Experimentally Observed Methods of Re-initiation during Detonation Diffraction into a Confined Volume

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1 Introduction

Diffraction of a planar detonation into a confined volume and subsequent transformation into a diverging cylindrical detonation is a complex process which has not been widely studied in the past. However, Murray and Lee[1] noted that there were two different methods, spontaneous and reflected re-initiation, by which the re-initiation of a detonation occurs after diffraction into a confined volume. They noted that the method of re-initiation was determined by the dimensionless parameter w/λ, where w is the distance from the exit of the tube to the endwall, and λ is the equilibrium detonation cell size. Their study showed that spontaneous re-initiation occurred for values of $w/\lambda > 11.5$, reflected re-initiation occurred for values of w/λ between 5.7 and 11.5, and that the detonation failed when w/λ was less than 5.7.

As a complement to the previous work in the literature, the current study also examined the diffraction of a planar detonation into a confined volume. However, in addition to the two re-initiation mechanisms, spontaneous and continuous reflected re-initiation, an additional re-initiation mechanism which makes re-initiation possible for values of $w/\lambda < 5.7$, termed discontinuous reflected re-initiation, was also observed. The present paper addresses the differences between the three observed re-initiation mechanisms and compares the results from the present study to those obtained by Murray and Lee[1] and Sorin et al.[2] Particular emphasis is placed on distinguishing discontinuous reflected re-initiation from continuous and spontaneous re-initiation. Following a brief overview of the experimental facility and methods of re-initiation, details on the main diagnostics are presented. The bulk of the present abstract focuses on results and their interpretation.

2 Experimental Facility

The experimental facility used in the present study consists of 2.75 m long detonation tube with an ID of 3.82 cm and an adjustable-width expansion volume, with an ID of 22.86 cm, which was attached to the end of the main detonation tube. The width of the expansion volume could be adjusted to a maximum of eleven different widths, ranging from 1 to 45.4 mm. Figure 1 shows a cutaway view of the expansion volume hardware. A more detailed description of the experimental facility is given in Polley et al.[3] Validation of the experimental facility and details on the experimental procedure are also given in Polley et al.[3,4].

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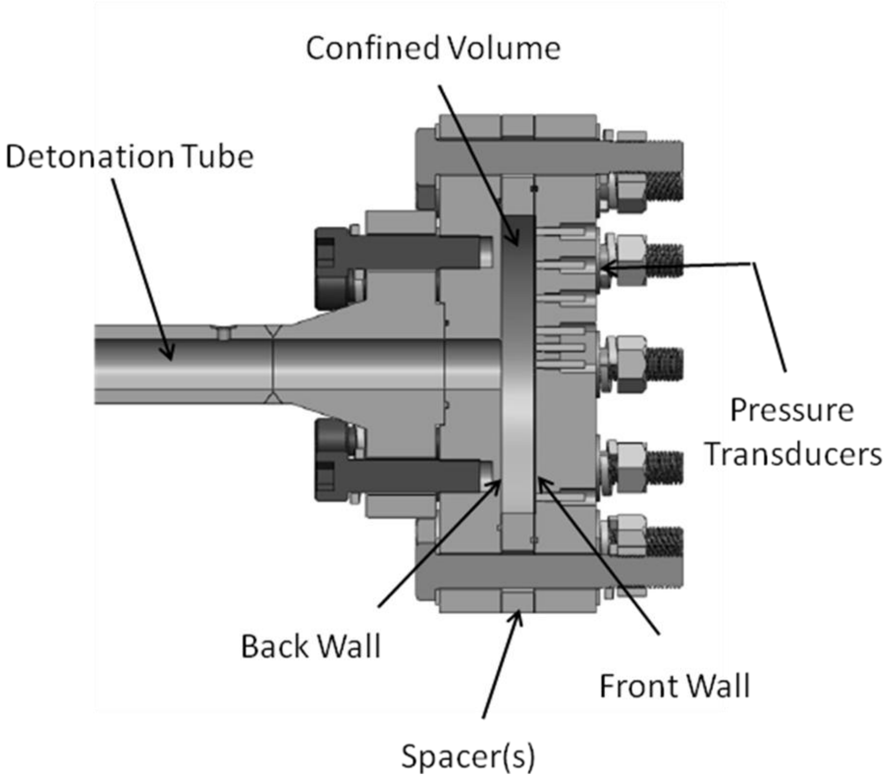


Figure 1. Cutaway of experimental facility.

