Study on the Jet Formation During Dispersal of Solid Particles by Shock and Blast Waves

V. Rodriguez, R. Saurel, G. Jourdan, and L. Houas

Introduction

During the last decade, investigations have been achieved to determine the physical mechanism which governs particle jet formation induced by the dispersion of a granular medium exposed to an impulsive pressure load, i.e., by a shock or a blast wave. This kind of such physical mechanism is observed during explosions or in nature as volcanic eruptions [1]. The formation of particle jets is also observed when a solid projectile impacts a particle layer [2]. Previous experiments have been conducted so far in three-dimensional spherical configurations using explosives surrounded by a granular layer [3–7]. In these experiments, the particle jet formation was obtained and clearly observed. The attempt was to correlate the particle jet distribution to the initial parameters like the particle diameter and density, the particle layer thickness and the strength of the incident shock wave in order to understand the breaking mode of a solid particle cluster. Even if it has been shown that the formation of particle jets depends both on the particle material properties and the ratio between the particle layer and the explosive mass [3], it was quite difficult to accurately relate the jet distribution with the initial conditions. More recently, cylindrical experiments were performed by Frost et al. [8] where it was easier to observe the particle jet formation. In spite of these studies, the selection mechanism is still not understood. The present experimental study was conducted in quasi two-dimensional geometry in order to ensure accurate characterization of the phenomenon. We present the concept of the two-dimensional experiments carried out. Parameters such as material density, strength of the incident shock wave, and the initial geometry of particle rings can be changed in order to find out what parameters can control the breaking mode of the particle clusters [9].

V. Rodriguez (✉) • R. Saurel • G. Jourdan • L. Houas
Aix-Marseille Université, CNRS–IUSTI UMR 7343, Marseille, France
e-mail: vincent.rodriguez@ensma.fr

Experimental Setup

Experiments were performed in the laboratory without the use of explosives but using a small conventional shock tube which produce moderate overpressure. The small conventional shock tube (T32) has a 32 mm diameter. It was vertically fitted beneath a Hele-Shaw cell inside which a ring of particles is located. The incident shock wave is directed onto the center of the ring. This one creates a blast wave at its exit, i.e., an impulsive pressure jump followed by a rapid pressure decrease. This blast wave propagates radially into the Hele-Shaw cell and sets in motion the ring of particles. The experimental apparatus is presented in Fig. 1. Thereby, the particle jet formation was visualized with a Photron SA1 high-speed video camera operating typically at 4000 fr/s. Moreover, pressure gauges located along the shock tube (C_1 and C_2) allow the determination of the incident shock wave Mach number. The C_{exit} pressure gauge records the pressure history at the center of the particle ring.

Experimental Conditions

We conducted several experiments for different initial conditions summarized in Table 1.

Results

Recorded frames covering the different steps of jet formation during dispersal of flour particles by a shock wave are presented in Figs. 2 and 3. This solid particle ring was subjected to an incident shock wave Mach number of 1.23. The two-dimensional configuration, through the transparent Hele-Shaw cell, allows the observation inside the ring during the radial dispersion. It highlights the presence of various perturbations in the particle layer exposed

