PRESENTATION 2.2.3

N91-28224

IGNITION AND COMBUSTION

OF

METALLIZED PROPELLANTS

IGNITION AND COMBUSTION OF METALLIZED PROPELLANTS

Stephen R. Turns
Department of Mechanical Engineering

I. Research Objectives and Potential Impact on Propulsion

The overall objective of our research is the development of a fundamental understanding of the ignition and combustion of aluminum-based slurry (or gel) propellant droplets using a combination of experiment and analysis. Specific objectives are the following:

1. The development and application of a burner/spray rig and single particle optical diagnostics to study the detailed ignition and combustion behavior of small (10-75 μm) droplets, typical of those encountered in practical applications.

2. Understanding the role of surfactants and gellants (or other additives) in promoting or inhibiting secondary atomization of propellant droplets.

3. The extension of previously developed analytical models and the development of new models to address the phenomena associated with microexplosions (secondary atomization).

Slurry or gelled propellants in which a solid constituent is suspended in a combustible liquid have been of interest for propulsion applications for several decades. Depending upon the application, these propellants are advantageous because of either their energy content per unit mass or per unit volume. Many solid chemical elements are attractive for formulating slurry or gelled propellants. For example, carbon, aluminum, and boron all offer substantial increases in volumetric heat of combustion compared to hydrocarbon fuels, while on a gravimetric basis, only boron provides an increased heating value [1].

For rocket applications, specific impulse and mass density control the payload capability for a fixed vehicle configuration. Thus, high mass density propellant systems, such as Al/RP-1/O_2, become attractive to consider as alternatives to more conventional propellant systems. Zurawski and Green [2] show that an RP-1/60% Al fuel has the potential of delivering 17% more payload than a pure RP-1 fuel for an upper-stage vehicle mission.

Several key technical issues impact the use of Al/RP-1 slurries or gels in propulsion systems. Among these are rheological properties and ignition and combustion characteristics. In the area of rheology, questions concerning the proper formulation to provide a stable easily pumpable slurry with acceptable spray characteristics remain unanswered. With regard to ignition and combustion, the issue of concern is the relatively long residence times associated with these processes and two-phase flow losses. These issues are the focus of our research. We have found in previous studies of Al/JP-10 slurries that the additives used to produce desirable rheological properties impact on the ignition characteristics [3]. For example, the addition of surfactants to a slurry blend tend to promote the break up of burning slurry droplets into a very large number of smaller droplets. The aluminum in these small drops readily ignites and burns rapidly. In addition, the particle sizes of the aluminum oxide products are smaller, thus decreasing two-phase flow losses. Achieving the research objectives will provide detailed knowledge of the effect of blending agents on ignition and combustion of slurry fuels. This information will help lead to formulation of propellants which provide an optimum combination, or an intelligent trade-off, of rheological and combustion characteristics. Moreover, understanding and being able to predict ignition times for small droplets will provide guidelines for feasibility and developmental studies of metallized propellant engine systems prior to the construction of costly demonstration hardware.

II. Current Status and Results

Our efforts to date have focused primarily on the design, fabrication, set-up, and calibration of the various experimental systems required to study the ignition and combustion of 10-100 μm diameter slurry droplets. The major systems are the burner/spray rig and the optical diagnostics. Schematics of these systems are shown in Figs. 1 and 2, respectively. The design objectives for the burner/spray rig were to provide a laminar, homogeneous post-flame region for slurry ignition; to allow flashback-free operation over a range of stoichiometries while operating with oxidizers ranging from air to 100% oxygen; to isolate the post-flame gases from the ambient atmosphere; to produce a spray of aluminum slurry droplets varying in size from approximately 10 to 100 μm in diameter and introduce a portion of this spray into the post flame region; and to provide for fixed mounting of laser optics through the use of a traversing burner support. A burner meeting these requirements was designed, fabricated, and installed in the laboratory. The system is operational, and its detailed performance is currently being evaluated. The burner head is based on a design discussed in Ref. [4]. Gaseous fuel enters the base of the burner and passes through a dispersion ring that evenly distributes the gas around the perimeter of a fuel chamber. From here, the fuel passes through 72 stainless steel tubes and exits the burner at the top surface of a honeycomb matrix. The oxidizing gas enters the middle section of the burner and passes through another dispersion ring above the manifold plate. This gas then flows up around the 72 fuel tubes and through the open cells of the honeycomb matrix surrounding these tubes. This configuration results in a small, laminar, diffusion flame at the exit of each fuel tube. These flames merge rapidly providing an excellent approximation of a pre-mixed, laminar, flat flame. Slurry droplets generated in the spray chamber at the bottom of the burner pass through a tube located along the centerline of the burner and exit into the hot product gases. The spray nozzle is of the gas atomizing type and was selected based on work with coal/water slurries [5]. Initial testing with water showed that the system delivers droplets of the desired size range into the hot product stream.

