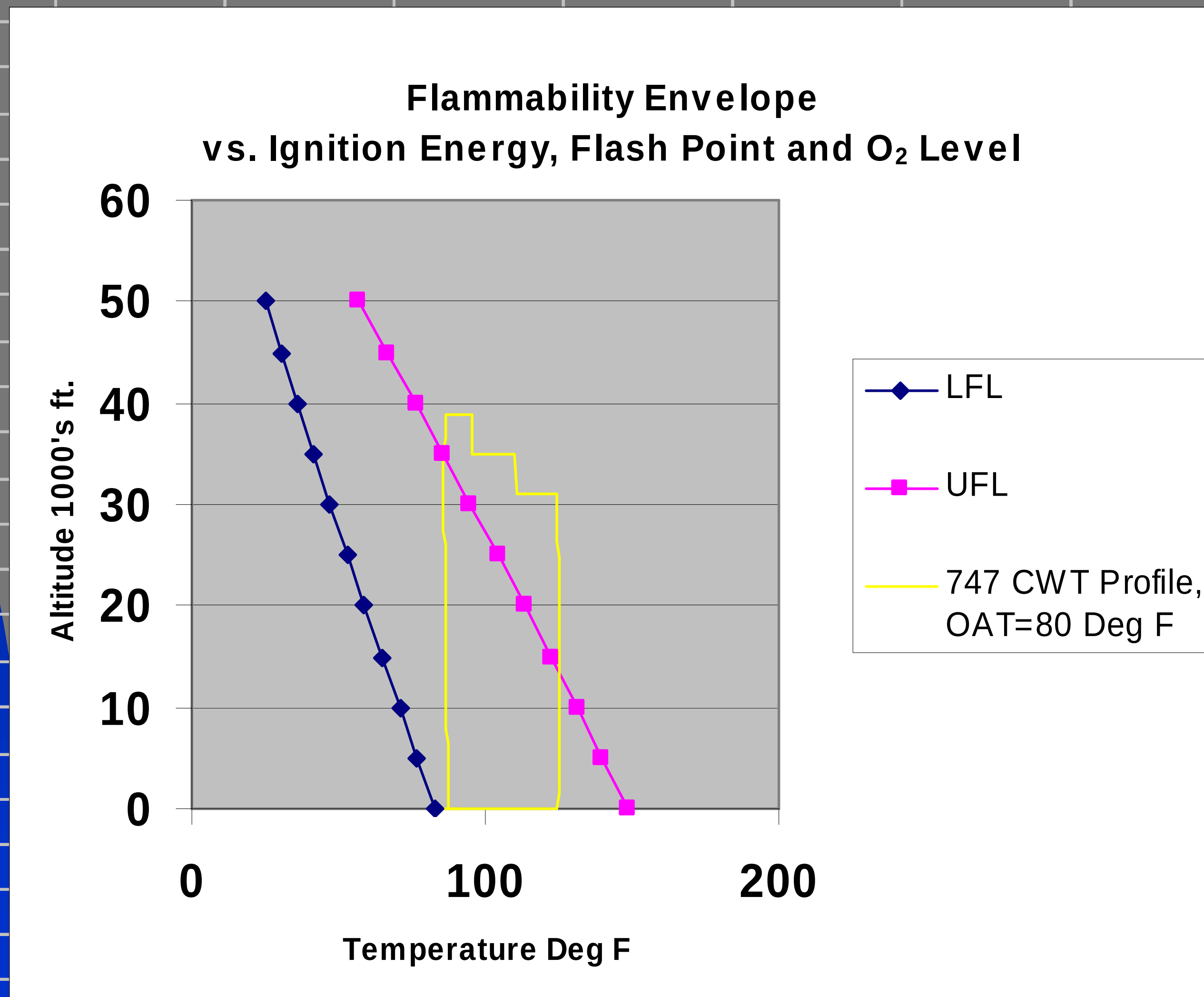




Minimum/Maximum Values for Ignition/Non-Ignition
Oxygen < 12%, to 30,000'
Oxygen < 14% over 30,000'
Oxygen Concentration (Vol %)
25%
20%
15%
10%
5%
0%
0
10
20
30
40
Altitude (kft)
Ignition
Non-Ignition


% Volume Concentration of Jet-A Vapors V. Ullage O2 Concentration - Ignition/Non-Ignition @ Sea Level Conditions
Jet A Vapors < 1%
Non-Ignition
Ignition
Fuel-Air Mass Ratio*
Fuel Concentration (% vol Jet-A)*
Oxygen Concentration (% vol)
0.0776
0.0690
0.0604
0.0518
0.0431
0.0345
0.0259
0.0173
0.0086
0.0000
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
22%
21%
20%
19%
18%
17%
16%
15%
14%
13%
12%
11%
10%
* Approximated Values

21% Oxygen, 1 J, 100 F



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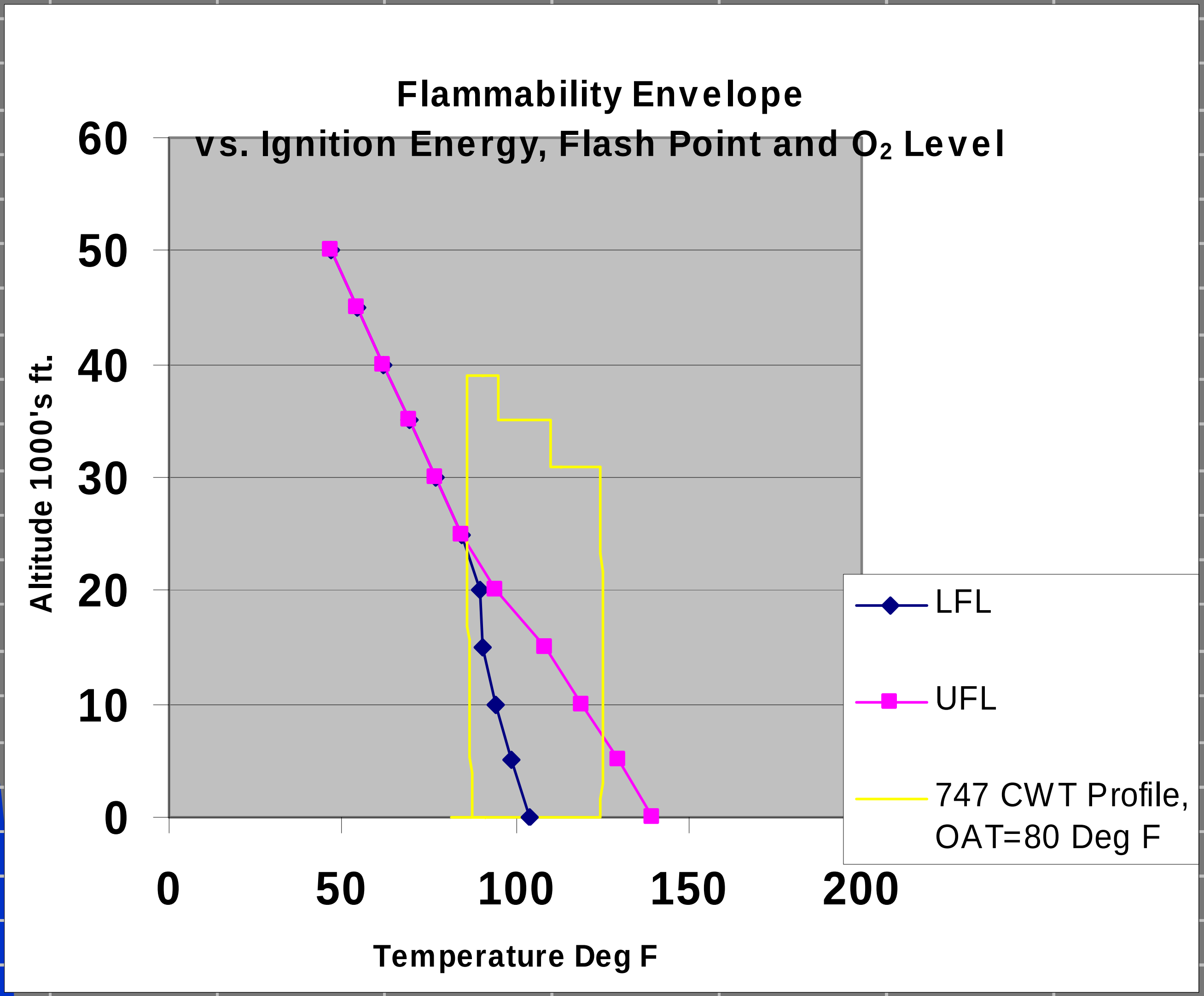
16% oxygen, 1 J, 100 F



