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MICROGRAVITY COMBUSTION DISCIPLINE WORKING GROUP SUMMARY OF REQUIREMENTS FOR NONCONTACT TEMPERATURE MEASUREMENTS

KURT SACKSTEDER
NASA LEWIS RESEARCH CENTER
CLEVELAND, OHIO

INTRODUCTION

Combustion systems consist of the complex interaction of competing, time-dependent mechanisms including: fluid motion (often multi-phase), various modes of heat and mass transfer, phase changes, and chemical reactions. Low gravity experiments are conducted in combustion research in support of practical combustion systems in earth-based normal-gravity environments as well as the low-gravity environment of space.

The motivations for conducting combustion experiments in a low-gravity environment are of four basic types. The direct influence on combustion systems of gravitational acceleration, the influence of other mechanisms that are obscurred or masked by gravitational influences in a normal-gravity environment, the unique initial or boundary conditions that can be created in low gravity, and a determination of the mechanisms that limit low-gravity combustion are the underlying justifications for each low-gravtity combustion project.

Gravitational potential, acting on the large density gradients caused by the heat release typical of combustion systems, induces buoyant convection that asserts an influence on the flow field which in turn affects the mechanisms that control the rate of heat release. Thus, density gradients are a result of the net action of the participating mechanisms and are also the means by which gravity acts upon the system. Through buoyancy, gravitational influence is coupled directly or indirectly to most of the fundamental mechanisms of combustion systems.

In combustion systems containing dispersed solid or liquid particulates in a host fluid, a gravitational field acts on the interfacial density differences and results in the settling, or sedimentation of the denser particulates through the surrounding fluid. In addition to creating uncertainties in the distribution of the particulates, gravitational settling induces secondary flows in the wake of the settling particles. Low-gravity experiments remove the complexity introduced by the settling action.

Non-buoyant driving potentials for fluid motion are usually present in normal-gravity combustion systems, but are often overwhelmed by buoyant flow. Normal-gravity studies of forced-flow influences are common in combustion research, but become difficult to interpret when the forced-flow and buoyant-flow velocities are of comparable size. In systems involving a free liquid surface that is unevenly heated, gradients in the liquid surface tension provide a driving potential for motion in the liquid phase and, through interfacial viscous interactions, motion in the vapor phase. Vaporization of a condensed phase fuel, because of the large density change associated with the phase transition, provides yet another source of fluid motion. Low-gravity studies permit the investigation of sub-buoyant velocities of each of these types.

Molecular diffusion of fuel, oxidizer, inert diluent and product species directly affect the statistical proximity of the reactant molecules in a combustion system. In systems where the fuel and oxidizer are not mixed before encountering the combustion zone, diffusion processes modified by buoyancy and perhaps other flow-field influences largely determined the flame characteristics. In low-gravity experiments the role of diffusional processes can be assessed under conditions of better flow-field control. Low-gravity experiments have also provided insight into premixed-gas systems where unequal rates of molecular diffusion of the reactants influence the limits of flammability.

Favorable boundary conditions, symmetries and initial conditions are possible in some low-gravity combustion experiments. Small masses of fuel can be mechanically isolated from the surroundings creating a spherical symmetry that is undisturbed by buoyant flows or motion of the fuel mass through the air. Dispersed fuel systems can be preconditioned for uniform distribution without contending with sedimentation or the various turbulent air disturbances that are required to distribute such fuels in normal-gravity environments.

Current efforts in low-gravity combustion research exploit each of these opportunities to obtain data of a fundamental nature for the enhancement of the modeling of normal-gravity combustion systems. As a distinct goal, a fundamental understanding of the limiting mechanisms of various combustion systems proceding in low-gravity environment is sought to enable the development of advanced concepts in spacecraft fire safety. To the extent that low-gravity experiment time becomes available, a data base for the combustion related properties of various potential spacecraft materials can be evolved.

Current Microgravity Combustion Efforts

Current work in the Microgravity Combustion Program includes efforts in solid, liquid and gaseous fuels. Work in solid fuels is concerned firstly with understanding the detailed physical mechanisms of the spreading of established flames and secondly with understanding the relationship between fuel properties and environmental conditions that together determine the flammability of a material. Work in quiescent and forced-flow systems of nonmetallic fuels is in progress and metals combustion efforts are contemplated. In related work, smoldering combustion is being studied to understand the controlling mechanisms of the propagation of the smoldering wave and the conditions under which the smoldering process transitions to either flaming combustion or extinction.

