Halon Replacement

Federal Aviation
Administration

Test Experience in a Civil Transport Aircraft Engine Nacelle using a Solid Aerosol Fire Extinguishant

Presented to: Seventh Triennial International Fire & Cabin Safety Research Conference

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Date: 5 December 2013

Presentation Overview

- **Purpose & Pertinent Background**
- **Test Article Description**

  …test article, telemetry

- **Test Conditions**

  …global test conditions & other associated information

- **Test Results**

  …observations, thermal & fire behaviors, outcomes

Purpose & Pertinent Background

- **To demonstrate proposed design criteria for a solid-aerosol fire extinguishing agent were reasonable**
  - demonstration testing part of MPSe rev04[(1)] testing
  - proposed design criteria from earlier NFS test outcomes
  - FAA/industry cooperation during project
  - industry-operated/-maintained firex system & analyzer
- **Timeline of the test project**
  - NFS testing, MPSe rev04, 2010-2011
  - demonstration build-up & testing, 2011-2012

MPSe = Minimum Performance Standard, Halon Replacement
rev = revision
NFS = nacelle fire simulator

Purpose & Pertinent Background

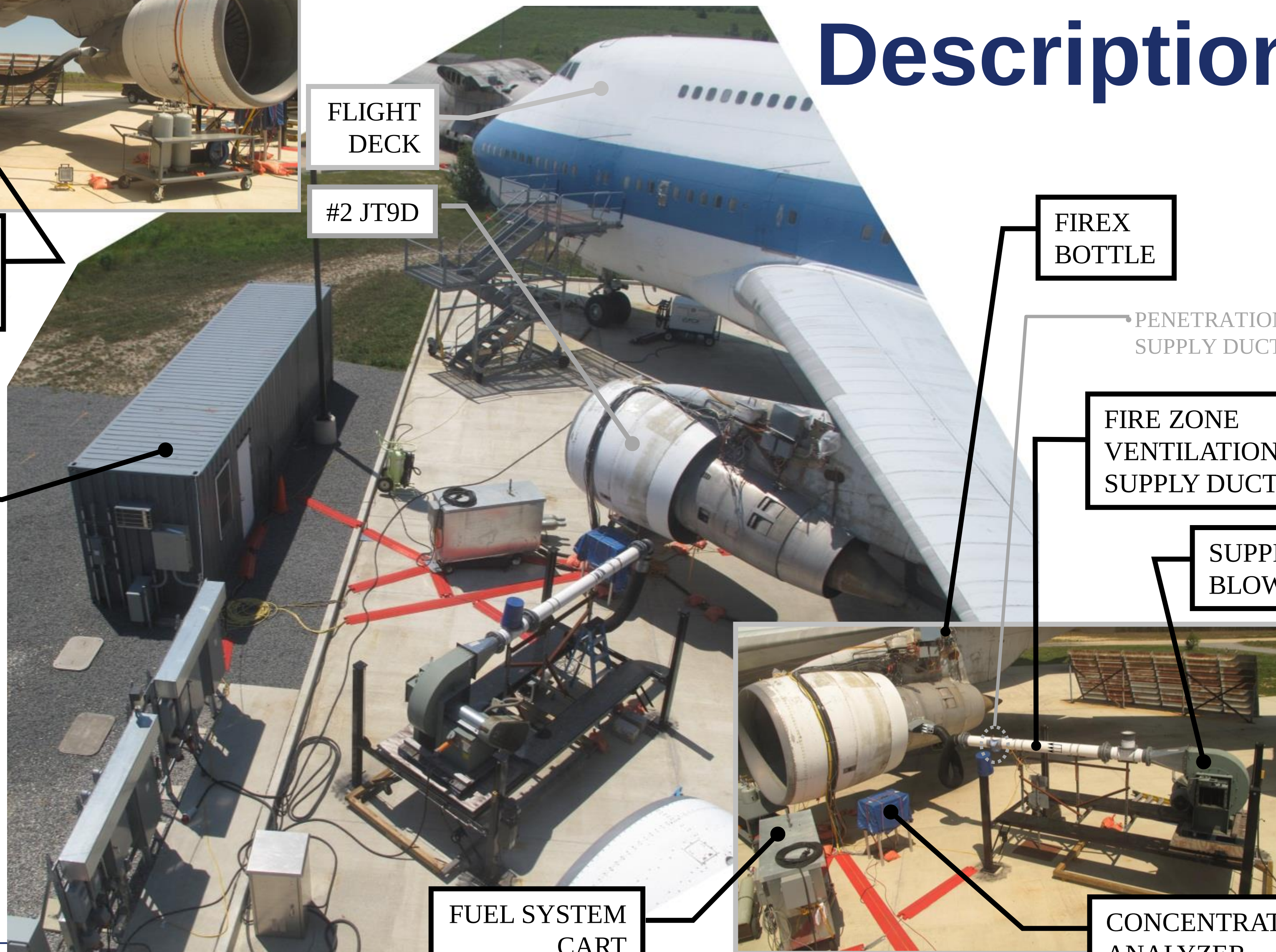
- **Performed a cumulative readjustment from a halon 1301- to aerosol-based mentality**
  - industry team, developed solid-aerosol fire extinguishing agent, its concentration analyzer, & use on an airplane
  - industry team/FAA, investigational MPSe rev03 testing
  - FAA IASFPWG[(2)], engine halon replacement task-group, MPSe revision, rev03 to rev04
  - FAA, recognition of the firex agent & its analyzer
  - industry team/FAA, MPSe rev04 testing, FAATC NFS
  - industry team/FAA, MPSe rev04 testing, turbine engine

FAATC = FAA Technical Center

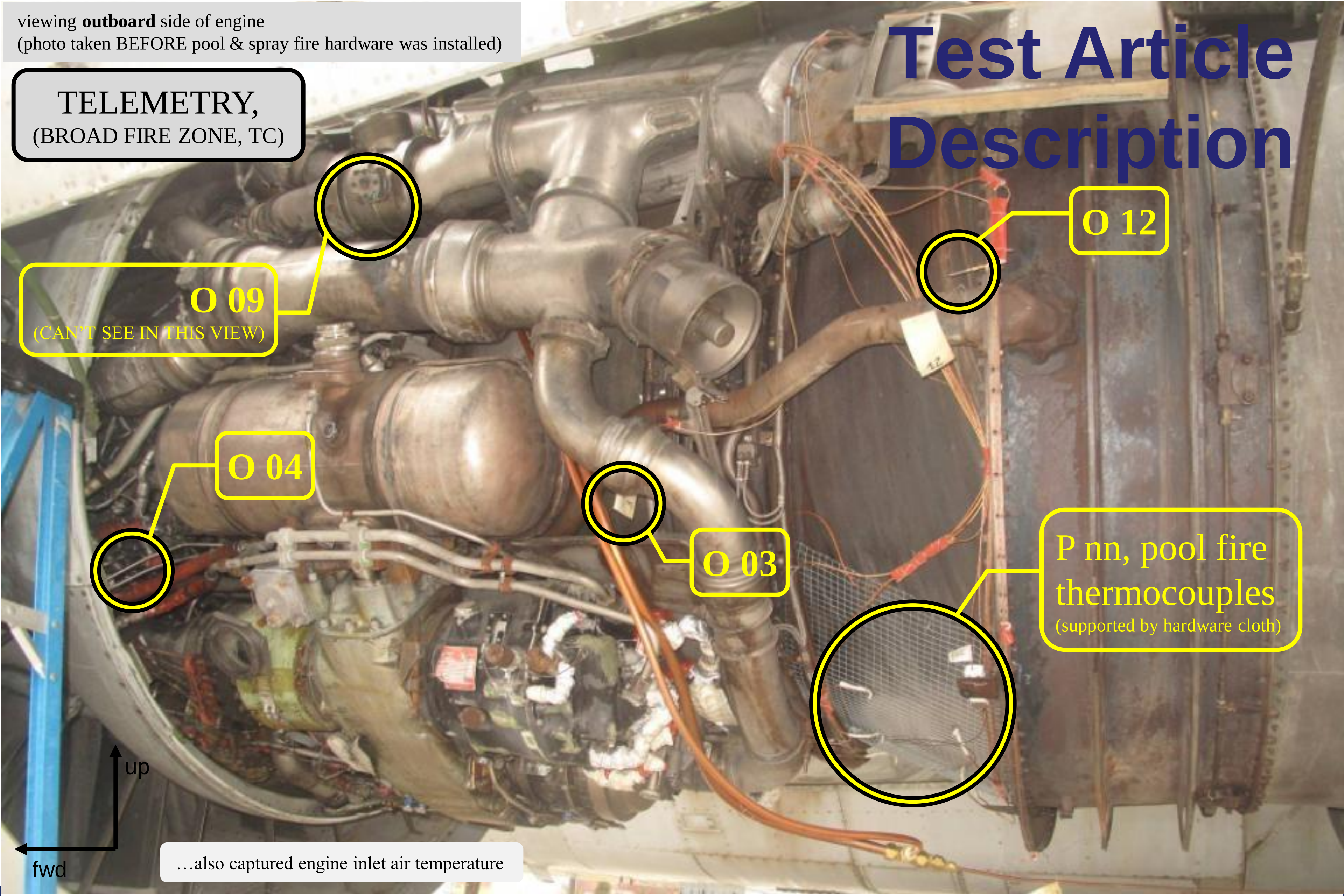
Test Article Description

- **Testing accomplished using…**
  - FAA-owned Boeing 747SP
  - #2 Pratt & Whitney JT9D turbine engine; operated from aircraft flight deck
  - ancillary ground-operated systems
    - external nacelle ventilation forced through engine fire zone
    - external fuel conditioning & supply
    - spray & pool fire threats included within engine fire zone
    - fire extinguishing system
    - data collection systems
      - numerical : temperature, pressure, & firex agent distribution
      - visual