3 Methods of Re-initiation

As noted in the introduction, three different re-initiation mechanisms were identified in the current study. The first, spontaneous re-initiation, was first observed by Murray and Lee[1] and is identical to the method of re-initiation which occurs when a planar detonation is allowed to diffract into an unconfined volume. During this method of re-initiation, the confining wall plays no role in the re-initiation of the detonation. As noted by Murray and Lee[1], this method of re-initiation occurs when $w/\lambda \geq 11.5$.

The second method of re-initiation, continuous reflected re-initiation, was also observed by Murray and Lee[1]. In this method of re-initiation, the confining wall does play an important role in the re-initiation process. The high-temperature and -pressure conditions produced when the diffracted shock wave from the de-coupled detonation wave reflects off the endwall are responsible for the re-initiation. This method of re-initiation was observed by Murray and Lee[1] when $5.7 < w/\lambda < 11.5$.

The final method of re-initiation, discontinuous reflected re-initiation, was not observed by Murray and Lee[1]. This method of re-initiation is similar to continuous reflected re-initiation in the fact that the confining wall plays an important role in the re-initiation process. However, unlike continuous reflected re-initiation--where the re-initiated detonation propagates as a stable, diverging cylindrical detonation--in discontinuous reflected re-initiation an additional failure and re-initiation process occurs prior to the formation of a stable, diverging cylindrical detonation.

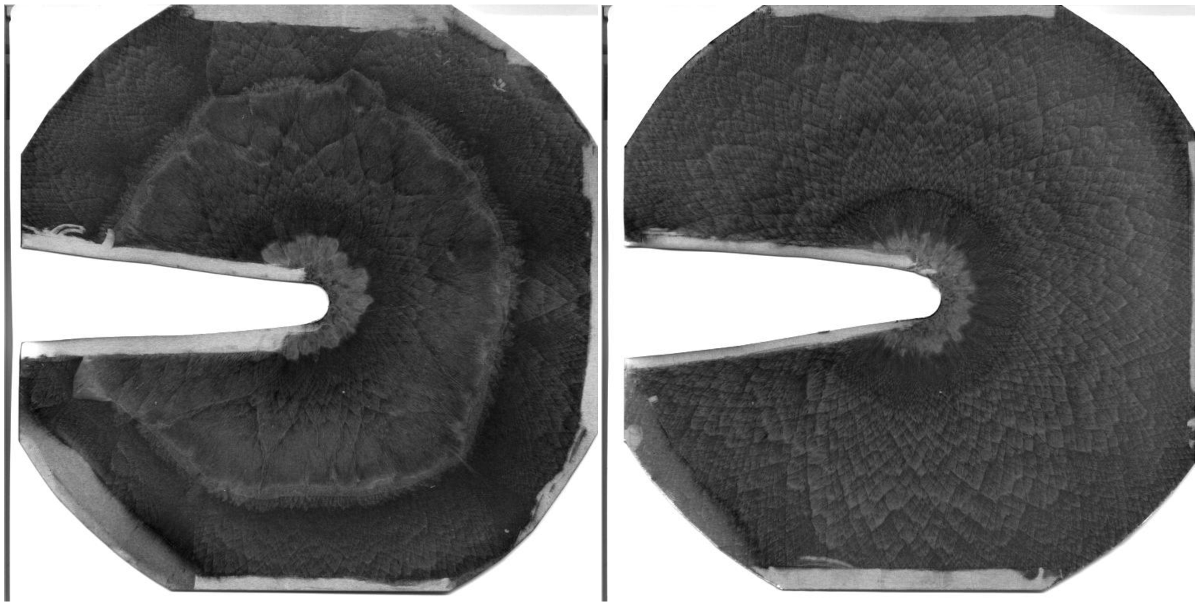
A more detailed explanation on spontaneous and continuous reflected re-initiation mechanisms can be found in both Murray and Lee[1] and Polley et al.[4], while a more detailed explanation on the discontinuous reflected re-initiation process can be found in Polley et al.[4]

4 Diagnostics

As discussed in Polley et al.[4], pressure transducers which were mounted in the endwall were the primary diagnostic used in the current study. A detailed discussion on the interpretation of the pressure transducer data and how they were used to distinguish between the different methods of re-initiation is given in Polley et al.[4] However, soot foils were also used as a secondary diagnostic in the current study, and in addition to confirming that the pressure transducer data were being correctly interpreted, offer additional information and insight into the different re-initiation mechanisms which cannot be obtained with pressure transducer data alone. A series of six soot foil records from the current study are presented in the following section.