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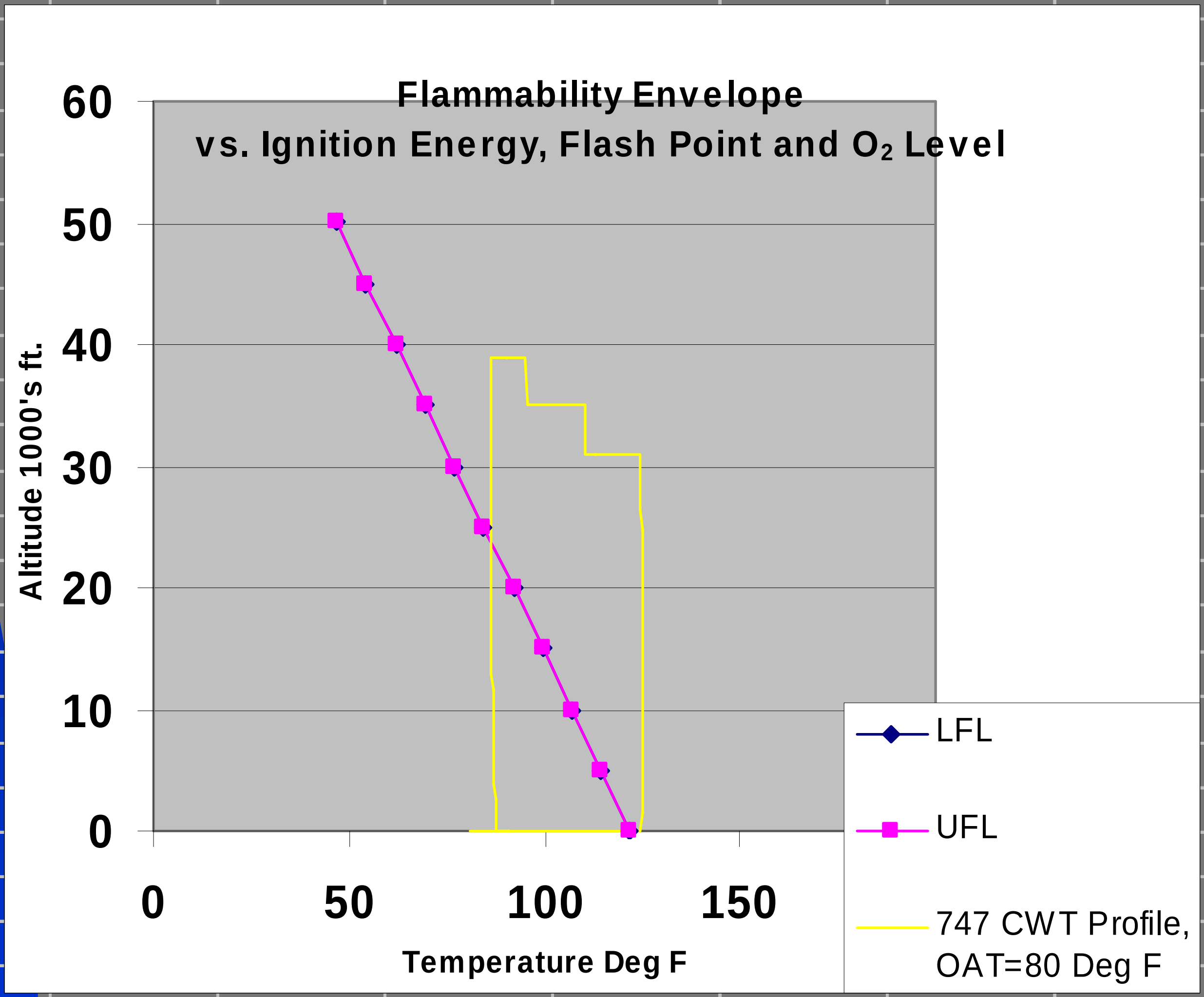
12% oxygen, 1 J, 100 F



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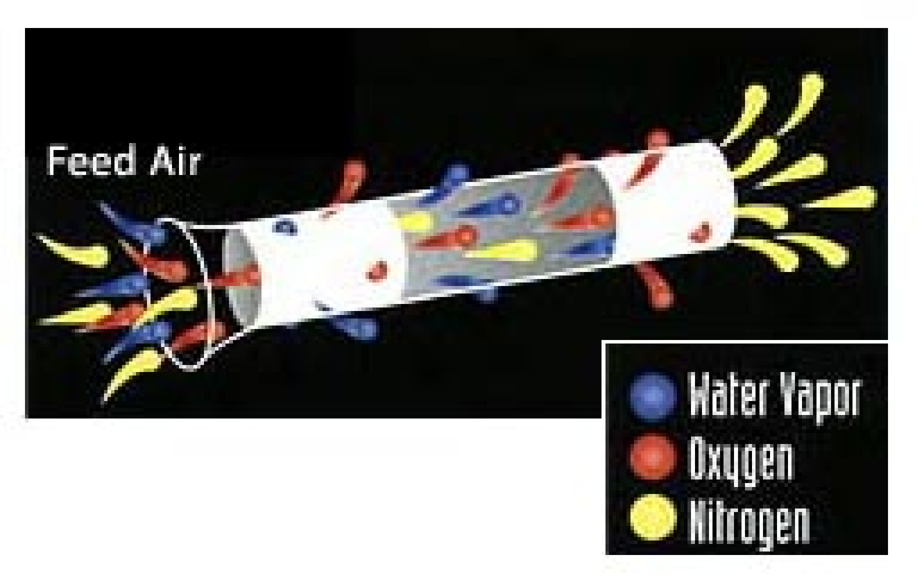
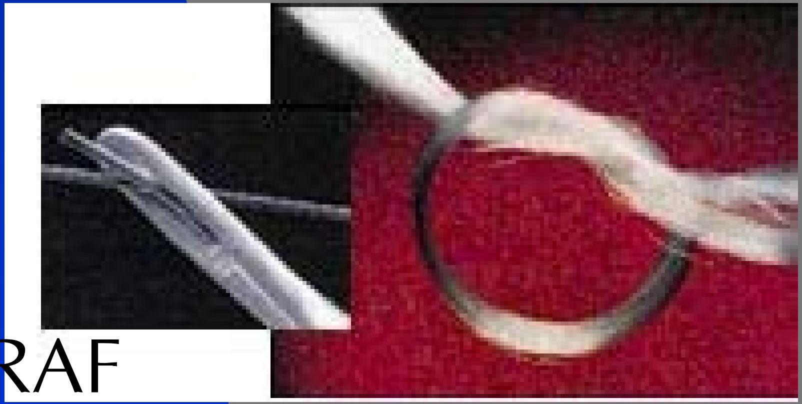
Brief History

