Flight Testing of the FAA Onboard Inert Gas Generation System

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Flight Testing of the FAA OBIGGS

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Flight Testing of the FAA OBIGGS

Testing Goals and Objectives

- Airbus A320 Testing:
  - Examine the ASM inerting system concept, validate the FAA dual flow methodology, and develop a primitive system performance model
  - Validate in flight inert gas distribution assumptions
  - Examine potential operational effects on the ability of a system to maintain inert conditions in a fuel tank
- NASA 747 SCA Testing:
  - Study the FAA dual flow methodology as well as a variable flow system methodology and expand upon existing system performance data
  - Develop/validate system sizing data
  - Validate previous in flight inert gas distribution modeling done by FAA

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OBIGGS - System Architecture

- Uses Air Separation Modules based on HFM technology
  - Accepts hot air from aircraft bleed system
  - Cools, filters, and conditions air
  - Air is separated by ASMs and NEA is plumbed to output valves to control flow
  - OEA is dumped overboard, H/X cooling air carried away from system
  - System configured to operate in a dual flow methodology for some tests and a variable flow methodology for others

- Prototype OBIGGS components wired to a single connector on system to interface system with control box by a single cable

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OBIGGS - System Installation

- Airbus A320 Test Aircraft
  - System installed in aircraft cargo bay for simplicity sake with the system interface engineered by Airbus
  - NEA deposited in rear of single vent, open bay, CWT with OEA being dumped overboard
  - H/X cooling air drafted from cargo bay and deposited near outflow valve
- NASA 747 SCA Test Aircraft
  - System installed in empty pack bay area by FAA as designed by Shaw Aero Devices with the System Interfacing
  - NEA deposited in bay 6 of the compartmentalized (6 bays) CWT with no cross-venting in tank (vent system half blocked)
  - H/X cooling air drafted from exterior and deposited overboard with OEA
- System controlled by box in cabin

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FAA OBIGGs Installation Drawing in A320 Cargo Bay

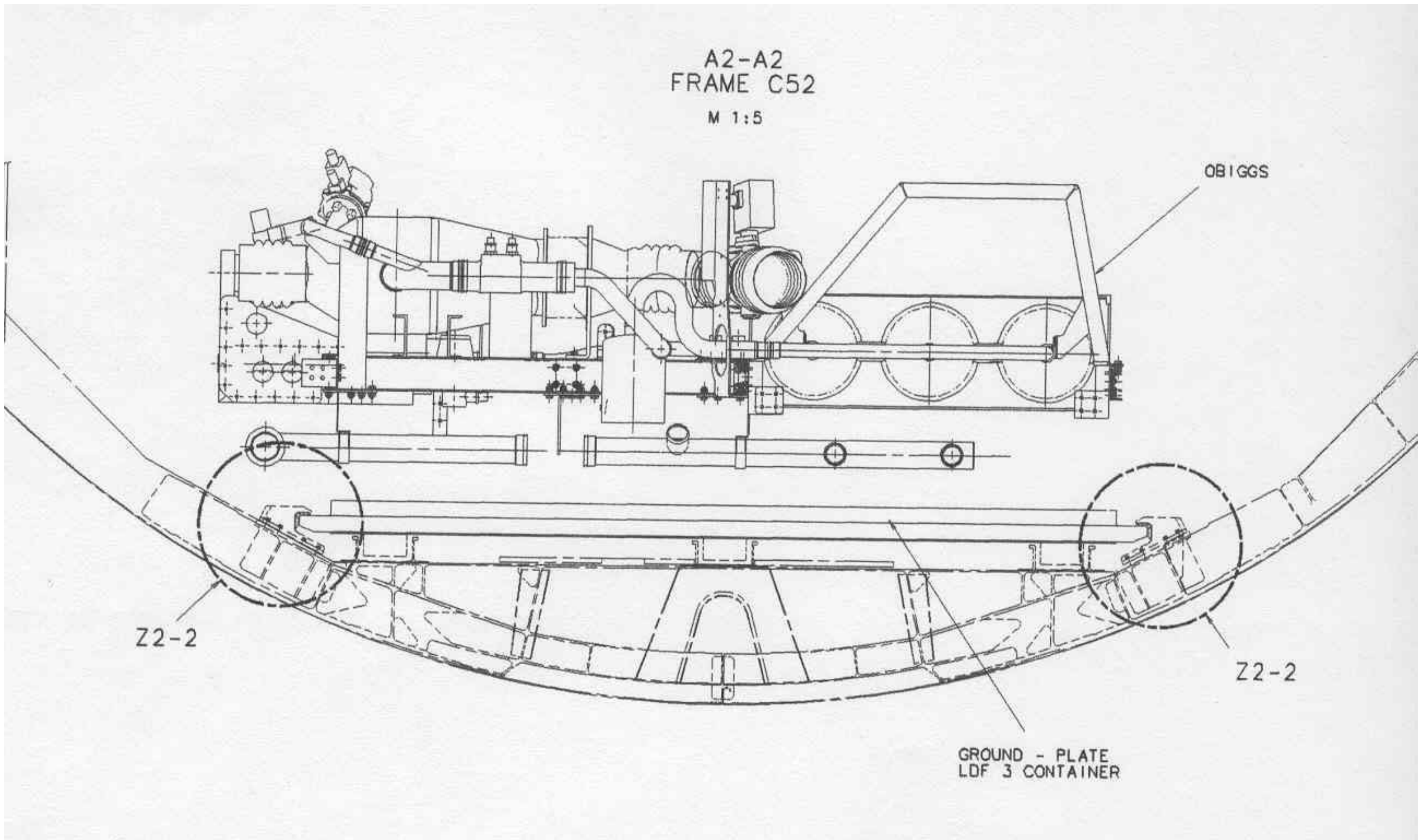

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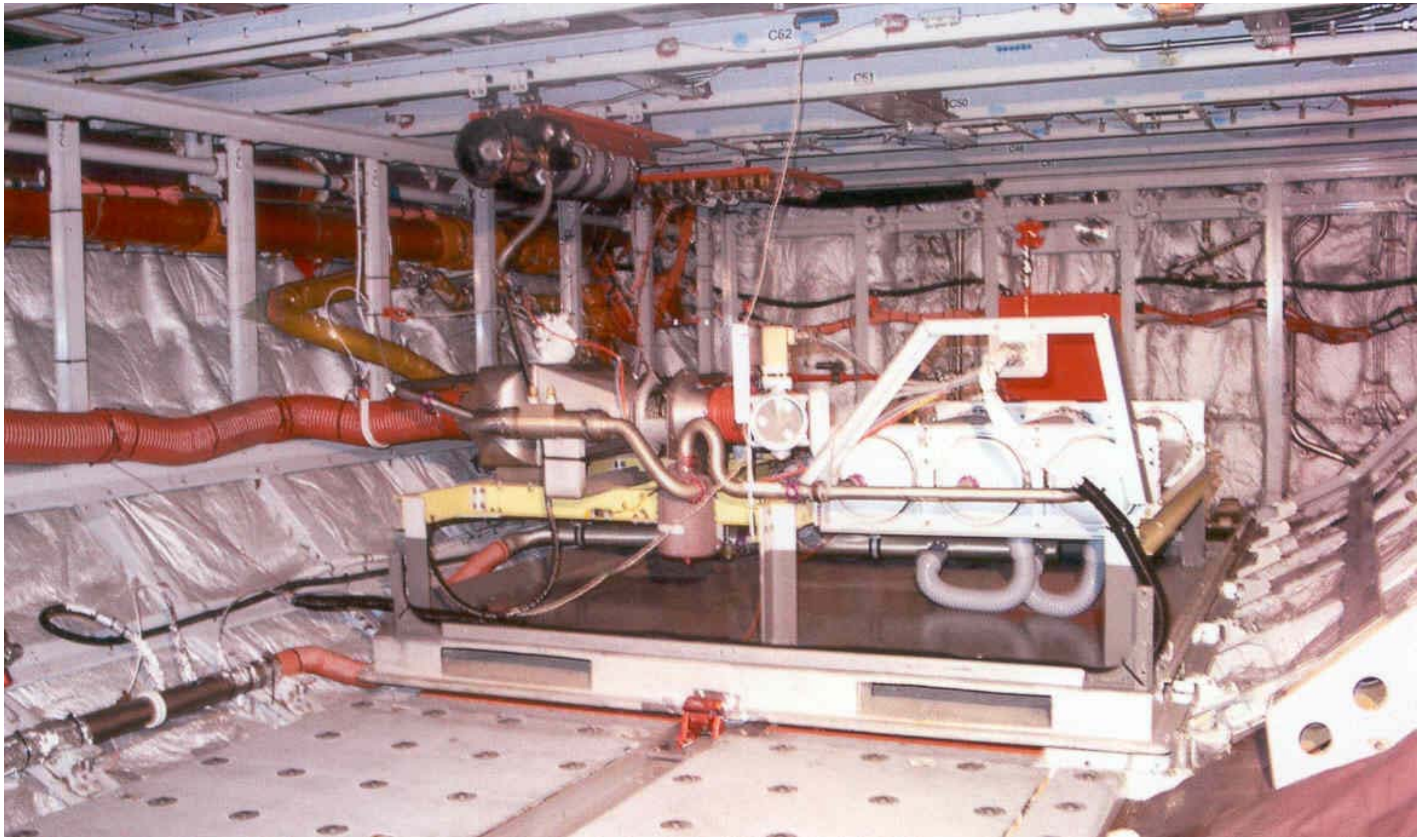
Photo of FAA OBIGGS Installation on A320



