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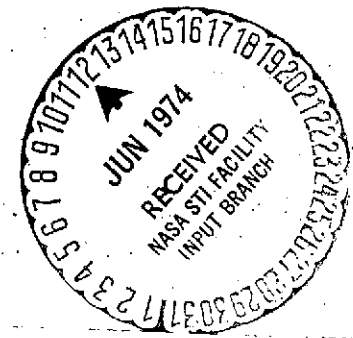
# DEVELOPMENT OF A PROTOTYPE FLUID VOLUME MEASUREMENT SYSTEM

For  
NASA Johnson Space Center  
Contract No. NAS-913461

April 1974

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(NASA-CR-134274) DEVELOPMENT OF A  
PROTOTYPE FLUID VOLUME MEASUREMENT SYSTEM  
(Geoscience, Ltd.) 38 p HC

N74-25927

CSSL 14B 63  
8/14 Unclas  
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## Preface

During the past year, Geoscience has conducted a program which involves the application of the company's axial fluid temperature differential flowmeter to a urine volume measurement system for space missions.

This work was conducted under contract NAS-913461 for NASA's Johnson Space Center. The program monitors were Mr. Richard Sauer, Head, Water and Waste Management, and Mr. Brock Westover.

The Fluid Volume Measurement System consists of two parts; (1) the Prototype Equipment Package (PEP) which includes an inlet cone, flexible tubing, the thermal flowmeter, supporting electronics and digital readout, and (2) the Supporting Equipment Package (SEP), consisting of a collection container and a blower with an odor control filter. Geoscience Ltd was responsible for the Prototype Equipment Package and General Electric Company was responsible for the total system.

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## I. INTRODUCTION

The work scope of the program as defined in the subject contract is shown in the Appendix under a Statement of Work. In brief, the tasks can be categorized as follows:

1. Construction and delivery of a breadboard Fluid Volume Measurement System (FVMS),
2. Design, fabrication and checkout of an optimized prototype PEP for the FVMS,
3. Preparation of a final report describing the breadboard system as well as the optimized prototype system.

Geoscience has completed all requirements stipulated in the subject contract. Specifically, a breadboard PEP has been fabricated and delivered to NASA and General Electric, breadboard FVMS demonstrations were made at JSC and an optimization effort for a prototype system has been completed. This work is reported in the following sections:

## II. FVMS BREADBOARD RESULTS

### A. Description of the PEP

The concepts that define the axial fluid temperature differential flowmeter have been described in a previous technical document.<sup>1</sup> A brief recapitulation of the major components involved would be appropriate. The axial wall temperature gradient of the latter portion of the flow tube in the flowmeter lies in the established flow region. Therefore, this wall temperature gradient (which, under these conditions, is equal to the fluid temperature gradient) is uniquely related to the mass flows through the tube for a constant and uniform tube wall heat addition by a small amount of thermal power. It has been shown that the enthalpy of the liquid phase in an air-liquid flow mixture controls the heat transfer for the air and liquid flow rate ranges of interest. The axial fluid temperature gradient or differential is measured by a thermopile in terms of a millivolt signal. The quantity of liquid flowing through the flowmeter during a volume discharge is obtained by integrating the transient flow rate over the time period involved. This process requires that the output voltage (which is inversely related to flow rate) must be inverted before the integration is performed. The details of the inverter-integrator electronic components were also previously described.<sup>1</sup>

Figure 1 shows a photograph of a two-phase flow mixture exiting from the thermal flowmeter during a test run. The photograph in Figure 2

