A STUDY OF METHODS USED IN

MEASUREMENT AND ANALYSIS OF SEDIMENT LOADS IN STREAMS

SUBCOMMITTEE ON SEDIMENTATION
FEDERAL INTER-AGENCY RIVER BASIN COMMITTEE

REPORT NO. 6

THE DESIGN OF IMPROVED TYPES OF SUSPENDED SEDIMENT SAMPLERS

MAY 1952

REPRINTED APRIL 1968

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Planned and conducted jointly by
an Interdepartmental Committee
representing the following agencies

Office of Indian Affairs, Bureau of Reclamation

Tennessee Valley Authority, Corps of Engineers

Geological Survey, Department of Agriculture

and Iowa Institute of Hydraulic Research

The functions of this committee
were transferred to
the Subcommittee on Sedimentation
Federal Inter-Agency River Basin Committee
in June 1946

Report No. 6

THE DESIGN OF IMPROVED TYPES OF SUSPENDED SEDIMENT SAMPLERS

Published by
Project Offices of Cooperating Agencies
at
St. Anthony Falls Hydraulic Laboratory
Minneapolis, Minnesota

May 1952

The cooperative study of methods used in

MEASUREMENT AND ANALYSIS OF SEDIMENT LOADS IN STREAMS

covers phases indicated by the following report titles.

SYNOPSIS

The investigation of fluvial sediment sampling problems conducted jointly by several Federal agencies since 1939 has pointed out the need for standardization and improvement of sampling methods and equipment and has led to the development of improved types of suspended sediment samplers. This forward step was considered essential in order that data collected in the future by various agencies and under diverse stream conditions might be correlated more readily than is possible with the aggregations of data available at the present time. A thorough study of existing samplers indicated that many of those in current use violate the basic principles of accurate sediment sampling. On the other hand, practical experience has dictated the design of many features in present samplers which facilitate their use in the field. The desirable features were incorporated in the improved models insofar as they were consistent with accurate sampling. The development of experimental models of depth-integrating and point-integrating samplers is presented in this report, together with some of the more important laboratory tests on the completed instruments. Photographs of the experimental samplers and photographs and drawings of final models are included.

Several duplicates of the samplers were constructed and distributed to field offices of the cooperating agencies for testing and for comparison of sampling characteristics with those of other types in current use. The results of field tests conducted prior to December 1944 are presented in the report, "Comparative Field Tests on Suspended Sediment Samplers." Many samplers of the final types have been manufactured and extensively used in routine field work with satisfactory results.

At a meeting in Washington, D. C., on March 28, 1944, the Interdepartmental Committee adopted the name "US Sediment Sampler D-43" for the improved depth-integrating sampler and "US Sediment Sampler P-43" for the improved point-integrating sediment sampler. The number 43 refers to the year in which the samplers were completed. Common usage has shortened these designations to simply US D-43 and US P-43 sediment sampler, respectively. Likewise the third experimental point-integrating sampler has been designated as US P-46 and the second experimental depth-integrating hand sampler US DH-48. When subsequent models were brought out with major improvements, they were designated similarly by numerals to indicate the years in which they were constructed, as for instance the more recently developed depth-integrating sampler, US D-49, and the point-integrating sampler, US P-50.

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THE DESIGN OF IMPROVED TYPES OF SUSPENDED SEDIMENT SAMPLERS

I. INTRODUCTION

1. The need for standardization of sediment sampling equipment-- In the past, samples of fluvial sediments have been collected from many streams, but usually during only short periods of time. In general, each investigator, with the means at his disposal, developed methods and equipment to meet his immediate requirements. Very little information is available concerning the accuracy of the many different types of equipment that have been used in past years. This situation was recognized by several agencies of the Federal Government concerned with sediment problems and an informal cooperative investigation was initiated in order to determine the reliability of the previous records, and to develop equipment and methods of making measurements which would provide more reliable data and permit better correlation of data obtained by various agencies under diverse stream conditions.

The first step was to investigate the apparatus which had already been used for this purpose. The results of this study are given in Report No. 1 of this series, entitled "Field Practice and Equipment Used in Sampling Suspended Sediment." This study disclosed that some 65 samplers, embodying a number of different designs, have been used since the first sediment samples were taken in the Rhone River, France, in 1808. Thirty of these samplers were of the instantaneous type, 20 of the point-integrating type, and 8 of the depth-integrating type, with several designed to obtain both point- and depth-integrated samples. It was anticipated that a study of the various samplers used in past years would indicate a type suitable for general use in all streams. However, this comprehensive survey of sediment sampling equipment revealed certain fundamental objections in all the samplers investigated and emphasized the need for improvement and standardization of such instruments. In considering a new design, it appeared that the point-integrating type of sampler would cover a greater range of the field conditions encountered in the routine determination of mean sediment concentrations of streams than would the simpler depth-integrating type. However, the initial cost of the former was estimated to be considerably greater. Therefore, it was decided that experimental models of both types of samplers should be developed with a view to providing practical and efficient equipment for as wide a range of field conditions as possible. This study did not provide for any further investigation or development of the point-instantaneous type of sampler.

The design of the depth-integrating sampler was predicated on the hypothesis that an integrated sample of the water-sediment mixture existing at the place and time of sampling would be obtained if the filling rate were such that the velocity at the point of intake is equal to the local stream velocity while the sampler is moved at a uniform vertical speed in the stream. The simple depth-integrating sampler is particularly suitable for use in fairly shallow streams. In operation, the sampler should be lowered to the bed of the stream and raised to the surface at a uniform rate such that the container will be nearly but not completely filled at the end of the trip. Since sampling would continue during the entire period of submergence and with a filling rate equal to the stream velocity, the sediment load would be integrated throughout the depth. For streams deeper than about 19 ft., it is necessary to modify the sampler so that filling will take place only on either the descending or ascending trip. For this purpose the sampler can be provided with a valve which is operated electrically or by a foot lever mechanism for closing or opening the intake nozzle and air exhaust at the stream bed. As before, the container should not be completely filled at the end of the sampling trip.

The point-integrating sampler was developed to take a sample at any point in a stream over a period of time. As in the depth-integrating sampler, the filling rate is governed by the stream velocity; the point-integrating sampler differing from the other principally in that it is designed to integrate the sediment load at any selected point during a short period of time instead of in a stream vertical. The principal use of the point-integrating sampler in routine sediment measurements would be in streams too deep to be sampled satisfactorily with a simple depth-integrating sampler. The sediment load can be determined from several point samples in each vertical, or the point sampler can be used for round-trip integration or for integration on either an ascending or descending trip. The point-integrating sampler would be particularly useful also in making investigations of sediment distribution and variations in particle size with respect to other variable stream conditions, and in studying the movement of sediment through deep reservoirs.

2. Requirements of an ideal suspended sediment sampler--A review of the literature as discussed in Report No. 1 of this series, together

with a detailed analysis of existing methods of collecting suspended sediment samples as discussed in Report No. 5, entitled "Laboratory Investigations of Suspended Sediment Samplers," has resulted in establishing a number of requirements for a suspended sediment sampler of the integrating type. These are set forth and discussed in the following subparagraphs:

a. The sampler must fill at a rate proportional to the stream velocity--The laboratory investigation of suspended sediment samplers described in Report No. 5 of this series indicated that, in order to collect a true suspended sediment sample under all conditions, the sampler must fill at such a rate that the velocity in the nozzle at point of intake is equal to the local stream velocity.

Laboratory tests indicated that, if the velocity in the intake is less than the stream velocity, the sediment concentration in the sample will be greater than the true value. Conversely, if the velocity in the intake is greater than the stream velocity, the concentration will be too low. The degree of error in each case increases with the extent of departure from the standard velocity ratio and with the size of sediment particles in suspension. The discrepancy in sediment concentration increases more rapidly with subnormal intake rates than with correspondingly supernormal rates.

b. The intake nozzle should point into the stream and protrude ahead of the sampler--Laboratory and field investigations have indicated that the intake nozzle of the sampler should point into the stream parallel to the flow and project sufficiently far in front of the body of the sampler so that the stream line pattern at the intake is not appreciably changed by the presence of the sampler. Laboratory investigation of the Rock Island sampler, Report No. 5, indicated that a 1-in. extension of the nozzle in front of the sampler gave satisfactory results when in a rigid horizontal position. No tests were made with the nozzle assembly at an angle with the flow.

c. Sampler should be smooth filling--Field tests of existing samplers clearly showed that those which were not fitted with separate intakes and air exhausts tended to fill at irregular rates, as by gulps. For best results the sampler should have an air exhaust separate from the intake nozzle.

d. Initial inrush--When a sediment sampler without a pressure equalizing device is opened below the water surface, there is a sudden inrush of the water-sediment mixture. The quantity entering is a function of the depth of submergence and represents the volume decrease of the air in the sampler required to equalize the pressure inside and outside of the container. Test data shown in Report No. 5 for several different types of samplers indicate that the inrush occurs in less than one second. The volume of initial inrush at various depths in terms of the capacity of the container, as determined from Boyle's law, is shown in Table 1. Occurring at excessively high velocity, the initial inrush will result in a sample of too low concentration, and the total sample is not a true time-integrated one due to excess inflow during the first second. The magnitude of error increases with the particle size in suspension and with the depth to the sampling point.

In the depth-integration method, initial inrush does not occur when collecting sediment samples from the water surface downward. However, if the downward transit rate is excessive in relation to the stream velocity, filling will occur too rapidly for the same reason that initial inrush takes place. Water may even enter the air exhaust as well as the intake nozzle. This condition is further discussed in Sections 7 and 8.

TABLE 1

RELATION OF INITIAL INRUSH TO DEPTH

Depth at which sampler is opened ft.	Initial inrush, per cent of total capacity of container
1	3
5	13
10	23
15	31
20	37
30	47
34	50
40	54
50	60
100	75

e. Desirability of a removable container--Tests made on existing types of samplers show that sediment particles tend to adhere to the sides of the container. To avoid this source of error, the sampler should be fitted with a removable sample container, preferably a fruit jar or milk bottle, which can be readily sealed for shipment to the laboratory, thus eliminating the necessity of transferring the sample to other containers in the field.

f. Sampler should permit sampling close to the stream bed--The concentration of sediment in a normal stream, especially for particle sizes greater than 1/16 mm., increases from the surface to the bed of the stream. Therefore, unless a depth-integrating sampler will function at points relatively close to the stream bed, the sample collected may not be representative of the mean concentration in the vertical. The results of analyses set up in Report No. 3, "Analytical Study of Methods of Sampling Suspended Sediment," indicate that an apparatus which will properly sample 95 to 98 per cent of a stream depth, or within 4 in. of the bed for any depth greater than 10 ft., is quite satisfactory.

g. General features in design--In addition to the requirements outlined in the preceding paragraphs, a suspended sediment sampler should be as streamlined as the space required for installing a removable container will permit, and heavy enough to eliminate excessive downstream drag if used in streams with high velocities. The sampler should be fitted with a rudder and lateral vanes which will hold the intake nozzle parallel to the flow. The rudder should be so shaped that the sampler behaves properly in high velocity flow and does not tilt appreciably when in transit. However, for a sampler suspended on a rod, sufficient stability may be obtained without the use of special weight and rudder. The sampler should be simply and sturdily constructed, especially its moving parts, to minimize the need for repairs in the field. Furthermore, the cost of constructing the samplers should be as low as possible consistent with good design and performance. It was not proposed to develop an entirely original form of sampler, but rather to utilize the tried and proven features of existing samplers which have been originated by the scores of persons who have given thought to this subject in the past.

3. Scope of the general study--The various phases covered in the general project, "A Study of Methods Used in Measurement and Analysis of Sediment Loads in Streams," of which the present study is a part, are indicated by the following titles and resumes of preceding reports in the series.

Report No. 1--"Field Practice and Equipment Used in Sampling Suspended Sediment" is a detailed review of the equipment and methods used in suspended sediment sampling from the earliest investigation to the present, with discussions of the advantages and disadvantages of the various methods and instruments. The requirements of a sampler which would meet all field conditions satisfactorily are set forth.

Report No. 2--"Equipment Used for Sampling Bed-Load and Bed Material" deals with bed-load and bed material in a manner similar to that in which Report No. 1 covers suspended load.

Report No. 3--"Analytical Study of Methods of Sampling Suspended Sediment" covers an investigation of the accuracy of various methods of sampling suspended sediment in a vertical section of a stream based on the latest developments in the application of turbulence theories to sediment transportation.

Report No. 4--"Methods of Analyzing Sediment Samples" describes many methods developed for determining the size of small particles in sediment analyses. Detailed instructions are given for many of the common methods in use for determining the particle size and the total concentration of sediment in samples as developed by agencies doing extensive work in these fields.

Report No. 5--"Laboratory Investigations of Suspended Sediment Samplers" describes investigations of the effects of various intake conditions on the accuracy of sediment samples and the filling characteristics of slow filling samplers under various conditions.

Report No. 7--"A Study of New Methods for Size Analysis of Suspended Sediment Samples" gives an account of a study to develop methods of size analysis more suitable for the conditions usually met in suspended sediment studies. It describes a simple form of apparatus developed and gives detailed procedures for its use.

Report No. 8--"Measurement of the Sediment Discharge of Streams" describes the most efficient methods and equipment to be used in making sediment measurements under the various conditions encountered in natural streams.

Report No. 9--"Density of Sediments Deposited in Reservoirs" presents data on the apparent density of sediment deposited in various existing reservoirs. The results are summarized and certain conclusions of value in engineering studies are given.

4. Authority and personnel--The cooperative project for investigation of sediment sampling problems, of which this report is a part, was planned and conducted jointly by an Interdepartmental Committee composed of representatives of the following agencies of the United States Government: Corps of Engineers, Geological Survey, Bureau of

Reclamation, Office of Indian Affairs, Flood Control Coordinating Committee of the Department of Agriculture, and the Tennessee Valley Authority. Prior to 1948, the investigation was conducted at the Hydraulic Laboratory of the Iowa Institute of Hydraulic Research, State University of Iowa, Iowa City, Iowa, under the direction of Professor E. W. Lane. The following representatives of the cooperating agencies participated in various phases of the general project: Paul C. Benedict; Clarence A. Boyll; Byrnon C. Colby; Russell P. Christensen; Morgan D. Dubrow; Cleveland R. Horne, Jr.; Victor A. Koelzer; Philip M. Noble; Vernon J. Palmer; Frank W. Parker; Donald E. Rhinehart; and John W. Stanley.

The original research work connected with the development of sediment samplers was conducted by Morgan D. Dubrow, Corps of Engineers, and John W. Stanley, U. S. Bureau of Reclamation. Later, Paul C. Benedict, U. S. Geological Survey, completed the design, supervised the construction of the initial experimental sampler models, and conducted laboratory and field tests. Since August 1946, further improvement in the experimental samplers, development of new models, and laboratory and field research to determine the characteristics and limitations of the samplers, have been carried on by Byrnon C. Colby and Russell P. Christensen under the general supervision of Paul C. Benedict and Martin E. Nelson.

At a meeting of the Interdepartmental Committee in April 1946, it was agreed to dissolve the Committee and to transfer its activities and functions to the recently established Federal Inter-Agency River Basin Subcommittee on Sedimentation. The Inter-Agency Committee is composed of representatives of the Department of the Army, Department of the Interior, Department of Agriculture, Department of Commerce, Tennessee Valley Authority, and Federal Power Commission, and has as one of its objectives the coordination of the hydrologic activities of these Federal departments through the assistance of its several subcommittees. The Subcommittee on Sedimentation formally took over the activities and the unfinished program of the Interdepartmental Committee in June 1946.

In June 1948 the project was transferred from the Iowa Institute of Hydraulic Research to the St. Anthony Falls Hydraulic Laboratory of the University of Minnesota in Minneapolis. Under the direction of Martin E. Nelson, Engineer, personnel of the Corps of Engineers Hydraulic Laboratory Sub-Office, stationed at the Iowa Institute of Hydraulic Research and at the St. Anthony Falls Hydraulic Laboratory, assisted in the administration of the project and in editing and publishing this report.

5. <u>Acknowledgments</u>--In the development of the equipment described in this report, suggestions and constructive criticisms were received from many individuals interested in the project. Martin E. Nelson made a number of valuable suggestions in the design and development of the samplers, and helpful suggestions were also made by Arthur H. Frazier, Chief, Division of Field Equipment, U. S. Geological Survey.

II. DEVELOPMENT OF DEPTH-INTEGRATING SAMPLERS

6. Definition of a depth-integrating sampler--A depth-integrating sampler is designed to accumulate a water-sediment sample from a stream vertical at such a rate that the velocity in the nozzle at point of intake is always as nearly as possible identical with the immediate stream velocity while running the vertical at a uniform speed. The inflowing water-sediment mixture collected will be weighted according to the instaneous stream velocity at the locus of the intake nozzle and, therefore, will be representative of the sediment load in the vertical. A simple depth-integrating sampler fills while it is being lowered from the water surface to the stream bed and while being raised to the surface again. A few of the earlier instruments of this type permitted closing the intake nozzle and air exhaust upon reaching the stream bed so that a sample could be collected on the descending trip only, if desired. In either case the sampling period should be long enough to nearly fill the container, but not so long as to completely fill it lest some of the accumulated sample should escape through the air exhaust.

The point-integrating sampler described in Chapter III may also be used as a simple depth-integrating sampler. In addition, it may be used to collect samples on either descending or ascending trips, as the intake nozzle and air exhaust can be closed or opened at any depth. The use of the point-integrating sampler to collect depth-integrated samples in deep streams is discussed in Section 26.

7. Intake nozzle and filling characteristics--At any instant during the operation of a depth-integrating sampler, the air mass in the

container is a function of the hydrostatic head and the prior rate of filling. For the purpose of deriving simplified relationships between the filling and lowering rates, it will be assumed (1) that the velocity in the nozzle at point of intake is always equal to the immediate stream velocity, (2) that a typical velocity distribution in the vertical prevails, and (3) that the sampler moves in a vertical line while in transit. However, in this theoretical analysis the requirement of a uniform lowering rate will be suspended. As the sampler is lowered into a stream, sufficient liquid must enter the container to compress instantaneously the inside air so that its pressure balances the external hydrostatic head. In order to satisfy the first of the above assumptions, the rate of air volume contraction due to increasing hydrostatic pressure must never exceed the normal volume rate of liquid inflow. Hence the maximum allowable speed of lowering the sampler obtains when these two factors are exactly equalized without air escaping from the container.

If the normal inflow at any instant is less than the air volume reduction necessary to balance a given change in hydrostatic head, the actual inflow will occur at a rate higher than the local stream velocity and, in addition, some inflow may occur through the air exhaust. Samples collected under these conditions will no longer be weighted according to the vertical velocity curve. On the other hand, if the normal inflow exceeds the air volume reduction necessary to balance a given change in hydrostatic head, air will escape from the sample container, permitting the actual inflow to occur at a rate equal to the stream velocity, and the sample collected will be weighted according to the vertical velocity curve. The relation of the lowering and filling rates and their effects upon the volume of air in the container may be analyzed if it is assumed that no air escapes from the container and that the air in the container will be compressed by the changing hydrostatic head so that the reduction in air volume is just balanced by the inflowing water. From Boyle's law it follows that,

$$hV = h_1V_1 \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ (1)$$

the temperature remaining constant.

The symbols used in this report have the following definitions:

A_n - area of intake nozzle at entrance, sq. ft.

D - vertical depth to any point in the stream, ft., = D_a at point "a," = D_b at point "b."

D_s - depth of stream or sampling depth, ft.

d - ratio of depth at any point to the total depth, = D/D_s.

h - absolute pressure head at any depth, = $h_1 + D$, ft.

h_1 - absolute pressure head at water surface, = 34 ft. of water at sea level.

r - ratio of the velocity at any point in the vertical to the mean stream velocity, = v/v_m.

r_o - ratio of the average velocity from the water surface down to point "a" to the mean stream velocity, = v_o/v_m.

R_L - lowering rate, ft./sec.

t - time from start of sampling, sec.

V - volume of air in container at any depth, cu. ft., = V_1 at water surface, = V_a at point "a," = V_b at point "b."

V_1 - volume of container, cu. ft. (1 pt. = 0.01671 cu. ft.)

V_w - volume of water in the container at any depth, cu. ft.

v - stream velocity at any point in the vertical, ft./sec.

v_m - mean stream velocity in sampling vertical, ft./sec.

v_o - average stream velocity between the water surface and point "a" ft./sec., $= r_o v_m$.

The rate of change in the air volume in the container at any depth is obtained by rewriting equation (1) and differentiating with respect to time.

$$V = \frac{h_1 V_1}{h} = \frac{h_1 V_1}{(h_1 + D)}$$

$$\frac{dV}{dt} = -\frac{h_1 V_1}{(h_1 + D)^2} \frac{dD}{dt} \quad \ldots\ldots\ldots\ldots \quad (2)$$

The rate of change in air volume at any depth may also be expressed in terms of the area of the intake nozzle and rate of inflow.

$$\frac{dV}{dt} = -A_n v \quad \ldots\ldots\ldots\ldots\ldots \quad (3)$$

The lowering rate, R_L, at any instant is obtained by equating (2) and (3) and solving for dD/dt .

$$-\frac{h_1 V_1}{(h_1 + D)^2} \frac{dD}{dt} = -A_n v$$

$$\frac{dD}{dt} = \frac{A_n v (h_1 + D)^2}{h_1 V_1} = R_L \quad \ldots\ldots\ldots \quad (4)$$

It will be noted that the lowering rate indicated by equation (4) varies with the depth and velocity. Rearranging and substituting for v and D,

$$\frac{R_L}{v_m} = \frac{A_n r (h_1 + D_s d)^2}{h_1 V_1} \quad \ldots\ldots\ldots\ldots \quad (5)$$

As indicated by equation (5) the maximum permissible lowering rates vary inversely with the volume of the sample container.

Values of R_L/v_m from equation (5) for a sampler having 3/16-in. diameter intake nozzle and a one-pint sample container for representative depths and velocities are shown in Fig. 1.

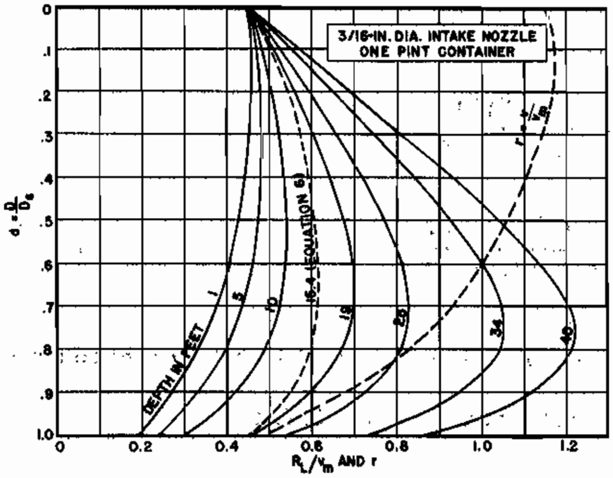

Fig. 1--Values of R_L/v_m for depth-integrating sampler based on equation (5) for a typical vertical velocity curve for any depth

8. Maximum lowering rate--The derivation of equation (5) in Section 7 and the data shown in Fig. 1 are based on certain assumptions that simplified the analysis of the sampling process but which introduced some deviations from conditions that actually occur in a field operation. In depth integration, it is necessary that a uniform transit rate be used and that the velocity in the nozzle at point of intake is always equal to the immediate stream velocity. Under these conditions, air must necessarily escape from the sample container. As soon as some air is expelled from the container, the factor "V," the volume of air in the container, in equation (5), becomes smaller, and it is apparent that somewhat faster lowering rates would be permissible for the bottom portions of the deeper depths than those indicated under the restrictive assumptions used in this analysis. A more accurate expression for the lowering rates applicable to field sampling operations may be derived as follows:

Assume a uniform lowering rate and consider two points "a" and "b" in the vertical path of the sampler nozzle sufficiently near to each other so that air loss through the exhaust is negligible while the sampler moves from point "a" to point "b."

