Engineering Requirements Document

Multi-user Gaseous Fuels Apparatus

September 2001

MG
FA

Glenn Research Center
Cleveland, Ohio

PREFACE

The NASA Glenn Research Center is developing a modular, multi-user experimentation "mini-facility" for conducting gaseous combustion science experiments in the microgravity environment of the International Space Station (ISS). This facility, called the Multi-user Gaseous Fuels Apparatus (MGFA), will reside in the Fluids and Combustion Facility (FCF) Combustion Integrated Rack (CIR) on-board the ISS. The MGFA Project Office located in the Microgravity Science Division at GRC manages MGFA.

The primary purpose of this document is to establish a consolidated list of science and operational requirements from the first four experiments planned to utilize MGFA. This document also serves to define the current engineering concept for addressing each requirement along with the proposed organization to be responsible for each science requirement: MGFA, CIR, or joint responsibility.

This initial baseline is to be provided to the FCF Project Office prior to the CIR Critical Design Review so that MGFA requirements can be assessed as part of the final CIR design including the assessment of CIR PDR Review Item Discrepancies (RID's). Based on the MGFA Science Concept Reviews and baselines of the respective Science Requirement Documents; revisions will be generated and released through the joint Phase A Combustion/MGFA configuration management.

ACKNOWLEDGEMENT

The MGFA Project is truly a team effort and contributions of that team to this document should be acknowledged. At NASA Glenn, these include project and experiment managers and project scientists. Supporting Glenn through the Glenn Engineering and Scientific Support Contract (NAS3-00145) is a team from Zin Technologies and Mr. Greg Funk especially provided significant input for this document.

MGFA Engineering Requirements Document

Prepared By:

Ann P. Over Date
MGFA Project Manager
NASA Glenn Research Center

Concurrence By:

Roger C. Forsgren Date
MGFA Deputy Project Manager
NASA Glenn Research Center

Approved By:

Dennis P. Stocker Date
Flame Design Project Scientist
NASA Glenn Research Center

Approved By:

Uday Hegde Date
PUFF Project Scientist
National Center for Microgravity Research

Approved By:

Douglas A. Feikema Date
s-Flame Project Scientist
NASA Glenn Research Center

Approved By:

Paul S. Greenberg Date
V-flames Project Scientist
NASA Glenn Research Center

Approved By:

David L. Urban Date
Chief, Microgravity Combustion Science Branch
NASA Glenn Research Center

Approved By:

Angel M. Otero Date
Chief, Combustion Flight Projects Branch
NASA Glenn Research Center

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GLENN RESEARCH CENTER AT LEWIS FIELD
MICROGRAVITY SCIENCE DIVISION

Multi-user Gaseous Fuels Apparatus (MGFA)

Engineering Requirements Document (ERD)

Project Manager: **Ann P. Over**
Deputy Project Manager: **Roger C. Forsgren**
Combustion Flight Projects Branch
Microgravity Science Division
NASA Glenn Research Center at Lewis Field

REVISION PAGE
MGFA ENGINEERING REQUIREMENTS DOCUMENT

Revision	Date	Description of Change or ECO's/ECP's Incorporated	Verification and Date
Draft	March, 2001	First draft incorporating Flame Design, PUFF, s-Flame and V-flames science requirements	
Draft	July, 2001	Second draft incorporating text clarifications and some updates to science requirements.	
Baseline	September, 2001	Updates including text clarifications and minor updates to the science requirements.	

1.0 INTRODUCTION

1.1 Purpose

The primary purpose of this document is to establish a consolidated list of Science, Project, Safety and Operational requirements associated with the Multi-user Gaseous Fuels Apparatus (MGFA) mini-facility and the first four experiments planned to utilize MGFA.

More specifically this document maps science requirements into an engineering response that includes: a restatement of the requirement to something verifiable (if needed), the design concept, the design envelope for MGFA, and the proposed organizational responsibilities for each element between MGFA, the Combustion Integrated Rack (CIR), or joint responsibilities.

The purpose of providing this engineering response to science requirements is three-fold:

1) Enables the Science Teams to review the engineering interpretation of their requirements for accuracy

2) Enables initial engineering feasibility and issues to be identified and resolved

3) Defines responsibilities between the MGFA and CIR teams, in order to ensure that the combined hardware will meet the individual experiment requirements; serves as an input into CIR for MGFA accommodations.

In addition to science requirements, an initial set of Project-based engineering requirements, Safety requirements, and Operational requirements for MGFA are provided and are explained in their respective sections of this document.

The interface requirements between the payload (MGFA) and the facility (CIR) will be defined in the MGFA Interface Control Document (ICD) and are <u>not</u> part of this document.

1.2 Scope

This document applies to the MGFA, a mini-facility that is designed to accommodate four gaseous fuel combustion experiments on the CIR. It includes two separate flight increments, MGFA-A and MGFA-B, each including specific pieces of flight hardware for two of the four experiments. As of the drafting of this document, MGFA-A is expected to include s-Flame and Flame Design, and MGFA-B is expected to include V-flames and PUFF. This order is subject to change based on project maturity. Although there are two increments, it is the goal of MGFA to maximize the use of common hardware.

Since MGFA is designed to initially accommodate a minimum of four gaseous combustion investigations having science requirements with different levels of maturity, this document represents a “snapshot in time” of understood and agreed upon science requirements for those Principal Investigators whose science requirements are not fully approved. As each Science Requirements Document (SRD) is updated and approved, a compatibility check will be performed between the SRD and this document to assess impacts to MGFA hardware, resources, and schedule. Likewise, when new gaseous combustion experiments are added in the future, their requirements will be added to this document

1.3 Applicable Documents

The most current draft SRD for each experiment was used as input to this document and are listed below. In addition if partial updates to the SRD (e.g. hardware requirements section) were received by the Project, they are also noted. For this document, the CIR Interface Definition Document (IDD) was used for general information regarding recommended responsibilities.

1. Preliminary Science Requirements Document for the Flame Design Experiment, Richard L. Axelbaum, Washington University; V 1.0, dated March 5, 2001.

2. Science Requirements Document for the Structure and Response of Spherical Diffusion Flames (s-Flame) Experiment, Chung K. Law, Princeton University; Draft 1.0, dated October 2000. Hardware requirements updated by Project Scientist March 2001.

3. Science Requirements Document for the PUlsed-Fully Flames Experiment (PUFF), James C. Hermanson, Worcester Polytechnic Institute; Draft 0.2 SRD, dated July 2001,
4. Science Requirements Document for Field Effects of Gravity on Lean Premixed Turbulent Flame (V-flames) Experiment, Robert K. Cheng, Lawrence Berkeley National Laboratory; Draft V1.0, dated March 2001.

5. Combustion Integrated Rack Interface Definition Document, Draft dated October 27, 2000.

2.0 MGFA OVERVIEW

2.1 MGFA Payload Description

MGFA is a mini-facility designed to support Principal Investigators (PI) interested in studying various aspects of gaseous combustion in a microgravity environment. The MGFA unique hardware and software will be integrated into the Fluids and Combustion Facility's (FCF) Combustion Integrated Rack (CIR) onboard the International Space Station to perform experiment operations. Currently, there are four experiments that have been selected to use the MGFA mini-facility.

2.2 MGFA Mission

The MGFA mission is to perform microgravity experiments in gaseous combustion science over the life of the CIR in order to better understand the combustion processes that occur on Earth. MGFA, in conjunction with the CIR, will allow experimenters to use various gaseous fuels in flow or quiescent environments and at various pressures, oxidizer compositions, and oxygen concentrations. The microgravity environment allows for measurement and observation of combustion processes that cannot be made in sustained gravity on Earth. The modular design of MGFA allows for flexibility in configuring for specific experiments, easy maintainability of the hardware and should result in lower hardware upmass.

2.3 MGFA Hardware Description

2.3.1 General

The MGFA is a set of multi-user hardware and software designed to accommodate, at a minimum, four of the gaseous burning experiments initially funded through Phase A:

1) Structure and Response of Spherical Diffusion Flames (s-Flame)
2) Flame Design Experiment (FlmDes)
3) Pulsed-Fully Flames Experiment (PUFF)
4) Field Effects of Gravity on Lean Premixed Turbulent Flame (V-flames)

The MGFA multi-user hardware is also called a "mini-facility" because it is analogous to the CIR facility, which also accommodates multiple users with minimal changes to a single set of hardware (i.e. MGFA is a facility within a facility, hence "mini-facility"). The major planned components are defined as follows:

1. Structure – CIR chamber insert structure; when fully outfitted with equipment the insert is called an "Experiment Mounting Structure (EMS)"
2. Burner/Ignitor – Consists of PI unique burner/nozzle and ignition system mounted on the EMS
3. Fluids Control – Fluids system for gas regulation provided by the combination of the MGFA EMS and CIR FOMA; may include flame verification system for safety, possibly mounted on the EMS

4. Internal Diagnostics/Sensors – Includes hardware mounted on the EMS to support external diagnostics such as mirrors and the various analog sensors such as thermocouples and radiometers
5. External Diagnostics – Includes the MGFA provided diagnostics to be mounted outside the CIR chamber at Universal Mounting Locations (UML's) such as cameras, illumination sources (lasers), and other optical systems
6. Experiment Avionics – Includes the MGFA unique electrical systems and software required to command, control , and power the MGFA insert and diagnostics

MGFA will provide a structure, complete with certain multi-use fluids regulation and diagnostic components for the performance of the listed experiments. Certain other diagnostic devices, particular to the requirements of the MGFA experiments will also be designed and built as a part of this effort to fit onto the Universal Mounting Locations (UML's) exterior to the CIR chamber.

2.3.2 MGFA Flight Increments

MGFA is planned to be delivered to the ISS in two flight increments, designated MGFA-A and MGFA-B. Based on the current experiment maturity and commonality, the first increment is planned to include the s-Flame and Flame Design experiments, and the second increment is planned to include the PUFF and V-flames experiments. Although there are two separate flight increments, the overall MGFA-A EMS design is planned to accommodate the later MGFA-B experiments without significant modifications. The next two sections cover more detail about the hardware concept for each increment.

2.3.3 MGFA-A

The first increment of MGFA, MGFA-A, is currently planned to support the performance of s-Flame and Flame Design, which share a common burner type and size. This commonality extends to the overall CIR chamber insert design and little or no modifications should be required on-orbit between the performance these two experiments. However, some changes are expected in the external diagnostic configuration between these experiments and each will require its own supply of unique gasses. For MGFA-A, only one external diagnostic is planned to be provided to meet the unique Science requirements for this phase, specifically, a Rainbow Schlieren system which is described below.

The major planned subsystems of the MGFA-A mini-facility are as follows: Structure, Burner/Ignitor, Internal and External Fluids Control, Internal and External Diagnostics and Experiment Avionics. Each component is discussed below in its designated section.

2.3.3.1 Structure

The structure of the MGFA-A will consist of a pair of plates, one forward (aisle end) and one aft, connected by structural rails that will interface with the CIR chamber guide rods. Currently, there is no requirement to rotate the structure to any orientation other than its initial, nominal insertion configuration. The burner mechanisms will be mounted on the backside of the forward plate, and the opposite side of that plate (front) will provide support for specialized components and controls. The aft plate will serve to mount diagnostic equipment and any other experiment specific hardware requiring that location.

2.3.3.2 Burner/Ignition

The burner required for the experiments planned for this increment contains a small spherical tip mounted on a narrow diameter support/supply tube. Currently, this tip is under development and its material type and configuration are not well defined. However, the desired tip size is approximately 6 mm, and the support tube will be approximately 1.5 mm OD and 50 mm in length. It is planned that this tip will be replaceable on orbit. The s-Flame experiment requires that this burner tip rotate, and therefore it is planned that it will be directly supported by a variable speed electric motor and that the combustion gas connection must not inhibit that rotation.

This burner requires a controlled gas input that varies with time over the course of a single test point.

Ignition will be accomplished by means of a hot wire coil attached to a movable arm (similar to Combustion Module-2 Laminar Soot Processes Experiment).

2.3.3.3 Fluids Control

There are several issues with respect to the Fluids Control system and they will be discussed at greater length in Section 7, Critical CIR Accommodations. It is uncertain as to whether or not the basic system will require additional controls to manage the experiments planned for MGFA-B. However, at a minimum, the MGFA-A insert will contain the following:

- Two solenoids to stop and start the flow of combustible and inert gas supplied by CIR
- One auxiliary gas supply system, including solenoids, a Mass Flow Controller (MFC), regulator, manual shutoff, quick disconnects and storage bottle(s)
- One in line mixing chamber, to assure complete blending of separate source gasses
- A flame verification system is currently under development, which is intended to control the timing system which regulates the amount of combustion gas that may be delivered to the CIR chamber, in order to extend the allowed burn times. This will ultimately be a Fluids Control system, mounted on the insert and interfacing with the CIR regulation system.
- Pressure transducers, relief valves, oxygen sensors, fittings, hand valves and quick disconnects as required to achieve the desired conditions and data listed in the Science Requirements Matrix Table.

Given that both CIR and MGFA are jointly responsible for providing fluids components and the associated controls, the MGFA design will not be complete until the development of the ICD with CIR is drafted.

2.3.2.4 Internal Diagnostics

Several of the diagnostic devices required for obtaining the Science data will be mounted on the MGFA-A insert. Thermocouples will be installed at various locations, and a (TBD) radiometer will be placed at a location suitable for good flame response. An adjustable mirror is required to be mounted on the insert to support the Rainbow Schlieren system discussed below. In some respects, the flame detection is also a diagnostic system, since it will rely on radiant energy in one form or another to generate a known response.

2.3.2.5 External Diagnostics

The s-Flame experiment currently requires a Rainbow Schlieren system to verify flame extinction. This system will consist of a light source, some beam splitting and focusing apparatus' and a three-chip color camera. This will be experiment specific hardware that will be required to interface with the UML standard interfaces. S-Flame and Flame Design both will utilize many of the standard CIR camera packages (see sections 3 and 6 for more detail).

2.3.2.6 Experiment Control and Data Management

MGFA shall provide the command and data management for all of its experiments. This will be based out of the MGFA Avionics Box. This box will have to work in conjunction with the MGFA EMS through the CIR chamber interface, and the following CIR subsystems: Input/Output Processor (IOP), Image Processing Packages (IPP), Image Processing and Storage Units (IPSU), the Fuel and Oxidizer Management Assembly (FOMA) and the FOMA Control Unit (FCU). MGFA will employ the CIR standard control systems, as outlined in subsequent sections. Test parameter uplink and real time ground commanding are within the scope of current planning. Data storage and downlink for both CIR and MGFA generated data will be downlinked via the CIR IOP. The MGFA Avionics Box will communicate for command and downlink with the CIR IOP and any other CIR processors such as the FCU over the CIR Ethernet or CAN bus networks.

