Comments on "An Airborne Cloud-Drop-Size Distribution Meter"

JAMES E. MCDONALD

University of Arizona

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In a recent paper[1] in the JOURNAL OF METEOROLOGY, D. P. Keily and S. G. Millen report the development of a new instrument for measuring cloud-drop sizes. The pressing need for improved drop-size devices, plus the particular suitability of this new device for measuring quite small cloud drops make it very important that its mode of operation be fully understood. The author's hypothesis concerning the physical processes producing the electrical effects used to discriminate drop sizes includes certain features that seem doubtful to the present writer.

The authors suggest that the observed oscilloscope pulses accompanying impact of cloud drops on their metal target result from neutralization of polarization charges on the nearer hemisphere of the drops as the drops come into electrical contact with the charged target. Consistent with this hypothesis of the mechanism of the exchange of charge, the drops are visualized as *bouncing intact off the target*, following which they are swept downstream by the aspirating airstream inside the instrument housing.

Because the velocity of aspiration is sonic in this device, the kinetic energies of the drops are relatively high, so high that it becomes extremely unlikely that bounce-off *without drop breakup* can be occurring at the target. The authors imply that intact bounce-off is to be "expected from the high surface tension of the drop sizes involved," but surface tension is not a function of drop size. Instead, a small drop strongly resists breakup because the drop's *total surface energy* undergoes a *relatively* large increase upon deformation if the drop is small.

However, that this latter resistance is not likely to suffice under the conditions prevailing in this particular device is readily shown as follows. Assume, for illustration, some very large degree of flattening on impact, say, distortion into a discoid form with radius ten times the thickness of the disc. Then the *net increase* of surface energy accompanying this quite large distortion is found to be about $2 \times 10^3\ r^2$, where the energy is in ergs when the initial (undistorted) drop radius r is expressed in cm and a surface tension of 75 dyne cm^{-1} is assumed. On the other hand, the drop's kinetic energy at sonic speed will amount to about $2 \times 10^9\ r^3$ (ergs). Hence, even for the smallest drop sizes which the authors believe the device can reliably detect, namely drops of about 1 micron radius, surface-distortion of even the extreme degree here assumed could, at impact, account for no more than about *one per cent* of the drop's initial kinetic energy. For the largest drops considered measurable in the device, those with $r = 30$ microns, this ratio falls to only 0.03 per cent. *If* the surface energy could store essentially *all* of the incident kinetic energy during deformation upon impact, the deformed drop might conceivably come to rest momentarily on the target, "elastically" recover its shape, and, by reaction, bounce off intact. But, if only one per cent or less of the kinetic energy can be so stored momentarily as surface energy, even for flattening of the large degree assumed above, it is clear that the drop cannot maintain its integrity under impact at the high aspiration speed used in this device.

To be sure, some small portion of the incident kinetic energy will disappear as drop heating (the impact conditions can be shown to preclude appreciable *target* heating). But the entire impact process will occupy a time of the order of only 10^{-8} seconds in this device (this being the time required for a drop to traverse a distance of a few drop-diameters travelling at sonic speed), so the drop's initial kinetic energy cannot be expected to be converted, by internal viscous processes, into heat at a rate fast enough to prevent the internal mass motions from causing breakup. To demonstrate the latter conclusion, we may calculate[2] the volume-mean vorticity that would have to be impulsively generated within the drop during impact to yield a viscous energy-dissipation rate great enough to use up all of the kinetic energy within the impact time of order 10^{-8} sec. The required vorticity is found to be about 2×10^8 sec^{-1}, independently of drop size. Now, if the internal motions are not themselves to tear the drop apart, they must be highly organized and must be compatible with the boundary conditions imposed by the drop surface during impact distortion, so we are not free to visualize anything more chaotic than circulations resembling those of, say, a deformed Hill spherical vortex. But the required mean vorticity, 2×10^8 sec^{-1}, could only prevail in drops of 1 micron radius having such internal circulations of the maximum speeds near the drop surface were about 10^5 cm sec^{-1} — *i.e.*, several times greater than the drops' impact velocity. It is interesting that this estimate of the required maximum internal circulation speed comes out even this close to the impact velocity, for this does suggest that viscous heating might use up some appreciable fraction of the kinetic energy (in the neighborhood of a third, if we give the process every benefit of the doubt). This, in turn, can