Test Article Description

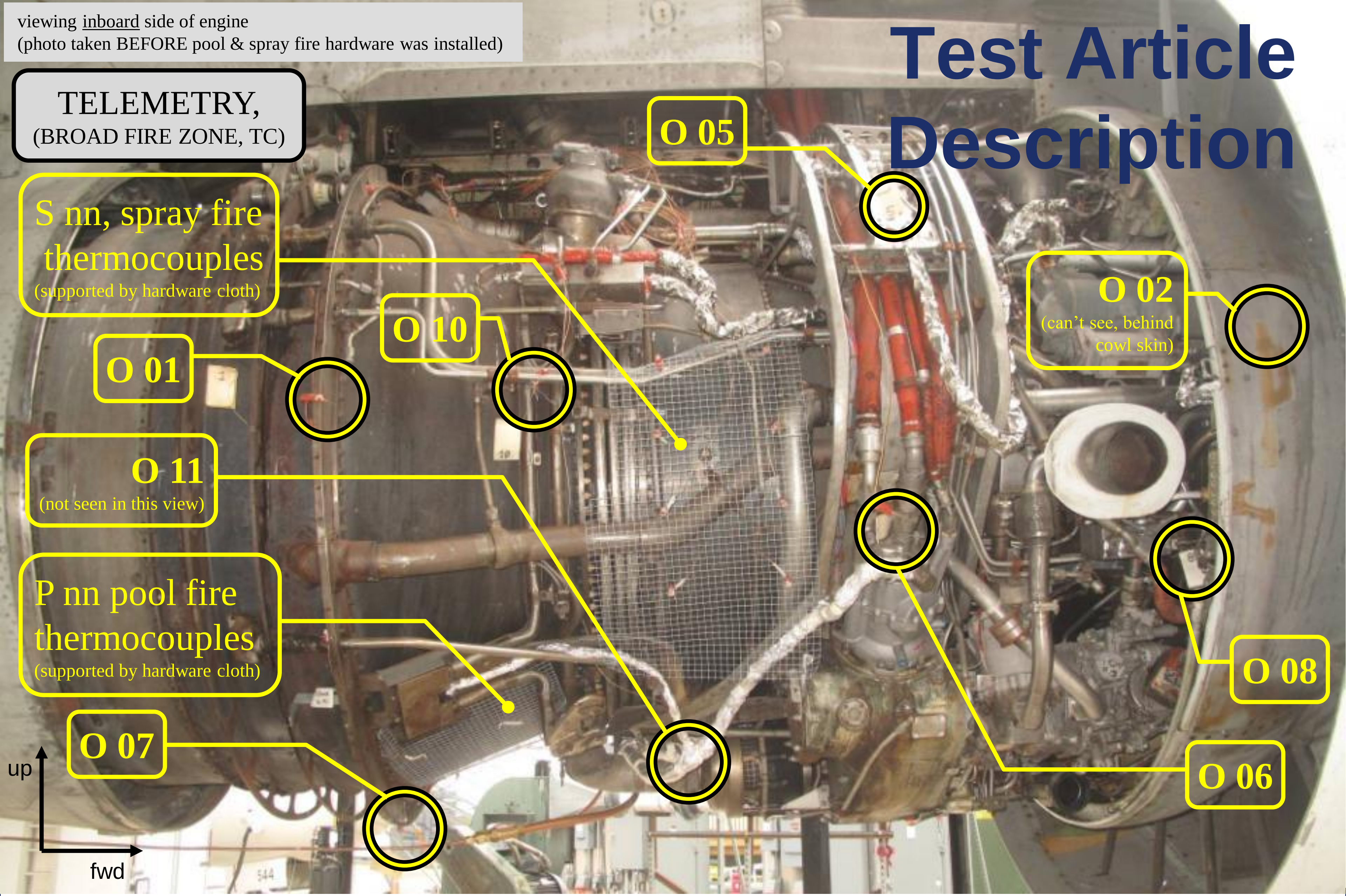


Test Article Description



TC = thermocouple
O = original
P = pool fire
nn = specific number of the 8 pool TCs