5 Results

Figure 2 shows a side-by-side comparison of two front-wall soot foil records which were created by two different re-initiation mechanisms. Fig. 2a, on the left, was created by discontinuous reflected re-initiation while Fig. 2b, on the right, was created by continuous reflected reinitiation. It should be noted that the value of w/λ for Fig. 2a was 3.2, while the value of w/λ for Fig. 2b was 5.3.



a.) Go. 20.1-mm spacer. C_2H_4+3 O_2. w/λ = 3.2. b.) Go. 20.1-mm spacer. C_2H_4+3 O_2. w/λ = 5.3.

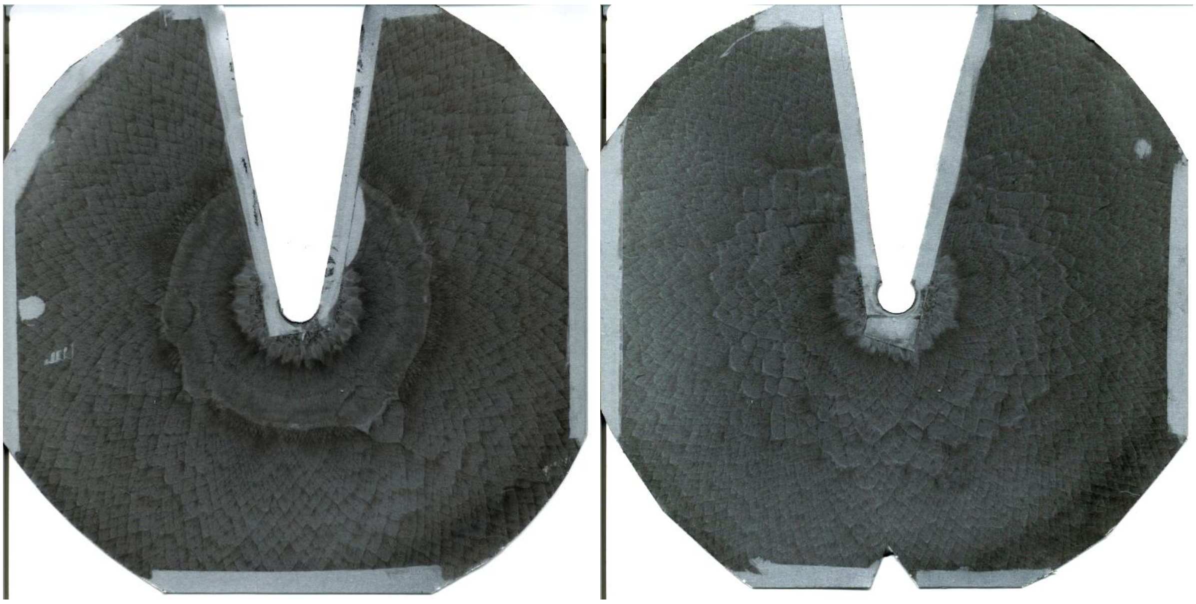
Figure 2. Comparison of soot foil records for different modes of re-initiation. The annular ring present in Fig. 2.a is a characteristic of discontinuous re-initiation.

As Fig. 2 shows, the distinguishing feature between Fig. 2a and Fig. 2b is the ring present in Fig. 2a. As noted by Murray and Lee[1], this ring is typically observed on backwall soot foil records and marks the location of the decoupled shock wave and reaction zone at the point the detonation is re-established along the back wall by a transversely propagating detonation which was first re-established at the front wall. This explanation has been extended to explain the formation of the annular ring observed in Fig. 2a by Polley et al.[4] in which a transversely propagating detonation originating at the back wall is responsible for the second re-initiation observed at the front wall.

Figure 2a shows that inside of the ring the detonation cellular structure disappears, indicating that the detonation had failed; but outside of the ring the detonation cellular structure is again present, indicating that the detonation had been re-established. The continuous cellular structure present and lack of an annular ring in Fig. 2b indicates that after the initial re-initiation a stable, diverging cylindrical detonation was formed.

Figure 3 shows a similar situation to Fig. 2. Discontinuous reflected re-initiation was responsible for creating Fig. 3a, while continuous reflected re-initiation was responsible for creating Fig. 3b. Again, it is important to note that the value of w/λ for Fig. 3a was 3.03, while the value of w/λ for Fig. 3b was 4.6.

