Propulsion Halon Replacement Activity at the FAA WJ Hughes Technical Center

Federal Aviation Administration

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By:

Douglas Ingerson, Engineer
Federal Aviation Administration
WJ Hughes Technical Center
Fire Safety Team
Atlantic City Int'l Airport, NJ USA
tel : 609-485-4945
email : Douglas.A.Ingerson@faa.gov

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Presentation Overview

- **Situational Review**
  - The "FAA Certification" Test
  - Trend of the Current Halon-replacing Candidates
- **Review Minimum Performance Standard Activity**
  - Ownership
  - Brief History
  - Descriptions of the Test Standards
  - Some Test Observations
- **Brief Comments Regarding Current Test Activity**

Situational Review
The "FAA Certification" Test

- **Verifying a Fire Extinguishing Agent :**
  - Acceptably envelopes a compartment during critical operating conditions
  - Can extinguish a fire at an unknown location within
- **Performance Assessment**
  - The typical concentration measurement system :
    - is compatible with gaseous agents
    - samples in the compartment at 12 or 24 points
  - Agent is discharged into the compartment for "critical operating conditions"
    - Agent storage
    - Compartment ventilation rate
  - No accidental combustion is present

Situational Review

Trends in the Current Candidates

- **The Current Halon-replacing Candidates are Becoming Less “Energetic” Substances, as Indicated by Reductions in Vapor Pressure Behaviors**

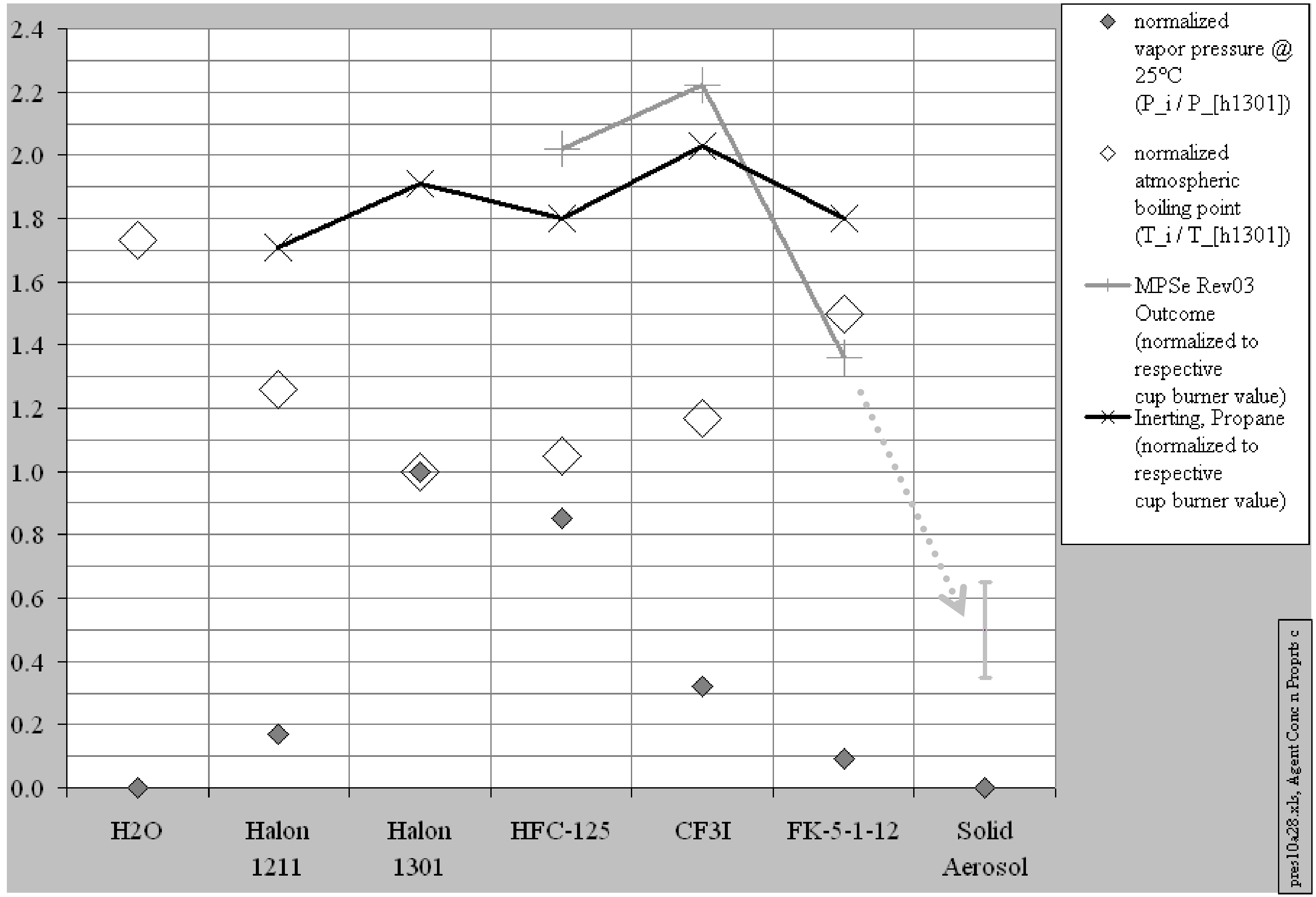
- **Current Candidates are :**
  - disconnecting from “total flood” & tending towards “streaming” behaviors
  - providing non-gaseous design challenges (measurement & function)

Situational Review

Trends in the Current Candidates

halon 1301 parameters	
normal boiling point	= -58°C / 215 K
vapor pressure @ 25°C	= 1619 kPa
flame extinction concentrations,	
cup burner, n-heptane	= 3.2 %v/v
peak inerting, propane	= 6.1 %v/v

Comparing Characteristics of Some Substances



Review MPS Activity

Title…

"Minimum Performance Standard for Halon 1301 Replacement in Civil Aircraft Engine Nacelle and Auxiliary Power Unit Compartments" (1)

====>>> also known as an MPS, the MPSe or MPSHRe…

Review MPS Activity
Ownership

- **Who "owns" the MPSHRe?**
  - FAA International Aircraft Systems Fire Protection Working Group
  - Composed of government and industry representatives
    - International
    - Manufacturer, regulator
    - Civilian, military

Review MPS Activity
Brief History

- **MPSHRe rev03**
  - Publicly available Sep 2006; terminated Oct 2008
  - Testing accomplished with :
    - HFC-125, 2003-2004
    - CF_3I, 2003, 2004, & 2006
    - FK-5-1-12, 2006
    - solid aerosol, 2007-2008

- **MPSHRe rev04** [(1)]
  - Publicly available Mar 2010
  - Testing underway with solid aerosol, 2010 (incomplete)

Review MPS Activity
Descriptions of the Test Standards

- **Commonality of MPSHRe revs 03 & 04**
  - Non-fire Testing Must be Acceptably Completed
    - Compatibility with the airframe
      - Structure and components
      - Flight envelope
    - Acceptable shelf-life
      - Warehouse
      - In-service life on aircraft
    - Acceptable safety
      - Compatibility with life
      - Maintained flight safety

Review MPS Activity
Descriptions of the Test Standards

- **Commonality of MPSHRe revs 03 & 04** **(continued)**
  - Test Process
    - Compares to halon 1301 performance for known conditions
    - Places representative fire threats against agent concentration distribution
    - Metric is the “Reignition Time Delay” (RTD)
      - Visual determination
      - Each test requires persistent ignition & fuel presences during agent migration
      - RTD starts when fire “extinguishes” and ends when fire “reignites”

Review MPS Activity
Descriptions of the Test Standards

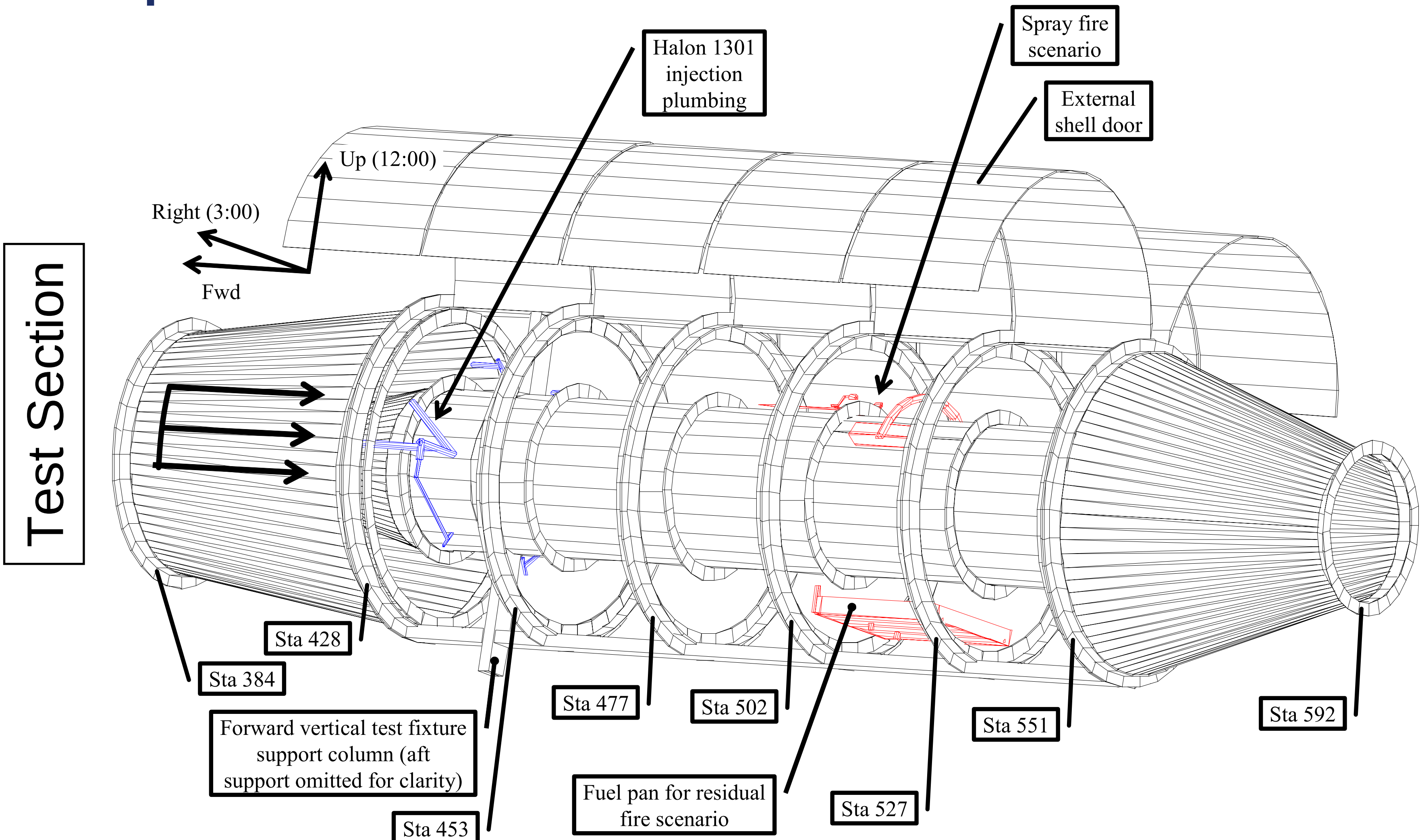
- **Commonality of MPSHRe revs 03 & 04 (continued)**
  - Generic Test Environment
    - Generic steel test fixture
    - Forcibly ventilated
    - Supports :
      - Differing ventilation conditions
      - Two fire threats
      - Replacement candidate injection upstream of the fire threats