The principal diagnostic being used to study droplet ignition, burning, and secondary atomization is a laser-based sizing and velocity measurement system. By measuring the evolution of the drop-size distribution with distance downstream of the burner face, we will be able to ascertain whether the droplets burn without disruption

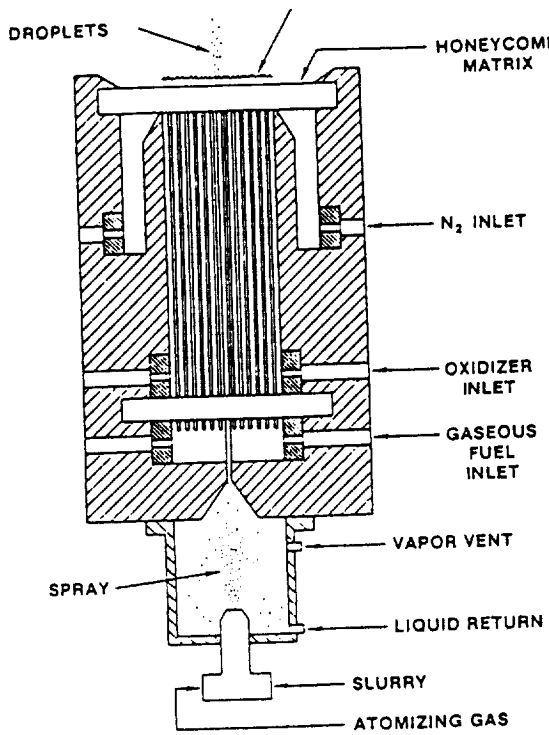

FIG. 1. Burner and spray rig.

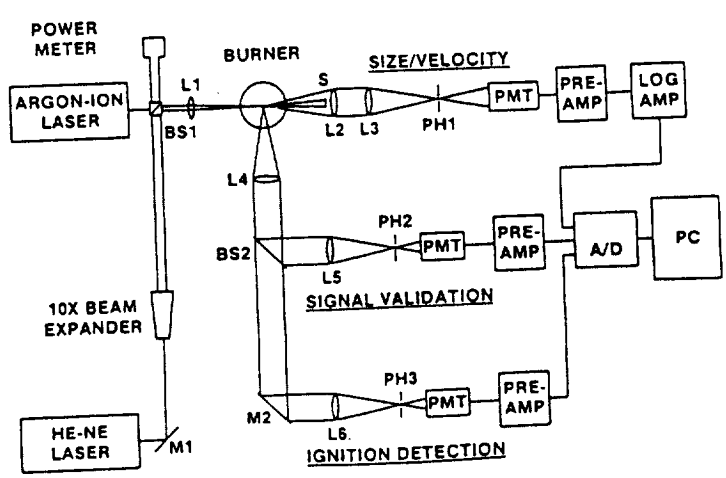

FIG. 2. Optical system for particle sizing and velocity measurements.

or if they disrupt. The laser light scattering system designed and built to accomplish these measurements is shown in Fig. 2. In principle, the two-color laser light scattering technique [6] operates as follows: droplets pass through the 350 μm diameter waist of a focused Ar-ion laser beam. Light scattered by the droplets in the forward direction is related to particle size, with larger particles producing a larger signal. Because of the Gaussian distribution of light intensity in the laser beam, only data from droplets that pass through the beam center should be accepted. This eliminates the ambiguity associated with the light scattered by droplets passing through the edge of the beam. For example, a large droplet at the edge of the beam would scatter the same amount of light as a small droplet passing through the center. To accomplish this discrimination, a second beam from a He-Ne laser is aligned concentrically with the Ar-ion beam, but focused to a much smaller waist of approximately 80 μm. Comparison of the time-dependent signals associated with scattering of the He-Ne and Ar-ion beams determines whether the droplet passed through the central region of the Ar-ion beam.