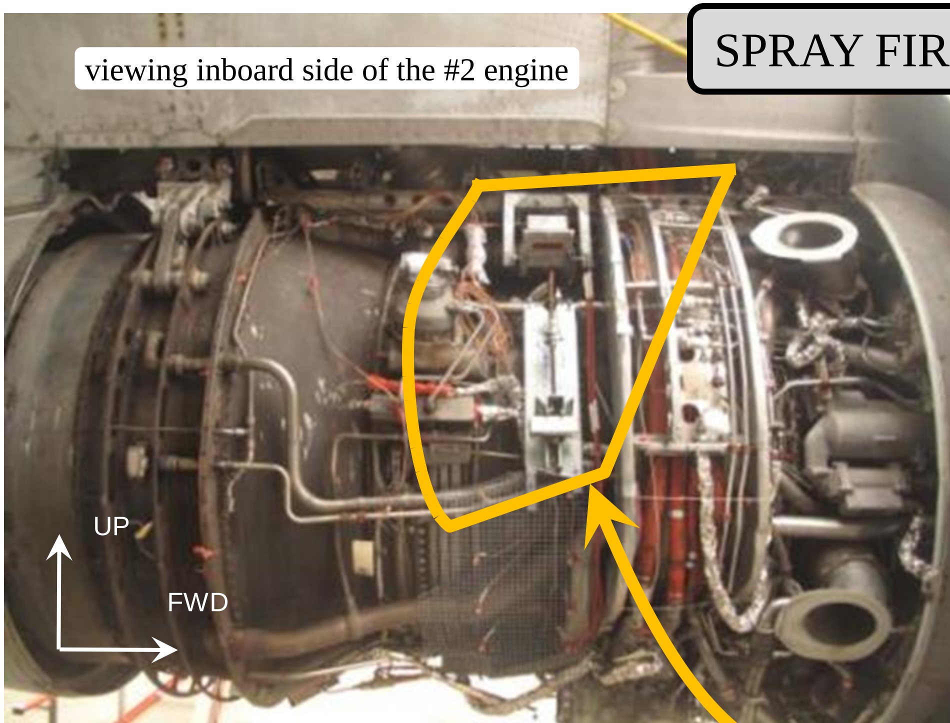
Test Article Description

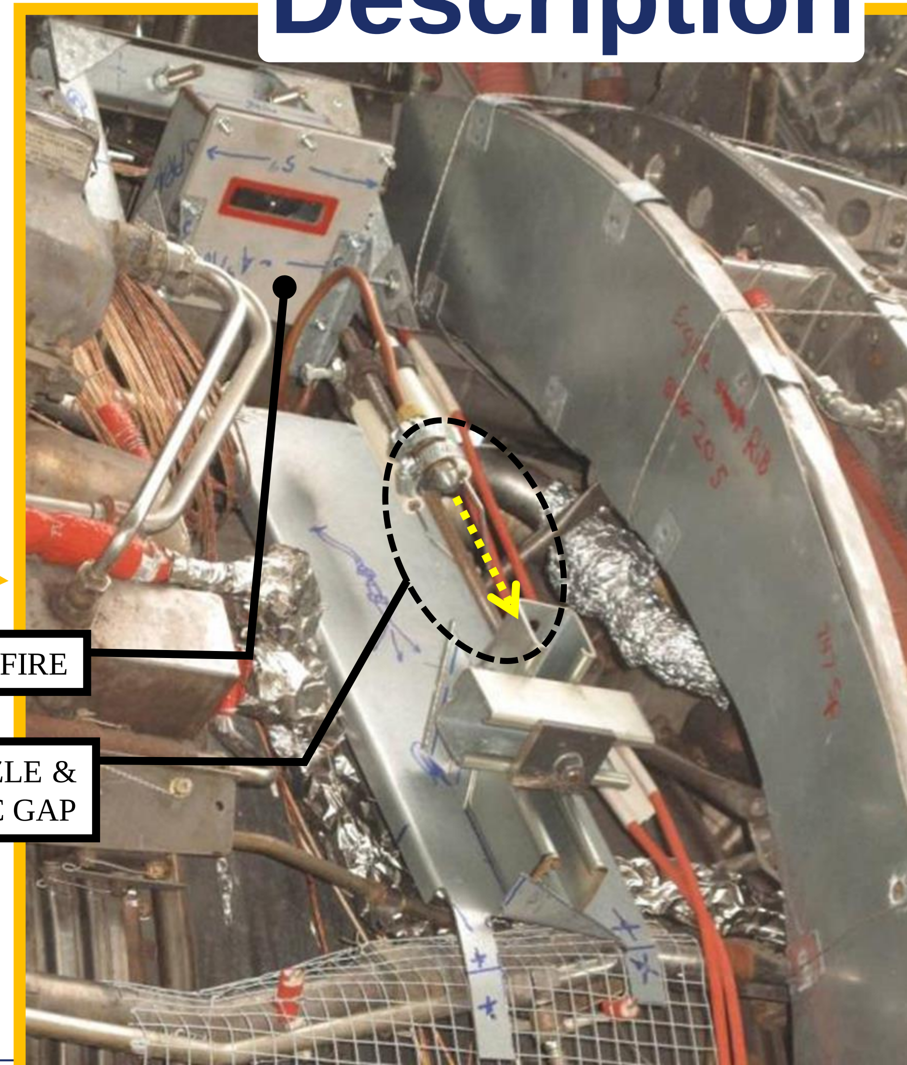


S = spray
nn = specific number of the 8 spray fire TCs

Test Article Description

SPRAY FIRE THREAT





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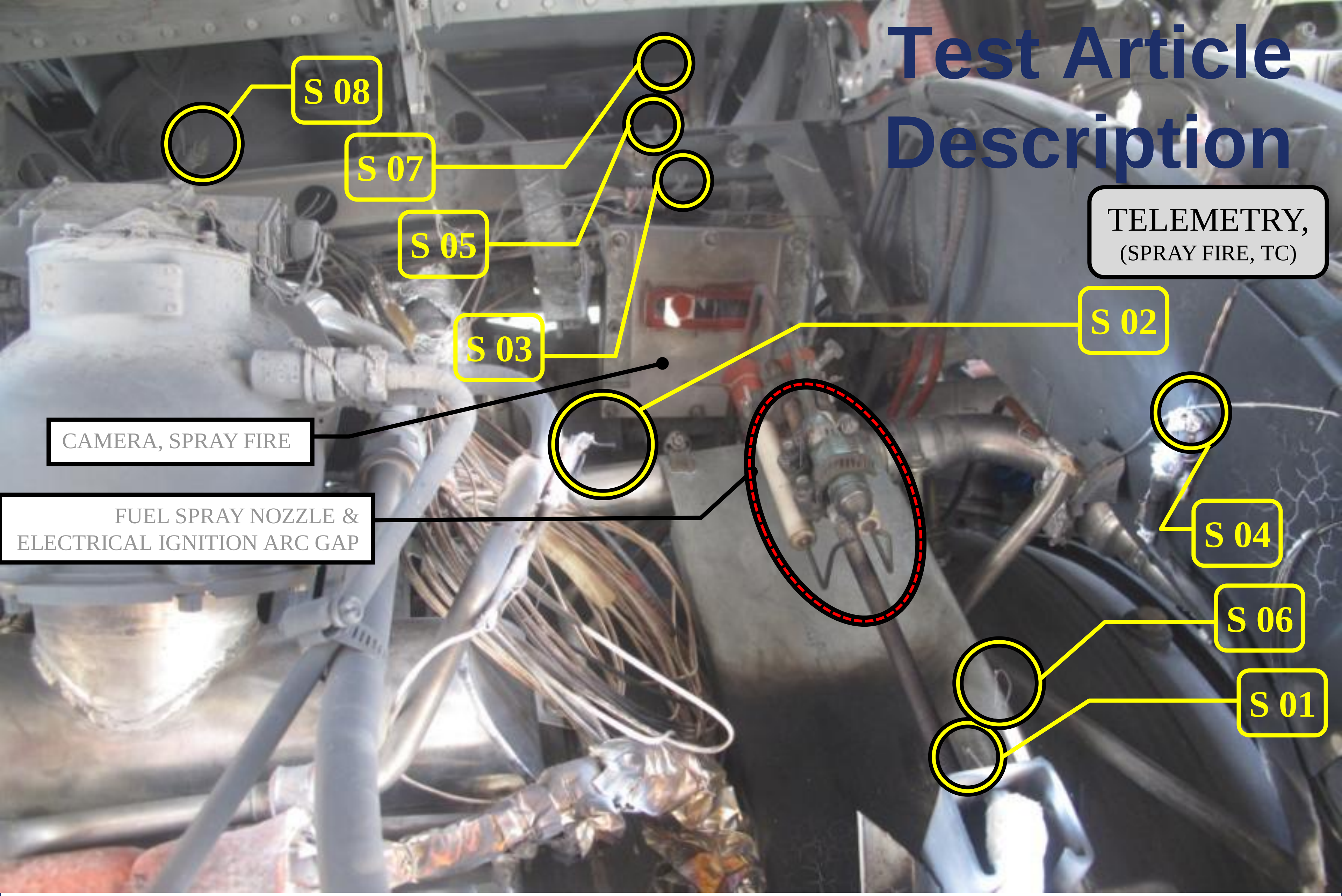

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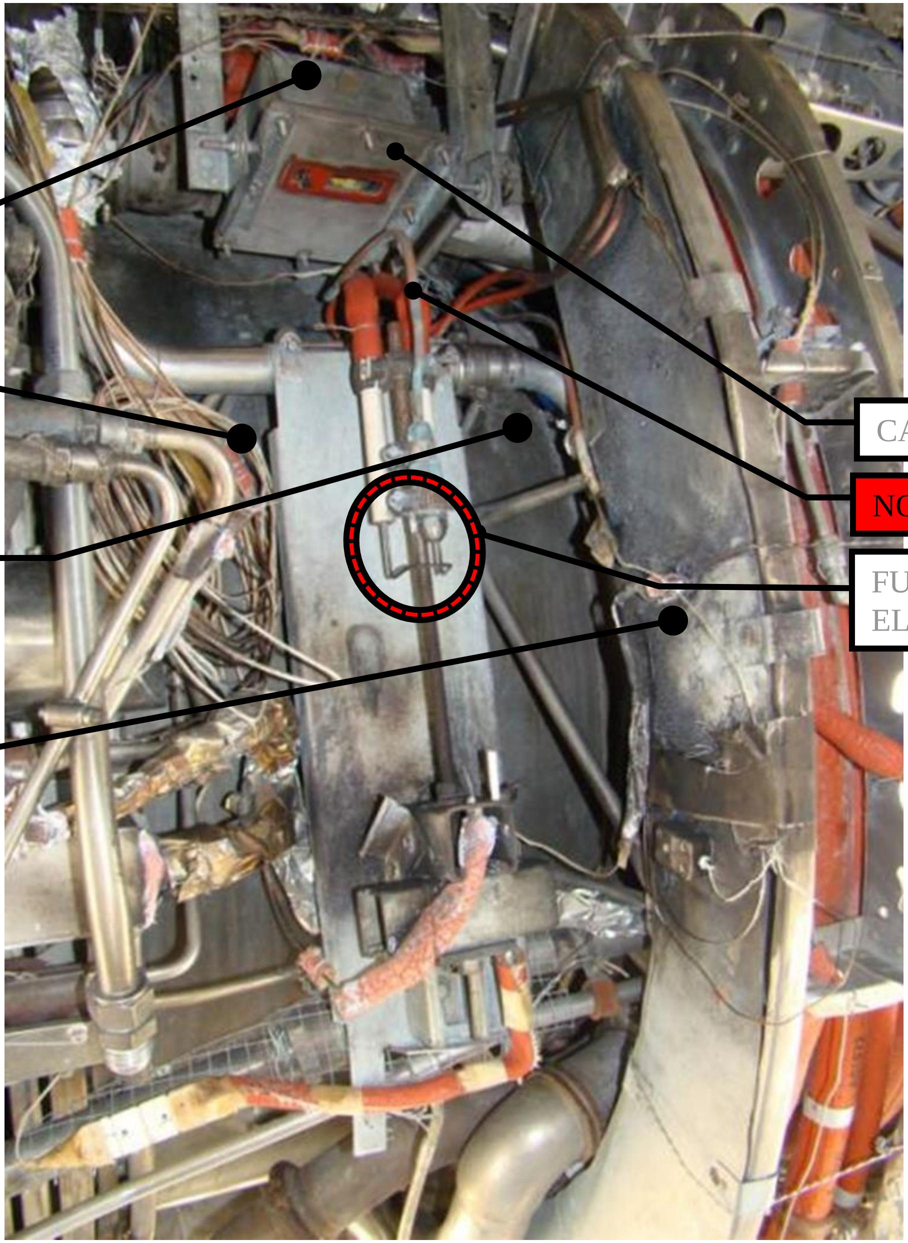
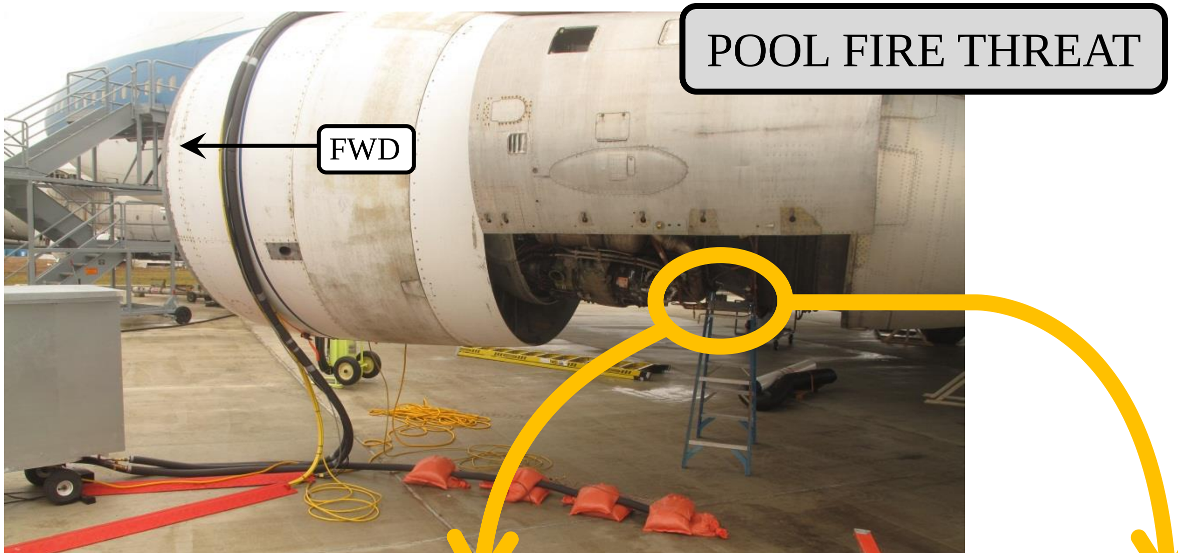
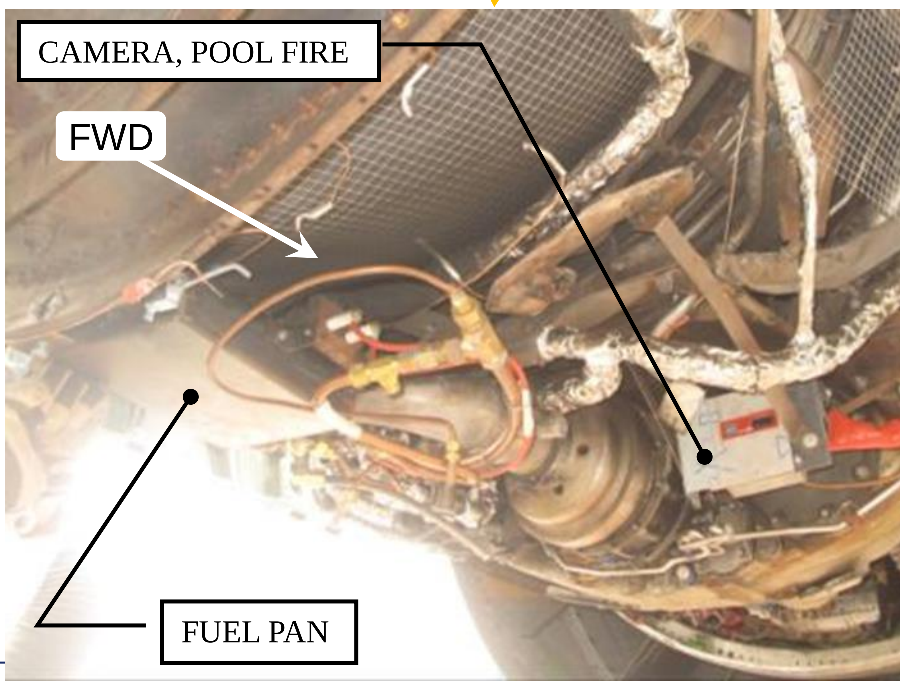
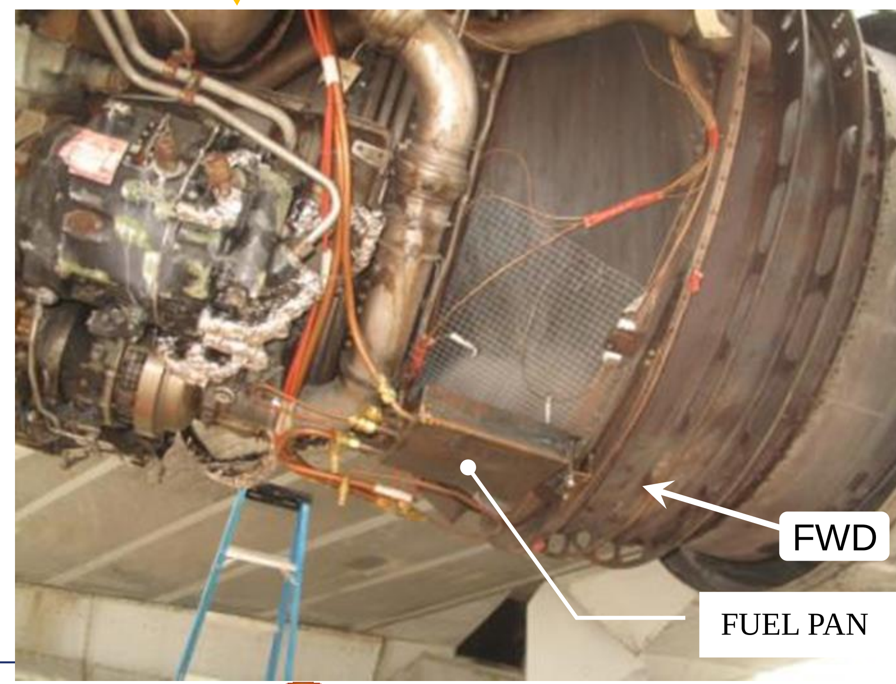


