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EVALUATION OF A DEVICE FOR IN-FLIGHT DETERMINATION OF SIZE AND DISTRIBUTION OF HAILSTONES

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16. Abstract

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SUMMARY

A recording instrument (distrometer) for surveying the hail environment aloft was calibrated with single simulated hailstones launched from the hailstone impact simulator at the Langley Research Center. The hailstone manufacture and characteristics, impact simulator, experimental test program, and resulting data are described in this report. Hailstones 1.3, 2.5, 3.8, and 5.1 cm in diameter were impacted on the distrometer at velocities ranging from 20 to 380 m/s. An evaluation of the distrometer based on data from these tests is presented.

INTRODUCTION

Airplanes flying through hailstorms experience structural damage in varying degrees of severity. Areas of the airplane that are frequently affected are leading edges, engine cowlings, turbine blades, radomes, and windshields. The severity of the damage depends on the size of the hailstones, frequency of impact, and the impact velocity. The size, mass distribution, and velocity of the hailstones in the atmosphere are not known. This information is needed to predict, with reasonable accuracy, the potential hail damage to airplanes. The airplane designer also needs this information for determining the degree to which the airplanes should be protected against hail. Langley Research Center has developed a hailstone impact simulator to investigate the damage from hail on airplane surfaces.

The Institute of Atmospheric Sciences, South Dakota School of Mines and Technology (Rapid City, South Dakota), has been involved in weather and hail phenomena research for several years. Part of the research has been directed toward the investigation of theories on the hail formation processes, hail intensity, and hail distribution. In order to gather in-flight data on the size and distribution of hailstones throughout the profile of a thunderstorm, the Institute has a program to equip an airplane with hailstone sensing devices and to perform in-flight measurements within thunderstorms. Several sensors including the distrometer are being investigated to detect the size and distribution of hailstones in the atmosphere.

The distrometer was initially developed by Jurg Joss and A. Waldvogel in Switzerland to record the distribution of raindrops at the ground (ref. 1).

In 1971, Jurg Joss was a visiting scientist at the Meteorology Laboratory, Air Force Cambridge Research Laboratories, Massachusetts. Joss together with William G. Myers, research engineer from the Institute of Atmospheric Sciences, worked in adapting the distrometer to the Institute's requirements for atmospheric studies. The new instrument is sensitive to the momentum of hailstones at impact and can be used to obtain in-flight data on the frequency and magnitude of the impacts. This information can then be translated into hailstone size and distribution to establish a hail distribution profile.

This paper describes the experimental test program used in calibrating the hail detector (distrometer) with single hailstones launched from the hailstone impact simulator at the Langley Research Center and presents an evaluation of the data obtained.

HAILSTONE IMPACT SIMULATION

Simulated Hailstones

Figure 1 shows the lower half of a silicone rubber mold used in the production of 5.1-cm-diameter synthetic hailstones. To produce hailstones, the mold half sections are first clamped together; then, the spherical cavities are filled with distilled water containing approximately one-sixth of 1 percent alcohol to prevent the formation of cracks during the freezing process. The molds are refrigerated at approximately 260 K to form synthetic hailstones with a specific gravity of 0.9. Some researchers have suggested that the specific gravity for hailstones varies from 0.4 to 0.9, depending on how the hailstones were formed (ref. 2). Natural hailstones are usually formed in concentric layers similar to those of an onion, leaving voids in the crystalline structure. The solid synthetic hailstone closely simulates the impact characteristics of natural hail but causes more structural damage than the lesser density natural hailstone. Natural hailstones range in size from approximately 0.3 to 15 cm in diameter. In the present series of tests, 1.3-, 2.5-, 3.8-, and 5.1-cm-diameter hailstones were used as representative of the most frequently encountered hailstones.

Hailstone Impact Simulator

The hailstone impact simulator at the Langley Research Center is shown schematically in figure 2. The simulator consists of a barrel, a coupling with rupture diaphragms, an air reservoir, and instrumentation. The barrel is chilled to prevent melting of the hailstone. The simulator is fired by quickly venting the pressure between the diaphragms.

For example, to fire at a reservoir pressure of 12 MN/m^2, two diaphragms designed to rupture at 7 MN/m^2 are inserted in the coupling, a hailstone is placed in the barrel, and the coupling bolted together. The coupling is then pressurized to 6 MN/m^2 and the reservoir to 12 MN/m^2. Venting the pressure in the coupling to less than 5 MN/m^2 will rupture both diaphragms and subject the hailstone to the full 12 MN/m^2 reservoir pressure. Most of the hail data obtained in the simulator have been at velocities ranging from 60 to 600 m/s, which are typical of airplane flight velocities.

A photograph of the hail impact simulator is shown in figure 3. A 2.5-cm-diameter barrel is mounted inside the wooden enclosures which insulate the cooled barrel. Other barrels of different bore dimensions are mounted on the rack above the gun. Shown also in the figure are the transducer (distrometer), high-speed cameras, and recording oscilloscope. A single hailstone is shown at two points of its flight and at impact in this multiple-exposure photograph.

Velocity Measuring System

The velocity measuring system presented schematically in figure 2 and pictorially in figure 3 consists of two image converter tube cameras that photograph the hailstone at two stations along its flight path and an oscilloscope that records the elapsed time between photographs. A metric scale is used to show the displacement of the hailstone at two positions along its trajectory for velocity determination. The cameras and oscilloscope are triggered by the hailstone breaking a fine wire or a laser beam. Two xenon-filled flash lamps are used for back lighting the projectile and scale. In addition to recording the velocity of the hailstone, the cameras also photograph its whole or fragmented shape.

Figure 4, a multiple-exposure photograph, shows a single, 2.5-cm-diameter hailstone passing through the two velocity measuring stations 1 and 2 and then impacting on the hail transducer bumper. The hailstone is shown shattering during impact and the debris is seen moving radially outward.