2.3.3 MGFA-B

The second increment for the Multi-user Gaseous Fuels Apparatus is planned to support the performance of PUFF and V-flames, each of which will require its own, separate burner mechanism. It is hoped that the design of the structure will be sufficiently advanced and adaptable so that only the burner mechanism and some fluids and control devices will require installation and/or replacement. PUFF currently requires a co-flow of replenished air to surround the burner. Both PUFF and V-flames require a diagnostic called Particle Image Velocimetry (PIV) to obtain flow stream velocities and flow paths. The PIV system requires a specialized laser light delivery system and camera, which will be provided by MGFA and mounted outside the chamber in two UML's. In addition, the PIV system relies upon the use of very small particles to be injected by a system mounted on the EMS; more details regarding these particles are included in the Science Requirements Matrix in section 3. The MGFA-B primary systems are discussed further below.

2.3.3.1 Structure

The structure of the MGFA-B will nominally be the same as MGFA-A. However for V-flames there is some consideration being given to mounting the burner mechanism on the rear end plate to more directly vent the by-products and to aid in the image capture of the flame area of interest. This approach requires a more difficult design (to route fluid and electrical lines down the length of the EMS) and might be prohibitive to do on-orbit, which may necessitate a second MGFA EMS flight unit.

2.3.3.2 Burner/Ignition

2.3.3.2.1 PUFF Burner

PUFF requires the pulsed release of the gaseous fuel at rates ranging from 0.1 – 100 Hz. It is required that this gas flow be delivered in a 'rectangular' wave with sharply defined on/off flows each time to generate a pulse or "puff" of flame when the fuel is flowing. This gas is to be ignited by a steady state hot wire located just downstream of the nozzle exit, which is designed to specific constraints. It is envisioned that a special burner, with a high-speed response solenoid will be designed, built and carried in stowage with the rest of the MGFA-B increment.

2.3.3.2.2 V-flames Burner

V-flames also requires a specialized burner with an internal, constantly activated ceramic heater (in this case called a "bluff body"). The heated bluff body acts as a flame anchor, which gives the flame a characteristic, cone shape, or V-shape as viewed from the side of the burner nozzle. A retractable spark ignitor is required for ignition of the pre-mixed gasses. (Due to the high flow velocities in the burner nozzle, hot wire ignitors do not work.) V-flames has a constant velocity burner which requires relatively high flow rates of fuel and oxidizer, and will require some modification of the CIR Safety Package to support its implementation (based on the current understanding of the CIR Safety controls). To obtain both laminar and turbulent flames, the burner is expected to have a turbulent generating screen that will be mechanically added for the turbulent test points. It is planned that this burner will be shipped to the ISS in much the same manner as the PUFF burner, and be installed on the MGFA structure by the crew, unless it requires a separate EMS structure as suggested above.

2.3.3.3 Fluids Control

It is uncertain as to whether or not the basic MGFA-A fluids system will require additional controls to manage the experiments planned for MGFA-B. PUFF requires that its burner be surrounded by a tubular shell of oxygen-replenished air, or "co-flow," traveling in a laminar, discrete fashion at a specified distance from the flame. This co-flow system will require both input gasses from the CIR connected to a circular gas distribution system that will concentrically surround the combustion volume. The parameters for this flow are included in the Science Requirements Matrix in section 3. V-flames may also require a co-flow of nitrogen gas, pending outcome of ground tests of the pressure control system.

Both experiments will require controlled continuous venting to maintain pressure within tolerance bands specified in their respective Science Requirements Matrix. This has been achieved during ground based testing by use of a mass flow controller on the vent line. This capability will need to be provided by the CIR and is one of the items highlighted in section 7 due to the concern that the current CIR capabilities, although enhanced from the original design, will only marginally meet the venting requirements. Undoubtedly future testing with the CIR FOMA will be required to determine if there is an issue or not. One final possible issue for V-flames is the production of water vapor and condensation on the chamber windows; further assessments are in work.

2.3.2.4 Internal Diagnostics

MGFA-B will include similar sensors as MGFA-A (e.g. thermocouple, radiometer), however the Rainbow Schlieren System will not be required. Included within the manifest for MGFA-B will be the components and supplies for a PIV particle injection system that will inject 2 – 10 micron silicon dioxide (or aluminum oxide) particles into the combustion gas flow stream. The amounts required are and will be further specified in the Science Requirements Matrix (SRM), and have been preliminarily assessed as a ‘nuisance’ rather than a toxic Safety hazard. Due to their vectoral inertia, most of these particles will be deposited onto the “flow baffle”, a sintered metal porous plate, which will be placed in line normal to the burner normal axis to disperse the outgoing gas.

2.3.2.5 External Diagnostics

One unique diagnostic for MGFA-B is the PIV. The PIV velocity imaging is to be accomplished over a relatively small area utilizing individual digitized frames and a carefully timed laser pulse. This will allow the velocity vector of each individual particle to be determined as to both length and direction from a single image. Both the light source and camera will be specialized devices, closely coupled with respect to time. These camera and illumination system requirements are currently deemed outside of the scope of present and future planned capabilities of the CIR diagnostics and will be provided by MGFA.

In addition, V-flames requires a special diagnostic called Turbulent Flame Front Dynamics. V-flames is considering the use of a Planar Laser Induced Fluorescence (PLIF) measurement or a Mie Scattering technique which includes the introduction of oil into the flame (see science requirement 8.19 in section 3.2 for more detail). Based on ground-based testing, either diagnostic technique appears to be viable and each has engineering challenges. MGFA desires a joint development with CIR in either case.

Last, each experiment will utilize some of the standard CIR camera packages.

2.3.2.6 Experiment Control and Data Management

MGFA-B experiment control is currently expected to have the same hardware as MGFA-A, and a unique set of software.

3.0 MGFA SCIENCE-BASED ENGINEERING REQUIREMENTS

In this section the science requirements are consolidated from each SRD and combined into a master requirements table. As mentioned in the purpose of this document, this table includes both the requirement and the engineering response and the content is covered more specifically in section 3.1. In addition, the test matrices from each SRD are included in section 3.2.

3.1 Format of the MGFA Science Requirements Table

An example of a line from the MGFA Science Requirements Table in this document is shown below. As the project team adds detail to the design, new headings will be added to this document to better track the engineering response and engineering design requirements.

MGFA Req't #	MGFA Sub-req't #	Subsystem/ Parameter	SRD origin of Req't	Requirement	Engineering Response	Responsible Org.
1		**Chamber**				
1	1	Chamber Volume	s-Flame	100 Liters free volume	Controlled by CIR, mixing insert will have to be removed	CIR

Explanations of each column:

MGFA Requirement #: Requirements are numbered sequentially for each major subsystem. Specific science requirements are mapped into one of the MGFA subsystem categories.

MGFA Sub-requirement #: Under each major subsystem the sub-requirements are numbered sequentially.

Subsystem/Parameter: The MGFA flight system is broken into major subsystems; this column indicates which subsystem. In addition other parameters such as acceleration limits are included.

SRD Origin of Requirement: This column indicates which Experiment SRD was the source for the requirement.

Requirement: This is the requirement extracted from the SRD.

Engineering Response: For this draft, this column includes a description of the current engineering concept planned to meet this requirement and highlights any issues associated with this requirement; critical CIR issues are also listed in section 7. Future drafts are planned to contain a more specific restatement of the requirement as an enveloping engineering requirement for the MGFA mini-facility.

Responsible Org: This column identifies the responsible organization for meeting and verifying that requirement – MGFA (PI), CIR, or joint. Joint responsibilities will be more specific with clear divisions in the ICD between MGFA and CIR.

3.2 MGFA Science Requirements Table

MGFA Req't #	MGFA Sub-req't #	Subsystem/ Parameter	SRD origin of Req't	Requirement	Engineering Response	Respon-sible Org.
1		**Chamber**				
1	1	Chamber Volume	s-Flame	100 Liters chamber	MGFA will require that the mixing baffle be removed from the back of the CIR Chamber to maximize internal volume. O_2 replenishment will make this requirement less important.	CIR
1	2	Chamber Dimension	s-Flame	200 mm interior diameter clear	Volume surrounding the combustion location for all MGFA experiments will be kept as free from obstruction as possible. Certain hardware, such as ignitors, TC's and soot samplers will be intrusive due to functional necessities. This requirement drives the length of the burner tip support (to 100 mm).	MGFA/CIR
1	3	Shape	PUFF	Axisymmetric combustion volume	The CIR chamber is axisymmetric, although not all window locations can support all diagnostics. If PUFF requires a flow tunnel, this may become an MGFA issue.	CIR
1	4	Size	PUFF	min diameter 200 mm, minimum length 600 mm	See items 1.1, 1.2 and 1.3 above.	CIR
1	5	Surface	PUFF	Smooth walls, 0.9 absorptivity in range from 0.3 - 10 microns	Absorptivity of CIR interior surface is to be TBD. All MGFA interior surfaces, excepting actual diagnostics, will be hard black anodized of absorptive epoxy paint.	MGFA/CIR
1	6	Free area	FlmDes	area within 50 mm radius of tip must be free of obstructions	See items 1.1 and 1.2 above.	MGFA
1	7	Optical Access	s-Flame	2 views minimum, which must be orthogonal, refer to optical requirements and schematic, Section 6.6 of MGFA ERD	Optical access is driven by the total number and type of diagnostic equipment required for each experiment. See Diagnostic portion of this matrix or Section 6.6 of the MGFA ERD, Optical Block Diagrams, for further information.	CIR/MGFA
1	8	Chamber wall emissivity	s-Flame	>0.9 over wavelength range 0.3 um to 40 um	See item 1.5 above.	CIR
2		**Chamber**				

MGFA Req't #	MGFA Sub-req't #	Subsystem/ Parameter	SRD origin of Req't	Requirement	Engineering Response	Respon-sible Org.
		Environment				
2	1	Pressure	s-Flame	Initial pressure, 1 atm +/- 3% Constant volume with pressure ranging from 1 - 3 atm and/or constant pressure combustion for test points	CIR has listed the capability of their outflow MFC to be 90 slpm, for direct venting with known, approved by-products. Based on pressure rise information from ground based testing and the maximum fuel flow rates listed below, this will be insufficient to maintain 1 atm pressure (~150 slpm req'd). (300 sccs X 60s X .001 l/cc X 8 (factor for expansion due to combustion) = 144 slpm)	CIR
2	2	Pressure	V-flames	regulated to 0.98 bar	Similar requirements for V-flames. See item 2.1 above. Depending on test matrix, V-flames flow could be even higher	CIR
2	3	Pressure accuracy/range	FlmDes	within 1% of set-point, 0.5 - 2 atm	This requirement envelopes the accuracy the pressure control/fill system for MGFA. CIR documents this capability in its PDR presentation, February, 01. Flame Design expects to run test points in a sealed chamber (i.e. constant volume).	CIR
2	4	Pressure	PUFF	0.95 - 1.05 atm, regardless of burner flow	See item 2.1 above.	CIR
2	5	Temperature	s-Flame	290 - 310 K	It is assumed that although the CIR has a cooling system that is independent from the ISS cabin air, the temperatures within the rack will be maintained close to 300^0 K (23^0 C). Some cooling of the internal chamber temperatures will happen due to the expansion of the fill gas, but a short stabilization time should allow the chamber to 'warm' the gas to support this requirement.	CIR
2	6	Temperature	FlmDes	uniform within 2^0 K throughout	Same as item 2.5 above. This requirement is linked to the 300+ seconds quiescence time required in item 35 under Fuel/Fluids delivery. Must be verified by TC's, one at chamber wall, one in gas environment.	CIR
2	7	Temperature	V-flames	maintain 27^0 C, +/- 2^0	Same as item 2.5 above. Should be tested under lab conditions to assure that neither temperature buildup nor cooling due to inlet gas expansion	CIR

MGFA Req't #	MGFA Sub-req't #	Subsystem/ Parameter	SRD origin of Req't	Requirement	Engineering Response	Respon-sible Org.
					disturbs temperature environment	
2	8	Temperature	PUFF	280 - 310^0 K, initial	Same as item 2.5 above.	CIR
2	9	Initial gas composition	s-Flame	Air mixed to current setpoint: O_2 = 21%, N_2 = 79%; +/-1%, verified by gas analysis	The atmosphere for combustion will be mixed from components, that is; O_2 supplied by MGFA through the CIR FOMA system and N_2, supplied by the ISS, similarly regulated. Gasses introduced into the chamber through CIR control to specified accuracy. Must be verified by Gas Chromatograph analysis.	CIR/MGFA
2	10	Composition	FlmDes	each gas component within 1% of setpoint	Same engineering comments as above, with the inclusion of a wider set of component ranges, and with the additional consideration of MGFA supplied fuel as a chamber component (see item 3.32 in Fuel/Fluids Delivery and item 2.14 below).	CIR
2	11	Comp. & temp stability	FlmDes	composition to remain +/- 0.01 mole fraction temperature +/- 50 C; with all environmental factors to remains +/- 10% for 120 s test duration (minimum)	Since Flame Design expects to operate in a closed chamber environment, these requirements, which are related to chamber volume, will be governed by both the mass/volume of the MGFA insert and the Science Test Matrix.	MGFA
2	12	Component purity				
2	13	Diluent	FlmDes	minimum purity: 99.99%	Only N_2 is currently planned to be used as a diluent. Purity of source is regulated by ISS and delivery by CIR.	ISS/CIR
2	14	Oxidizer	FlmDes	minimum purity: 99.99% (of designated constituents)	MGFA (FlmDes) can provide the gasses to the specification, CIR must assure delivery purity.	MGFA/CIR
2	15	Normal	FlmDes	Oxygen content from 0 - 85%, balance Nitrogen	CIR must allow required O_2 concentration and provide method or justification for venting. It is assumed that all N_2 required for either chamber or venting dilution will come from ISS resources. MGFA must assess impacts of additional O_2 to up-mass.	MGFA/CIR
2	16	Component purity	PUFF	Purity > 99.9%	Purity of the O_2 is the responsibility of PUFF, supplied to the FOMA; ISS requirements determine	MGFA/CIR