- Changes that enable a cost effective, practical FRS
  - FAA Testing validated that an Inert Benchmark of 12% O2 precludes significant pressure rise for vast majority of commercial conditions
  - Use of Hollow Fiber Membranes
  - Focus on high flammability exposure center wing tanks only

NEA from hollow fiber membrane separators





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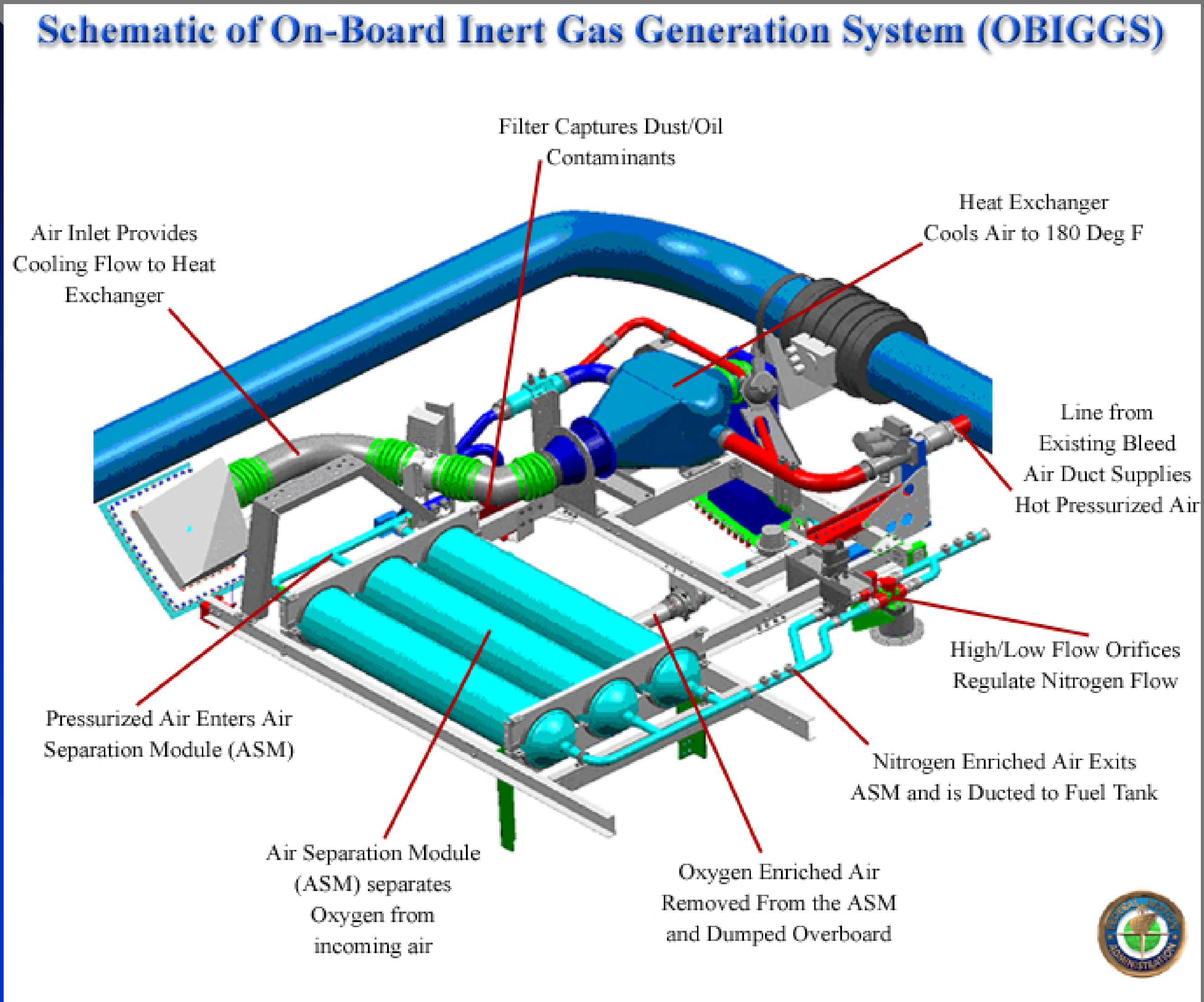
FAA Inerting System Prototype



