Halon Replacement, Aircraft Engine Nacelle

HFC-125 Over-pressure Observations at the FAA Technical Center

Presented to: International Aircraft Systems Fire Protection Working Group

By: On behalf of :

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

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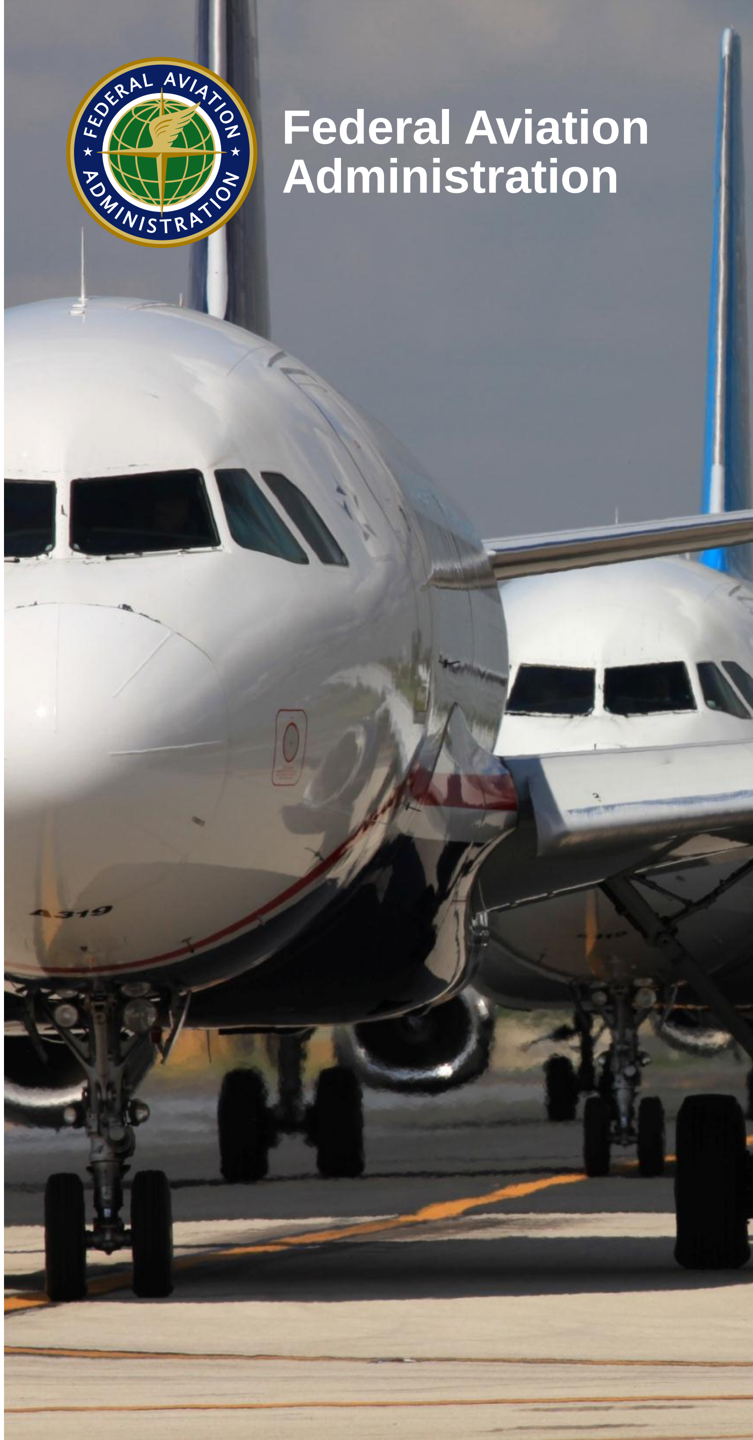


Presentation Overview

- **Review of testing with HFC-125 at the FAA Technical Center**

- **Provide information regarding test environments and behaviors**

- **Creates map of the *over-pressure* behavior of HFC-125 as related to test condition**

Identifying Pertinent Tests

- Cargo compartment tests
  - 8July1997
  - 18Sep1997
- Pressure vessel tests, Dec 2003 – Jan 2004
- Nacelle fire simulator tests, Dec 2004

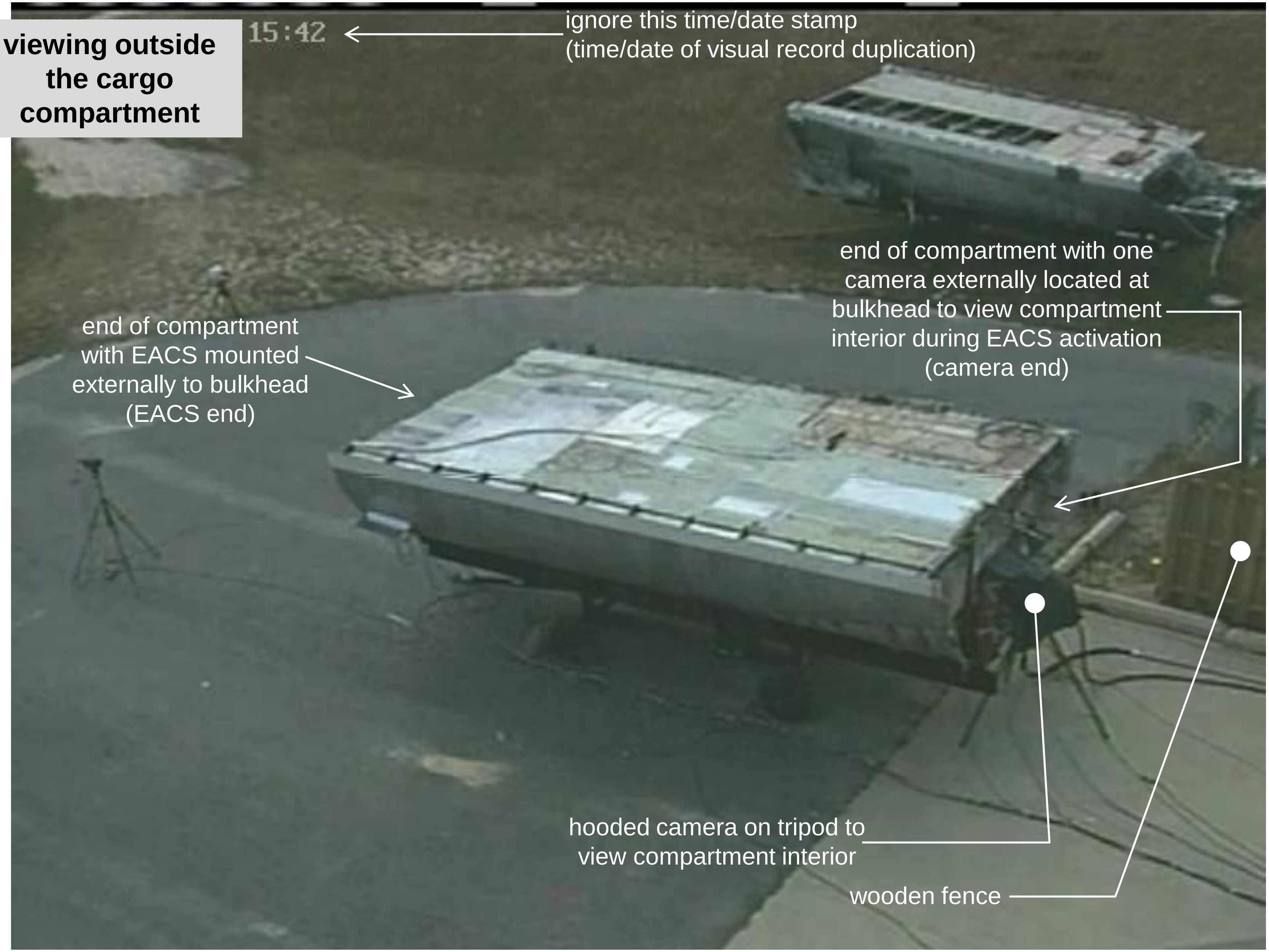
Cargo compartment, 8July1997

- B727 lower-lobe, forward cargo compartment, ≈11 m^3
- Compartment characteristics
  - “somewhat” modified aircraft structure
  - “empty” volume
  - functionally-porous; “leakage” flow(s) possible
  - no proximal forced ventilation
- Fire threat = exploding aerosol can simulator (EACS), 1997-variant
  - EACS filled with ≈91 g propane and ≈71 g isopropyl alcohol
  - pressurized by heating then discharged into compartment
  - ignited by a “small” pan of burning hydrocarbon fuel
- HFC-125 use = none

To review this test and the 1997-variant EACS, see Marker (1998) :

Marker, T., “Initial Development of an Exploding Aerosol Can Simulator,” FAA report DOT/FAA/AR-TN97/103, April 1998.

viewing outside the cargo compartment



- Subsequent images for this test were lifted from a duplicated digital visual history captured at 30 frames/second.
- Frame numbers are sequential; can be used to determine inter-frame durations
- Frame #10 links the different visual histories to the same point in time.