The double-exposure photograph in figure 5 depicts a side view of the hail impact on the transducer. At 2.5 ms, the hailstone has shattered and formed a concentrated inner annulus of crushed ice fragments. At 4.5 ms, the hailstone fragments are shown further dispersed.

DISTROMETER

Distrometer Description

The hail distrometer is an instrument designed for detecting the frequency of hailstone impacts and their mass and was designed by Jurg Joss from Osservatorio Ticinese, Switzerland. The distrometer (fig. 6(a)) consists of a transducer, which has a surface exposed to hail impact, and a processor.

The transducer (fig. 6(b)) is an electromechanical device that converts the impluse of hailstones into electrical pulses. The transducer consists of a rubber bumper cemented to a stack of metal disks, a fluid which flows through the disks, and an electrical coil concentric to a plunger. The coil is attached to the last disk opposite the bumper.

A hailstone impacting the transducer produces an impluse on the bumper which is transmitted to the plunger by the fluid. The plunger is forced to move axially within the coil thereby generating an electrical pulse which is sent to the processor. In the processor the pulses are then amplified, filtered from extraneous noise, and sent to the recording unit by the processor. This action is repeated each time a hailstone impacts the rubber bumper.

Test Description

Approximately 100 single shots were fired normal to the transducer's rubber bumper. Mounting of the transducer is shown in figures 3, 4, and 5. Hailstones ranging in diameter from 1.3 to 5.1 cm and having impact velocities from 20 to 380 m/s were used in the tests. The transducer was sensitive to all impacts within the sizes and velocities tested. The transducer has a wider sensitivity range but was not tested beyond the values specified.

The output signal from the distrometer was recorded by an oscilloscope (fig. 6(c)). The duration of the processed output voltage signal was approximately 1 ms and had a rise time of 0.3 ms. The signal is sufficiently short and more than adequate to record impact rates faster than the expected natural hail impact rate of 50/s (calculated by the Institute of Atmospheric Sciences). The hail gun can fire only single shots and no attempts were made to record multiple impacts.

RESULTS AND DISCUSSION

The processor output signal plotted as a function of hailstone impact velocity and radial distance of impact from the center of the transducer is shown in figure 7(a) for the 2.5-cm-diameter hailstone. The upper line represents the impacts at the center of the transducer; the lower line represents the impacts farthest away (10.2 cm) from the center. This plot indicates that the output signal is directly proportional to the impact velocity for impacts at one radial location on the transducer. Impacts closer to the center produce stronger signals than impacts away from the center of the transducer. The impacts at the center and those closer to the edge form an envelope of data points for that particular hailstone diameter.

Envelopes for the four hailstone diameters used in the tests are shown in figure 7(b), from which the following observations can be made:

(1) The distrometer output signal varies linearly with hailstone impact velocity at a specific radial impact location.

(2) The slope of each line varies with hailstone diameter and impact location.

(3) The output signal varies with the distance of impact from the center of the transducer. A larger signal is obtained from impacts at the center for constant velocity and hailstone size.

(4) There is overlapping between lines representing the data points obtained from impacts at the center for a certain size hailstone and those obtained towards the edge of the transducer for the next larger size hailstone. For example, a higher signal was obtained for a smaller hailstone (3.8 cm diameter) impacting at the center than for a large hailstone (5.1 cm diameter) impacting near the edge of the transducer.

The output signal represented by log(100 × volts) as a function of hailstone momentum in kilograms-meters per second represented by log(100 × momentum) is shown plotted in figure 8. From the figure it can be observed that each line encompasses all hailstone sizes and the difference between the lines is due to the difference in radial impact locations. Figure 8 shows that the output signal is a function of hailstone momentum for each radial impact location. Conversely, it shows that for the same momentum the output signal varies with the impact location.

An example of how the distrometer would be used is as follows:

Suppose a hailstone impacts the transducer at the center ($r/R = 0$) and a 1-volt output signal is obtained. (The symbol r is distance of impact from center and R is transducer radius.) The log of (100 × 1 volt) is 2.0, and from figure 8, log(100 × momentum) is found to be 0.92. This value represents a momentum of 0.08318 kg-m/s. If it is assumed that the hailstone is spherical and has a specific gravity of 0.9 and its impact velocity is known to be 100 m/s, this momentum then corresponds to a mass of 0.8318 gram and a diameter of 1.2 cm.

If the hailstone impacts near the edge of the transducer ($r/R = 0.8$) and the same signal is obtained, then from figure 8, log(100 × momentum) is 1.54 and a momentum of 0.3467 kg-m/s is obtained. A mass of 3.467 grams and a hailstone diameter of 1.9 cm are calculated. These values are acceptable provided that the impact location is known. However, the distrometer cannot discern the location of the impact, and hence, the user cannot accurately determine from figure 8 the momentum corresponding to the output signal.

One method to determine an approximate momentum (with a corresponding error tolerance) is to assume an impact radius, $r/R = 0.7$, on the distrometer. This radius divides the transducer into two equal concentric areas with the effect of having a 50-percent probability of hit on either side of this radius. A hailstone impacting the transducer at this radius ($r/R = 0.7$) has a momentum of 0.2399 kg-m/s $\left(\log(100 \times \text{momentum}) = 1.38\right.$ from fig. 8$\left.\right)$. Thus for an impact producing a signal of 1 volt, the mass of the hailstone is calculated to be 2.399 grams and its diameter 1.72 cm.

A hailstone impacting at the center of the transducer ($r/R = 0$) would result in a calculated mass of 0.8318 gram and a diameter of 1.2 cm; the error tolerance associated with the 50-percent probability of hit assumption would be a 65-percent error in mass and a 30-percent error in diameter. An impact near the edge of the transducer ($r/R = 0.8$) would result in a mass of 3.467 grams and a diameter of 1.9 cm with corresponding errors of 45 percent and 13 percent, respectively.

