Flight Testing of the FAA Onboard Inert Gas Generation System

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Flight Testing of the FAA OBIGGS

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  – NASA 747 SCA

• Summary

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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

- FAS Rack
- NDIR Analyzer
- OBOAS Rack
- DAS Rack
- Existing Power Distribution Rack

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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

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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

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Results - Airbus A320 System Performance

• System performed as expected with predictable ASM dynamic characteristics given difficulty in maintaining 180°F 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
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

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

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

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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

![Graph showing oxygen concentration over time and altitude](image)

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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
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
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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
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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

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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 [O₂] 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

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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
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
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

![Graph showing oxygen concentration distribution for 747 CWT Bay-to-Bay Oxygen Concentration Distribution for a 12-Hour Overnight Sit with Fuel Transfer.](image-url)
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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
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Summary

• Fuel tank inerting results illustrated expected relationships between system performance and ullage oxygen concentration
  – Dual flow methodology allows for relatively small system to provide complete flight cycle protection in many cases
  – Inert gas distribution accomplished easily in single bay tank while differences in multiple-bay tank [O₂] 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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