The air volume at point "a" is

$$V_a = V_1 - V_w = V_1 - A_n v_o \left[\frac{D_a}{R_L}\right]$$

In moving downward from "a" to "b," the hydrostatic pressure differential causes a reduction in air volume in obedience to Boyle's law.

$$V_b = V_a \left[\frac{h_1 + D_a}{h_1 + D_b}\right]$$

The change in air volume is

$$-\Delta V = (V_a - V_b) = V_a \left[\frac{D_b - D_a}{h_1 + D_b}\right]$$

and the rate of change of air volume becomes

$$-\frac{\Delta V}{\Delta t} = V_a \left[\frac{D_b - D_a}{h_1 + D_b}\right] \left[\frac{R_L}{D_b - D_a}\right] = \frac{V_a R_L}{h_1 + D_b}$$

Introducing the expression for V_a derived above and allowing Δt to approach zero and "a" to approach "b," so that, in the limit, $D_a = D_b = D$,

$$-\frac{\Delta V}{\Delta t} = -\frac{dV}{dt} = \frac{V_1 R_L - A_n v_o D}{h_1 + D}$$

But the maximum allowable speed of lowering the sampler obtains when the rate of air volume contraction due to increasing hydrostatic pressure exactly equals the normal volume rate of liquid inflow given by equation (3).

$$-A_n v = -\frac{V_1 R_{L_{Max}} - A_n v_o D}{h_1 + D}$$

Converting to relative depth and velocity, and solving for the maximum relative transit rate

$$\left[\frac{R_L}{v_m}\right]_{Max} = \frac{A_n}{V_1}\left[r(h_1 + D_s d) + r_o D_s d\right] \quad \ldots\ldots\ldots\ldots (6)$$

Equation (6) may be solved for any stream depth and velocity distribution. As the lowering rate must be uniform for any one integration, the maximum allowable lowering rate for any stream depth is the smallest value of R_L/v_m obtainable from equation (6) for that depth. For depths over 15.4 ft. the maximum permissible uniform lowering rate is that shown for the surface of the stream where both equations (5) and (6) reduce to

$$\left[\frac{R_L}{v_m}\right]_{Max} = \frac{A_n r h_1}{V_1}$$

For depths less than 15.4 ft. the maximum rate varies with the depth and stream velocity. Values of R_L/v_m, the maximum permissible uniform lowering rate with respect to the mean stream velocity, to be used with intake nozzles of 1/8-, 3/16- and 1/4-in. diameter in streams of various depths as determined from equation (6), are shown in Fig. 2. If the uniform lowering rate selected for given sampling conditions does not exceed the maximum indicated by Fig. 2, air will escape from the container while the sampler is in transit. As the sampler descends, the pressure in the container will vary directly with the hydrostatic pressure surrounding the sampler. The velocity in the nozzle at point of

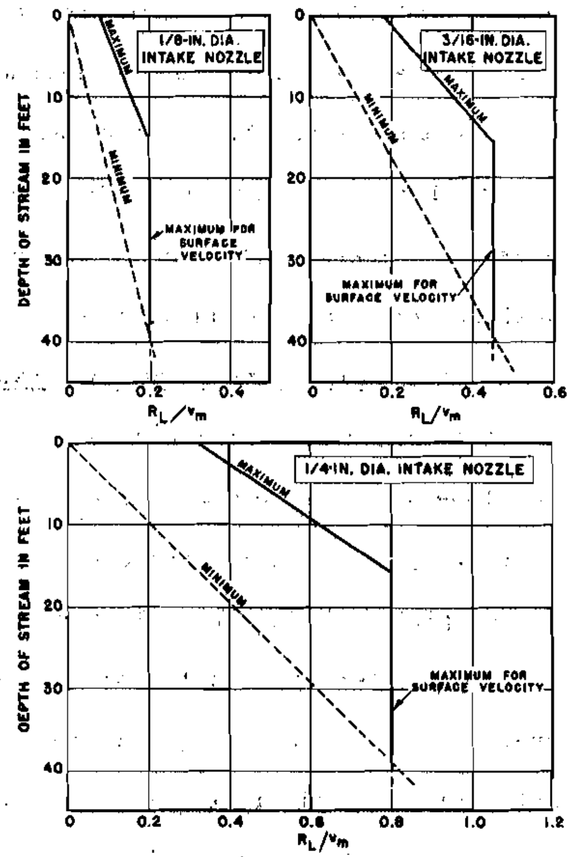

Fig. 2--Maximum and minimum values of R_L/v_m for one-way depth integration with sample container of one-pint capacity

intake will be equal to the local stream velocity, and air will be expelled from the container at a rate dependent on the inflow and the change in hydrostatic head.

The shape of the curves of Fig. 1 would vary with any change in the distribution of velocities within the vertical. If the velocity were uniform throughout the depth of the stream, v would equal v_m, and evaluating R_L/v_m for 1/8-in., 3/16-in., and 1/4-in. diameter nozzles at the water surface would give values of 0.17, 0.39, and 0.69 respectively. For a sampler used for depth integration from the water surface downward, these would be the theoretical limiting lowering rates regardless of the depth of stream.

9. Minimum transit rate--The minimum lowering rate which will allow the sample container to become full just at the instant the sampler reaches the bottom is given by the equation

$$R_L = \frac{A_n v_m D_s}{V_1} \quad \ldots\ldots\ldots\ldots\ldots \quad (7)$$

The minimum values of the relative lowering rate, R_L/v_m, given by this equation for samplers of one-pint capacity with intake nozzles of 1/8-, 3/16-, and 1/4-in. diameter are shown in Fig. 2. In computing these values it was assumed that the stream would be sampled downward throughout the entire depth, and that air would escape from the container in proportion to the liquid inflow and the change in hydrostatic head. However, equation (7) applies to minimum transit rates for upward as well as for downward integration.

10. Other limitations on transit rates--There are certain other factors involved in sediment sampling which may tend to place a limit on the lowering rate somewhat less than the computed maximum values shown in Fig. 2, such as, (1) the equipment available for lowering and raising the sampler, and (2) the velocity of the stream relative to the velocity of the sampler when in transit. The first factor is a very practical one, as ordinary stream gaging reels of 1- and 2-ft. circumferences will not permit transit rates greater than about 2 and 3.5 ft. per sec., respectively. The second factor varies with the transit rate of the sampler and the stream velocity. Assuming that the axis of the intake nozzle remains parallel to the water surface and the sampler moves along a vertical line while in transit, the vector which represents the water velocity relative to the sampler crosses the nozzle at an angle. The resulting flow, therefore, approaches the intake nozzle at an angle and the conditions, insofar as the intake nozzle is concerned, are the same as though the nozzle were held in a fixed position but at a corresponding angle to the lines of flow. The magnitude of error due to the motion of the sampler is a function of (1) the velocity of the water, (2) the transit rate of the sampler, and (3) the particle size of the sediment in suspension.

The effect of orienting the standard test nozzle with respect to the direction of flow, when in a fixed horizontal position, is described in Report No. 5. The test data are presented in Fig. 15 of that report in terms of the errors in sediment concentration and the relative sampling rate which is the ratio of the intake nozzle velocity to the local stream velocity.

The results, while informative, do not permit an evaluation of the effects of orienting the nozzle with respect to the direction of flow under field sampling conditions. Such information could only have been obtained by setting up the desired relative sampling rates with the nozzle parallel to the flow lines and then rotating the nozzle to various angular positions with no further adjustment in the flow conditions. For comparative purposes the data in Fig. 15, Report No. 5, have been replotted basing the intake ratio on the velocity vector parallel to the nozzle, which under field sampling conditions is equivalent to the stream velocity. The data as replotted are shown in Fig. 3.

A study of the curves of Fig. 3 indicates that the angle (α) at which the flow approaches the intake nozzle has little effect on the accuracy of sediment samples collected as long as the velocity in the intake is equal to the stream velocity vector ($v \cos \alpha$) which is parallel to the axis of the intake nozzle, and as long as the angle (α) does not exceed 30°. The data for an angle of 10° are not plotted but would determine a curve very close to that for 0°.

The laboratory tests described in Report No. 5 to determine the effect of orientation of the nozzle with respect to the direction of the flow were limited to a "standard" intake nozzle and, therefore, the

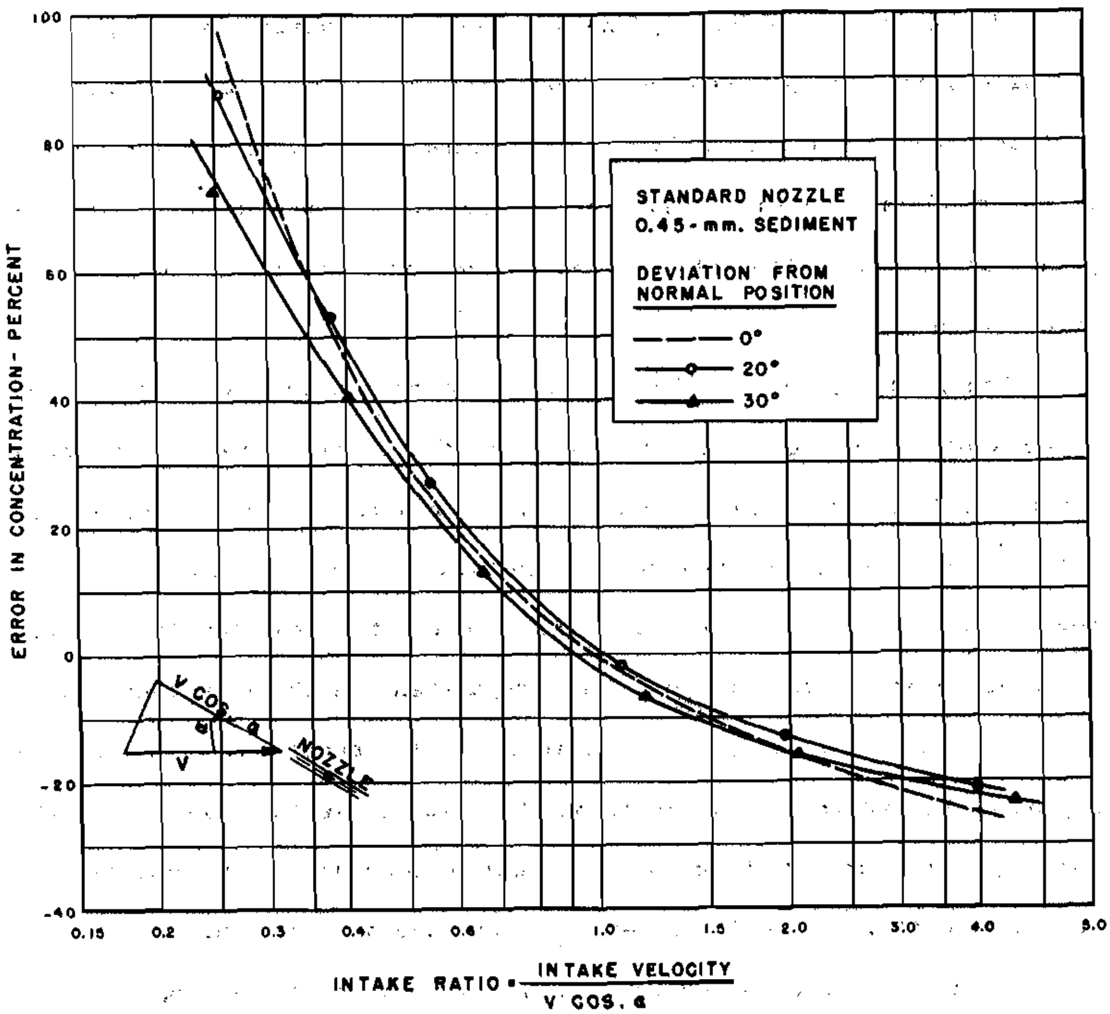

Fig. 3--Effect of small deviations from normal nozzle orientation on errors in sediment concentration

results are not entirely applicable to the conditions obtaining when the intake nozzle is a part of the sampler. The distortion of the flow pattern around the sampler with a 1-in. nozzle extension is believed to be negligible when the angle of the relative velocity is zero. However, as the angle of relative velocity increases, the zone of distortion will eventually introduce some error. This error will also vary with the direction of the movement of the sampler owing to the location of the air exhaust and the nonsymmetrical shape of the sampler.

Studies of the several factors limiting the maximum transit rates for average sampling conditions indicate that a 1/8-in., and generally a 3/16-in., intake nozzle could be used for transit rates as shown in Fig. 2 without introducing appreciable errors in the sediment content of the sample collected. For 1/4-in. intake nozzles it will be necessary to reduce the maximum lowering rate for best results. The maximum satisfactory raising rates for the 3/16- and 1/4-in. nozzles are somewhat less than the lowering rates for similar conditions. It should be remembered, however, that the maximum transit rates will be used only when sampling in streams with great depths and high velocities. When sampling in average streams the factors tending to limit the transit rates will be of minor importance.

When samples are collected by lowering the sampler to the stream bed and raising it to the surface, much the same limitations in transit rate apply as previously discussed. The minimum transit rates for a given depth must be twice those shown in Fig. 2, in order to complete the round-trip integration before the sample container is completely filled. The maximum depth of sampling on this basis is half of that for downward integration in one direction only.

11. Maximum sampling depth--Since the maximum permissible uniform lowering rate for depths over 19 ft. is that shown for the surface of the stream, the maximum sampling depth is obtained by substituting the maximum value for R_L/v_m from Fig. 1 in equation (7) or D_s = 39 ft. That is, by closing the intake and air exhaust upon making contact with the stream bed, a stream 39 ft. in depth could be sampled if the

velocity distribution is comparable to that shown in Fig. 1 for a typical vertical velocity curve. When the velocity distribution is uniform in the vertical section, r is equal to unity at any point, and the maximum sampling depth, D_s , will be 34 ft. The maximum depth that can be sampled by lowering and raising the sampler at a uniform transit rate would be one-half of the above values for the respective conditions. These limiting depths will obtain regardless of nozzle size and sample bottle capacity.

12. Shape and weight of sampler--In the course of the investigation it was recognized that the collection of sediment samples and the measurement of the flow of streams are very closely interrelated. On occasion it might be desirable to use the sampler as a sounding weight or to collect samples by removing the meter from the hanger bar. Therefore, full advantage was taken of the field work and experience gained by the U. S. Geological Survey in the design of a satisfactory sounding weight for use with the small Price current meter. The present C-type sounding weight, (1)* varying in size from 15 to 500 pounds, is the result of a progressive change in design over a period of many years. Sounding weights of the C-type have been used for the past 15 years and are considered a major improvement over earlier models.

Several important requirements for a satisfactory sounding weight approximate those for a sediment sampler, but in addition ths sampler must be shaped to accommodate a container. Also, the streamlining must be such that there will be a minimum disturbance to the flow pattern,

* Numbers refer to references in the bibliography.

particularly in the vicinity of the intake nozzle, if the best intake characteristics are to be obtained.

In the design of the experimental samplers it became evident that it would be impractical to design a single sampler that could be satisfactorily used for very large rivers as well as for very small streams. As with sounding weights, it was anticipated that possibly several weight sizes would be needed in order to simplify field operations and meet practical requirements. Likewise, it was evident that for certain types of streams, where sediment measurements can be made by wading, a hand sampler could be used to advantage. However, since the proposed equipment was to be of an experimental nature it appeared desirable to limit the design to samplers of moderate size and weight in order that they might be tested over the widest range of field conditions as the first step in the orderly development and standardization. In the event the sampler proved practical, heavier samplers could then be made with the improvements resulting from the field tests and the base design modified to suit the requirements of a hand-operated sampler.

13. Type of suspension--In an effort to standardize the type of connection necessary to attach the sampler conveniently to a sounding line, it was decided to adopt the hanger bar which has been developed and widely used by the Geological Survey with the C-type sounding weight. With this type of connection, concurrent stream gaging and sediment sampling will be facilitated in the field. It is also believed that a current meter can be conveniently rated with the sampler as a sounding weight if such an arrangement is considered necessary. Thus, the equipment and suspension could be standardized for flexibility and

general utility for a variety of field conditions. However, in this connection it should be emphasized that the satisfactory collection of samples with the current meter suspended above the sampler will depend upon the degree of error introduced, if any, by the effect of the current meter upon the flow pattern around the intake nozzle and the air exhaust.

Experience in making current-meter measurements has led to the use and development of reels and cranes to simplify operations and improve the accuracy of the field work. Similar equipment can be used to a decided advantage in a sediment sampling program.

14. Type of tail vanes--In the most recent designs of sampler tail vanes, a modified form of the type in use on the standard C-type current meter sounding weight was adopted. Extensive laboratory tests in a glass flume indicated that these vanes are quite effective and, when properly designed, eliminate practically all tendency for the sampler to yaw. The area of the horizontal vane was reduced to a minimum in order to keep the intake nozzle essentially horizontal while in transit. If the area of the vane were large enough to cause the sampler to tilt up or down appreciably, the inclination varying with the transit rate, variable intake velocities in the nozzle would result. Furthermore, if the sampler tips appreciably when descending, the intake nozzle may nose into the stream bed, and an erroneous sample would be obtained. This condition could readily occur if the stream bed were composed of dunes of sand or other fine material. Due to its irregular shape, the sampler as constructed will tilt up and down, but only a few degrees when operated at ordinary transit rates.

15. Type of containers--In selecting a container for the sampler, a number of factors had to be considered. The container should be of a standard type which can be procured readily. It should be made of transparent material and be easily sealed for transfer to the laboratory. It is also desirable that the shape of the container be such that it will have a maximum inside volume and still be compact so as to reduce the over-all size of the sampler. Furthermore, it should be constructed so as to reduce the laboratory work to a minimum.

A standard fruit jar of one-pint capacity was first selected, as the shape is similar to that of a special type of container then under consideration. However, due to lack of materials and facilities, the development of a special container was not feasible and a pint milk bottle was finally adopted. Because of a number of desirable features this container had already been adopted by several organizations engaged in measuring the quantity and character of sediment transported by streams.

The time necessary to fill a one-pint container at various intake velocities with nozzles of 1/8-, 3/16-, and 1/4-in. diameter is shown in Fig. 4.

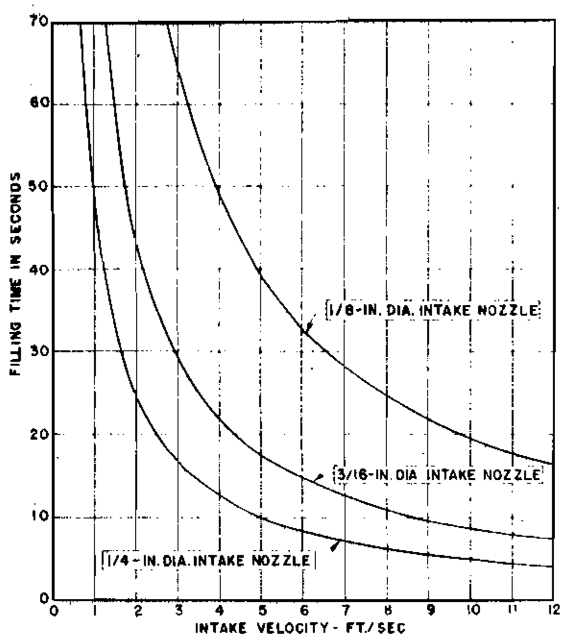

Fig. 4--Relation of filling time to intake velocity for a one-pint container

16. Construction and testing of samplers--The first stage in the development of a depth-

integrating sampler consisted of making drawings and plaster models until a size and shape which appeared satisfactory was obtained. The drawings were then revised and a finished metal sampler was constructed and subjected to a number of laboratory and field tests. The tests disclosed certain weaknesses in the design and construction of the sampler, which led to further revisions. In the following paragraphs, the experimental samplers are discussed in the order in which they were designed, constructed, and tested.

17. First experimental depth-integrating sampler--After completing a working drawing, a plaster model was built to enable the designer to see the sampler in its three dimensions without incurring the cost of constructing the finished apparatus. Inspection of the plaster model led to revisions in the shape of the sampler. The original drawings were revised accordingly. Fig. 5 is a photograph of the plaster model of the sampler.

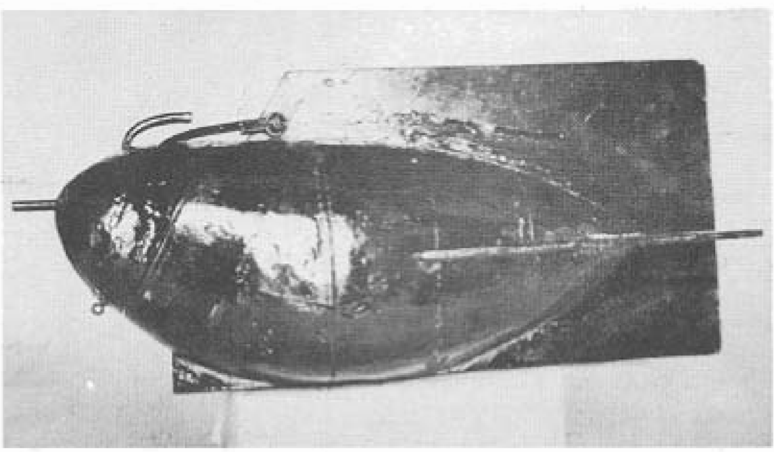

Fig. 5--Plaster model of depth-integrating sampler

After revising the drawings, construction of the first experimental sampler was begun. This sampler was made up of a brass cylinder with vanes attached, around which was cast a lead jacket. A photograph of this sampler appears in Fig. 6.

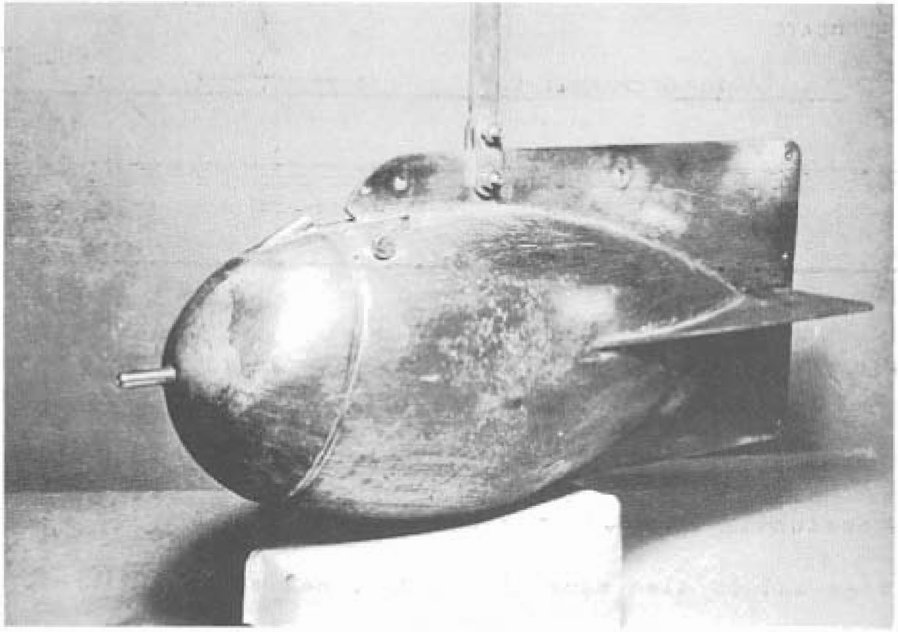

Fig. 6--First experimental depth-integrating sampler

The nozzles for this sampler could be removed by unscrewing from the inside of the head when the sampler was open. These nozzles were designed with a straight 3/16-in. bore extending 1 in. from the intake followed by a tapered section 2-1/4 in. long.

The sampler was first tested for leakage by plugging the air exhaust and intake nozzle of the sampler and submerging it in water. A slight leakage was remedied by using a gasket material of live rubber and by increasing the size of the spring which holds the container in firm contact with the inside of the sampler head.

The sampler was suspended from a standard-type USGS stream gaging reel which was placed on supports across a 10-ft. channel through which river water was allowed to flow at velocities varying between 1 and

6 ft. per sec. The type of suspension used is illustrated in Fig. 7.

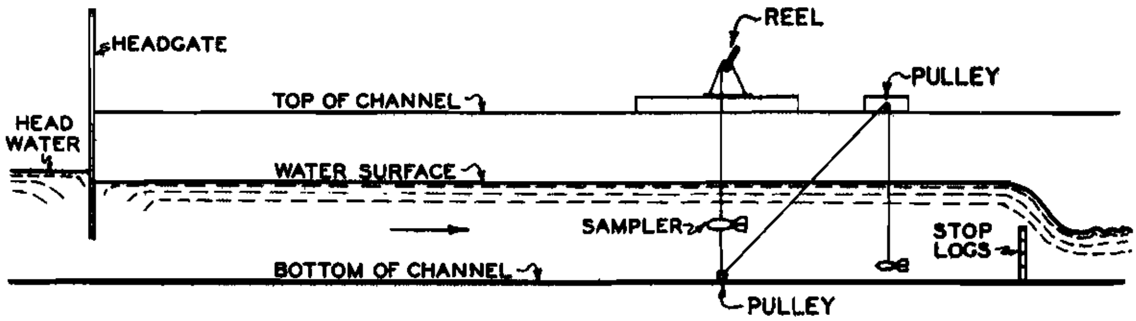

Fig. 7--Apparatus for testing samplers in laboratory channel

This procedure served a double purpose in that it afforded an excellent opportunity to study the behavior of the sampler at different velocities and it also made it a simple matter to calibrate the sampler and thereby ascertain the relation between the filling rate and the stream velocity. In order to accomplish this, the nozzle and air exhausts were plugged with small corks which could be removed quickly. The general procedure was to lower the sampler to a point 1.0 ft. below the water surface, then remove the corks and start a stop watch at the same instant. The initial inrush at this depth and the error introduced thereby were considered negligible. At varying time intervals, the sampler was raised from the water, the watch was stopped, and the time of sampling and volume of water in the container were recorded. From these data the intake velocities were computed. The stream velocities at the same point were measured with a Price current meter.

The results of these calibration tests using both the straight and tapered nozzles are presented in Fig. 8 and show that the intake velocities for the first experimental sampler were, in general, too high.

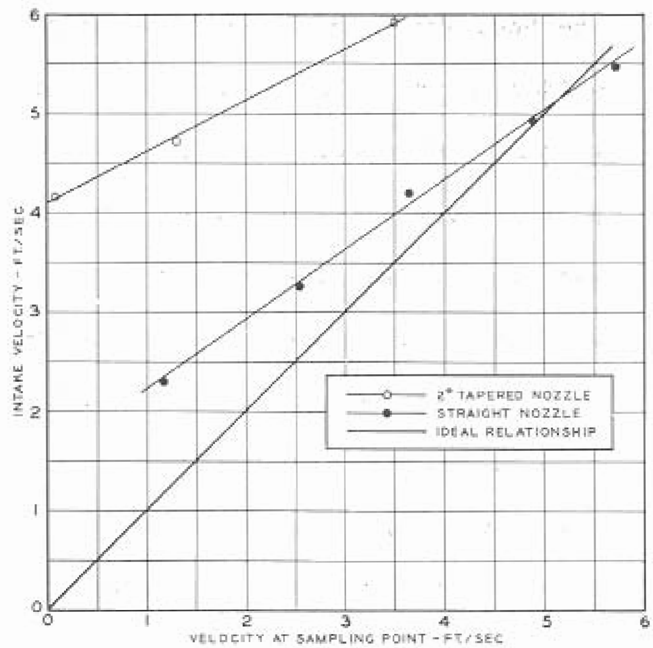

Fig. 8--Intake characteristics of first experimental depth-integrating sampler

18. Second experimental depth-integrating sampler--The tests on the first sampler indicated that some changes in the design were desirable. The second sampler was constructed smaller and lighter than the first one, weighing only 45 lbs. All moving parts, as the latches and hinge, were more sturdily constructed and operated much better than did those of the first model. In other respects, the construction was practically the same. A photograph of this sampler is shown in Fig. 9. A brass cylinder provided a recess in

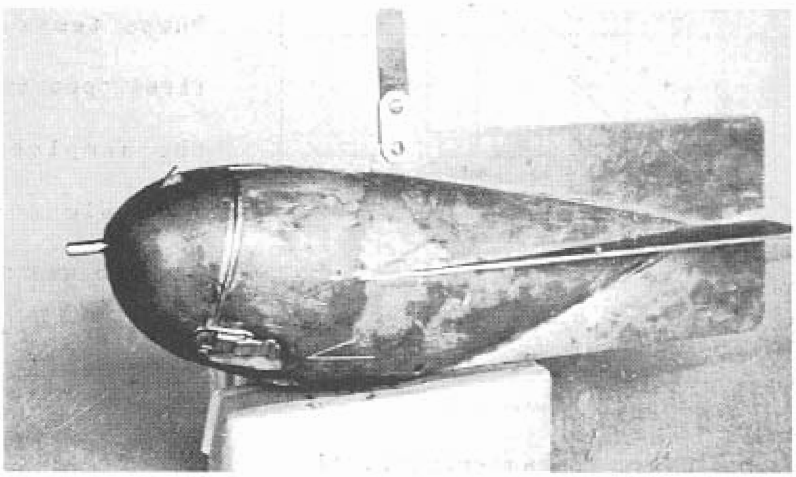

Fig. 9--Second experimental depth-integrating sampler

the body for a pint fruit jar sample container. The tail vanes were welded to the cylinder and to a circular plate which formed the bottom of the sample container recess. A well was attached to the bottom plate into which a spring was inserted to force the container firmly up against a gasket fitted into the sampler head. As before, the sampler was placed in a mold and a lead jacket cast around it to form the body.

