The Relationship Between Imprint Size and Drop Diameter for an Airborne Drop Sampler

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ABSTRACT

Data are presented on the relationship between drop size and imprint diameter produced by the impact of water drops with aluminum foil in an aircraft precipitation sampler at speeds of 140 and 230 kt. Examination of the data obtained for drops of from <1 mm diameter to ~5 mm diameter indicates that the ratio of imprint to drop diameter lies in the range 1.0–1.30.

1. Introduction

The imprints resulting from the impact of precipitation drops on thin aluminum foil in airborne drop samplers have been used by various investigators as a means of determining the size distribution of precipitation drops (Bigg *et al.*, 1956; Brown, 1958; Cornford, 1966; Duncan, 1966). An important requirement in using such devices is a knowledge of the relationship between drop size and imprint diameter at known speeds. This relationship is affected not only by the speed of the aircraft but by the aerodynamic configuration of the drop sampler and the manner in which the foil is exposed to the impinging drops. A technique will be described for determining this relationship.

2. Description of drop sampler

The drop sampler (Fig. 1) is a commercially available instrument (Meteorology Research, Inc., Altadena, Calif.) and consists essentially of a supply roll of aluminum foil, a cylindrical drum around which the foil passes, and a take-up spool. The drum is positioned behind an aperture in the leading edge of the sampler through which rain or cloud drops pass during flight. An impinging drop forces the aluminum foil down into fine grooves (4 grooves per millimeter) engraved in the surface of the drum. The resulting imprint is then a function of the drop size and velocity at which the sampler was traveling. The aperture is closed with a shutter except during the time when drops are actually being sampled.

3. Experimental procedure

Calibration of the drop sampler was performed at the Naval Research Laboratory (NRL) whirling arm facility. This facility (Fig. 2), previously used in the development of various types of aircraft meteorological probes, consists of an airfoil-shaped arm, 25 ft in length, which is rotated by a gasoline engine. The speed of the arm tip, to which the sampler is attached, can be varied over a range of from <100 kt to 400 kt. The speeds at which the drop sampler was calibrated were selected to correspond with the average airspeeds of the particular aircraft on which the sampler would be flown.

As the complete drop sampler weighed ~20 lb and would have imposed excessive centrifugal loadings on the arm structure, a lightweight model (Fig. 3) was constructed. The shape of the leading edge of this model and the foil exposure were identical with the actual

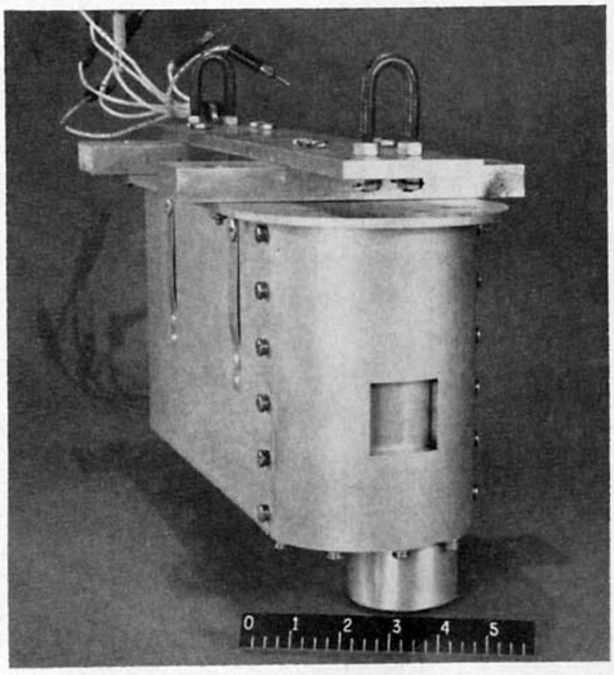

FIG. 1. Airborne precipitation drop sampler. The scale is marked in inches.

