# Soot-foil recordings of cellular detonation propagating in annular tubes

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## 1 Introduction

The present study reports some experimental results on the detonation propagation in an annular cross-section tube. The reactive mixture was the stoichiometric hydrogen-oxygen at initial pressures ranging from 12 kPa to 20 kPa. The cross-section outer diameter was 50 mm, with a width $w$ of the annular gaps of 5, 10 mm, and 15 mm. In the near-limit cases, such as in the helical case [1, 2, 3, 4, 5, 6], boundary layers can play a significant role in the decreasing of the detonation velocity [7, 8]. Section 2 presents the experimental set-up and methodology, and section 3 the results from soot-foil recordings. Section 4 concludes the study. We plan to do further experiments with hydrogen-air at the stoichiometric composition and hope to present the results for the latter case during the oral presentation at ICDERS.

## 2 Experimental set-up and methodology

The experimental set-up was a detonation tube composed of two concentric main parts: a circular outer tube (the detonation tube) and a smaller circular one inserted inside the latter. The circular detonation tube was 4 m long, and its cross-section diameter was 50 mm. The annular section was positioned in the last 2 m of the set-up. The width $w$ of the annular gaps were 5, 10 mm, and 15 mm. The thickness of the soot foil was 1 mm. The aim of the first 2-m long section was to generate a steady detonation from a deflagration-to-detonation transition, enhanced with a Shchelkin spiral. Then a Chapman-Jouguet (CJ) detonation entered in the annular section.

Figure 1 shows the experimental set-up and a schematic of the annular configuration. Two series of experiments varying the initial pressure $p_0$ were carried out: one for the reference state in the circular tube and a second for the annular case. The CJ cell sizes were measured from the reference experiments. Soot-covered semi-circular foils of 1.5 m long positioned at the end of the tube were used to record the structure of the detonation cells for the circular tube and the annular configuration. The inner tube can also be covered by soot to record the cellular structure of the detonation propagating at the inner wall of the annular section, but it was not easy to analyze because of the poorer quality of mirror polish steel. A semi-circular mirror-polish soot foil was inserted to record the cellular structure at the outer wall of the annular section. The detonation was initiated by the spark of an automotive plug. The transition to detonation was then obtained by a 1 m-long Shchelkin spiral positioned immediately ahead of the plug. The tube was vacuumed before injecting the premixed composition prepared in a separate tank using the partial-pressure method. Two Kistler 603B pressure transducers (1 µs response time, 300 kHz natural frequency, each coupled with a Kistler 5018A electrostatic charge amplifier with 200 kHz bandwidth) were used to check that the CJ detonation regime was achieved before entering the annular section. The reactive mixture was the stoichiometric $H_2 + \frac{1}{2} O_2$.