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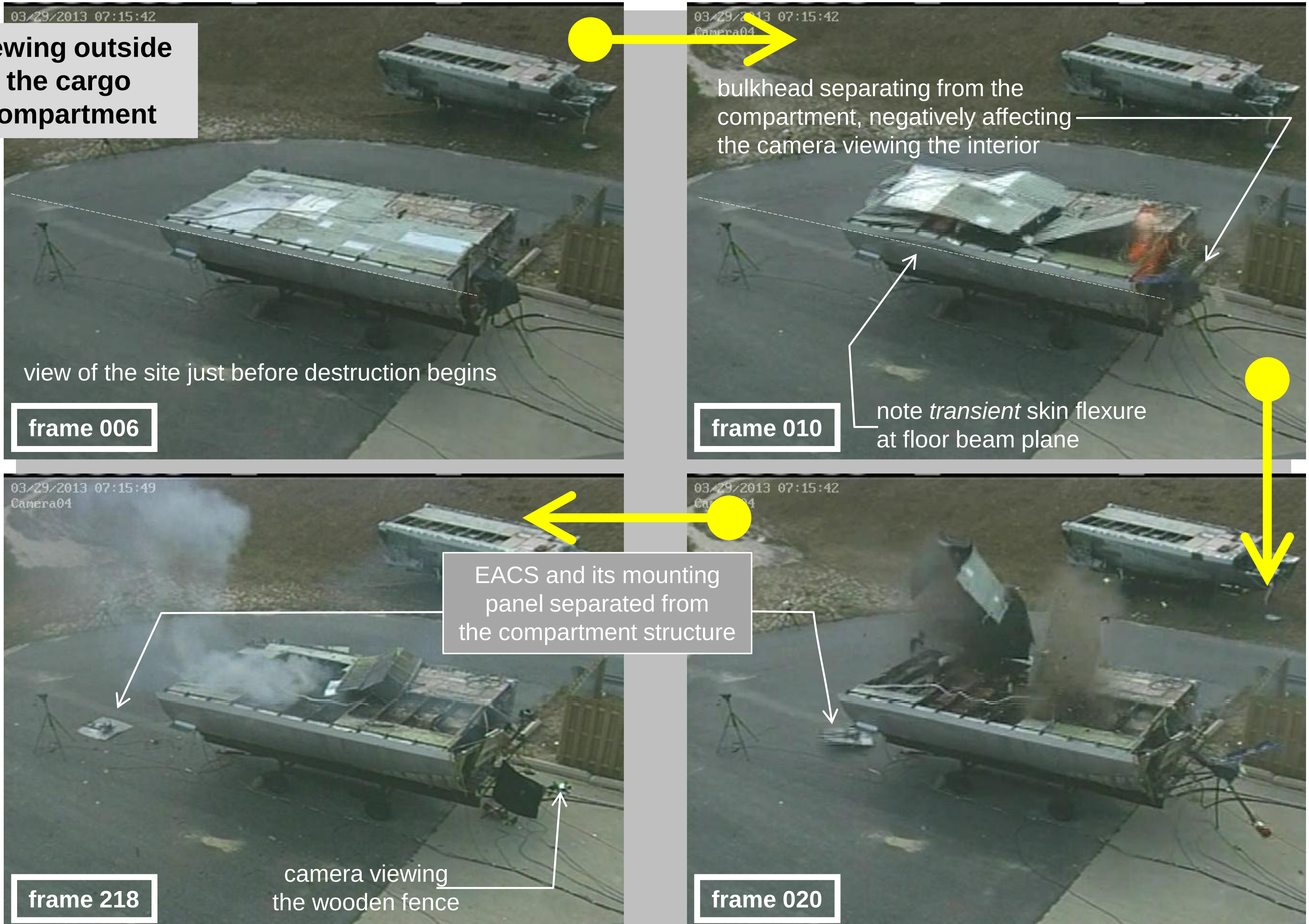
viewing outside the cargo compartment



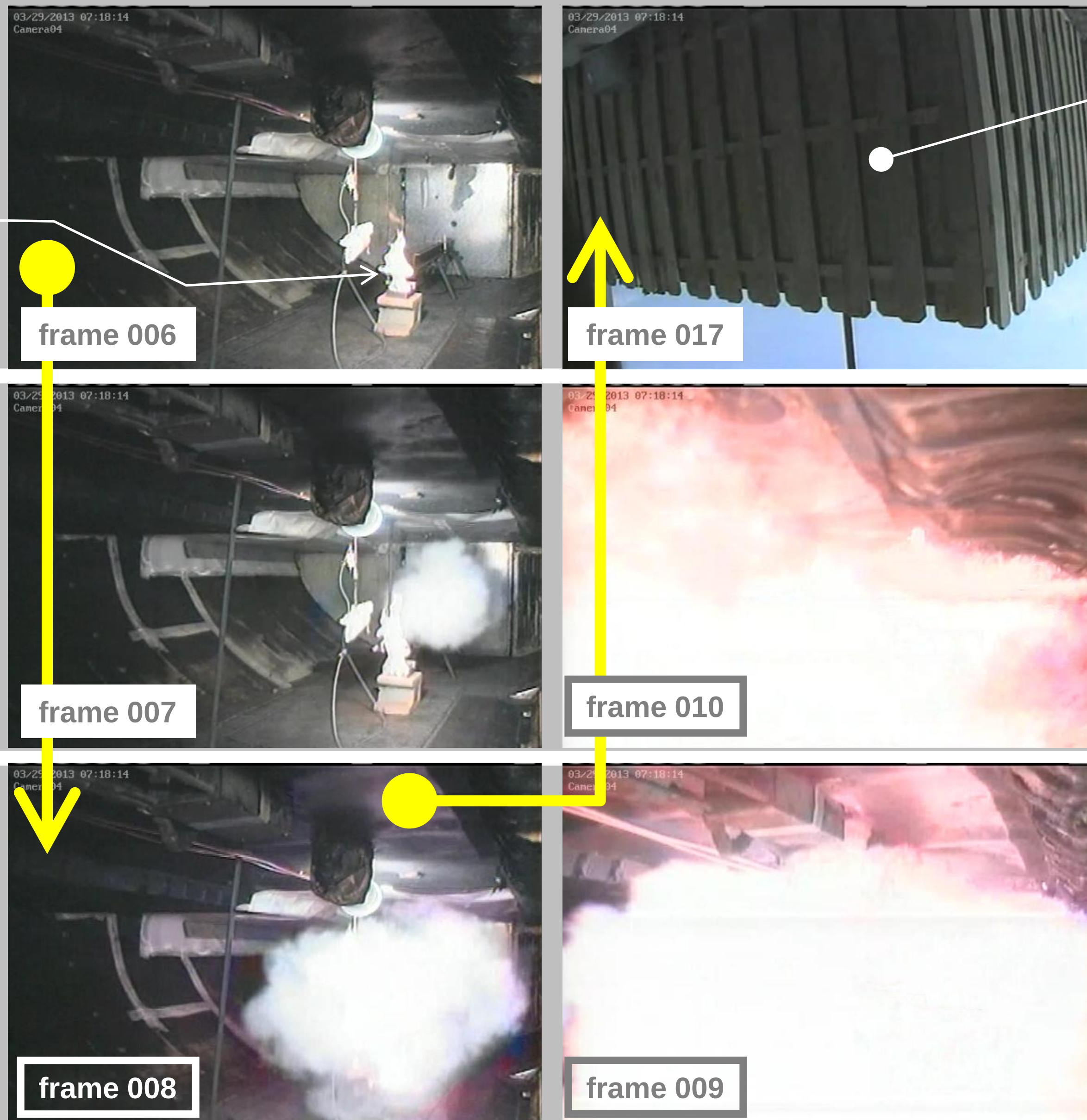
OUTCOME :
Compartment suffered notable pressure-related damage resulting from the use of the 1997-variant EACS.

viewing inside the cargo compartment

- ignition source is burning
- EACS injection plume not yet visible

- 1ST video frame of the EACS injection plume

- EACS injection plume expanding



- viewing the wooden fence from this camera's new location

- the bulkhead the camera is peering through is beginning its partial separation from other compartment structure

- plume expanding and starting to burn

Cargo compartment, 18Sep1997

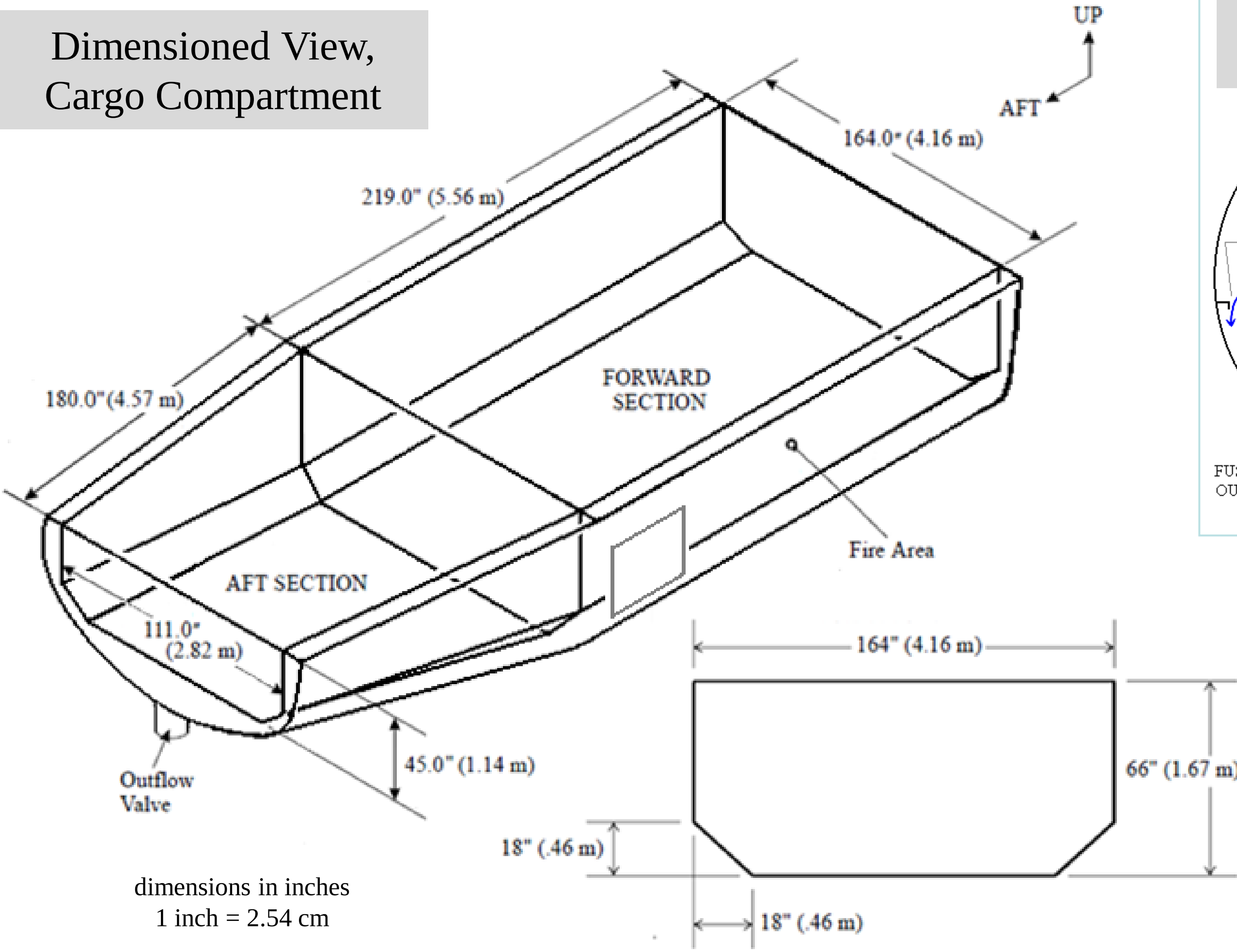
- Bldg 275’s DC-10 lower-lobe cargo compartment, ≈67 m^3
- Compartment characteristics
  - “notably” modified aircraft structure; sheet metal boundary
  - approximately a 70% empty volume
  - forced-ventilation moved through fuselage around compartment
  - “leakage” flow occurred through compartment; 102 mm dia duct exhausted compartment to atmosphere
- Fire threat = 202 kg of cardboard boxes filled with shredded-paper
  - thermal ignition source contained in 1 box and buried inside pile
  - fire propagated from initial box throughout pile during ≈90 minutes
- HFC-125 use
  - a “high”-rate injection occurred upon smoke detector activation
  - upon deficient concentration from initial injection, metered HFC-125 injection established to maintain concentration

