High-Speed Photography of Airborne Atmospheric Particles

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Atmospheric particles $\gtrsim 10\ \mu$ in diameter have been successfully photographed *in situ* using cameras with microsecond-duration flash lamps. Several such cameras developed and used in the past are discussed in this article. A bright-field camera for photographing precipitation particles, and a light-weight portable dark-field camera for photographing cloud particles have been developed at this laboratory. Several representative photographs are presented to demonstrate these cameras' imaging properties and to illustrate their use. The cameras have been used successfully to photograph particles at ground level. Mechanical motion compensation will be required at aircraft speeds if nonstreaked images are to be produced.

1. Introduction

Individual, airborne, precipitation size particles (100 μ to several millimeters diameter), and cloud particle size droplets and ice crystals (10–100 μ diameter) are difficult to photograph because they are small and often have high velocity-to-size ratios. If they are photographed *in situ*, one has no control over focus and must either limit in-focus volume in some manner or decide when a particle is in focus from the appearance of its image. Because of the low reflectance of the particles, it is usually necessary to use nonstandard methods of photographic illumination. In spite of these difficulties, photography of freely moving particles has the advantage of providing information about the particles and their concentrations in an undisturbed, or relatively undisturbed, state.

FIG. 1. Camera for photographing precipitation particles using bright-field illumination. Camera is shown set up at the edge of Old Faithful Geyser; it was used to photograph drops from the plume as well as snow and graupel particles.

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This paper discusses two cameras: one uses bright-field illumination to photograph precipitation particles, and the second uses dark-field illumination to photograph cloud particles.

2. Photography of precipitation size particles

Photography of precipitation size particles can be used to obtain size distributions, make liquid water content studies, or identify types and shapes of particles. Jones and Dean (1953) used a camera capable of photographing particles >0.5 mm in diameter to obtain raindrop size measurements, study their shapes, and observe the onset of drop shattering. Because of the small number of these particles normally encountered per unit volume, a magnification of less than one-to-one and a rather large film size were employed. Mueller and Sims (1966) also devised a camera for photography of precipitation particles. Both the Jones-Dean and Mueller-Sims cameras used bright-field illumination and successfully photographed particles at ground level.

The precipitation particle camera described in this report operates with approximately one-to-one magnification, and uses a 400-mm focal length telephoto lens with extension tubes to photograph airborne water drops, snow and ice. The particles in focus are in a volume 27 mm by 40 mm by about 20 mm in depth at a distance of 118 cm from the lens. In this way free particles in the atmosphere can be photographed relatively undisturbed by the presence of the camera.

Fig. 1 shows the camera set up near Old Faithful Geyser where water drops, graupel and ice crystals were photographed during the Seventh Annual Yellowstone Field Research Expedition (Cannon, 1967). Bright-field illumination was provided by a high-speed light source in front of the lens. With this type of illumination, particles appear as shadows on the brightly illuminated background. Fig. 2 shows several water drops falling

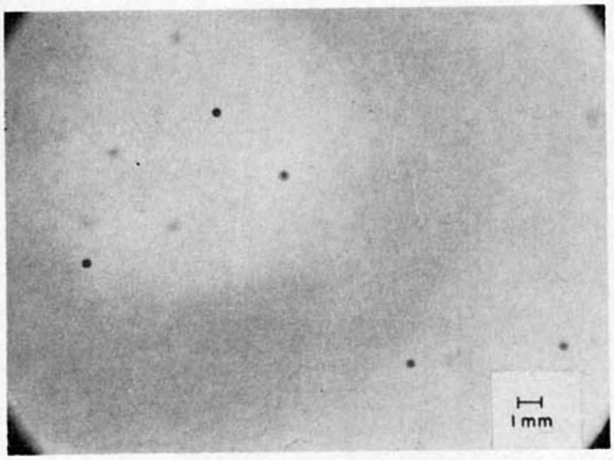

Fig. 2. Water drops falling from the plume of Old Faithful Geyser during an eruption. In-focus particles show a small white dot in their centers as a result of light refraction by the water spheres.

from the plume of the geyser during an eruption. A small white dot appears at the center of those drops which are in focus; this dot is the result of light refraction by the transparent spheres of water. In-focus drops are distinguished from those which are out of focus by the intensity of the images, the appearance of their boundaries, and the presence of the center dot of light. Drops in this photograph are about 400 μ in diameter.

Two translucent graupel particles are shown in Fig. 3. Here the images are darker and the center bright spot is missing. The large blurred images are clusters of wet snow which were falling at the same time as the graupel, but which were far out of focus. The larger graupel particle has a 600 μ diameter, the smaller a 400 μ diameter.

