Effect of Transmission of Detonation from Smaller to Larger Tube on the Performance of PDE

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1 Introduction

Pulse Detonation Engine has been envisaged as a high efficieny engine as compared to the conventional turbo engine. The propulsive force generated in the engine is due to the high pressure generated by the detonation wave. These engines have no moving parts hence it makes it further more attractive for the aerospace applications. If a given fuel air mixture is ignited using conventional spark ignition system it leads to production of deflagration wave.To generate the Detonation wave two methods are used.

Direct detonation Here a high amount of energy is dumped so that detonation wave is generated.

DDT In the second method, Deflagration to Detonation Transition (DDT), the deflagration wave is produced by ignition of air-fuel mixture which gets accelerated to higher velocity leading to the formation of detonation waves.

The primary focus of this experimental investigation is based on the second transition mechanism. The use of spiral for the production of detonation wave was first conceived by Schelkin [1] and this methodology has been extensively used later by many groups for studying the DDT transition. A number of studies have been carried out on deflagration to detonation transition in tubes of varying diameters, and it has been generally found that L_{DDT} scales with the diameter of the tube, larger the diameter longer the length taken for transition to take place. The tubes of smaller diameter will hold a very small amount of fuel-air mixture and if flame is able to accelerate and undergo transition in this section then we can effectively achieve the DDT with the consumption of very small amount of fuel. The study of transition of detonation from smaller tubes to large has earlier been carried out by Meyer et al. [2] and Katta et al. [3]. Earlier experiments [4] have shown large improvement of specific impulse in the case of partial filling. In this paper, a series of experiments have been carried to study the effect of using smaller tube as the device for flame acceleration to near detonation regimes and then transmitting it to larger tube, and to see the effect on the specific impulse produced for various fill fractions. Similar experiments have been performed earlier using different setups by Schauer et al. [5] and this was numerically studied by Katta et al. [3]

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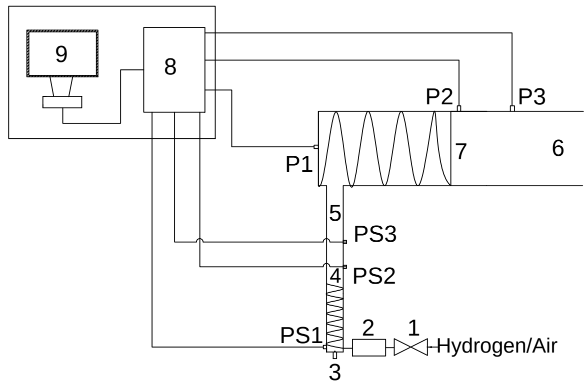

PART NO	DESCRIPTION	PART NO	DESCRIPTION
1	Solenoid Valve	PS1, PS2, PS3 P1, P2, P3	Pressure Transducer
2	Check Valve	6	Larger Tube
3	Spark Plug	7	Shchelkin Spiral
4	Shchelkin Spiral	8	Signal Conditioner
5	Smaller Tube	9	Digital Oscilloscope

Figure 1: The experimental setup

2 Experimental Setup

The experimental setup used is shown in Fig. 1. Here stainless steel tubes of diameter 42 mm and length 1 m and 2 m have been used. The tubes had provision for attaching small diameter tube to the closed end. This extension pipe is of 5 mm diameter and 1 m long. The main tube had pressure transducers mounted at the head end, and at 50 and 80 cm from the head end. The spark plug and the fuel-air filling attachment are mounted at the head end of the small tube. The volume of this tube is $1/70^{\text{th}}$ of the larger tube (of 1 m length) and hence requires very small amount of mixture for initial flame acceleration. The extension pipe can be attached to the head end of main tube either along the length or perpendicular to it. Shchelkin spirals are used in both tubes to enhance the flame propagation velocity for the transition to detonation to occur in minimum length. The larger tube was fitted with additional orifice plate which enhanced the impulse as has been studied earlier [6]. Detonation did not occur or failed to produce the required pressure on the removal of Shchelkin spiral from either of the tubes. The experiments were carried out by filling metered quantity of Hydrogen-Air mixture of unity equivalence ratio in the tubes for varying periods of times depending on the required fill fraction. The ignition was triggered by a spark plug attached at the head end of the small tube. The pressure data obtained at various locations along the length of larger tube ware recorded on oscilloscope and used for further analysis. Impulse and specific impulse were calculated by integrating the pressure at the head end of the main tube.

