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Research on Negative Pressure Effect Caused by Explosion in Limited Space

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Abstract

The shock wave generated by explosive explosion in a limited space is reflected, focused and interacted to form several positive and negative pressure zones in the limited space. In order to study the negative pressure effect caused by the explosion of aluminum-containing explosives in a limited space, the formulations of aluminum-containing explosives with aluminum powder content of 30% and 40% were designed, and explosion experiments were carried out in an explosive fort in an axisymmetric space. The pressure test system is used to obtain the shock wave overpressure-time curve, and the positive pressure impulse and the negative pressure impulse are extracted for comparative analysis. The results show that: in the axisymmetric explosion fort, the negative pressure effect is the strongest in the area closer to the explosion center, then weakens, and then slightly increases near the side wall; the negative pressure impulse near the explosion center is higher than the positive pressure impulse, but at the side The vicinity is lower than the positive pressure impulse; the formula with higher aluminum content has a lower negative pressure impulse near the core, but a higher negative pressure impulse near the sidewall. Measured by the negative pressure effect, the damage efficiency near the explosion center and the side wall of the explosion castle is higher.

Keywords: Negative Pressure Effect, Limited Space, Shock Wave Impulse.

1. Introduction

In a limited space, the detonation products formed by the explosion of explosives in the process of adiabatic expansion compress air to form an air shock wave that spreads outward, and at the same time generates a sparse wave that spreads inward, thereby forming a negative pressure zone below atmospheric pressure behind the shock wave front, forming a vacuum effect. In the open space, the negative pressure area is relatively small, and the impact is negligible. However, in a limited space, due to the reflection of the solid wall surface and the interaction between shock waves, several positive and negative pressure areas are created. Since negative pressure also has a harmful effect on the organism [1], the negative pressure area cannot ignore.

Because the aluminum powder in the aluminum-containing explosive uses the oxygen in the air as the oxidant, the energy that can be released per unit mass of the charge can be greatly increased, and it has become a common charge for the target of a closed or semi-closed space. Aluminum-containing explosives are mostly used in limited space explosion experiments. Scholars conducted explosion experiments on aluminum-containing explosives in containers of different volume levels for different research purposes. Ji Jianrong et al. [2] conducted explosion experiments on TNT-based aluminum-containing explosives in small explosive containers to study the content of aluminum powder and subsequent combustion The

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relationship of phenomena. Li Zhirong et al. [3] studied the difference in explosive output between air and nitrogen in a medium-sized closed container with an inner diameter of 2.6m. Zhang Fan et al. [4] conducted explosion experiments on TNT-based aluminum-containing explosives in a 26m3 explosive tank, and studied the effects of two charging methods on static pressure and other parameters. Ruggirello K P et al. [5] used the explosive device of Sandia National Laboratory in the United States to conduct explosion experiments on RDX-based aluminum-containing explosives to determine the influence of the initial diameter and equivalent ratio of aluminum powder on the calculation model. The above-mentioned research mainly focuses on the positive pressure effect of explosive overpressure. Li Xiuli [6] observed significant negative pressure in experiments in limited space, but did not study in depth.

In this paper, aluminum-containing explosives are used to conduct explosion experiments in the explosion fort, and the shock wave parameters at different positions are collected through the shock wave test system to analyze the negative pressure in the explosion fort.

2. Experiment

The experiment was carried out in a cylindrical reinforced explosion chamber with a semicircular dome with a diameter of 6m and a height of 5m. The internal dimensions are shown in Figure 1. The experimental explosive is an aluminum-containing explosive composed of RDX, ammonium perchlorate (AP), aluminum powder (Al) and a binder. Since the content of aluminum powder will affect the amount of gas in the explosion castle and the release of afterburning energy, considering the influence of different aluminum powder ratios, two formulas are used, RDX/AP/Al/Binder: 42.88/21.12/30/ 6 (Formulation 1) and 36.18/17.82/40/6 (Formulation 2).

