NASA
National Aeronautics and
Space Administration

November 15, 1999

NRA-99-HEDS-04

RESEARCH ANNOUNCEMENT

Microgravity Combustion Science: Research and Flight Experiment Opportunities

Letters of Intent Due: .... **January 5, 2000**

Proposals Due: ……………. **February 15, 2000**

OMB Approval No. 2700-0042

MICROGRAVITY COMBUSTION SCIENCE:
RESEARCH AND FLIGHT
EXPERIMENT OPPORTUNITIES

NASA Research Announcement
Soliciting Research Proposals
for the Period Ending
February 15, 2000

NRA-99-HEDS-04
Issued: November 15, 1999

Office of Life and Microgravity Sciences and Applications
Human Exploration and Development of Space (HEDS) Enterprise
National Aeronautics and Space Administration
Washington, DC 20546-0001

NASA RESEARCH ANNOUNCEMENT
MICROGRAVITY COMBUSTION SCIENCE:
RESEARCH AND FLIGHT EXPERIMENT OPPORTUNITIES

TABLE OF CONTENTS

NASA RESEARCH ANNOUNCEMENT

MICROGRAVITY COMBUSTION SCIENCE: RESEARCH AND FLIGHT OPPORTUNITIES

This NASA Research Announcement (NRA) solicits proposals for flight experiments and for ground-based experimental and theoretical microgravity research in combustion science. The combustion science discipline represents a broad range of research areas including but not limited to gaseous flames (premixed and non-premixed), droplet, particle, spray, and dust flames, ignition and flamespread over liquid and solid fuel surfaces, smoldering combustion, and combustion synthesis. **Please note in Appendix A, significant changes in this announcement relative to previous Microgravity Combustion Science NRA's.** Further descriptions of the microgravity combustion science research activities and interests are given in Appendix B.

Investigations selected for flight experiment definition must successfully complete a number of subsequent development steps, including NASA and external peer reviews of the proposed flight experiment, in order to be considered for a flight assignment. NASA does not guarantee that any investigation selected for definition will advance to flight experiment status. Investigations selected for support as ground-based research under the Microgravity Research Division (MRD) ground-based research program generally must propose again to a future solicitation in order to be selected for a flight opportunity.

Participation is open to U. S. and foreign investigators and to all categories of organizations: industry, educational institutions, other nonprofit organizations, NASA centers, and other U. S. Government agencies. **Though NASA welcomes proposals from non-U.S. investigators, NASA does not fund Principal Investigators at non-U.S. institutions.** Proposals may be submitted at any time during the period ending February 15, 2000. (Late proposals will be considered if it is in the best interest of the Government.) Proposals will be evaluated by science peer reviews and engineering feasibility reviews.

Appendices A-D provide technical and program information applicable only to this NRA. Appendix E contains general guidelines for the preparation of proposals solicited by a NRA.

This Announcement will not comprise the only invitation to submit a proposal to NASA for access to the reduced-gravity environment and is part of a planned sequence of solicitations inviting proposals in the various disciplines of the microgravity program.

NASA Research Announcement Identifier: NRA-99-HEDS-04

NRA Release Date:	**November 15, 1999**
Letters of Intent Due:	**January 5, 2000**
Proposals Due:	**February 15, 2000**
Selection Announcement	**September, 2000**

This NRA is available electronically from and Letters of Intent can be submitted electronically via the Microgravity Research Division Web Page at:

http://microgravity.hq.nasa.gov/

Alternatively, Letters of Intent may be submitted via e-mail to the following address:

loi@hq.nasa.gov

If electronic means are not available, you may mail Letters of Intent to the address given below. Proposals are to be submitted to the following address:

Dr. Merrill K. King
c/o Indyne, Inc.
Subject: NASA Research Proposal (NRA-99-HEDS-04)
300 D Street SW, Suite 801
Washington, DC 20024
Telephone for delivery services: (202) 479-2609

NASA cannot receive deliveries on Saturdays, Sundays, or federal holidays.

Proposal copies required: …………..15

Proposers will be notified by electronic mail confirming receipt of proposal approximately 10 working days after the proposal due date.

Obtain Programmatic Information about this NRA from:

Dr. Merrill K. King
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Obtain additional reference information at the following address:

Mr. Thomas J. Sutliff
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Selecting Official:

Director
Microgravity Research Division
Office of Life and Microgravity Sciences
and Applications
NASA Headquarters

Your interest and cooperation in participating in this effort are appreciated.

Dr. Arnauld E. Nicogossian
Associate Administrator for
Life and Microgravity Sciences and Applications

APPENDIX A
NRA-99-HEDS-04

SIGNIFICANT CHANGES FROM PREVIOUS MICROGRAVITY COMBUSTION SCIENCE ANNOUNCEMENTS

- As part of the proposal, the proposer must, in addition to filling out the forms for costs for which the institution is to be reimbursed, also use Form E and the accompanying instructions to arrive at an estimated dollar value for Government Furnished Equipment and Services (GFE). This information is needed by the Glenn Research Center to enable accurate predictions of their annual budgets.

- For potential flight programs, we anticipate little or no access to the Space Shuttle in the time period appropriate to programs that will be funded from this NRA. The available orbital facilities will be limited to the Combustion Integrated Rack (CIR) and the Microgravity Science Glovebox (MSG), both on the International Space Station (ISS). In addition, there may be a very limited number of Sounding Rocket flights available for conduct of limited-duration flight experiments. (See Appendix C for description of these facilities.) The proposer should make every effort to ensure that his/her flight experiment can be conducted either in the MSG or in one of the three multi-user inserts currently planned for development for use in the CIR since the overall experiment development costs, used in calculating anticipated cost/benefit ratios for proposed experiments will be considerably higher for experiments “outside the envelope.” (Again, see Appendix C for more detail regarding the planned multi-user inserts.)

- Included in Appendix B-III is a description/listing of extra requirements on the part of the PI and his/her institution associated with flight experiments to help in the generation of more realistic budget estimates by the proposer.

- The proposer is required to indicate on Form B whether the proposal is for a flight experiment or for ground-based research. It should be noted, however, that a proposal for a flight experiment will also be considered for inclusion in the ground-based program if the proposed work or a significant portion of it can produce significant results in such a venue.

- In the event that the proposer is conducting related work for another U.S. government agency, he/she must show how the proposed work differs from that being performed for the other agency.

- Proposed plans for education and/or public outreach activities are now included in the evaluation criteria. (See Appendix B, Section VIII-B, Evaluation factors.)

APPENDIX B
NRA-99-HEDS-04

TECHNICAL DESCRIPTION

MICROGRAVITY COMBUSTION SCIENCE: RESEARCH AND FLIGHT EXPERIMENT OPPORTUNITIES

I. INTRODUCTION

A. BACKGROUND

The Human Exploration and Development of Space (HEDS) Enterprise, one of four National Aeronautics and Space Administration (NASA) strategic enterprises, conducts a program of basic and applied research using the reduced-gravity environment to improve the understanding of fundamental physical, chemical, and biological processes. The scope of the program, sponsored by the Microgravity Research Division (MRD), ranges from applied research into the effects of low gravity on the processing of various materials, to basic research that uses low gravity to create test conditions to probe the fundamental behavior of matter. This announcement is part of an ongoing effort to develop research in a single specific scientific discipline, Microgravity Combustion Science. The Division last released a NASA Research Announcement (NRA) for Microgravity Combustion Science in 1997 and expects to continue to release NRA's in this discipline approximately every two years.

NASA has supported research in Microgravity Combustion Science for over two decades. This extensive research program supports theoretical and experimental investigations in ground-based laboratories. Also, many investigations are conducted using combustion research apparatus built to take advantage of the limited low gravity test times available in ground-based facilities such as the drop-towers at the NASA Glenn Research Center, or NASA's Parabolic Low Gravity Flight research aircraft. These ground-based experiments, along with theoretical modeling, form the basis for most of our current understanding of the effects of gravity on combustion processes and phenomena.

In the MRD program, ground-based research has been used to gain a preliminary understanding of phenomena, and to define experiments to be conducted in the extended low gravity test times available in spacecraft in low-Earth orbit. MRD is developing multiple instruments for conduct of combustion research offering improved control and diagnostic capabilities relative to earlier experiments. These instruments are configured to investigate phenomena such as gaseous flames (premixed and diffusion), individual droplet and particle combustion, flame propagation in sprays and dusts, flame spread across solid and liquid surfaces, smoldering combustion, and combustion synthesis of novel materials. MRD also anticipates limited near-term flight opportunities for investigations capable of making use of existing hardware where no or minor modifications would be required.

MRD is currently preparing for flight opportunities using International Space Station research hardware, including development of modular research instruments that can be configured (or reconfigured) to accommodate multiple experiments and multiple users. This is envisioned as an evolutionary program with the objectives of providing experimental data in response to increasingly sophisticated science requirements and of permitting the evolution of experimental approaches and technologies as needed for scientific investigations throughout the era of the International Space Station. This announcement is being released as part of a coordinated series of discipline-directed solicitations intended to span the range of the MRD program. Other MRD-supported solicitations planned for periodic release over the next several years encompass the areas of biotechnology, fluid physics, fundamental physics, and materials science.

B. RESEARCH ANNOUNCEMENT OBJECTIVES

The combustion science program seeks a coordinated research effort involving both space- and ground-based research. Ground-based research forms the foundation of this program, providing the necessary experimental and theoretical frameworks for development of rigorous understanding of basic combustion phenomena. This research can eventually mature to the point where it becomes the focus of a well-defined flight experiment. This NRA has the objective of broadening and enhancing the MRD microgravity combustion science program through the solicitation of:

1. Experimental studies which require the space environment to test clearly posed hypotheses, using existing or slightly modified instruments in space-based experiments to increase the understanding of combustion;

2. Experiment concepts which will define and utilize new instruments for space-based experiments in combustion science with emphasis on research concepts that can be accommodated by small simple instruments; and

3. Ground-based theoretical and experimental studies which will lead to the definition or enhance the understanding of existing or potential flight experiments in combustion science, with emphasis on research leading to technologies required by future human space missions.

Further programmatic objectives of this NRA include goals broadly emphasized by the civil space program, including: the advancement of economically significant technologies; technology infusion into the private sector; and enhancement of the diversity of participation in the space program, along with several objectives of specific importance to the microgravity science and applications program. These latter objectives include the support of investigators in early stages of their careers, with the purpose of developing a community of established researchers for the International Space Station and other missions in the next 10-20 years, and the pursuit of microgravity research that shows promise of contributing to economically significant advances in technology.

In support of the HEDS Enterprise goal to “Enrich life on Earth through people living and working in Space,” individuals participating in the MRD Program are encouraged to help foster the development of a scientifically informed and aware public. The MRD Program represents an opportunity for NASA to enhance and broaden the public’s understanding and appreciation of the value of research in the microgravity environment of Space. Therefore, all participants in this NRA are strongly encouraged to promote general scientific literacy and public understanding of the microgravity environment and microgravity combustion science through formal and/or informal education opportunities. Where appropriate, supported investigators will be required to produce, in collaboration with NASA, a plan for communicating to the public the value and importance of their work.

C. DESCRIPTION OF THE ANNOUNCEMENT

With this NRA, NASA is soliciting proposals to conduct research in microgravity combustion science, including experimental efforts sufficiently mature to justify near-term flight development. The goals of the discipline along with several research areas of interest are described in Section II. Proposals describing innovative low-gravity combustion science research beyond that described there are also sought.

NASA is in the process of developing several types of multi-user flight hardware for microgravity combustion science research. Brief descriptions of the planned capabilities are given in Appendix C. NASA anticipates future flight opportunities for investigations with requirements that can be met by existing apparatus with only minor modifications. Successful proposals for use of the existing apparatus will be funded for advanced definition studies leading to a detailed Science Requirements Document (SRD). Authorization to proceed into flight development is contingent upon successful peer review of the experiment and SRD by science and engineering panels. NASA does not guarantee that any experiment selected for definition that plans to use existing hardware will advance to flight experiment status.

Though researchers should not feel limited by these capabilities, it must be emphasized that experiments calling for equipment significantly outside these envelopes will involve considerably higher expense to NASA, a factor that must be taken into consideration in funding decisions. Selected proposals requiring development of new capabilities "outside the envelope", will be funded for flight definition studies to define flight experiment parameters and conditions and the appropriate flight hardware. The length of the definition phase will be based on the experiment requirements, but will normally range from 6 to 24 months and will culminate in the preparation of an SRD and successful conduct of a Science Concept Review (SCR).

Authorization to proceed into flight development is contingent upon successful peer review of the SRD by both science and engineering panels at a Requirements Definition Review (RDR). NASA does not guarantee that any experiment selected for flight definition that requires new instrument development will advance to flight experiment status. Investigations that do not proceed into flight development will normally be required to submit a proposal for continuation of support at the conclusion of a typical four-year period of funding.

Promising proposals that are not mature enough to allow development of a flight concept within two years of definition may be selected for support in the MRD Research and Analysis (R&A) Program. Investigations selected into the R&A program must generally propose again to a future announcement in order to be selected for a flight opportunity.

II. MICROGRAVITY COMBUSTION SCIENCE RESEARCH

A. PROGRAM OVERVIEW

Combustion is of particular importance to NASA exploration missions in terms of fire safety, particularly as regards materials selection leading to minimization of risk of ignition and flame spread over these materials. Included in this area is development of better approaches to producing more-fire-retardant materials. In addition, development of sensors which will identify fire initiation in minimum time and of procedures for optimal extinction of such fires once they are detected are of major importance to space platform safety. NASA is also vitally interested in combustion in terms of handing of propellants for future space transportation systems and in development of combustion systems to be used in reduced gravity environments such as those encountered on the moon or on Mars. While there is considerable emphasis in NASA's fire safety efforts toward space applications, the importance of extending the results of these studies to Earth-based applications is also recognized.