The second experimental model was tested in the laboratory in the same manner as the first model. The sampler was lowered into flowing water to study its performance at a fixed depth at high and low velocities, and calibration tests were also made. Fig. 10 shows the test data for a 3/16-in. diameter intake nozzle with a straight bore.

In order to study the action of the sampler under practical conditions, a number of samples were collected from the Iowa River at the gaging station located immediately south of the Hydraulic Laboratory of the State University of Iowa. These tests afforded the first opportunity to study the sampler under field conditions in which the sampler was suspended from a standard reel mounted on a cable car. The samples were analyzed in the laboratory to determine the

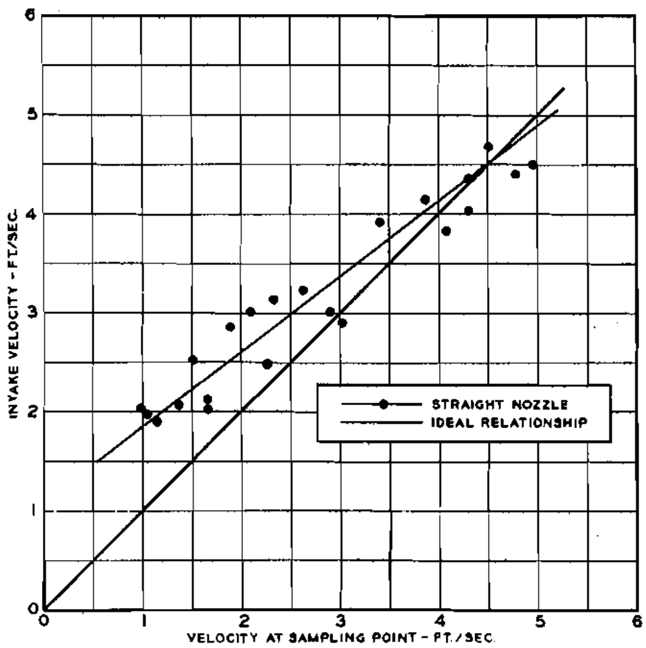

Fig. 10--Intake characteristics of second experimental depth-integrating sampler

sediment concentration and dissolved solids content. Since the Iowa River usually carries fine sediment, all the samples had about the same concentration. However, these tests indicated that further improvements in the sampler should be made.

19. Third experimental depth-integrating sampler--The third experimental sediment sampler embodied the best features of the two previously constructed samplers and some added improvements which were unique to this model. The tail vanes were changed to conform with those used on the USGS 50-lb. C-type sounding weight and the sampler was built so that it could be suspended from a standard hanger bar. This sampler was fitted with two studs on the bottom so that it could be set upright when not in use and would not overturn with the sampler and a current meter attached to the same hanger bar. The sampler body was made entirely of cast brass and its weight was reduced to about 32 lbs.

This sampler was fitted with an auxiliary head with a valve which, when rotated, closed the intake nozzle and air exhaust. When a foot lever attached to the bottom of the body made contact with the stream bed, this valve was actuated, thereby making it possible to integrate a stream vertical on the descending trip alone, if desired. With this feature it would be possible to take depth-integrated samples in streams which are too deep to sample with the previous model. Photographs of this sampler together with the auxiliary head are shown in Fig. 11.

This sampler was calibrated in one of the laboratory flumes, using a procedure somewhat different from that used in the 10-ft. channel. The velocity at the sampling point, usually about 0.5 ft. below the water surface, was determined with a pitot tube. No corks were used to

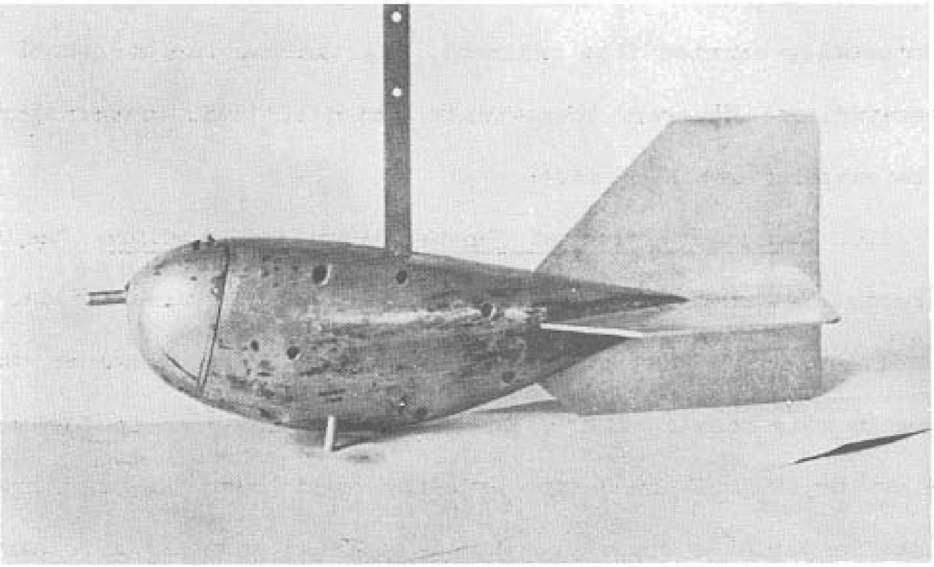

Fig. 11a--Third experimental depth-integrating sampler

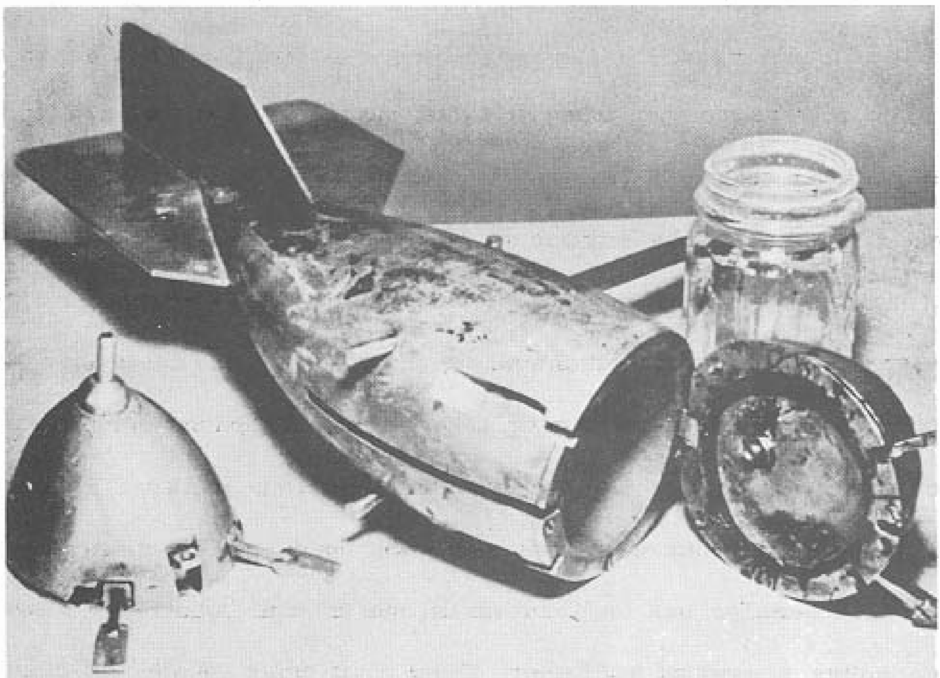

Fig. 11b--Third experimental depth-integrating sampler with auxiliary head close the intake or air exhaust. Since the velocity in the flume was nearly uniform in the upper 0.5 ft. of depth, the error introduced by lowering the sampler into the water and raising it at the end of the sampling period by means of a reel was believed to be quite small. In the intake calibration tests the filling time was measured from the instant the nozzle was submerged until it was brought up out of the water again.

The pitot tube coefficient was determined with a pygmy meter which had been calibrated by the U. S. Bureau of Standards. The velocity measurements obtained with the pitot tube were considered more accurate than those obtained with the current meter because the pitot tube could be held rigidly at a point at the same level and directly ahead of the sampler nozzle, whereas the current meter did not always remain in a fixed location, being swung back and forth transversely by the turbulent flow.

The improved tail vanes and the hanger bar type of suspension greatly improved the action of the sampler throughout the velocity range of 1 to 5 ft. per sec. As a further test, the sampler was introduced into the flow at varying angles with the current and each time it righted itself very quickly. It was noted also that the sampler had no tendency to whip about as did earlier models.

The standard head was equipped with a 3/16-in. diameter intake nozzle with a straight bore 1-5/8 in. long followed by a section 1-3/4 in. long, tapered 1/4 in. per ft. The auxiliary head was equipped with the equivalent of a 3/16-in. diameter nozzle 3-7/8 in. long, the tapered section being 3/4 in. in length. Results of the calibration tests for both the standard and auxiliary heads are shown in Fig. 12.

Sediment samples were taken with this sampler also in the Iowa River at the gaging station near the University Hydraulic Laboratory, and a decided improvement in behavior, in respect to the earlier models, was noted.

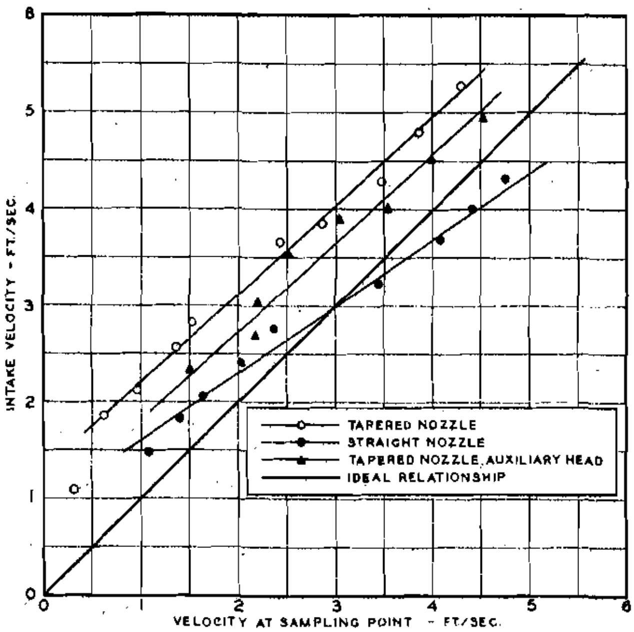

Fig. 12--Intake characteristics of third experimental depth-integrating sampler

20. Fourth experimental depth-integrating sampler--Although the third sampler was fairly satisfactory, it was decided to construct another model utilizing a pint milk bottle as a container. This change was made because pint milk bottles were believed to be more readily available on the market, sturdier, and easier to handle. Also, the use of waxed paper sealing caps would simplify the field and laboratory work.

In each of the previous samplers, the air was exhausted from the fruit jar container by means of a 3/16-in. diameter tube through the top of the head. The elevation of the end of the exhaust tube above the center line of the intake nozzle varied from 1-3/4 in. to 2-3/4 in. Filling rates in these samplers were somewhat irregular and too high at low velocities. Further study of the factors affecting the intake action indicated that the height of the air exhaust above the intake nozzle provided a greater head than was necessary to overcome the losses for low velocities and that the shape and position of the air exhaust materially affected the intake action due to its location in a low pressure area. In the fourth sampler, the air exhaust was placed on the side of the head and 1/2 in. above the center line of the intake nozzle. The tube was bent in the downstream direction as shown in Fig. 13. Laboratory tests with the air exhaust tube exposed indicated ideal intake action. For protection, the tube was later covered with lead and finished by hand as shown in Fig. 14.

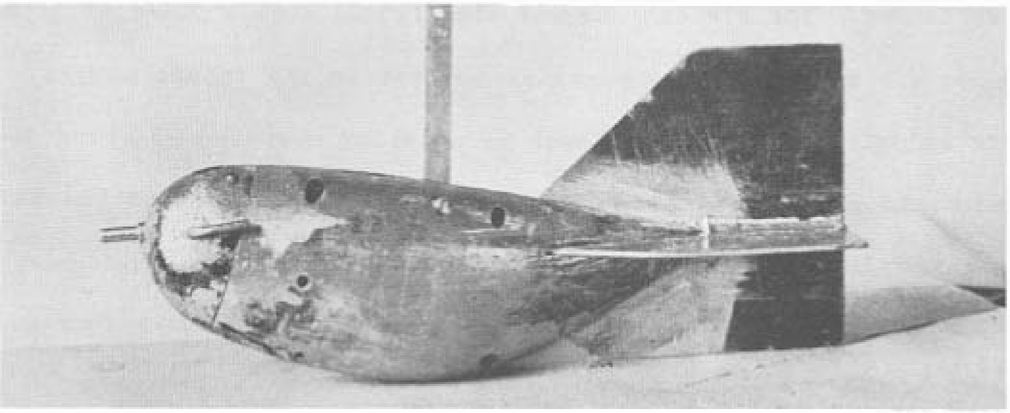

Fig. 13--Fourth experimental depth-integrating sampler with air exhaust exposed

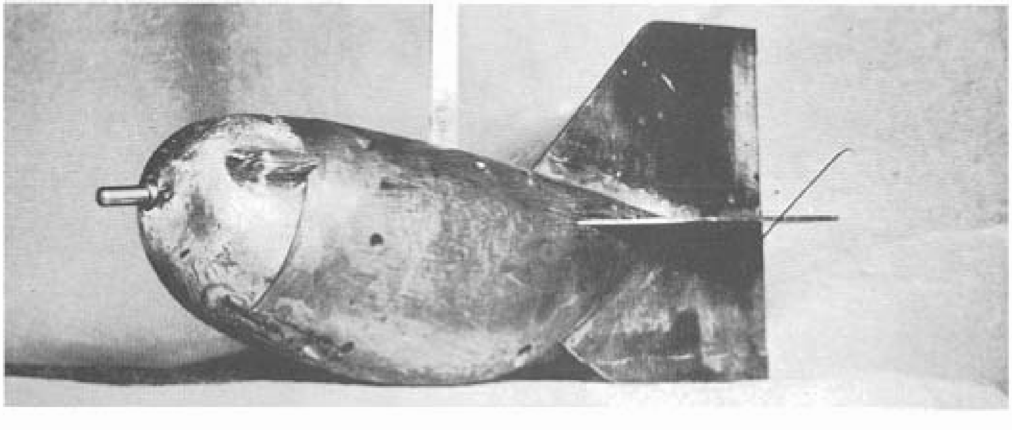

Fig. 14--Fourth experimental depth-integrating sampler with air exhaust encased

This sampler also was provided with two auxiliary heads and a foot lever device which could be attached beneath the body. The first auxiliary head described in Section 19 was refinished to fit this sampler. The air exhaust tube was brought out at the side of the head and shielded to prevent damage. The shape of the head cover was modified and the tapered section of the nozzle was lengthened to 1/4 in. In the second auxiliary head, the intake nozzle was composed of a straight tube, 3/16-in. bore, 2-1/2 in. long, and a tapered tube, 1-1/8 in. long, tapered 1/4 in. per ft., joined by a section of gum rubber tubing. The air exhaust was also fitted with a piece of 3/16-in. diameter gum rubber tubing parallel to that in the intake nozzle. The intake and air exhaust were closed by a spring operated clamping device which would be released when the foot lever, attached to the bottom of the sampler, made contact with the stream bed. A photograph of the sampler with the first auxiliary head in place is shown in Fig. 15.

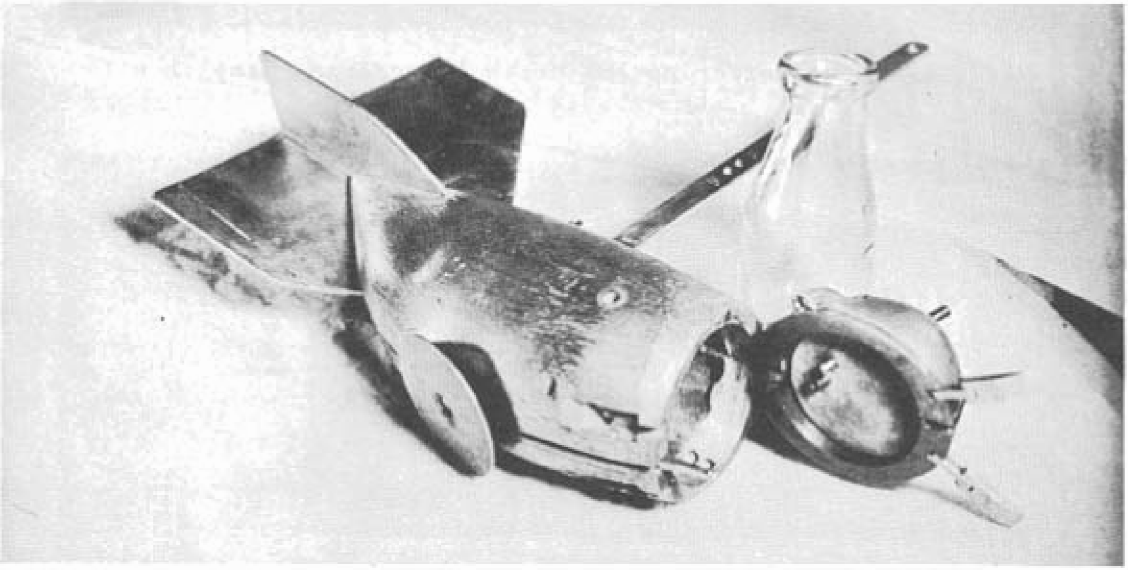

Fig. 15--Fourth experimental depth-integrating sampler with auxiliary head and trip mechanism in place

Photographs of the two auxiliary heads with the covers removed are shown in Fig. 16.

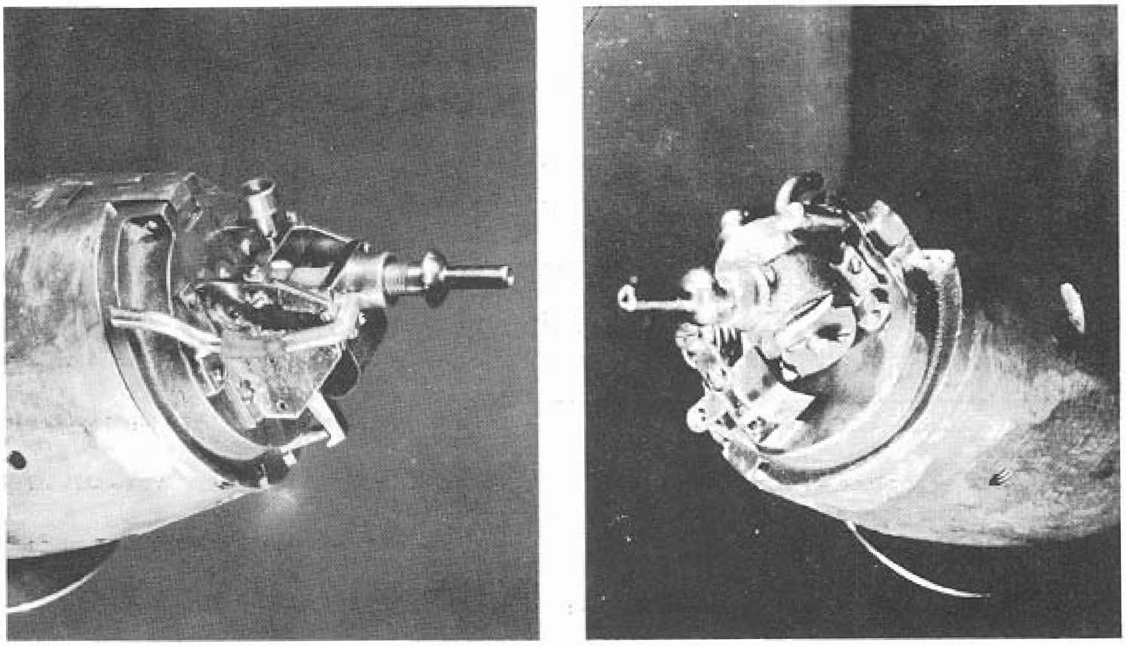

Fig. 16--Auxiliary heads for fourth sampler with covers removed

The test work on this sampler was more exhaustive than on the earlier models, as it was found necessary to determine experimentally the type of streamlining required for the most efficient operation of the air exhaust. Results of laboratory tests made with the air exhaust shown in Fig. 13 indicated that the filling rates approached the ideal. As it was desirable to shield the exhaust tube to prevent damage, several tests were run with a wax cover in order to determine the shape that would produce the minimum turbulence. This general shape was then reproduced in lead on the sampler head and finished by hand until the desired degree of streamlining was obtained. Results with three nozzles of 3/16-, 5/32-, and 1/8-in. diameter used in the standard

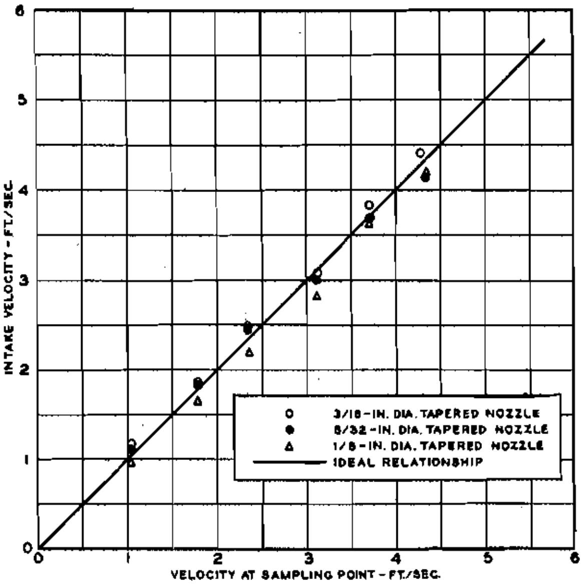

Fig. 17--Intake characteristics of fourth experimental depth-integrating sampler

head are shown in Fig. 17. These nozzles were 3-1/2 in. long and had the inner end tapered 1/4 in. per ft. for lengths of 3/4, 1-3/4, and 1-1/2 in., respectively. The taper in the 5/32-in. nozzle did not increase the velocity as might be expected. An examination of this nozzle after the tests were made indicated some irregularities in the bore which apparently reduced the effectiveness of the taper.

Results of similar tests on the two auxiliary heads previously described are shown in Fig. 18.

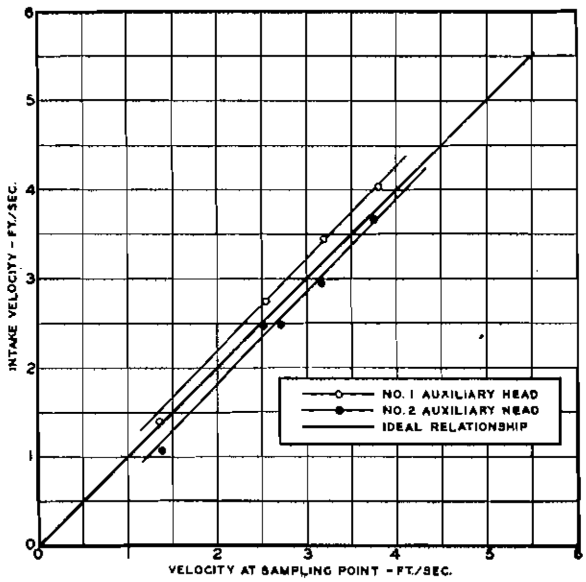

Fig. 18--Intake characteristics of auxiliary heads for fourth experimental depth-integrating sampler

This sampler was given a greater number of field tests than the earlier models. Sediment samples were taken in the Cedar River near Conesville and in the Iowa River at Iowa City and near Coralville. Results of these tests indicated the necessity of having the vertical tail vane extended below the bottom of the sampler in order that the sampler might orient itself more readily before being lowered into the stream. It was found also that the tail vanes, as originally designed, tipped the sampler excessively at medium and high transit rates, thereby increasing the intake velocity beyond that of the stream.

The following improvements, not incorporated in the earlier models, were effected in the design and construction of the fourth experimental depth-integrating sampler. (1) The air exhaust port was lowered to reduce the static differential between it and the intake nozzle. The nodular enclosure was streamlined to minimize turbulence at the outlet end of the air exhaust tube. (2) The tail vanes were altered somewhat from those shown in Fig. 13 in order to keep the intake nozzle essentially horizontal while in transit. (3) A coil spring was placed in the bottom of the container recess to press the mouth of the bottle firmly against the sponge rubber sealing gasket in the head of the sampler. (4) The studs provided on the bottom of the third sampler were eliminated and instead the bottom of the sampler was flattened so that it would remain upright when resting on this flat and on the bottom edge of the vertical tail vane. (5) The air exhausts on the auxiliary heads were likewise relocated and shielded for protection, the shields being streamlined in order to reduce the turbulence at the outlet end.