The annular ring, which indicates that discontinuous reflected re-initiation occurred, is again present in Fig. 3a but absent in Fig. 3b. However, the radius of the annular ring in Fig. 3a is a much smaller radius than the annular ring in Fig. 2a. This difference is due to the difference in gap width between Fig. 2a and Fig. 3a. The soot foil record in Fig. 2a was created with a gap width of 20.1 mm, while the soot foil record in Fig. 3a was created with a gap width of 10.5 mm. This behavior is expected because, prior to the formation of the annular ring, a transversely propagating detonation must propagate from the original re-initiation location at the front wall to the back wall and finally again back to the front wall. Therefore, an increase in gap width will increase the distance the transversely propagating detonation must propagate and therefore will result in an increase in the radius of the annular ring.

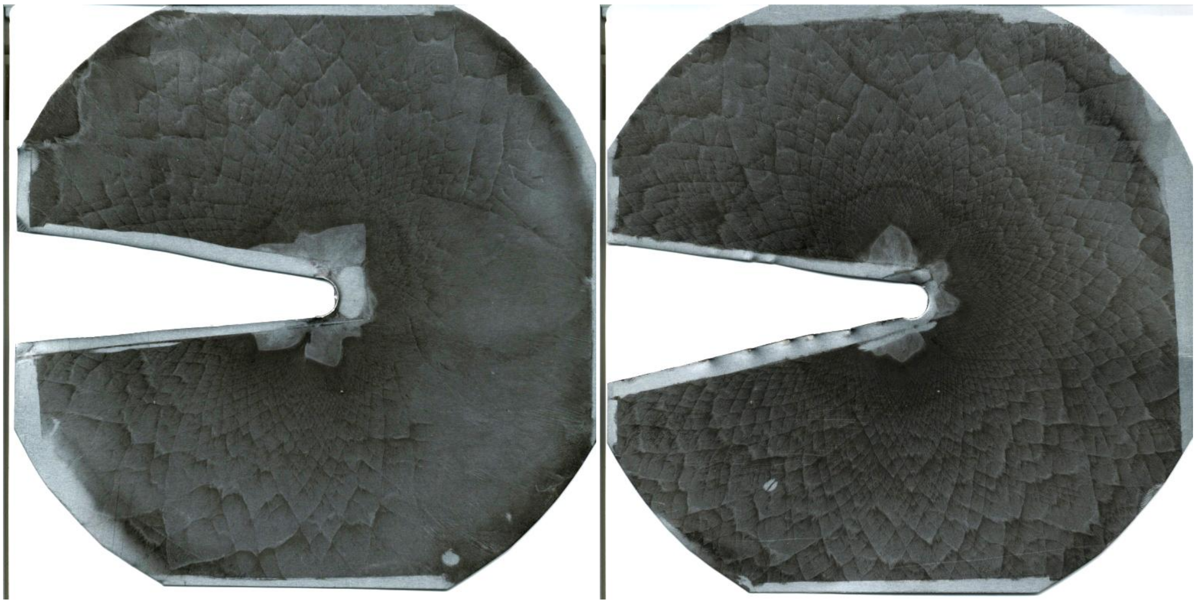


a.) Go. 10.5-mm spacer. C_2H_2+2.5 O_2. w/λ = 3.03. b.) Go. 13.7-mm spacer. C_2H_2+2.5 O_2. w/λ = 4.6.

Figure 3. Comparison of soot foil records for different modes of re-initiation. The radius of the annular ring in Fig. 3a is smaller than that in Fig. 2a because of the difference in gap widths.

Finally, Fig. 4 shows two soot foil records obtained at the largest gap size tested in the current study. Figure 4a shows a soot foil record where the detonation had failed or was failing at the edge of the soot foil record, while Fig. 4b shows a soot foil record where a stable, diverging cylindrical detonation was established.

It is interesting to note that for large gap widths discontinuous reflected re-initiation was not observed. As noted above, as the gap width is increased the radius of the annular ring also increases, and it is unclear if the diameter of the expansion volume was too small to capture this method of re-initiation or whether this method of re-initiation does not occur at larger gap sizes.



a.) No Go. 45.4-mm spacer. $C_2H_4 + 3\ O_2$. $w/\lambda = 4.6$. b.) Go. 45.4-mm spacer. $C_2H_4+3\ O_2$. $w/\lambda = 5.9$.