Combustion is a key element of many critical technologies used by contemporary society. For example, electric power production, home heating, surface and air transportation, space propulsion, and materials synthesis all utilize combustion as a source of energy. Yet, although combustion technology is vital to our standard of living, it poses great challenges to maintaining a habitable environment. For example, pollutants, atmospheric change and global warming, unwanted fires and explosions, and the incineration of hazardous wastes are major problem areas that would benefit from improved understanding of combustion. Listed below are a number of scientific and technological questions of major current interest in the combustion community:

How can a quantitative predictive understanding of turbulent combustion, with its inherent interactions of multiple disparate temporal and spatial scales, be developed?

What are the gas-reaction, pyrolysis, and devolatilization kinetics for various hydrocarbon-fuel/oxidizer combinations and how can they be predicted or extrapolated? What controls soot formation, agglomeration, and oxidation in combustion processes?

What mechanisms control flammability limits and what controls detonations and instabilities?

How can the influences of a variety of transport phenomena, including thermophoresis, preferential diffusion, and electrical or magnetic field effects, on combustion be understood and quantified?

What factors control material ignitability, smolder, flame spread, and extinction? How do smolder waves transition to flames? How do flames propagate and fires grow? How can they be inhibited?

How do chemical kinetics and fluid dynamics couple? What occurs in and controls boundary-layer interactions, acoustic-reaction feedbacks, and development of coherent structures in flames?

How can we make continued progress toward controlling generation and emission of pollutants from combustion processes in a cost-effective manner?

How can we modify fossil fuel combustion systems to make greater use of alternative fuels while maintaining or even improving efficiency, pollutant control, safety, and reliability?

How can fire and explosion control processes provide improved protection without contributing to destruction of high-altitude ozone?

How can combustion technology help enable safe, economical destruction of hazardous wastes?

How can we utilize combustion processes to synthesize useful types and amounts of high-value materials such as fullerenes, nanotubes, carbon black, silica, and ceramic/metallic composite materials?

How can we improve combustion technologies for advanced ground, air, and space propulsion systems?

Effects of gravitational forces impede combustion studies more than most other areas of scientific study since combustion involves production of high-temperature gases whose low-density results in buoyant motion, vastly complicating the execution and interpretation of experiments. Effects of buoyancy are so ubiquitous that their enormous negative impact on the rational development of combustion science is generally not recognized. Buoyant motion also triggers the onset of turbulence, yielding complicating unsteady effects. Finally, gravity forces cause particles and droplets to settle, inhibiting deconvoluted studies of heterogeneous flames important to furnace, incineration and power generation technologies. Thus, effects of buoyancy have seriously limited our capabilities to carry out “clean” experiments needed for fundamental understanding of flame phenomena. Combustion scientists can use microgravity to simplify the study of many combustion processes, allowing fresh insights into important problems via a deeper understanding of elemental phenomena also found in Earth-based combustion processes and to additionally provide valuable information concerning how fires behave in microgravity and how fire safety on spacecraft can be enhanced. Several topic areas in the field of combustion which have been the subject of recent microgravity research emphasis include:

Turbulence and Combustion. Virtually all practical combustion devices involve turbulent flows; the wide range of turbulence length and time scales present generally precludes exact numerical simulation and also presents a significant challenge to experimental investigations. Microgravity uniquely limits the range of length and time scales to those large enough to be tractable experimentally and more readily simulated. Preliminary μg experiments reveal that buoyancy plays a role in the turbulence characteristics in regimes where it had been previously assumed that the flow field and flame behavior were independent of gravitational influence. One particularly powerful approach for treating the coupling between fluid motion and combustion chemistry based on studies of laminar flames is currently under development; this approach, referred to as laminar flamelet theory, shows promise as a tractable representation of turbulent combustion. The extension of laminar flamelet theories to predict fully turbulent flames cannot presently be exploited, however, due to limitations of our current knowledge base caused by the buoyancy-induced interferences occurring during laminar flame studies. Microgravity combustion studies provide an opportunity to eliminate these interferences and, thus, markedly advance our capability to address turbulent combustion phenomena.

Gaseous Flames. A major portion of the microgravity combustion program involves the study of gaseous flames including diffusion flames, premixed flames, partially premixed flames, edge flames, flame-vortex interactions, sooting in gaseous flames, effects of electric fields on flames, and flame suppression. Of growing interest are transient processes in gaseous flames. Numerous types of instabilities are possible in combustion of flowing gases, some being gravity-dependent and others being gravity-independent. Such phenomena as ignition, extinction, and unsteady response of flames to externally imposed perturbations (e.g., pressure oscillations) are of major importance as regards fire safety, production of pollutants, and combustion efficiency. Research studies in a microgravity environment provide for examination of fundamental phenomena involved in these transient phenomena without the confounding effects of buoyancy-induced flows which will, under normal gravity conditions, also respond in an unsteady manner to such imposed perturbations, often masking fundamental phenomena of interest. With understanding of these phenomena, strategies for controlling ignition, extinction, and responses of flames to externally imposed perturbations in practical combustion devices can better be devised.

Soot Processes. Soot is a critical element in many combustion systems, strongly affecting combustor lifetime, efficiency, peak power output, and pollution generation. The short time scales and small spatial volumes affecting soot formation and destruction processes under normal gravity conditions preclude experimental probing. Furthermore, buoyancy accelerates, in an uncontrolled fashion, the flow field in which soot is formed and oxidized; this too inhibits scientific investigations. Microgravity offers a unique opportunity for controlling the flow environment and through this control extending the range of germane experimental conditions that can be studied. The lack of buoyantly-induced, accelerated flow results in longer residence times for primary soot formation, clustering, cluster-cluster agglomeration, and oxidation in a variety of flames. In addition, soot particle pathlines are strongly altered under microgravity conditions, resulting in major changes in the environmental history seen by the soot precursors and particles. From the perspective of practical benefit, the fundamental understanding of the processes controlling soot formation, aggregation, and oxidation is of vital importance since such understanding would allow us to develop methods to predict and control sooting associated with combustion processes under a wide variety of circumstances.

Measurement (Species, Velocity, Temperature) Technology. A historic (and valid) criticism of microgravity experimental research is lack of quantification of meaningful variables (e.g., species concentrations). Advancement in understanding of chemical kinetic mechanisms is inhibited by an inability to measure progress of reactions and to quantify the detailed temperature and flow fields in which those reactions take place. Improved measurement methods in both normal gravity and microgravity are a growing focus of terrestrial research. Technological improvements in measurement capabilities will lead directly to improved kinetic and flow field modeling leading to enhanced capability for design of combustors with reduced pollutant generation and improved fuel efficiency. Spin-offs of these technologies can and are being used not only in laboratories distant from the inventor's own, but also in the monitoring of pollutant emissions from various sources. In the future these technologies will be used to evaluate fuel consumption, product generation, heat transfer efficiency, and pollutant control in manufacturing processes, and to serve as in-situ engine performance and emission levels monitors. The resulting combination of diagnostic sensors and computational algorithms will allow electronic controls to play a larger part in practical combustion systems, enabling so-called "intelligent combustors".

Droplet/Particle Combustion at High Pressures. Microgravity is of particular benefit in studies of particle and liquid droplet ignition and combustion inasmuch as it permits elimination of settling effects and of buoyancy-induced flows around the droplets, thus leading to truly symmetrical (and hence one-dimensional) geometry and allowing droplets to be restrained within the field-of-view of various diagnostics. Currently, high-pressure (including the supercritical regime) operation of combustion devices is being examined for increased efficiency. Unfortunately, pollutant (e.g., soot and oxides of nitrogen) generation increases with increasing pressure; hence military and NASA aeropropulsion research is heavily populated with studies aimed at realization of the theoretical efficiency improvements with simultaneous minimization of pollutants. Another application of this technology is in the area of hazardous waste disposal: supercritical water oxidation of hazardous wastes has been predicted as an important technology of the future, hopefully yielding only benign products (carbon dioxide and water). Much of our detailed knowledge in the area of combustion of droplets and particles has been obtained at low pressure; extension of studies to high pressure is required. For example, soot studies have mostly been performed near ambient pressures with flame temperatures of less than 2000K; diesel engines operate at over 50 atmospheres and 2800K. Much of our knowledge of soot kinetics may not be applicable to these high temperature, high pressure regimes. High pressure operation is accompanied by increased buoyant flow effects; microgravity experiments will enable, as in other situations, an isolation of the effects of the buoyancy on flame structure, flammability limits, and flame speeds.

Classical Model Validation/Benchmark Data. Combustion textbooks are replete with theories that are incompletely tested though widely accepted (through historical precedent). These theories often neglect buoyancy effects and assume simplified transport processes; moreover, one-dimensional behavior is often assumed in situations where buoyant effects preclude such one-dimensionality. Microgravity continues to offer the unique ability to test, via ideal truly one-dimensional experiments, the accuracy of specific aspects of theories and to provide a benchmark database against which extensions to existing theories and altogether new theories can be tested. At this time, the Microgravity Combustion Science Discipline Working Group (external advisory group) is working with NASA personnel to develop a list of "fundamental data sets" needed for better understanding of basic combustion processes, testing of combustion models, and design of improved practical combustion devices. Included in this effort is an attempt to prioritize the resulting list in terms of both utility and need for microgravity in filling out the data sets, both in terms of model testing and subsequent use of models in combustor design/optimization. Categories of data sets being considered include: Physico-Chemical Constants (e.g., thermal and mass diffusivity at high temperature and pressure of various species including combustion intermediates); Fundamental Combustion Parameters which are not System/Device Dependent (e.g., laminar burning velocities, extinction strain rates, soot inception points, Markstein lengths); Classical Well-Defined Benchmark Systems for Model Validation and Calibration (e.g., flame spread rates, Burke-Schumann flame shapes); and, Emerging Topics (e.g., Spacecraft fire safety, SHS, Flame-synthesized materials).

Flame Structure and Elementary Mechanisms. A fruitful approach to achieving meaningful technology gains in combustion processes must be centered on development of better understanding of the fundamentals of the unit processes involved. Without such an understanding, approaches taken to improving combustion devices tend to involve incremental trial-and-error perturbations around current state-of-the-art designs, with opportunities to achieve possible major improvements with radically different approaches being missed. However, if one fully understands the physics and chemistry involved in a given combustion process, including detailed understanding of the unit subprocesses and how they interact, this understanding can be combined into physically accurate models which can then be used for parametric exploration of new combustion domains via computer simulation, with possible definition of radically different approaches to accomplishment of various combustion goals. Accordingly, emphasis needs to be placed on studies of combustion fundamentals which are not currently well understood; gravitational effects associated with normal earthbound combustion studies have prevented study of many elementary processes which tend to be overshadowed by gravitation-induced processes such as buoyancy or settling.

Direct Numerical Simulation and Large Eddy Simulation. DNS and LES analyses are being widely pursued for definition of detailed features of the flame structure and transport processes (and their interactions) associated with combustion. Due to the large range of length and time scales, however, direct numerical simulation of practical or even idealized devices is considered to be, at best, a technology of the future. DNS modeling to date has, however, shown the need to account for preferential mass diffusion even in turbulent flame environments. Microgravity experiments again lessen the range of scales and may make problems tractable at least for model validation of laboratory-scale experiments, a first step toward DNS validation. DNS is expected to ultimately play a major role in the design of practical combustion systems and obviate the need for the expensive construction and modification of a wide range of breadboards, prototypes, and experimental models of combustion devices; it may also be used for optimization of design elements, subsystems, controls, and overall system performance at reduced cost/time.

Spray and Aerosol Combustion. Realistic sprays include a liquid breakup region, dispersed multiphase flow, turbulent mixing processes, and various levels of flame interactions throughout the spray. Idealization of spray configurations in a quiescent environment (the starting point for models) has been impossible in 1g due to settling of large droplets and buoyant pluming of post-combustion gases. Microgravity offers the promise of such idealization, but has just begun to provide experimental data on ignition, fire spread, and interactions in idealized linear and planar arrays of monosized droplets. Spray and aerosol cloud combustion accounts for 25% of the world's energy use, yet remains poorly understood from both a fundamental and practical perspective. Improved understanding of the flammability and flame interactions of sprays can be expected to yield improved combustion efficiency in practical devices, but this will only occur with an improved detailed theoretical description. In the area of combustion safety, dust clouds contribute to accidental fires and explosions (grain elevators, underground mines). Finally, improved spray technology can be applied to improvements in hazardous waste incineration.

Combustion Synthesis. The use of flames to synthesize materials is expanding rapidly. Products include valuable vapors (e.g. acetylene), ultrafine particles (fullerenes, silicon oxides, titanium oxides), coatings (diamonds), monolithic solids (boron carbide, titanium boride), and nanotubes. Fullerene production is being investigated extensively, but the product yields of fullerenes are currently typically less than 5%, leaving tremendous potential for improvement. Sedimentation and buoyant plumes yielding limited critical residence times again interfere with present investigations into both the scientific mechanisms of material production and the quality of the actual industrial product. For example, pressure and buoyancy effects on soot-filled flames are not understood sufficiently to determine the ideal operating conditions to maximize fullerene generation in either premixed or diffusion flames. Microgravity offers the promise of isolating the effects of pressure by removing the influence of buoyancy on the material production process. A major difficulty in self-propagating, high-temperature synthesis (SHS) of materials is the control of porosity and the microstructure of the products. SHS reactions generating gaseous, liquid, or combined phases are prone to gravity-induced fluid flows, leading to non-uniform microstructure and undesirable properties of the product material due to segregation and density gradient effects. Gravitational forces have been shown to play a dominant role in controlling both the combustion-synthesis reactions and the morphologies of the synthesis products. Current research is geared towards interpreting the differences between normal- and low-gravity processing.

Partial Gravity Studies. The utilization of partial gravity environments enables systematic scientific testing of effects of this parameter on fundamental processes as well as tying directly to the nation's desire for space exploration. Both the Moon and Mars are in NASA's future; microgravity and normal gravity studies have already shown that combustion processes are distinctly affected by reductions in gravity, with a conclusion that the partial gravitational levels on the Moon and Mars may yield increased flammability. In addition, partial gravity environments may have strong effects on in-situ propellant production processes as well as on utilization of these products.