One factor that may affect the sensitivity of the transducer but was not investigated is the accumulation of crushed ice on the rubber bumper after a hailstone impact. During the tests the bumper was wiped clean after each impact to obtain uniformity of results by eliminating variables.

CONCLUDING REMARKS

The distrometer has a good potential to accurately measure the size and distribution of hailstones in flight. It has the necessary fast response for measuring the distribution of hailstones in their environment and has a wide sensitivity to detect small and large size hailstones at a wide range of impact speeds. However, in its present state, the instrument is inaccurate in discerning hailstone mass or size because of its varying sensitivity to impact location. This sensitivity to impact location may be compensated for by redesigning the fluid flow distribution or by sensing the location of the impact.

The instrument is portable and easily adaptable for airplane attachment. After mounting on an airplane, the instrument should be checked to determine the effect of airplane vibration and noise on its performance.

The rubber bumper had a tendency to retain crushed ice after each impact and this may reduce its sensitivity to other impacts in the same area. To avoid possible in-flight icing problems, the distrometer must be made less susceptible to the retention of crushed ice, possibly by coating the bumper with teflon or another material with a low coefficient of friction. The bumper surface abraded slightly at the higher impact velocities but this was not considered a serious problem since the bumper is readily replaceable.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., July 13, 1973.

REFERENCES

1. Joss, J.; and Waldvogel, A.: Ein Spektrograph für Niederschlagstropfen mit automatischer Auswertung. Pure & Appl. Geophys., vol. 68, 1967/III, pp. 240-246.

2. Souter, Robert K.; and Emerson, Joseph B.: Summary of Available Hail Literature and the Effects of Hail on Aircraft in Flight. NACA TN 2734, 1952.

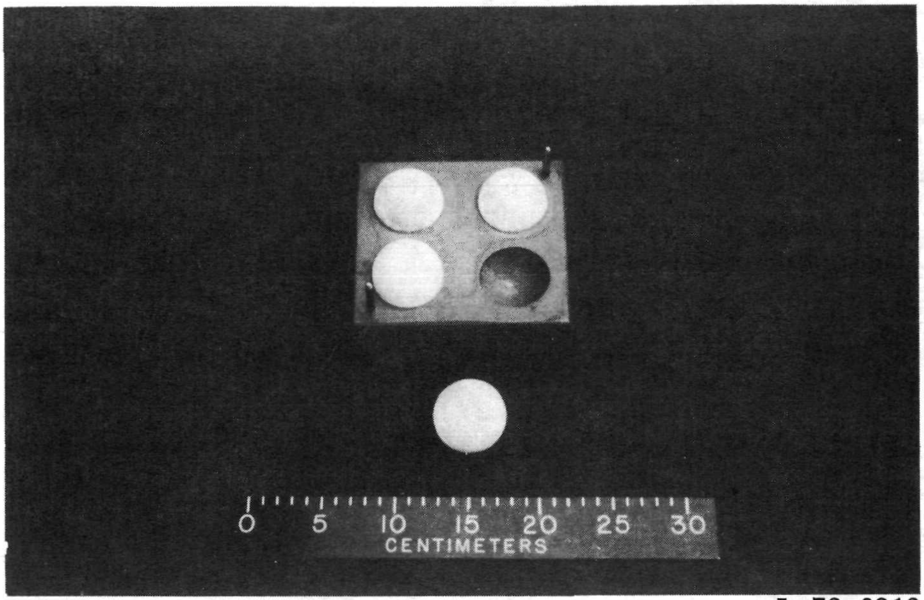

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Figure 1.- Lower half of silicone rubber mold with 5.1-cm-diameter hailstones.

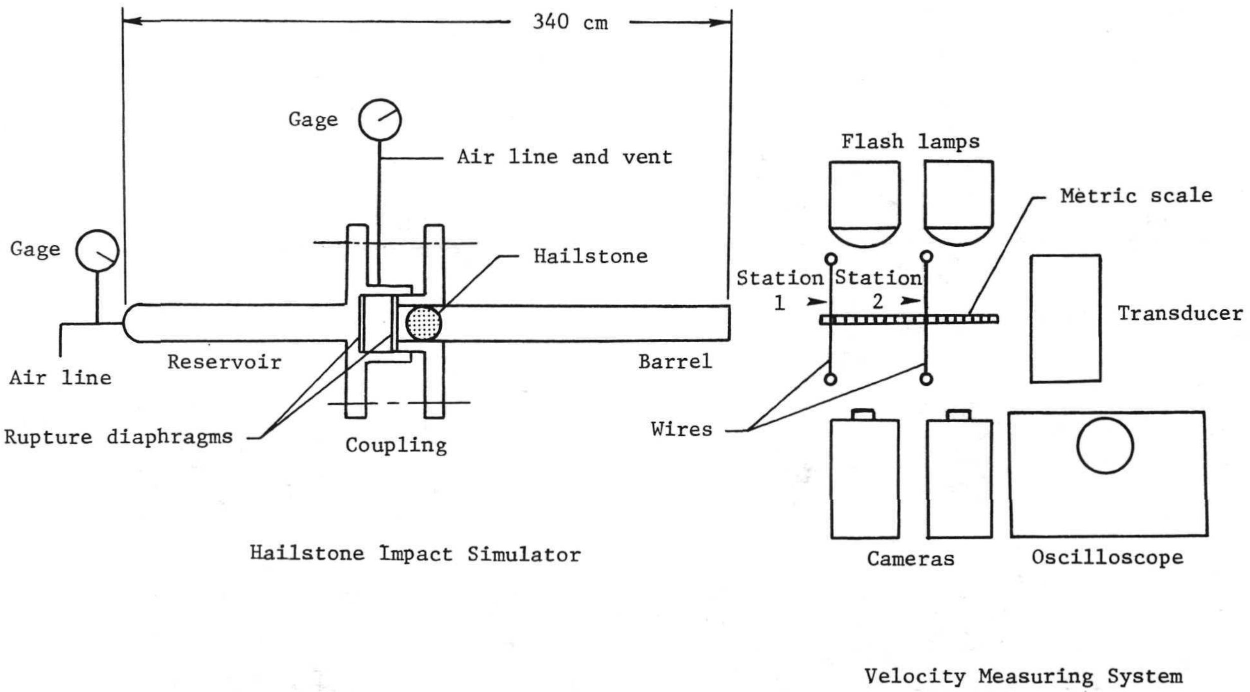

Figure 2.- Schematic of hailstone impact simulator and velocity measuring system.