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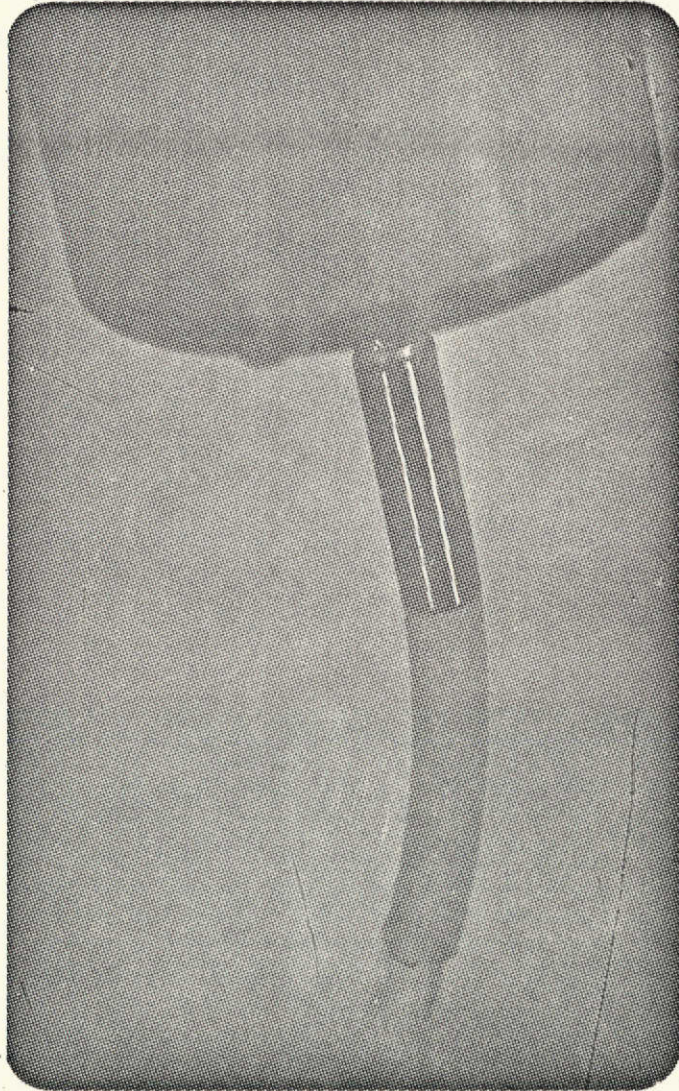


Figure 1. Photograph of two-phase flow exiting the thermal flowmeter during a test run.

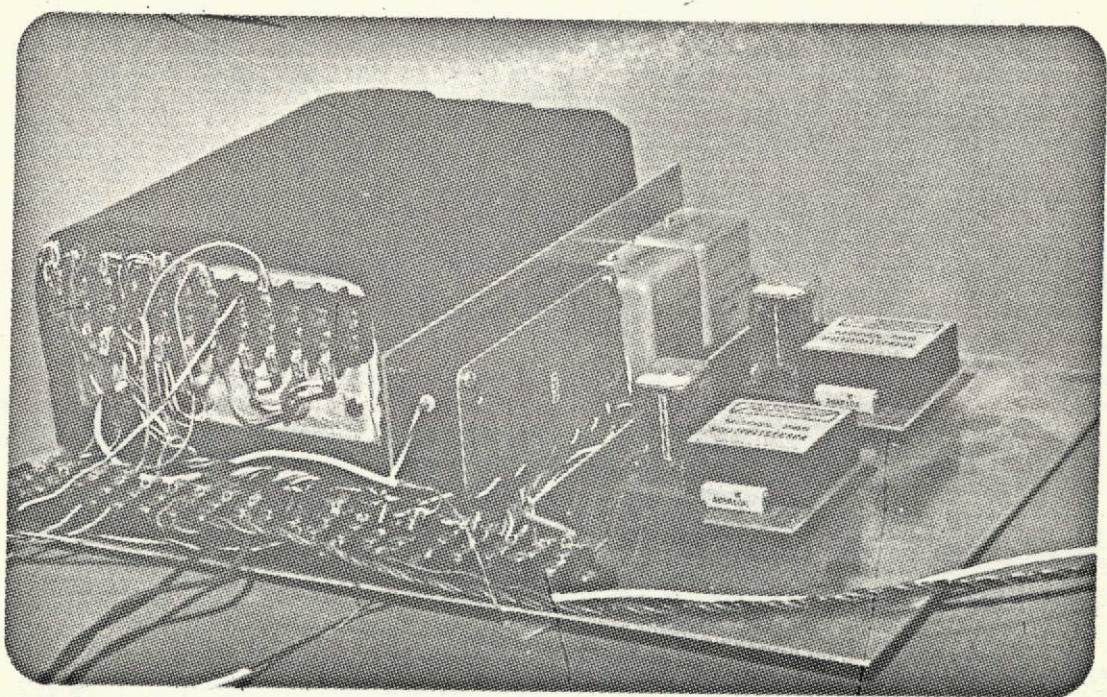


Figure 2. Photograph of the inverter-integrator electronic package.

depicts the inverter-integrator electronics package for the flowmeter. The PEP installation in the FVMS breadboard housing prior to shipment to the General Electric Company is shown in Figure 3.

