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ACME

Advanced Combustion via Microgravity Experiments

SCIENCE OPERATIONS REQUIREMENTS

Derived from ACME's Integrated Science Requirements Document (ISRD)

Revision A

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Four fundamental investigations using gas-fueled laminar diffusion flames

Coflow Laminar Diffusion Flame (CLD Flame)

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OUTLINE

NOMENCLATURE

ACME *Advanced Combustion via Microgravity Experiments*
CIR *Combustion Integrated Rack*
GCIP *Gas Chromatograph Instrumentation Package (which is a CIR instrument)*
IPSU *Image Processing and Storage Unit (for CIR cameras)*
ISS *International Space Station*
ISRD *Integrated Science Requirements Document (for all 4 ACME experiments)*
MFC *Mass Flow Controller (which are found in both ACME and CIR hardware)*
mm *millimeter*
ops *operational / operations*
PMT *Photomultiplier Tube (instrument for measuring chemiluminescent emission)*
s *second*
SAMS *Space Acceleration Measurement System*
TFP *Thin Filament Pyrometry (technique for measuring the temperature distribution)*

Science Summary

The Advanced Combustion via Microgravity Experiments (ACME) project is now under development with a set of four independent experiments which are each focused on advancing combustion technology through fundamental research. The current ACME experiments are specifically directed at addressing energy and environmental concerns. The overall goals are to improve our understanding of (1) combustion at fuel lean conditions where both optimum performance and low emissions can be achieved, (2) combustion of fuels with increased hydrogen content which could enable reduced greenhouse emission, (3) soot control and reduction, (4) oxygen enriched combustion which could enable practical carbon sequestration, and (5) use of electric fields for combustion control. Unlike the Flame Extinguishment Experiment (FLEX), ACME is not focused on the advancement of spacecraft fire safety technology, although it is likely that some ACME findings will be relevant. While distinct, the experiments share several significant traits. The principal unifying feature of the ACME experiments is their use of gaseous fuels (e.g., methane and ethylene) rather than liquid or solid fuels. With this in common, the experiments will be conducted within the Combustion Integrated Rack (CIR) through the use of a single modular insert. In addition to the fuel state, the current set of ACME experiments all use laminar, non-premixed (i.e., diffusion) flames for their studies. To simplify analysis, these flames are either one or two dimensional, depending upon the experiment.

A general goal of the current ACME experiments is to gain fundamental understanding that can enable improved efficiency and reduced emissions in practical combustion processes, for example through the development and verification of models for chemical kinetics and transport processes in computational simulations. In addition to enhanced performance, improved modeling capability can lead to reductions in the time and cost for combustor design. In summary, microgravity investigations of non-premixed flames could lead to eco-friendly combustion systems providing our nation with green power for the future.

Coflow Laminar Diffusion Flame (CLD Flame)

Research, especially including that already conducted in microgravity, has revealed that our current predictive ability is significantly lacking for flames at the extremes of fuel dilution, namely for sooty pure-fuel flames and dilute flames that are near extinction. The general goal of the Coflow Laminar Diffusion Flame (CLD Flame) experiment is to extend the range of flame conditions that can be accurately predicted by developing and experimentally verifying chemical kinetic and soot formation submodels. The dependence of normal coflow flames on injection velocity and fuel dilution will be carefully examined for flames at both very dilute and highly sooting conditions.

Measurements will be made of the structure of diluted methane and ethylene flames in an air coflow. Lifted flames will be used as the basis for the research to avoid flame dependence on heat loss to the burner. The results of this experiment will be directly applicable to practical combustion issues such as turbulent combustion, ignition, flame stability, and more.

Electric-Field Effects on Laminar Diffusion Flames (E-FIELD Flames)

An electric field can strongly influence flames because of its effect on the ions present as a result of the combustion reactions. The direct ion transport and the induced ion wind can modify the flame shape, alter the soot or flammability limits, direct heat transfer, and reduce pollutant emission. The purpose of the Electric-Field Effects on Laminar Diffusion Flames (E-FIELD Flames) experiment is to gain an improved understanding of flame ion production and investigate how the ions can be used to control non-premixed flames. Outside reviewers concluded that the experiment "… will contribute to our critical understanding to our knowledge of combustion processes in the presence of electric fields." The experiment will be conducted with a simple gas-jet flame, where an electric field will be generated by creating a high voltage (up to 10 kV) differential between the burner and a flat circular mesh above (i.e., downstream of) the burner. Measurements, as a function of field strength and fuel dilution, will be made of the ion current through the flame and the flame's response time to electric forcing.

Flame Design

The primary goal of the Flame Design experiment is to improve our understanding of soot inception and control in order to enable the optimization of oxygen enriched combustion and the "design" of non-premixed flames that are both robust and soot free. An outside review panel declared that Flame Design "… could lead to greatly improved burner designs that are efficient and less polluting than current designs." Flame Design will investigate the soot inception and extinction limits of spherical microgravity flames, created in the same manner as for the s-Flame experiment. Tests will be conducted with various concentrations of both the fuel (i.e., ethylene or methane) and oxygen in order to determine the role of the flame structure on the soot inception. The effect of the flow direction on soot formation will be assessed by studying both normal flames and inverse flames, where in the latter case an oxygen/inert mixture flows from the spherical burner into a fuel/inert atmosphere. The Flame Design experiment will explore whether the stoichiometric mixture fraction can characterize soot and flammability limits for non-premixed flames like the equivalence ratio serves as an indicator of those limits for premixed flames.

Structure and Response of Spherical Flames (s-Flame)
The purpose of the Structure and Response of Spherical Flames (s-Flame) experiment is to advance our ability to predict the structure and dynamics, including extinction, of both soot-free and sooty flames. The spherical flame, which is only possible in microgravity, will be created through use of a porous spherical burner from which a fuel/inert gas mixture will issue into the CIR chamber. Flames will be ignited at non-steady conditions and allowed to transition naturally toward extinction. Tests will be conducted with various inert diluents, in both the fuel and chamber atmosphere. The fuel gases include hydrogen and methane for soot-free flames, and ethylene for sooty flames. One experiment objective is to identify the extinction limits for both radiative and convective extinction (i.e., at high and low system Damkohler numbers, respectively). Another objective is to determine the existence, onset, and nature of pulsating instabilities that have been theoretically predicted to occur in such flames with fuel/diluent mixtures that are above a critical Lewis number.

INTRODUCTION

The ACME project currently includes four distinct experiments and will tentatively include even more in the future. Therefore, it is critical that the project adopt a flexible approach to experiment control. This flexibility can be achieved through a set of explicit, and generally predefined and verified, functions which can be selected, repeated as needed, and ordered to create a variety of overall experiment sequences. Functions can include variable parameters, e.g., flow rate(s), providing additional flexibility. Furthermore, experiments can be run via either operator or software control. This approach to operational (ops) control is similar to the ordered stringing of beads to make a necklace, where each bead represents a function, and where each bead's characteristics (e.g., color, shape, size) represent its function and the associated variable parameters. The approach is further explained in section 1 of this document, i.e., General Requirements.

As defined herein, the control functions almost always occur in a serial fashion, but multiple operations may occur simultaneously. For example, sequential functions may in turn activate non-imaging and imaging data acquisition, the CIR illumination package, and fuel flow such that all are active at the same time. While these are operating, a timed function can also occur, e.g., translating the TFP fiber array. Normally, only a single timed function will be operative at a time, given their serial arrangement. However, there is at least one critical exception, namely the automated detection of extinction, where that function should normally always be active following ignition when the burner reactant(s) are flowing. Note that extinction detection requires *measurement filtering over time (e.g., time averaging) to avoid the false detection that could result from signal noise.*

The following requirements provide a great deal of operational control, allowing for stepped, stair-cased, ramped, rectangular-wave, and triangular-wave changes in the flow or electric field potential (i.e., voltage), and ramped or triangular-wave translation of the TFP fiber array. Examples of such control are shown graphically in Appendix A. Provisions are included for operator control to allow for determination of, or operation at (or near), limit conditions such as soot inception, lifting, and extinction.

While operational sequences specific to each experiment are described in section 4 of the ACME ISRD, these should be considered as specific examples of possible sequences. Furthermore, it should be understood that important operational requirements can be found in at least the following additional sections of the ISRD.

1.7 Electric Field
1.9 Burner Gas Delivery
1.0 Ignition
1.11 Ambient Environment
1.12 Data Synchronization and Recording
2.3 Gas Flow Rates
3.1 Color Imaging for Operations
3.2 Color Imaging for Data Analysis
3.4.3 Temperature: Hot Soot-Free Regions
3.5 Soot Volume Fraction
3.7 Chemiluminescent Emission
3.9 Post-Test Gas Composition

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FUNCTIONAL REQUIREMENTS

The functions are tentatively identified as being instant or timed (or sometimes general) and are categorically associated with either CIR or ACME operations. Key associated requirements from ISRD sections 1-3 are also cited at the end of each functional requirement, but specific citations are not provided for ISRD section 4.

1. [CIR & ACME] **General Requirements**
   1.1. [general] ACME shall provide flexible experiment control based on explicit functions which can be selected, repeated as needed, and ordered (*like colored beads on a string*) to create a variety of overall experiment sequences. Where possible, flexibility shall be provided within the individual functions by allowing the specification of relevant parameters (*like the flow rate, or by analog the size of the bead*). *Flexibility is critical for avoiding limitations that could hinder operations or limit ACME science. For example, the SOFBALL experiment (STS-83, STS-94, and STS-107) initially had a hard shutoff at 5 minutes because it was fully expected that the flames would extinguish by that time. However, that assumption was found to be faulty and the tests terminated while flames were still burning diminishing the scientific return. The test duration could not be extended until a subsequent spaceflight. Flexible experiment control will also enable future ACME experiments which differ operationally from the current set of ACME experiments.*

   1.2. [general] During at least combustion, ACME shall be capable of operations by either automated software control or operator control. ACME shall furthermore be capable of both automated and operator control within a single test, but where automated and operator control are not required simultaneously. *Software control allows for a higher fidelity of time control (e.g., as can be important for some experiments or tests), while operator control allows a human response to downlinked measurements, which can be especially valuable when trying to either identify or test at (or near) limit conditions, e.g., for soot inception, lifting, or extinction.*

   1.3. [general] ACME shall provide for automated software control through sequences of functions that are each either instant (i.e., without a duration) or timed, i.e., with a variable duration that is a parameter of that function.