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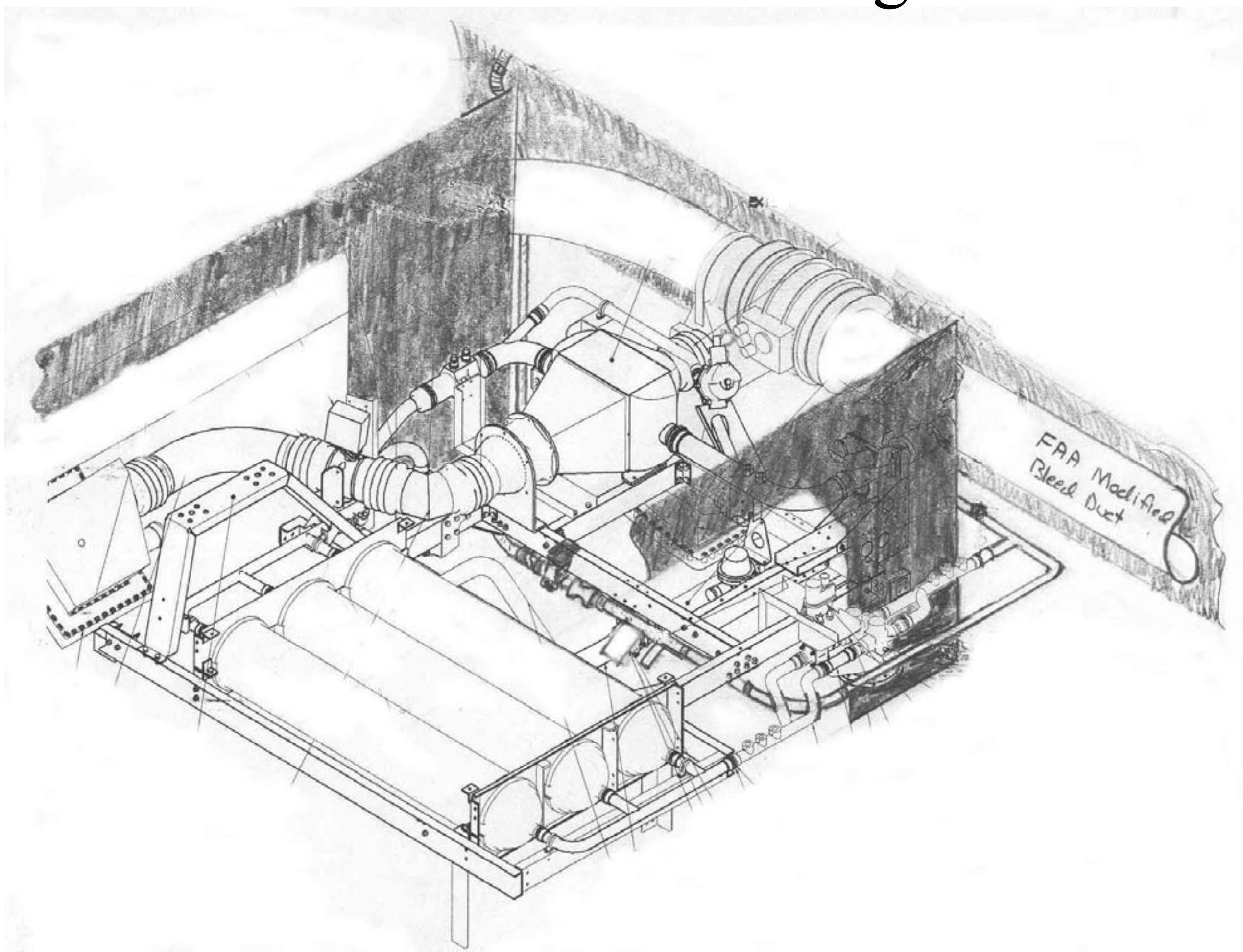
FAA OBIGGS Installation Drawing in 747 Pack Bay



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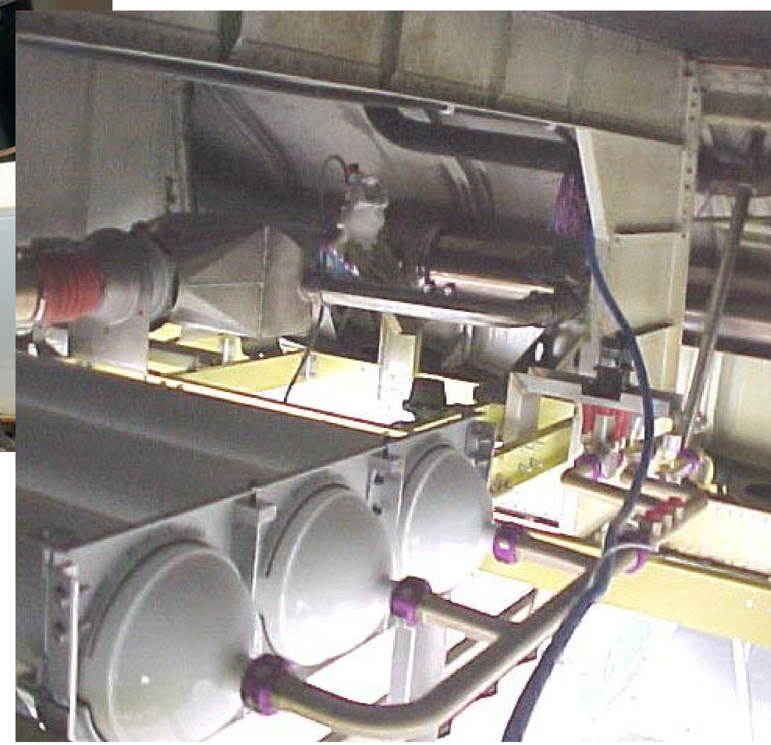
Photos of FAA OBIGGS Installation on 747 SCA



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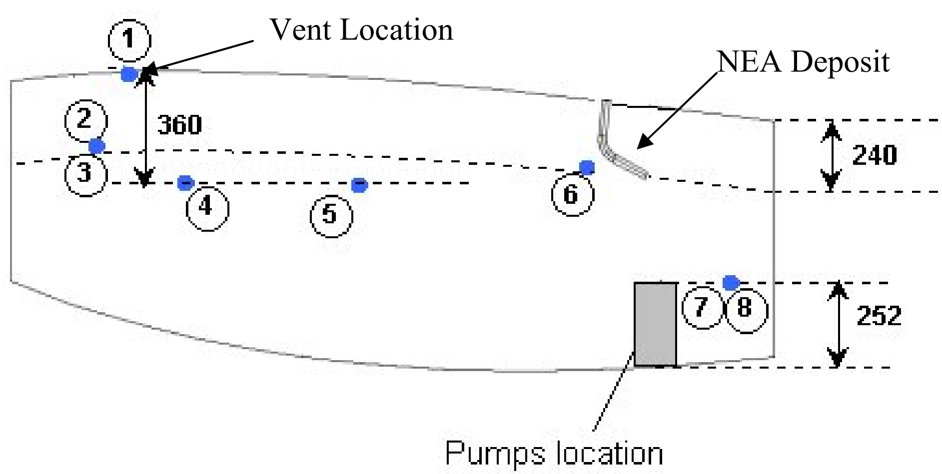
Instrumentation and DAS – Airbus A320

- OBIGGS system performance measured with various thermocouples and pressure transducers as well as a system flow meter and 2-channel oxygen analyzer for NEA and OEA
- Eight sample locations within the single bay CWT measured by the FAA Onboard Oxygen Analysis System (OBOAS)
- Aircraft parameters measured by Airbus
- Airbus data acquisition system utilized
  - Full-up flight worthy DAS



