Flow of Dusty Plasma Around an Obstacle

John K. Meyer, Robert L. Merlino, Jonathon R. Heinrich, and Su-Hyun Kim

***Abstract*— Single frame video images of dusty plasmas flowing around a conducting wire are presented in this paper. The images were obtained by laser illumination of the dust suspension with the reflected light recorded using a fast video camera. The images from two different configurations are shown. The first image records the formation of a bow shock formed when a supersonic dust cloud impinges on a thin-wire biased to repel the negatively charged dust. The second image shows the deflection of a thin stream of dust particles around a negatively charged wire.**

***Index Terms*— Dusty plasmas.**

MICROSPHERES are often added to a fluid to make the flow patterns visible allowing quantitative measurements to be made. The particles are illuminated with a sheet of laser light for visualization of thin slices of the fluid, revealing complex flow structures. Particle image velocimetry or particle tracking techniques have also been used to provide spatial mapping of the time-resolved particle positions and velocities. In dusty plasmas—plasmas with embedded suspensions of micrometer-sized charged particles [1], visualization of the laser-illuminated particles is the primary diagnostic technique used to study their behavior. Under typical laboratory conditions, the dust particles acquire a negative charge and exhibit collective behavior in response to interactions with the background plasma and electric fields. The ability of researchers to study the collective behavior of the dusty plasmas has been greatly enhanced over the last 20 years by the availability of high-speed megapixel video cameras coupled directly to computers capable of real-time acquisition of thousands of megabyte video images. This has replaced the frame grabber devices used to capture and digitize individual still frames from an analog video stream on VHS tapes that stored images recorded with video cameras operating at 30 frames/s [2].

The ability to investigate the dynamics of the dusty plasmas at the (single particle) kinetic level allows us to study fluid flows at the smallest spatial scales [3]. Here, we present images of flowing dusty plasmas interacting with a cylindrical obstacle biased to repel the negatively charged dust particles. The dusty plasmas were formed using a dc glow discharge on a 3.2-cm anode disk located on the axis and in the center of a cylindrical stainless steel vacuum vessel, 90-cm long and 60 cm in diameter. The discharges were made in argon at pressures ~150 mTorr and discharge currents in the range of a few milliampere. An axial magnetic field of 3 mT was applied to produce an elongated cylindrical glow discharge. Dust particles (1-μm diameter glass spheres) were initially loaded on a tray under the anode, and were incorporated into the discharge when it was ignited.

Two different configurations were used to produce the flowing dusty plasmas. In one configuration, an L-shaped mesh electrode was located ~20 cm from the anode. This electrode was biased to trap a secondary dust cloud. When the bias was suddenly switched off, the secondary cloud was released and flowed supersonically toward the anode with a speed ~1–3 times the dust acoustic speed. We studied the interaction of this flowing dust cloud with a 0.5-mm diameter wire located downstream of the flow. The wire was biased to repel the negatively charged ($Q_d \approx -2000$ e) dust grains, and a dust void was formed around the wire, which was the effective obstacle. A thin (<2 mm) sheet of 532-nm laser light was used to illuminate the dust particles and the reflected light was recorded using a CMOS video camera (Photron, FASTCAM 1023 PCI) at a rate of 500 frames/s. A single frame image of the interaction is shown in Fig. 1(a). A bow shock was formed in front of the obstacle and an extended wake region behind it. In addition, evident in the image are dust acoustic waves, which are excited by the argon ions drifting with respect to the dust. An interesting feature of the interaction is the merging of the dust acoustic waves with the bow shock. Further details can be found in [4].

