Minimum Performance Standards for Halon 1301 Replacement in the Fire Extinguishing Agents/Systems of Civil Aircraft Engine and Auxiliary Power Unit Compartments

(MPSHRe rev04)

EDITORIAL COMMENTS. THIS PAGE WILL BE DELETED UPON FORMAL PUBLICATION.

“TBD” = to be determined; either a result of incomplete outcome from rev04 ancillary testing or a basic lack of information

HISTORY.

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5Mar2010, Fri : revise draft-02 with pencil mark-ups and publicly release

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1. Introduction.

A fire extinguishing system ("system") is required for each engine nacelle and auxiliary power unit (APU) compartment for certain categories of civilian aircraft. To address these requirements for large transport aircraft, 2 considerations are typically made. First, an applicant satisfactorily stores and delivers some form of fire extinguishing agent ("agent") to the protected compartment, typically halon 1301. This distribution of the halon 1301 can described by a set of distribution criteria; a concentration is resident from some duration. Second, an applicant measures the quantity of the agent within the protected compartment over time during and following the agent injection event. The principal success of such a system is based upon the measured history of the agent distribution meeting or exceeding the minimum level of safety as required by the appropriate regulatory authority. The culmination of these 2 considerations represents approximately 60 years of knowledge and experience exchanged between regulatory authority and industry.

To preclude confusion regarding the use of the word "fuel" in this document, fuel is defined here as any substance that can combust in an unintended manner in an engine nacelle or APU compartment. Fuel, as commonly understood, is not defined in this document as the substance used for propulsion, although turbine fuel can fuel an unintended fire in an engine nacelle or APU compartment. Further, since FAA regulations do not address combustible metal fires by the regulations cited, metals acting as fuel, as described here, are excluded from consideration. Additionally, the cited regulations do not apply when the containment of the engine core combustion processes fail, permitting "cutting torch" flames to enter these fire zones, where turbine fuel and oxidizer are reacting at temperatures and pressures which are multiples larger than those found at atmospheric conditions.

Commonly accepted practice for this application, demonstrated by the typical circumstances found in existing civil aircraft, has 3 components. First is the use of halon 1301, a total-flooding agent. Second, the fire extinguishment system used to deliver the halon is composed of at least one storage vessel containing the agent and some super-pressurizing nitrogen, release valving, plumbing fittings, distribution plumbing, and nozzling for injection into the protected compartment. Third and finally, during developmental and certification evaluations, a gas analyzer utilizing a pressure drop across an orifice, commonly referred to as a Statham- or Halonyzer-variant gas analyzer, is used to measure the distribution behavior of the halon 1301 inside the protected compartment. The sample histories evaluated are drawn from locations in the tested environment through tubes to the remotely located sensors.

The goal of this document is to provide a process for an applicant, or its designee(s), to determine some quantity of a replacement candidate ("candidate") that can be used acceptably for fire extinguishment in place of halon 1301 for these applications. Explanatory descriptions potentially valuable to an entity using this process are included in the procedural documentation. The process requires a test fixture, the ability to produce 2 different fire threats based on flammable fluids typically found in a nacelle or APU compartment, a system to deliver a conditioned candidate, and some means to measure the time-varying behavior of the agent during its delivery to and transport through the test environment. The experience to develop this process is contained in a report titled **"TBD"**, of which this document is an appendix. The reader should know that at some point in the future, halon 1301 will no longer be the commonly accepted practice.

Knowledge and judgment regarding what is acceptable will always change. To account for this, the definition for a candidate within this process can span from a substance that may "drop-in" the hardware used to store the halon 1301 with little or no modification and use the existing gas analysis technique for quantification to something requiring novel methods unfamiliar to civil aviation for storage, delivery, and/or quantification. This process is currently fit to the commonly accepted practice relating to the halon 1301 system and Statham/Halonyzer analysis concept. Provisions have been made to permit variation, as needed.

An applicant must assess the applicability of this process to their own halon replacement efforts based on their own circumstances. There are 2 scenarios for replacing halon. One is for an existing airplane and the second for a new. Given an existing airplane, this process is the likely method to complete a replacement effort based on the economic considerations of fire testing with actual aircraft components versus a simulation model. For a new airplane, an applicant may elect to forego this process and directly engage the pertinent regulations since no halon 1301 baseline exists. However, an applicant in either scenario may capitalize on results from this process if information is already publicly available for a candidate that is desirable.

Any entity using this process must remain diligent during testing. Observations will be the most important aspect to assess whether a candidate will acceptably perform. Additionally, observations may lead to changes in current philosophy regarding fire protection for these applications. One should recognize that a notable shift in design philosophy may again require a revision of this document.

A successful application of the process described herein will allow the definition of an equivalent level of safety in terms of the performance of the candidate, as compared to that of halon 1301.

An applicant intending to use this process in a stand-alone approach to replace halon 1301 is clearly advised to involve their certifying, regulatory authority at the earliest possible point in the program to prevent the loss of time and money associated with later discrepancy related to differing opinion or experience. Additionally, successfully completing this process does NOT satisfy the requirements for certification by the Federal Aviation Administration (FAA) or any other regulatory authority recognizing the use of this process. An applicant must adequately address all issues that are not evaluated by this process for these applications.

1.A. Discussion.

U.S. Federal Airworthiness Regulations (FAR) 23.1195, 25.1195 are the regulations that require fire extinguishment systems for the engine nacelle and APU compartments in certain types of U.S. aircraft. In the case of U.S. general aviation airplanes, special conditions may exist requiring the applicant to provide fire extinguishment systems as well. Similar regulations are also found in other aviation regulatory bodies located on the continents of Asia, Australia, Europe, North America, and South America.

The current fire extinguishing systems using halon 1301 are deemed to satisfy these requirements if the system can distribute halon 1301 in the compartment in accordance with guidance provided in FAA Advisory Circular 20-100 (FAA AC 20-100). This AC reports the performance of halon 1301 from historical testing including high-fidelity, large-scale fire tests. The process described here is intended for use in large-scale fire testing for the purpose of developing design criteria for systems using candidates.

One challenge for this process is to reasonably represent a nacelle fire but not restrict the applicability of the outcomes to one particular nacelle, knowing the purpose to use an agent in a nacelle or APU fire extinguishment system is to extinguish the unintended fire threat. Therefore, this process was tuned to minimize any flame extinction mechanisms that are not related to an agent, based on the assumption that the agent is the main factor in flame extinction. Flame strain is the principal example of a minimized flame extinction mechanism. Agent injection is specified not to “blow” the fire out. If the flame-straining effect is notable, as a planned or unintended component of a candidate’s function, this process will require modification. Appropriate planning must occur to account for this deviation and, at a minimum, would require involvement from the regulatory authority. However, this revision is perceived and intended to permit evaluating aerosols.

The process to demonstrate equivalence is based on 4 test configurations. Each of these 4 configurations is intended to represent pertinent factors found in a nacelle or APU fire. By varying parameters to achieve these 4 configurations, a spread of behavior can be observed.

One can readily reason that 4 points is a small sample of a potentially infinite array of possible solutions when considering the numbers of engine nacelles and APU compartments flying today, in addition to each’s varied attendant operational regimes. However, those involved in the work to develop this process believe this spread, and that buried within to attain the spread, is adequate to challenge and provide a method to compare and ultimately quantify a candidate for the purpose of replacing halon 1301. As a precaution, the testing entity is required to identify any deficiency and respond accordingly, if a candidate possessed a potential weakness entering into testing or such observations were made during testing.

The 4 test configurations are each a unique combination of compartment ventilation and fire threat. Inherent to all are flame-holding geometries, persistent ignition threats represented by electrical arc and/or hot surfaces, and the persistent presence of fuel during candidate injection and transport through the test fixture.

An important practical aspect for this testing will be the maintained control of the experiment. The highest state of cleanliness within the test fixture must be maintained. Additionally, processes like candidate handling while servicing, and candidate and fuel conditioning prior to test, require consistent procedure and endpoint to effect reliable test behavior. Understanding the tolerances in cleanliness and conditioning and their impact on test outcome will likely be an evolving experience as any testing progresses.

The evaluation method of this revision is conceptually simple. It is a proof-test of some consistent distribution criteria for a candidate challenged by 4 acceptably intense test configurations and smaller sets of verification tests, resulting in a go/no-go outcome.

The comparison with halon 1301 is provided by the character of the test environment in which the evaluations occur. One of 2 environments is possible. First, a nacelle fire simulator (NFS) has existed at the FAA's WJ Hughes Technical Center (FAATC). A test database, including halon 1301 performance, exists for the FAATC NFS, based on previous work related to MPSHRe rev03. Any testing conducted in the FAATC NFS will reference that information as the assessment threshold. The second possible environment is some future, new test fixture. Its test environment will relate to the FAATC NFS in terms of combustion character and flame extinction performance for its associated fire threats.

The candidate performance is assessed based on the interaction with the different fire threat and ventilation combinations. The behavior tracked to make the assessment is simply a duration observed between the times of flame extinction and reignition as an agent pulse moves through the test fixture while enduring persistent fuel flow and ignition threat(s). This duration is an effective indicator of agent performance and should demonstrate a direct relationship with varying quantities of agent discharged into a test fixture. As agent quantity increases, the duration the fire is extinguished increases. The relationship appears linear in the normal ranges of interest but eventually ceases at some low endpoint once a threshold mass of agent is crossed. In simple words, if an amount of agent discharged into the test section does not extinguish a fire, there is no duration between flame extinguishment and reignition. Although not observed to date, and likely impractical, there is a theoretical point where there would be such a large quantity of agent released into a test fixture, the fire would be permanently extinguished based on the test parameters used. For this case, the duration is infinite.

The final outcome, the successful design criteria, for any given candidate from this process, would be the distribution criteria which succeeds in equaling or exceeding the respective flame extinction duration for the 4 test configurations. Also, a final report will require describing attendant observations, particularly those which are noteworthy. The expected activities after completing such a project would then be moving forward with recommending the successful design criteria for any certification effort, resolve any anomalous behaviors discovered during this testing, acceptably satisfy all other remaining issues not evaluated by this process, and finally, demonstrate all required goals are satisfied for the aircraft installation to the applicable regulatory authority.

1.B. Overview of the Test Procedure.

The process is composed of three groups of requirements and a group of comments providing additional background. The first set describes what is expected of the candidate by the regulatory authority and industry before any candidate is considered for evaluation by use of this process. Any future candidate must meet operational demands if it were to be considered for use. These operational demands are not directly related to fire extinguishment performance and will be evaluated elsewhere. Additionally, any methods not consistent with commonly accepted practice will require identification, discussion, review, and acceptance from the applicable regulatory authority. The second set describes the infrastructure required to accomplish comparative testing between agents. The infrastructure would require design, investigation, and optimization, typically requiring attention for a single period of time. Once these infrastructure issues are resolved, they will be taken as constant, but should be maintained and checked on some basis in a sensible manner to ensure continuity. The third set describes the comparative testing. These requirements will be repeatedly visited and will become familiar to any testing entity. See figure 1 for a diagrammatic flow.

The process requires a test fixture, 2 ventilation regimes, 2 fire scenarios, the delivery of the candidate, and methods to capture the test environment’s behaviors. The following comments relate to the infrastructure and must be fulfilled prior to beginning any evaluative testing.

The test fixture will be some size larger than an acceptable minimum, defined by cross section and volume. Within the test fixture, the testing entity must establish 2 representative, ventilation regimes. Additionally, 2 fire threats must be designed within the test fixture so that they demonstrate adequate combustion intensity. Both threats will be based on diffusion combustion of fuels representative of the engine nacelle and APU compartments. One scenario will be based on a fuel spray and the other on a residual pool. The spray scenario will have persistent ignition threats represented by an electrical arc and a hot surface. The residual pool will have a persistent ignition threat represented by an electrical arc. Fuels feeding the spray at any given point during testing will be turbine fuel, lubricant or hydraulic fluid. Turbine fuel will be the basis for the residual pool.

By pairing 1 ventilation regime with 1 fire threat, a single test configuration is specified. The pairings create the 4 major test configurations.

For each ventilation regime, the candidate must challenge a spray fire threat, based on the fuel producing the most severe fire threat, being indicated by the largest measured thermal output, and a pool fire threat. In the spray fire configurations, the candidate must also be evaluated with verification testing against different fuels to ensure test outcomes with these other fuels remain acceptable.

The evaluation of a candidate requires establishing distributions of the substance in the ventilation flows, as measured by a collection of a minimum of 12 concentration sampling points. The ability of the candidate to distribute is challenged by requiring a separation between injection locations and fire threat, plus concentration sampling in at least 1 wake region, where the wake region is associated with flame-holding structure in the test fixture. Different distributions will be used to assess the acceptability of a candidate’s initial design criteria, where the initial criteria must be identified prior to commencing any formal MPSHRe evaluative testing.

The process to prove the initial design criteria requires the testing of distribution criteria smaller and larger than the initial, in concentration alone, by approximately 15%, for each combination of fire threat and ventilation rate. By performing testing in this bracketed manner, the systemic behavior of a candidate is observed, which contributes to experiential understanding, and permits arithmetical manipulation to assess the ability of the candidate's initial design criteria. See figure 2 for a conceptual illustration.

Given the systemic behavior of the candidate, performance is assessed by comparing a calculated flame extinction duration associated with the concentration of some initial candidate design criteria to some appropriate halon 1301 threshold criteria. The analytic assessment is first begun by coupling 2 points, 1 at the lower bracket boundary and the 2nd at the larger, with the concentration of the evaluated design criteria, and interpolating an average flame extinction duration. The interpolated average flame extinction duration is associated to the evaluated candidate design concentration. The assessment concludes by comparing the interpolated average flame extinction duration to the appropriate halon 1301 threshold criterion. Success requires showing the evaluated candidate design criteria will produce a flame extinction duration which is the same or larger than the threshold criterion. If successful behavior can be shown for the 4 major test configurations and no faults are noted during fuel verification testing, the criteria are considered successful and would then be considered the design criteria.

If a fault occurs during evaluation, the initial design criteria would require review and modification. At this time, the singular modification expected would be the enlargement of the concentration parameter contained in the design criteria. Subsequently, the outcomes from the test process at the time of fault would require review, and a new plan would require development to efficiently incorporate that known with what requires completion to successfully prove a set of design criteria.

Upon completion, a report capturing all observations and pertinent information must then be written and submitted for consideration to the regulatory authority upon program completion.

1.C. References.

The following references form the basis to understand the current halon 1301 performance criteria for aircraft engine and APU fire extinguishing systems (refs 1 - 7). The balance are included to enhance a reader’s knowledge regarding other discussions which occur within this document.

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2. Requirements for Candidates in Addition to Testing in a Generic Nacelle Fire Simulator.

2.A. Requirements for All Candidates that are not Addressed by this Document.

Any candidate considered for use in an engine nacelle or APU fire extinguishing system must adequately satisfy the following requirements. These requirements are evaluated elsewhere.

