Effects of Head-End Geometry and Ignition Location on the Operation of a JP-10/O_2 Fueled Pulse Detonation Engine

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Abstract

A modular liquid-fueled pulse detonation engine has been constructed which operates on liquid JP-10 and gaseous oxygen at frequencies up to 10 Hz. The modular designed allowed rapid modification of the existing configuration and retesting of various geometries. The geometries investigated were kept as simple as possible in order to investigate the effects of fundamental changes in geometry and ignition location on the generation of a detonation wave. The criteria used to evaluate each engine configuration was based upon two performance issues, the repeatability of producing a detonation wave and the distance required from the ignition source to form the detonation. Configurations including coflowing oxygen, swirl, spray injection diffusion ramps, and variable ignition location were investigated. The configuration which included an injection diffuser with rearward facing steps was found to produce the most reliable detonation and the shortest deflagration-to-detonation distance.

Summary

The concept of utilizing a detonation cycle for a propulsion system is not new. Previous publications by Dabora [1] have discussed the history, role, and applicability of detonations in the field of propulsion. Companies such as Adroit Systems Inc.[2] have presented arguments for the successful use of a detonation cycle in an engine class known as Pulse Detonation Engines (PDE). These engines inherently have an increased thermodynamic efficiency, but the capability to produced an increase in propulsive efficiency and lower specific fuel consumption is still in the process of being examined.

The Naval Postgraduate School (NPS) has undertaken a project to investigate the characteristics and performance of liquid-fueled pulse detonation engines. Most of the work existing currently has pertained to the use of gaseous fuels in such devices. Earlier work at NPS has involved the investigation of critical requirements on droplet size, equivalence ratio, and timing concerns for successful detonations to be produced in JP-10/O2 aerosol sprays [3]. The baseline geometry investigated is shown below in Figure 1. It consisted of a modular design which allowed various head-end configurations and ignition locations to be evaluated. Ignition heights were varied from x/D=0 to x/D=2.0 in half-inch increments from the head end of the combustor. Variable geometries could easily replace or be inserted into the first combustor segment.

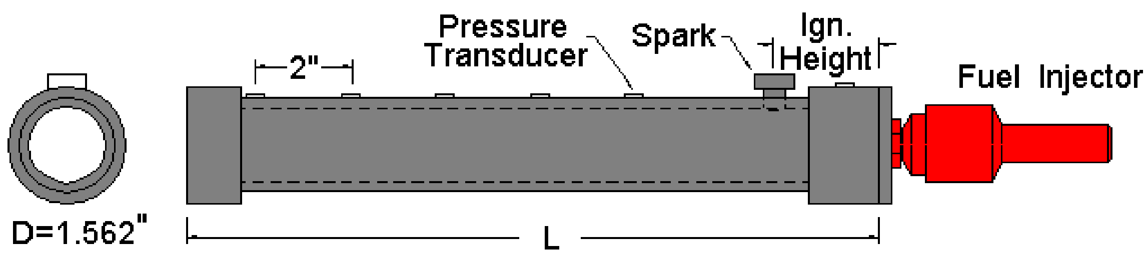

Figure 1: Baseline geometry

Head end modifications such as the one shown in Figure 2 allowed for the coflowing oxygen configuration and a similar geometry produced the swirl configuration capability. Figure 3 depicts the stepped-ramp diffuser inserted into the head-end of the combustor. This geometry resulted in very little fuel being deposited on the combustor wall and produced the best performance of the head-end configurations evaluated.

The effect of varying ignition location on the baseline geometry can be seen in Figure 4. As the axial ignition location increased, the deflagration-to-detonation (DDT) distance reached an apparent minimum when the ignition source was located at $x/D \approx 1.0$ from the head-end of the combustor. Ignition locations further down the combustor at x/D values greater than 1.5 did not produce any further benefits and actually produced an increase in the deflagration to detonation distance.

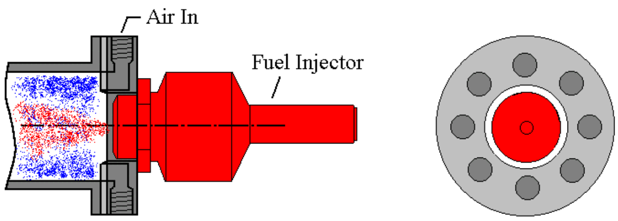

Figure 2: Modification to head-end of combustor for co-flowing air/O_2 configuration

