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AN EXPERIMENTAL METHOD TO DETERMINE THE CATCH EFFICIENCY OF ARBITRARY BODIES BY WEIGHING THE ICE ACCRETION

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SUMMARY

A simple method is described for determining the catch efficiency of arbitrary objects experimentally by weighing the ice accretion directly

Experimental results from a series of tests under natural weather conditions on the summit of Mt. Washington during the past season are presented.

AN EXPERIMENTAL METHOD TO DETERMINE THE CATCH EFFICIENCY OF ARBITRARY BODIES BY WEIGHING THE ICE ACCRETION

Introduction

The first requirement in designing suitable protection of aircraft structures against icing is knowledge of the location of ice accretion on such structures and the intensity of the icing. This information can be obtained analytically for certain two-dimensional shapes of simple geometry and with the aid of electronic computers for all two-dimensional shapes and three-dimensional bodies of revolution. There is, therefore, a need for an accurate and yet inexpensive method for more complicated configurations for which the above approach is not feasible and for checking the results obtained from computers. Such a method was developed by the University of Michigan Icing Research (under this contract) and tested under natural icing conditions on Mt. Washington during the 1952-1953 season.

The method is essentially as follows. The area of impingement is covered with a thin plastic sheet. After exposure of the model to known icing conditions for a certain period of time, this sheet is removed and weighed, both with the ice and dry. The total ice accretion can be determined from these weighings with a considerable amount of accuracy since the "tare" reading, the weight of the plastic sheet, is of the same order of magnitude as the weight of the ice-collected.

The model chosen for the experiments was a symmetrical, 15%-thick Joukowski airfoil for which the collection data are known (Reference 3).

Description of the Apparatus

The test apparatus consists of the following:

1. the wing model to be exposed, mounted permanently on the support;

2. the knife-edge box, which serves to cut the ice collected on the center section of the wing from that collected on the end pieces by means of electrically-heated brass knife-edges; and

3. scales, plastic sheets, electrical adhesive tape, and knife or razor blade.

1. The Model. Figure 1 shows the 15%-thick symmetrical Joukowski airfoil (A) having a 20-inch span and an 8-inch chord. It is built up of 1-inch-thick mahogany chordwise laminae, glued together and finished to the proper contour by hand.

The center section, 10-inches wide, forms the actual test section while the two outboard 5-inch sections serve to guarantee two-dimensional flow over the center section. The contour over the latter section was recessed 0.01 inch, which dimension corresponds to the thickness of the plastic sheet used. After installation of the plastic sheet the entire contour of the front half of the wing was smooth.

At the 35% chordwise station and well beyond the furthest point of impingement a brass strip (B) was inserted with a groove along the span of the test section. This groove serves as a guide for the cutting instrument during the removal of the ice-coated plastic sheet.

The 9/16-inch-diameter support rod (C) was threaded into the wing for a distance of 5 inches and the wing was locked in position by the lock-nut (D). This support rod, in turn, was fixed into the housing (E) which contained two ball bearings, allowing the entire assembly to rotate freely with respect to the shaft (F) so that the wing "weathervaned" and remained at zero angle of attack. The dimensions of a tapered hole in this shaft correspond to several mounting posts on the parapet of the Mt. Washington Observatory.

2. The Knife-Edge Box. The knife-edge box, shown in Figure 2, is the structure in which the wing assembly is placed immediately after exposure. The most important parts are the two brass knife-edges (G). They consist of 1/4-inch-thick brass plates, in the center of which a V-shaped cutout is made. The lower part of this cutout is shaped exactly to conform to the leading-edge contour of the model. The cutout departs from the shape of the contour at a point well beyond the furthest possible impingement area and then diverges to the top of the plate. The relative position of wing and knife-edge is shown schematically in Figure 3. The portion of the cutout that makes contact with the wing contour is wedge-shaped so as to guarantee a clean cut of the ice. The knife-edges, which are, of course, 10 inches apart are heated shortly before insertion of the iced model by means of heating elements cemented to the back of the brass plates.

The bag (H), attached to a metal frame, is placed under the test section of the wing and receives the plastic sheet with the ice as it is removed from the wing. The bag is lightly attached to its frame so that the frame itself need not be weighed.