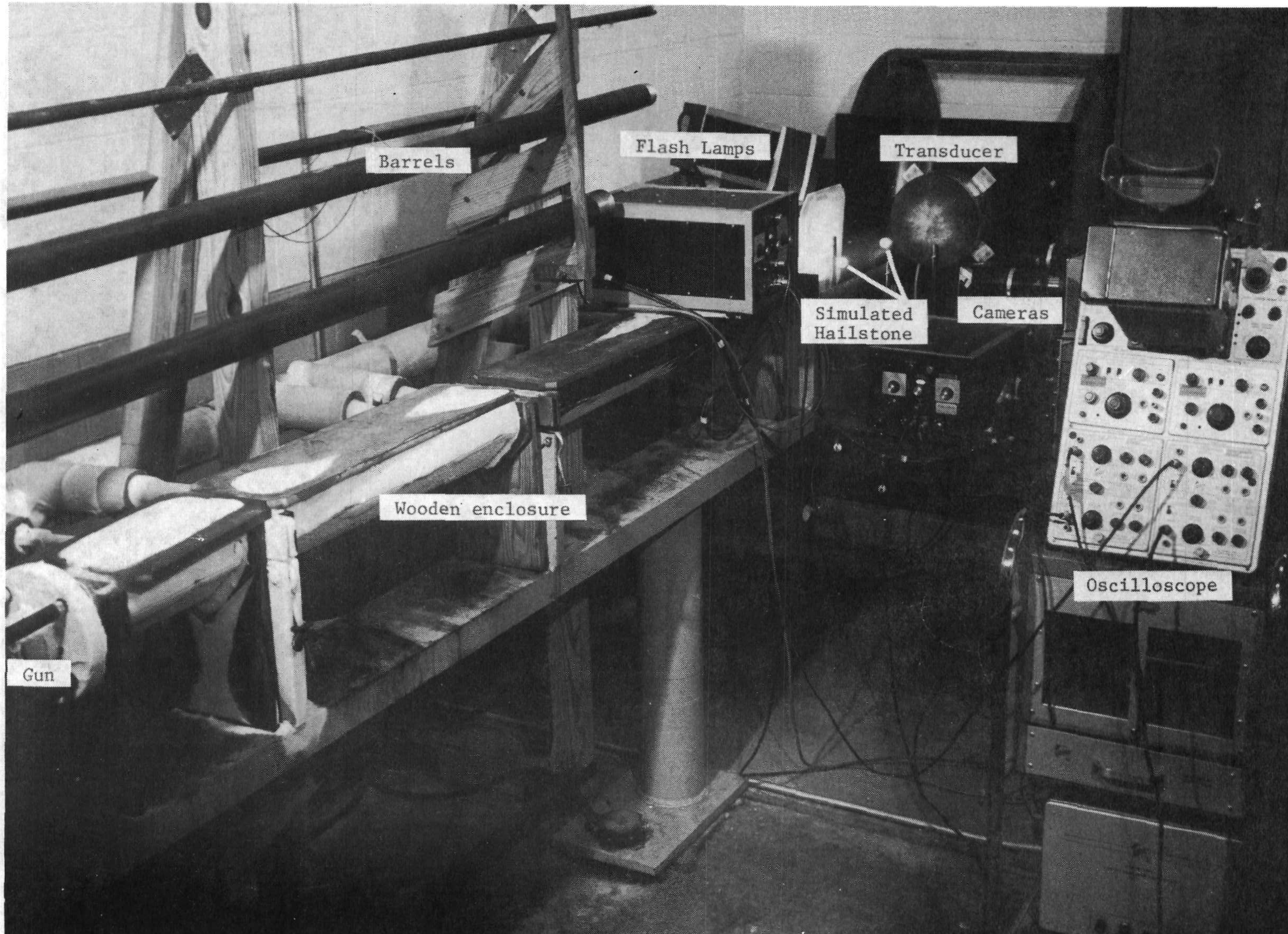

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Figure 3.- Hailstone impact simulator at the Langley Research Center.