G. Ben-Dor et al. (eds.), *30th International Symposium on Shock Waves 1*, DOI 10.1007/978-3-319-46213-4_128

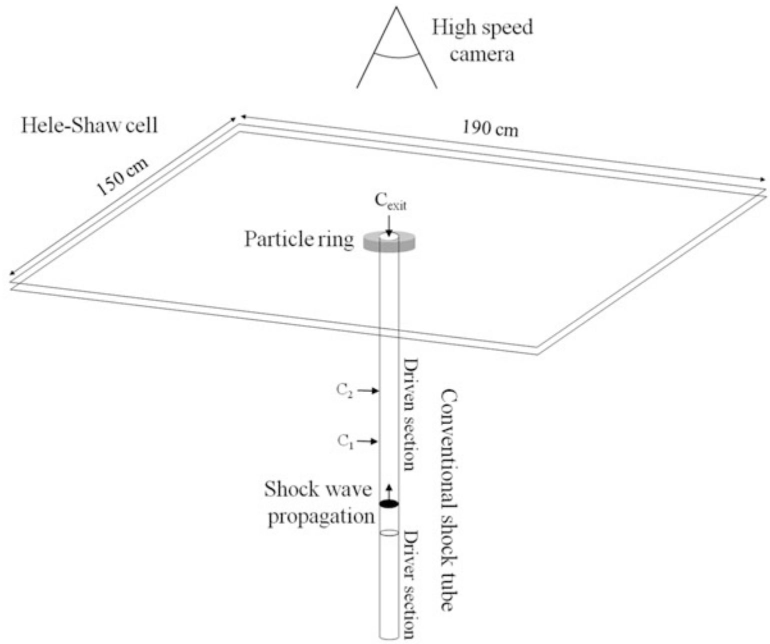

Fig. 1 Sketch of the experimental setup. The driver section of the shock tube is 210 mm long and its driven section is 945 mm long. The space between the plates is 4 mm

Table 1 Experimental conditions

Material	Density (kg/m^3)	Diameter (μm)	Ring diameter D_{ext} (mm)	Thickness of the particle layer (mm)	Incident shock wave Mach number	Overpressure (bars)
Flour	1500	10	40–90	20	1.1–1.45	0.7–4.5
Polystyrene	1050	10				
PMMA	1250	10				
Talc	2500	10				

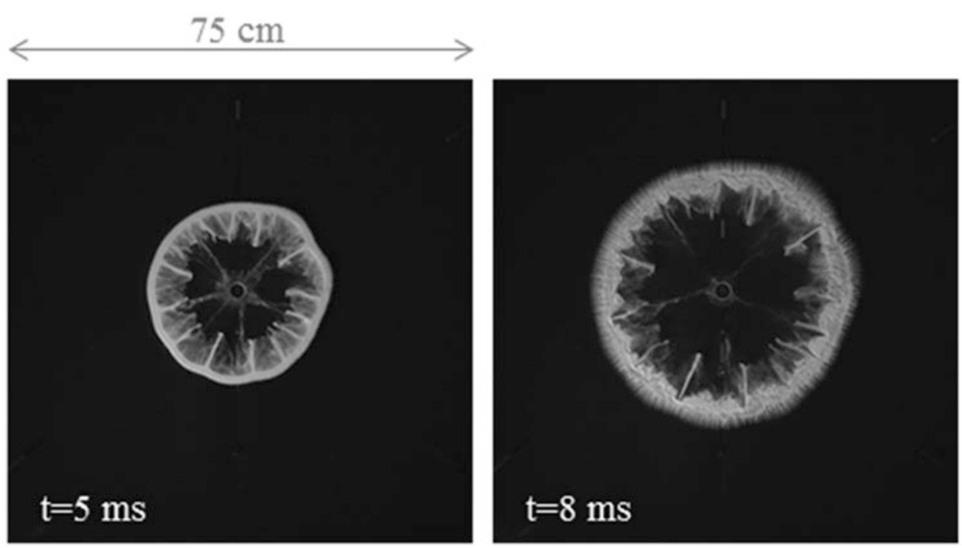

Fig. 2 Sequence of recorded frames covering the beginning of jet formation during dispersal of flour particles by a shock wave. The incident shock wave Mach number is 1.23

to a shock wave. At $t = 0$, the incident shock wave interacts with the particle ring and the dispersion of particles starts. After a very short time (between 0 and 5 ms), particle concentrations appear inside the ring resulting in regular particle jet distribution around the inner surface of the ring, as shown in Fig. 2. During the first moments of the particle propagation, the external front of the particle ring propagates with a smooth interface. After a few milliseconds, very thin perturbations appear around it, as shown in the second frame of Fig. 2. The dispersion of solid particles continues to grow radially inside the Hele-Shaw cell. Then, internal jets go on with the same direction as the particle front propagation which slows down. Thus, internal jets cross the front and are expelled outside as shown in Fig. 3 at $t = 14$ ms. Finally, these external jets continue to grow outside the particle front from $t = 18$ ms to $t = 36$ ms as shown in Fig. 3.

