Artificial Growth of "Icicle" Lobe Structure of a Hailstone in a Wind Tunnel

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1. Introduction

The lobe structures found on natural hailstones are very important, in that they must be taken into account in any treatment of the growth of large hail. These structures can be divided into two categories: the cusped type and the "icicle" type.

The cusped type has been discussed by Sarrica (1965), Browning (1966), and Knight and Knight (1968, 1970). It has been suggested that this lobe structure grows due to a "collection efficiency" effect. An original small protrusion on the hailstone grows faster than its surroundings by shielding the adjacent areas from receiving droplets. Bailey and Macklin (1968) were able to grow these structures in the laboratory.

Icicle lobes have received much less attention, being mentioned by only Weickmann (1953) and Knight and Knight (1970). It is suspected that these lobes may form in the same manner as icicles with the flow of water over the hailstone and more rapid freezing at the tips of projections. In an effort to shed more light on the factors important in the growth of these structures, we have suspended an artificial hailstone in a large wind tunnel capable of freely suspending hundreds of water drops. It is the purpose of this note to report on the icicle-type lobes which formed when a hailstone was artificially grown in this manner.

2. Experimental arrangement

A ping-pong ball served as the original hailstone. A length of wire ran through the ball and was fastened at both ends. This arrangement, which allowed the ball to rotate about 180° but restricted its vertical movement, was placed in a large vertical wind tunnel (Spengler and Gokhale, 1970; Spengler, 1971a). Many hundreds of water drops could be suspended simultaneously in the updraft, thus simulating some of the conditions for the growth of a hailstone in a cloud. Water drops were produced by a vibrostaltic pump which pulses a stream of water into 120 drops sec^{-1}. The drops had a narrow size distribution about a mean drop size diameter of ~ 5 mm, and the updraft speed was set at ~ 10 m sec^{-1}. The temperature in the updraft at the time of the trial was -17C. While the suspended drops did not have sufficient time to cool to the ambient ice bulb temperature, calculations of the thermal relaxation times for these temperatures and drop sizes [from the modified Kinzer and Gunn (1951) equation] indicate that the drops had sufficient time to cool to at least -5C. See Gokhale and Spengler (1972) for cooling rates of drops of different sizes at the temperatures used in wind tunnel experiments.

Detailed observation of the hailstone and freely-suspended hydrometeors was made possible by the use of high magnification and high-speed photography (Spengler and Gokhale, 1971). The film strips were taken using a 16-mm camera, with close-up attachments, using framing rates of 200 and 1000 frames sec^{-1}, thus facilitating the study of the high-speed water drop impactions.

3. Description of the photographic results

Initially, the hailstone was assumed to be at the same temperature as the ambient air. The suspended hydrometeors, some of which were either partially or completely frozen, began to strike the hailstone and froze on contact. The latent heat of fusion gradually warmed the sphere until it was covered by a thin film of liquid water. The water that began to accumulate as more drops struck the hailstone collected around the equatorial region. Blanchard (1957) described a similar observation concerning the distribution of water on the surface of a melting ice pellet.

When the water drops suspended in the updraft drifted into the turbulent wake of the hailstone, they quickly accelerated downward, usually striking the sphere. If several drops were in the wake region simul-

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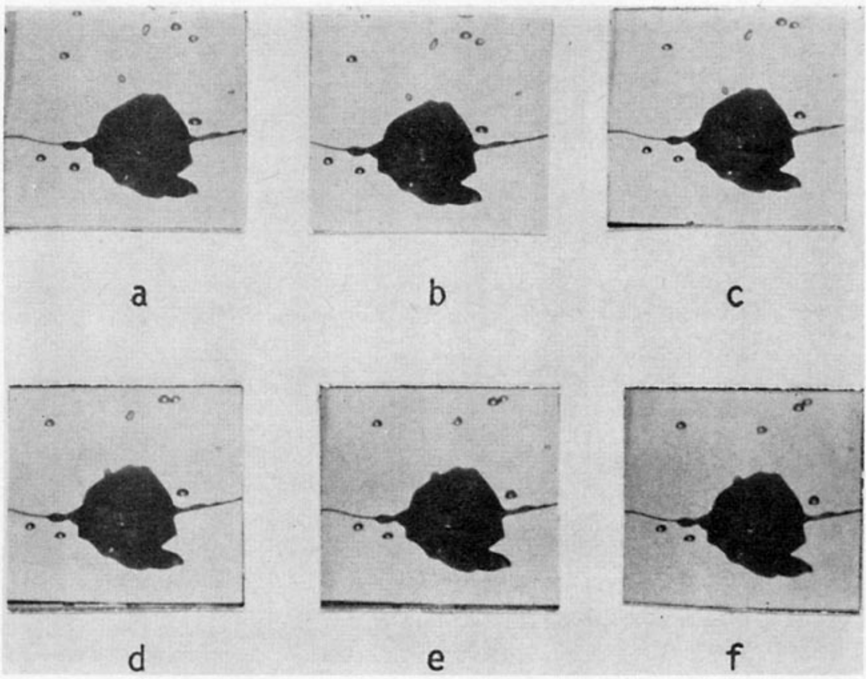