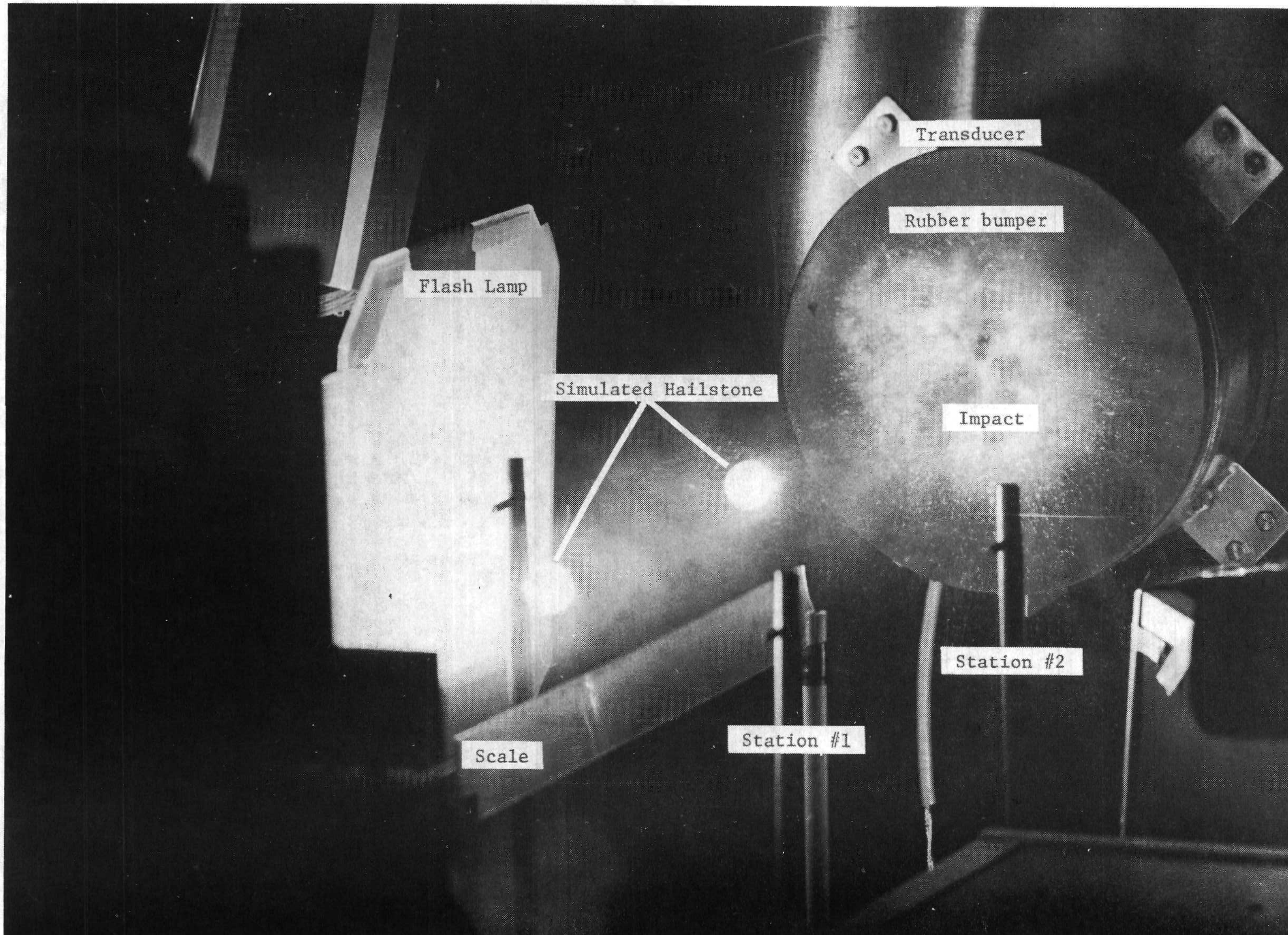

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Figure 4.- Multiple-exposure photograph of a hailstone in flight before and after impact on the transducer.