Review MPS Activity
Descriptions of the Test Standards

- **Commonality of MPSHRe revs 03 & 04 (continued)**
  - Generic Test Environment (continued)
    - Test Fixture
      - Test fixture is :
        - » a flow pathway composed of the inlet, approach duct, test section, and exhaust duct
        - » instrumented with a collection of thermocouples, pressure transducers, hot-wire anemometers, and video cameras
      - Test section has an annular/circular working cross-section
        - » 1.2 m outside diameter (OD) shell x 0.61 m OD “core” x 3.1 m long
        - » Core & shell ~ 6 mm thick steel
        - » Both ends have conical sections which transition to adjacent ducting
      - Test section contains the fire threats & receives an agent pulse resulting from upstream injection

Review MPS Activity

Descriptions of the Test Standards

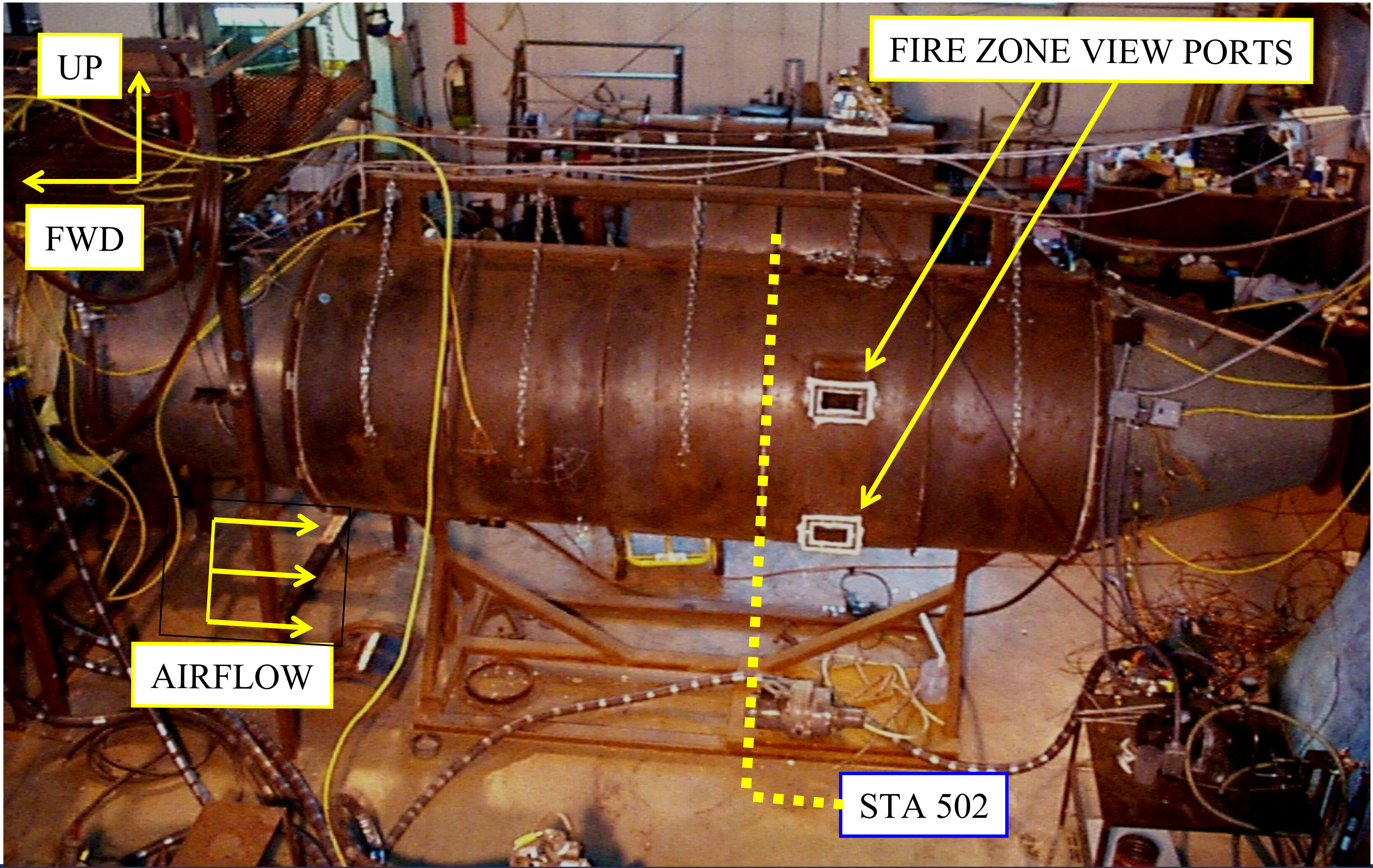


Review MPS Activity

Descriptions of the Test Standards

TEST SECTION DIMENSIONS
48 INCH (1.22 m) OD SHELL
24 INCH (0.61 m) OD CORE
~ 10.25 FEET (3.12 m) LONG

Test Section

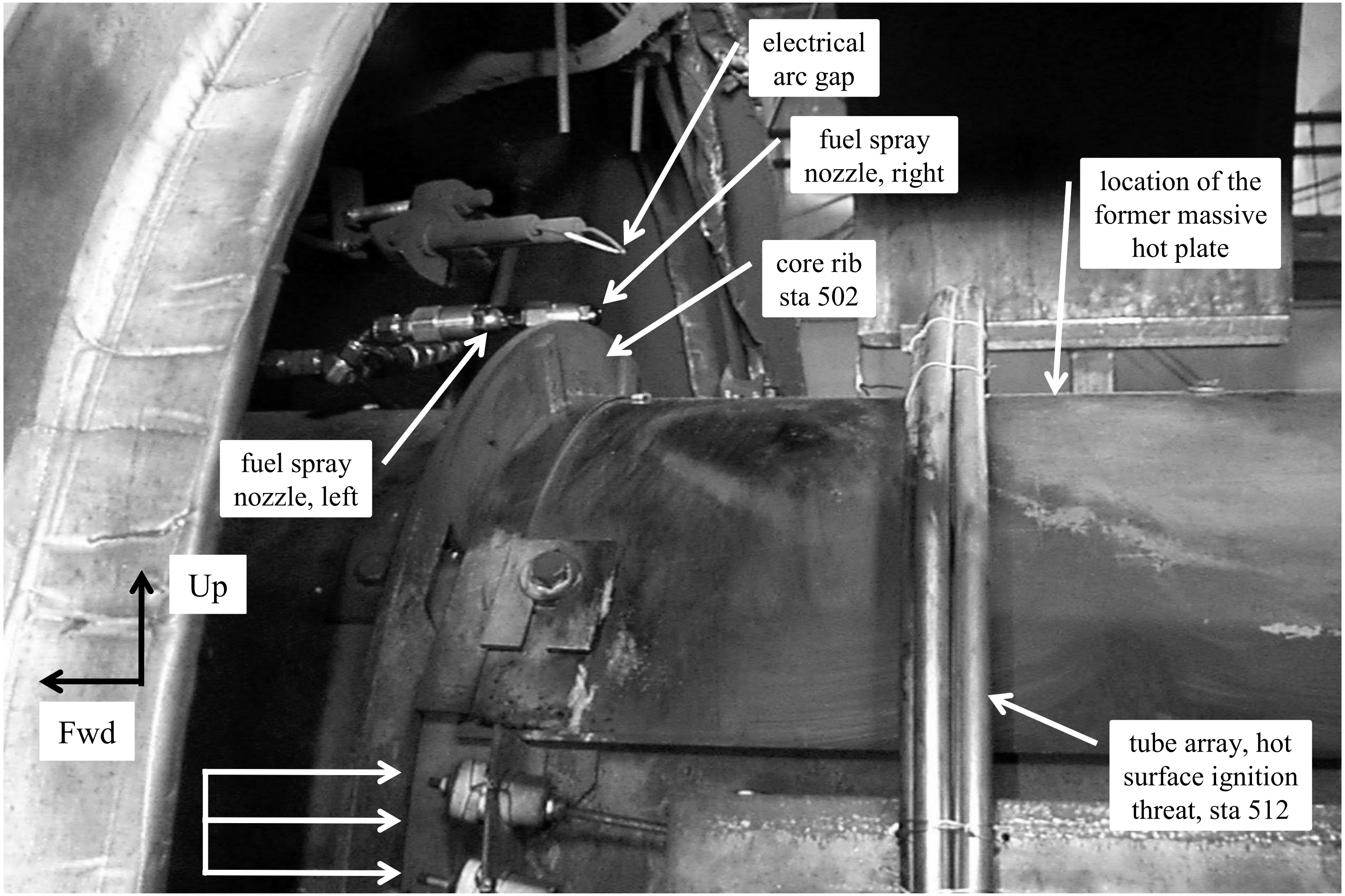


Review MPS Activity
Descriptions of the Test Standards

- **Commonality of MPSHRe revs 03 & 04 (continued)**
  - Generic Test Environment (continued)
    - Test Environment
      - Two ventilation regimes
        - » "High" = 1.2 kg/s @ 38°C (2.7 lbm/s @ T = 100°F)
        - » "Low" = 0.45 kg/s @ 127°C (1.0 lbm/s @ T= 250°F)
      - Two fire threats
        - » Both are baffle-stabilized
        - » Both have persistent ignition & fuel sources
        - » Spray fire using JP8, lubricating oil OR hydraulic fluid
        - » Fuel sprays delivered 0.95L/min & 66°C (0.25 US gal/min & 150°F)
        - » Pool fire using JP8 alone

