Cargo Fire Suppression Using Oxygen Depleted Air from a Hydrogen Fuel Cell

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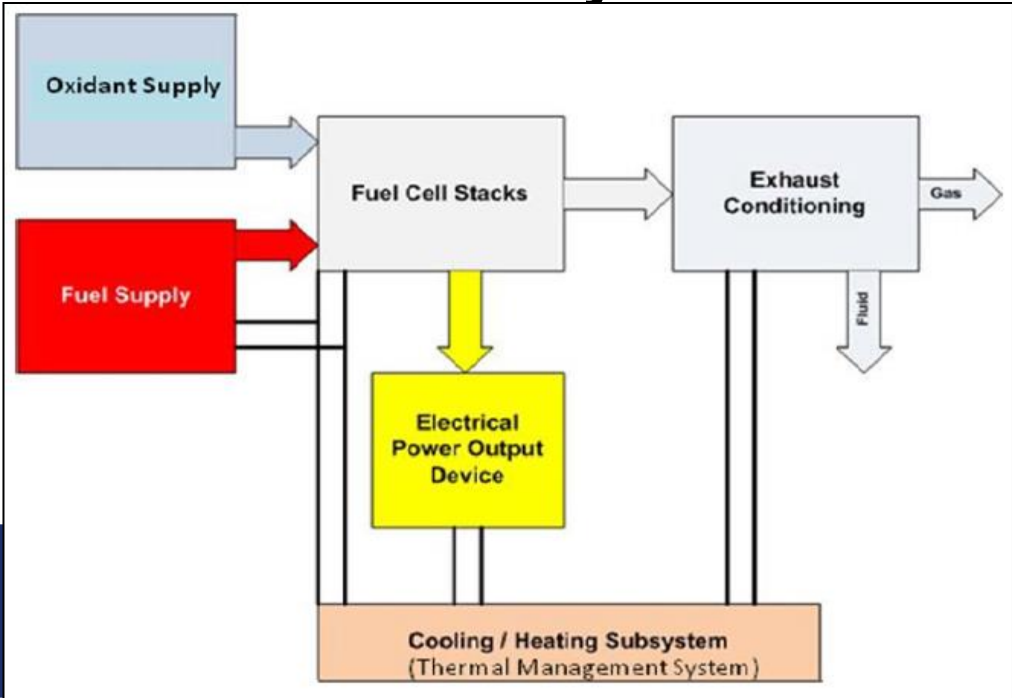
http://www.fire.tc.faa.gov

Background

- **Aviation industry is pursuing efforts to install Hydrogen Fuel Cells on aircraft for a number of potential operations, such as the main battery, ram air turbine, APU, galley power, etc.**

- **In addition, the byproducts of a Fuel Cell System are being looked at to supply water onboard as well as Oxygen Depleted Air (ODA) for fuel tank inerting or cargo fire suppression**