3 Results and Discussion

The shock velocity measured between the two transducers located on the small tube was approximately 900 m/s which is much less than the CJ velocity as is expected for the small tube diameters possibly

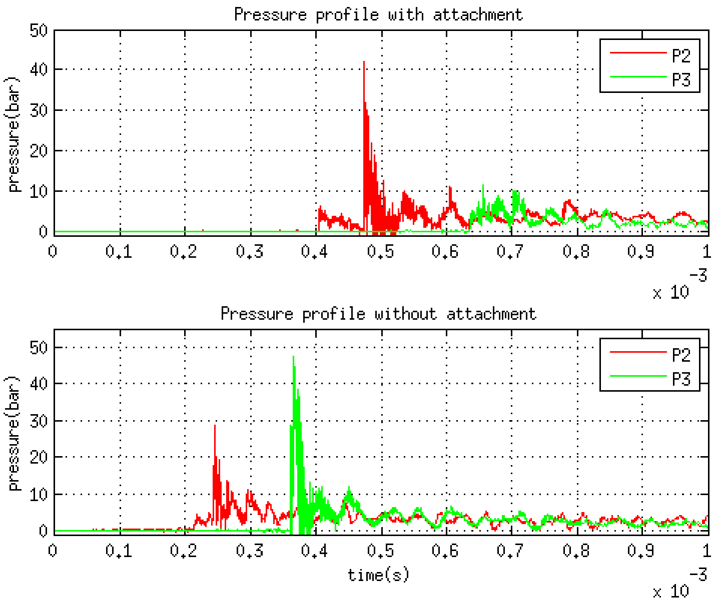

Figure 2: Pressure time data obtained with the two transducers at 50 and 70 cm from the head end with and without the small tube attachment.

due to the wall heat losses and detonation propagating as galloping detonation. The transmitted shock propagates into the larger tube, and the pressure-time data were measured in the larger tube at locations mentioned earlier. Fig. 2 show these pressure time data measured in the central locations of the larger tube (at 50 and 80 cm from the head end) for the cases with and without attachment of the small tube. The velocity of propagation with attachment is approximately 850 m/s while that without attachment it is 1700 m/s. The large pressure spike at P2 is possibly because this transducer is located very close to the end of the Schelekin spiral. The comparison of pressure profile clearly shows that the transition to stable detonation has not occurred for the case when detonation is transmitted from smaller to the larger tube. The velocity of propagation of this wave is almost half of the propagation speed of CJ detonation, and the wave travels as a decoupled shock wave followed by the combustion front. These waves are metastable and can propagate for long lengths of the order of 100 tube diameters [7] before either decaying to sonic wave or accelerating to CJ detonation wave.

The head end pressures for 1 m and 2 m tubes filled with reactive mixture for a length of 1 m are shown in Fig. 3 (fill fraction = 1 for 1 m long tube and 0.5 for 2 m tube) and is compared with the case when detonation is initiated in the main tube (1 m) without attachment. There is an initial pressure spike in the case of tubes with attachment which may be due to a temporary explosion, taking place when detonation exits the smaller tube. This pressure decreases abruptly and in the latter phase there is a gradual increase of head end pressure, reaches a constant mean pressure and then decreases to atmospheric pressure. In the normal case (tube without attachment) the region of constant pressure is for much shorter duration. The specific impulse obtained in the two cases is almost equal to each other as was also reported earlier by Schaur et al. [5], though the tube with attachment showed slightly larger value.