Review MPS Activity
Descriptions of the Test Standards

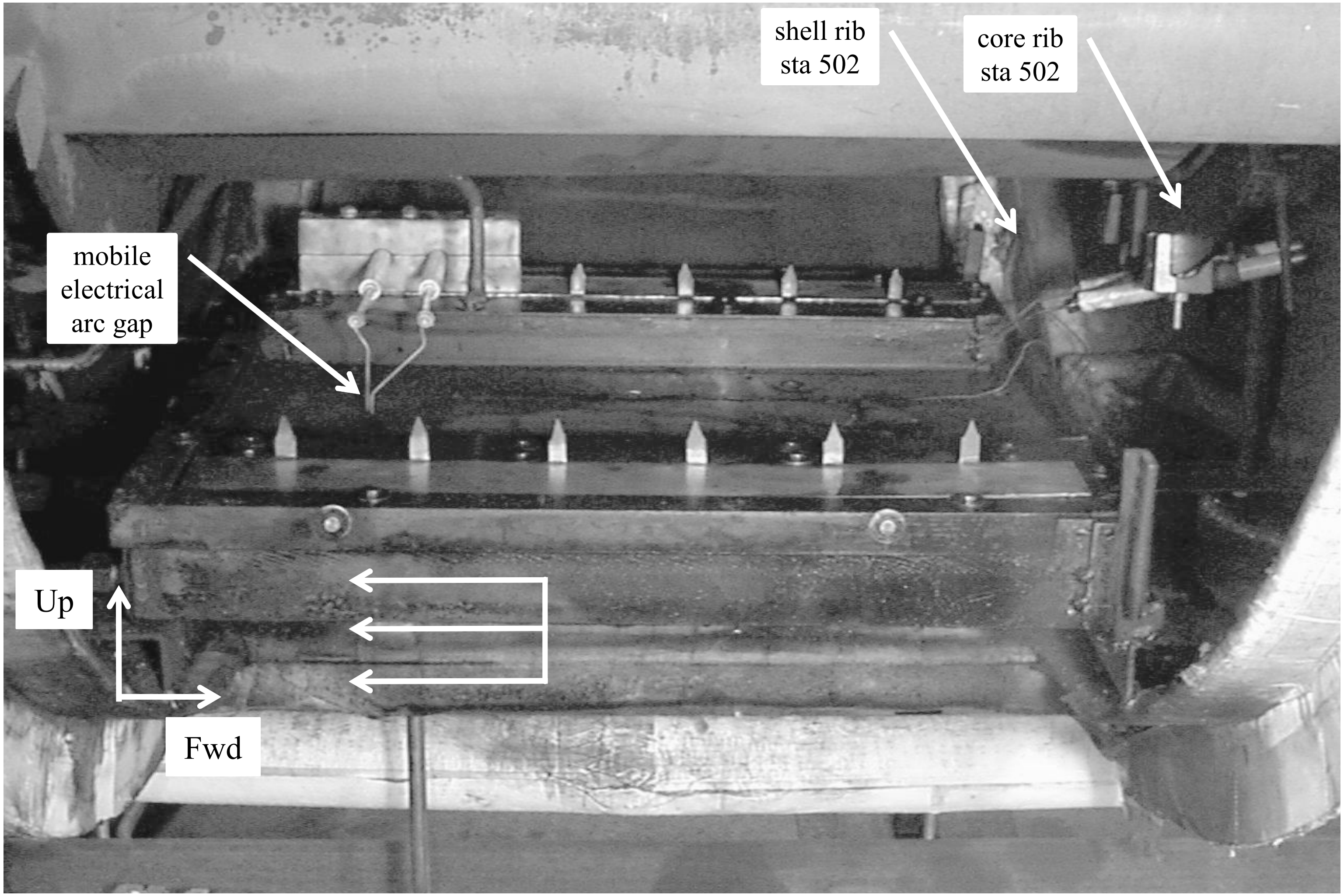
Spray Fire Threat



Review MPS Activity

Descriptions of the Test Standards

Pool Fire Threat



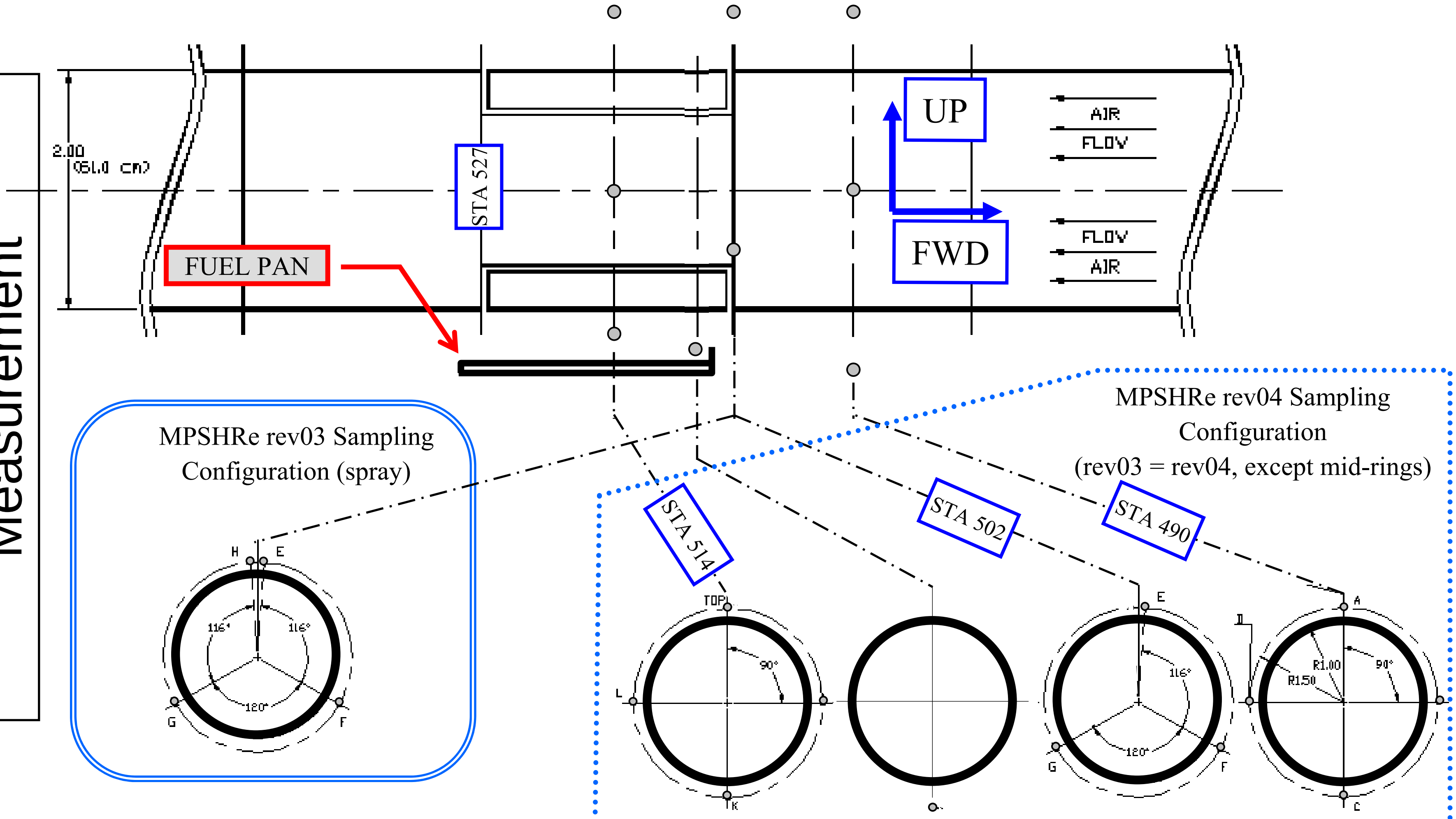
Review MPS Activity
Descriptions of the Test Standards

- **Commonality of MPSHRe revs 03 & 04** **(continued)**
  - Generic Test Environment (continued)
    - Test Environment (continued)
      - Assessment thresholds based on halon 1301 performance
        - » Halon 1301 stored at 38°C (100°F)
        - » Delivery met intent of FAA certification, 6%v/v for 0.5 sec
        - » Not a complete, structurally-bound, design volume