21. <u>Fifth experimental depth-integrating sampler</u>--The fifth experimental sampler was very similar to the fourth model and identical with the 38-lb. samplers constructed for the cooperating agencies for field testing. Photographs of the sampler are shown in Fig. 19 and a working drawing in Fig. 20. The exterior shape of the air exhaust was reproduced on the wood pattern used in making the sand molds for the

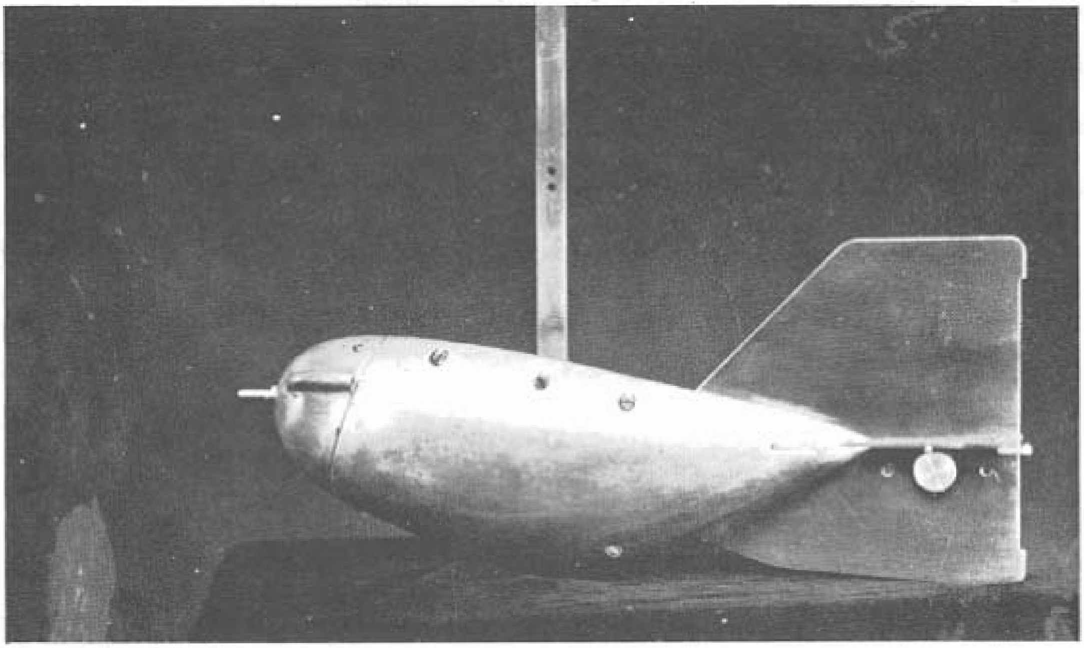

Fig. 19a--Fifth experimental depth-integrating sampler (38 lb.)

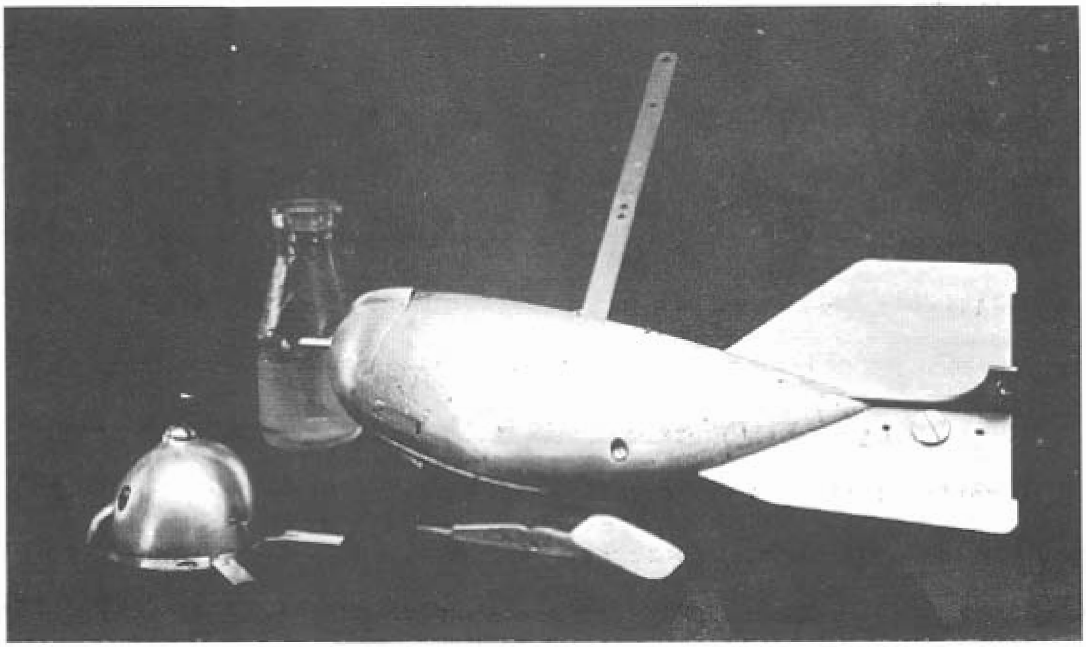

Fig. 19b--Fifth experimental depth-integrating sampler (38 lb.) with auxiliary head

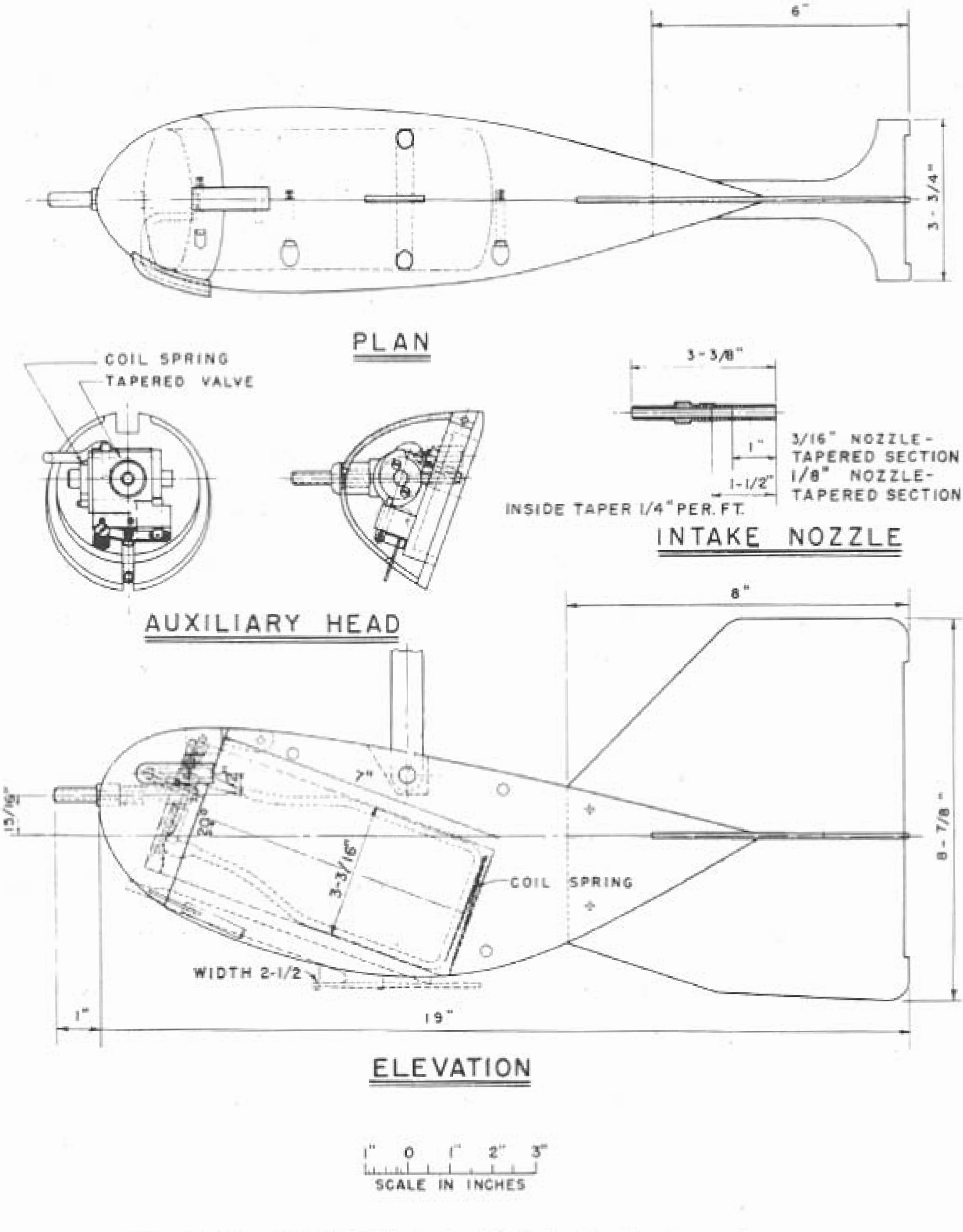

Fig. 20--Fifth experimental depth-integrating sampler (38 lb.)

sampler heads and the air passage was drilled in the finished casting. The body was cast in two halves which were subsequently fitted and joined together by screws. The tail vanes, adopted from the developments made in the fourth sampler, were made of steel and were nickel-plated to reduce corrosion. The sampler was balanced under water as the center of buoyancy did not coincide with the center of gravity. The 38-lb. sampler has not been generally used, and is no longer manufactured. The bottom tripping devices used with the auxiliary heads did not prove very practical for routine field work and the development of these modifications has been suspended.

A 50-lb. model of the fifth depth-integrating sampler, designated US D-43, was constructed for field testing by the cooperating agencies. This sampler was essentially similar to the 38-lb. model except that it was larger and heavier, and the body was cast in one piece. The 50-lb. sampler was later provided with a more rugged catch for holding the head in the closed position. This model has proved very practical and has had extremely wide use in routine sediment work. Photographs are shown in Fig. 21, and a working drawing in Fig. 22.

The laboratory tests on the fifth sampler were similar to those made on the earlier models but the velocity range was increased to 7 ft. per sec. Results of tests with the 3/16-in. and 1/8-in. diameter nozzles are shown in Fig. 23. The 3/16-in. nozzle had a straight bore 2-3/8 in. long followed by a 1-in. section tapered 1/4 in. per ft. The 1/8-in. nozzle had the same over-all length, but the tapered section was increased to a length of 1-1/2 in.

A few field tests relative to the inflow characteristics of this

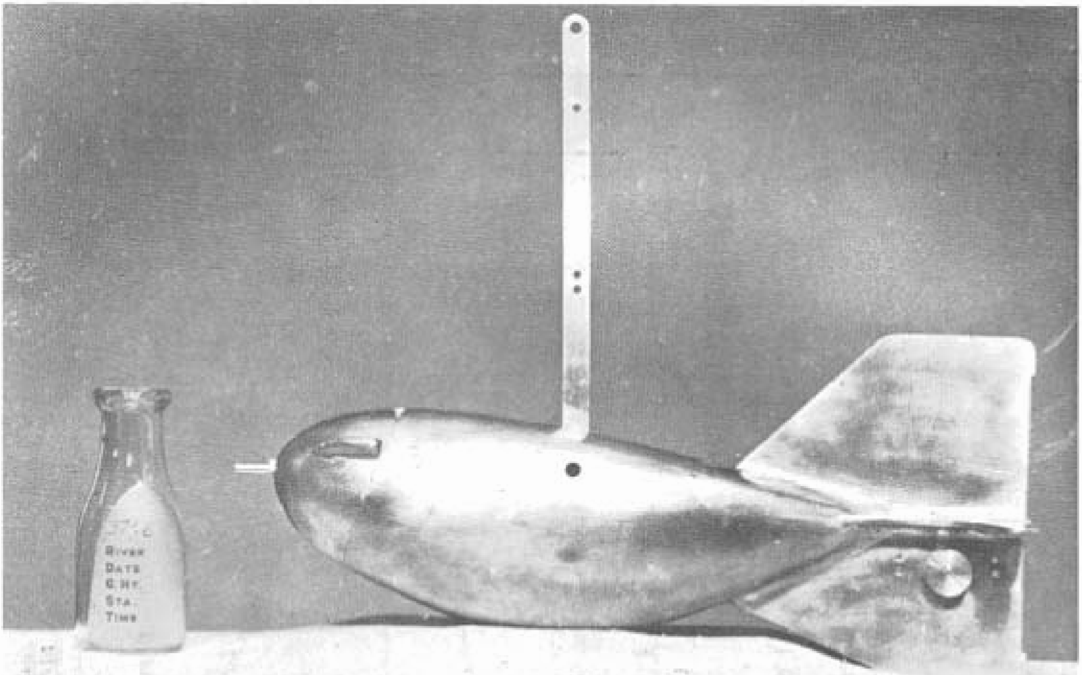

Fig. 21a--Fifth experimental depth-integrating sampler, US D-43 (50 lb.)

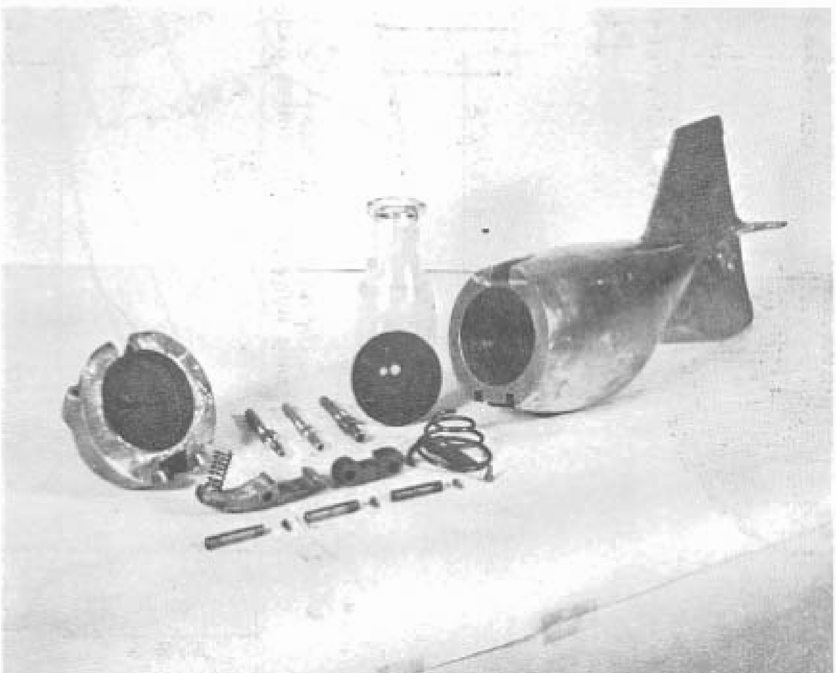

Fig. 21b--Fifth experimental depth-integrating sampler, US D-43 (50 lb.), disassembled

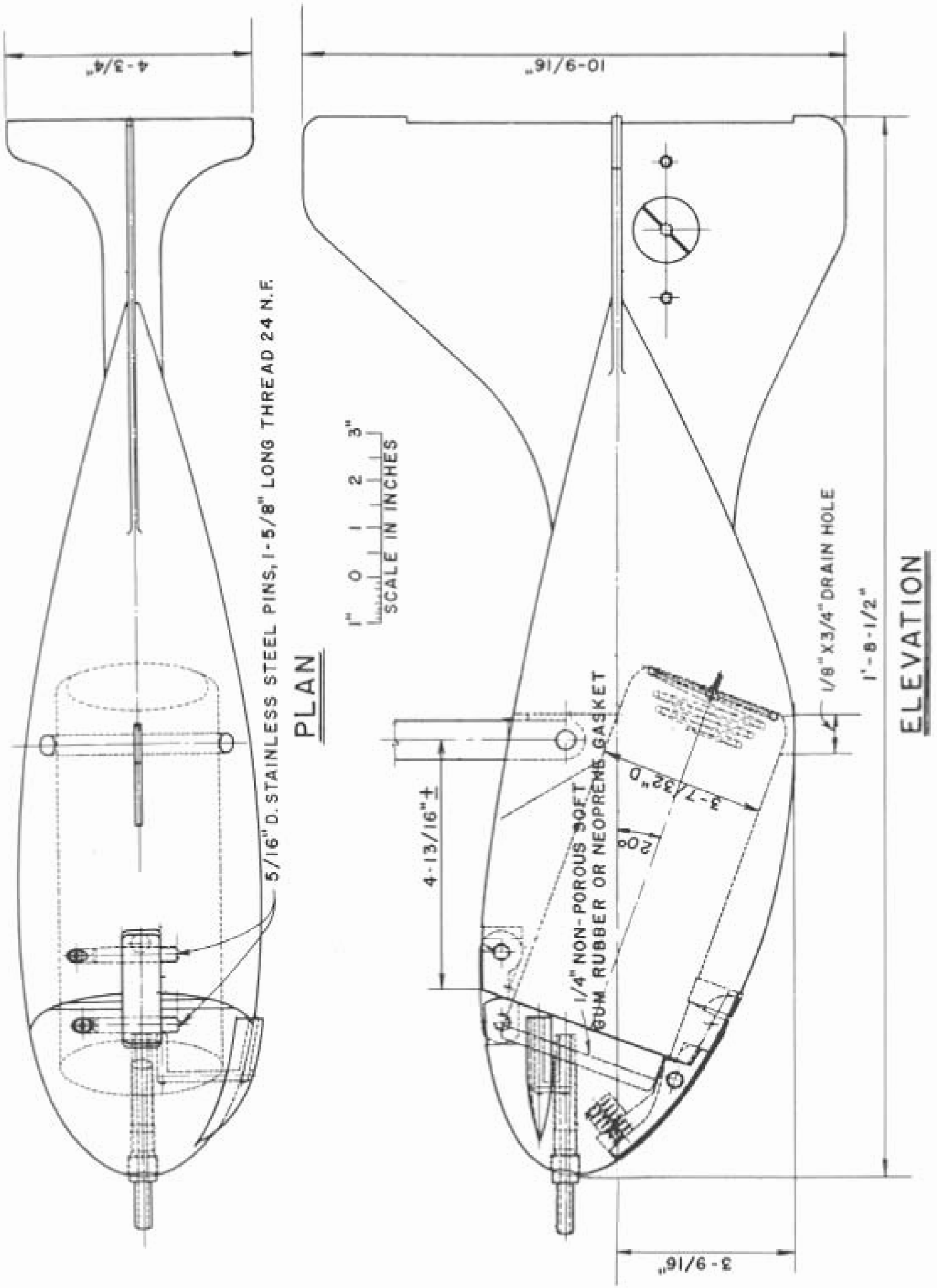

Fig. 22--Fifth experimental depth-integrating sampler, US D-43 (50 lb.)

sampler were made in the Cedar and Iowa Rivers. The sampler was lowered and raised at a transit rate as nearly uniform as practicable, using a sounding reel and crane normally used in making discharge measurements from bridges. The sampling interval was determined by means of a stop watch. The velocity observations, from which the average velocity for the sampling vertical was obtained, were made with a small Price current meter in accordance with the usual stream gaging practice.

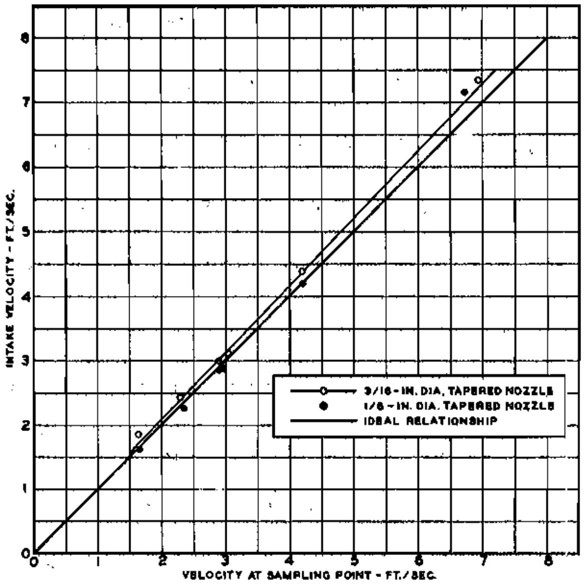

Fig. 23--Intake characteristics of fifth experimental depth-integrating sampler based on laboratory tests

The results of the field tests are shown in Fig. 24. The data, while not conclusive due to the shallow depths and low velocities encountered, indicate that the average velocity in the intake nozzle was about 0.95 of the average stream velocity for the sampling depth.

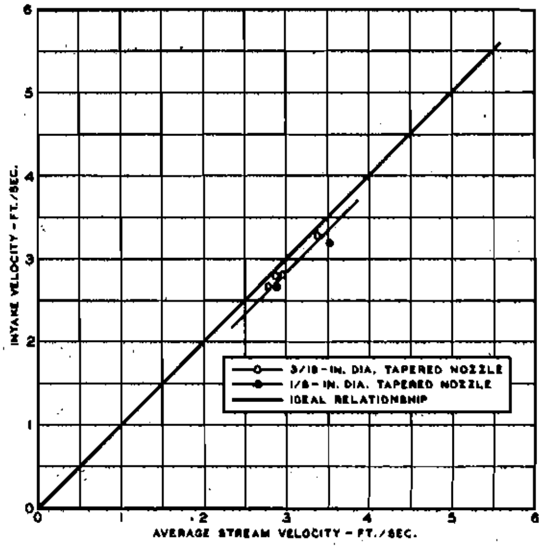

Fig. 24--Intake characteristics of fifth experimental depth-integrating sampler based on field tests

The variation between the laboratory and field test data with reference to intake characteristics is believed to be due largely to the difference in the test procedures. In the laboratory the sampler was suspended in the testing flume at a predetermined depth, whereas in the field the sampler was lowered and raised at a virtually uniform transit rate. The vertical movement of the sampler produces turbulence around the intake nozzle at the point of intake. Likewise, the determination of the average velocity in the intake nozzle may be subject to some error, owing to lack of absolute uniformity in the transit rate and to the pause made in reversing the direction of the sampler upon contact with the stream bed. The total time that the nozzle was submerged is the value that was used in the computations.

The results of other field tests on the D-43 sampler are presented in the report "Preliminary Field Tests of the US Sediment-Sampling Equipment in the Colorado River Basin, April 1944" and in the progress report "Comparative Field Tests on Suspended Sediment Samplers, December 1944." Additional information is also presented in the progress report, "Field Tests on Suspended Sediment Samplers, Colorado River at Bright Angel Creek near Grand Canyon, Arizona, August 1951."

22. Development of hand sampler--The depth-integrating suspended sediment sampler, US D-43, discussed in the preceding section of this report, which was adopted for field use, weighs about 50 lbs. and was designed for use with cable and reel suspension. Consequently, the sampling operation with that instrument is comparable to a stream flow measurement from a cableway or bridge. In some localities most of the stream flow measurements are made by wading, and there was urgent demand for a light weight, inexpensive sampler to be used in the smaller

streams and canals; that is, for sediment sampling equipment which would be analogous to the stream gaging equipment used in wading measurements.

The operational criteria for a light weight sampler are practically the same as for the heavier depth-integrating sampler. The sampling action is the same, and the curves shown in Fig. 4 are applicable with respect to the time for filling the container. The theoretical limitations on transit rates and on the sampling depth apply to all depth-integrating samplers regardless of weight. However, because the lighter sampler is ordinarily used only in shallow streams, these limitations on transit rates are seldom restrictive.

The first experimental hand sampler, shown in Fig. 25, was developed to fill the most immediate demands for a depth-integrating sampler of this type. This model consisted of a bottle holder of strap brass with provision for attaching to the foot plate of the standard 1/2-in.

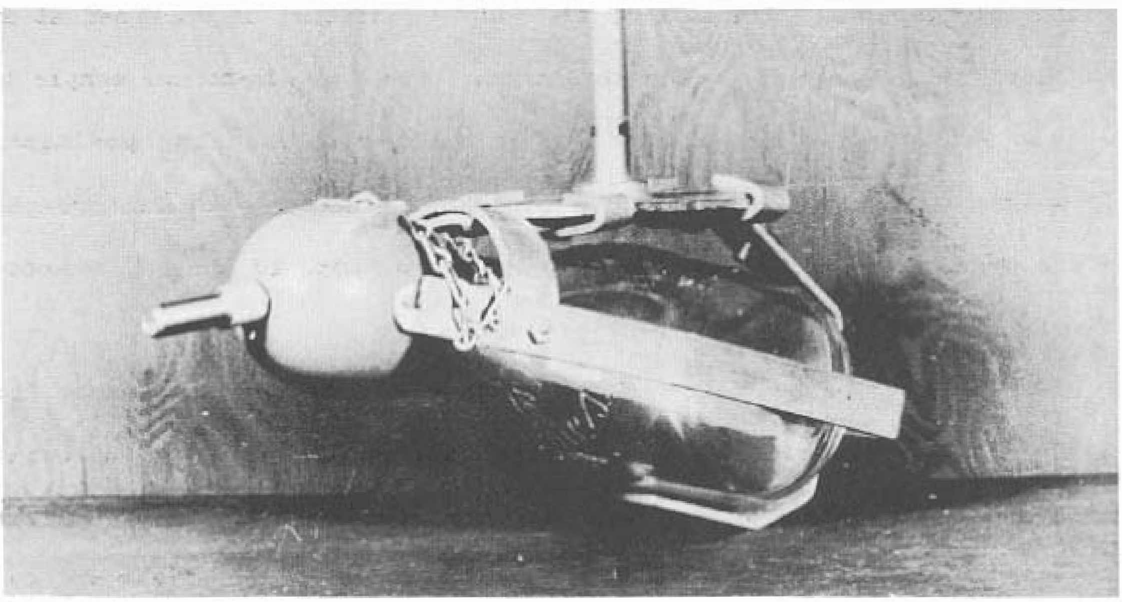

Fig. 25--First experimental depth-integrating hand sampler

round wading rod which is widely used in stream gaging. The bottle holder also supported the rounded wooden head for the bottle. The head, with a rubber base to fit the top of the bottle, was equipped with an air exhaust tube and intake nozzle. The intake characteristics of the sampler were satisfactory.