#### B. Flowmeter Calibration

Several breadboard flowmeters were fabricated in the program. Calibrations were performed both by pressurized two-phase flow into the flowmeter and by vacuum suction at the flowmeter exit. No difference in calibration was observed between the two methods. In all cases, air flow was metered by a rotameter and liquid flow by measuring the time required to collect a known volume. Figure 4 shows a flowmeter output voltage recording as a function of liquid flow rate during a calibration run. Note the high sensitivity of the flowmeter to the turbulent two-phase flow. A typical calibration curve for one of the flowmeters is shown in Figure 5. From the flowmeter theory it is known that the calibration curve of liquid flow rate versus the output voltage signal should fall along a linear curve on a log-log plot having a slope of minus one. The straight line shown plotted through the points in Figure 5 has this function. As a matter of fact, the difference between the experimental straight line and the predicted one, based on heat input and system geometry, was found to be 2.2 percent.

#### C. Electronic Signal Processing and Control Package

The electronic equipment associated with the PEP is required to perform several separate functions. Equipment for most of these functions has been packaged into a single housing. The principal functions are:



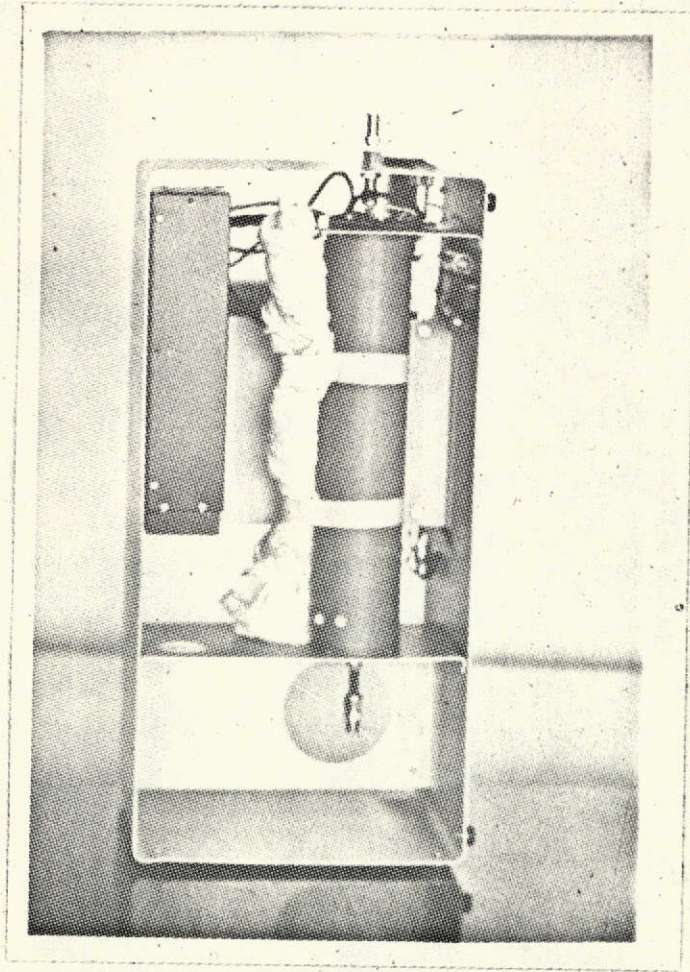


Figure 3. Photograph of the PEP installation in the FVMS breadboard.

