

Submit to AIAA Propulsion and Energy Forum and Exposition (AIAA Propulsion and Energy 2018); Duke Energy Convention Center, Cincinnati, OH, 9 - 11 July 2018

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In liquid propellant rocket engines, spark igniters are often used indirectly to light preburners, gas generators, and main chambers [1]. Attraction for spark igniters is strongly influenced by their ability for repeatable engine starts and high reliability. In the case of spark igniters, however, ignition is reliant upon an ignitable mixture passing near the spark tip very early in the engine start transient, prior to pressure quenching of the spark. While direct ignition of rocket engine combustion chambers is possible and has been successfully implemented in engines such as RL-10, the development time can be significant since ignition requires precise and repeatable control of the propellant mixture ratio within the very small volume and short duration of the spark plasma. Generally, the preferred method of implementing spark igniters within rocket engines is especially larger engines, igniting the propellant in a pre-chamber in which propellant injection and mixture ratio near the spark plasma can be controlled independent of the engine injector. The resultant combustion products within the small pre-chamber are directed into the larger engine chamber via a torch tube. An augmented spark igniter is advantageous because the output torch flame that is much larger and more energetic than a discrete train of small spark plasmas.

Even within the smaller volume of the augmented spark igniter pre-chamber, immediate and reliable ignition can still be a design challenge, especially with hydrocarbon-based fuels. To date, the only use of spark igniters in human-rated rocket engines has been with pure hydrogen, which has much broader flammability limits than hydrocarbon fuels, when combined with oxygen. In order to enhance the spark plasma within an augmented spark igniter, a fraction of the propellant (usually the oxidizer), may be injected so that it passes through the electrical arc of the spark igniter. In doing this, the spark plasma is pushed out further from the spark tip, where it is more likely that an ignitable mixture exists and cold wall quenching of the initial combustion kernel is less of a concern.

The objective of the research conducted in this study is to examine and better understand how the spark plasma is effected by the flow of oxidizer through the electrical spark. In the field of spark ignition for combustion devices, research has ranged from studies of electrical characteristics [2] [3] [4] to imaging of ignition kernels following the discharge [5] [6]. The

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majority of this literature focuses on pronged electrodes, which had input parameters and geometric shapes thoroughly varied [5] [7] [8]. Often such work focuses on stagnant conditions as information for flowing gases will rely on specifics of an application. Literature exists showing qualitative trends for the electrical discharge [7], yet information is not available regarding the effects on the gas mixture excited by and immediately following the arc. To fulfill this gap, the research at hand focuses on non-reactive gas mixtures flowing through annular electrode configurations. The aims are to parametrically determine what input (electrical, flow, fluid properties) and geometric (spark gap) variables create the largest spatial volume and longest duration cloud of plasma products.

Schlieren imaging of the electrical discharge and subsequent product clouds will be (were) taken using the experimental setup shown in Figure 1. The system consisted of two f/10 6 inch diameter parabolic mirrors spaced 72 inches apart with the light source slit and knife edge 7.5 inches from the centerline of the collimated light. The light source and power supply were a VIC single LED module model 93534 and model 200960 video strobe-flood controller, respectively. A condenser array followed the LED module with two 50 mm diameter, 100 mm focal length achromats spaced for a 1:1 magnification, which was then cropped by a horizontal slit and iris aperture. A Phantom v310 high speed camera was used in conjunction with a Sigma aspherical 170-500 mm f5-6.3 lens, and provided a spatial resolution of 280 micron as determined by a 1951 USAF resolution chart. Electrical measurements were taken with a model 410 Pearson current monitor, model P6015 Tektronix high voltage probe, fast photo diode (model DET36A), and recorded by a Teledyne LeCroy WaveRunner 8054 oscilloscope.

A Teledyne-Hastings TCHD-400 power supply was used to command a Teledyne-Hastings HFC-202 flow controller which was accurate to 1% full scale as verified by laminar flow elements. Fluid properties were measured using Omega Type K C d Y b ' h] d ž ' i b [f c i b X Y X ž ' \$ " thermocouples, and Omega PX309-500A5V pressure transducers. Measurements were recorded by a LabView cRIO-9064. Timing of measurements was synchronized by a DG645 digital delay generator. Sparks were generated from a variety of different exciters, each powered by a Tektronix PWS2326 DC power supply.

Both air and pure oxygen will be used as oxidizers with flow rates varying from stagnant conditions up to 300 SLPM with the spark gap ranging in width from 0.015 to 0.150 inches. The oxidizer will be injected into a cavity upstream of the spark gap, then directed through an annulus formed by two electrodes as shown in Figure 4. Sparks form within the annulus, and are extended c i h k U f X ' h c ' Z c f a ' U ' í l î ' g \ U d Y X ' U d i s c h a r g e e n d s , a n d t h e \] [\ ` excited gas is carried downstream by the bulk flow where it will inevitably reach equilibrium.