A second model, later designated US DH-48, was designed for quantity production and field use. This sampler consists of a streamlined aluminum casting which encloses a pint milk bottle sample container. A pre-shaped stainless steel tube, invested in the aluminum casting, provides the air exhaust. A brass intake nozzle extends horizontally upstream. The main portion of the instrument contains an extended circular skirt section and a support beam to partially enclose and orient the sample container. The beam provides two recesses, one threaded to receive a standard round wading rod and the other to form a cylindrical housing for a spring tensioned clamping rod which holds the sample bottle in position. The axis of the sample container is inclined at an angle of 17-1/2 degrees to the horizontal. The instrument can sample to within 3-1/2 in. of the stream bed in the normal sampling position. It weighs 4-1/2 lbs. including the pint bottle container. Photographs and a drawing of the instrument are shown in Figs. 26 and 27, respectively.

This sampler is believed to be adaptable to any conditions for which a rod suspension of the sampler is practicable. The velocity of flow in the intake nozzle will be very close to that in the stream for all stream velocities over 2 ft. per sec. For lower stream velocities, the velocity in the intake nozzle will exceed that in the stream,

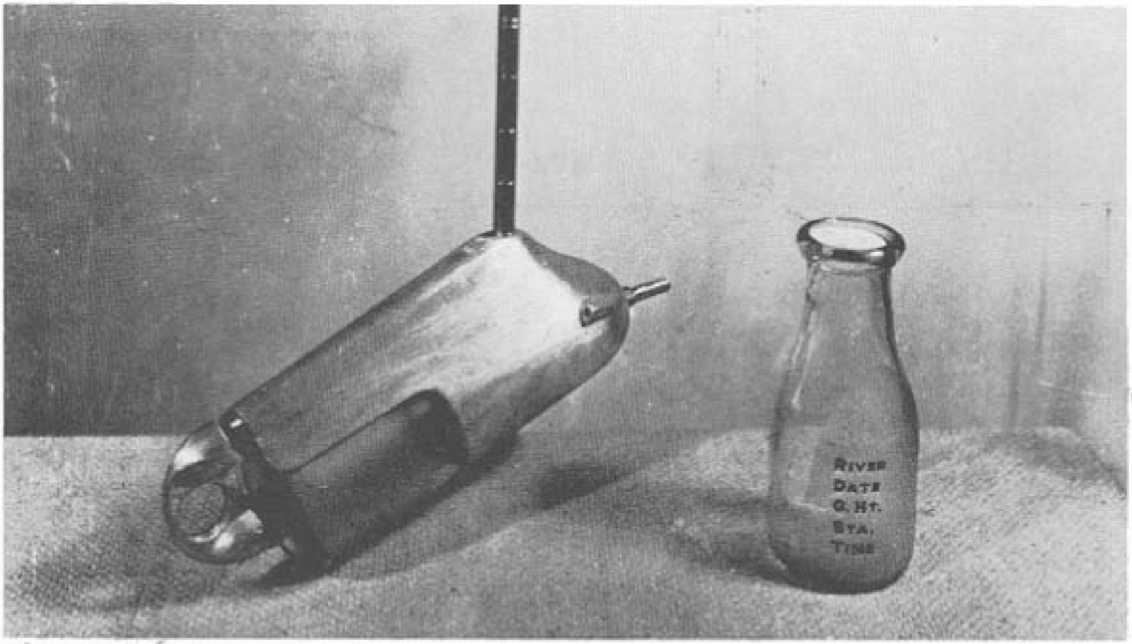

Fig. 26a--Depth-integrating hand sampler, US DH-48

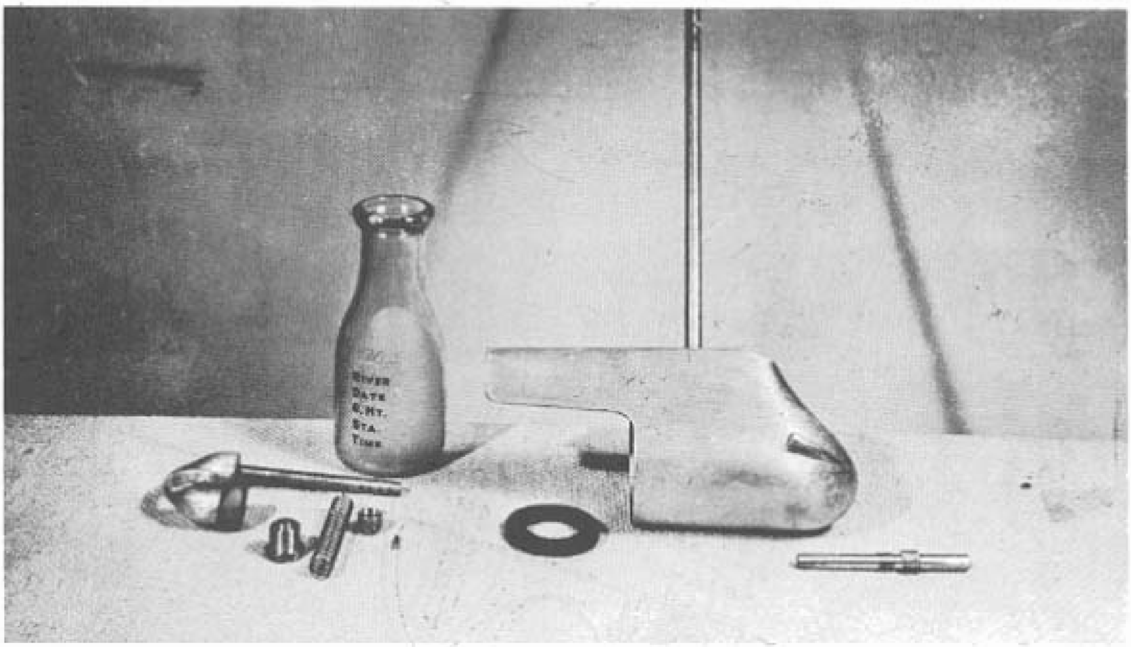

Fig. 26b--Depth-integrating hand sampler, US DH-48, disassembled

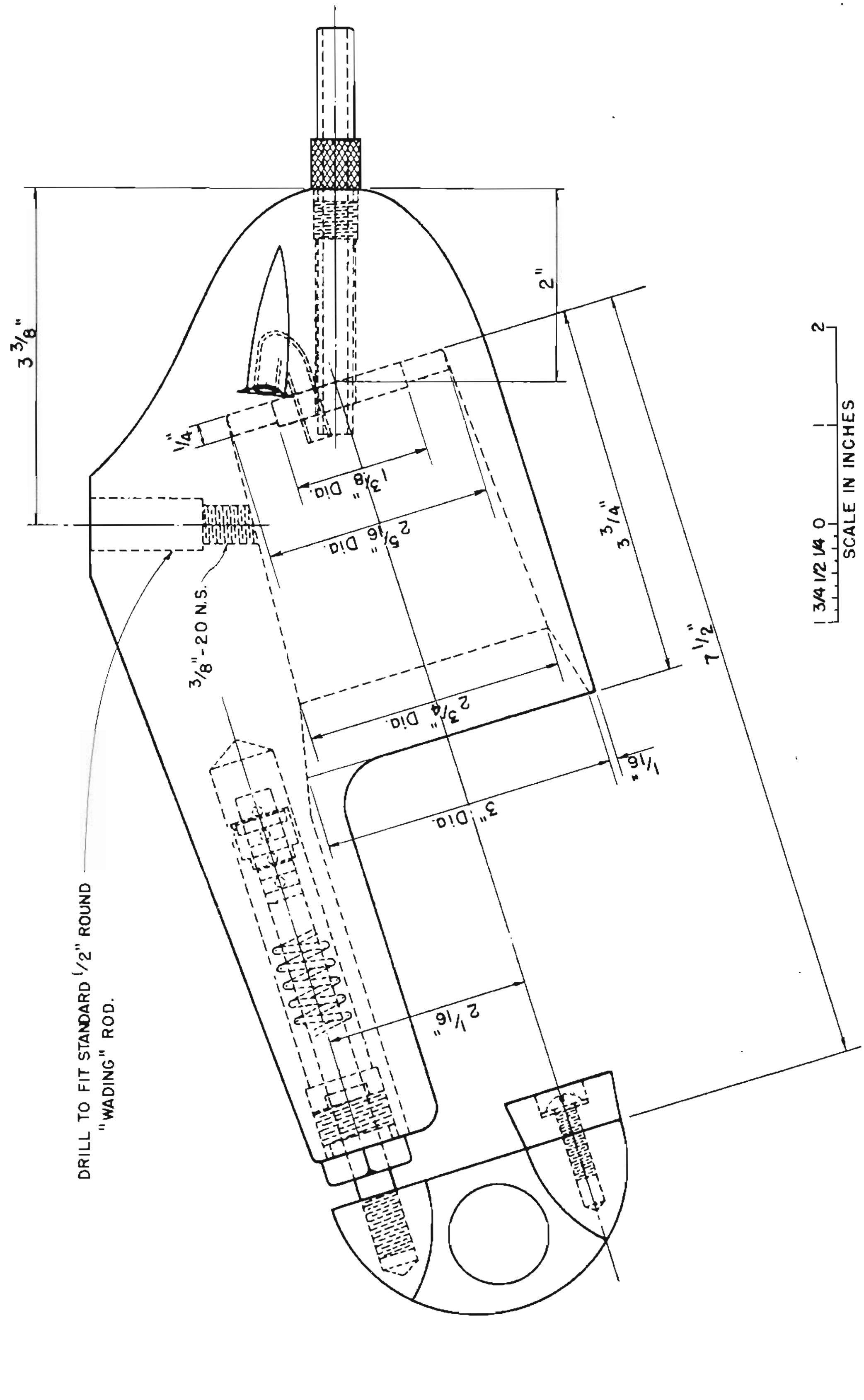

Fig. 27--Depth-integrating hand sampler, US DH-48

but the error introduced is considered negligible. The sampler is calibrated with nozzles of 1/4-in. diameter, without taper; but smaller diameter nozzles may be used provided they are tapered as required to give proper velocities within the nozzle. Fig. 28 shows some calibration results obtained with the US DH-48 hand sampler.

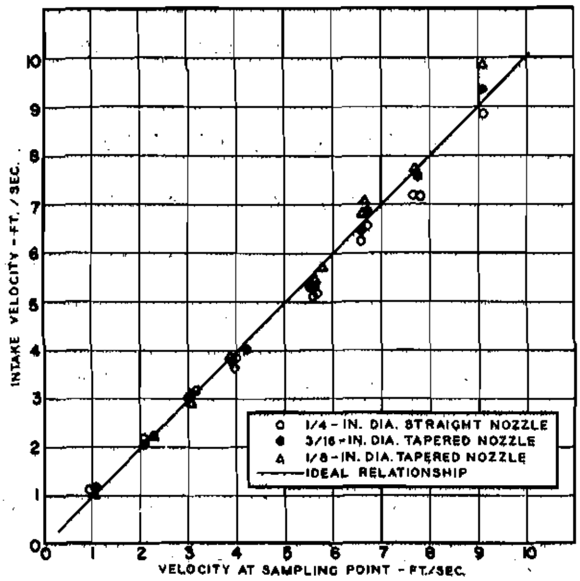

Fig. 28--Intake characteristics of depth-integrating hand sampler, US DH-48

III. DEVELOPMENT OF POINT-INTEGRATING SAMPLERS

23. Definition of point-integrating sampler--A point-integrating sampler is designed to accumulate a water-sediment sample which is representative of the mean sediment concentration at any selected point in a stream vertical during a short interval of time. Nearly all point-integrating samplers developed prior to the inauguration of this investigation are subject to initial inrush when the intake is opened below the water surface of the stream and, therefore, do not take samples representative of the mean sediment concentration at the sampling point. The so-called initial inrush is due to the pressure differential between the inside and outside of the sampler, as pointed out in the discussion in Sectior 2 of this report and in Section 30 of Report No. 5 of this series.

A point-integrating type of suspended sediment sampler embodies all the features set forth in the discussion of the design of a depth-integrating sampler. In addition, the point-integrating sampler should be so designed that with the air exhaust and water-sediment intakes closed it can be submerged to any sampling point at which the operator desires to take a sample. At the same time, the air pressure in the sample container and the external hydrostatic head should be equalized at all depths to eliminate initial inrush when the intake and air exhaust are opened. Furthermore, the sampler should be so constructed that the water-sediment intake and air exhaust may be opened and closed at any depth.

24. First experimental point-integrating sampler--In the first

experimental point-integrating sampler the pressures within and without were equalized at all points by utilizing the diving-bell principle. The sampler was constructed with an inner chamber to hold the sample container and an outer air chamber having a volume about five times that of the sample container. The air chamber and the sample container were interconnected by means of a brass tube with a passage through a spring actuated valve. When the water-sediment intake and air exhaust, which were also controlled by this valve, were closed, prior to lowering the sampler into a stream or river, the pressure-equalizing passage was open. The outer air chamber had a permanent opening at the bottom of the sampler through which water could enter, thereby compressing the air in the sample container as the sampler was submerged. Consequently, the pressures outside and inside of the sample container were always essentially equalized. When a messenger weight was dropped along the suspension cable, operating the tripping mechanism, the valve would turn about 1/4 revolution. Thus the connection between the sample container and the air chamber was automatically closed and at the same instant the water-sediment intake and the air exhaust were opened. When another weight was dropped, the valve rotated another 1/4 revolution and the intake and air exhaust were again closed, the connection between the air chamber and sample container remaining closed. The sampler, with the trapped sample, could then be raised to the surface. The first experimental sampler was fitted with a nozzle 3/16 in. in diameter, with a straight bore 1-7/8 in. long, followed by a section 1-3/4 in. long, tapered 1/4 in. per ft.

The tripping mechanism used on the first point-integrating sampler was an adaptation of that used on the Frazier sampler which is described in Report No. 1. The falling messenger weight striking the tripping mechanism would permit the sampler to drop about 1 in. This movement in turn operated a lever system which released the valve. The first experimental point-integrating sampler, shown in Fig. 29, was made of brass and weighed 33 lbs.

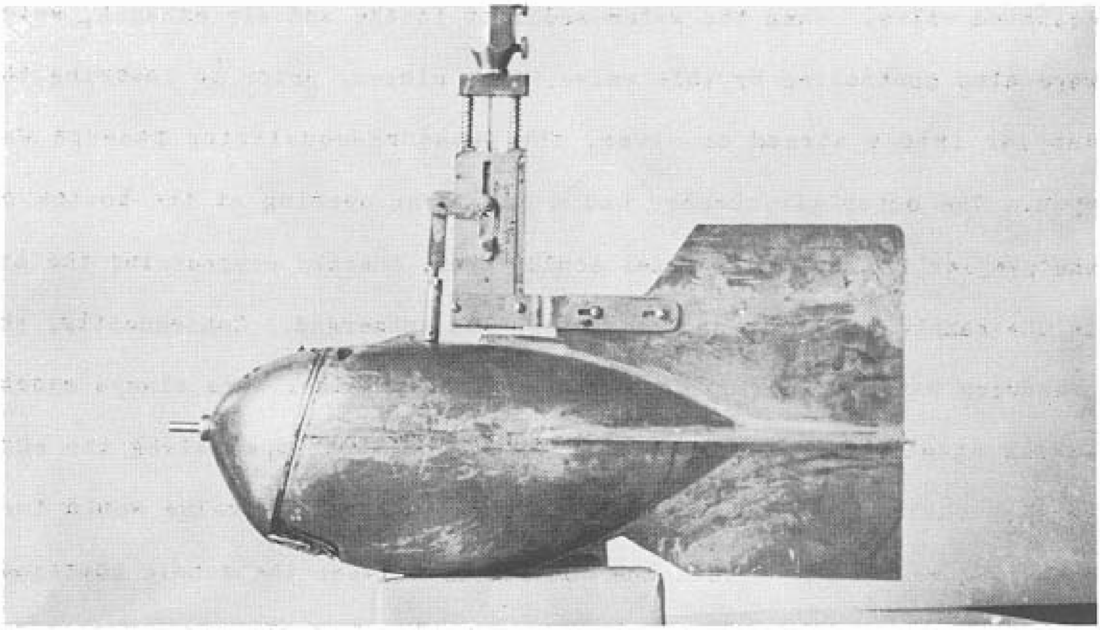

Fig. 29--First experimental point-integrating sampler

The point-integrating sampler was tested for leakage and performance at high velocities and was calibrated in the 30-in. laboratory flume. In the original design, the air escaped through a 3/16-in. unprotected vent on the top of the head. The tests indicated that the intake nozzle velocities were too high. In an effort to improve the filling characteristics, the air exhaust was brought out on the side of the head, 1/2 in. above the intake nozzle and was shielded by means of a streamlined brass cover. Results of tests with the air exhaust in the two different positions are shown in Fig. 30.

The sampler with the air exhaust in the new position was tested and sediment samples were collected in the Iowa River at the gaging station just below the Hydraulic Laboratory at Iowa City. The equipment included a standard stream gaging reel mounted on a cable car. Sediment samples were collected also from the Cedar River near Conesville. At this station a portable stream gaging crane equipped with a reel was used from a highway bridge. Results of the tests indicated satisfactory intake characteristics for the depths and velocities encountered.

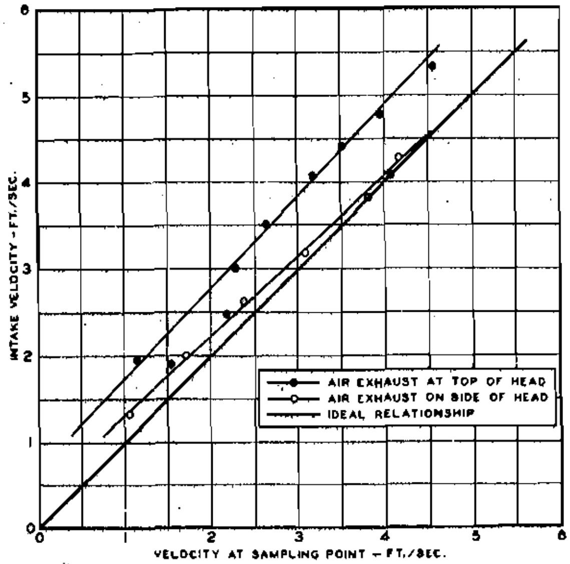

Fig. 30--Intake characteristics of first experimental point-integrating sampler

25. Second experimental point-integrating sampler--The field tests on the first sampler indicated that the valve mechanism was not entirely satisfactory. The impact of the messenger weight did not always release the tripping mechanism and in some instances the device would permit the valve to turn to the second position with the first messenger weight. Further study of the problem indicated that many of the undesirable features of the mechanical closing device could be eliminated by using an electrically operated valve mechanism. However, due to the lack of materials and machine shop facilities for the development of such a mechanism, the changes in the second model were at

first limited to improvements in the mechanical closing device. The body of the first sampler was used in making the second with such modifications as were necessary to adapt it to the new valve and tripping mechanism. An improved head catch was also developed for the second sampler.

The valve tripping mechanism in the second sampler is actuated directly by the impact of messenger weights. The impact moves a pin-connected lever system which in turn operates a modified escapement that momentarily releases the flat bronze driving spring. The valve rotates through 120° each time the escapement is tripped. As the valve turns, the released ratchet tooth slides against the curved face of the pawl, squeezing the pawl back against the ratchet wheel in time to engage the next tooth, thereby making the movement and arrest of the valve positive.

As in the first model, the sampler is fitted with a 3/16-in. diameter nozzle. However, the length of the tapered section was reduced to 3/4 in. as an inspection of the nozzle in the first sampler revealed that the valve was not in exact alignment, thereby reducing the effect of the taper. A photograph of the second point-integrating sampler is shown in Fig. 31, and a view of the valve mechanism in Fig. 32. A drawing of the sampler is shown in Fig. 33. This sampler was calibrated in the 30-in. laboratory flume, the procedure being the same as for the first model. Samples were taken in the Iowa River at the Iowa City gaging station below the Hydraulic Laboratory. Results of the field tests indicated that the performance of the sampler was satisfactory for the depths and velocities encountered. Results

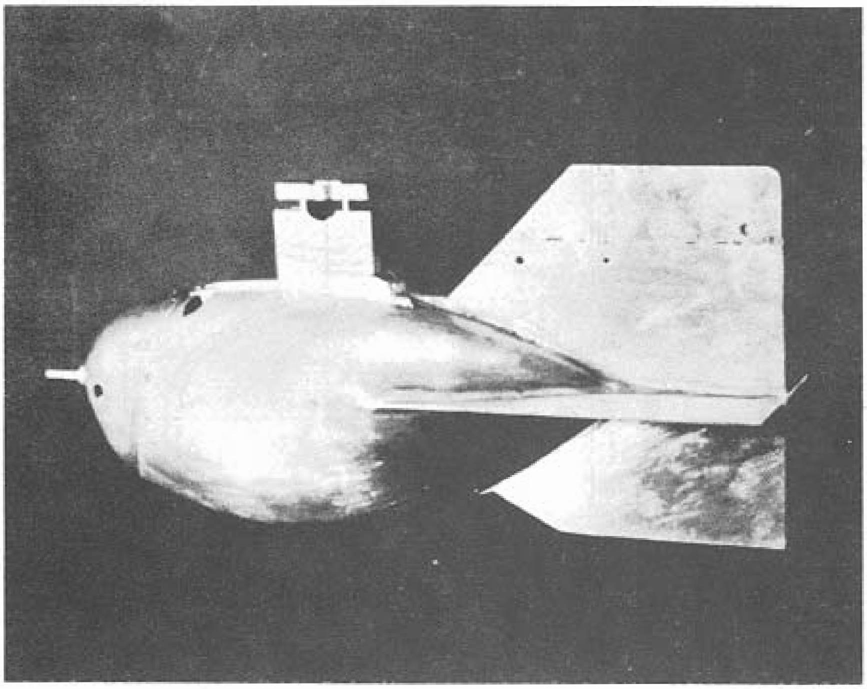

Fig. 31--Second experimental point-integrating sampler

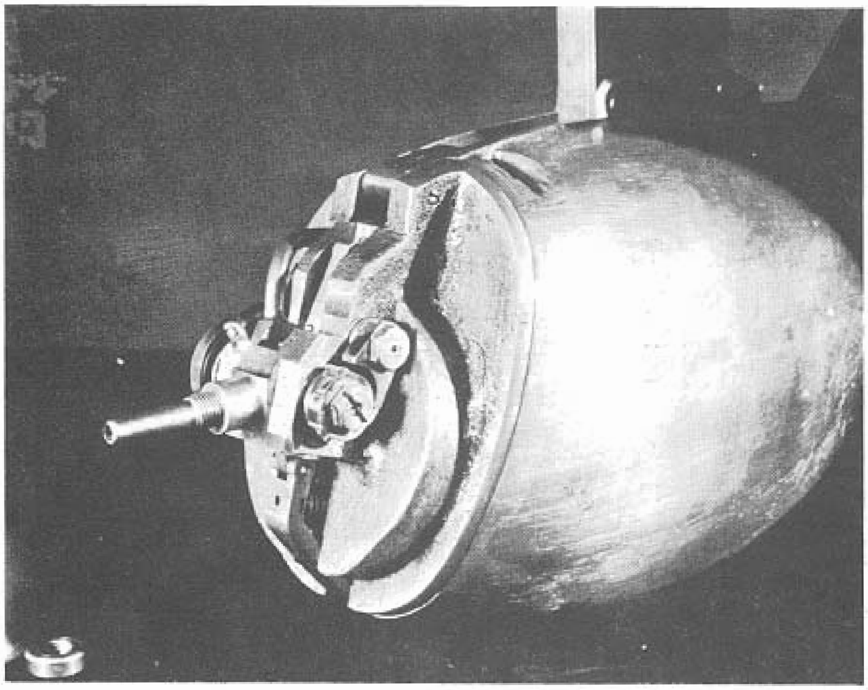

Fig. 32--Valve mechanism for second experimental point-integrating sampler

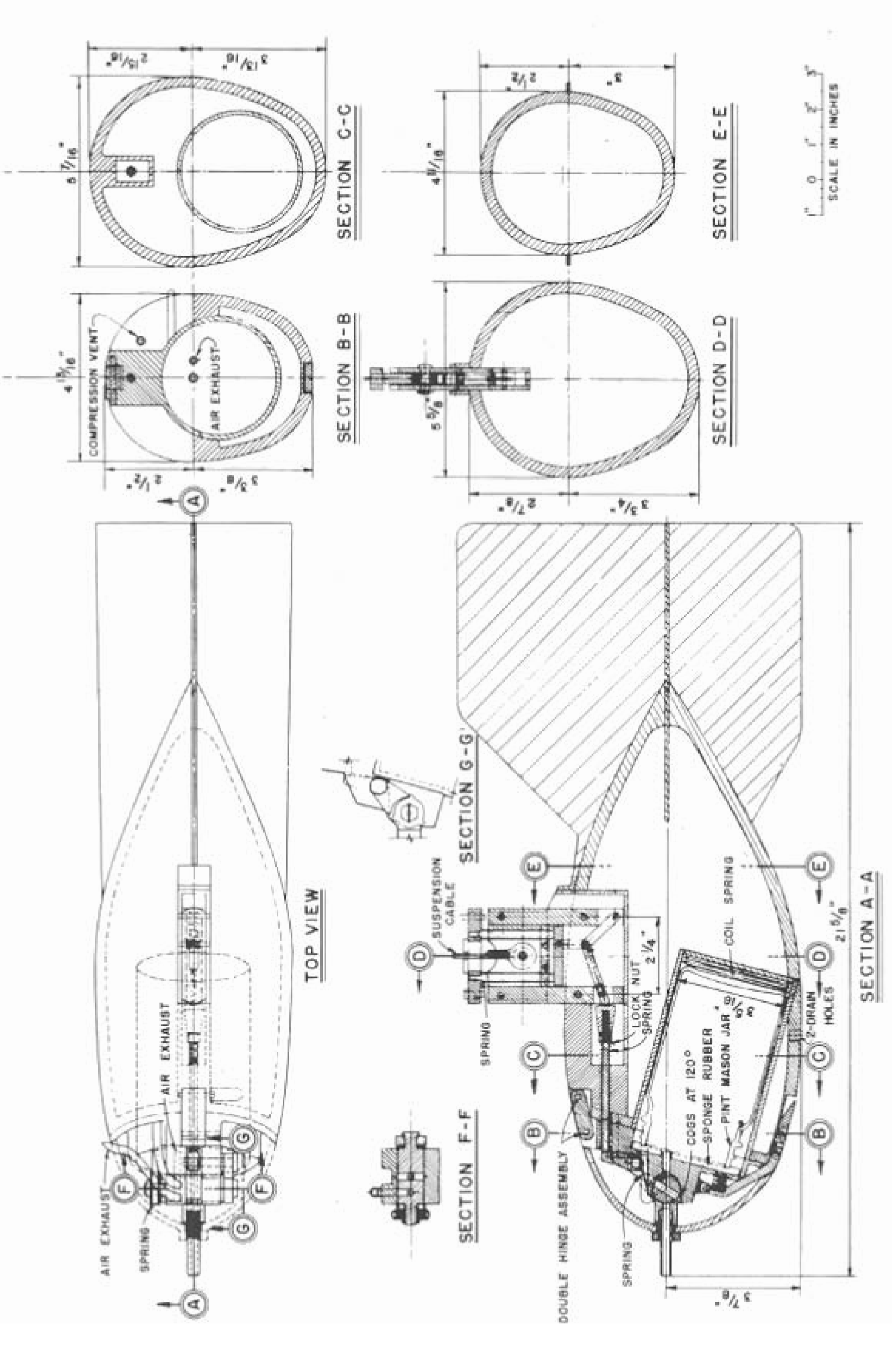

Fig. 33--Second experimental point-integrating sampler

of these tests are shown in Fig. 34.