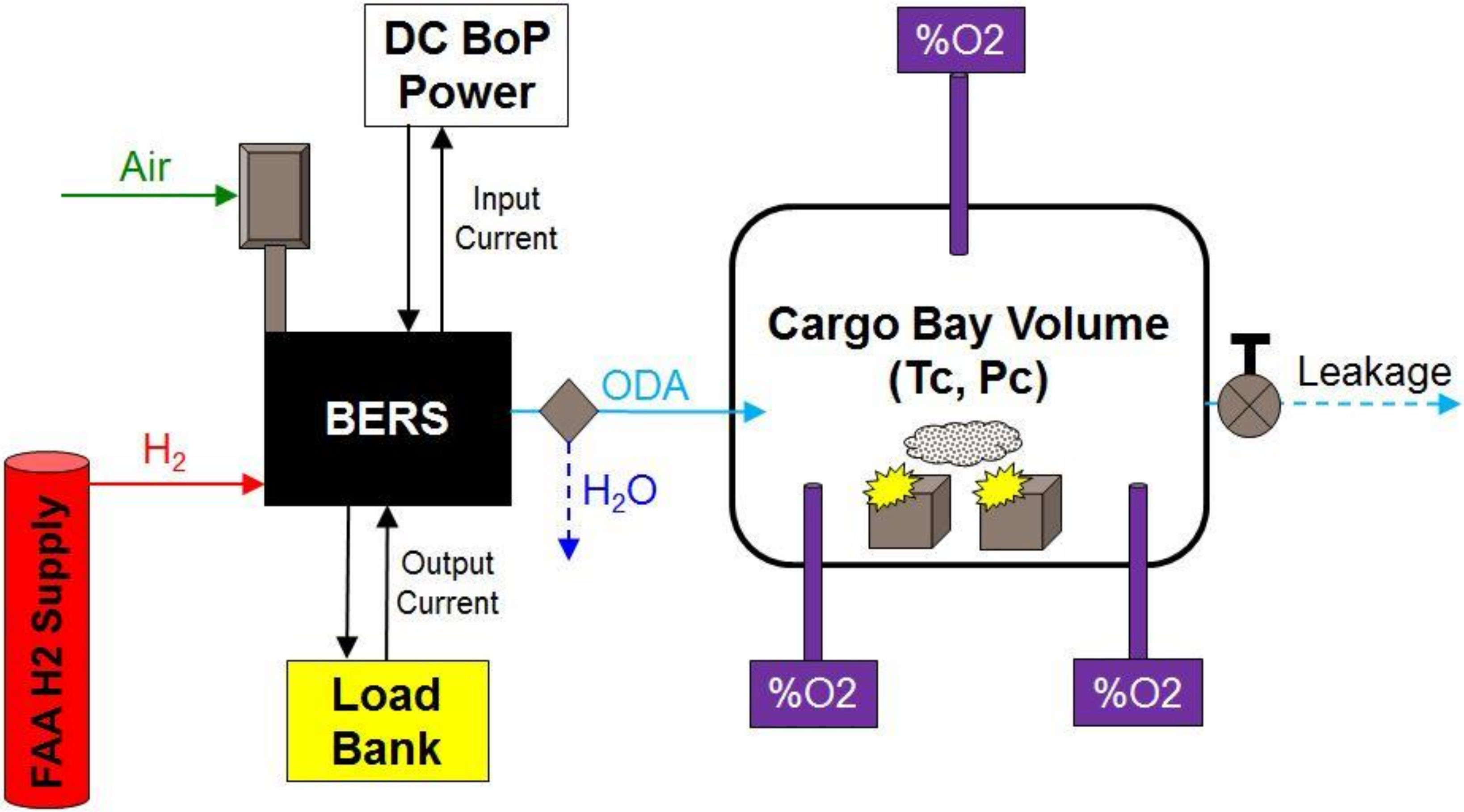


Objective

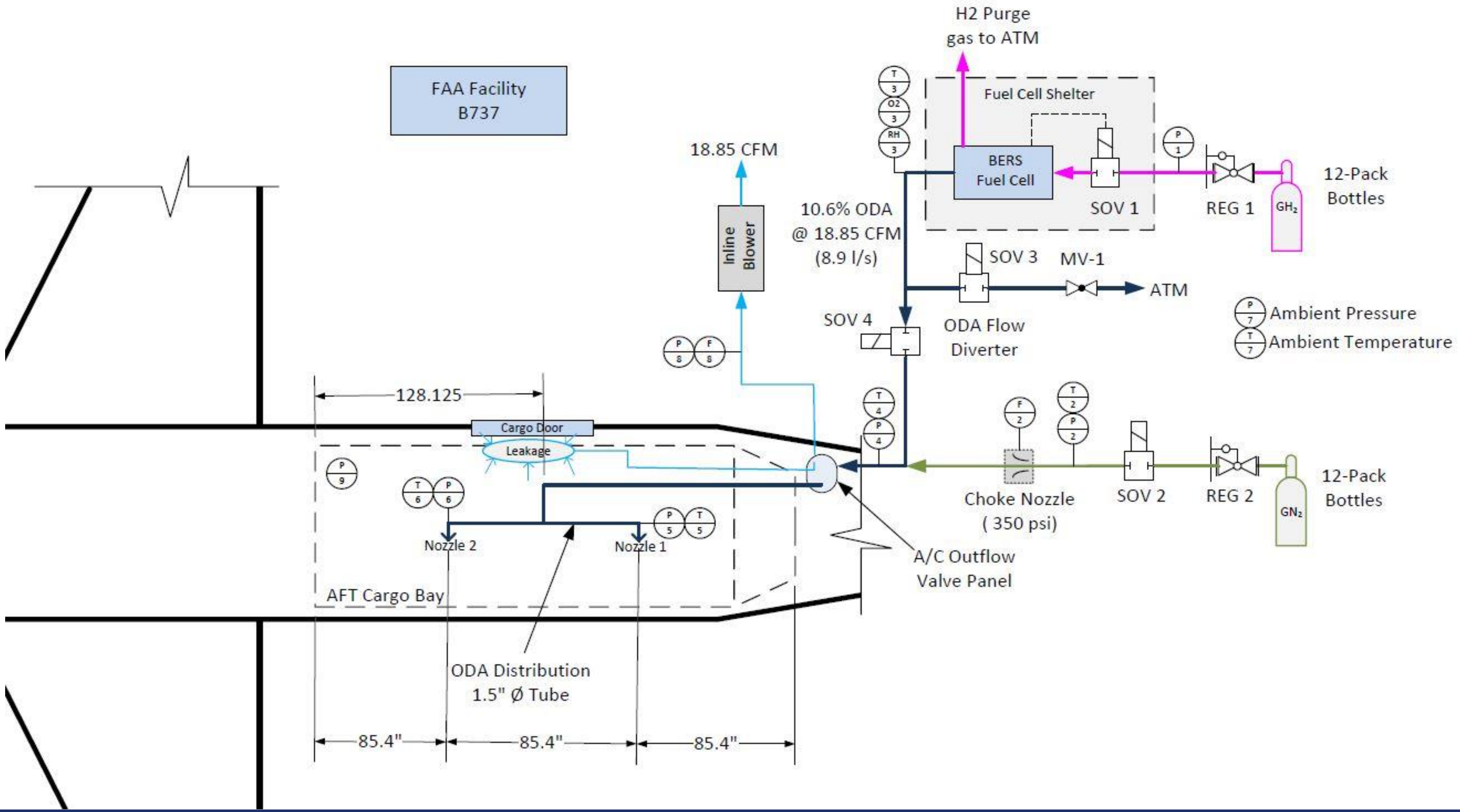
- **Key objective of this research activity was to evaluate the effectiveness of ODA from a Hydrogen Fuel Cell system at maintaining fire suppression O_2 levels following an initial nitrogen knockdown in an aircraft cargo compartment.**

- **This testing was conducted in conjunction with Parker Aerospace, Airbus and Ballard Power Systems on board the FAA Fire Safety Branch's 737 test aircraft**

