AFCRL-65-921

MEASUREMENT OF DROP SIZE DISTRIBUTIONS IN NATURAL CLOUDS AND RAIN

D. P. Keily

Department of Meteorology
Massachusetts Institute of Technology
Cambridge, Mass. 02139

Contract No. AF19(628)-4085
Project No. 8620
Task No. 862006

FINAL REPORT

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Period Covered: April 1964 - March 1965
Date of Report: 31 March 1965

Prepared for

AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
OFFICE OF AEROSPACE RESEARCH
UNITED STATES AIR FORCE
BEDFORD, MASSACHUSETTS

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ABSTRACT

Some fog drop size distributions taken during Operation Catfeet are presented. Calibration droplets with a range of positive and negative charges may be generated by control of the bulk water supply voltage, without affecting the response of the electrostatic probe used to size and count them.

1. Introduction

The primary purpose of this study was to test the airborne electrostatic drop probe in a fog on the ground, in company with a number of other cloud instruments concentrated at Otis Air Force Base, Massachusetts as a part of AFCRL Operation Catfeet. In the previous summer, the same instrument was set up at Otis as part of Catfeet's first effort, but was not operated there due to lack of fog.

Secondary purposes of this effort were to continue the study of recording devices for the electrostatic probe and to continue laboratory studies of the electrostatic phenomena which occur within the probe.

The application of this instrument to liquid particle sizes and counts in natural cloud has been described in reports of previous contracts, e.g., Scientific Report No. 5 of 15 August 1957 AF19(604)-1287, AFCRC-TN-58-472. Drawings of the final form of the probe proper and descriptions of the other components are included in this report.

2. Observations and Results of Field Tests

The electrostatic drop counter was set up in a military van near a taxiway on the east side of the airfield at Otis Air Force Base near Falmouth, Massachusetts, about five miles from the sea coast. Instruments of other cloud physics projects were located in the same van. Several of the sensors including our probe were exposed on top of the van in a wind tunnel with a speed of 70 mph. As part of AFCRL operation Catfeet, these several instruments were used simultaneously in ground fog to compare their characteristics.

Considerable difficulty was experienced initially with the electrostatic drop counter electric circuitry, due to the relatively low temperature and consequently high humidity within the power cooled van. Other undesirable aspects of the environment during these tests were the crowding and noise in a van full of technicians and equipment all keyed to operate simultaneously at infrequent intervals, sometimes with little notice. Lacking systematic weather observations at the site, the observations and forecasts of the Air Force Base weather station a mile across the field were used where possible.

The capacity of the electrostatic probe for continuous observation of fog, drop by drop, was limited to the endurance of the camera recorder. A one-hundred foot roll of 35 mm film was consumed in 5 seconds when run at sufficient speed to resolve individual pulses produced by each fog drop. It is intended that the system be used with a magnetic tape recorder, having an endurance of several to many minutes of continuous observations. This capacity was not available during operation Catfeet, due to lack of funds for purchasing a magnetic tape recording system. With single observations limited to five seconds of time, and considering the known variations in density in some ground fogs, it is apparent that observations with the electrostatic probe will frequently not be directly comparable to observations of clouds taken over longer inclusive periods and expressed as an average fog condition.

We are advised by Mr. Bruce Kunkel of AFCRL that no 1964 Catfeet drop size distribution data are available yet from the other systems for comparison with ours. A limited amount of liquid water content (lwc) data are available and will be quoted below. With these reservations, the results of our few trials of the electrostatic probe in the 1964 season are presented.

The equipment was operated during reported periods of fog on three dates: July 10, August 22 and August 24. On July 10 the base weather station observed fog with visual ranges of one quarter mile to one sixteenth mile between 9 a.m. and 1 p.m. At one unrecorded time during this period, when visual range at the Catfeet sight was observed as "less than the distance to the other van", about 1000 feet, a cloud observation was made with the electrostatic probe. No oscilloscope pulses were recorded, indicating that during the five seconds that the system was recording, no droplets were aspirated from the air sample passing the probe in the wind tunnel atop the van. The further implication is that either there were no droplets in the particular air volume aspirated or all droplets were smaller than four microns, the minimum size resolved by the system. No further observations were made at that time because of the thinness of the visually observable fog.

The next observation of fog was some forty days later, on August 22nd. The Base Weather Station reported visual ranges less than three quarters mile between 5 p.m. and midnight. At an unrecorded time during the period, the cloud probe was operated for one four-second run. Figure 1 shows the size distribution of the 4,642 droplets in that brief interval. The liquid water content is computed to be 0.004 grams per cubic [illegible] No comparative values are yet available for other instruments. This value, while low, may not be inconsistent with the visual ranges at the nearby weather station.

The third observation was made on 24 August at 0200. A count of 1210 drops caught in about five seconds had the distribution shown in Fig. 2. Inadvertantly, the probe vacuum pump was not operated during this exposure. Nevertheless drops were caught due to their acceleration by the wind tunnel in which the probe was supported. In this mode of operation, very small drops would be discriminated against by the probe. Figure 2 shows such a decrease in the smallest sizes, which are usually found by the probe to be dominant in almost all distributions, particularly in airborne cloud observations. See the previous project reports.