Review MPS Activity

Descriptions of the Test Standards

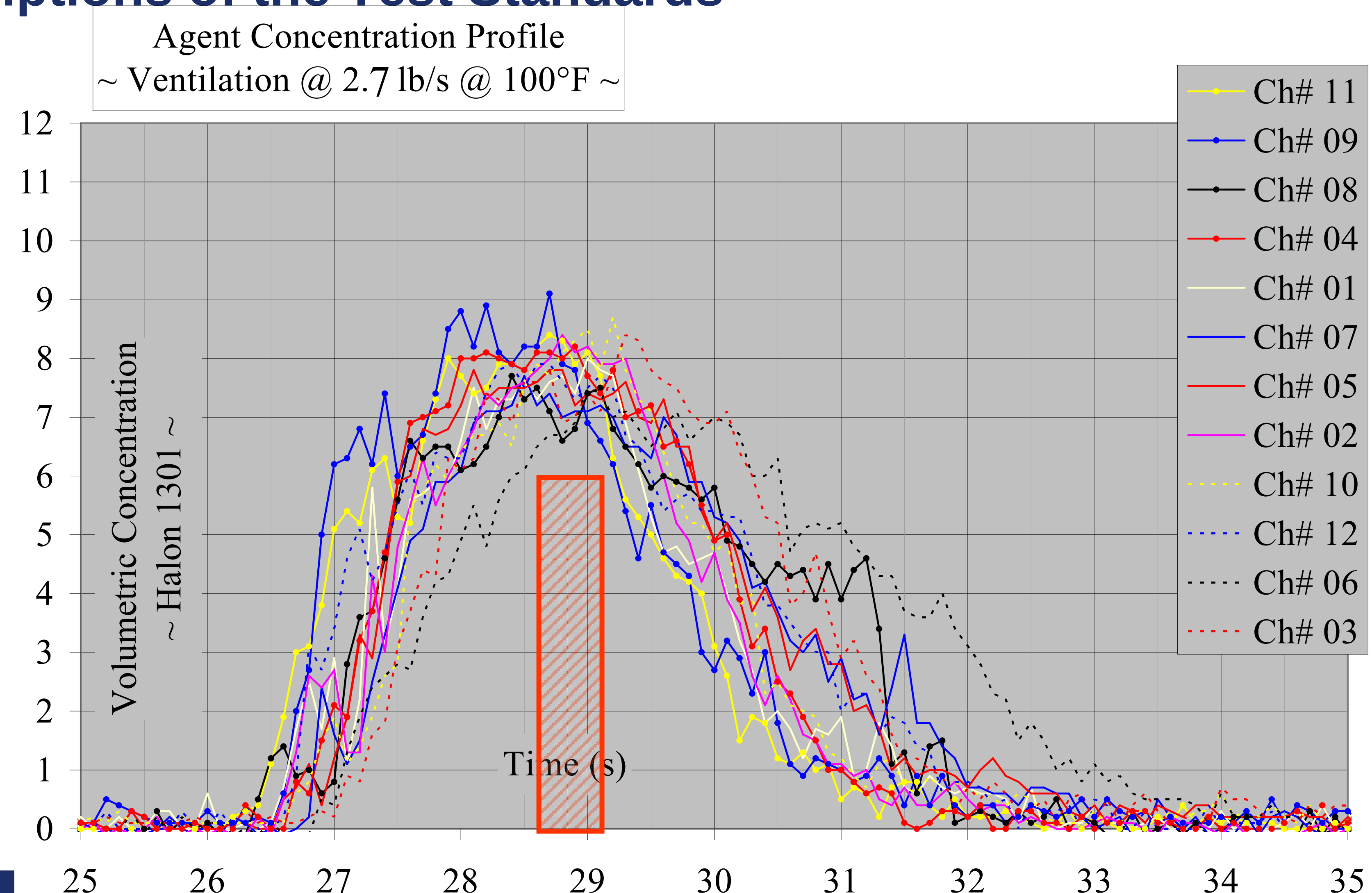
Halon 1301 Concentration Measurement



Review MPS Activity

Descriptions of the Test Standards

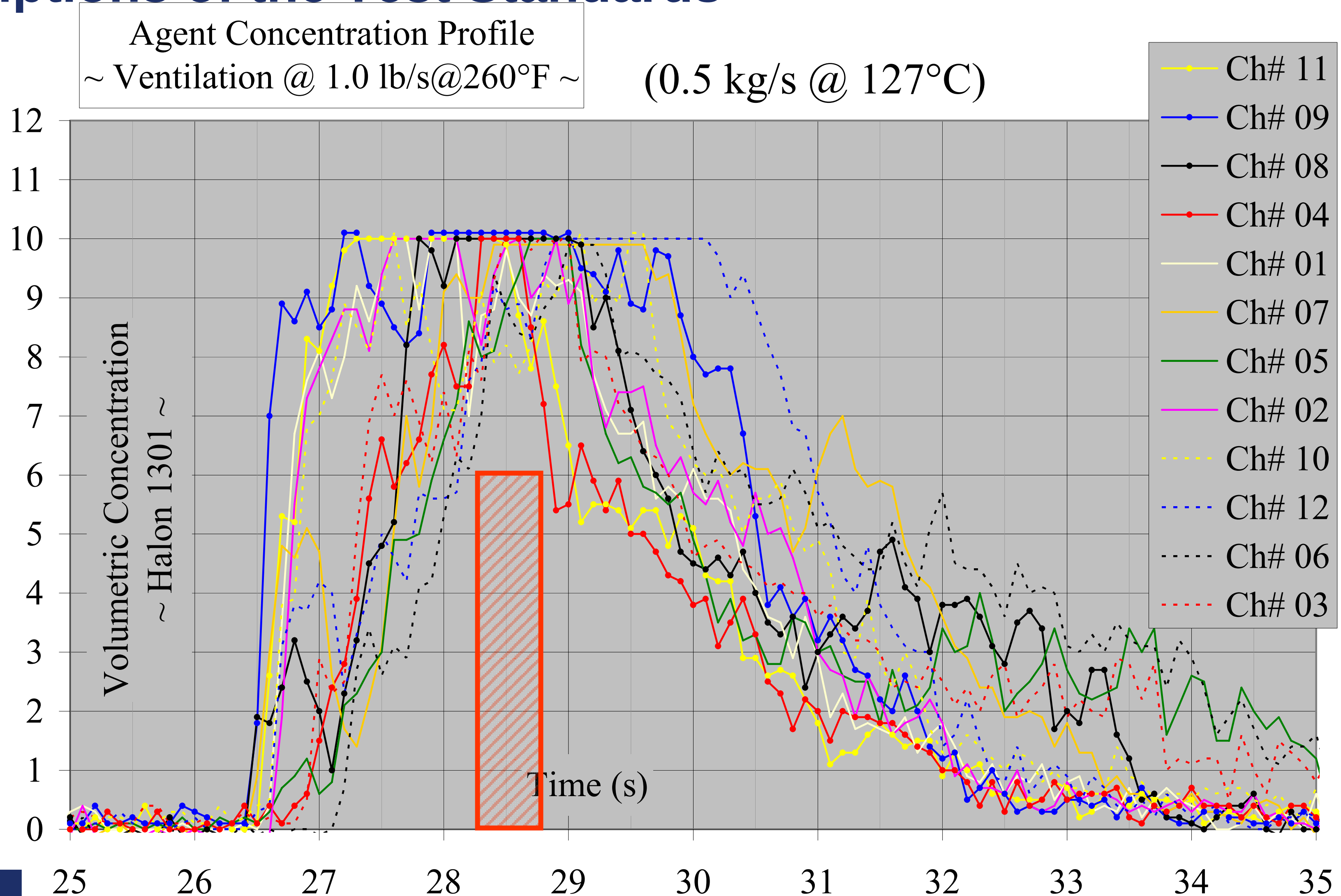
Meeting Intent of FAA Certification (MPSHRe rev03)



Review MPS Activity

Descriptions of the Test Standards

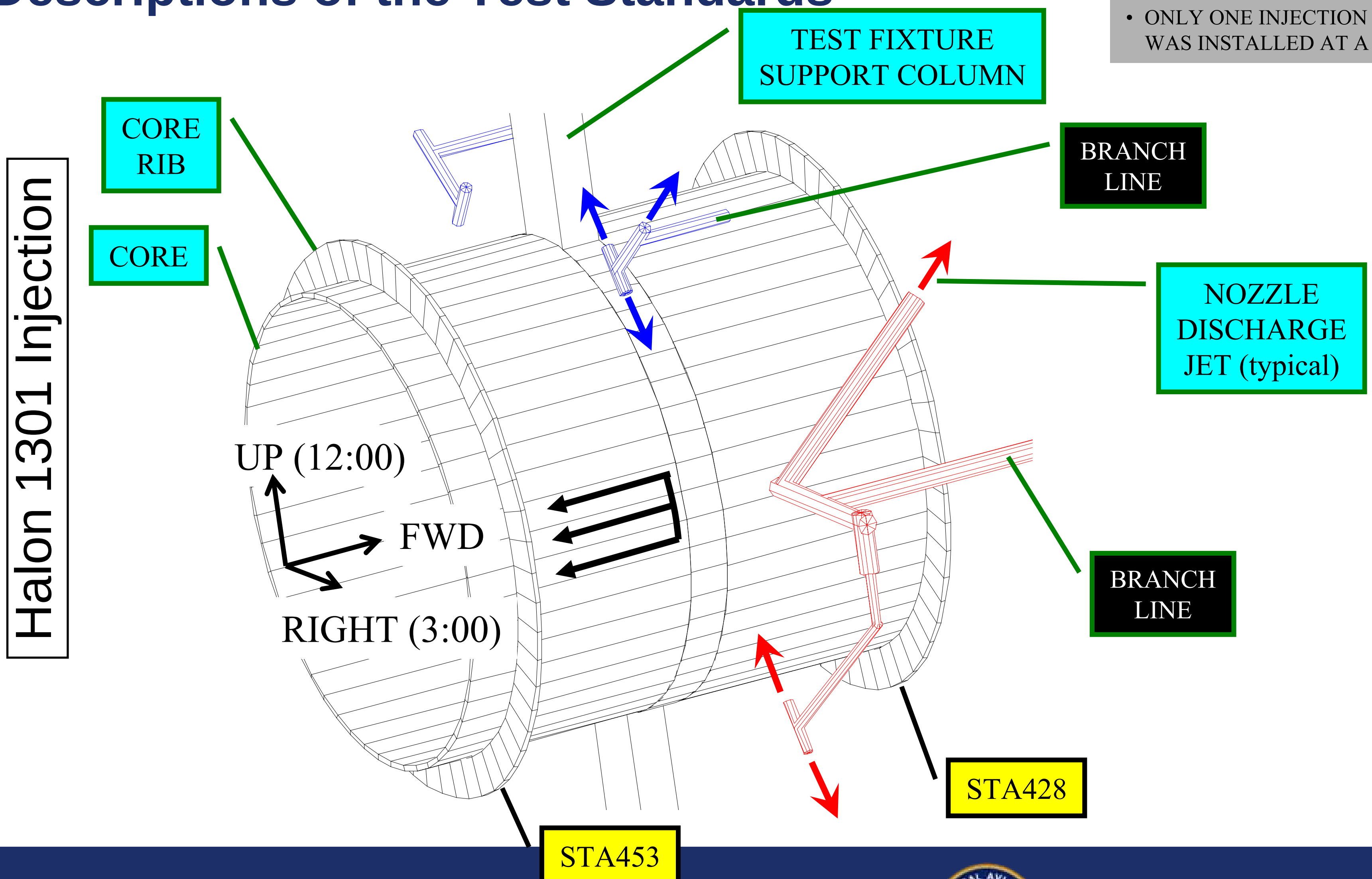
Meeting Intent of FAA Certification
MPSHRe rev03



Review MPS Activity

Descriptions of the Test Standards

- **BLUE**-COLORED PLUMBING IS FOR **LOVENT-CERT** INJECTION
- **RED**-COLORED PLUMBING IS FOR **HIVENT-CERT** INJECTION PLUMBING
- ONLY ONE INJECTION SYSTEM WAS INSTALLED AT A TIME



Review MPS Activity
Descriptions of the Test Standards

- **MPSHRe Revision 03**
  - Empirical Basis
    - Equivalent concentrations (recommendations) derived from "RTD versus localized agent concentration distribution"
    - Concentration distributions were measured for ventilation flows without fire
    - Recommendations :
      - HFC-125 : 17.6 %v/v
      - CF_3I : 7.1 %v/v
      - FK-5-1-12 : 6.1 %v/v