To review this test, see Blake, et al. (1998) :

Blake, D., Marker, T., Hill, R., Reinhardt, J., Sarkos, C., "Cargo Compartment Fire Protection in Large commercial Transport Aircraft," FAA Report DOT/FAA/AR-TN98/32, July 1998.

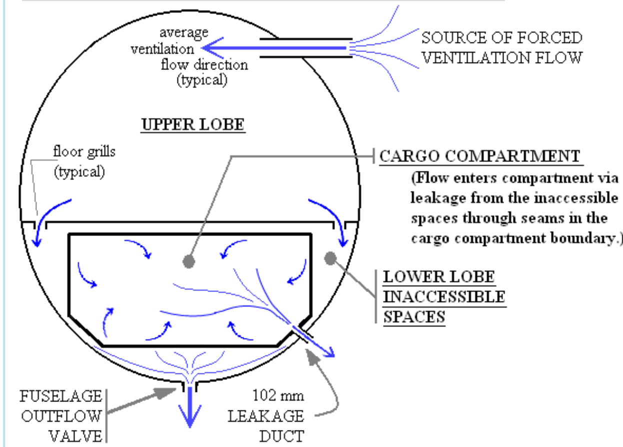
Cargo compartment, 18Sep1997

Dimensioned View,
Cargo Compartment

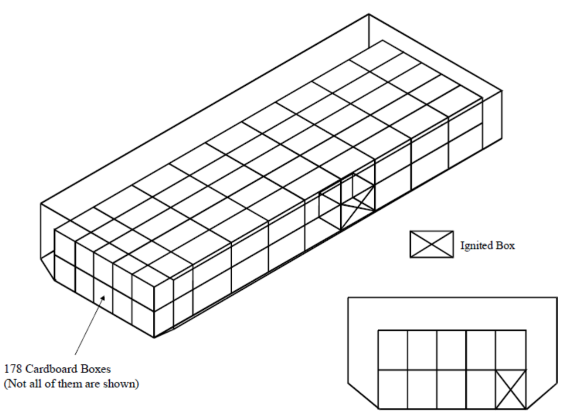


dimensions in inches
1 inch = 2.54 cm

Schematic View,
Ventilation Flow Paths

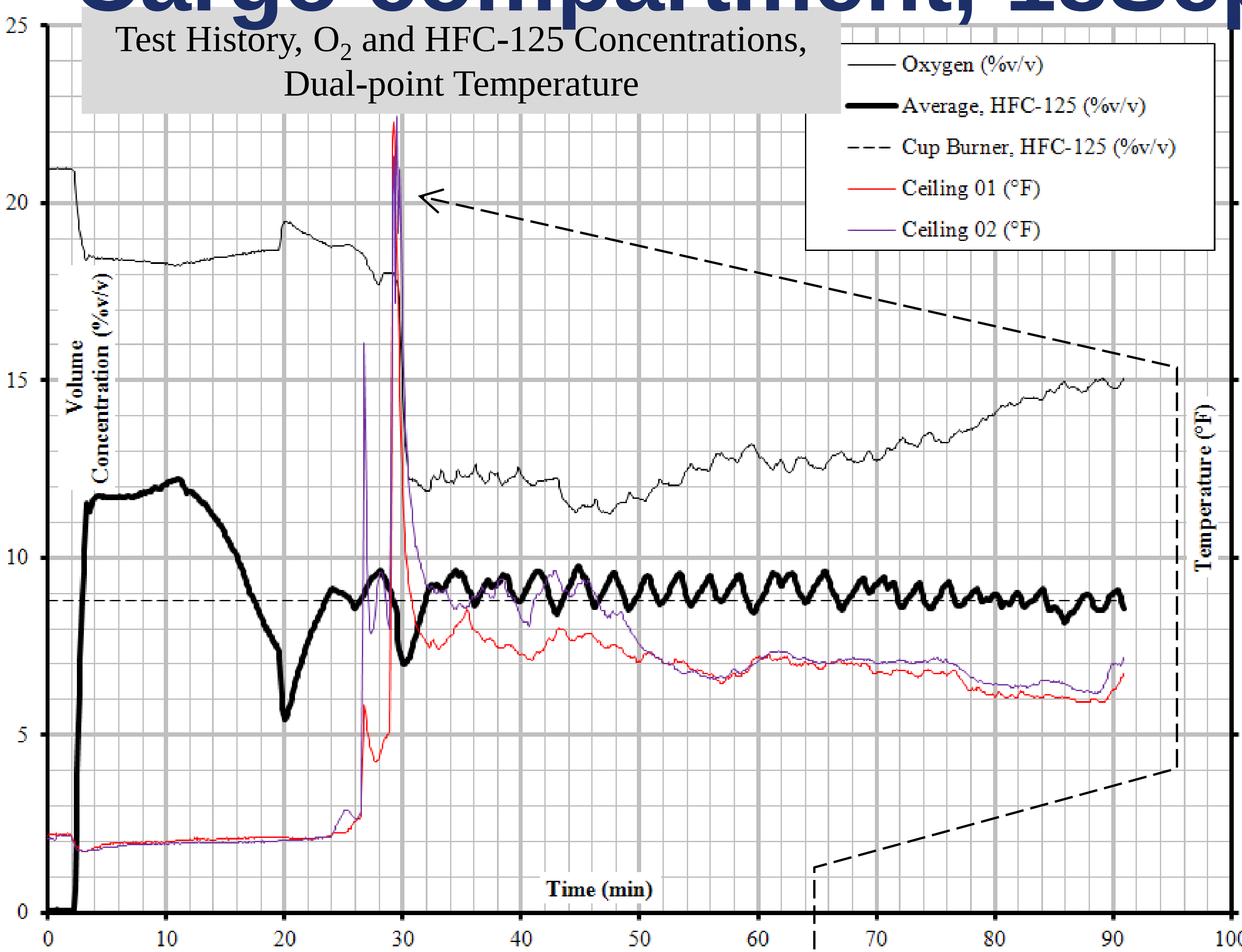


Schematic View,
Compartment Loading



Modified images of figures 1 & 2, p.17, taken from
Reinhardt, J., Blake, D., Marker, T., "Development of a Minimum Performance Standard for Aircraft Cargo Compartment Gaseous Fire Suppression Systems," FAA Report DOT/FAA/AR-00/28, September 2000

Cargo compartment, 18Sep1997



T(°C) = 5/9 * (T(°F) – 32)

Similar to figure 2, p.6, of :

Blake, D., Marker, T., Hill, R., Reinhardt, J., Sarkos, C., "Cargo Compartment Fire Protection in Large commercial Transport Aircraft," FAA Report DOT/FAA/AR-TN98/32, July 1998.

OUTCOME :
The compartment's "hot" gas layer experienced a notable thermal excursion, a 2ND volume of fire, attributed to HFC-125. Subject authors reported not observing such things previously. Compartment suffered no pressure-related damage.

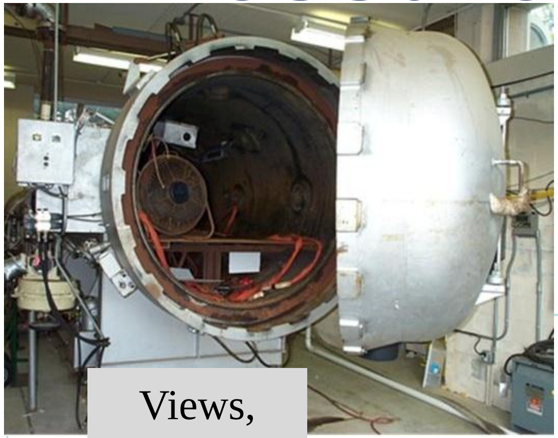
Pressure Vessel, Dec2003-Jan2004

- Bldg 276's pressure vessel, ≈11 m^3
- Compartment characteristics
  - not aircraft structure; "thick" plate/cast steel
  - "empty" volume
  - no ventilation and pressure-tight; i.e. no leakage
- Fire threat = EACS, 2003-variant
  - filled with ≈90 g propane, ≈270 g ethyl alcohol, and ≈90 g water
  - pressurized by heating then discharged into compartment
  - ignited by alternating-current (AC) electrical arc
- HFC-125 use
  - injected into compartment then compartment contents were mechanically stirred
  - homogenous mixture established prior to fire threat activation

To review this testing, see Reinhardt (2004) :