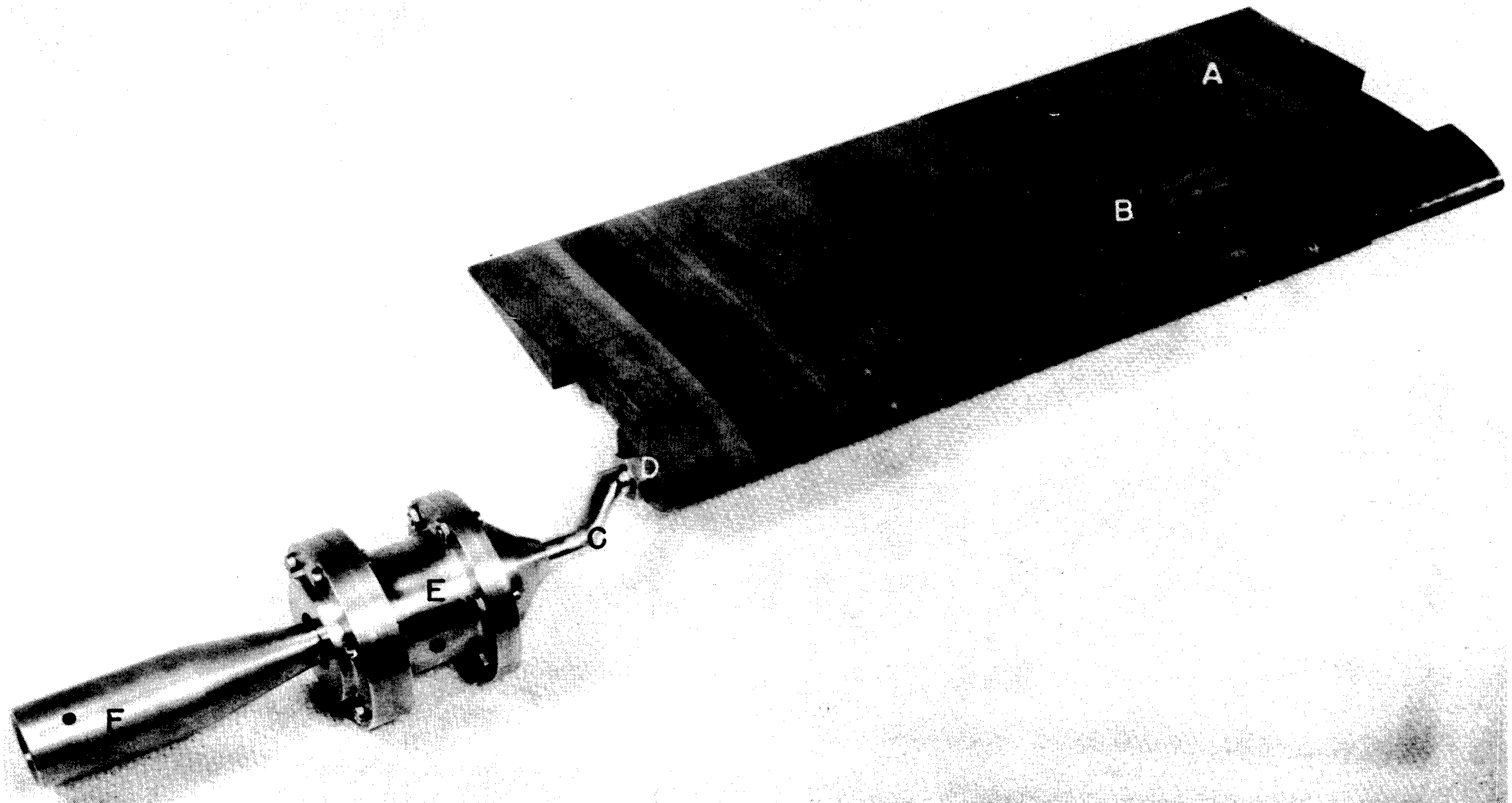

FIG. I

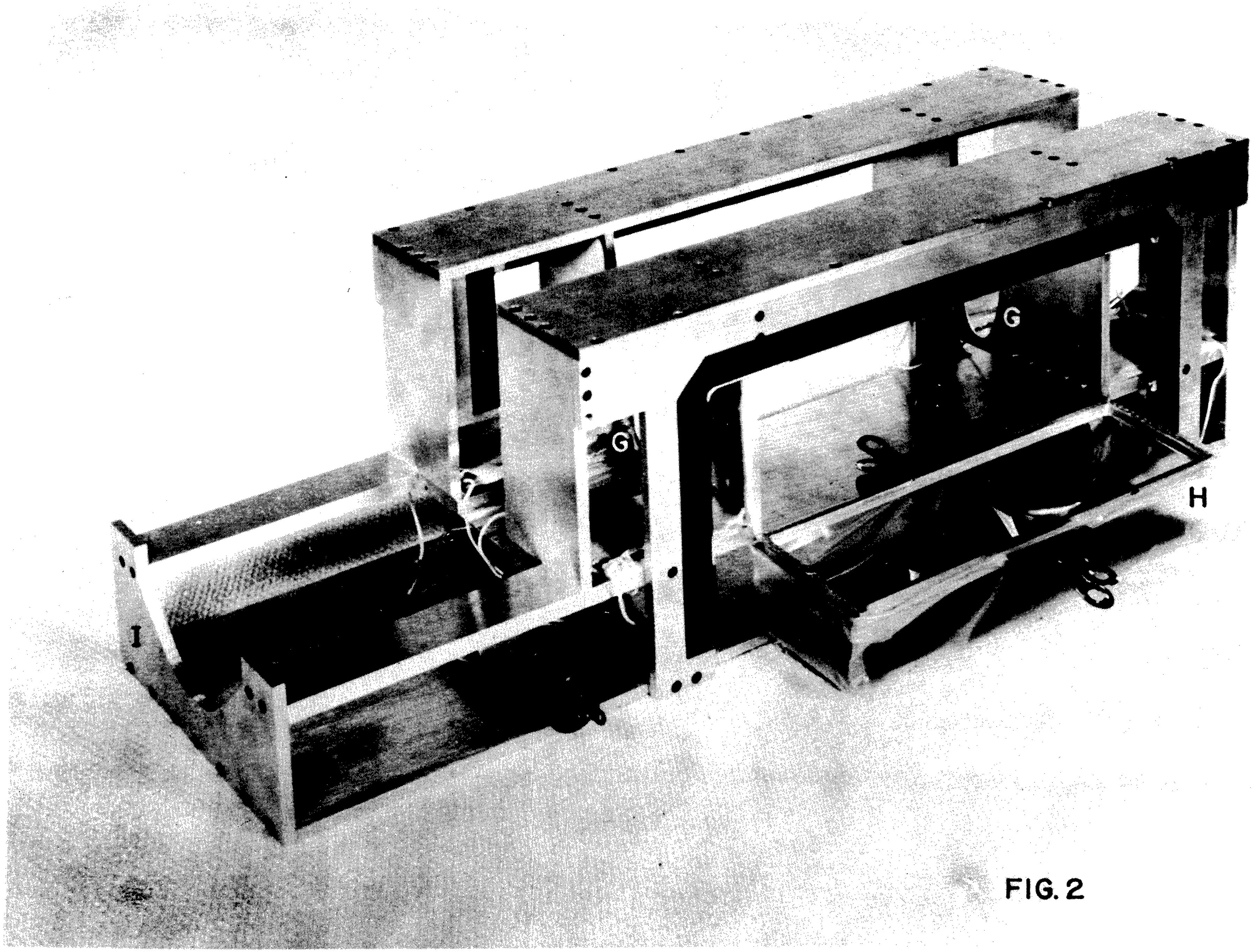

FIG. 2

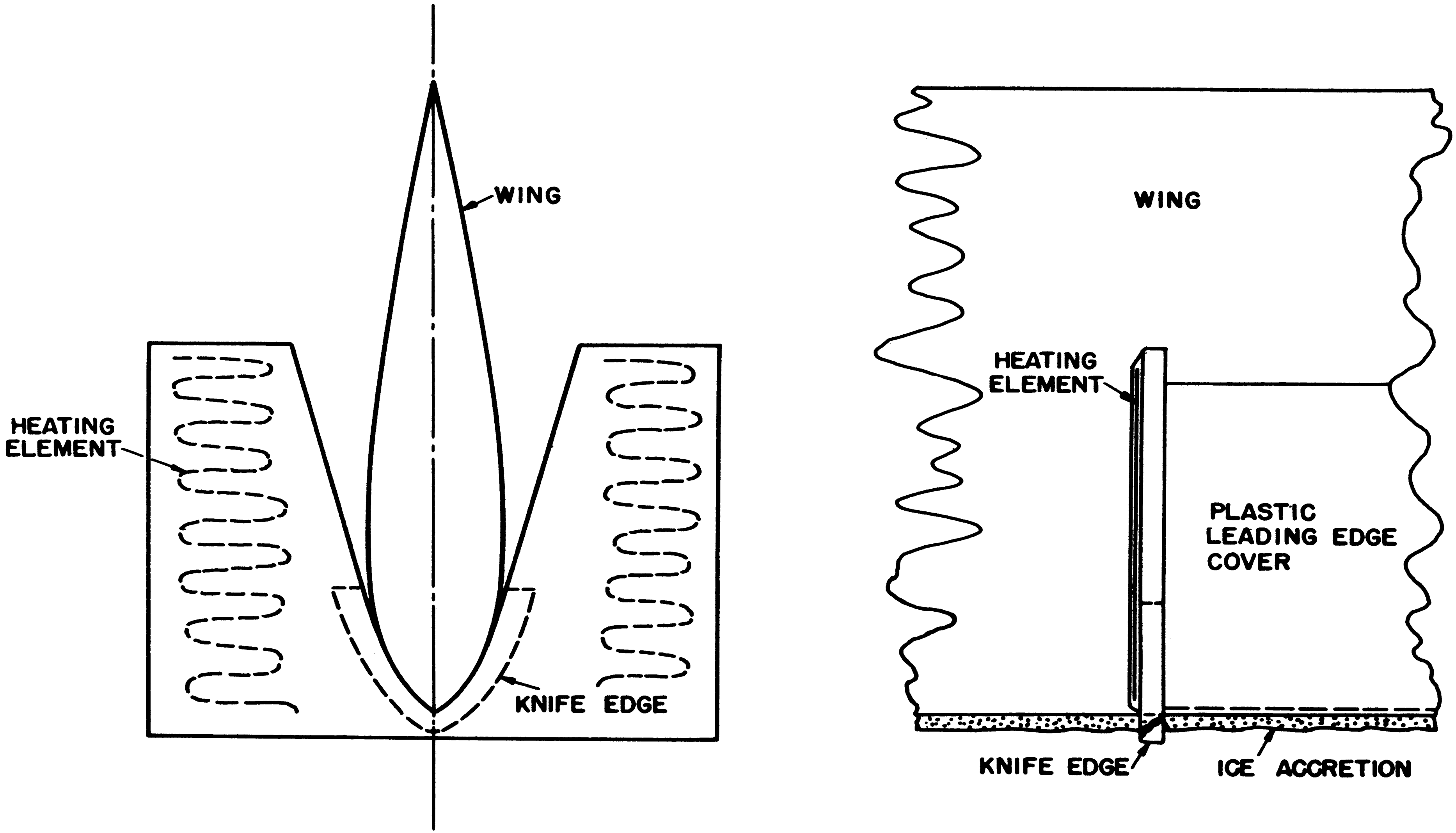

FIG. 3 DETAILS OF KNIFE EDGE

The stand (I) is to support the ball-bearing housing (E) and serves the dual purpose of locating the position of the wing so that the test section and the knife-edges match, and of taking the weight of the rather substantial housing off the support points of the wing.

Figures 4 and 5 show the knife-edge box with wing inserted.

Description of Test Procedure

Test runs were made whenever it was possible to obtain reliable data on drop-size and liquid water content from a multiple cylinder exposure.

The test procedure was roughly as follows. The wing assembly was prepared by attaching the plastic sheet and cooling the wing to approximately outside-air temperature. The plastic sheet, cut 7 by 10 inches, was wrapped around the leading edge and attached to the wing by four pieces of tape, which proves sufficient for the relatively low wind velocities encountered. By stretching the sheet slightly before applying the tape a smooth surface is obtained and no "billowing" occurred at the low-pressure points. The entire wing assembly was brought to outside-air temperature by storage in the tower of the observatory building.