The second experimental point-integrating sampler was later modified by adapting a solenoid to the sampler in such a manner that the mechanism could be tripped electrically instead of by the impact of a messenger weight. The sampler is shown with the solenoid in place in Fig. 35. However, this feature proved inadequate for field operation.

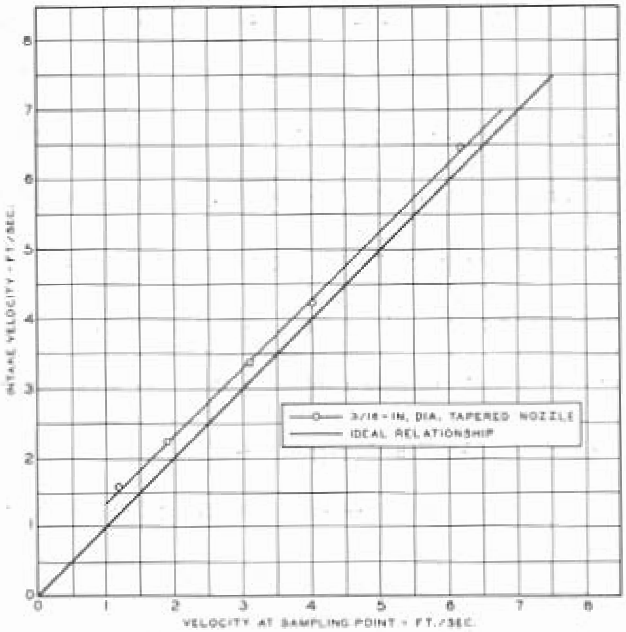

Fig. 34--Intake characteristics of second experimental point-integrating sampler

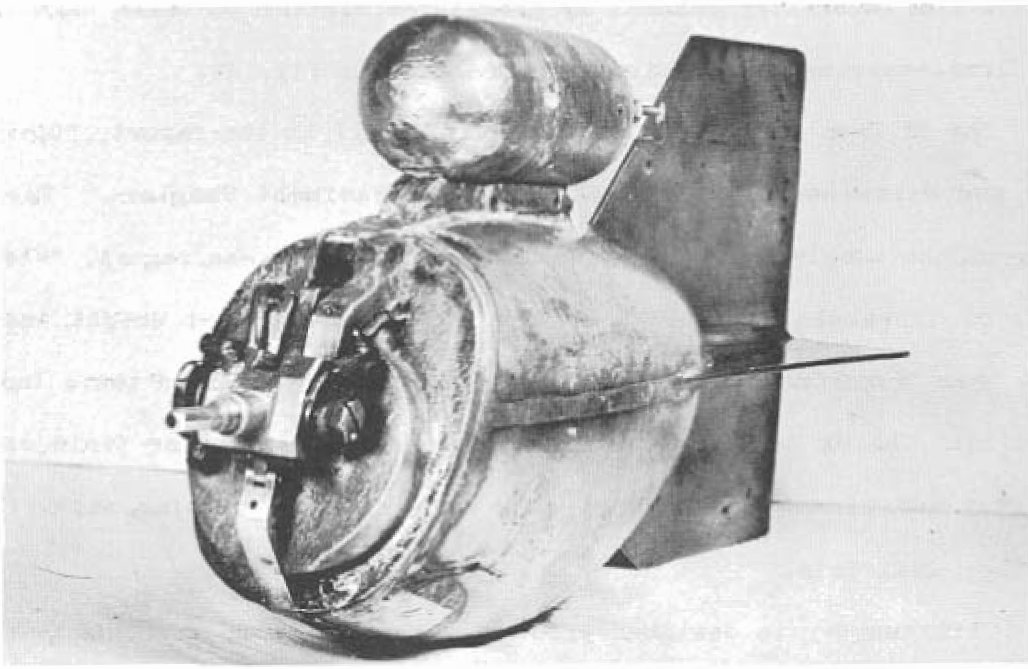

Fig. 35--Second experimental point-integrating sampler with solenoid

26. Third experimental point-integrating sampler--The results of the field tests on the second experimental sampler indicated that a point-integrating sampler was required for investigations of fluvial sediments and that a satisfactory sampler could be developed. An electrically operated tripping device for the valve mechanism appeared to be desirable, as well as improved streamlining and greater weight. Consequently, a complete new design was made for the sampler body and the valve tripping mechanism.

The diving-bell principle of equalizing pressures proved very practical and was carried over into the design of the third experimental point-integrating sampler. The sampler was made larger and the weight was increased to nearly 100 lbs. This sampler, completed in 1946 and designated US P-46, is illustrated in Figs. 36 and 37. Drawings of the sampler are shown in Figs. 38a and b. The results of calibration tests made in the laboratory channel by procedures similar to those used for the first experimental sampler are presented in Fig. 39.

The US P-46 sampler is discussed in detail in the report, "Operation and Maintenance of US P-46 Suspended Sediment Sampler." Field tests of the sampler have been published in the progress report, "Field Tests on Suspended Sediment Samplers, Colorado River at Bright Angel Creek near Grand Canyon, Arizona." The results of the field tests indicated that the US P-46 sampler is entirely satisfactory for field use, but that additional development work on the valve tripping mechanism would be desirable.

This sampler is designed primarily for obtaining accurate point-integrated samples and has been widely used in the field for that

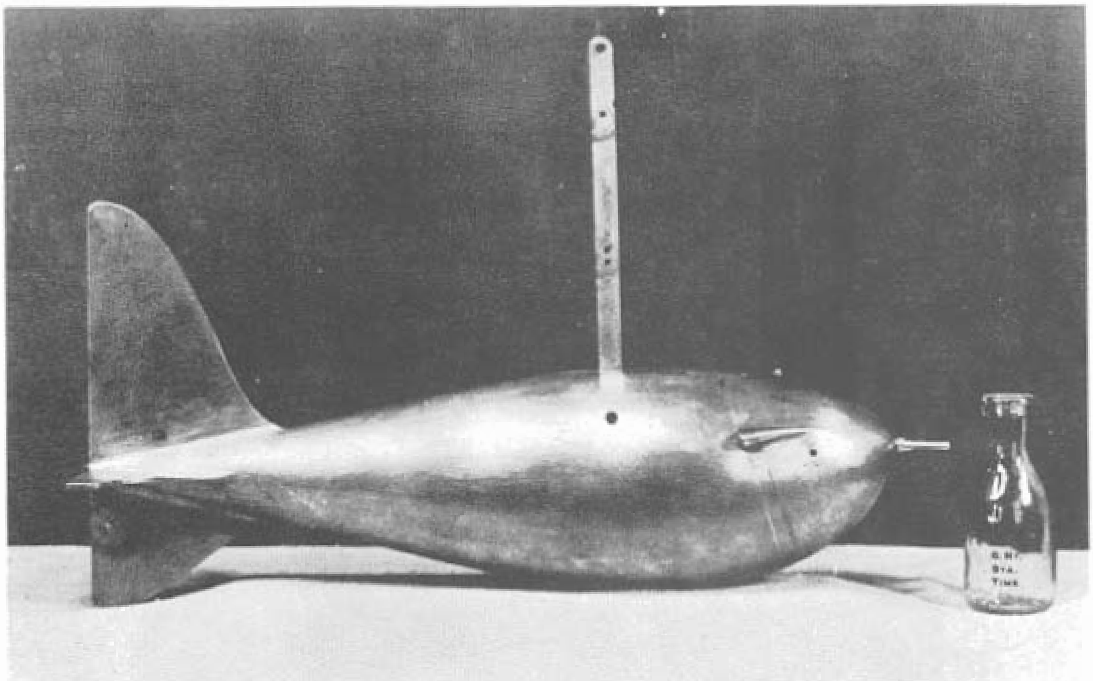

Fig. 36a--Third experimental point-integrating sampler, US P-46

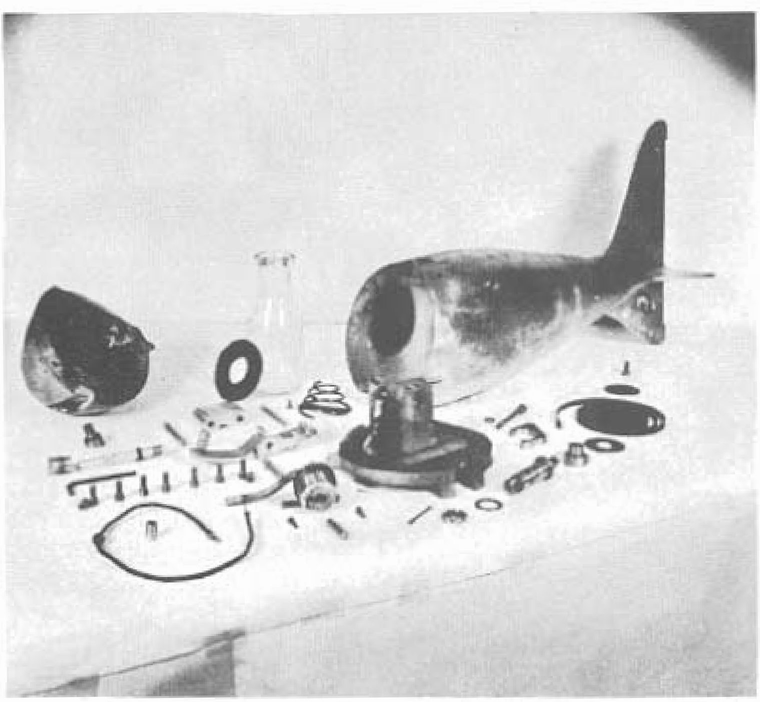

Fig. 36b--Third experimental point-integrating sampler,
US P-46, disassembled

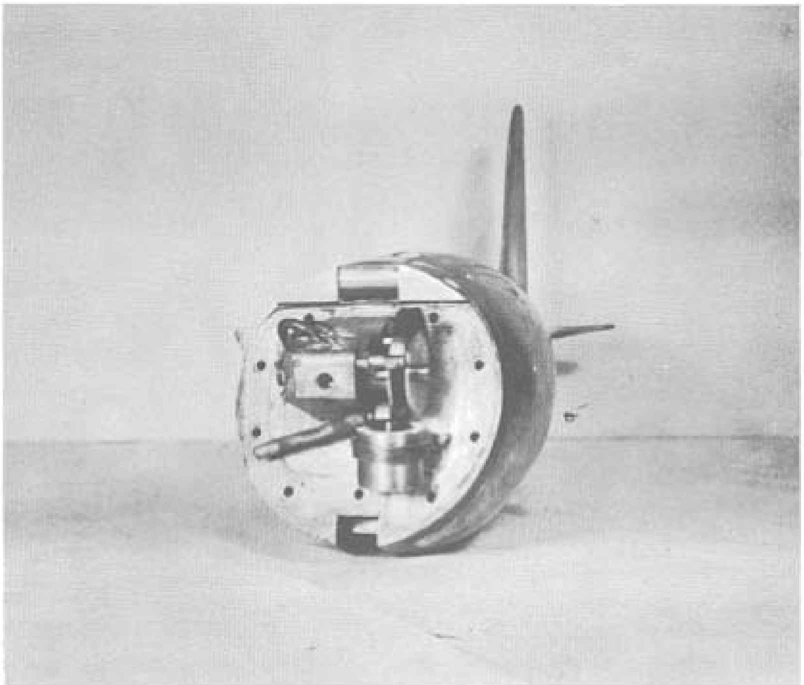

Fig. 37a--Valve mechanism for third experimental point-integrating sampler, US P-46

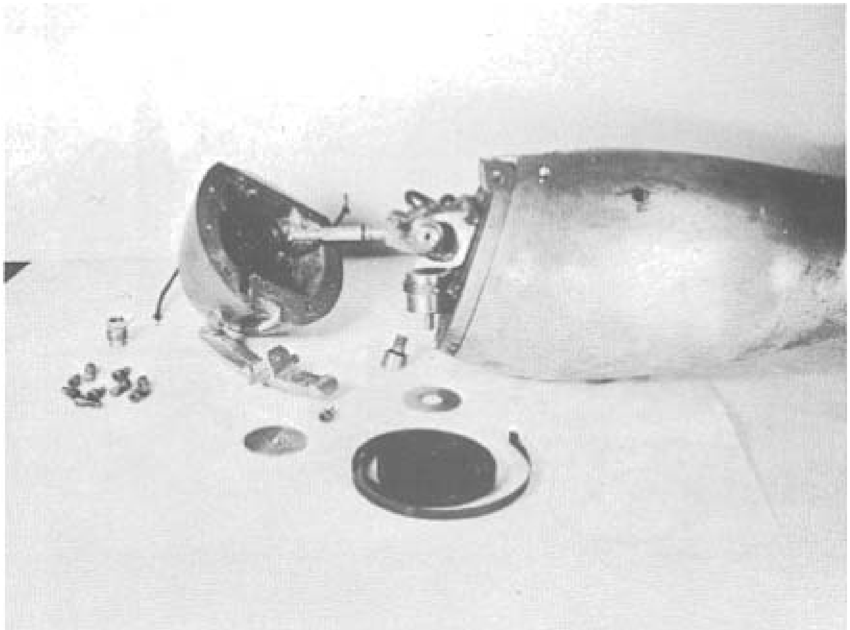

Fig. 37b--Valve mechanism for third experimental point-integrating sampler, US P-46, partially disassembled

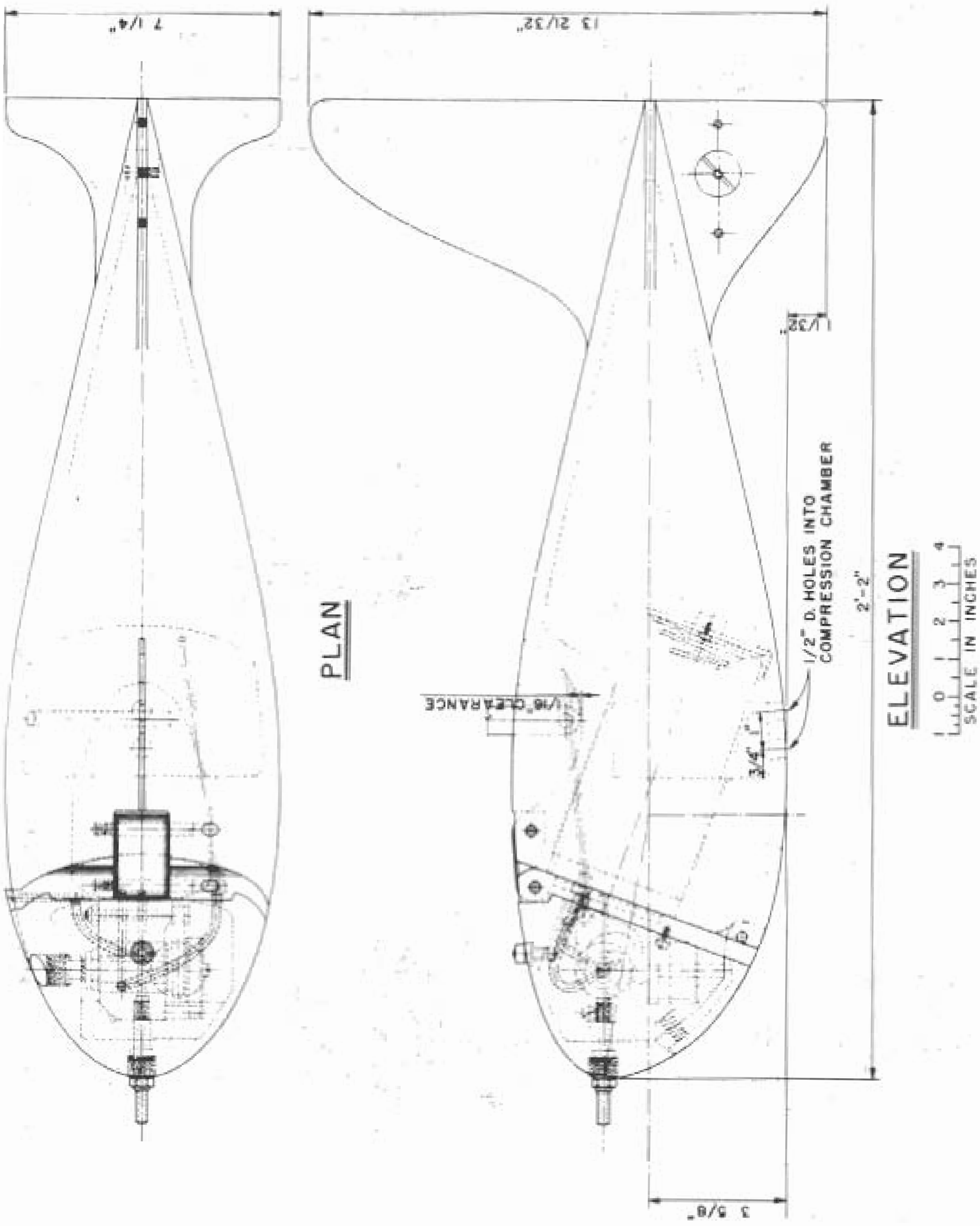

Fig. 38a--Third experimental point-integrating sampler, US P-46

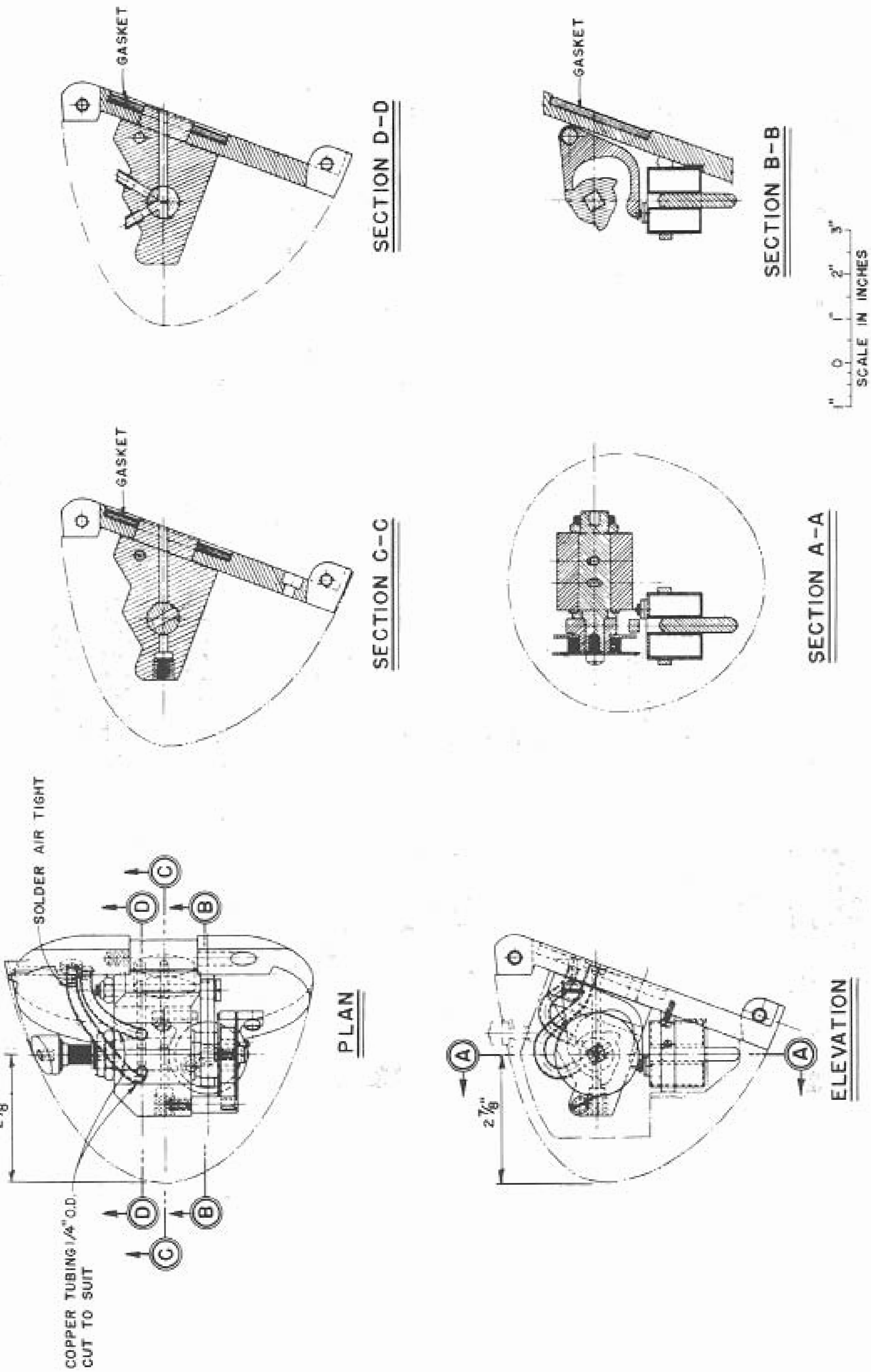

Fig. 38b--Third experimental point-integrating sampler, US P-48, valve mechanism

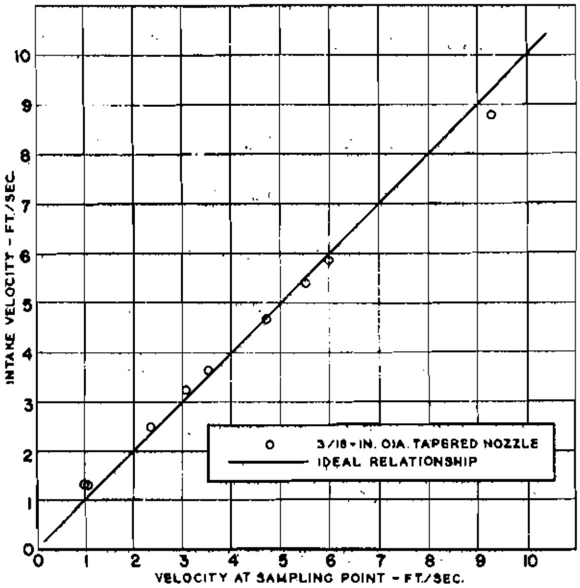

Fig. 39--Intake characteristics of third experimental point-integrating sampler, US P-46

purpose. In addition it has been used extensively as a depth-integrating sampler for sampling throughout a stream vertical either on a round-trip basis or in one direction only. When used as a depth-integrating instrument, the sampler is subject to the depth limitations discussed in Section 11. Depth-integrated samples have been obtained satisfactorily in deeper streams by integrating portions of the depth successively. The results of such samples must be weighted properly in accordance with the stream discharge which each represents. However, if uniform rates of lowering or raising the sampler are maintained during collection of all samples in a given vertical, these samples may be composited into one sample which will be representative of the entire vertical. In sampling portions of the vertical, no part of the depth should be omitted and none should be sampled twice without giving those facts proper weight.

IV. STUDIES OF INTAKE CHARACTERISTICS OF SEDIMENT SAMPLERS

27. Effect of water temperature on intake characteristics--The laboratory investigations discussed in Report No. 5 do not include any studies relative to the effects of water temperature on the intake characteristics of the standard nozzle. It was generally felt at the time of those tests that the intake velocities were outside the range of laminar flow and the effects of temperature changes were insignificant. However, as the development of the samplers continued, the effect of temperature became increasingly evident, and allowance was made in the sampler calibrations for the effect of temperature on the relative sampling rate, or intake ratio. In addition some data were available in engineering literature to support the fact that temperature does definitely affect the flow of water in small tubes. For small smooth pipes the loss of head has been found to increase about 4 per cent for each 10° fall in temperature from 70° to 40° F. (2)*. Recent laboratory investigations indicate that the velocity of water in small glass tubes may be increased as much as 20 per cent when the temperature is increased from 32° to 77° F. (3)*.

Results of intake velocity tests on D-43 sampler No. 81 with water temperatures at approximately 32° and 67° F. are shown in Fig. 40. The effect of temperature shows up markedly at the lower velocities, but seems to decrease rapidly as the velocities increase. There is some inconsistency in the results at 1.0 and at 2.0 ft. per sec. for the

* Numbers in parentheses refer to references in the bibliography.