The liquid water content would be little effected by loss of 4 and 5 micron diameter drops in the presence of 15 and 20 micron sizes. It is computed to be 0.002 grams per cubic meter. This compares to values of 0.18 gram reported for a capillary collector, 0.23 gram for a multicylinder impactor and 0.30 gram for a hot wire meter, all exposed for longer periods at about the same hour and minute. The multicylinder distribution was also reported as of class "B" with 28 micron volume median size. Considering on the one hand that the probe can and has observed drops of up to 200 microns in diameter and, on the other, that this distribution had, in 1200 drops, only five in the largest observed sizes of 18, 20 and 22 microns, one may believe that this observed distribution, taken in five seconds, sampled a small non-representative volume, free of the volume median size reported by the multicylinder instrument. A dozen such five second observations taken in rapid succession might have shown other distributions. This was not possible with the available camera recorder. It may be of some significance that the electrostatic probe is calibrated by observing its response to individual water spheres of known size and number at 100 percent collection efficiency while the other instruments named above are calibrated by means which include computations of theoretical and empirical collection efficiencies and heat transfer functions.

The fourth test to be reported was made a few minutes after the third at 0208 on 24 August. By arrangement, all instruments in the van were to be operated at the same time. On signal, the probe was operated for the usual five second period. Examination of the camera film showed timing marks but no drop pulses. All settings were normal. The inference is that no droplets over the resolvable size of four microns were present in the air volume sampled. The base weather station was reporting hourly, visual ranges of one eighth mile, from 0100 to 0800. Local wind was calm.

The office of Catfeet subsequently reported that between 0212 and 0216, but not exactly at the scheduled time of 0208 at which the probe was exposed, the multicylinder collector gave a "B" distribution with 26 micron volume median size and lwc of 0.25 grams per cubic meter. The capillary collector then read 0.18 grams and a third (J.W.) instrument 0.30 grams. In the 1/16 mile fog and calm as reported by Base Weather, any tendency toward thin or clear patches in the fog would have been accentuated by the van due to its own heat.

These very few observations during operation Catfeet 1964 are indicative of the scarcity of fog at Otis during that particular summer. A review of the Flying Weather pages of the Uniform Summary of Surface Weather Observations for Falmouth FMH (Otis AFB), as furnished by National

Weather Records Center at Asheville shows that in ten particular years between 1943 and 1957, fog occurred at a maximum of about seven hourly observations in every one hundred in May, June and July and at a secondary maximum of four in every hundred in August and September. The lowest minimum of 3.5 percent occurred in November and December. Of these hourly fog observations, the peak occurrences were at 1 and 2 a.m., particularly in summer. The major conclusion from this quick look at the climatology of Otis AFB is that one might expect fog at some hour of the day, generally between 0100 and 0300, on about half the days of summer through July. It is unfortunate for this operation that in 1964 there were only about two occurrences per month in July and August of 1964.

It is concluded that the rapid sampling and high resolution (drop by drop) of the electrostatic proce made it useful for indicating the great small-scale variations in cloud density but prevent it from indicating longer term average values of size distribution and liquid water content except it be provided with appropriately large recording capacity in the order of millions of drops and minutes rather than seconds of endurance. This is equally true for ground observations and flight observations. The five second endurance and the five minute film change time of the present experimental system, together with the few occurrences of fog in the 1964 season did not result in sufficient records to give a valid comparison of this system with the others in "simultaneous" operation at Otis AFB.

3. Laboratory Observations of Charge Relations within the Probe

(a) Attempts to microphotograph collisions of droplets with the charged probe target had not been successful in earlier work. This was due largely to the difficulty of applying lens and lamp to the area of collision while maintaining form and size of the probe. Observations at full scale air pressure, probe size and voltage gradients were desired. To have scaled up the probe dimensions would have required scaling up of air velocity and target voltage to inconvenient and perhaps practically impossible values.

Direct visual or camera observation of collision had therefore been abandoned and efforts returned toward observing relations between probe target current and controlled charges on incoming droplets. By noting current output and variable charge input, it was expected that some feeling would be acquired for the nature of charge conversion at the target, and particularly whether a stream of single sized droplets on breakup would create variable impact charges.

The earlier studies in this direction had shown a peculiar and interesting relation between target current and drop generator applied voltage. Diagram 1 shows typical observed relations. When not deliberately grounded, the vibrating glass reed ejects droplets having a measurable negative charge. 200 micron drops at 1200 per second develop an electrometer target current of about minus 1.6×10^{-10} amperes, (Point A). On rare occasions, for reasons uncertain, an ungrounded reed has produced a neutral or positively charged stream of drops. On the other hand when the reed is operated within an electrostatic shield, the electrometer output is unusually steady.

When the reed is artificially charged by inserting one battery electrode as far as possible into the tip of the vibrating reed and wrapping the opposite electrode around the outside of the reed, some centimeters above its tip, the relations of diagram 1 are obtained (Curves b and c), depending upon polarity. The arrangement of the charging circuit is shown in diagram 2. Note that the reed voltage and the grounded battery terminal are independently reversible, giving four circuit combinations related to the four portions of the characteristic in diagram 1. Characteristic (b) is obtained when the battery negative terminal is grounded and characteristic (c) when the positive is at ground.