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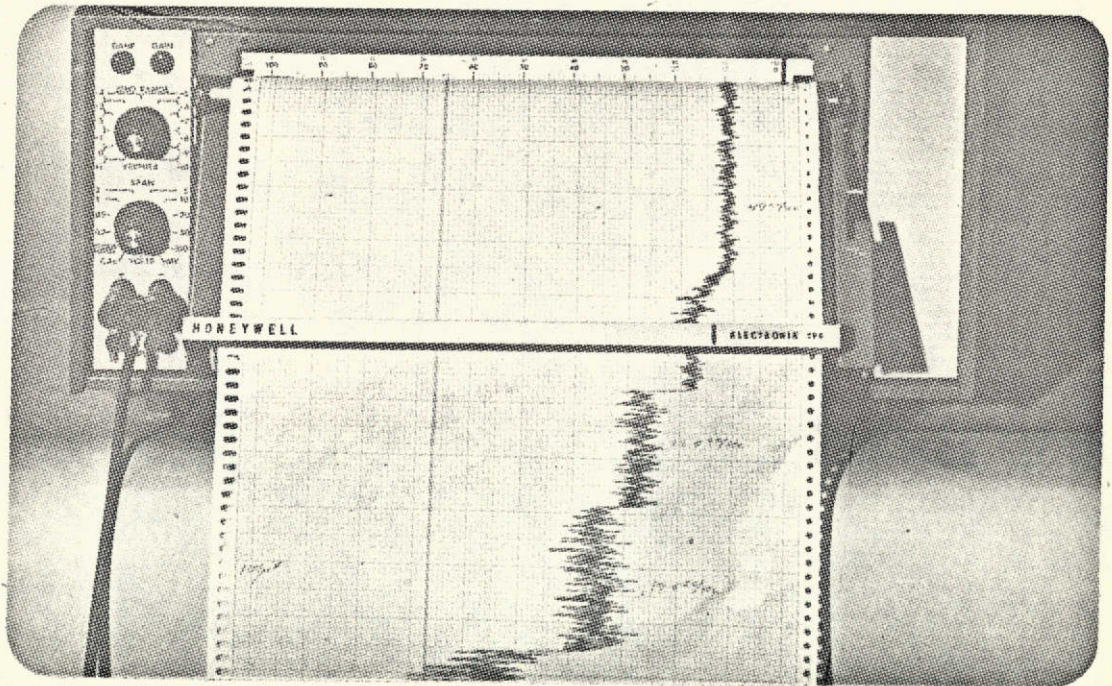


Figure 4. A typical flowmeter output voltage recording during a calibration run.