The wing and the multiple cylinder were then exposed simultaneously on the parapet of the tower. After the exposure, the duration of which was noted, the model was brought down and placed on the knife-edge box, which was preheated to facilitate the cutting of the ice. As soon as the knife-edges made contact with the wing either the tape was removed or the plastic cut, and the sheet with the ice was dropped into the plastic bag. After the bag was removed from its metal frame the plastic was weighed with the ice. The plastic was then dried and weighed again and the difference of these two weighings gave the ice accretion, per 10 inches of span, per t seconds of exposure.

The duration of exposure varied depending on the icing conditions. It was found that a 5- to 10-minute exposure was sufficient to collect a measurable amount of ice while the contour was not changed appreciably. The amount of ice measured varied from 2 to 20 grams.

The tests were conducted by Messrs. Sloat, Miller, Middleton, and Hastings of the Mt. Washington Observatory.

Sample Calculation

The symbols used in the reduction of the data are the following:

A = frontal area of wing center section, ft^2 (span x maximum thickness = 0.0833 ft^2 for these tests)

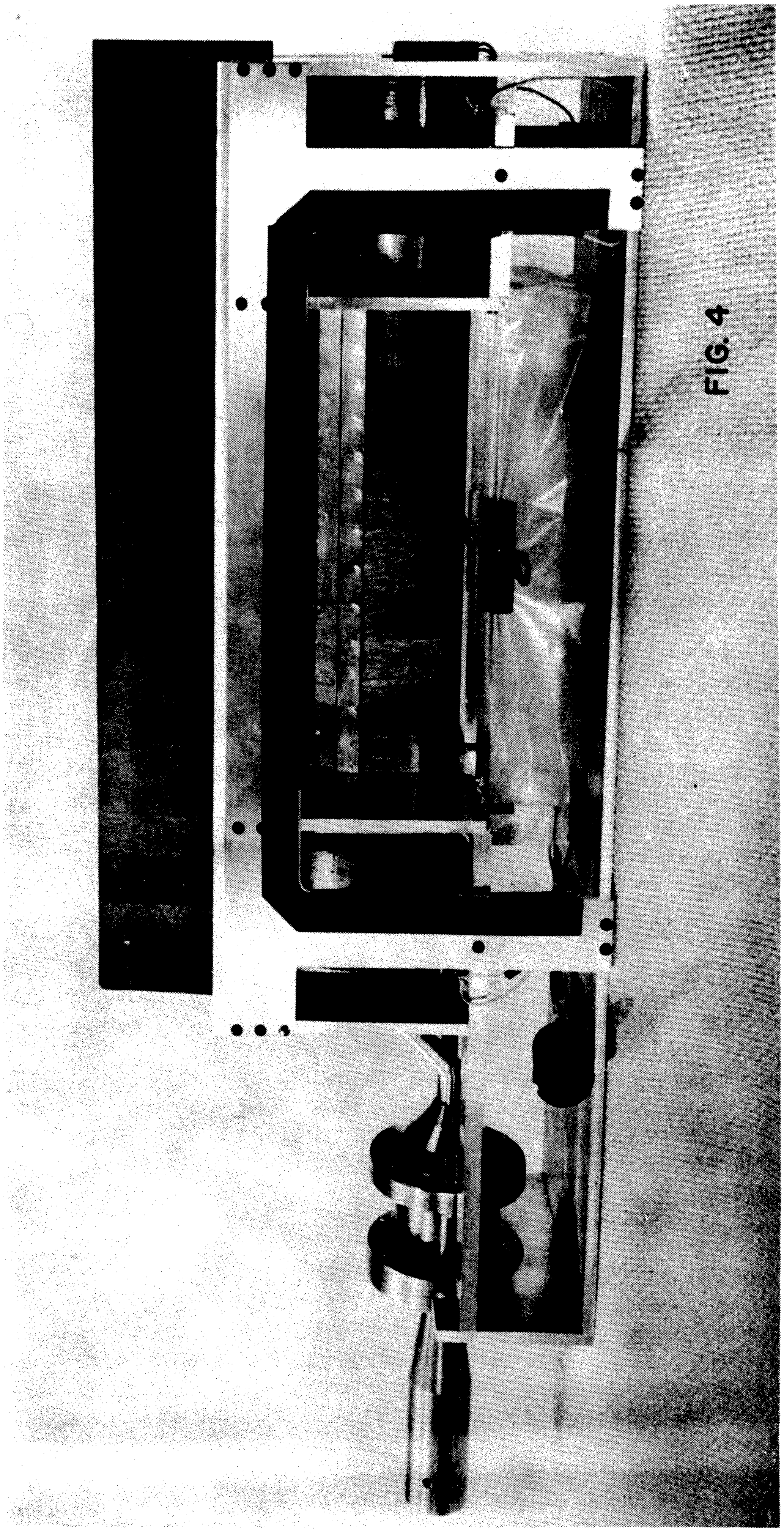

FIG. 4

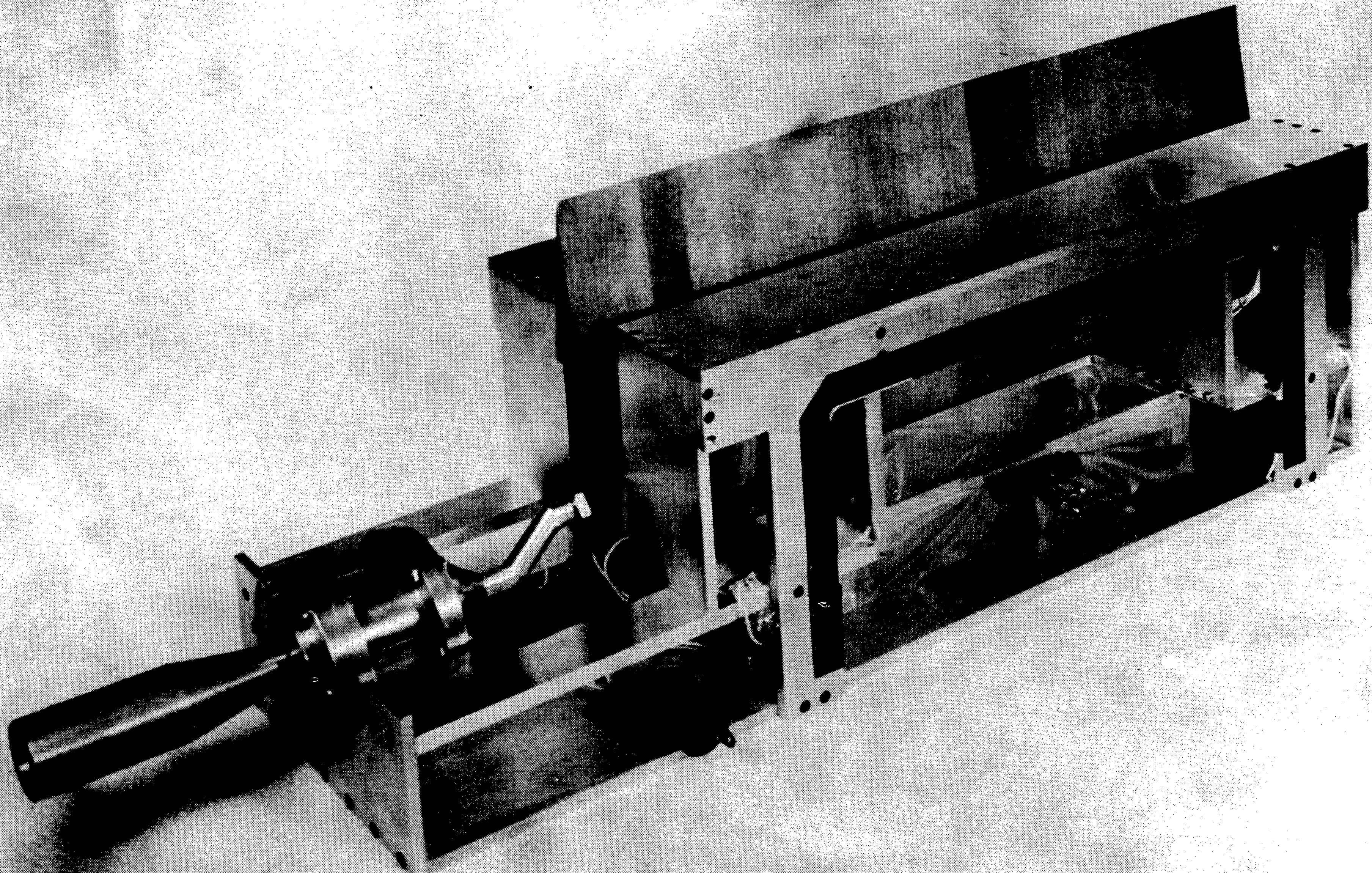

FIG. 5

C = chord length, ft (0.667 ft for these tests)