CONC = firex agent concentration

Test Article Description







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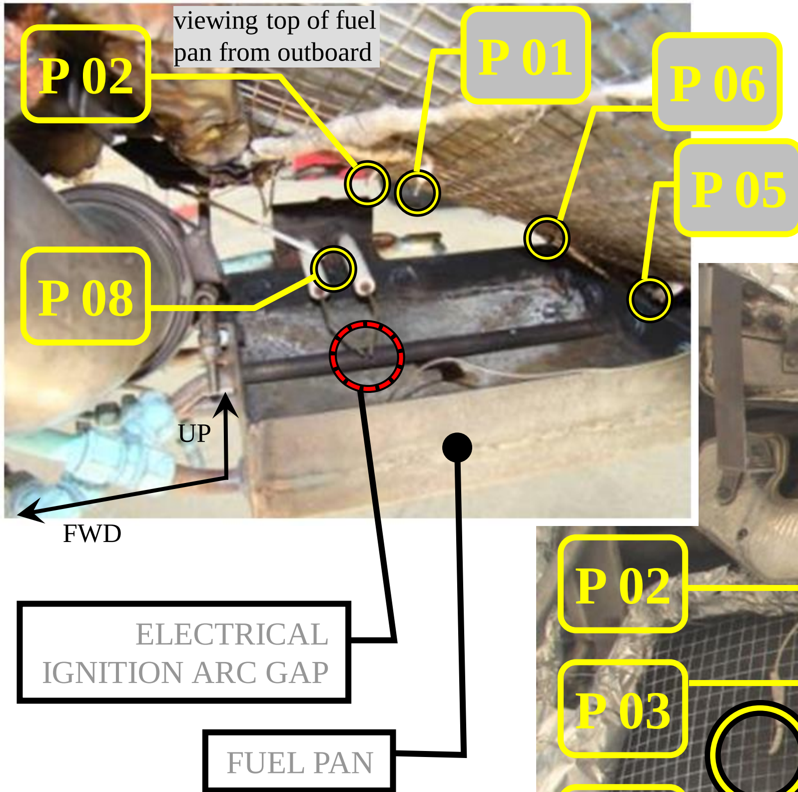