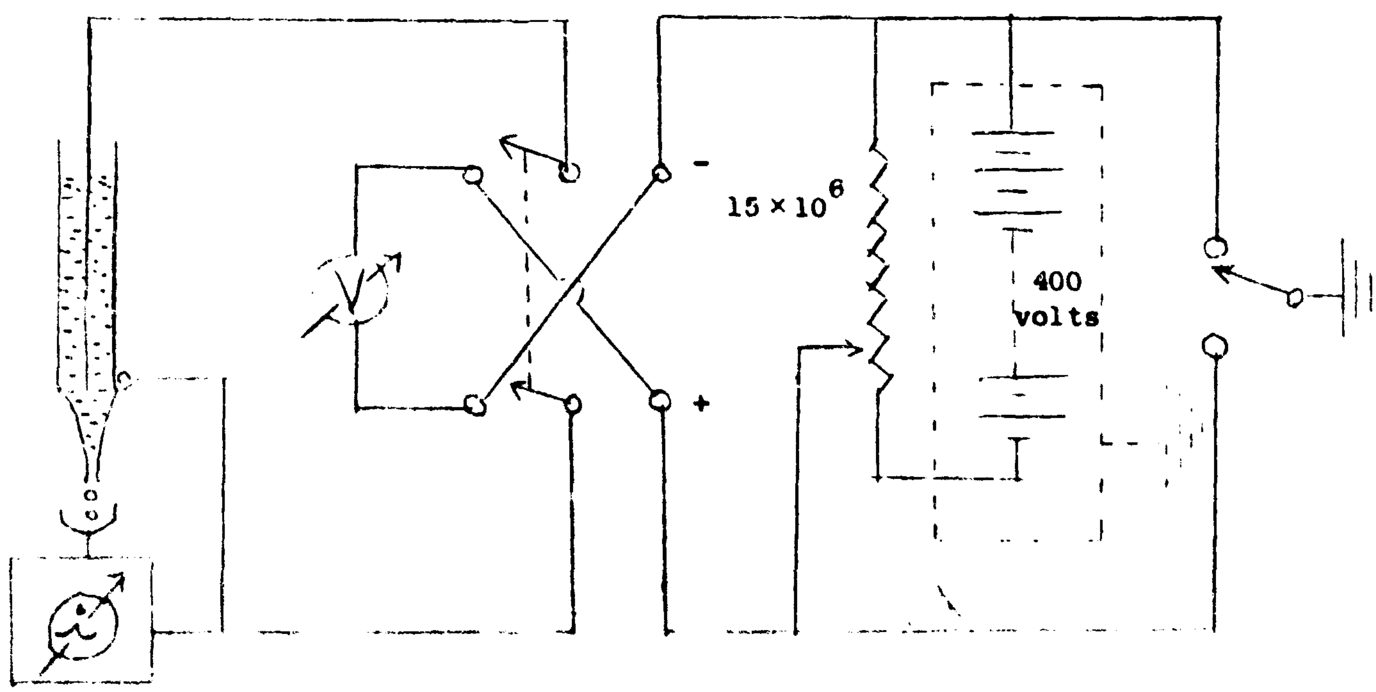


Diagram 2

Diagrams 1 and 2 are corrections of Figures XIII (a) and (b) in the Final Report of 15 February 1964 (AFCRL-64-621). From diagram 1, as corrected, it is obvious that a linear current/voltage characteristic results if the electrometer is kept at ground potential, whatever the sign of reed potential. No sign of saturation of current appeared up to 1500 volts positive or 750 volts negative on the reed.

This linear characteristic indicates that zero sensor output current may be obtained by voltage biasing the vibrating reed generator. A comparison of three such voltage/current characteristics for drop sizes of 50, 100 and 200 microns diameter (all at 1200 drops per second), shows a nearly linear relation of sensor current to drop diameter squared or area. This relation is the same as the sizing