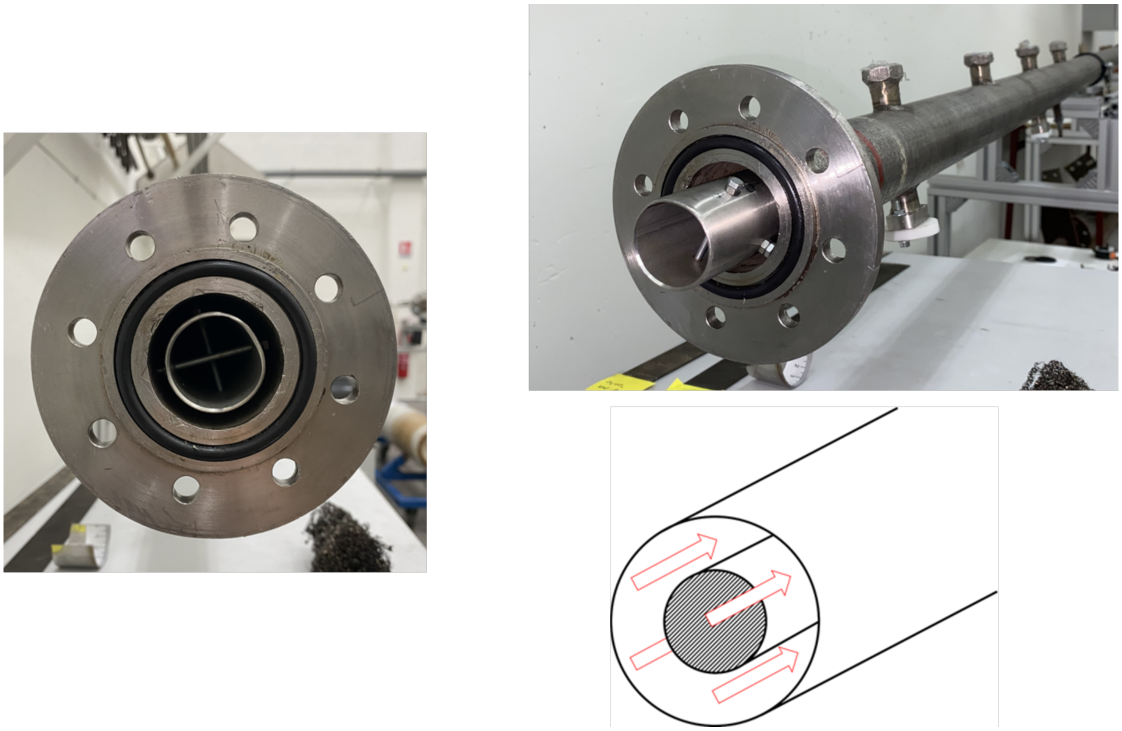

Figure 1: Pictures of the experimental set-up and a schematic of the annular configuration. The red arrows represent the direction of the detonation propagation.

# 3 Results

Soot-foil recordings show that above 20 kPa, the detonation propagated steadily at CJ state. At 20 kPa, Fig. 2 shows that the detonation front was multi-cellular with an apparent helical trajectory front inside the annular tube. For lower initial pressure, below 12 kPa, the detonation was no more transmitted in the annular section. For intermediate initial pressures, the detonation cell size increased. Moreover, figure 3 shows that at 13.75 kPa with a width of 5 mm, a band of re-ignition with very small cells was also present. This phenomenon is repeated several times along the soot foil in the annular tube. Later on, Fig. 4 shows that this detonation was quenched.

Figure 5 shows a soot-foil recording at the outer wall of the annular tube at 13.3 kPa with an annular width of 5 mm. The detonation propagated from right to left. The patterns imprinted in the soot shows a repeated feature of extinction and re-ignition with the presence of small cells along a global seemingly helical structure.

# 4 Discussions and conclusion

Figure 6 represents the detonation cell size as a function of the annular tube length for several initial pressures. Shot #14 is the reference CJ detonation cell size without the annular tube. Experiments were conducted with annular tubes of 1 m and 2 m long. The width of the annular section $w$ was 5 mm and 10 mm, corresponding to inner tubes of 30 mm and 40 mm, respectively. Figure 6 shows that the mean cell size was almost stable and slightly larger than the CJ cell size when the pressure was high enough (shots #2, #3, #4, and #8). At low enough initial pressure, below 12 kPa, the detonation quenched.

For intermediate pressure and smaller annular width (Fig. 6, shot #10: initial pressure of 13.75 kPa with a 5 mm annular width), the evolution of the detonation-cellular structure inside the annular tube became more unstable. The cell size oscillated between small and very large. Indeed, a smooth increase