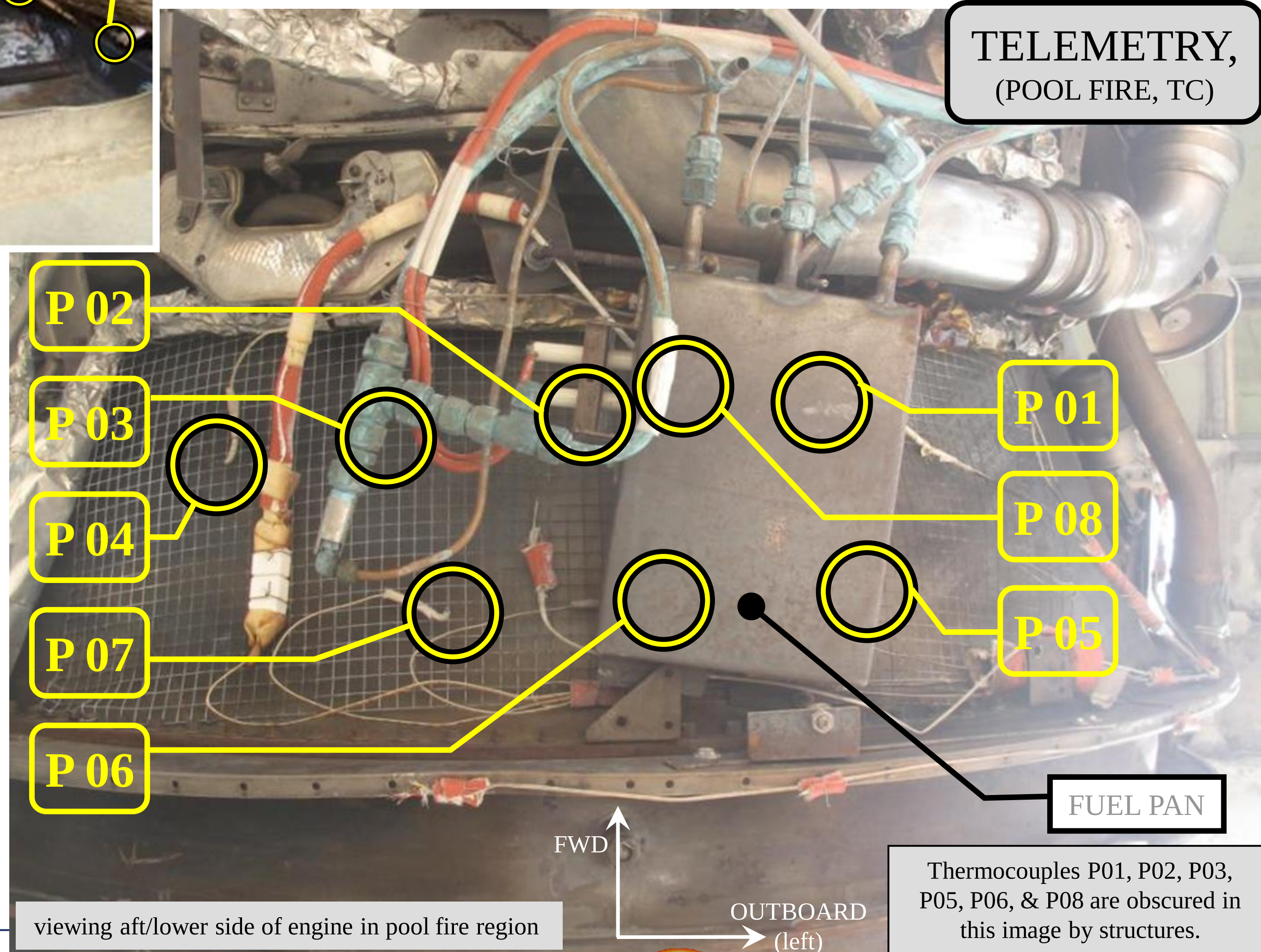

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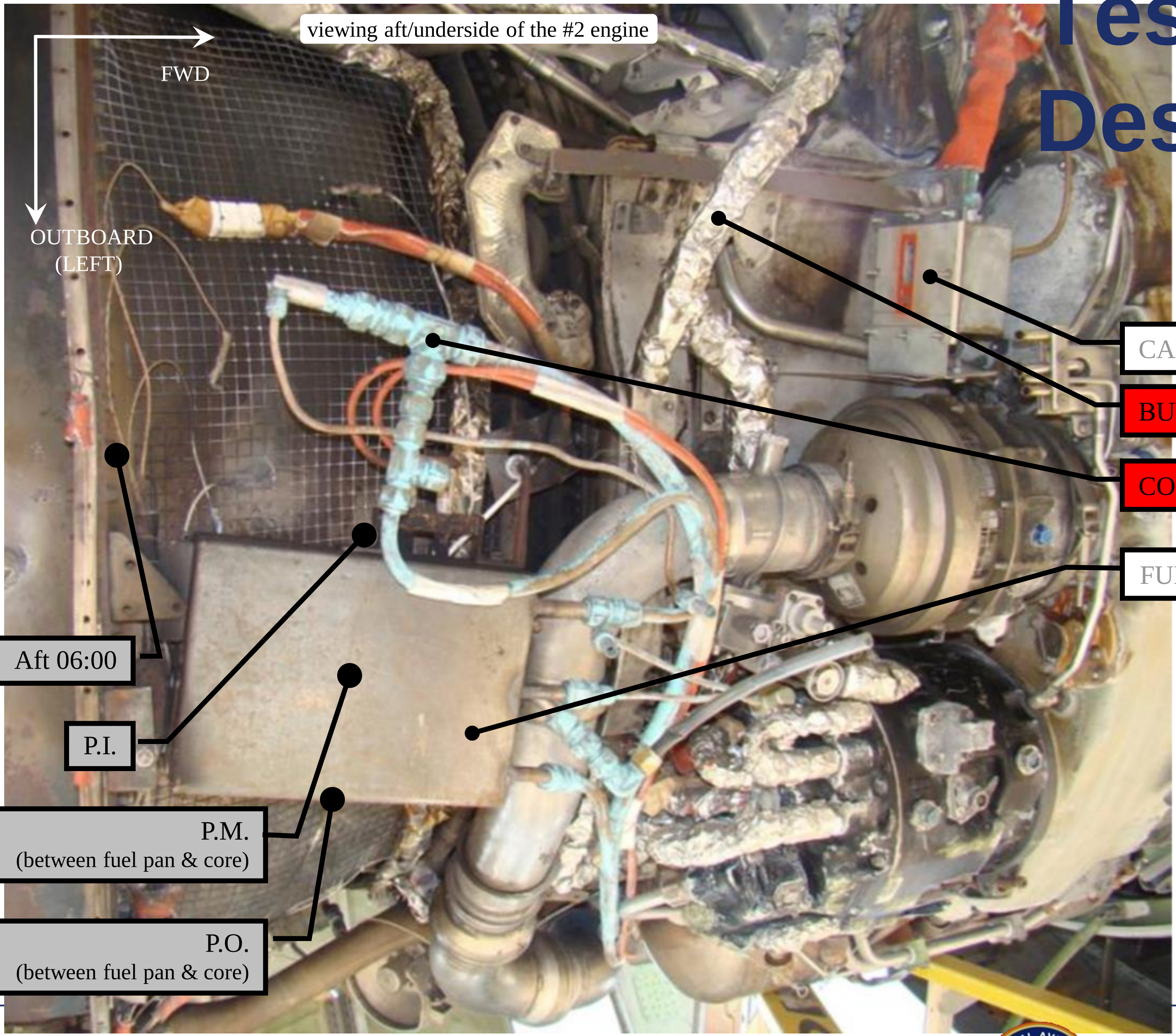


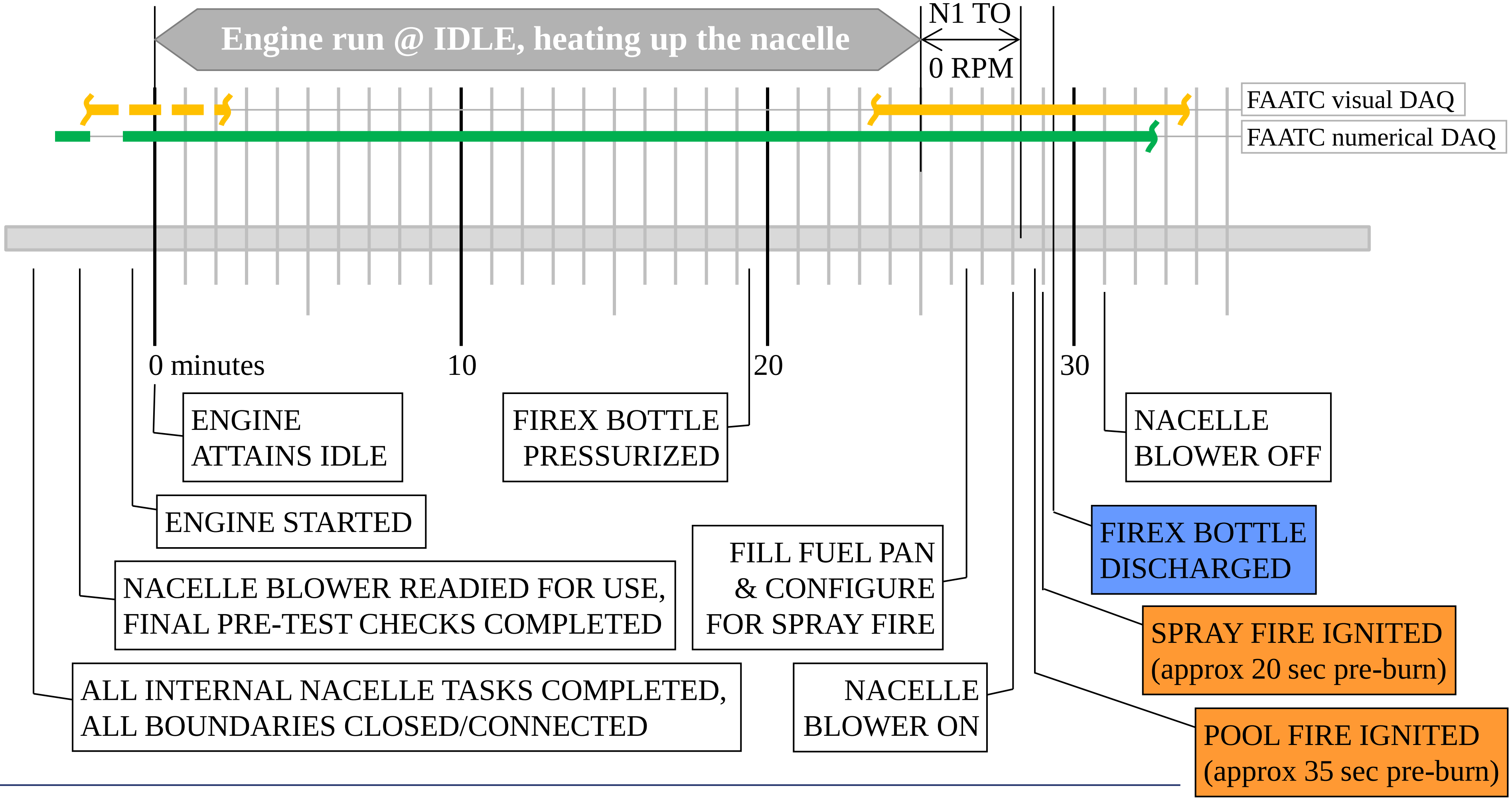
Test Conditions

- **Global details of the fire extinguishment test**
  - fire zone ventilation
    - 0.5 kg/s fire zone forced ventilation rate
    - T = ambient atmosphere, P ≈ 1 atm
  - fires
    - burning JP-8 fuel conditioned to 46°C
    - spray fuel flow : 180 mL/min, single atomizing nozzle
    - fuel pool : 19.1 x 26.8 x 1.3 cm (water-jacketed base)
    - electrical arcs used to ignite each fire; turned off after ignition
    - fire intensity assessed via pressurized nitrogen (N_2) injection from the firex system
  - engine surfaces "hot"; followed an engine run