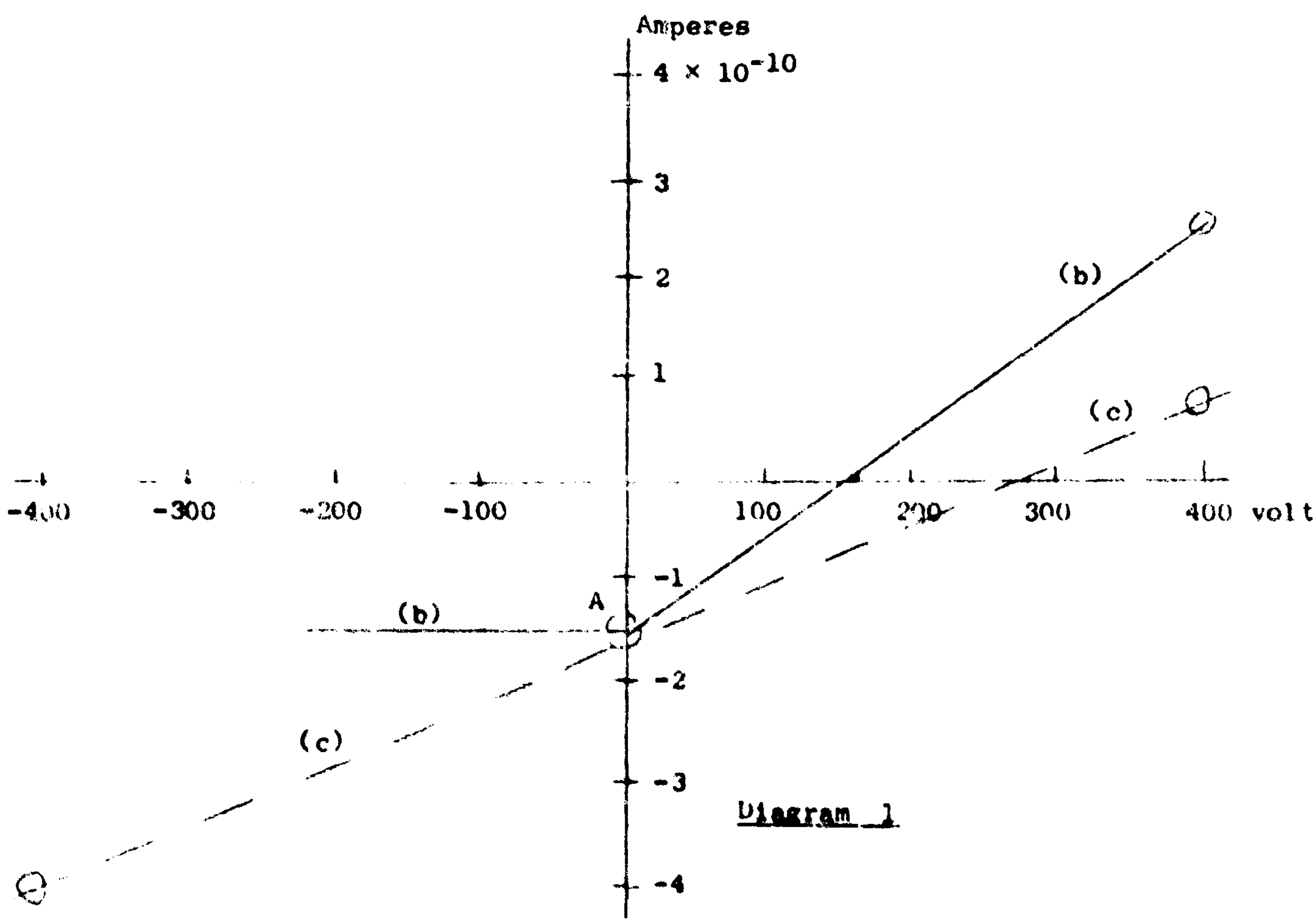


Diagram 1

characteristic of the electrostatic cloud probe. As reported last year, however, the output characteristics of electrometer and of cloud probe are different by orders of magnitude.

(b) Oscilloscopic traces of the charge pulse produced in the cloud probe had indicated the complexity of the collision process, as an electrostatic charge exchange or series of exchanges. Efforts to photograph the collision process within the probe were resumed during the first part of this project extension period. These efforts were again unsuccessful, largely due to inability to obtain sufficient light intensity of sufficiently short duration to stop droplet motion.

4. Recorder Specifications

The facilities of the contract extension did not permit further study of the requirements of a field or airborne recording system. The problem remains to record some 5000 pulses per second, each of 50 to 300 microseconds duration, for at least 5 consecutive minutes. The pulse amplitude must be resolvable to 10 per cent or less. The obvious recorder with this capacity and resolution is the magnetic tape recorder. The basic requirements of a tape system are:

(a) two or three channels, one for droplet pulse recording, one for time signal recording and possibly a third for voice recording of notes and comments of the operator. The first channel must have a band width of about 500 kilocycles per second, if the shape as well as the amplitude of the pulse is to be recorded. If only amplitude is necessary, a band width of about 40 kilocycles is required. Corresponding tape transport speeds are 60 and 15 inches per second. The recording mode would be "direct" rather than FM in either case. The FM recording mode is suitable for time code signal and voice channels. A typical machine with 7-inch reels will record for 6 minutes at 60 inches per second.

(b) a playback machine, which need not be integral with the recorder since it is used on the ground for subsequent data raduction. Monitoring of operations in the air is best done on an oscilloscope.

(c) small multichannel oscilloscopes which may be included as components of a complete field recorder.

(d) a time code generator which may also be a built-in component of the recorder. Such a system with or without the built-in monitors and timers may be purchased from one of the best known manufacturers for from twenty-eight to forty thousand dollars. The monitor and timer features, if included, can be applied to other instrument systems in the aircraft or field station.

It is reported that new models of tape recorders just reaching the market will provide recording in the FM mode rather than in the direct mode, with band widths of 500 kilocycles at 30 inches per second (12 minutes duration with 7 inch reels, much more with 14 inch reels). For pulse amplitude recording only, without resolution of pulse shape, only 40 kilocycles band width is necessary. The newest model recorder would then have a continuous recording time of several hours

A magnetic tape recording system with the capability outlined above is considered essential to routine use of the electrostatic cloud probe whether airborne or on the ground.

5. Final Form of Probe

The original cloud probe and its several modifications have been described at length in earlier reports. Since the most recent model is considerably simplified in design, it is described again. The probe proper is shown in Fig. 3. This size probe has been designed to count cloud drops and drizzle drops up to 100 microns diameter. The size of the aspiration hole in the tip of the housing is limited by the capacity of the vacuum pump, which should maintain a vacuum of less than half ambient air pressure in order to assure a constant velocity and charging time of droplets entering.