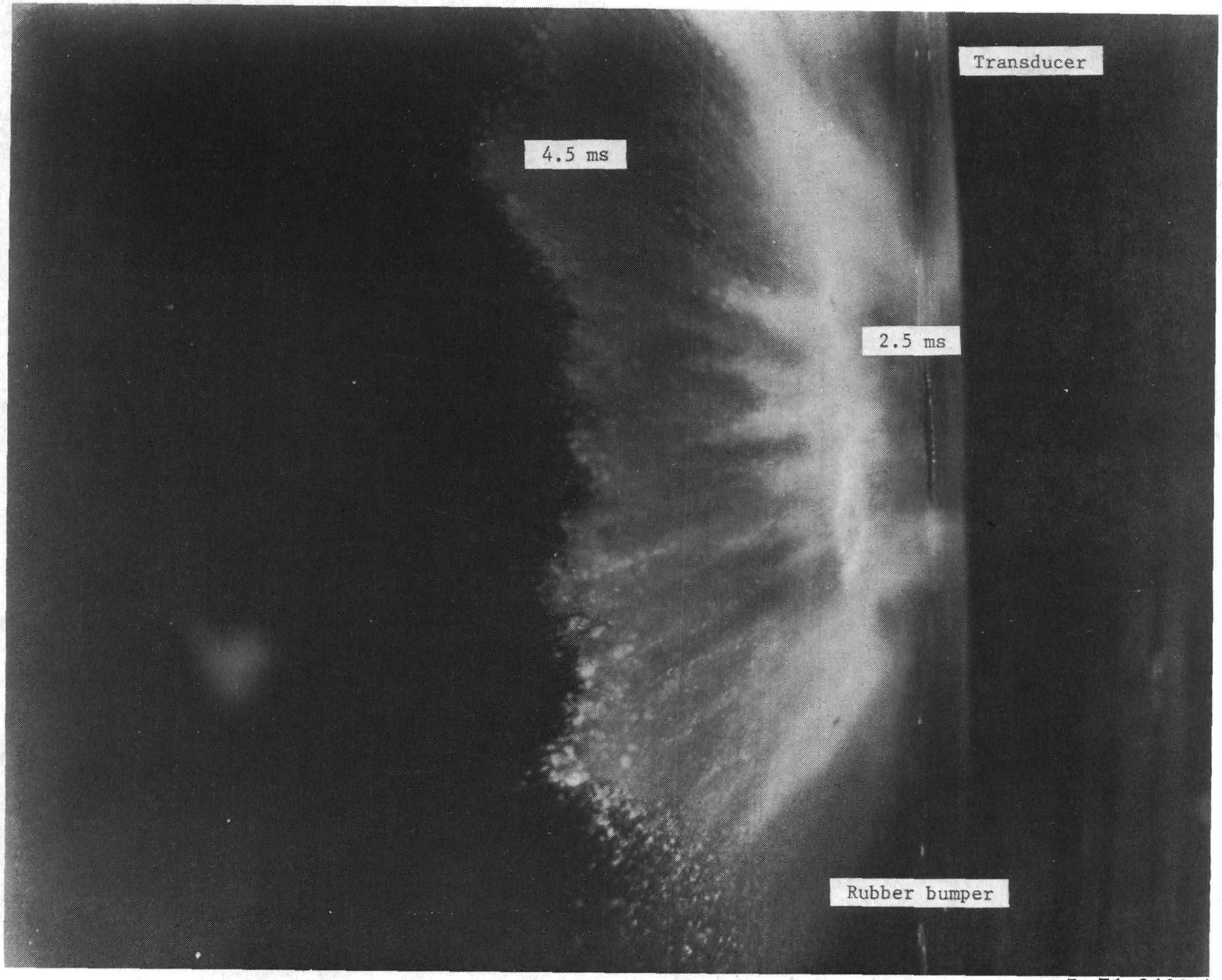

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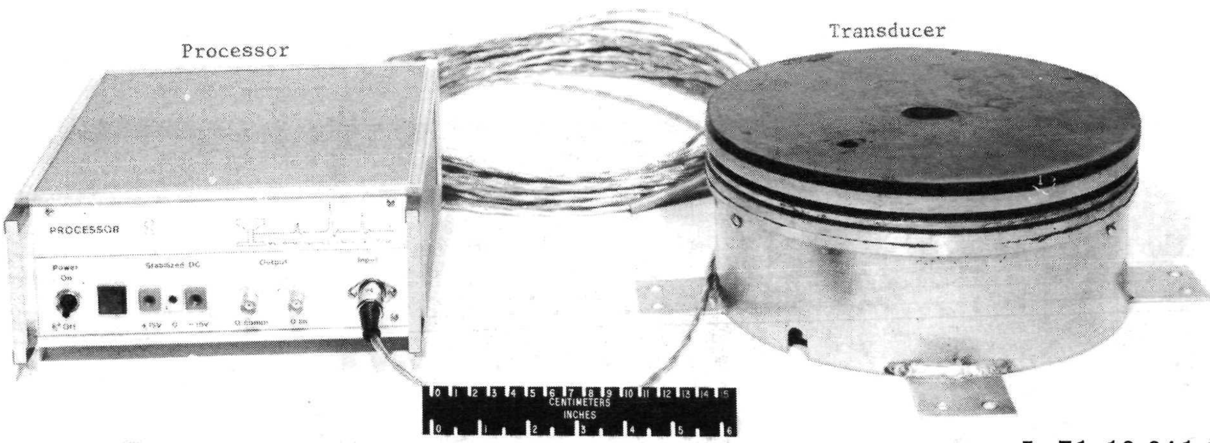
Figure 5.- Double-exposure side-view photograph of a hailstone impacting the hail transducer.



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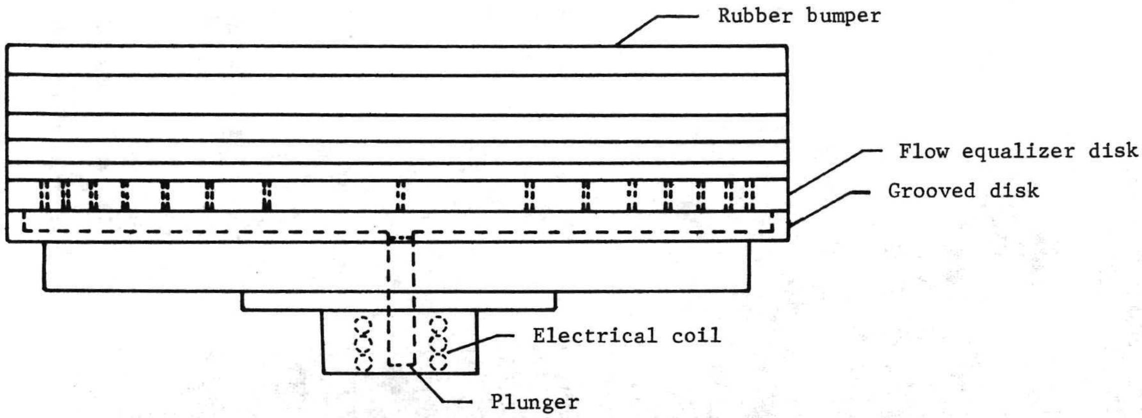
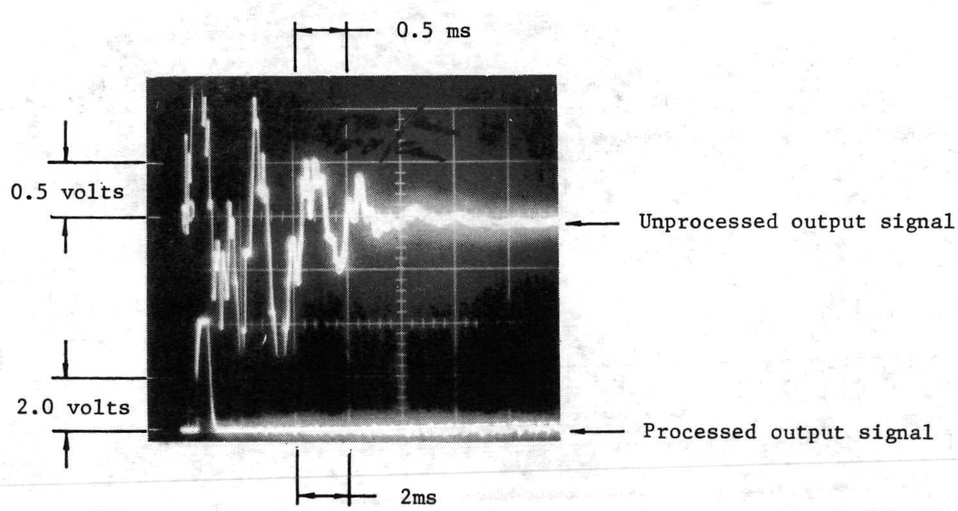
(a) Distrometer.



(b) Transducer.