Reinhardt, J., "Behavior of Bromotrifluoropropene and Pentafluoroethane When Subjected to a Simulated Aerosol Can Explosion," FAA report DOT/FAA/AR-TN04/4, May 2004

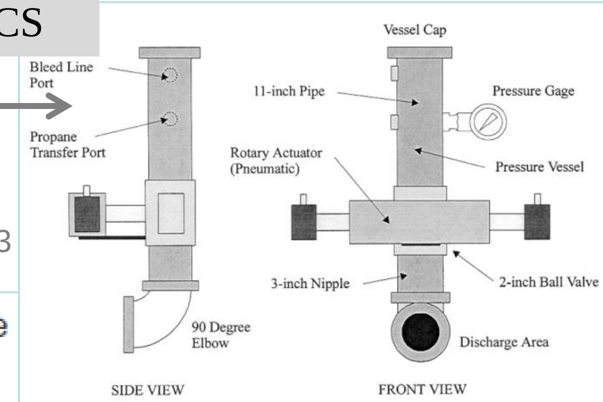
Pressure Vessel, Dec2003-Jan2004

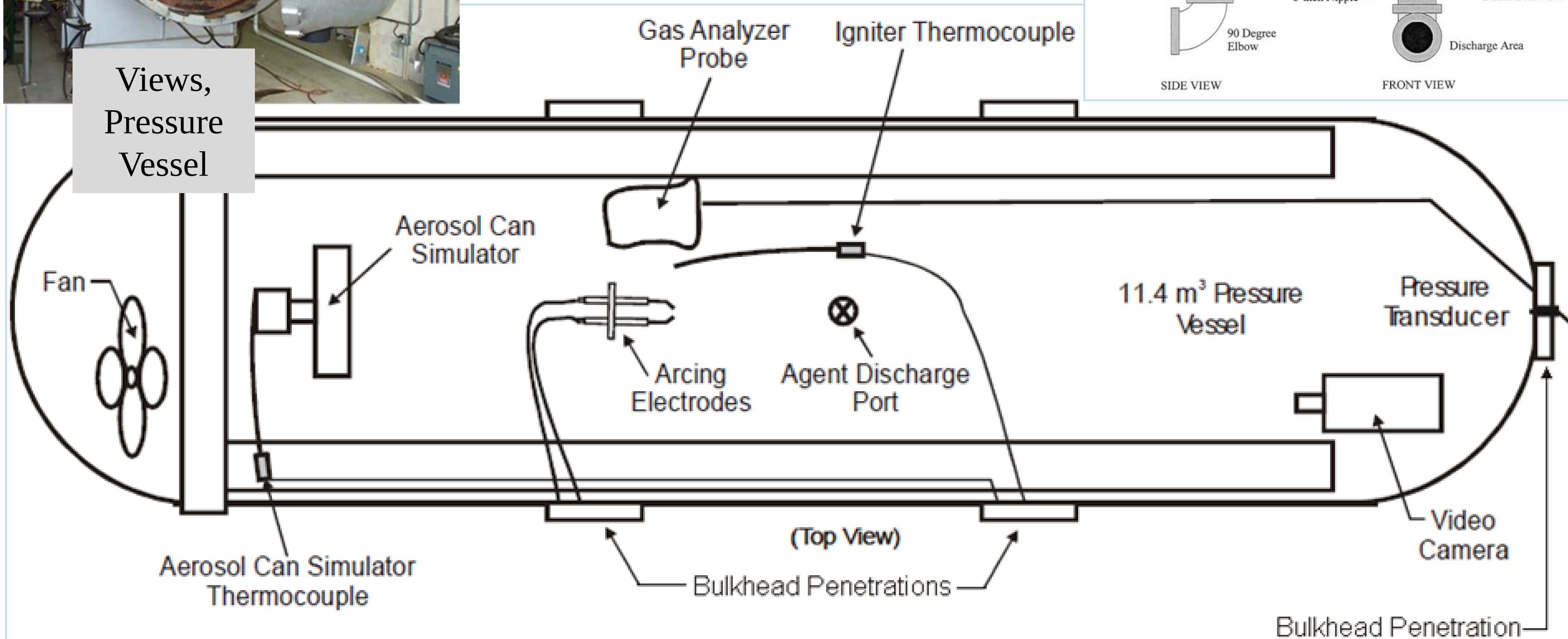


Views, Pressure Vessel

EACS

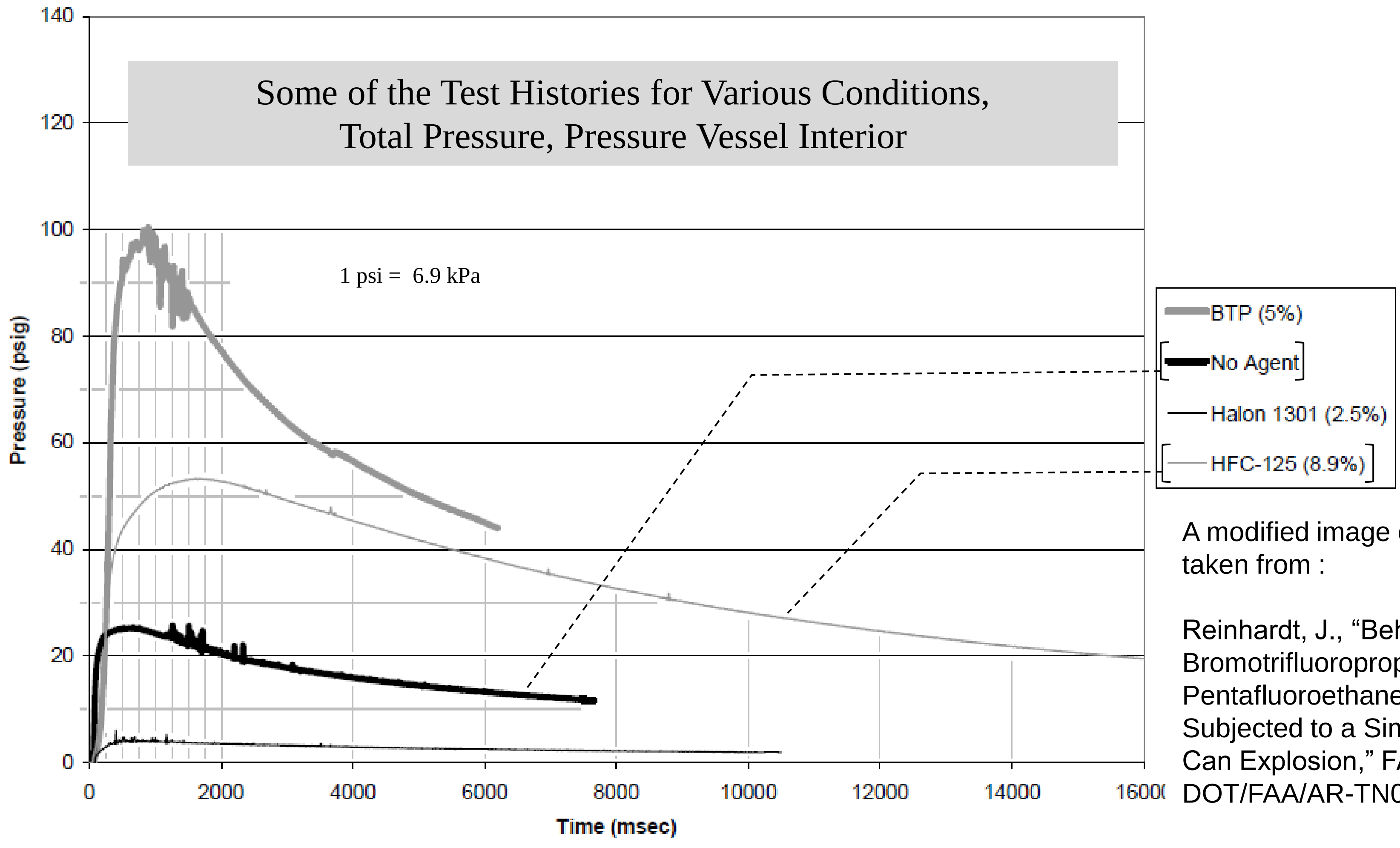
This EACS schematic is figure 8, p.15 taken from Reinhardt, J., "Minimum Performance Standard for Aircraft Cargo Compartment Halon Replacement Fire Suppression Systems," DOT/FAA/AR-TN03/6, April 2003





This pressure vessel schematic is a modification of figure 1, p.6 taken from Reinhardt, J., "Behavior of Bromotrifluoropropene and Pentafluoroethane When Subjected to a Simulated Aerosol Can Explosion," FAA report DOT/FAA/AR-TN04/4, May 2004

Pressure Vessel, Dec2003-Jan2004



A modified image of figure 2, p.6, taken from :

Reinhardt, J., "Behavior of Bromotrifluoropropene and Pentafluoroethane When Subjected to a Simulated Aerosol Can Explosion," FAA report DOT/FAA/AR-TN04/4, May 2004