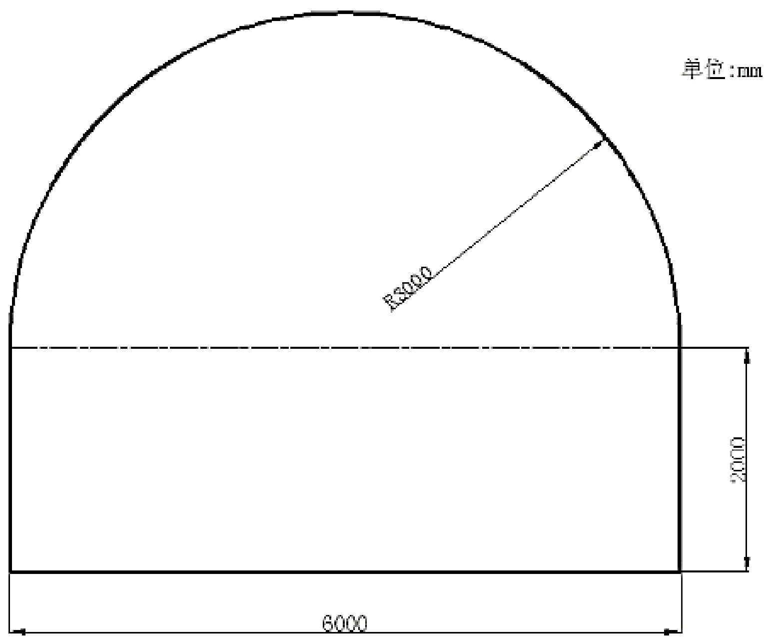

Figure 1. The internal dimensions of the explosion castle

The experiment uses a shock wave overpressure test system to obtain shock wave signals. The shock wave overpressure test system consists of sensors, signal conditioners, data acquisition and analyzers. Among them, the pressure sensor uses 6 wall pressure sensors and 4 free field sensors. The layout of the sensor in the explosion castle is shown in Figure 2. Six wall pressure sensors are fixed on the ground, respectively, on two test lines at a distance of 1.25m, 2m and 2.75m from the burst projection. The angle between the two test lines is 45°. Four free-field sensors are placed on two test lines 1.2m and 1.8m away from the burst projection. The installation height is 60cm, and the angle between the two test lines is also 45°.

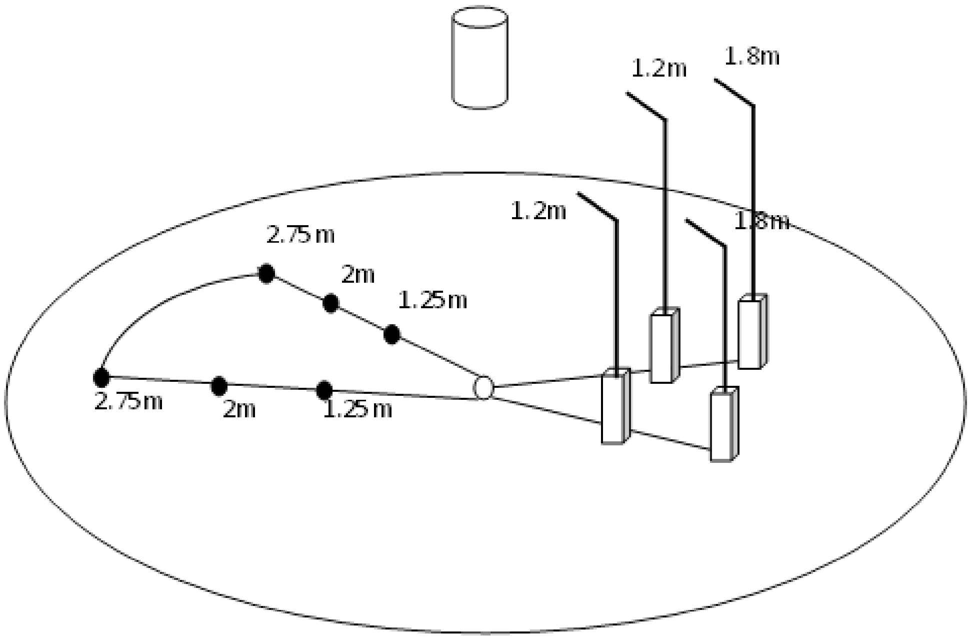

Figure 2. Schematic diagram of pressure sensor layout

The pressure-time curve is obtained through the data acquisition instrument. The shock wave parameters collected by the wall pressure sensor are reflected wave parameters, which need to be converted into incident wave parameters. The free field sensor obtains directly the incident wave parameters. Therefore, the free-field sensor parameters and the wall sensor parameters are used to verify each other to determine the rationality of the signal, remove abnormal signals, and analyze the shock wave parameters obtained by the wall sensor.