The construction and assembly of the internal parts has been greatly simplified. See Fig. 4. The resonant acoustic frequency of the target has been raised by stiffening the rod to the limits permitted by available volume.

The amplifier housing has also been stiffened and simplified. See Fig. 5. It is contained within the streamlined strut tubing which supports the probe two feet from the aircraft skin. The Raytheon CK-5703 cathodefollower vacuum tube amplifier is wrapped in one layer each of netic and co-netic alloy tape for magnetic as well as electrostatic shielding.

Signal and power cables leading from the strut preamplifier to the remote amplifiers and recorder are contained within two concentric electrostatic shields in Faraday configuration. With these precautions, a signal line noise level as low as five to fifteen microvolts may be obtained under favorable conditions. A noise level of twenty-five microvolts or lower allows observation of droplets of three microns diameter or larger. The main amplifier chain includes a Keithley type 103, battery operated amplifier and the input amplifying stages of the recording and indicating devices. The latter may be any suitable and available components, as discussed in section 4 above.

Scientists, engineers and graduate research assistants who contributed to this work are:

David Tweedy, graduate student

Carl Morey, graduate student

This contract was effectively a continuation of the following previous contracts:

AF 19(628)-259	15 February 1962-15 February 1964
AF 19(604)-7495	1 January 1961-31 July 1961
AF 19(604)-3050	1 January 1958-31 July 1960
AF 19(604)-1267	1 October 1954-31 December 1957
AF 19(122)-245	1 June 1950 -30 September 1954

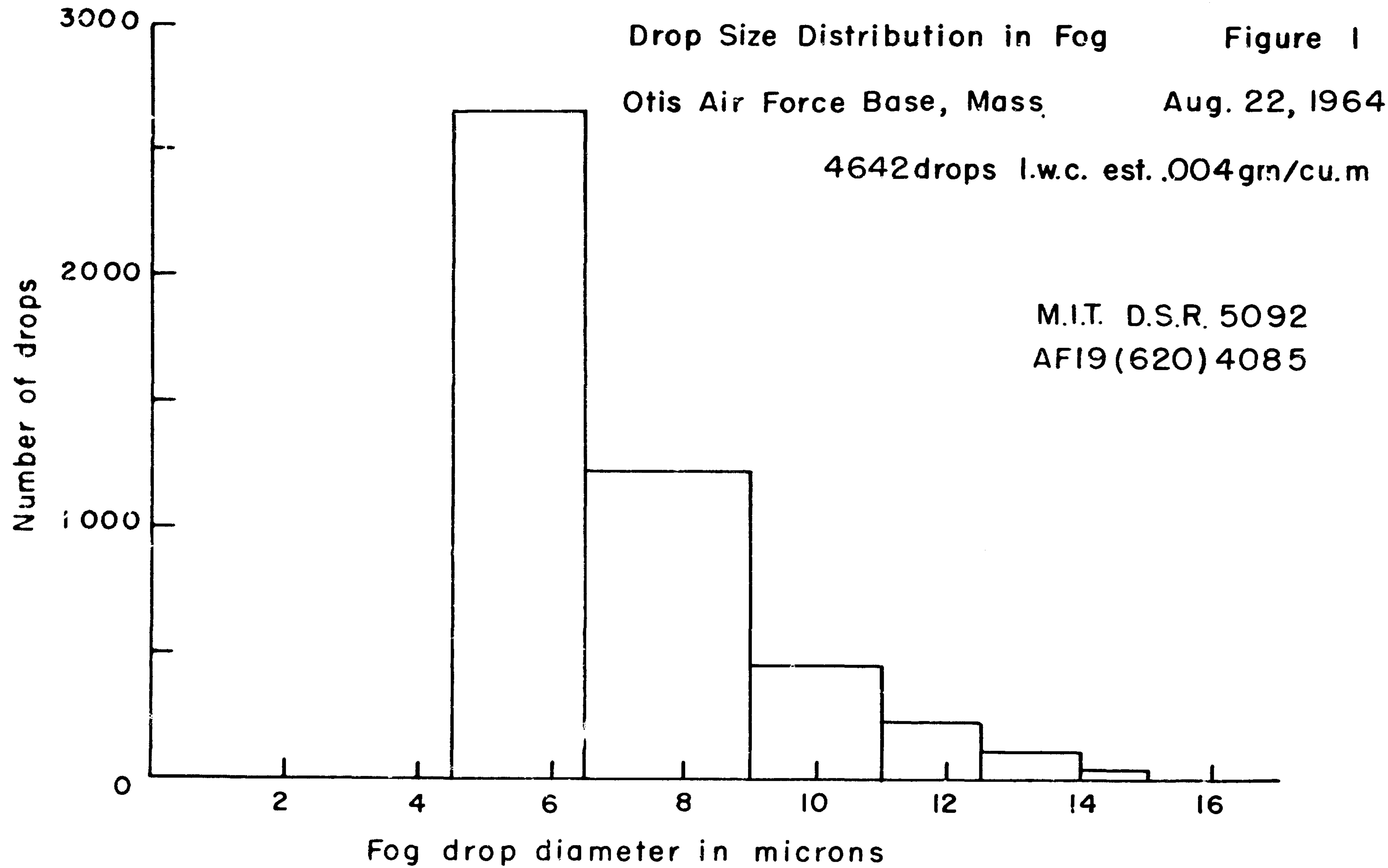
Publications, other than project scientific and final reports, derived in whole or in part from this and the preceeding contract work include:

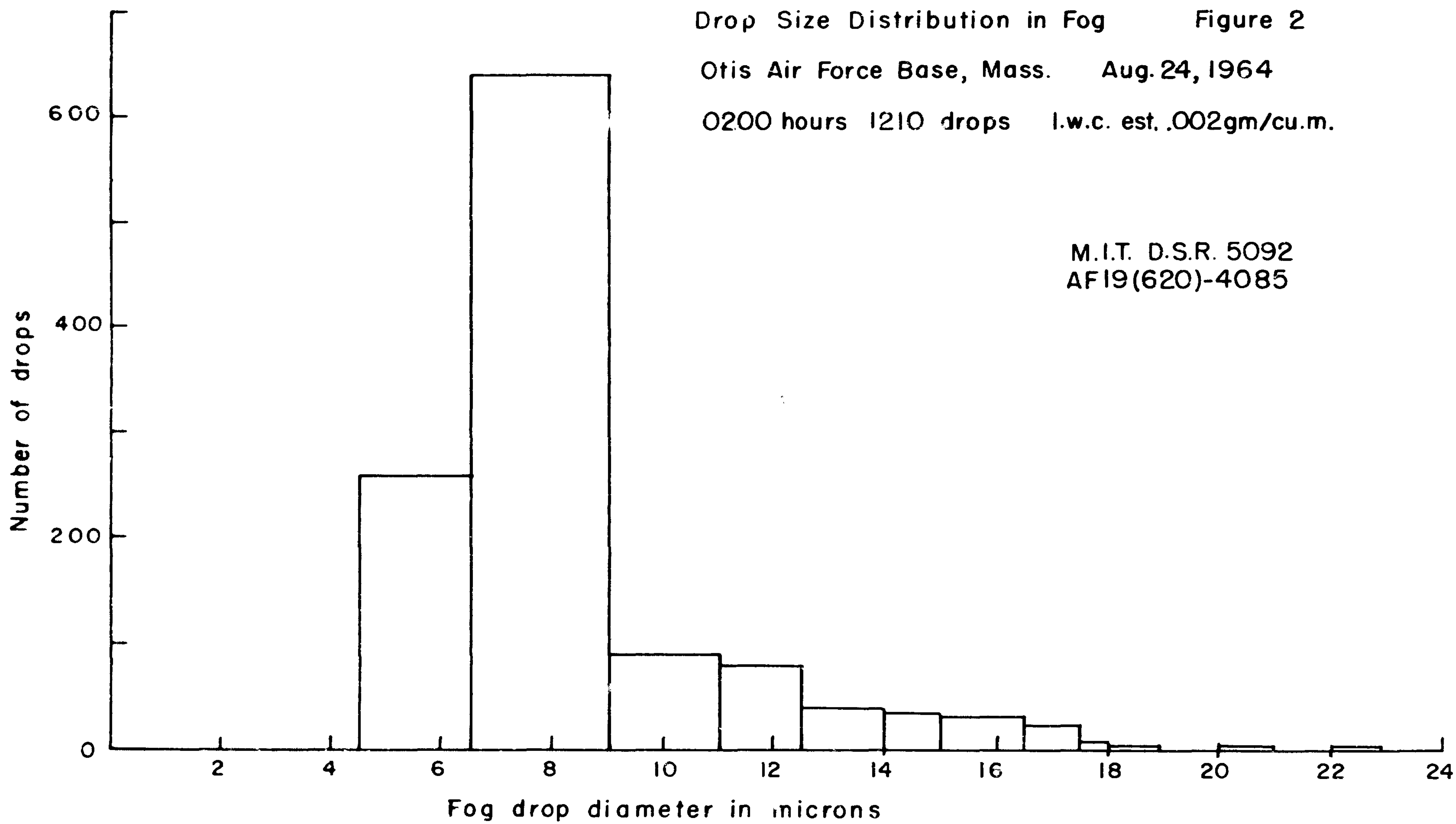
Johnson and Terrell (1955), J. Opt. Soc. Am., 45/6/451-454, (June)

Eldridge (1957), J. Meteorology, 14/55-59 (Feb); reply 574-577 (Dec.)

Keily and Millen (1960), J. Meteorology, 17/3/349-356 (June); replies (1961) 18/3/424-425 (June) and 18/6/829-831 (Dec.)

Keily (1963), Air, Space and Instruments, S. Lees, editor, pp 427-434, McGraw-Hill, New York.