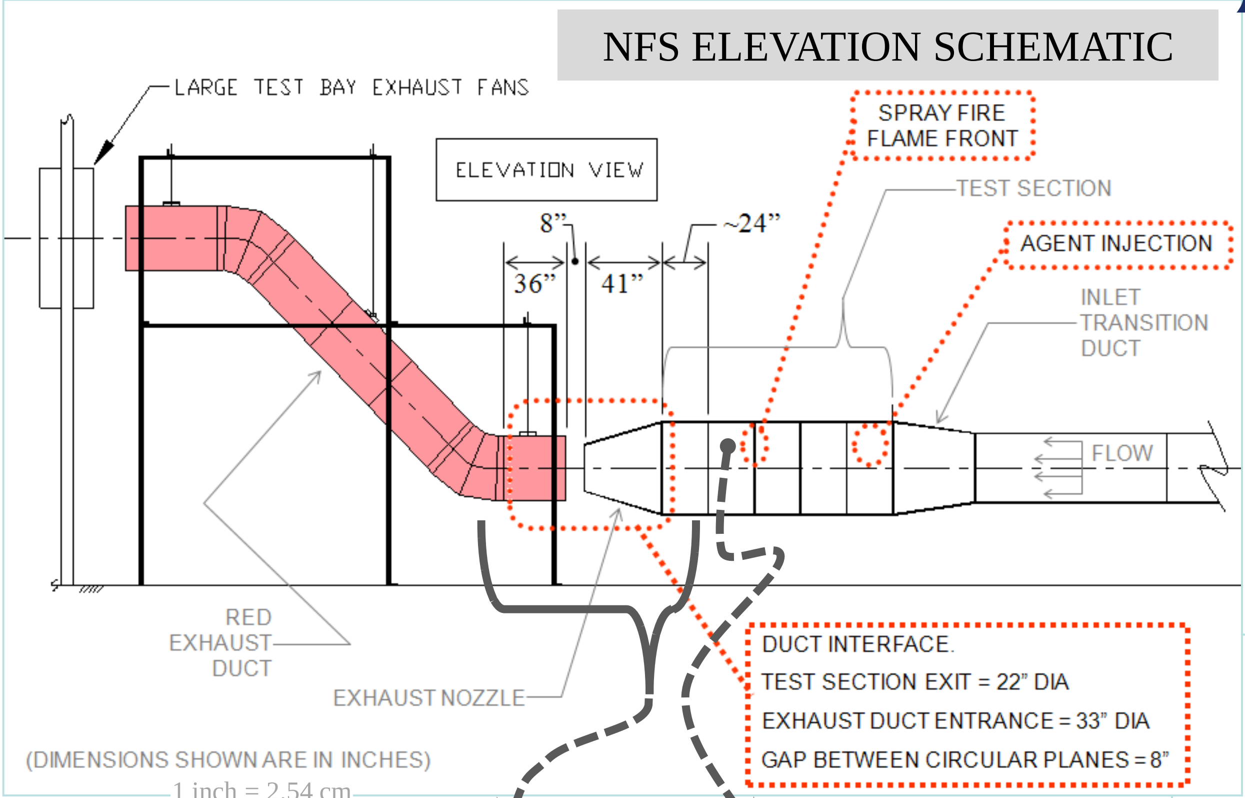
OUTCOME :
Compartment experienced repeated and notable over-pressures, which exceeded the result from the 2003-variant EACS alone. ≈11%v/v HFC-125 threshold related to over-pressure occurrence. Compartment suffered no pressure-related damage.

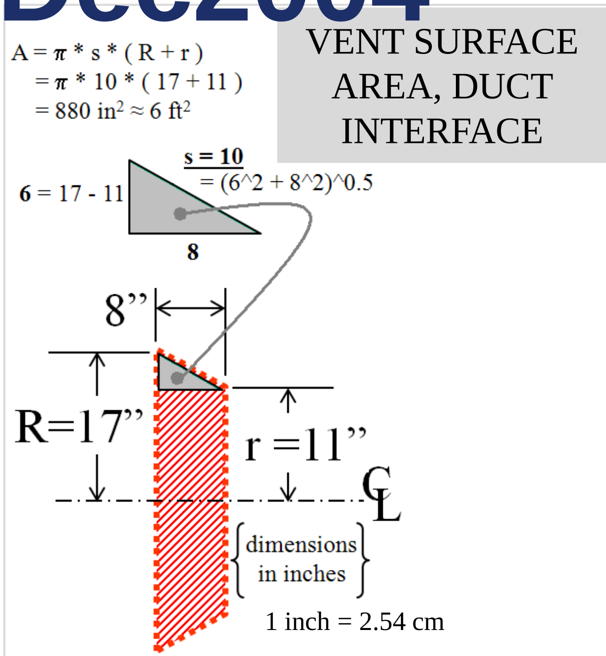
Nacelle Fire Simulator, Dec2004

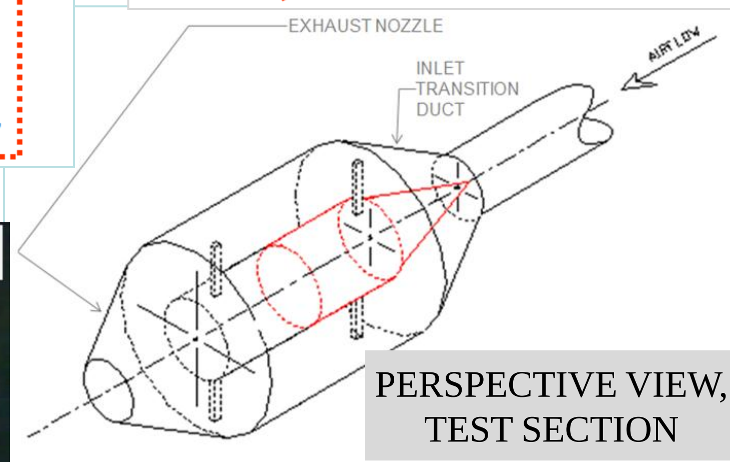
- Bldg 205 nacelle fire simulator (NFS), ≈4 m^3
- Compartment characteristics
  - not aircraft structure; rolled sheet metal & “thin” plate steel
  - “empty” volume
  - has 1 atmospheric gap (duct interface); ≈0.7 m^2 (6 ft^2); the gap is typically at negative pressure, drawing in test bay air
  - forced ventilation, flow ≈0.5 kg/s @ 121°C, average speed just upstream of the flame fronts ≥1.2 m/s (increases in exhaust nozzle)
- Fire threat = atomized spray fire, ≈563 g sprayed over 45 sec
  - JP-8 or Mil-PRF-23699 lubricating oil (MJO2)
  - ignited by AC electrical arc; reignition by the same arc or “hot” surface (reignition event is created, intentional, & typical)
  - fuel sprayed during flame extinction duration; flame extinction due to the presence of HFC-125
- HFC-125 use = a single, initial “high”-rate injection

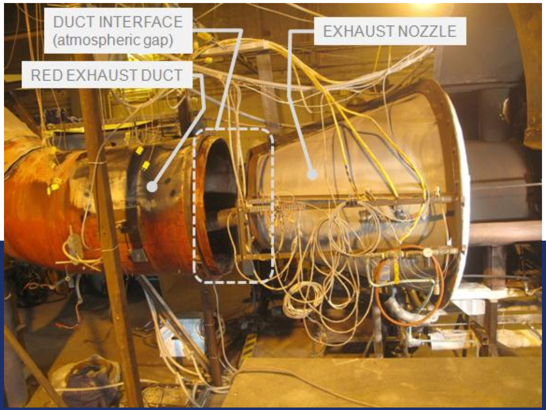
To review this testing, start at http://www.fire.tc.faa.gov/systems/sysarchive.stm, then find the link within the Feb 2005 (2/05) Systems Fire protection Working Group meeting for "2. Engine Nacelle Halon Replacement (20MB Zip file)“, and download.

Nacelle Fire Simulator, Dec2004





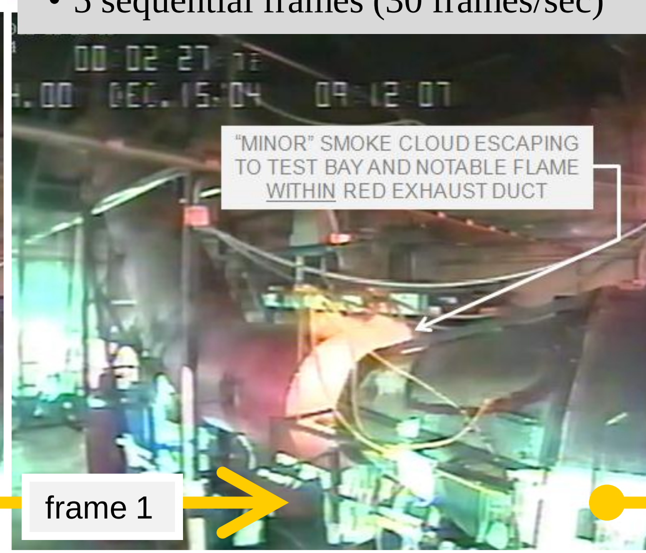




Test 2004c15-10, 0910 EST

Nacelle Fire Simulator, Dec2004

- Providing imagery from 1 of the 2 NFS tests with an over-pressure event at the duct interface
- Behavior of the other NFS test qualitatively produced outcome of lesser magnitude
- 5 sequential frames (30 frames/sec)



OUTCOME :
Two of 16 total tests over-pressurize. Over-pressures characterized as "minor" smoke quantity discharged into test bay through the duct interface/atmospheric gap. Fire extinction behaved typically within test section. No structural damage.

Nacelle Fire Simulator, Dec2004

Providing images from 2 other tests; provides somewhat of a relative understanding…

- 2 sequential frames (30 frames/sec), analogous testing with 2-BTP instead of HFC-125, Sep 2004
- 1 frame, analogous testing with CF_3I, Sep 2006

OBSERVATIONS COLLECTIVELY INDICATE COMPLEXITIES EXIST AT THE DUCT INTERFACE, WHICH AFFECT DIFFERENT SUBSTANCES DIFFERENTLY…

Summarizing Pertinent Tests

- **B727 cargo compartment**
  - "severe" pressure-related damage to altered aircraft structure
  - "near-instant" duration propane/alcohol fire threat
  - without forced ventilation with leakage
  - without HFC-125 use

- **DC-10 cargo compartment**
  - no pressure-related damage to altered aircraft structure
  - "long" duration cellulosic fire threat
  - without forced ventilation with leakage
  - HFC-125 "high"-rate injection and metered delivery

Summarizing Pertinent Tests

- **Pressure vessel**
  - no pressure-related damage to non-aircraft structure
  - “near-instant” duration propane/alcohol fire threat
  - without forced ventilation and without leakage
  - varied HFC-125 use; all premixed homogenous HFC-125/air

- **NFS**
  - no pressure-related damage to non-aircraft structure
  - “short” duration turbine fuel/lubricating oil spray fire threats
  - with forced ventilation and leakage
  - HFC-125 “high”-rate injection delivery

