Fuel/Air Initiator Development for Pulse Detonation Engines

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The practical operation of a fuel/air pulse detonation engine(PDE) relies on the ability to produce a detonation wave rapidly and by reliable means over many combustion cycles. The current method used to initiate a detonation in the fuel/air mixtures of air-breathing PDEs is to employ a fuel/oxygen initiator unit[1,2]. These units rapidly develop a detonation wave in a mixture which is more sensitive than the fuel/air mixture and therefore more easily detonated. The wave transitions from the fuel/oxygen mixture into the fuel/air mixture which is less reactive and therefore overdrives the new mixture. After a certain distance, the resulting fuel/air detonation wave relaxes to steady-state Chapman-Jouget values for that mixture.

Currently, a JP10/air PDE operated at NPS is initiated by a JP10/O2 initiator unit. The initiator unit is show in Figure 1 and has been previously reported [3,4]. An effort is underway to potentially eliminate the required oxygen for the initiation process. Tests have been performed to investigate methods to increase the energy release rate of fuel/air conditions to promote the rapid development of a detonation wave. A baseline geometry has been chosen to be a 101.4 mm diameter tube closed at one end and 1.25 meters in length. An optical section exists at the head end and may be relocated to provide images of the initiation process at selected axial locations. The geometry is shown below in Figure 2, along with sample plate geometries. Various porous plates and screens are being evaluated at initial pressures ranging from 1 to 6 atmospheres and initial temperatures ranging from 285K to 450K. The pressure and temperature range studied is representative of possible initial conditions available on a typical flight system.

The conditions required for the onset of detonation in various tubes has been investigated by a number of researchers. Peraldi, et al.[5] determined the limiting criteria for the onset of detonation. He states that the flame speed achieved prior to the onset of detonation must be at least on the order of the speed of sound of the combustion products. He also provides geometry limitations on wall-mounted obstacles intended to increase flame speed. Another method to rapidly increase the effective flame speed is to rapidly vent hot jets into an unreacted mixture. It has been demonstrated by Knystautas et al.[6] that rapid turbulent mixing of hot combustion products with the reactants can lead to the onset of detonation. Carnascialy, et al.[7] performed similar work and established well defined initial conditions between the driving and driven sections of the apparatus. Since much of the previous work in this area involved flow development before the venting of the jets, the work greatly improved the quantitative value of the results. The study being reported in this paper involves the use of this and other bodies of work to investigate the practical development of a fuel/air initiator for PDE applications.

Since the successful generation of a detonation wave in various combustion tube geometries is often preceded by the formation of a combustion driven shock wave, it should be possible to utilize this event and promote early detonation wave development. Teodorczyk, et al.[8] has previously shown the importance of shock reflection on the transition or re-intiation of a detonation wave. It is hoped that by employing various shock reflection fences to both reflect and focus the generated normal shocks, a reduction in the required run-up or DDT distance will be observed.

Results to date have shown no substantial pressure rise was observed within the first 24 inches along the combustor for many of the 1 to 3 atm tests without the orifice plates. Initial tests at 1 atmosphere have only revealed a slight benefit the venting jets. Figure 3 shows the resulting pressure waves along the combustor axis indicating the pressure wave steepening as it propagated down the combustor axis. A pressure rise in the reservoir was only 30-40 psig due to the slow reaction rates and simultaneous venting of the resulting pressure rise. As the initial mixture pressure was increased, the resulting reservoir pressure accordingly increased and the success of the generating weak shock waves down the combustor improved, eventually resulting a detonation wave shown in Figure 4. It can be seen that shortly after the jets initiated combustion in the main combustor, the resulting pressure waves steepen rapidly forming the expected shock wave.