Review MPS Activity
Descriptions of the Test Standards

- **MPSHRe Revision 03 (continued)**
  - MPSHRe rev03 terminated Oct 2008 (review slide #5)
    - Trend of MPSHRe rev03 outcomes vary for FK-5-1-12 as compared to ratio between peak inerting and cup-burner concentrations(2)
    - FK-5-1-12's MPSHRe rev03 outcome > 1.3 * cup-burner
      - Cup-burner taken as limiting case for flame extinction for this application
        - » Minimal strain on applicable flame structure during extinction
        - » GENERALLY, flame suppression concentration decreases with increasing ventilation flow speed
      - 30% factor of safety included in concentrations intended for design based on cup-burner outcome(3)
    - Based on a sample of tests with a solid aerosol in 2007-2008, the MPSHRe rev03 outcome was indicated deficient to a cup-burner expectation

Review MPS Activity
Descriptions of the Test Standards

- **MPSHRe Revision 03 (continued)**
  - MPSHRe rev03 terminated Oct 2008 (continued)
    - MPSHRe rev03 deemed inappropriate
      - "Built around" 2-phase compressible fluids serving as clean fire extinguishing agents (HFC-125 & CF_3I outcomes shown agreeable)
      - Outcomes were calculated *empirically* from demonstrated fire extinction behaviors AND localized concentration distribution behaviors measured in ventilation flow without fire
      - The empiricism apparently played a role creating a disconnect for atypical candidates (other unmeasured flow field parameters?)
      - As replacement candidates tended more towards "streaming" characteristics, the process started breaking down
      - Given the FAA certification test is only a concentration test, an MPSHRe rev03 outcome less than cup-burner was rationalized as unacceptable

Review MPS Activity
Descriptions of the Test Standards

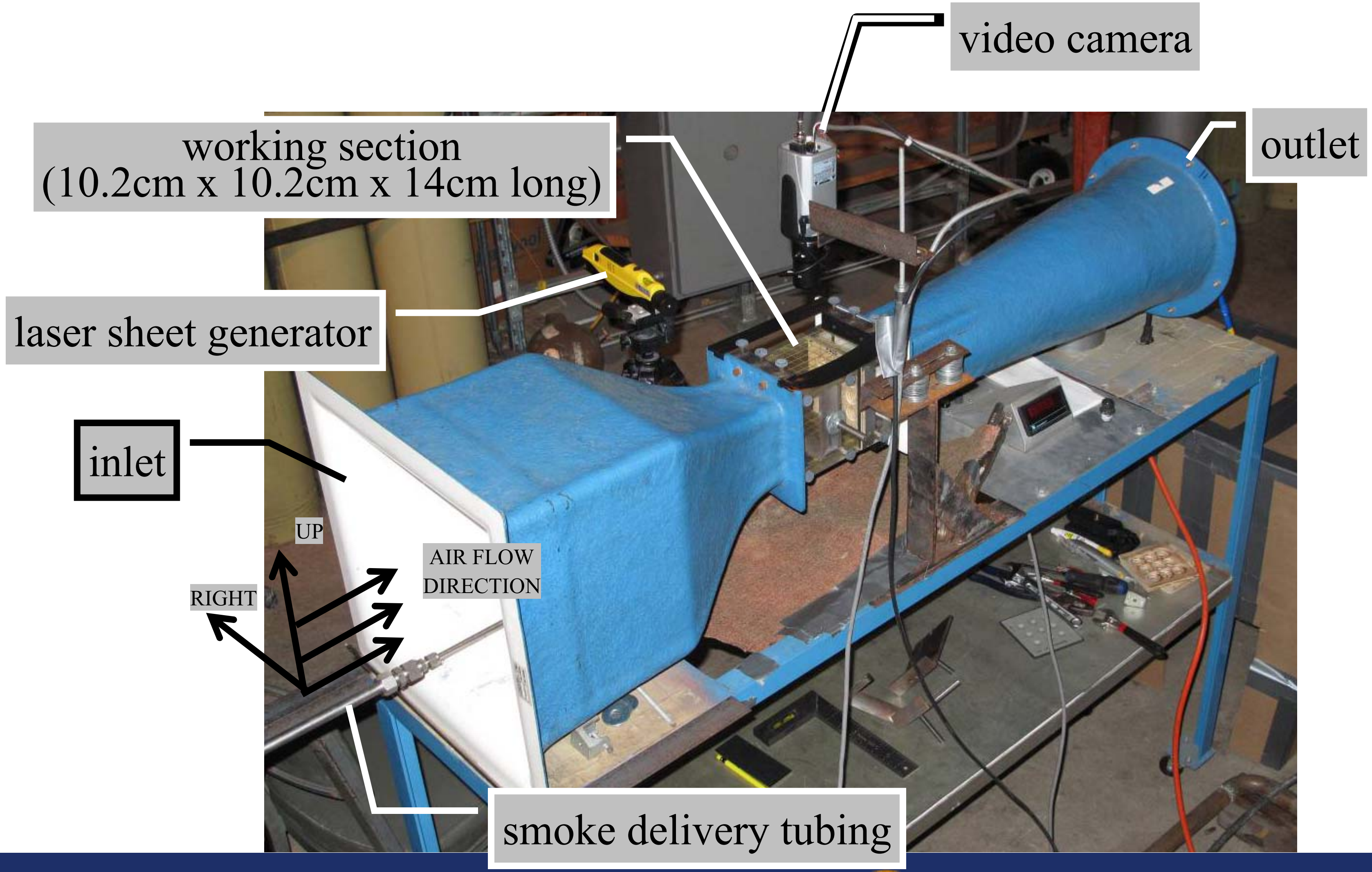
- **MPSHRe Revision 04**
  - Wanted to improve upon MPSHRe rev03
    - Stop halon 1301 discharges, as required by MPSHRe rev03
    - Permit the process for use to evaluate any injectable candidate
    - Turn the process into a proof-test
      - Removes the empiricism of MPSHRe rev03
      - Requires interested party to identify a design goal prior to full-scale test
    - Provide opportunity to incorporate current thought into the process
      - Long-standing FAA certification criteria resembles inerting rationale(4)
      - Other recent activities suggest the cup-burner value is the predictor(5)

Review MPS Activity
Some Test Observations

- **MPSHRe Revision 04**
  - Support testing
    - Small-scale wind tunnel (SSWT) activity
      - Wanted better qualitative understanding of the agent concentration distribution around some pertinent Nacelle Fire Simulator (NFS) features
        - » spray fire feature : the tube array (review slide #16)
        - » pool fire feature : the forward (FWD) fuel pan lip (review slide #17)
      - Observed theatrical smoke (liquid aerosol) flow near similar features for varied air flows so the wake regions could be characterized
      - Outcome : qualitatively, the most challenging wake for the smoke to penetrate was the forward lip of the fuel pan (a “short” wall perpendicular to the wall of the tunnel’s working section)