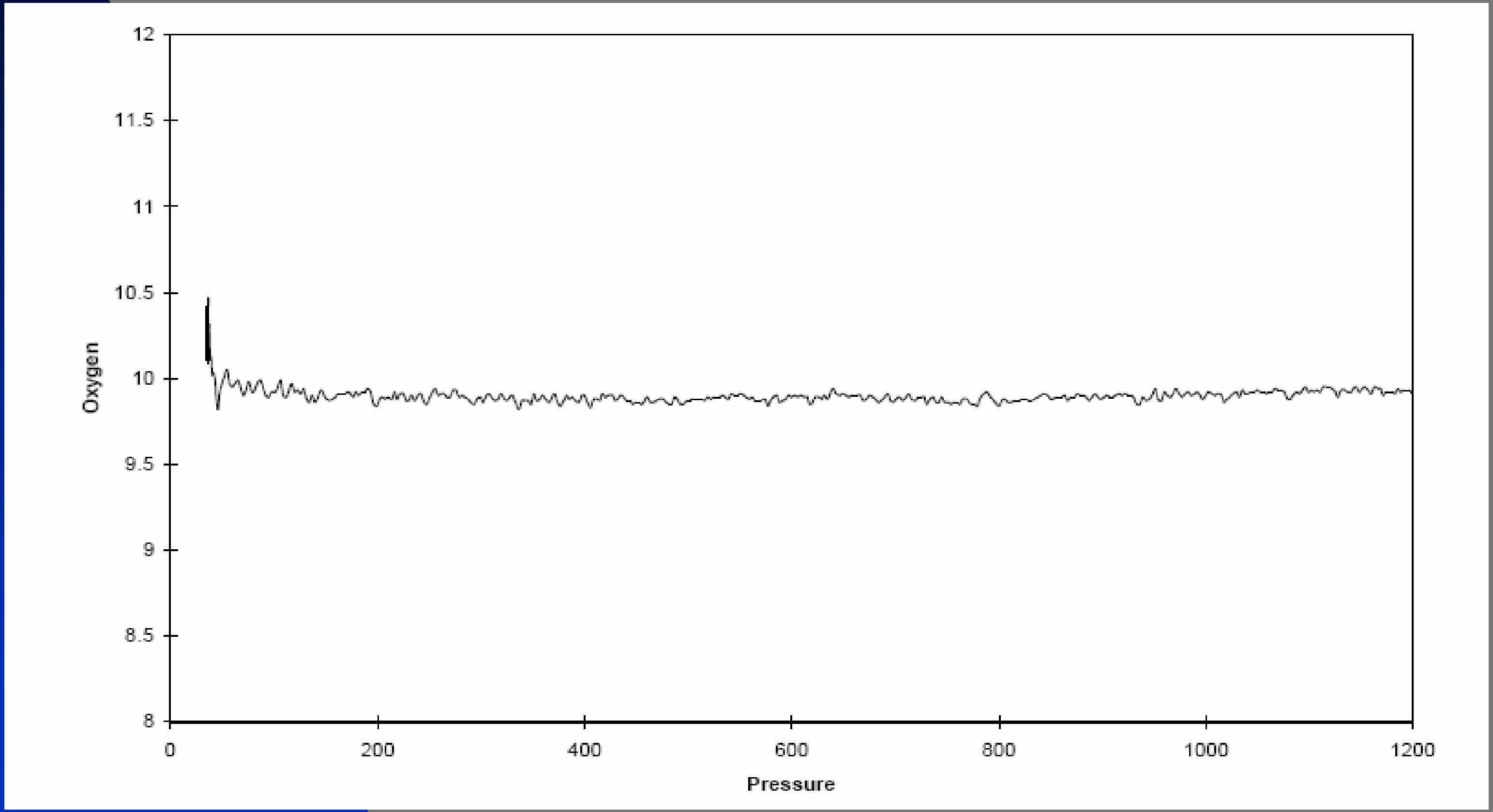
Boeing Philosophy

- Safe and Efficient Global Air Transportation
  - Minimize potential for future accidents
  - NGS is a safety enhancement
  - Ignition protection alone has achieved its maturity limits
  - NGS provides a secondary level of protection to mitigate human factors in design, manufacture, operation and maintenance

- Leading the Effort to Develop NGS
  - Practical design
  - Service Ready Systems available
    - 747-400 4th Quarter 2005
    - 737NG 2nd Quarter 2006
    - 777, 737-3/4/500, 767 and 757 to follow
    - NGS is standard for all tanks on 787

- NGS as an additional level of protection is the future for Boeing airplanes

Measuring 10% Oxygen to 40,000' using tunable diode lasers



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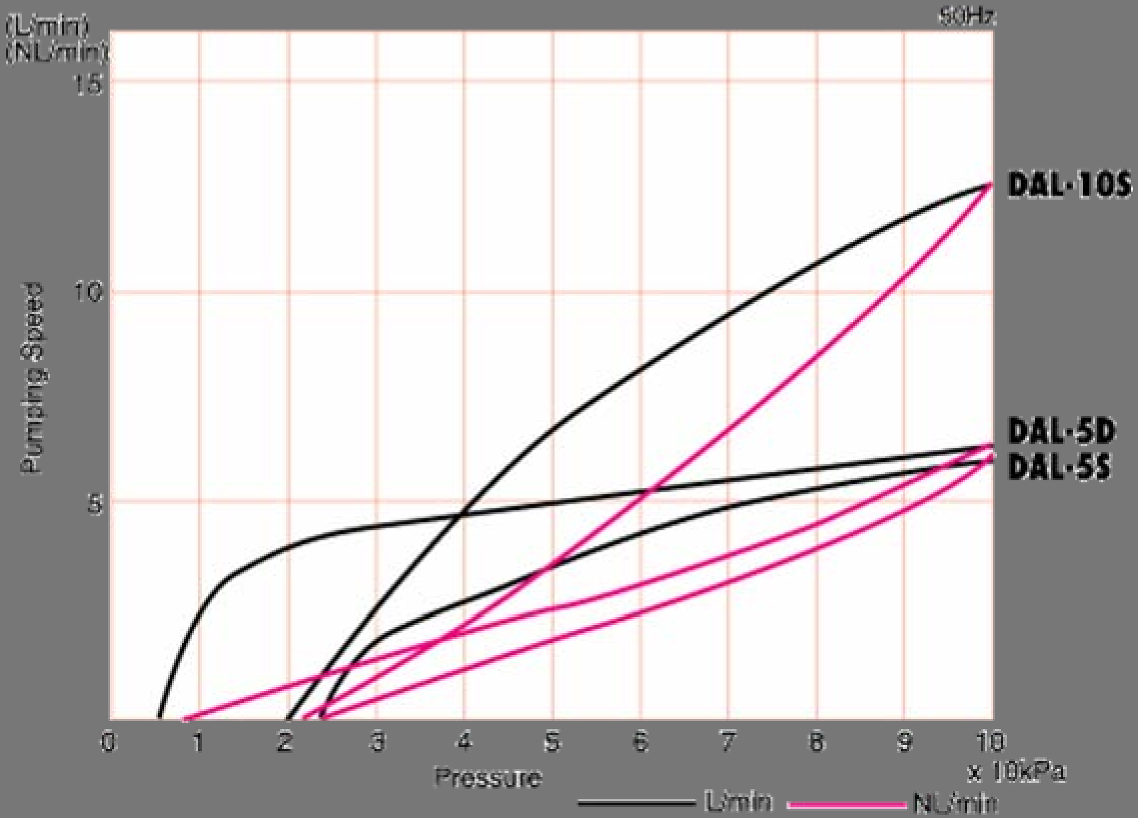
Sidestream Sampling

- Two-stage dry diaphragm vacuum pump:
- 6 l/min at atmospheric 100 kPa
- Ultimate pressure: 7 kPa
- 1 l/min at 10 kPa



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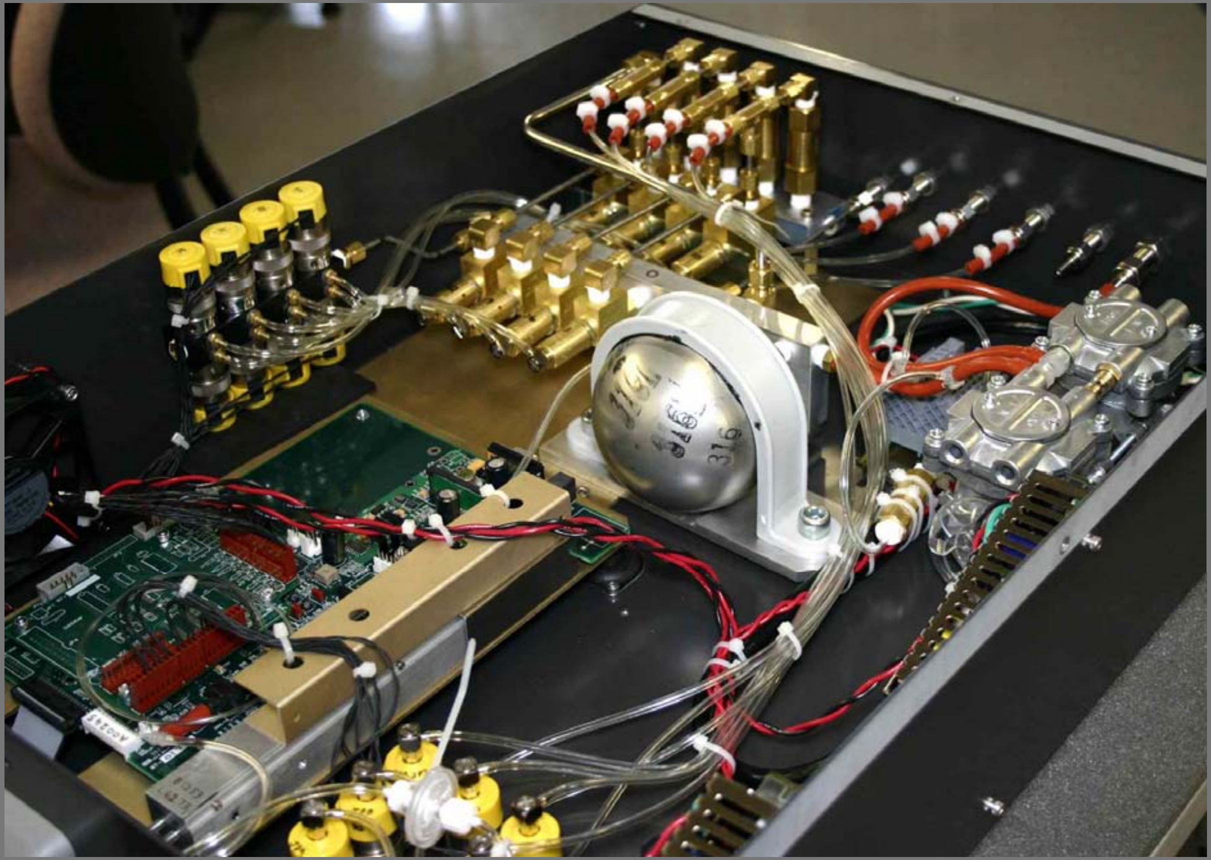
4-channel Sidestream Sampling