- 2.A-1. Environmental Characteristics.
  - 2.A-1.a. The environmental characteristics of a candidate must comply with international laws and agreements.
  - 2.A-1.b. The candidate should be listed in the US Environmental Protection Agency's Significant New Alternatives Policy program. Since engine nacelle and APU compartments are not normally occupied spaces, candidates identified for use in such spaces are permissible.
  - 2.A-1.c. The candidate does not require listing with the US Environmental Protection Agency's Significant New Alternatives Policy program, if the candidate :
    - 2.A-1.c-i. has an demonstrably acceptable service history.
    - 2.A-1.c-ii. it has no ozone depletion potential.
  - 2.A-1.d. Health and Safety. Processes and equipment associated with a candidate's service life, from conception to completion, must employ features which prevent workers from hazardous exposure during all related activities.
  - 2.A-1.e. Flight Safety. The use and operation of the candidate in the aircraft should not result in any additional hazard such as:
    - 2.A-1.e-i. Malfunction of components critical for flight control necessary for continued safety of flight.
    - 2.A-1.e-ii. Damage to other critical components and areas within the compartment being protected, which would create a hazard either immediately or remain undetected and be a hazard after a passage of time.
    - 2.A-1.e-iii. Products resulting from the discharge of the neat candidate or decomposition by-products resulting from combustion exposure in these compartments must not be conveyed into spaces occupied by living things within the pressure vessel of the aircraft
    - 2.A-1.e-iv. Ignition sources in any area of the aircraft not designed for accommodating ignition sources
- 2.A-2. The candidate, whether neat or decomposed, should be compatible with all materials of construction for :
  - 2.A-2.a. its storage and delivery system
  - 2.A-2.b. the protected compartment in which it will be injected
    - 2.A-2.b-i. This applies to all definitely and potentially wetted boundaries of any test apparatus and any aircraft installation.
    - 2.A-2.b-ii. Decomposition products resulting from fire and extinguishment exposure are aggressive. This is not avoidable. However, post-incident evaluation and related cleaning or repair are the mechanisms used to thwart negative material compatibility outcomes.

2.A-3. The candidate must have an acceptable shelf-life while installed on the aircraft.

2.A-4. The candidate must have acceptable performance for the aircraft's operational envelope.

2.A-4.a. The testing entity must know by reasonable evaluation that the candidate can demonstrate any future design point recommended as certification for all storage conditions that will be found on the associated airframe.

2.A-4.b. The applicant will be required to demonstrate adequate distribution at the thermal endpoints of the airplane's operational envelope to the respective airworthiness authority.

2.A-4.c. This test procedure does not require hot- or cold-soaked storage conditions for gaseous candidate testing. The disparity of the environments between the test process and the end-use is explained by accounting for the environment in the nacelle and understanding how flammable systems generally behave when exposed to varied levels of thermal energy.

2.A-4.c-i. The general behavior of flammable systems indicates decreasing temperature offers decreasing flammability.

2.A-4.c-i.A. Persistent hot surface areas in the presence of spilling liquid fuel may exist, thus producing an environment where air and fuel vapors may be mixing. A measure related to this condition, although not identical, is the testing related to determining flammability limits, such as ASTM E-681 or E-918. Regardless, a system of air and fuel in a gaseous state is more hazardous (favoring combustion) than that of air and a liquid fuel, where the liquid fuel must change phase and diffuse.

2.A-4.c-i.B. Flammability envelopes produced for premixed, gaseous, flammable systems incorporating various mixtures of an agent, fuel, and oxygen, within a detonation tube or an explosion sphere, demonstrate that :

2.A-4.c-i.B-i. peak inerting agent concentrations decrease when the temperature for the flammable system is decreasing.

2.A-4.c-i.B-ii. the areas inside these flammability curves decrease with decreasing temperature, implying the flammable range is decreasing also.

2.A-4.c-i.C. Given two flammable systems, the colder of the two will require a lower inerting agent concentration

2.A-4.c-ii. The environment at a cruise altitude is not consistent with the nacelle ambient environment. Citing the standard atmosphere, one will find at altitudes in the 9.1 km (30,000 ft) range having ambient temperatures on the order of -40°C (-40°F). The average operational environment within the nacelle will be on the order of 38°C (100°F).

2.A-4.c-iii. Consider the accepted practice to demonstrate FAA certification with halon 1301. A fire extinguisher bottle cold-soaked to -54°C (-65°F) is discharged into the fire zone. For success, the measurement history must indicate all points simultaneously achieve 6%v/v halon 1301 for 0.5 second.

- 2.A-4.c-iii.A. The cold-soaked bottle condition is related to the storage environment of the bottle outside the nacelle that is conditioned by exposure to the ambient environmental conditions.
- 2.A-4.c-iii.B. The 6%v/v Halon 1301 can be traced back to flammability testing completed at room temperature.

2.A-4.c-iv. Conclusions.

- 2.A-4.c-iv.A. The cold-soaked bottle is not related to the fire extinguishment demand. Instead, the cold-soaked condition is related to the agent storage environment which inhibits its ability to diffuse upon expulsion. This is an agent delivery issue. This issue does not require fire testing to establish behavior.
- 2.A-4.c-iv.B. The fire extinguishment demand is similar to the nacelle environment. This test process is intended to establish the fire extinguishment demand.

2.B. Possible Additional Requirements for Novel Solutions.

Commentary is provided here which identifies additional demands requiring attention due to the deviation from commonly accepted practice.

2.B-1. Proving the viability of novel measurement equipment.

- 2.B-1.a. If measurement equipment is planned for use during testing and future certification activities which is atypical, the testing and/or regulatory authority will require review and decision regarding the acceptance of the novel equipment. The principle example cited here is the development of some new machine to measure the concentration history of a fire extinguishing agent in a given environment. Commonly accepted practice is defined by a Statham-derivative gas analyzer.
- 2.B-1.b. This issue must be satisfactorily resolved prior to the commencement of evaluative equivalence testing for any candidate.

2.B-2. A requirement for candidate demonstration testing.

- 2.B-2.a. Depending upon the nature of the proposed fire extinguishing concept, the regulatory authority may require additional testing.
- 2.B-2.b. The determination of the extent of the additional testing will be based on the novelty of the proposed concept (i.e., differences from the commonly accepted practice), and will depend upon the observations and conclusions of the testing meeting the requirements of this document.

3. Infrastructure.

The items contained within this section must be completed then proven reliable and repeatable prior to attempting any equivalence testing.

- 3.A. Establish the Test Fixture.
  - 3.A-1. Specifications regarding specific machinery and components to fabricate a nacelle fire simulator are not provided in this document. However, details which can be used to select such components follow.
  - 3.A-2. Structure.
    - 3.A-2.a. The materials of construction for current nacelles consist of either metal or composite fiber construction. Either material is permissible for use providing the structural design of a nacelle fire simulator includes
      - 3.A-2.a-i. allowances for :
        - 3.A-2.a-i.A. the stresses of repeated fire testing without significant alteration
        - 3.A-2.a-i.B. environmental behaviors which would not unreasonably interfere with interpreting equivalence testing results (i.e. agent distribution versus flame extinction)
        - 3.A-2.a-i.C. reasonable access to the interior for cleaning, maintenance, and alteration or repair
        - 3.A-2.a-i.D. the ability to observe and record the internal environmental behaviors
      - 3.A-2.a-ii. the ability to accept :
        - 3.A-2.a-ii.A. various forced ventilation flows.
        - 3.A-2.a-ii.B. two fire scenarios plus their related workings.
        - 3.A-2.a-ii.C. the injection hardware for the fire extinguishing system.
        - 3.A-2.a-ii.D. all required telemetry to record environmental behavior.
    - 3.A-2.b. Geometry.
      - 3.A-2.b-i. The engine compartment (nacelle fire) simulator should have an annular fire zone having a minimum volume 1.84 m^3 (65 ft^3) and a minimum annular cross section of 0.511 m^2 (5.5 feet^2), both before reductions due to clutter.
      - 3.A-2.b-ii. The volume of the nacelle fire simulator excludes any internal volume representing flow path required to deliver ventilation air.
      - 3.A-2.b-iii. Non-specified clutter must be incorporated in the flow path of the nacelle fire simulator. The clutter must present some resistance to the distribution of a candidate in the ventilation flow.
        - 3.A-2.b-iii.A. Some clutter will necessarily result, given pending comments regarding fire intensity.
        - 3.A-2.b-iii.B. Flame-holding structure should not be the only clutter in the fixture’s cross section.
      - 3.A-2.b-iv. The inner cylinder in this configuration will represent the engine case.
      - 3.A-2.b-v. The test section must be equipped to allow a real time visual observation of the fire.

- 3.A-3. Telemetry.
  - 3.A-3.a. The histories of events occurring in each test must be captured to record the environmental behavior. These behaviors will be used to observe and learn about what is occurring within the environment of the test fixture, compare consistency or difference between tests, evaluate a candidate, and track the changes of the fixture over its life time.
  - 3.A-3.b. A complete record is required for each evaluation test accomplished. The complete record requires individual records from visual and non-visual sensors.
    - 3.A-3.b-i. Each record should focus on the regions containing the fire threats.
    - 3.A-3.b-ii. A non-visual telemetry package should be used to capture and review the history of the test environment during each test. This record should include :
      - 3.A-3.b-ii.A. methods using sensors such as thermocouples and pressure transducers to capture thermal and pressure gradients related to the test environment. Other sensors may also be used to enhance understanding.
      - 3.A-3.b-ii.B. methods to quantify the varying concentration behavior of the candidate, resulting from its injection into the test environment. If different than accepted practice, review comments under the section "*Possible Additional Requirements for Novel Solutions*".
      - 3.A-3.b-ii.C. some non-concentration sample points well away from the fire threats so the behavior of the test environment can be monitored over time.
    - 3.A-3.b-iii. A visual record will be the principal means to observe the performances of a candidate, which should :
      - 3.A-3.b-iii.A. come from a camera located to acceptably view the fire threat behavior.
      - 3.A-3.b-iii.B. include appropriate date and time indications.
    - 3.A-3.b-iv. Recommended minimum requirements.
      - 3.A-3.b-iv.A. Must be able to appropriately record the histories of :
        - 3.A-3.b-iv.A-i. the visible behavior of the fire threat
        - 3.A-3.b-iv.A-ii. mass flow of the air through the test fixture
        - 3.A-3.b-iv.A-iii. temperature of the :
          - 3.A-3.b-iv.A-iii.a. air through the test fixture
          - 3.A-3.b-iv.A-iii.b. fuel in each fire threat
          - 3.A-3.b-iv.A-iii.c. candidate in the firex
        - 3.A-3.b-iv.A-iv. the pressure of the fire extinguisher storage vessel
        - 3.A-3.b-iv.A-v. concentration of the candidate in the test fixture
      - 3.A-3.b-iv.B. Judgment is left to the discretion of the testing entity. Including the applicable regulatory authority regarding the decisions of type, number, and location of the sensors in the telemetry package is advised.
      - 3.A-3.b-iv.C. Data must be collected reliably at rates sufficient to produce useful data from the testing environment for review.

3.B. Establish the operational test environment within the test fixture

3.B-1. Ventilation Regimes.
  - 3.B-1.a. At least two internal (ventilation) airflow rates should be selected, one each from the following two ranges.
    - 3.B-1.a-i. high, 1.0 – 1.4 kg/s (2.2 - 3.0 lbm/sec).
    - 3.B-1.a-ii. low, 0.091 – 0.45 kg/s (0.2 – 1.0 lbm/sec).
  - 3.B-1.b. At least two (ventilation) air temperatures of 38°C (100°F) and 121°C (250°F) or greater should be used.

3.B-2. Fire Threats within the test fixture.
  - 3.B-2.a. Ignition sources for the fire scenarios.
    - 3.B-2.a-i. Initiating ignition sources are those used to reliably ignite test fires. They can be any concept that can reliably ignite a test fire. If an initiating ignition source is foreign to a nacelle, control must be employed to ensure it does not interfere with test results.
    - 3.B-2.a-ii. Secondary ignition sources are those providing a persistent reignition threat in the fire scenario during flame extinguishment by the agent.
      - 3.B-2.a-ii.A. They must be related to features that exist in a nacelle or APU compartment.
      - 3.B-2.a-ii.B. Electrical arc and/or hot surface threats are acceptable due to their presence in actual aircraft engine nacelle and APU fire zones.
  - 3.B-2.b. General comments regarding the fuels used during testing.
    - 3.B-2.b-i. The fuels used in this evaluation must include those expected in the protected compartment; typically a turbine fuel, a lubricant, and a hydraulic fluid.
    - 3.B-2.b-ii. The fuel temperature should begin each test near 66°C (+/- 5.5°C) (150°F +/-10°F) for both fire scenarios. Fuel-flow path should be temperature-controlled throughout the test fixture to ensure this control remains reasonably intact during the length of a test. Any fuel-flow temperature should be measured as close to the fire as possible.
    - 3.B-2.b-iii. Fire tests should be run without discharging any fire extinguishing agent so the combustion behaviors of the various fuel types can be observed and understood. They should be understood and ranked in terms of thermal output.
    - 3.B-2.b-iv. Large batches of fuel stock should be acquired before embarking on equivalence testing to ensure that batching changes will not confound test results. A prime example for this concern is the use of 2 separate bulk sources of turbine fuel within one test program. If noticeable changes in test result are observed, a change in fuel flash point between the batches should be checked and eliminated as a cause for the discrepancy.
  - 3.B-2.c. Acceptable fire intensity.

The fire intensity must be adequate or misleading outcome may result. Acceptable fire threat intensity will be shown by 2 means.

  - 3.B-2.c-i. Attain a minimum measured thermal output.
    - 3.B-2.c-i.A. For the spray fire based on turbine fuel, **"TBD"** (kW?) at high ventilation and **"TBD"** (kW?) at low.

3.B-2.c-i.B. For the pool fire, **"TBD"** (kW?) at high ventilation, and **"TBD"** (kW?) at low.

3.B-2.c-ii. Maintaining notable flaming combustion when the 4 ventilation/fire threat configurations are exposed to the discharge of a fire extinguisher storage vessel filled with pressurized gaseous nitrogen.

3.B-2.c-ii.A. The expansion of the injected nitrogen shall undergo at least a 100-fold volume increase, as referenced between storage and ambient conditions.

3.B-2.c-ii.B. The nitrogen shall be :

3.B-2.c-ii.B-i. stored in a volume comparable to that used in service

3.B-2.c-ii.B-ii. injected through hardware reasonably similar to what is expected during testing. Typically, this will mean the plumbing is composed of properly rated metallic tube and fittings.

3.B-2.c-ii.C. The discharge of nitrogen stored in 5.2 L (315 in^3) at 10.3 MPa (1500 psig) and 16°C (61°F) within 1 second, to the test environment, satisfies this demand.

3.B-2.d. There should be structural features in both fire threats to provide flame attachment so the associated flaming combustion is self-sustaining once the initiating ignition source is removed.

3.B-2.e. During each test, the fire should burn for some consistent, prescribed preburn duration to permit heating the local structure prior to discharging the candidate. Temperature histories are needed to understand what rates of change are occurring. The test length should be chosen to permit the fixture to attain a near-steady-state condition when agent is discharged. Preburn durations of 45-90 seconds are typically reasonable.

3.B-2.f. The geometric position and operational condition of the following should be consistently and rigorously maintained during any test program.

3.B-2.f-i. All initiating ignition sources.

3.B-2.f-ii. All secondary ignition sources.

3.B-2.f-iii. Any nozzle(s) delivering fuel to the test fires.

3.B-2.f-iv. The vessel containing the pool fire.

3.B-2.g. Describing the fire threats.

3.B-2.g-i. The test fixture must provide the simulation of a flaring fire (leaking fuel stream on fire, also called a spray fire) and a residual fire (baffle stabilized pan fire due to the ignition of pooled fuel in some part of the fire zone).

3.B-2.g-ii. Spray fire scenario

3.B-2.g-ii.A. Provide a fuel flow rate of 0.1 to 1 gpm. The fuel flow rate should remain constant for the length of testing during any test program. The choice of fuel flow may be an arbitrary one. It does not necessarily need to reflect an actual aircraft. What it must do is provide an adequate fire intensity that is described in the comments pertaining to "*Acceptable fire intensity*".