Figure 4. Comparison of soot foil records for different modes of re-initiation. As the gap size is increased the range of conditions over which discontinuous re-initiation occurs shrinks.

6 Comparison to Previous Results from Literature

Figure 5 compares the results of the current study to the results of Murray and Lee[1] and Sorin et al.[2]. Sorin et al.[2] were the first to report results on a plot of λ_s/λ vs w/D, where λ_s is the cell size necessary for successful transmission of a planar detonation into an unconfined volume. It can be seen that in the current study transmission was possible for a much wider range of conditions when compared to either Sorin et al.[2] or Murray and Lee[1]. This difference might at first seem like a discrepancy because in the present study we consider a discontinuous reflected re-initiation to be a “go” condition for detonation propagation. However, when the boundary between continuous and discontinuous re-initiation is considered, Fig. 5 shows that the data from the current study agree rather well with the data from both Sorin et al.[2] and Murray and Lee[1].

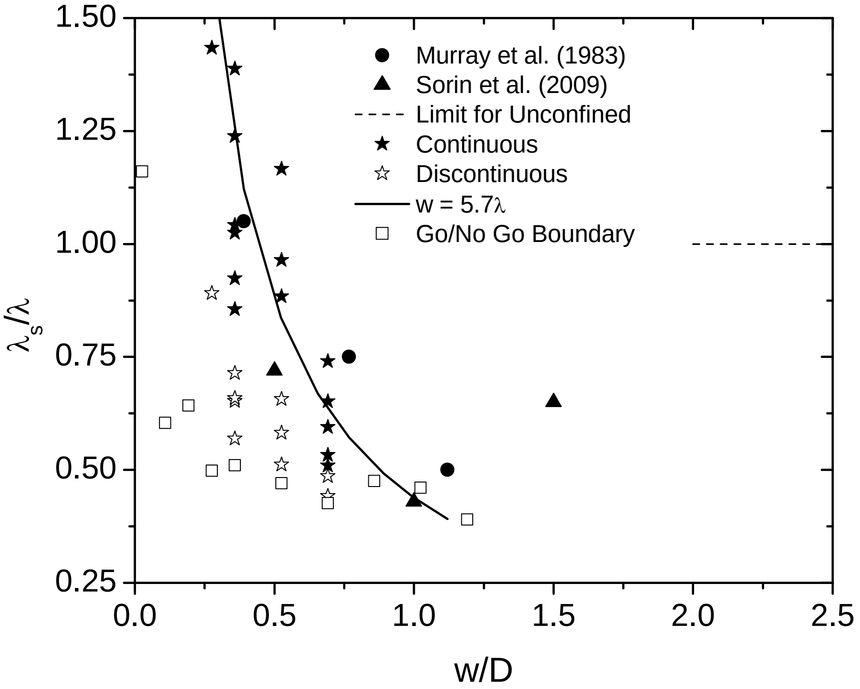


Figure 5. Comparison of results from current study to Murray and Lee[1] and Sorin et al.[2]

6 Conclusions and Future Work

The diffraction of a planar detonation into a confined volume and its transformation into a diverging, cylindrical detonation was the subject of the current study. Three different re-initiation mechanisms which are responsible for the successful transformation of the planar detonation wave have been experimentally observed. Two of the re-initiation mechanisms, spontaneous and continuous reflected re-initiation have been previously observed in the literature, while a new method of re-initiation, discontinuous reflected re-initiation, has also been identified. The observance of discontinuous reflected re-initiation is believed to be responsible for the apparent discrepancy between the results of the current study and the studies by Murray and Lee[1] and Sorin et al.[2]. Efforts are currently underway to more clearly define the boundary between continuous and discontinuous re-initiation over a wide range of test mixtures and gap size.

References

[1] Murray, S.B. and Lee, J. H., (1983) On the Transformation of a Planar Detonation to Cylindrical Detonation. Combust. Flame. 52:269.

[2] Sorin, R., Zitoun, R. and Desbordes, D. (2006) Optimization of the Deflagration to Detonation Transition: Reduction of Length and Time of Transition. Shock Waves. 15:137.

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[4] Polley, N., Egbert, M. and Petersen, E.L. Methods of Re-initiation and Critical Conditions for the Transformation of a Planar Detonation to a Cylindrical Detonation. Submitted to Combust. Flame.