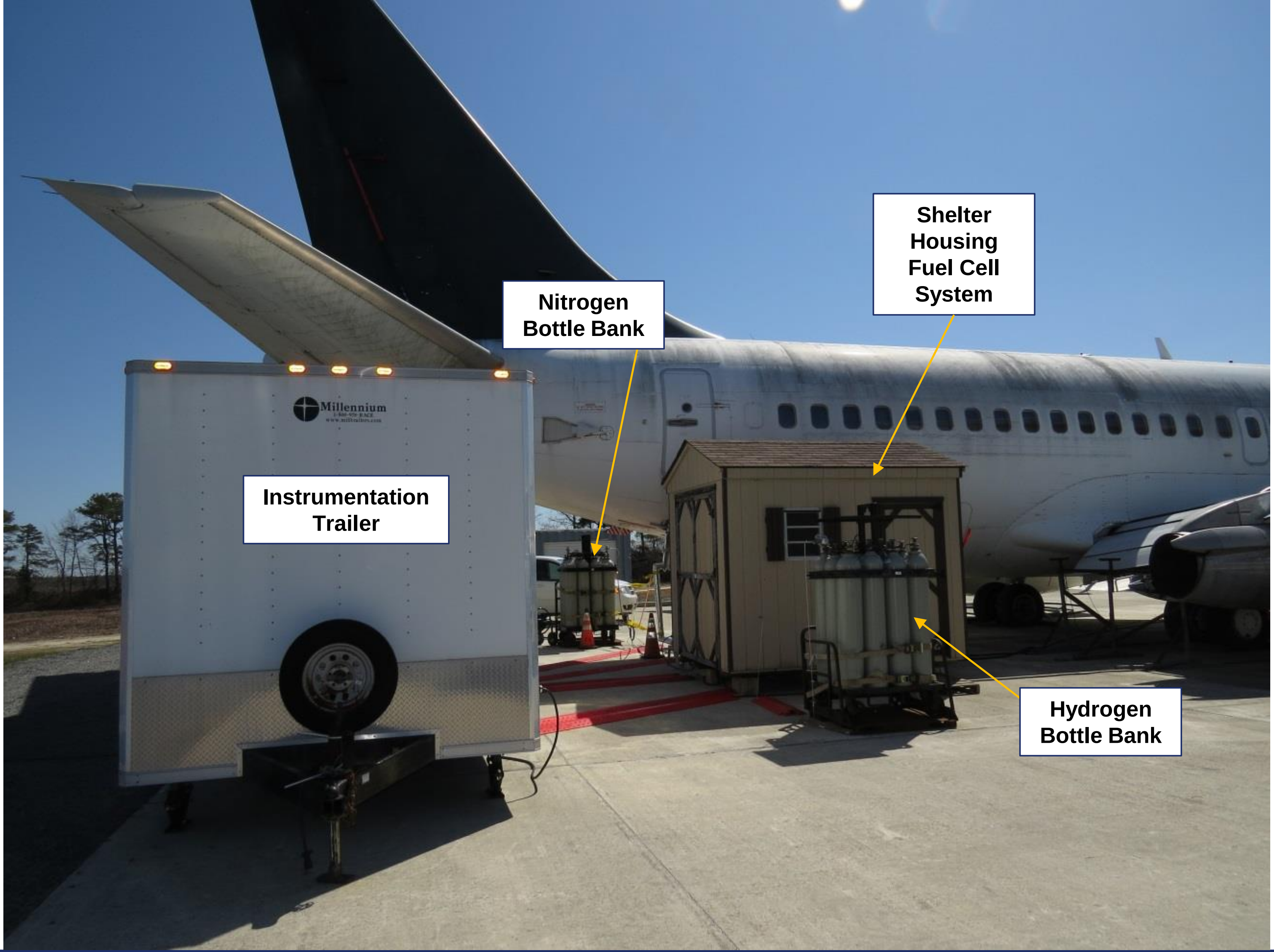
Test Concept

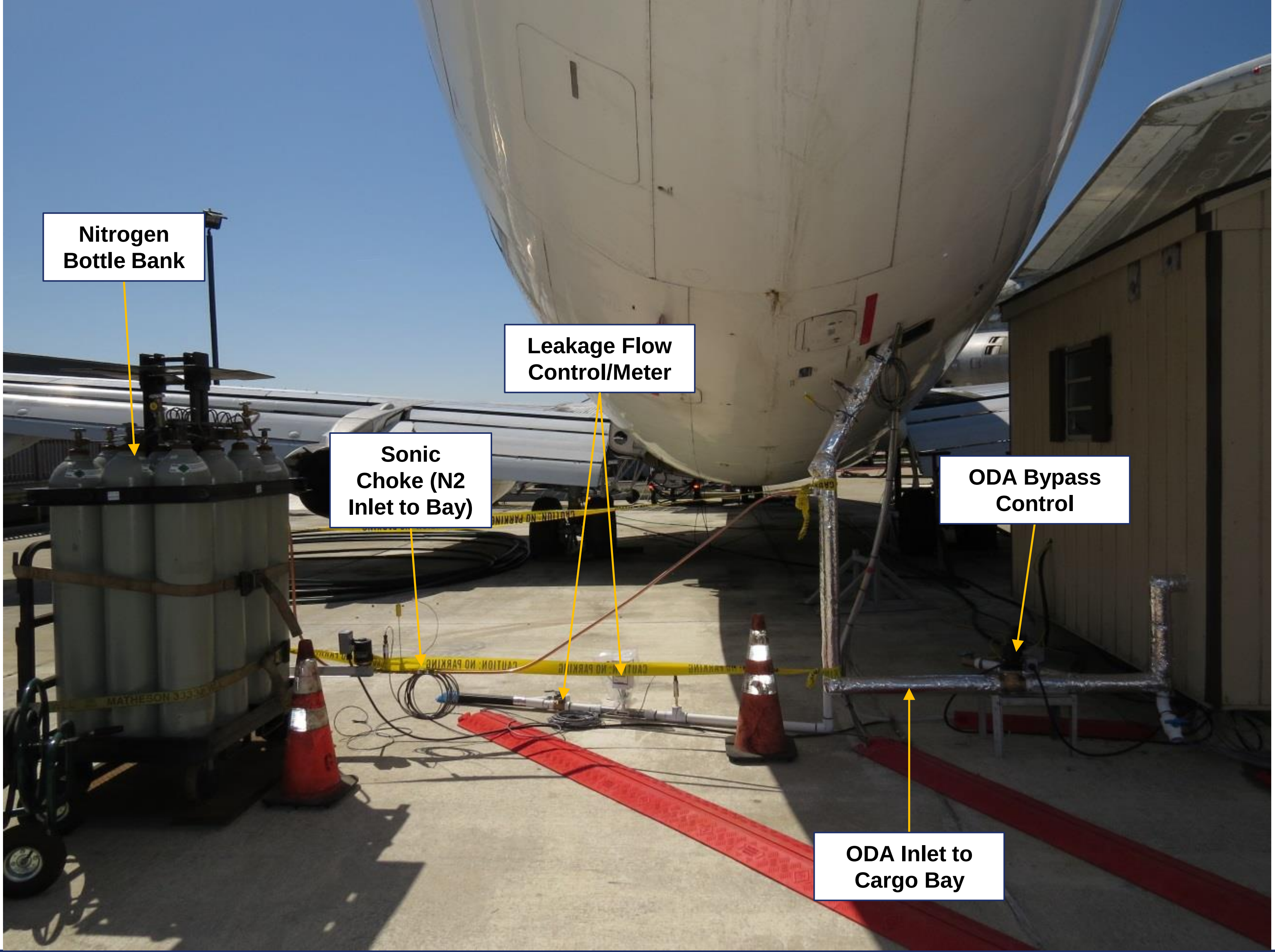


Test Setup

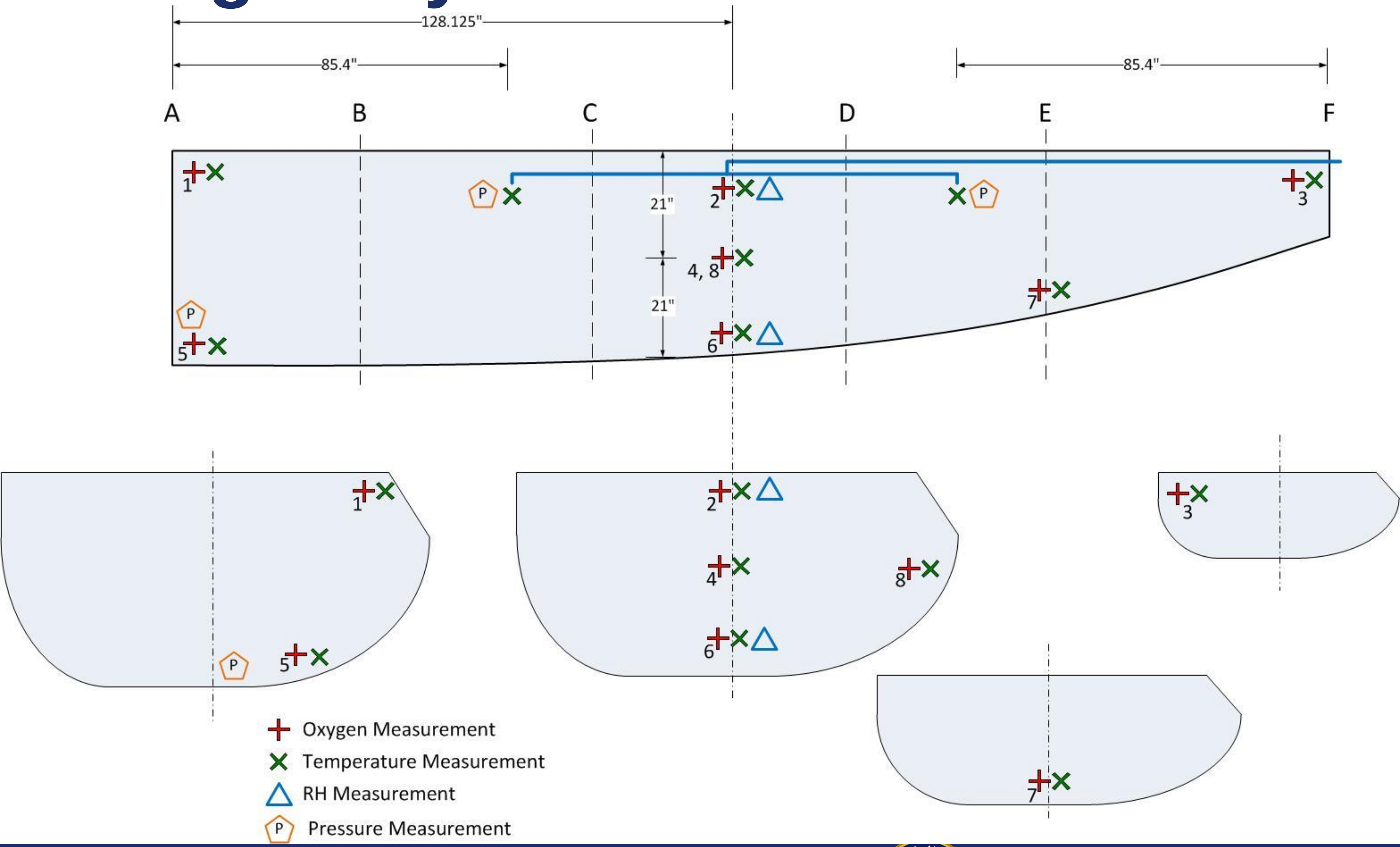


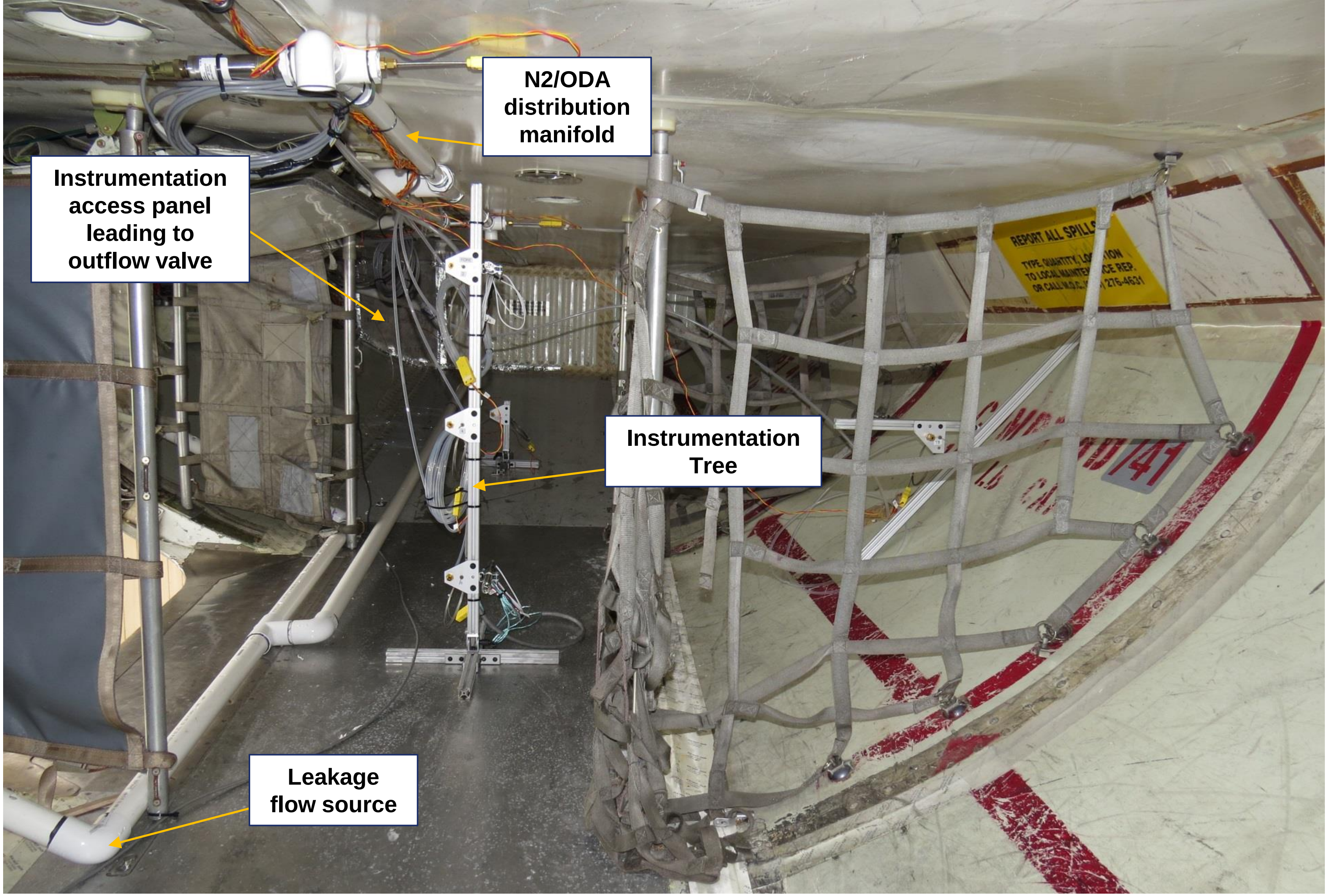
H2 Purge
gas to ATM
FAA Facility
B737
Fuel Cell Shelter
18.85 CFM
BERS
Fuel Cell
12-Pack
Bottles
SOV 1
REG 1
10.6% ODA
@ 18.85 CFM
(8.9 l/s)
Inline
Blower
SOV 3
MV-1
ATM
SOV 4
ODA Flow
Diverter
Ambient Pressure
Ambient Temperature
128.125
Cargo Door
Leakage
Choke Nozzle
(350 psi)
SOV 2
REG 2
12-Pack
Bottles
Nozzle 2
Nozzle 1
A/C Outflow
Valve Panel
AFT Cargo Bay
ODA Distribution
1.5" Ø Tube
85.4"
85.4"
85.4"


Shelter Housing Fuel Cell System
Nitrogen Bottle Bank
Millennium
Instrumentation Trailer
Hydrogen Bottle Bank


Nitrogen Bottle Bank
Leakage Flow Control/Meter
Sonic Choke (N2 Inlet to Bay)
ODA Bypass Control
ODA Inlet to Cargo Bay

