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Transient Plasma Ignition for Delay Reduction in Pulse Detonation Engines

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Abstract— This presentation reviews testing and evaluation at four laboratories of transient plasma for pulse detonation engine (PDE) ignition, and presents data showing significant reductions in times required for detonation. The aerospace community has ongoing interests in the development of propulsion technologies based on pulse detonating engines (PDE), and work is underway to determine whether this is a feasible technology. The PDE provides impulse through fuel detonation, and potential advantages include efficient operation at both subsonic and supersonic speeds. In theory a PDE can efficiently operate from Mach 0 to more than Mach 4 [1,2]. In order to achieve almost continuous thrust firing rates of 100 Hz or more are needed. Critical to achieving high repetition rates are minimal delay to detonation times. In work supported by the Office of Naval Research and the Air Force Office of Scientific Research, transient plasma ignition (TPI) has consistently shown substantial reductions in ignition delay time for various fuels [3,4,5]. Experiments have been conducted at the University of Southern California and in collaboration with researchers at the Naval Postgraduate School, Wright Patterson Air Force Research Laboratory, Stanford University, the University of Cincinnati, and California Institute of Technology [6]. In these studies it was observed that TPI significantly reduces delay times in both static and flowing systems. Transient plasma ignition is attractive as an ignition source for PDEs because it produces reductions in ignition delay times, can reduce Deflagration to Detonation Transition (DDT) times, and has been shown to provide the capability to ignite under leaner conditions. This allows for high repetition rates, high altitude operation, and reduced NO_x emissions [7,8]. The geometry of the discharge area is such that ignition is achieved with a high degree of spatial uniformity over a large volume relative to traditional spark ignition. The short timescale of the pulse ($<$ 100 ns) prevents formation of an arc, and a voluminous array of streamers is used for ignition. It is possible that energetic electrons in the highly non-equilibrated electron energy distribution of the streamers cause dissociation of hydrocarbon chain molecules, producing active radicals throughout the ignition volume [9]. A further advantage of TPI is that a smaller fraction of the electrical energy goes into thermal heating of the mixture. These effects allow for large numbers of active species to be generated throughout the volume.

Figure 1 shows data taken in collaboration with Professor Hanson's group at Stanford University. The different levels of OH indicate a potentially new combustion pathway of transient plasma ignition. Currently the physics behind transient plasma ignition is poorly understood, however, work is underway to better understand this process.

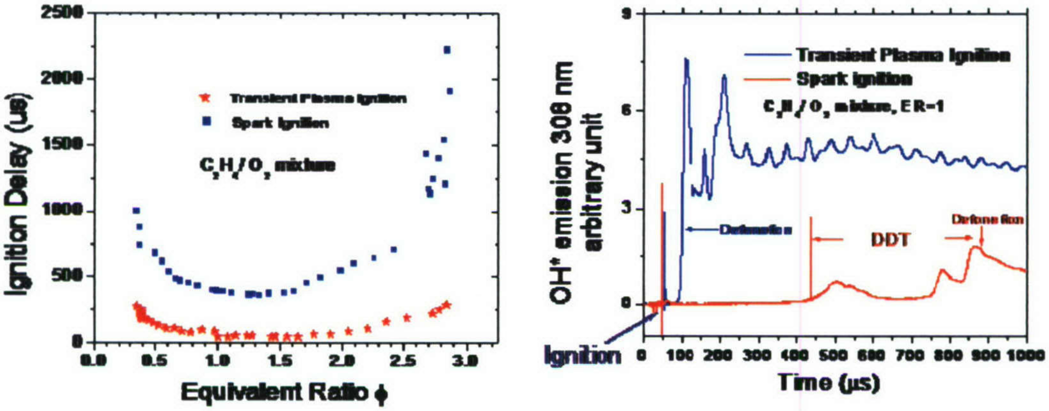

Figure 1
Ignition delay (left) and OH emission (right) in Stanford PDE. TPI enabled a factor of 9 reduction in delay to detonation.

The igniter operates reliably in repetitive modes with pulse lengths typically between 50 ns and 75 ns. In some situations with the appropriate shielding and grounding it will operate with less electromagnetic interference than conventional spark ignition. A summary of experiments conducted with multiple laboratories is seen in Figure 2. These experiments demonstrated considerable reduction in delay to detonation, and improvement in repetition rate, while retaining low energy cost.

The experiments were under varying conditions, and in each case a dramatic reduction in delay was observed. The results suggest a potential solution to one of the most serious limitations to the development of PDEs. Desired pulse amplitude depends on the exact geometry of the combustor, ignition chamber as well as corona electrode. Typical voltages employed are 50 kV – 70 kV for these studies, with pulse energies of the order 100 mJ to 1.16 J depending on how well matched the ignition system is to the load. The ignition system typically consists of a pseudospark based pulse generator, a rapid charger or HV DC supply, and an electrode interface assembly [10, 11].

	Lab	Fuel	Oxidizer	Ignition Delay (msec)	DDT (msec)	Energy Delivered (Joules)
TPI	Stanford	C2H4	O_2	0.05	0.05	1.16
Spark	Stanford	C2H4	O_2	0.5	0.45	?
TPI	NPS	C2H4	Air		2	0.3
Spark	NPS	C2H4	Air		8	0.2
TPI	WPAFB	AVGAS	Air	6	2.25	0.67
Spark	WPAFB	AVGAS	Air	10	1.7	?
TPI	WPAFB	AVGAS	Air	5	2.5	0.87
Spark	WPAFB	AVGAS	Air	10	1.7	?
TPI	WPAFB	H2	Air	0.4	0.57	0.67
Spark	WPAFB	H2	Air	0.51	0.61	?
TPI	WPAFB	H2	Air	0.3	0.67	0.87
Spark	WPAFB	H2	Air	0.51	0.61	?