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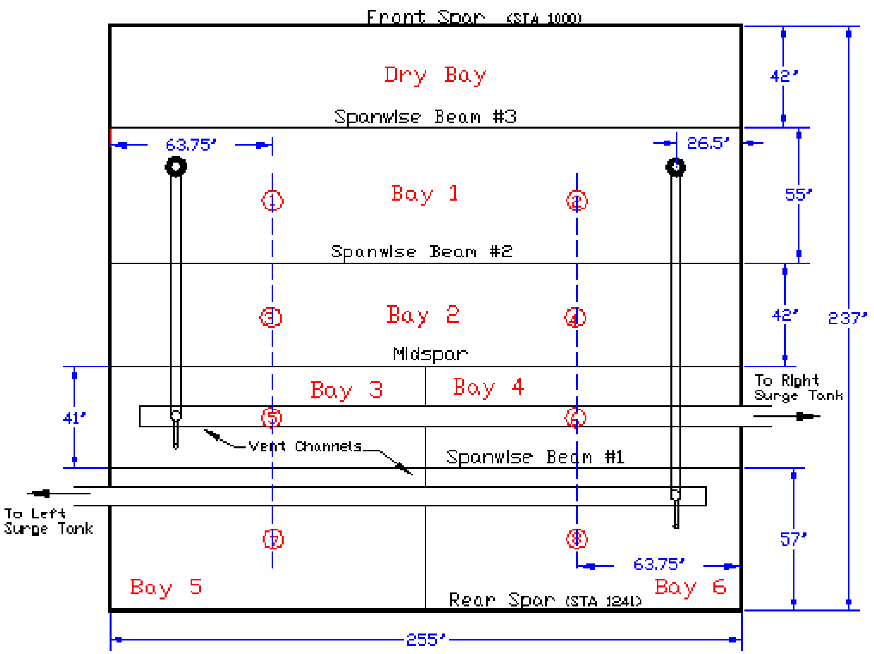
Instrumentation and DAS – 747 SCA

- OBIGGS system performance measurements same as with Airbus Testing, but some different sensors
- Eight sample locations within the CWT in six different bays
  - FAA (OBOAS) utilized
- Aircraft altitude measured by pressure transducer
- Measured flammability of CWT and #2 wing tank
- Laboratory DAS utilized
  - Simple out-of-the-box solution



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Instrumentation Racks Mounted in NASA 747 SCA

Existing Power Distribution Rack

OBOAS

DAS Rack

NDIR Analyzer

FAS Rack

Flight Testing of the FAA OBIGGS

Test Plan – Airbus A320 Testing

- Operated system in dual flow configuration for a series of tests with a 39,000 ft cruise altitude and a high rate of descent (4k ft/min)
  - Descended to 3,000 feet for operational purposes
  - Nine total tests, 6 relative to FAA testing goals and objectives
  - Used OBIGGS in both a single ASM configuration and a 2-membrane configuration to evaluate sizing requirements
- Testing examined the effects of several operational conditions
  - Studied effect of fuel on an inert ullage
  - Studied effect of the high flow mode on the inert ullage
  - Studied effect of bleed air on the ASM performance degradation

Flight Testing of the FAA OBIGGS

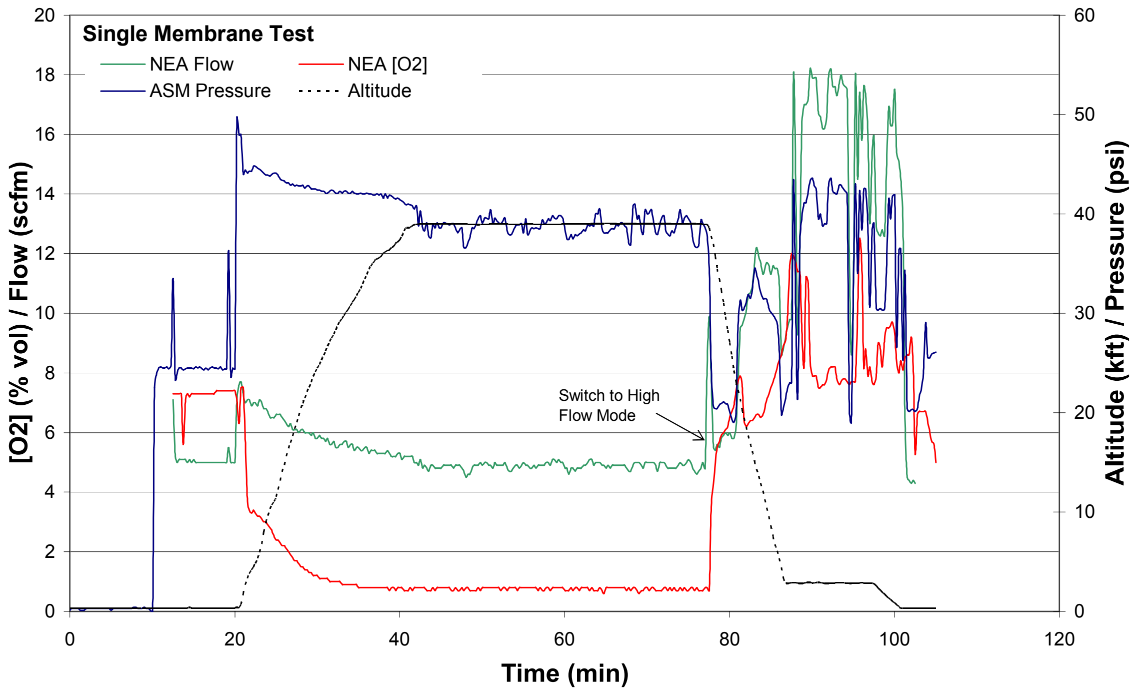
Test Plan – NASA SCA Testing

- Operated system in dual flow configuration for first test and in variable flow configuration for remainder of testing
- Did a series of 7 flight tests ranging from 2 to 5 hours totaling approximately 30 hours of flight time
  - Validated the two-flow mode methodology and studied maximizing system flow during top of descent
  - Studied effect of CWT fuel on inerting and demonstrated the ability of a system to reduce the flammability exposure of an aircraft
  - Examined the effects of long cruise times on system performance
  - Examined existing fleet flammability with baseline flammability testing

Flight Testing of the FAA OBIGGS

Results - Airbus A320 System Performance

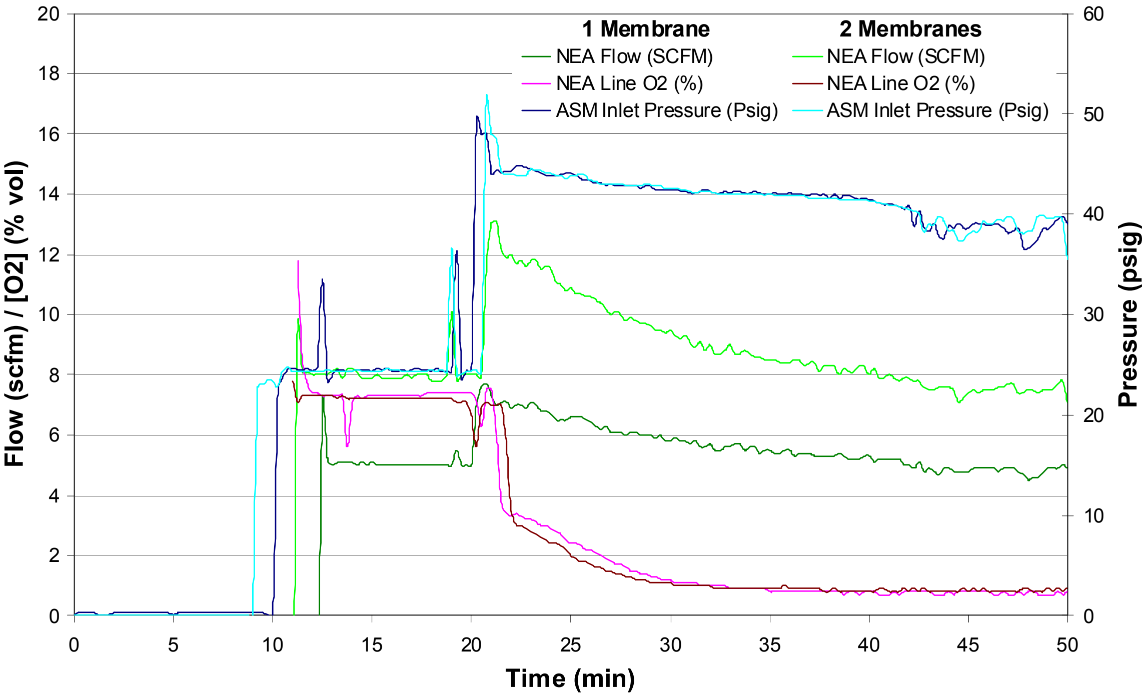
- System performed as expected with predictable ASM dynamic characteristics given difficulty in maintaining 180ºF ASM supply temp
  - Difficult to see hand-to-mouth relationship of flow and purity as it relates to ASM pressure due to lag in oxygen concentration instrumentation



Flight Testing of the FAA OBIGGS

Results - Airbus A320 System Performance

- One vs. Two ASM Performance Data
  - 2-membrane system configuration gave approximately double the NEA most times, but at cruise did not perform as expected
  - Performance deficit most likely due to OEA back pressure which was measured as high during top of ascent and cruise, not descent