Surface Flame Spread. Anyone who has observed the combustion of solid fuels, particularly flame spread across and burning of vertical walls, is well aware of the dominant effects of buoyancy on such processes under normal gravity conditions, a dominance which makes understanding of other phenomena involved very difficult (an example of how buoyancy can "mask" such phenomena). Accordingly, microgravity studies of flame spread across solid fuels and liquid pools are of considerable interest from a fundamental point of view as well as being very important in terms of fire safety on various space platforms. On Earth, the fluid mechanics of large-scale fires are complicated by buoyancy-fed turbulent processes and thermal radiation interactions with surrounding materials, terrain, and building structure. Current models are still somewhat primitive, with little elucidation of the role of thermal radiation in almost any aspect of fires. Investigations of large-scale fires under microgravity conditions have yet to begin, but it has been shown that radiation takes on heightened importance in small-scale fires in microgravity, indicating that results from laboratory-scale experiments in microgravity might be utilized in modeling of large-scale fires. In terms of NASA's own direct interests, ongoing investigations of material flammability and fire behavior in microgravity have yielded vital guidance to improved fire safety aboard orbiting spacecraft. There does remain, however, a need for normal-gravity versus microgravity correlations of ignition, flame spread, flammability, and extinction conditions.

The research categories listed above are not meant to be all-inclusive; proposals which do not fall into any of these areas are encouraged. In the future, as discussed further later in this Appendix, the Microgravity Research Division also plans to support fundamental research and enabling technologies associated with space studies, recognizing the need of supporting a vigorous theoretical and experimental ground-based program which supports space research and from which new ideas for space research can grow.

Studies of combustion phenomena, particularly in terms of opportunities for combustion research in space, can be considered according to their fundamental science and to anticipated consequences of greatly diminished gravitational effects. Much research in microgravity combustion science can be discussed within this conceptual structure: (1) how gravity, when eliminated or greatly reduced, results in elucidating effects otherwise masked, (2) the role of gravity as an additional independent parameter in model validation, and (3) how combustion systems perform in extraterrestrial environments.

B. CURRENT PROGRAM SCOPE

As stated in NASA's Microgravity Research Program Strategic Management Handbook, the Microgravity Research Program mission is "To use the microgravity environment of space as a tool to advance knowledge; to use space as a laboratory to explore the nature of physical phenomena, contributing to progress in science and technology on Earth; and to study the role of gravity in technological processes, building a scientific foundation for understanding the consequences of gravitational environments beyond Earth's boundaries." For accomplishment of this mission, both a ground-based program and a flight experiments program are employed; in addition, development of facilities, diagnostic tools, and experiment modules for conduct of multiple experiments is supported. The ground-based program has two major objectives: (1) nurturing and development of ideas and concepts that may be later developed into flight experiments; and, (2) providing theoretical and experimental underpinnings to support understanding of phenomena being studied in a microgravity environment. Ground-based investigations include theoretical and experimental laboratory research, drop-tower tests, and parabolic aircraft flight experiments. In the flight program, experiments judged to justify use of the flight environment are developed and executed. These experiments are conducted in microgravity environments provided by suborbital sounding rockets, the Space Shuttle mid-deck or isolated cargo bay support structures, the Shuttle-based Spacelab or Spacehab pressurized laboratory facilities, International Space Station (ISS) facilities, and other available carriers. **It should be noted, however, that future opportunities are anticipated to be mainly limited to the ISS.**

In April 1997, (STS-83) and July 1997, (STS-94), a major suite of microgravity combustion experiments were carried out. These included the Structure of Flame Balls at Low Lewis Numbers (SOFBALL) experiments, the Laminar Soot Processes (LSP) experiments, the Droplet Combustion Experiment (DCE) series, and the Fiber-Supported droplet Combustion (FSDC-2) series. (The first three of these series were carried out in major facilities, while the last was performed in the Shuttle Middeck Glovebox.).

In addition to the flight experiments on MSL-1, a large number of other microgravity combustion experiments have been and are being carried out in various flight facilities. These facilities include middeck locker facilities (such as the Combustion Module used on MSL-1 for the SOFBALL and LSP experiments, Get Away Special Cannisters (GASCANS), in which fully automated experiments with relatively simple diagnostics are carried out, a Middeck Glovebox Faciltiy, and Sounding Rockets. The Middeck Glovebox (MGBX) facility is an enclosed volume that provides physical isolation of various small-scale experiments from the middeck and enables crew member manipulation of these experiments through gloveports and occupies two standard lockers in the space shuttle middeck. The overall philosophy of the Glovebox program is to provide the ability to conduct smaller, less complex science experiments or technology demonstrations in a microgravity environment in a faster, better, and cheaper manner. The Sounding Rockets used to date are Black Brant/Terrier combinations providing approximately 6 minutes of high quality microgravity time; these have been employed on two sets of microgravity combustion projects.

Combustion flight experiments covering numerous categories of combustion processes have been carried out to date, with others still in the development stage. Included in the area of gaseous flames, are the LSP experiment mentioned earlier, multiple studies of candle flames, a study of Transitional/Turbulent Gas Jet Diffusion Flames (TGDF), investigation of Enclosed Laminar Flames (ELF), and a Smoke Point in Coflow Experiment (SPICE). In the area of liquid droplet combustion are the DCE investigation, the Bi-Component Droplet Combustion Experiment (BCDCE), and the FSDC experiment. In addition, the spread of flames across liquid surfaces (SAL) is being studied using Sounding Rocket experiments. Numerous studies of ignition and flamespread across solid surfaces have been and are being carried out: these include the Solid Surface Combustion Experiment (SSCE), the Wire Insulation Flammability (WIF) study, a study of Diffusive and Radiative Transport in Fires (DARTFire), also carried out using Sounding Rockets, the Forced Flow Flame Spread Test (FFFT) series, the Radiative Ignition and Transition to Spread Investigation (RITSI), and the Opposed-Flow Flame Spread on Cylindrical Surfaces (OFFS) Glovebox Investigation. Additionally, in a closely related area, two investigations of smoldering combustion (Smoldering Combustion in Microgravity (SCM)) and Microgravity Smoldering Combustion (MSC) have been (and are still being) carried out using GASCAN facilities. Finally, another Glovebox Facility program aimed at characterizing smoke detector response under microgravity conditions (Comparative Soot Diagnostics (CSD)) has been carried out, while still another glovebox program entitled Front Interaction with Vortex Experiment (FIVE) is under development.

Besides these experiments, which have been completed, are in progress, or will be flown shortly, there are eleven other sets of microgravity combustion flight studies in the early development phases, five in the area of gaseous combustion (Cool Flames, Fully-Modulated Turbulent Diffusion Flames, Lean Premixed Turbulent Flames, Spherical Diffusion Flames, Flame Design: A Novel Way to Clean Efficient Diffusion Flames), two in the area of droplet combustion (Droplet Extinction by Slow Convective Flows, Sooting and Radiation Effects in Droplet Combustion), and four more in the area of ignition/combustion of solid fuel surfaces (Diffusion Flame Tip Instability, Flammability Diagrams, Transport and Chemistry Effects on Flame Spread over Surfaces, Flame Characteristics and Flammability Limits of Solids at Zero and Very Low Convective Velocities).

Flight investigators in the NASA Microgravity Combustion Program often need to conduct reduced gravity experiments in ground-based facilities during the experiment definition and technology development phases; in addition, the duration of microgravity time available in ground-based facilities is adequate for many investigations. (Given the difference in cost, it is important that investigations be carried out in ground-based facilities where feasible.) The NASA ground-based reduced gravity research facilities include two drop towers at Glenn Research Center (GRC) and an aircraft capable of providing low gravity operation for times of up to 20-25 seconds (via parabolic trajectories); this aircraft is based at JSC but is available for campaigns out of GRC. In addition, NASA has made arrangements to use a Japanese dropshaft facility in Hokkaido capable of providing 10 seconds of quality microgravity time.

One Drop Tower at GRC provides 2.2 second of low-gravity test time for experiment packages consisting of up to 125 kilograms of hardware. Eight to twelve tests can be performed in one day with data from experiments being acquired by high speed motion picture cameras with rates up to 1,000 frames per second and by on-board data acquisition systems used to record data supplied by thermocouples, pressure transducers, and flow meters. A second drop tube at GRC, evacuated by a series of pumpdown procedures to a final pressure of 1 Pascal, has a 132-meter free fall distance, providing 5.18 seconds of high quality microgravity. Experiments utilizing hardware weighing up to 450 kilograms are mounted in a one-meter diameter by 3.4-meter high drop bus with gravitational acceleration of less than 10^{-5}g is obtained. Visual data are acquired through the use of high-speed motion picture cameras. Also, other data such as pressures, temperatures, and accelerations are either recorded on board with various data acquisition systems or are transmitted to a control room by a telemetry system capable of transmitting 18 channels of continuous data. Due to the complexity of drop chamber operations and time required for pump-down of the drop chamber, typically only one test is performed per day.

The KC-135 can provide periods of low-gravity for up to 23-second intervals, accommodating a variety of experiments. Qualified observers or operators may fly with their experiment packages. The KC-135 obtains a low-gravity environment by flying a parabolic trajectory. Gravity levels twice those of normal gravity occur during the initial and final portions of the trajectory, while the brief pushover at the top of the parabola produces less than one percent of Earth's gravity. The interior KC-135 bay dimensions are 6 feet wide and 6.4 feet high by 60 feet long. Several experiments, including a combination of attached and free-floated hardware (which can provide effective gravity levels of nominally 10^{-3} g for periods up to 10 seconds) can be integrated in a single flight. Instrumentation and data collection capabilities must be contained in the experiment packages.

As of July, 1999, NASA is supporting 20 flight or flight definition investigations and 58 ground-based programs, including several which are purely theoretical in nature and several more which are dedicated to development of sophisticated low-weight, low-power-requirement diagnostic tools for use in future experiments, particularly aboard the Space Station. More information regarding these programs can be obtained from papers presented in the Proceedings the Fifth International Microgravity Combustion Workshop (May, 1999), available at:
http://www.ncmr.org/events/combustion1999.html,
while brief (approximately one-half page each) overviews of each project currently in the program can be obtained from Dr. Merrill K. King, who can be contacted by telephone at (202) 358-0817 or by e-mail at merrill.king@hq.nasa.gov.

To date, microgravity combustion studies have demonstrated major differences in structures of various types of flames from that seen in normal gravity. One approach to defining the utility of the microgravity combustion program is through definition of desirable benefits, key scientific barriers to achievement of such benefits, and how microgravity studies can be utilized to overcome these barriers. Besides the practical implications of results obtained to date, these studies establish that better mechanistic understanding of individual processes making up the overall combustion process can be obtained by comparing of results gathered in microgravity and normal gravity tests, with potential for major improvements in design of combustion processes and hardware for use on earth as well as in space. Further discussion of the potential of the microgravity combustion research program for developing or enhancing combustion technologies are presented in Section II-D of this Appendix.

C. LOOKING TO THE FUTURE: INTERNATIONAL SPACE STATION

Microgravity Combustion experiments on International Space Station (ISS) will mainly be carried out either in a dedicated Combustion Integrated Rack (CIR) with Experiment Unique Inserts which will fit into one of three multi-user minifacilities described in Appendix C, or in the Microgravity Science Glovebox, a major upgrade from the Middeck Glovebox on the Shuttle, mentioned earlier. As with all microgravity disciplines, the ISS will offer the ability to conduct more microgravity combustion experiments per year, a big advantage over available opportunities on the Space Shuttle; regular access to a laboratory in space should bring flight-based research more closely in line with experimentation done on Earth.

The CIR is one part of the Combustion Element (CE) of the larger Fluids and Combustion Facility (FCF). The FCF system infrastructure includes three racks of on-orbit hardware/software, nine racks of ground based hardware/software, training, operations, and virtually all other equipment and activities needed to support fluids and combustion experimentation on the ISS. The sharing of the common infrastructure by both the Fluid Physics and Combustion Science disciplines increases scientific production and lowers costs for both of them.

The CIR performance requirement is to support an average of 5 typical combustion experiments per year within all known on-orbit and on-earth resource limitations, including budget. In addition, if the limiting resources are increased, the CIR shall be capable of supporting up to 15 experiments per year. Over its life cycle, the CIR shall be capable of supporting 80 percent of the proposed experiments. Since the CIR will be on-orbit for the life of the ISS, as many as120 combustion experiments may eventually be conducted.

Designing a facility to accomplish 80 percent of the combustion experiments that may be proposed over the possible 15-year life of ISS is a challenge. To bound that challenge, the Microgravity Combustion Program developed 11 Basis Experiments and their requirements. The Basis Experiments span the scope of experiments likely to be proposed, and FCF is required to accommodate them as well as the first 10, or so, real experiments now planned for flight over the next few years. Thus, a manageable quantity of experiments was considered by the design team; yet, the likelihood is that an FCF so designed will serve the program well for many years.

Central to giving the FCF the required flexibility is the use of Principal Investigator (PI) unique combustion experiment hardware/software to customize the CIR to fully meet the PI's requirements. The FCF infrastructure contains all those items common to many or all combustion experiments. These include a combustion chamber, optical diagnostics, other diagnostics, fuel and oxidizer management, on-orbit and on-earth data reduction and analysis, communications with earth, a network of internet-based communications that will distribute near real time data to PIs at their home institutions, and many other commonly needed features. Each individual PI hardware team will develop unique equipment to manage the geometry of the combustion event, lenses to customize light sources and cameras, occasionally a unique illumination or camera system, and any other unique equipment and software the PI requires. Because so much is supplied by the FCF infrastructure, the PI equipment should be simple and cheap relative to equipment traditionally used in SpaceLab; however, the quality and capability of the entire system including the PI equipment should be much greater.