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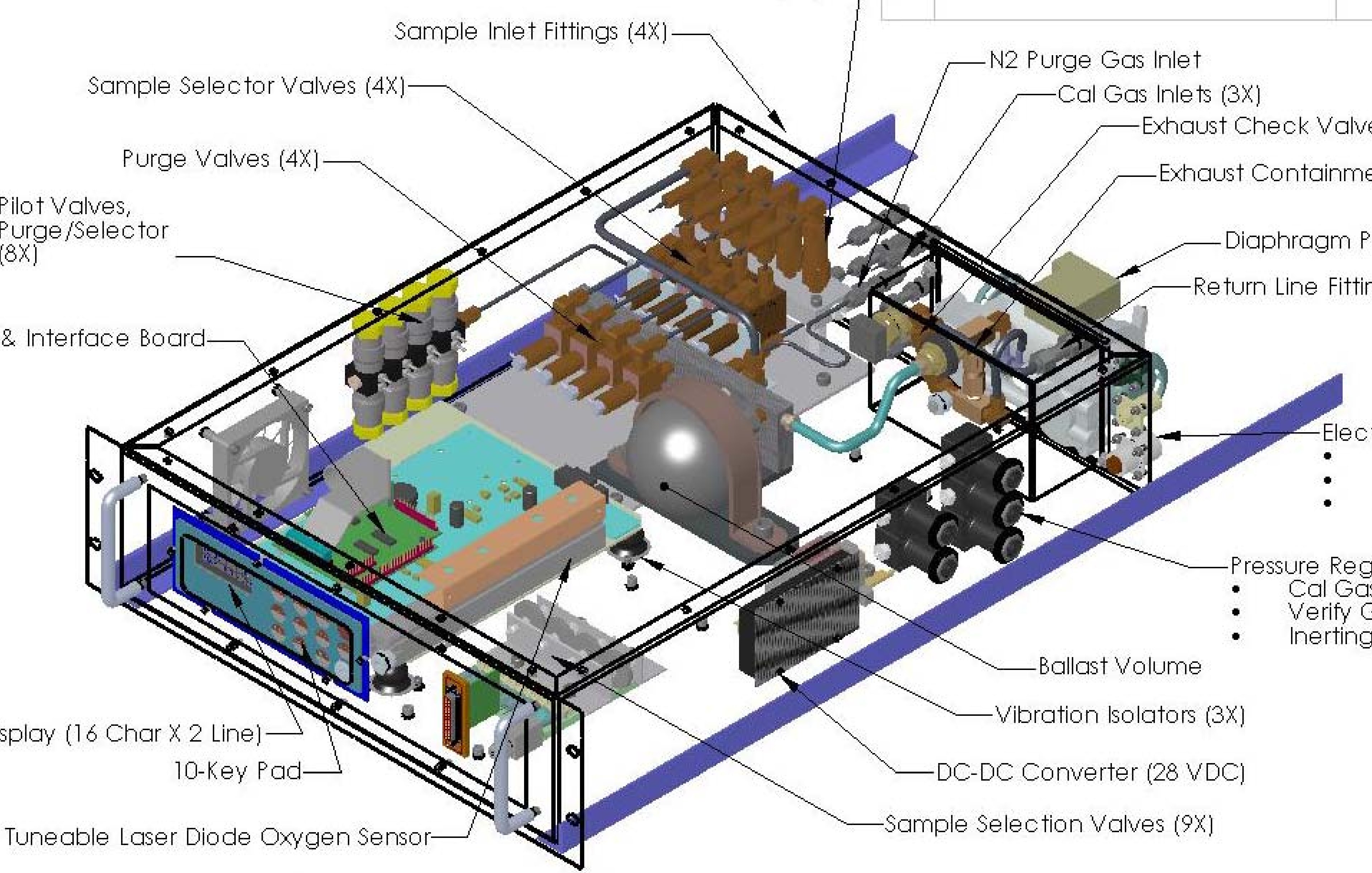

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FRACTIONS	DECIMALS	ANGLES
± X/X	.XX ± .01 .XXX ± .005	± 1 °

MATERIAL:

OXIGRAF, Inc.