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Results - Airbus A320 System Performance

- ASM degraded during the ground and flight testing (~ 100 hours) giving a reduction in productivity
  - More than normal expected “break-in” of ASM
  - ASM performance change normally occurs during first 100 hours of life to make ASM less permeable but more selective

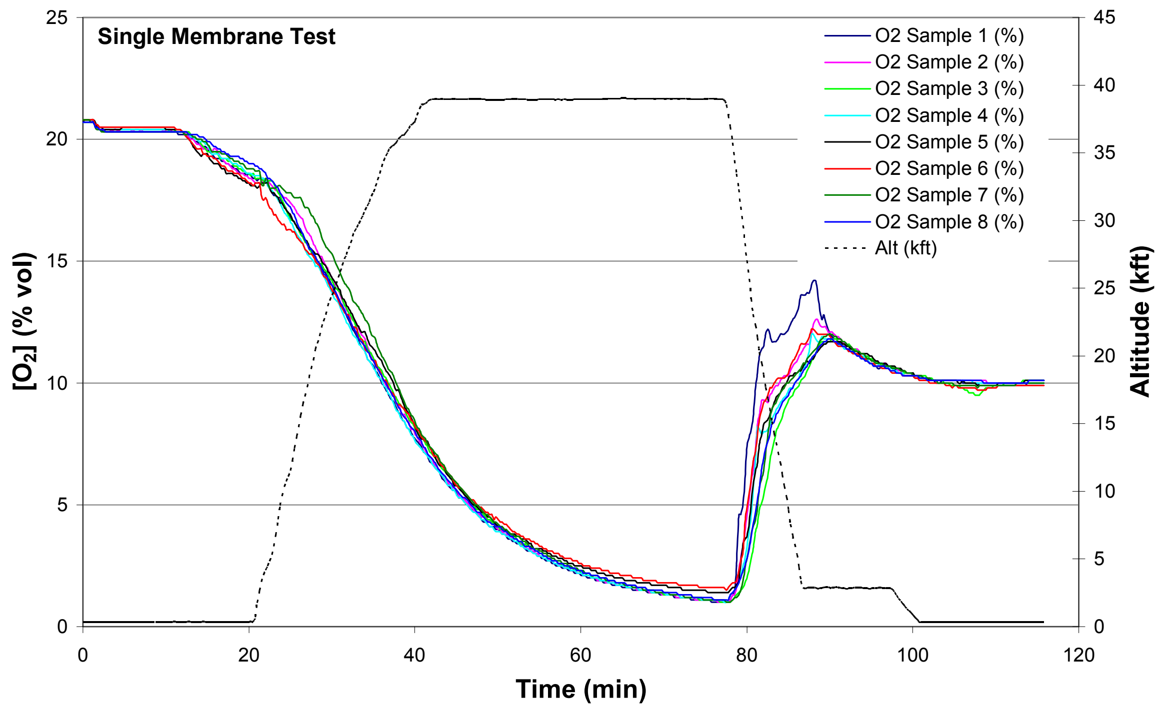
Membrane State	ASM Inlet Temperature	ASM Inlet Pressure	Altitude	NEA Purity	NEA Flow	ASM Inlet Flow
Before	172°F	25 psig	Sea Level	5%	0.36 lbs/min	1.48 lbs/min
After	169°F	25 psig	Sea Level	5%	0.31 lbs/min	1.25 lbs/min
Difference					0.05 lbs/min	0.23 lbs/min

  - ASM performance change causes 16% reduction in permeability which results in a 14% reduction in productivity with a 0.5% increases in selectivity

Flight Testing of the FAA OBIGGS

Results - A320 Fuel Tank Inerting

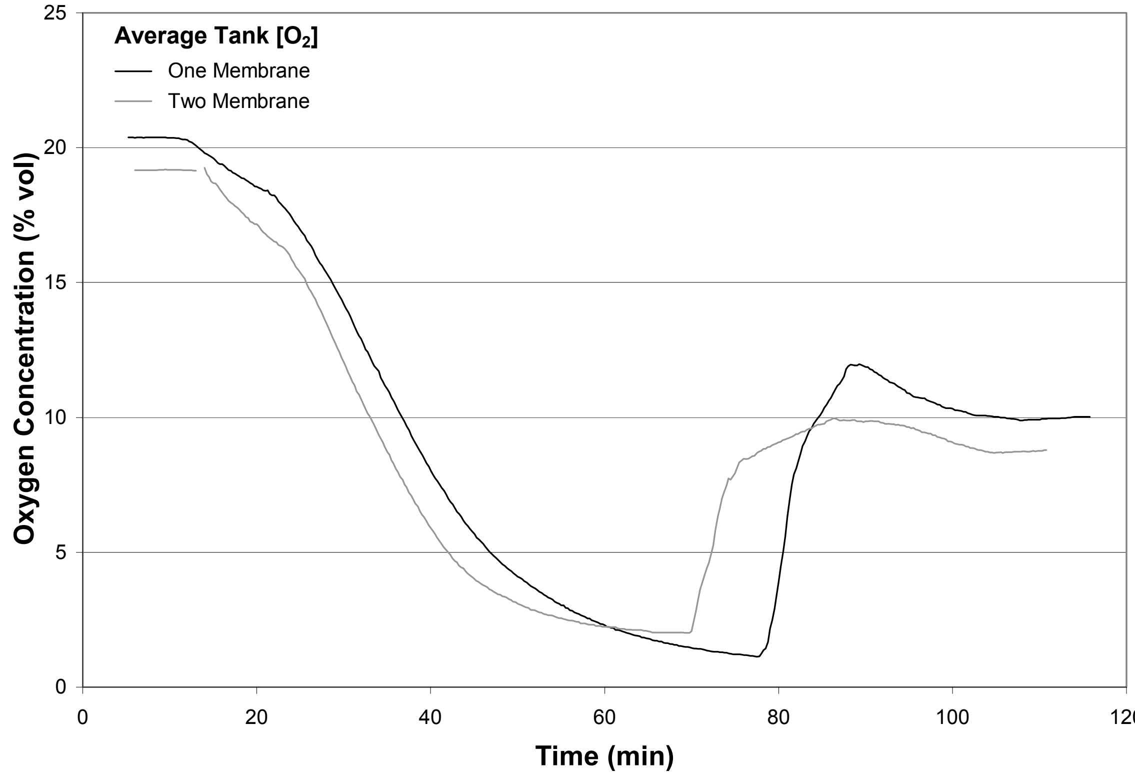
- CWT inerting oxygen concentration data very consistent
  - Inerting CWT occurred easily with no stratification/gradients in $[O_2]$ observed, ullage acted in a very homogenous manner
  - Gas sample from area close to vent exhibited deviations from the average during descent when air enters the tank



Flight Testing of the FAA OBIGGS

Results - A320 Fuel Tank Inerting

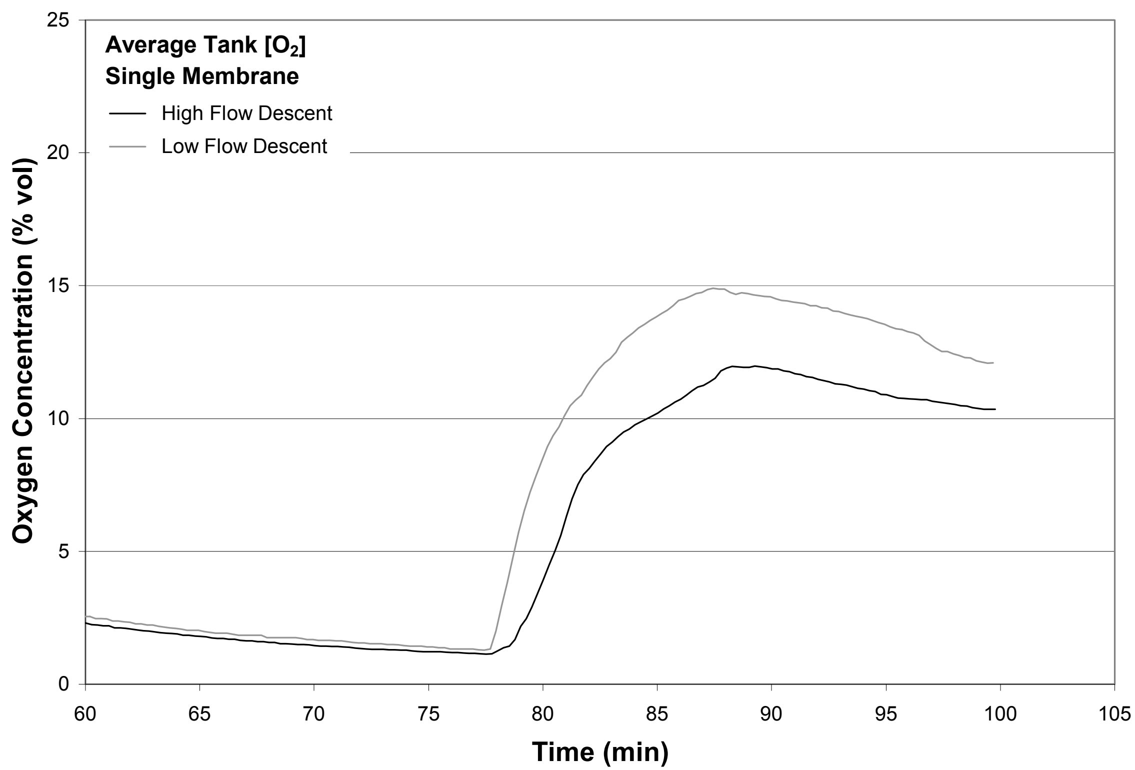
- One versus two ASM system configuration CWT inerting data
  - Two ASM inerting gave very little benefit compared to a single ASM
  - Changing the system "tuning" could improve system capability for the flight profile



