**Promoting Detonation Diffraction from Circular Tube to Cone by Obstacles**

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## Introduction

Several studies have shown that the presence of obstacles can promote transition to detonation in a tube. For example, Thomas and co-workers (2002) carried out an experimental and numerical study concerning critical conditions for detonation initiation by shock reflection in a tube. They used a conventional shock tube with rectangular cross-section and produced the shock reflection by means of an obstacle giving a blockage ratio of 50%. They expressed a condition to establish detonation as $\eta > 1$, with $\eta = \dfrac{h}{a_r \cdot \tau_r}$, where $h$ is the height of the obstacle, $a_r$ is the sound speed and $\tau_r$ is the ignition delay time ($r$ indicates conditions in the undisturbed reflected shock region). This criterion does not concern some obstacle features, such as inclination of frontal wall, but only its dimension $h$.

Since the role of obstacles in promoting detonation transmission in cones is not yet well understood, here we present an experimental study of influence of such obstacle characteristics like their size, longitudinal position along the cone wall and inclination of their frontal wall. Numerical simulations confirm the experimental trends and in major cases reasonably agree with measured critical pressures necessary for detonation transition. Promoting detonation transmission by decreasing the critical pressure is advantageous for such applications as Pulsed Detonation Engine.

## Experimental Study

We study detonation transition in a stoichiometric $C_2H_2 + 2.5O_2$ mixture from a tube to a diverging cone. The experimental setup is similar to that used by Khasainov et al. (2003), but here we use longer tube (7 m versus 4 m) and mount some obstacle at the cone wall. Figure 1 shows the scheme of our set-up: a 7-m long and 52-mm i.d. shock tube is connected with a 500-mm long and 380-mm i.d. chamber. A cone with a half-divergence angle $\alpha = 35°$ was placed inside the chamber at the end of the tube. Obstacles with triangular or trapezoidal cross-section forms (see Fig. 2 and Fig. 3) were mounted at the cone wall at a distance of $\Delta x$ = 25 or 50 mm from the tube exit, so we studied the influence of type and number of obstacles on the critical pressure above which detonation transmission occurs. All experiments were conducted at room temperature.

Triple point traces were recorded on soot-covered plate located at the axial plane of the flow to visualize the history of detonation transition or failure in the cone. Detonation velocity measured just before the end of the tube was always close to the CJ velocity within 1%.

