Engine Nacelle Halon Replacement

Point of Contact: **Doug Ingerson**

Department of Transportation
Federal Aviation Administration
WJ Hughes Technical Center
Fire Safety Branch, AJP-6320
Bldg 205
Atlantic City Int'l Airport, NJ 08405 USA

tel: 609-485-4945
fax: 609-485-7074
email: Douglas.A.Ingerson@faa.gov
web page: www.fire.tc.faa.gov
PRESENTATION CONTENTS

- OVERVIEW OF THE EQUIVALENCE METHODOLOGY
- EXAMPLE OF MASS EQUIVALENCE
- EXAMPLE OF GAS CONCENTRATION EQUIVALENCE
- RESULTS
- CONCLUSION
EQUIVALENCE METHODOLOGY ~ OVERVIEW ~
TESTING OCCURS IN A GENERIC REPRESENTATION OF AN ENGINE NACELLE ENVIRONMENT

EQUIVALENCE METHODOLOGY IS TWO-PART

- ESTABLISH A **MASS EQUIVALENCE** BETWEEN AGENTS
  - COMPARES **FIRE EXTINGUISHMENT PERFORMANCE**
  - HALON 1301 (H1301) BENCHMARK IS ESTABLISHED
  - REPLACEMENT CANDIDATE PERFORMANCE EQUALS OR EXCEEDS THE BENCHMARK

- ESTABLISH A **CONCENTRATION EQUIVALENCE**
  - MEASURES **AGENT DISTRIBUTION** BEHAVIOR OF THE MASS EQUIVALENT
  - GAS ANALYSIS IS USED TO CAPTURE PERFORMANCE
  - RELATES DIRECTLY TO FIRE EXTINGUISHMENT PERFORMANCE

PROCESS IS REPEATED FOR 4 TEST CONFIGURATIONS

- 2 VENTILATIONS REGIMES x 2 FIRE THREATS
- LARGEST EQUIVALENT CONCENTRATION IS INTENDED AS THE RECOMMENDATION FOR CERTIFICATION
IMAGERY - TEST FIXTURE

- Inlet duct
- Supply blower
- Housing for the electrical resistance heaters
- Exhause duct (difficult to see)
- Test section (difficult to see)
- Fire extinguisher
- Approach duct
- Inlet duct supplying the blower
IMAGERY - TEST SECTION

TEST SECTION DIMENSIONS
48 INCH (1.22 m) OD SHELL
24 INCH (0.61 m) OD CORE
~ 10.25 FEET (3.12 m) LONG
IMAGERY - TEST SECTION
(3-D MODEL, CORE)

24 +/- 1 inches (typical)
(61 +/- 2.5 cm)

~ 123 Inches
(3.12 m)
IMAGERY - TEST SECTION (3-D MODEL, +DOORS)

- Spray fire scenario
- External shell door
- Halon 1301 injection plumbing
- Forward vertical test fixture support column (aft support omitted for clarity)
- Fuel pan for residual fire scenario

Sta 592, Sta 551, Sta 502, Sta 477, Sta 384, Sta 428
EQUIVALENCE METHODOLOGY, PART I
~ MASS EQUIVALENCE ~
PROCESS

♦ SELECT VENTILATION REGIME

♦ UTILIZE APPROPRIATE H1301 CERTIFICATION INSTALLATION

♦ ESTABLISH H1301 BENCHMARK

♦ SEARCH, FIND, & DEMONSTRATE EQUIVALENT BEHAVIOR WITH THE REPLACEMENT CANDIDATE
TEST FIXTURE VENTILATION IS SET TO 1 OF 2 POINTS

- **WANT TO SPAN AND OBSERVE BEHAVIOR**
- **HIGH VENTILATION (HiVent) ≈ 2.7 LBM/S @ 100°F (1.2 kg/s @ 38°C)**
- **LOW VENTILATION (LoVent) ≈ 1.0 LBM/S @ 260°F (0.5 kg/s @ 127°C)**

H1301 CERTIFICATION IS KNOWN FOR BOTH CASES

- **AGENT IS STORED AT 100°F (38°C)**
- **AGENT DISCHARGE IS ≈ 1 SECOND**
- **H1301 BENCHMARK (FIRE TESTING) IS ACCOMPLISHED WITH THE APPLICABLE CERTIFICATION PROFILE**
- **H1301 DISTRIBUTION IS REASONABLY SYMMETRIC**
- **DISCHARGE IS NOT DIRECTED AT THE FIRE THREAT**
- **MINIMUM DISTANCE OF 5 FT (1.52 m) SEPARATES AGENT INJECTION AND THE FLAME FRONTS**
IMAGERY – SAMPLING PROBE LOCATIONS, SPRAY

