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DROPLET-TURBULENCE INTERACTIONS IN SUBCRITICAL AND SUPERCRITICAL EVAPORATING SPRAYS

DROPLET-TURBULENCE INTERACTIONS IN SUBCRITICAL AND SUPERCRITICAL EVAPORATING SPRAYS

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I. Research Objectives and Potential Impact on Propulsion

The objective of this research is to obtain an improved understanding of droplet-turbulence interactions in vaporizing liquid sprays under conditions typical of those encountered in liquid fueled rocket engines. The interaction between liquid droplets and the surrounding turbulent gas flow affects droplet dispersion, droplet collisions, droplet vaporization and gas-phase, fuel-oxidant mixing, and therefore has a significant effect on the engine's combustion characteristics. An example of this is the role which droplet-turbulence interactions are believed to play in combustion instabilities. Despite their importance, droplet-turbulence interactions and their effect on liquid fueled rocket engine performance are not well understood. This is particularly true under supercritical conditions, where many conventional concepts, such as surface tension, no longer apply. Our limited understanding of droplet-turbulence interactions, under both sub-critical and supercritical conditions, represents a major limitation in our ability to design improved liquid fueled rocket engines. It is expected that the results of this research will provide previously unavailable information and valuable new insights which will directly impact the design of future liquid fueled rocket engines, as well as, allow for the development of significantly improved spray combustion models, making such models useful design tools.

II. Current Status and Results

The primary efforts to date have been devoted to the development of the experimental apparatus and diagnostic techniques required for this study. This includes the development of a flow system which is capable of simulating the broad range of turbulent flow conditions encountered in the peripheral regions of coaxial and impinging type rocket sprays. It is in this region (see Figure 1) where droplet-turbulence interactions are most important and have significant effects on droplet vaporization, droplet dispersion and droplet collisions, as well as, on gas-phase, fuel-oxidant mixing. The basic concept of this flow system is illustrated in Figure 2. A novel turbulence generator [1] is used to produce turbulent flow conditions which are uniform over the cross-section of the test section to within ±10%, with relative turbulence intensities of up to 70% and mean velocities of up to 50 m/sec. A uniform, 10mm diameter, polydispersed spray of variable droplet density and size distribution is produced using a low pressure spray nozzle and skimmer combination, as illustrated in Figure 2. Droplet size distributions between 10 and 200 microns, droplet number densities between 10^3/cc and 10^4/cc, and mean drop velocities of up to 10m/sec. can be achieved with this device. This spray is transversely injected into the one-dimensional turbulent flow, thereby providing a well defined region of droplet turbulence interactions. A single droplet generator is also being developed in order to study the interaction between individual droplets and turbulence.

An atmospheric pressure, room temperature version of this system is currently in operation and has been used extensively for diagnostic development. A high pressure (70 atm) elevated temperature (300°C) turbulent flow system has also been designed and is currently being fabricated. This system will be capable of achieving supercritical conditions for a number of liquids including liquid oxygen, liquid nitrogen, as well as most liquid hydrocarbons. A schematic drawing of this system is shown in Figure 3, along with the single droplet generator which is being fabricated for use in this study.

Droplet-turbulence interactions basically refer to the mass, momentum and energy transport processes which occur between individual droplets and the surrounding turbulent gas. This interaction is important both under conditions of low droplet number density, where the droplets can be treated as individual, isolated droplets, as well as under conditions of high droplet number density, where droplet-droplet interactions become important. In order to characterize the exchange of mass, momentum and energy between the droplets and the turbulent gas flow it is necessary to measure the properties of individual droplets (i.e. size, velocity, temperature) and of the gas (i.e. mean velocity, turbulence intensity, integral scales, energy spectrum, and fuel/oxidant). In the case of the droplets, since the transport rates depend on the droplet size, it is necessary to simultaneously measure the size and velocity, for example, of individual droplets in order to characterize droplet drag. The desired size-velocity and size-temperature correlations can be obtained with point measurement techniques, however, it was decided to use two-dimensional, laser sheet imaging which also provides information on the spray structure. The technique which has been developed for these measurements is referred to as double-pulsed, laser sheet, fluorescence imaging [2]. This technique is