3.B-2.g-ii.B. The fuel flow and reignition threats must remain active before and after the candidate discharge to ensure that the flame extinction duration will end. This persistence also assures that the candidate extinguished the flames, and flame extinction did not result from ignition deprivation nor fuel starvation.

- 3.B-2.g-ii.C. The secondary ignition sources must be located in the fuel spray pattern to ensure effective operation. Both types of ignition source are required to simultaneously provide fire ignition opportunity. At least one reliable, persistent, ignition source must be provided from each of the following types.
  - 3.B-2.g-ii.C-i. an electrical arc
  - 3.B-2.g-ii.C-ii. a hot surface
- 3.B-2.g-ii.D. The spray fire scenario at varying times in a test program will be based on turbine fuel, a lubricant or a hydraulic fluid.
  - 3.B-2.g-ii.D-i. The fire threat intensity for the 3 fuels must be understood as related to fuel type and ventilation regime, then ranked from least to most severe, as indicated by measured thermal output.
  - 3.B-2.g-ii.D-ii. The less-severe fuels should be delivered through the same nozzles and at the same flow conditions as the most-severe fuel.

3.B-2.g-iii. Pool fire scenario

- 3.B-2.g-iii.A. The singular secondary ignition source is an electrical arc.
- 3.B-2.g-iii.B. The pool fire is based on turbine fuel (Jet-A, JP-8).
- 3.B-2.g-iii.C. Experimentation will be important to determine the optimal reignition characteristics of this fire scenario.
  - 3.B-2.g-iii.C-i. The area of the exposed fuel surface for combustion is not specified. It can either be selected by expected pool sizes that may be found in an actual aircraft or it can be sized to the confines of the test fixture.
  - 3.B-2.g-iii.C-ii. The recirculation zone that sets up over the fuel surface behind flame attaching structure will vary with free-stream flow speed. Ensure that the recirculation aerodynamics do not provide an opportunity to confuse the interpretation of test results.
  - 3.B-2.g-iii.C-iii. Observing flame spread across the fuel surface to understand the different behaviors and then permit optimizing the reignition event prior to any equivalence testing is recommended.

3.B-3. Candidate Storage, Delivery, and Concentration Measurement.

3.B-3.a. Candidate Storage.

3.B-3.a-i. Requirements for candidates stored in a pressurized vessel and subsequently expelled.

- 3.B-3.a-i.A. The candidate must be appropriately and safely stored in some containment that is acting as a fire extinguisher vessel. Thermal and pressure vessel ratings must appropriately relate to the work expected.
- 3.B-3.a-i.B. The containment will serve multiple purposes for each test.
  - 3.B-3.a-i.B-i. Candidate conditioning during test preparation.
  - 3.B-3.a-i.B-ii. Candidate discharge into the test fixture during a test.

3.B-3.a-i.C. There must be an ability to persistently observe the candidate’s temperature and pressure during pre-test conditioning and test.

3.B-3.a-i.D. The candidate should be conditioned to a storage temperature of 38°C (100°F) for each test.

3.B-3.a-i.D-i. It should be stored consistent with industry practice, if such guidance exists.

3.B-3.a-i.D-ii. This requirement is likely unnecessary for solid aerosol candidates. Discussion with the applicable regulatory authority before summarily dismissing this requirement is advised.

3.B-3.a-i.E. The storage vessel must have a releasing mechanism that can be remotely and reliably actuated to discharge the candidate into the test fixture.

3.B-3.a-ii. Requirements for other means of candidate storage.

3.B-3.a-ii.A. Other means of storage are known at this time

3.B-3.a-ii.B. The maturity of these technologies within the civil aviation community are infantile, thus the lack of maturity prevents the inclusion of specification or guidance here at this time.

3.B-3.a-ii.C. Discussions within the community will be required at the time of consideration of such atypical solutions. See comments for “*Possible Additional Requirements for Novel Solutions*”.

3.B-3.a-ii.C-i. The applicability of this document to the proposed solution should be determined by discussions with the pertinent regulatory authority.

3.B-3.a-ii.C-ii. Secondarily, input from the the task group overseeing this activity may be needed to revise this document.

3.B-3.b. Candidate Delivery.

3.B-3.b-i. All candidate injection plumbing must be capable of the thermal and pressure insults typical of candidate injection (discharge) events. It must be secured to prevent damage to persons or structure during normal testing in the event of failure.

3.B-3.b-ii. Candidate injection must minimize the insult on the fire threats from phenomena not evaluated. Injection nozzles should :

3.B-3.b-ii.A. be located some distance away from the fire scenarios.

3.B-3.b-ii.B. not be pointed at or in the general direction of the fire scenarios. When oriented to the direction of the bulk ventilation flow, the plumbing should direct the candidate injection jet(s) :

3.B-3.b-ii.B-i. perpendicular

3.B-3.b-ii.B-ii. upstream

3.B-3.b-ii.B-iii. some combination of each

3.B-3.b-iii. There is no constraint on the duration of the candidate injection.

3.B-3.c. Candidate Concentration Measurement.

3.B-3.c-i. A minimum of 12 sample points is required. They should provide behavioral indications within some volume of the test fixture for the full cross section that encompasses the fire threats.

        - 3.B-3.c-i.A. The sampling points must be chosen wisely and then consistently maintained during each test program. Reviewing FAA Advisory Circular 20-100 is advised.
        - 3.B-3.c-i.B. The sampled volume will likely be smaller than the test fixture volume.
        - 3.B-3.c-i.C. At least 1 wake region of flame-holding structure must be sampled.
            - 3.B-3.c-i.C-i. Testing not related to evaluating a candidate by this process will likely require accomplishment.
            - 3.B-3.c-i.C-ii. A more challenging wake region is a logical and reasonable choice for this measurement location. Placement behind a wall-mounted obstruction is more challenging than one suspended in the ventilation flow.
    - 3.B-3.c-ii. Measurement methods.
        - 3.B-3.c-ii.A. Gaseous candidates. A Statham-derivative analyzer is widely recognized in this community as the appropriate tool for this need. If the analyzer planned for use is not of this lineage, then see comments under “*Possible Additional Requirements for Novel Solutions*” for guidance.
        - 3.B-3.c-ii.B. Non-gaseous candidates. The technology being used to quantify the candidate is novel. It will require appropriate regulatory consideration prior to testing. See comments under “*Possible Additional Requirements for Novel Solutions*” for guidance.

- 3.C. Operating, Monitoring, and Maintaining the Test Fixture and its Environment during its Life-span.
    - 3.C-1. The test fixture must be appropriately operated, monitored, and maintained during its life-span
    - 3.C-2. A life-span may have the duration of 1 test program or several programs.
    - 3.C-3. If operated through multiple programs, life-span benchmarks must be captured during each test program to permit monitoring the test environment and its changes over time.
        - 3.C-3.a. Each life-span benchmark should be captured for a consistent configuration of fixture and environment.
        - 3.C-3.b. This configuration should be consistent for the fixture’s life-span.
        - 3.C-3.c. One life-span benchmark is required when the fire threat/ventilation configuration includes a spray fire. The spray fire should be based on a turbine fuel.
        - 3.C-3.d. Monitoring the pool fire in similar manner is optional.

4. Testing Procedures.

By attaining this part of the process, the testing entity, in accordance with all previous descriptions, has successfully addressed and satisfied all applicable items discussed under the heading "*Additional requirements for candidates that are not addressed by this document*". The entity also has access to an instrumented generic nacelle fire simulator, where it can be reliably operated, monitored, and maintained, the behaviors of the 2 fire threats in its test environment are understood, and a candidate can be reliably delivered to its test environment. If true, evaluative testing by this process is now possible.

4.A. Important Definitions.
  4.A-1. Distribution Criteria.
    4.A-1.a. These criteria are generally used to characterize the diffusion of a substance in a ventilation stream resulting from its attendant injection.
    4.A-1.b. Two parameters define the criteria.
      4.A-1.b-i. The concentration of the substance.
      4.A-1.b-ii. The residence time of the substance's concentration.
    4.A-1.c. Distribution criteria are measured in the test environment over a minimum of 12 sampling points, where these points are specified elsewhere in this document.
    4.A-1.d. Two sets of distribution criteria per ventilation regime will be used to evaluate future candidate design criteria.
      4.A-1.d-i. One should produce distribution criteria where the concentration is 15-20% larger than the concentration of the design criteria being evaluated, given constant residence time.
      4.A-1.d-ii. The second should produce distribution criteria where the concentration is 15-20% smaller than the concentration of the design criteria being evaluated, given constant residence time.
      4.A-1.d-iii. Reasonable judgment must be applied here regarding the tolerance of the distribution criteria surrounding the design criteria being evaluated, given the future possibilities of candidates to be evaluated.
      4.A-1.d-iv. Any reference elsewhere in this document to concentrations, distribution criteria or candidate configurations that :
        4.A-1.d-iv.A. are 115%, are being related to distribution criteria which have a concentration 15-20% larger than the concentration of the evaluated design criteria.
        4.A-1.d-iv.B. are 85%, are being related to distribution criteria which have a concentration 15-20% smaller than the concentration of the evaluated design criteria.
  4.A-2. Design Criteria.
    4.A-2.a. Design criteria are a sub-set of distribution criteria.
    4.A-2.b. The candidate design criteria successfully resulting from this test process are intended to extinguish fire threats in the end-use.
    4.A-2.c. The design criteria discussed in the various parts of this document indicate the status of the evaluation.

    - 4.A-2.c-i. The descriptions indicate whether the design criteria are initial, faulted, or successful.
    - 4.A-2.c-ii. Successful design criteria will be the initial recommendation for certification criteria.
  - 4.A-2.d. Requirements for the initial design criteria.
    - 4.A-2.d-i. They must be identified before evaluation testing commences.
    - 4.A-2.d-ii. The initial design concentration will not be less than the 30% increase of a measured cup-burner flame extinction value, where n-heptane of 99% purity is used as the fuel in the cup-burner test apparatus.
    - 4.A-2.d-iii. The residence time can be any value. The FAA typically recognizes 0.5 second as being sufficient.
- 4.A-3. Candidate Configuration.
  - 4.A-3.a. This is a unique arrangement of candidate storage and injection conditions which provides a specific set of distribution criteria.
  - 4.A-3.b. Different configurations will result, where they relate to distribution criteria which are smaller or larger than the design criteria being evaluated, when measured at the specified concentration sampling points in the test environment.
  - 4.A-3.c. Two configurations per ventilation regime will require determination.
  - 4.A-3.d. During a completed test program in the generic test environment, if the test process :
    - 4.A-3.d-i. concluded successfully without flaw, there would be 4 candidate configurations defined and used; 2 were needed for the high ventilation regime and 2 for low.
    - 4.A-3.d-ii. concluded successfully with a single flaw,
      - 4.A-3.d-ii.A. the design criteria required modification
      - 4.A-3.d-ii.B. six or more candidate configurations required definition by the end of the test program. The actual number of configurations would depend upon when the fault condition occurred and the logical relationship with the work already completed.
  - 4.A-3.e. Successfully demonstrating a candidate configuration requires equaling or reasonably exceeding the distribution criteria for a minimum of 3 repeated candidate distribution tests.
- 4.A-4. Reignition Time Delay (RTD).
  - 4.A-4.a. This is the difference in time between the 2 events of fire extinction and reignition related to a candidate discharge in the test fixture. The duration of time is the direct result of a candidate concentration pulse passing through the actively combusting fire threat in the presence of a forced ventilation flow, persistent ignition source(s), and the persistent presence of fuel.
  - 4.A-4.b. This duration should be assessed from a visual record. i.e. the fire extinguished at 04:23.06, indicated by a superimposed stop watch in the video record, and then reignited at 04:24.37. The RTD = 24.37-23.06 = 1.31 seconds.
  - 4.A-4.c. An near-zero RTD indicates a test fire threat was not extinguished.
- 4.A-5. Principal Fuel.

- 4.A-5.a. This fuel produces the largest measured energy release from the spray fire threat in the generic test fixture for a given ventilation regime.
- 4.A-5.b. The initial evaluation of a candidate's performance against the spray fire threats is completed with the principal fuel being delivered to the spray fire threat.

4.A-6. Fuel Verification Testing.

- 4.A-6.a. The assessment compares candidate performance against spray fire threats using other fuels typically found in an aircraft engine nacelle.
- 4.A-6.b. If the fire threat is a spray fire, this smaller testing activity is completed when the candidate is delivered to extinguish spray fires based on other fuels to assure test outcome remains acceptable.

4.A-7. Life-span benchmark.

- 4.A-7.a. This is a collection of 5 repeated fire extinguishment tests.
- 4.A-7.b. The set of test conditions/configurations can be arbitrary. However, the conditions/configurations should preferably relate to something of meaning.
- 4.A-7.c. The outcome from a single life-span benchmark test should be equal to or larger than 1 second, and smaller than or equal to 6 seconds. After completing the benchmark, the standard deviation of the RTDs resulting from the 5 repeated tests should be no more than 20% of the average RTD.
- 4.A-7.d. This collection of repeated tests will provide insight regarding the changes in the generic test environment over time. Such observations *may* contribute to explaining anomalous behavior during future efforts.

4.A-8. High-fidelity Demonstration Testing.

- 4.A-8.a. This testing activity is conducted in a test environment that is very similar to or is an actual aircraft engine nacelle, where the conditions tested within the structure are representative of conditions experienced in flight.
- 4.A-8.b. This testing activity will occur in a test fixture which may not meet the fixture descriptions provided in the commentary under the heading of "*Infrastructure*". The commentary under the heading "*Infrastructure*" is intended to provide a generic nacelle fire simulator.
- 4.A-8.c. The requirement to perform this testing activity is optional and subject to the decision of the applicable regulatory authority.

4.B. Describing the Testing Cycle.

The test cycle includes testing specific to this process. The activity requires testing within a generic nacelle fire simulator and possible demonstration testing in a high-fidelity test environment. See figure 3 for a diagrammatic flow.

4.B-1. Prove the acceptability of the candidate's design criteria by fire test.

- 4.B-1.a. Assessing the candidate's performance in a generic test environment.
  - 4.B-1.a-i. Monitoring, assessing, and defining successful performance.
    - 4.B-1.a-i.A. The individual RTDs and their accumulating behavior, resulting from repeated tests for various conditions, are the primary metrics used to observe, monitor, and/or assess systemic behavior.
    - 4.B-1.a-i.B. The candidate's successful design criteria require the indication of successful behavior for the following conditions.

4.B-1.a-i.B-i. against each of the fire threats presented by the 4 fire threat/ventilation test conditions.

4.B-1.a-i.B-ii. during fuel verification testing.

4.B-1.a-i.C. Defining the candidate's assessment and successful performance for a single fire threat/ventilation combination.

4.B-1.a-i.C-i. The intent is to bracket the halon 1301 threshold criterion for flame extinction with 2 points indicating the candidate's flame extinction performance. The smaller (85%) and larger (115%) bracket boundaries will also respectively relate to 2 concentrations, 1 smaller and 1 larger. From these 2 ordered pairs of concentration and average RTD, and the concentration value in the evaluated design criteria, an interpolated average RTD value can be calculated, which is then compared to the halon 1301 threshold criterion to assess acceptability. This method requires maintaining a residence time for all concentrations at 0.5 second. See figure 2 for illustration.