The fuel-rich 3 atm through 6 atm tests reliably produced this situation and will be investigated further at higher initial temperatures. The effects of decreasing the equivalence ratio to a leaner value (0.9) can be seen in Figure 5. Although the initial pressure was set at 5 atm, the reactivity of the leaner mixture delayed the formation of the shock wave and detonation. A later run which included the combustor extension allowed the resulting detonation wave to be observed at a slightly later axial position (not shown).

This study is not only looking at the effects of pressure and temperature on detonation initiation of fuel/air mixtures, but also at techniques which may be used to relect/focus shock waves generated downstream of the various plate configuration. The overall goal being to rapidly, both temporally and spatially, generate a detonation wave in a fuel/air mixture in a reasonable fashion. Initial testing has evaluated ethylene/air mixtures while later testing will be characterizing propane/air mixtures to better simulate heavy hydrocarbons.

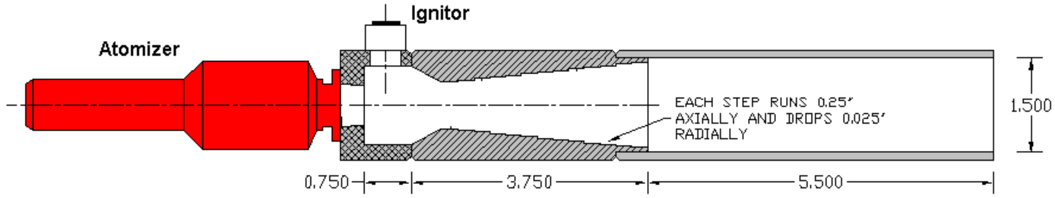

Figure 1: JP-10/O_2 Initiator Unit

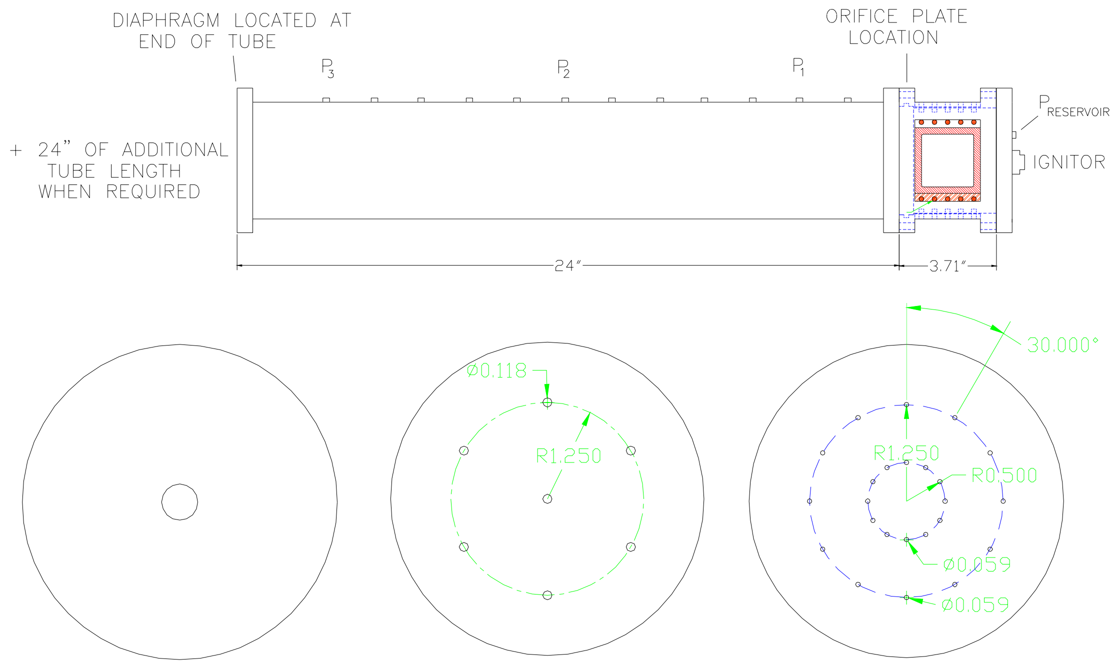

Figure 2: Fuel/Air Initiator Geometry with 3 Orifice Plate Configurations Shown (Perforated plate disks not shown)