MGFA Req't #	MGFA Sub-req't #	Subsystem/ Parameter	SRD origin of Req't	Requirement	Engineering Response	Respon-sible Org.
					N_2 purity.	
3		**Fuel/Fluids Delivery**				
3	1	Flow supply system	s-Flame	Supply fuel, oxidizer and diluent for 300s minimum	At the fuel flow rates required by s-Flame, this requirement, which is actually intended to satisfy the search for radiative extinction, may exceed the limits established for fuel flow by adiabatic combustion/pressure analysis alone. MGFA expects to develop a flame verification system (schematic in section 6.6 of the MGFA ERD) to augment and temporarily interrupt the CIR fuel flow timing mechanism to achieve greater total fuel flow volumes than would be allowable based on the adibiatic combustion analysis. This will be a CIR and ISS Safety issue to be negotiated prior to flight design.	CIR/MGFA
3	2	Fuel flow	PUFF	Up to 4.3 slpm pure ethylene, 4.4 slpm pure propane	This does not envelope current MGFA requirements, but may be above planned FOMA capability. May need to consider MGFA provided Mass Flow Controller (MFC).	CIR
3	3	Flow rate	s-Flame	10 - 300 sccs (0.6 - 18 slpm), +/-1% setting, combined fuel and diluent. Fuel rate 5 - 150 sccs.	This requirement envelopes the expected flow rates for MGFA. MGFA expects to utilize the FOMA systems to control this flow to these accuracies. May need to consider MGFA provided MFC.	CIR/MGFA
3	4	Fuel Mixture	s-Flame	see test matrix, uniformity 95% or better	Uniformity of the required premixed gasses loaded into FOMA compatible bottles is within current technology. Due to test matrix requirements, a second fuel bottle with solenoid, mixing device and MFC is planned to be included as a part of the MFC insert. This hardware is experiment specific.	CIR/MGFA
3	5	Fuel	PUFF	Gaseous Hydrocarbon, added H_2, N_2; fuel to be up to 50% of total flow	PUFF intends to utilize the extra fuel delivery system required by s-Flame (on the MGFA insert) to blend H_2 into the Propane which is being supplied through the CIR/FOMA fuel system. Both fuels (and diluent) must have the ability to be	CIR/MGFA

MGFA Req't #	MGFA Sub-req't #	Subsystem/ Parameter	SRD origin of Req't	Requirement	Engineering Response	Respon-sible Org.
					ramped during test points.	
3	6	Mixture accuracy	PUFF	+/- 0.01 volume fraction	This should be within the capability of either system.	CIR/MGFA
3	7	Fuels	FlmDes	minimum purity: 99.9% (ethylene, propane, propylene, TBD)	Purchased gas of this purity can be loaded into FOMA compatible bottles within this limit. CIR to verify purity of delivery.	MGFA/CIR
		Fuel Pulsing				
3	8	Pulse Timing	PUFF	Injection time: 2 - 2000 msec, capability for continuous fuel injection	This is a wide range of delivery times and at the low end requires a very fast response control. MGFA will need to develop this experiment specific control.	MGFA
3	9	Pulse Shape	PUFF	"nominally rectangular wave", closes fully between pulses, independent of other variables	This requirement reiterates the need for a fast response, and requires that the orifice be large enough to quickly initiate flow.	MGFA
3	10	Pulse Flow	PUFF	each pulse volume must be known	Ground testing to provide data	MGFA
3	11	Reactant	FlmDes	reactant flow rate (O_2 or fuel) = +/- 1% setpoint	This control is allocated to CIR and is within their current capability. NOTE: O_2 must go to burner tip previously used for fuel	MGFA/CIR
3	12	Diluent	FlmDes	diluent flow rate () = +/- 1% setpoint, dynamically blended w/ reactant, variable during test point, response time < 1 s	Control of this function and its possible mixing with O_2 will be under CIR/FOMA control. Blending this with flowing fuel will be performed by MGFA device.	MGFA/CIR
3	13	Composition	FlmDes	composition known to within 1%	This will be verified by CIR performance specifications and ground testing.	MGFA/CIR
3	14	Control	FlmDes	shutoff capability required	Shutoff capability will be provided by CIR/FOMA only. No additional MGFA controls on this fuel flow system are planned.	CIR
3	15	Fuel	FlmDes	0 - 3 mg/s (0 - 0.262 slpm)	This control is allocated to CIR and is within their current capability. Fuel supplied to FOMA from MGFA	CIR

MGFA Req't #	MGFA Sub-req't #	Subsystem/ Parameter	SRD origin of Req't	Requirement	Engineering Response	Respon-sible Org.
3	16	Oxygen	FlmDes	0 - 10 mg/s (0 - 0.460 slpm)	This control is allocated to CIR and is within their current capability. O_2 supplied to FOMA from MGFA	CIR
3	17	Nitrogen	FlmDes	0 - 70 mg/s (0 - 3.67 slpm)	This control is allocated to CIR and is within their current capability. N_2 is expected to be supplied to FOMA from ISS	CIR
3	18	Pseudo-Flammability limit	FlmDes	N_2 flow rate must be ramped during test point	This control is allocated to CIR and is within their current capability.	CIR
		Component flow rate				
3	19	N_2 purge gas	V-flames	TBD based on burner size	It is unknown at this time if N_2 will be required to be run through the V-flames burner to purge it. If so, it is within current CIR/FOMA capabilities.	CIR
3	20	Oxygen/Nitrogen	V-flames	290 - 630 sccs (17.4 - 37.8 slpm)	This requirement envelopes the expected flow rates for MGFA. MGFA expects to utilize the FOMA systems to control this flow to this level and to perform the required mixing of these components. This must be supplied to the burner as shown in the schematic in Section 6.6 of the MGFA ERD. Specified as 'air'.	CIR
3	21	Fuels (Methane)	V-flames	66 - 141 sccs (3.96 - 8.46 slpm)	This control is allocated to CIR with the flame verification system mentioned in item 3.1 of this section being applicable.	MGFA/CIR
3	22	Fuel Inlet Temperature	V-flames	27^0 C	There are currently no plans to provide any temperature moderation systems to the fuel delivery equipment. Gas will be delivered as it comes from the bottle through the FOMA.	CIR
3	23	Fuel supply temperature	s-Flame	300 K +/- 10%	Same as 3.22.	CIR/MGFA
3	24	**Oxidizer Co-Flow**	PUFF	axisymmetric and without swirl	This is a laminar flow, tubular shell, oxygenated, surrounding flame area. Implementation of this requirement may require the use of a flow duct attached to the MGFA insert. CIR must provide a method to connect mixed gas (N_2 (from ISS) and O_2 (from FOMA) in 'air' ratio) to diffuser and provide flow regulation.	MGFA/CIR

MGFA Req't #	MGFA Sub-req't #	Subsystem/ Parameter	SRD origin of Req't	Requirement	Engineering Response	Respon-sible Org.
3	25	Velocity	PUFF	0 - 25 cm/s, maximum 0.5% nozzle velocity adjustable, same direction as nozzle flow	This system performance will have to be thoroughly developed tested and verified on the ground, probably using the PIV system to correlate flow to velocity. A requirement to use a flow duct complicates design, but makes true compliance to SRD easier. If smaller nozzles are used, this velocity may go up.	MGFA/CIR
3	26	Velocity Profile	PUFF	coaxial with fuel to 2%, independent of position, plug type profile, +/- 0.5 cm/s within 10 cm radius of nozzle, constant with time	A manifold/diffuser will have to be designed that is attached to the burner, with its outlets sufficiently close to the burner tip to meet these requirements, but far enough away that the swirl inertia has been dissipated.	MGFA
		Co-flow concentration	PUFF			
3	27	Oxidizer	PUFF	0.2 - 0.4 O_2 volume fraction, balance N_2	Since both the Co-flow and the burner supply will require blending with N_2, PUFF wishes to utilize the ISS system to supply the larger use function (Co-flow). This will require dynamic blending. Accuracy of the system will be verified on the ground. Recirculation system is being considered to conserve resources.	CIR
3	28	Mixture accuracy	PUFF	+/- 0.005 volume fraction (of total)	This requirement should be within current CIR/FOMA capability.	CIR
		General				
3	30	Physical state	PUFF	All gaseous (no liquid)	There should be no problem meeting this requirement.	CIR
3	31	Gas SupplyTemperature	PUFF	280 - 310^0 K, gas supply temperature at inlet	PUFF accepts that if the co-flow is supplied by incoming gas, as is the baseline presented herein, that the temperature of the inlet gas is whatever the system will deliver under nominal operating conditions. However, the possibility exists that due to up-mass constraints, a recycling system may be required for this system. If this is the case, then the gas temperature may have to be modulated, downward, due to the heat of combustion.	MGFA/CIR

MGFA Req't #	MGFA Sub-req't #	Subsystem/ Parameter	SRD origin of Req't	Requirement	Engineering Response	Respon-sible Org.
3	32	Inverse Burns (fuel in chamber, air flows thru burner)	FlmDes	Fuel content from 0 - 100%, balance Nitrogen	To be explicit, the Scientist requires the chamber to be filled with fuel, or a mixture dominated by it, while a diluted oxidizer is supplied to the burner, creating inverse flames. Issues that need addressing include: 1) are there CIR imposed limits to the amount of fuel in the chamber, 2) is it safe to run the O2 through the same tubing that has previously be used to pipe fuel in the mixer and burner, 3) can the same controls used to regulate the fuel flow (timer system) be used for the oxidizer? Clarifications as to feasibility and explicit capabilities of the FOMA and the Chamber operation must precede design.	MGFA/CIR
3	33	Gas Reconditioning	FlmDes	partial vent/refill, scrubbing permitted for conservation of resources	Compliance with this important requirement will necessitate utilizing the FOMA Absorber cartridge and system to scrub by-products from both but separately a fuel dominant and oxidizing mixture. CIR is responsible for the gas handling, MGFA for for the gas handling, MGFA for the canister fill determination and (possibly) packing.	CIR/MGFA
3	34	Physical stability	FlmDes	Quiescent: + 300 s after fill or vent prior to test	This is actually an Operations and Software issue, but it is mentioned here for planning purposes. This quiescense requirement applies to s-Flame too.	CIR/MGFA
4		**Burner**				
4	1	Size	s-Flame	Porous sphere: 6.3 - 12.7 mm diameter	s-Flame and FlmDes Science teams have agreed that they can find one burner tip that should satisfy the needs of both experiments. Although this specification remains allowing a 1/2" tip, as of the writing of this document, all serious development and and testing is taking place utilizing a 1/4 " (6.3 mm) tip. To date, none of the various production techniques have been ruled out and development continues.	MGFA
4	2	Flow uniformity	s-Flame	Flame must exhibit 0.99 sphericity, 0.97	Science team for s-Flame is working to redefine this requirement in a more objective format. S-Flame	MGFA

MGFA Req't #	MGFA Sub-req't #	Subsystem/ Parameter	SRD origin of Req't	Requirement	Engineering Response	Respon-sible Org.
				concentricity*	requires a flame that is both highly spherical and concentric.	
4	3	Flame geometry	FlmDes	flame r_{min}/r_{max}>0.8 in 2 sec drop tower	Flame Design's requirement is less stringent with regard to sphericity and has no concentricity requirement.	MGFA
4	4	Support	s-Flame	1.5 mm OD tube, max.	Compliance with this is somewhat complicated by the requirement for a 10 cm clear radius around the tip, making this tube almost 4" long. Since s-Flame wishes to rotate the burner at up to 1200 rpm, this tube must be very rigid and straight.	MGFA
4	5	Tip supply	FlmDes	supply/support < 20% burner diameter	The common burner design should also satisfy this requirement	MGFA
4	6	Burner rotation	s-Flame	Adjustable speed, 300 - 1200 RPM	This is an s-Flame specific requirement and will mean that the common burner will need to be mounted on an electric, variable speed motor and be connected to the gas supply system using a dynamic seal. This has been successfully demonstrated in the lab and for KC-135 flight and is not expected to be a problem.	MGFA
		Nozzle (V-flames)				MGFA
4	7	Mean axial velocity	V-flames	0.5 - 4 m/s	V-flames/MGFA-B will develop a modular burner to be attached to the structure supplied as a part of MGFA-A that will deliver gas that meets these requirements, as verified on the ground. Note that the particle injection system utilized for the PIV system will be a part of this assembly. Location of this burner (either on the front or aft interior plate surface) is uncertain at this time.	MGFA
4	8	Mean transverse velocity	V-flames	2 m/s either direction	Same response as item 4.7.	MGFA
4	9	Rms axial velocity	V-flames	0.05 - 0.4 m/s	Same response as item 4.7.	MGFA
4	10	Rms transverse velocity	V-flames	0.05 - 0.4 m/s	Same response as item 4.7.	MGFA
4	11	Flame wrinkle structure	V-flames	radius of curvature 1 mm	Same response as item 4.7.	MGFA

MGFA Req't #	MGFA Sub-req't #	Subsystem/ Parameter	SRD origin of Req't	Requirement	Engineering Response	Respon-sible Org.
4	12	Temperature	V-flames	uniform within 2^0 K throughout	Same response as item 4.7.	MGFA
		Nozzle (PUFF)				MGFA
4	13	Dimensions	PUFF	circular cross section	PUFF/MGFA-B will develop a modular burner to be attached to the structure supplied as a part of MGFA-A that will deliver gas that meets these requirements, as verified on the ground.	MGFA
4	14	Inner diameter	PUFF	1 - 2 mm	Same response as item 4.13. It should be noted that as the nozzle size decreases, the velocity must increase.	MGFA
4	15	Wall thickness	PUFF	< 0.5 mm	Same response as item 4.13.	MGFA
4	16	Orientation	PUFF	Coaxial with structure and co-flow (+/- 1^0), > 3 cm from obstructions to nozzle outlet	Since PUFF expects the length of the flame to vary greatly, as well as the area of interest, this burner must translate axially to utilize the PIV system.	MGFA
4	17	Primary Variables				MGFA
4	18	Puffing frequency	PUFF	0.1 - 100 Hz	PUFF alone requires pulsed flow, and this function, being unique, will be a included as a portion of their burner assembly. PI has successfully demonstrated this capability in ground testing, with off the shelf components.	MGFA
4	19	Puffing duty cycle	PUFF	0.01 - 0.9; duty cycle is the amount of time the fuel is on divided by the sum of the fuel on and off times. Continuous burns to be supported as well.	Same response as item 4.18.	MGFA
5		**Particle Image Velocimetry Particle Deployment/Removal**				
5	1	PIV Particle Insertion	V-flames	1 - 5 micron, desired: Silicon Dioxide, "micro feathers", 30 second duration per TP, velocity = flame	Science has working ground based system. Micro-g system has not been researched. Insertion in "fluidized' form, may or may not work in micro-g, not required to be continuous. Must inject particles into flame stream for V-flames.	MGFA