A snow crystal in free fall is shown in Fig. 4. Since the crystal fell near the point of focus of the camera, the image is fairly sharp and shows detail in the crystal quite well.

Figs. 2–4 were taken on Kodak Panatomic-X film with 1.2 μsec flash duration measured at one-third of

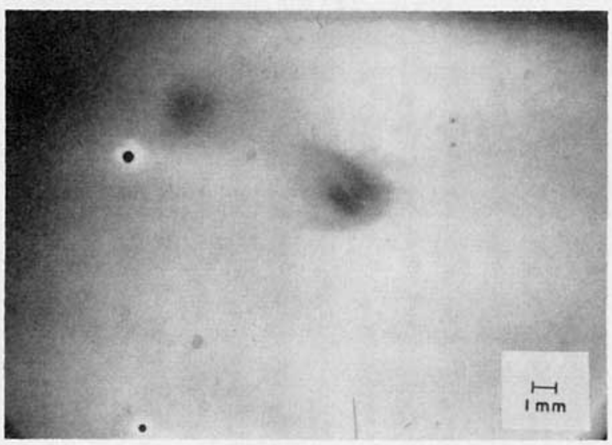

Fig. 3. Graupel particles falling during winter snowstorm at Old Faithful. Shadows are darker than water drops and show no center white dot.

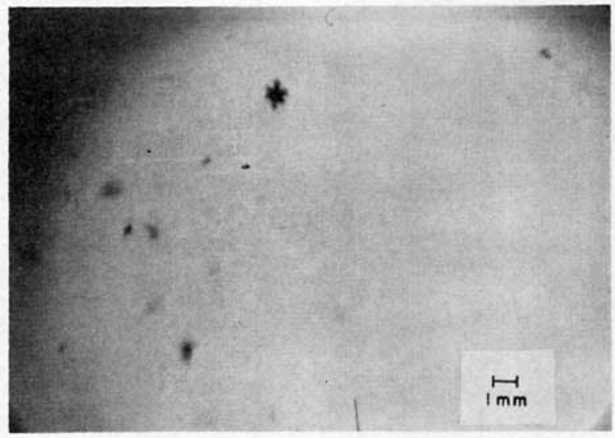

Fig. 4. Snowflake in free fall during snowstorm at Old Faithful.

peak light intensity. A 35-mm film format was used for this particular camera, but larger film size is preferred in order to get more images per exposure.

3. Photography of cloud droplet size particles

As particle size diminishes, it becomes desirable to increase magnification so that the photographic image is sufficiently large compared with film granularity and detail is preserved. The problem of imaging without motion blur also becomes increasingly difficult, especially in the case of cloud particles photographed from aircraft. Elliott (1947, 1950) and McCullough and Perkins (1951) developed cameras for determining size and concentration of particles photographed from airplanes. These cameras used magnifications of 6× and 32×, respectively, and were designed to photograph diameters as small as 10 μ using bright-field illumination. They both used microsecond duration lights, but required mechanical motion compensation to get clear images. Because of the high magnification, rather large film was used (5 inches in the Elliott camera and 7 inches in the McCullough-Perkins camera.)

We use a 35-mm camera to photograph atmospheric particles at ground level, combining the advantages of a relatively fast fine-grain microfilm with light-weight high-speed lights. A 100-mm lens with bellows is used for this application, so the camera operates at one-to-one magnification. The arrangement of the camera, with its parts identified, is shown in Fig. 5. As shown, the camera is set up for dark-field illumination. I ight is forward-scattered at about 25° by the illuminated particles. If bright-field operation is desired, the light trap is replaced by the third lamp unit directed toward the lens.

By using very high resolution microfilm, it was found that particles down to 15 μ in diameter could be photographed accurately enough for sizing and spacial distribution purposes at one-to-one magnification. An area 24 mm by 36 mm is photographed to a depth of field depending on particle size.