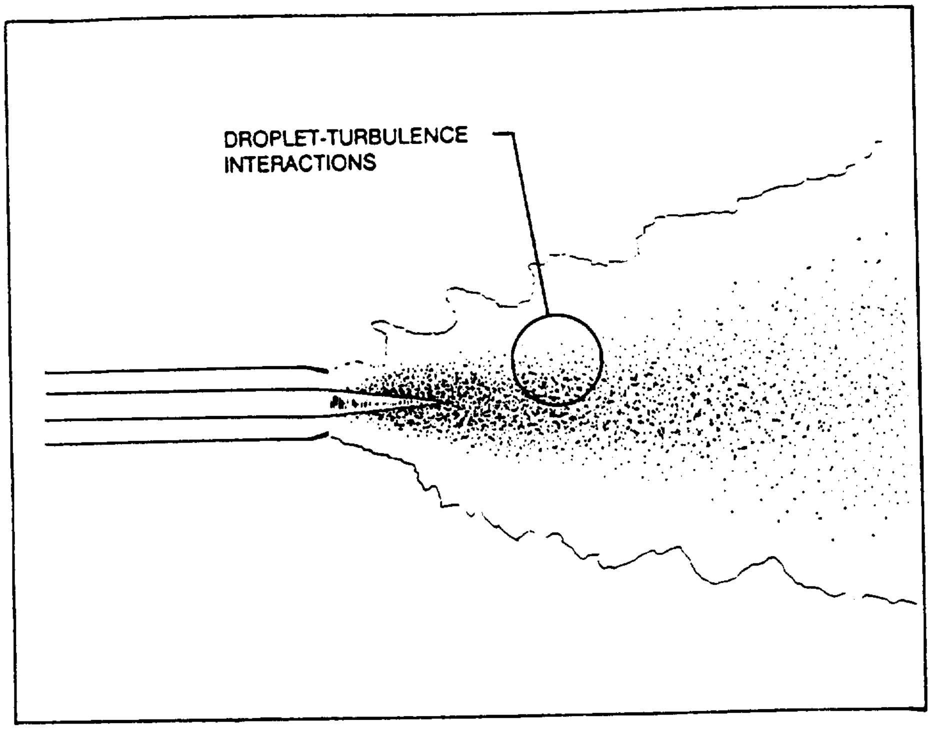

Figure 1. Region of droplet-turbulence interactions in co-axial liquid rocket spray.

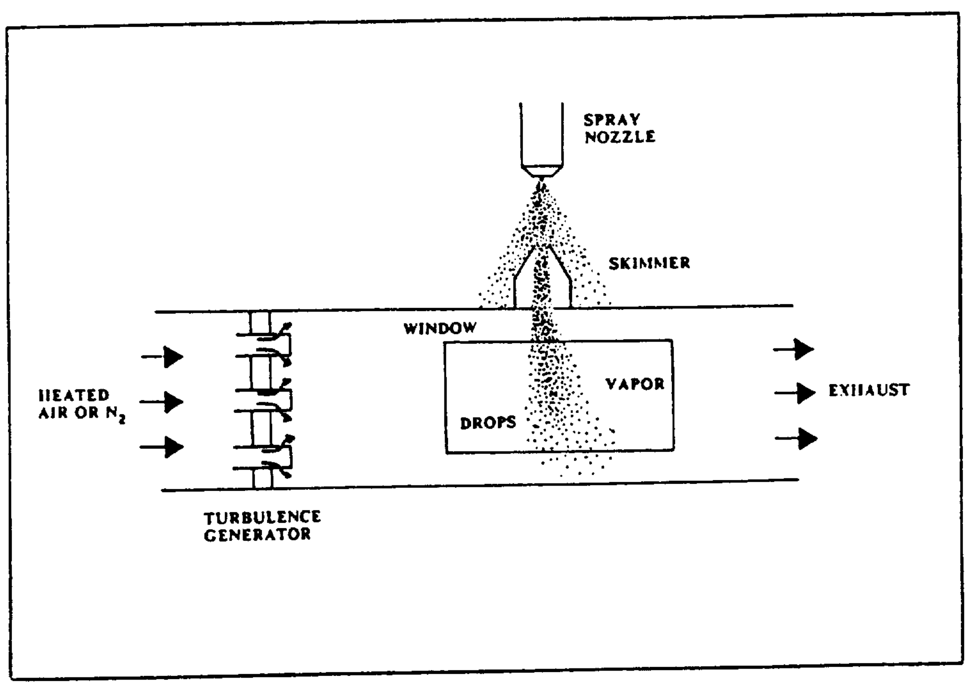

Figure 2. Turbulent flow system for study of droplet-turbulence interactions.