   1.4. [general] ACME shall be capable of software upgrades, i.e., capable of developing and using new operational functions, for ISS operations after the ACME hardware has already been delivered to the ISS. *The purpose for this requirement is to support future, and as of yet undefined, ACME experiments.*

   1.5. [general] ACME shall not prevent the possible implementation of future closed-loop software functions, where control of some parameter(s) (e.g., gas flow) is based on one or more non-imaging measurements, e.g., temperature, thermal radiation, chemiluminescent emission. This requirement only applies to control parameters and measurements for the ACME chamber insert and does not apply to parameters or measurements associated with other hardware, such as CIR and SAMS. *The purpose for this requirement is to support future, and as of yet undefined, ACME experiments.*

1.6. [general] Unless otherwise specified, ACME shall be capable of carrying out operational functions while simultaneously doing any specified subset or all of the following in a time-constant manner: (1) acquiring imaging and non-imaging data, (2) flowing gas, (3) illuminating the chamber, (4) projecting light from the CIR illumination package, (5) energizing the electric field, and (6) sensing for flame extinction. *For operational reasons (e.g., to conserve fuel or protect hardware), there could also be simultaneous monitoring for out-of-range measurements (e.g., chamber pressure or temperature) that could initiate an alert or automatically shut down the test.*

1.7. [general] ACME shall provide a detailed time log of commands issued (i.e., functions enacted) for each test conducted. *This will aid in the analysis of results, e.g., to determine whether a flame naturally extinguished (where extinction detection would lead to automated termination of the burner flow) or whether it extinguished as the direct result of commanded flow termination (e.g., because the flow time duration was reached).*

2. [CIR & ACME] **Pause Functions**

2.1. [timed] ACME shall be capable of pausing for a specified duration between functions, where it shall be possible to specify a duration in the range of at least 0.01 to 999.99 s, with a precision of 0.01 s or less, *where a precision smaller than 0.0001 s is probably more than adequate*. *Pauses of specified duration, especially when short, can or should be controlled by software. This function has a single parameter: the specified duration.*

2.2. [general] ACME shall be capable of pausing for a specified duration between functions, where it shall be possible to specify a duration in the range of at least 10 s to 99 minutes, with an uncertainty of no more than the larger of (a) 5 s or (b) 10% of the specified duration. *Long pauses can be operator controlled, where the operator initiates the start and end through separate instant functions. This function has a single parameter: the specified duration.*

3. [CIR & ACME] **Hardware Set Up Functions**

3.1. [general] ACME shall be capable of installing and removing specified CIR or ACME hardware at specified positions external to the CIR chamber, where the hardware shall include (at a minimum) all of the following or any specified subset thereof: ACME avionics package, the GCIP, CIR and ACME imaging packages, IPSUs, the CIR illumination package, gas bottles, and a filter cartridge.

3.2. [general] ACME shall be capable of installing and removing specified ACME hardware at specified positions on the ACME chamber insert assembly, where the hardware shall include (at a minimum) all of the following or any specified subset thereof: burner, igniter tip (associated with the burner), electric field components (including the electrode mesh, high-voltage power supplies, and associated electronics), mass flow controllers, Thin Filament Pyrometry (TFP) fiber array, far-field thermocouple array, and the Photomultiplier Tube (PMT) array.

3.3. [general] ACME shall be capable of cleaning the soot off of gas-jet burners *where this could be necessary if an unacceptably high leak current is measured for the tests with an electric field. The cleaning should be a rare event and could be done by manually wiping off the burner tip or perhaps by igniting a flame with certain flow conditions*.

4. [CIR] **Chamber Ops Functions**

4.1. [general] ACME shall be capable of venting the CIR chamber atmosphere to a specified pressure within a range of at least 0.01 to 3 bar, with an uncertainty of no more than the greater of 0.01 bar or 1% of the specified pressure, *where a precision smaller than 0.1% of the specified pressure is probably more than adequate*. *This function has a single parameter: the specified pressure.* [ISRD 1.11.1]

4.2. [instant] ACME shall be capable of activating and deactivating the scrubbing of the CIR chamber atmosphere, i.e., circulating it through a specified filter cartridge without venting. *Such scrubbing will allow for reuse of the chamber atmosphere, where the upmass requirement for gas bottles is dominated by the gas used to fill the chamber. Furthermore, only a very small fraction of the reactant in the atmosphere (i.e., oxygen for normal flame testing) is consumed in a test.* [ISRD 1.11.1]

4.3. [general] ACME shall be capable of verifying that the CIR chamber is sealed, i.e., gas tight. *This is important for safety following any operation in which the chamber is opened.*

4.4. [general] ACME shall be capable of adding specified gas to the CIR chamber to a specified pressure with a precision that shall meet the composition and pressure requirements (e.g., when the atmosphere is filled by partial pressure mixing) documented in ISRD 1.11.1 and 1.11.4*. This allows for filling of the chamber after partial or complete venting. It also allows for replenishment of reactant (ideally enriched relative to the chamber composition), potentially without initial venting, but normally followed by venting to return to the specified pressure. Per the baselined ACME requirements, the initial total pressure (not partial pressure) can range from 0.1 to 3 bar, and the composition is to be within ±0.01 mole fraction.* [ISRD 1.11.1, 1.11.4]

4.5. [instant] ACME shall be capable of activating and deactivating the CIR chamber fan. *The duration for the chamber mixing (via the chamber fan) is not explicitly specified in the ISRD, but the current plan is to run the fan for a duration that is at least 100 times the chamber volume divided by the fan's volumetric flow rate.* [ISRD 1.11.2, 1.11.3]

4.6. [general] If the GCIP is available, ACME shall be capable of operations providing species concentration measurements of the chamber atmosphere using the GCIP. *Assuming availability of the GCIP, the measurements will be made before and/or after tests and with and/or without mixing of the atmosphere via the chamber fan.* [ISRD 3.9.1]

5. [CIR & ACME] **Initiation & Shut Down Functions**

5.1. [instant] ACME shall be capable of powering and de-powering all CIR and ACME components that are electrically powered or any specified subset thereof.

All such devices shall be powered up in advance of operation, including data acquisition, by at least the minimum warm-up durations recommended by their manufacturers *so that they function properly and provide accurate measurements, if any. For ACME, the warm-up of the Mass Flow Controllers (MFCs) is particularly important.* [ISRD 1.9.3, 1.9.4, 2.3.1]

5.2. [instant] ACME shall be capable of inserting and removing optical filters (e.g., BG7) from the ACME data analysis camera unless there are multiple data analysis cameras providing each required configuration. *Per the baselined requirements, the data analysis imaging is required both with and without a BG7 filter, where that requirement could be met by two cameras (i.e., one with the filter and one with no filter) and without this function.* [ISRD 3.2.11]

5.3. [instant] ACME shall be capable of configuring the CIR and ACME camera settings, e.g., as specified in ISRD 3.1.4 and 3.2.1.3. [ISRD 3.1.4, 3.2.13]

5.4. [instant] ACME shall be capable of starting and stopping non-imaging data acquisition (i.e., recording) for instruments specified in 1.12.7. *The data acquisition could be initiated in advance of ignition by as much as the value specified in ISRD 1.12.2, and stopped after extinction by as much the value specified in ISRD 1.12.2. Per the baselined requirements, each of those durations could be as much as 5 minutes. It should also be understood that some experiments or specific tests may not use the full suite of possible instruments. For example, the ion current measurement is only applicable to experiments using the electric field. In contrast, the removable thermocouple rake will not be used in tests with the electric field because of the resulting interference. However, it is anticipated that the acquisition for all measurements from the ACME chamber insert would begin and end together, but measurements from other hardware, e.g., CIR or SAMS, could begin or end at different times. As such, it is envisioned that multiple copies of the function might be used.* [ISRD 1.12.2, 1.12.7]

5.5. [instant] ACME shall be capable of starting and stopping imaging data acquisition (i.e., recording) for all cameras specified in 1.12.7 or any specified subset thereof. *The data acquisition could be initiated in advance of ignition by as much as the value specified in ISRD 1.12.3, and stopped after extinction by as much the value specified in ISRD 1.12.3. Per the baselined requirements, each of those durations could be as much as 1 minute. Note that the pre-ignition and post-extinction durations may vary between cameras (i.e., through multiple uses of this function). Furthermore, it should be understood that some experiments or specific tests may not use the full suite of cameras.* [ISRD 1.12.3, 1.12.7]

6. [ACME] **Chamber Illumination Functions**

6.1. [instant] ACME shall be capable of activating and deactivating any specified bank(s) of chamber lights. *While not explicitly required, a specific variation of this function could be used to turn off all chamber light banks (where that variation would require no parameters). This function's parameters are the independent specification (i.e., on or off) of each bank of chamber lights, i.e.,* *where the number of parameters is equal to the number of light banks.* [ISRD 3.1.8]

6.2. [timed] ACME shall be capable of activating any specified bank(s) of chamber lights for a specified duration (where it shall be possible to specify a duration in the range of at least 0.03 s to 999.99 s with a precision of 0.01 s or less, *where a precision smaller than 0.001 s is probably more than adequate*), and then deactivating those same bank(s) of chamber lights which had been activated. *This function's parameters include the duration (for all specified lights) plus independent specification of each bank of chamber lights. Therefore, the number of parameters is one greater than the number of light banks.* [ISRD 3.1.8]

6.3. [timed] ACME shall be capable of activating any specified bank(s) of chamber lights for a specified lights-on duration (where it shall be possible to specify a duration in the range of at least 0.03 s to 999.99 s with a precision of 0.01 s or less) and then deactivating those same bank(s) of chamber lights (i.e., which had been activated) for a specified lights-off duration (where it shall be possible to specify a duration in the range of at least 0.03 s to 999.99 s with a precision of 0.01 s or less) for a specified number of cycles (ranging from at least 1 to 9,999). *For the two specified durations, a precision smaller than 0.001 s is probably more than adequate. This flashing on-off illumination is useful for alternating imaging of both the flame and a solid fuel, i.e., to see the char pattern, as might be required in future ACME experiment(s). Function 6.3 is a repeated sequence of coupled 6.2 and 2.1 (pause) commands. This function's parameters include two durations (for all specified lights), the specified number of cycles, plus independent specification of each bank of chamber lights. Therefore, the number of parameters is three greater than the number of light banks.* [ISRD 3.1.8]

7. [CIR] **Illumination Package Functions**

7.1. [instant] ACME shall be capable of activating the CIR illumination package at a specified intensity (within its full operational range). *This function has a single parameter: the specified intensity.* [ISRD 3.5.4, 3.5.6]

7.2. [instant] ACME shall be capable of adjusting the intensity of the illumination (within its full operational range) while the illumination package is activated, i.e., without deactivating and reactivating it. *This function has a single parameter: the specified new intensity.* [ISRD 3.5.4, 3.5.6]

7.3. [instant] ACME shall be capable of deactivating the CIR illumination package. *No parameters are required for this function.* [ISRD 3.5.4, 3.5.6]

8. [ACME] **Ignition Functions**

8.1. [timed] ACME shall be capable of translating the igniter at a specified rate (where it shall be possible to specify a rate in the range of at least 0.0 to 50.0 mm/s with an uncertainty of no more than 0.1 mm/s, *where a precision smaller than 0.001 mm/s is probably more than adequate*), neglecting the initial acceleration, to a specified position (with a precision of 1 mm or less and over a range extending nominally from the burner tip to at least beyond the free area specified in ISRD 1.11.8 or 1.11.9 corresponding to the burner in use). *Per the* *baselined requirements, the igniter insertion is to be at least 30 s prior to ignition and the retraction is to be within 0.5 s of ignition detection, although such detection is currently not planned. Note that specification of the end position and travel time is functionally equivalent to specifying the translation speed. This function has two parameters: the translation speed (or duration) and the end position.* [ISRD 1.10.2, 1.11.8, 1.11.9]

8.2. [timed] ACME shall be capable of energizing the igniter at a specified voltage (with a precision of 2% or less, *where a precision smaller than 0.2% is probably more than adequate,* and within a range of at least 50% to 100% of the maximum power), for a specified duration (with a precision of 0.1 s or less, *where a precision smaller than 0.01 s is probably more than adequate,* and within a range that is at least that specified in 1.11.4) and de-energizing the igniter. *Per the baselined requirements, the igniter is to be energized from 0 to 10 s. This command could be repeated in (near) immediate succession using two different voltages to allow for igniter pre-heating, e.g., before the initiation of fuel flow in order to shorten the ignition time. This function has two parameters, i.e., the voltage and the duration.* [ISRD 1.10.2, 1.10.3, 1.10.4, 1.11.8, 1.11.9]

9. [CIR & ACME] **Flow Control Functions**

9.1. [instant] ACME shall be capable of zeroing all ACME MFCs or any specified subset thereof *to improve the accuracy of the flow control and measurement*. *This function has three parameters for the independent specification (i.e., to zero or not) of the three ACME MFCs (for fuel, oxidizer, and inert).* [ISRD 1.9.3, 1.9.4, 2.3.1]

9.2. [general] ACME shall be capable of venting all gas delivery lines or any specified subset thereof.