Figure 4 shows the number of particle jets, N_j, normalized by both the ratio of density R and the initial perimeter of the ring, $\pi D_{ext,}$ versus the initial ring acceleration γ averaged on the first 3 ms. R represents the ratio between the density of the used particles and the density of the polystyrene particles taken as reference in this study. All these points are issued from several experiments conducted with different shock wave Mach numbers, particle materials (change in the particle density), and initial ring sizes (change in the external diameter, but keeping constant the thickness of the particle layer). As we can see in Fig. 4, all the experimental points plotted merge into a single curve following a power law of the form $N_j R/\pi D_{ext} = 128.5 + 0.14\gamma^{2.6}$. We can observe that this relation is valid for initial particle layer acceleration until 13 ms^{-2}. Beyond this limit, the number of jets does not increase significantly and logically tends to a maximum number of jets. This point has to be checked.

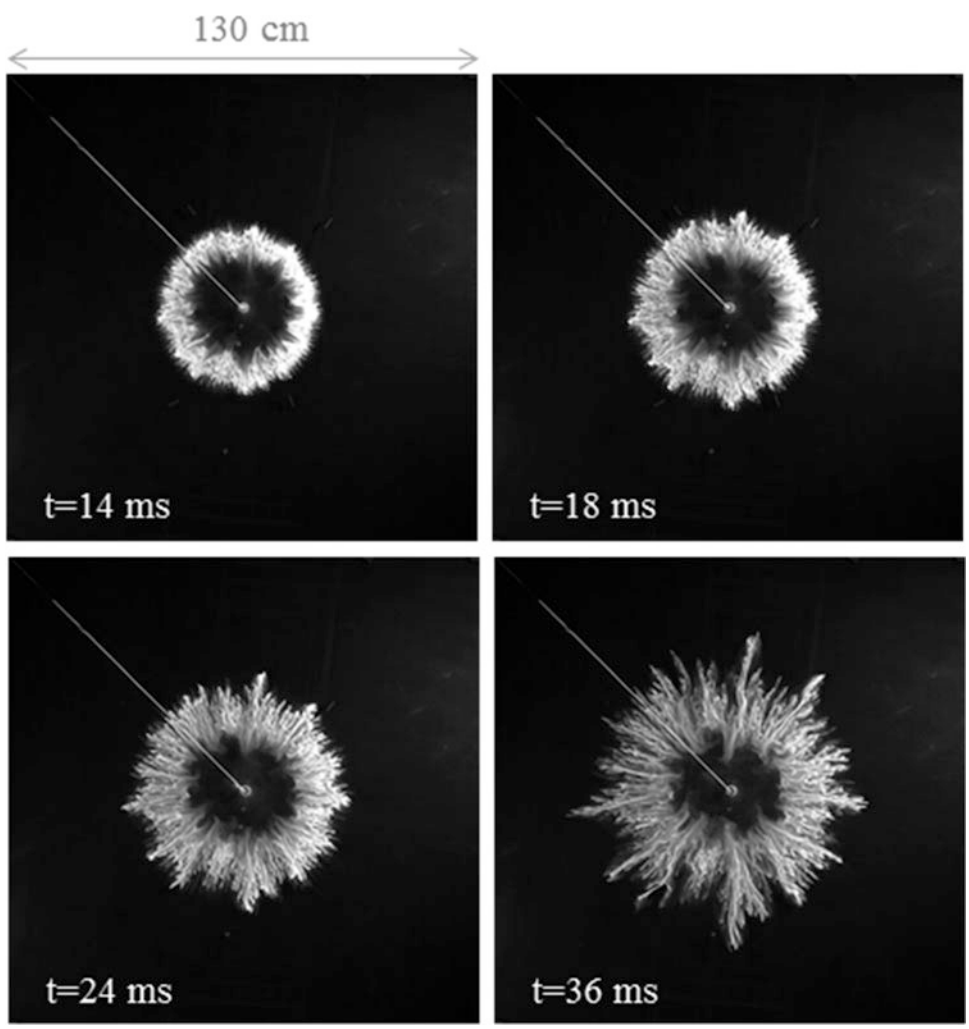

Fig. 3 Sequence of recorded frames covering the subsequent steps of jet formation during dispersal of flour particles by a shock wave. The incident shock wave Mach number is 1.23