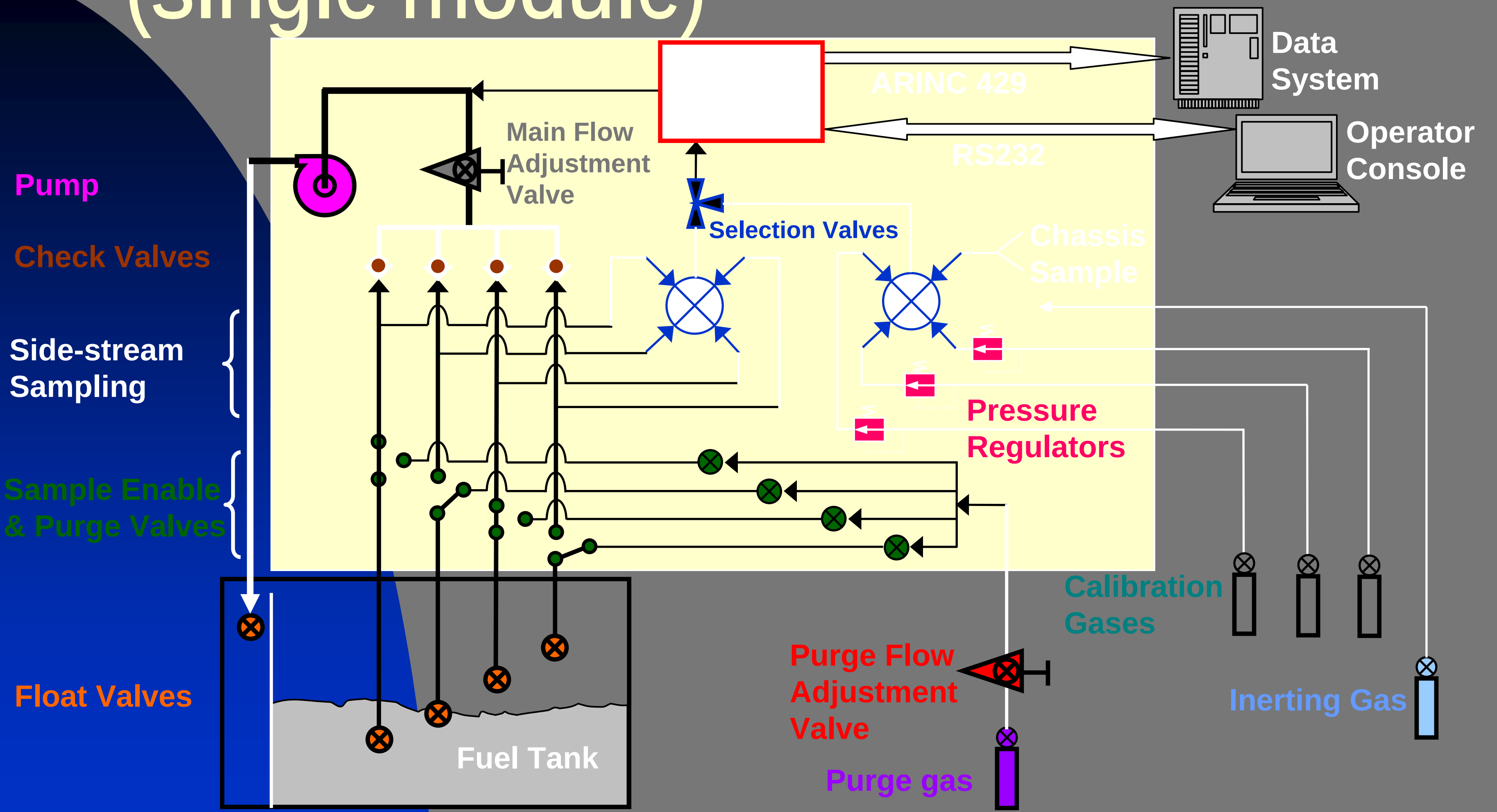
1170 Terra Bella Ave. - Mtn. View,
(650) 237-0155 PHONE (650) 237-

APPROVALS		DATE
DRAWN	TMW	8-21-2006
CHECKED	--	--

TITLE

ASSEMBLY, RACKMOU

O2N2 Process Schematic (single module)



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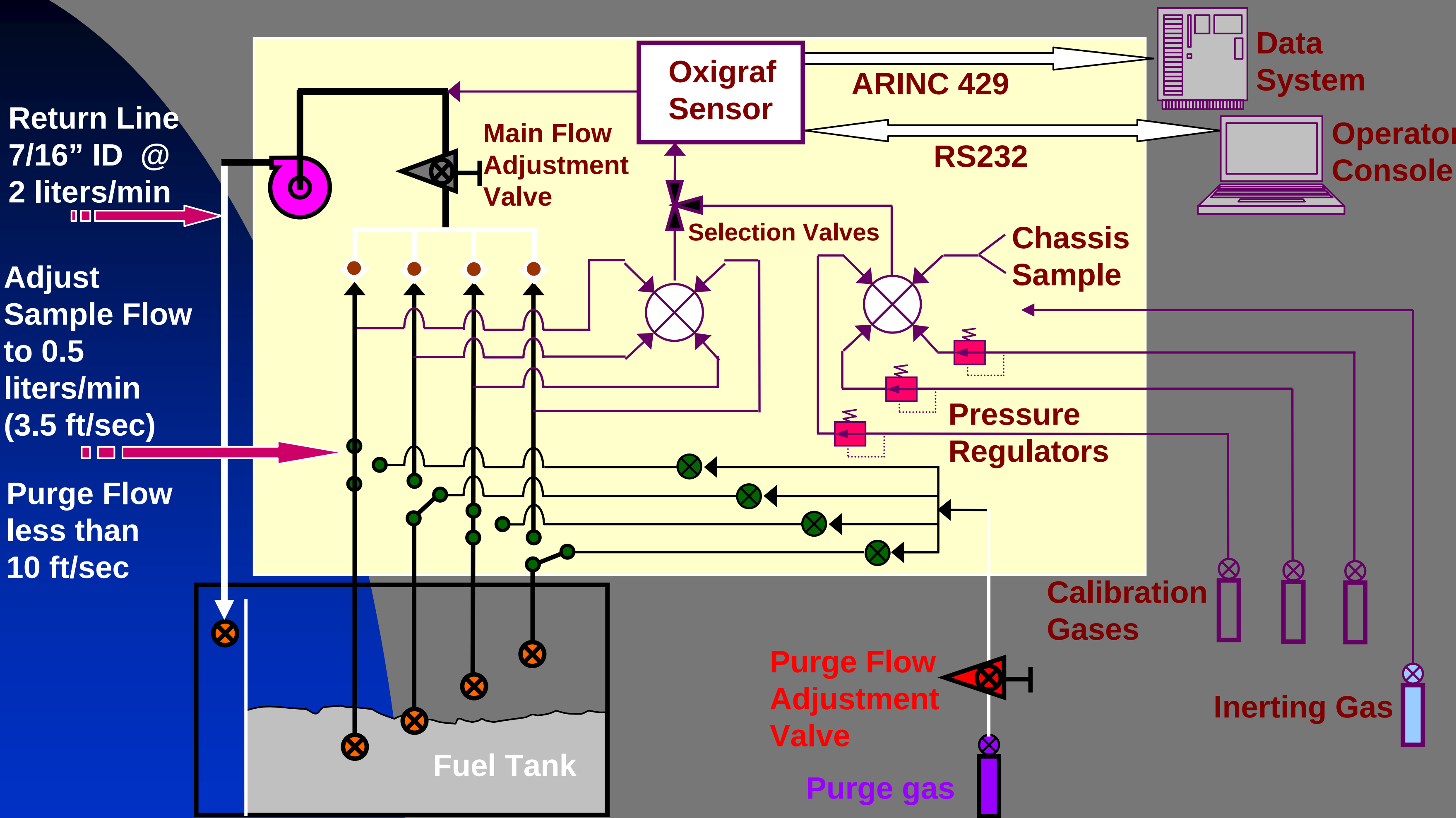
Primary Sample & Purge Plumbing