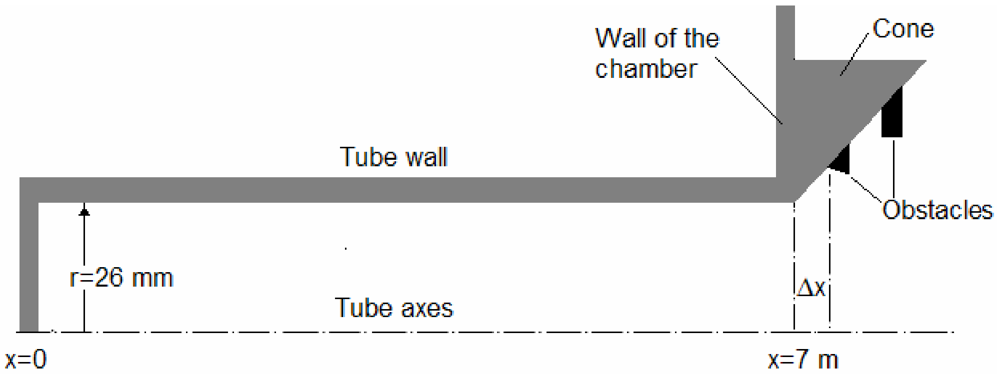



**Figure 1.** Scheme of the experimental set-up

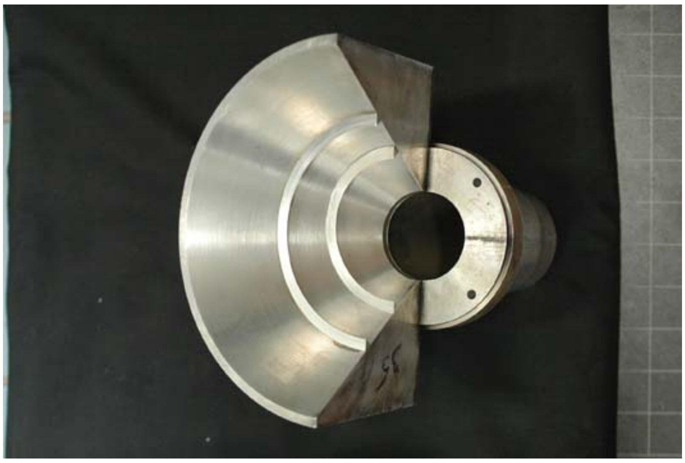


**Figure 2.** Cone with two triangular obstacles located at $\Delta x$ = 25 mm and 50 mm from tube exit

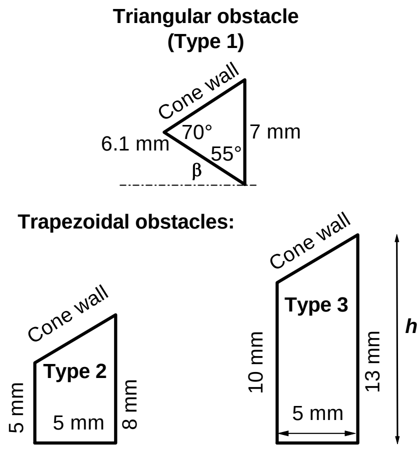
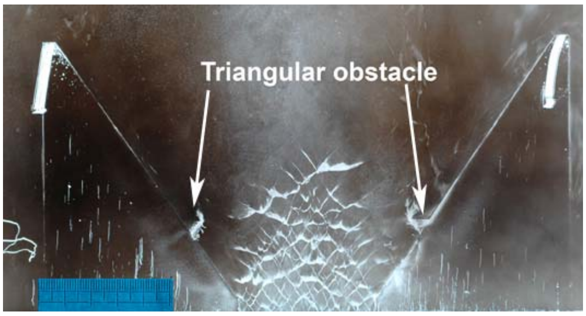



**Figure 3.** Scheme of different obstacles

Under these experimental conditions and without any obstacle on the cone wall the critical pressure for successful detonation transmission is about 34 mbar. The study of the effect of shape, size and longitudinal position of obstacles on critical transition pressure shows that triangular obstacles are more efficient than trapezoidal ones. Hence, the angle between cone wall and frontal wall of the obstacle plays an important role in the process of detonation reinitiation. Furthermore, we observed that between two triangular obstacles with the same shape the one placed at $\Delta x$ = 50 mm is noticeably more efficient than that placed at $\Delta x$ = 25 mm from the tube exit. Indeed, Figure 4 shows a soot-plate corresponding to detonation quenching at $P_0$ = 28 mbar, with the triangular obstacle placed at $\Delta x$ = 25 mm along the axis from tube end, while Fig. 5 displays detonation transition at $P_0$ = 26 mbar with the triangular obstacle at $\Delta x$ = 50 mm. Hence,(i) critical pressure can be decreased by 30 % and (ii) there is an optimal distance $\Delta x$ between the obstacle and tube exit for promoting the detonation transmission in terms of the critical pressure. Figure 5 shows the trace of the superdetonation that starts near the obstacle at “left” side of the witness soot-plate and propagates towards the axis in the layer of compressed fresh mixture between shock and flame front leaving very fine detonation cells. One can also notice that flow pattern is not axisymmetric since the right side of the soot plate shows in the same layer the so-called “impact” detonation cells due to impact of detonation arriving from above the plate.



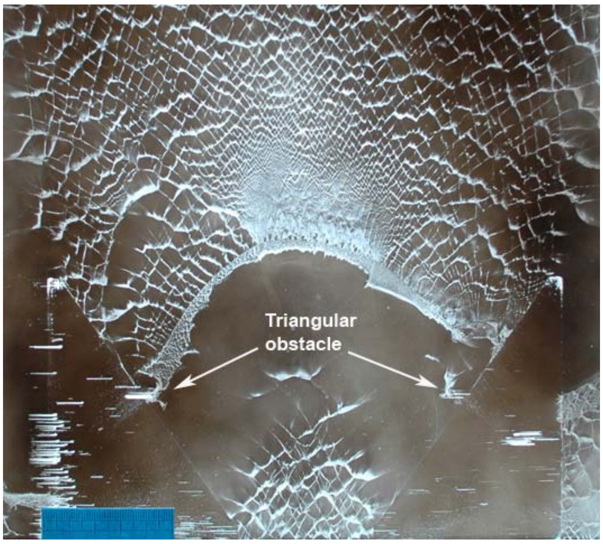




**Figure 4.** Detonation extinction at $P_0 = 28$ mbar with 1 triangular obstacle at $\Delta x$=25 mm

**Figure 5.** Detonation transition at $P_0 = 26$ mbar with one triangular obstacle at $\Delta x = 50$ mm

**Numerical Study**

Numerical simulations of 2D detonation diffraction from a tube to a cone with obstacles at its wall were performed assuming that flow is axially symmetric and using the LCPFCT numerical technique developed by Oran and Boris (1987). The adaptation procedure and global chemical kinetics for stoichiometric $C_2H_2/O_2$ mixture were similar to those used by Khasainov et al. (2003) to simulate detonation transition from a tube to a cone at different values of initial pressure and divergence angle. However, here we have chosen to vary the minimal mesh size with initial pressure ($\Delta x = \Delta r = \mathrm{Const}/P_0^{1.2}$) keeping constant number of meshes in the induction zone so that relative resolution is the same in the domain of studied initial pressures.