The determination of the particle size is accomplished by a calibration of the scattered intensity associated with light diffracted through pinholes of known size and by performing measurements in a stream of monodisperse water droplets. Droplets of known size are generated with a Berglund-Liu droplet generator. Results of a typical droplet size calibration are shown in Fig. 3. In addition to obtaining information on droplet size, knowing the beam diameter readily permits the calculation of droplet velocity from the droplet time-of-flight through the beam. Figure 4 illustrates a typical voltage-versus-time trace for a 90 μm water droplet passing through the probe volume. The peak voltage of approximately 5.5 volts from the upper trace provides the size information (c.f. calibration curve in Fig. 3.). The droplet velocity computed from the width of the trace is 1.3 m/s. The signal validation pulse associated with the light scattered from the concentric red beam is the smaller signal centered below the primary scattering signal.

III. Proposed Work for Coming Year

During the next 12-month period, the following tasks are planned:

Task 1. Completion of software development for data acquisition and signal processing.

Task 2. Integrated operation of the complete system (burner, spray rig, particle sizing and velocimetry systems, data acquisition, and data processing) using pure liquids and aluminum slurry fuels.

Task 3. Perform screening study to establish which slurry formulation should be used as a baseline.

Task 4. Conduct parametric study using baseline slurry.

Task 5. Begin modeling effort.

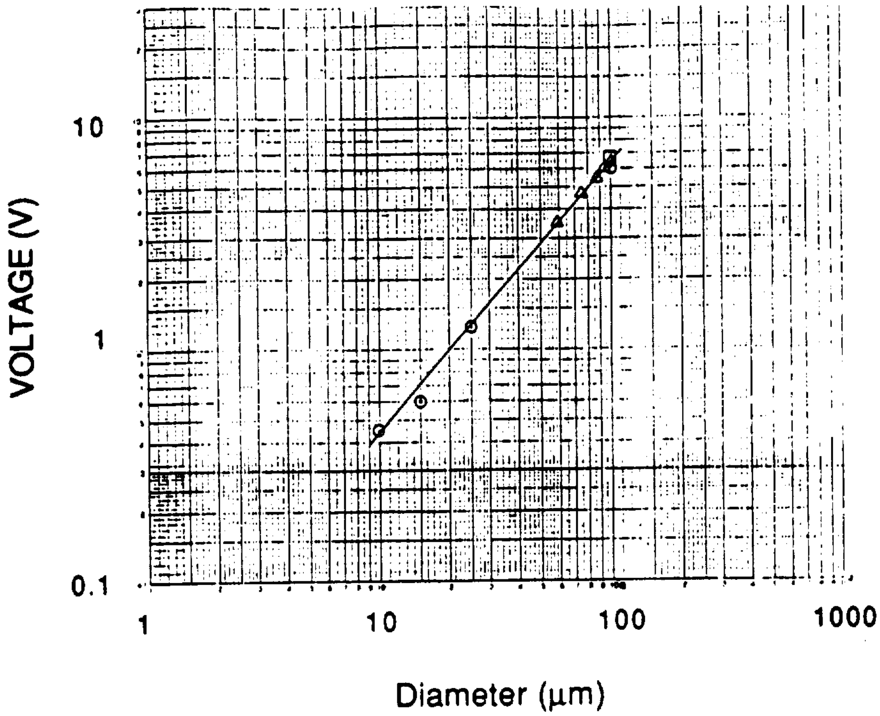

FIG. 3. Particle sizing calibration.

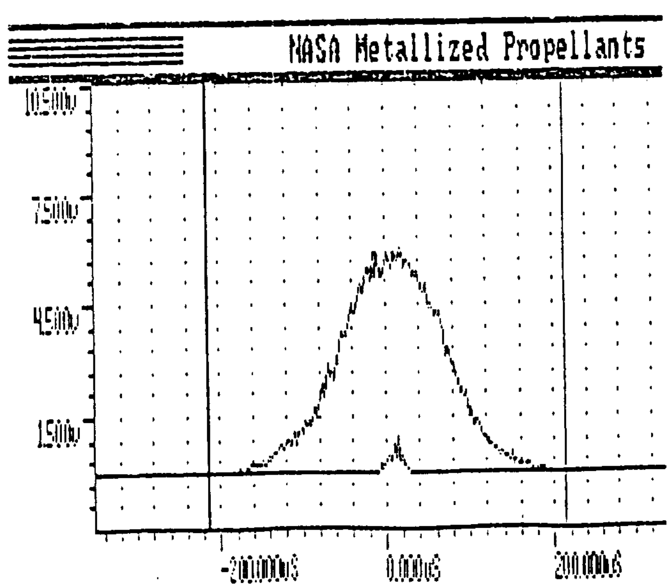

FIG. 4. Voltage-vs.-time trace for water droplet passing through probe volume.