3. Results and Analysis

3.1. Typical Waveform of Explosion Shock Wave in A Limited Space

In the limited space, due to the reflection of the solid wall surface, the shock wave overpressure-time curve has completely different characteristics from the unconstrained explosion shock wave. Select the overpressure-time curve of the aluminum-containing explosive of the same formula in the confined explosion and unconfined explosion environment at the same contrast distance for comparison, as shown in Figure 3. The overpressure of the main shock wave at the same contrast distance in a confined explosion is significantly higher than that of an unconstrained explosion, and has a more obvious negative pressure action zone. The overpressure is the overpressure impulse when the integral of the overpressure is over time. The amplitude of the pulse wave after the main peak of overpressure even reaches 80% of the main peak, forming a greater impulse over a longer action time.

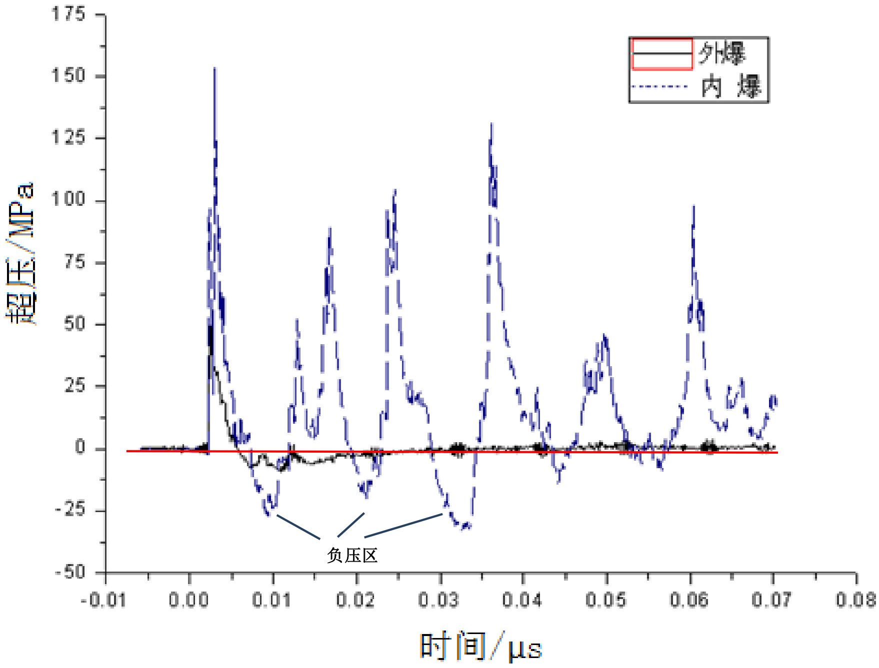

Figure 3. Comparison of shock waves between confined explosion and unconfined explosion

Select the shock wave curve of formula 1 at different positions and observe the shock wave characteristics at different positions in the explosion castle. Figure 4 shows the shock wave overpressure-time curve obtained by the ground sensor at 1.25m. It can be seen that the peak value of the main shock wave is higher in the area near the center of the explosion, the reflected wave is not strong, and the negative pressure has a long time.