9.3. [general] ACME shall be capable of purging all gas delivery lines or any specified subset thereof with the gas(es) with which those lines are currently connected.

9.4. [instant] ACME shall be capable of setting all CIR MFCs or any specified subset thereof for specified steady flow rate(s) (within a range of 0 to 100% and a precision of 0.1% or less *but where it is understood that the resulting flow accuracy is a function of the specified value, gas, calibration, MFC response time, etc.*). *A gas flow rate precision smaller than 0.01% is probably more than adequate. Note that the specified flows may have different values and some flows may be zero (i.e., no flow). This function can be used to start flows, stop flows (by setting them to zero), or make a single step in flows. This function has five parameters which are the flow rates for each of the five CIR MFCs (where one is for fuel, three are for oxidizers and diluents, and one is for venting).* [ISRD 1.9.4]

9.5. [instant] ACME shall be capable of setting all ACME MFCs or any specified subset thereof for specified steady flow rate(s) (within a range of 0 to 100% and a precision of 0.1% or less *but where it is understood that the resulting flow accuracy is a function of the specified value, gas, calibration, MFC response time, etc.*). *A gas flow rate precision smaller than 0.01% is probably more than adequate. Note that the specified flows may have different values and some* *flows may be zero (i.e., no flow). This function can be used to start flows, stop flows (by setting them to zero), or make a single step in flows. This function has three parameters which are the flow rates for each of the three ACME MFCs (where there is one each for fuel, oxidizer, and inert).* [ISRD 1.9.4]

9.6. [timed] ACME shall be capable of setting all ACME flows or any specified subset thereof to step upward and/or downward by specified value(s) (within a range of 0 to 100% and a precision of 0.1% or less *but where it is understood that the resulting flow accuracy is a function of the specified value, gas, calibration, MFC response time, etc.*) and pausing to hold all flows steady for a specified wait duration (with a precision of 0.1 s or less, *where a precision smaller than 0.01 s is probably more than adequate,* and within a range of at least 0.1 to 999.9 s) for a specified number of cycles (ranging from at least 1 to 999). *A gas flow rate precision smaller than 0.01% is probably more than adequate. This function approximately allows for either a single step or a staircase of repeated steps, as shown in Appendix A. Of course, the flow rates are limited and will remain within the operational range of the associated MFCs. Note that some flows may be steady or even zero while others are stepped, and the step deltas (i.e., heights) may be different for each gas flow. Furthermore, some flow(s) may step upward while other(s) step downward, e.g., to maintain a total flow rate while varying the composition. This function's five parameters include the step size for each of the three ACME MFCs (where any step might be positive, negative, or zero), the wait duration (for all flows), and the number of cycles.* [ISRD 1.9.4]

9.7. [timed] ACME shall be capable of setting all ACME flows or any specified subset thereof to linearly ramp upward and/or downward by specified value(s) (within a range of 0 to 100% and a precision of 0.1% or less *but where it is understood that the resulting flow accuracy is a function of the specified value, gas, calibration, MFC response time, etc.*) for a specified ramp duration (with a precision of 0.1 s or less, *where a precision smaller than 0.01 s is probably more than adequate,* and within a range of at least 0.1 to 999.9 s), and pausing with all flows held steady for a specified wait duration (with a precision of 0.1 s or less, *where a precision smaller than 0.01 s is probably more than adequate,* and within a range of at least 0.0 to 999.9 s) for a specified number of cycles (ranging from at least 1 to 999). *A gas flow rate precision smaller than 0.01% is probably more than adequate. This function allows (approximately) for either a single ramped step or a staircase of repeated ramp steps, as shown in Appendix A. Of course, the flow rates are limited and will remain within the operational range of the associated MFCs. Note that some flows may be steady or even zero while others are ramped, and the ramp deltas (i.e., heights) may be different for each gas flow. Furthermore, some flow(s) may ramp upward while other(s) ramp downward, e.g., to maintain a total flow rate while varying the composition. This function's six parameters include the step size for each of the three ACME MFCs (where any step might be positive, negative, or zero), the ramp and wait durations (where both are for all flows), and the number of cycles.* [ISRD 1.9.4]

9.8. [timed] ACME shall be capable of setting all ACME flows or any specified subset thereof to step upward and/or downward by specified step-A value(s) (within a range of 0 to 100% and a precision of 0.1% or less *but where it is understood that the resulting flow accuracy is a function of the specified value, gas, calibration, etc.*), pausing with all flows held steady for specified "A" duration (with a precision of 0.1 s or less, *where a precision smaller than 0.01 s is probably more than adequate,* and within a range of at least 0.1 to 999.9 s), stepping the flow(s) downward and/or upward by specified step-B value(s) (within a range of 0 to 100% and a precision of 0.1% or less *but where it is understood that the resulting flow accuracy is a function of the specified value, gas, calibration, MFC response time, etc.*), pausing with all flows held steady for a specified "B" duration (with a precision of 0.1 s or less, *where a precision smaller than 0.01 s is probably more than adequate,* and within a range of at least 0.1 to 999.9 s) for a specified number of cycles (ranging from at least 1 to 999). *A gas flow rate precision smaller than 0.01% is probably more than adequate. Examples of such flow control are depicted in Appendix A. The step-A and step-B values should be equal in magnitude but of opposite sign to approximately create a rectangular wave with a constant average. And the A and B durations should also be equal if a 'square' wave form is desired. Of course, the flow rates are limited and will remain within the operational range of the associated MFCs. Note that some flows may be steady or even zero while others are stepped, and the step deltas (i.e., heights) may be different for each gas flow. Furthermore, some flow(s) may step upward while other(s) step downward, e.g., to maintain a total flow rate while varying the composition. It should be understood that functions 9.6 and 9.8 are quite similar, where 9.6 steps in one direction (for each specified gas flow) while 9.8 can step back and forth. As such, function 9.8 could be accomplished via a repeated sequence of alternating 9.6 commands, with a pair for each "wave" in the flow(s). However, 9.8 can also be used to create a staircase with alternating steps of different heights in the same direction (where this possibility is not shown in Appendix A). This function's nine parameters include the step A and step B sizes for each of the three ACME MFCs (where any step might be positive, negative, or zero), the wait duration (for all flows) for both step A and B, and the number of cycles.* [ISRD 1.9.4]

9.9. [timed] ACME shall be capable of setting all ACME flows or any specified subset thereof to ramp upward and/or downward by specified ramp-A value(s) (within a range of 0 to 100% and a precision of 0.1% or less *but where it is understood that the resulting flow accuracy is a function of the specified value, gas, calibration, MFC response time, etc.*) for a specified ramp-A duration (with a precision of 0.1 s or less and within a range of at least 0.1 to 999.9 s), pausing with all flows held steady for specified hold-A duration (with a precision of 0.1 s or less and within a range of at least 0.0 to 999.9 s), ramping the flow downward and/or upward by specified ramp-B value(s) (within a range of 0 to 100% and a precision of 0.1% or less *but where it is understood that the resulting flow accuracy is a function of the specified value, gas, calibration, MFC response* *time, etc.*) for a specified ramp-B duration (with a precision of 0.1 s or less and within a range of at least 0.1 to 999.9 s), pausing with all flows held steady for a specified hold-B duration (with a precision of 0.1 s or less and within a range of at least 0.0 to 999.9 s) for a specified number of cycles (ranging from at least 1 to 999). *A gas flow rate precision smaller than 0.01% is probably more than adequate. For the durations, a precision smaller than 0.0001 s is probably more than adequate. To approximately create a triangular wave with a constant average, (1) the hold-A and hold-B durations should be zero, and (2) the ramp-A and ramp-B values should be equal in magnitude but of opposite sign. By setting appropriate durations to zero, the flow can be set in a sawtooth pattern. Of course, the flow rates are limited and will remain within the operational range of the associated MFCs. Note that some flows may be steady or even zero while others are ramped, and the ramp deltas (i.e., heights) may be different for each gas flow. Furthermore, some flow(s) may ramp upward while other(s) ramp downward, e.g., to maintain a total flow rate while varying the composition. It should be understood that functions 9.7 and 9.9 are quite similar, where 9.7 ramps in one direction (for each specified gas flow) while 9.9 can ramp back and forth. As such, function 9.9 could be accomplished via a repeated sequence of alternating 9.7 commands, with a pair for each "wave" in the flow(s). However, 9.9 can also be used to create a ramped staircase with alternating steps of different heights in the same direction (where this possibility is not shown in Appendix A). This function's eleven parameters include the step A and step B sizes for each of the three ACME MFCs (where any step might be positive, negative, or zero), the ramp and hold durations (for all flows) for both step A and B, and the number of cycles.* [ISRD 1.9.4]

9.10. [instant] ACME shall be capable of opening and closing all CIR solenoid valves or any specified subset thereof. [ISRD 1.9.4]

9.11. [instant] ACME shall be capable of opening and closing all ACME solenoid valves or any specified subset thereof. *This function's ten parameters correspond to the ten solenoid values on the ACME chamber insert, i.e., so that the open/close state of each valve can be specified.* [ISRD 1.9.4]

10. [ACME] **TFP Pyrometry Functions**

10.1. [timed] ACME shall be capable of translating the TFP fiber array at a specified rate (as high as at least 100 mm/s with an uncertainty of no more than 0.1 mm/s, *where an uncertainty smaller than 0.0001 mm/s is probably more than adequate*) to a position within its operational range which shall extend from at least the center of the CIR chamber window axes (except that it shall not touch the burner) to the edge of the free zone as specified in ISRD 1.11.8-1.11.9. *It should be understood that translation to a specified position at a specified rate is equivalent to translation to that position in a specified duration. Of course, the TFP fiber array position must remain within its operational range, where it is critical that it not be moved into the burner. This function's two parameters include the translation rate (or duration) and the final TFP array position.* [ISRD 1.11.8, 1.11.9, 3.4.3.3, 3.4.3.4]