Summarizing Pertinent Tests

Date(s) of Testing	Number of Tests		Test Compartment Descriptions			Fire Threat Descriptions			HFC-125 Use Descriptions	Noteworthy Atypical Behavior
	Total	Atypical	Type, Volume	Pre-fire Ventilation	Leakage Possible ?	fuel package	combustion mode	life span		
08Jul1997	1	1	"cargo", altered aircraft structure, ≈ 11 m^3	buoyant	yes	propane, isopropyl alcohol	evaporative boiling to diffusion flames	≈ 0.003 min (a)	none	compartment overpressure with structural damage
18Sep1997	1	1	"cargo", altered aircraft structure, ≈ 67 m^3	buoyant	yes	cardboard boxes filled with shredded paper (cellulosic)	pyrolysis to diffusion flames	≈ 90 min	"high-rate" and metered injections; all accomplished during the fire	fire in compartment's "hot"gas layer without pressure-related structural damage
07-14Jan2004	8	4	pressure vessel, non-aircraft structure, ≈ 11 m^3	buoyant	no	propane, ethyl alcohol (water included in EACS contents also)	evaporative boiling to diffusion flames	≈ 0.03 min (b)	"high-rate" injection then compartment stir and soak; all completed before the fire	compartment overpressure without structural damage
09-21Dec2004	16	2	"engine", non-aircraft structure, ≈ 4 m^3	forced	yes	JP-8 or Mil-PRF-23699 oil	evaporative "boiling" to diffusion flames	≈ 0.75 min	"high-rate" injection completed during the fire	smoke released to test bay through an atmospheric gap without structural damage

Notes :

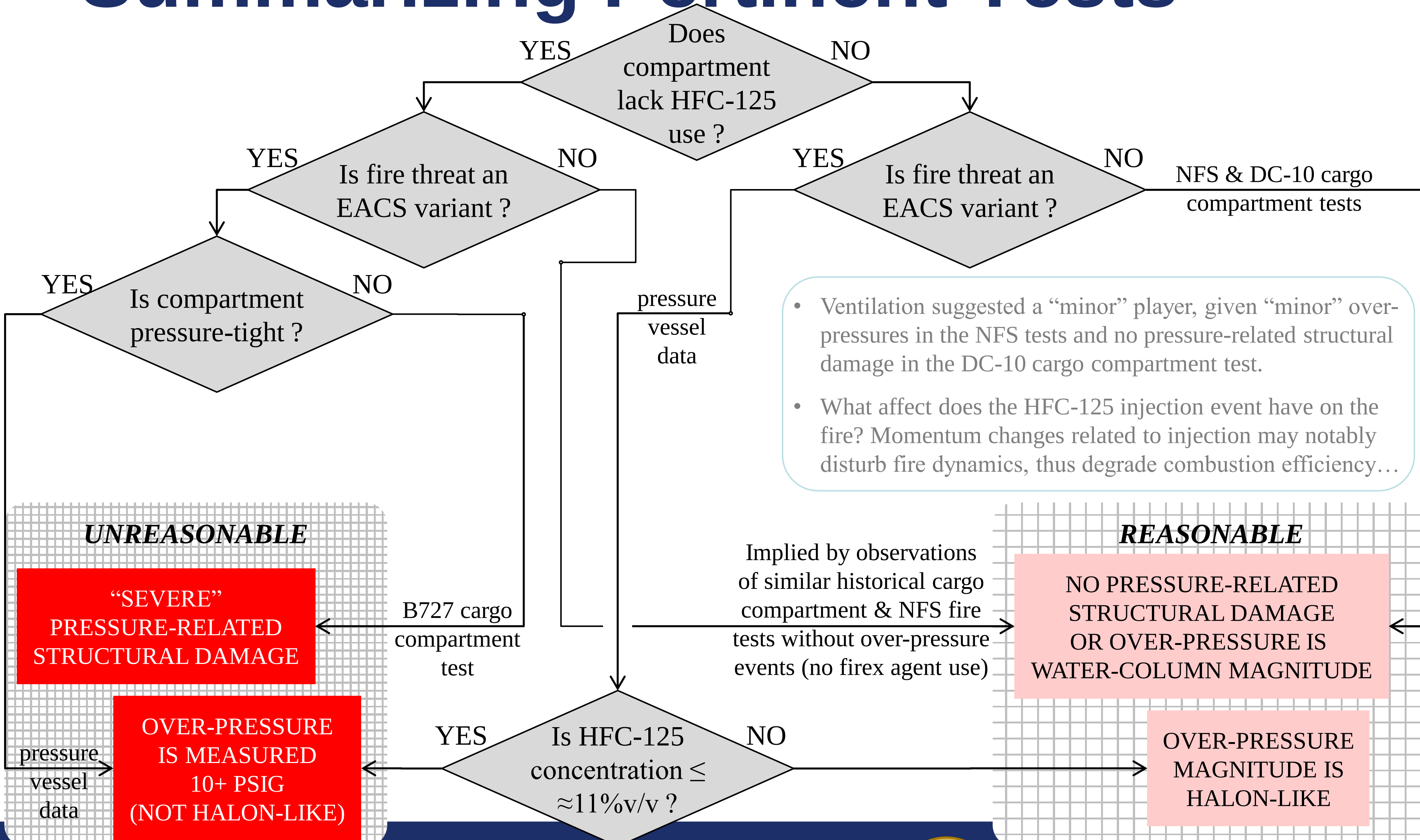
(a) Lifted frame numbers from the visual record of the external "camera end" view. The duration is for the motion of the viewed compartment bulkhead from its initial position to the point of farthest separation and subsequent reversal in motion. The duration represents the pressure creation within the compartment; i.e. indicative of the reaction occurring.

(b) Taken from pressure vessel's pressure history, shown in figure 2/p.6 of Reinhardt (2004). Duration is from the start to peak of pressure history, indicative of the reaction occurring. Reaction completion indeterminate by pressure history as the pressure vessel fully retains pressure rise from the reaction, and associated decay is due to cooling.

Summarizing Pertinent Tests

- **Fire threat intensity appears significant**
  - EACS variants capable of psi-magnitude pressure increases
    - combusting NFS fuel sprays & paper-filled cardboard boxes create compartmental pressure increases of water-column magnitude
    - attributable to propane as 1 of its constituent fuels
      - expansion & vaporization upon release are the most active of these fuels
      - expansion & vaporization assist with dispersing other EACS contents
  - EACS >> NFS fuel sprays > paper-filled cardboard boxes
- **Compartment ventilation and leakage not so much**
  - NFS > cargo compartments >> pressure vessel
- **Considerations of structural similarity with aircraft**
  - Cargo compartments > NFS >> pressure vessel

Summarizing Pertinent Tests



- Ventilation suggested a "minor" player, given "minor" over-pressures in the NFS tests and no pressure-related structural damage in the DC-10 cargo compartment test.
- What affect does the HFC-125 injection event have on the fire? Momentum changes related to injection may notably disturb fire dynamics, thus degrade combustion efficiency…

Summarizing Pertinent Tests

- **Suggested over-pressure considerations**
  1. The type of fire present
     - energy availability – fuel type (propane, Jet-A, cellulose), quantity
     - rate of energy release – state/phase, vapor pressure, subdivision
  2. HFC-125 use
     - quantity
     - fire/HFC-125 interaction? – pre-/post-fire injection, resident duration
     - state? – “cold”-/”hot”-soaked at discharge
  3. Aspects of the compartment that attenuate over-pressure
     - ventilation – dilutional flow and cooling, over-pressure bleed pathway
     - ability to “leak” – over-pressure bleed pathway
     - structural composition – ability to withstand over-pressure
     - filled/cluttered volume? – quenching? fluid flow & mixing dynamics?