Test Conditions

- **Global details of the fire extinguishment test**
  - firex system & the sodium bicarbonate solid aerosol
    - multiple injection nozzles (butt-cut tube)
    - injected from upper region of the fire zone, fore-aft, to both sides
    - “protected” region
      - localized to each fire threat simultaneously
      - reduced from original intent to protect the entire fire zone
    - firex agent injected against simultaneously burning fires
  - goals :
    - not to extinguish fires with the injected N_2
    - extinguish fires with the solid aerosol’s proposed design criteria
    - reignition set aside; discussion point contingent upon outcome

Test Conditions



DAQ = data acquisition

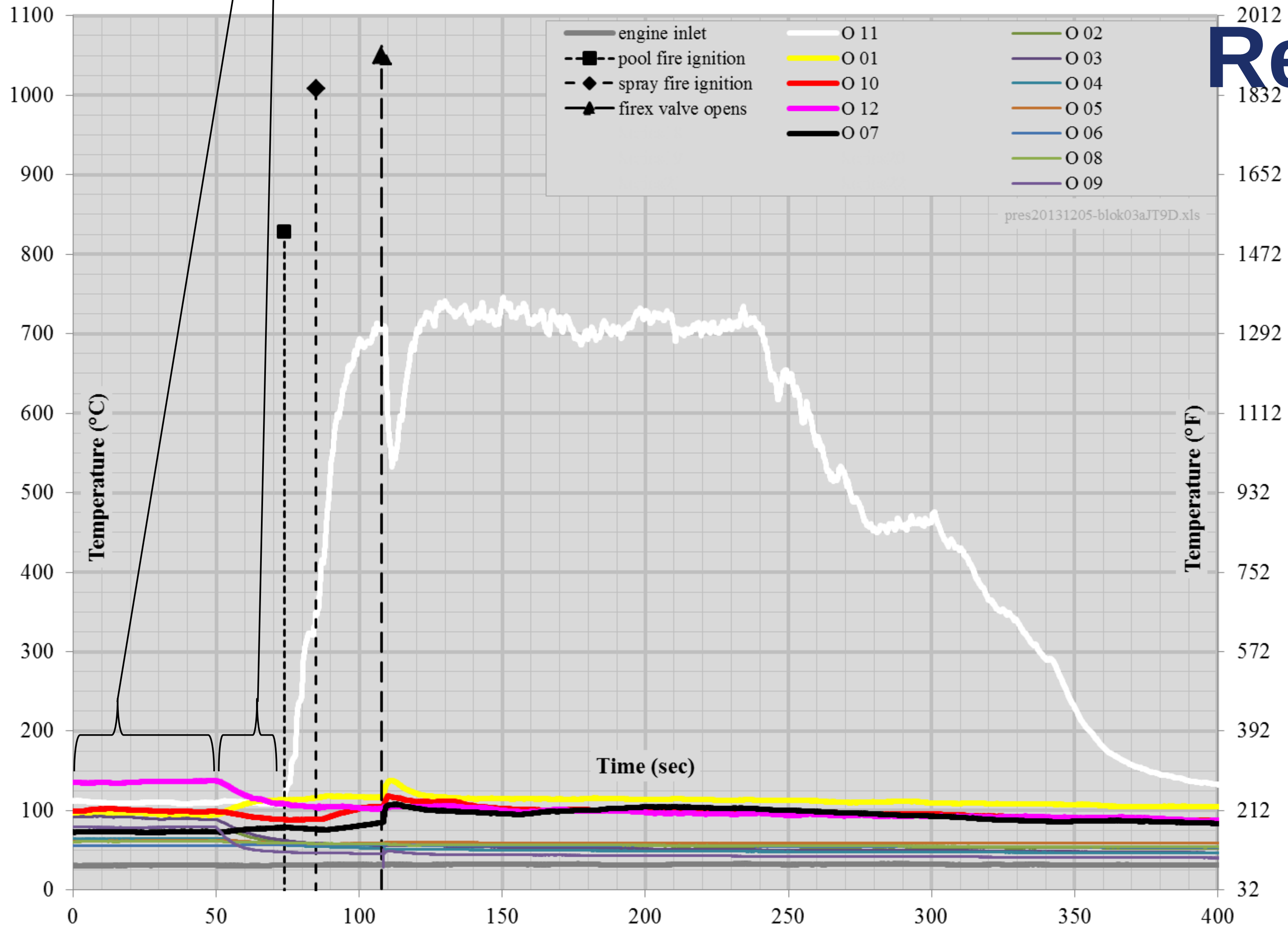
Test Results

- **Two demonstration tests occurred 11Jul2012**
  - 1st test : N_2 versus the fires (2012071103)
  - 2nd test : solid aerosol versus the fires (2012071106)

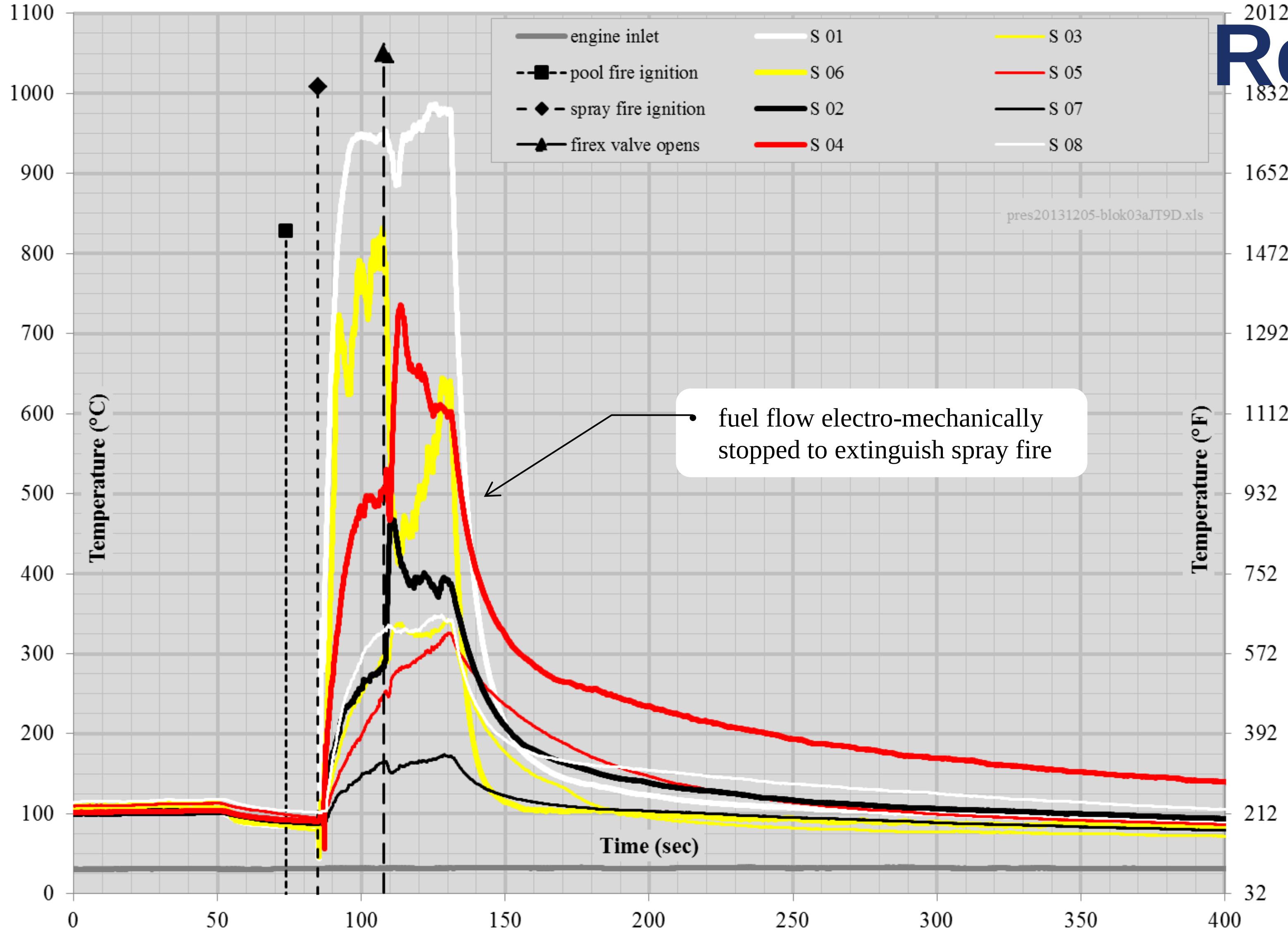
- **Reviewing data from 2nd test**
  - temperature histories
  - visual record (by way of still images)