10.2. [timed] ACME shall be capable of translating the TFP fiber array upward and/or downward (i.e., downstream from or upstream toward the burner, respectively) at a specified rate (as high as at least 100 mm/s with an uncertainty of no more than 0.1 mm/s, *where an uncertainty smaller than 0.0001 mm/s is probably more than adequate*) to a position within its operational range which shall extend from at least the center of the CIR chamber window axes (except that it shall not touch the burner) to the edge of the free zone as specified in ISRD 1.11.8-1.11.9) and pausing for a specified wait duration (with a precision of 0.01 s or less, *where a precision smaller than 0.001 s is probably more than adequate,* and within a range of at least 0.00 to 999.99 s) for a specified number of cycles (ranging from at least 1 to 999). *This function allows for either a single ramped step or a staircase of repeated ramp steps, as shown in Appendix A. It should be understood that translation to a specified position at a specified rate is equivalent to translation to that position in a specified duration. Of course, the TFP fiber array position must remain within its operational range, where it is critical that it not be moved into the burner. Function 10.2 is a repeated sequence of coupled 10.1 and 2.1 (pause) commands. This function's four parameters include the translation rate and direction (or change in position), the translation and hold durations, and the number of cycles.* [ISRD 1.11.8, 1.11.9, 3.4.3.3]

10.3. [timed] ACME shall be capable of translating the TFP fiber array upward (i.e., downstream from the burner) at a specified ramp-up value (as high as at least 100 mm/s with an uncertainty of no more than 0.1 mm/s), pausing for a specified high-position duration (with a precision of 0.01 s or less, and within a range of at least 0.00 to 99.9 s), ramping the TFP fiber array downward (i.e., upstream toward the burner) by a specified ramp-down values as high as 100 mm/s with an uncertainty of no more than 0.1 mm/s), pausing for a specified low-position duration (with a precision of 0.01 s or less, and within a range of at least 0.00 to 99.99 s) for a specified number of cycles (ranging from at least 1 to 999). *For the translation of the TFP fiber array and hold durations, uncertainties smaller than 0.0001 mm/s and 0.001 s, respectively, are probably more than adequate. Examples of such control are depicted in Appendix A. To approximately create a triangular wave with a constant average, (1) the high-position and low-position durations should be zero, and (2) the ramp-up and ramp-down values should be equal. It should be understood that translation to a specified position at a specified rate is equivalent to translation to that position in a specified duration. Of course, the TFP fiber array position must remain within its operational range, where it is critical that it not be moved into the burner. Function 10.3 is a repeated sequence of a pair of 10.2 commands, i.e., to achieve the back and forth translation. This function's seven parameters include the translation rate (or change in position) for both up and down ramps, the translation and hold durations for both up and down ramps, and the number of cycles.* [ISRD 3.4.3.3]

11. [ACME] **Electric Field Functions**

11.1. [instant] ACME shall be capable of activating the electric field at the specified polarity (positive or negative) and voltage with a precision and range at least meeting ISRD 1.7.1. *Per the baselined ACME requirements, the electric field shall have a range of (at least) -10 kV to +10 kV with an accuracy of ±0.1% of the set point. This function's single parameter is the specified voltage (which may be positive, negative, or zero).* [ISRD 1.7.1, 1.7.4]

11.2. [instant] ACME shall be capable of resetting the electric field potential, by a step change, adjusting the polarity (positive or negative) and/or voltage of the electric field (with a precision and range at least meeting ISRD 1.7.1), while the electric field is activated, *i.e., without deactivating and reactivating it. Of course, the electric field voltage is limited and must remain within its operational range. Per the baselined ACME requirements, the electric field shall have a range of (at least) -10 kV to +10 kV with an accuracy of ±0.1% of the set point. This function's single parameter is the specified voltage (which may be positive, negative, or zero).* [ISRD 1.7.1, 1.7.4]

11.3. [instant] ACME shall be capable of deactivating the electric field. *No parameters are required for this function.* [ISRD 1.7.2, 1.7.4]

11.4. [timed] ACME shall be capable of stepping the electric field voltage upward and/or downward by a specified value (corresponding to as much as the total range and the precision specified in ISRD 1.7.1) and pausing with the voltage held steady for a specified wait duration (with a precision of 0.005 s or less, *where a precision smaller than 0.0001 s is probably more than adequate,* and within a range of at least 0.000 to 999.999 s) for a specified number of cycles (ranging from at least 1 to 9,999). *This function allows for either a single step or a staircase of repeated steps, as shown in Appendix A. The electric field polarity might or might not change as a result of the stepping. Of course, the electric field voltage is limited and must remain within its operational range. Function 11.4 is a repeated sequence of coupled 11.2 and 2.1 (pause) commands. This function's three parameters include the step size (which can be positive or negative), the hold duration, and the number of cycles.* [ISRD 1.7.1, 1.7.2, 1.7.4]

11.5. [timed] ACME shall be capable of ramping the electric field voltage upward and/or downward at a specified step size (or rate, with a precision and range at least meeting ISRD 1.7.1) for a specified ramp duration (with a precision of 0.01 s or less and within a range of at least 0.005 to 999.999 s), and pausing with the voltage held steady for a specified wait duration (with a precision of 0.01 s or less and within a range of at least 0.000 to 999.999 s) for a specified number of cycles (ranging from at least 1 to 9,999). *For the durations, a precision smaller than 0.0001 s is probably more than adequate. This function allows for either a single ramped step or a staircase of repeated steps, as shown in Appendix A. The electric field polarity might or might not change as a result of the ramped stepping. Of course, the electric field voltage is limited and must remain within its operational range. This function's four parameters include the ramp rate step size (or rate, where either can be positive or negative), the ramp and hold durations, and the number of cycles.* [ISRD 1.7.1, 1.7.2, 1.7.4]

11.6. [timed] ACME shall be capable of stepping the electric field voltage upward by specified step-up values (with a precision and range at least meeting ISRD 1.7.1), pausing with the voltage held steady for a specified high-voltage duration (with a precision of 0.005 s or less and within a range of at least 0.005 to 999.999 s), stepping the voltage downward by a specified step-down value (with a precision and range at least meeting ISRD 1.7.1), pausing with the voltage held steady for a specified low-voltage duration (with a precision of 0.005 s or less and within a range of at least 0.005 to 999.999 s) for a specified number of cycles (ranging from at least 1 to 9,999). *For the durations, a precision smaller than 0.0001 s is probably more than adequate. Examples of such control are depicted in Appendix A. The step-up and step-down values should be equal to create a rectangular wave with a constant average. And the high-voltage and low-voltage durations should also be equal if a 'square' wave form is desired. The electric field polarity might or might not change as a result of the stepping. Per the baselined ACME requirements, ACME shall be capable of operating with the polarity alternating at frequencies of up to 100 Hz. Of course, the electric field voltage is limited and must remain within its operational range. Function 11.6 is a repeated sequence of a pair of 11.4 (step) commands, i.e., to achieve the voltage increase and decrease. This function's five parameters include the step-up and step-down sizes, the high-voltage and low-voltage durations, and the number of cycles.* [ISRD 1.7.1, 1.7.2, 1.7.3, 1.7.4]

11.7. [timed] ACME shall be capable of ramping the electric field voltage upward by a specified ramp-up step size (or rate, with a precision and range at least meeting ISRD 1.7.1) for a specified ramp-up duration (with a precision of 0.005 s or less and within a range of at least 0.000 to 999.999 s), pausing with the voltage held steady for specified high-voltage duration with a precision of 0.005 s or less and within a range of at least 0.000 to 999.999 s), ramping the electric field voltage downward by a specified ramp-down step size (or rate, with a precision and range at least meeting ISRD 1.7.1) for a specified ramp-down duration (with a precision of 0.005 s or less and within a range of at least 0.000 to 999.999 s), pausing with the voltage held steady for specified low-voltage duration (with a precision of 0.005 s or less and within a range of at least 0.000 to 999.999 s) for a specified number of cycles (ranging from at least 1 to 9,999). *Examples of such control are depicted in Appendix A. For the durations, a precision smaller than 0.0001 s is probably more than adequate. To create a triangular wave with a constant average, (1) the high-voltage and low-voltage durations should be zero, and (2) the step-up and step-down values should be equal. The electric field polarity might or might not change as a result of the ramped stepping. Of course, ramp-up and ramp-down durations should not both be zero. Furthermore, the electric field voltage is limited and must remain within its operational range. Function 11.7 is a repeated sequence of a pair of 11.5 (ramp) commands, i.e., to achieve the voltage increase and decrease. This function's seven parameters include the ramp-up and ramp-down step sizes (or rates), the ramp-up and ramp-down durations, the high-voltage and low-voltage hold durations, and the number of cycles.* [ISRD 1.7.1, 1.7.3, 1.7.4]

12. [ACME] **Extinction Functions**

12.1. [timed] ACME shall be capable of detecting flame extinction after ignition, by monitoring one or more specified non-imaging instruments and verifying that time-filtered (e.g., averaged) measurement(s) over a specified duration (with a precision of 0.1 s or less, *where a precision smaller than 0.01 s is probably more than adequate,* and within a range of 0.0 to 99.9 s) are beyond (*e.g., below*) specified value(s), and responding to that event. This requirement only applies to measurements from the ACME chamber insert and does not apply to measurements associated with other hardware, such as CIR and SAMS. When multiple instruments are specified for extinction detection, it shall be possible (at least) to further specify whether that detection is based on when (1) any specified measurement indicates extinction, (2) at least half of the specified measurements indicate extinction, or (3) all specified measurements indicate extinction. *It is expected that extinction detection will normally be based on optical measurements, i.e., chemiluminescent emission and/or thermal radiation, because of their rapid response time compared to other measurements. While the PhotoMultiplier Tubes (PMTs) that will tentatively be used for the chemiluminescent emission measurements have an especially rapid response time, it is possible that they may be either inoperable or removed for some tests (e.g., because of spatial interference with especially large spherical flames), so the capability to detect extinction through other instrumentation (e.g., thermopile detectors) is required. Other instrumentation could be effective, e.g., the ion current in the E-FIELD Flames tests, and this is especially true if longer detection times are acceptable, where for example the burner or far-field temperature(s) might be appropriate. Extinction detection is not required during ignition, but will generally be operative whenever there is fuel flow. As such, this function occurs simultaneously with other functions. Extinction detection should be monitored and verified over a short time to avoid false detection as could result from measurement noise. This function's parameters include the specified duration, the possible non-imaging measurements on the ACME chamber insert, and the detection method (where three options are described above). There could be a large number of parameters for this function given the instrumentation that will be available on the ACME chamber insert, e.g., where there are at least nine optical instruments alone, i.e., six radiometers and three PMTs (or alternate devices for measuring chemiluminescent emission).* [ISRD 3.7.1]

12.2. [timed] In response to extinction detection, ACME shall be capable of setting all gas flows to zero after a specified duration (with a precision of 0.1 s or less, *where a precision smaller than 0.01 s is probably more than adequate,* and within a range of at least 0.0 to 99.99 s) following extinction detection, *where the specified duration could be zero*. *This function's single parameter is the specified duration.* [ISRD 1.9.4, 3.7.1]