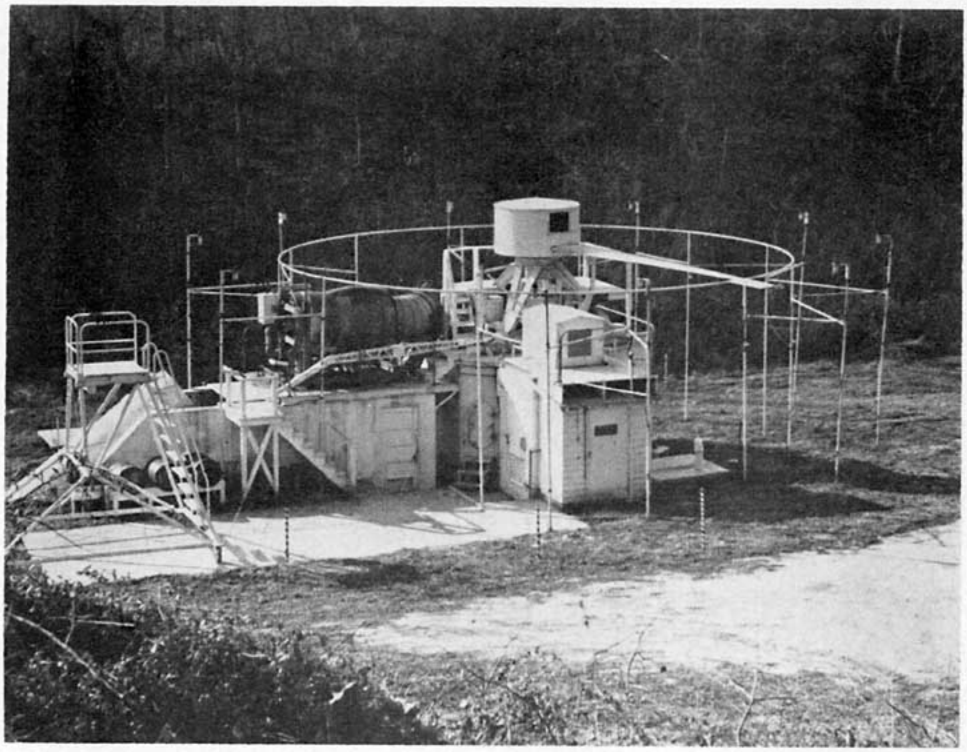

FIG. 2. NRL whirling arm facility for drop sampler calibration.

sampler. Its weight was well within the centrifugal force tolerance of the arm. The sampler model was mounted on the outer tip of the arm and drops of a known size were permitted to fall through its path as the arm was rotated.

Drop generators located above the path of the sampler were used to produce uniform drops. Drops in the range of 1–5 mm in diameter were formed by dropping water under a very low head pressure from hypodermic tubing positioned so that the drops fell into the path of the sampler. Tubing of gage Nos. 15–28 produced drops in the range of $\sim$1–4 mm diameter. Larger drops, 5 mm in diameter, were made by allowing water to drop from a glass pipet, the tip of which had been reformed into a slightly bell-shaped configuration. The smallest drops, $\lesssim 1$ mm in diameter, were formed by forcing water through a vibrating hollow needle similar to the method described by Mason *et al.* (1963).

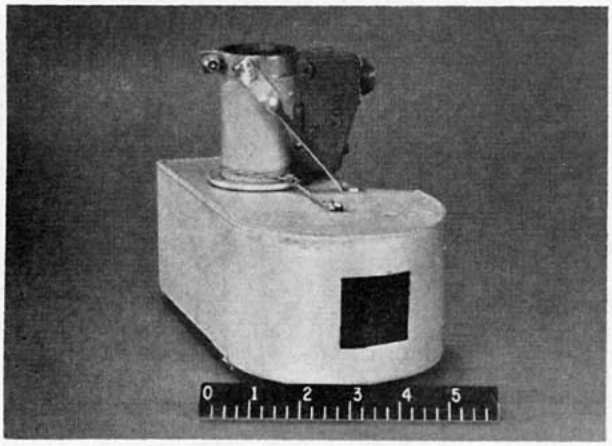

FIG. 3. Lightweight model of precipitation drop sampler.