Review MPS Activity
Some Test Observations

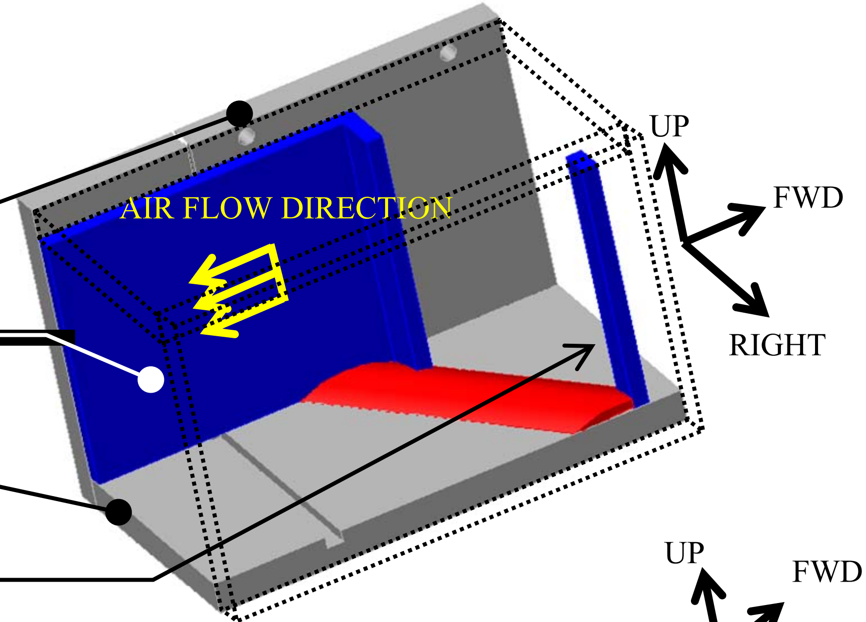
SSWT Background, SSWT



Review MPS Activity

Some Test Observations

SSWT Background, Models

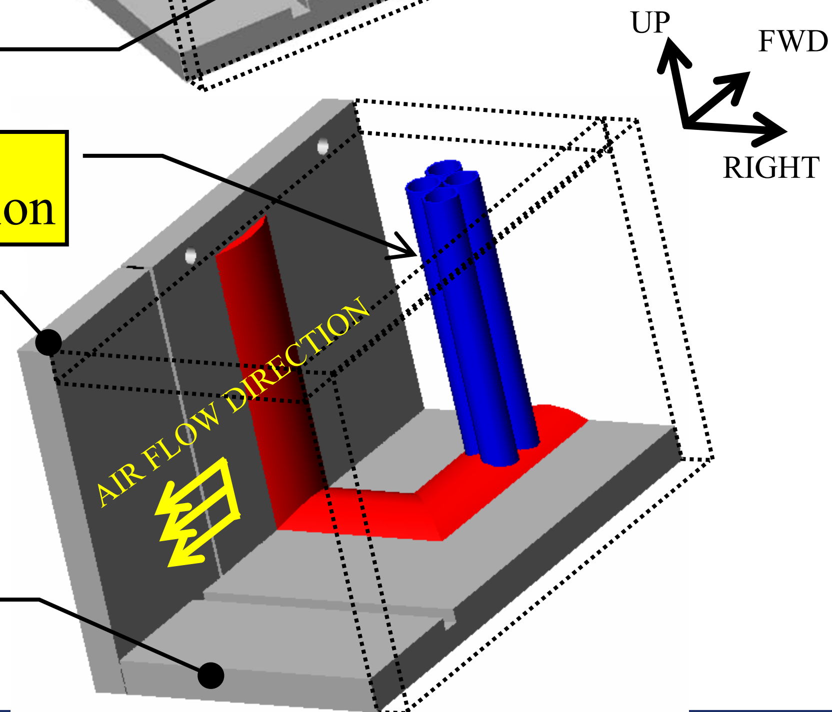


left wall, working section, SSWT

- fuel pan representation -
2.54 cm tall FWD fuel pan lip

floor, working section, SSWT

core rib representation



4 x 13mm OD
tube array representation

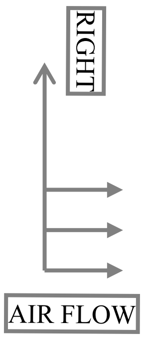
left wall, working section, SSWT

floor, working section, SSWT

Review MPS Activity

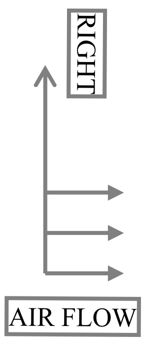
Some Test Observations

Wake Imagery,
Tube Array



Review MPS Activity
Some Test Observations

Wake Imagery,
FWD Fuel pan Lip



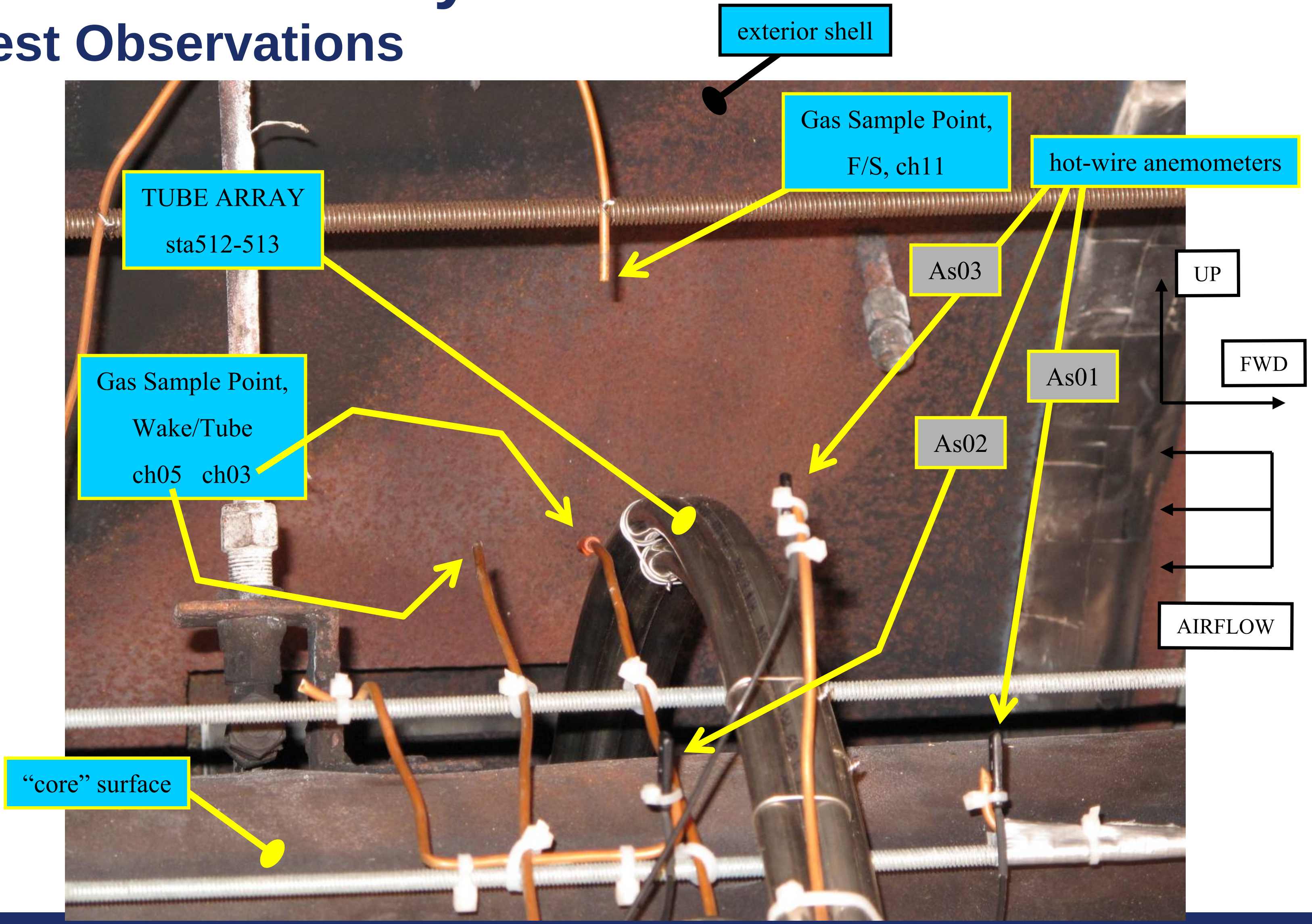
Review MPS Activity

Some Test Observations

- **MPSHRe Revision 04**
  - Support testing (continued)
    - NFS activity, agent concentration distribution testing
      - Sampled halon 1301, HFC-125, & CF_3I
      - Placed sample points in free stream (F/S) & wake regions related to SSWT observations
      - Captured some localized flow speeds during agent injections
        - » Observed speeds “spike” and/or “trough”
        - » Hot-wire anemometers (HWAs) were calibrated only for air
      - Outcomes
        - » Halon 1301 still met the intent of FAA certification with sample points buried in both wake regions
        - » “High-” and “Low-vent certification” injection hardware generally improved concentration distribution profiles for HFC-125 & CF_3I

Review MPS Activity
Some Test Observations

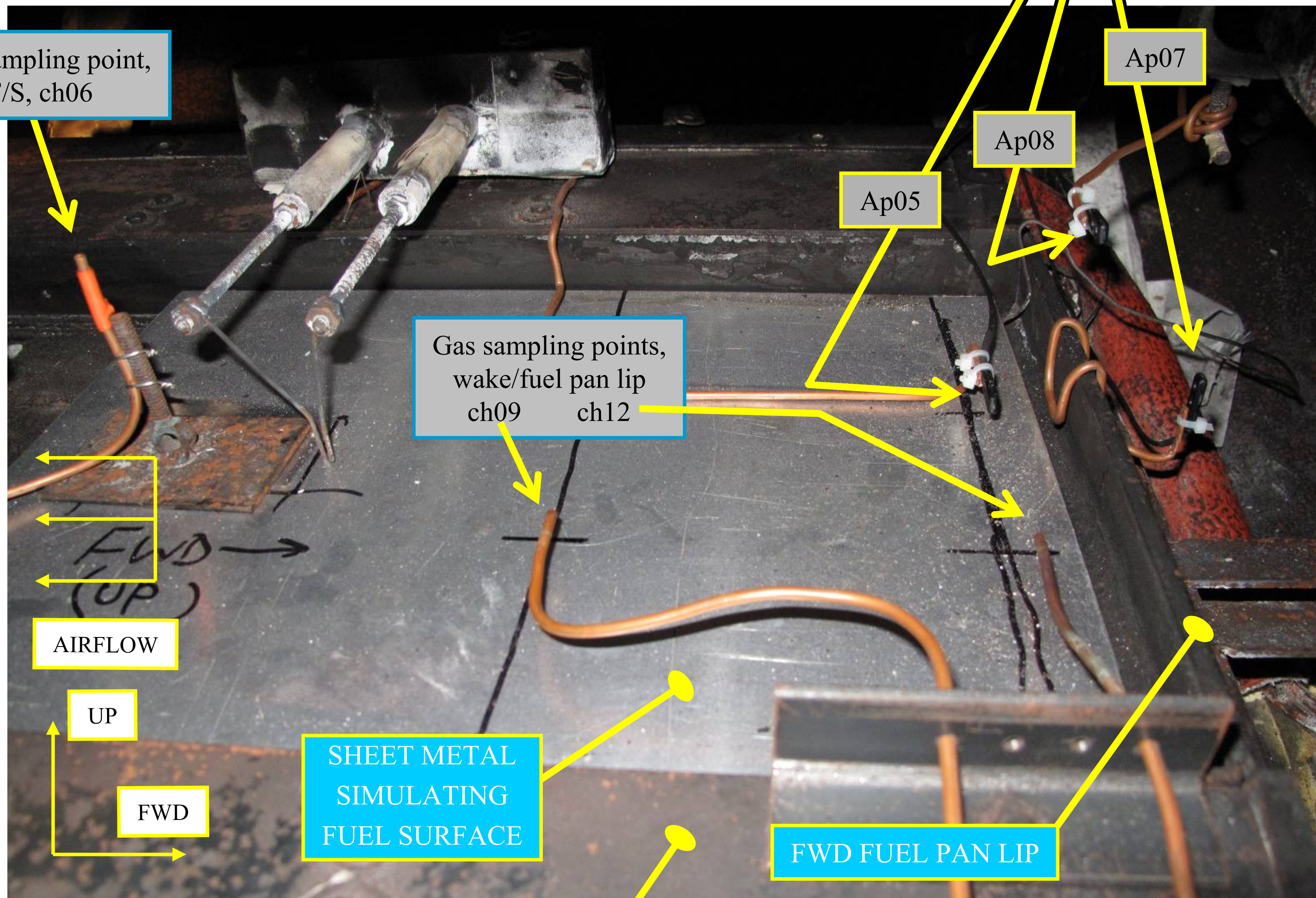
Concentration Distribution,
Wake Region/Tube Array



