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

DC BoP Power

Input Current

Air

BER

Output Current

H₂

FAA H₂ Supply

Cargo Bay Volume (Tc, Pc)

%O₂

Leakage

%O₂

%O₂

H₂O
Test Setup
Cargo Bay Instrumentation

- Oxygen Measurement
- Temperature Measurement
- RH Measurement
- Pressure Measurement
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Cargo Bay Instrumentation – View looking Aft

Instrumentation access panel leading to outflow valve
Leakage flow source
N2/ODA distribution manifold
Instrumentation Tree
Hydrogen Fuel Cell System – Ballard Engineering Reference System (BERS)

System Power Supply
System Control Panel
Load Bank
## Ballard ERS Features (FCvelocity®-9SSL)

### Product Specifications

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Cell Stack</td>
<td>FCvelocity®-9SSL 110 Cell</td>
</tr>
<tr>
<td>Output Voltage</td>
<td>60 - 110 VDC</td>
</tr>
<tr>
<td>Output Current</td>
<td>0 - 300 A</td>
</tr>
<tr>
<td>Rated Gross Power</td>
<td>19 kW</td>
</tr>
<tr>
<td>Rated Net Power</td>
<td>15 kW</td>
</tr>
<tr>
<td>Minimum Net Power</td>
<td>1.4 kW</td>
</tr>
<tr>
<td>Efficiency</td>
<td>43-54% - Based on LHV of Hydrogen</td>
</tr>
<tr>
<td>Dimensions</td>
<td>1065mm x 660mm x 360mm (Module Only)</td>
</tr>
<tr>
<td>Mass (Dry)</td>
<td>153 kg (Module and Electrical Enclosure)</td>
</tr>
<tr>
<td>Fuel Inlet Pressure</td>
<td>7 barg nominal</td>
</tr>
<tr>
<td>Fuel Consumption</td>
<td>0.20 g/s at rated power</td>
</tr>
<tr>
<td>Ambient Temperature</td>
<td>2°C to 40°C</td>
</tr>
<tr>
<td>Control System</td>
<td>CoDeSys</td>
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</tbody>
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Self-Contained Fuel Cell System Developed as an Engineering Design & Integration Tool
Test Plan

• Conduct initial $\text{N}_2$ knockdown to $\sim 11\% \text{ O}_2$, 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 %O₂)
• Perform initial N₂ knockdown (~160 cfm for approximately 2 minutes)
• Switch ODA flow to Cargo Bay
• Allow for stabilization of Cargo Bay O₂ concentrations
• Modify leakage and BERS conditions based on test plan
• After each change of condition, allow time for stabilization of Cargo Bay O₂ concentrations
Leak in ODA bypass valving led to incomplete N2 knockdown of cargo bay.

Leakage Flow Off
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

Key Points:
- N2 On
- N2 Off
- ODA Valve Open
- ODA Valve Closed
- Door Open
- Leakage Flow Off

Elapsed Time (seconds)
Cargo Bay Oxygen Concentrations & Relative Humidity - Test #3

Key:
- 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

Events:
- 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
- ODA Off
- Cont Leak
- Leakager Off
- Incr Leak
- 2x=36 cfm

Elapsed Time (seconds):
- 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 N2/ODA flowrate and concentration along with leakage flow data will be performed.
• Further data is needed on actual O2 concentration required to suppress a cargo fire, particularly with increased humidity resulting from ODA flow
Questions?

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