Drop Size Distribution in Fog
Figure I
Otis Air Force Base, Mass.
Aug. 22, 1964
4642 drops l.w.c. est. .004 gm/cu.m
M.I.T. D.S.R. 5092
AF19(620)4085
3000
2000
1000
0
Number of drops
2
4
6
8
10
12
14
16
Fog drop diameter in microns


Drop Size Distribution in Fog
Figure 2
Otis Air Force Base, Mass.
Aug. 24, 1964
0200 hours 1210 drops
l.w.c. est. .002gm/cu.m.
M.I.T. D.S.R. 5092
AF19(620)-4085
Number of drops
0
200
400
600
2
4
6
8
10
12
14
16
18
20
22
24
Fog drop diameter in microns

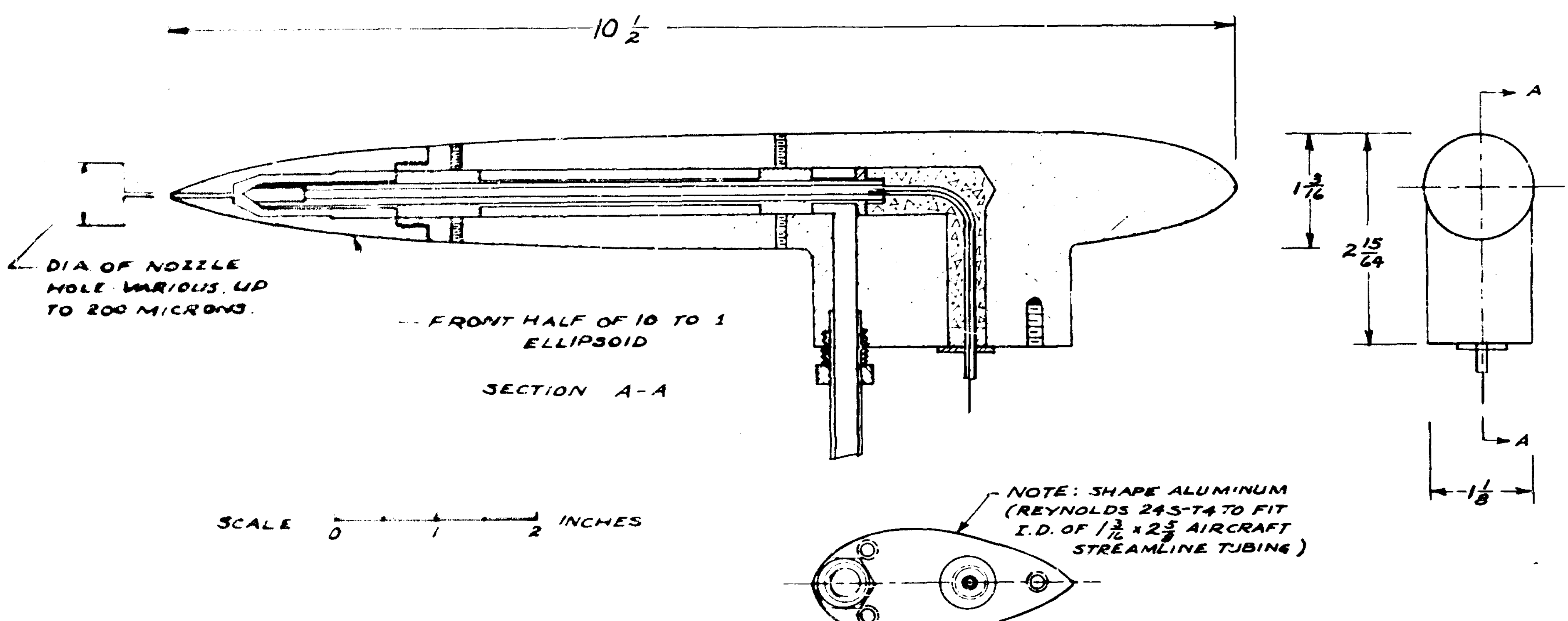


FIG. 3 DRIZZLE PROBE

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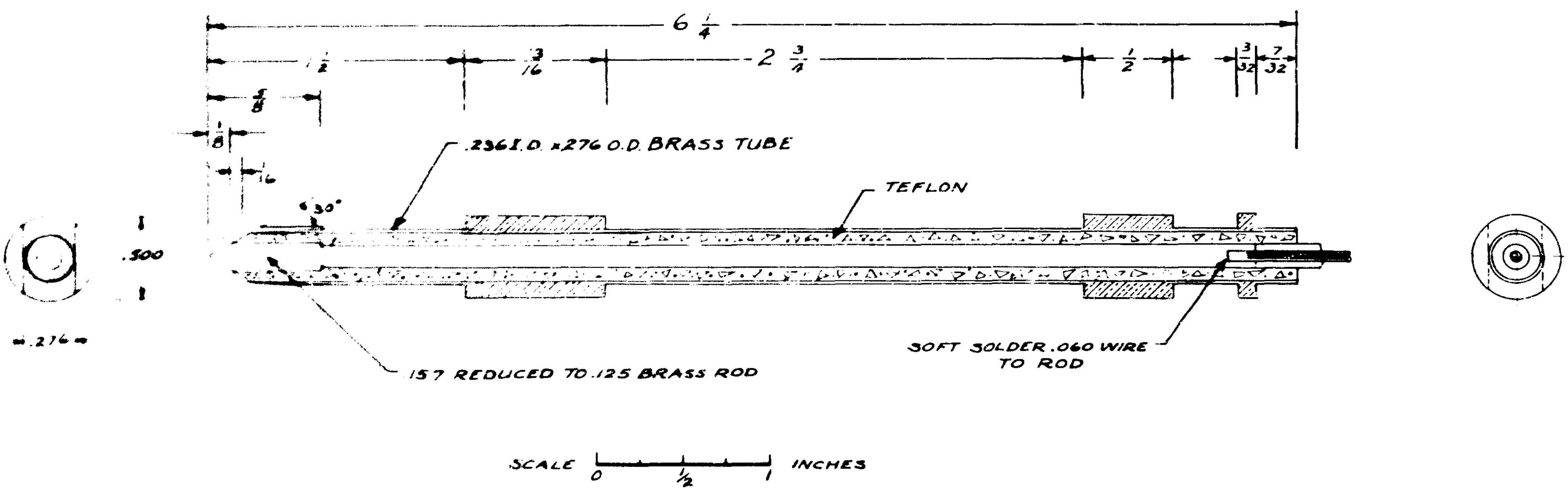