As seen in prior work [2] [7] and shown in Figure 2, the distance traveled by the electrical arc is expected to follow fundamental analytic calculations. The subsequent plasma cloud, sketched in Figure 3, is not hypothesized to travel linearly with velocity due to quenching from high turbulence and lower energy delivered per unit volume at high speeds. It is anticipated that an [optimal zone,] where the plasma cloud travels the farthest before reaching equilibrium, will lie below transonic speeds ($Ma < 0.8$) of the gas mixture exiting the spark gap. Preliminary Schlieren images are shown in Figure 5 for air. Final results are expected to include measurements of (1) distances traveled longitudinally with flow by the electrical arc and plasma cloud, (2) maximum

widths of the plasma, and (3) plasma cloud dissipation timescales for a variety input energies, volume flow rates, spark gaps, and temperatures. Results of spark breakdown voltage vs. spark

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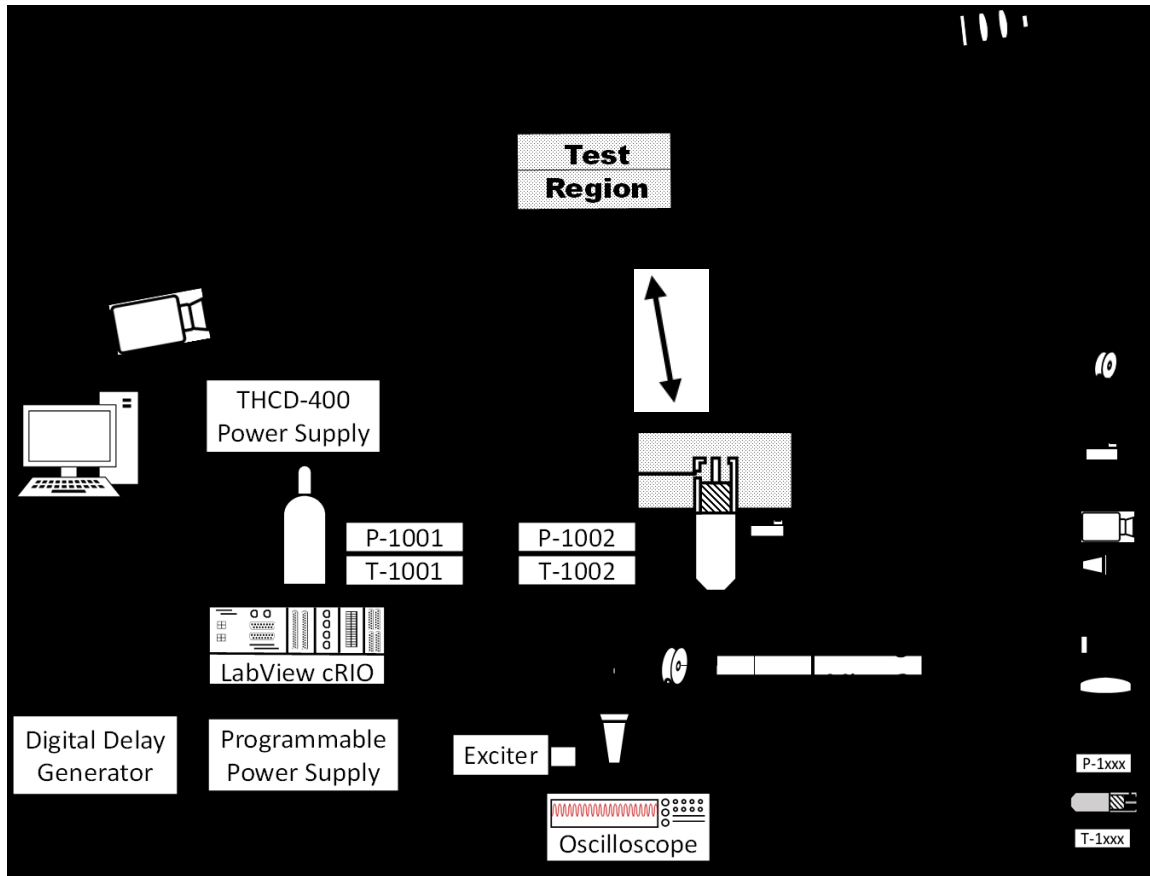


Figure 1 - Detailed schematic of experimental setup for Schlieren imaging and other common measurements

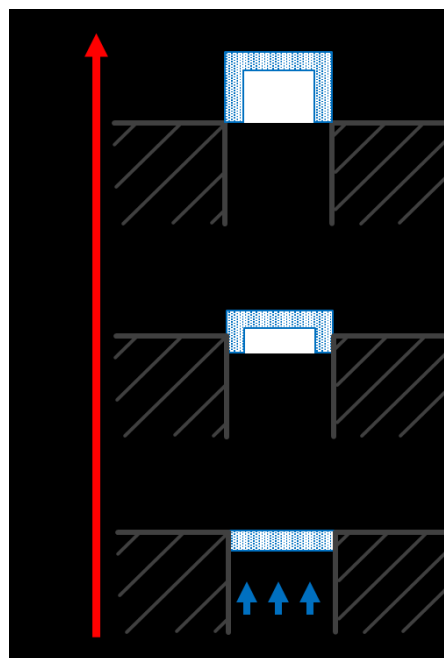


Figure 2 - Conceptual sketch of a single spark from the initial discharge at t_0 to termination at t_n