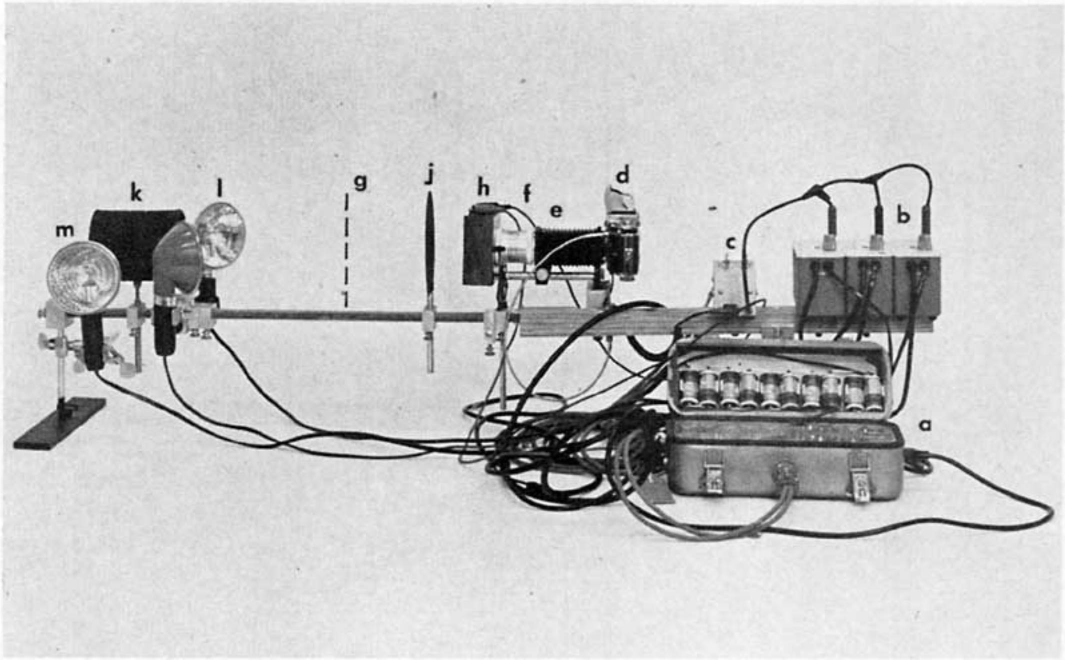

FIG. 5. Camera for photographing cloud particles. Inverter unit (a) supplies 400 cycle power for lamp power supplies (b). Control box (c) contains pulser unit for operating lamps in repetitive mode for visual examination of cloud and check of optical system for fogging. Thirty-five mm camera (d) with bellows (e) and 100-mm focal length lens (f) is focused at a point (g) about 200 mm in front of the lens. Block (h) contains a conductive glass window which is heated to prevent fogging of the front element of the lens. Occulting disk (j) and light trap (k) prevent stray light from entering the lens. Two lamp heads (l) are used for dark-field illumination, while the light trap is replaced by the third lamp head (m) if bright-field illumination is desired. The 24-V battery for window heating is not shown.

The camera's depth of field was determined by photographing transparent plastic spheres of known size at various distances from the lens. The method is described in detail elsewhere (Cannon, in preparation). Representative depth-of-field values are 0.4 mm for 20 μ diameter particles and 1.1 mm for 45 μ diameter particles. Flash duration of the lights was $\sim$3 μsec, which was adequate for stopping motion of the particles in clouds at ground level.

FIG. 6. Particle camera in operation at edge of Grotto Geyser, Yellowstone National Park.

Dark-field illumination is used for photographing particles below $\sim$50 μ in diameter for four reasons. 1) Hallation effects in the film are not nearly so severe as they are with bright-field illumination. 2) When there is motion of the particles during exposure, dark-field illumination produces streaked images, but the images would be completely annihilated in a bright-field. 3) When several exposures are made on a given frame, the images partially or completely disappear when bright-field illumination is used. 4) Two dots formed by refraction of light from the two lamps placed to the side of the illuminated volume in dark-field illumination are useful for distinguishing transparent particles (water drops) from translucent particles (ice), and for obtaining the size of the transparent particles.

In Fig. 6 the camera is shown in operation during the 1968 Yellowstone Field Research Expedition (Cannon, 1968). The entire unit, including the power supply, weighed about 23 lb. The power supply and batteries were carried in a back pack, and the camera supported by a shoulder strap.