MGFA Req't #	MGFA Sub-req't #	Subsystem/ Parameter	SRD origin of Req't	Requirement	Engineering Response	Respon-sible Org.
5	2	PIV Particle Density	V-flames	6 particles/mm^3	This is estimated density from acquired ground data. Delivery to be verified in lab.	
5	3	PIV Particle Insertion	PUFF	Preliminary requirements same as V-flames, items 5.1 and 5.2	PUFF has similar requirements as far as imaging and particle density and expects to utilize the system developed by V-flames. Particles are to be inserted into co-flow stream.	MGFA
5	4	PIV Particle Removal	V-flames/MGFA	Particles are to be captured by MGFA/CIR and/or vented by CIR.	V-flames expects to use a baffle (or 'frit') on the surface opposite end of the chamber from the nozzle, to help diffuse outgoing gas, and to catch the majority of the PIV particles. Some will be lost to the chamber environment, therefore the cleanup of these particles is an issue that must be worked with CIR. Toxicity does not seem to be a part of this issue based on particles currently in use in lab testing (also planned for flight).	MGFA/CIR
6		**Ignition**				
6	1	Ignition mechanism	s-Flame	50 W, 200 ms minimum	This is within normal ignition requirements for this type of flame. The CM-1(2) mechanism for LSP provides a good example of the rotating action type hot wire ignitor, but other types of moving systems may be considered to minimize disturbances to the environment.	MGFA
6	2	Igniter deployment	s-Flame	~3mm from burner tip for ignition, retraction time< 200 ms	The retraction time may be altered if it is determined that this speed disturbs the quiescence.	MGFA
6	3	Enablement	FlmDes	not more than 5 s prior to fuel delivery	This is an Operations requirement.	MGFA
6	4	Detection	FlmDes	automatic detection required	Computer control can sense voltage changes in the hot wire to comply with this requirement.	MGFA
6	5	Removal	FlmDes	igniter shall be removed from required free area < 1 s	One ignitor should satisfy s-Flame and FlmDes. S-Flame envelopes this requirement.	MGFA
6	6	Ignition	PUFF	Ignite all puffs, minimum flow disturbance, energy addition, no interference	PUFF's unique burner will include its own ignitor which operates continuously during the experiment. Ground testing is utilizing a hot wire coil mounted	MGFA

MGFA Req't #	MGFA Sub-req't #	Subsystem/ Parameter	SRD origin of Req't	Requirement	Engineering Response	Respon-sible Org.
				with FOV	just downstream of the burner outlet. This is satisfactory for flight.	
		Ignition	V-flames	Not covered by Science Requirement, but is a required component of burner.	For current ground testing, V-flames is utilizing a heated bluff body (a cone shaped flow deflector positioned in the nozzle opening) to condition the mixture and serve as a flame anchor, and accomplishes initial ignition by means of an electrical spark	MGFA
7		**Data Measurements**				
7	1	Chamber pressure	s-Flame	+/- 5% full scale, 1 atm at 1 Hz	This is within current CIR capability	CIR
7	2	Chamber pressure	PUFF	+/- 0.01 atm, 1 Hz	This is within current CIR capability, and bounds re MGFA requirements.	CIR
7	3	Chamber gas temperature	s-Flame	+/- 2K, 6 points near chamber walls, at 1 - 30 Hz	The actual locations of all of these TC's has not yet been determined. As a minimum, the temperature of the far field must be captured. Other TC's may be set at discrete distances to capture gradients. Sampling rate is uncertain and will be tied to response.	MGFA
7	4	Chamber gas temperature	PUFF	+/- 1 K, 1 Hz	This is a chamber gas, outer boundary condition temperature measurement requirement. Instrumentation for s-Flame bounds this measurement.	MGFA
7	5	Oxygen concentration	s-Flame	+/- 2%, 2 - 3 points near chamber walls, at 1 Hz	Given the currently available technology, this requirement may not be able to be accomplished. Although the measurements will be near the range of atmospheric composition only (22 - 12%), neither the accuracy nor the response time implied by the sampling rate may be able to be achieved. Engineering trade study followed by negotiations with the PI are required to determine the final actual requirement before beginning system design.	MGFA

MGFA Req't #	MGFA Sub-req't #	Subsystem/ Parameter	SRD origin of Req't	Requirement	Engineering Response	Respon-sible Org.
7	6	Burner temperature	s-Flame	+/- 10 K, at 120 Hz	PI strongly prefers a non-interference technique, but preliminary investigation did not reveal a viable concept. A thermocouple can produce the required accuracy, though not the response time, but will require a wire and a ring contact (since the burner must rotate) for signal transmission. Requires further study before design.	MGFA
7	7	Burner surface temperature	FlmDes	precision: +/- 2^0 C; accuracy +/- 5^0 C same time constraints	A thoroughly characterized TC can perform to this accuracy. Since common burner is to be employed, s-Flame requirements for size and geometry dominate.	MGFA
7	8	Temperature measurements	V-flames	time synchronized data from "within the chamber" and on the "draft reduction shield"	Engineering assumes that these are TC measurements that can be time synced with the rest of the data. Locations can be specified during design.	MGFA/CIR
7	9	Temperatures	PUFF	Range: 250 - 1700^0 K Accuracy: +/- 1 K Frequency: 100 Hz Response time: < 0.1 s	Thermocouple locations unspecified at this time. Data must be time synchronized with video.	CIR
7	10	Radiation flux	s-Flame	2 units +/- 10%, at 120 Hz, Broad Band	Refer to item 7.12.	MGFA
7	11	Thermal Radiation	PUFF	Radiometer: Spectral Range: 0.2 - 9.0 microns FOV: TBD	Refer to item 7.12.	MGFA
7	12	Radiant emission	FlmDes	Near IR (0.13 - 11 um) and UV (308 nm) req'd relative accuracy: 5%; absolute accuracy: 10% (radiometers recommended)	The engineering goal for these experiments is to design as many common components as possible to save on both up-mass and development costs. It has not been determined if these requirements are sufficiently similar to allow this to be the case for the radiometry system.	MGFA
7	13	Species sampling	FlmDes	resolution: 3 mm TEM grid; spatial accuracy: 1 mm insertion time: 15 ms; dwell: 0.1 - 1 s (no chamber gas release)	Conceptually, this is the same piece of hardware that the CM-1 (2) experiment called 'Soot Samplers', which can perform to these specifications. However, a complete redesign of the housing and a reevaluation of the actuators will be	MGFA

MGFA Req't #	MGFA Sub-req't #	Subsystem/ Parameter	SRD origin of Req't	Requirement	Engineering Response	Respon-sible Org.
					required due to "no chamber gas release" requirement and differing geometry.	
7	14	Measured quantities	FlmDes	at steady state, I.e. all quantities vary < 1% over 5 s	This is an environmental requirement which defines "steady state" with respect to this experiment. Hardware participates in as much as it doesn't interfere.	MGFA/CIR
7	15	Experiment parameters	V-flames	record: fuel and air flow rates, burner configuration, turbulence generator type, laser power, vent rate all data to be time synchronized	MGFA data collected by the PI Avionics or CIR will be nominally saved and downlinked by the CIR IOP; communication to and from the PI Avionics Box and CIR packages like the IOP is done via Ethernet or CAN Bus. If the downlink of all data is not possible, MGFA may consider using a data recording device and requesting crew time and down-mass.	MGFA/CIR
8		**Imaging**				
8	1	Standard color video	s-Flame	CIR provides one, other in Schlieren system, at 30 Hz	PI and PS are examining this requirement, which is based on the need to see orthogonal views of the flame. The Rainbow Schlieren camera may not be properly situated to provide an optimal second view. One color camera only required presently.	CIR/MGFA
8	2	Standard color video	FlmDes	one required, two orthogonal views desired FOV: 0.4 < r_f < 4; resolution: 0.0025 FOV panning and zoom capability desired	The nominal optical wavelength requirements for Flame Design are being examined by Science. Emphasis is being placed on utilizing equipment as currently planned to be provided by CIR.	CIR/MGFA
8	3	Views	PUFF	2 orthogonal views, ortho to burner axis, one color	CIR Provided hardware will be utilized, see included schematics, Section 6.6 of the MGFA ERD. The HFR/HR is proposed for the second view orthogonal to the color camera.	CIR
8	4	Frequency	PUFF	req.: 25 Hz; desired, 200 Hz	Frequency requirements will be refined at a later point in time, based on available downlink and down-mass. This envelopes the requirements.	CIR/MGFA

MGFA Req't #	MGFA Sub-req't #	Subsystem/ Parameter	SRD origin of Req't	Requirement	Engineering Response	Respon-sible Org.
8	5	FOV for Color Camera	PUFF	Required: 300 mm, desired: 500 mm length, height 200 mm minimum	Compliance to this requirement will necessitate that the color camera be outfitted with a wide angle lens to extend the field of view. Cost and impact have yet to be assessed.	CIR/MGFA
8	6	Resolution for Color Camera	PUFF	1 - 2 mm	This should be within current CIR capability.	CIR/MGFA
8	7	HFR/HR Camera	s-Flame	View orthogonal to Color Camera	Use of this camera package for nominal imaging is under consideration. This is not a requirement at this time, however, a second visible light image is.	CIR
8	8	Radial temperature distance. (Captured by HiBIMS Camera Package)	FlmDes	spatial resolution of 0.25mm where $T>1000^{0}$ K precision: +/- 250 C; accuracy: +/- 500 C minimum temporal res.: 10 s; 1 Hz; complete scan: 30 s	This should be within current CIR capability.	MGFA
8	9	IR Imaging	s-Flame	CIR provided, at 30 Hz	Use of the CIR Near-IR Camera Package with Filter Wheel, as specified, satisfies this requirement	CIR
8	10	UV Imaging	s-Flame	CIR provided, at 30 Hz	Use of the CIR LLL-UV Camera Package as specified satisfies this requirement	CIR
8	11	Imaging	PUFF	one view 300 - 320 nm (OH emissions)	Use of the CIR LLL-UV Camera Package as specified satisfies this requirement	CIR
8	12	Rainbow Schlieren	s-Flame	120 mm diameter beam desired, requirement linked to actual window ID, color camera at up to 120 Hz	This diagnostic is required by the s-Flame PI for flame extinction verification. Experiment specific as currently specified. Engineering has verified on benchtop that producing an acceptable image is possible utilizing a single window with a mirror which would be mounted internal to the chamber, and a minimum of parts. PS is attempting to correlate images to temperature gradient, and if possible, it will increase the number of potential users and thereby the possible funding for this unit. In situ breadboarding is planned.	MGFA

MGFA Req't #	MGFA Sub-req't #	Subsystem/ Parameter	SRD origin of Req't	Requirement	Engineering Response	Respon-sible Org.
8	13	Soot volume fraction distribution.	FlmDes	precision: 5%; accuracy: 10% temporal res.: 1 s; 1 Hz; brightness; 8 bits over FOV filter spatiality: 0.5^0 (laser extinction recommended)	Use of the HiBIMS Camera Package in conjunction with the Illumination Package as specified satisfies this requirement, however, timeline to use this camera for dual purposes is critical.	CIR/MGFA
8	14	Laser-Light scattering (or equivalent: i.e. PAH) this is a PI desirement	FlmDes	signal to background ratio: 1:1 (at limit) same optical requirements as above laser diode (100 mW at 660nm w/ intensified, gated CCD	Flame design would have to provide the laser required to illuminate hydrocarbons. Experiment specific hardware to be mounted outside the chamber.	CIR/MGFA
8	15	PIV imagery	V-flames	time synchronized, digitized images required for two laminar and two turbulent flames minimum	This required system is based on a relatively powerful laser (up to 5.0 W) illuminating particles in the flame for very brief but carefully timed exposures that capture position, direction and velocity in one combined, integrated frame. Both laser and camera will be experiment provided hardware as currently specified.	MGFA
8	16	Field Of View (PIV)	V-flames	2 X 2 cm	The field of view specified is dependent on the anticipated particle velocity and the image exposure control specified.	MGFA
8	17	Velocity Resolution	V-flames	Desired range: 20 - 500 cm/sec, req'd sampling 10 Hz, +/- 1% accuracy; -30 - 30 cm/sec transverse	PS currently has breadboard system working to these specifications. Safety issues regarding laser power (up to 5.0 W) must be resolved, as well as packaging issues. Flight configuration has not been examined.	MGFA
8	18	PIV imagery	PUFF	10 - 200 cm/s, accuracy 3 - 5%, sampling 15 Hz	PUFF Science team has determined that requirements for this system levied by V-flames will be sufficient for their use as well. All data to be time synchronized.	MGFA/CIR
8	19	Turbulent Flame Front Dynamic Measurement: OH - PLIF (Planar Laser	V-flames	time synchronized, digitized images required for two laminar and two turbulent flames minimum to evaluate	MGFA desires CIR to provide this diagnostic hardware. PI Ground-based studies have been successfully done and hardware requirements might be derived from either of these systems. One	MGFA/CIR

MGFA Req't #	MGFA Sub-req't #	Subsystem/ Parameter	SRD origin of Req't	Requirement	Engineering Response	Respon-sible Org.
		Induced Fluorescence) imagery or Mie Scattering		turbulent flame front dynamics	item that is expected to be a challenge is the laser which might be a Nd:YAG laser (bigger volume and comparable power to the PIV laser). In addition, the PI has an alternate diagnostic that has been ground tested. It uses a Mie scattering technique to image the result of introducing a vegetable oil into the flame with an atomizer; oil contamination is a concern that needs to be addressed. The choice for diagnostic will be addressed at the V-flames SCR.	
8	20	By-products	PUFF	Gas analysis of combustion by-products desired; minimum components: CO, CO_2, O_2, N_2, NO_X, +/- 2% constituent	This should be within the capability of the CIR Gas Chromatograph system. Calibration gas may be required to maintain accuracy. Actual number of samples per run, testpoints to be examined and sample timing during test are TBD	CIR
9		**Acceleration Environment**				
9	1	Acceleration Levels	s-Flame	< 5 ug, every axis, < 25 ug-s over 5 s	PIMS Provided	CIR
9	2	Acceleration measurement	s-Flame	+/- 5 %	PIMS Provided	CIR
9	3	Acceleration environment	V-flames	3 - axis, in vicinity (no co-location requirement)	PIMS Provided	CIR
9	4	Acceleration	PUFF	maximum 100 ug, 0 - 25 Hz	PIMS Provided	CIR/ISS
9	5	Acceleration	PUFF	Range: 10 - 10000 ug accuracy: +/- 1 ug frequency: 0 - 25 Hz alignment: at least one axis with nozzle	CIR/ISS/PIMS (PI Microgravity Services) provided data, time stamped to allow cross reference	CIR/ISS
10		**Crew Involvement**				

MGFA Req't #	MGFA Sub-req't #	Subsystem/ Parameter	SRD origin of Req't	Requirement	Engineering Response	Respon-sible Org.
10	1	Crew involvement	MGFA	Design to minimize crew time.	Current planning for the operations of the MGFA intends to minimize crew interaction with the experiment, due to anticipated severe limitations on their availability. Planned activities are limited to EMS integration/deintegration, hardware set-up and/or replacement (camera installations, Mass Flow Controller replacement, etc.) and resource bottle replacement. All other functions will be automatic or ground commanded.	CIR/MGFA
11		**Uplink Capability**				
11	1	Commanding	MGFA	uplink of parameters required for every test	The ability to obtain command window time will be crutial to the experiments because many of them include parameters that can be reset during the performance of a test point. Although portions of every experiment will be automatic, the ability to uplink and downlink commands will be critical to the operation of the hardware and the quality of the Science data obtained.	CIR/MGFA
12		**Downlink Capability**				
12	1	Engineering/sensor data	s-Flame, FlmDes, V-flames, PUFF	downlink of all data required, before subsequent test	The implication for this data has to do with the monitoring and housekeeping data that is required for the safe operation of the experiment. Each experiment will have unique requirements that will be documented when the hardware and software become more flight-like.	CIR/MGFA
12	2	Imaging data	s-Flame, FlmDes, V-flames, PUFF	selected image downlink required, before subsequent test	Current downlink limitations will require Science to assess trade off betrween complete data and the expediting of the complete test matrix.	CIR/MGFA

3.3 MGFA Science Test Matrices

This section includes the current test matrices as taken from the latest SRD's.