Flight Testing of the FAA OBIGGS

Results - A320 Fuel Tank Inerting

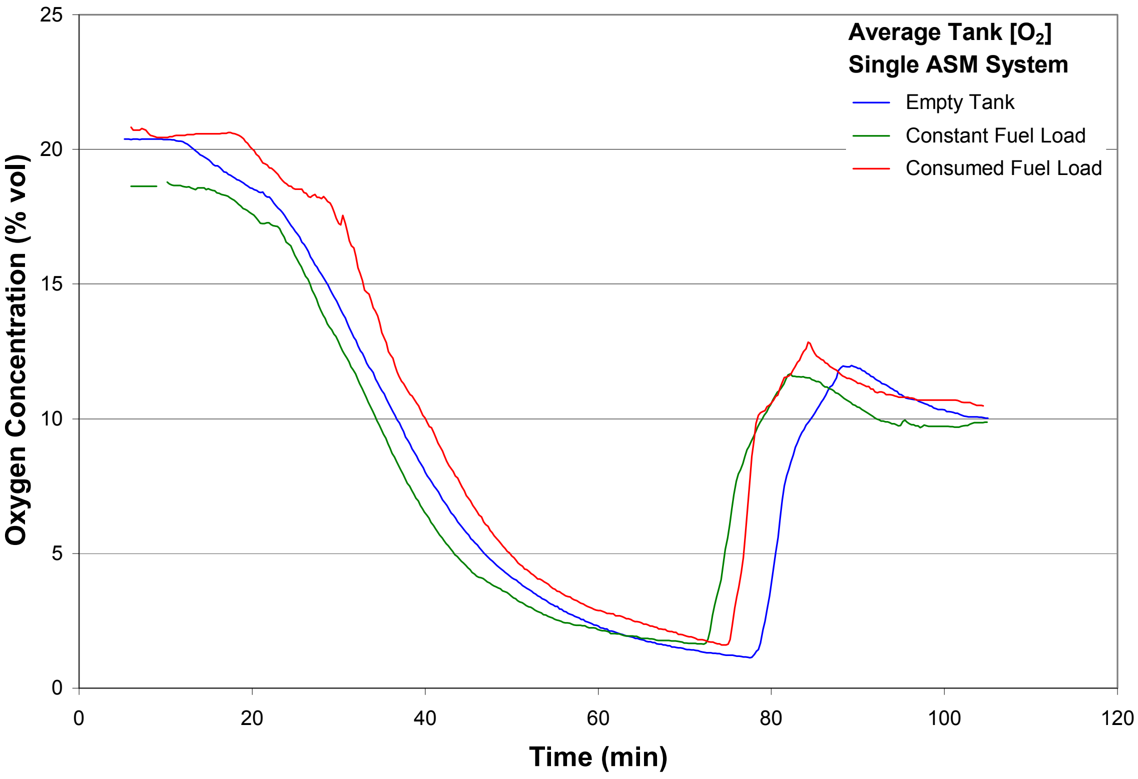
- Benefit of high flow mode on tank inerting significant during descent
  - High flow mode effective at minimizing peak ullage oxygen concentration and helping maintain an overall low resulting ullage oxygen concentration during descent



Flight Testing of the FAA OBIGGS

Results - A320 Fuel Tank Inerting

- Measured effects of fuel on inert ullage data not discernable
  - Effect of fuel load hardly observable for both static and consumed fuel loads
  - Any air evolution effect would be small on relatively large ullage and system operation masks effects



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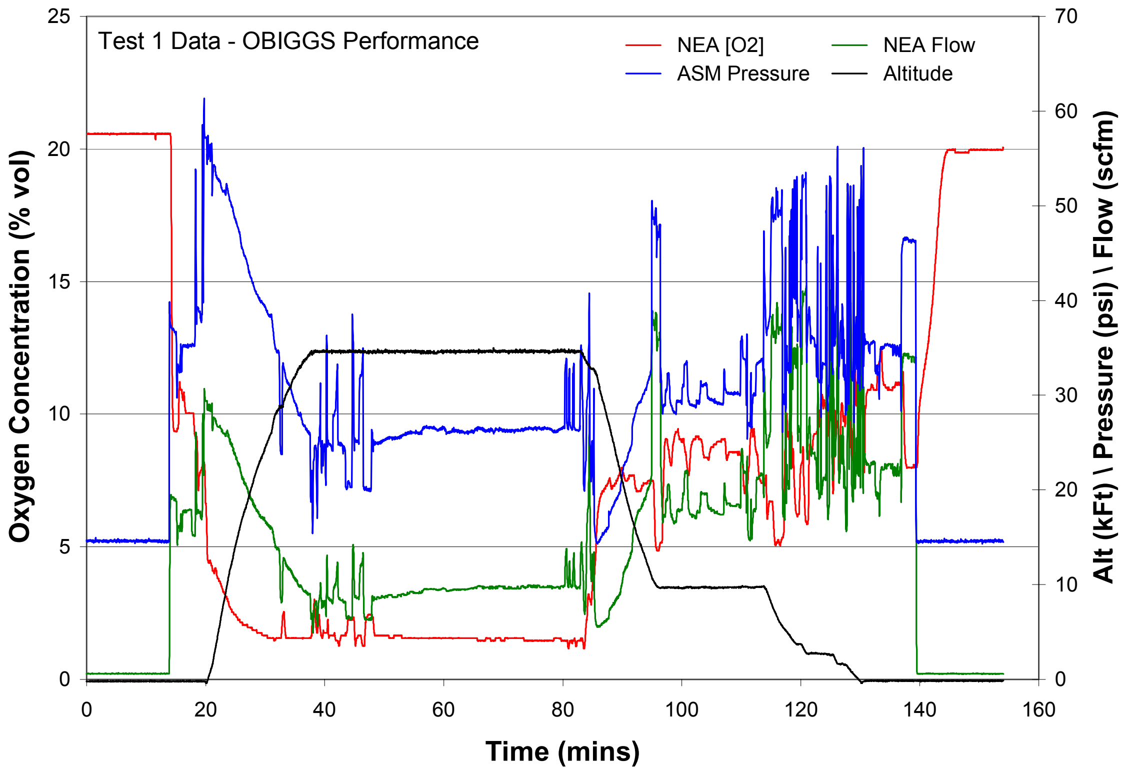
Results - 747 SCA System Performance

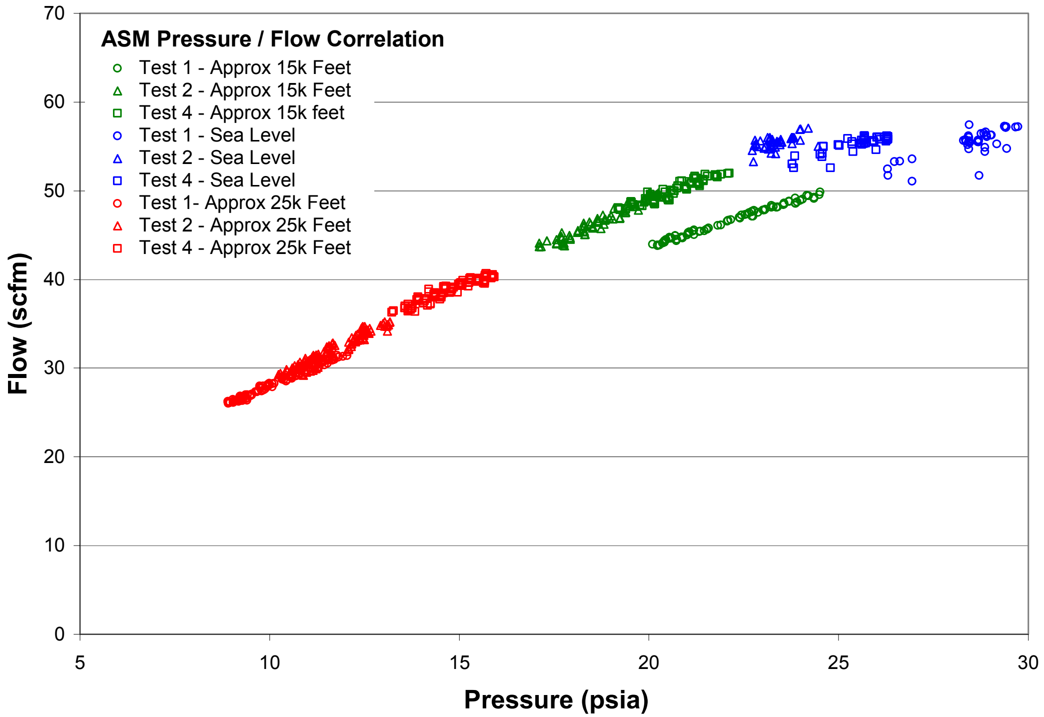
- System performed as expected with predictable ASM dynamic characteristics
  - Less bleed air pressure in cruise and greater deviations
  - The data does not indicate deviations decreases the system efficiency