4.B-1.a-i.C-ii. This assessment is intended as a go/no-go assessment. It is not intended for use to "find" or modify the concentration of a candidate from an initially-stated set of criteria. However, the failure of some initially-stated criteria will result in a search to find successful criteria.

4.B-1.a-i.C-iii. Flame extinction performance is based on 5 repeated fire tests for 2 candidate configurations, where one set of distribution criteria has a concentration 15-20% :

4.B-1.a-i.C-iii.a. larger than the concentration of the evaluated design criteria

4.B-1.a-i.C-iii.b. smaller than the concentration of the evaluated design criteria

4.B-1.a-i.C-iv. For each cluster of 5 repeated fire tests using the candidate, 2 values are calculated.

4.B-1.a-i.C-iv.a. The average RTD.

4.B-1.a-i.C-iv.b. The standard deviation of the RTD behavior.

4.B-1.a-i.C-v. Evaluation method.

4.B-1.a-i.C-v.a. Identify the 2 points, where each is an ordered pair of concentration and average RTD, ($C_{85\%}$, $RTD_{85\%}$) and ($C_{115\%}$, $RTD_{115\%}$).

4.B-1.a-i.C-v.b. The average RTD threshold criterion should be bracketed (surrounded) by the ordered pairs.

4.B-1.a-i.C-v.c. Using linear interpolation in conjunction with the concentration value in the evaluated design criteria (C_{DESIGN}) and the 2 ordered pairs, calculate an interpolated average RTD for the design concentration.

4.B-1.a-i.C-v.d. Compare the interpolated average RTD to the halon 1301 threshold criterion (RTD_{H1301}).

- 4.B-1.a-i.C-vi. Success exists if the applicable conditions are true. The threshold criteria are based on historical halon 1301 RTD behaviors in the FAATC nacelle fire simulator. See figure 4.
  - 4.B-1.a-i.C-vi.a. If in the current FAATC nacelle fire simulator :
    - 4.B-1.a-i.C-vi.a-(a) the interpolated average RTD is equal to or larger than the average RTD of the historical halon 1301 behavior for the same test condition.
    - 4.B-1.a-i.C-vi.a-(b) the standard deviation for the candidate's RTD behaviors are similar to or smaller than that of the historical halon 1301 behavior for the same test condition.
  - 4.B-1.a-i.C-vi.b. If in a new generic nacelle fire simulator :
    - 4.B-1.a-i.C-vi.b-(a) a candidate average RTD must be 1 second or larger.
    - 4.B-1.a-i.C-vi.b-(b) for the high ventilation regime, the interpolated average RTD from the pool fire must be equal to or larger than 1.82 times that for the spray fire based on the principal fuel
    - 4.B-1.a-i.C-vi.b-(c) based on the respective principal fuels, the interpolated average RTD for the low ventilation spray fire must be equal to or larger than 2.05 times that for the high ventilation spray fire
    - 4.B-1.a-i.C-vi.b-(d) for the low ventilation regime, the interpolated average RTD from the pool fire must be equal to or larger than 3.15 times larger that for the high ventilation spray fire based on the principal fuel
    - 4.B-1.a-i.C-vi.b-(e) the standard deviation of the candidate's RTD behaviors is equal to or smaller than 20% of the average RTD.

4.B-1.a-i.D. Defining the candidate's assessment and successful performance for fuel verification testing. See figure 5 for past behaviors. Threshold conditions here are based on these behaviors.

- 4.B-1.a-i.D-i. The intent here is to show when the candidate is challenged by other fuels of lesser combustion threat, the candidate's distribution criteria also demonstrate this trend. If this trend is not indicated, some mechanism is inhibiting acceptable performance which must be accounted for and shown mitigated.
- 4.B-1.a-i.D-ii. The testing is accomplished with the test fixture configured to deliver candidate distribution criteria smaller than the design criteria being evaluated for the given spray fire threat/ventilation condition.
- 4.B-1.a-i.D-iii. For 3 repeated fire extinguishment tests, for each non-principal fuel, 2 values are calculated.
  - 4.B-1.a-i.D-iii.a. The average RTD.
  - 4.B-1.a-i.D-iii.b. The standard deviation of the RTD behavior.
- 4.B-1.a-i.D-iv. Success exists if the following conditions are true.

4.B-1.a-i.D-iv.a. the candidate’s average RTD, against a non-principal fuel, is equal to or larger than the related average RTD against the principal fuel.

4.B-1.a-i.D-iv.b. the standard deviation for each of the candidate’s RTD behaviors is less than 20% of the related average RTD.

4.B-1.a-ii. Assessing the candidate performance in the generic test environment. See figure 6 for a diagrammatic flow.

4.B-1.a-ii.A. Before starting any creditable testing to evaluate a candidate by this process, some initial design criteria for the candidate will be identified.

4.B-1.a-ii.B. Establish and document the various candidate configurations for the high & low ventilation regimes within the test environment.

4.B-1.a-ii.B-i. These configurations should provide candidate distributions that acceptably deliver the required distribution criteria to the fire threats.

4.B-1.a-ii.B-ii. Once established, these configurations are rigid and will not change during the evaluative testing activity unless a subsequent fault condition results.

4.B-1.a-ii.C. Procedure to complete one fire threat/ventilation condition.

4.B-1.a-ii.C-i. Configure the test fixture for 1 fire threat/ventilation condition.

4.B-1.a-ii.C-ii. If the fire threat is a spray fire :

4.B-1.a-ii.C-ii.a. and the test fixture will be used for more than one test program (multiple candidates), capture a life-span benchmark for a spray fire based on turbine fuel.

4.B-1.a-ii.C-ii.b. the principal fuel must be delivered to the fire threat.

4.B-1.a-ii.C-iii. Challenge the fire threat/ventilation condition, continuously monitor, and assess candidate performance while fire testing. See figure 7 for a diagrammatic flow.

4.B-1.a-ii.C-iii.a. Configure the test fixture with the related candidate configuration that delivers the larger candidate distribution criteria. This is the process to find the large bracket boundary. See figure 8 for a diagrammatic flow.

4.B-1.a-ii.C-iii.b. Complete 5 fire tests.

4.B-1.a-ii.C-iii.c. Calculate the average RTD and associated standard deviation.

4.B-1.a-ii.C-iii.d. Compare these calculations to the related threshold criteria.

4.B-1.a-ii.C-iii.e. If the average RTD does not exceed the related threshold criterion

4.B-1.a-ii.C-iii.e-(a) the evaluated design criteria have failed

4.B-1.a-ii.C-iii.e-(b) the criteria require modification

4.B-1.a-ii.C-iii.e-(c) repeat this challenge until finding an average RTD that exceeds the related threshold criterion

4.B-1.a-ii.C-iii.e-(d) do not complete testing to characterize the distribution originally identified as the smaller, as the distribution criteria resulting from the fault are now the smaller distribution criteria.

4.B-1.a-ii.C-iii.f. If the standard deviation does not satisfy threshold criterion

4.B-1.a-ii.C-iii.f-(a) troubleshoot

4.B-1.a-ii.C-iii.f-(b) resolve problem

4.B-1.a-ii.C-iii.f-(c) explain actions in final report

4.B-1.a-ii.C-iii.g. If the calculations compare acceptably with the threshold criteria, continue with general procedural test flow

4.B-1.a-ii.C-iii.h. Configure the test fixture with the related candidate configuration that delivers the smaller distribution criteria. This is the process to find the small bracket boundary. See figure 9 for a diagrammatic flow.

4.B-1.a-ii.C-iii.i. Complete 5 fire tests.

4.B-1.a-ii.C-iii.j. Calculate the average RTD and associated standard deviation.

4.B-1.a-ii.C-iii.k. Compare these calculations to the related threshold criteria.

4.B-1.a-ii.C-iii.l. If the average RTD is not smaller than the related threshold criterion

4.B-1.a-ii.C-iii.l-(a) the evaluated design criteria are successful

4.B-1.a-ii.C-iii.l-(b) continue with general test procedure flow

4.B-1.a-ii.C-iii.m. If the standard deviation does not satisfy threshold criterion

4.B-1.a-ii.C-iii.m-(a) troubleshoot

4.B-1.a-ii.C-iii.m-(b) resolve problem

4.B-1.a-ii.C-iii.m-(c) explain actions in final report.

4.B-1.a-ii.C-iii.n. If the calculations compare acceptably with the threshold criteria, continue with general procedural test flow

4.B-1.a-ii.C-iv. If 2 points are found that bracket and satisfy threshold criteria, assess the evaluated design criteria per previous guidance.

4.B-1.a-ii.C-v. If assessment is

4.B-1.a-ii.C-v.a. successful, continue with general procedural test flow

4.B-1.a-ii.C-v.b. unsuccessful, review circumstances and determine an appropriate course of action.

4.B-1.a-ii.C-vi. If 2 points are found that satisfy and exceed the threshold criteria, then continue with general procedural test flow

4.B-1.a-ii.C-vii. If the fire threat is a spray fire, complete fuel verification testing. See figure 10 for a diagrammatic flow.

4.B-1.a-ii.C-vii.a. Challenge the candidate with the spray fire based on the non-principal fuels.

- 4.B-1.a-ii.C-vii.b. Configure the test fixture with the related candidate configuration that delivers the smaller distribution criteria.
- 4.B-1.a-ii.C-vii.c. For each non-principal fuel, repeat 3 fire tests.
- 4.B-1.a-ii.C-vii.d. Compare performance with the applicable threshold references.
- 4.B-1.a-ii.C-vii.e. If successful, continue the test process by testing with a different fire threat/ventilation condition.
- 4.B-1.a-ii.C-vii.f. If unsuccessful, review circumstances and determine an appropriate course of action.

- 4.B-1.b. Assessing the candidate's performance in a high-fidelity, full-scale test environment.
  - 4.B-1.b-i. Explicit test conditions and descriptions of the evaluative process flow are not stated at this time, due to the unknown circumstances which would exist at the time a regulatory authority invokes this requirement. Discussion to define these details would occur at an appropriate time.
  - 4.B-1.b-ii. This testing activity will :
    - 4.B-1.b-ii.A. follow the testing activity in the generic test environment.
    - 4.B-1.b-ii.B. occur in a test environment that is highly similar to or is an actual aircraft engine nacelle representative of the end-use that includes test conditions representative of flight.
    - 4.B-1.b-ii.C. require fully acceptable demonstration of the candidate's successful design criteria from the testing activity accomplished in the generic test environment.

- 4.B-2. Report the outcomes from the testing activities.
  - 4.B-2.a. Collect all information and summarize in a final report.
  - 4.B-2.b. The information contained in the report at a minimum should include :
    - 4.B-2.b-i. an overview of the structural and telemetry aspects of the test fixture
    - 4.B-2.b-ii. the test fixture's operational conditions during the testing
    - 4.B-2.b-iii. references to and explanations regarding any observed anomalous behaviors
    - 4.B-2.b-iv. the identification of all candidate design criteria evaluated and the resulting outcomes, whether successful or not.

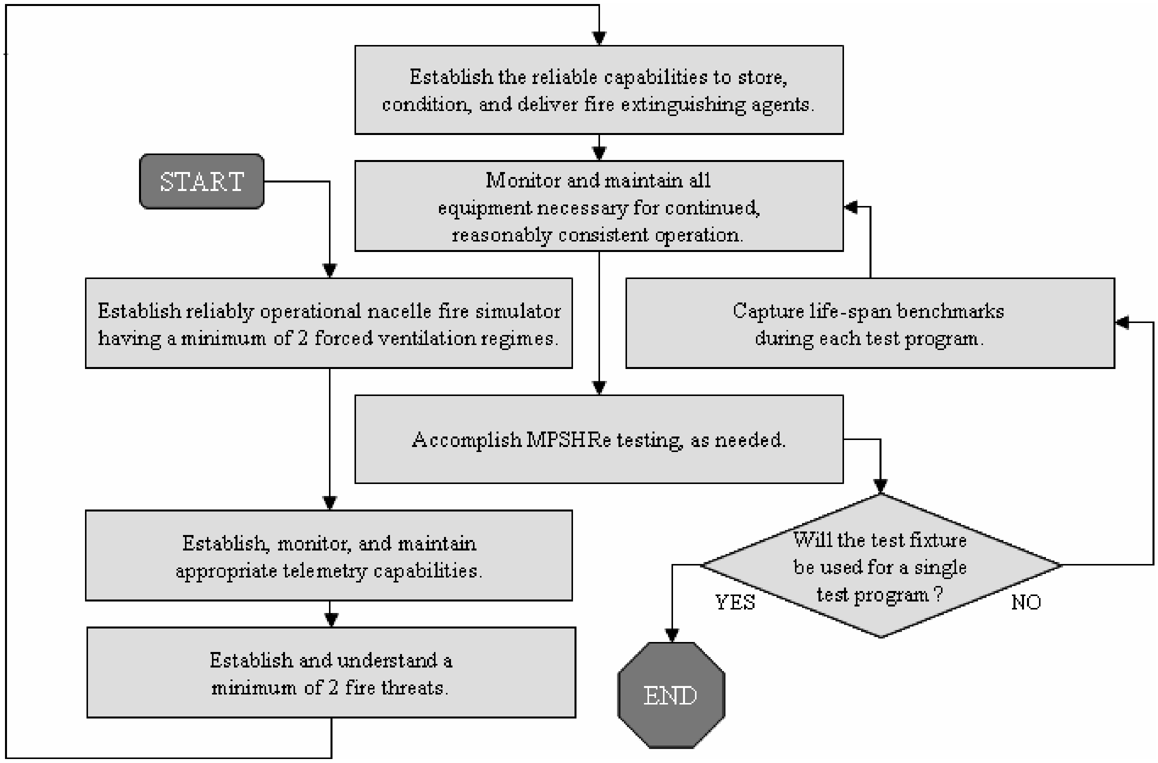
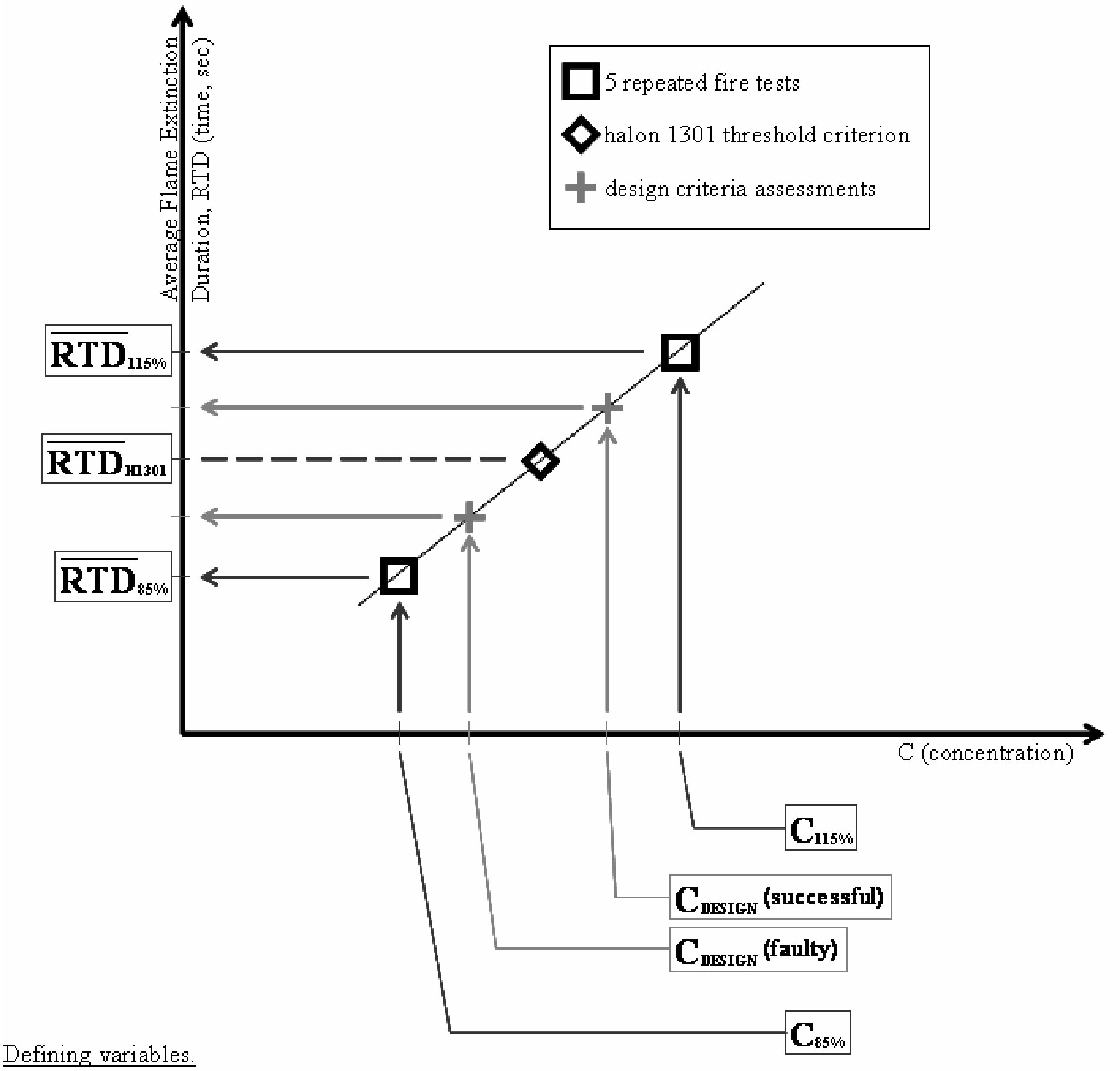


Figure 1. Illustrating the Complete Cycle of MPSHRe rev04 Process.