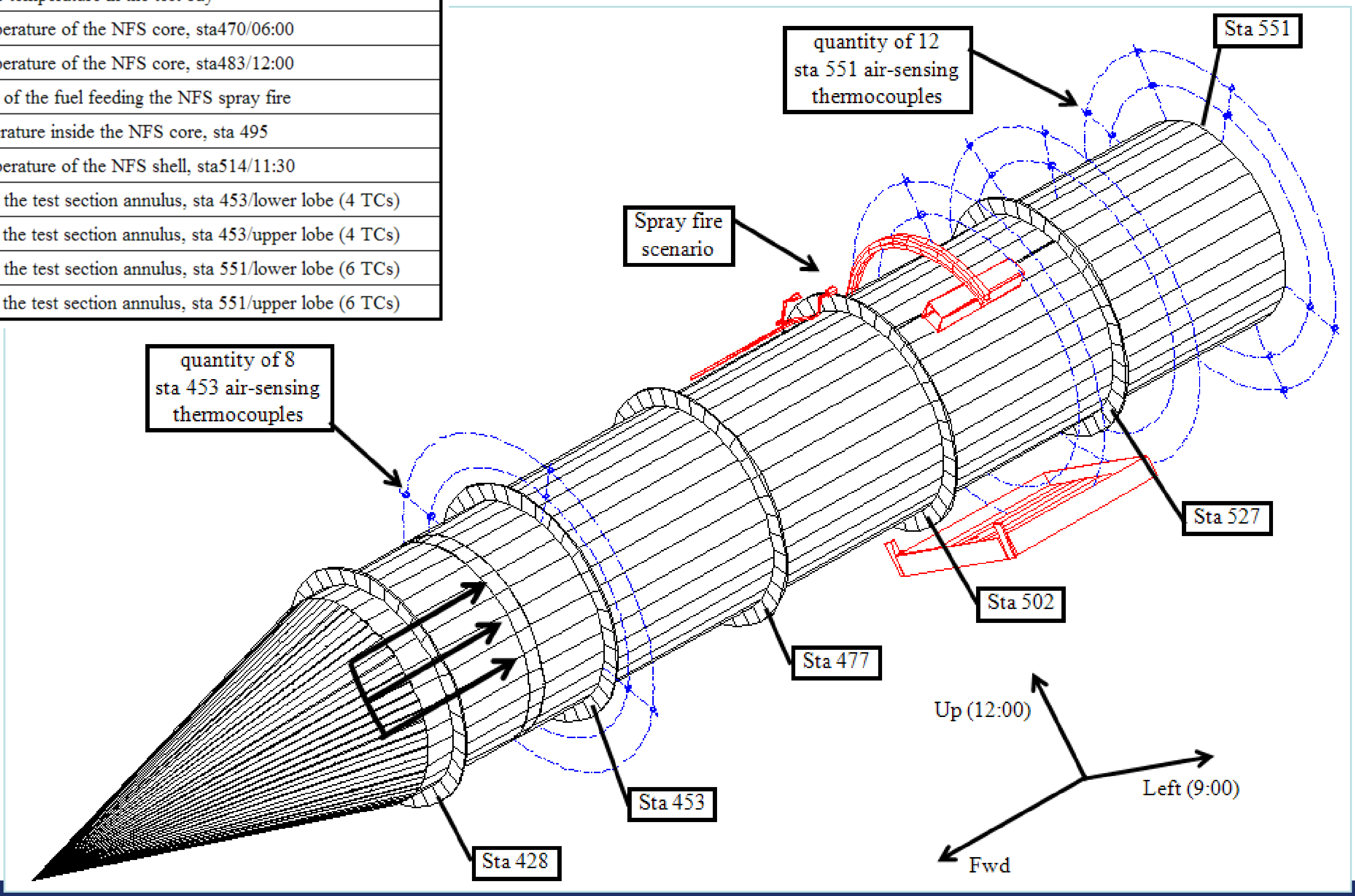
NFS Appendix Information

- Additional information is here provided to permit further review of the complexities of the NFS testing, which exceed the need-to-know for this meeting presentation.
- This information is provided for those having further interest in this topic.

Nacelle Fire Simulator, Dec2004

Name of Thermocouple or Sensor in Graph	Description of Thermocouple or Sensor
sen/FRX botl p/t	pressure signal from pressure transducer sampling inside firex bottle
sen/Inlt HWA	flow speed signal from hot-wire anemometer at NFS inlet
TCel Temp (TC)	air temperature in the test bay
tst/470/t/csfc_06	surface temperature of the NFS core, sta470/06:00
tst/483/t/csfc_12	surface temperature of the NFS core, sta483/12:00
tst/490/t/spr_f.1	temperature of the fuel feeding the NFS spray fire
tst/495/t/c_int	air temperature inside the NFS core, sta 495
tst/514/t/ex11:30	surface temperature of the NFS shell, sta514/11:30
ave_sta453lwr	average air temperature in the test section annulus, sta 453/lower lobe (4 TCs)
ave_sta453upr	average air temperature in the test section annulus, sta 453/upper lobe (4 TCs)
ave_sta551lwr	average air temperature in the test section annulus, sta 551/lower lobe (6 TCs)
ave_sta551upr	average air temperature in the test section annulus, sta 551/upper lobe (6 TCs)

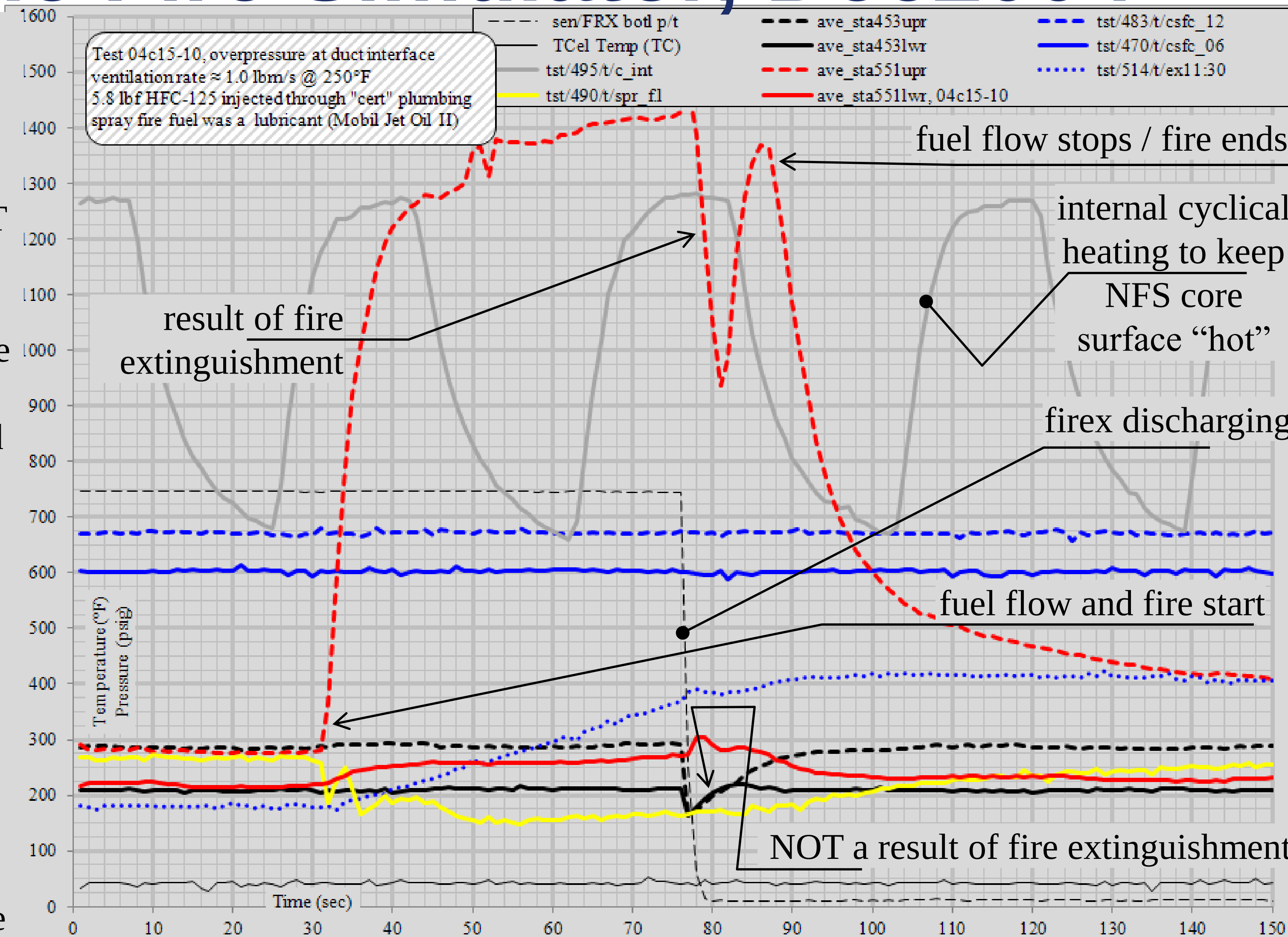
SCHEMATIC VIEW OF SOME PERTINENT NFS THERMOCOUPLES



Nacelle Fire Simulator, Dec2004

GRAPH OF THE TYPICAL NFS ENVIRONMENT DURING A FIRE EXTINGUISHMENT TEST

- Test 04c15-10 is here shown, 1 of 2 tests that over-pressurized the NFS duct interface
- Thermal variations seen just after the firex discharge are associated with the HFC-125 injection into the NFS environment
- 5.8 lbf HFC-125 extinguished this fire for 4.15 sec.



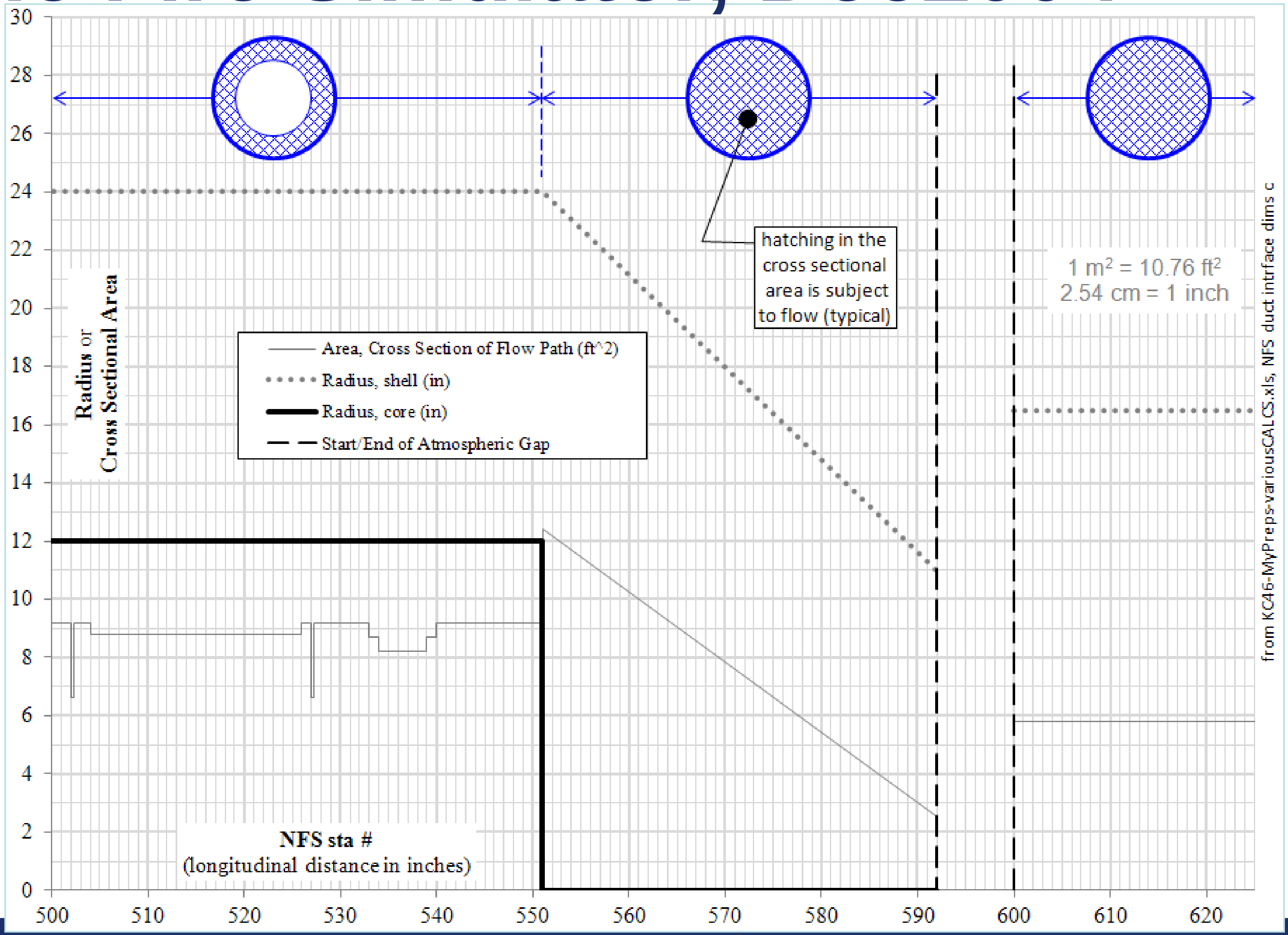
T(°C) = 5/9 * (T(°F) – 32)