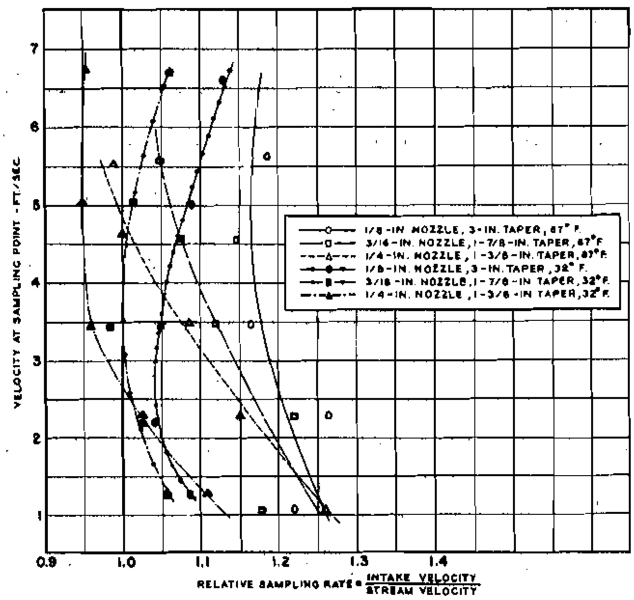

Fig. 40--Effect of temperature on intake characteristics of US D-43 sampler

1/8- and 3/16-in. diameter nozzles at the higher temperature, but the trend is quite definite.

A combination of some of the temperature data available from laboratory tests on two D-43 samplers is presented in Fig. 41. The velocities were approximately 3.5 ft. per sec. in all these tests. Similar, but not always identical, nozzles were

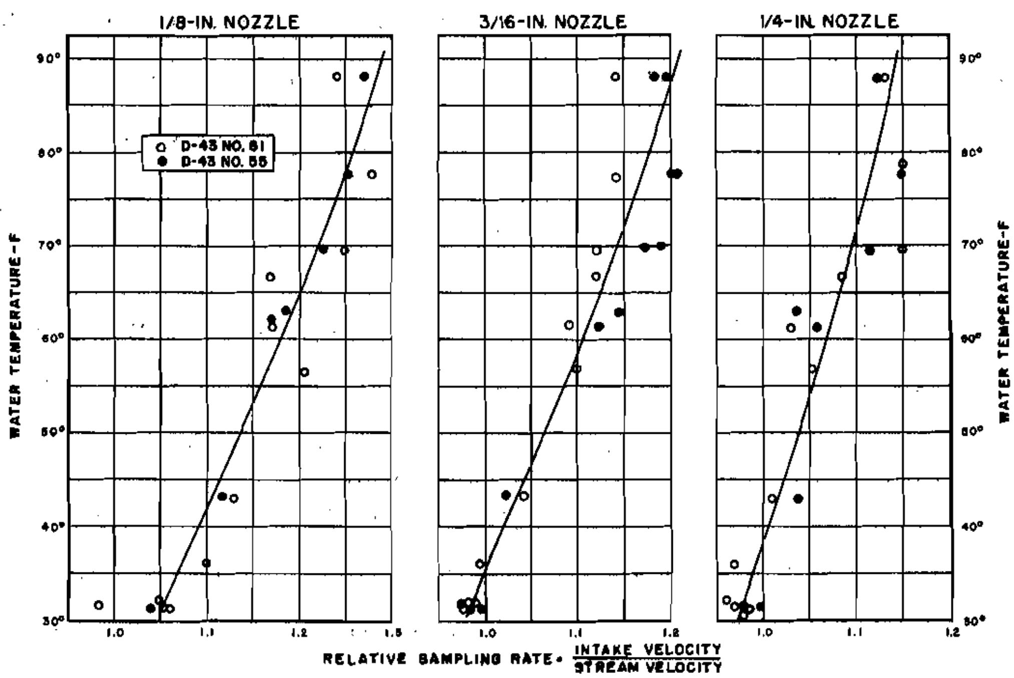

Fig. 41--Effect of temperature on intake characteristics at velocities of 3.5 ft. per sec.

used throughout the tests.

28. Effect of transit rate on intake characteristics--In the development of the depth-integrating samplers, it was recognized that the laboratory tests made with the sampler in a fixed position and the nozzle horizontal would not provide complete information on the intake characteristics that prevail when the sampler is in transit. Laboratory facilities did not permit studies to be made of normal depth-integration sampling. However, some limited laboratory tests were made with the nozzle and sampler tilted 10, 20, and 30 degrees in the vertical. These tests are comparable to collecting samples when the transit rate is such that the relative velocity vectors are likewise 10, 20, and 30 degrees. Results for a D-43 sampler with 3/16-in. diameter nozzle and at a water temperature of 32° F. are shown for two different velocities in Fig. 42. The data in terms of the relative sampling rate (intake velocity divided by the stream velocity, v) plotted against the angle of inclination (α) are shown in Fig. 42a. The same data expressed as intake ratio (intake velocity divided by v cos α) plotted against the angle of inclination (α) are shown in Fig. 42b.

The expression "relative sampling rate" as used in Report No. 5 was defined merely as the ratio of the velocity in the intake nozzle to that in the stream at the sampling point. This simply relates two velocities, but the relation has a somewhat different significance when stream velocity refers to a velocity approaching a sampler nozzle which is held in a fixed position at an angle to the flow, or when stream velocity denotes a horizontal velocity approaching a sampler nozzle which is being moved across the lines of flow.

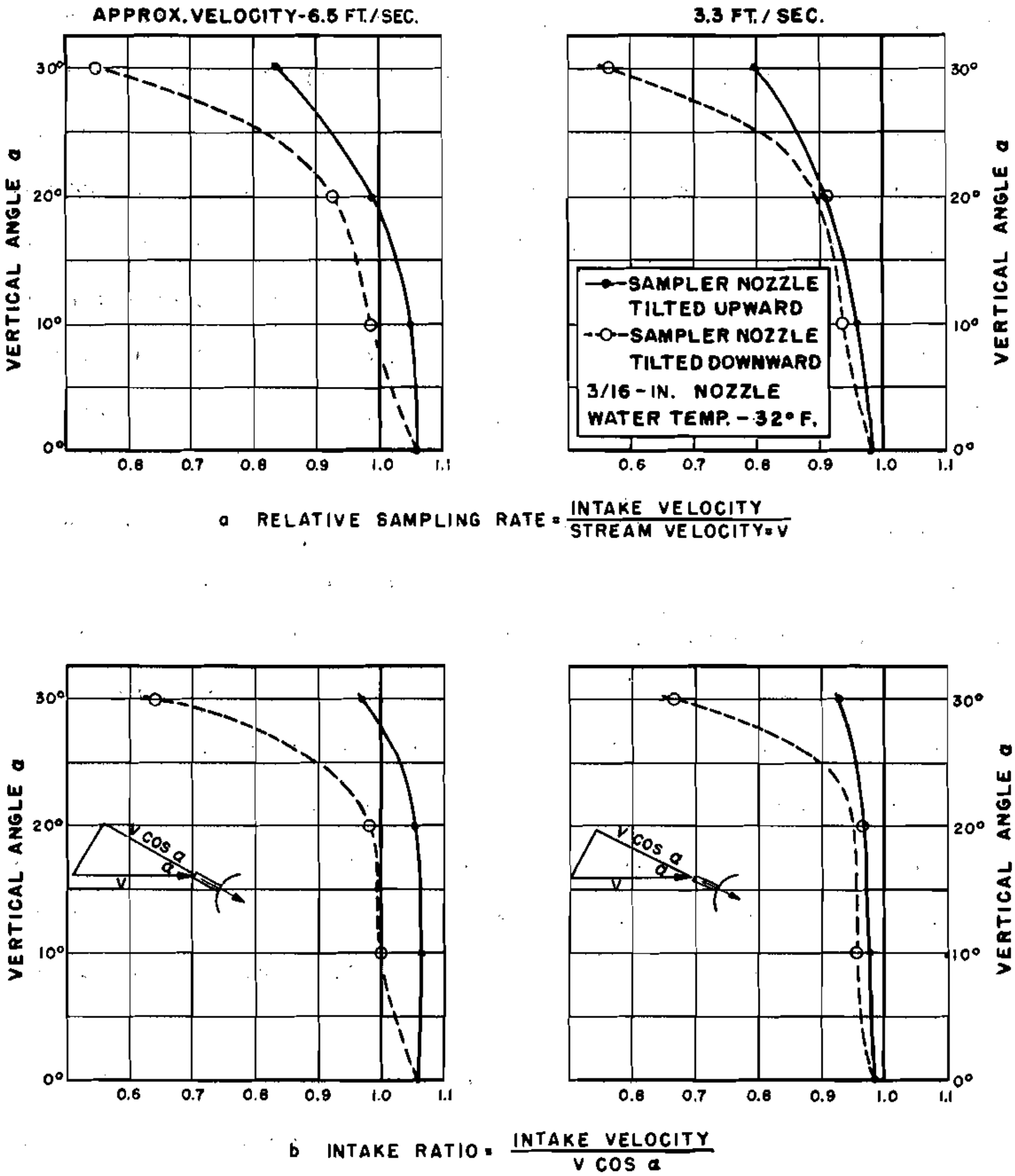

Fig. 42--Effect of small deviations from normal nozzle orientation on intake characteristics of US D-43 sampler

The data presented in Fig. 3 are a replot of data from Report No. 5 showing the intake velocity relation, the factor which determines the accuracy of the sampling process, as the ratio of the velocity in the intake nozzle to that vector of the stream velocity which approaches the intake nozzle along its axis. This vector is $v \cos \alpha$ when α is the angle between the approaching velocity and the intake nozzle as shown in the small sketches in Fig. 42b. This concept of intake velocity relations has been termed the "intake ratio." Obviously, whenever the intake nozzle is parallel to the flow, the two expressions "intake ratio" and "relative sampling rate" are equivalent, because $\cos \alpha$ is then unity.

The data shown in Fig. 42b are analogous to the results to be expected from actual depth integration with the sampler moving vertically, in which case the vector velocity would be equivalent to the stream velocity. The upward tilt of the nozzle and sampler as given here is comparable to downward transit in normal depth-integration sampling. These data seem to indicate that the maximum rate of vertical movement of the sampler for dependable operation would be about 0.36 of the stream velocity, corresponding to a vertical angle of 20 degrees. Possibly a somewhat higher rate would be allowable for downward than for upward integration.

A study of the available data indicated the desirability of determining the intake characteristics for depth-integrating samplers under controlled conditions. Laboratory tests were conducted on this basis at the David Taylor Model Basin in still water with the sampler supported on a movable carriage. This arrangement made it possible to determine the intake velocities in the sampler nozzle through a range of vertical and horizontal transit rates.

In the original plans for the tests, the sampler was to have been supported on a rigid frame assembly. However, as such equipment was not immediately available, the tests were conducted by suspending the sampler on a cable attached to a revolving drum. This procedure made it necessary to correct for downstream drift of the sampler at most horizontal transit rates.

The investigation at the David Taylor Model Basin was conducted under conditions corresponding to those in a stream in which the velocity is the same from the water surface to the bottom and in which there is no turbulence. The results, which are summarized in Table 2, verify the limiting downward transit rates obtained from equations (5) and (6) for conditions at the water surface, where the permissible lowering rates are always determined for conditions of uniform velocity; and as far as applicable these results also substantiate the limiting lowering rates of Fig. 2. The allowable relative transit rate for upward integration probably does not vary with depth, so that the limiting ratio of raising rate to stream velocity should not be exceeded at any point. Because of the shape of the normal vertical velocity curve in a stream, the velocity at the bottom will establish the limiting transit rate for upward integration. The allowable transit rate for upward integration may be found to be much smaller than the allowable transit rate for downward integration in the same stream, depending upon the depth, velocity distribution, and size of nozzle used. In order to determine the transit rate which is applicable in any specific case the limitations for both upward and downward integration should be investigated. For round-trip integration, the minimum indicated for either trip should be used.

TABLE 2

DETERMINATION OF MAXIMUM RELATIVE TRANSIT RATES

Sampler	Nozzle diameter in.	Direction of integration	Maximum relative transit rate - R_L/v_m		
			*Laboratory tests, David Taylor Model Basin $v = v_m$		Field tests, Colorado River nr Grand Canyon from equation (5)
			Test data	From equation (5)	
P-46	3/16	downward	0.45	0.39	0.40
		upward	0.35	-	-
(100 lbs.)	1/8	downward	0.20	0.17	0.18
		upward	0.30	-	-
D-43	3/16	round-trip	0.50	-	-
(50 lbs.)	1/8	round-trip	0.25	-	-

* Report entitled "Investigation of Intake Characteristics of Depth-Integrating Suspended Sediment Samplers at the David Taylor Model Basin."

The maximum relative transit rates based on the David Taylor test data are not those at which the transit rate begins to affect the intake ratio, but are the rates at which the effect on the intake ratio is the maximum which may be allowed without introducing the possibility of noticeable error in the sediment content of the sample. Consequently, the maximum relative transit rates computed by use of equation (5) are somewhat more restrictive than those determined from the test data.

The maximum transit rates shown for the conditions of the field tests in the Colorado River near Grand Canyon, Arizona, were computed by use of equation (5). At these rates, the first effect of the transit rate should appear for the conditions of velocity distribution found at the Grand Canyon station.

V. DEVELOPMENT OF NEW MODELS

29. Introductory statement--Subsequent to the developmental work on the sediment samplers previously described in this report, the cooperative project offices were moved from Iowa City, Iowa, to the St. Anthony Falls Hydraulic Laboratory of the University of Minnesota at Minneapolis, Minnesota, in the spring of 1948. The design of new models of suspended sediment samplers and the improvement of previous models were continued at the new location. Two new models recently developed are described in this chapter.

A modification of the valve and operating mechanism of the US P-46 sampler as designed and developed by the Omaha Office of the Corps of Engineers is also presented. This modified sampler has been termed P-46 E.

30. Depth-integrating sampler, US D-49--Extensive use of the 50-lb. US D-43 sampler under a wide range of field conditions indicated that it was satisfactory for streams of moderate depth and where velocities do not exceed about 5 ft. per sec. However, the tests indicated also an increasing lack of stability as the sampling depth, the velocity, or the degree of turbulence increased. The tail vane of the D-43 sampler projects below the bottom contour of the body in order to facilitate orienting the sampler into the stream flow prior to submergence. It was found that, when the bottom tip of the tail vane struck the stream bed and the tension in the suspension cable slackened, the body of the sampler would be turned sideways by the current before the suspension cable was tightened again for the ascending trip. In order to

correct these deficiencies and to incorporate other indicated improvements in the depth-integrating sampler, it was decided to develop another model.

In the new sampler, designated the US D-49, improved stability was obtained by more effective streamlining, increasing the length from 20.5 in. to 24 in., and by shifting the center of gravity forward to bring the point of suspension of the instrument relatively closer to the front of the sampler. Under some field conditions where the stream flow was very turbulent and the velocities around 5 to 8 ft. per sec., the D-43 sampler would weave about in the flow and drift downstream considerably. As anticipated during the development of the D-49 sampler, increasing the weight to about 63 lbs., together with improvements in the body design, largely remedied this condition.

To bring the center of gravity forward in the US D-49 sampler, a cavity was formed in the rear portion of the body casting, which was later filled with plastiflex, a rubber-like substance with a specific gravity slightly over unity. The presence of a light-weight section within the body of the sampler displaces the center of buoyancy backward from the center of mass. Consequently, the instrument can be balanced in water so that it will operate in a horizontal position. Yet when the instrument is suspended in air the tail will sag slightly, thus helping to align the sampler with the stream flow even though the bottom of the tail does not project below the body when the sampler is in a horizontal position.

As originally designed, the head of the D-43 sampler was mounted on the body with the hinge on the top and the catch on the bottom to permit use of a bottom tripping device. Reversing the position of the catch and hinge, with the hinge on the bottom so that the sampler head would swing downward to open, had been under consideration for some time as a means of making the sampler safer and easier to operate. This change was made on the new model, and the hinge was also simplified, giving better operating characteristics and reducing the cost of manufacture.

The development of the stainless steel air exhaust in the US DH-48 sampler and improvement in casting methods made it possible to invest a similar pre-shaped tube in the head casting for the D-49 sampler. Thus an expensive machining operation to provide the air exhaust passage was eliminated. Lugs were cast in the bottom of the container cavity to hold the bottle spring, and the bottle gasket was also simplified somewhat.

Photographs of the US D-49 depth-integrating sampler are shown in Fig. 43 and partial plans are shown in Fig. 44.

The intake characteristics of this new model are the same as those of the D-43, and the same accuracy, methods of operation, etc., are applicable. With the improved air exhaust, less taper is required in the nozzles of this instrument to provide the desired intake ratio.

31. Alternate valve mechanism for P-46 sampler--An alternate valve mechanism for the P-46 sampler has been developed in the Omaha District Office, Corps of Engineers. Samplers equipped with this mechanism are designated P-46 E. The valve includes a bypass to divert flow out of the intake nozzle prior to sampling, the purpose being to avoid any possibility of developing an accumulation of sediment in the nozzle

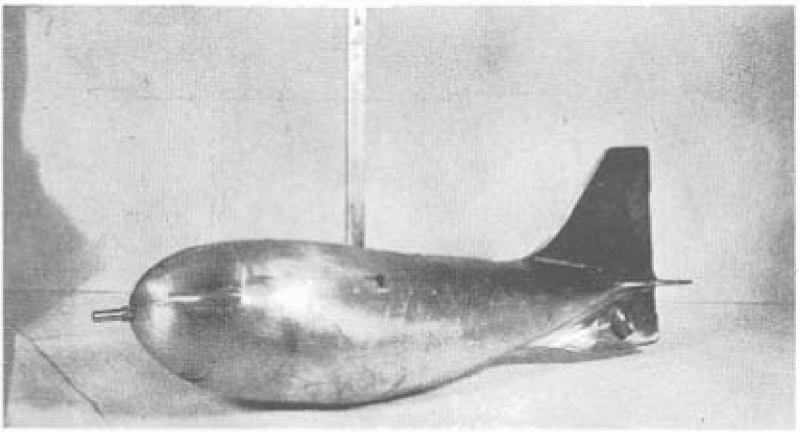

Fig. 43a--Depth-integrating suspended sediment sampler, US D-49

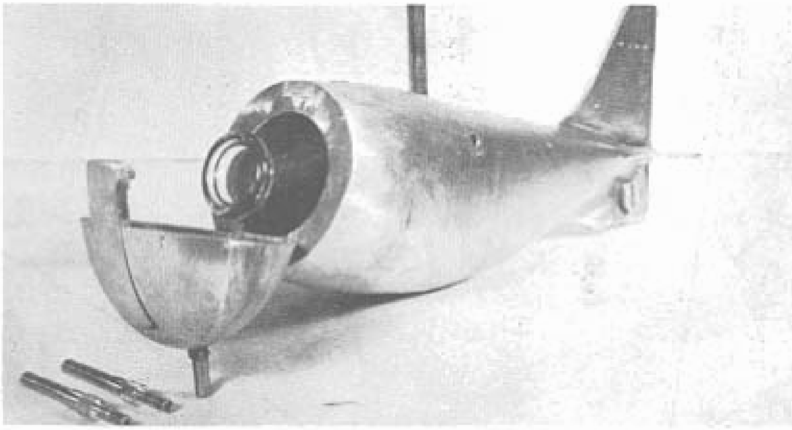

Fig. 43b--Depth-integrating suspended sediment sampler, US D-49, head open

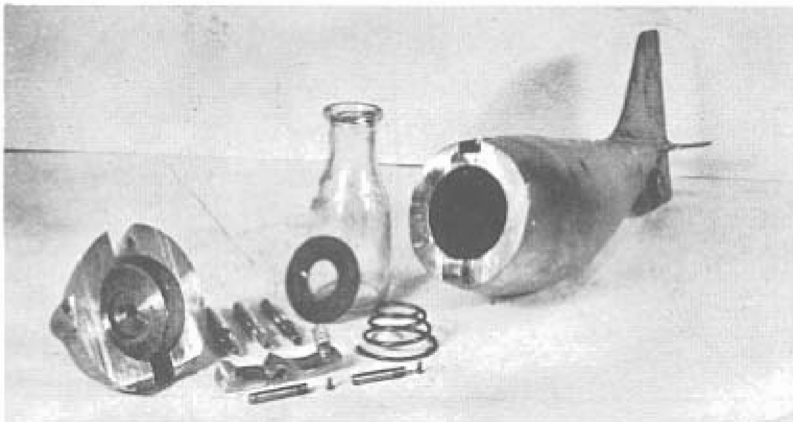

Fig. 43c--Depth-integrating suspended sediment sampler, US D-49, disassembled

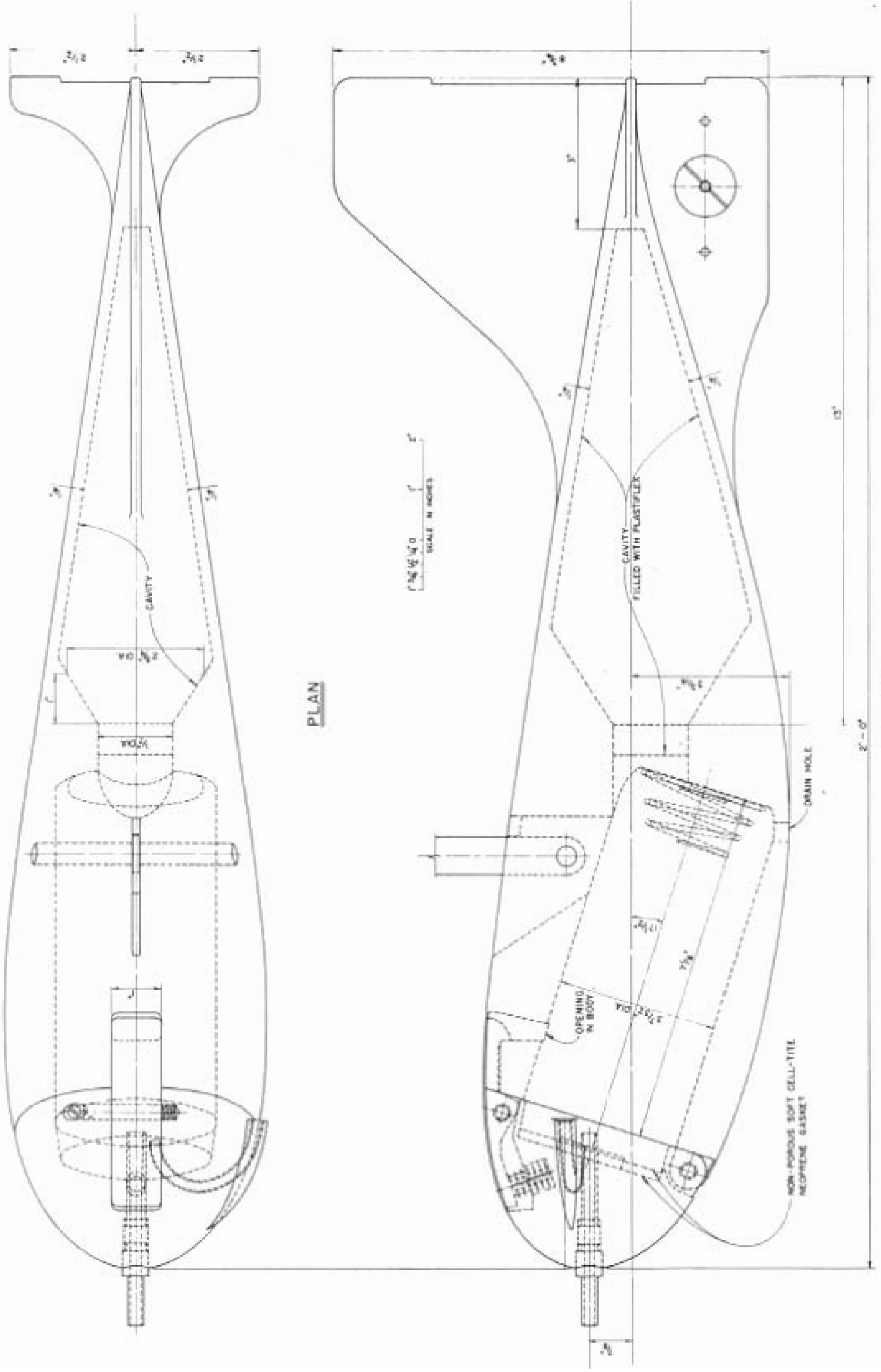

Fig. 44--Depth-integrating suspended sediment sampler, US D-49

which would be washed into the sample bottle when the valve is opened for sampling. There seems to be some doubt as to the complete effectiveness of this bypass and no conclusive data are available on this point. Tests presented in the progress report "Field Tests on Suspended Sediment Samplers, Colorado River at Bright Angel Creek near Grand Canyon, Arizona, August 1951" indicate that even without a bypass there was very little accumulation of sediment in the sampler nozzle prior to sampling.

The head of the sampler is pressurized, that is the compression chamber and the head cavity are connected at all times by an air passage, but the passage of air from the head cavity into the sample bottle is controlled by the valve. This arrangement reduces the theoretical depth to which the sampler can be operated from about 140 ft. to about 75 ft. By making the pressure inside the head equal to that outside, the tendency for leakage into the head and through the valve is reduced. Some of the regular US P-46 samplers have been similarly pressurized by making a hole in the compression line inside the head cavity. Pressurizing the head is optional on any of the US P-46 samplers.

The movable portion of the valve slides longitudinally rather than rotating as in the standard US P-46 mechanism. Apparently either type of motion is reasonably satisfactory. The P-46 E mechanism does not require winding, but there is no simple provision for loosening the valve to start operation if the valve should stick or become hard to operate.