Defining variables.

$C_{115\%}$ = A concentration that is 15-20% larger than the concentration of the design criteria being evaluated.
$C_{85\%}$ = A concentration that is 15-20% smaller than the concentration of the design criteria being evaluated.
C_{DESIGN} = The concentration of the design criteria being evaluated.
$RTD_{115\%}$ = The average flame extinction duration produced by $C_{115\%}$.
$RTD_{85\%}$ = The average flame extinction duration produced by $C_{85\%}$.
RTD_{H1301} = The average halon 1301 flame extinction duration. This is a historically-based threshold criterion.

The varied concentrations in the various distribution criteria are all based on a constant residence time.

Figure 2. Illustrating the Evaluation Concept for Proposed Candidate Design Criteria.

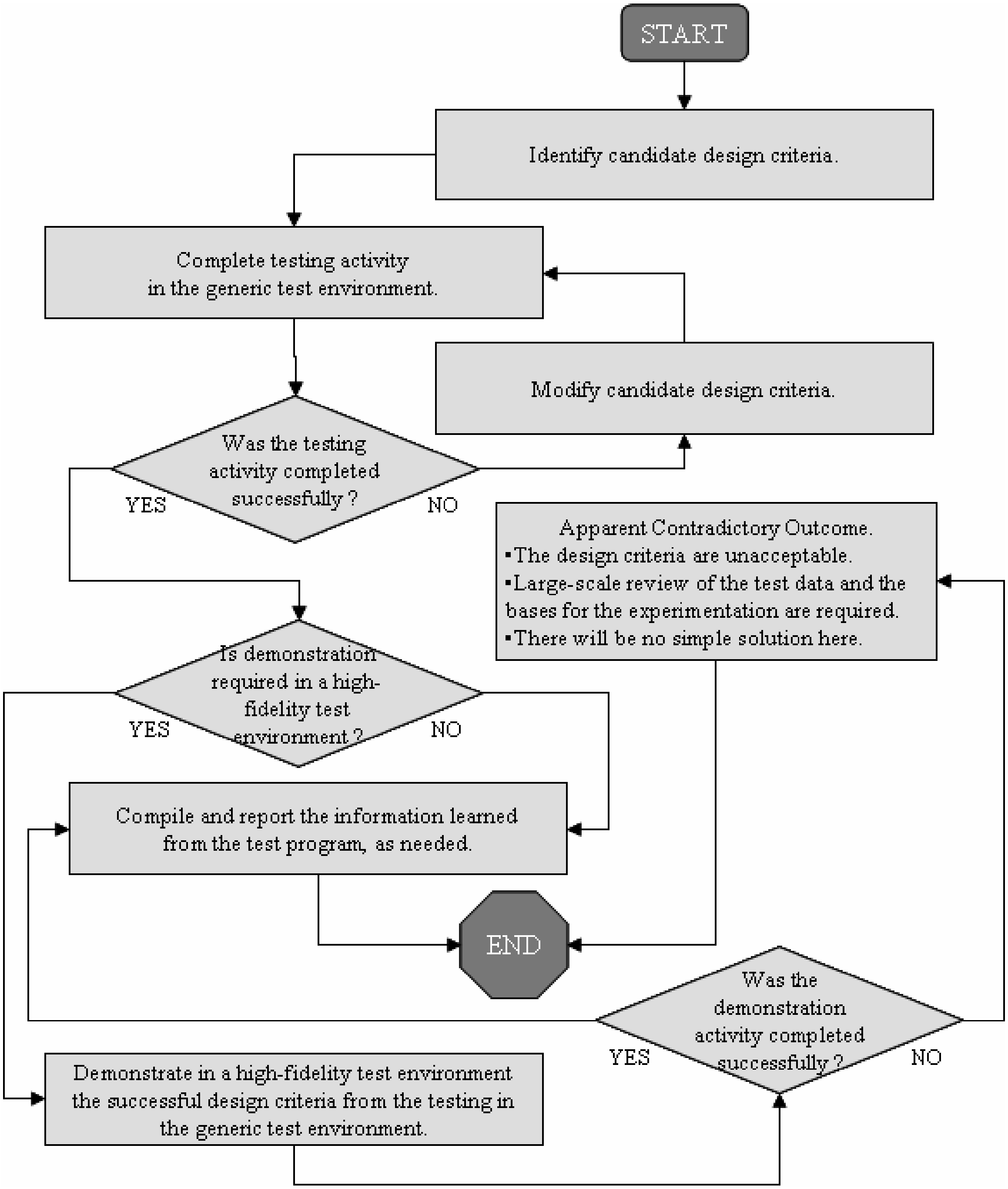
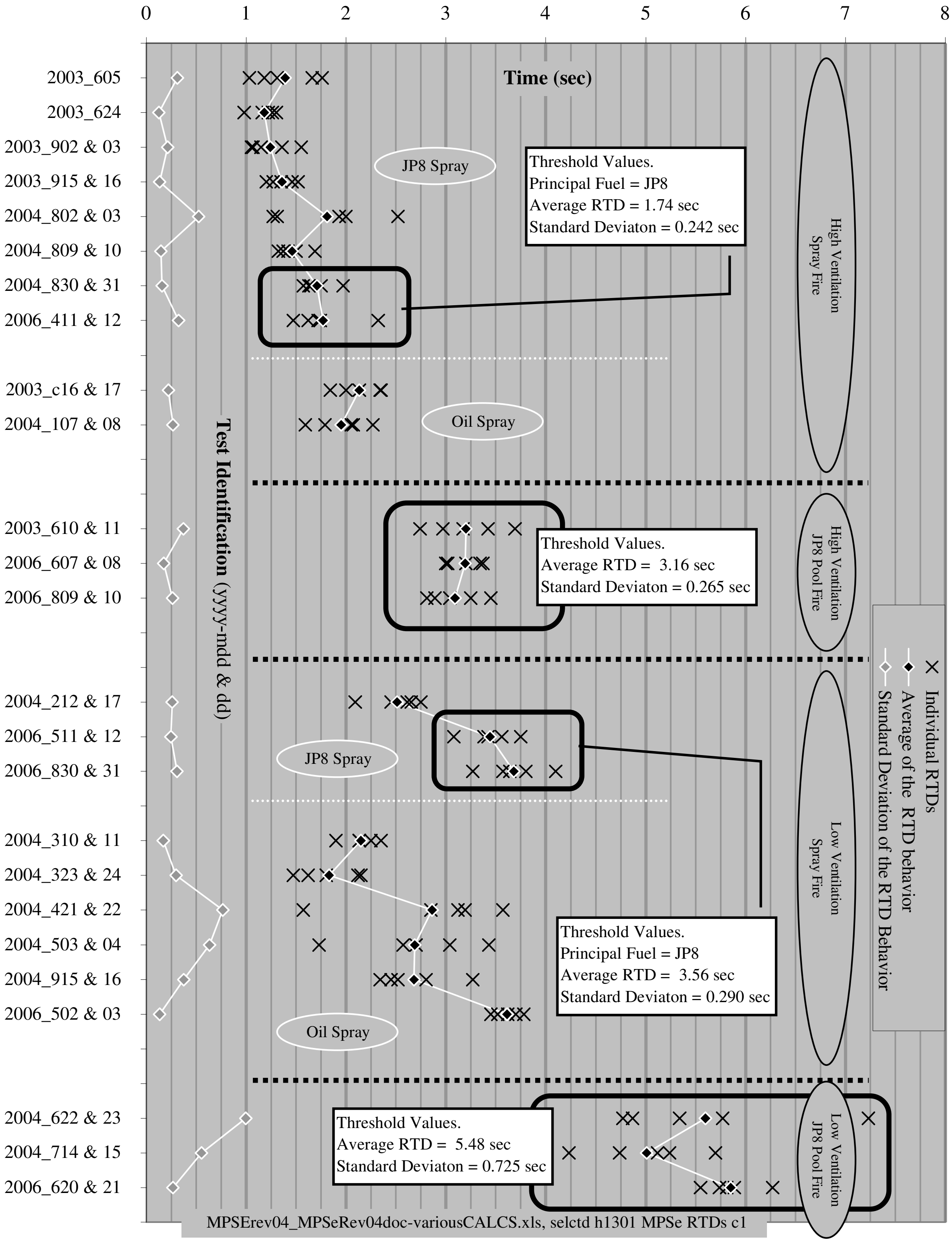


Figure 3. Illustrating the Testing Cycle of MPSHRe rev04.



Threshold Values.
Principal Fuel = JP8
Average RTD = 1.74 sec
Standard Deviaton = 0.242 sec

Threshold Values.
Average RTD = 3.16 sec
Standard Deviaton = 0.265 sec

Threshold Values.
Principal Fuel = JP8
Average RTD = 3.56 sec
Standard Deviaton = 0.290 sec

Threshold Values.
Average RTD = 5.48 sec
Standard Deviaton = 0.725 sec

MPSErev04_MPSeRev04doc-variousCALCS.xls, selctd h1301 MPSe RTDs c1

Figure 4. The Historical Performance of Halon 1301 in the FAATC Nacelle Fire Simulator.

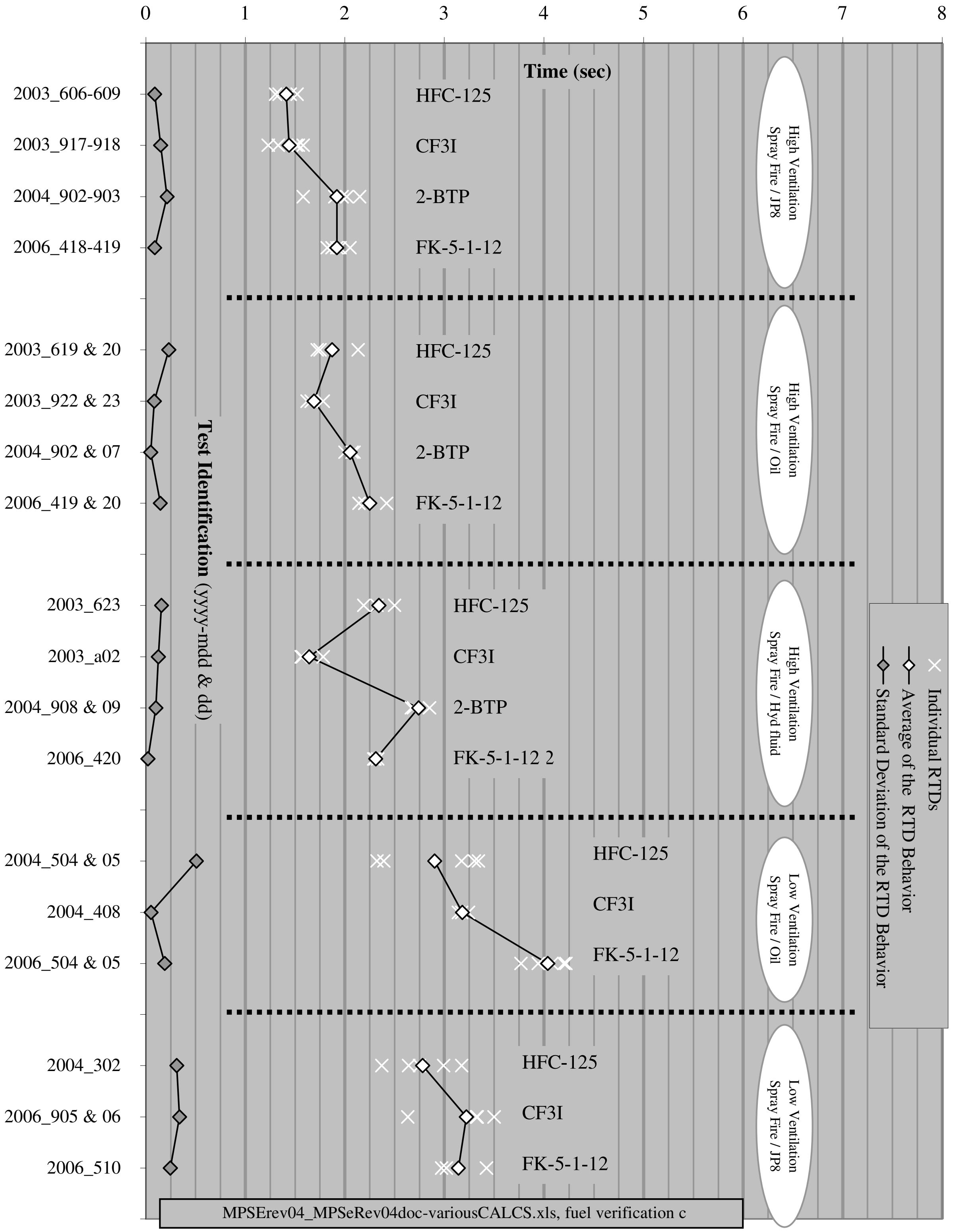


Figure 5. The Historical Candidate Performances During Fuel Verification Testing in the FAATC Nacelle Fire Simulator.