In a second configuration, a 4-cm diameter wire ring was placed 1−4 cm in front of the anode and biased to repel the dust particles. By adjusting the position of the ring with respect to the anode and its bias voltage, both the shape and speed of the dust trapped in the anode glow could be changed. The anode/ring configuration was used to produce a cylindrical pencil-like dust stream with a diameter of ~2 mm and speed ~10 cm/s. Fig. 1(b) shows a single frame video image, obtained in a manner similar to that used in Fig. 1(a) of the thin-dust beam as it flowed around the negatively biased wire obstacle. Notable in this image is the details of the stagnation region just in front of the obstacle. A relatively low-frame rate (60 frames/s) was used so that the dust particles appear as streaklines, a technique used to map fluid streamlines in aerodynamics. Further details can be found in [5].

In summary, images of a flowing dust cloud and a cylindrical dust stream interacting with obstacles set transverse to the flow have been presented. The images were obtained by laser sheet illumination of the dust particles and digital video recording of the reflected light with a high-speed CMOS camera. These images illustrate that the dusty plasmas, which

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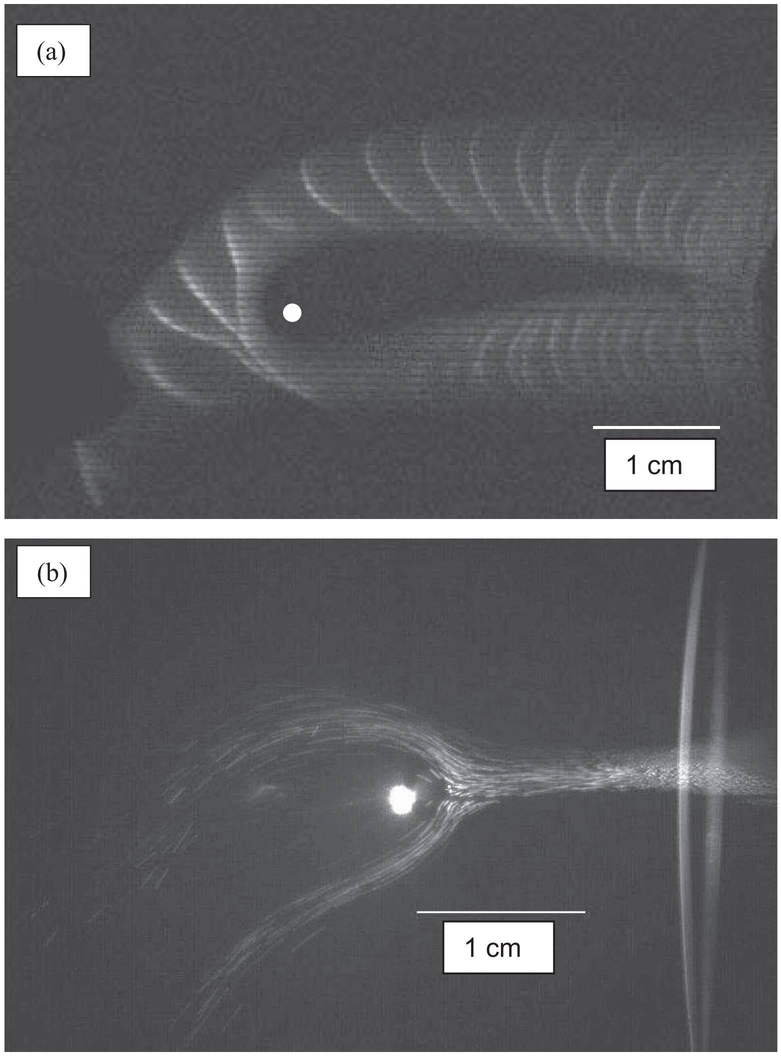

Fig. 1. Single frame video images of the interaction of flowing dusty plasmas with a negatively biased wire. (a) Supersonically flowing dust cloud impacts the negative potential structure around a wire and a bow shock is formed. Dust acoustic waves are also excited by an ion-dust drift instability. The small scale horizontal striations are due to the laser light passing through the grid. (b) Thin stream of dust particles flow around with a negative wire. The dust stream is produced by the ring electrode shown on the right.

exist in a liquid-like state, can be used as a surrogate system to study fluid flows at the individual particle level.

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