Effect of Transient Gas Dynamic Processes on Impulse of Pulse Detonation Engines

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Introduction

In a pulse detonation engine (PDE), thrust is produced by the venting of high pressure and temperature combustion products of a detonation. Much of the effort in PDE development addresses the rapid promotion of deflagration to detonation transition (DDT), in order to achieve detonation in a distance compatible with the dimensions of an engine. The question of whether impulse depends on the different gas dynamic processes such as direct initiation, DDT, fast flames or constant volume explosion, becomes a valid one.

In the present study, the impulse produced by a single cycle hydrogen-oxygen PDE is experimentally investigated. The goal is to determine the effect of transient gas dynamic processes on impulse. The impulse is measured in two ways: the ballistic pendulum method and integration of the end wall (thrust wall) pressure. The former method, the ballistic pendulum, was first applied to measuring the impulse generated by detonation by Nicholls et al. [1] and has recently been used by Desbordes et al. [2] and Cooper et al. [3] to measure the effect of nozzles and obstacles on the impulse generated by a single detonation pulse. In this technique, the amplitude of swing of a pendulum-mounted PDE provides a direct measurement of the total integrated thrust. The latter technique, integrating the end wall pressure, is more typically used in PDE experiments, but will only produce a measurement of impulse if friction and other momentum transfer to the tube are negligible (e.g., no obstacles or area change is present).

Impulse produced by a direct initiation is compared to that produced by DDT. The direct initiation and the DDT are achieved with an exploding wire and a weak automotive spark, respectively. The equivalence ratio is varied in order to compare direct initiation to various DDT distances.

Experimental Setup

The experimental setup consisted of a stainless steel detonation tube 2.05 m long with a 6.35 cm inner diameter. The smooth wall tube had one closed end (thrust wall) while the open end was sealed with a 0.025-mm mylar diaphragm. Control experiments were done with diaphragm thicknesses ranging from 0.023 to 0.13 mm, and no variation larger than the usual shot-to-shot variation in the measured impulse was obtained. The tube was evacuated and then filled with a hydrogen-oxygen mixture by means of calibrated choked orifices. The tube was filled to one atmosphere and then continuously flushed for five minutes to ensure a uniform mixture. The tube was equipped with 10 ports along its length to accommodate pressure transducers and/or ionization probes to measure end wall pressure, leading shock and combustion front time of arrival. The mixture was ignited in one of two ways: a 30-mJ weak automotive-type spark or an 800 J exploding wire. The detonation tube was suspended by metal wires from a support 2.3 m overhead, and was free to swing like a pendulum. A video camera captured the motion of the pendulum, from which the total impulse could be determined.

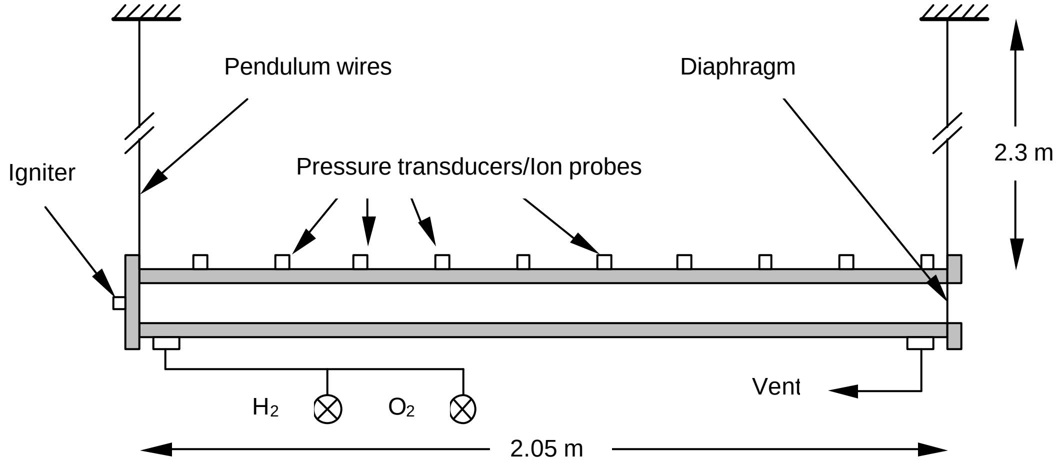

Fig. 1 Schematic of experimental apparatus.