REGION OF FLAME DURING FIRE TEST

DIMENSIONS ARE IN FEET UNLESS NOTED OTHERWISE

International Aircraft Systems Fire Protection Working Group
25-26 October 2006 Atlantic City, NJ USA

Federal Aviation Administration ~ WJ Hughes Technical Center
Fire Safety Branch, AJP-6320 ~ Atlantic City Int’l Airport, NJ 08405 USA
IMAGERY – TYPICAL H1301 CERTIFICATION GRAPH, HiVent

Agent Concentration Profile
~ Ventilation @ 2.7 lb/s @ 100°F ~ (1.2 kg/s @ 38°C)
IMAGERY – TYPICAL H1301 CERTIFICATION GRAPH, LoVent

Agent Concentration Profile
~ Ventilation @ 1.0 lb/s@260°F ~ (0.5 kg/s @ 127°C)

Volumetric Concentration
Halon 1301

Time (s)

0 1 2 3 4 5 6 7 8 9 10 11 12

International Aircraft Systems Fire Protection Working Group
25-26October2006 Atlantic City, NJ USA

Federal Aviation Administration – WJ Hughes Technical Center
Fire Safety Branch, AJP-6320 ~ Atlantic City Int’l Airport, NJ 08405 USA
DEFINING THE H1301 BENCHMARK

- DETERMINED FOR EACH TEST CONFIGURATION
  - RESULT FROM 1 FIRE TEST = REIGNITION TIME DELAY (RTD)
  - RTD = time (FIRE EXTINCTION) – time (FIRE REIGNITION)
  - RTD IS ASSESSED FROM VIDEO RECORD OF EACH FIRE TEST
  - H1301 BENCHMARK = AVERAGED RTDs FROM 5 REPEATED FIRE TESTS = RTD_ave (H1301)

- SPRAY FIRE THREAT – JP8, LUBRICANT OR HYDRAULIC FLUID
  - ≈ 155°F @ 0.25 GPM (68°C @ 0.95 LPM)
  - FUEL SPRAY, ELECTRICAL ARC, & HOT SURFACE PERSIST DURING AGENT INJECTION
  - SUFFICIENTLY INTENSE; RTD(1/2 H1301 CERTIFICATION) ≈ 0 SECOND

- POOL FIRE THREAT – JP8
  - ≈ 155°F @ 220 IN^2 x 0.5IN DEEP (68°C @ 0.14 m^2 x 1.27 cm)
  - ELECTRICAL ARC PERSISTS DURING AGENT INJECTION
  - SUFFICIENTLY INTENSE; RTD(1/2 H1301 CERTIFICATION) ≈ 0 SECOND
IMAGERY – SPRAY FIRE VIDEO CLIP

(04914_14, Halon 1301, HiVent OIL SPRAY)
IMAGERY - POOL FIRE ZONE

POOL FIRE SCENARIO

STA 503

FW

D

UP

FWD

AIRFLOW

station 518, 6:00 @ 2" (10.2cm)

station 518, 6:00 @ 4" (5.1cm)

range of locations the mobile electrodes were positioned

approximate boundary of the fuel puddle (1/2" deep)

gas analyzer probe (not present during pool fire testing)

reference marks (typical)

0' flame stabilization rib

STA 503

(1.27 cm)
IMAGERY – POOL FIRE VIDEO CLIP

(03610-12, Halon 1301, HiVent jp8 POOL)

ELECTRICAL ARC

AIRFLOW

Federal Aviation Administration ~ WJ Hughes Technical Center
Fire Safety Branch, AJP-6320 ~ Atlantic City Int’l Airport, NJ 08405 USA

International Aircraft Systems Fire Protection Working Group
25-26 October 2006 Atlantic City, NJ USA
MASS EQUIVALENCE FOR A REPLACEMENT CANDIDATE

♦ COMPARISON BASIS: AVERAGE RTD FROM 5 REPEATED TESTS
♦ EQUIVALENCE DEFINED AS:

\[ \text{RTD}_{\text{ave}} (H1301) \leq \text{RTD}_{\text{ave}} \text{ (EQUIVALENT MASS)} \]