12.3. [instant] In response to extinction detection, ACME shall be capable of setting all flows or any specified subset thereof to step upward and/or downward by specified value(s) (within a range of 0 to 100% and a precision of 0.1% or less *but where it is understood that the resulting flow accuracy is a function of the specified value, gas, calibration, etc.*). *A gas flow rate precision smaller than 0.01% is probably more than adequate. Note that some flows may be zero (i.e.,* *no flow), and the step deltas (i.e., heights) may be different for each gas flow. Furthermore, some flow(s) may step upward while other(s) step downward, e.g., to maintain a total flow rate while varying the composition. Function 9.4 allows the operator to subsequently set the flows to zero and terminate the test. This function's three parameters correspond to the three MFCs on the ACME chamber insert, i.e., to specify the step size for each flow (where any step might be positive, negative, or zero).* [ISRD 1.9.4, 3.7.1]

12.4. [timed] In response to extinction detection, ACME shall be capable of setting any flows by specified value(s) (within a range of 0 to 100% and a precision of 0.1% or less *but where it is understood that the resulting flow accuracy is a function of the specified value, gas, calibration, etc.)* for a specified ramp duration (with a precision of 0.1 s or less, *where a precision smaller than 0.01 s is probably more than adequate,* and within a range of at least 0.1 to 999.9 s) and holding the flows at their new values. *Of course, the flow(s) are limited and will remain within the operational range of the associated MFC(s). Note that some flows may be steady or even zero while others are ramped, and the ramp deltas (i.e., heights) may be different for each gas flow. Furthermore, some flow(s) may ramp upward while other(s) ramp downward, e.g., to maintain a total flow rate while varying the composition. Function 9.4 allows the operator to subsequently set the flows to zero and terminate the test. This function's four parameters include the ramp step for each of the three ACME MFCs (where any step might be positive, negative, or zero), and the ramp duration (for all flows).* [ISRD 1.9.4, 3.7.1]

12.5. [timed] In response to extinction detection, ACME shall be capable of setting all ACME flows or any specified subset thereof to step upward and/or downward by specified values (within a range of 0 to 100% and a precision of 0.1% or less) and pausing with all flows held steady for specified wait duration (with a precision of 0.1 s or less, *where a precision smaller than 0.01 s is probably more than adequate,* and within a range of at least 0.0 to 99.9 s), and setting all gas flows to zero. *A gas flow rate precision smaller than 0.01% is probably more than adequate. Of course, the flow time for the limiting reactant (normally fuel) is ultimately limited by the safety timers. Note that some flows may be steady or even zero while others are stepped, and the step deltas (i.e., heights) may be different for each gas flow. Furthermore, some flow(s) may step upward while other(s) step downward, e.g., to maintain a total flow rate while varying the composition. Function 12.5 is quite similar to 12.3 but has the additional feature of terminating all gas flows after a specified duration (as in 12.2), whereas 12.3 is reliant on additional command(s) to terminate the gas flows. This function's four parameters include the step size for the three ACME MFCs (where any step might be positive, negative, or zero) and the wait duration (for all flows).* [ISRD 1.9.4, 3.7.1]

12.6. [timed] In response to extinction detection, ACME shall be capable of setting all ACME flows or any specified subset thereof to ramp upward and/or downward by a specified value (within a range of 0 to 100% and a precision of 0.1% or less) over a specified ramp duration (with a precision of 0.1 s or less and within a range of at least 0 to 99.9 s) and pausing with all flows held steady for specified wait duration (with a precision of 0.1 s or less and within a range of at least 0 to 99.9 s), and then setting all gas flows to zero. *Gas flow rate and duration precisions smaller than 0.01% and 0.01 s, respectively, are probably more than adequate. Of course, the flow time for the limiting reactant (normally fuel) is ultimately limited by the safety timers. Note that some flows may be steady or even zero while others are stepped, and the ramp deltas (i.e., heights) may be different for each gas flow. Furthermore, some flow(s) may ramp upward while other(s) ramp downward, e.g., to maintain a total flow rate while varying the composition. Function 12.6 is quite similar to 12.4 but has the additional feature of terminating all gas flows after a specified duration (as in 12.2), whereas 12.4 is reliant on additional command(s) to terminate the gas flows. This function's five parameters include the ramped step size (or rate) for each of the three ACME MFCs (where any step might be positive, negative, or zero), and the ramp duration and wait durations (where both are for all flows).* [ISRD 1.9.4, 3.7.1]

12.7. [instant] ACME shall be capable of deactivating extinction detection. *No parameters are required for this function.* [ISRD 3.7.1]

APPENDICES

There are no requirements in the appendices; they are only provided for design reference.

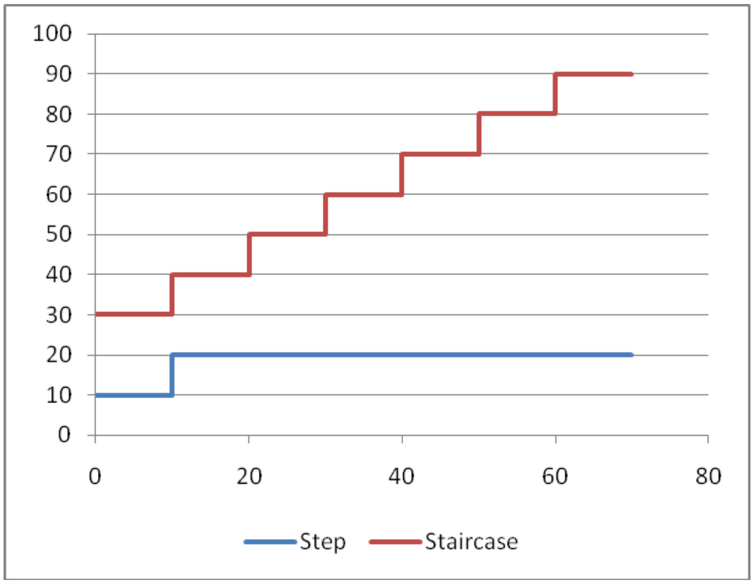
A. Variation Examples
B. CLD Flame (2 example sequences)
C. E-FIELD Flames (3 example sequences)
D. Flame Design (1 example sequence)
E. s-Flame (1 example sequence)

The sequences in Appendices B-E are based on the baselined ISRD and are not meant to be a complete list, but are simply examples of possible likely operations for each experiment. Even neglecting pre-ignition and post-extinction operations, each experiment may have several different operational sequences, and at least one example is provided here for each experiment.

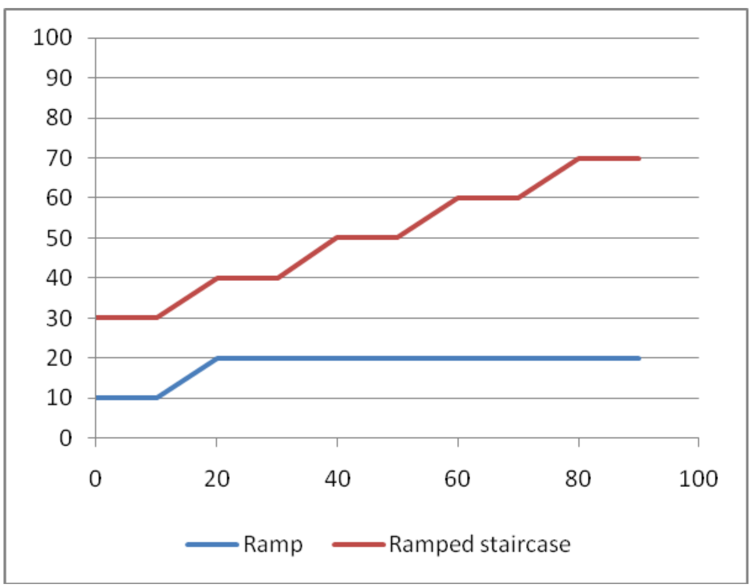
The provided examples are quite similar, especially in the pre-ignition and post-extinction operations. In other words, the principal differences are typically related to the control of the flow, TFP fiber array, or the electric field. However, other operations are certainly possible in any section of the operations.

Appendix A: Variation Examples

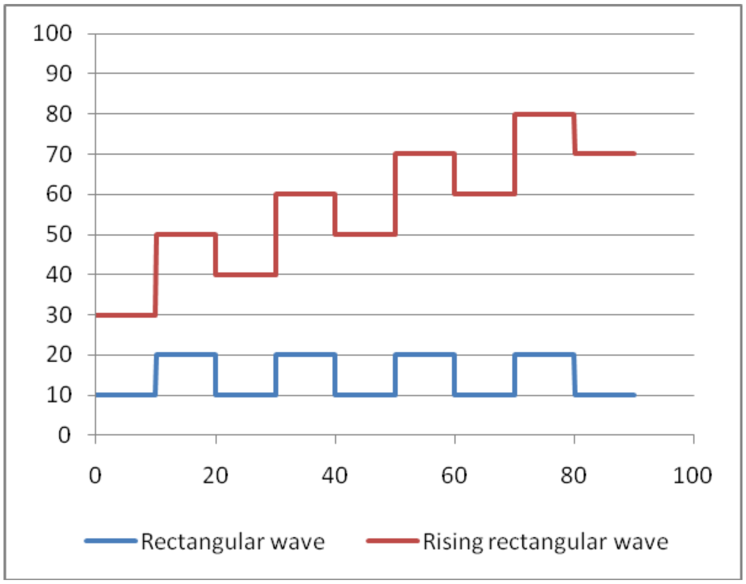
This section provides depictions of major ways in which the three ACME gas flows, TFP array position, and electric field potential can be varied. Note that the TFP array cannot be moved instantaneously so the stepped and rectangular wave functions are not applicable. And while relatively abrupt changes in flow are possible (at least in the gas-jet burners), it should be understood that the control will not be accurate during rapid transitions because of the limited response time of the Mass Flow Controllers. Finally, note that while time durations are generally shown as either 0 or 10 seconds in the presented examples, this was done as a convenience and the functions allow for durations of varying values. Finally, it should be emphasized that these are just examples, where a careful review of the function requirements will reveal additional details.