Test Results

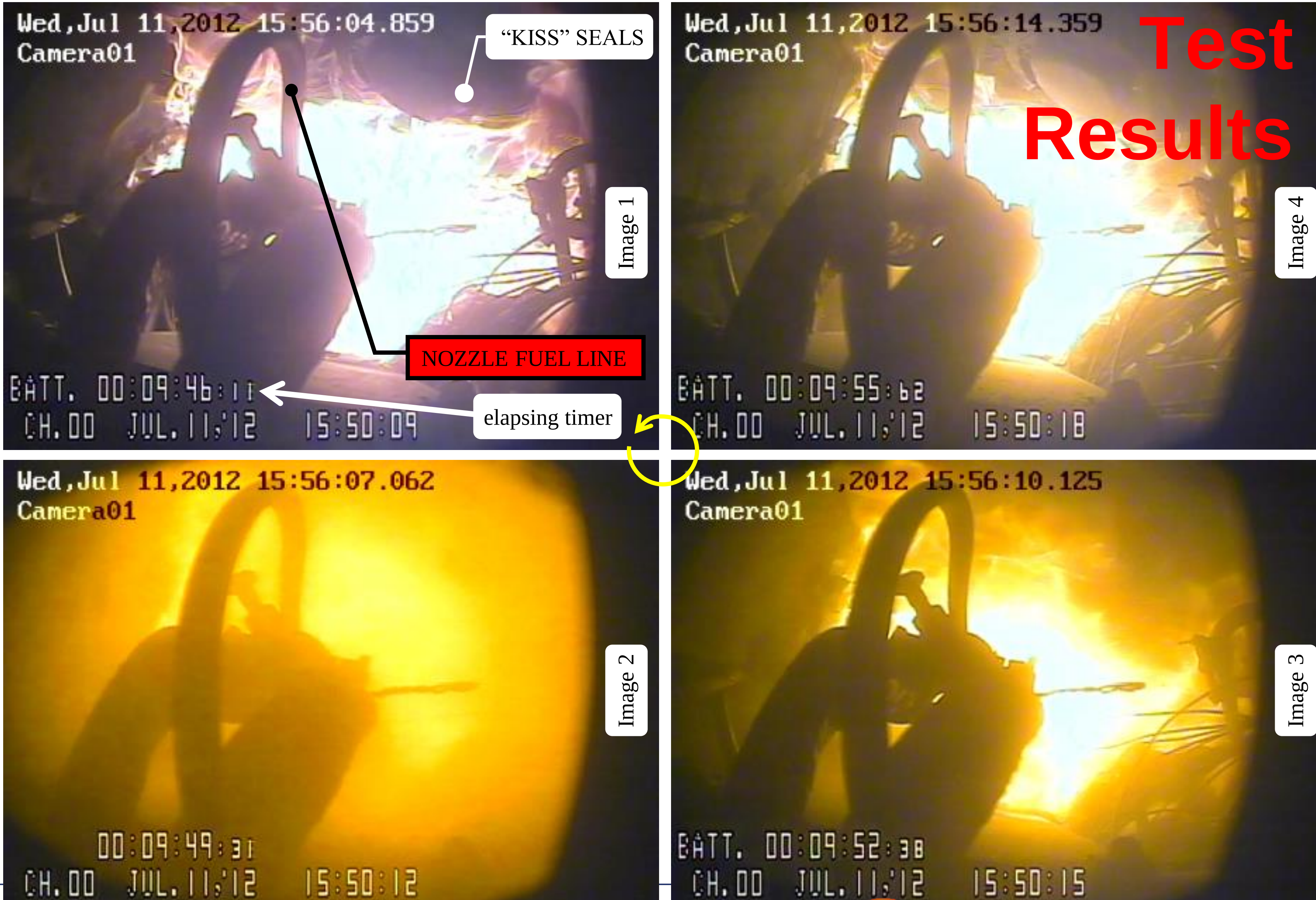
general conditions resulting from engine run; engine already shutdown
transients occurring due to external forced ventilation flow
(typical for these graphs)