The CIR will be the first of three FCF racks deployed to ISS. It is currently scheduled to be launched on UF-3 in October, 2002 and to begin its scientific work immediately. Seventeen combustion experiments are tentatively planned during the first three years of CIR operation. The rest of the FCF system including the Fluids Integrated Rack (FIR) and Shared Accommodations Rack (SAR) will be launched on UF-5 and UF-7, currently scheduled for June, 2003 and May, 2004. Several experiment-specific inserts are also currently under development. (Again, see Appendix C for more detail.)

The Microgravity Science Glovebox (MSG) for the International Space Station (ISS) will be a larger version of the Shuttle Middeck Glovebox and will be a containment facility designed for supporting a wide range of microgravity science investigations. In the sealed mode, the MSG serves as a single level of containment by providing a physical barrier to the surroundings. In the air circulation mode, the MSG serves as a one-failure-tolerant containment by providing a physical barrier and a negative pressure relative to the cabin. The video system included with the MSG consists of 1 B&W and 3 color cameras. The work volume of the MSG is approximately 260 liters, with dimensions of 92cm wide x 65cm high x 50cm deep. Power, up to a total draw of 1000W, is available at several voltages, and maximum heat dissipation is also 1000W. 540 Lux of general illumination is also available. Filtration is supplied by a HEPA/charcoal/catalyst train, replaceable on orbit. Other resources available include nitrogen and vacuum. It is envisioned that MSG experiments will be conducted in the areas of fluid physics, combustion science, materials science, and biotechnology. The MSG is being developed by the European Space Agency (ESA) and will be available for use soon after the deployment of the U.S. Laboratory Module of the ISS.

D. ENTERPRISE FOR HUMAN EXPLORATION AND DEVELOPMENT OF SPACE (HEDS)

In early 1994, as part of ongoing reorganization at NASA, the agency established six major enterprises, later reduced to four. In the current organization, the Microgravity Research Division (MRD) of the Office of Life and Microgravity Sciences and Applications (OLMSA) has become part of the Human Exploration and Development of Space (HEDS) Enterprise. In January, 1996, a Strategic Plan for HEDS was put into place and development of "roadmaps" for the future directions of activities within HEDS was initiated. The three major charges of the HEDS activities are: (1) To advance and communicate scientific knowledge and understanding of the Earth, the solar system, the universe, and the environment of space for research; (2) To explore, use, and enable the development of space for human enterprise; and, (3) To research, develop, verify, and transfer advanced aeronautics, space, and related technologies.

The HEDS Enterprise has as a major goal contributing significantly to the opening of the space frontier and expanding the human experience into the far reaches of space. The focus of the MRD program in the HEDS Strategic Enterprise is to foster fundamental understanding of physical and chemical processes, building a foundation of knowledge that can be applied to Earth- and space-based technologies. Specifically, understanding of the fundamental role of gravity in the space environment on these processes is needed to achieve breakthroughs in science and to develop enabling technology for exploration and colonization of space. The need for improved understanding of combustion phenomena to enable future space technologies and operations should be recognized as one of the primary opportunities of the discipline. Included are the development of spacecraft combustion/propulsion systems, fire safety, use of in-situ resources, and power generation in extraterrestrial environments. Many of the combustion or other chemical conversion process principles involved are relevant to several technology areas simultaneously.

A rapidly developing area of particular relevance to exploration of other bodies in the solar system is In Situ Resource Utilization (ISRU). Due to the cost constraints associated with carrying all the necessary resources for a sustained visit and return trip from either the Moon or Mars, utilization of natural resources at the landing site is receiving strong consideration. Basic physical and chemical methods will be applied to process local resources into usable commodities. The focus of activities of the research community must be to develop an understanding of operation of these processes in a non-Earth environment. Proposals are encouraged on efforts to advance the current understanding of unit operations in a low gravity environment with the goal of improved process design and development. Examples of local resource utilization related processes include chemical reaction engineering for production of fuels and/or oxidizers, combustion of such products in a reduced gravity environment, and fire safety during such operations. Lunar regolith (soil) contains significant amounts of oxygen, chemically bound in various minerals, which will require processing to produce oxygen for use in propulsion and life support systems. Similarly, it is believed that Martian soil contains significant amounts of water that can be electrolyzed into oxygen and hydrogen, again for propellants and life support. Utilizing the Martian atmosphere for the production of oxygen, carbon monoxide and methane for propellants is also possible. In all of these scenarios a fundamental understanding of the chemical conversion processes involved is vital.

At a HEDS Technology Workshop held in August, 1997, several fire research areas of interest with respect to a manned Mars mission were defined. These included: (1) Development of earlier more sensitive fire detection systems for use under microgravity and Mars gravity (0.38g) scenarios; (2) Extended studies of the flammability of thick fuels and of degradation of polymers at microgravity and Mars gravity at various oxygen mole fractions and radiant heat flux loadings; (3) Study of combustor performance and fire safety for premixed methane/oxygen systems at 0.38g; (4) Experimental and modeling studies of extinguishment by dilution with various agents under microgravity and 0.38g conditions; and, (5) Study of potential fire safety problems associated with various in-situ resource utilization scenarios.

A major performance goal of the Microgravity Combustion program is development of a microgravity test program directed to identify the mechanisms controlling ignition and transition to flame spread, improve fire detection and suppression in extraterrestrial environments (including spacecraft as well as lunar and Martian environments), to conduct experiments and analyses to validate all of NASA's spacecraft and fire detection and suppression policies and practices and to make technology and policy recommendations leading to significant hazard reduction.

While basic research into fundamentals is still considered to be of major importance to our program, there is obviously a major shift of emphasis toward “mission-oriented” research; that is, research aimed at specific problems in combustion applications on Earth as well as under reduced or microgravity conditions. Thus, it is important that firmer linkages between the research being done using microgravity and applications to practical applications on Earth (e.g., increased efficiency of conversion of chemical energy contained in fuels to useful work, reduction of combustion-generated pollutants from automobile engines and other combustors, decreased fire and explosion hazards) need to be established for an increasing percentage of efforts funded under this program.

Included among the long-term goals of the HEDS microgravity combustion program are: (1) Melding microgravity combustion space experiments together with ground-based combustion studies, using gravity as an added independent variable, to provide better understanding of the physical and chemical mechanisms involved in combustion and to provide more rigorous testing of analytical models; (2) Utilizing basic research to provide technological advances in various combustion processes/devices (e.g., internal combustion engines, turbines, combustion synthesis, incinerators); (3) Creating the understanding that will permit lessons learned in microgravity combustion experiments and modeling to be used in optimizing combustion devices here on Earth; (4) Providing quantum leaps in the areas of fire safety and minimization of combustion-generated pollution; (5) Providing the understanding which will permit efficient use of present and alternative fuels, which will be increasingly needed as we deplete our oil and gas reserves; and, (6) Developing a better understanding of various combustion synthesis processes, opening the door to production of novel tailored materials here on Earth as well as in space.

Potential combustion technologies which can be developed or enhanced for terrestrial and space exploration applications include: (1) Active control over thermal efficiency and pollutant generation through sensor development and miniaturization accompanied by development of algorithms relating sensor readings, control settings, and system performance; (2) Use of magnetic and electric fields to improve thermal efficiency (microgravity enables improved isolation of and thus understanding of field effects on ions and paramagnetic molecules such as oxygen); (3) Improved atomization methods for diesel and gas turbine engines, leading to improved fuel utilization, through improved understanding of fundamentals of liquid jet breakup and droplet interactions in sprays; (4) Flame-zone pollution control in premixed and diffusion burners, reducing the need for post-combustion cleanup devices, through fundamentally improved understanding of flame structure and of mechanisms of formation of soot and oxides of nitrogen; (5) Improved exhaust gas monitoring for cars and other combustion devices combined with development of “smart” controls to compensate for fuel variations and/or degradation of engine components to decrease pollution emissions; (6) New flame-stabilization/control technologies for burners, enabling reliable, ultra-lean premixed combustion, through improved understanding of flame stabilization zones in engines, burners, etc.; (7) Development of improved strategies and procedures for fire prevention, detection, and suppression in the microgravity environment associated with Space Station and in the reduced gravity Lunar and Martian environments; (8) Reduction of hazards associated with gaseous fuel combustion through better mapping and understanding of flammability limit and combustion instability phenomena; (9) Development of improved protection against large-scale fires (house fires, forest fires) via better fundamental understanding of material ignition and flamespread phenomena; (10) Reduction of mine and grain silo explosion hazards through development of understanding of fundamentals associated with these phenomena; (11) Improved reliability in hazardous liquid waste incineration, resulting from studies of droplet and spray burning and of pollution generation; (12) Industrial-scale, combustion-generated fullerene production through determination of approaches for improving the yields of fullerenic material in flame systems; (13) Production of combustion-generated composite materials with improved strength, reliability, and ductility through better understanding of how to improve micro-structural uniformity and control porosity via gravitational control; and, (14) Development of methods for producing and utilizing alternate fuel/oxidizer combinations associated with Lunar, Martian, or other extraterrestrial habitats.

As indicated earlier, while conduct of fundamental science investigations remains a cornerstone of the Microgravity Combustion Science program, more weight will be placed in the future on relevance to HEDS goals, with linkage of the proposed research to attainment of these goals receiving increased emphasis. Establishment of scaling laws with respect to gravitational effects on combustion processes and definition of where such laws break down due to changes in dominant physics are of interest. However, future proposals are not limited to the topic areas discussed in this Appendix; extension to combustion topics not currently included in the Microgravity Combustion program is strongly encouraged to permit us to broaden the program scope. It appears that the most fruitful approach to achieving meaningful technology gains in processes involving combustion is to concentrate on developing better understanding of the fundamentals of the individual processes involved. With such understanding, including definition of details of the unit processes and their interactions, physically accurate models which can be used for parametric exploration of new combustion domains via computer simulation can be developed, with potential resultant definition of radically different approaches to accomplishment of various combustion goals. As discussed earlier, normal-gravity conditions have prevented study of many elementary processes which are over-shadowed by processes such as buoyancy, making it difficult to develop mechanistic understanding of unit phenomena making up overall combustion processes. It cannot be emphasized too strongly that our program is dedicated to taking advantage of microgravity to untangle these complications, allowing major strides in our understanding of combustion processes and in subsequent development of improved combustion devices leading to improved quality of life here on Earth.

III. EXPERIMENTAL APPARATUS AND FLIGHT OPPORTUNITIES

A. EXPERIMENTAL APPARATUS

In order to accommodate aspects of the research described in Section II, a number of pieces of flight hardware are being developed by NASA and its international partners for use on the International Space Station (ISS). Experimental apparatus for the early utilization of the ISS will primarily be in facilities such as the Microgravity Science Glovebox (MSG) and the Combustion Integrated Rack (CIR), in the latter scenario in one of three multi-user inserts, described in Appendix C, Section 1. A high-capacity communications network will support ISS payload operations. Downlink channels will enable users to monitor their instrument status and science data streams in real time. An uplink channel enables them to act on that information. The effective use of these downlink and uplink capabilities enables telescience on a near real-time basis. Section II of Appendix C lists the ground-based facilities that are available to support definition studies

B. DIAGNOSTIC MEASUREMENTS

The capability to characterize science experiments in reduced-gravity is essential to scientific progress in this program. NASA, in ground-based normal and reduced-gravity studies, is developing techniques for enhancing imaging and visualization, and improving measurements of temperature and velocity fields and of particle-size distributions. As these techniques mature, those most required by investigators will be reviewed for space flight development as part of the future flight equipment capability.

C. FLIGHT OPPORTUNITIES

Flight opportunities under this NRA will be mainly on the International Space Station (ISS), with possible limited opportunities on sounding rockets, depending on availability of funds for their purchase, and on the Space Shuttle (minimal opportunities during ISS assembly). During sounding rocket flights five to ten minutes of microgravity (10^{-4} g) experimentation time is available. These flight opportunities will be dependent on the progress of the construction of the International Space Station and on Microgravity Research Division budget considerations. **The complexity of the hardware required to complete the investigation may have a significant impact on flight definition selection, based on cost/benefit ratio analyses.**

D. EXPERIMENT DEFINITION AND FLIGHT ASSIGNMENT PROCESS

Ground-based research is usually necessary to clearly define flight experiment objectives. This research may involve experimentation in NASA-provided ground-based facilities, including those that can provide a limited duration low gravity environment. (These facilities are described in Appendix C, Section II.) Successful proposals for flight opportunities will be supported for a ground-based definition phase before review for flight assignment. The amount of support (technical, scientific, and budgetary) and the length of the definition period (usually from 6 months to 2 years) will depend on the specific investigator needs and the availability of resources from NASA. However, in preparing their budget plan for this research announcement, all respondents should estimate their annual costs for four years.

Shortly after selection of projects for flight definition, NASA will initiate a process to identify fundamental technical feasibility issues. A small team of engineers and scientists at the NASA field centers will work with the Principal Investigator to translate requirements into the appropriate experiment technical requirements. The result is a systems engineering approach which prioritizes and links the facets of the experiment development process assuring that the objectives of the experiment can be met. The process will help determine whether there are any outstanding issues that would inhibit the success of the flight project, considering both technical challenges and required resources. At that point NASA may make a judgment as to whether a project will continue the flight definition process or revert to the ground-based program (see below).

1. Near-Term Flight Opportunities. Successful proposals for use of existing hardware and instrumentation will be funded for a period of advanced definition work, after which time the investigator will generate a detailed Science Requirements Document (SRD). The SRD, a detailed experiment description outlining the specific experiment parameters and conditions, as well as the background and justification for flight, must be prepared jointly by a NASA-appointed project scientist and the Principal Investigator and submitted for peer review. This formal review by both science and engineering panels will determine if space flight is required to meet the science objectives and if instrument capabilities can be provided to meet the science requirements. Following approval by the panels, subject to program resources, continuation support will be awarded and the hardware will be modified to meet the science requirements. NASA does not guarantee that any experiment selected for definition will advance to flight experiment status. Investigations with unresolved science or engineering issues at the review of the SRD may be placed in ground-based status with support of limited duration (normally from one to three years), and asked to submit a proposal to a subsequent solicitation for further support.