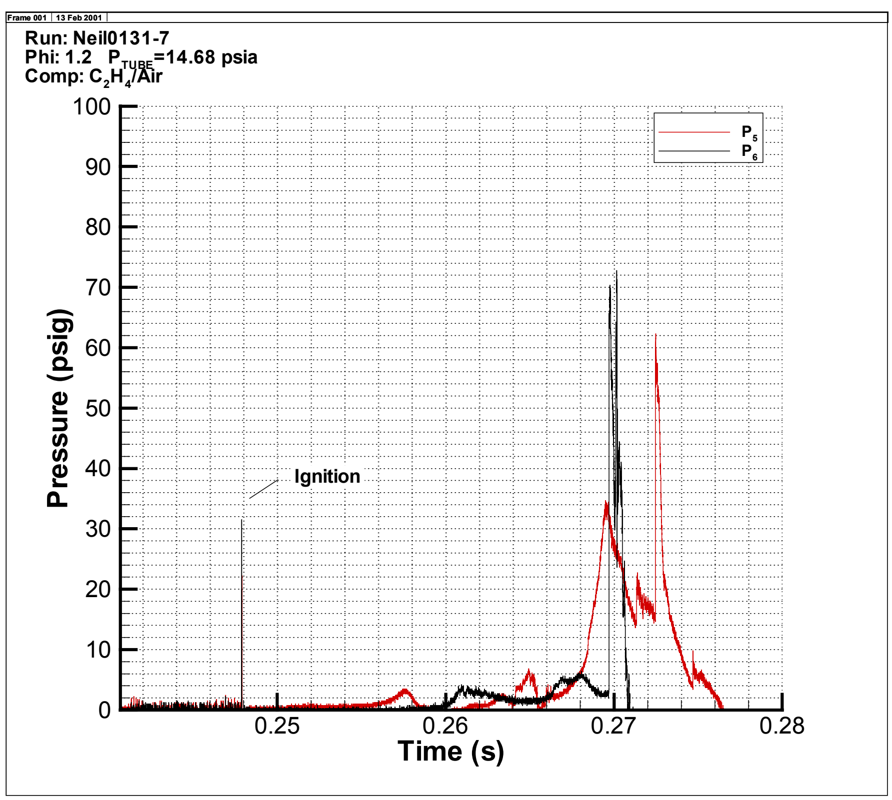

Figure 3: 7-Hole Orifice Plate Results for Ethylene/Air at a phi=1.2 and P_{init}=1 atm