♦ IF A SPRAY FIRE THREAT, USE EQUIVALENT MASS AND VERIFY SUCCESS AGAINST OTHER FUELS

✦ HiVent VERIFICATION – LUBRICANT & HYDRAULIC FLUID
✦ LoVent VERIFICATION – JP8
✦ REPEAT 3 TESTS FOR EACH FUEL
✦ SUCCESS DEFINED AS:

\[ \text{RTD}_{\text{ave}} \text{ (EQUIVALENT MASS)} \leq \text{RTD}_{\text{ave}} \text{ (VERIFICATION)} \]
EQUIVALENCE METHODOLOGY, PART II
~ CONCENTRATION EQUIVALENCE ~
TREATING THE VOLUMETRIC GAS CONCENTRATION AS THE PARAMETER FOR EQUIVALENCE (NOT CITING ANY MASS USED IN THE FIREX AS A BASIS FOR EQUIVALENCE!!)

- REPLACEMENT CANDIDATE IS DELIVERED THROUGH NON-OPTIMIZED PLUMBING
- SOME NON-OPTIMIZED QUANTITY OF THE REPLACEMENT CANDIDATE WILL ACHIEVE PARITY WITH H1301 BENCHMARK
- CONCENTRATION EQUIVALENCE EVALUATED AT THE FLAME FRONT ONLY (2 CHANNELS PER TEST)

EQUIVALENT GAS CONCENTRATION IS BASED ON:

- CAPTURED GAS ANALYSIS DATA AT FLAME FRONT
- OBSERVED FIRE EXTINCTION BEHAVIOR
SAMPLE POINTS, STA 490 & 514, 6:00

SAMPLE POINTS, STA 490, 502, & 514, 12:00

Volumetric Concentration (%v/v)

~ 14.5 lbm CF3I, Low Ventilation JP8 Spray

Time (sec)
PROCESS

♦ Capture gas distribution of the equivalent mass with 3 repeated tests
♦ Collect the 2 flame front curves for each test
♦ Transform flame front, gas concentration curves
  ✪ Curves are typically exponential growth/decay
  ✪ Transform each curve to “concentration vs. duration@concentration”
  ✪ Create a single data pool of all points from the transformed curves
♦ Model the data pool with polynomial best-fit function
♦ Recall average RTD from replacement candidate
♦ Use average RTD of the equivalent mass in the best-fit function to calculate equivalent concentration
EQUIVALENCE METHODOLOGY – ILLUSTRATE TRANSFORMED CURVES

Volumetric Concentration, HFC-125 (%v/v)

- Ch# 01
- Ch# 02

Time (sec)

International Aircraft Systems Fire Protection Working Group
25-26October2006 Atlantic City, NJ USA

Federal Aviation Administration ~ WJ Hughes Technical Center
Fire Safety Branch, AJP-6320 ~ Atlantic City Int’l Airport, NJ 08405 USA
EQUIVALENCE METHODOLOGY – ILLUSTRATE TRANSFORMED CURVES

Volumetric Concentration, HFC-125 (%v/v)

- Ch# 01
- Ch# 02
- data pool, 8.0# H125, JP8 HiV Spray
- 6th Order best-fit polynomial

International Aircraft Systems Fire Protection Working Group
25-26October2006 Atlantic City, NJ USA

Federal Aviation Administration ~ WJ Hughes Technical Center
Fire Safety Branch, AJP-6320 ~ Atlantic City Int’l Airport, NJ 08405 USA
EQUIVALENCE METHODOLOGY – FIND EQUIVALENT CONCENTRATION

FICTITIOUS DATA USED IN THIS EXAMPLE…

1.75 second RTD_ave PRODUCES 12.3%v/v EQUIVALENT CONCENTRATION
EQUIVALENCE METHODOLOGY – PROCEDURAL FLOW CHART

~ START ~
SELECT TEST CONFIGURATION

CHANGE FUEL TO WORST CASE

FIRE TESTING

GAS ANALYSIS TESTING

ARE ALL 4 CONFIGURATIONS EVALUATED?

NO

YES

ESTABLISH BENCHMARK FOR HALON 1301 CERTIFICATION

FIND MASS EQUIVALENT FOR REPLACEMENT CANDIDATE

IS TEST CONFIGURATION A POOL FIRE?

NO

YES

VERIFY MASS EQUIVALENT IS ACCEPTABLE AGAINST OTHER FUELS

IS FUEL VERIFICATION ACCEPTABLE?