2. Future Flight Opportunities. Successful proposals for the development of new apparatus will be funded for a period of definition. The length of the definition period will be based on the experiment requirements, but will generally be from 6 to 24 months. At the end of the experiment definition phase, the investigator will generate a detailed SRD. Following successful peer review of the SRD by science and engineering panels, the experiment will proceed into flight development and be considered for flight. As with opportunities for existing instruments, NASA does not guarantee that any experiment selected for definition will advance to flight development status, and the possibility exists that investigations may be placed in ground-based status, with continuing support from NASA for a limited period.

3. Ground-Based Definition Opportunities. Promising proposals for experimental research which are not mature enough to allow development of an SRD after two years of definition, and proposals for development of theory in areas of current or potential microgravity experiments, may be selected for support in the MRD ground-based research program. Ground-based studies are funded for periods of up to four years. A new proposal to a future announcement is currently required in order to be selected for a flight opportunity or to continue ground-based studies if appropriate. Proposals for development of new technologies for flight experiments that will provide new capabilities for microgravity combustion science research are encouraged.

E. GOING TO SPACE FLIGHT---THE PROCESS AND WHAT IT MEANS TO THE PI

The purposes of this section are: (a) to describe the development process for space flight experimentation; (b) to provide some guidance on the level of effort (and likely funding requirement) by a PI in the flight definition and development category. Spaceflight investigation requires work that the PI may not have previously planned, and it may require funding from NASA above and beyond what is performed in ground-based studies to pay for this work. In general, the additional level of staffing and funding involves the hiring of a post-doctorate fellow to assist the PI with these tasks. In addition, travel to NASA Centers occurs 2-4 times each year. Finally, the annual level of effort by the PI often requires more than 10% of full time, with weeklong periods in each year of nearly 100% time. From the initial award to the conclusion of NASA funding -- marked by the PI's publication of results from spaceflight investigation -- a period elapses of (usually) more than 6 years. The PI, students, post-doctorates and staff are supported by NASA funding throughout this entire period, as established in the grant or contract awards.

When NASA initially selects and awards a spaceflight proposal, it is categorized as a "flight definition investigation." These proposals are generally ranked by the peer review panel to be in the top 10% of the proposals received in response to the NRA. After the details of the spaceflight experiment are defined and successfully peer reviewed again, as described below, the investigations are categorized as flight investigations. Each of these categories is described below.

1. <u>Flight Definition Investigation</u>

A "flight definition investigation" goes through the following activities, unlike a ground-based study. The PI will be assisted through this process by a NASA-assigned Project Scientist (PS) and a NASA engineering team.

a. Kickoff Meeting

Within 2 months after an award, the Principal Investigator's kick-off meeting is held. The PI gives a presentation to a NASA team at this time. The presentation includes the scientific objectives, goals, and motivation, and also identifies the challenging technological areas of the experiment to be conducted in space. Especially important in the presentation by the PI are the relevant experimental techniques with which he thinks his objectives can be met. A NASA engineering team makes its own first, independent assessment of the most challenging elements of the experiment.

b. Drafting and Defining the Science Requirements Document

The PI is required to write a Science Requirements Document (SRD) to establish a very clear scientific goal(s), approach, and feasibility of the concept of the exact experiment ***to be performed in space***. This document includes specific theoretical hypotheses from which are derived the detailed objectives of the experiment (this must be consistent with the scope outlined in the peer reviewed and approved proposal). Most importantly, a set of experimental specifications must be developed to meet the objectives. These requirements specify the initial operating conditions of the experiment, and what is to be measured and how precisely it is to be measured. Finally, a clear rationale of the need for space-based, microgravity experiments must be documented. Science requirements, may include for example: levels and stability of heat flux, flow rate, temperature, solidification growth rate, species concentration, acceleration, optical imaging, radiant emission, pressure, force, etc.

About 3 to 4 months after award, the PI shall produce a "Zeroeth Draft" of the Science Requirements Document that consists of the following: the table of contents, executive summary, experiment objective, preliminary list of science requirements, the preliminary test matrix, and the post-flight data deliverables. Before the investigation is completed in space, the SRD may be augmented or updated nearly 10 times. It is the vital document that determines which experiments are actually run in space.

c. Establishing the Feasibility of the Science Requirements of the Space Experiment

It is necessary to establish the feasibility of the operating conditions and of making such measurements as specified in the SRD. This is done through ground-based tests in the PI's lab or in NASA's ground based facilities. A small NASA engineering team may support the PI by designing and developing bench-top hardware (breadboards) and rigs for laboratory and low-gravity tests. The feasibility issues are usually identified through a process called the Quality Function Deployment method. This method identifies which requirements in the SRD are both the most important (as determined by the PI) and the most difficult to meet (as determined by the NASA team). This method therefore prioritizes the areas that the most effort should be expended. A QFD final report outlines the science concept feasibility issues, safety and reliability concerns, the design, fabrication, testing and analyses, that must be accomplished before SCR and who (NASA team or PI) will be responsible for each development issue.

For a period up to 3.5 years after award (though shorter is highly preferred), work continues to resolve the feasibility issues, the major safety and reliability concerns, and to gather scientific data in support of the space experiment. This work involves several meetings by the PI with NASA personnel and significant work in the NASA drop towers and low-gravity aircraft. The PI may be required to perform various safety analyses (e.g. level of combustion product concentrations that will occur under worst case conditions). The PI must continuously review progress made by the NASA team, and vice versa, often through biweekly telecons.

d. The Science Concept Review Meeting

When the NASA team and the PI think they have completed the SRD and resolved the feasibility issues satisfactorily (typically within two years of program inception), the first of two peer reviews is scheduled. This first review is called the Science Concept Review (SCR). The SCR requires one full day and is conducted by NASA's Enterprise Discipline Scientist (EDS). The EDS selects a panel of external scientists who are knowledgeable in the PI's area of interest. They are chartered to assess the scientific need and merit of the experiment's objectives and the technical approach, and to recommend whether the experiment should continue to proceed toward spaceflight experimentation.

A few weeks before the SCR meeting, the panel is sent the SRD and the SCR's presentation materials as planned by the PI and the NASA team. At the meeting itself, the PI's presentation lasts 3 to 5 hours and the NASA team's is typically 1/2 to 1 hour. The peer panel then privately holds a caucus to establish their approval or disapproval and any residual issues and concerns they may have. The panel will submit written findings to the EDS, whose organization subsequently will approve or deny further activity toward spaceflight experimentation.

e. Post – SCR Flight Definition Research and Development

If approval to continue to proceed toward a spaceflight experiment is given after the SCR, the PI and NASA team work to resolve any of the peer review panel's issues and concerns, as well as to refine the SRD and experimental approach. During this time, discussions with the peer review panel may take place to try to clarify and resolve their issues and concerns. Much more detail is developed about the form, fit, and function of the spaceflight hardware as it may fit into an actual spacecraft.

f. The Requirements Definition Review Meeting

After up to a year of such research activity, the second peer review is held. This second review is called the Requirements Definition Review (RDR). Prior to the review, the PI and team establishes the final SRD, and resolves the final feasibility issues, and again sends out the presentation material. At the one day RDR meeting, a process similar to the SCR occurs. More emphasis is placed on the feasibility issues, the integration of the conceptual flight hardware into the spacecraft and a formal engineering review takes place. The peer panel returns to reaffirm their approval for the experiment to proceed to spaceflight; they especially look to determine if their previously raised issues and concerns were satisfactorily addressed.

Again, the panel submits their written findings to the EDS, whose organization subsequently will approve or deny further activity toward spaceflight experimentation. Once the RDR is passed successfully, a formal “Authorization To Proceed” letter is issued by NASA to the PI that assures, pending available funding and spacecraft availability and any other intervening factors, the experiment will be performed in space. At this point the investigation is no longer a “flight definition” investigation, but is now categorized by NASA as a “flight investigation”.

2. Flight Investigation

a. Spaceflight Hardware Definition, Qualification, and Testing

As NASA sponsors the design, fabrication and assembly of the spaceflight hardware to the specifications established in the final SRD, the PI is asked to review and approve test plans, test data and analyses, operating procedures and to perform additional safety analyses and tests. Decisions about automation versus ground commanding or in-space crew operations will be required. In parallel, the PI performs scientific research in support of the spaceflight experiment or as outlined in the originally awarded proposal. This research may take place in the PI’s labs, NASA’s ground-based laboratories and low-gravity facilities, or, upon a successful proposal in response to a NASA-initiated competitive solicitation, in a glovebox facility that flies in space.

Frequent questions may be asked to the PI about his intent regarding a requirement in the SRD. Detailed plans on the experiment’s data reduction, analysis and archiving are established with the PI during this period.

b. Spaceflight Mission Training and Operations

In the last year before the spaceflight mission, the PI will be asked to prepare and present materials to train the astronaut crew and ground support personnel so that they can support the conduct of the experiment in space. During this time, nominal, alternate, and malfunction procedures for operating the experiment are reviewed and updated by all parties. Many practice sessions may be held to simulate and prepare for possible events in the flight tests. When the spaceflight hardware is integrated into the spacecraft’s rack, the PI may be asked to review and accept or reject final test data on the hardware’s performance.

During the spaceflight testing itself, the PI will be required to support mission operations, particularly as unplanned situations arise. These may affect the test sequence, the number of tests, the schedule of test periods, revisions in the planned procedures, etc. The PI also will, almost always, participate in various interviews and events with the media (in fact, this may take place throughout the entire flight investigation process).

3. Post-flight Data Reduction, Analysis, Archiving, and Reporting

After the flight, the PI must reduce and analyze the data, and work with the PS to select the data that will be permanently archived by NASA. There is a requirement to publish in archival literature within 1 year after the data from the flight experiment are received. Approximately 12 to 18 months after flight, the experiment is considered complete and the funding to the PI by NASA for this effort is concluded.

IV. PROPOSAL SUBMISSION INFORMATION

This section delineates the requirements for submission of proposals in response to this announcement. The research project described in a proposal submitted under this announcement must be directed by a Principal Investigator who is responsible for all research activities and may include one or more Co-Investigators. Proposers must address all the relevant selection criteria (described in Section VIII) in their proposal and must format their proposal as described in this section. Additional general information for submission of proposals in response to NASA Research Announcements may be found in Appendix D.

A. LETTER OF INTENT

Organizations planning to submit a proposal in response to this NRA should notify NASA of their intent to propose by electronically sending a Letter of Intent (LOI) via the MRD Web Page:

http://microgravity.hq.nasa.gov/

Alternatively, Letters of Intent may be submitted via e-mail to the following address:

loi@hq.nasa.gov.

If electronic means are not available, you may mail Letters of Intent to the address given for proposal submission in the following section, or Facsimile transmission is acceptable; the MRD Fax number is (202) 358-3091.

The Letter of Intent, which should not exceed two pages in length, must be typewritten in English and include the following information:

- The potential Principal Investigator (PI) name, position, organization, address, telephone, Fax, and e-mail address.
- A list of potential Co-Investigators' names, positions, and organizations.
- General scientific/technical objectives of the research.
- Intent to participate in the Undergraduate Student Research Opportunities, if appropriate.
- The equipment listed in this NRA which is of interest, if appropriate.

The Letter of Intent should be received at NASA Headquarters no later than January 5, 2000. The Letter of Intent is being requested for informational and planning purposes only, and is not binding on the signatories; institutional authorizations are not required. The Letter of Intent allows NASA to better match expertise in the composition of peer review panels with the response from this solicitation. In the Letter of Intent, investigators may request more detail on the capabilities of the specific equipment (Appendix C) that might be used to accomplish their scientific objectives and/or items listed in the Bibliography (Appendix B, Section IX).

B. PROPOSAL

The proposal should not exceed 20 pages in length, exclusive of appendices and supplementary material, and should be typed on 8-1/2 x 11 inch paper **with a 10- or 12-point font**. Extensive appendices and ring-bound proposals are discouraged. Reprints and preprints of relevant work will be forwarded to the reviewers if submitted as attachments to the proposal, with the understanding that the reviewer is not required to read them.

The guidance in Appendix D, Section D regarding the content of renewal proposals is not applicable to this NRA. Renewal proposals should not rely on references to previous proposals for any information required for a complete proposal. **It is particularly important that proposers who**

seek to extend an existing NASA research activity that is relevant to this NRA submit a proposal that clearly identifies and documents achievements on their current effort and how the work proposed in the current proposal supports their request for additional sponsorship. Such follow-on proposals will be reviewed on an equal basis with all other submitted proposals.

Fifteen copies of the proposal must be received at NASA Headquarters by February 15, 2000, 4:30 PM EST to assure full consideration. Treatment of late proposals is described in Appendix D, Section G. Send proposals to the following address:

Dr. Merrill K. King
c/o Indyne, Inc.
Subject: NASA Research Proposal (NRA-99-HEDS-04)
300 D Street, SW, Suite 801
Washington, DC 20024
Telephone number for delivery services: (202) 479-2609

NASA cannot receive deliveries on Saturdays, Sundays or federal holidays.