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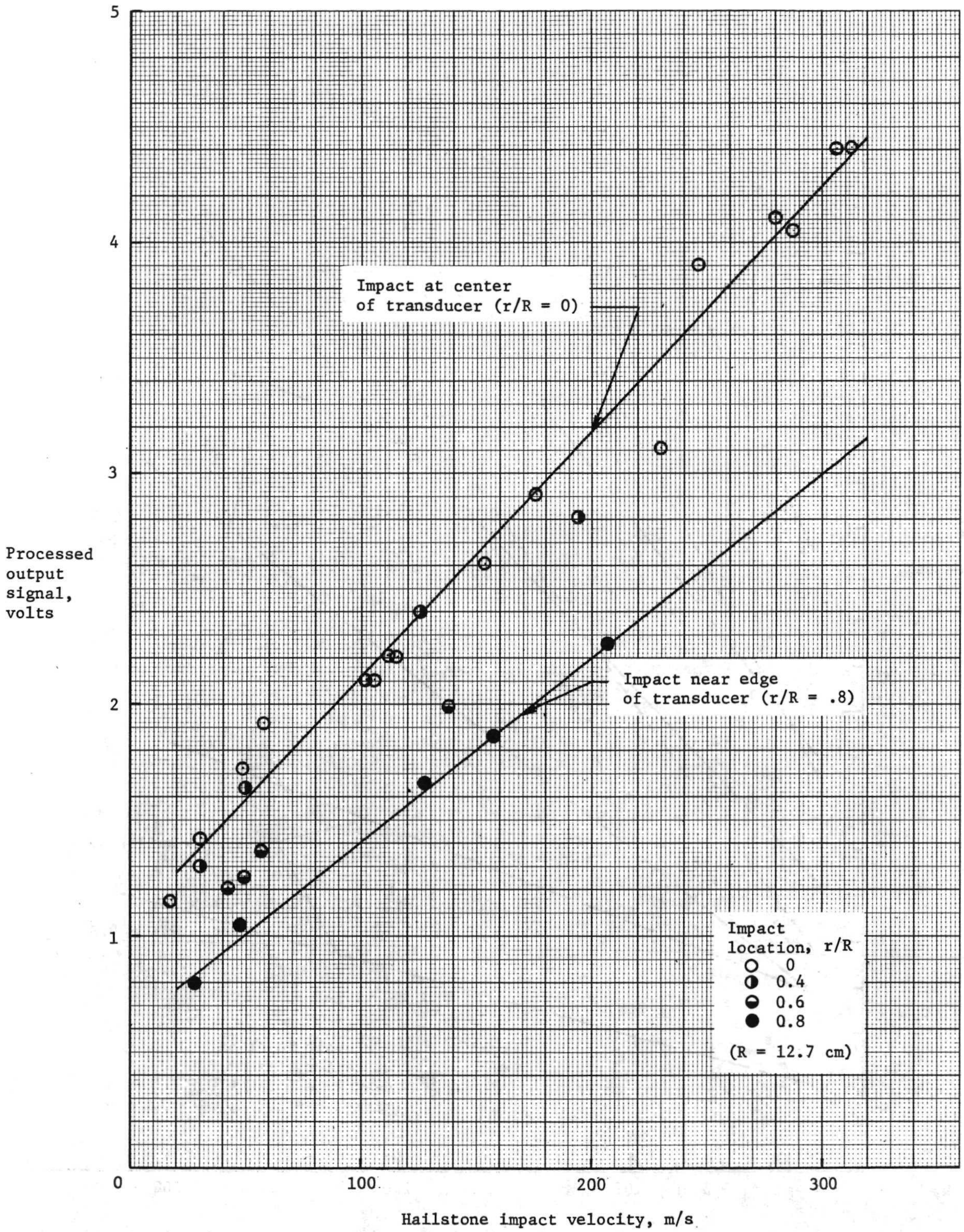
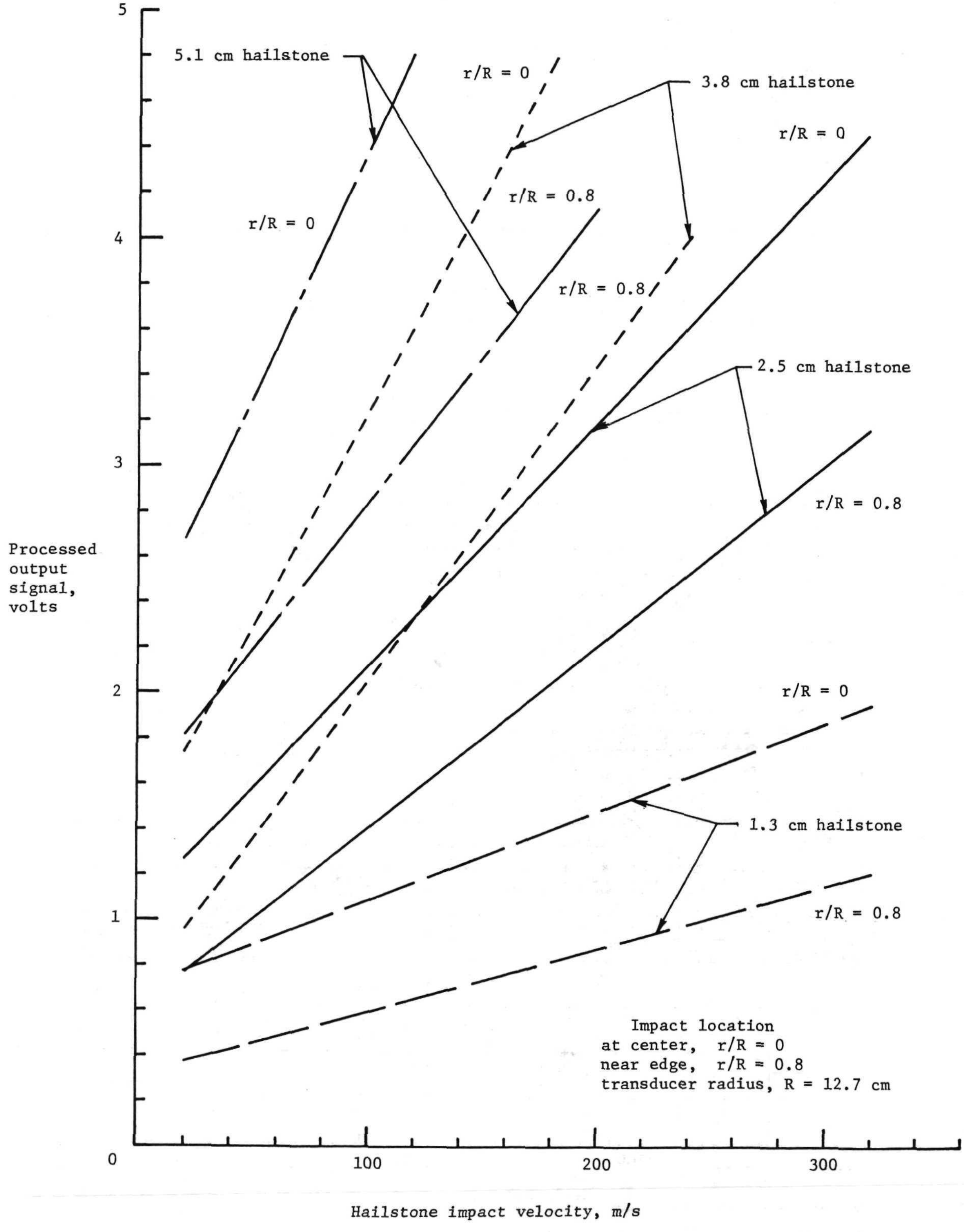
(c) Output signal.