Results and Analysis

The first set of experiments compared the impulse produced by the direct initiation of a detonation and the delayed initiation of detonation via DDT. For this reason, the equivalence ratio was varied to control DDT distance (DDT distance increases as equivalence ratio moves away from one). Clearly, the comparison of impulse between two different mixtures is not a valid one, since the energy content of the two mixtures will be different. However, for any given mixture, the impulse produced by direct initiation can be compared to that produced by DDT.

Both impulse measurement techniques have good reproducibility (scatter less than 10%), but the impulse from the pressure integration is consistently larger by 15 to 30 %.

Figure 2 shows the DDT distance as a function of equivalence ratio, for the case of weak spark and exploding wire. The DDT distance is minimum for an equivalence ratio of unity since that is the most sensitive mixture. The DDT distance increased as the equivalence ratio was varied, and no DDT was observed in the 2.05 m long tube for mixtures leaner than an equivalence ratio of 0.2. The plot does not show a DDT distance of zero for the case of direct initiation because the first reliable velocity measurement was between the first two ports.

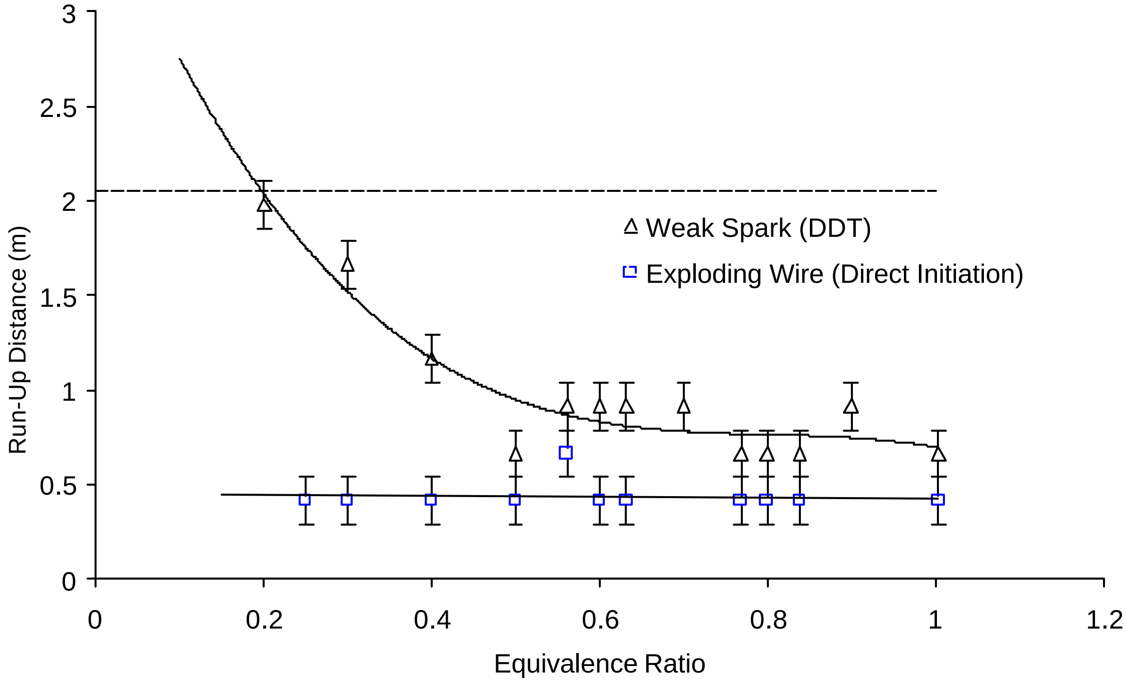

Fig. 2 DDT distance as a function of equivalence ratio for weak spark and exploding wire.