The sizes of the larger drops were determined by counting the number of drops required to fill a volumetric flask. After filling the flask the flow of drops continued uninterrupted and they were permitted to fall onto a filter paper lightly dusted with rhodamine dye (Bigg *et al.*, 1956). The size of the resulting spot on the filter paper was then measured and the relationship of this spot diameter to the drop diameter, as determined by volumetric count, was established.

Sizes of the smallest drops, as produced by the vibrating needle, were determined by a microscopic examination of their imprints in a film of magnesium oxide on a glass slide. Calibration of drop imprints in magnesium oxide as reported by May (1950) have shown that for water drops in the range of 20–200 μ in diameter the ratio of imprint size to drop size is constant at 1.16.

One advantage of using a whirling arm type of calibration as compared to a wind tunnel calibration is the fact that drops can fall undisturbed through the air until being impacted by the sampler traveling on the tip of the arm without being distorted or broken up as might be the case in a wind tunnel where the drops are injected into the moving airstream.

The following procedure was established for all calibration runs. The flow of drops was started and the drop

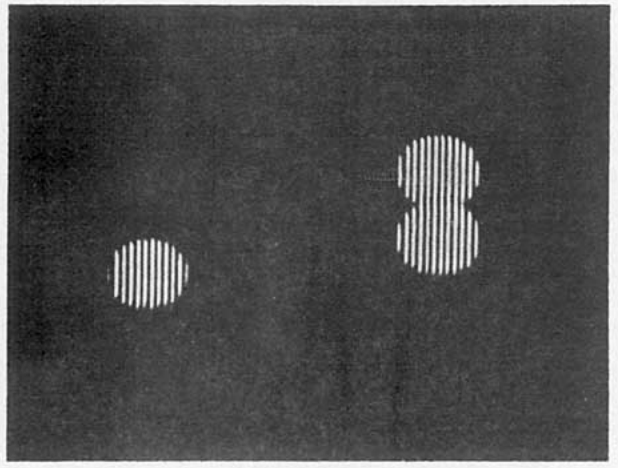

FIG. 4. Imprint of 2.5-mm diameter drops at 140 kt.

diameter was determined by either the filter paper or the magnesium oxide method, depending on the drop size. The arm was then brought up to speed, the sampler passing through the stream of drops. After the arm had been stabilized at the desired speed the foil was exposed to the drops by briefly opening a shutter behind the aperture. The shutter, actuated by an electric motor, was remotely controlled through slip rings around the main drive shaft of the whirling arm. This arrangement permitted the shutter to remain closed to the falling drops until the arm had attained the desired speed. At that time it was opened to expose the foil to the drops and then closed to prevent further impaction of drops while the arm was decelerated to a stop. Immediately after stopping the arm the size of the falling drops was again measured. An average of the before-and-after drop measurements was considered to be the size of the drops for that particular run.

4. Results

Photographs of typical imprints of drops which impacted with the foil are shown in Figs. 4 and 5, the drop diameter being 2.5 mm. Fig. 4 shows imprints made at 140 kt, while the imprints in Fig. 5 are of the same drop size impacting at a speed of 230 kt.

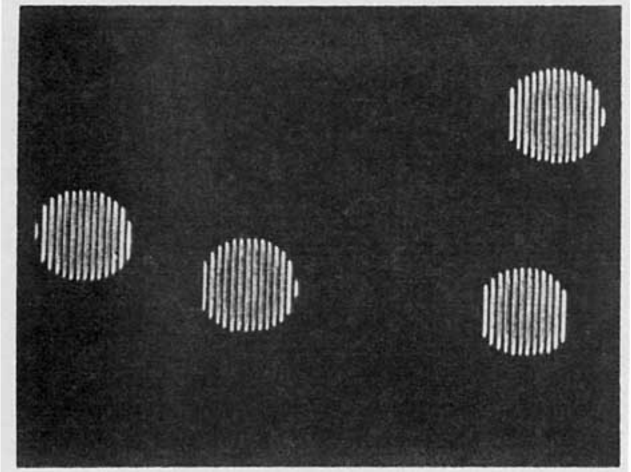

FIG. 5. Imprint of 2.5-mm diameter drops at 230 kt.