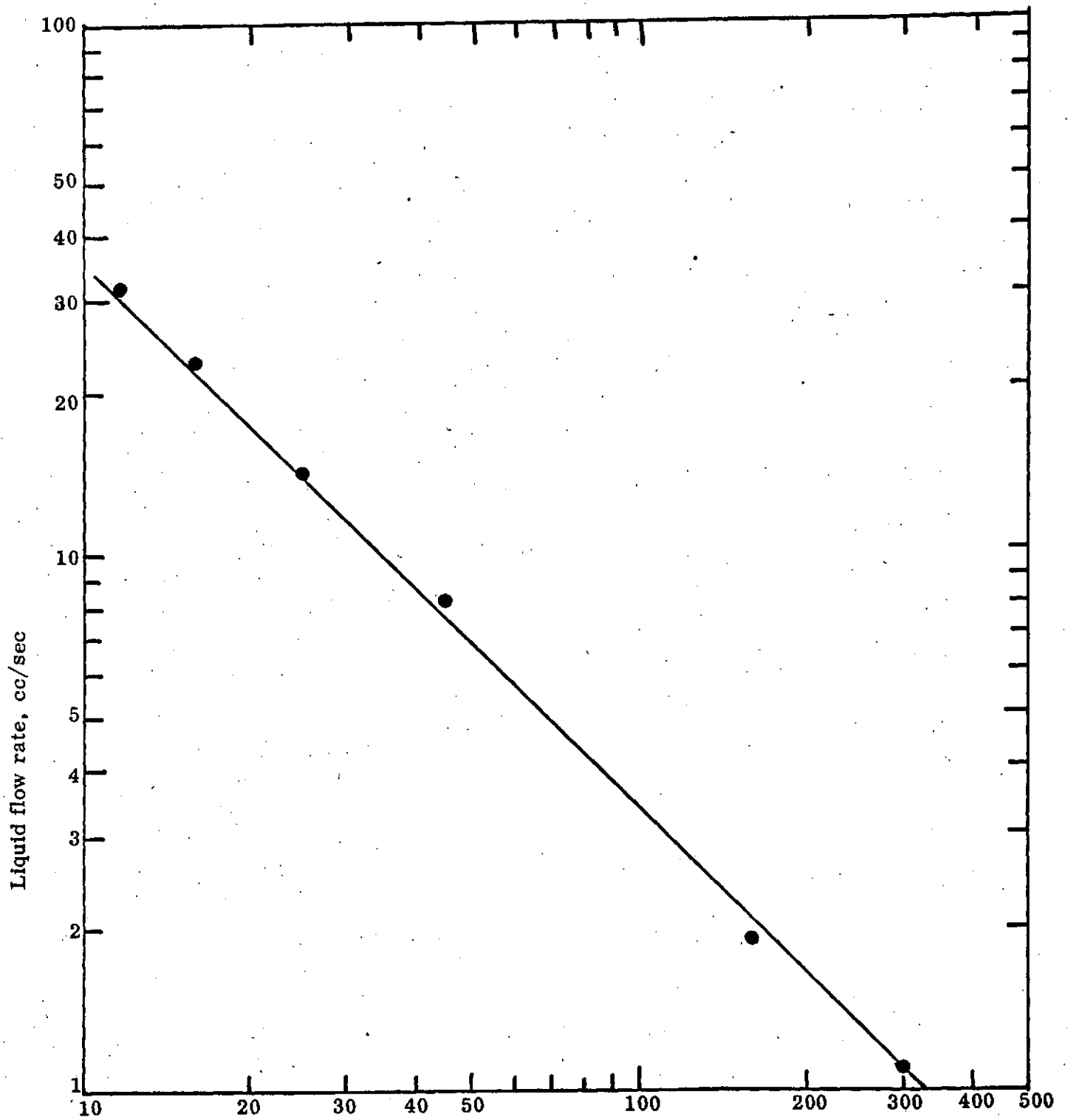


Figure 5. Breadboard flowmeter calibration at 20 watts power input (airflow 160 cc/sec).

1. Supply 25 watts of low voltage 400 Hz power to the flow tube during operation
2. Invert and integrate flowmeter signal
3. Switch integrator on at start of flow and off at end of flow
4. Switch flowmeter power on and off
5. Provide temperature control for the flowmeter guard heater.

A number of subsystems are also required which assist in accomplishing the functions listed.

A number of modifications were made to the electronics package during the program. The majority of these modifications were made for convenience in the test and operating procedures required during the program, but a few were necessary to improve performance of individual subsystems. Some of the modifications made are described below:

1. Inverter-Integrator Package

Two complete versions of the inverter-integrator assembly were constructed during the program. The first of these was replaced when an analog inverter with a considerably wider dynamic range became available. The one presently in use is linear within 0.5 percent over an input signal range of 100 to one. At the time this component was replaced, some other detail circuit modifications were made to simplify adjustment and internal monitoring functions for the breadboard use, and construction of a complete new assembly.

(utilizing the same subcomponents) proved to be the simplest means of accomplishing these changes. Typical performance of the inverter-integrator unit is shown in Figure 6.

## 2. Switching Functions

The functions of flowmeter power control and integrator control received the principal attention during the program, since the basic inverter-integrator and flowmeter power assemblies proved to be suitably accurate and reliable to meet the overall volume measurement specifications. Many of the electronic switch modifications were required to improve electrical isolation of one component from another. Although the assembly used during the development effort (shown in Figure 2) was satisfactory when the volume measurement equipment was operated alone, the addition of the centrifuge, vacuum pump, sample storage pump, timer, and other equipment necessary to the operation of the FVMS caused significant changes in electrical noise level and erratic switch operation. This difficulty was overcome by a combination of careful shielding, elimination of electrical ground loops, and filtering of some power circuits. Several of the switch functions are controlled by thermocouple outputs, and these inherently low level signals must be shielded with care when large currents are being switched in adjacent circuits.

The electronics assembly provided with the breadboard FVMS is contained within two separate packages, since it was impractical