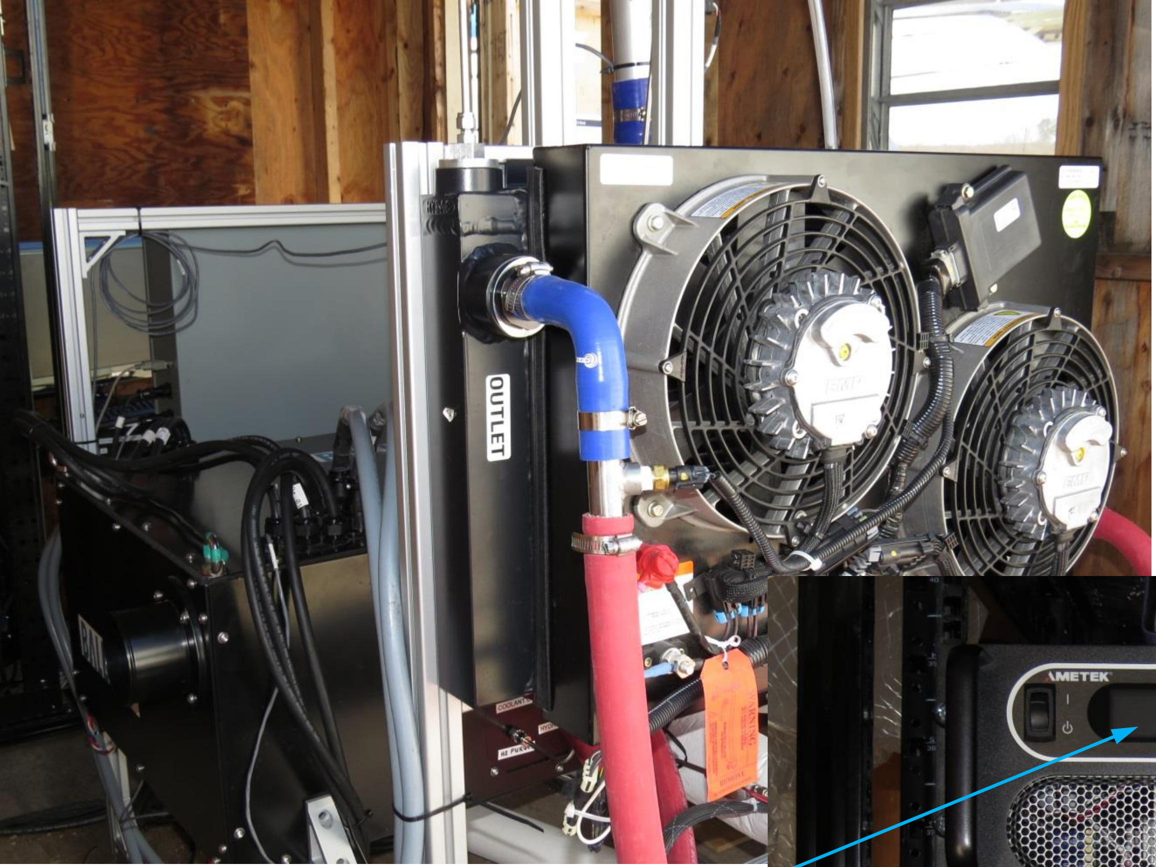
Cargo Bay Instrumentation





Cargo Bay Instrumentation – View looking Aft

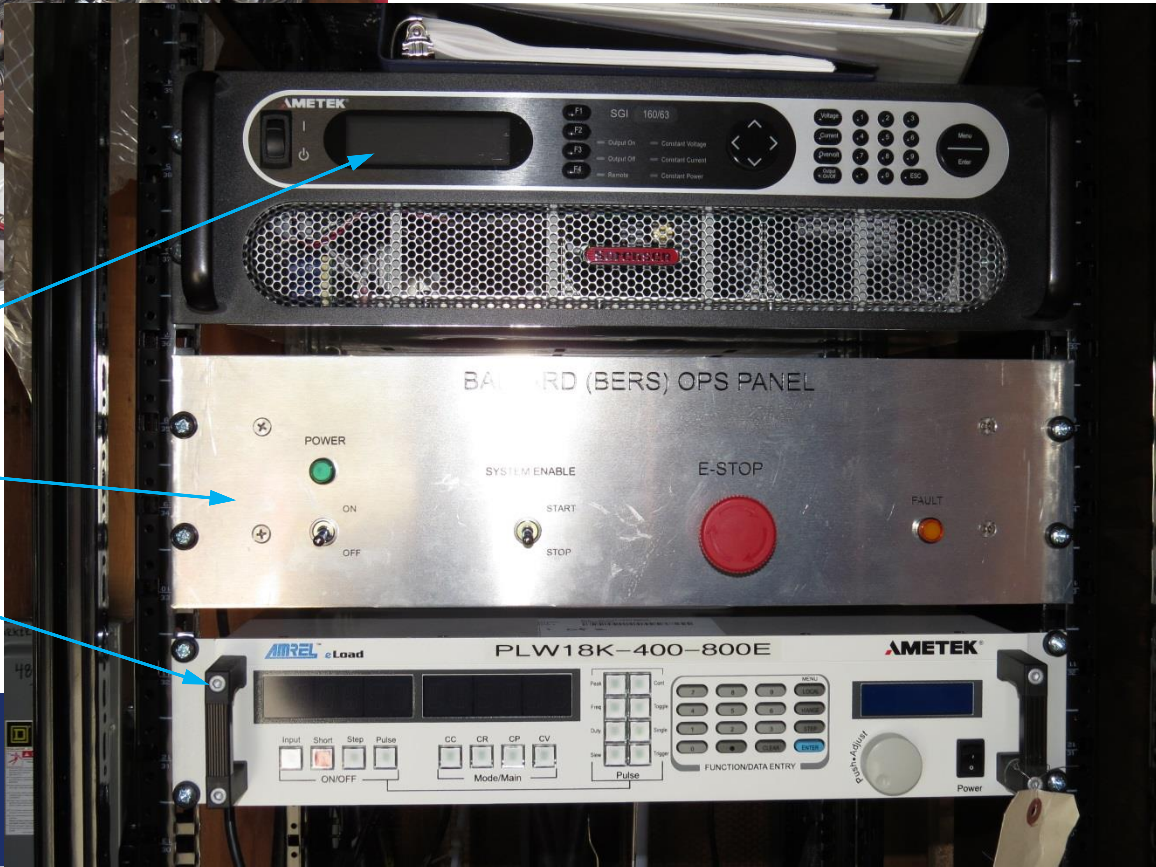
Hydrogen Fuel Cell System – Ballard Engineering Reference System (BERS)



System Power Supply

System Control Panel

Load Bank



Ballard ERS Features (FCvelocity®-9SSL)

PRODUCT SPECIFICATIONS

Fuel Cell Stack	FCvelocity®-9SSL 110 Cell
Output Voltage	60 - 110 VDC
Output Current	0 - 300A
Rated Gross Power	19 kW
Rated Net Power	15 kW
Minimum Net Power	1.4 kW
Efficiency	43-54% - Based on LHV of Hydrogen
Dimensions	1065mm x 660mm x 360mm (Module Only)
Mass (Dry)	153 kg (Module and Electrical Enclosure)
Fuel Inlet Pressure	7 barg nominal
Fuel Consumption	0.20 g/s at rated power
Ambient Temperature	2°C to 40°C
Control System	CoDeSys

Self-Contained Fuel Cell System Developed as an Engineering Design & Integration Tool