Review MPS Activity

Some Test Observations

Concentration Distribution, Wake Region /Fuel Pan Lip

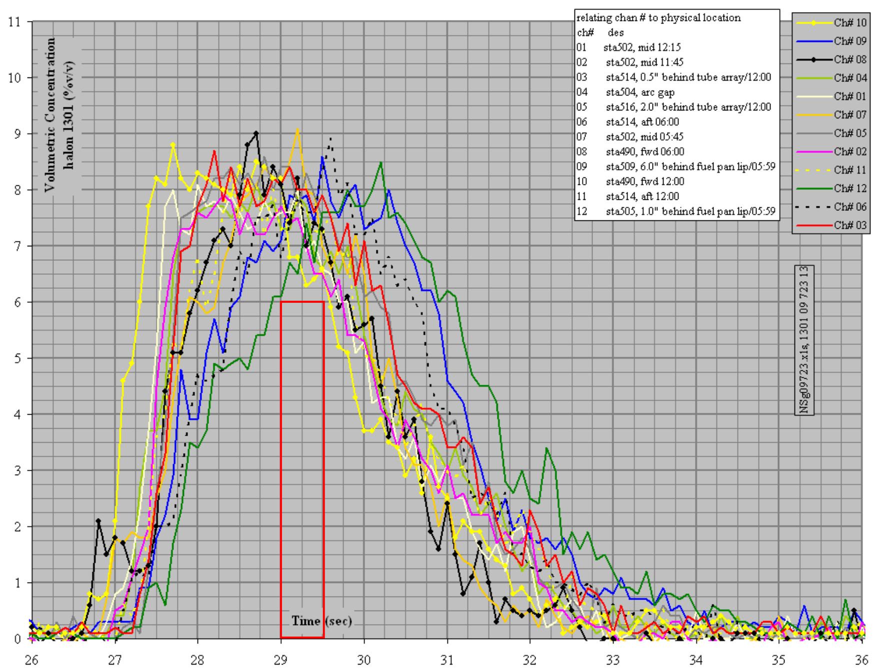


Review MPS Activity

Some Test Observations

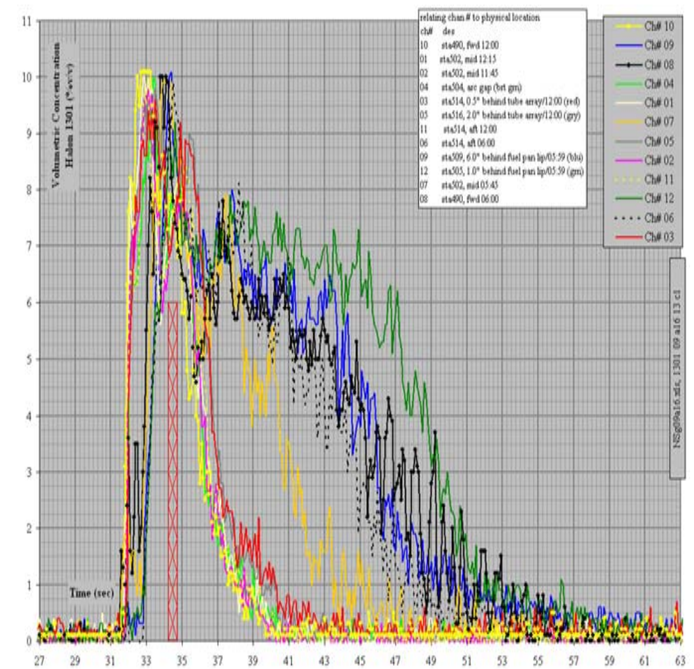
Meeting Intent of FAA Certification
MPSHRe rev04

"High" ventilation



$\Delta t = 10$ sec

"Low" ventilation



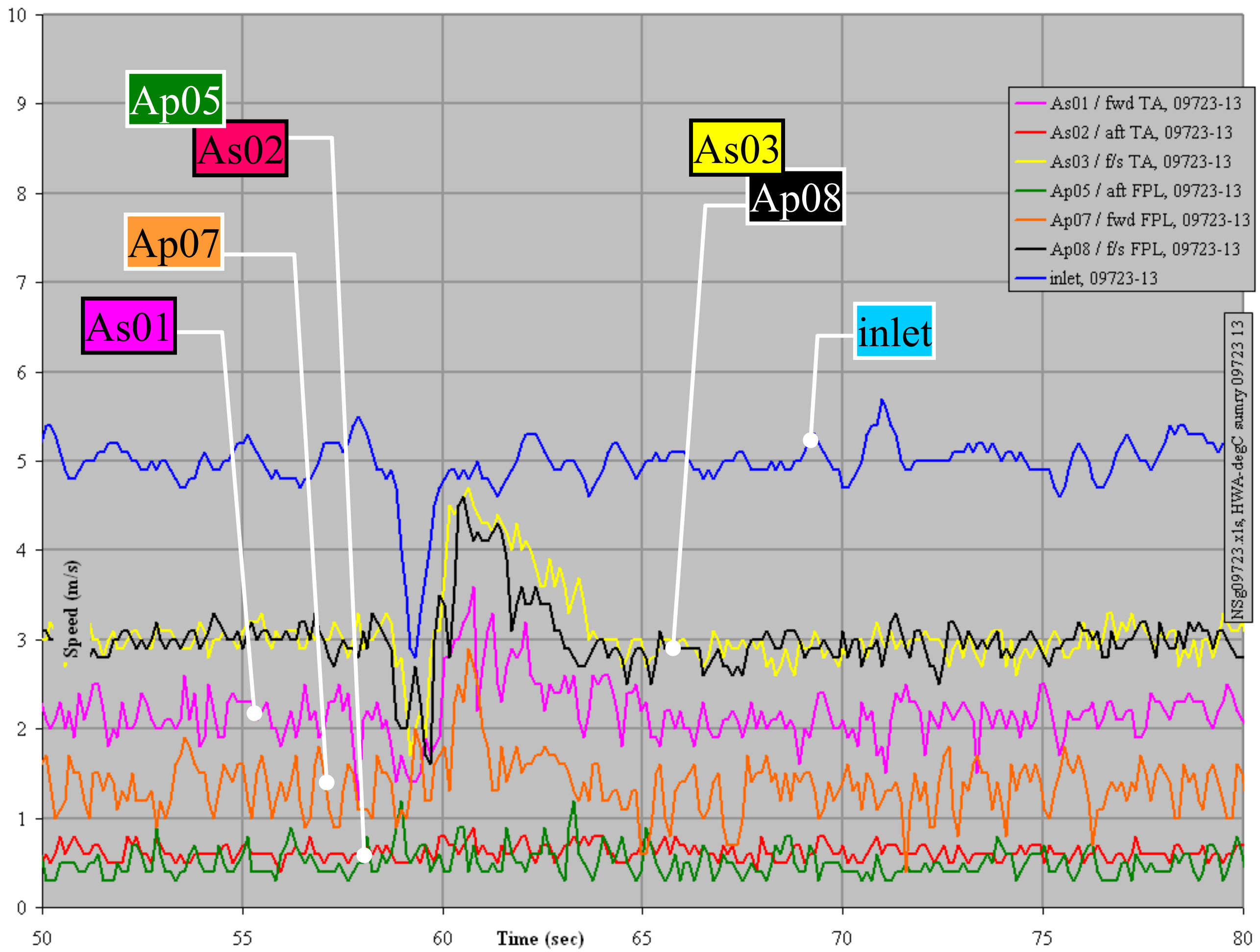
$\Delta t = 35$ sec

Review MPS Activity

Some Test Observations

"High" rate NFS ventilation
"High-vent certification" injection
halon 1301

Speed Profiles, Wake Regions



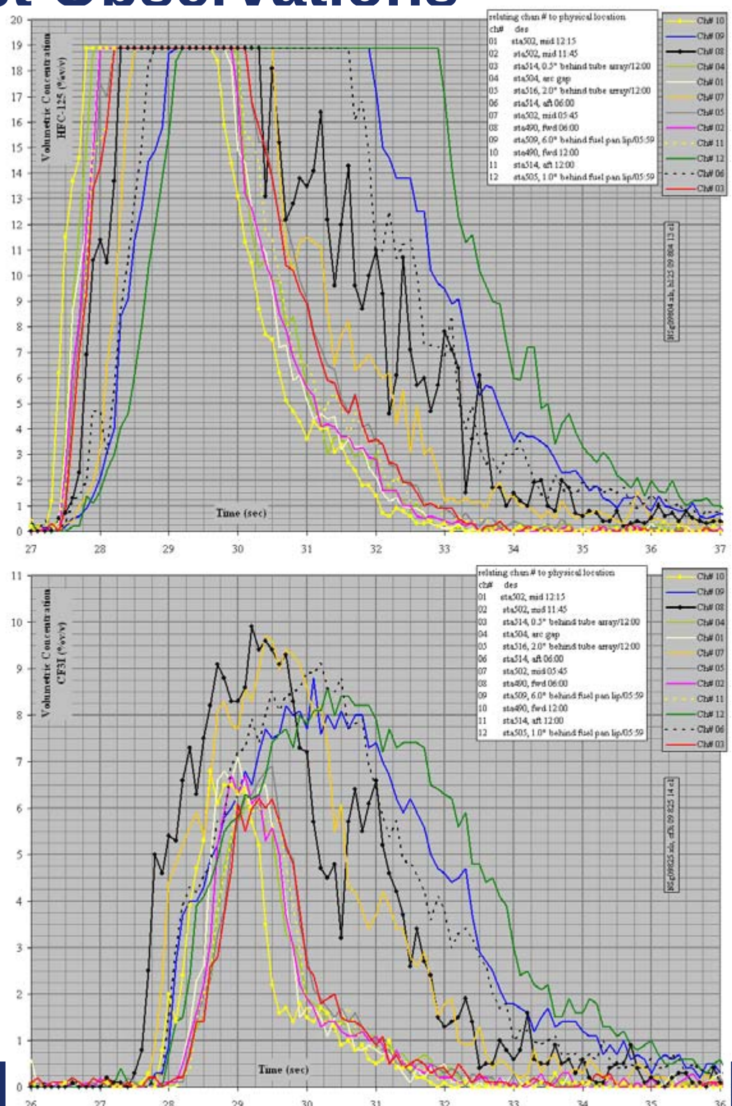
Review MPS Activity

Some Test Observations

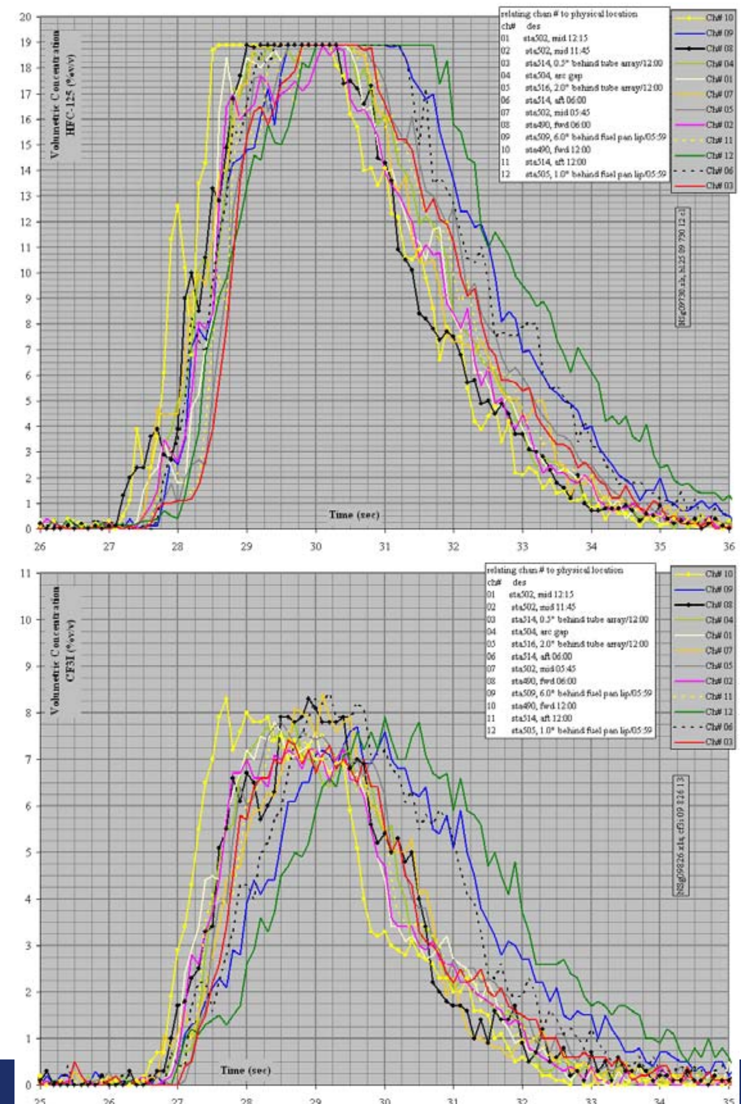
“High” rate NFS ventilation
Upper graphs - 8.0 lbf HFC-125
Lower Graphs - 3.5 lbf CF_3I