Proposals submitted in response to this Announcement must be typewritten in English and contain at least the following elements (in addition to the required information given in Appendix D) in the format shown below:

- Form A (Solicited Program Application)
- Form B (Proposal Executive Summary – replaces Abstract). The executive summary should succinctly convey, in broad terms, what it is the proposer wants to do, how the proposer plans to do it, why it is important, and how it meets the requirements for microgravity relevance and/or relevance to HEDS goals
- Form C (Budget for Entire Project Period ---Direct Costs Only)
- Form D (Summary Proposal Budget --- 1 copy for each year, include only remuneration to be received by the proposing institution(s))
- Form E (Estimated value of requested Government-Furnished Equipment and Services; see accompanying instructions for completing this form)
- Table of Contents
- Research Project Description containing the following elements:
    - Statement of the hypothesis, objective, and value of this research.
    - Review of relevant research.
    - Justification of the need for low gravity to meet the objectives of the experiment.
    - Description of the diagnostic measurements that would be required to satisfy the scientific objectives of any proposed low gravity experiments.
    - Estimation of time profile of reduced-gravity levels needed for the experiment or series of experiments.
    - A clear and unambiguous justification of the need to perform the experiment in space as opposed to ground-based reduced-gravity facilities (flight definition proposals only).
    - A description of a ground-based testing program that might be needed to complete the definition of the space flight experiment requirements in terms of experiment conditions, acceleration levels and durations, control and diagnostic measurement requirements, etc.
    - Management plan appropriate for the scope and size of the proposed project, describing the roles and responsibilities of the participants
- **Prior Period of Support:**
    - **For follow-on proposals of ongoing MRD sponsored projects, a summary of the objectives and accomplishments of the prior period of support, including a list of**

published papers derived from that support, must be included as part of the proposer's justification for continued support.

- Appendices:
  - Supplementary budget information and budget explanations. The cost detail desired is explained below
  - Summary of current and pending support for the Principal Investigator and Co-Investigators**. If the proposer is currently performing similar work under funding from another government agency, he/she must clearly explain the difference between this proposed project and the other work.**
  - Complete current curriculum vita for the Principal and Co-Investigators, listing education, publications, and other relevant information necessary to assess the experience and capabilities of the senior participants.
- **3.5 inch computer diskette containing electronic copy of Principal Investigator's name, address, complete project title, and executive summary**

Proposal Cost Detail Desired. Sufficient proposal cost detail and supporting information will facilitate a speedy evaluation and award. Dollar amounts proposed with no explanation (e.g., Equipment: $58,000, or Labor: $10,000) may cause delays in evaluation or award. The proposed costing information should be sufficiently detailed to allow the Government to identify cost elements for evaluation purposes. Generally, the Government will evaluate cost as to reasonableness, allowability, and allocability. Enclose explanatory information, as needed; each category should be explained. Offerors should exercise prudent judgment as the amount of detail necessary varies with the complexity of the proposal. **The proposer is strongly urged to be realistic as to the time-phasing of their funding requirements, rather than simply "straight-lining" the costs over four years. Very often, funds will be expended at a relatively low level during the first few months of a project, with higher than "straight-line" expenditures during the remaining grant period; if the proposer anticipates this being the case, he/she should indicate this in their proposed funding profile, since "carry-over" funding from year to year is being strongly discouraged by NASA management.**

V. NRA FUNDING

The total amount of funding for this program is subject to the annual NASA budget cycle. The Government's obligation to make awards is contingent upon the availability of appropriated funds from which payment for award purposes can be made and the receipt of proposals which the Government determines are acceptable for an award under this NRA.

For the purposes of budget planning, we have assumed that the Microgravity Research Division will fund 0 to 3 flight experiment definition proposals. These efforts are typically funded at an average of $175,000 per year. It is also anticipated that approximately 15-20 ground-based study proposals will be funded, at an average of approximately $100,000 per year, for up to 4 years. The initial fiscal year (FY) 2001 funding for all proposals will be adjusted, if required, to reflect partial fiscal year efforts. **It is particularly important that the proposer realistically forecast the projected spending timeline rather than merely assuming an equal amount (adjusted for inflation) of requirements for each year.** The proposed budget for ground-based studies should include researchers' salaries, travel to science and NASA meetings (for a flight investigation, roughly eight meetings per year with NASA should be anticipated, though travel activity will vary over the development of the experiment), other expenses (publication costs, computing or workstation costs), burdens, and overhead. During subsequent years, NRA's similar to this NRA will be issued, and it is planned that funds will be available for additional investigations.

VI. GUIDELINES FOR INTERNATIONAL PARTICIPATION

(a) NASA welcomes proposals from outside the U.S. However, investigators working outside the U.S. are not eligible for funding from NASA. Proposals from non-U.S. entities should not include a cost plan. Proposals from outside the U.S. and U.S. proposals that include non-U.S. participation must be endorsed by the respective government agency or funding/sponsoring institution in that country from which the non-U.S. participant is proposing. Such endorsement should indicate that the proposal merits careful consideration by NASA, and if the proposal is selected, sufficient funds will be made available to undertake the activity as proposed.

(b) Successful and unsuccessful proposers will be contacted directly by the NASA sponsoring office. Copies of these letters will be sent to the sponsoring government agency. Should a non-U.S. proposal or a U.S. proposal with non-U.S. participation be selected, NASA's Office of External Relations, Human Space Flight and Research Division will arrange with the non-U.S. sponsoring agency for the proposed participation on a no-exchange-of-funds basis, in which NASA and the non-U.S. sponsoring agency will each bear the cost of discharging their respective responsibilities. Depending on the nature and extent of the proposed cooperation, these arrangements may entail:

1. A letter of notification by NASA, and
2. An exchange of letters between NASA and the sponsoring foreign governmental agency; or
3. A formal Agency-to-Agency Memorandum of Understanding (MOU).

(c) As stated in Paragraph b. above, foreign proposals accepted under this NRA will be implemented on the customary no-exchange-of-funds basis in which NASA and the sponsoring foreign agency will each bear the cost of discharging their respective responsibilities. Additionally, NASA funding may not be used to purchase a launch service from a non-U.S. source. However, the direct purchase of goods and/or services from non-U.S. sources by U.S. Principal Investigators or U.S. Co-Investigators is permitted. Proposers are advised that international purchases must meet NASA and Federal regulations, including those relating to export and import control, and that these regulations may place an additional burden on the successful proposer that should be explicitly included in discussions of the proposed budget.

VII. NASA/NEDO COOPERATIVE ACTIVITIES

NASA has entered into an agreement with the New Energy and Industrial Technology Organization (NEDO) in Japan resulting in establishment of a Microgravity Combustion Coordination Group (MCCG) for identifying areas of potential cooperation related to combustion research in a microgravity environment in which each side might utilize facilities of the other side, primarily NASA's Glenn Research Center facilities and the dropshaft (10 second microgravity duration) of the Japanese Microgravity Center (JAMIC). Possible personnel exchanges and joint utilization of microgravity facilities of both sides for programs proposed jointly by Japanese and US investigators will be reviewed on a case-by-case basis by the MCCG subsequent to acceptance of the proposal via peer review in each country; any specific cooperative activities recommended by the MCCG will be implemented through individual agreements negotiated between NASA and NEDO. As regards this solicitation (NRA), US proposers may include such cooperative activity as part of their proposal. However, since participation by the Japanese investigators will depend on their being funded by their own sponsoring agencies via a separate review process, it is recommended that the proposal be structured so as to permit accomplishment of significant defined goals without the participation of the Japanese investigator(s). For further information/clarification, potential proposers should contact Dr. Merrill K. King at (202) 358-0817.

VIII. EVALUATION AND SELECTION

A. EVALUATION PROCESS

The evaluation process for this NRA will begin with a scientific and technical external peer review of the submitted proposals. NASA will also conduct an internal engineering review of the potential hardware requirements for proposals that include flight experiments. The external peer review and the internal engineering review panels will be coordinated by the NASA Enterprise Scientist for Combustion Science. Consideration of programmatic objectives of this NRA, as discussed in the introduction to this Appendix, will be factored in by NASA to ensure enhancement of program breadth, balance, and diversity; NASA will also consider the cost of the proposal. The MRD Director will make the final selection based on science panel and programmatic findings. Upon completion of all deliberations, a selection statement will be released notifying each proposer of proposal selection or rejection. Offerers whose proposals are declined will have an opportunity for a debriefing regarding the reasons for their not being selected for award. Additional information on the evaluation and selection process is given in Appendix D.

B. EVALUATION FACTORS

This section replaces Section I of Appendix D. The principal elements considered in the evaluation of proposals solicited by this NRA are: relevance to NASA's objectives, intrinsic merit, and cost. Of these, intrinsic merit has the greatest weight, followed by relevance to NASA's objectives, of slightly lesser weight. Both of these elements have greater weight than cost. Evaluation of the intrinsic merit of the proposal includes consideration of the following factors, in descending order of importance:

1. Overall scientific or technical merit, including evidence of unique or innovative methods, approaches, or concepts, and the potential for new discoveries or understanding, or delivery of new technologies/products;

2. Qualifications, capabilities, and experience of the proposed Principal Investigator, team leader, or key personnel who are critical in achieving the proposal objectives;

3. Institutional resources and experience that are critical in achieving the proposal objectives;

4. Proposed plan for education and public outreach activities. Examples include such items as involvement of students in the research activities, technology transfer plans, public information programs that will inform the general public of the benefits being gained from the research, and/or plans for incorporation of scientific results obtained into educational curricula.

Evaluation of the cost of a proposed effort includes consideration of the realism and reasonableness of the proposed cost, and the relationship of the proposed cost to available funds.

Responding to the following questions should be kept in mind by proposers:

1. Is microgravity of fundamental importance to the proposed study, either in terms of unmasking effects hidden under normal gravity conditions or in terms of using gravity level as an added independent parameter?

2. Do the issues addressed by the research have the potential to close major gaps in the understanding of fundamentals of combustion processes?

3. Is there potential for elucidation of previously unknown phenomena?

4. Is the project likely to have significant benefits/applications to ground-based as well as space-based operations involving combustion processes?

5. Are the results likely to be broadly useful, leading to further theoretical or experimental studies?

6. Can another project in the specific subarea be justified in terms of limited resource allocation?

7. Is the project technologically feasible, without requirements for substantial new technological advances?

8. How will this project stimulate research and education in the combustion area?

9. What is the potential of this project in terms of stimulating future technological applications, and when?

10. Are there strong well-defined linkages between the research and HEDS goals? (See Section II- D of this Appendix)

C. SELECTION CATEGORIES, PERIOD OF SUPPORT, AND FLIGHT DEFINITION PROCESS

Proposals selected for support through this NRA will be selected as either ground-based or flight definition investigations. Investigators offered support in the ground-based program normally will be required to submit a new proposal for competitive renewal after no more than four years of support. Investigators offered flight definition status are expected to begin preparing detailed experiment requirements and concepts for flight development shortly after selection in cooperation with the assigned representative from the Glenn Research Center. (See Section III-E of this Appendix for more detailed description of the procedures required for a flight definition investigation.) The selected investigations will be required to comply with MRD policies, including the return of all appropriate information for inclusion in the MRD archives during the performance of and at the completion of the contract or grant.

Commitment by NASA to proceed from flight definition to the execution of a flight experiment will be made only after several additional engineering and scientific reviews and project milestones have established the feasibility and merit of the proposed experiment. Investigations that do not pass these reviews will be funded for a limited period (generally no more than four years from the initial award date) to allow an orderly termination of the project.

The Principal Investigator in flight definition must prepare a Science Requirements Document (SRD) early in the development of a flight experiment to guide the design, engineering, and integration effort for the instrument. The SRD describes specific experiment parameters, conditions, background, and justification for flight. Ground-based, normal, and reduced-gravity experimentation, as well as any necessary parallel modeling efforts, may also be required to prepare an adequate Science Requirements Document. The amount of support (technical, scientific, and budgetary) provided to investigators by NASA will be determined based upon specific investigator needs and the availability of resources to NASA and MRD.

It should be noted that while a proposer can propose multiple flights, in general NASA will not commit to more than one flight without a reflight review after the first flight.

IX. BIBLIOGRAPHY

Background materials are available to NRA proposers upon written request to:

Mr. Thomas J. Sutliff
Space Experiments Division
Mail Stop 500-115
Glenn Research Center
National Aeronautics and Space Administration
Cleveland, OH 44135-3191
(216) 433-3887
thomas.j.sutliff@grc.nasa.gov

Documents that may provide useful information to proposers are listed below:

Microgravity Science & Applications Program Tasks and Bibliography for FY1998. NASA Technical Memorandum 209007, March 1999. Also available on the Web at **http://:@peer1.idi.usra.edu/peer_review/taskbook/taskbook.html.**

Microgravity Combustion Science: Progress, Plans, and Opportunities, NASA Technical Memorandum 105410, April 1992.

Microgravity Combustion Science: 1995 Program Update, NASA Technical Memorandum 106858, April, 1995.

Microgravity Combustion Research: 1999 Program and Results, R. Friedman, S. Gokoglu, and D. Urban, Microgravity Combustion Science Branch, NASA/TM-1999-209198, June, 1999.

Proceedings of the Second International Microgravity Combustion Workshop, NASA Conference Publication 10113, September 15-17, 1992.

Proceedings of the Third International Microgravity Combustion Workshop, NASA Conference Publication 10174, April 11-13, 1995.

Proceedings of the Fourth International Microgravity Combustion Workshop, NASA Conference Publication 10194, May 19-21, 1997.

Proceedings of the Fifth International Microgravity Combustion Workshop, NASA Conference Publication 1999-208917, May, 1999. Also available on the Web at **http://www.ncmr.org/events/combustion1999.html.**

STS Investigators' Guide, NASA Marshall Space Flight Center.

In addition, considerable information on Glenn Research Center facilities, experiments, educational activities, missions, and services are available on the Web at **http://zeta.grc.nasa.gov**

APPENDIX C
NRA-99-HEDS-04

HARDWARE AND FACILITY DESCRIPTIONS

MICROGRAVITY COMBUSTION SCIENCE: GROUND-BASED AND FLIGHT EXPERIMENT OPPORTUNITIES

The Microgravity Research Division (MRD) is pursuing a program for the development of International Space Station (ISS) payloads that can be configured (or reconfigured) to accommodate multiple users. This evolutionary program is expected to meet the science requirements of increasingly sophisticated microgravity investigations and to permit the development of a system of experiment racks that will accommodate fluids and combustion for research throughout the era of the ISS. The facility will be launched in 3 major increments and when complete will be the Fluids and Combustion Facility (FCF). The first module to be launched will be the Combustion Integrated Rack (CIR) which will be capable of accommodating a wide range of investigations by integrating PI specific hardware into its chamber, diagnostic and fluids systems. At the same time, the division is continuing its drive to maximize the science return from its ground-based facilities. To achieve this goal, more rig development guidance and more common hardware is being provided. The goal of this process is to shorten the time it takes PI's to start using a facility and to further minimize the time needed to move an investigation from one ground-based facility to another. This will allow investigations to mature in the 2.2 second drop tower before moving to the 5.2 second facility or the parabolic aircraft.