In liquid fuels two classes of problems are being addressed. Droplet vaporization and combustion studies are concerned with the rates at which these processes occur, the occurance of related processes such as soot formation and droplet microexplosions, and an understanding of the scaling of these processes between droplets large enough to observe and the microscopic droplets that are characteristic of engines, furnaces, etc. Pool fire studies are concerned with the effects of the extended-surface properties particularly surface tension, and how these properties affect both the ignition of such fires and their propagation.

Flames in gaseous fuels are of particular fundamental interest and provide insight into more complex multiphase systems. Premixed and unpremixed systems are being studied to understand the role of diffusional processes in propagation rates and flammability characterizations.

Temperature Measurement Requirements

Knowledge of the temperature field in a combustion system provides information about several of the key participating mechanisms. The maintenance or propagtion of a flame depends upon the magnitude and modes of heat transfer from the reaction zome to the unburnt fuel. The reinvestment of the chemical energy released in the flame is applied to the generation of fresh fuel through a phase change in a multiphase system such as solid surface flame spreading or droplet combustion; and is also applied to the continued ignition of fresh fuel and exidizer mixture. Multiphase heat conduction, convection and radiation are each characterized in part by a determination of temperatures and their first and second derivatives at well chosen locations in the system.

The chemistry of combustion systems and the rate at which the reactions occur are strong functions of local temperature. Models of system chemistry range in complexity from a lumped model of a single-step reaction to a detailed array of perhaps scores of elementary reactions. In each case the rate of such reactions are exponential functions of local temperature, and any approach to accurate modeling requires temperature information of fairly high quality.

Many of the combustion systems that are studied in the low-gravity environment are near-limit systems, that is, systems that are acting near the limit of flammability in terms of oxygen concentration or fuel concentration. Systems of this type are normally weak in the sense that there is a delicate balance between the heat released in the flame and the heat required to sustain the flame. Any externally induced losses of heat from the system can drive the system unnaturally to extinction. Intrusive or perturbative temperature measurement probes such as thermocouples can be inaccurate in these situations and in the limiting case extinguish the flame. Noncontact or nonperturbative techniques then become the only way to obtain the required measurements.

In the general sense, a temperature measurement system for use in combustion research must be capable of probing the temperature field in each thermodynamic phase of the system. In the gas phase local measurements must be made in the presence of highly luminous flames and soot particles. While measurements of temperature in the depth of condensed phases(s), viz. solids and/or liquids are helpful, quite often the determination of the surface temperature will yield the more important information of surface properties such as local surface tension in liquids, phase transition rates (sublimation or boiling,) and surface emissivity. Often these measurements must be attempted where the surface location changes with time because of such things as surface-tension induced distortions and phase-change induced surface regression.

While it would always be desireable to have complete knowledge of the temperature field throughout the vicinity of a combustion system, a choice must often be made between local or point measurements and two-dimensional measurements in a plane passing through the system. Even in systems that are temporally stationary, the durations of most combustion experiments are limited. Thus many repeated experiments can be required to map the temperature field using point measurement techniques. The limited number of experiments that can be performed in the various low gravity facilities thus result generally in unacceptable spatial resolutions for the temperature measurements. Planar measurements while providing full-field information generally do so at the cost of considerable reduction in the measurement accuracy and precision. Perhaps the best comprise for many combustion systems is to obtain planar measurements as a matter of course, augmented as required by carefully selected point measurements. Confronted with a choice of measurements of only one type, the planar measurement would most often be reluctantly selected.

The table below summarizes the noncontact temperature measurement requirements of the Microgravity Combustion Discipline, providing measurement ranges and resolutions in space and time for each of three thermodynamic phases.

MICROGRAVITY COMBUSTION DISCIPLINE
NONCONTACT TEMPERATURE MEASUREMENT REQUIREMENTS

	Temperature Range (^{o}K)	Resolution		Measurement Accuracy (^{o}K)
		Spatial (mm)	Temporal (msec)	
Solid Phase (Surface)	270-800	1	20	5
Liquid Phase (Surface)	270-350	0.5	40	0.2
Vapor Phase	300-3000	1	20	5

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