3.3.1 S-flame Test Matrix

I. Primary Test Matrix (to meet the complete success criteria)

Exp. Set	Fuel Mixture	Range of x% fuel	x% fuel increment	Initial flow rate (cc/s)	Continuous additional flow rate (cc/s) and mixture	Spinning rate (RPM)	Runs per case	Total number of runs
1	x%H_2/10%CH_4/N_2	20 to 40	10	100	0 to 200 same mix	N/A	2	6
2	x%H_2/10%CH_4/N_2	20 to 40	10	150	0 to –130 same mix	N/A	2	6
3	x%H_2/N_2	20 to 50	10	100	0 to 200 same mix	N/A	2	8
4	x%H_2/N_2	20 to 50	10	150	0 to –130 same mix	N/A	2	8
5	x%CH_4/N_2	30 to 50	10	100	0 to 200 same mix	N/A	2	6
6	x%C_3H_8/N_2	20 to 30	10	100	0 to 200 same mix	N/A	2	4
7	40%H_2/10%CH_4/N_2	N/A	N/A	100	N/A	300 600 1000	2	6
8	50%H_2/N_2	N/A	N/A	150	N/A	300 600 1000	2	6
9	35%CH_4/N_2	N/A	N/A	100	N/A	300 600 1000	2	6
10	30%C_3H_8/N_2	N/A	N/A	100	N/A	300 600 1000	2	6
11	40%H_2/10%CH_4/N_2	N/A	N/A	150	0-100 N_2	N/A	2	2
12	40%H_2/10%CH_4/N_2	N/A	N/A	150	0-100 He	N/A	2	2
13	40%H_2/10%CH_4/N_2	N/A	N/A	150	0-100 CO_2	N/A	2	2
14	40%H_2/10%CH_4/N_2	N/A	N/A	150	0-10 O_2	N/A	2	2
								Total: 70

II. Secondary Test Matrix (to be conducted if time permits)

Exp.	Fuel Mixture	Range of	x% fuel	Initial flow	Continuous	Spinning	Runs	Total

Set		x% fuel	increment	rate (cc/s)	additional flow rate (cc/s) and mixture	rate (RPM)	per case	number of runs
15	x%C_2H_4/N_2	20 to 30	10	100	0 to 200 same mix	N/A	2	4
16	x%C_4H_{10}/N_2	20 to 30	10	100	0 to 200 same mix	N/A	2	4
17	30%C_2H_4/N_2	N/A	N/A	100	0 to 200 N_2	N/A	2	4
18	30%C_2H_4/N_2	N/A	N/A	150	0 to 10 O_2	N/A	2	4
19	30%C_4H_{10}/N_2	N/A	N/A	100	0 to 200 N_2	N/A	2	4
20	30%C_4H_{10}/N_2	N/A	N/A	100	0 to 10 O_2	N/A	2	4
21	30%C_2H_4/N_2	N/A	N/A	100	N/A	300 600 1000	2	6
22	30%C_4H_{10}/N_2	N/A	N/A	100	N/A	300 600 1000	2	6
								Total: 36

3.3.2 Flame Design Test Matrix

Test	Flame type	Temp (Y/N)	Ambient Y,reactant	Ramp [1]	Comments
1	D	N	0.08,C_2H_4	none	Identify quasi-steady state (Qs)
2	D	Y	0.08,C_2H_4	Increase m to extinction (ext)	Identify peak T as function of m
3	D	Y	0.08,C_2H_4	Decrease m to burner limit (bl)	Same as above
4	D	Y	0.08,C_2H_4	Increase m(N2) to ext.	Extinction limit
5	B	N	0.75,O_2	none	Identify Qs
6	B	Y	0.75,O_2	Increase m to ext.	
7	B	Y	0.75,O_2	Decrease m to bl	
8	B	N	0.75,O_2	Increase m(N2) to soot limit (sl).	
9	B	Y	0.75,O_2	Increase m(N2) to ext.	
10	A		0.23,O_2	none	Identify Qs
11	A		0.23,O_2	Increase m to ext.	
12	A		0.23,O_2	Decrease m to bl	
13	A		0.23,O_2	Increase m(N2) to soot limit (sl) and ext.	
14	A		0.23,O_2	Increase m(N2) to sl and reverse and ext.	
15	C		1.0, C_2H_4	Ignite with air fluent and quickly reduce m(N2) to sl and ext (R3)	
16	C		1.0, C_2H_4	Increase m(N2) to soot limit (sl)	
17	C		1.0, C_2H_4	Decrease m(N2) to sl	
18	C		1.0, C_2H_4	Re-ignite and ramp slowly (R1) to sl	
19	A,B		0.75 O_2	Increase m(N2) to soot limit (sl). [2]	
20	A,B		0.75 O_2	Increase m(N2) to ext.[2]	
21	A,B		0.65 O_2	Increase m(N2) to soot limit (sl). [2]	
22	A,B		0.65 O_2	Increase m(N2) to ext.[2]	
23	A,B		0.55 O_2	Increase m(N2) to soot limit (sl). [2]	
24	A,B		0.55 O_2	Increase m(N2) to ext.[2]	
25	A,B		0.45 O_2	Increase m(N2) to soot limit (sl). [2]	
26	A,B		0.45 O_2	Increase m(N2) to ext.[2]	
27	A,B		0.35 O_2	Increase m(N2) to soot limit (sl). [2]	
28	A,B		0.35 O_2	Increase m(N2) to ext.[2]	
Test	Flame type	Temp	Ambient	Ramp [1]	Comments

	type	(Y/N)	Y,reactant		
29	A,B		0.30 O_2	Increase m(N2) to soot limit (sl). [2]	
30	A,B		0.30 O_2	Increase m(N2) to ext.[2]	
31	A,B		0.25 O_2	Increase m(N2) to soot limit (sl). [2]	
32	A,B		0.25 O_2	Increase m(N2) to ext.[2]	
33	A,B		0.15 O_2	Increase m(N2) to soot limit (sl). [2]	
34	A,B		0.15 O_2	Increase m(N2) to ext.[2]	
35	C,D		1.0 C_2H_4	Increase m(N2) to soot limit (sl).	May not get soot limit. Important case!
36	C,D		1.0 C_2H_4	Increase m(N2) to ext.	
37	C,D		C_2H_4[3]	Increase m(N2) to soot limit (sl). [4]	Reduce X_{fuel} by 5% absolute
38	C,D			Increase m(N2) to ext.	Diluted fuel in ambient, (see above) [3]
39	C,D			Increase m(N2) to soot limit (sl). [4]	Continue experiments like 37 and 38 until fuel concentration is 5%.[3]
40	C,D			Increase m(N2) to ext.	Continue experiments like 37 and 38 until fuel concentration is 5%.[3]
41					Switch to methane and run tests 1-18

[1] Ramp rates:

R1: .2 mg/s^2; R2: .5 mg/s^2; R3: 2 mg/s^2

Ramp rate is R2 unless specified otherwise.

[2] Identify starting condition for fuel concentration from coarse plot of limits obtained from previous runs. Continue to refine plot with new data.

[3] Identify ambient fuel concentration from coarse plot obtained from previous runs. Continue to refine plot with new data.

[4] If coarse plot shows that soot limit has definitely been exceeded, skip this test and go to next (extinction limit

3.3.3 V-flames Test Matrix

The V-flames test matrix below includes 16 test points. Half the test points will focus on velocity data studies using the PIV diagnostic. The other half will focus on turbulent flame front dynamics studies using a scalar measurement. Two primary options for the scalar measurement have been tested in ground based studies: OH PLIF and Mie scattering which are mentioned in more detail in Section 2.3.

Flames	PIV	Scalar
CH_4/air turbulent 1	run 1	run 2
CH_4/air turbulent 2	run 3	run 4
C_3H_8/air laminar 1	run 5	run 6
C_3H_8/air laminar 2	run 7	run 8
CH_4/air laminar 1	run 9	run 10
CH_4/air laminar 2	run 11	run 12
C_3H_8/air turbulent 1	run 13	run 14
C_3H_8/air turbulent 2	run 15	run 16

3.3.4 PUFF Test Matrix

A test matrix will be defined, varying the three primary variables of core fuel velocity, pulsing frequency (0.1 – 100 Hz), and duty cycle (0.01 - 0.9 plus steady state). The Duty Cycle is the fraction of time that flow is "on" in a single pulse cycle, i.e., flow-on time divided by sum of flow-on and flow-off times. Secondary variables include the co-flow velocity, fuel type and dilution, and co-flow oxygen concentration. A basic test sequence (after hardware set-up) would consist of filler the chamber with air, starting data collection, initiating co-flow re-circulation and venting, starting the annular fuel flow and activating, then retracting, the ignitor, the starting the core nozzle fuel flow, with the desired input pulsations. Data collection intervals would occur between each step in the sequence.

Test Parameters

Primary variables	Range	Discrete Range	Primary Test Values
Fuel flow - core (slpm)	1 to 2	1 to 2 by tenths	1.0,1.2,1.4,1.6,1.8,2.0
Puffing frequency (Hz)	0 to 15	0,0.5,1,1.5,2,3,5,6,10,15	0, 0.5,1,2, 3, 6
Puffing duty cycle	0.1 to 0.9*	0.1-0.9 by tenths	0.1, 0.3, 0.5, 0.7, 0.9

* For "puffed" tests

Secondary variables
Co-flow velocity
Fuel type & dilution
Co-flow dilution

Preliminary Test Matrix for Complete Success
~50 points with parameters varying similar to the following:

Tests	description
3	steady, no puff tests for 3 core fuel flows
15	frequency of 0.5,1,2,3,6 at duty cycle of 0.5 (for example) for 3 fuel flows
36	duty cycle of 0.1,0.3,0.7,0.9 at 3 (of 5) frequencies and 3 fuel flow
54	total tests

4.0 MGFA PROJECT-BASED ENGINEERING REQUIREMENTS

This section is included to cover overall MGFA requirements that are derived or implied as part of the implementation of the engineering concept design to meet the science requirements. At this time, there are only general requirements.

4.1 Flight Hardware

MGFA shall provide all the flight hardware outlined in section 2.3 of this document. In addition, MGFA shall provide the required harnessing, mounting hardware and any special stowage accommodations. The flight hardware shall be designed to simultaneously meet Safety, ISS/FCF/CIR, and Science requirements in that order of priority.

4.2 Flight Software

The general requirements for MGFA flight software are analogous to flight hardware requirements. Unique flight software shall reside in the MGFA Avionics Package and may reside elsewhere if the need exists to supplement CIR provided image acquisition and storage. In general, MGFA flight software will control the experiment through interfaces to the EMS and to CIR subsystems including the FOMA and IOP.

4.3 Operations Concept

MGFA shall develop a detailed flight operations concept for each of the experiments in conjunction with the operations concept for CIR. Preliminary operations concepts are included in Section 6 of this document.

4.4 Ground Support Equipment

MGFA shall provide the necessary Ground Support Equipment (GSE) to develop the flight hardware and software, and to support risk mitigation activities such as low gravity testing. MGFA shall also provide the capability to mix flight gasses (as required) and fill CIR provided bottles that are compatible with the FOMA.

4.4 CIR Provided Hardware

The MGFA Team is responsible for obtaining the resources required from CIR and the ISS program. These resources will be negotiated on a case by case basis over the maturity of the project and will be documented in the MGFA /CIR ICD, once that document has been released.

5.0 MGFA SAFETY-BASED ENGINEERING REQUIREMENTS

This section specifies the preliminary Safety Requirements for the MGFA hardware, software and flight operations. A more formal and thorough safety assessment will be performed on the MGFA hardware, software and flight operations and the results will be contained within the MGFA/CIR ICD. This ERD draft addresses Flight Safety only.

5.1 Over-pressurization

MGFA is currently making provisions to include a secondary fuel bottle and supply system on its EMS that will be installed and operated from within the CIR chamber. MGFA will work closely with the CIR Safety group to design a system that will be compatible with the controls that prevent over pressurization due to detonation.

5.2 Flame Extinguishing

MGFA plans to extinguish the flames by turning off the flow of gasses.

5.3 Structural Integrity

The structural design shall provide ultimate factors of safety of TBD for STS phases and TBD for ISS phases. Verification of design shall be in compliance with NSTS 14046 for STS and SSP52005. Design shall meet the requirements of FCF-CIR-IDD.

5.4 Touch Temperatures

Structural hardware shall be designed to meet the criteria of NSTS 18798A letter, MA2-95-048, such that the crew will not be exposed to excessive high or low touch temperatures. The temperature range of -18 Celsius to +49 Celsius (0 Fahrenheit to 120 Fahrenheit) is the acceptable range for “bare skin contact”.

5.5 Sharp Edges

All systems shall be designed to meet the requirements of SSP 50005 for the removal of sharp corners, edges and protrusions.

5.6 Flammable Materials/Fluids Compatibility

Nonmetallic materials with “A” flammability ratings in their use thickness per MSFC-HDBk-527/JSC 09604, or the Materials and Processes Technical Information Systems (MAPTIS) database will be used to the maximum extent possible. All other nonmetallic materials will require evaluation per NSTS 22648. Test gases and byproducts shall be evaluated for compatibility with CIR hardware and materials, and the ISS vent line. Special consideration may be required to control the hazards associated with the proposed internal chamber oxygen concentration of 85% required for some test points.

5.7 Material Offgassing

Nonmetallic materials with “K” or “A” toxicology ratings per the MAPTIS database will be used to the maximum extent possible. An assembly level offgassing test will be used for final acceptance of each MGFA assembly, including the inserts and diagnostic elements.

5.8 Electrical Shock

Electrical shock requirements are TBD.

5.9 EMI

Electromagnetic Interference (EMI) requirements are defined in the CIR IDD.

5.10 Electrical Connectors Handled by the Crew

Circuits that are connected by the crew at connectors shall be designed to terminate in sockets.

5.11 Emergency Return and Landing

MGFA design and operations shall be designed to require no more than TBD seconds to power down and be made safe for emergency evacuation of the module. The CIR Project has the overall responsibility for this rapid safing requirement and MGFA will support CIR as required.

5.12 Rupture of Combustion Chamber during MGFA Operations

MGFA will rely on the CIR Project to demonstrate that the CIR chamber meets all the safety requirements. .

5.13 Release of Experiment By-products into the Cabin Atmosphere

MGFA will rely on the integrity of the CIR chamber and vent system to prevent release of by-products into the module during normal operations. Prior to chamber accesses following combustion testing, the by-products will be cleaned real-time with the CIR Exhaust Vent Package (EVP) to bring the byproducts to safe levels in terms of toxicity (and to remove water vapor as required). In some cases, the entire chamber volume may be evacuated and refilled with clean bottled gasses from the CIR FOMA system; this option has the major drawback of requiring MGFA to send more bottles up to the CIR and require more stowage space (and less space for test gasses).