The specific impulse obtained in 1 m and 2 m tubes with and without attachment at various fill lengths are shown in Fig. 4. At low fill lengths, the specific impulse obtained using tubes with attachment are clearly larger than those without attachment. The reason for this may be the peak pressure due to sub CJ detonation will be less than that of a CJ detonation, leading to weaker Taylor expansion and

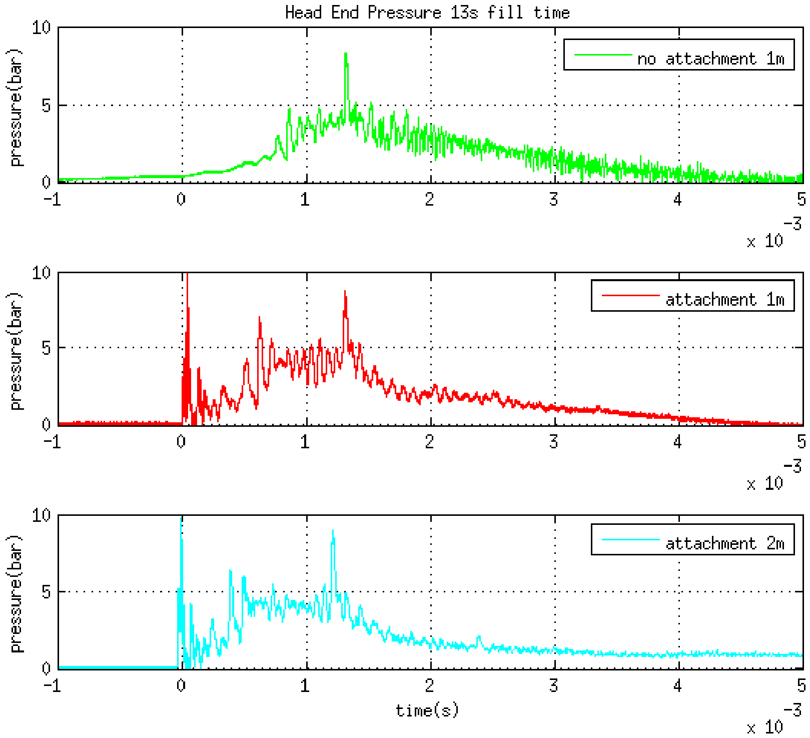

Figure 3: Comparison of pressure profile at head end for same fill length of 1 m.

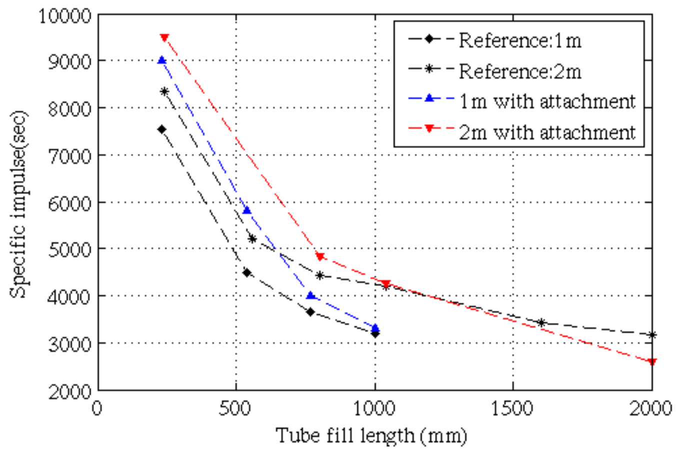

Figure 4: Specific impulse obtained in 1 m and 2 m tubes with and without attachment at various fill lengths.