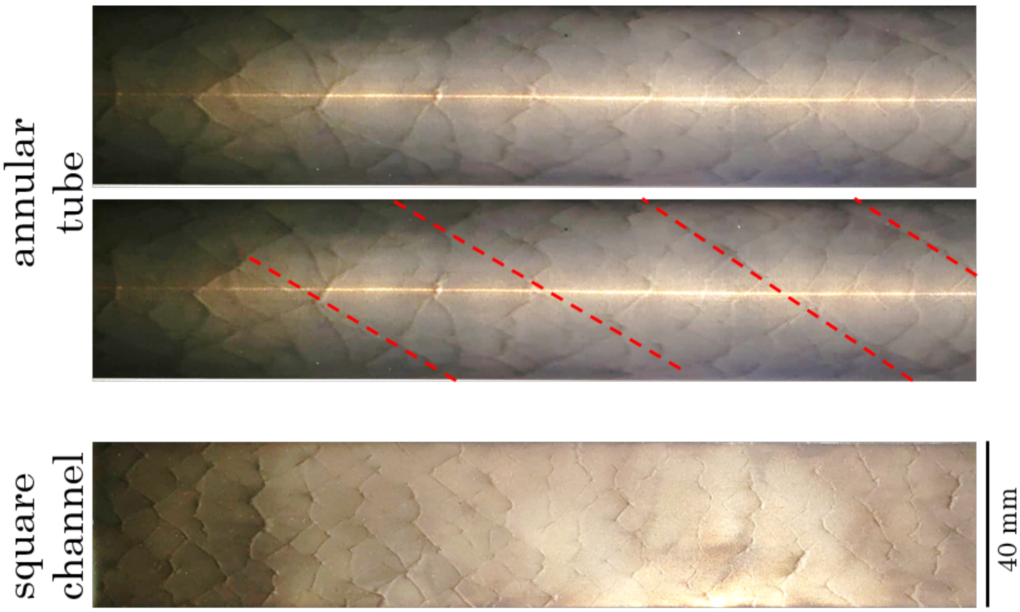


Figure 2: Soot-foil recordings of detonation cells for $H_2 + \frac{1}{2}\,O_2$ mixture at 20 kPa. The width was 10 mm. Bottom: Square cross section results. Upper: annular cross section, with and without the tracing of the helical structure. The detonation propagated from right to left.

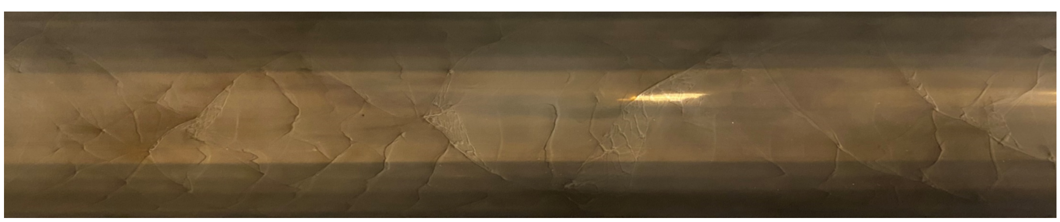

Figure 3: Soot-foil recording of detonation cells for $H_2 + \frac{1}{2}\,O_2$ mixture at 13.75 kPa. The annular width was 5 mm. The detonation propagates from the right to the left. Shot #10.

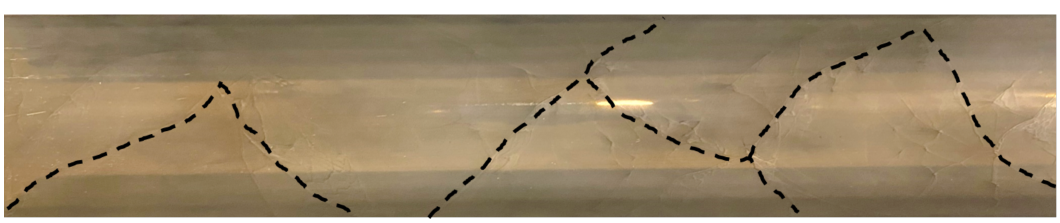

Figure 4: Soot-foil recording showing the transition from a multi-cellular detonation to a spinning detonation before quenching. The detonation propagated from the right to the left. The annular width was 5 mm, the mixture was $H_2 + \frac{1}{2}\,O_2$ at initial pressure 13.75 kPa. End of the annular tube. Shot #10.

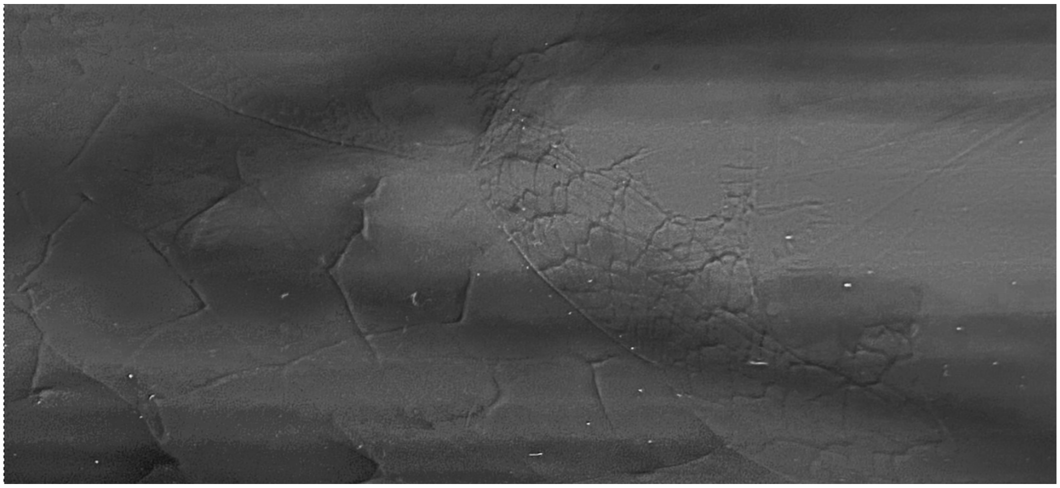

Figure 5: Soot-foil recording showing the helical detonation propagation in the annular channel. The detonation propagated from the right to the left. The annular width was 5 mm, the mixture was $H_2 + \frac{1}{2} O_2$ at initial pressure 13.3 kPa. Shot #12.