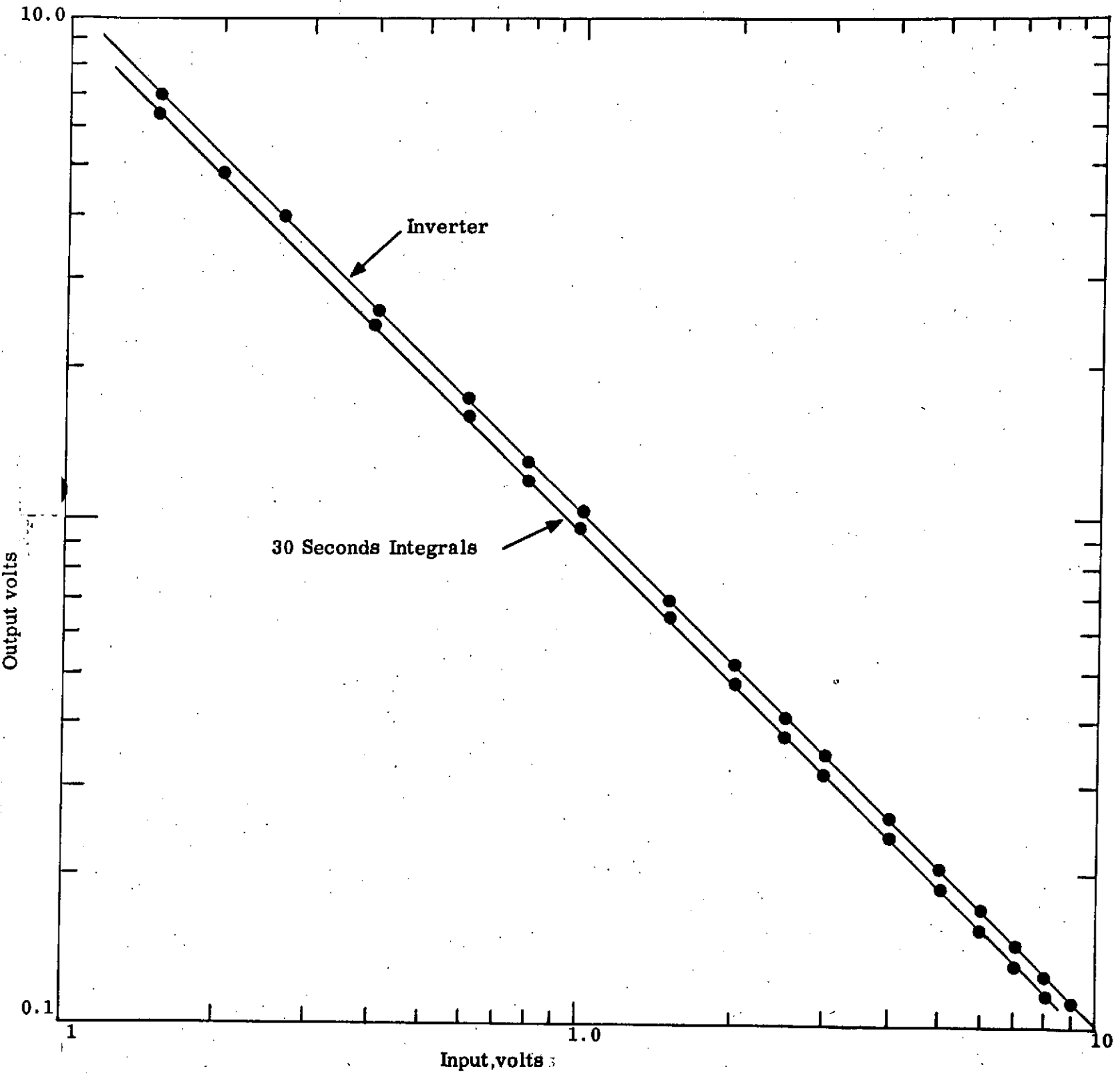


Figure 6. Calibration curves for inverter-integrator.

to rearrange existing components in the original housing so that the isolation modifications could be incorporated. Other electronics assembly modifications made during the program are described in Section III.

The present breadboard PEP circuit arrangement has not been optimized for either volume or weight, and a single package incorporating the necessary circuit isolating features in size reduced from the larger of the two breadboard packages could be achieved even with the presently used components. With the anticipated changes to more compact components where such components are available, the package size required for the FVMS flight hardware can be readily achieved.

#### D. Typical Void Volume Measurements

The PEP breadboard system was tested and calibrated in the laboratory using an air suction flow arrangement in the FVMS breadboard system. Figures 7 and 8 show some of the initial volume-signal calibrations obtained in July, 1973. In these tests, graduated flasks of 100° F water (150 cc, 200 cc, 255 cc, 300 cc, 400 cc, 500 cc, and 755 cc volumes) were emptied into the cone receptacle at the inlet of the flowmeter with suction air on. In Figure 7, two of the twenty-two data points fall slightly out of the  $\pm$  five percent error bands shown; the mean error was found to be  $\pm$  2.6 percent. In Figure 8, one of the eleven data points shown falls outside of the  $\pm$  three percent error bands, the average error being  $\pm$  1.8 percent. It was felt that the error percentage obtained was satisfactory for a breadboard system composed of components that were not fully optimized or of the highest quality obtainable.