In Fig. 3, the specific impulse is plotted as a function of equivalence ratio of the mixture. Both initiation methods produced the same impulse for equivalence ratios larger than 0.3. For equivalence ratios greater than 0.15 and less than 0.3, direct initiation produced significantly more impulse. Over this range of equivalence ratios, direct initiation was still possible, however, DDT either occurred in the last quarter of the tube or did not occur in the tube at all. The fact that less impulse was generated in the case of a weak spark in this range of equivalence ratio is believed to be the result of reactants venting out the end of the tube before they are burned. For example, when there is no DDT in the tube, the leading shock is decoupled from the reaction zone. The leading shock being some distance ahead breaks the diaphragm and results in venting of the unburned reactants. When DDT occurs late in the tube, the detonation is unable to catch up to and overtake the compression waves from the initial flame. It is this compression that breaks the diaphragm. In cases where the DDT occurs earlier in the tube, the detonation overtakes these compression waves and no reactants are lost. Consequently, less impulse is produced when there is venting of unburned reactants since less energy is released.

As the mixture was made even less sensitive, a point was reached where direct initiation was no longer possible for the amount of energy of the exploding wire (equivalence ratios less than 0.15). In this case, the impulse produced with an exploding wire decreased to the same level as that produced with a weak spark. When the initiation energy was less than the critical energy for direct initiation, the actual amount of energy in the ignition source had little apparent effect on DDT or the impulse generated. When the exploding wire is no longer able to initiate the mixture directly, DDT must form by a similar DDT process as the weak spark.

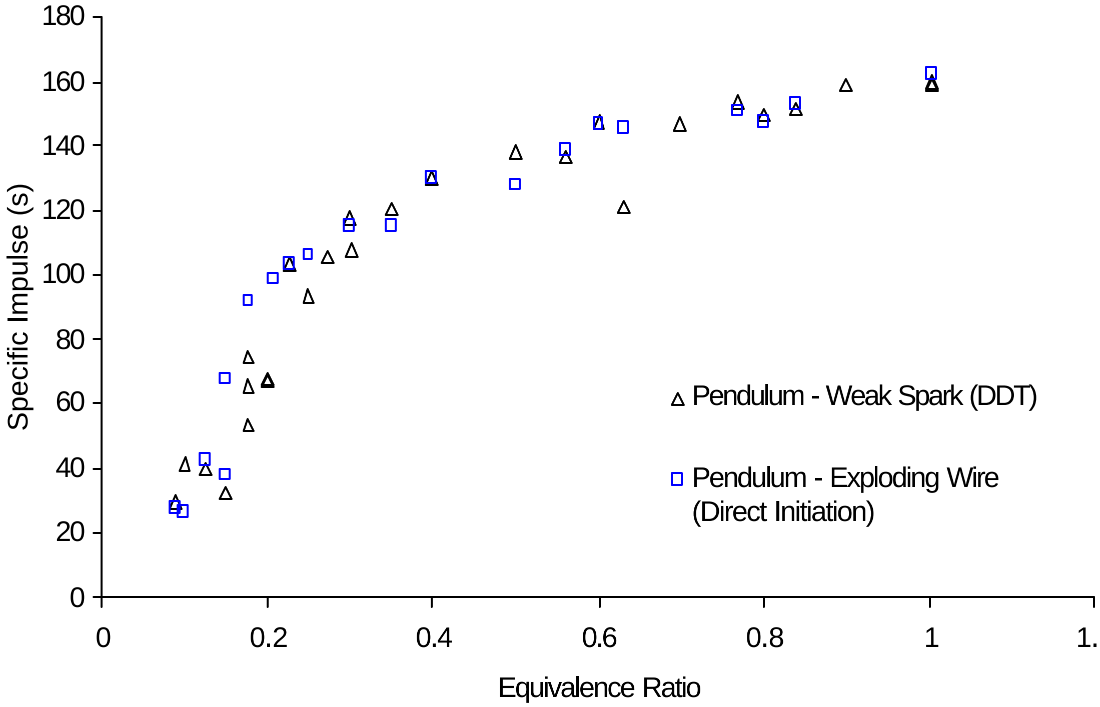

Fig. 3 Specific impulse as a function of equivalence ratio for weak spark and exploding wire.

Conclusions

The results of the present experiments show that the impulse produced by direct initiation and DDT is the same as long as all the mixture is burned inside the tube. No dependence of impulse on time or distance required to reach detonation was found, despite the differences in the gas dynamic processes of DDT versus direct initiation.

References

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