Examples of photographs taken with this camera are of interest. Fig. 7 was taken of steam cloud water droplets near Crested Pool. The camera was taken to the edge of the pool one night when the sky was overcast and there was a light breeze blowing. Steam from the pool was observed visually by operating the lights in the repetitive mode. Because of the combined action of

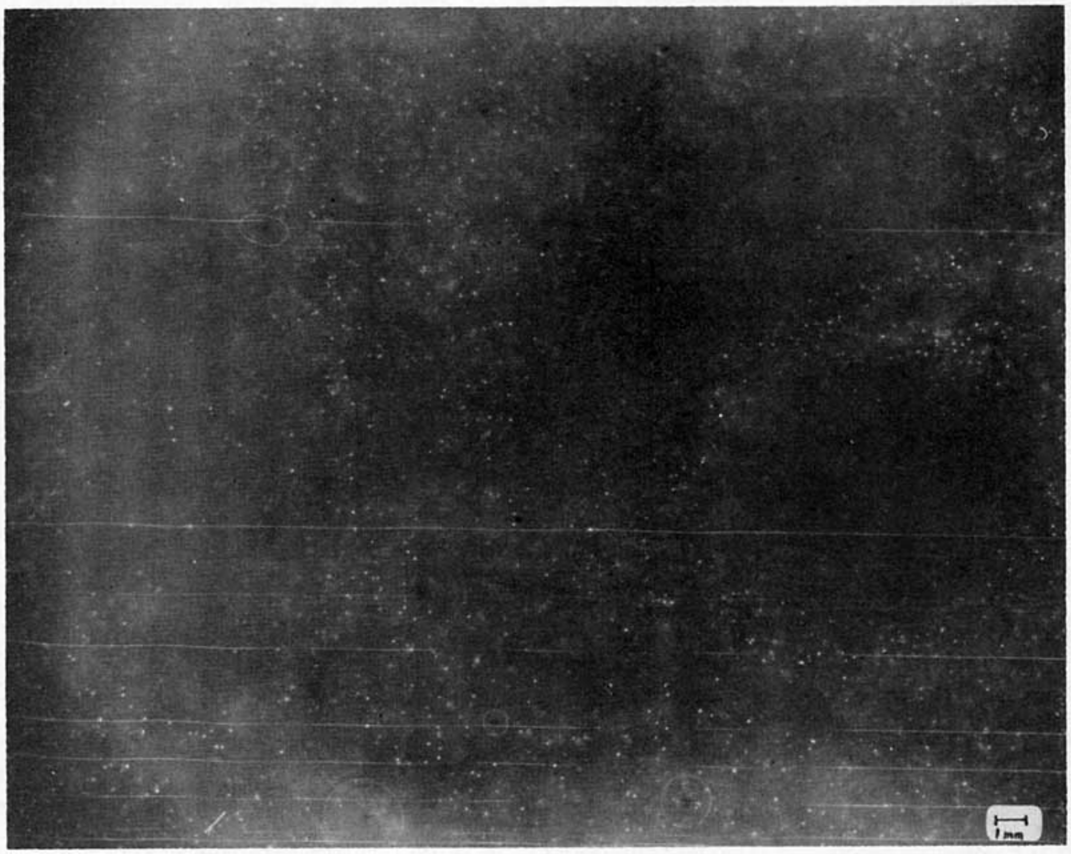

FIG. 7. Water droplets in turbulent air at edge of Crested Pool in Yellowstone National Park. Note swirl and clustering of droplets. Droplet diameters are $\leq 50\ \mu$, with concentration at edge of swirl being about 3000 droplets cm^{-3}. Film was developed in Yellowstone Park water which contained many impurities causing scratches and circular blotches on the film. Exposure was $\sim 3\ \mu$sec on pre-exposed Recordak 5459 film.

the breeze and convection currents above the hot water, the air was quite turbulent. The droplets were observed to move in swirls and clusters as they were transported by the turbulent air. The spatial distribution of the particles is evident from the photograph. The swirl at the right is particularly impressive. It shows a high concentration of droplets surrounding a void which is about 8 mm in diameter. Droplets surrounding the periphery are concentrated about 3000 cm^{-3}, and are $\leq 50\ \mu$ in diameter. Concentration inhomogeneities in natural rainclouds would certainly have some influence on the manner and rate of growth of raindrops and ice particles.

In order to make measurements and shape identifications from the photographs of particles $\lesssim 100\ \mu$ in diameter, it is necessary to examine the negatives with a microscope. Fig. 8 is a 20× photomicrograph of a section of a negative showing two supercooled water particles and an ice crystal; the photograph was taken in a cloud chamber while the cloud was being seeded. The transparent water particles act like small lenses, forming refracted images of the two lights. The 45 μ droplet at a is considered to be in focus, while the droplet at b is considered to be out of focus since the two dots are no longer resolved. Particle c appears to be an ice crystal because of the absence of the two dots and the relatively sharp boundary. The ice crystal is about 25 μ wide. It has been demonstrated that with high-contrast microfilm such as that used to make this photograph, the number of in-focus and out-of-focus particles imaged on the film is quite sensitive to light intensity; considerable discrimination against out-of-focus particles is obtained by selecting the lowest practical light level. It is still necessary to discriminate against out-of-focus particles by visual examination of the film when making particle size distribution studies. It is sometimes difficult to tell the difference between ice crystals and out-of-focus water drops for diameters $\lesssim 25\ \mu$.