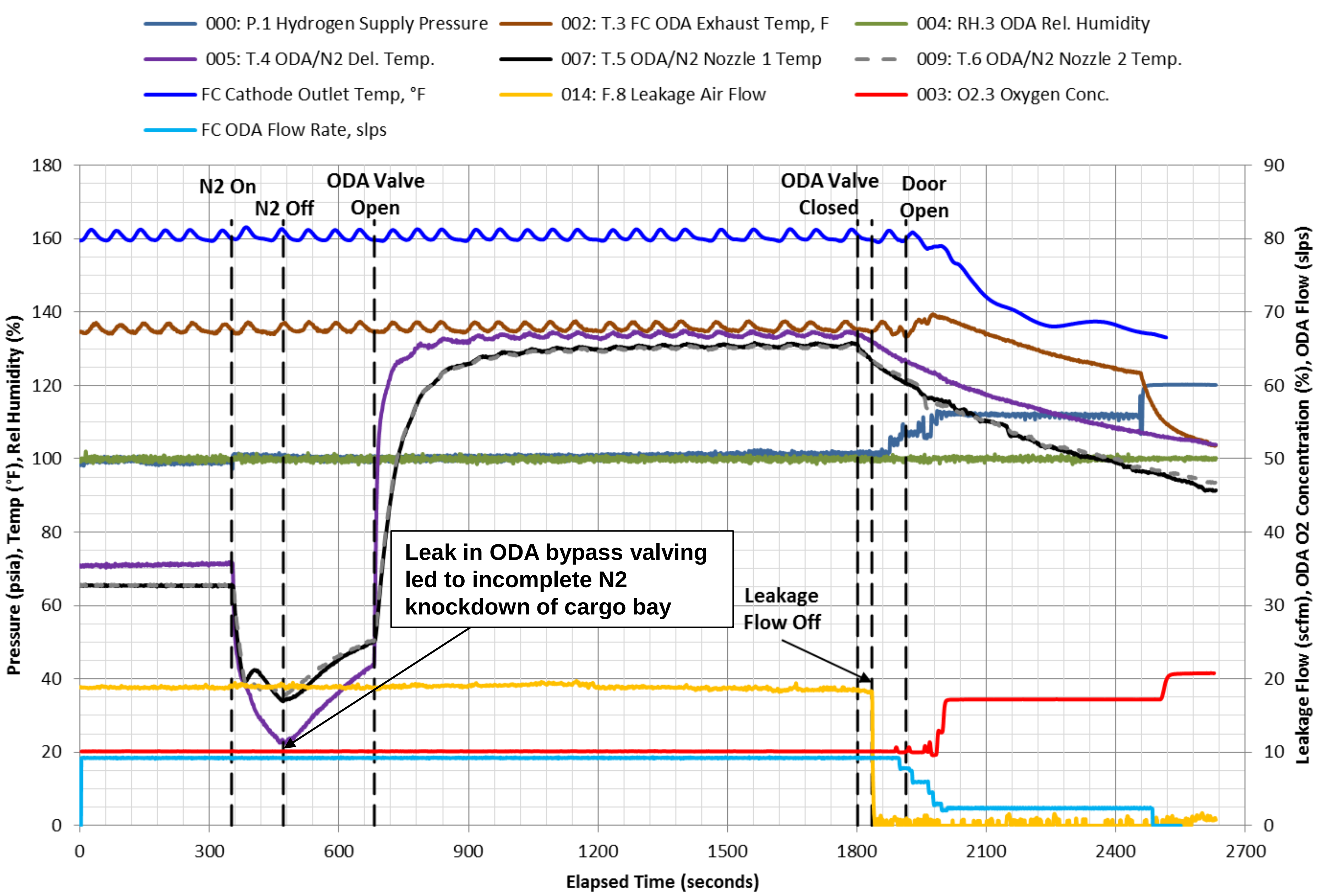
Test Plan

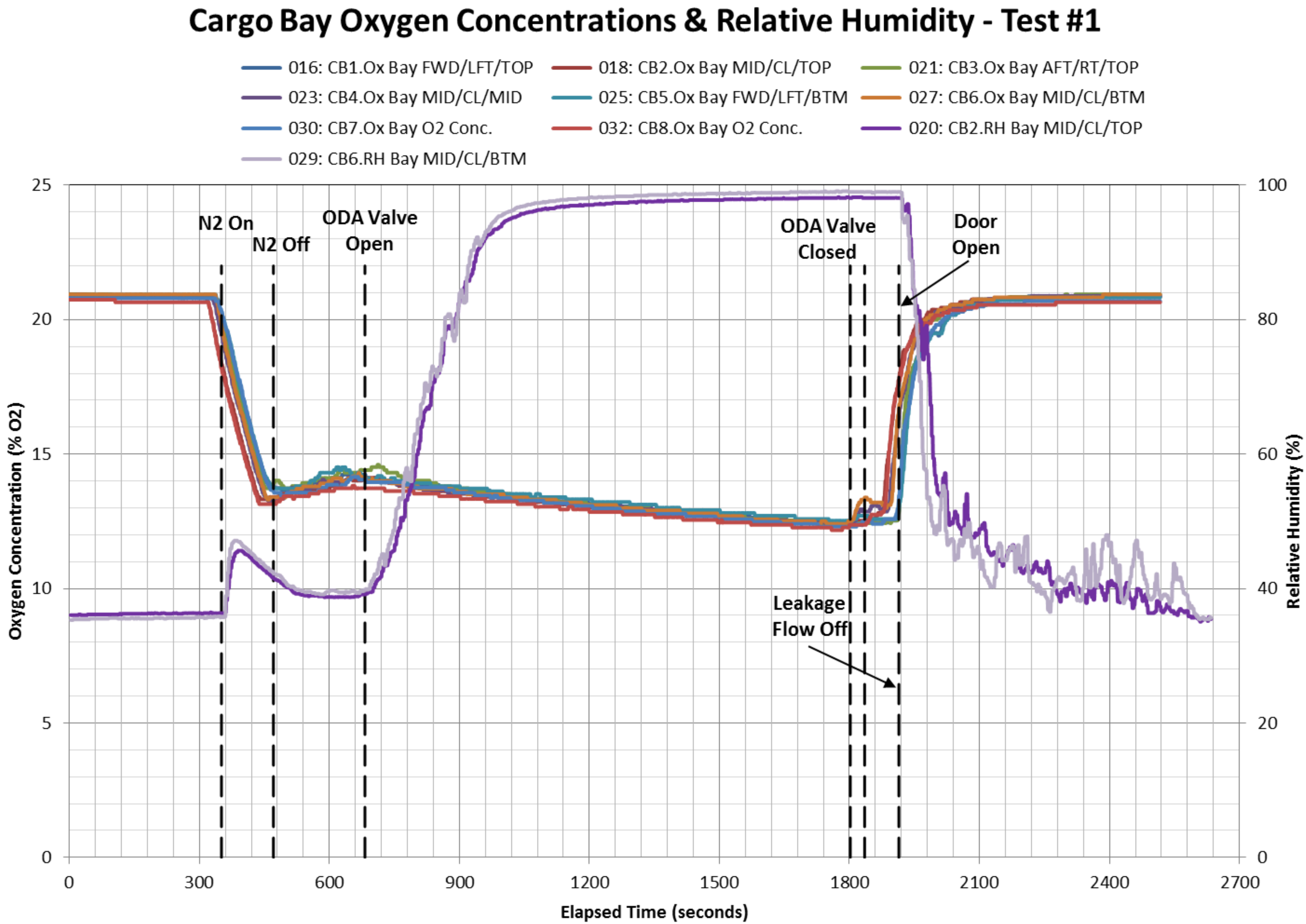
- Conduct initial N_2 knockdown to ~11% O_2, followed by ODA to evaluate capability of maintaining the inert environment
- Once target suppression achieved vary flows to evaluate sensitivity
- Conduct three tests to evaluate repeatability of results

Test Procedures

- Initiate leakage flow (initial flowrate of ~18.85 scfm)
- Initiate ODA flow to ambient (@ BERS initial conditions of 1.8 stoich, 18.85 scfm, 10.6 %O_2)
- Perform initial N2 knockdown (~160 cfm for approximately 2 minutes)
- Switch ODA flow to Cargo Bay
- Allow for stabilization of Cargo Bay O_2 concentrations
- Modify leakage and BERS conditions based on test plan
- After each change of condition, allow time for stabilization of Cargo Bay O_2 concentrations