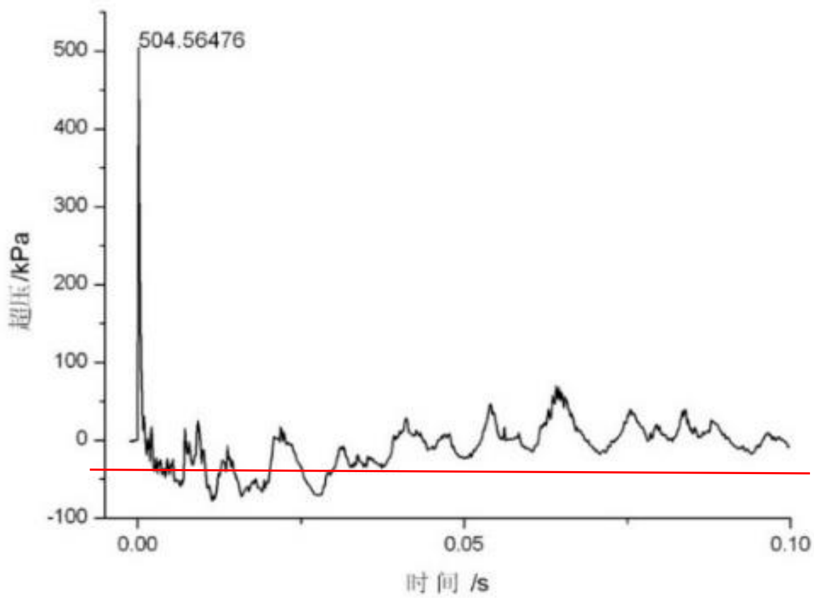

Figure 4. Shock wave overpressure-time curve at 1.25m

The shock wave overpressure-time curve obtained by the ground sensor at 2m is shown in Figure 5. It can be seen from the figure that there is an obvious oscillating waveform at 2m. Although the main overpressure peak has attenuated to about 133kPa, the three subsequent peaks are all above 50kPa, which can cause serious damage to personnel. The negative pressure at this location The effect is relatively small. Therefore, discussing the damage capability of aluminum-containing explosives cannot only consider the peak overpressure and impulse of the main shock wave. The damage capability should be measured by the number of shock wave peaks above a certain value, the positive pressure impulse and the negative pressure impulse.

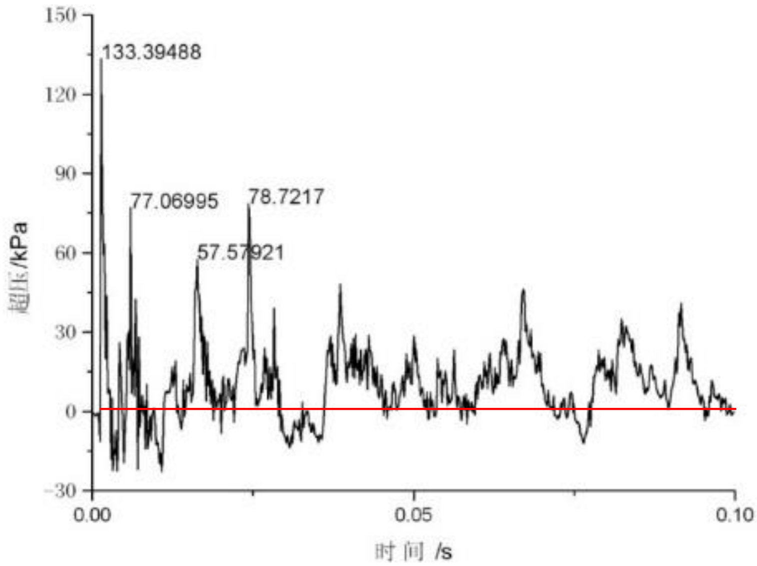

Figure 5. Shock wave overpressure-time curve at 2m

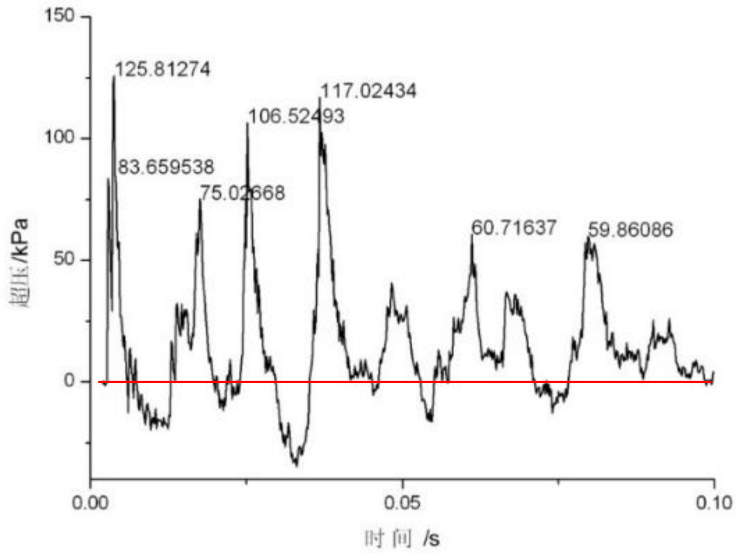

Figure 6. Shock wave overpressure-time curve at 2.75m

The shock wave overpressure-time curve obtained by the ground sensor at 2.75m is shown in Figure 6. This position is close to the side wall of the explosion fort. The figure shows that the shock wave waveform oscillates more violently. The peak overpressure of the shock wave reflected by the side wall is 40kPa higher than the peak of the main shock wave at this point. There is still a shock wave above 60kPa at about 80ms. The pressure, the intensity of the negative pressure and the action time have been significantly increased.