I. FLIGHT HARDWARE

The experimental apparatus described in this section are under development for flight on ISS. NASA anticipates additional future flight opportunities for investigations capable of using this hardware. To accommodate as many investigations as possible, the chamber inserts and diagnostics systems are being designed to be as modular as possible. This will allow PI's to share many major systems, reducing cost and time to flight. These multi-PI subsystems are referred collectively as "Mini-facilities" at present three such facilities are envisioned to provide for droplet combustion, solid surface flame spread and gaseous jet diffusion flame investigations. Investigations that are proposed to use existing or shared hardware will have priority in the cost-benefit analysis.

More detailed descriptions of the planned systems are available on the web servers at:

http://microgravity.grc.nasa.gov/MSD/MSD_htmls/piinfo.html.

A. ISS COMBUSTION INTEGRATED RACK (CIR))

The United States Laboratory Module on the International Space Station will contain the Fluids and Combustion Facility (FCF). The FCF is a modular, multi-user, microgravity science facility that will occupy three powered payload instrumentation racks plus the equivalent volume of one unpowered stowage rack. Together the three racks will provide the fundamental physical and functional infrastructure necessary to perform combustion science, fluid physics, and adjunct science experiments on-board the International Space Station.

The Combustion Integrated Rack (CIR) will be the first FCF rack to be launched, with launch currently targeted for 2003. It will be equipped to operate as a single integrated rack to provide the initial set of Principal Investigators with the functionality required to perform their experiments. The CIR features a fold down optics plate, a combustion chamber, replaceable diagnostics, and an integrated gas mixing assembly. In approximately 2006 the Shared Accommodations Rack (SAR) will be launched and installed between the CIR and the Fluids Integrated Rack (FIR). This will complete the FCF and will enhance the diagnostics and data handling capabilities of the CIR. In particular, two additional window locations for optical access to the combustion chamber will be freed up by movement of image processing units to the SAR.

Optics Bench Features:

- Folds down and slides out for full and easy access
- Diagnostics can be easily replaced and interchanged
- Gas mixing system is integrated with the Combustion Chamber Assembly

Optics Bench Specifications:

- Width x Length x Depth: 86.5 x 124.5 x 10 cm
- Tubing and Wiring internal to bench

Diagnostics Specifications:

- 8 locations (6 until the SAR is available), Replaceable on-orbit
- W x L x D: 23 cm x 50 cm x 25 cm
- Baseline - Digital Cameras
  - soot volume fraction by laser light extinction, soot temperature by imaging multi-color pyrometry, Illumination, high frame rate with automatic object tracking, low light level ultraviolet, mid infra-red
- Up to 36 Giga-Bytes of data storage

Combustion Chamber Features:

- Breech Lock Hinged Front Lid
- Replaceable Windows
- Provides Interfaces to PI-Specific Hardware

Chamber Specifications:

- 40 cm Internal Diameter
- 90 cm Overall Length
- 100 Free Liters
- Maximum pressure of 10 atmospheres

Window Specifications:

- 8 Windows, 12 cm Viewable Diameter (until the SAR is on station, up to two windows may be obscured by image processing systems), 4 Pairs 180 degrees apart
- Replaced from inside chamber

PI Hardware Specifications:

- Maximum 40 cm Diameter
- Maximum 60 cm Overall Length

Instrumentation Ring:

- Provides interfaces internal to chamber
- 3 Electrical Connectors, Water Cooling Ports (2)
- Vacuum Port, Gas Delivery Port
- Exhaust Vent Port, Sample Port

Additional Features:

Fluid System Specifications:

- Capable of Mixing 3 Gases
- Three 3.8 L Bottles up to 14 MPa (-2000 PSI) each
- Static Blending
  - Partial Pressures
  - ~0.1 % Accuracy with 2 ideal gases
  - Accommodates pre-mixed bottles
- Dynamic
  - Mass flow controllers
  - ~0.1% Accuracy
  - Flow Rate
  - Oxidizer: Up to 2910 cc/sec
  - Fuel: Up to 8.33 cc/sec
  - Chemical Bed and Particle Mesh Filters
  - Designed to clean: Methane, Propane, n-Heptane, CO, CO_2, Sulfur Dioxide, Nitrous Oxide, plus others
- Gas Chromatograph

Data Acquisition Specifications:

- 48 Analog inputs, 16 Bits
- 1000 kHz sampling rates
- Stores 9 Gbytes
- High Rate Data Link: 20 Mbits/sec

Operations & Telescience:

- The FCF will be operated from the NASA Glenn Research Center Telescience Support Center. In concert with the Cleveland-based Operations Team, the Principal Investigator's experiment will be remotely monitored and controlled from the PI's home site.

More extensive discussion of the CIR and FCF capabilities are on the web site :

http://zeta.lerc.nasa.gov/fcfwww/fcf/tech.htm

B. MINI-FACILITY INSERTS

The inserts that are initially planned for the CIR are the Multi-user Droplet Combustion Apparatus (MDCA), the Multi-user Solid Fuel Apparatus (MSFA) and the Multi-user Gaseous Fuels Apparatus (MGFA). The MDCA design is based upon the Droplet Combustion Experiment (DCE) design and can deploy and ignite fuel droplets ranging from 1 mm to 5 mm. Multiple viewing angles (back lit and dark field) are supported. The droplets can be freely deployed or deployed onto a fiber. The fiber tether restrains the droplet from drifting, allowing higher resolution imaging.

The MSFA design is under development. The hardware is planned to support the study of solid fuel combustion under quiescent and slow air flows. The MGFA design is also under development but will benefit form the Laminar Soot Processes design heritage. The distance between the insert end plates will be approximately 400 mm and the radial clearance around the central axis will be better than 50 mm. More details of these mini-facilities are on the web site:

http://microgravity.grc.nasa.gov/MSD/MSD_htmls/piinfo.html.

C. ISS MICROGRAVITY SCIENCE GLOVEBOX

The Microgravity Science Glovebox (MSG) for the International Space Station (ISS) will be a larger version of the Middeck Glovebox used previously on space shuttle flights. The MSG is an enclosed volume that provides physical isolation of various small-scale experiments from the crew cabin and enables a crew member manipulation of these experiments through glove ports. It provides containment of powders, splinters, liquids, flames, or combustion products that may be produced from experiment operations.

The MSG will have a larger work area than the Middeck Glovebox to allow larger size and mass experiments to be conducted inside the Glovebox. The MSG will provide up to 1000 watts of experiment power, a vent connection, a nitrogen connection, an airlock, illumination, color and black and white video cameras and recorders for viewing, recording, or downlinking, and miscellaneous tools and cleaning supplies. It is envisioned that experiments will be conducted in the areas of fluid physics, combustion science, materials science, and biotechnology. The MSG will be developed by the European Space Agency and will be available for use soon after the deployment of the U.S. Laboratory Module of the ISS.

The overall philosophy of the Glovebox program is to provide the ability to conduct smaller, less complex science experiments or technology demonstrations in a microgravity environment in a faster, better, and cheaper manner. The hardware development cycle runs approximately 2 to 3 years. At this time, multiple Glovebox Investigations in the disciplines of materials science, fluid physics, biotechnology, and combustion science have been flown on USML-2 (September 1995), USMP-3 (February 1996), MSL-1 (July, 1997), and USMP-4 (November, 1997). The combustion science investigations have included Fiber Supported Droplet Combustion (FSDC), Comparative Soot Diagnostics (CSD), Forced Flow Flame spreading Test (FFFT), and Radiative Ignition and Transition to Spread Investigation (RITSI). The FFFT was also flown on the Russian Mir Space Station in November 1995, as was a reflight of Candle Flames in Microgravity (CFM), which flew earlier on USML-1. Future Glovebox combustion flight experiments currently in the development stage include another set of FSDC experiments, a Flame Interaction with Vortex Experiment (FIVE), and a Smoke Point in Coflow Experiment (SPICE); at this point it is not clear whether these will be flown in the Middeck Glovebox or the new ISS Microgravity Science Glovebox.

D. SOUNDING ROCKETS

A limited number of sounding rocket flights will be possible in future years. The sounding rocket is best suited to short duration experiments (5 minutes or less) that require limited real time human interaction and limited test matrices. Two microgravity combustion experiments, Spread Across Liquids (SAL) and Diffusive and Radiative Transport in Fires (DARTFire) have flown to date as sounding rocket experiments, utilizing the Terrier-Black Brant as a carrier. Five SAL tests and 4 DARTFire tests have been flown to date. In the configuration being employed, these sounding rockets provide approximately 7 minutes of quality microgravity time for an experiment weighing 450 pounds. The experiment can be up to 10 feet long and is fitted inside cylindrical skin sections that are optionally 15 inches or 22 inches in diameter.

The SAMS-FF experiment will provide a high-quality detailed characterization of the sounding rocket microgravity environment. This experiment will gather data at a high frequency triaxial sensor head and a roll rate sensor. The raw data will be post processed by the SAMS project and made available to the DARTFire Science team and prospective sounding rocket experimenters.

II. GROUND-BASED FACILITIES

Investigators often need to conduct reduced gravity experiments in ground-based facilities during the experiment definition and technology development phases. The NASA ground-based reduced-gravity research facilities that support the MRD combustion program includes two drop towers at Glenn Research Center (GRC) and a KC-135 aircraft that is based at JSC but may fly 6 campaigns per year from GRC. NASA data handling resources include wide area network connectivity, supercomputing, and directory services for NASA and non-NASA data holdings. Each of these facilities and resources has different capabilities and characteristics that should be considered by an investigator to determine which are best suited for conducting combustion science research.

A. 2.2-SECOND DROP TOWER

The 2.2-Second Drop Tower at GRC provides 2.2 seconds of low-gravity test time for experiment packages consisting of up to 125 kilograms of hardware. The experiment package is enclosed in a drag shield, and a gravitational acceleration of less than 10^{-5}g is obtained during the fall since the experiment package falls freely within the drag shield. The only external force acting on the falling experiment packages is the air drag associated with the relative motion of the package within the enclosure of the drag shield. At the end of a drop, the drag shield and the enclosed experiment are decelerated in a 2.2-meter-deep sand pit by the deceleration spikes. The peak deceleration rate can be as high as 70gs. Eight to twelve tests can be performed in one day. Data from experiments are acquired by high-speed motion picture cameras with rates of up to 1,000 frames per second and by on-board data acquisition systems used to record data supplied by thermocouples, pressure transducers, and flow meters.

B. 5.18-SECOND ZERO-GRAVITY FACILITY

The 5.18-Second Zero-Gravity Facility at GRC has a 132-meter free fall distance in a drop chamber that is evacuated to a final pressure of 1 Pa. Experiments utilizing hardware weighing up to 450 kilograms are mounted in a one-meter diameter by 3.4-meter high drop bus. Gravitational acceleration of less than 10^{-5} g is obtained. At the end of the drop, the bus is decelerated in a 6.1-meter deep container filled with small pellets of expanded polystyrene. The deceleration rate is typically 60g (for 20 ms). Visual data is acquired through the use of high-speed motion picture cameras. Also, other data such as pressures, temperatures, and accelerations are either recorded on board with various data acquisition systems or are transmitted to a control room by a telemetry system capable of transmitting 18 channels of continuous data. Due to the complexity of drop chamber operations and time required for pump-down of the drop chamber, typically only one test is performed per day.

C. REDUCED-GRAVITY AIRCRAFT

The KC-135 can provide periods of low gravity for up to 23-second intervals. The aircraft accommodates a variety of experiments and is often used to refine space flight experiment equipment and techniques and to train crew members in experiment procedures, thus giving investigators and crew members valuable experience in working in a weightless environment. Qualified observers or operators may fly with their experiment packages. The KC-135 obtains a low-gravity environment by flying a parabolic trajectory. Gravity levels twice those of normal gravity occur during the initial and final portions of the trajectory, while the brief pushover at the top of the parabola produces less than one percent of Earth's gravity (10^{-2} g). The interior KC-135 bay dimensions are 6 feet wide and 6.4 feet high by 60 feet long. Several experiments, including a combination of attached and free-floated hardware (which can provide effective gravity levels of nominally 10^{-3} g for periods of up to 10 seconds) can be integrated in a single flight. For small payloads, use of a Canadian vibration isolation system is also possible. This facility can either reduce the g-levels below the aircraft ambient or induce known acceleration disturbances. The aircraft can supply a total of 80 amps of 28 volt dc, 50 amps of 110 volt ac 60Hz and 20 amps open each phase of 3 phase 110 volt ac 400 Hz. These are maximum powers available to all users. Instrumentation and data collection capabilities must be contained in the experiment packages.

III. <u>DIAGNOSTICS/MEASUREMENTS CAPABILITY</u>

NASA has adapted or developed a large number of diagnostic/measurement techniques for use in the Microgravity Combustion research program, with some of these techniques, including particle imaging velocimetry, laser light scattering, and Rainbow Schlieren Deflectometry having already been demonstrated in flight. A brief list of techniques, already in use or under development and possibly available for use in future programs appears below.

1. Soot Temperature Measurements Using Pyrometric Techniques

2. Rainbow Schlieren for Measurement of Temperature Distributions

3. Planar 2D Temperature and CH and OH Concentration Measurements via Rayleigh Scattering and Laser-Induced Fluorescence

4. Light Sheet Flow Visualization and/or Velocimetry

5. Laser Doppler Velocimetry

6. Liquid Surfaces Temperature and Vapor Phase Concentration Measurements via Exciplex Fluorescence

7. Determination of CH4, CO2, and H2O Concentrations via Line Absorption Techniques

8. Planar Laser-Induced Fluorescence for Determination of Flame Front Position

9. Particle Imaging Velocimetry

10. Liquid Phase Thermometry and Fluorescence of Aromatics to Evaluate Droplet Surface Transport and Internal Flow

11. Diode Laser Wavelength Modulation Spectroscopy for Quantitative Molecular Oxygen Concentration Measurements.

12. Compact Laser-Diode CCD Array for Measuring Instantaneous Radial Variations of the Temperature Fields within a Burning Droplet and in the Gas-Phase Around it While Also Instantaneously Measuring Droplet Size and Regression rate.