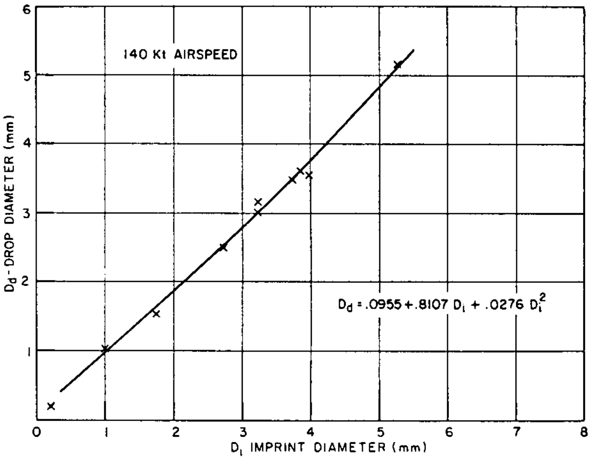

FIG. 6. Imprint diameter vs drop diameter at 140 kt.

Figs. 6 and 7 are the plotted data points obtained at sampler speeds of ~140 and 230 kt, respectively. The actual speed was controlled within 5% of these values. The curves fitted to these data points are the least-squares best fit to a parabola having the equation given adjacent to the respective curve.

Tables 1 and 2 are tabulations of drop diameters corresponding to imprint diameters for sampler speeds of 140 and 230 kt, respectively. Also listed are the corresponding ratios of imprint to drop diameter. These tabulated values are derived from the respective parabolas which were fitted to the data points as shown in Figs. 6 and 7.

At 140 kt (Table 1) the ratio of imprint to drop diameter rises from slightly less than unity (0.98) for drops of <0.5 mm diameter to a value of ~1.06 for drops in the 1.5–5.0 mm range. At a speed of 230 kt (Table 2) the ratio of imprint to drop diameter is about unity (1.04) for drops ⩽0.5 mm. It rises to about 1.25

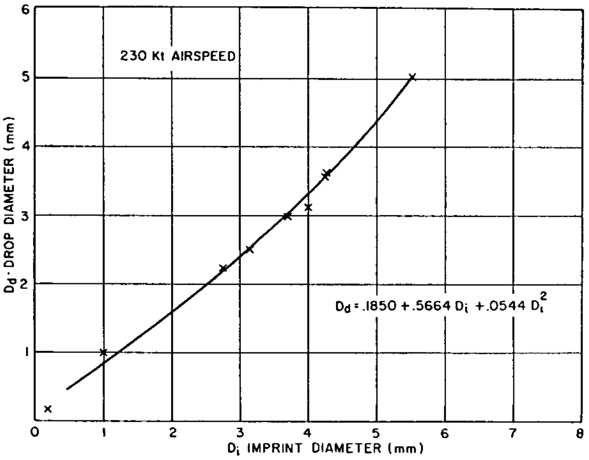

FIG. 7. Imprint diameter vs drop diameter at 230 kt.