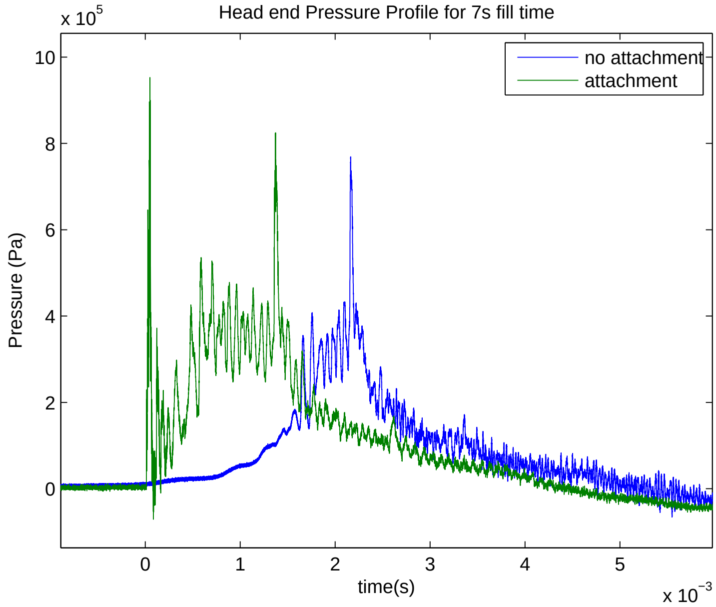

Figure 5: Comparison of head end pressures of 1 m tube with 0.5 m filled with reactive mixture with and without small tube attachment.

consequently lower density within the Taylor wave and higher density closer to the head end. (The average density of the gas between the detonation wave and the head end is constant.) This will produce higher pressure at the head end closer to the constant volume combustion condition. This explanation may partially be inferred to some extent from the head end pressure profiles of both the cases shown Fig. 5. Both the duration and level of constant pressure are larger in the case of tube with attachment compared to the case without attachment. Sharp rise in the head end pressure is obtained because the detonation wave is formed in the large tube as soon as it exits the small tube, while it takes some time for the detonation to form in the tube without attachment. This point can be taken as one of the plausible arguments for obtaining higher specific impulse with weaker detonation waves, though further investigation is required. However at larger fill lengths, the difference comes down and at fill lengths greater than 1 m, the tube with attachment shows lower specific impulse compared to the tube without attachment. In order to examine this behaviour, the head end pressures obtained in completely filled 2 m tube with and without attachment are compared in Fig. 6. The figure clearly shows that the duration of constant pressure and the tail off are much larger in the case of the tube without attachment, though the constant pressure level is slightly larger in the case of the tube with attachment. The sharp cut off of the head end pressure in the case of tube with attachment indicates the possibility of failure of detonation at length greater than 1.2 m.

4 Conclusions

Experiments conducted in tubes with detonation initiated using small diameter tube attached at the head end has shown that significantly improved specific impulse can be achieved compared to the normal detonation tubes. This increase in specific impulse is obtained in spite of the fact that CJ detonation is not achieved in these cases. However there is a tendency for failure of the detonation wave in tubes of large lengths (more that 1.2 m in the present case). The details of the mode of propagation of the detonation wave needs further study.

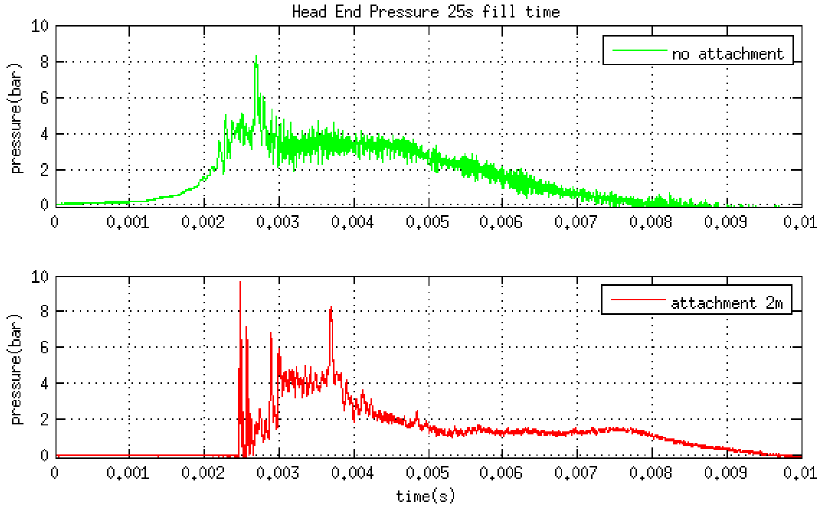

Figure 6: Head end pressure obtained in completely filled 2 m tube without and with small tube attachment

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