Figure 2
Transient Plasma Ignition results.

Research directed towards more compact versions of the pulse generation technology to ensure it is a viable option for airborne platforms and for use in other applications, is briefly discussed. A miniaturized back-lighted thyratron (BLT) switch is to be discussed as a feasible replacement for the relatively large pseudospark switch [12]. The BLT is a laser triggered (can be electrically triggered also) hollow cold cathode thyratron and is able to switch 40 kV, 9 kA. The other methodology we are exploring is to entirely replace the pseudospark/lumped Blumlein architecture with a pulse generator based on magnetic compression (solid state pulse generator) [13]. This pulse generator takes a long relatively low voltage pulse and compresses it though a series of LC resonant stages. What is novel in this architecture is that a diode chain is used to sharpen the final output pulse. Currently this pulse generator is capable of producing a 20 ns pulse of 60 kV. The advantage of this pulse generator is that it can potentially deliver more energy into a gap prior to breakdown than the pseudospark pulse generator. Additionally the solid state pulse generator is greatly reduced in size and weight relative to the current pseudospark based pulse generator that was used for the data reported in this conference. An immediate application for the solid state pulse generator is internal combustion engines, and smaller gap PDEs. To date our research indicates for small gap systems this type of system can perform better than the pseudospark pulse generator because it can deposit more energy prior to arcing. The caveat to that is due to the solid state pulse generators short pulse width, for a large gap system the output pulse voltage needs to be approximately 1.5 times the pseudospark pulse generator's output pulse voltage to perform on the same level, resulting in higher insulation requirements.

Based on these studies, transient plasma ignition is potentially an enabling technology for pulse detonating engines. The reduction in ignition delay times allows for higher repetition rates, and improved lean burn operation.

Key Figures:

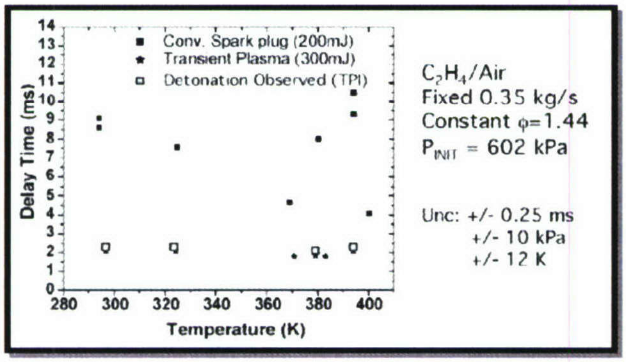

Figure 3
C_2H_4 Ignition Delay
USC-NPS

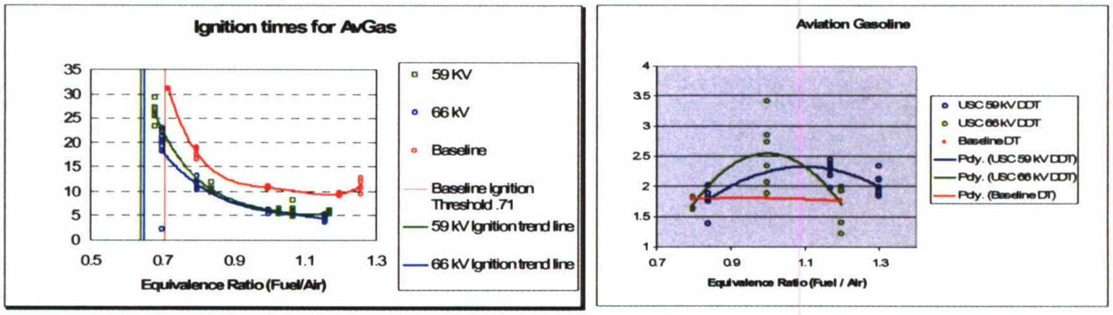

Figure 4
AVGAS Data
USC-WPAFB

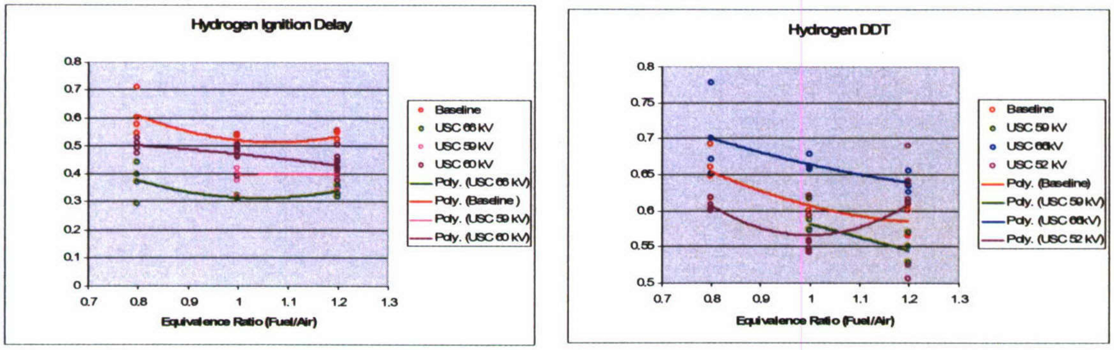

Figure 5.
H_2 Data
USC-WPAFB

Acknowledgements

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