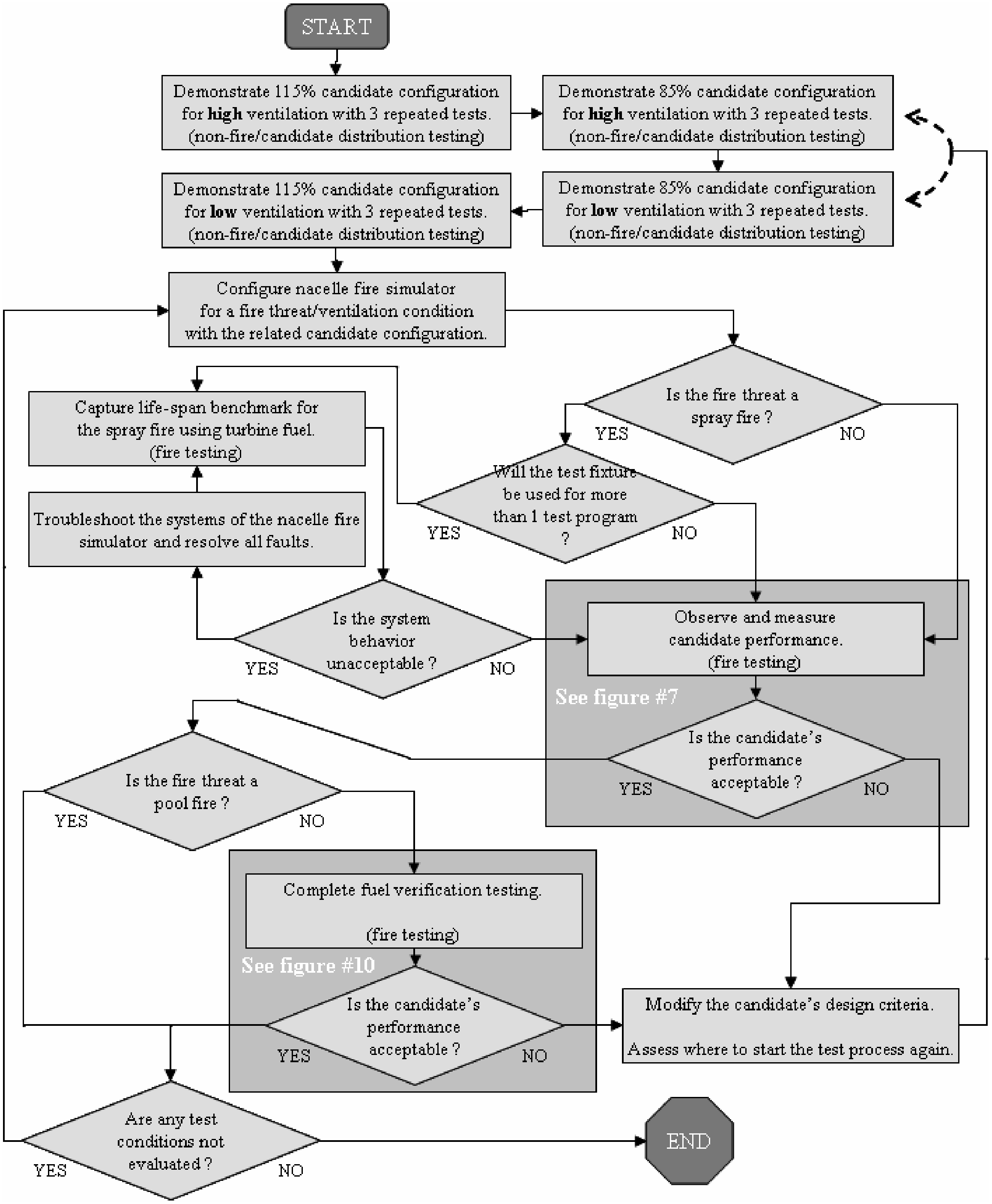


Figure 6. Illustrating the Full Testing Cycle of MPSHRe rev04 for a Generic Test Environment.

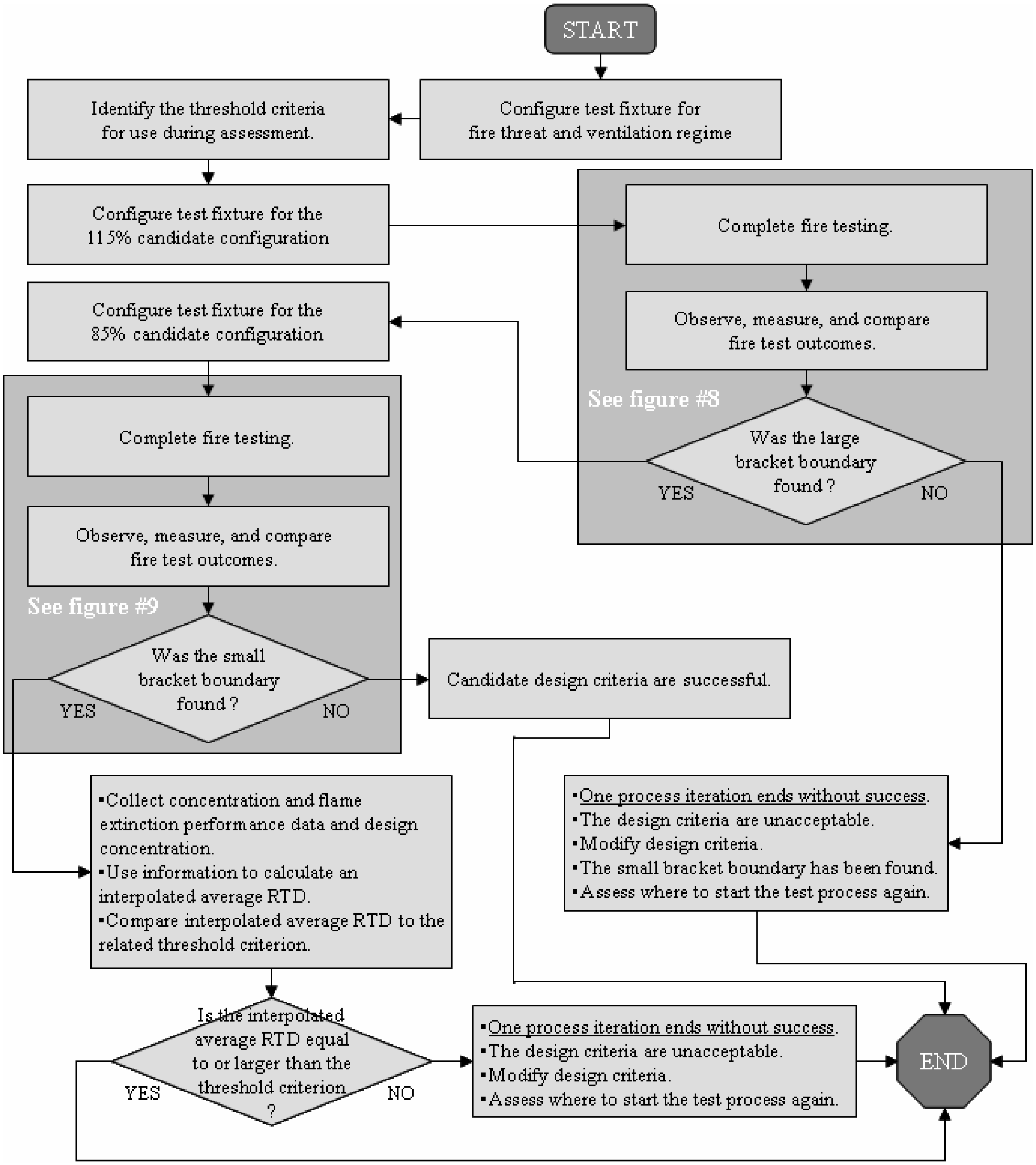
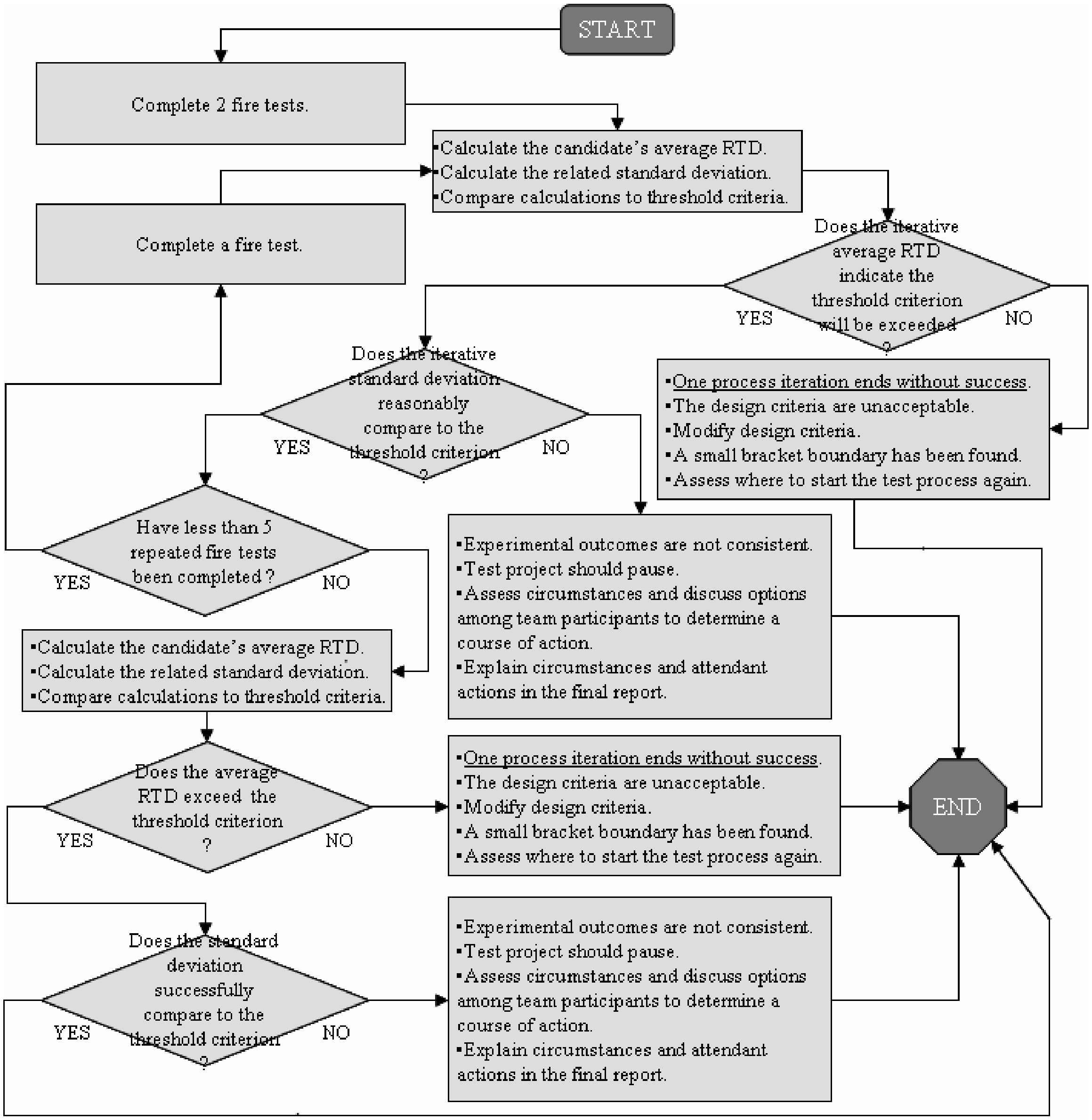


Figure 7. Illustrating the Process of Monitoring and the Assessment of the Reignition Time Delay for a Fire Threat/Ventilation Condition for a Generic Test Environment.



NOTE : As the number of fire tests completed increases, "reasonably" must tend to "successfully". The testing entity must exercise judgment to determine whether the incrementing and iterative candidate RTD behavior will result in final values that produce successful outcome.

Figure 8. Illustrating the Process for the Large Bracket Boundary Associated with 115% of the Candidate Design Concentration.

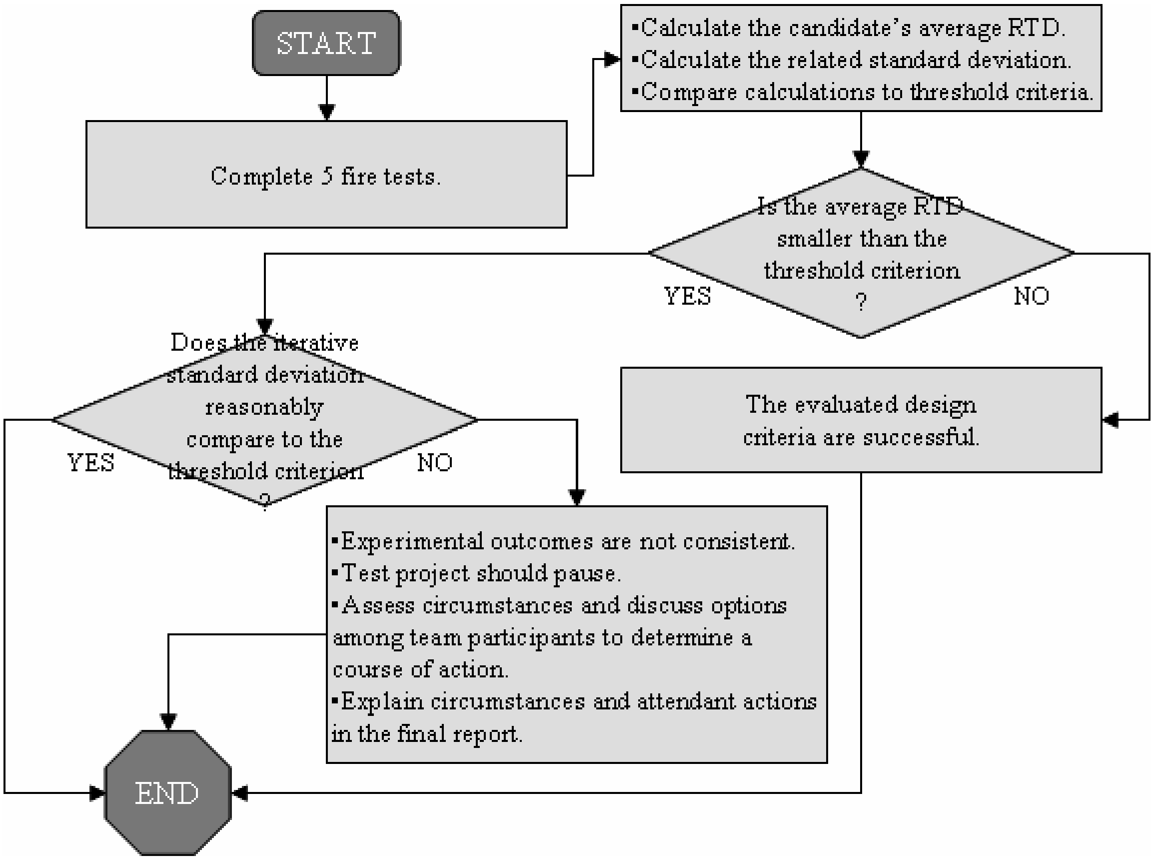
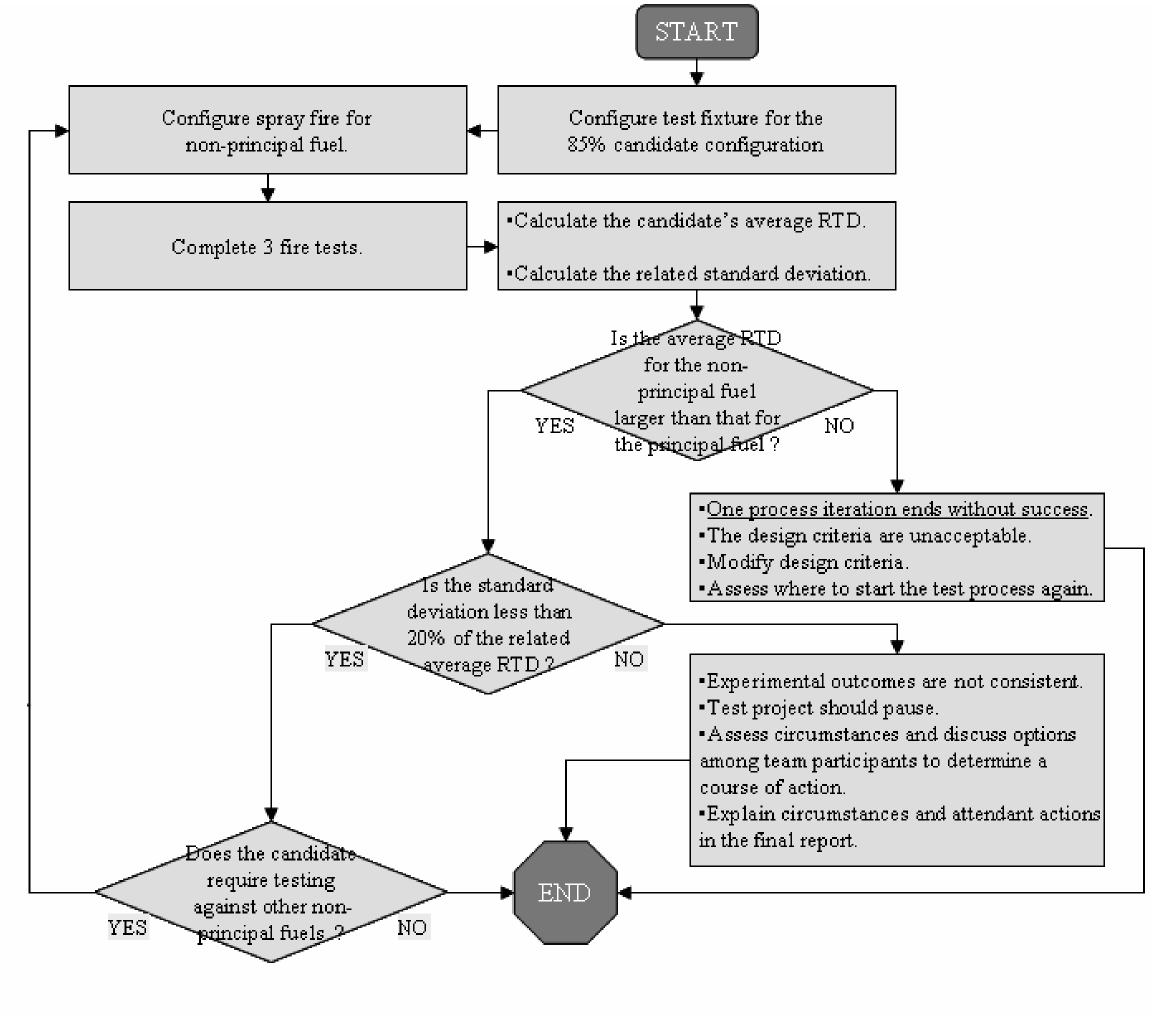