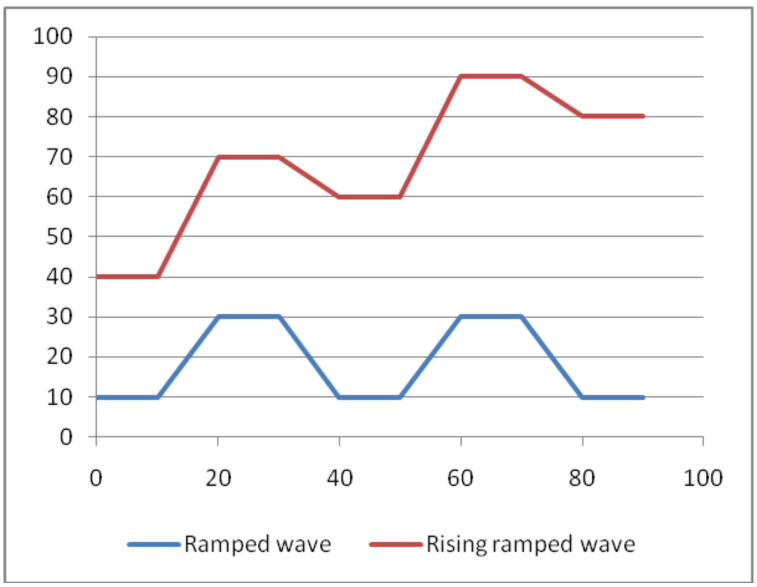
Functions 9.6 (flow) and 11.4 (electric field) *- Stepped changes, where there can be one step or repeated steps. While upward steps are shown in the plot above, downward steps are also possible.*



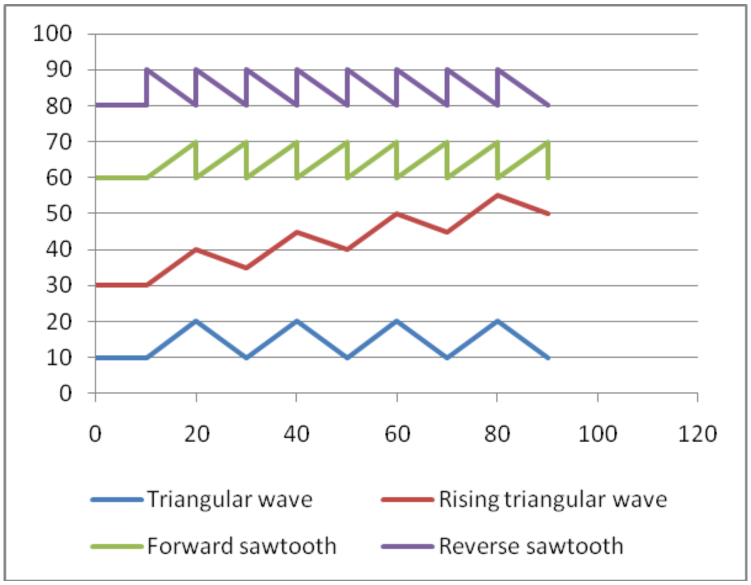
Function 9.7 (flow), 10.2 (TFP array), and 11.5 (electric field) *- Ramped changes, where there can be one ramp or repeated ramps. While upward ramps are shown in the plot above, downward ramps are also possible.*



Functions 9.8 (flow) and 11.6 (electric field) *– Rectangular wave, which can be steady or changing when time averaged. Although not shown, the variation can also be just a single wave. And while this plot shows up/down examples (i.e., after wave initiation at 10 s), down/up control is also possible. Furthermore, both can be done together in function 9.8, e.g., with fuel and nitrogen flow to vary the dilution while keeping the total burner flow constant. Function 6.3 (chamber illumination) is similar.*



Functions 9.9 (flow), 10.3 (TFP array), and 11.7 (electric field) *– Ramped wave, which can be steady or changing when time averaged. Note that this same function can produce triangular-wave or sawtooth patterns; see the next image. Although not shown, the variation can also be just a single wave. And while this plot shows up/down examples (i.e., after wave initiation at 10 s), down/up control is also possible.*



***Functions 9.9 (flow), 10.3 (TFP array), and 11.7 (electric field)** – Triangular wave, which can be steady or changing when time averaged. It can also be set in a sawtooth pattern, where two examples are shown. The sawtooth examples shown above are both steady when time-averaged, but it is also possible to create a sawtooth pattern where the time average increases or decreases with time. And while not shown, any of these patterns can be established for just a single wave. And while this plot shows up/down examples (i.e., after wave initiation at 10 s), down/up control is also possible. Furthermore, both can be done together, e.g., with fuel and nitrogen flow to vary the dilution while keeping the total burner flow constant.*

Appendix B: CLD Flame

CLD Flame: ISRD Table 4.1.1

Exploratory test procedures to determine final test limits.	
Extinction Limit Test	***Approx. Start Time***
1. Prepare chamber atmosphere *2. Start coflow and fuel/inert flow at uplinked ignition condition (e.g., a 40% CH4 flame or a 20% C2H4 flame)* *3. Ignite flame and retract igniter* *4. Slowly ramp flow (0.5 cm/s2) to starting velocity, if needed* *5. Begin scan for a specific dilution: Increase velocity at a rate of 0.5 cm/s2* *6. Stop test when extinction is detected by PMT or 50 cm/s is reached* *7. Extinguish flame and vent the chamber to 1 bar* *8. Reduce fuel concentration by 5% and repeat steps 2-7 for the next dilution* *9. Keep reducing fuel concentration by 5% and repeating steps 2-7 until minimum fuel concentration (see test matrix in Tables 4 and 5) is reached* *10. Reset apparatus*	 *0 sec.* *10 sec.* *20 sec.* *30 sec.* *110 sec.*
Sooting Limit Test *(for smoke point of ethylene flames)*	
1. Prepare chamber atmosphere *2. Start coflow and fuel/inert flow at uplinked ignition condition (e.g., a 40% C2H4 flame)* *3. Ignite flame and retract igniter* *4. Ramp flow velocity (at uplinked value) to 40% C2H4, 10 cm/s* *5. Begin scan of 40% C2H4: Increase velocity at a rate of 0.5 cm/s2* *6. Stop test when 35 cm/s is reached* *7. Extinguish the flame and vent chamber to 1 bar* *8. Ignite flame, retract igniter, and ramp flow velocity (at uplinked value) to 45% C2H4, 10 cm/s* *9. Begin scan of 45% C2H4:* *Increase velocity at a rate of 0.5 cm/s2* *10. Stop test when the velocity reaches the smoke point determined in the previous run, or 35 cm/s* *11. Extinguish the flame and vent chamber to 1 bar* *12. Repeat steps 8-11for 50% C2H4* *13. Repeat steps 8-11 for 50% C2H4, double fuel velocity* *14. Reset apparatus*	 *0 sec.* *10 sec.* *20 sec.* *30 sec.* *80 sec.*

Sample Sequence of Functions: CLD Flame: Limit Test (extinction or sooting)

This sample sequence generally does not include the many pause functions (i.e., 2.1 and 2.2).

Pre-Ignition Operations (including action 1)

3.1 set up hardware external to the CIR chamber, if needed
3.2 set up burner, MFCs, and other hardware on ACME chamber insert, if needed
5.1 energize hardware and warm up MFCs, etc.
9.1 zero MFCs
4.1 vent chamber
4.4 fill chamber (repeated for each gas)
4.5 mix chamber atmosphere (activate chamber fan, pause, deactivate)
9.3 purge burner lines (i.e., open valves, set MFC(s), pause, close valves)
5.2 set up BG-7 filter, if needed
5.3 set up cameras
6.1 activate chamber illumination
10.1 position TFP fiber array
8.1 insert igniter
5.4 start non-imaging data acquisition
5.5 start imaging data acquisition
6.1 deactivate chamber illumination
7.1 activate the CIR illumination package for reference imaging
7.3 deactivate the CIR illumination package

Flame Operations (including actions 2-6 and part of action 7)

8.2 preheat igniter, if needed
9.10 open CIR gas delivery valves
9.11 open ACME gas delivery valves
9.4 set CIR gas flows (e.g., at 100%)
9.5 set ACME gas flows at ignition values
8.2 ignite flame
8.1 retract igniter
12.1 initiate extinction detection
12.2 set flow(s) to zero if extinction is detected
10.1 reposition TFP fiber array, if needed after ignition
9.7 ramp gas flows to initial test condition (with built-in pause for flame duration)
7.1 activate illumination package
9.7 ramp gas flows
9.5 set ACME gas flow(s) to zero (after completion of ramp or extinction detection)
9.4 set CIR gas flow(s) to zero
9.11 close ACME valves

9.10 close CIR valves
12.7 stop extinction detection
Post-Flame Operations (including part of action 7 and actions 8-10)
5.5 stop imaging data acquisition
7.3 deactivate illumination package
5.4 stop non-imaging data acquisition
10.1 return TFP fiber array to retracted position
4.6 gas chromatography of unmixed chamber
4.5 (activate, pause, deactivate) mix chamber atmosphere
4.6 gas chromatography of mixed chamber
4.2 scrub chamber atmosphere to prepare for next test
…
conduct additional tests
…
turn off hardware

CLD Flame: ISRD Table 4.1.2

Coflow Laminar Diffusion Flame Overall Operational Sequence.	
Action	***Approx. Start Time***
1. Take reference images	*-5 min.*
2. Fill/scrub/vent chamber to 1 bar	
3. Start coflow and fuel/inert flow at ignition condition	*0 sec.*
4. Ignite flame and retract igniter	
5. Ramp flow velocity (at uplinked value) to initial test condition, if needed	*10 sec.*
6. Wait for flame to stabilize	*20 sec.*
7. Run data acquisition	
8. Extinguish flame	*30 sec.*
9. Repeat 2 to 8 until (10 cases each run):	
a) the extinction limit	
b) the sooting extreme	
Limits determined from exploratory tests.	
Continue at next dilution for test duration	
10. Take reference images, if applicable	
11. Downlink data	
12. Reset apparatus	

Sample Sequence of Functions: CLD Flame (standard test)

This sample sequence generally does not include the many pause functions (i.e., 2.1 and 2.2).

Pre-Ignition Operations (including actions 1-3)

3.1 set up hardware external to the CIR chamber, if needed
3.2 set up burner, MFCs, and other hardware on ACME chamber insert, if needed
5.1 energize hardware and warm up MFCs, etc.
9.1 zero MFCs
4.1 vent chamber
4.4 fill chamber (repeated for each gas)
4.5 mix chamber atmosphere (activate chamber fan, pause, deactivate)
9.3 purge burner lines (i.e., open valves, set MFC(s), pause, close valves)
5.2 set up BG-7 filter, if needed
5.3 set up cameras
6.1 activate chamber illumination
10.1 position TFP fiber array
8.1 insert igniter
5.4 start non-imaging data acquisition
5.5 start imaging data acquisition
6.1 deactivate chamber illumination
7.1 activate the CIR illumination package for reference imaging
7.3 deactivate the CIR illumination package

Flame Operations (including actions 4-8)

8.2 preheat igniter, if needed
9.10 open CIR gas delivery valves
9.11 open ACME gas delivery valves
9.4 set CIR gas flows (e.g., at 100%)
9.5 set ACME gas flows at ignition values
8.2 ignite flame
8.1 retract igniter
12.1 initiate extinction detection
12.2 set flow(s) to zero if extinction is detected
10.1 reposition TFP fiber array, if needed after ignition
9.7 ramp gas flows to test condition (with built-in pause for flame duration)
10.3 translate TFP fiber array up and down in a triangular wave pattern, if desired
7.1 activate illumination package
9.5 set ACME gas flow(s) to zero (after completion of post-ramp duration)
9.4 set CIR gas flow(s) to zero
9.11 close ACME valves

9.10 close CIR valves

12.7 stop extinction detection

Post-Flame Operations (including actions 9-12)

5.5 stop imaging data acquisition

7.3 deactivate illumination package

5.4 stop non-imaging data acquisition

10.1 return TFP fiber array to retracted position

4.6 gas chromatography of unmixed chamber

4.5 (activate, pause, deactivate) mix chamber atmosphere

4.6 gas chromatography of mixed chamber

4.2 scrub chamber atmosphere to prepare for next test

…

conduct additional tests

…

turn off hardware

Appendix C: E-FIELD Flames

E-FIELD Flames: ISRD Table 4.2.1

Voltage Sweep Procedure	*Time*
A. Prepare Chamber	
1. Fill chamber (with N_2 for coflow; O_2/N_2 for gas jet)	
2. Select fuel/diluent mixture	
B. Initiate Experiment	*0 sec.*
1. Initiate data acquisition	*5 sec.*
2. Initiate gas flows	*5 sec*
3. Ignite flame and retract igniter	*8 sec.*
4. Allow 10 seconds settling time	*18 sec.*
5. Set the desired voltage (initially to 0V)	*19 sec.*
6. Initiate high voltage power supply	*20 sec.*
C. Measurements[1]	
1. Wait 0.3 seconds for flame to settle	
2. Collect data over 0.5 seconds	
D. Step 100V (assuming approx. 5ms ramp)	
E. Repeat steps C & D until (+/-) 5kV or flame blowout	*60.25 sec.*
F. Pause in Experiment	
1. Stop gas flows/extinguish flame (zero ion current)	
2. Stop video	
3. Zero voltage	
G. Repeat Steps C-E without flame to measure leakage current. Stop testing if burner current leakage is at unacceptable level	*100.5 sec.*
H. Reverse high voltage polarity	
I. Repeat sequence steps (B)–(H)	*201 sec.*

[1]The time between voltage steps for flame adjustment and data collection shall be adjustable via uplink between the values of 0-10 seconds.