LWC = liquid water content, lbs/ft^3

ν = kinematic viscosity, ft^2/sec (constant for these tests = 1.81×10^{-4} ft^2/sec at altitude of 6000 feet)

r = drop radius, ft

ρ_a = density of air, lbs/ft^3 (constant for these tests = 0.064 lbs/ft^3 at altitude of 6000 feet)

ρ_w = density of water, 62.4 lbs/ft^3

t = time of exposure, seconds

U = wind velocity, ft/sec

W = weight of ice accretion, lbs

The sample calculation made below was for run number 40, during which the following data were taken:

Date: 4-28-53	Time: 10:00 A. M.
Wind direction: W	LWC: 0.86 g/m^3
Free air temp.: 21.7°F	Drop dia: 14.2 microns
Wind velocity: 49 mph	Drop dist: A

Duration of exposure: 4 minutes
Weight of bag + nose cover + ice: ....19.56 grams
Weight of bag + nose cover dry:.......12.40 grams
Net weight of ice accretion:.......... 7.16 grams

(a) Compute:

$$R_u = \frac{2rU}{\nu} = 0.0266 \left[2r \text{ microns}\right] \times \left[U \text{ mph}\right]$$

$$\psi = \frac{9C\rho_a}{r\rho_w} = \frac{3760}{\left[2r \text{ microns}\right]}$$

$$E_M = \frac{W}{tUA(LWC)} = 4.8 \frac{\left[W \text{ grams}\right]}{\left[t \text{ min}\right] \left[U \text{ mph}\right] \left[LWC \text{ g/m}^3\right]}$$

$$R_u = (0.0266)(14.2)(49) = 18.5$$

$$\psi = \frac{3760}{14.2} = 265$$

$$E_M = 4.8 \frac{(7.16)}{(4)(49)(0.86)} = 0.204$$

(b) From these results compute:

$$K = \frac{R_u}{\Psi}$$

$$K = \frac{18.5}{265} = 0.0698$$

(c) Find $\frac{\lambda}{\lambda_s}$ from a curve of $\frac{\lambda}{\lambda_s}$ vs R_u obtained from a table on page 5 of Reference 2.

$$\frac{\lambda}{\lambda_s} = 0.603$$

(d) Find

$$K_o = \frac{\lambda}{\lambda_s} K$$

$$K_o = (0.603)(0.0698) = 0.0421$$

(e) Plot $E_M = 0.204$ vs $K_o = 0.0421$ as shown in Figure 6.

During the icing season 40 test runs were made by the Mt. Washington Observatory staff. During each run the icing condition was evaluated from the exposure of a multiple cylinder. The catch efficiency E_M was then computed and compared with values obtained with a differential analyser by Guibert, Jansen, and Robbins (Reference 3). The data are, however, presented on a K_o vs E_M plot as suggested by Sherman, Klein, and Tribus in Reference 1. The advantage of this method is that the catch efficiency becomes independent of the Reynolds number. Figure 6 shows the experimental points as well as the E_M vs K_o curve taken from Reference 1, representing the differential analyser results of Reference 3. This curve was extended to a value of $K_o = 0.01$ and it was found that the divergence of the curves for $E_M < 0.20$ at various Reynolds numbers is not as great as indicated in Reference 1.

Conclusion

Although the results show a considerable amount of scatter and a limitation in range, it is likely that these are due, respectively, to the rather uncertain character and the narrow range of the icing conditions. This can be remedied by testing in a wind tunnel in which the different parameters can be controlled carefully.