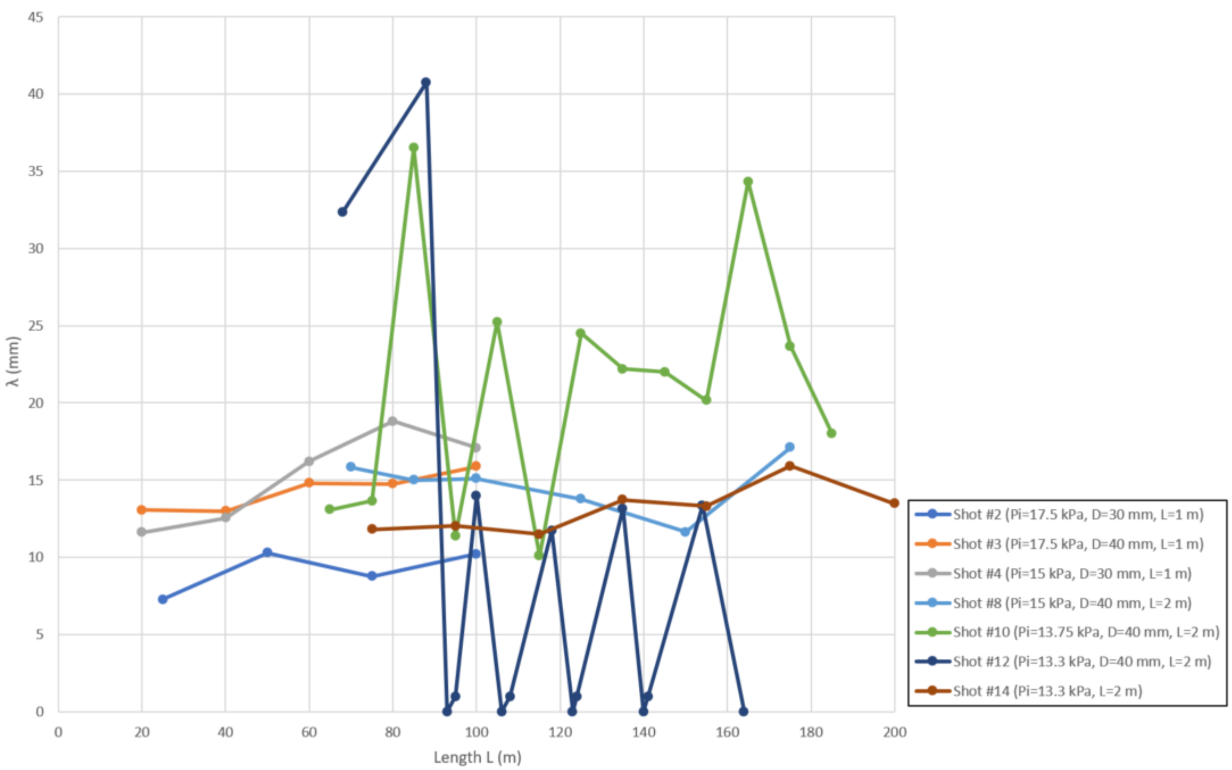


Figure 6: Detonation cell size $\lambda$ as a function of the position in the annular tube of length $L$ and annular gas $w$.

was followed by a sudden decrease, as shown in Fig. 3.
During the stage where the detonation re-accelerated, the cells became suddenly smaller and transverse bands of very small cells were observed. They may correspond to pre-compressed initial fresh gas with a transverse shock that could be due to a partially decoupled reaction zone before recoupling with a Mach wave.

Finally, at the critical pressure (near 13.3 kPa for a 5 mm annular width in our experiments, shot #12 in Fig.6), a sequence of detonation quenching and re-ignition was observed. At the re-ignition locations, a band of very small cells followed by an increase of the cell size were observed. The global trajectory of this multi-cellular detonation front was helical, as shown in the soot foil in Fig. 5. We hope to present additional results during the oral presentation, including stoichiometric hydrogen-oxygen mixtures diluted by nitrogen or argon.

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