Sample Sequence of Functions: E-FIELD Flames: Voltage Sweep Procedure

This sample sequence generally does not include the many pause functions (i.e., 2.1 and 2.2).

Pre-Ignition Operations (including action A and part of action B)

3.1 set up hardware external to the CIR chamber, if needed
3.2 set up burner, MFCs, and other hardware on ACME chamber insert, if needed
5.1 energize hardware and warm up MFCs, etc.
9.1 zero MFCs
4.1 vent chamber
4.4 fill chamber (repeated for each gas)
4.5 mix chamber atmosphere (activate chamber fan, pause, deactivate)
9.3 purge burner lines (i.e., open valves, set MFC(s), pause, close valves)
5.2 set up BG-7 filter, if needed
5.3 set up cameras
6.1 activate chamber illumination
8.1 insert igniter
5.4 start non-imaging data acquisition
5.5 start imaging data acquisition
6.1 deactivate chamber illumination
7.1 activate the CIR illumination package for reference imaging
7.3 deactivate the CIR illumination package

Flame Operations (including part of action B, actions C-E, and part of F)

8.2 preheat igniter, if needed
9.10 open CIR gas delivery valves
9.11 open ACME gas delivery valves
9.4 set CIR gas flows (e.g., at 100%)
9.5 set ACME gas flows at ignition values
8.2 ignite flame
8.1 retract igniter
12.1 initiate extinction detection
12.2 set flow(s) to zero if extinction is detected
7.1 activate illumination package
2.1 pause
11.1 initiate the electric field
11.4 voltage sweep, i.e., staircase steps in voltage
11.2 set voltage to zero
9.5 set ACME gas flow(s) to zero
9.4 set CIR gas flow(s) to zero
9.11 close ACME valves

9.10 close CIR valves

12.7 stop extinction detection

Post-Flame Operations (including part of action F and actions G-I)

11.2 set voltage at initial value (e.g., 0) for voltage sweep to measure the leak current

11.4 voltage sweep to measure leak current, i.e., staircase steps in voltage

11.3 deactivate the electric field

5.5 stop imaging data acquisition

7.3 deactivate illumination package

5.4 stop non-imaging data acquisition

4.6 gas chromatography of unmixed chamber

4.5 (activate, pause, deactivate) mix chamber atmosphere

4.6 gas chromatography of mixed chamber

4.2 scrub chamber atmosphere to prepare for next test

…

conduct additional tests

…

turn off hardware

E-FIELD Flames: ISRD Table 4.2.2

Step Response Procedure	***Time***
A. Prepare Chamber	
1. Fill chamber (with N_2 for coflow; O_2/N_2 for gas jet)	
2. Select fuel/diluent mixture	
B. Initiate Experiment	*0 sec.*
1. Initiate data acquisition	*5 sec.*
2. Start gas flows	*5 sec.*
3. Ignite flame and retract igniter	*8 sec.*
4. Allow 10 seconds settling time	*18 sec.*
5. Set the desired voltage (initially to 0V)	*19 sec.*
6. Initiate high voltage power supply	*20 sec.*
C. Measurements (if blowout occurs anytime; zero voltage and proceed to Step D)	
1. Collect data over 2 seconds[1]	*22 sec.*
2. Step voltage 0V to 1000V; Collect data over 2 seconds[1]	*24 sec.*
3. Step voltage 1000V to -1000V; Collect data over 2 seconds[1]	*26 sec.*
4. Step voltage -1000V to 1000V; Collect data over 2 seconds[1]	*28 sec.*
5. Step voltage 1000V to -2000V; Collect data over 2 seconds[1]	*30 sec.*
6. Step voltage -2000V to 2000V; Collect data over 2 seconds[1]	*32 sec.*
7. Step voltage 2000V to -2000V; Collect data over 2 seconds[1]	*34 sec.*
8. Step voltage -2000V to 3000V; Collect data over 2 seconds[1]	*36 sec.*
9. Step voltage 3000V to -3000V; Collect data over 2 seconds[1]	*38 sec.*
10. Step voltage -3000V to 4000V; Collect data over 2 seconds[1]	*40 sec.*
11. Step voltage 4000V to 5000V; Collect data over 2 seconds[1]	*42 sec.*
12. Step voltage 5000V to 0V; Collect data over 2 seconds[1]	*44 sec.*
13. Step voltage 0V to -4000V; Collect data over 2 seconds[1]	*46 sec.*
14. Step voltage -4000V to -5000V; Collect data over 2 seconds[1]	*48 sec.*
15. Step voltage -5000V to 0V; Collect data over 2 seconds[1]	*50 sec.*
16. Step voltage 0V to -1000V; Collect data over 2 seconds[1]	*52 sec.*
17. Step voltage -1000V to 0V; Collect data over 2 seconds[1]	*54 sec.*
18. Step voltage 0V to -500V; Collect data over 2 seconds[1]	*56 sec.*
19. Step voltage -500V to 0V; Collect data over 2 seconds[1]	*58 sec.*
20. Step voltage 0V to 1000V; Collect data over 2 seconds[1]	*60 sec.*
21. Step voltage 1000V to 500V; Collect data over 2 second[1]	*62 sec.*
22. Step voltage 500V to 0V; Collect data over 2 seconds[1]	*64 sec.*
D. Shut off gas flows (extinguish flame)	*64 sec.*
E. Repeat Step C beginning from 0V without flame to measure leakage current. Stop testing and report if leakage is at unacceptable level	*106 sec.*

[1]The time between voltage steps for flame adjustment and data collection shall be adjustable via uplink between the values of 0-10 seconds.

Sample Sequence of Functions: E-FIELD Flames: Step Response Procedure

This sample sequence generally does not include the many pause functions (i.e., 2.1 and 2.2).

Pre-Ignition Operations (including action A and part of action B)

3.1 set up hardware external to the CIR chamber, if needed
3.2 set up burner, MFCs, and other hardware on ACME chamber insert, if needed
5.1 energize hardware and warm up MFCs, etc.
9.1 zero MFCs
4.1 vent chamber
4.4 fill chamber (repeated for each gas)
4.5 mix chamber atmosphere (activate chamber fan, pause, deactivate)
9.3 purge burner lines (i.e., open valves, set MFC(s), pause, close valves)
5.2 set up BG-7 filter, if needed
5.3 set up cameras
6.1 activate chamber illumination
8.1 insert igniter
5.4 start non-imaging data acquisition
5.5 start imaging data acquisition
6.1 deactivate chamber illumination
7.1 activate the CIR illumination package for reference imaging
7.3 deactivate the CIR illumination package

Flame Operations (including part of action B and actions C-D)

8.2 preheat igniter, if needed
9.10 open CIR gas delivery valves
9.11 open ACME gas delivery valves
9.4 set CIR gas flows (e.g., at 100%)
9.5 set ACME gas flows at ignition values
8.2 ignite flame
8.1 retract igniter
12.1 initiate extinction detection
12.2 set flow(s) to zero if extinction is detected
7.1 activate illumination package
2.1 pause
11.1 initiate the electric field
11.2 reset the voltage
2.1 pause
Repeat 11.2 and 2.1 as often as desired to step the voltage in an irregular pattern
9.5 set ACME gas flow(s) to zero
9.4 set CIR gas flow(s) to zero
9.11 close ACME valves

9.10 close CIR valves

12.7 stop extinction detection

Post-Flame Operations (including action E)

11.2 set voltage at initial value (e.g., 0) for voltage sweep to measure the leak current

11.2 reset the voltage

2.1 pause

Repeat 11.2 and 2.1 as often as desired to step the voltage in an irregular pattern

11.3 deactivate the electric field

5.5 stop imaging data acquisition

7.3 deactivate illumination package

5.4 stop non-imaging data acquisition

4.6 gas chromatography of unmixed chamber

4.5 (activate, pause, deactivate) mix chamber atmosphere

4.6 gas chromatography of mixed chamber

4.2 scrub chamber atmosphere to prepare for next test

…

conduct additional tests

…

turn off hardware

E-FIELD Flames: ISRD Table 4.2.3

Electric Field Effects on Soot	***Time***
A. Prepare Chamber	
1. Fill chamber (with N_2 for coflow; O_2/N_2 for gas jet)	
2. Select fuel/diluent mixture	
B. Initiate Experiment	*0 sec.*
1. Initiate data acquisition	*5 sec.*
2. Start gas flows (with coflow at 0 cm/s)	*5 sec.*
3. Ignite flame and retract igniter	*8 sec.*
4. Allow 10 seconds settling time	*18 sec.*
5. Set the desired voltage (initially to 0V)	*19 sec.*
6. Initiate high voltage power supply	*20 sec.*
C. Collect reference data for 1 second	*21 sec.*
D. Measurements	
1. Increase coflow velocity to 1cm/s; collect over 3 sec. [1]	*24 sec.*
2. Increase coflow velocity to 2cm/s; collect over 3 sec. [1]	*27 sec.*
3. Increase coflow velocity to 3cm/s; collect over 3 sec. [1]	*30 sec.*
4. Increase coflow velocity to 4cm/s; collect over 3 sec. [1]	*33 sec.*
5. Increase coflow velocity to 5cm/s; collect over 3 sec. [1]	*36 sec.*
6. Increase coflow velocity to 6cm/s; collect over 3 sec. [1]	*39 sec.*
7. Increase coflow velocity to 7cm/s; collect over 3 sec. [1]	*42 sec.*
8. Increase coflow velocity to 8cm/s; collect over 3 sec. [1]	*45 sec.*
9. Increase coflow velocity to 9cm/s; collect over 3 sec. [1]	*48 sec.*
10. Increase coflow velocity to 10cm/s; collect over 3 sec. [1]	*51 sec.*
11. Increase coflow velocity to 11cm/s; collect over 3 sec. [1]	*54 sec.*
12. Increase coflow velocity to 12cm/s; collect over 3 sec. [1]	*57 sec.*
13. Increase coflow velocity to 13cm/s; collect over 3 sec. [1]	*60 sec.*
14. Increase coflow velocity to 14cm/s; collect over 3 sec. [1]	*63 sec.*
15. Increase coflow velocity to 15cm/s; collect over 3 sec. [1]	*66 sec.*
16. Increase coflow velocity to 16cm/s; collect over 3 sec. [1]	*69 sec.*
17. Increase coflow velocity to 17cm/s; collect over 3 sec. [1]	*72 sec.*
18. Increase coflow velocity to 18cm/s; collect over 3 sec. [1]	*75 sec.*
19. Increase coflow velocity to 19cm/s; collect over 3 sec. [1]	*78 sec.*
20. Increase coflow velocity to 20cm/s; collect over 3 sec. [1]	*81 sec.*
21. Increase coflow velocity to 21cm/s; collect over 3 sec. [1]	*84 sec.*
22. Increase coflow velocity to 22cm/s; collect over 3 sec. [1]	*87 sec.*
23. Increase coflow velocity to 23cm/s; collect over 3 sec. [1]	*90 sec.*
24. Increase coflow velocity to 24cm/s; collect over 3 sec. [1]	*93 sec.*
25. Increase coflow velocity to 25cm/s; collect over 3 sec. [1]	*96 sec.*
F. Stop gas flows/extinguish flame	

