Normal Shock Structure in Granular Gases: Instability and Non-Equilibrium Effects

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Shock waves in granular gases are generated when particles collectively collide with a wall [1]. Granular gases provide a means to investigate the non-equilibrium structure of gaseous shock waves in the hypersonic limit. Numerical studies of granular shocks, based on molecular dynamics and continuum formulations, have predicted a hydrodynamic instability whose wavelength is comparable to the shock thickness [2]. Despite these predictions, this instability has not yet been confirmed experimentally and its physical origin remains uncertain. The present study seeks to isolate shock waves in granular gases and examine the nature of this instability. An experimental setup was constructed consisting of a gravity-driven chute flow confined within a narrow channel, allowing quasi-two-dimensional particle motion. The channel inclination angle was adjustable between 90° and 30°, enabling exploration over a range of flow conditions. In each experiment, approximately 10^5 spherical steel beads of 1 mm diameter were released from a hopper and allowed to fall freely through the channel. Upon impact with and reflection from the bottom plate, the particles rapidly compacted, giving rise to a normal shock structure. The dynamics were recorded using a Phantom v1210 high-speed camera. A representative frame is shown in Fig. 1 (top). The experiments show the emergence of a corrugation instability with a wavelength comparable to the shock thickness, in qualitative agreement with the numerical results of Sirmas and Radulescu [2] (Fig. 1, bottom). In addition, particle tracking was used to analyze particle kinematics before and after shock formation, enabling the evaluation of local mean velocity, number density, and granular temperature. The results indicate that clustered regions exhibit reduced granular temperature compared to surrounding regions. This reduction in granular pressure produces a pressure gradient directed toward the clustered zones, which promotes further particle accumulation and strengthens the clustering. In addition, a continuum-based model is used to resolve the shock structure and provide a theoretical reference for comparison with the experimental data.

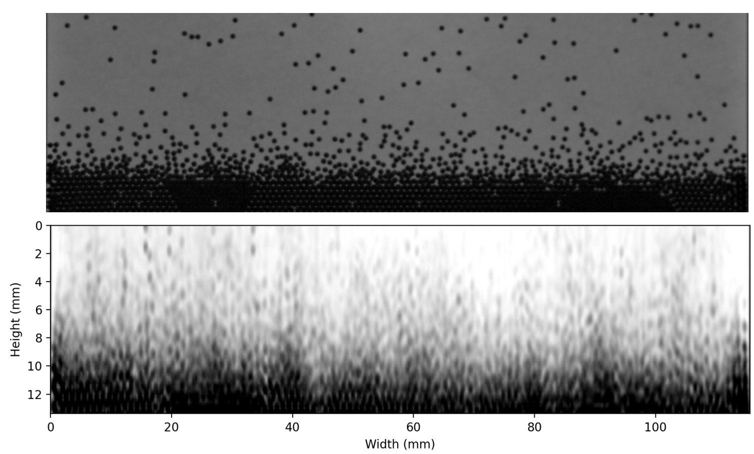

Fig. 1. Top: A single frame from direct visualization of the beads falling at an inclination of 80°; Bottom: Overlaid and intensity-averaged shock-aligned sequence over a time window comparable to the particle crossing time.

References

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