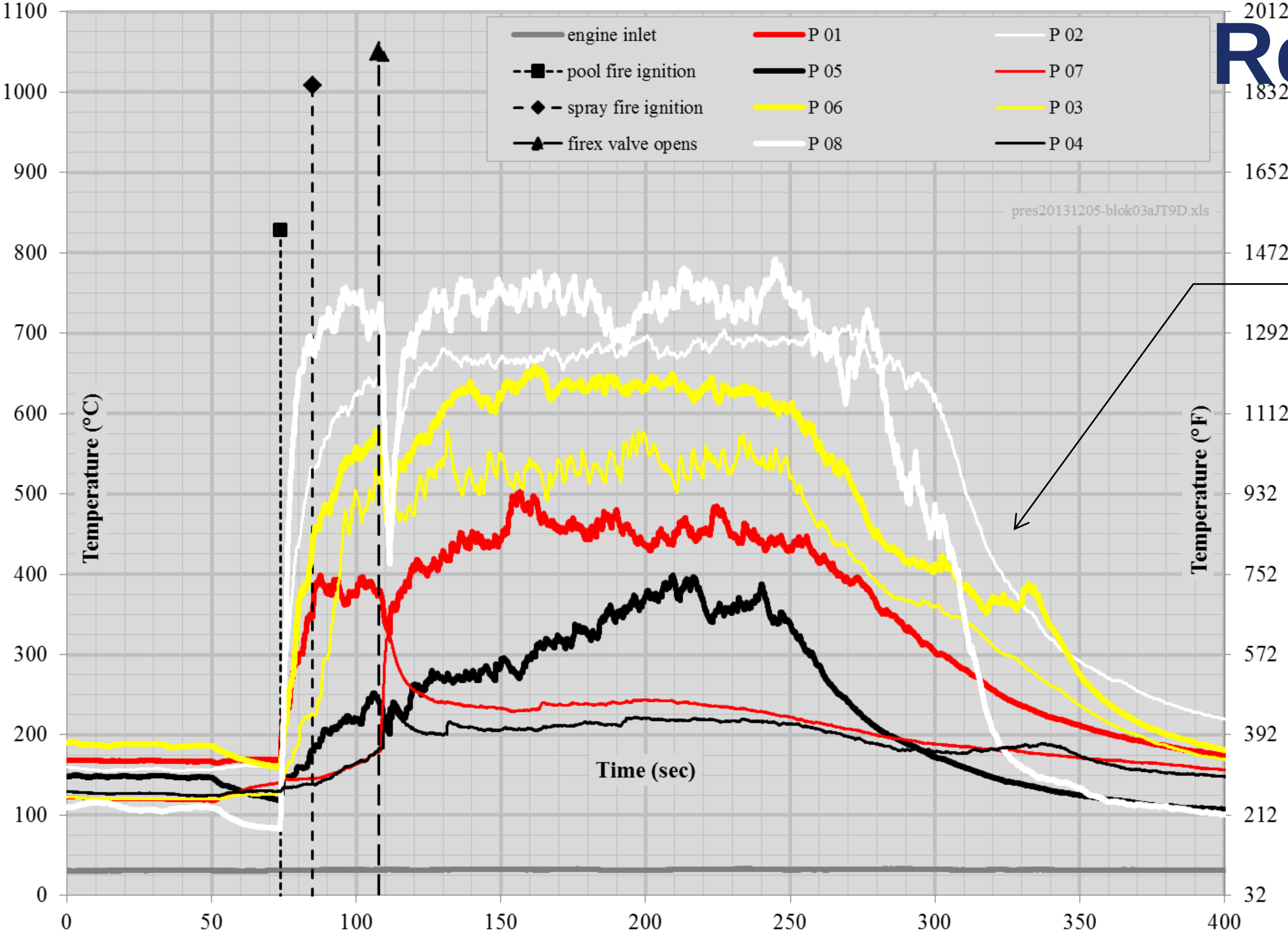
Test Results



Test Results

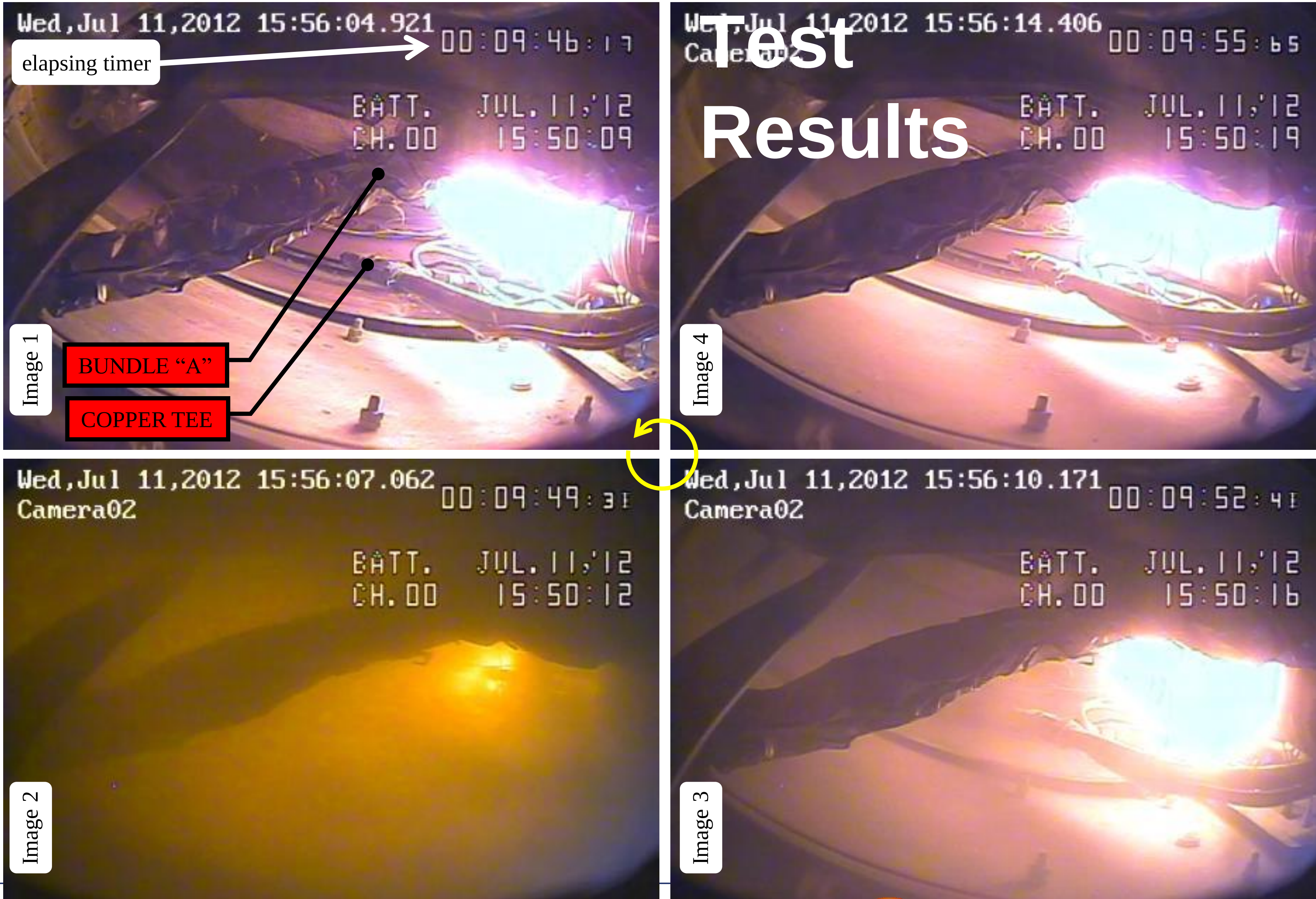


Test Results



- fuel drained from fuel pan to extinguish pool fire

Test Results



Test Results

- **Outcomes/Observations**
  - test 2012071103, N_2 injection against both fires
    - injected N_2 did not extinguish either fire; fires sufficiently intense
    - seals on inboard door near spray fire continued burning after fuel flow cessation
      - seal of fiberglass & “high” temperature silicone (“kiss” seals)
      - externally/manually extinguished with halon 1301; injected from penetration in the ventilation supply duct

Test Results

- **Outcomes/Observations…**
  - test 2012071106, solid aerosol against both fires
    - spray fire
      - region remained illuminated for duration of firex agent pulse
      - spray fire burning after firex agent pulse passed
      - no intentional reignition threats present
      - “kiss” seals continued burning after fuel flow cessation
      - thermal histories indicate fire being pushed around

Test Results

- **Outcomes/Observations…**
  - test 2012071106, solid aerosol against both fires…
    - pool fire
      - region remained illuminated for duration EXCEPT for 1 portion
      - duration of less then 0.23 sec in visual record is dark
        - » implies no fire existed
        - » elapsed time from 9:46 to 9:48 fire is interesting
          - ▪ flames detached from pool & rotated around core inboard
          - ▪ stopped its inboard rotation somewhere outside view field
          - ▪ light became prominent at 06:00 & propagated back to fuel pan
      - pool fire was burning after firex agent pulse passed
      - no intentional reignition threats present
      - thermal histories indicate fire being pushed around

Test Results

- **Outcomes/Observations…**
  - since the fires did not extinguish, the proposed design criteria do not appear reasonable
  - this project produced other items requiring attention
    - repeated solid aerosol usage creates accumulating residue
      - thoroughly clean the test article after *each* test, *particularly if ever "certification" testing*
      - verify residue is negligible with subsequent test
        - » conduct pressurized N_2 injection
        - » operate concentration analyzer during injection; review output
        - » goal is negligible residue; adjust as needed to attain goal

Test Results

- **Outcomes/Observations…**
  - this project produced other items requiring attention…
    - atmospheric moisture
      - if fire zone surfaces are damp (possible with static/”cold” engine)…
        - » aerosol can adhere; possibly detrimental to aerosol distribution
        - » defeated condition by heating fire zone above water dew point
      - damp fire zone surfaces suggest included optical instrumentation may be dew-coated; defeated by heating above dew point
      - engine start-up created observable quantities of fog
        - » fog interferes with optical instrumentation not calibrated for fog
        - » “certification” testing not typically done during engine start
        - » however, this condition reminds one to assure the variables measured are the only ones that are varying

Test Results

- **Considerations**
  - why no fire extinguishment ?
    - the step from NFS to demonstration testing inconsistent; unlikely
      - NFS environment provides similar & more challenging conditions
        - » roughly, double the spray fire fuel flow rate & fuel pan surface
        - » purposeful flame attachment & persistent ignition threats
      - industry established proposed criteria from its NFS data review
      - comparison to other flame extinction benchmarks favorable
    - JT9D fire threat environment unreasonably challenging; unlikely
      - fuel availability & fire thermal outputs not excessive
      - fires existed openly in the fire zone volume; i.e. no gross sheltering
      - ventilation rate & both combustion modes reasonably represent reality; this was an engine fire zone…

Test Results

- **Considerations**
  - why no fire extinguishment ?
    - “protected” region not the full fire zone; possibly
      - propagation of flames from seats into ill-protected regions?
      - unlikely; flames moved around by “push” from adequately protected regions by the source aerosol injection plumes
      - producing a reasonable representation of design criteria across fire zone is challenging
        - » trying to show a minimum set of criteria are effective
        - » anything excessive interferes with such assessment
    - disconnect via fire, distribution or extinguishment test; possibly
    - distribution variation observed over repeated test; possibly

Test Results

- **Considerations**
  - why no fire extinguishment ?
    - design criteria mismatched; possibly
      - FAA design criteria[(3)] are 2-part : "concentration" & residence time
      - aerosol concentration associated favorably by other benchmarks
      - residence time left at ½ sec (going after "total-flood", not "direct application"…)
        - » time to get firex agent into useful form for flame extinction?
          - ▪ halon 1301? heat neat form to decomposition…
          - ▪ aerosol? phase change & decomposition…
        - » also accounts for diffusion/permeation into complex structure
          - ▪ halon 1301 readily diffuses & permeates
          - ▪ aerosol particles possess greater momentum, opposing diffusion, perhaps disagreeing with permeation

HRD = high-rate discharge

Test Results

- **Considerations**
  - why no fire extinguishment ?
    - design rationale mismatched; possibly
      - total flood versus local application/streaming agent
      - firex agent is a solid aerosol & not a gas
      - consider a "low"- versus "large"-strain design concentration
      - the condition of flame extinction for this application ? a function of :
        - » firex agent concentration alone
        - » firex agent concentration + flow field speed

Test Results

- **Considerations**
  - why no fire extinguishment ?
    - design rationale mismatched; possibly…
      - FAA design criteria cites concentration & residence; nothing else
        - » halon 1301 concentration ties to “low”/”no”-strain condition
        - » ½ second ties to ? engineering judgment…
        - » so, get “low”-strain concentration by injecting with much strain, and probability of fire-out is “large” (…given all else is “normal”…)
        - » but if not gas, then particles (droplets…)
          - ▪ particles have momentum; can blow by flame attachments…
          - ▪ require sufficient residence to get into useful form and permeate complex structure…

Test Results

- **Conclusions**
  - the proposed design criteria do not appear reasonable
  - sodium bicarbonate is known as an effective fire extinguishing agent
  - reasons exist that explain the lack of fire extinguishment in this activity; explicit discovery is underway
  - industry interest/activity continues

Recognition of Contributions by Others

Please recognize additional contributions to this body of work from the following individuals :

- Mr. Pete Ferguson, Mr. Alan Macias, Mr. Sham Hariram, Mr. Robert Wright, Boeing Commercial Airplanes, Seattle, WA, USA.
- Mr. Len Seebaluck, Mr. Mark Fazzio, Mr. Louis Rance, Mr. Chris Frazier, Kidde Aerospace, Wilson, NC, USA.
- Mr. Constantine “Gus” Sarkos, Mr. Dick Hill, Mr. Dave Blake, Mr. Jason Fleming, Mr. Mark Materio, Mr. Anthony “Mickey” Sacco, Mr. Rob Morrison, Mr. Dave Mills, Mr. Joe DeFalco, Mr. Wayne Eichner, Mr. Tom Carmen, Mr. Larry Fitzgerald, Mr. Tim Smith, Mr. Mike Donio, FAA Technical Center, Atlantic City Int’l Airport, NJ, USA.
- Mr. Steve Happenny, FAA Transport Airplane Directorate, Renton, WA, USA
- Mr. Tom Thorson, FAA Seattle Aircraft Certification Office, Renton, WA, USA

Referable Information

1. Working Copy of Draft MPSe Revision 04, found at
   http://www.fire.tc.faa.gov/pdf/systems/MPSErev04_MPSeRev04doc-02submtd.pdf
2. FAA International Systems Fire Protection Working Group, information found at:
   http://www.fire.tc.faa.gov/systems.asp
3. Advisory Circular 20-100, 1977, "General Guidelines for Measuring Fire-Extinguishing Agent Concentrations in Powerplant Compartments," United States Department of Transportation, Federal Aviation Administration, Washington, DC,
   http://rgl.faa.gov/Regulatory_and_Guidance_Library/rgAdvisoryCircular.nsf/list/AC%2020-100/$FILE/AC20-100.pdf