13. Laser-Induced Incandescence for measurement of soot volume fractions

For further information on the state of development of these techniques for use in Microgravity Combustion research activities, please contact Dr. Paul Greenberg (NASA/Glenn Research Center) at 216-433-3621.

INSTRUCTIONS FOR RESPONDING TO NASA RESEARCH ANNOUNCEMENTS

(JANUARY 1997)

A. General

(1) Proposals received in response to a NASA Research Announcement (NRA) will be used only for evaluation purposes. NASA does not allow a proposal, the contents of that are not available without restriction from another source, or any unique ideas submitted in response to an NRA to be used as the basis of a solicitation or in negotiation with other organizations, nor is a pre-award synopsis published for individual proposals.

(2) A solicited proposal that results in a NASA award becomes part of the record of that transaction and may be available to the public on specific request; however, information or material that NASA and the awardee mutually agree to be of a privileged nature will be held in confidence to the extent permitted by law, including the Freedom of Information Act.

(3) NRA's contain programmatic information and certain requirements that apply only to proposals prepared in response to that particular announcement. These instructions contain the general proposal preparation information that applies to responses to all NRAs.

(4) A contract, grant, cooperative agreement, or other agreement may be used to accomplish an effort funded in response to a NRA. NASA will determine the appropriate instrument. Contracts resulting from NRA's are subject to the Federal Acquisition Regulation and the NASA FAR Supplement. Any resultant grants or cooperative agreements will be awarded and administered in accordance with the NASA Grant and Cooperative Agreement Handbook (NPG 5800.1).

(5) NASA does not have mandatory forms or formats for responses to NRA's; however, it is requested that proposals conform to the guidelines in these instructions. NASA may accept proposals without discussion; hence, proposals should initially be as complete as possible and be submitted on the proposers' most favorable terms.

(6) To be considered for award, a submission must, at a minimum, present a specific project within the areas delineated by the NRA; contain sufficient technical and cost information to permit a meaningful evaluation; be signed by an official authorized to legally bind the submitting organization; not merely offer to perform standard services or to just provide computer facilities or services; and not significantly duplicate a more specific current or pending NASA solicitation.

B. NRA-Specific Items. Several proposal submission items appear in the NRA itself: the unique NRA identifier; when to submit proposals; where to send proposals; number of copies required; and sources for more information. Items included in these instructions may be supplemented by the NRA.

C. Proposal Content. The following information is needed to permit consideration in an objective manner. NRAs will generally specify topics for which additional information or greater detail is desirable. Each proposal copy shall contain all submitted material, including a copy of the transmittal letter if it contains substantive information.

(1) ***Transmittal Letter or Prefatory Material.***

(i) The legal name and address of the organization and specific division or campus identification if part of a larger organization;

(ii) A brief, scientifically valid project title intelligible to a scientifically literate reader and suitable for use in the public press;

(iii) Type of organization: e.g., profit, nonprofit, educational, small business, minority, women-owned, etc.;

(iv) Name and telephone number of the principal investigator and business personnel who may be contacted during evaluation or negotiation;

(v) Identification of other organizations that are currently evaluating a proposal for the same efforts;

(vi) Identification of the NRA, by number and title, to which the proposal is responding;

(vii) Dollar amount requested, desired starting date, and duration of project;

(viii) Date of submission; and

(ix) Signature of a responsible official or authorized representative of the organization, or any other person authorized to legally bind the organization (unless the signature appears on the proposal itself).

(2) ***Restriction on Use and Disclosure of Proposal Information.*** Information contained in proposals is used for evaluation purposes only. Offerors or quoters should, in order to maximize protection of trade secrets or other information that is confidential or privileged, place the following notice on the title page of the proposal and specify the information subject to the notice by inserting an appropriate identification in the notice. In any event, information contained in proposals will be protected to the extent permitted by law, but NASA assumes no liability for use and disclosure of information not made subject to the notice.

Notice

Restriction on Use and Disclosure of Proposal Information

The information (data) contained in [insert page numbers or other identification] of this proposal constitutes a trade secret and/or information that is commercial or financial and confidential or privileged. It is furnished to the Government in confidence with the understanding that it will not, without permission of the offeror, be used or disclosed other than for evaluation purposes; provided, however, that in the event a contract (or other agreement) is awarded on the basis of this proposal the Government shall have the right to use and disclose this information (data) to the extent provided in the contract (or other agreement). This restriction does not limit the Government's right to use or disclose this information (data) if obtained from another source without restriction.

(3) ***Abstract***. Include a concise (200-300 word if not otherwise specified in the NRA) abstract describing the objective and the method of approach.

(4) ***Project Description.***

(i) The main body of the proposal shall be a detailed statement of the work to be undertaken and should include objectives and expected significance; relation to the present state of knowledge; and relation to previous work done on the project and to related work in progress elsewhere. The statement should outline the plan of work, including the broad design of experiments to be undertaken and a description of experimental methods and procedures. The project description should address the evaluation factors in these instructions and any specific factors in the NRA. Any substantial collaboration with individuals not referred to in the budget or use of consultants should be described. Subcontracting significant portions of a research project is discouraged.

(ii) When it is expected that the effort will require more than one year, the proposal should cover the complete project to the extent that it can be reasonably anticipated. Principal emphasis should be on the first year of work, and the description should distinguish clearly between the first year's work and work planned for subsequent years.

(5) ***Management Approach.*** For large or complex efforts involving interactions among numerous individuals or other organizations, plans for distribution of responsibilities and arrangements for ensuring a coordinated effort should be described.

(6) ***Personnel***. The principal investigator is responsible for supervision of the work and participates in the conduct of the research regardless of whether or not compensated under the award. A short biographical sketch of the principal investigator, a list of principal publications and any exceptional qualifications should be included. Omit social security number and other personal items that do not merit consideration in evaluation of the proposal. Give similar biographical information on other senior professional personnel who will be directly associated with the project. Give the names and titles of any other scientists and technical personnel associated substantially with the project in an advisory capacity. Universities should list the approximate number of students or other assistants, together with information as to their level of academic attainment. Any special industry-university cooperative arrangements should be described.

(7) ***Facilities and Equipment.***

(i) Describe available facilities and major items of equipment especially adapted or suited to the proposed project, and any additional major equipment that will be required. Identify any Government-owned facilities, industrial plant equipment, or special tooling that are proposed for use. Include evidence of its availability and the cognizant Government points of contact.

(ii) Before requesting a major item of capital equipment, the proposer should determine if sharing or loan of equipment already within the organization is a feasible alternative. Where such arrangements cannot be made, the proposal should so state. The need for items that typically can be used for research and non-research purposes should be explained.

(8) ***Proposed Costs.***

(i) Proposals should contain cost and technical parts in one volume: do not use separate "confidential" salary pages. As applicable, include separate cost estimates for salaries and wages; fringe benefits; equipment; expendable materials and supplies; services; domestic and foreign travel; ADP expenses; publication or page charges; consultants; subcontracts; other miscellaneous identifiable direct costs; and indirect costs. List salaries and wages in appropriate organizational categories (e.g., principal investigator, other scientific and engineering professionals, graduate students, research assistants, and technicians and other non-professional personnel). Estimate all staffing data in terms of staff-months or fractions of full-time.

(ii) Explanatory notes should accompany the cost proposal to provide identification and estimated cost of major capital equipment items to be acquired; purpose and estimated number and lengths of trips planned; basis for indirect cost computation (including date of most recent negotiation and cognizant agency); and clarification of other items in the cost proposal that are not self-evident. List estimated expenses as yearly requirements by major work phases.

(iii) Allowable costs are governed by FAR Part 31 and the NASA FAR Supplement Part 1831 (and OMB Circulars A-21 for educational institutions and A-122 for nonprofit organizations).

(9) ***Security***. Proposals should not contain security classified material. If the research requires access to or may generate security classified information, the submitter will be required to comply with Government security regulations.

(10) ***Current Support.*** For other current projects being conducted by the principal investigator, provide title of project, sponsoring agency, and ending date.

(11) ***Special Matters***.

(i) Include any required statements of environmental impact of the research, human subject or animal care provisions, conflict of interest, or on such other topics as may be required by the nature of the effort and current statutes, executive orders, or other current Government-wide guidelines.

(ii) Proposers should include a brief description of the organization, its facilities, and previous work experience in the field of the proposal. Identify the cognizant Government audit agency, inspection agency, and administrative contracting officer, when applicable.

D. Renewal Proposals.

(1) Renewal proposals for existing awards will be considered in the same manner as proposals for new endeavors. A renewal proposal should not repeat all of the information that was in the original proposal. The renewal proposal should refer to its predecessor, update the parts that are no longer current, and indicate what elements of the research are expected to be covered during the period for which support is desired. A description of any significant findings since the most recent progress report should be included. The renewal proposal should treat, in reasonable detail, the plans for the next period, contain a cost estimate, and otherwise adhere to these instructions.

(2) NASA may renew an effort either through amendment of an existing contract or by a new award.

E. Length. Unless otherwise specified in the NRA, effort should be made to keep proposals as brief as possible, concentrating on substantive material. Few proposals need exceed 15-20 pages. Necessary detailed information, such as reprints, should be included as attachments. A complete set of attachments is necessary for each copy of the proposal. As proposals are not returned, avoid use of “one-of-a-kind” attachments.

F. Joint Proposals.

(1) Where multiple organizations are involved, the proposal may be submitted by only one of them. It should clearly describe the role to be played by the other organizations and indicate the legal and managerial arrangements contemplated. In other instances, simultaneous submission of related proposals from each organization might be appropriate, in which case parallel awards would be made.

(2) Where a project of a cooperative nature with NASA is contemplated, describe the contributions expected from any participating NASA investigator and agency facilities or equipment which may be required. The proposal must be confined only to that which the proposing organization can commit itself. “Joint” proposals which specify the internal arrangements NASA will actually make are not acceptable as a means of establishing an agency commitment.

G. Late Proposals. A proposal or modification received after the date or dates specified in an NRA may be considered if doing so is in the best interests of the Government.

H. Withdrawal. Proposals may be withdrawn by the proposer at any time before award. Offerors are requested to notify NASA if the proposal is funded by another organization or of other changed circumstances which dictate termination of evaluation.

I. Evaluation Factors.

(1) Unless otherwise specified in the NRA, the principal elements (of approximately equal weight) considered in evaluating a proposal are its relevance to NASA's objectives, intrinsic merit, and cost.

(2) Evaluation of a proposal's relevance to NASA's objectives includes the consideration of the potential contribution of the effort to NASA's mission.

(3) Evaluation of its intrinsic merit includes the consideration of the following factors of equal importance:

(i) Overall scientific or technical merit of the proposal or unique and innovative methods, approaches, or concepts demonstrated by the proposal.

(ii) Offeror's capabilities, related experience, facilities, techniques, or unique combinations of these which are integral factors for achieving the proposal objectives.

(iii) The qualifications, capabilities, and experience of the proposed principal investigator, team leader, or key personnel critical in achieving the proposal objectives.

(iv) Overall standing among similar proposals and/or evaluation against the state-of-the-art.

(4) Evaluation of the cost of a proposed effort may include the realism and reasonableness of the proposed cost and available funds.

J. Evaluation Techniques. Selection decisions will be made following peer and/or scientific review of the proposals. Several evaluation techniques are regularly used within NASA. In all cases proposals are subject to scientific review by discipline specialists in the area of the proposal. Some proposals are reviewed entirely in-house, others are evaluated by a combination of in-house and selected external reviewers, while yet others are subject to the full external peer review technique (with due regard for conflict-of-interest and protection of proposal information), such as by mail or through assembled panels. \The final decisions are made by a NASA selecting official. A proposal which is scientifically and programmatically meritorious, but not selected for award during its initial review, may be included in subsequent reviews unless the proposer requests otherwise.

K. Selection for Award.

(1) When a proposal is not selected for award, the proposer will be notified. NASA will explain generally why the proposal was not selected. Proposers desiring additional information may contact the selecting official who will arrange a debriefing.

(2) When a proposal is selected for award, negotiation and award will be handled by the procurement office in the funding installation. The proposal is used as the basis for negotiation. The contracting officer may request certain business data and may forward a model award instrument and other information pertinent to negotiation.

L. Cancellation of NRA. NASA reserves the right to make no awards under this NRA and to cancel this NRA. NASA assumes no liability for canceling the NRA or for anyone's failure to receive actual notice of cancellation.

APPENDIX E
NRA-99-HEDS-04

NASA RESEARCH ANNOUNCEMENT (NRA) SCHEDULE

MICROGRAVITY COMBUSTION SCIENCE: RESEARCH AND FLIGHT EXPERIMENT OPPORTUNITIES

All proposals submitted in response to this Announcement are due on the date and at the address given below by the close of business (4:30 PM EST). NASA reserves the right to consider proposals received after this deadline if such action is judged to be in the interest of the U.S. Government. A complete schedule of the review of the proposals is given below:

NRA Release Date: ....November 15, 1999

Letter of Intent Due: ....January 5, 2000

Proposal Due: ....February 15, 2000

Submit Proposal to:

Dr. Merrill K. King
c/o Indyne, Inc.
Subject: NASA Research Proposal (NRA-99-HEDS-04)
300 D Street, SW, Suite 801
Washington, DC 20024
Telephone number for delivery services: (202) 479-2609

Final Selections: ....September, 2000

Funding commences: ....No sooner than October, 2000
(dependent upon actual selection and procurement process)