Another interesting application of dark-field photography is shown in Fig. 9. This shows the nose of an electric probe used for the airborne measurement of cloud particles. An electronic "burst" generator was connected to the lights, causing them to fire five successive times when the camera shutter was opened, thus giving a series of images as the particles approach the probe. This photographic technique is useful for observing particle trajectories and their probability of collision with other objects in a fast moving air stream or at high particle velocities. The technique is also useful for photographing freely moving pairs or groups of droplets in an air stream. Trajectories and collision probabilities may be determined for the pairs or groups under different simulated atmospheric conditions, including electric fields and particle charges.

4. Conclusions

Although many difficulties are encountered in photographing atmospheric particles in their natural state, it is now practical to take reasonably good photographs using light weight and relatively inexpensive equipment. For taking photographs of cloud particles from aircraft, light-weight high-intensity lights of shorter than 1 μsec duration are needed to eliminate the mechanical motion compensation required for sharp, nonblurred images. The need continues to exist for some method of illuminating only the in-focus volume of the cloud. A combination isodensitracer-computer system would be useful for automatic analysis of the negatives.

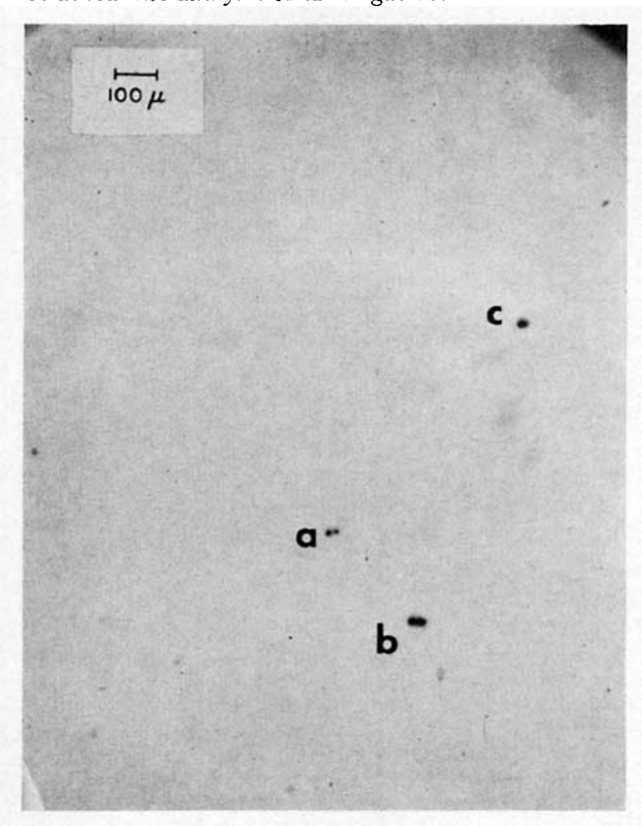

FIG. 8. A 20× photomicrograph of a negative taken with particle camera in cloud chamber during seeding of supercooled cloud. Two water droplets are identified by a and b, and an ice crystal by c.

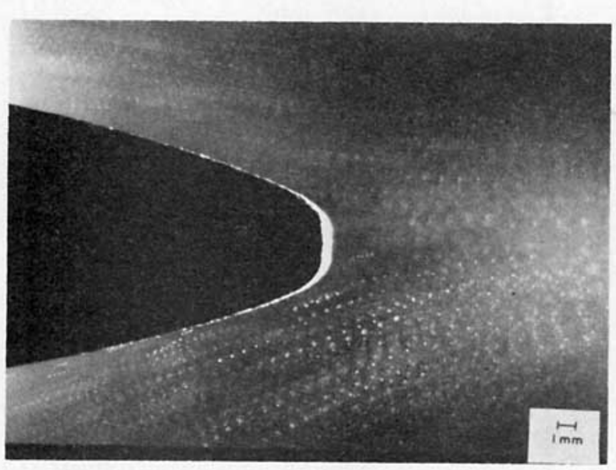

FIG. 9. Particle trajectories near nosepiece of electric probe. Droplets are $\leq 30\,\mu$ in diameter, and are exposed by five 2.4-μsec flash pulses at 150 flashes sec^{-1}.

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