At first we have numerically simulated the experiments in the case of cone without obstacles and with the triangular obstacle, since experiments showed that it is the most efficient one. Numerical results are in general in reasonable agreement with experimental data as they show that the presence of obstacles at the cone wall promote detonation transmission by decreasing the critical pressure. Nevertheless, the numerical results overestimate (up to 30%) the experimental values, which is acceptable in view of simplified kinetics we used (a reaction scheme with only one global stage: R$\rightarrow$P). We can also observe that, as in experiments, the triangular obstacle placed at $\Delta$x = 50 mm (see Fig. 6) is more efficient than the one placed at 25 mm (see Fig. 7).

All values of calculated critical pressure have an uncertainty more important than that observed with experiments. For example, for the triangular obstacle at $\Delta$x = 25 mm, detonation fails definitively at $P_0 \leq 26$ mbar and always transits at $P_0 \geq 38$ mbar. However, in the intermediate domain of pressure, detonation failure and transmission take place non-monotonously with increasing pressure. We have supposed that this phenomenon is probably due to stochastic deviation of number of detonation cells present at the moment of diffraction at the end of the tube from the average value of cells number. Comparing the number of detonation cells calculated in the tube with the one observed experimentally (that follows the empiric law $\lambda \sim P_0^{-1.2}$) we have remarked that in general there is reasonable agreement but calculated detonation structure seems more irregular. Control calculations at a given $P_0$ show that a number of cells smaller than the average value does not always mean a more difficult transmission, and in the same way a number of cells larger than the average does not always promote transmission. Non monotonous behaviour of simulations results does not seem therefore to depend on the irregularity of cellular structure. To study this non monotonous effect one should use the same fine grid for all initial pressures, but this is too expensive in terms of time.

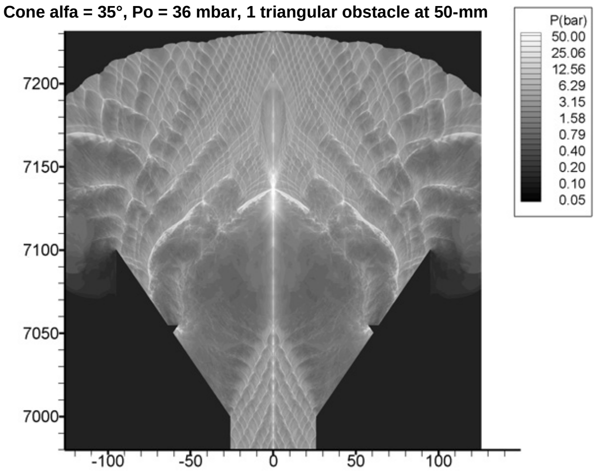



**Figure 6.** Calculated traces of maximum pressure at $P_0$ = 36 mbar with one triangular obstacle at $\Delta x$ = 50 mm

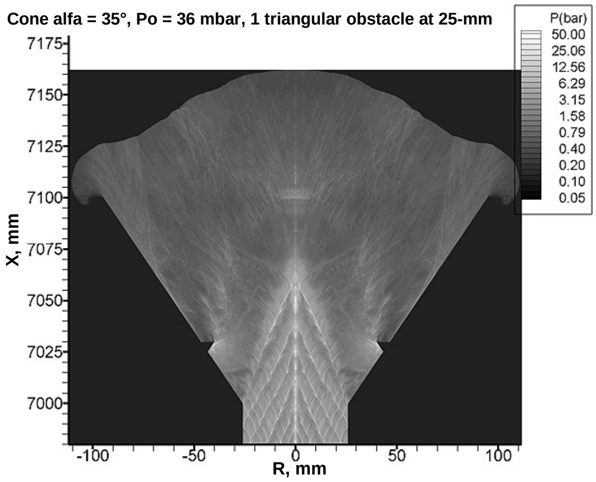



**Figure 7.** Calculated traces of maximum pressure at $P_0$ = 36 mbar with one triangular obstacle at $\Delta x$ = 25 mm

The purpose of the second part of the numerical study was to find numerically optimal obstacles main parameters, such as position along $x$ axis, size and angle between the cone wall and the obstacle wall. Besides, we have numerically studied the effect of one or two additional obstacles. Here we consider only the obstacle with triangular section and two values of pressure: 26 mbar (this case was quite critical for detonation transmission during the previous simulations) and 36 mbar (at this pressure transmission is easier than at 26 mbar).