5.14 Release of PIV Material

Some of the MGFA experiments plan to use a Particle Image Velocimetry diagnostic system. These particles must be assessed for toxicity and the CIR provided particle capture/exhaust system must show that particles will not be released into the crew cabin, nor cause a block in the vent line.

5.15 Laser Radiation

Both the PIV and the proposed PAH systems will require the use of a laser with a power rating that is in excess of that supplied by the Illumination Package. Although MGFA is assuming the responsibility for the design and the internal safety of these devices, a portion of the containment of this light and the verification of such will be the responsibility of the CIR. Both of these systems are planned for the –B phase of this project, and the system and its specifications are still under development however, at the time of this writing, the apparent power required is in excess of 100 mW.

6.0 MGFA OPERATIONAL SCENARIOS AND BLOCK DIAGRAMS

This section outlines the basic MGFA operational scenarios block diagrams for the major operations of each experiment. The operational scenario for each experiment will be provided first, followed by the Mechanical/Fluids, Optics, and Electrical Block Diagrams. These tools serve to map the science requirements into a set of operations and hardware design components. For this draft, more emphasis was placed on mapping out the Mechanical/Fluids operating modes.

6.1 s-Flame Operational Scenario

6.1.1 Operating Cycle for Tests

A) Pretest Set-up:
1) Make connections
2) Purge lines
3) Set up test parameters (flow control/pressure/mixture setting).

B) Cycle:
1) Fill chamber to 1 atm pressure with 21% O_2, 79% N_2.
2) Start fuel flow/ energize igniter/ retract igniter.
3) Burn last up to 5 minutes.
4) During the burn, the following will occur:
   i. Some tests will require changing the fuel flow rates during the burn.
   ii. Some tests will involve blending the fuel/diluent mixture while the flame is burning.
   iii. Some tests will require blending and changing the ratios of two different fuels.
   iv. A rainbow Schlieren system will be used to measure flame temperature and observe flame extinction.
5) Flame extinguished.
   i. Remove N2/02 mixture from the chamber.
   ii. Scrub out combustion products (water/CO2/NOX/CO).
   iii. Return N2/O2 to chamber.

6.1.2 Gasses required and Gas Supply Concept

Type	Compositions	Supply Source	Comments
Fuel	Hydrogen/Methane/Inert Hydrogen/Inert Methane/Inert Ethane/Inert Propane/Inert	CIR bottle with prime fuel and/or pre-mixed fuel; second fuel TBD	Ramping %fuel is difficult to control (don't want step function). MFC reaction time concern for accuracy needed.
Diluent or Inert	Nitrogen Argon Helium Carbon Dioxide (tbd)	CIR bottle or ISS Nitrogen with mixer on EMS	
Oxidizer	Oxygen/Nitrogen Oxygen/Argon (tbd)	CIR small bottle (85/15 O2/N2) + ISS Nitrogen OR CIR large air bottle	

6.1.3 Clean-up, Venting, and Gas Chromatograph Requirements

During the burn:

- Trace amounts of soot will form. Slight possibility windows may need to be cleaned after several cycles.

Pre and/or Post-combustion:

- Chamber volume scrubbed after pre-determined number of burns.
- Chamber is vented after several burns.
- Chamber will require routine cleaning after S-Flame experiment has been removed from the chamber.

6.1.4 Total Test Points

- 70 burn cycles planned.

6.1.5 Other notes on Operational Scenario

- Burner will be required to rotate (300-1200 rpm) during certain test points and produces a ‘pancake-like’ flame.

6.2 Flame Design Operational Scenario

6.2.1 Operating Cycle for Tests

– Pretest Set-up:
  7. Make connections
  8. Purge lines
  9. Set up test parameters (flow control/pressure/mixture settings)

B) Cycle:
  1) Fill chamber nitrogen/oxygen mixture.
  2) Energize igniter.
  3) Begin fuel flow.
  4) Flame starts/igniter retracts.
     i. During burn (generally 5 minute duration) the following may occur:
     ii. Optical measurement using thin filament fibers inserted into flame and recorded with HiBMS camera.
     iii. Some tests will require changing the fuel flow rates during the burn.
     iv. Most tests will involve blending the fuel/diluent mixture while the flame is burning.
  5) Flame extinguished.

6.6.1 Remove N2/02 mixture from the chamber.
6.6.2 Scrub out combustion products (water/CO2).
6.6.3 Return N2/O2 to chamber.

6.2.2 Gasses required and Gas Supply Concept

Type	**Compositions**	**Supply Source**	**Comments**
Fuel	Ethylene (for approximately 80% of the burns) Methane	CIR bottle with prime fuel and/or pre-mixed fuel; second fuel TBD	Ramping %fuel is difficult to control (don't want step function). MFC reaction time concern for accuracy needed.
Diluent or Inert	Nitrogen	ISS Nitrogen with mixer on EMS	
Oxidizer	Oxygen mixed with nitrogen	CIR small bottle (85/15 O2/N2) + ISS Nitrogen OR CIR large air bottle	Air replenishment during burn not possible with variable fuel concentration; 85% O2 bottle implies extra safety work

6.2.3 Clean-up, Venting, and Gas Chromatograph Requirements

During the burn:

- Not much soot is expected to form. If it does a procedure for cleaning it may be required.
- If soot deposits on windows then cleaning will be required.

Pre and/or Post-combustion:

- Chamber volume scrubbed after pre-determined number of burns.
- Chamber is vented after several burns.

- Chamber will require routine cleaning after Flame Design experiment has been removed from the chamber.

6.2.4 Total Test Points

- 60 test points (burns) planned for flight

6.2.5 Other notes on Operational Scenario

- Some test points will be chemically inverted – i.e. the chamber is filled with a fuel mixture and the burner has oxidizer/diluent flow.
- Fuels/oxidizers/diluent compositions will be the same for normal and inverted burns.
- Flame temperature will be measured using HiBMS camera.
- Thermocouple required to measure burner surface temperature.
- Thermocouple required to measure chamber gas temperature near the chamber walls.
- Camera/laser required to measure soot volume fraction.

6.3 V-flames Operational Scenario

6.3.1 Operating Cycle for Tests

A) PRETEST SETUP:

Burner (EMS) installed, fluid connections made, flow baffle/cooler in place, laser and optics ready, PIV seeder and/or aerosol generator ready, vent control system ready.

B) TEST CYCLE:

1) Fill chamber with GN2 to atmospheric pressure. (This is optional. The assumption is that pre-fill with GN2 improves the length of time we can run the fuel flow before safety constraints require us to stop, due to fuel concentration reaching danger level with no ignition.)
2) Bluff body heater on. (manual setpoint or computer control)
3) Air flow on. (computer control)
4) Methane fuel on. (computer control)
5) Exhaust pressure control on. (computer control)
6) Activate cameras and recording devices
7) Ignite, verify flame, and allow temperature to stabilize to steady state. (1-10 seconds)
8) Laser on, PIV camera on, seeder on (PIV or Aerosol for Mie Scattering) Take data for approx. 30 seconds to get valid velocity statistics. (computer control)
9) Everything off, cool down and setup for next point.

6.3.2 Gases required and Gas Supply Concept:

Type	Compositions	Supply Source	Comments
Fuel	Pure methane (CH_4) or propane (C_3H_8)	CIR bottle	Number of fuel bottles depends on test matrix. 0.014 l/sec to 0.066 l/sec flow range.
Oxidizer	Oxygen/Nitrogen (compressed air)	CIR large air bottle	0.29 l/sec to 0.63 l/sec flow range
Purge/ pre-test	Nitrogen	ISS GN2	Only if effective safety feature

6.3.3 Clean-up, Venting, and Gas Chromatograph Requirements:

During the burn:

Vent to maintain atmospheric pressure in chamber, no pressure rise due to heat or fuel/air flow. Very clean burning lean combustion.

Pre and/or Post-combustion:

At some point after a series of tests, or at the conclusion of experiment, cleanup of PIV particles from chamber will be needed.

6.3.4 Total Test Points:

8 test points for velocity data
8 test points for turbulent flame front dynamics

6.3.5 Other notes:

Predetermined setpoints, uniform turbulent flow 0.5 to 3 meter/sec velocity at the nozzle, fuel ratio from 0.6 to 1.0 stoichiometric combustion. Resulting flows are from 0.014 liters/sec methane + 0.29 liters/sec air to 0.07 methane + 0.63 air

PIV and flame front dynamics are two entities, and are not done simultaneous. PIV uses a particle seeder, and flame front dynamics requires an aerosol generator or PLIF laser measurement (see Section 3.2, requirement 8.19 for more information).

6.4 PUFF Operational Scenario

6.4.1 Operating Cycle for Tests

A) PRETEST SETUP:
- Make appropriate connections.
- Purge lines
- Set up the puffing frequency, duty cycle and flow rate.

B) A TYPICAL TEST CYCLE:

1) Fill chamber to:
   - 1 atmosphere
   - 20 – 40% O2, Balance N2
2) Start data acquisition.
3) Pause for approximately 30 seconds to acquire no-flow baseline data.
4) Start fuel flow, co-flow, and ignitor.
5) Start PIV as required.
   - Turn laser, cameras, and seeder (when required) on.
6) Collect data for 30-60 seconds.
7) Stop fuel flow, co-flow, and ignitor.
8) Shut – down.
9) Scrub the contents, readjust chamber environment:
   - Bleed in O2.
   - Vent excess pressure.

6.4.2 Gases required and Gas Supply Concept:

Type	Compositions	Supply Source	Comments
Fuel	Gaseous hydrocarbon fuel, potentially diluted with nitrogen(up to 50%) Ethylene (likely candidate).	CIR bottle with prime fuel and/or pre-mixed fuel; TBD.	• 0.0 – 4.3 slpm. • Mixture composition within TBD (e.g., +/-0.01) of specified volume fraction. • TBD minimum purity (e.g.,99.9%) • Gas shall be completely vaporized, i.e., liquid droplets not acceptable.
Diluent	Nitrogen	ISS Nitrogen with mixer on EMS TBD.	
Oxidizer	Oxygen/Nitrogen (compressed air)	CIR bottle TBD.	• O2/N2 mixture of TBD composition(s) (e.g.,0.2 to 0.4 O2 volume fraction.) • Mixture composition within TBD (e.g.,+/-0.005 of specified volume fraction • Gas shall be completely vaporized, i.e., liquid droplets not acceptable.

			• TBD minimum purity (e.g.,99.9%) • Flow rate, TBD.

6.4.3 Clean-up, Venting, and Gas Chromatograph Requirements:

During the burn:

- Continuous venting is preferred.
- For emissions measurements, we require gas chromatography during the burn.

Pre and/or Post-combustion:

- PIV cleanup as required.
- Chamber volume scrubbed / oxidizer added after TBD number of burns.
- Chamber is vented after TBD number of burns.

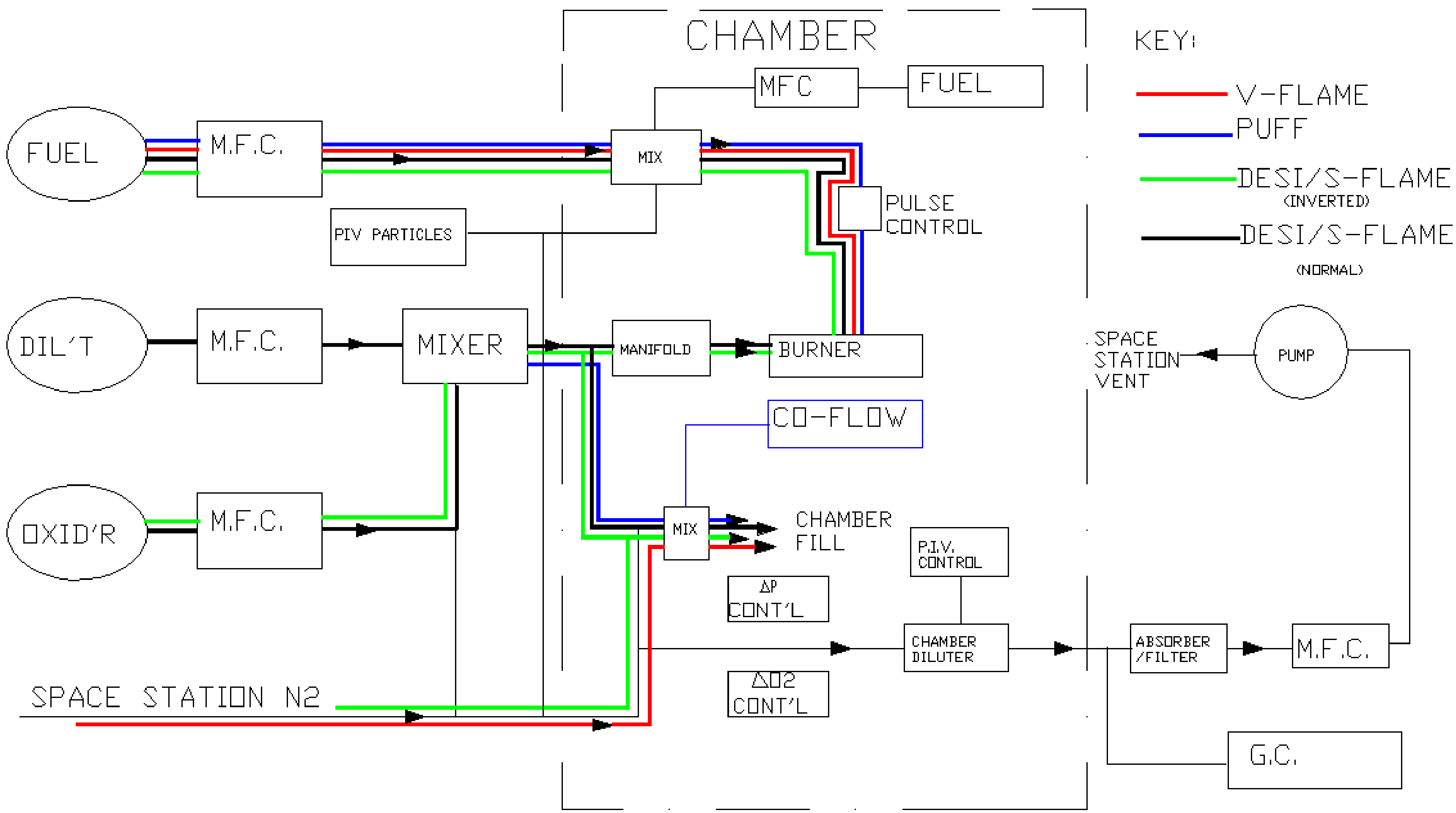
6.4.4 Total Test Points:

- 50 test points planned for flight.