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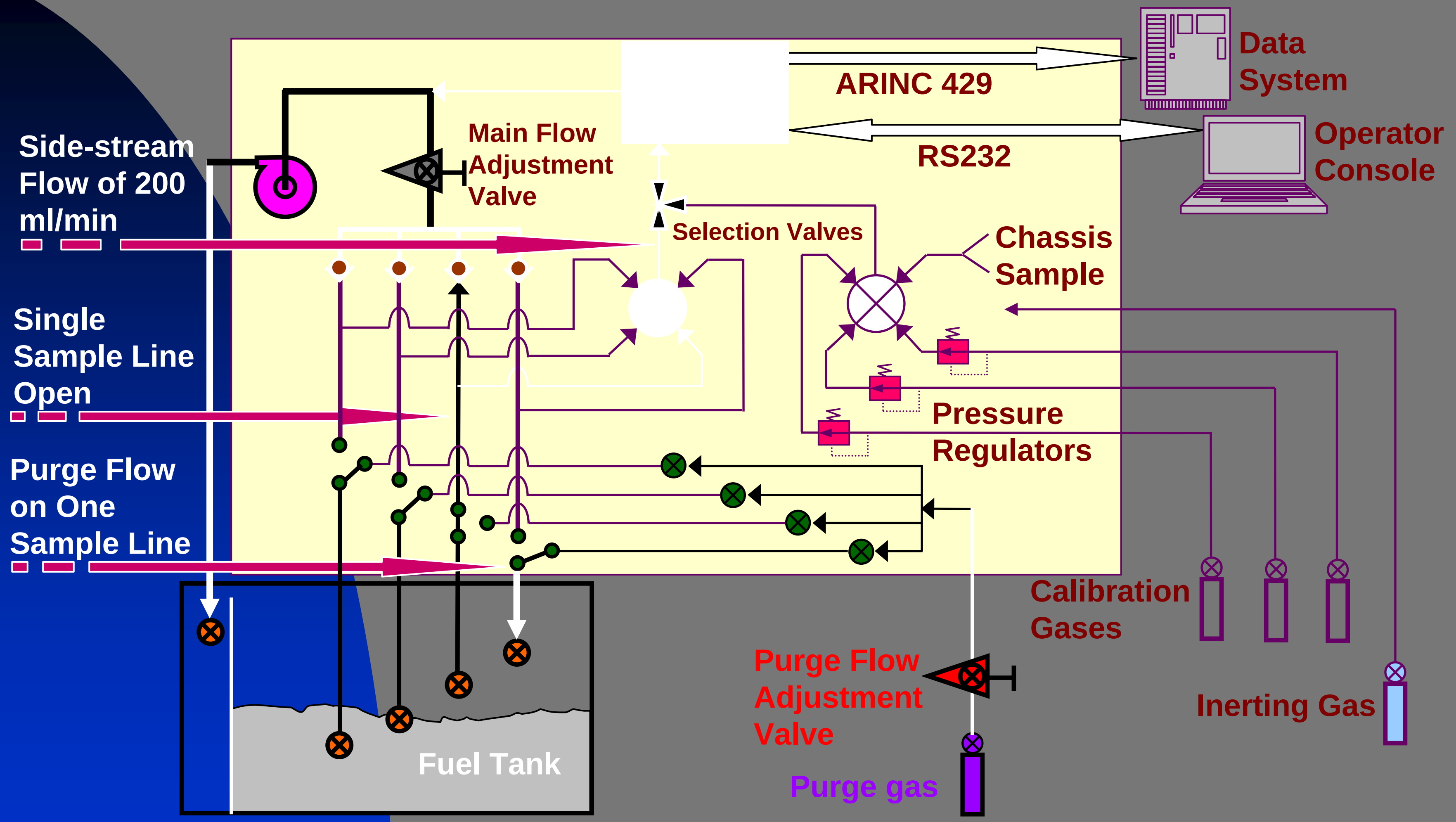
Purge Flow Example



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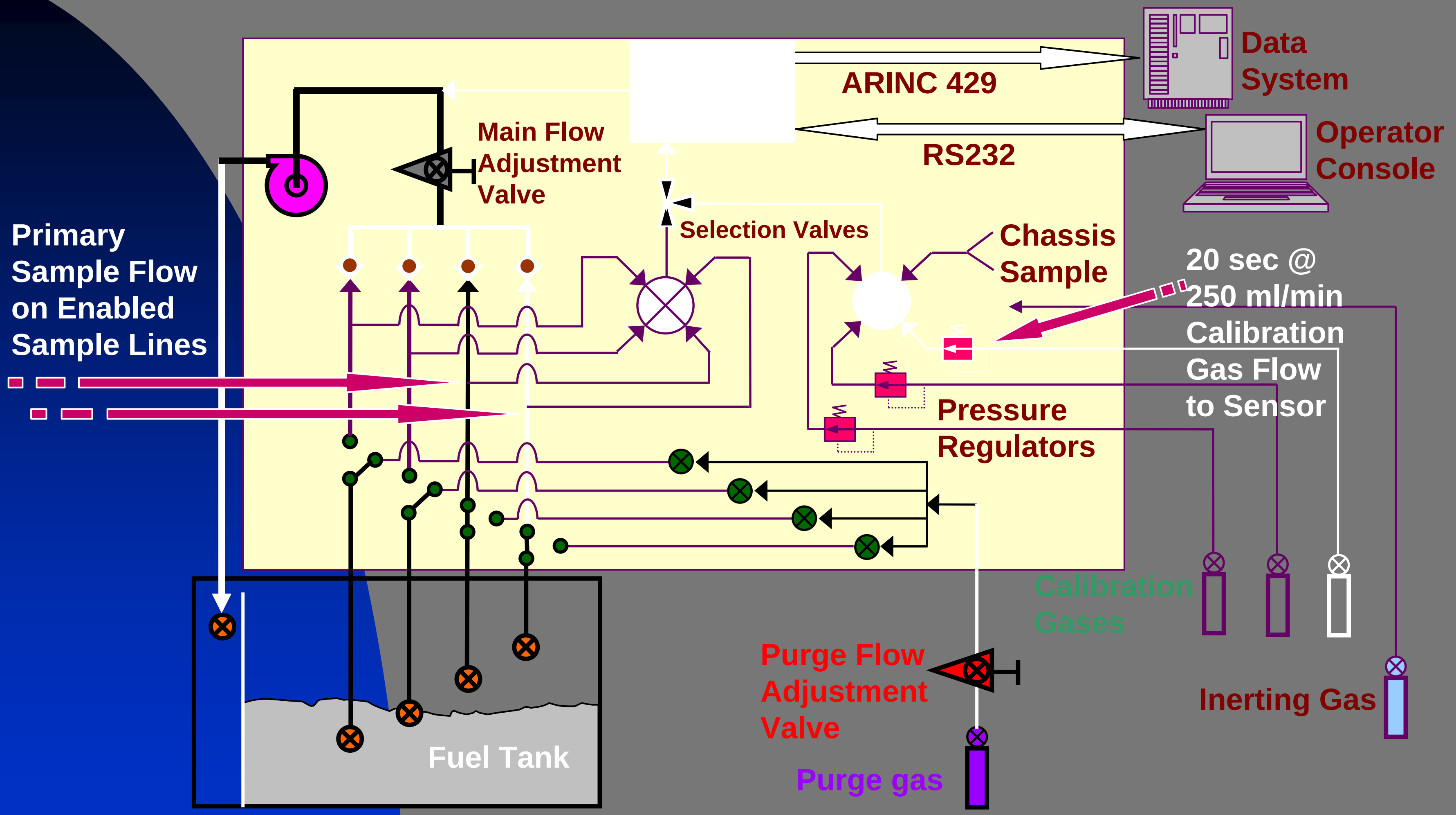
Calibration Example



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Risk Analysis

Hazard	Condition	Effect Class	Mitigation
Static discharge from tubing	Static build-up from high vapor flow rate	Catastrophic	1
Fuel vapor leakage into Oxigraf enclosure	Tubing, fitting or valve leaks	Hazardous	2, 3, 4
Liquid fuel drawn into cabin	Sample inlet submerged in fuel tank	Hazardous	5, 6, 7
Fuel vapor leakage into cabin from sample tubing	Fitting fails, tube breaks	Hazardous	8
Enclosure bursts from overpressure	2nd stage regulator failure	Hazardous	9
Compressed gas discharge into cabin	Cylinder valve or 1st stage regulator failure	Hazardous	10, 11
Electrical spark or concentrated heat source	Electrical component fails	Hazardous	3, 12, 13, 14, 15