3.2. Analysis of Explosion Negative Pressure Parameters in Limited Space

In the above shock wave overpressure-time curve, intercept a curve from the initial to the pulse wave stable at 10% overpressure peak, and integrate the positive pressure section and the negative pressure section respectively to obtain the positive pressure impulse IB+ and the negative pressure impulse IB- , Comparative analysis of the negative pressure impulse of different positions and the negative pressure impulse of different explosion sources.

There are two test lines on the ground in the experimental field. The negative pressure generated at the measuring points on the ground after the explosion of formula 1 is shown in Figure 7. It can be seen from the figure that the error of the results of the two test lines is small, and the result of one test line can be used to characterize the shock wave characteristics at the same radius. The negative pressure impulse is the largest in the area closest to the burst center, and the negative pressure impulse is smaller at 2m. At 2.75m closer to the side wall, the negative pressure impulse increases again due to the existence of a large number of reflected waves.

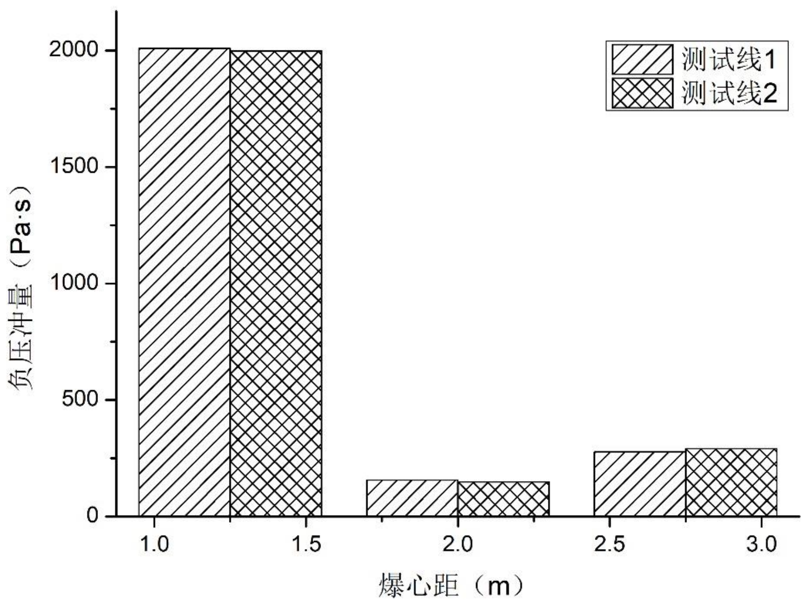

Figure 7. Negative pressure impulse of formula 1 at different measuring points

For formula 1, extract the positive pressure impulse and negative pressure impulse of each measuring point on the test line 1, as shown in Figure 8. At 1.25m, the negative pressure impulse is much larger than the positive pressure impulse, and the vacuum effect is obvious. The positive pressure impulse near the side wall (2.75m) is much greater than the negative pressure impulse. Therefore, although the negative pressure impulse has increased at the side wall, the positive pressure impulse plays the main damage role.