6.4.5 Other notes:

- Fuel flow control will be accomplished via pulse valve controller.
- FOMA mass flow controllers disabled open.
- FUEL
    - Injection time 2-2000 milliseconds.
    - Rectangular wave valve closes fully between pulses.
    - Each pulse volume must be known.
- PIV seeding in oxidizer co-flow.

6.5 Mechanical/Fluids Block Diagram

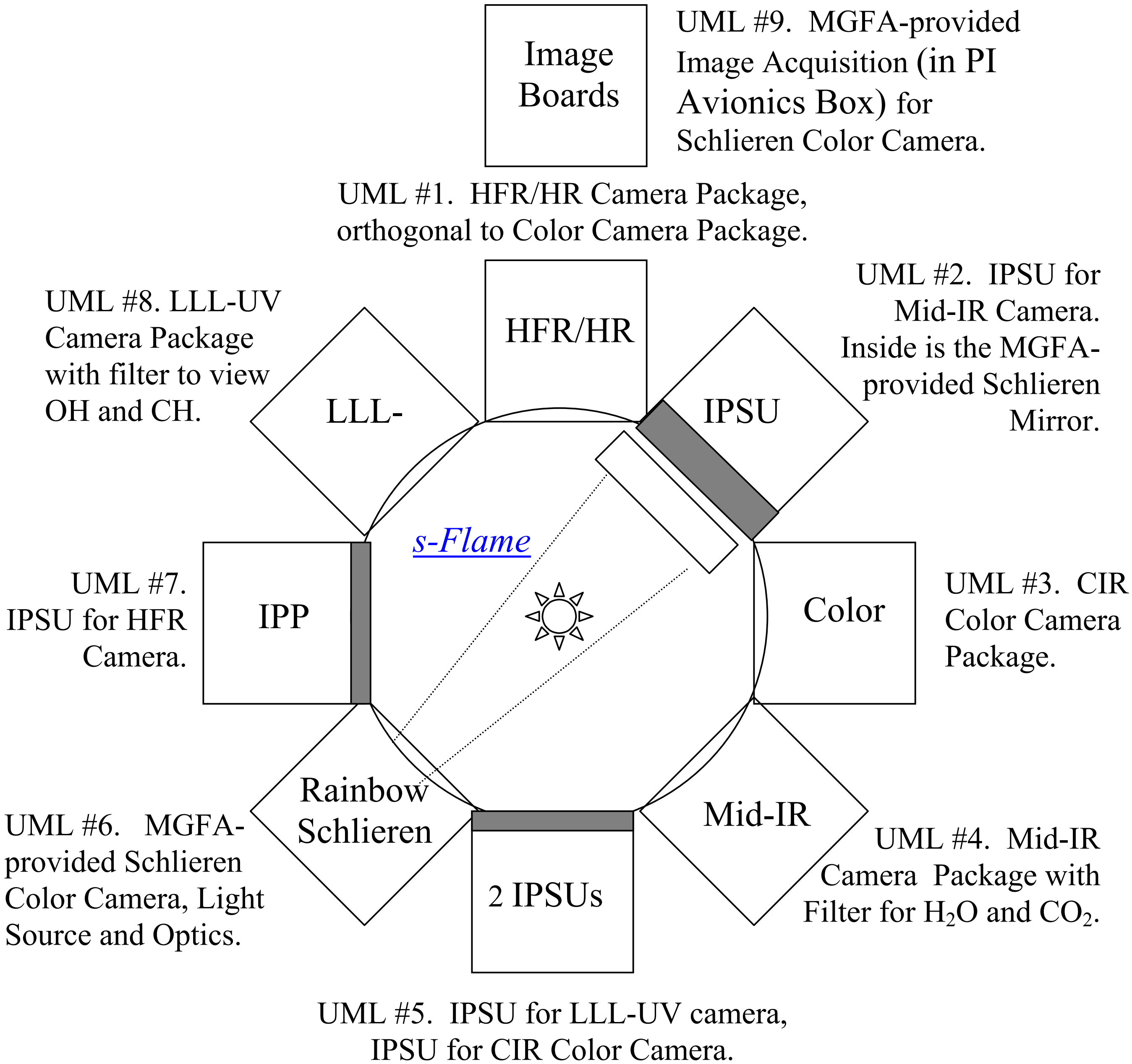


6.6 MGFA Diagnostic Summary and Optical Block Diagrams

The following table is a summary of the current MGFA diagnostics requirements. Each diagnostic hardware element is listed by the Science Requirement Matrix number from Section 3.2. Desirements are shown in parentheses and a requirement number of 8.0 means that the requirement has been stated, but not yet added to the current SRD. The total number of cameras, the number of IPP's/IPSU's, and the total UML's required (not including the PI Box in UML #9) is summarized. The MGFA provided cameras (PIV, Rainbow Schlieren, and possibly Mie) are assumed to require unique PI acquisition system in the PI Avionics Box. For more detailed information on each experiment, refer to the Optical Block Diagrams that follow.

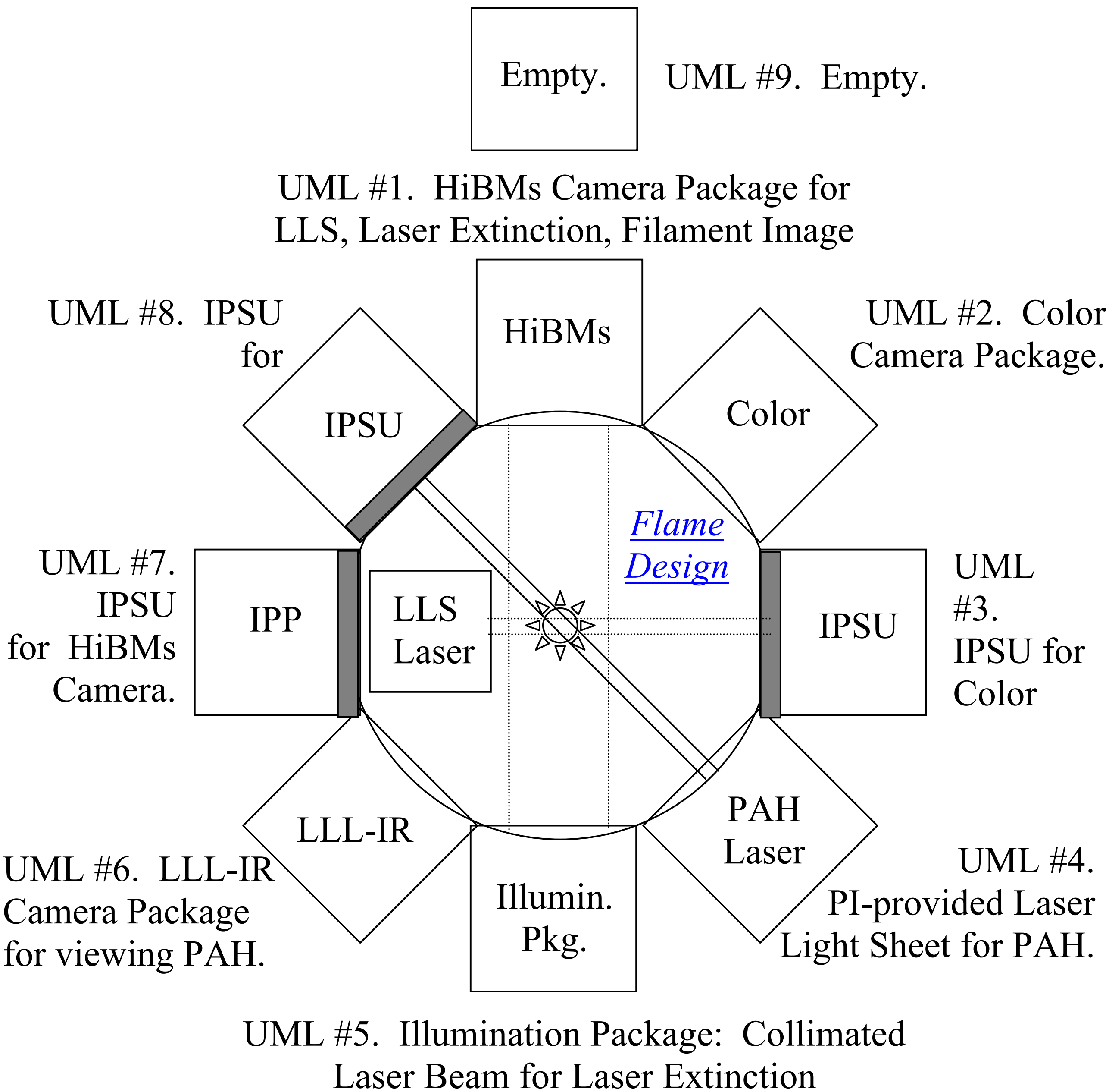
Diagnostic	s-Flame	Flame Design	V-Flames	PUFF
Color Camera	8.1	8.2	8.0	8.3
HiBMs		8.8/8.13		
HFR/HR	8.7			8.3
LLL-UV	8.10		8.19 - PLIF	8.11
LLL-IR		(8.14)		
Mid-IR	8.9			(8.0)
Illumination Package		8.13		
Rainbow Schlieren Color Camera & Illumination (MGFA)	8.12			
PAH - Laser		(8.14)		
PIV Camera (MGFA)			8.15	8.18
PIV Laser			8.15	8.18
PLIF/Mie Camera (IR?)			8.19 - Mie	
PLIF/Mie Laser			8.19	
Total Cameras	5	2 (3)	3	4 (5)
IPP's/IPSU's	3	2 (3)	1	2
Other UML Items (illumination/laser)	0	1	2	1
Total UML Slots Needed	8	5 (7)	6	7 (8)

6.6.1 Optical Block Diagram for s-Flame



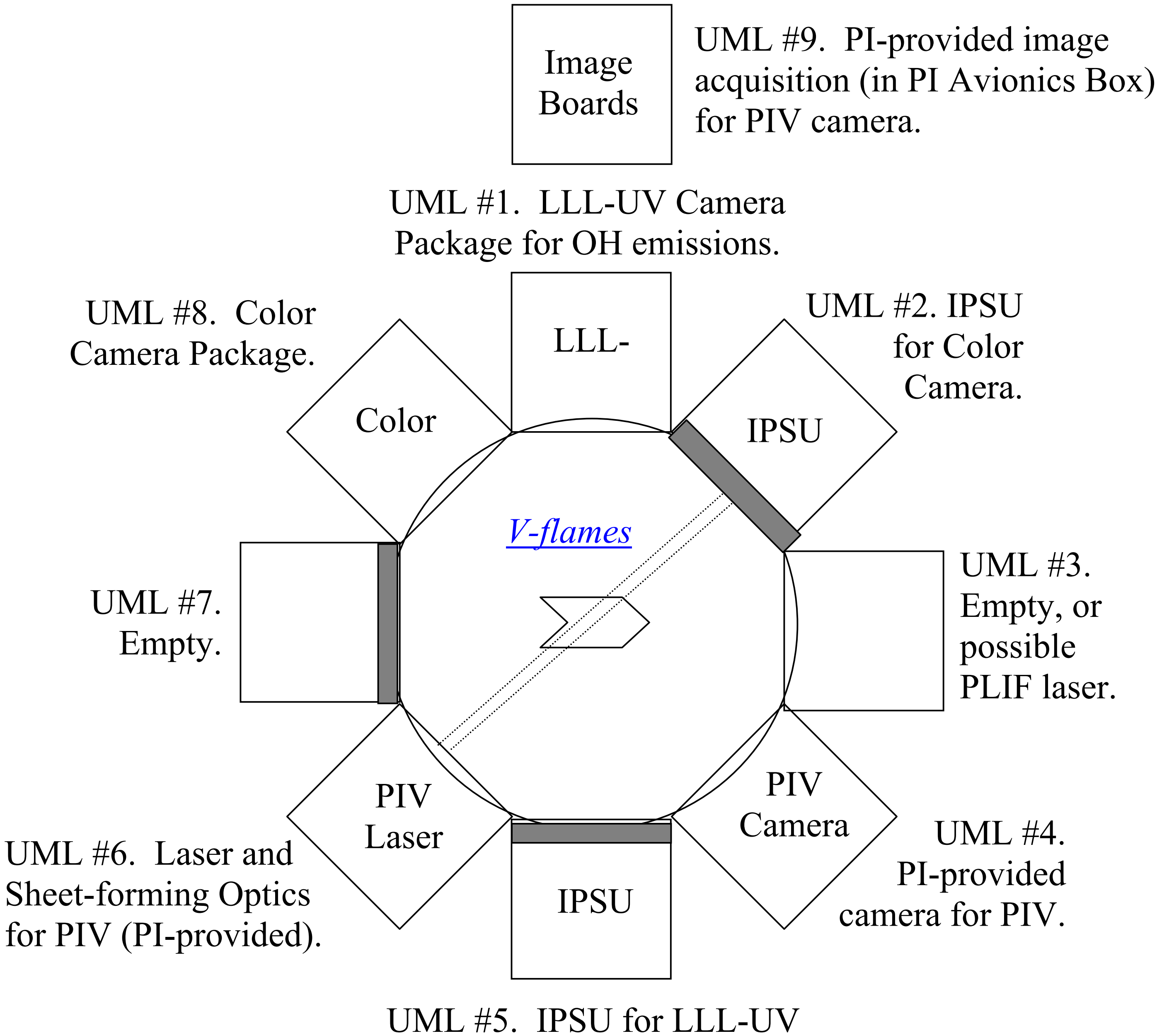
Acronyms:
- HFR/HR = High Frame Rate, High Resolution
- IPP = Image Processing Package
- IPSU = Image Processing and Storage Unit
- LLL-UV = Low Light Level UV
- UML = Universal Mounting Location