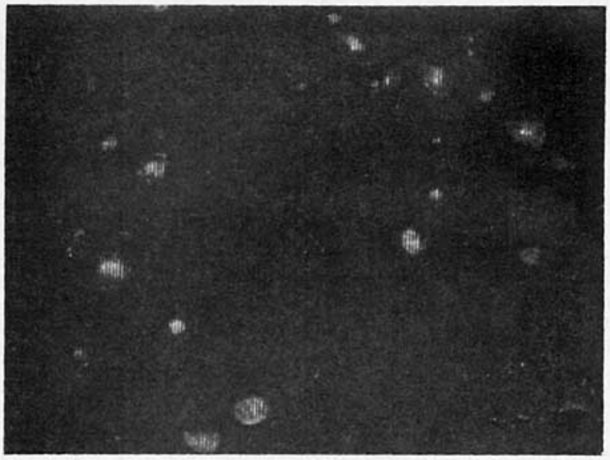

FIG. 8. Imprints of raindrops measured under the base of a precipitating tropical cumulus cloud.

for drops in the 1.5–3.5 mm range and then decreases to a value of ~1.1 for drops of 5.0 mm diameter.

5. Discussion

Calibrations by others (Bigg *et al.*, 1956) have indicated ratios of imprint to drop diameter, for a speed of 140 kt, to be on the order of 1.5 for 1.0-mm drops, decreasing to ~1.26 for 4.0-mm drops. The same investigators found that at speeds above 190 kt the ratio was almost a constant 1.4. These values have been generally accepted to this date by those engaged in the measurement of drop size by the foil impaction method (Cornford, 1966; Duncan, 1966). In a wind tunnel calibration of thin foils Brown (1958) measured ratios on the order of 1.7–2.5 for drops in the 100–1000 μ diameter range at speeds of up to ~250 mph. Examination of the data obtained from the NRL whirling arm foil calibrations indicates that the ratios of imprint to drop diameter over the range of drop sizes and airspeeds investigated lies in the range of 1.0–1.30 for the particular sampler configuration used.

A possible explanation for the differences in imprint diameters as measured by NRL and by other investigators may lie in the configurations of the samplers as they impacted with the known drops. As reported in Bigg *et al.* (1956) the foil strip was backed up by a flat piece of metal mesh and thus presented a flat surface to the drop. In the NRL tests the foil was backed up by a curved drum in the same manner that it would be in the airborne sampler. The NRL whirling arm tests, using a full-scale model of the aircraft instrument, were intended to accurately duplicate the aerodynamic configuration that the actual airborne sampler would have during flight. Further whirling arm tests are planned with drop samplers having different aerodynamic configurations. These tests will investigate the effects of varying the radius of curvature of the sampler housing and methods of exposing the foil on the sizes of imprints obtained.

TABLE 1. Aluminum foil drop sampler NRL whirling arm calibration for a speed of 140 kt.

Imprint diameter (mm)	Drop diameter (mm)	Imprint diameter / Drop diameter
0.5	0.51	0.98
1.0	0.93	1.07
1.5	1.37	1.09
2.0	1.83	1.10
2.5	2.29	1 09
3.0	2.77	1.08
3.5	3.27	1.07
4.0	3.77	1.06
4.5	4.29	1.05
5.0	4.83	1.04
5.5	5.38	1.03

TABLE 2. Aluminum foil drop sampler NRL whirling arm calibration for a speed of 230 kt.

Imprint diameter (mm)	Drop diameter (mm)	Imprint diameter / Drop diameter
0.5	0.48	1.04
1.0	0.81	1.24
1.5	1.16	1.30
2.0	1.54	1.30
2.5	1.94	1.29
3.0	2.37	1.26
3.5	2.83	1.23
4.0	3.32	1.20
4.5	3.84	1.17
5.0	4.38	1.14
5.5	4.95	1.11

During the spring of 1968, drop samplers of the type calibrated on the whirling arm were flown on aircraft investigating the structure of precipitating tropical cumulus clouds. A typical section of foil exposed to precipitation during flight is shown in Fig. 8. The imprints were made by raindrops while the sampling aircraft was flown under the base of a precipitating cloud and correspond to drops ranging from about 0.8–2.1 mm in diameter. The complete foil records of drop size spectra encountered during these flights are at present being analyzed on the basis of the calibrations discussed in this paper.

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