Flight Testing of the FAA OBIGGS

Results - 747 SCA System Performance

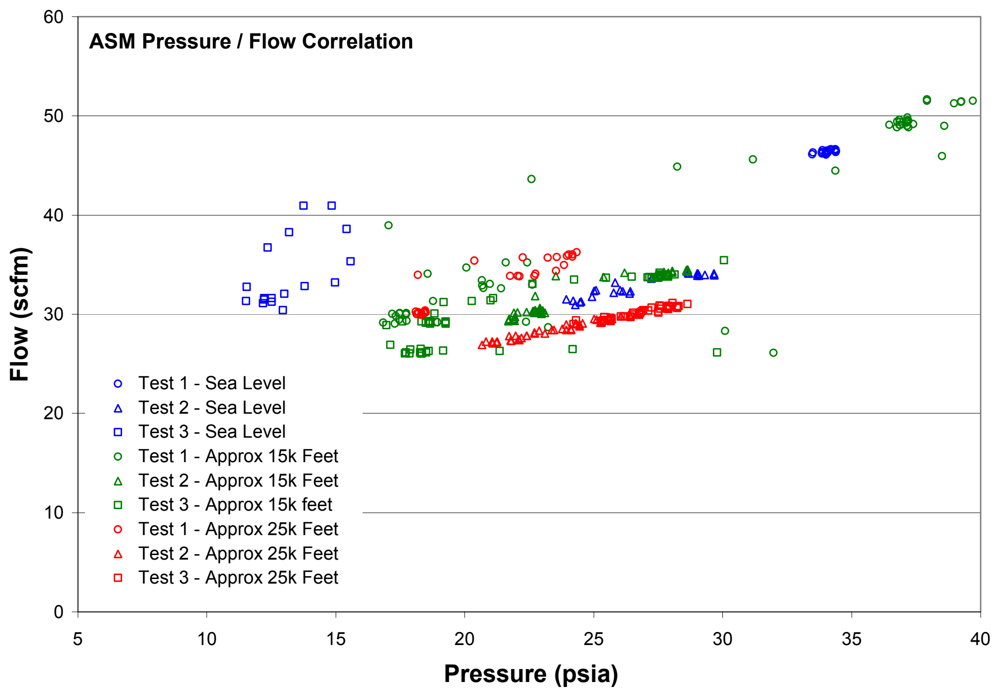
- Correlation of pressure and flow for low flow mode as expected with test 1 data slope deviating from test 2 and 4 slope somewhat
  - Probably an indication of system being operated (warmed up) before start of flight test
  - As fiber gets warmer it becomes more permeable but more selective



Flight Testing of the FAA OBIGGS

Results - 747 SCA System Performance

- Correlation of pressure and flow for high flow difficult to see because of constantly varying ASM pressure
  - Some data illustrates excellent correlation because of the stabilization of system temperature
  - Other data illustrates wide range of results probably due to constantly changing ASM conditions due to jockeying ASM pressure
  - Delays in [O_2] Instrumentation make this even more difficult



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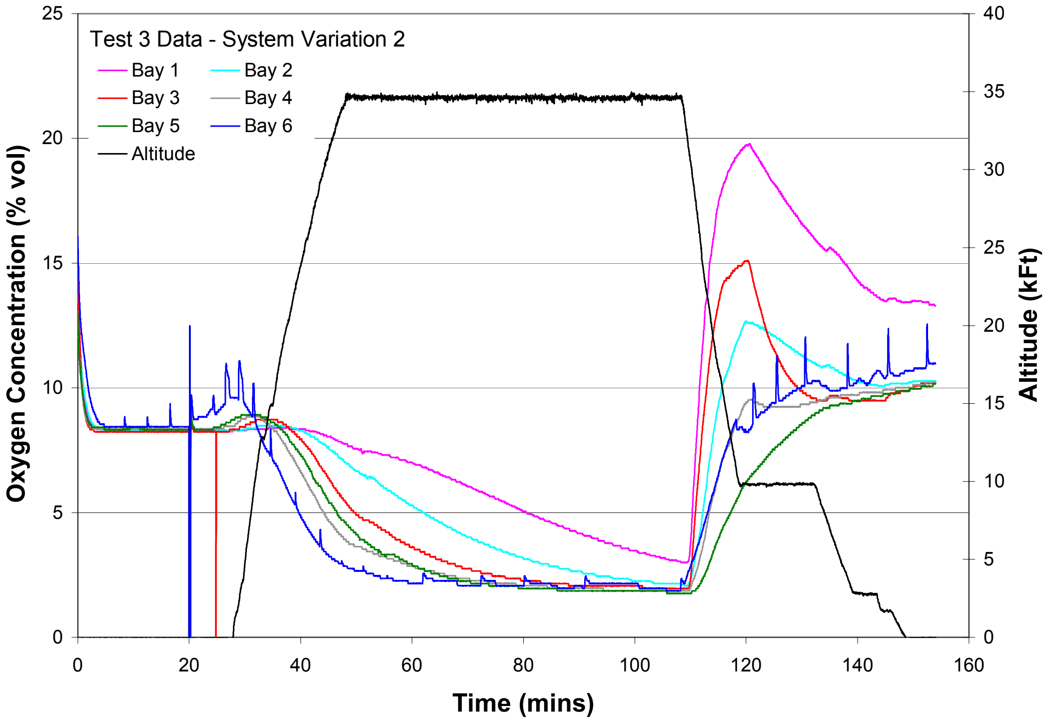
Results - 747 SCA Fuel Tank Inerting

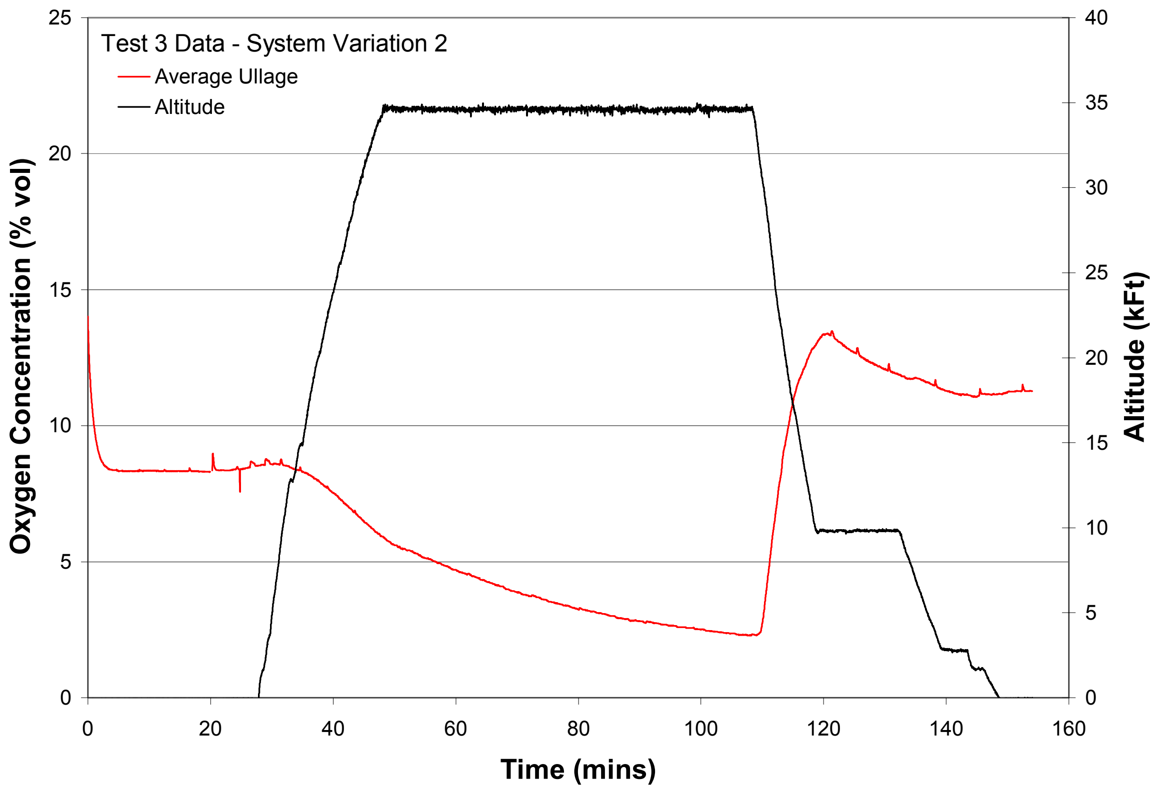
- Evolution of oxygen concentration from bay-to-bay typical of previous scale model and ground testing
  - Oxygen concentration spike in bay 1 greater than in modeling exercises (spiked to 19.5%)
  - Obtaining higher NEA flows with a wider orifice (variable flow valve) at the top of cruise more difficult than anticipated due to high back pressure on NEA output at times