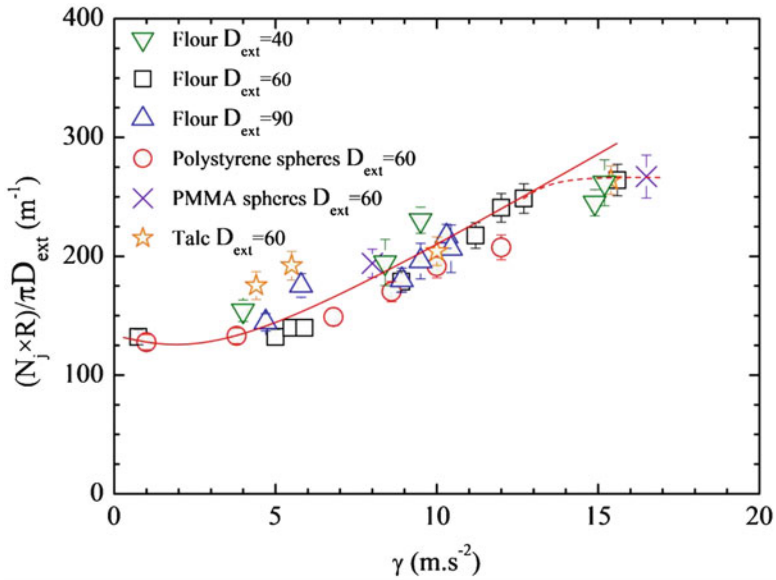

Fig. 4 Number of particle jets, N_j, normalized by both the ratio of density R and the initial perimeter of the ring, πD_{ext}, versus the initial ring acceleration γ averaged on the first 3 ms for different initial ring accelerations, material densities, and sizes of the particle ring

Conclusions

This chapter summarizes an experimental investigation and the aim is to consider in two dimensions the jet formation issued from impulsively dispersed solid particles. Several initial parameters such as the particle density, the strength of the initial pressure pulse, and the initial geometry of the ring have been studied. From fast flow visualizations, we notice, in all instances, that the jets are initially generated inside the particle ring and thereafter expelled outward. The number of jets that were generated during the dispersal of solid particles could be extracted. We showed that the normalized number of jets as a function of the initial ring acceleration shows a power law valid for all studied configurations involving various initial conditions but presents a saturation for great accelerations.

References

1. Kedrinsky, V.: Hydrodynamic aspects of explosive eruptions of volcanoes: simulation problems. Shock Waves **18**, 451–464 (2009)
2. Lohse, D., Bergmann, R., Mikkelsen, R., Zeilstra, C., van der Meer, D., Versluis, M., van der Weel, K., van der Hoef, M., Kuipers, H.: Impact on soft sand: void collapse and jet formation. Phys. Rev. Lett. **93**, 198003 (2004)
3. Frost, D.L., Goroshin, S., Zhang, F.: MABS 21, Israel (2010)
4. Zhang, F., Frost, D.L., Thibault, P.A., Murray, S.B.: Explosive dispersal of solid particles. Shock Waves **10**, 431–443 (2001)
5. Frost, D.L., Ornthanalai, C., Zarei, Z., Tanguay, V., Zhang, F.: Particle momentum effects from the detonation of heterogeneous explosives. J. Appl. Phys. **101**, 113529 (2007)
6. Milne, A.M., Parrish, C., Worland, I.: Dynamic fragmentation of blast mitigants. Shock Waves **20**, 41–51 (2010)
7. Parrish, C., Worland, I.: ISSW 28, Manchester (UK) (2011)
8. Frost, D.L., Grégoire, Y., Oren, P., Goroshin, S., Zhang, F.: Particle jet formation during explosive dispersal of solid particles. Phys. Fluids **24**, 091109 (2012)
9. Rodriguez, V., Saurel, R., Jourdan, G., Houas, L.: Solid-particle jet formation under shock-wave acceleration. Phys. Rev. E **88**, 063011 (2013)