Figure 9. Illustrating the Process for the Small Bracket Boundary Associated with 85% of the Candidate Design Concentration.



NOTE : In the FAATC nacelle fire simulator, for high ventilation, the principal fuel is JP8. A lubricant and hydraulic fluid must be evaluated as non-principal fuels. Historically, hydraulic fluid was not checked at low ventilation. At low ventilation, the principal fuel has swapped from oil to JP8, leaving the alternate as the single non-principal fuel. If a novel candidate is being evaluated, testing against hydraulic fluid will also be required at low ventilation.

Figure 10. Illustrating the Process of Fuel Verification Testing for a Generic Test Environment.

5. Additional Commentary

- 5.A. Structure.
  - 5.A-1. The size of the zone was selected on the basis of the range of fire zone sizes of actual aircraft installations and considerations for a practical simulator where physical parameters can be properly simulated and controlled.
  - 5.A-2. A separate simulator for APU compartments is not necessary because experience from testing by the U. S. Air Force has shown that the requirements developed for the engine compartment provide equal or higher level of safety for the APU compartment.
  - 5.A-3. The FAATC nacelle fire simulator sits on a 372 m^2 (4000 ft^2) concrete floor. It is composed of 27 m (90 ft) of air flow pathway. The *test section*, the nacelle fire simulator, has an approximate volume of 2.83 m^3 (100 ft^3) with an annular cross section of 0.873 m^2 (9.4 ft^2). Its core is a 6.4 mm x 610 mm (0.25 x 24 inch) outside diameter steel tube surrounded by a steel skeleton holding 5 pairs of steel doors that are hinged at the top and close to form a concentric shell around the core. The up- and down-stream duct transitions are fabricated from 16 gage, galvanized, sheet metal. This fixture has withstood some 7 years of active fire testing using appropriate fire hardening, maintenance, and repair as required. The access to the interior of the test section's full length is possible after every test.
- 5.B. Telemetry
  - 5.B-1. The duration fire extinguishes then reignites is typically too quick to interpret from thermocouple response, even if fine-wire, due to the sensor's thermal inertia. Comparison of various recording methods (thermocouple, video, photodiode) from FAATC records clearly demonstrated superiority laid with visual means to observe the fire extinction. Since the human interpretation from video tape was the initial means to assess performance, it remains the choice method so links to historical data can be maintained.
  - 5.B-2. The visual records created at the FAATC reside on standard VHS tape as recorded by a surveillance camera. The camera image passes through a video time-date generator, having a stop watch capable of 0.01 second, before being recorded to tape. The limitation of the store-bought video cassette recorder permits a viewer to observe test behavior one video frame at a time, which represents a duration of 0.02-0.04 second between frames.
    - 5.B-2.a. These definitions are simplistic and have not been modified through the various programs.
    - 5.B-2.b. Fire extinction was defined by the complete lack of persistent flame in the camera's view field.
    - 5.B-2.c. Fire reignition was defined as the "notable" change in the camera's view field that indicated the onset of the sequential and incrementally intensifying change resulting with the fire again attaining the intensity observed before candidate discharge.

- 5.B-2.d. The pool and spray fire behaviors each had different characters, which required variations of the aforementioned definitions of extinction and reignition.
- 5.B-2.e. For a new simulator, testing is required prior to any evaluation programs to understand how to reliably and consistently determine the fire extinction duration.

5.B-3. Data-collection hardware and telemetry used at the FAATC includes :

- 5.B-3.a. There are two pieces of non-visual data collection hardware used at the FAATC.
  - 5.B-3.a-i. The first system has 88 channels. The unit is dedicated to capture thermocouple and pressure transducer histories. Events for the pressure transducers require sampling rates of 25 Hz or greater, whereas 5 Hz provides useful thermocouple data. A single test is controlled by the data collection system, given its ability to control relay functions.
  - 5.B-3.a-ii. The second system has 13 channels. The unit is dedicated to capturing the varying concentrations of gaseous fire extinguishing agents. It samples at 10 Hz.
- 5.B-3.b. Fine-wire (28-32 AWG), exposed bead, thermocouples sense air temperatures inside the test section at different locations to assess the air temperature. The bulk ventilation temperature is calculated at one of these locations (not exposed to fire). Other thermocouples are located inside the volume of flame resulting from the fire threat.
- 5.B-3.c. Probe thermocouples measured agent temperature and air temperatures where the air-sensing thermocouples were persistently bathed in flame during testing.
- 5.B-3.d. No thermocouples were corrected for radiation heat transfer error (analytically or physically).
- 5.B-3.e. A hot wire anemometer measured the center-line airflow of the inlet duct for the nacelle fire simulator so the air mass flow passing through the fixture could be recorded.
- 5.B-3.f. Pressure transducers were used to measure agent storage pressure in the fire extinguisher assembly, static pressure at the inlet, in the test section, and the exhaust duct; the static pressure transducers were added later in the project.
- 5.B-3.g. Additional sensors have been employed over time on an as-needed basis to better observe events of interest.

5.C. Ventilation Regimes

5.C-1. High ventilation corresponds to about 57 air changes per minute for the fire zone having 1.84 m^3 (65 ft^3) volume and 0.511 m^2 (5.5 feet^2) cross sectional area. For significantly different volume and cross section, the airflow rates should be adjusted appropriately. These flow rates cover the significant range of air flows in modern engine installations. This information is based on a US Air Force survey. Note that ventilation airflow is a commonly used term for airflow through the engine compartment.

- 5.C-2. Air temperature as low as -40°C (-40°F) could exist in some cases. Measurements have been made showing these temperatures can be experienced in different places in a flight envelope. However, under these conditions an engine fire threat is unlikely due to low power demand from the engine, cold fuel and relatively cooler surfaces in the fire zone. In addition, these conditions could delay the detection of a small fire which could result in an increase in air temperature. These are adequate reasons to conclude that this fire threat could be easily overcome by a system designed for larger fire threats which are likely when the air and surface temperatures are higher. Therefore, it is not necessary to simulate air temperatures below the ambient conditions in the test facility. However, for consistency between tests conducted during different ambient conditions, a controlled air temperature is preferred. Therefore 38°C (100°F) is selected to represent the lower end of the temperature range.
- 5.C-3. FAATC test fixture.
  - 5.C-3.a. The amount of air flow through the test fixture is controlled by perforated baffles that choke the inlet suction of the supply blower that pressurizes the simulator. A more restrictive baffle is used to provide the lower air flow rate, a less restrictive baffle for the higher. Recent measurements and somewhat more complex calculations based on flows through the inlet duct indicate the low ventilation rate is around 0.45 kg/s (1.0 lbm/s) and the high ventilation rate around 1.2 kg/s (2.7 lbm/s). Variation is observed to be +/- 0.1 lbm/s for both instances.
  - 5.C-3.b. The air heating is completed by electrical resistance heaters upstream of the test section to attain the 38°C (100°F) design point. The same heaters are used in conjunction with an oil burner to attain the second design point. The oil burner is ducted into roughly the first half of internal volume of the core. Its effluent is exhausted through pipes downstream from and around the fire scenarios. The core surface is known to reach 371°C (700°F) at one location away from the fire scenarios during this type of operation.
  - 5.C-3.c. The average airflow temperature is calculated from a collection of 8 type-K thermocouples distributed over the free-stream path in one cross section near the front of the test section, approximately 1.2 m (4 ft) forward of the fire threats.

5.D. Candidate Storage, Delivery, and Quantification.

- 5.D-1. Candidate Storage.
  - 5.D-1.a. The fire extinguisher storage vessel used at the FAATC has varied between a frequently-used, uniquely-designed assembly and true aircraft fire extinguisher bottles.
  - 5.D-1.b. The fire extinguisher at the FAATC is a unit formerly provided to the FAA by the USAF.
    - 5.D-1.b-i. The unit is a uniquely designed/fabricated assembly composed of a modified, steel, 20.7 MPa (3000 psig), 18.9 L (5 gal) hydraulic accumulator, strapped by circular band heaters with electric controls, and capped by a 31.8 mm (1.25 inch) pneumatically-controlled ball valve to discharge the agent. The agent containment can be varied both in volume

and temperature. The firex valve is remotely actuated by electrical signal, either manually or from a data collection system.

5.D-1.b-ii. The agent storage temperature is indicated by a probe thermocouple in the center of the discharge throat cross section at the bottom of the assembly just above the discharge valve. A pressure transducer records the pressure inside the containment in the discharge throat from a tap 90° from the thermocouple tap.

5.D-2. Candidate Delivery.

5.D-2.a. The specifications in the section are purposely vague. The future can not be predicted well. However, an applicant must meet the intent of this section, yet reasonably deliver the candidate being considered.

5.D-2.b. Candidate injection must reasonably minimize the insult on the fire threats from phenomena not evaluated by this process.

5.D-2.b-i. The parameters being evaluated per this process are candidate concentration and residence time. The phenomena being evaluated are the effects of a dispersed agent concentration and residence time on the fire threat behaviors. Nothing else.

5.D-2.b-ii. Injection plumbing must be installed in the test section to reasonably minimize, if not eliminate, any flame extinguishment mechanisms except for the candidate concentration.

5.D-2.c. The injection plumbing used at the FAATC has typically been bent stainless steel tubes of varying diameter from 12.7 – 31.8 mm (0.5 – 1.25 inch), wall thickness, and length with hand-swaged compression fittings that connect the agent containment to the interior of the test section.

5.D-2.d. No injection plumbing points at or in the general direction of the fire threats and separation exists between the injection planes and the fire threats.

5.D-2.d-i. Halon 1301 Injection

5.D-2.d-i.A. For high ventilation, halon 1301 injection occurs approximately 1.8 m (6 ft) forward of the fire scenarios and at low, approximately 1.5 m (5 ft) forward.

5.D-2.d-i.B. Nozzle orientation

5.D-2.d-i.B-i. The high ventilation nozzles inject agent through 6 nozzles. There are 3 on either side of the core in the test fixture. One nozzle, one each at approximately 02:00 and 10:00, directs agent upstream 45° above horizontal and into the ventilation stream at 12:00. A tee provides 2 nozzles, one each at 04:00 and 08:00, that radially inject opposed jets impacting the core and shell surfaces. Radial injection is perpendicular to the bulk flow.

5.D-2.d-i.B-ii. Low ventilation nozzles inject agent through 6 nozzles, 3 per side, at approximately 1:00 and 11:00. The injection is perpendicular to the bulk ventilation. On each side, two tees form a single injection nozzle assembly. One tee ends the branch line, where one outlet feeds the 2nd tee and the other opposed outlet discharges fire extinguishing agent on the shell. The 2nd tee produces 2 opposed jets, one directed at 12:00 on the shell and the opposed jet to hit another location on the shell., as described by the chord of a circle.

5.D-2.d-ii. Past Candidate Injection.

5.D-2.d-ii.A. The injection plumbing was conceptually similar for all candidate configurations.

5.D-2.d-ii.B. There were 8 nozzles which injected the candidate. The nozzles result from the use of 4 tees which provide opposed injection jets during agent discharge.

5.D-2.d-ii.C. The tees were positioned near where the branch lines penetrated the test fixture's shell at approximately 01:30, 04:30, 07:30, and 10:30. The bodies of the tees were aligned so the opposed jets laid against and ran along the inner surface of the test fixture shell. Hypothetically, the agent formed a circumferential cloud when injected.

5.D-2.d-ii.D. The line diameters were varied to choke the agent flow during discharge, dependent on needed outcome.

5.D-3. Quantification

5.D-3.a. A cup-burner assay will be the basis for the smallest design concentration to be evaluated by MPSHRe rev04 processes, due to similarity of combustion challenge posed by an accidental nacelle fire and that of the cup-burner flame.

5.D-3.a-i. Acceptable guidance describing a cup-burner assay is offered by the National Fire Protection Association.

5.D-3.a-ii. Work has also been accomplished at the U.S. National Institute of Standards and Technology.

5.D-3.b. Candidate Concentration Measurement.

5.D-3.b-i. Ancillary testing was accomplished during May-September 2009 looking at the wake region behaviors of some flow obstructions relating to the FAATC nacelle fire simulator. Outcomes are used here to assist with identifying how sample points to measure candidate concentration should be selected.

5.D-3.b-i.A. Two efforts were accomplished.

5.D-3.b-i.A-i. Wake regions behind 2 flow-obstructions similar to those in the FAATC nacelle fire simulator were observed in a small-scale wind tunnel using smoke-laden flow visualization. The observations were used to guide the placement of hot-wire anemometer and gas analyzer sample points in the FAATC nacelle fire simulator for subsequent testing.