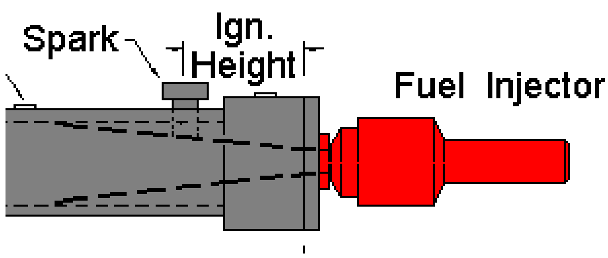

Figure 3: Stepped diffuser configuration

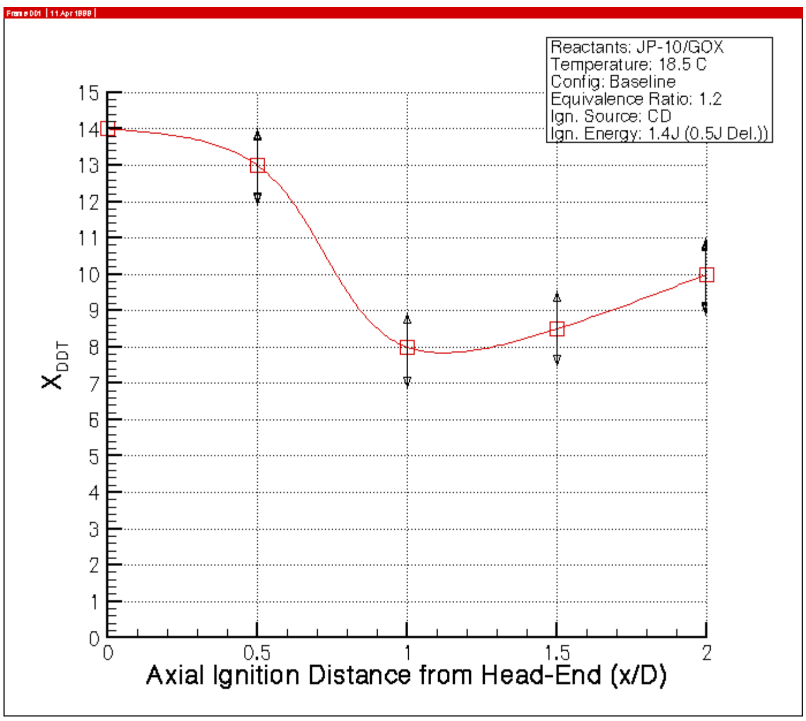

Figure 4: Effects of Ignition location on Deflagration-to-Detonation Distance

CURRENT AND FUTURE WORK

Testing is currently underway to further characterize the importance of ignition location, timing, and geometry under higher frequency operating conditions and to investigate the effects of elevated fuel and air/oxygen temperatures. Other efforts also include investigating the effects of non-uniform fuel distribution on the propagation and stability of a detonation wave. This effort will include imaging of the detonation wave diffracting from the predetonator geometry to the larger combustor and later as it propagates down the main combustor axis. Figure 5 shows the existing combustor geometry for the current efforts, highlighting the areas of current efforts.

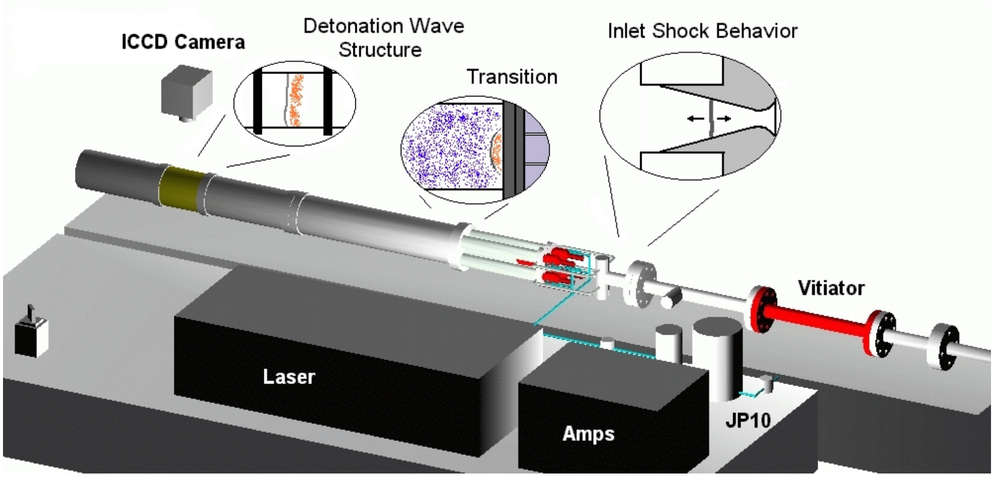

Figure 5: Current PDE combustor geometry used for JP-10/air detonation studies

References

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[2] Bussing, T., and Pappas, G., "An Introduction to Pulse Detonation Engines," AIAA Paper 94-0263

[3] Brophy, C.M., Netzer, D.W., and Forster, D., "Detonation Studies of JP-10 with Oxygen and Air for Pulse Detonation Engine Development", JANNAF Propulsion Meeting, Cleveland, Ohio, July 1998

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