FIG. 1. An example of a hydrometeor being captured in the wake of the artificial stone, contacting, and fusing to the surface.

taneously, the wake effect region would be extended vertically and other drops as high as 2 m above the stone began to accelerate toward the hailstone. Some drops broke up into many smaller sized drops after rupturing in the turbulent wake or touching the side of the hailstone. A few supercooled drops and frozen hydrometeors struck the hailstone from above and remained where they hit, forming small protrusions (Fig. 1).

As the water collected around the equator and froze there, we observed small, smooth bumps gradually forming in that region. In addition there were a few small, frozen pellets on top. The water flowing over and over these bumps gradually formed a larger protrusion, 0.5 cm long, in the equatorial region. The unsymmetrical distribution of icicle formations caused the hailstone to vibrate and twist back and forth in the updraft, and the protrusion oscillated between a downward and a horizontal position.

The protrusion or icicle-type lobe then grew faster as

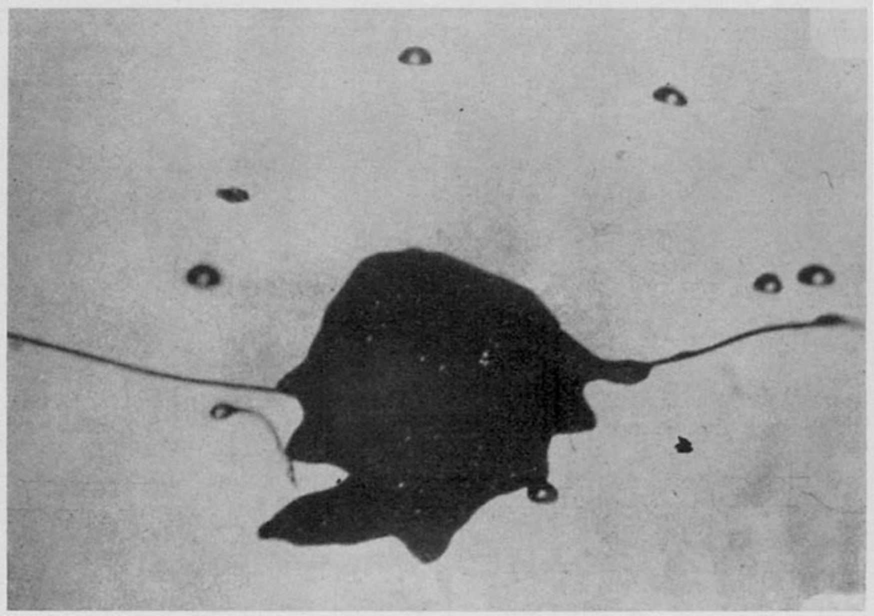

FIG. 2. Hailstone with icicle lobes grown in a wind tunnel.

more water accumulated, ran down the length of the icicle, and finally was partially shed at its tip (Fig. 2). Gradually, the icicle grew so large (about 2 cm in length and around 1 cm across) that it always pointed downward. However, other smaller protrusions started to grow in all directions.

After about 10 min of total growth time, the hailstone was ~5 cm in diameter as compared with a starting size of 4 cm. In addition, the largest icicle growth was 3 cm long and 1.5 cm across, while about four other protrusions were approximately 1 cm in length. A liquid water content of about 5 gm m^{-3} would account for this growth assuming an average fall velocity of 10 m sec^{-1} and a stone of 2 cm radius.

4. Conclusion

Even with some unnatural limitations of this laboratory experiment, the films of hailstone growth strongly suggest a mechanism for protuberance formations. Supercooled or frozen hydrometeors in the wake of a growing stone can contact and freeze or fuse to the surface forming a protuberance. Further supportive evidence for this occurring is found in earlier wind tunnel investigations on freely suspended hydrometeor interactions (Spengler and Gokhale, 1972), and in natural hailstone cross sections (Rogers, 1971). Further collection and shedding of water by the hailstone causes preferential growth of the protuberances. There are three reasons for this preferential growth. First, it has been demonstrated that protuberances have their own stagnation points (Bailey and Macklin, 1968; Spengler, 1971b), and are therefore locally efficient collectors of supercooled water. Second, since the entire stone is free to rotate, the unfrozen liquid water on the surface is forced to the region of highest angular velocity which would be the protuberance. The films show water being shed from the growing protuberances as expected. Third, as Browning (1966) has described, surface lobes on hailstones significantly enhance the efficiency of heat loss from the surface.

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