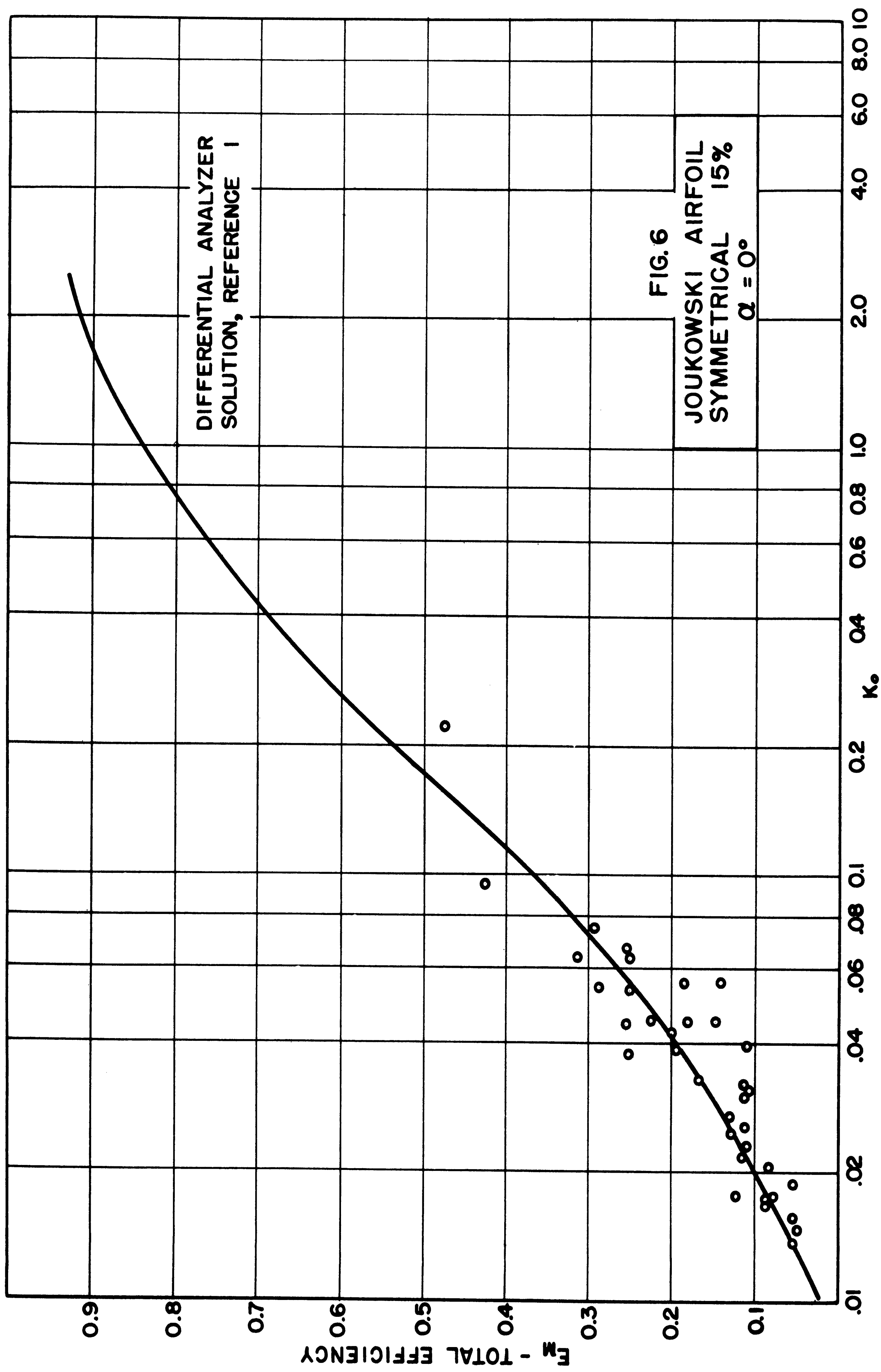
FIG. 6
JOUKOWSKI AIRFOIL
SYMMETRICAL 15%
$\alpha = 0°$

The experimental results and the operating experience with the apparatus indicate that the method described in this report is satisfactory for determining catch efficiencies experimentally.

REFERENCES

1. P. Sherman, J. S. Klein, M. Tribus, "Determination of Drop Trajectories by Means of an Extension of Stokes' Law", University of Michigan, ERI Report, Contract No. AF 18(600)-51, April, 1952.

2. I. Langmuir and K. B. Blodgett, "A Mathematical Investigation of Water Droplet Trajectories", General Electric Company Report, 1945 (also AAF. Tech. Report 5418).

3. A. G. Guibert, E. Jansen, and W. M. Robbins, "Determination of the Rate, the Area, and the Distribution of Impingement of Waterdrops on Various Airfoils from Trajectories Obtained on the Differential Analyser", University of California, Department of Engineering, September, 1948.