NO

YES

CAPTURE THE CONCENTRATION PROFILE OF THE MASS EQUIVALENT

TRANSFORM THE CONCENTRATION PROFILE OF THE MASS EQUIVALENT

DETERMINE THE EQUIVALENT CONCENTRATION

DETERMINE RECOMMENDATION “CERTIFICATION”

~ END THE PROCESS ~
EQUIVALENCE METHODOLOGY ~ EXAMPLE ~
MASS EQUIVALENCE EXAMPLE (actual data)

EQUIVALENCE ITERATION = HiVent JP8 SPRAY FIRE

H1301 BENCHMARK = RTD\_ave (H1301) = 1.39 SECONDS

<table>
<thead>
<tr>
<th>RTD</th>
<th>RTD#01</th>
<th>RTD#02</th>
<th>RTD#03</th>
<th>RTD#04</th>
<th>RTD#05</th>
<th>AVERAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>RESULT</td>
<td>1.76</td>
<td>1.03</td>
<td>1.18</td>
<td>1.31</td>
<td>1.66</td>
<td>1.39</td>
</tr>
</tbody>
</table>

REPLACEMENT CANDIDATE WORK WITH HFC-125

<table>
<thead>
<tr>
<th>GUESSED MASS OF HFC-125 (LBM)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>AVERAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 (3.7 kg)</td>
<td>1.45</td>
<td>1.52</td>
<td>1.30</td>
<td>1.45</td>
<td>1.34</td>
<td>1.41</td>
</tr>
<tr>
<td>7.5 (3.4 kg)</td>
<td>1.48</td>
<td>1.26</td>
<td>1.32</td>
<td>1.19</td>
<td>1.09</td>
<td>1.27</td>
</tr>
<tr>
<td>8.0 (3.7 kg)*</td>
<td>1.72</td>
<td>2.13</td>
<td>1.75</td>
<td>--</td>
<td>--</td>
<td>1.87</td>
</tr>
<tr>
<td>8.0 (3.7 kg)**</td>
<td>2.32</td>
<td>2.19</td>
<td>2.5</td>
<td>--</td>
<td>--</td>
<td>2.34</td>
</tr>
</tbody>
</table>

* VERIFICATION TESTS AGAINST LUBRICANT
** VERIFICATION TESTS AGAINST HYDRAULIC FLUID

EQUIVALENT MASS = 8.0 LBM (3.7 kg) HFC-125
EQUIVALENT CONCENTRATION EXAMPLE

THIS EXAMPLE IS BASED UPON DATA FOR THE DISTRIBUTION OF 8.0 LBM (3.7 kg) HFC-125

RESTRICT DATA REVIEW TO THE 2 ANALYZER CHANNELS LOCATED AT THE SPRAY FLAME FRONT

CALCULATIONFollows in graphical format
EQUIVALENCE METHODOLOGY – EXAMPLE, CONCENTRATION

![Graph showing volumetric concentration over time](image)

Volumetric Concentration (%v/v) ~ High Ventilation JP8 Spray

Time (sec)

Ch# 01, 8.0 lb H125, 03618-13
Ch# 02, 8.0 lb H125, 03618-13
Ch# 01, 8.0 lb H125, 03619-10
Ch# 02, 8.0 lb H125, 03619-10
Ch# 01, 8.0 lb H125, 03619-11
Ch# 02, 8.0 lb H125, 03619-11
EQUIVALENCE METHODOLOGY – EXAMPLE, CONCENTRATION

17.6 %v/v, 1.41 sec

Concentration Behavior, 8.0 lb H125, HiV spray, Mass Equivalent
RTD_ave, Mass Equivalent, 8.0 lb H125
RTD_ave, Halon 1301 Benchmark
HiV JP8 spr, success

Volumetric Concentration (%v/v), 8.0 LBM HFC-125
RESULTS
### RESULTS - TABULAR

<table>
<thead>
<tr>
<th>Agent</th>
<th>Fire Threat</th>
<th>Equivalent Concentration (%v/v)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>high ventilation</td>
</tr>
<tr>
<td>HFC-125</td>
<td>JP8 spray</td>
<td>17.6</td>
</tr>
<tr>
<td></td>
<td>OIL spray</td>
<td>12.2</td>
</tr>
<tr>
<td></td>
<td>pool</td>
<td>7.7</td>
</tr>
<tr>
<td>CF3I</td>
<td>JP8 spray</td>
<td>5.6</td>
</tr>
<tr>
<td></td>
<td>OIL spray</td>
<td>not evaluated</td>
</tr>
<tr>
<td></td>
<td>pool</td>
<td>2.7(a, c)</td>
</tr>
<tr>
<td>FK-5-1-12</td>
<td>JP8 spray</td>
<td>6.1(a, c)</td>
</tr>
<tr>
<td></td>
<td>OIL spray</td>
<td>not evaluated</td>
</tr>
<tr>
<td></td>
<td>pool</td>
<td>5.2(a, c)</td>
</tr>
</tbody>
</table>