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Risk Mitigations

1. Tubing linear flow rates limited to less than 6 ft/second
2. Pressurized enclosure to direct leaks into rather than from tubing
3. N2 blanketed enclosure
4. Double containment of pressurized exhaust in enclosure
5. Float valves on tubing inlets in fuel tanks
6. Flow sensor detects blocked sample line
7. Sample line purged by pressurized back-flush upon multiple blockages
8. Jacketed sample lines possible in cabin area
9. Relief valve on enclosure to prevent accidental over-pressure
10. Compressed gas cylinders securely anchored to rack
11. Calibration and other gas cylinders integral to system rack
12. 24 VDC maximum voltage in enclosure
13. No ignition sources inside enclosure
14. Pump motor outside enclosure wall
15. Power draw less than 25 W per enclosure, typical

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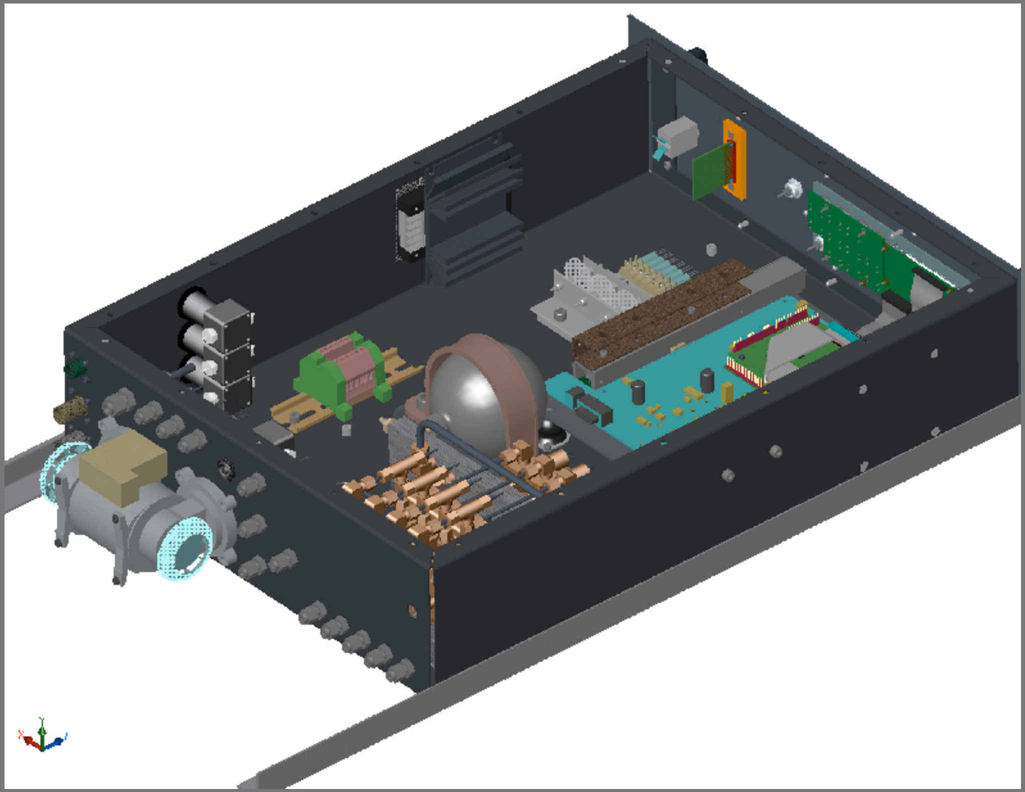
Risk Mitigations

Pump motor outside enclosure wall



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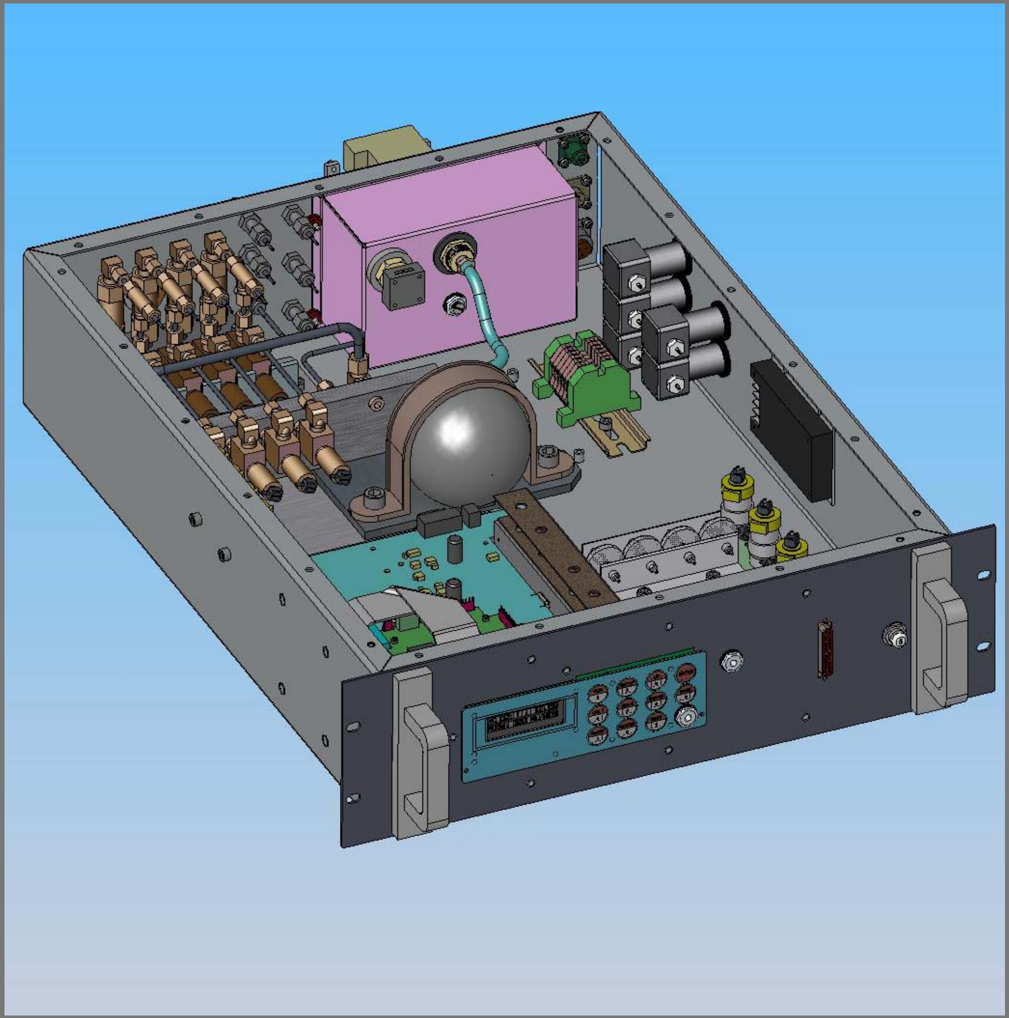
Risk Mitigations

Secondary containment of pressurized exhaust



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Summary

- Laser Diode Oxygen Analyzers Viable for Airliner Fuel Tank Inerting Validation
  - Fast response: Verify nitrogen inerting and sensor calibration in real time
  - Measure explosive mixtures safely
  - Measurement unaffected by organics
  - Reliable VCSEL laser diodes

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