Task 1. At present, our data acquisition capability is limited to obtaining voltage-versus-time records for the scattering signals associated with the transit of a single particle through the focal volume. Software for a main menu control has been written which provides set-up of the acquisition parameters for all A/D boards. The following describes the software that will be completed in the early portion of the upcoming year. The data collection software performs the signal validation and records the pulse height and width of the Ar-ion signal and whether or not the particle was ignited. Signal validation involves checking for the presence of multiple particles in the probe volume, peak saturation, pulse shape, and whetber the Ar-ion pulse is completely contained within the data sample taken. The program will only accept complete single particle signals for analysis, rejecting all other data. The peak and the leading and trailing edges of the Ar-ion signal also are located at this time. The Ar-ion signal pulse width is then calculated, and the pertinent information is passed to storage. This extraction of the critical information from the signal drastically reduces the disk space required to define a single particle, making possible the storage of a large number of samples. The data analysis portion of the software reads particle data from a specified file and performs the necessary sizing and velocity calculations based on drop-size calibrations of the laser system. After this is done, the results are written to a second data file for further statistical and graphical analysis.

Task 2. This task is the final shakedown of the complete experimental system. Initial experiments will be conducted with pure liquids to simplify fuel handling. The burner operation limits will be investigated to determine maximum and minimum gas velocities that can be achieved with different mixture fractions and oxygen content of the oxidizer stream.

Task 3. At present, three Al/hydrocarbon gelled fuels are available: a 55 wt. % Al/RP-1 fuel formulated by Sun Advanced Research and Marketing; a 53.8 wt. % Al/RP-1 blend formulated by TRW Space & Technology Group; and a 55 wt. % Al/RP-1 gelled fuel from Aerojet TechSystems. Different blending agents were used in each of these formulations, so each fuel is likely to exhibit different secondary atomization characteristics. Tests will be conducted on each blend to ascertain which fuel provides the best secondary atomization characteristics for a limited set of test conditions. The fuel selected will be used in the following task.

Task 4. Using the baseline fuel, an extensive set of parametric experiments will be carried out. These experiments will explore the effects of the hot gas environment on secondary atomization. The parameters to be investigated include: gas temperature, oxygen concentration, and residence time. A second set of experiments will be planned to investigate the effects of the minor constituents in the fuel blends on secondary atomization.

Task 5. In support of the experimental efforts in Task 4, data will be analyzed using codes which predict droplet ignition and combustion times. Existing codes are presently being modified for this task. A physical model for crust formation on slurry droplets during the RP-1 burnout phase will be formulated, and the appropriate conservation laws applied.

IV. References

1. Pinns, M. L., Olson, W. T., Barnett, H. C., and Breitwieser, R., "NACA Research on Slurry Fuels," NACA Report 1388, 1958.

2. Zurawski, R. L., and Green, J. M., "An Evaluation of Metallized Propellants Based on Vehicle Performance," AIAA paper AIAA-87-1773, presented at the 23rd Joint Propulsion Conference, San Diego, CA, June 29-July 2, 1987.

3. Wong, S.-C., and Turns, S. R., "Disruptive Burning of Aluminum/Carbon Slurry Droplets," Combust. Sci. and Tech., 66:75-92, 1989.

4. Barlow, R. S., Dibble, R. W., Chen, J.-Y., and Lucht, R. P., "Effect of Damkohler Number on Superequilibrium OH Concentration in Turbulent Nonpremixed Jet Flames," AIAA paper AIAA-89-0061 presented at the 27th Aerospace Sciences Meeting, January 9-12, 1989.

5. Holve, D. J., and Meyer, P. L., "Coal/Water Slurries: Fuel Preparation Effects on Atomization and Combustion," Combustion Science and Technology, 52:243-268, 1987.

6. Wang, J. C. F., and Hencken, K. R., "In Situ Particle Size Measurements Using a Two-Color Laser Scattering Technique," Applied Optics, 25: 653-657, 1986.