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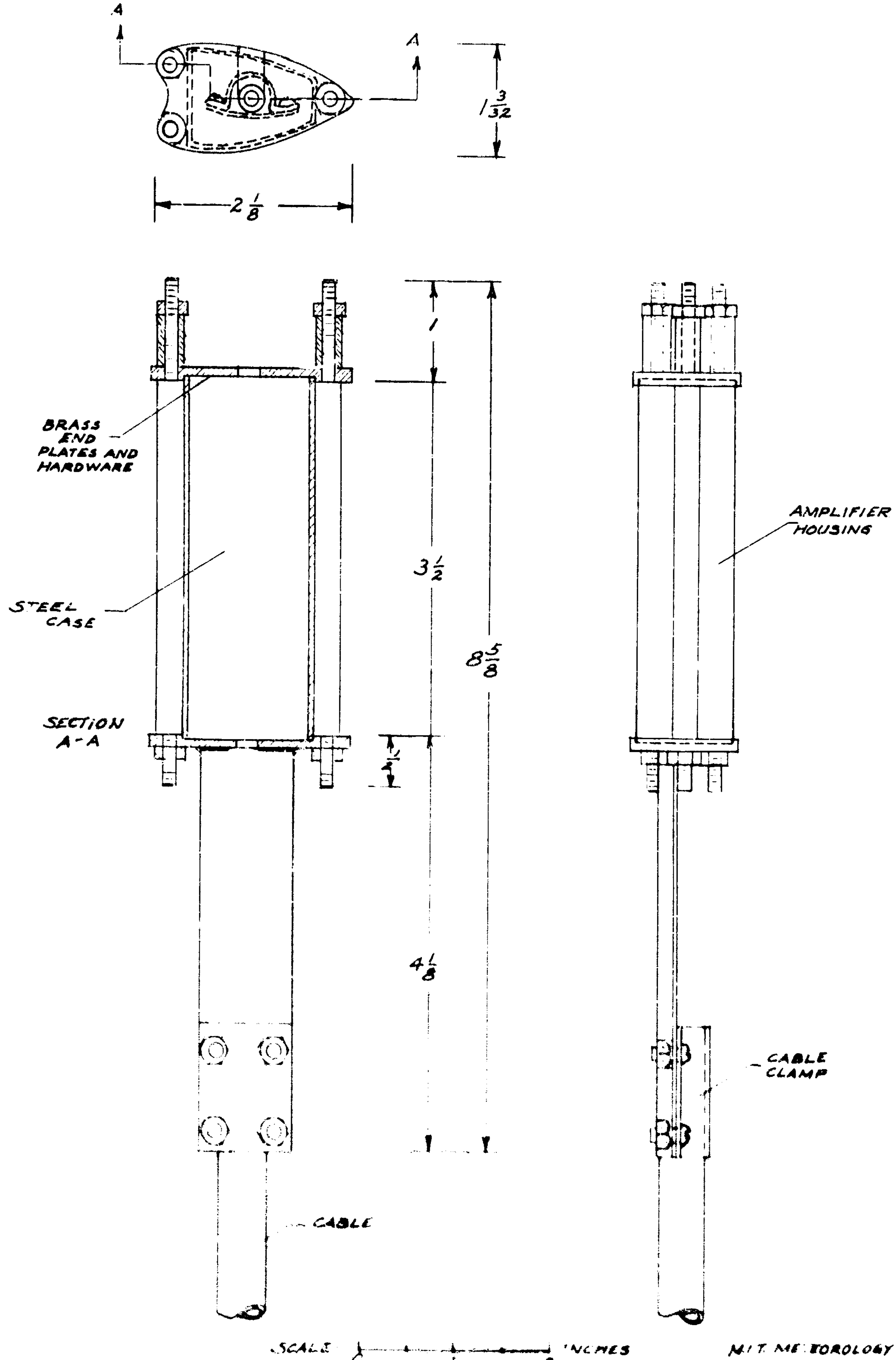
FIG 4 TARGET ASSEMBLY FOR DRIZZLE PROBE



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report on precharging of droplets generated for calibration purposes.	Hq. AFCRL, OAR (CRH) United States Air Force L. G. Hanscom Field, Bedford, Mass.

13. ABSTRACT

Some fog drop size distributions taken during Operation Catfeet are presented. Calibration droplets with a range of positive and negative charges may be generated by control of the bulk water supply voltage, without affecting the response of the electrostatic probe used to size and count them.

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Cloud Drops	5					
Rain Drops	5					
Drizzle Drops	5					
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