[1]The time between voltage steps for flame adjustment and data collection shall be adjustable via uplink between the values of 0-10 seconds.
Note: return to step B and reignite as needed if flame fails during experiment

Sample Sequence of Functions: E-FIELD Flames: Electric Field Effects on Soot

This sample sequence generally does not include the many pause functions (i.e., 2.1 and 2.2). This example is notably different from the other E-FIELD Flames procedures in that there is absolutely no use of an electric field.

Pre-Ignition Operations (including action A and part of action B)

3.1 set up hardware external to the CIR chamber, if needed
3.2 set up burner, MFCs, and other hardware on ACME chamber insert, if needed
5.1 energize hardware and warm up MFCs, etc.
9.1 zero MFCs
4.1 vent chamber
4.4 fill chamber (repeated for each gas)
4.5 mix chamber atmosphere (activate chamber fan, pause, deactivate)
9.3 purge burner lines (i.e., open valves, set MFC(s), pause, close valves)
5.2 set up BG-7 filter, if needed
5.3 set up cameras
6.1 activate chamber illumination
8.1 insert igniter
5.4 start non-imaging data acquisition
5.5 start imaging data acquisition
6.1 deactivate chamber illumination
7.1 activate the CIR illumination package for reference imaging
7.3 deactivate the CIR illumination package

Flame Operations (including part of action B and actions C-F)

8.2 preheat igniter, if needed
9.10 open CIR gas delivery valves
9.11 open ACME gas delivery valves
9.4 set CIR gas flows (e.g., at 100%)
9.5 set ACME gas flows at ignition values
8.2 ignite flame
8.1 retract igniter
12.1 initiate extinction detection
12.2 set flow(s) to zero if extinction is detected
7.1 activate illumination package
9.6 increase gas flow(s) in a staircase pattern
9.5 set ACME gas flow(s) to zero
9.4 set CIR gas flow(s) to zero
9.11 close ACME valves
9.10 close CIR valves
12.7 stop extinction detection

Post-Flame Operations

5.5 stop imaging data acquisition

7.3 deactivate illumination package

5.4 stop non-imaging data acquisition

4.6 gas chromatography of unmixed chamber

4.5 (activate, pause, deactivate) mix chamber atmosphere

4.6 gas chromatography of mixed chamber

4.2 scrub chamber atmosphere to prepare for next test

…

conduct additional tests

…

turn off hardware

Appendix D: Flame Design

Flame Design: ISRD Table 4.3.1

Operational Sequence for Flame Design Spherical Flame Tests	
Action	***Approx. Time***
1. Ensure that 6.4 mm spherical burner is installed. Preflow the burner fluent gas at the composition of the upcoming test point to flush the plumbing system.	
2. Establish chamber conditions. These consist of a set point pressure and species compositions, as specified in the test matrix. Conditions are obtained in four ways: from cabin air (desired); from the preceding test; from scrubbing and replenishing; or from a complete evacuation and recharge.	
3. Allow chamber contents to reach equilibrium. A hold time of 5 minutes is required for quiescent, isothermal, and well-mixed conditions.	
4. Take reference images (if applicable). Establish framing rates for video cameras. Begin color imaging. Begin monitoring measurements. After 15 s, commence fluent flow, ignite flame, and retract ignitor.	*-15 s* *0 s*
Perform either Steps 5, 6, and 8 ***OR*** *Steps 7 and 8.*	
5. <u>Soot inception limit.</u> Allow the flame to pass its soot-inception limit. Continuously record temperature distributions.	*15 s*
6. <u>Radiative extinction.</u> Detect radiative extinction with a PMT or with near real-time video. Continuously record temperature distributions. At uplinkable time (estimated 3 s) after extinction, reduce flow rate by uplinkable amount (estimated 50%) for uplinkable time (estimated 5 s) to confirm extinction. If the flame reappears, return to the initial flow rate and return to the beginning of Step 6. Otherwise terminate the fluent flow.	*30 s*
7. <u>Kinetic extinction.</u> After an uplinkable time (estimated 10 s), decrease fluent flow rate linearly in time such that flow rate becomes zero at uplinkable time (estimated 30 s) after ignition. Detect kinetic extinction with a PMT or with near real-time video. Continuously record temperature distributions. At uplinkable time (estimated 3 s) after extinction detection, increase flow rate by uplinkable amount (estimated 100%) for uplinkable time (estimated 5 s) to confirm extinction. If the flame reappears, return to the initial flow rate and return to the beginning of Step 7. Otherwise terminate the fluent flow.	*10 s* *30 s*
8. Record reference images (if applicable). After 60 s terminate color imaging and monitoring measurements. Select data for downlink and downlink data.	*30 s*

Sample Sequence of Functions: Flame Design
with a spherical flame and radiative extinction (i.e., actions 5-6 instead of 7)
This sample sequence generally does not include the many pause functions (i.e., 2.1 and 2.2).

Pre-Ignition Operations (including actions 1-3 plus part of 4)
3.1 set up hardware external to the CIR chamber, if needed
3.2 set up burner, MFCs, and other hardware on ACME chamber insert, if needed
5.1 energize hardware and warm up MFCs, etc.
9.1 zero MFCs
4.1 vent chamber
4.4 fill chamber (repeated for each gas)
4.5 mix chamber atmosphere (activate chamber fan, pause, deactivate)
9.3 purge burner lines (i.e., open valves, set MFC(s), pause, close valves)
5.2 set up BG-7 filter, if needed
5.3 set up cameras
6.1 activate chamber illumination
10.1 position TFP fiber array
8.1 insert igniter
5.4 start non-imaging data acquisition
5.5 start imaging data acquisition
6.1 deactivate chamber illumination
7.1 activate the CIR illumination package for reference imaging
7.3 deactivate the CIR illumination package

Flame Operations (including some of action 4 plus actions 5-6)
8.2 preheat igniter, if needed
9.10 open CIR gas delivery valves
9.11 open ACME gas delivery valves
9.4 set CIR gas flows (e.g., at 100%)
9.5 set ACME gas flows at ignition values
8.2 ignite flame
8.1 retract igniter
7.1 activate illumination package
12.1 initiate extinction detection
12.5 step flow(s) after extinction detection
9.5 set ACME gas flow(s) to zero
9.4 set CIR gas flow(s) to zero
9.11 close ACME valves
9.10 close CIR valves
12.7 stop extinction detection

Post-Flame Operations (including action 8)

5.5 stop imaging data acquisition
7.3 deactivate illumination package
5.4 stop non-imaging data acquisition
10.1 return TFP fiber array to retracted position
4.6 gas chromatography of unmixed chamber
4.5 (activate, pause, deactivate) mix chamber atmosphere
4.6 gas chromatography of mixed chamber
4.2 scrub chamber atmosphere to prepare for next test

…

conduct additional tests

…

turn off hardware

Appendix E: s-Flame

s-Flame: ISRD Table 4.4.1

Action	***Approx. Start Time***
I. Establish chamber at constant pressure and species concentration.	*0 s*
II. Discharge fuel mixture through porous burner at the initial flow rate.	
III. Ignite fuel mixture with hot wire coil and retract upon successful ignition.	*0 s*
IV. Allow for spherical diffusion flame to evolve.	
V. Apply one of the following:	
a. Maintain flow rate with same initial mixture for duration of test (25 s) or until extinction.	
b. Single step decrease in flow rate with same initial mixture at specified time, maintaining new flow rate for duration of test (25 s) or until extinction.	
VI. Terminate fuel supply to the burner after 25s.	*25 s*

Sample Sequence of Functions: s-Flame (for case V.b. with a flow step)

This sample sequence generally does not include the many pause functions (i.e., 2.1 and 2.2).

Pre-Ignition Operations (including action I.)

3.1 set up hardware external to the CIR chamber, if needed
3.2 set up burner, MFCs, and other hardware on ACME chamber insert, if needed
5.1 energize hardware and warm up MFCs, etc.
9.1 zero MFCs
4.1 vent chamber
4.4 fill chamber (repeated for each gas)
4.5 mix chamber atmosphere (activate chamber fan, pause, deactivate)
9.3 purge burner lines (i.e., open valves, set MFC(s), pause, close valves)
5.2 set up BG-7 filter, if needed
5.3 set up cameras
6.1 activate chamber illumination
10.1 position TFP fiber array
8.1 insert igniter
5.4 start non-imaging data acquisition
5.5 start imaging data acquisition
6.1 deactivate chamber illumination
7.1 activate the CIR illumination package for reference imaging
7.3 deactivate the CIR illumination package

Flame Operations (including actions II. to VI.)

8.2 preheat igniter, if needed
9.10 open CIR gas delivery valves
9.11 open ACME gas delivery valves
9.4 set CIR gas flows (e.g., at 100%)
9.5 set ACME gas flows at ignition values
8.2 ignite flame
8.1 retract igniter
7.1 activate illumination package
12.2 initiate extinction detection – which continues to flow shut down
2.1 pause
9.6 step flow (which includes a pause)
9.5 set ACME gas flow(s) to zero
9.4 set CIR gas flow(s) to zero
9.11 close ACME valves
9.10 close CIR valves
12.7 stop extinction detection

Post-Flame Operations

5.5 stop imaging data acquisition
7.3 deactivate illumination package
5.4 stop non-imaging data acquisition
10.1 return TFP fiber array to retracted position
4.6 gas chromatography of unmixed chamber
4.5 (activate, pause, deactivate) mix chamber atmosphere
4.6 gas chromatography of mixed chamber
4.2 scrub chamber atmosphere to prepare for next test

…

conduct additional tests

…

turn off hardware