In experiments we have placed obstacles in the divergent cone only at two different $\Delta x$ distances from the tube exit, $\Delta x$ = 25 mm and 50 mm. Therefore we have carried out numerical simulations placing the triangular obstacle also at the distances of 15 mm, 37.5 mm, 43.75 mm, 60 mm and 75 mm to see if there are more favourable cases, in comparison to those already studied, for detonation transmission. At $P_0$ = 26 mbar we have not noted any improvement. At $P_0$ = 36 mbar the optimal distance for transmission is $\Delta x$ = 37.5 mm (Fig. 8) rather than $\Delta x$ = 50 mm or $\Delta x$ = 25 mm. In the same figure one can observe that detonation build-up is due to superdetonation that originates at the vicinity of obstacle.

We have carried out some simulations to examine the influence of the obstacle size, keeping the same obstacle shape. We have used three other values of the obstacle height $h$ (see Fig. 3): $h$ = 14 mm, 21 mm and 28 mm corresponding to two, three and four times the obstacle size used in experiments ($h$ = 7 mm). We have noticed, observing numerical traces of maximal pressure, that the obstacle with the double size ($h$ = 14 mm) is the optimal one, hence the criterion proposed by Thomas et al. (2002) hardly can be applied in the cone case.

To study the effect of inclination of frontal wall of obstacle, we have carried a few simulations at different values of angle β (see Fig. 3) between tube axis and obstacle frontal wall, at a fixed obstacle position. Analysing the results we have noticed that for both $P_0$ = 26 mbar and $P_0$ = 36 mbar, the more favourable conditions for detonation transmission correspond to β = 30° (see Fig. 9). Therefore, there is an optimal value of β at given $h$ and $\Delta x$.

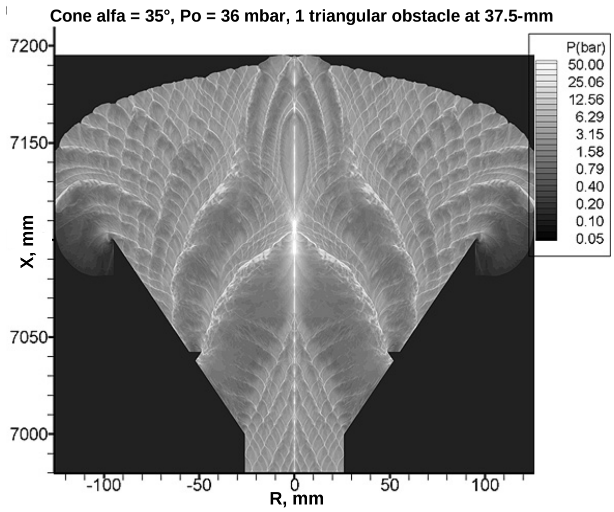



**Figure 8.** Calculated traces of maximum pressure at $P_0$ = 36 mbar with one triangular obstacle at $\Delta x$ = 37.5 mm

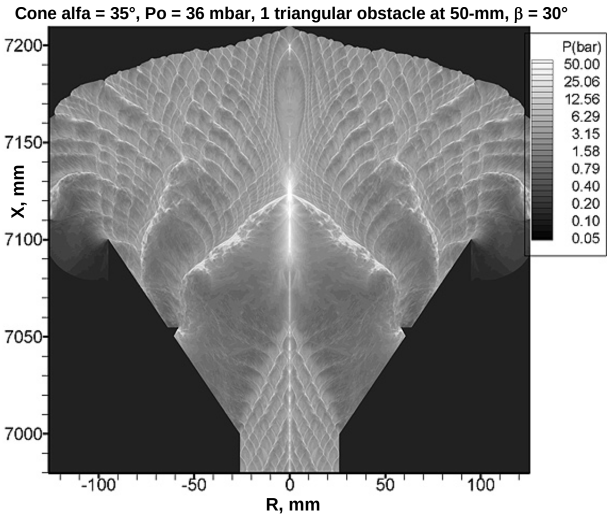



**Figure 9.** Calculated traces of maximum pressure at $P_0$ = 36 mbar with one triangular obstacle at $\Delta x$ = 50 mm, β = 30°