The modified mechanism returns the valve to the closed position at all times when the instrument is not electrically activated. Besides the closed position, there are two other positions, (1) the equalizing position which is used just prior to sampling to equalize the pressure in the sample bottle at the same time the bypass is open to allow flow to circulate through the intake, and (2) the sampling position in which the intake nozzle passage into the sample bottle and the air exhaust passage from the sample bottle are both open. Two solenoids are provided for the operation of the valve. One operates to slide the valve into the equalizing position, and the other does the same for the sampling position. The direction of the operating current, which must pass through a rectifier in the sampler head, determines which of the solenoids will operate. The electrical circuit is closed through the suspension line and sampler in one certain direction to place and hold the valve in the equalizing position, then the direction of the current flow is reversed to move the valve into the sampling position. The current supply is shut off at the end of the desired sampling time and the valve moves back to the closed position. With the mechanism operating properly, the position of the switch automatically indicates the position of the valve. Operation of this mechanism requires direct current of about 80 volts capable of supplying about 3 amperes for the duration of the sampling time.

The cost of manufacture of the P-46 E type of mechanism has been about the same as that for the standard US P-46 mechanism, although the latter is generally considered the simpler to make.

Photographs and partial plans of the P-46 E valve mechanism are shown in Figs. 45 and 46, respectively.

32. Point-integrating sampler, US P-50--The demand for a point-integrating sampler for use in extremely deep rivers of high velocity

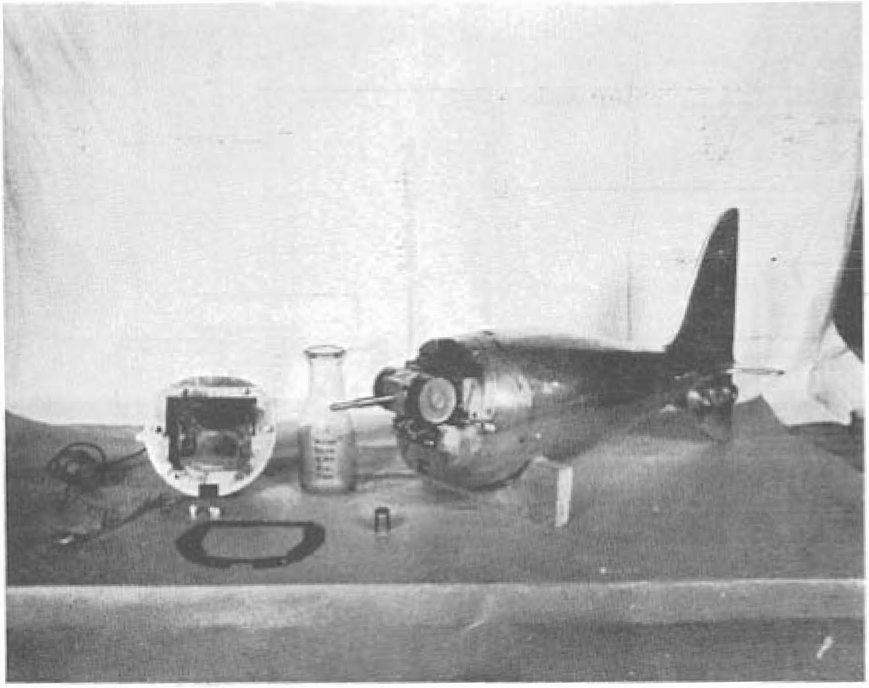

Fig. 45a--Valve mechanism for P-46 E sampler

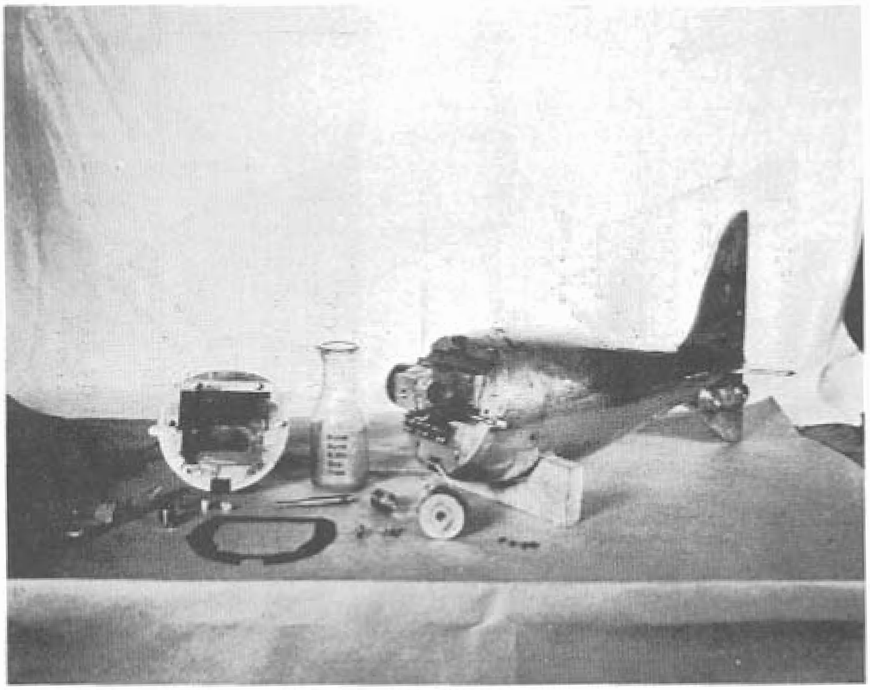

Fig. 45b--Valve mechanism for P-46 E sampler, disassembled

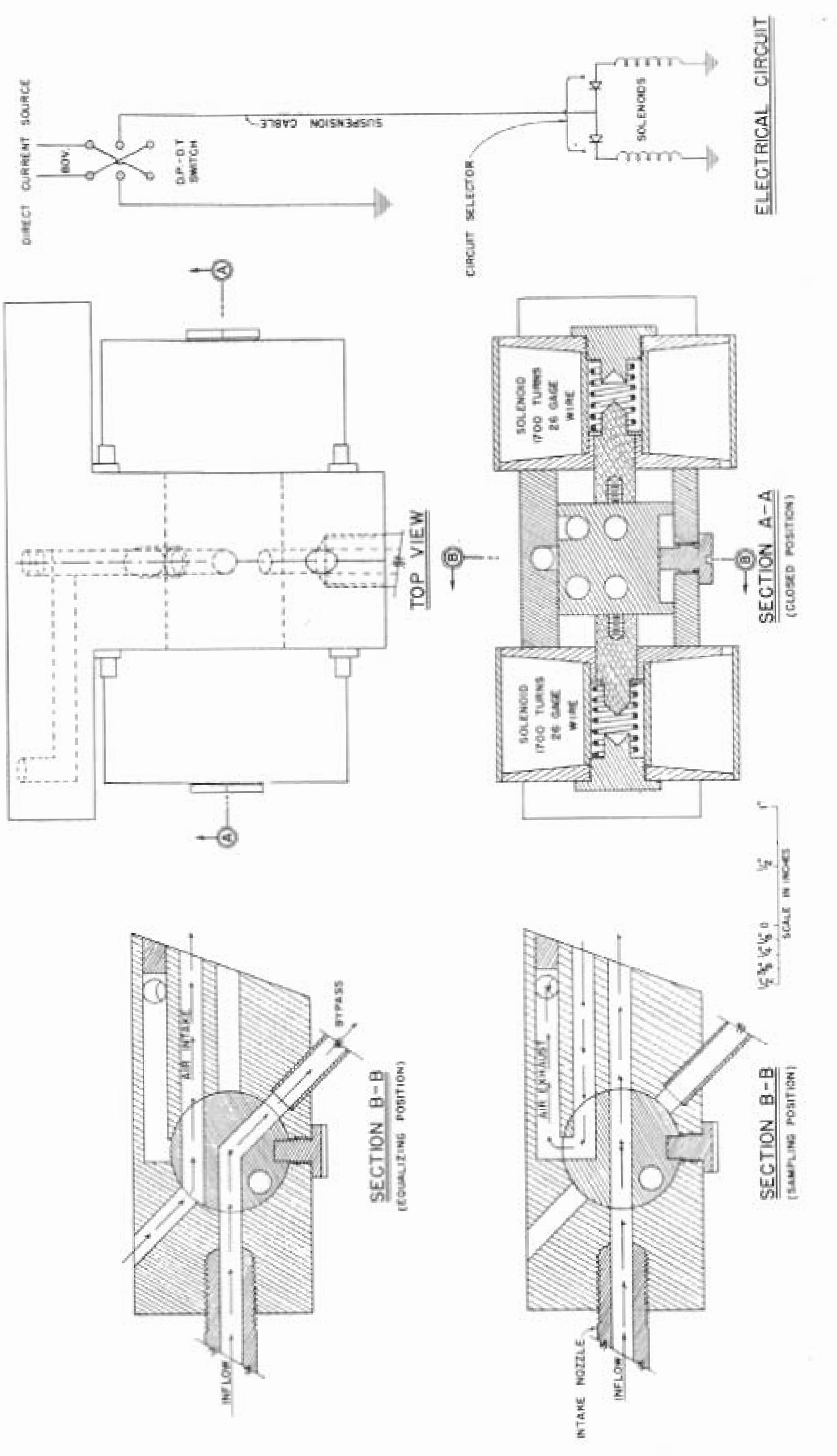

Fig. 48--Valve mechanism for P-46 E sampler

resulted in the design of a 300-lb. point-integrating suspended sediment sampler designated US P-50.

This sampler was designed primarily for use under conditions such as encountered in the Lower Mississippi River where the stream depths and velocities preclude the use of the US P-46 sampler. The body is sufficiently large to accommodate a quart bottle as a sample container, and a compression chamber in the body to permit operation of the sampler to depths of 200 ft. with the head cavity pressurized. The compression chamber is located approximately on the center of gravity of the sampler so that the instrument will not tilt appreciably as the compression chamber is filled with water. The center of gravity is located as far forward as possible in order to provide stability in turbulent flow. The sampler head, being hinged at the bottom, opens downward for ease and safety in handling.

The sliding type of valve operated directly by solenoids was adopted. However, for simplicity of operation, only two positions are used. A spring holds the valve in the equalizing position, and the solenoids when electrically energized hold it in the open position. In the equalizing position, the intake and air exhaust passages are both closed, but the air passage from the sample bottle into the pressurized sampler head is open. The sample could thus be contaminated by the almost complete filling of the sampler head with water, and sample could be lost if the sampler were to nose downward at an angle of about 15 degrees. Both solenoids exert pressure in the same direction. The direction of electrical current flow is immaterial, and no rectifier is needed. The solenoids are arranged so that one acts as a starter and booster for the slide valve, and a limit switch cuts out that solenoid when the slide valve has nearly reached the sampling position. The limit switch is not an essential feature as the starting solenoid may be used throughout the sampling time, but by de-energizing this solenoid the current requirements are reduced and the action of the holding solenoid is slightly strengthened. The holding solenoid is always in use when the current supply is turned on, and this solenoid will operate the slide valve alone under favorable conditions.

Sampling takes place during the time the solenoids are energized. Operation on bench tests has been satisfactory at 14 volts. Presumably 20 to 50 volts of direct current capable of supplying about 1 ampere over the time of sampling would be needed for field operation, the voltage requirements increasing with the length of suspension line.

The US P-50 sampler is designed for the same type of sampling and is expected to have the same sampling characteristics and accuracy as the US P-46. Photographs and partial plans of the US P-50 are shown in Figs. 47 and 48, respectively.

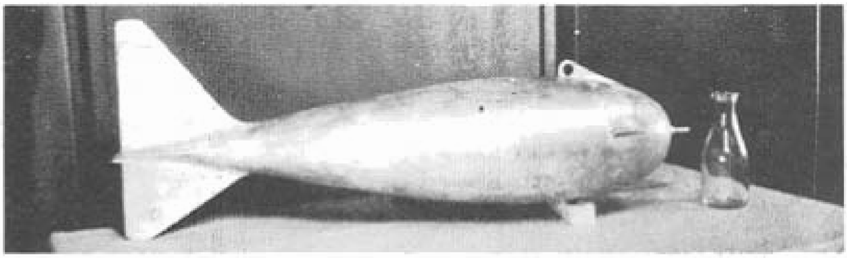

Fig. 47a--Point-integrating suspended sediment sampler, US P-50

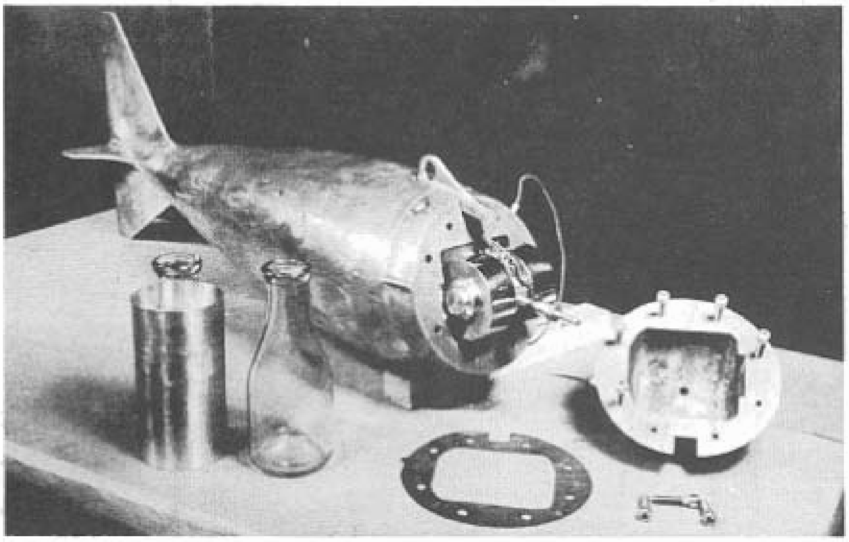

Fig. 47b--Point-integrating suspended sediment sampler, US P-50, head cover removed

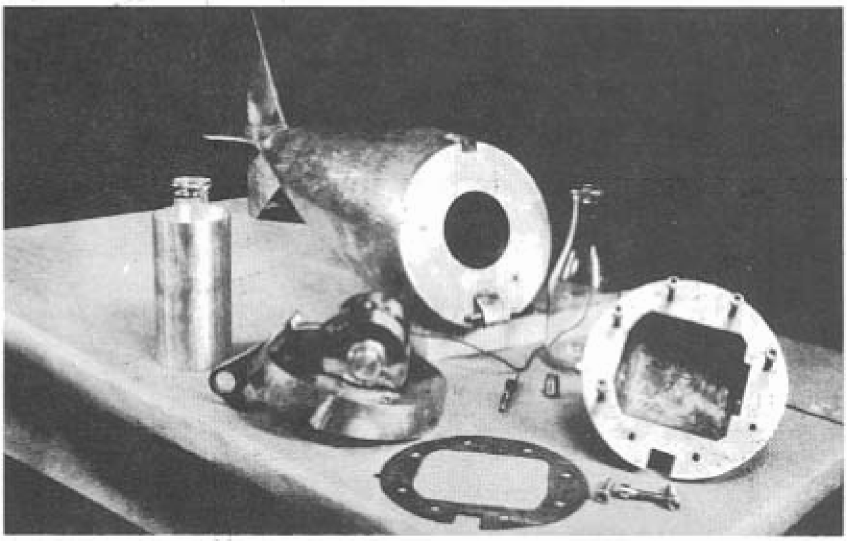

Fig. 47c--Point-integrating suspended sediment sampler, US P-50, head cover and head base removed

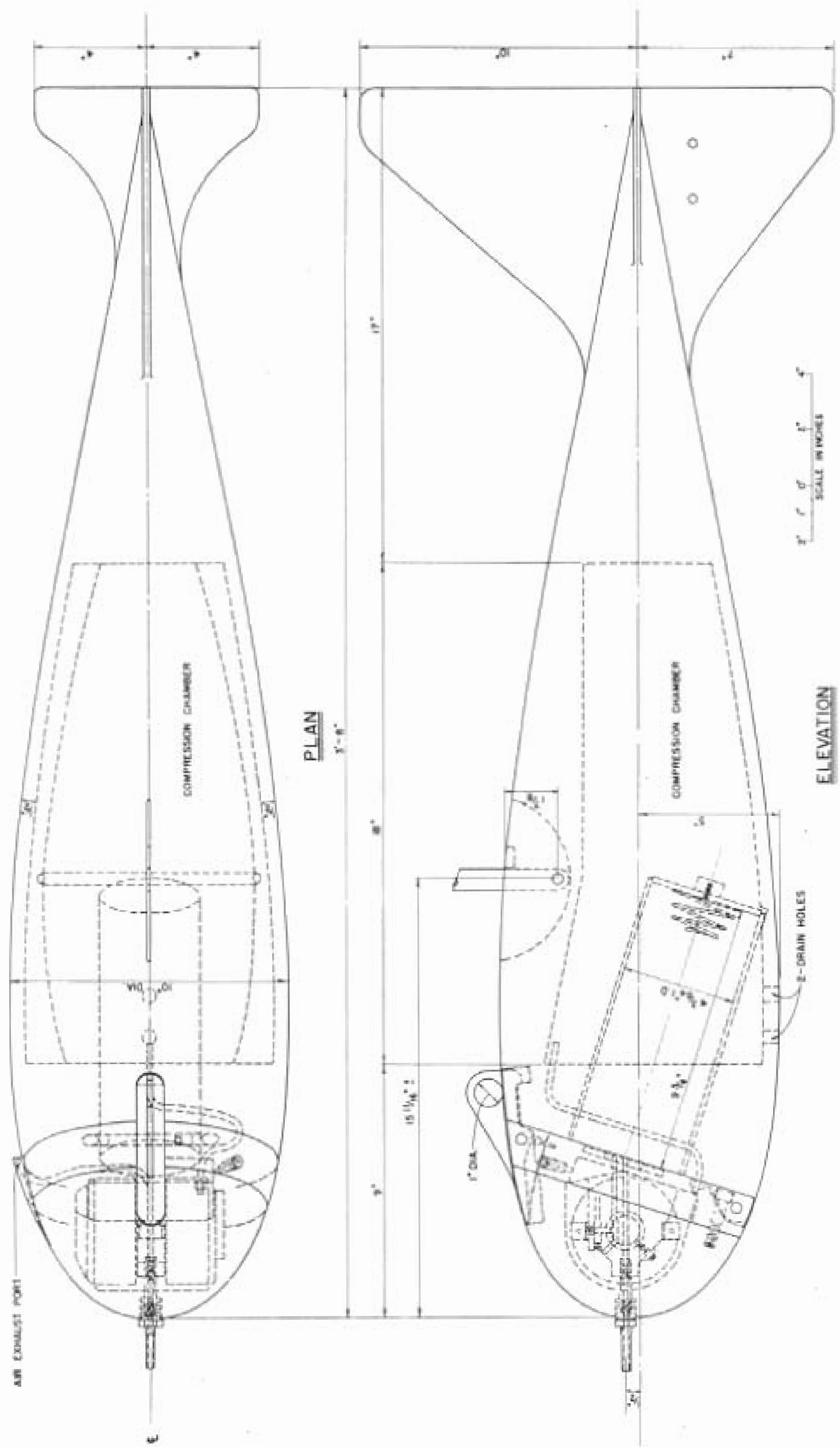

Fig. 48a--Point-integrating suspended sediment sampler, US P-50

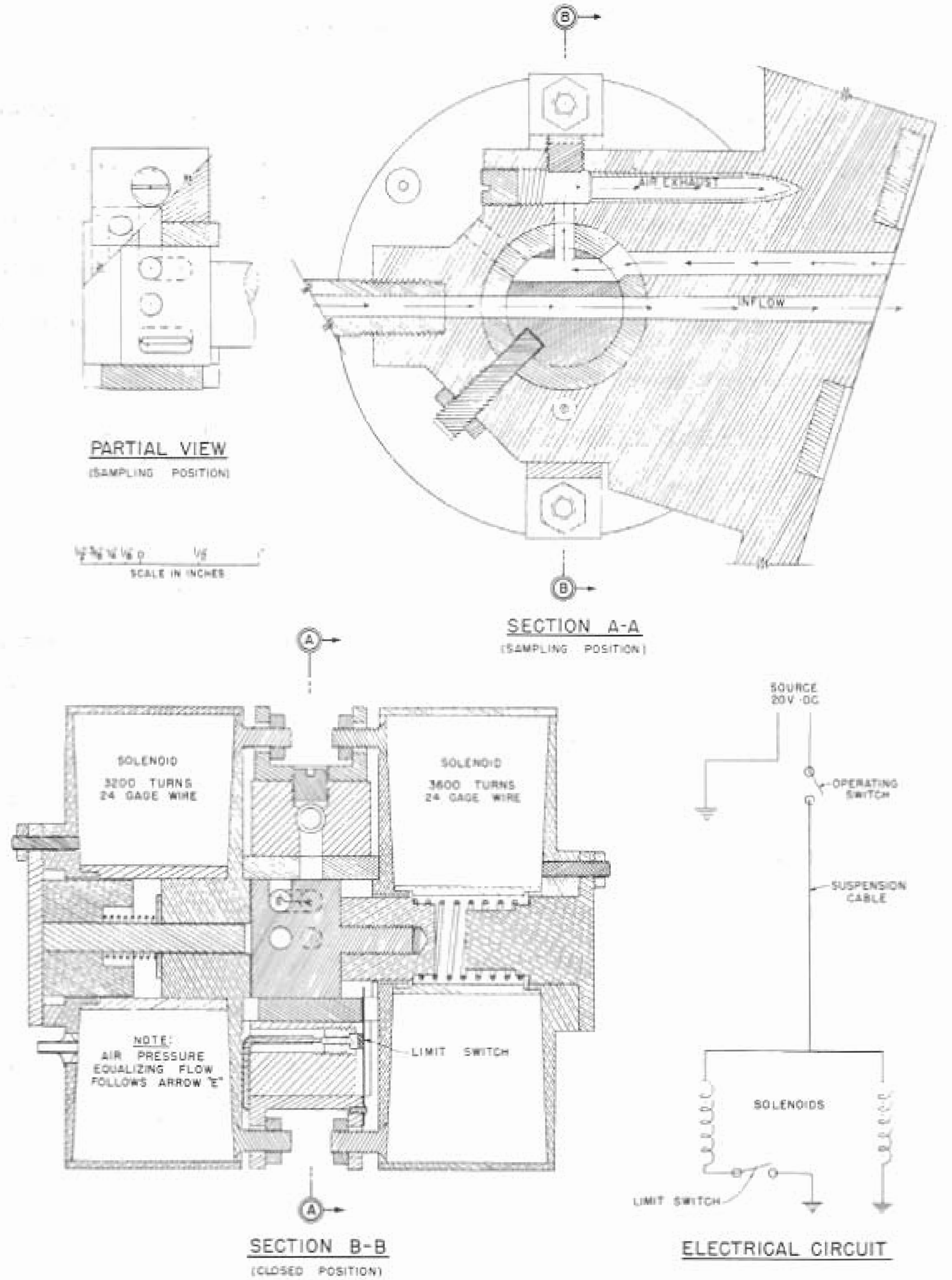

Fig. 48b--Point-integrating suspended sediment sampler, US P-50, valve mechanism

VI. DEFERRED INVESTIGATIONS

33. General--During the course of developing the sediment samplers, a number of pertinent features under consideration were necessarily left in abeyance because the war emergency made it necessary to curtail the initial project. Some of these items have since been investigated in connection with continued sampler development, others are mentioned here as possible projects for future investigation.

34. Collapsible bag sample container--Consideration was given to using a collapsible bag, possibly of some transparent flexible plastic, instead of a rigid vessel for the reception of the sample. The bag might be attached by means of a metal ring to the inside of the sampler head. The head would be fitted with an intake nozzle only, no air exhaust being required because the bag would be collapsed when placed in the sampler. Ports in the walls of the recess enclosing the deflated bag would permit water to surround the bag, thereby eliminating any initial inrush due to unequal pressures. The velocity of the stream would force water into the collapsed bag while the water within the bag recess would escape through the ports in the sides and bottom. This type of container could be used in both point- and depth-integrating samplers.

While the collapsible bag container would have several desirable features, it probably would not be as satisfactory as the glass bottle adopted for the US samplers. The removal of the collapsible bag from the sampler to a rigid container in the field would present some practical difficulties. The valve in the intake nozzle would have to be positively tight in order to keep the bag collapsed and the fittings required to attach the bag to the head would complicate its removal in the field. In addition, the procedure in pouring and flushing the sediment sample from the bag to a laboratory container such as an evaporating dish or Gooch crucible would be more difficult than from a rigid container.

35. Rigid plastic container--In the use of the present sample container, frequently the sample is allowed to settle for a given period and the clear water drawn off by means of a siphon. Then the remainder of the water-sediment mixture is washed into a Gooch crucible or evaporating dish. As this procedure is rather laborious, some thought was given to the design of a special container which could be used in connection with a modified form of the present evaporating dish. The container would be made of a colorless plastic having straight sides graduated between 350 and 450 ml., with a milk-bottle type of lid, and a hole in the bottom threaded for a removable plug. A special evaporating dish would be made to fit the top of the container. Thus with the container inverted the sediment would settle directly into the evaporating dish. The clear water would then be drawn off through the hole in the bottom. The study given to this type of container was not carried beyond a limited design because it was thought that the development costs would be excessive.

36. Pressure equalized by means of gas or compressed air--It is believed that for most sampling purposes the pressure equalizing method used in the design of the present point-integrating samplers will be satisfactory. It is automatic, utilizing materials at hand, namely, air and water, without any attention from the operator except an occasional

inspection to insure that water and air passages remain open. However, if the requirements of a particular sampling program should preclude use of the diving-bell principle, initial inrush could probably be overcome by introducing into the air chamber a small amount of frozen carbon dioxide or carbide, and plugging the hole in the bottom of the sampler. The gas generated would create pressure in the chamber and sample container. Then if the water intake and air exhaust were opened and the connection to the gas chamber closed, any excess pressure within the sampler container would be instantly relieved and the sampler would immediately begin filling at a rate equal to the stream velocity at the point. Pressure in the chamber and container might be supplied by threading a valve into the hole at the bottom of the sampler and pumping air into the chamber. This would necessitate designing the connections, container, etc., to carry a pressure of about 20 lbs. per sq. in.

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