Flight Testing of the FAA OBIGGS

Results - 747 SCA Fuel Tank Inerting

- Average ullage oxygen concentration data illustrates system worked as expected for a approximately 42 minute descent
  - Resulting ullage oxygen concentration about 11%
  - Average spiked to 13.5% oxygen by volume
  - Descent had a 10 minute hold



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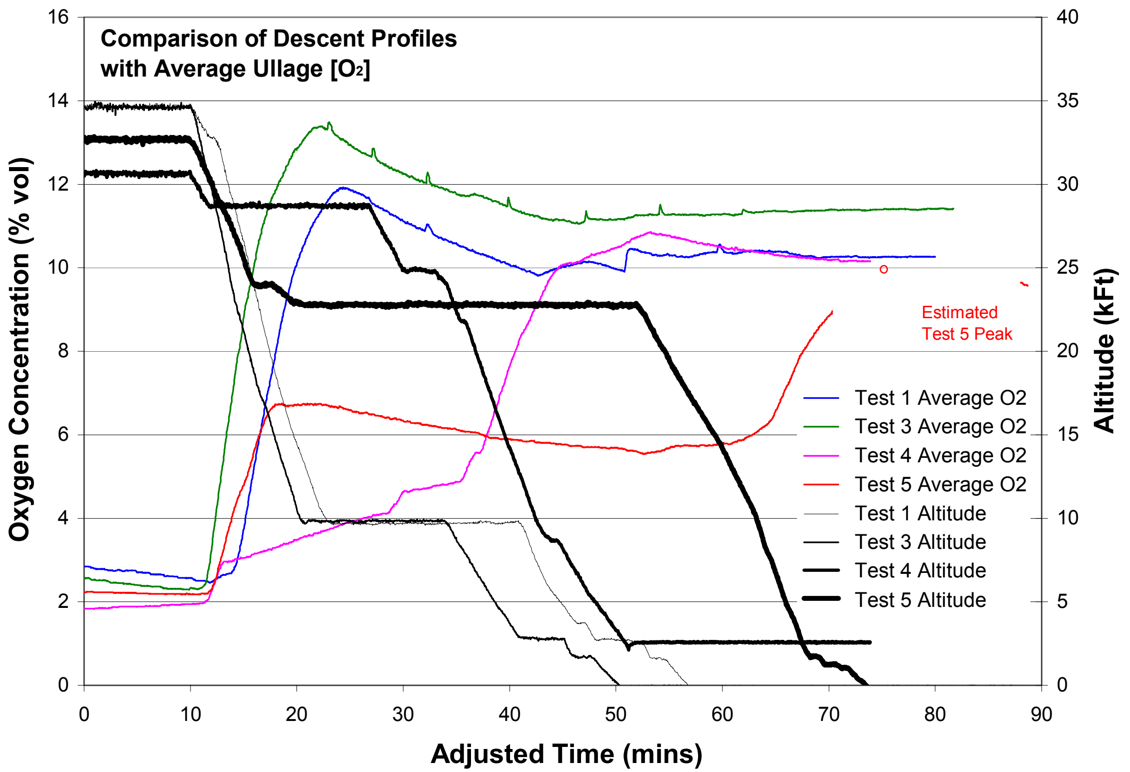
Results - 747 SCA Fuel Tank Inerting

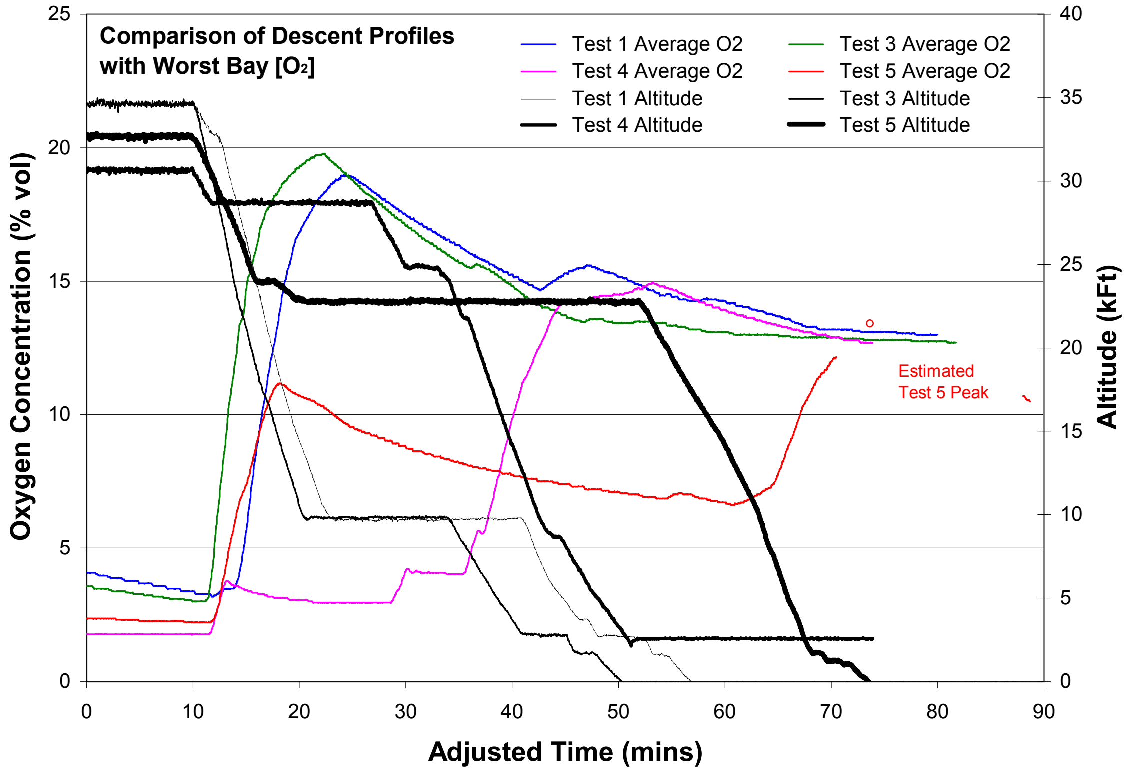
- Comparison of average ullage oxygen concentration for 4 tests with different descent profiles that have similar features
  - Main parameters that effect the average ullage oxygen concentration are descent time and change in altitude



Flight Testing of the FAA OBIGGS

Results - 747 SCA Fuel Tank Inerting

- Comparison of peak worst bay (bay 1) oxygen concentration for same 4 tests illustrates very similar relationships
  - Average peaks correlate directly with worst bay peaks in oxygen concentration
  - Worst bay peak tends to be sensitive to average peak oxygen concentration