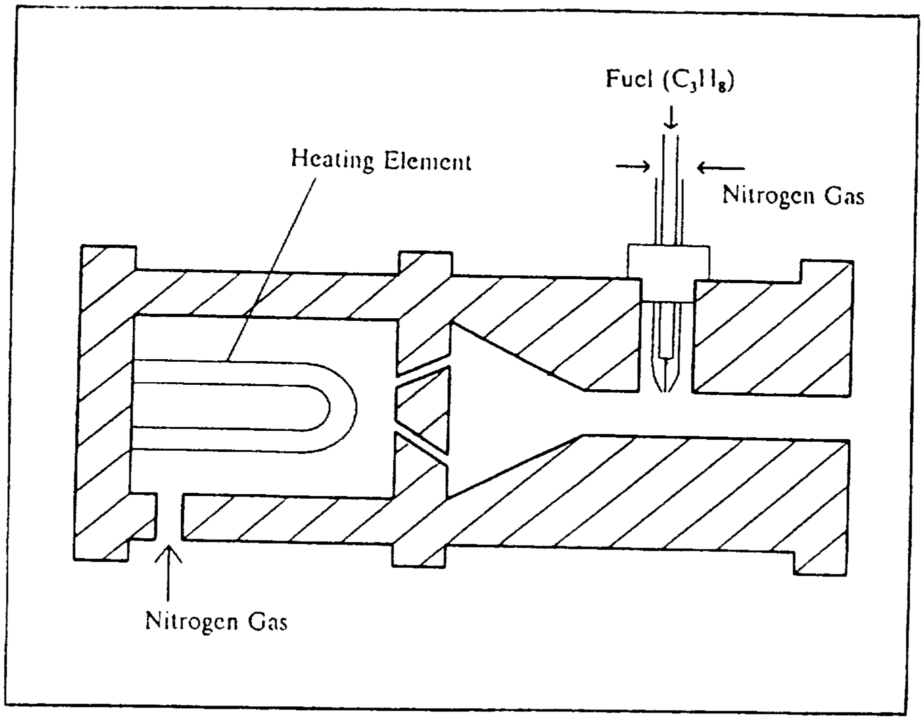

Figure 3. High pressure, high temperature turbulent flow system for study of droplet-turbulence interactions under supercritical conditions.

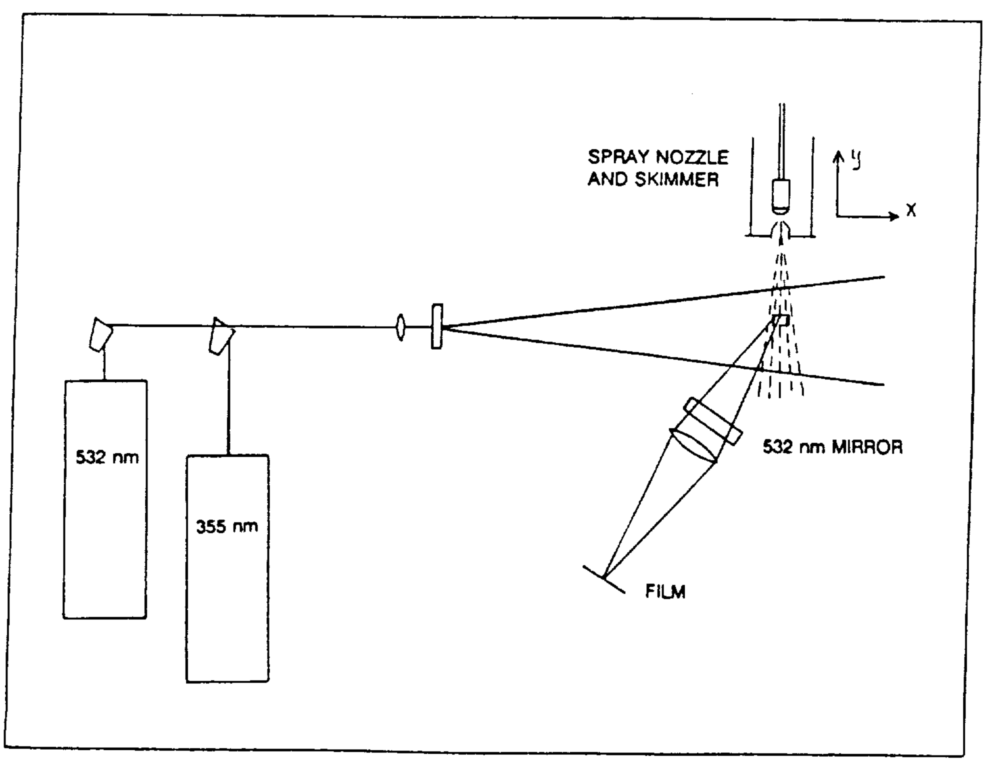

Figure 4. Double pulse, laser sheet, fluorescence imaging technique.

illustrated in Figure 4. It involves the use of two pulsed Nd:YAG lasers which are focused to form two coincident laser sheets of approximately 500 micron thickness which pass through the spray. The two lasers are synchronized, but with a variable delay (e.g. 100 microseconds) between the two pulses. The first laser operates at 532 nm and the second at 355 nm. Two fluorescent dyes are added to the spray liquid, one which is excited by the 532 nm laser sheet and produces red fluorescence and the second which is excited by the 355 nm laser sheet and produces blue fluorescence. The droplet images are then recorded on color slide film, through a 532 nm mirror which eliminates the Mie scattering, and appear as red and blue droplet pairs. The spacing between the droplets defines the x and y components of the droplet velocity and the size of the droplets are determined directly from the image. In addition, one of the dyes, i.e. the one excited at 355 nm, is what is referred to as an exciplex [3]. Exciplex fluorescence has a number of unique characteristics depending on the dye concentration. One of these is that the ratio of the fluorescence intensity at two different wavelengths, e.g. 400 nm and 500 nm, is linearly proportional to the droplet temperature. Combining these techniques, provides simultaneous measurements of the size, velocity and temperature of individual droplets. A PC-controlled stepping motor and image analysis system is then used for automated signal processing of such images. The data can then be examined in a number of different formats, e.g. droplet velocity distribution versus droplet size, from which quantitative information on droplet drag and vaporization rate can be determined. It is also important to characterize the effect of the droplets on the turbulence properties of the surrounding gas. In order to do so, laser Doppler velocimetry is used to obtain measurements of the mean velocity, turbulence intensity, integral scales and energy spectrum.

References

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