1 psi = 6.9 kPa

@ 1g, 1 lbf has a mass = 1 lbm, 1 kg = 2.205 lbm

Nacelle Fire Simulator, Dec2004

GEOMETRY OF THE DUCT INTERFACE (atmospheric gap)



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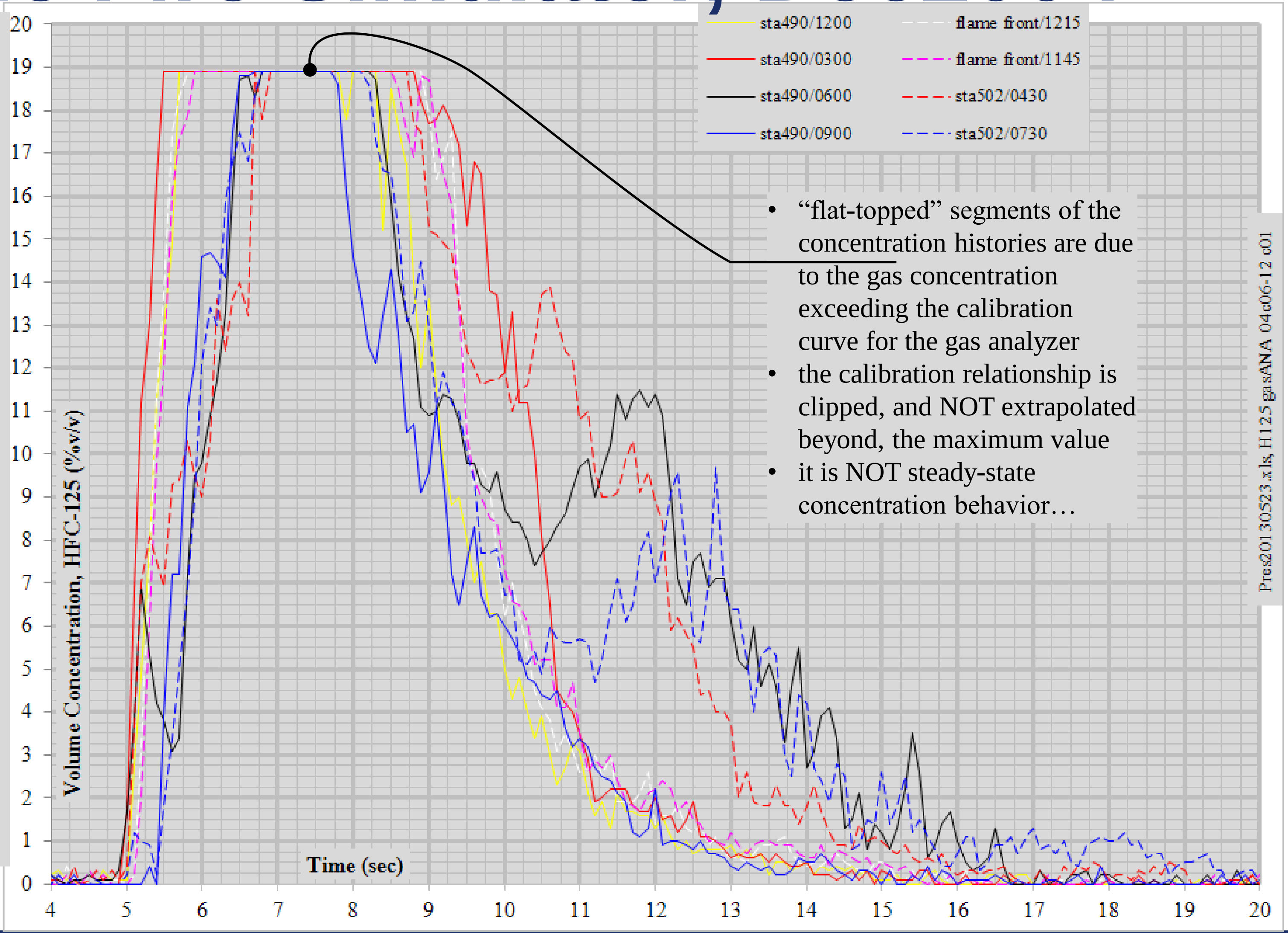
Nacelle Fire Simulator, Dec2004

HFC-125 CONCENTRATION HISTORIES, 5.8 LBF INJECTED

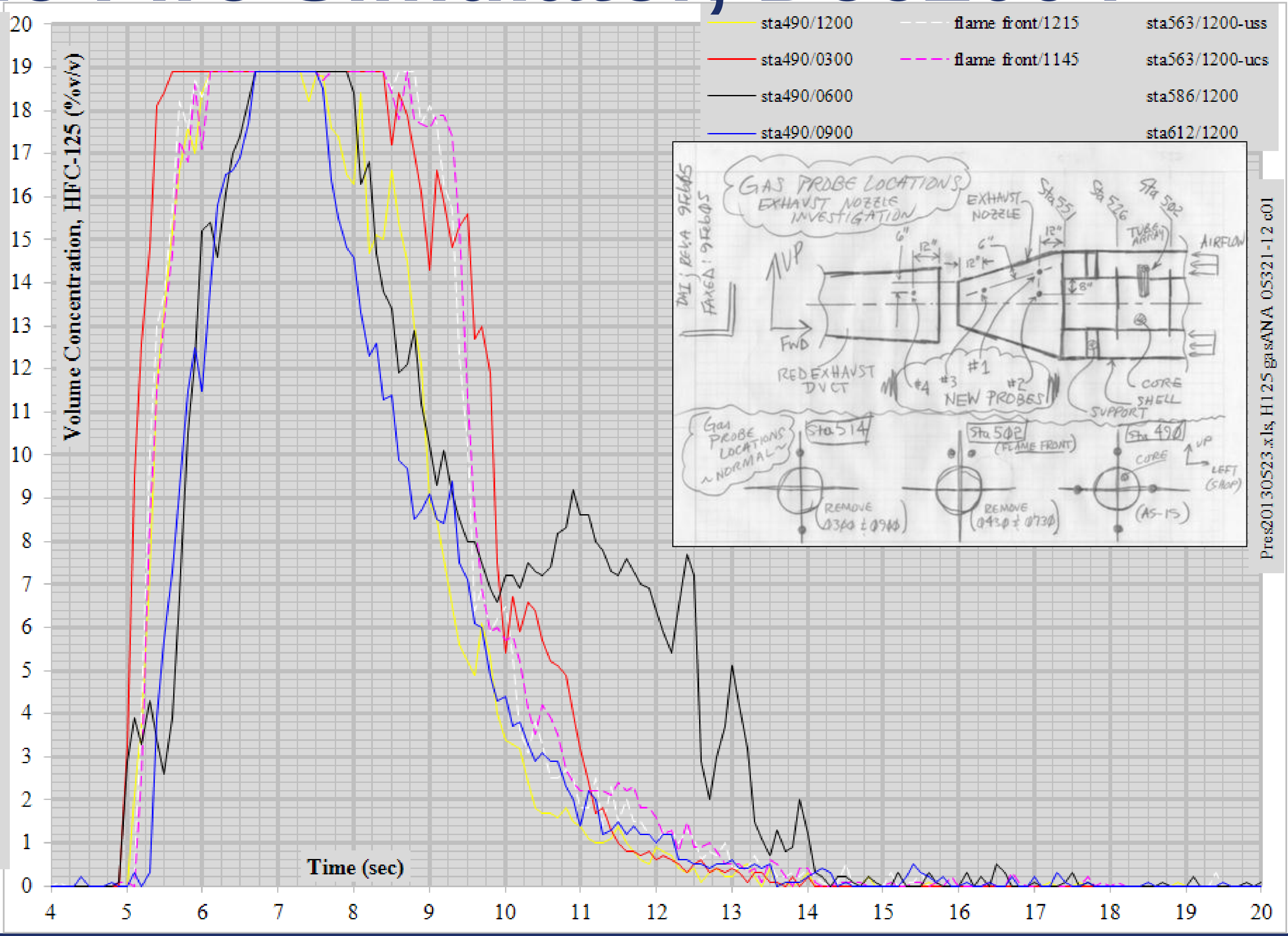
- measured without fire present
- test # 2004c06-12
- 12 sample points dispersed about the sta502 spray flame front per MPSe rev03
- only 8 sample points shown in this graph
- all sample points are in the free stream



Nacelle Fire Simulator, Dec2004

HFC-125 CONCENTRATION HISTORIES, 5.8 LBF INJECTED

- measured without fire present
- test # 2005321-12
- 12 sample points used, 3 relocated within the NFS exhaust nozzle and 1 inside the red exhaust duct
- all sample points EXCEPT “sta563/1200-ucs” are in the free stream



Nacelle Fire Simulator, Dec2004

HFC-125 CONCENTRATION HISTORIES, 5.8 LBF INJECTED

- measured without fire present
- test # 2005321-12
- 12 sample points used, 3 relocated within the NFS exhaust nozzle and 1 inside the red exhaust duct
- all sample points EXCEPT “sta563/1200-ucs” are in the free stream