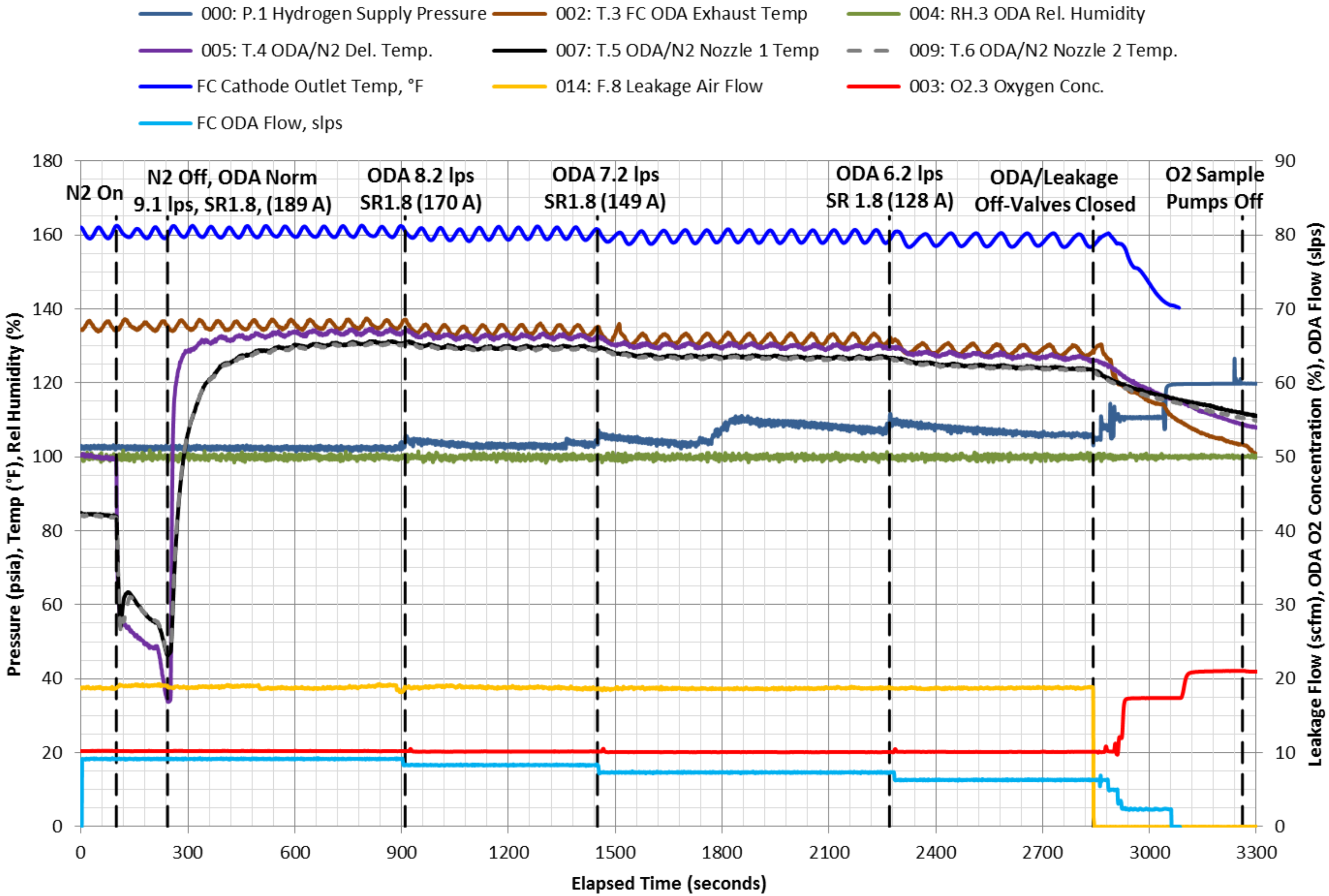
ODA Delivery Characteristics - Test #1

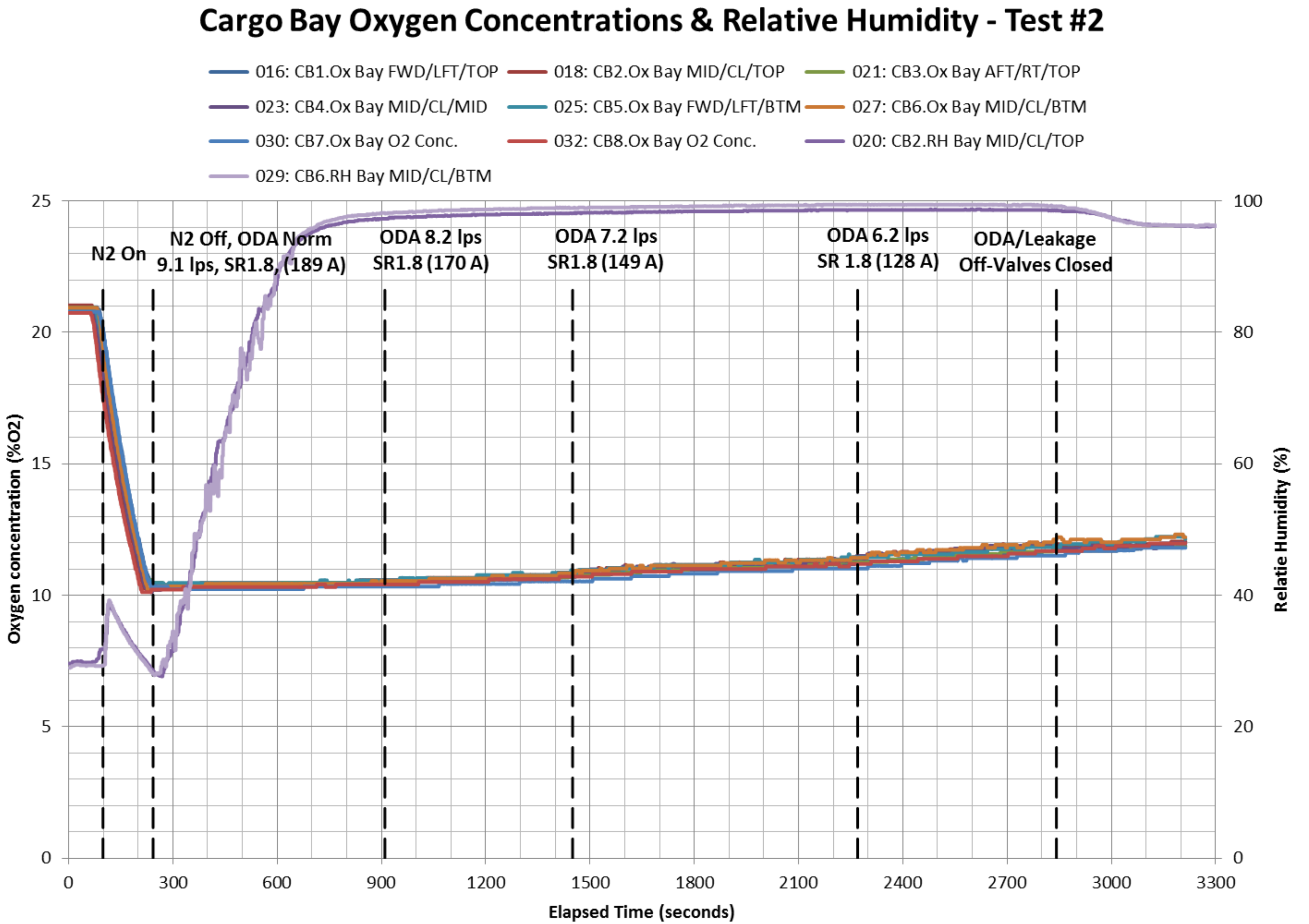




Cargo Bay Oxygen Concentrations & Relative Humidity - Test #1
016: CB1.Ox Bay FWD/LFT/TOP
018: CB2.Ox Bay MID/CL/TOP
021: CB3.Ox Bay AFT/RT/TOP
023: CB4.Ox Bay MID/CL/MID
025: CB5.Ox Bay FWD/LFT/BTM
027: CB6.Ox Bay MID/CL/BTM
030: CB7.Ox Bay O2 Conc.
032: CB8.Ox Bay O2 Conc.
020: CB2.RH Bay MID/CL/TOP
029: CB6.RH Bay MID/CL/BTM
N2 On
N2 Off
ODA Valve Open
ODA Valve Closed
Door Open
Leakage Flow Off
Oxygen Concentration (% O2)
Relative Humidity (%)
Elapsed Time (seconds)
0
5
10
15
20
25
0
20
40
60
80
100
0
300
600
900
1200
1500
1800
2100
2400
2700