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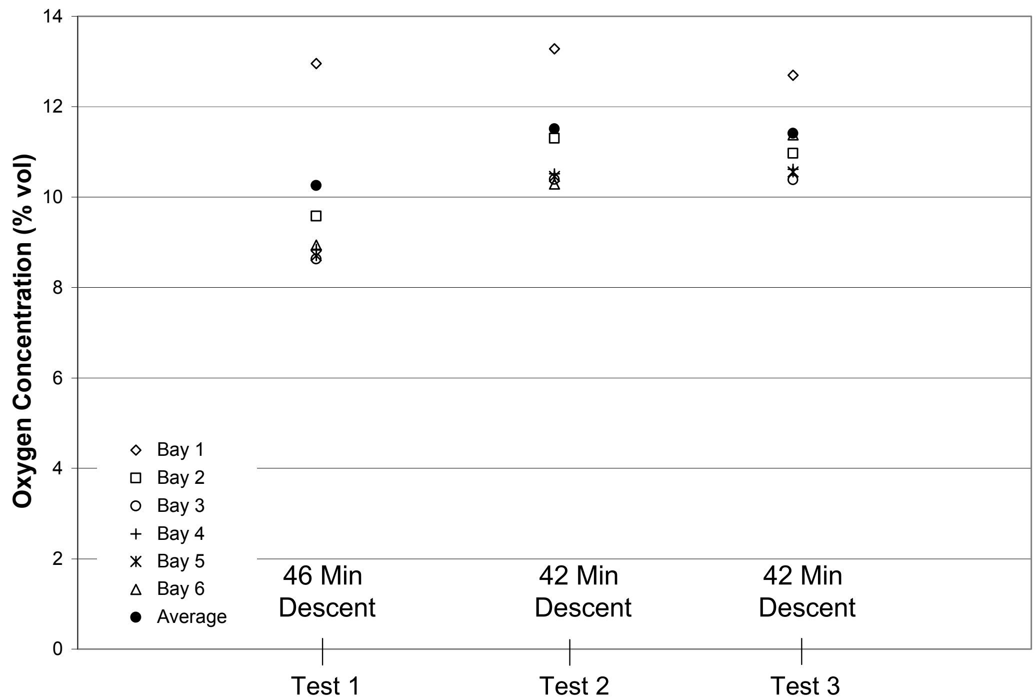
Results - 747 SCA Fuel Tank Inerting

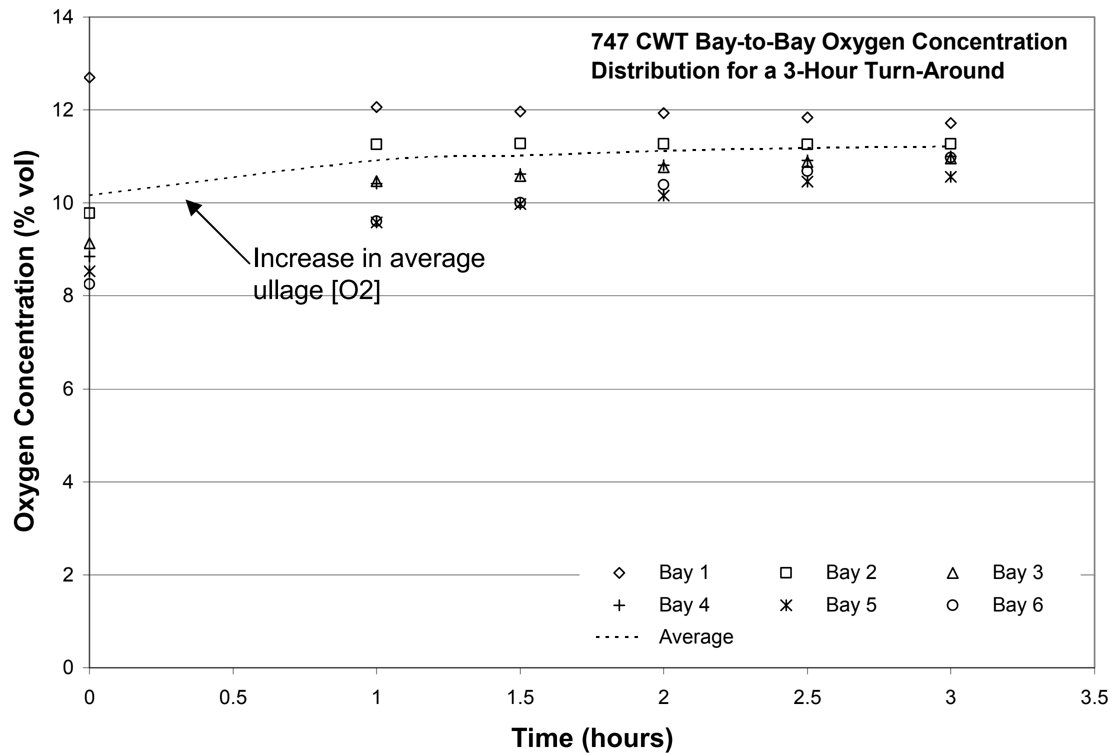
- Comparison of oxygen concentration distribution for same 3 tests with similar descent profiles illustrates pattern
  - Have to extrapolate test 1 because does not have 42 min descent
  - Greater flow tended to allow better distribution but had little if any effect on the resulting oxygen concentration



Flight Testing of the FAA OBIGGS

Results - 747 SCA Fuel Tank Inerting

- Tank oxygen concentration evolution after landing shows previously measured relationship
  - Worst bay $[O_2]$ goes from 13% to 12% in one hour
  - After 3 hours band of oxygen concentration is about 1%
  - Increase in average ullage $[O_2]$ probably not real



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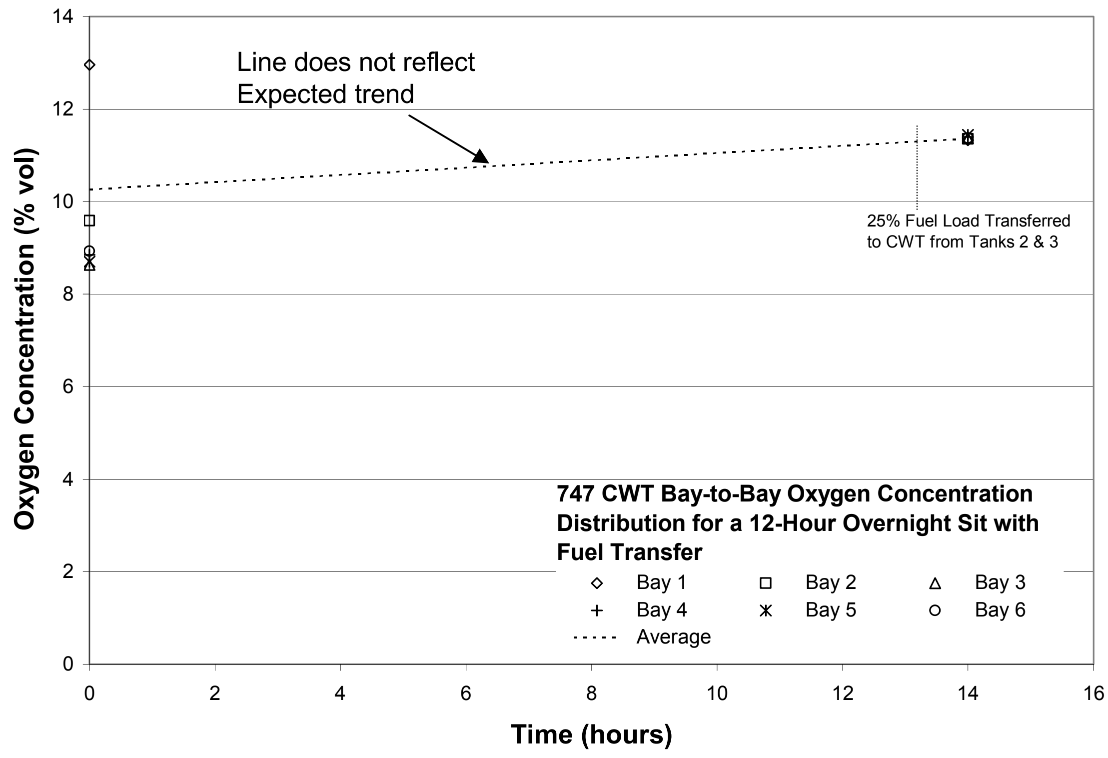
Results - 747 SCA Fuel Tank Inerting

- Tank oxygen concentration change overnight illustrated expected results
  - Overall average ullage oxygen concentration rose about 1%
  - Bay oxygen concentrations completely equilibrated



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Summary

- FAA dual flow OBIGGS concept validated and variable flow methodology studied
  - System performance predictable but sensitivity of bleed air consumption to ASM pressure at altitude should be examined in depth
  - ASM performance degradation over time needs to be studied further to ensure OBIGGS performance reliability comparable to commercial transport maintenance cycles
  - Lower ASM pressures will give less NEA production from OBIGGS but wide varying system aircraft parameters had no noticeable adverse effect on the resulting system performance
  - Increasing flow during the bottom of descent (variable flow valve) had little effect on the resulting oxygen concentration but did increase inert gas distribution in a compartmentalized tank

Flight Testing of the FAA OBIGGS

Summary

- Fuel tank inerting results illustrated expected relationships between system performance and ullage oxygen concentration
  - Dual flow methodology allows for relatively small system to provided complete flight cycle protection in many cases
  - Inert gas distribution accomplished easily in single bay tank while differences in multiple-bay tank [O_2] tend to equilibrate readily
  - Fuel load effected ullage oxygen concentrations very little if at all
  - Proper sizing of inerting system will tend to minimize peak worst bay oxygen concentrations in multi-bay CWTs
  - Inert gas dispersion from CWT during long ground operations and overnight sits does not appear to be a problem


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