Concentration Distribution, Wake Regions

Injected via “replacement candidate” plumbing



Injected via “high-vent certification” plumbing



Review MPS Activity

Some Test Observations

“High” rate NFS ventilation
Upper graphs - 8.0 lbf HFC-125
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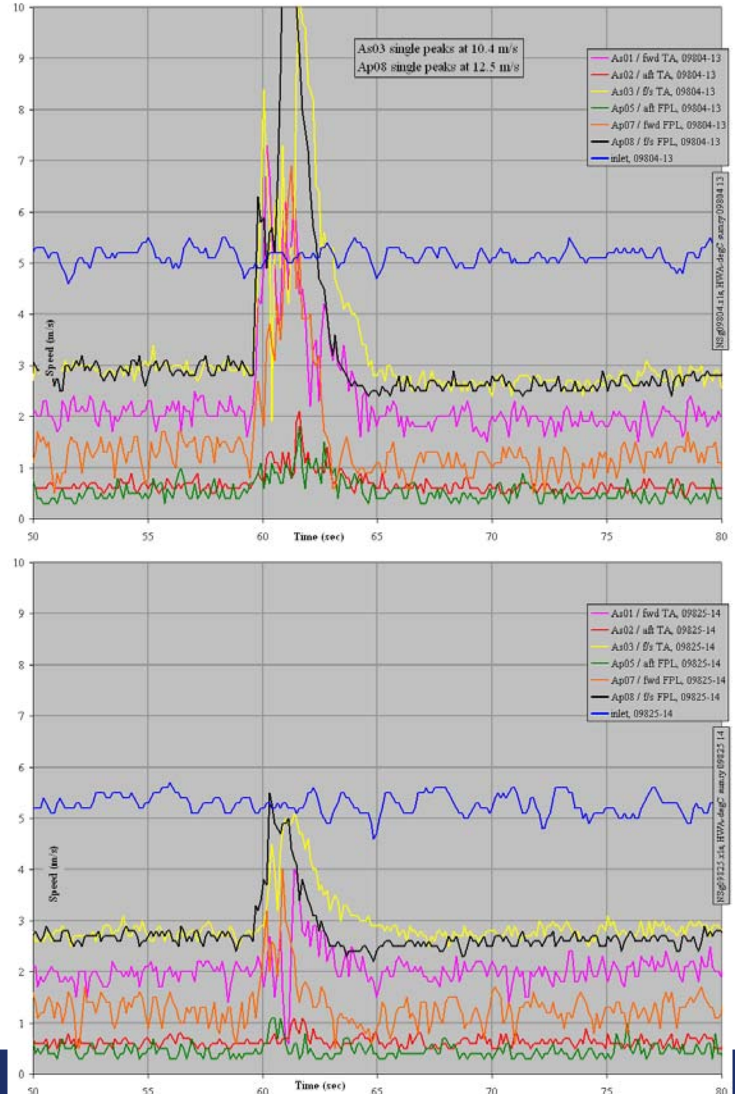
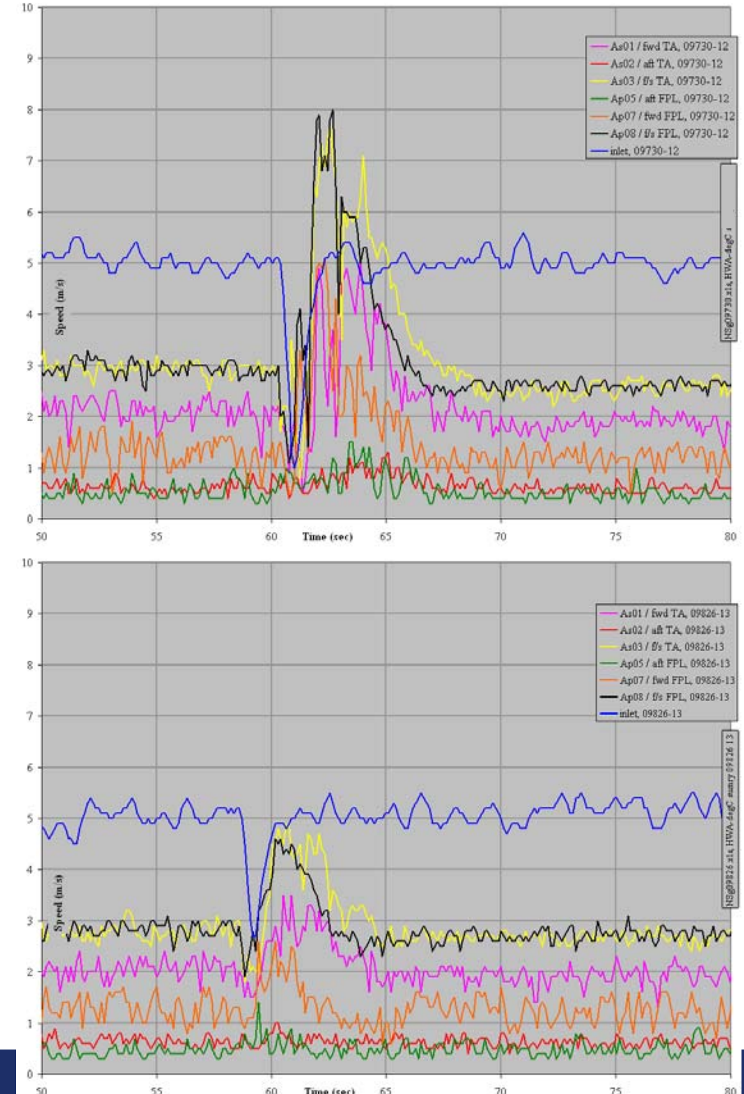
Speed Profiles, Wake Regions

Injected via “replacement candidate” plumbing



Injected via “high-vent certification” plumbing



Review MPS Activity
Some Test Observations

- **MPSHRe Revision 04**
  - Support testing (continued)
    - NFS activity, fire extinction testing
      - Accomplished to remove rev03-required halon 1301 discharge
      - Performance thresholds for replacement candidates remain the halon 1301 performance observed during MPSHRe rev03 testing
      - Established "life-span benchmark" for fixtures expected to undergo repeated test programs
        - » Two HFC-125 configurations, each unique to ventilation regime
        - » Intended to track changes in the test environment over time

Review MPS Activity
Some Test Observations

- **MPSHRe Revision 04**
  - Summary
    - New 12-point concentration sampling scheme (review slide #19)
    - Halon 1301 discharge is no longer required
    - Test process is a proof-test
      - Design criteria requires credible identification and replication in the test environment
      - If initial design criteria fail, testing reverts to empirical search-and-learn
    - Second-tier testing requirement added for atypical candidates
      - High-fidelity/full-scale demonstration testing; i.e. test in a “real” nacelle
      - An “atypical” candidate is one obviously deviant from the typical halon 1301 & associated concentration measurement, storage, and/or delivery techniques

Brief Comments on Current Test Activity

- **Working with Solid Aerosol Again**
- **Using Manufacturer-Supplied Concentration Measurement System**
- **2 of 4 Test Configurations Completed**
- **High-fidelity/Full-scale Demonstration is Required Following the Generic Fixture Testing**

References/Citations.

Bennett, J.M., Gann R.G., 2007, “Chapter 11 : Verification of Fire Suppression Principles,” NIST Special Publication 1069, National Institute of Standards & Technology, Building and Fire Research Laboratory, Gaithersburg, MD.

Chamberlain, G., 1970, "Criteria for Aircraft Installation and Utilization of an Extinguishing Agent Recorder," Report No. FAA-DS-70-3, Federal Aviation Administration, National Aviation Facilities Experimental Center, Atlantic City, NJ.

Hamins, et al., 1994, “Flame Suppression Effectiveness,” NIST Special Publication 861, National Institute of Standards & Technology, Building and Fire Research Laboratory, Gaithersburg, MD.

National Fire Protection Association, 2007, “NFPA 2001 Standard on Clean Agent Fire Extinguishing Systems,” 2008 Edition, Quincy, MA.

National Fire Protection Association, 1989, “NFPA 12A Standard on Halon 1301 Fire Extinguishing Systems,” 1989 Edition, Quincy, MA.

National Fire Protection Association, 1990, “NFPA 12B Standard on Halon 1211 Fire Extinguishing Systems,” 1990 Edition, Quincy, MA.

1. http://www.fire.tc.faa.gov/pdf/systems/MPSErev04_MPSeRev04doc-02submtd.pdf
2. (Referencing from slide 24, subsequently referencing to the bases for the graph on slide 05)
    - Cup-burner test protocol : NFPA, 2007, Annex B, p.95; discussion of earlier methodology located in Annex A.5.4.2, p.50.
    - Peak-inerting test protocol. NFPA, 2007, Annex A.5.4.3, p.54.
    - halon 1301 cup-burner & peak inerting concentration values
        - cup-burner : Hamins, 1994, table 5, p.395.
        - peak inerting : NFPA, 1989, derived from table A-2-3.2.1, p.15.
    - halon 1211 cup-burner & peak inerting concentration values
        - cup-burner : NFPA, 1990, table A-2-3.2.2, p.34.
        - peak inerting : NFPA, 1990, table A-2-3.2.3, p.34.
    - HFC-125, CF_3I, & FK-5-1-12 cup-burner & peak inerting concentration values
        - cup-burner : NFPA, 2007, Tables A.5.4.2(a) & A.5.4.2(b), p.50.
        - peak inerting : NFPA, 2007, Table A.5.4.3, p.55.
3. NFPA, 2007, §5.4.2.3, p.16.
4. Chamberlain, 1970, p.34.
5. Bennett & Gann, 2007, p.1142.