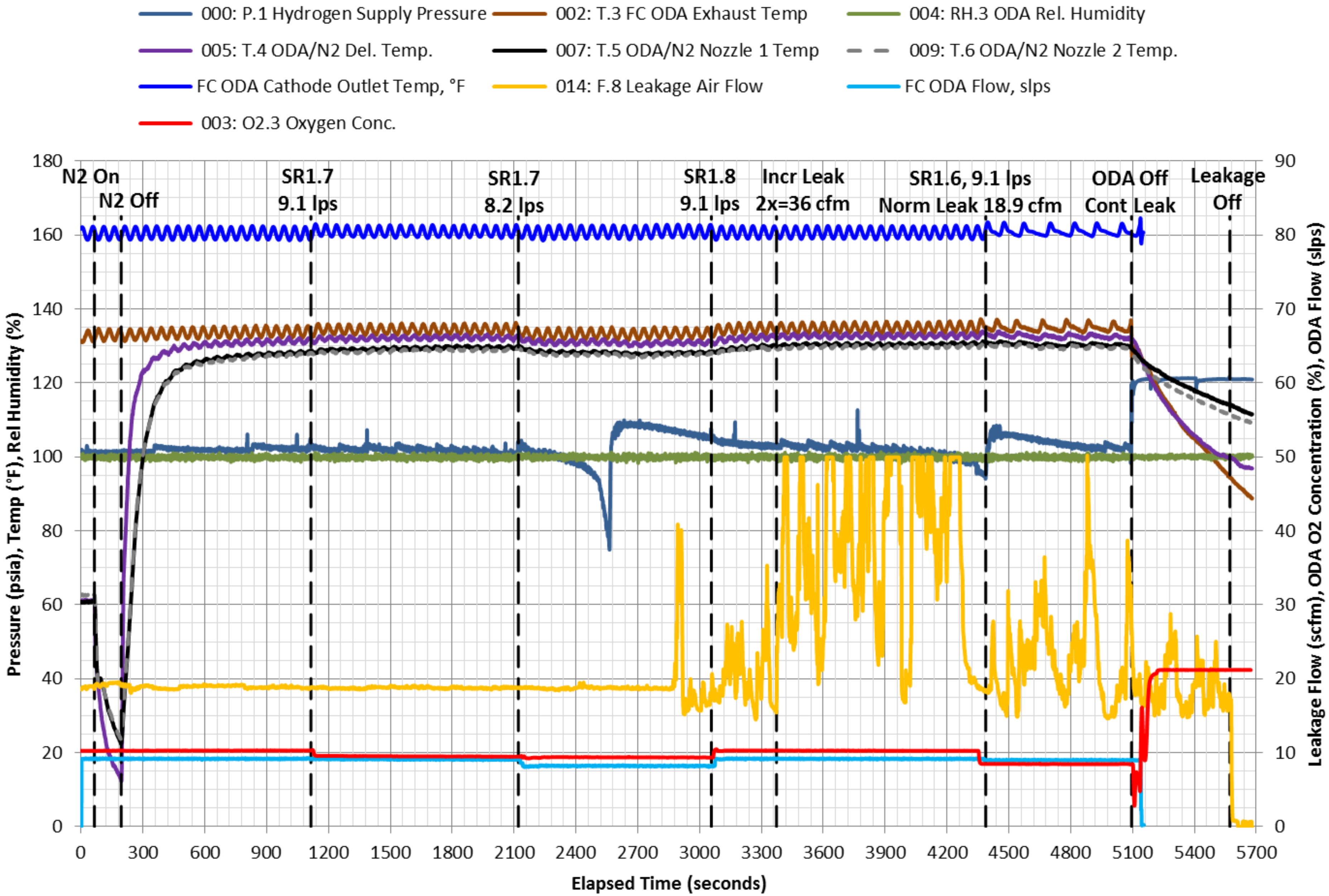
ODA Delivery Characteristics - Test #2

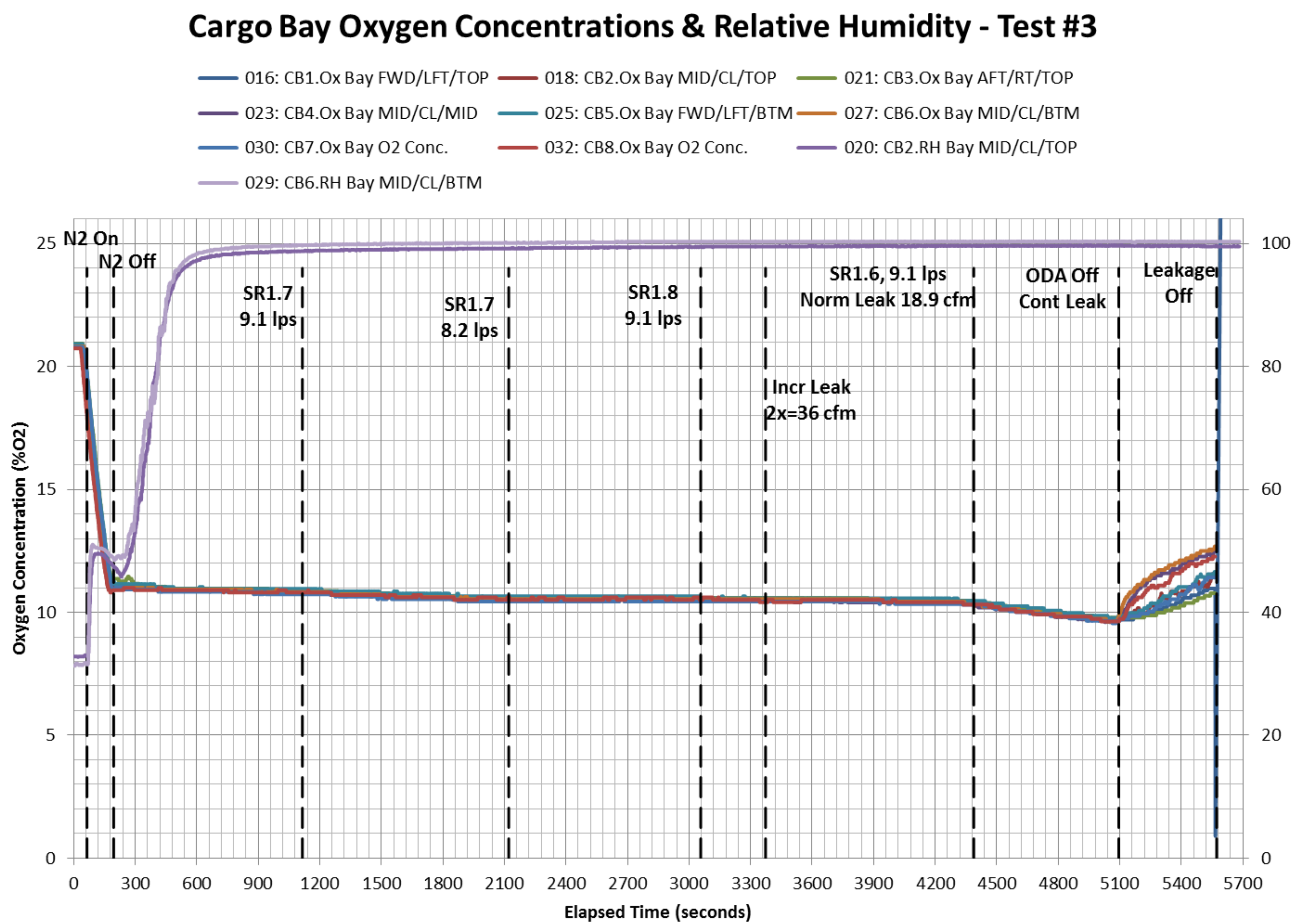




Cargo Bay Oxygen Concentrations & Relative Humidity - Test #2
016: CB1.Ox Bay FWD/LFT/TOP
018: CB2.Ox Bay MID/CL/TOP
021: CB3.Ox Bay AFT/RT/TOP
023: CB4.Ox Bay MID/CL/MID
025: CB5.Ox Bay FWD/LFT/BTM
027: CB6.Ox Bay MID/CL/BTM
030: CB7.Ox Bay O2 Conc.
032: CB8.Ox Bay O2 Conc.
020: CB2.RH Bay MID/CL/TOP
029: CB6.RH Bay MID/CL/BTM
N2 On
N2 Off, ODA Norm
9.1 lps, SR1.8, (189 A)
ODA 8.2 lps
SR1.8 (170 A)
ODA 7.2 lps
SR1.8 (149 A)
ODA 6.2 lps
SR 1.8 (128 A)
ODA/Leakage
Off-Valves Closed
Oxygen concentration (%O2)
Relatie Humidity (%)
Elapsed Time (seconds)
0
5
10
15
20
25
0
20
40
60
80
100
0
300
600
900
1200
1500
1800
2100
2400
2700
3000
3300

ODA Delivery Characteristics - Test #3




Cargo Bay Oxygen Concentrations & Relative Humidity - Test #3
016: CB1.Ox Bay FWD/LFT/TOP
018: CB2.Ox Bay MID/CL/TOP
021: CB3.Ox Bay AFT/RT/TOP
023: CB4.Ox Bay MID/CL/MID
025: CB5.Ox Bay FWD/LFT/BTM
027: CB6.Ox Bay MID/CL/BTM
030: CB7.Ox Bay O2 Conc.
032: CB8.Ox Bay O2 Conc.
020: CB2.RH Bay MID/CL/TOP
029: CB6.RH Bay MID/CL/BTM
N2 On
N2 Off
SR1.7
9.1 lps
SR1.7
8.2 lps
SR1.8
9.1 lps
SR1.6, 9.1 lps
Norm Leak 18.9 cfm
Incr Leak
2x=36 cfm
ODA Off
Cont Leak
Leakage
Off
Oxygen Concentration (%O2)
Elapsed Time (seconds)
0
5
10
15
20
25
0
20
40
60
80
100
0
300
600
900
1200
1500
1800
2100
2400
2700
3000
3300
3600
3900
4200
4500
4800
5100
5400
5700

Summary

- **ODA from the fuel cell system exhibited potential to maintain an oxygen deprived environment under a variety of operating conditions.**
- **Results with increased leakage flow raise questions, as expected increase in O2 concentration was not observed.**
  - Cause can potentially be attributed to irregular leakage flow pattern in cargo bay, variation between calculated vs actual flowrate of ODA, or ???

Next Steps

- **Further analysis of both the cargo bay and BERS data is ongoing.**
- **Leakage tests to be conducted to verify flow pattern within cargo bay.**
- **Comparison with analytical model based on inputs of N_2/ODA flowrate and concentration along with leakage flow data will be performed.**
- **Further data is needed on actual O_2 concentration required to suppress a cargo fire, particularly with increased humidity resulting from ODA flow**

Questions?

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