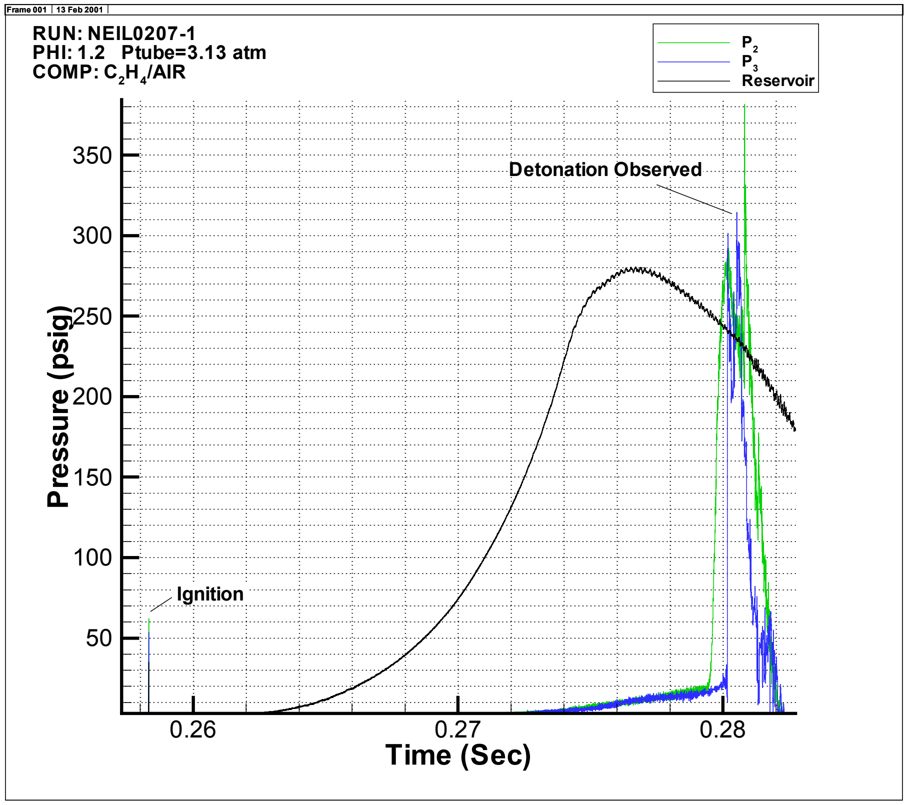

Figure 4: 24-Hole Orifice Plate Results for Ethylene/Air at a phi=1.2 and P_{init}=3.13 atm

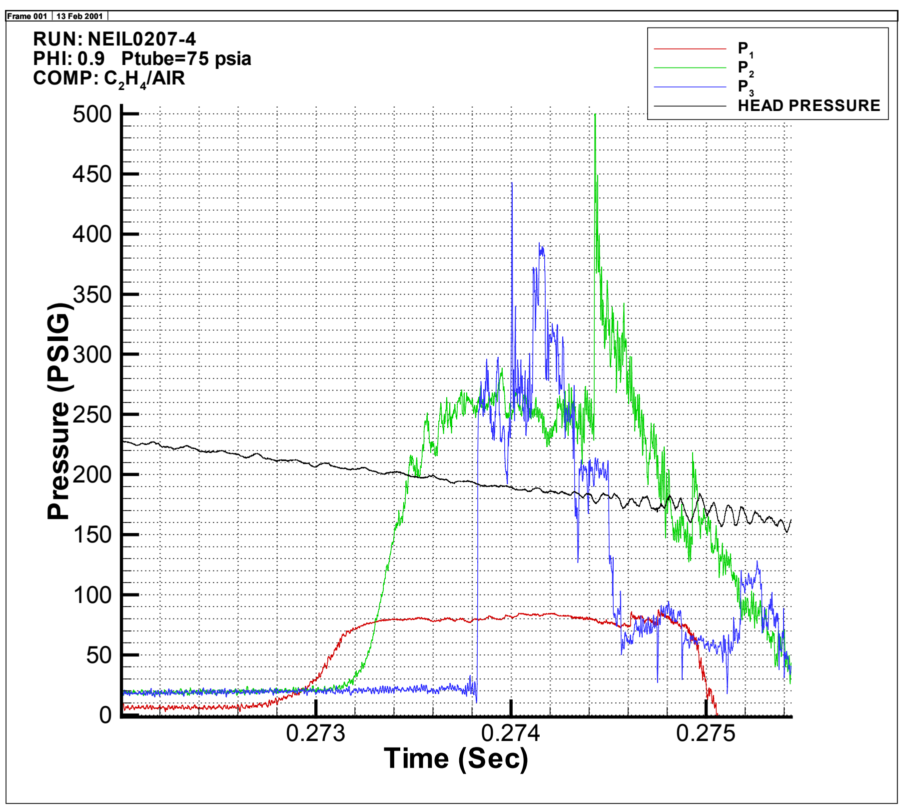

Figure 5: 24-Hole Orifice Plate Results for Ethylene/Air at a phi=0.9 and P_{init}=5 atm

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