Finally we have studied the effects of one or two additional obstacles. As a basic case we have chosen an extinction where there are two triple point traces that begin at the obstacle and impact on the tube axis, however without giving re-initiation of detonation. The chosen case (see Fig. 10) is for initial pressure $P_0$= 26 mbar, with a triangular obstacle placed at 37.5 mm, and with size and β like in experiments ($h$ = 7 mm and β = 35°). We have added an obstacle along the trajectory of triple points trying to encourage temperature and pressure increase to obtain detonation re-initiation. We have placed an annular obstacle with a rectangular cross section with a size much larger than the first one. We have used five different values of angle $\beta_1$ between the basis and the direction of tube axis: 20°, 35°, 62°, 90° and 120°. There is always extinction except for the two cases of $\beta_1$ = 90° and $\beta_1$= 120°, but detonation re-initiation takes place very far from the cone exit. On the other hand, we have noticed that for $\beta_1$ = 20° the impact of triple points takes place earlier along the $x$ axis, but does not give re-initiation. Further simulations have investigated the effect of a second additional obstacle (see Fig. 11) for different combinations of angles $\beta_1$ and $\beta_2$. Calculations with additional obstacles show that their presence does not allow getting detonation transmission for the given case ($P_0$= 26 mbar, with a triangular obstacle placed at 37.5 mm), even if for some values of $\beta_1$ and $\beta_2$ we have obtained that triple points impact earlier on the tube axis.

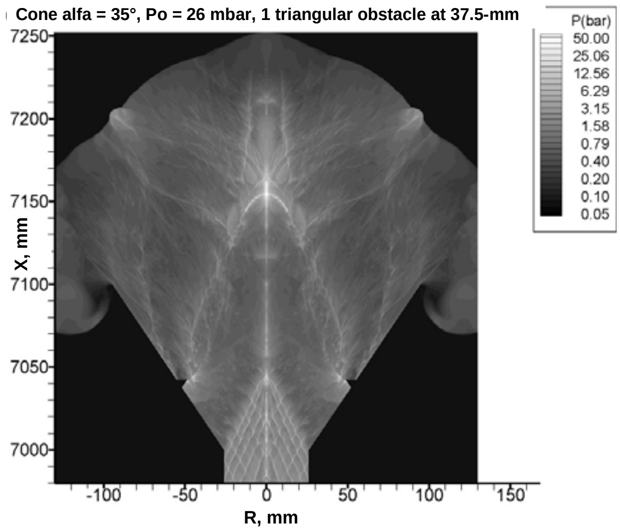



**Figure 10.** Calculated traces of maximum pressure at $P_0$ = 26 mbar with one triangular obstacle at $\Delta x$ = 37.5 mm

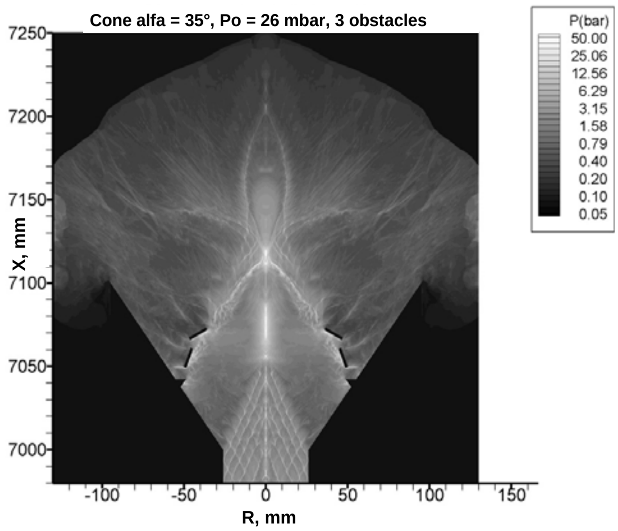



**Figure 11.** Calculated traces of maximum pressure at $P_0$ = 26 mbar with two additional obstacles

## Conclusion

The experimental study has shown that annular obstacles at the cone wall can promote detonation transmission by decreasing the critical pressure. Depending on longitudinal position, shape and number of obstacles (one or two) one can reduce the critical transmission pressure by 30%, which is interesting for practical applications. Numerical simulations results give reasonable agreement with most of experimental trends. It is shown numerically that there are optimal values of obstacle parameters and additional experiments will be done to check the predicted effect of obstacle angle, size and position.

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