On the Use of Hot-Film Anemometry to Measure Turbulence in the Presence of Heavy Rain

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The author recently completed tests to determine whether commercially available hot-film anemometers are suitable for measuring severe storm turbulence. It appears that with certain restrictions these instruments are adequate (Merceret, 1968, 1969). Most of these restrictions depend critically on the system used. This

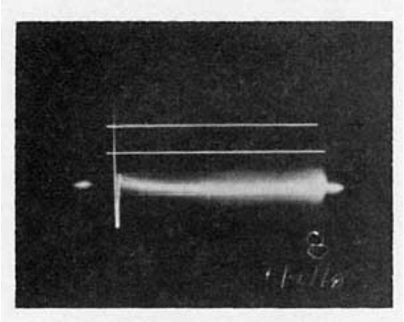

FIG. 1. Signal characteristic of droplet impact.

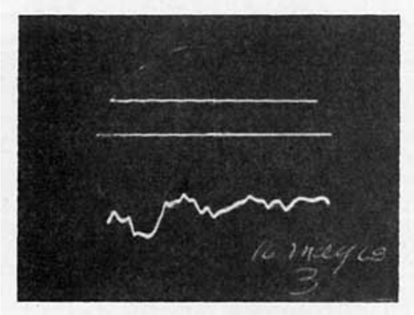

FIG. 2. Signal characteristic of turbulence.

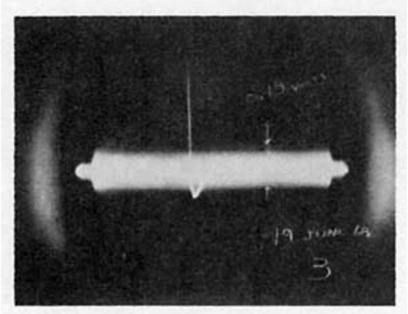

FIG. 3. Two minutes of signal showing a single droplet impact during turbulence in a thunderstorm.

paper will discuss only the effects of the presence of heavy rain, these effects being dominated by the nature of the rain field and the probes, and would thus be quite similar for the majority of hot-film sensors likely to be used for atmospheric measurements.

To examine the reaction of the anemometer and probe to raindrop impacts on the sensing element, a 6 inch plexiglass column 3 ft long was placed vertically beneath a capillary tube supplied by a reservoir through a flexible hose which was clamped to regulate the flow. The probe was mounted on a laboratory stand and the tip inserted in the column through a small access port. The purpose of the column was to minimize flow effects allowing the effects of droplet impacts to be isolated.

By varying the size of the capillary and the flow rate, it was possible to obtain single drop sizes ranging in diameter from that of large raindrops (0.5 cm) to that of medium raindrops (0.3 cm), and a heavy shower of very small raindrops or large drizzle drops (0.04 cm). Laboratory data were compared with measurements made from a 5-ft tower which rests on the roof of the laboratory building and which has unobstructed exposure to raindrops arriving from all directions in winds <20 m sec^{-1} during actual rainstorms.

The high spike in the signal betraying an impact (Fig. 1) has been noted previously by Goldschmidt and Householder (1966), and is a desirable characteristic since it can be readily differentiated from atmospheric turbulence as illustrated in Fig. 2. Unlike hot-wires, the hot-films are not overly sensitive to the droplet wakes. This is also desirable since for most atmospheric applications one would expect the contributions from the wakes of droplets to the dynamics of the systems being studied to be negligible. The wake signals from wires might be expected to mask more dynamically significant information. Fig. 3 shows a 2-min time exposure taken with the probe on the tower during heavy rain with a light breeze. There is no difficulty distinguishing the raindrop impact from the turbulence.

Since each drop obliterates at most something slightly more than 100 msec of the record, it is important to have some estimate of the number of impacts to be expected per unit time in the field. Calculations made on the basis of the collision cross sections of the raindrops and probes gave estimates for collision frequencies which far exceeded those actually observed during moderate and heavy rainfall. For this reason, the following method was used to provide the desired estimates. In the test column, there occurred one impact per 100 msec, on the average, in a field of droplets for which the droplet density $N_D = 2.75\times10^6$ m^{-3}. The terminal velocity U_T for these drops is about 1.25 m sec^{-1}. We should be able to relate this to the expected frequency of impact during a test run aboard an aircraft, for instance, at velocity $\bar{U}$ by

$$F(\mathrm{ATM}) = [\bar{U} N_D(\mathrm{ATM})/U_T N_D(\mathrm{LAB})] F(\mathrm{LAB}), \tag{1}$$

where $\bar{U}$ is measured in m sec^{-1} and $N_D(\mathrm{ATM})$ in drops m^{-3}.

To obtain a representative figure for $N_D(\mathrm{ATM})$ as a function of rainfall rate, the formula of Marshall and Palmer (1948) as presented and experimentally confirmed in a hurricane by Kessler and Atlas (1956) is integrated over all drop sizes. This formula has also been verified in thunderstorms (Battan and Theiss, 1968) and should thus be generally applicable for our purpose. The Marshall-Palmer formula relates the number of drops per volume per unit diameter to the rainfall rate R such that

$$dN_D(D) = N_0 e^{-\lambda D} dD, \tag{2}$$

where

$$\lambda = 41 R^{-0.21} \quad \text{and} \quad N_0 = 0.08 \text{ cm}^{-4},$$

if R is measured in mm hr^{-1}. Let

$$N_D = \int_0^\infty dN_D(D). \tag{3}$$

TABLE 1. Representative values from Eq. (4).

R (mm hr^{-1})	N_D (m^{-3})	R (mm hr^{-1})	N_D (m^{-3})
10	3.16×10^3	50	4.33×10^3
25	3.84×10^3	75	4.83×10^3

The result is

$$N_D = 1.95\times10^3\times R^{-0.21}\ [\mathrm{m}^{-3}]. \qquad (4)$$

Some values are given in table 1.

Since $R = 75$ mm hr^{-1} is rarely exceeded even in severe hurricanes, a safe upper bound on N_D is 5000 m^{-3} and 3.4×10^3 m^{-3} is not unreasonable for milder storms. This gives an upper limit of $F(\mathrm{ATM}) \approx 0.02U[\mathrm{sec}^{-1}]$ if U is given in m sec^{-1}. The more reasonable expectation is about half of this value. At 100 m sec^{-1} we would lose at most roughly 20% of our record and correspondingly less at lower velocities or rainfall rates. This is not comfortable but it is tolerable at the present state of the art in atmospheric convective turbulence measurements.

Since physical contamination of the probes by airborne or rain carried particulate matter and chemicals in solution on the water hitting the probe could affect calibration constants, the author attempted to determine the seriousness of the threat posed by this possibility. Microscopic examination of the probes used on the tower indicated that no contamination occurred during several runs >2 hr in city air which is certainly dirtier than that at most field sites.

The author concludes that the presence of heavy rain should not make it impossible to measure severe storm turbulence using commercial hot-film anemometers.

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