6.6.2 Optical Block Diagram for Flame Design



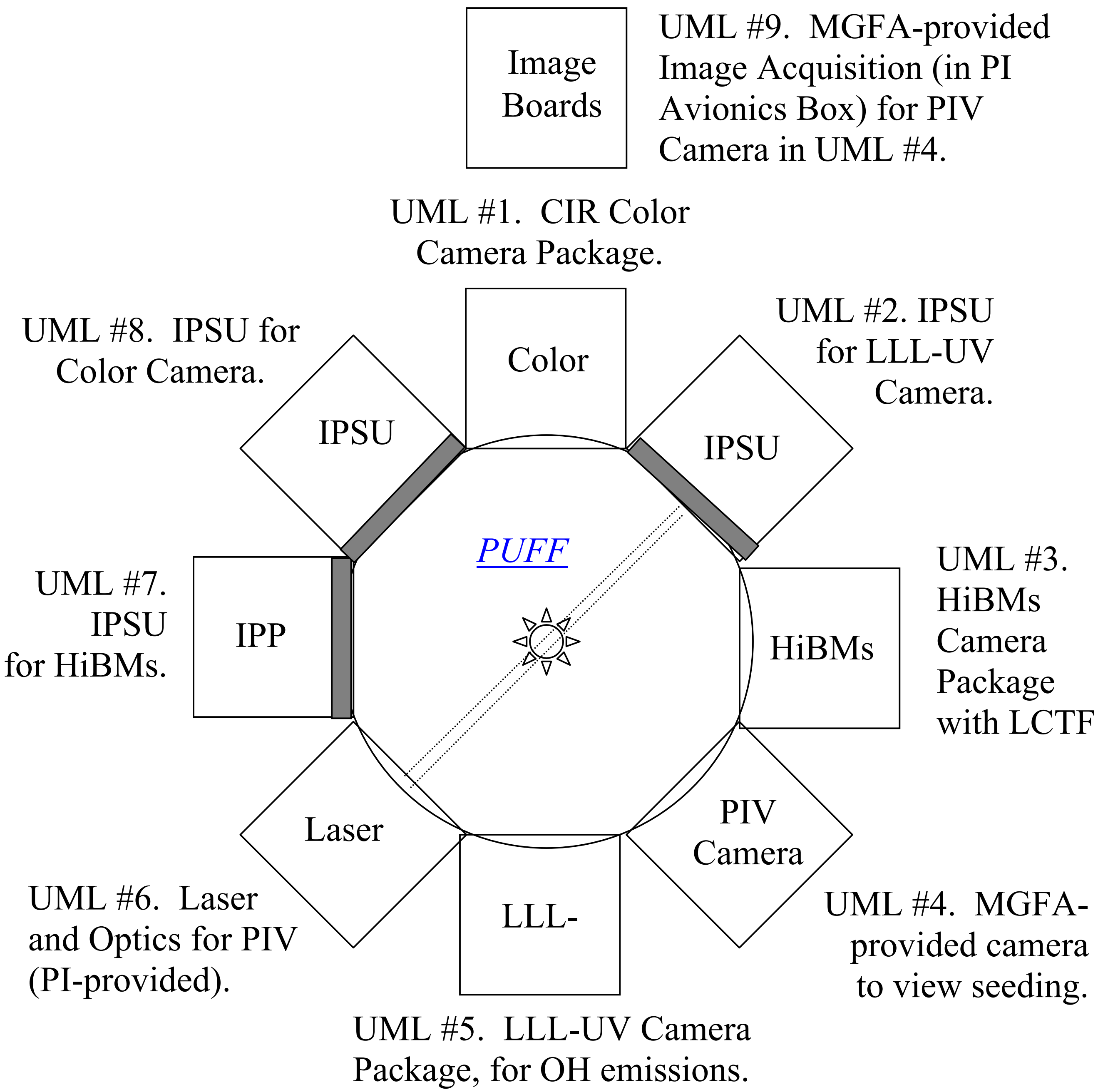
Acronyms:
- HiBMs = High Bit-depth, Multi-spectral
- IPP = Image Processing Package
- LLS = Laser Light Scattering
- PAH = Polycyclic Aromatic Hydrocarbons

6.6.3 Optical Block Diagram for V-flames



Acronyms:
IPSU = Image Processing and Storage Unit
LLL-UV = Low Light Level UV
PIV = Particle Imaging Velocimetry
UML = Universal Mounting Location

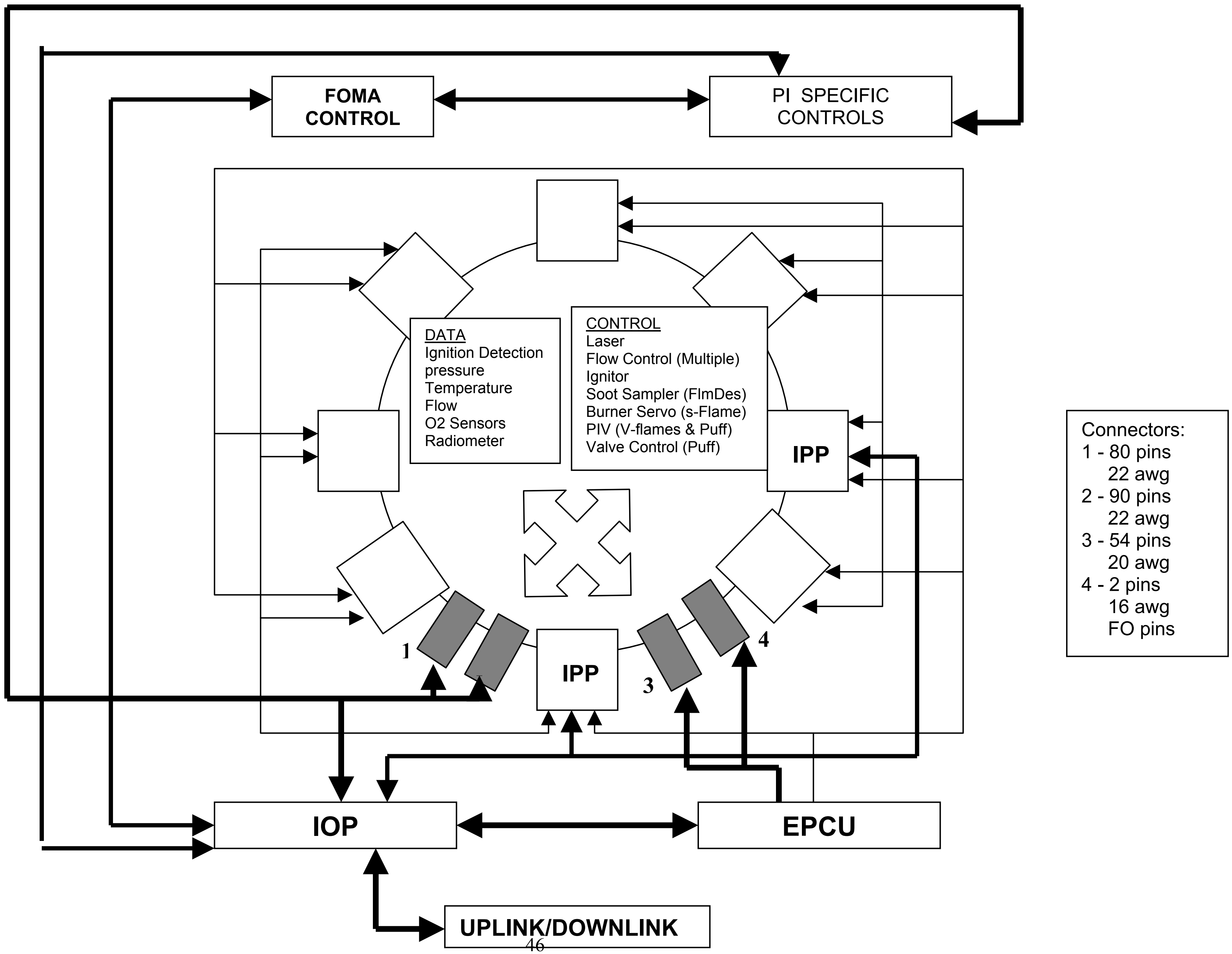
6.6.4 Optical Block Diagram for PUFF



Acronyms:
HiBMs = High Bit-depth, Multi-spectral
IPP = Image Processing Package
LCTF = Liquid Crystal Tunable Filter
LLL-UV = Low Light Level UV
PIV = Particle Imaging Velocimetry

6.7 Electrical Block Diagram

6.7 Electrical Block Diagram



7.0 CRITICAL CIR ACCOMMODATIONS

Given that the ICD between CIR and MGFA has not been drafted, the MGFA team has identified three areas that will require special consideration by CIR: Fluids Control/Capabilities, Diagnostics, and Resources. This section of the document includes a preliminary summary of the key CIR capabilities that will be required to meet the Science, Operations and Safety requirements for MGFA, as documented in sections 3-6. The initial draft of the ICD will make this section obsolete and it will be deleted at that time.

7.1 Fluids Control and Capabilities

The following is a generalized listing of some of the extreme limits for the fluids handling capabilities that are required by MGFA for phases A and B (as taken from Section 3 of this document). These extreme limits may be issues for the baseline CIR design that is based on the Science Requirements Envelope Document (SRED). The list is sorted by the MGFA Team's current understanding of which items may be most difficult to accommodate. If a Review Item Discrepancy (RID) was submitted during the FCF PDR, that is also noted.

#	CIR Fluids System Accommodation Needed	Origin of Req't	Difficulty (H/M/L)/ FCF PDR RID#	Status/Notes
1	Accommodation of fuel flow total volumes in excess of limits imposed by adiabatic combustion calculations, through the use of MGFA provided flame verification system (or other TBD Safety control) appended to the CIR timers	SRM items 3.1, 3.3	H/#281	Based on the flow rates and burn times, the current safety timer system is proposed to be replaced/augmented by PI provided safety controls.
2	Chamber fills ranging from 0 – 100% fuel, balance ISS supplied N_2 for inverse combustion (O_2 through burner)	SRM item 3.32	H/#282	There are no timers on the O_2 flow system; PI provided safety controls might be implemented.
3	Flow rates to MGFA burners: Pure Fuel: 5–150 sccs (0.3 to 9.0 slpm) Fuel/ISS N2: 10–300 sccs (0.6 – 18 slpm) Air (V-flames): 290-630 sccs (17.4–37.8 slpm)	SRM items 3.3, 3.20, 3.21	H (related to #281)	CIR has replaceable mass flow controllers, so physical accommodation exists. Need to make sure analytical accommodation is provided, especially for Safety assessments. Note: Need to take into consideration conversion of slpm from N_2 to given fluid.
4	Ability to replace the fuel supply bottle when empty without a total power down of the system and the discarding of the gas mixture residing in the chamber	Operations	M-H (related to #281)	The current fuel line safety timer design also causes a significant loss of air resources and the time to evacuate and refill the chamber.
5	Accommodation of PIV particles (2 – 10 micron diameter) released into chamber	SRM items 5.1 – 5.4	M-H (CIR PDR RID)	In general based on a CIR PDR RID, the chamber clean-up criteria, procedures, etc. need to be determined.
6	Vent up to 85% O2 from chamber	SRM item 2.15	M	The chamber environment needs to diluted with N2 before venting.
7	Oxygen/Diluent replenishment during the performance of the combustion experiment Maintenance of chamber pressure to within 5% of original setpoint during the performance of the combustion experiment. This will require dynamic blending or other flow dilution methodology of the oxygen-enriched atmosphere for s-Flame, V-flames and PUFF test points.	SRM items 2.1, 2.2, 2.4	M	CIR should be able to accommodate this in the future.
8	Controlled continuous venting to maintain pressure within tolerance bands specified in the Science Requirements Matrix for s-Flame, PUFF and V-flames	SRM items 2.1, 2.2, 2.4	M	CIR should be able to accommodate this in the future.
9	Chamber fills utilizing MGFA supplied O_2 , in percentages ranging from 20 – 85% and the balance being ISS supplied N_2; mixed to +/- 1% constituent and filled to +/- 1% of the setpoint pressure, verified by GC analysis.	SRM Section 2 (chamber environ.) and 8.20 for GC	L-M	CIR should be able to accommodate.
10	Vacuum resource required to purge insert fuel systems for sample purity.	SRM Section 3.	M	MGFA needs quick disconnect to allow direct access to vacuum resource.

7.2 Diagnostic Equipment

This is a generalized listing of the optical equipment that will be required from CIR for each of the experiments taken from the information in section 6. In addition to providing all the equipment, there may be some special considerations required for the data management and accommodation of MGFA unique diagnostics in addition to the CIR provided diagnostics. For example, for 3 out of 4 experiments, there may not be adequate space to accommodate the IPP's and IPSU's required for the total number of CIR and MGFA provided cameras and a possible PI provided image acquisition capability is shown in the optics layouts of section 6. The following is a draft listing of CIR provided optical diagnostics by experiment:

s-Flame: Mid-IR Camera Package with filter wheel (may not be available with initial CIR)
LLL-UV Camera Package
CIR Color Camera Package (three-chip)
HFR/HR Camera Package
3 – IPSU's
1 – IPP

Flame Design: HiBMs Camera
LLL-IR Camera Package
Illumination Package
2 - CIR Color Camera Package (three-chip)
3 – IPSU's
1 – IPP

PUFF: HiBMs Camera with LCTF
LLL-UV Camera Package
2 - CIR Color Camera Package (three-chip)
4 – IPSU's
1 – IPP

V-flames: LLL-UV Camera Package
CIR Color Camera Package (three-chip)
3 – IPSU's

7.3 MGFA Resource Summary Table

In this table, critical high level MGFA resources are summarized. Other documents (to be created) such as the MGFA mass properties report and the CIR/MGFA ICD shall include more details. Assessments of these resources are currently in work and are planned to be available for the next formal revision to the ERD.

Resource Item	s-Flame	Flame Design	Total Increment A	V-flames	PUFF	Total Increment B
Up-Mass						
Insert	TBD	TBD	TBD	TBD	TBD	TBD
PI Avionics Box	TBD	TBD	TBD	TBD	TBD	TBD
Bottles (incl. quantity/type)	TBD	TBD	TBD	TBD	TBD	TBD
Other PI Hardware (diagnostics, fluids, etc.)	TBD	TBD	TBD	TBD	TBD	TBD
Operations						
Crew Time	TBD	TBD	TBD	TBD	TBD	TBD
Total Ops Time	TBD	TBD	TBD	TBD	TBD	TBD
Power	TBD	TBD	TBD	TBD	TBD	TBD
Data Downlink	TBD	TBD	TBD	TBD	TBD	TBD
Other Resources/Notes						

8.0 ACRONYMS AND ABBREVIATIONS

Acronym/Abbreviation	Name
CIR	Combustion Integrated Rack
EMS	Experiment Mounting Structure (chamber insert)
EPCU	Electrical Power Control Unit (CIR)
ERD	Engineering Requirements Document
FCF	Fluids and Combustion Facility
FD (or FlmDes)	Flame Design Experiment
FOMA	Fuel and Oxidizer Management Assembly (CIR)
GRC	Glenn Research Center
HFR/HR	High Frame Rate/High Resolution Camera (CIR)
HiBMs	High Bit-depth, Multi-spectral Camera (CIR)
ICD	Interface Control Document
IOP	Input/Output Processor (CIR)
IPP	Image Processing Packages (CIR)
IPSU	Image Processing and Storage Units (CIR)
ISS	International Space Station
LCTF	Liquid Crystal Tunable Filter
LLL-IR	Low Light Level Infrared Camera (CIR)
LLL-UV	Low Light Level Ultraviolet Camera (CIR)
LLS	Laser Light Scattering
MGFA	Multi-user Gaseous Fuels Apparatus
MSD	Microgravity Science Division
PAH	Polycyclic Aromatic Hydrocarbons (PI)
PI	Principal Investigator
PIV	Particle Imaging Velocimetry
PLIF	Planar Laser Induced Fluorescence
PUFF	PUlsed-Fully Flames Experiment
s-Flame	Structure and Response of Spherical Diffusion Flames Experiment
SRD	Science Requirements Document
TBD	To be determined
Tbs	To be supplied
UML	Universal Mounting Location (CIR)
V-flames	Field Effects of Gravity on Lean Premixed Turbulent Flame