[1] Keily, D. P., and S. G. Millen, 1960: An airborne cloud-drop-size distribution meter. *J. Meteor.*, **17**, 349–356.

[2] Milne-Thomson, L. M., 1950: *Theoretical hydrodynamics*, 2d ed. New York, Macmillan, 600 pp. (see p. 511.)

be shown to imply that there probably is drop-heating of the order of a degree or two Centigrade, during impact. But the fact that viscous heating must consume 99 per cent or more of the incident kinetic energy in order to prevent drop-breakup clearly constitutes a requirement that cannot be fulfilled. Too much energy is still unaccounted for even after allowing an excessively large degree of surface distortion and after invoking a quite generous model for viscous dissipation by internal vortical motions.

It thus seems almost certain that impact of drops on the metal target must result in atomization of the drops since there exists no other mechanism than breakup capable of momentarily taking up the excessively large kinetic energy of impact of drops at the epoch of instantaneous rest that would have to occur if *intact* bounce-off were to take place. The authors' comments on observation of ink erosion on the target face are too brief to make it clear why they felt that such erosion effects confirmed intact bounce-off. Their remarks that drop impact on a preflooded target face gave distinctively different oscilloscope pulses is certainly no evidence against impact breakup. Rather, it seems to argue against their own hypothesis of neutralization of polarization charges on the lower hemispheres of the drops. If it were true that the latter processes controlled the charge transfer responsible for the voltage pulses used to discriminate drop sizes in this instrument, then, since a film of water would alter neither the hypothesized induction of the polarized charge nor the ease of draining off that charge on electrical contact, a flooded target would be expected to give voltage pulses no different from those observed with a dry target, *unless* breakup were involved.

It appears necessary to conclude that violent drop-breakup must be occurring on impact in this instrument. Since it is well known that drop breakup is almost invariably accompanied by charge-separation, it is probable that the voltage pulses observed under normal operating conditions depend in some important way upon this physical process and not at all upon the organized draining-off (neutralization) of hemispheric induced charges envisaged by the authors. Although there can be no doubt that the drops arrive polarized (as *conductors*, not as the *dielectric* spheres suggested by the authors), it would seem quite out of the question for selective neutralization of only the polarization charges on the *nearer* hemisphere to occur at impact if violent fragmentation takes place. This, of course, raises the question of why the observed pulse amplitudes should be proportional to the initial surface areas of the drops, as reported by the authors. Although the physics of charge transfer attending violent breakup is not well understood, it seems reasonable to expect that total charge removed by the high-potential target face should be roughly proportional to the total area of all fragments bouncing off the target, and this total area can be shown to vary as the initial drop area only if the number of fragments were the same for breakup of all drops, regardless of initial drop size. There is no basis known to this writer for either accepting or rejecting this possibility, yet it seems intuitively unlikely; Hence, the authors' report of close dependence of pulse amplitude on drop-diameter squared seems difficult to reconcile with the present conclusion that breakup processes should govern the charge transfer at the target, and should perhaps be critically reexamined, since this relation is basic to the practical use of the instrument.

The suggestion, made here on the basis of energy considerations, that breakup phenomena must be intimately involved in the charge-transfer upon which this interesting new drop-size meter depends might be partially checked by use of ultra-high-speed motion-picture techniques applied to a replica of the device having a transparent housing. If this or some alternative method of testing this point could be carried out, useful new insights into the operating principles of this promising instrument might be obtained.