5.D-3.b-i.A-ii. The wake regions behind 2 flow obstructions in the FAATC nacelle fire simulator were observed during varied ventilation conditions during the discharges of halon 1301, HFC-125, and CF3I. The data collected included gas analysis and hot-wire anemometry histories. One flow obstruction was the tube bundle, representing the hot surface reignition threat for the spray fire threat. The second flow obstruction was the forward lip of the fuel pan used in the pool fire threat.

5.D-3.b-i.B. Outcomes.

5.D-3.b-i.B-i. In both efforts, the concentration behaviors in the wake regions were expectedly seen deficient to or lagging behind the free-stream flow behaviors, as indicated by measured concentration from the different markers (smoke and fire extinguishing agents).

5.D-3.b-i.B-ii. When considering the flow obstructions presented by the tube bundle and fuel pan lip, the more challenging wake region was behind the fuel pan lip.

5.D-3.b-i.B-ii.a. Such observation is reasonable, given the fuel pan lip is attached to a wall, and the tube bundle is not.

5.D-3.b-i.B-ii.a-(a) The geometric height of both obstructions were similar, approximately 25 mm (1 inch) each, as seen by the flow.

5.D-3.b-i.B-ii.a-(b) The tube bundle is suspended in and perpendicular to the bulk flow. The flow splits around the obstruction's cross section, where its wake forms downstream from the cross section.

5.D-3.b-i.B-ii.a-(c) The fuel pan lip is attached to a wall and perpendicular to the flow. The flow does not split around the obstruction's cross section. It passes to one side, where its wake forms downstream from the cross section.

5.D-3.b-i.B-ii.b. The practical understanding relates to the increased washing of the tube bundle's wake region by a larger flow volume.

5.D-3.b-i.B-ii.b-(a) Due to the bundle's suspension in the flow, the wake is washed by flow passing around and coming from both sides of the assembly's cross section.

5.D-3.b-i.B-ii.b-(b) The wake region of the fuel pan lip is washed from only one side of the lip's cross section.

5.D-3.b-i.B-iii. The fire extinguishing system configurations originally used in the FAATC nacelle fire simulator to meet the intent of FAA certification for halon 1301 maintained acceptable behavior when the wake regions behind the tube bundle and the fuel pan lip were sampled for both ventilation regimes.

5.D-3.b-ii. Agent concentration measurement at the FAATC.

5.D-3.b-ii.A. General comments.

5.D-3.b-ii.A-i. A modified, Pacific Scientific HTL Halonyzer II is used to capture the behaviors of gaseous agents within the FAATC test fixture.

5.D-3.b-ii.A-ii. A varying 0-5 direct current voltage is used to indicate the gaseous concentration.

5.D-3.b-ii.A-iii. Twelve sample points are captured for each distribution test.

5.D-3.b-ii.A-iv. The analyzer is maintained on-site.

5.D-3.b-ii.B. Gas analyzer sample probe installation per MPSHRe rev03.

5.D-3.b-ii.B-i. The 12 sample points were separated into 3 rings of 4 points.

5.D-3.b-ii.B-ii. Each point was positioned at the midpoint between any structural surfaces inside the test section proximal to the sampling point. The intent was to capture the free stream concentration behavior.

5.D-3.b-ii.B-iii. The forward and aft rings were separated by 0.61 m (2 ft) and have the same clock positions of 12:00, 03:00, 06:00, and 09:00 for the sampling points.

5.D-3.b-ii.B-iv. The mid ring was positioned at the flame front, was equidistant between the fore and aft rings, and had a pseudo-120° separation scheme in the simulator's cross section. The fourth point on the ring was a redundant sample point used at the flame front. Clock positions were chosen based on the fire scenario; a pool fire had 01:30, 05:45, 06:15, and 10:30 positions, and the spray fire had 12:15, 04:30, 07:30, and 11:45 positions.

5.D-3.b-ii.B-v. The tubing used for sampling was a 3.6 m (12 ft) length of 3.18 mm (0.125 inch) outside diameter soft copper refrigeration line. The tube dimensions were chosen to minimize the internal volume to enhance the analyzer response yet access the internal sampling locations. The material was chosen to resist the thermal insult from low ventilation air flow. The orifice's circular plane for each tube end was parallel to the average direction of the ventilation flow.

5.D-3.b-ii.C. Gas analyzer sample probe installation per MPSHRe rev04.

5.D-3.b-ii.C-i. All previous statements remain accurate with one modification.

5.D-3.b-ii.C-ii. The modification affects the mid ring of sample points.

5.D-3.b-ii.C-ii.a. The mid ring will remain positioned at the cross section of the fire threat flame fronts, equidistant between the fore and aft rings.

5.D-3.b-ii.C-ii.b. A 120° separation will again be used, and a single point will removed and placed to sample the wake region behind the fuel pan lip of the pool fire.

5.D-3.b-ii.C-ii.b-(a) The 3 points of the mid ring will be located at the geometric midpoint between the shell and core structure on the radius.

5.D-3.b-ii.C-ii.b-(b) One point will be located each at clock positions of 04:30, 07:30, and near 12:00.

5.D-3.b-ii.C-ii.b-(c) The fourth point of the mid ring will be removed and placed in the wake region of the fuel pan lip of pool fire threat. The point will be 25 mm (1 inch) aft of the lip and 13 mm (0.5 inch) below the top of the lip. This location is approximately at 06:00 in the cross section of the FAATC nacelle fire simulator.

5.E. Fire Threats.

5.E-1. General Comments.

5.E-1.a. A fire in an engine or an APU compartment is probable when a fuel and air mixture come in contact with an ignition source and result in a sustainable combustion reaction. Airflow through an engine or APU compartment is normal and a fuel source is possible due to leakage of aviation engine fuel, hydraulic fluid or engine oil or due to a failure expelling these fuels. The ignition source could be any surface at a temperature above the hot surface ignition temperature for the fuel in the compartment. Electrical arcs or frictional sparks as a result of a failure may also provide potential ignition sources. Ignition can also occur if the fuel enters an environment in which rapid heating causes it to exceed its autoignition temperature. Three typical combustible fluids for the fire must be considered: aviation engine fuel, hydraulic fluid and engine oil.

5.E-1.b. In an aircraft installation, when the fire alarm is received an action is initiated resulting in a sequence of events. The engine fuel supply is shut off first. Hot air and electrical sources may also be shut off before activation of the fire extinguishing system. If the alarm occurs during the climb phase of the flight, more than a minute may elapse between the alarm and the discharge of the agent. In other cases, this elapsed time may be shorter than a minute.

5.E-1.c. Proper operation of the fuel delivery system for a simulator, including nozzles, should be checked to assure that the fire size and intensity are reproducible in tests with similar conditions. A measurement of heat flux density to characterize the fire is not necessary. Undue importance could be attached to this parameter as a means to determine reproducibility of fires while the measurement itself could depend on a variety of different factors.

5.E-1.d. If keeping the candidate’s injection duration reasonably similar, when the injected mass is increased, the RTD should increase.

5.E-1.d-i. If mapping the RTD behavior as related to injected candidate mass, the relationship has demonstrated a linearity for gaseous candidates, in particular HFC-125.

5.E-1.d-ii. However, the limitations imposed by the injection plumbing on the discharge flow and/or the candidate properties may invalidate this observation.

5.E-1.d-iii. Testing required to define the candidate configurations will provide insight.

5.E-1.e. Fuel verification failed once during testing at the FAATC for the duration between 2003-2006 while evaluating HFC-125, CF3I, and FK-5-1-12.

5.E-1.f. A second concept is rationalized to assist with evaluating a candidate’s design criteria in a more confident manner, beyond the go/no-go conditions offered in this document. This process requires the assessment of 2 design criteria. One would be deficient, and the second successful. This methodology perhaps offers more confidence in the subsequent outcome for successful criteria.

5.E-2. Fire Threat Intensity

- 5.E-2.a. The fire scenario intensity is established purely by experimentation. Combinations of ventilation rate, flame-holder (clutter) geometry, fuel spray flow rate or pool geometry, electrical arc type and position, and hot surface type and position are all factors which require investigation so that the collective scenario can produce a sufficiently intense fire consistent with citation “*Acceptable fire intensity*”.
- 5.E-2.b. Since halon 1301 will not be discharged in MPSHRe rev04 and beyond, any new test fixture will be subject to multi-point verification to prove sufficiently intense fire threats exist.
- 5.E-2.c. The existing test fixture at the FAA Technical Center has been shown to provide conditions for adequately intense fire threats, and that experience is the basis for the criteria specified.
  - 5.E-2.c-i. Intensity in the FAATC nacelle fire simulator was established by :
    - 5.E-2.c-i.A. not attaining any fire extinction by injecting half the design criteria for halon 1301 for the total residence time.
    - 5.E-2.c-i.B. injection of volumes of pressurized nitrogen over past test activities spanning the last 7 years. The nitrogen discharge portrayed in this document represents the most invasive insult offered in the test database for the FAATC nacelle fire simulator.
  - 5.E-2.c-ii. Combustion intensity was calculated for the fire threats in the FAATC nacelle fire simulator.
    - 5.E-2.c-ii.A. These calculations were based on measurements made with type-K thermocouples that surrounded a portion of the flame volume for the respective fire threats. Symmetry was invoked where advantageous.
    - 5.E-2.c-ii.B. The thermocouples measured temperature histories of steel boundaries and the airflow moving through the a portion of the cross section. These temperature histories were analyzed. A representative temperature increase was calculated.
    - 5.E-2.c-ii.C. Thermal energy output was calculated by summing the products of an individual temperature increase, mass of the substance related to the temperature increase, and the specific heat related to the substance and appropriately accounting for the duration of measure.
    - 5.E-2.c-ii.D. The thermocouple indications were not corrected for radiation error.

5.E-3. FAATC spray fire scenario.

- 5.E-3.a. The fuel line supplying the 2 fuel nozzles is contained within a water jacket for 95% of its length inside and outside of the test section. Reasonable control for the fuel temperature is maintained during testing.
- 5.E-3.b. Flame attachment provision is accomplished by discharging the fuel sprays from the 2 nozzles whose orifices are each approximately 25 mm (1 inch) above a 50.8 mm tall x 6.4 mm thick (2 x 0.25 inch) rib fastened to the

core surface. The nozzle spray plumes are directed downstream along the core parallel to the ventilation flow. Upon attaining the initial ignition, if the arc is turned off, the fire continues at its initial intensity. The spray fire demonstrates repeatable and acceptable intensity at a total flow rate of 0.25 gpm.

5.E-3.c. The electrical arc is maintained in the right-most fuel spray cone and left continually operating for the full length of the test. It is persistently checked and maintained.

- 5.E-3.c-i. The tips are cleaned after every test by wiping off debris and residue with a cloth wetted by a non-aggressive cleaner.
- 5.E-3.c-ii. The tips are maintained at a consistent gap in a consistent location.
- 5.E-3.c-iii. The tips are stainless steel electrodes which can be found at any company capable of repairing most home-heating, oil burning appliances.
- 5.E-3.c-iv. The arc is provided by stepping up 120 VAC, 60 Hz electricity to 10,000 VAC using a transformer. A suitable transformer can be taken from any home-heating oil burning appliance.
- 5.E-3.c-v. The electrical arc used in the FAATC facility is based on locally available hardware. A testing entity can use resources readily available to them ranging from store-bought material from local stores to parts scavenged from aircraft. Regardless of approach, note that the arc must be shown to reliably ignite the fuel spray and be persistently present during any test.

5.E-3.d. The hot surface is an array of tubes.

- 5.E-3.d-i. A tube array is located roughly 381 mm (15 inch) downstream from the fuel nozzles. It is a collection of four 12.7 mm (0.5 inch) diameter, 864 mm (34 inch) long x 0.889 mm (0.035 inch) wall stainless steel tubes. Cutting a cross section through one finds the centers of the four circles making the corners of a rhombus. The upper pair of tubes straddles the top of the rear tube in the lower pair. They are bent to a radius which is concentric with the core. They are held approximately 64 mm (2.5 inch) above the core surface. The four tubes are bound tightly together with safety wire and worm-gear clamps and are wired to a pair of rigid core mounting bracket. A probe thermocouple is bound in between the tubes and the bead sits near 12:00.
- 5.E-3.d-ii. Typical temperatures observed from this thermocouple range between 760 - 982°C (400-1800°F). The range of temperature is related to the structural alteration of the tube array during repeated heating and cooling cycles resulting from testing. The tip is exposed to direct flame (higher temperature) or hidden by tube (lower temperature). In the testing between 2003 – 2006, there is only one observed instance that the tube array alteration affected the behavior of the test outcomes. A problem was discovered then resolved, and normal test behavior subsequently resumed.
- 5.E-3.d-iii. The tube array is heated by the preburn duration of the fire threat and functions as a hot surface ignition threat reliably. It has a finite life

span of 10 tests, as its properties begin to change somewhere beyond this number which then affects the reliability of the reignition delay.

- 5.E-4. FAATC pool fire scenario
  - 5.E-4.a. The pool of fuel is 13 mm deep x 274 mm wide x 521 mm long (0.5 x 10.8 x 20.5 inch). The long dimension is parallel to the central axis of the test fixture and ventilation stream. The pool sits inside a steel pan assembly that has water passages in its bottom to cool the fuel and assembly to a reasonable extent during each fire test. The forward lip of the pool provides a 25 mm (1 inch) tall baffle for flame attachment purposes.
  - 5.E-4.b. There is no active effort to maintain a constant fuel depth during a test.
  - 5.E-4.c. The electrical arc is found on the longitudinal center-line 432 mm (17 inch) aft of the forward lip for high ventilation and 254 mm (10 inch) aft for low. The actual arc gap is located at the fuel surface because testing indicated the reliability of reignition was an abrupt function of height above the fuel's surface. The electrical arc is maintained on for the full length of each test and is cleaned afterwards. Descriptions of the electrical system producing the arc and the cleaning process are provided in comments in this section for the spray fire threat, titled "*FAATC spray fire scenario*".
  - 5.E-4.d. The preburn duration is 90 seconds.
- 5.E-5. Ranking the spray fire intensities in the FAATC nacelle fire simulator.
  - 5.E-5.a. Establishing the relationship was completed by simply recording the thermal energy behaviors of the fire by thermocouple.
  - 5.E-5.b. Intensity ranking proved easily at high ventilation. The largest areas under the thermocouple traces indicated which fuel was most severe for the evaluated conditions. The duration the fire was extinguished given a constant agent and mass corroborated the thermal observations. Turbine fuel is the most severe for these conditions in the FAACT nacelle fire simulator.
  - 5.E-5.c. Intensity ranking at low ventilation was confounding. Early thermal histories recorded for oil produced larger areas under the thermocouple traces instead of the turbine fuel. Hydraulic fluid character was similar to oil. As a contradiction, during work with FK-5-1-12 in 2006, the duration the fire was extinguished for an oil spray fire was longer than that for turbine fuel. Halon 1301 repeated the contradiction. Work in 2003 with HFC-125 did not indicate this contradiction. During the fuel verification testing, the contradiction was caught and permitted determining outcome based on the most severe fire threat condition (turbine fuel). As of this writing, reasons explaining why this change occurred remain unclear and will not be investigated.

5.F. Life-span Benchmarks.

- 5.F-1. In the case of the FAATC nacelle fire simulator, the life-span benchmark configurations are being worked to relate to previous experimentation.
- 5.F-2. The configurations are planned to relate to the performance of HFC-125, based its recommended criteria from MPSHRe rev03 of 17.6%v/v HFC-125 for 0.5 second..