Figure 6.- Distrometer for hailstones.



(a) 2.5-cm-diameter hailstones.

Figure 7.- Output signal envelope.



(b) 1.3-, 2.5-, 3.8-, and 5.1-cm-diameter hailstones.

Figure 7.- Concluded.

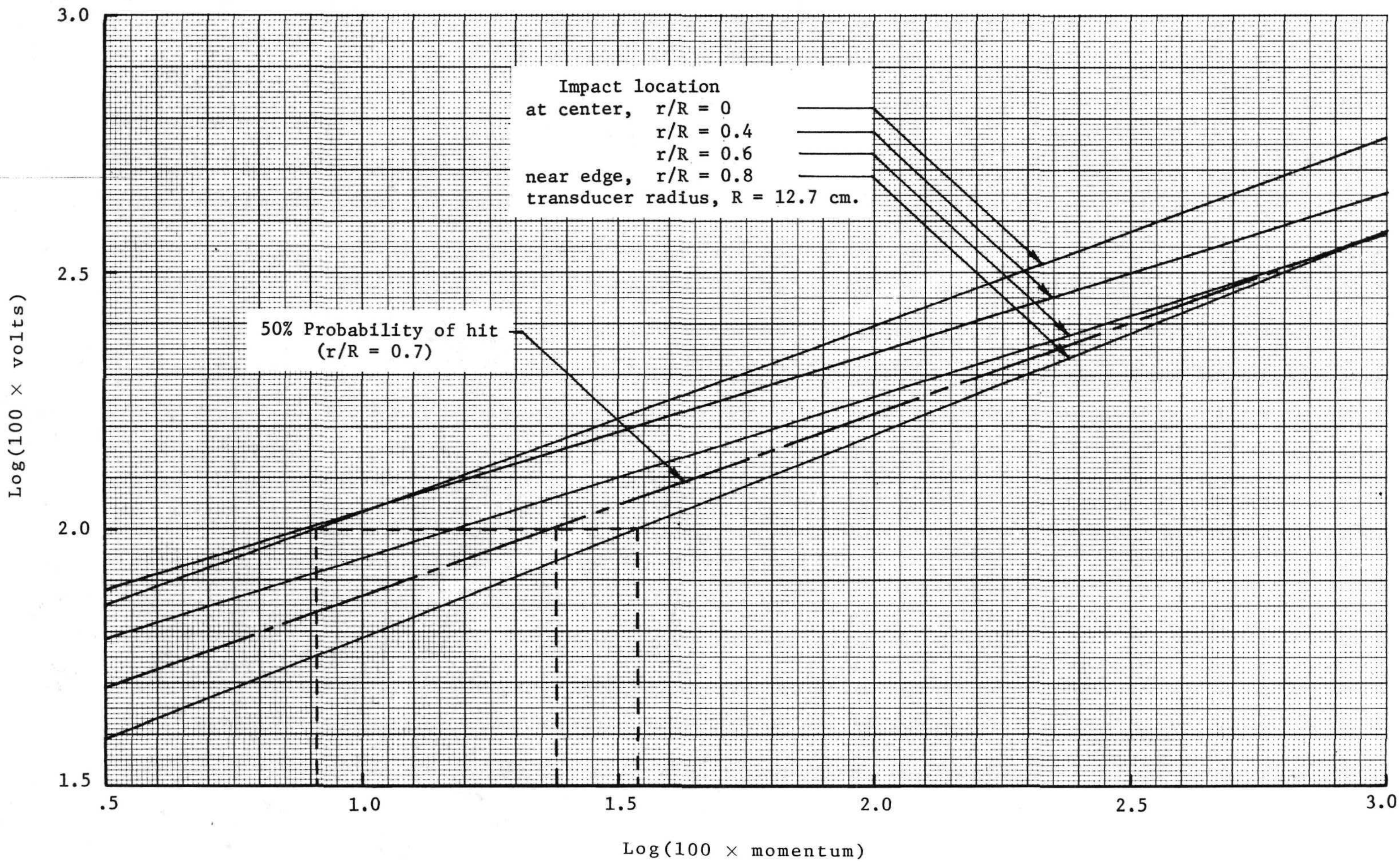


Figure 8.- Output signal represented by log(100 × volts) as a function of hailstone momentum represented by log(100 × momentum) and impact location for hailstone diameters of 1.3, 2.5, 3.8, and 5.1 cm.

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