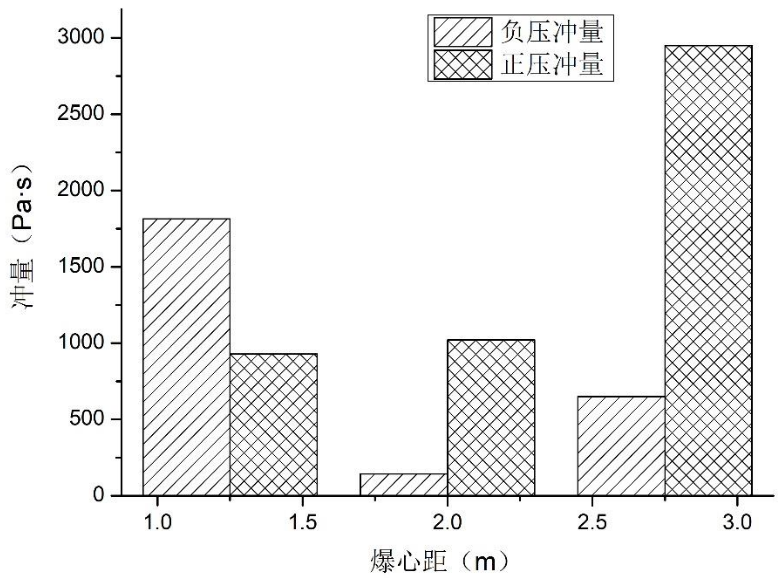

Figure 8. Positive pressure impulse and negative pressure impulse of formula 1 at different measuring points

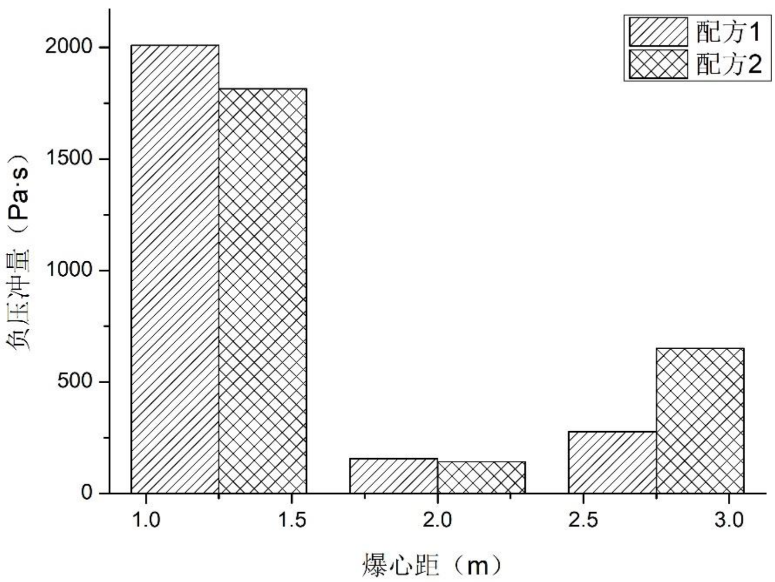

Figure 9. Negative pressure impulse of formula 1 and formula 2 at different measuring points

Comparing the negative pressure impulse of formula 1 and formula 2 at different measuring points as shown in Figure 9, it can be seen that formula 2 with 40% aluminum powder content is slightly lower than formula 1 with aluminum powder containing 30% aluminum in the near field. But near the side wall, the negative pressure impulse of formula 2 is higher than that of formula 1. This is because a formula with a higher aluminum content has a lower pressure of the detonation product, and the resulting shock wave pressure is lower, the sparse wave is also weaker, and the negative pressure impulse formed is lower. In the far field near the side wall, the formula with higher aluminum powder content has a stronger afterburning effect, which strengthens the shock wave. With the reflection and convergence of the shock wave, its negative pressure impulse is also strengthened. Therefore, in the axisymmetric explosion fort, the negative pressure effect is stronger in the area near the explosion center and near the side wall, and the negative pressure effect of the formula with high aluminum content is stronger than the negative pressure effect of the formula with low aluminum content.

5. Conclusions

Through the explosion experiment of aluminum explosives with 30% and 40% aluminum content in an axisymmetric space explosion castle, the shock wave overpressure-time curve was collected, and the positive pressure impulse and negative pressure impulse were analyzed and the following conclusions were obtained:

(1) In the axisymmetric explosion fort, the negative pressure effect is the strongest in the area closer to the explosion center, and then weakens, and then slightly increases near the side wall. Measured by the negative pressure effect, the explosion center is near the explosion center and the side wall. The damage efficiency is higher;

(2) The negative pressure impulse near the burst center is higher than the positive pressure impulse, but it is lower than the positive pressure impulse near the side wall;

(3) The formula with higher aluminum content has lower negative pressure impulse near the core, but higher negative pressure impulse near the side wall.

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