(a) Two mass equivalents used to calculate concentration equivalent
(b) Methods other than “normal” process used to determine equivalent concentration
(c) Flame attachment or existence elsewhere in the test fixture during RTD
“BRACKETING” MASS EQUIVALENCE

1. USE 2 DIFFERENT MASSES OF THE REPLACEMENT CANDIDATE
   - ONE MASS PRODUCES AVERAGE RTD < BENCHMARK (DEFICIENT)
   - ONE MASS PRODUCES AVERAGE RTD > BENCHMARK (SUCCESS)
   - CAPTURE THE AGENT DISTRIBUTION PROFILES OF BOTH

2. CALCULATE EQUIVALENT CONCENTRATIONS FOR EACH
   - SINGLE ORDERED PAIR RESULTS FOR EACH MASS EQUIVALENT
   - ORDERED PAIR = (AVERAGE RTD, EQUIVALENT CONCENTRATION)

3. USE THE 2 ORDERED PAIRS AND THE BENCHMARK TO CALculate THE EQUIVALENT CONCENTRATION VIA LINEAR INTERPOLATION
RESULTS – EXPLAINING FOOTNOTES (a) IN TABULAR RESULTS

<table>
<thead>
<tr>
<th>2.7</th>
<th>2.8</th>
<th>2.9</th>
<th>3.0</th>
<th>3.1</th>
<th>3.2</th>
<th>3.3</th>
<th>3.4</th>
<th>3.5</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>4.7</th>
<th>4.8</th>
<th>4.9</th>
<th>5.0</th>
<th>5.1</th>
<th>5.2</th>
<th>5.3</th>
<th>5.4</th>
<th>5.5</th>
<th>5.6</th>
<th>5.7</th>
</tr>
</thead>
</table>

### Volumetric Concentration

**FK-5-1-12 (v/v)**

- Concentration behavior, FK-5-1-12 mass equivalent, success, HiV pool
- Concentration behavior, FK-5-1-12 mass equivalent, deficient, HiV pool
- RTD, FK-5-1-12 mass equivalent, success, HiV pool
- H1301 Benchmark, HiV pool
- RTD, FK-5-1-12 mass equivalent, deficient, HiV pool

**MPSE_rev03_BLOK2-N1230_equivCONC.xls**, equivalent conc mdl HiV pdl

**5.2 %v/v**
RESULTS – EXPLAINING FOOTNOTES (b) IN TABULAR RESULTS

- **CF3I; LOW VENTILATION, OIL SPRAY FIRE (7.1 %v/v)**
  - BULK AGENT ON-HAND RUNNING LOW
  - RAN 3 FIRE TESTS FOR DEFICIENT MASS EQUIVALENT
  - RAN 4 FIRE TESTS FOR SUCCESSFUL MASS EQUIVALENT
  - CAPTURED EACH MASS WITH 3 REPEATED GAS ANALYZER TESTS

- **HFC-125; LOW VENTILATION, JP8 POOL (7.4 %v/v)**
  - TWO MASS EQUIVALENTS USED; BOTH SUCCESSFUL
  - EXTRAPOLATION USED TO CALCULATE EQUIVALENT CONCENTRATION
  - NO PHYSICAL WAY TO PRODUCE THE LARGEST EQUIVALENT CONCENTRATION (...17.6%v/v for JP8 HiVent SPRAY)

- **HFC-125; LOW VENTILATION, OIL SPRAY (16.9 %v/v)**
  - DETERMINED ONE SUCCESSFUL MASS EQUIVALENT
  - DETERMINED SLOPE FROM PREVIOUS TESTING USING 2 MASS EQUIVALENCES AT LOW VENTILATION, JP8 SPRAY
  - RAN JP8 SLOPE THROUGH THE OIL DATA POINT
CONCLUSION

SUMMARY/STATUS
CONCLUSORY STATEMENTS

- CONCLUDED (for now?)

- LARGEST EQUIVALENT CONCENTRATIONS DETERMINED
  - CF3I, 7.1 %v/v
  - FK-5-1-12, 6.1 %v/v
  - HFC-125, 17.6 %v/v

- REPORT FOR THE RELATED WORK PLACED IN FAA DOCUMENT REVIEW PROCESS
  - PUBLICATION DATE UNKNOWN
  - MINIMUM PERFORMANCE STANDARD IS APPENDIX A