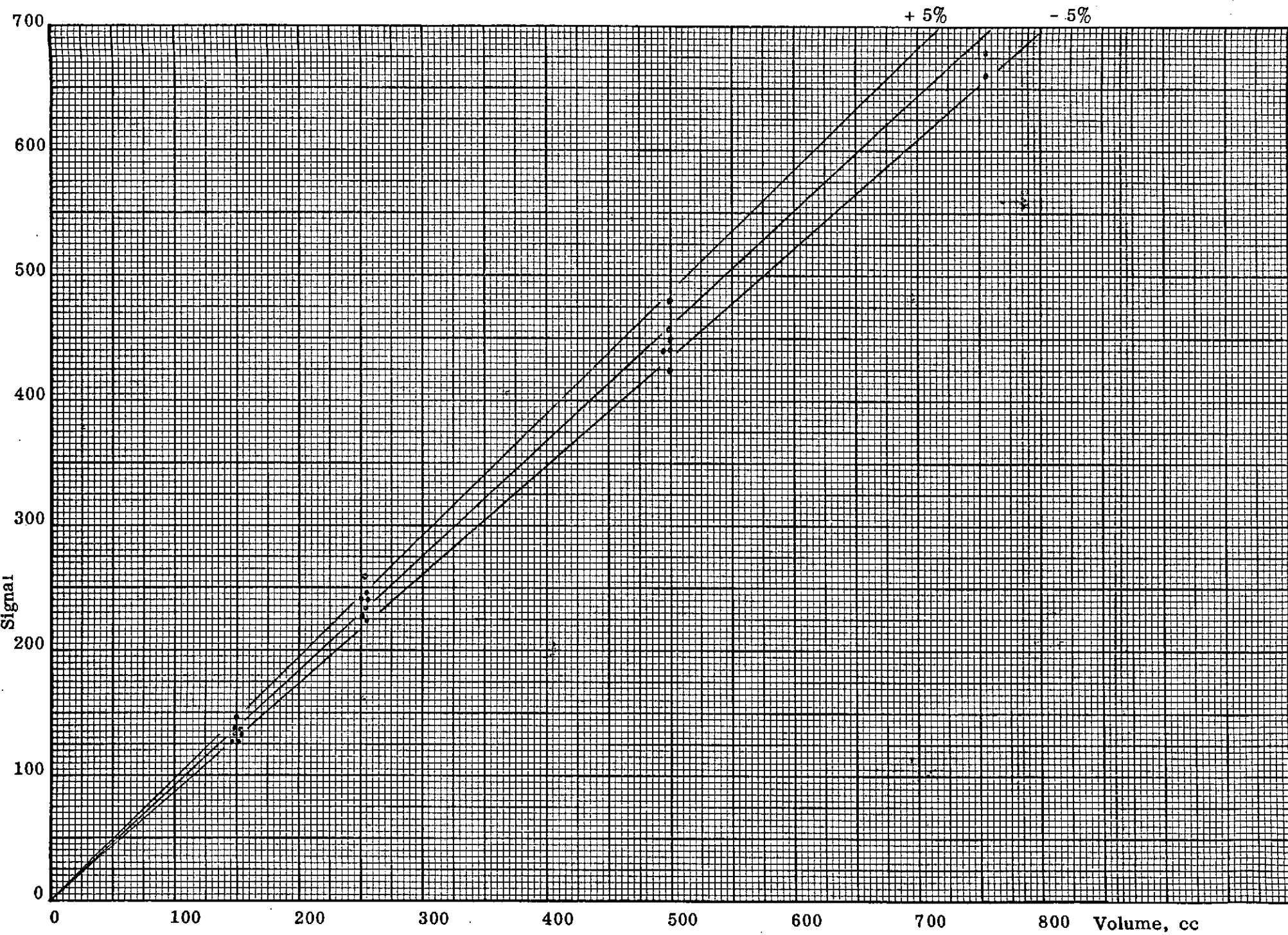


Figure 7. Early volume measurements with breadboard PEP (data set 1; July 1973).



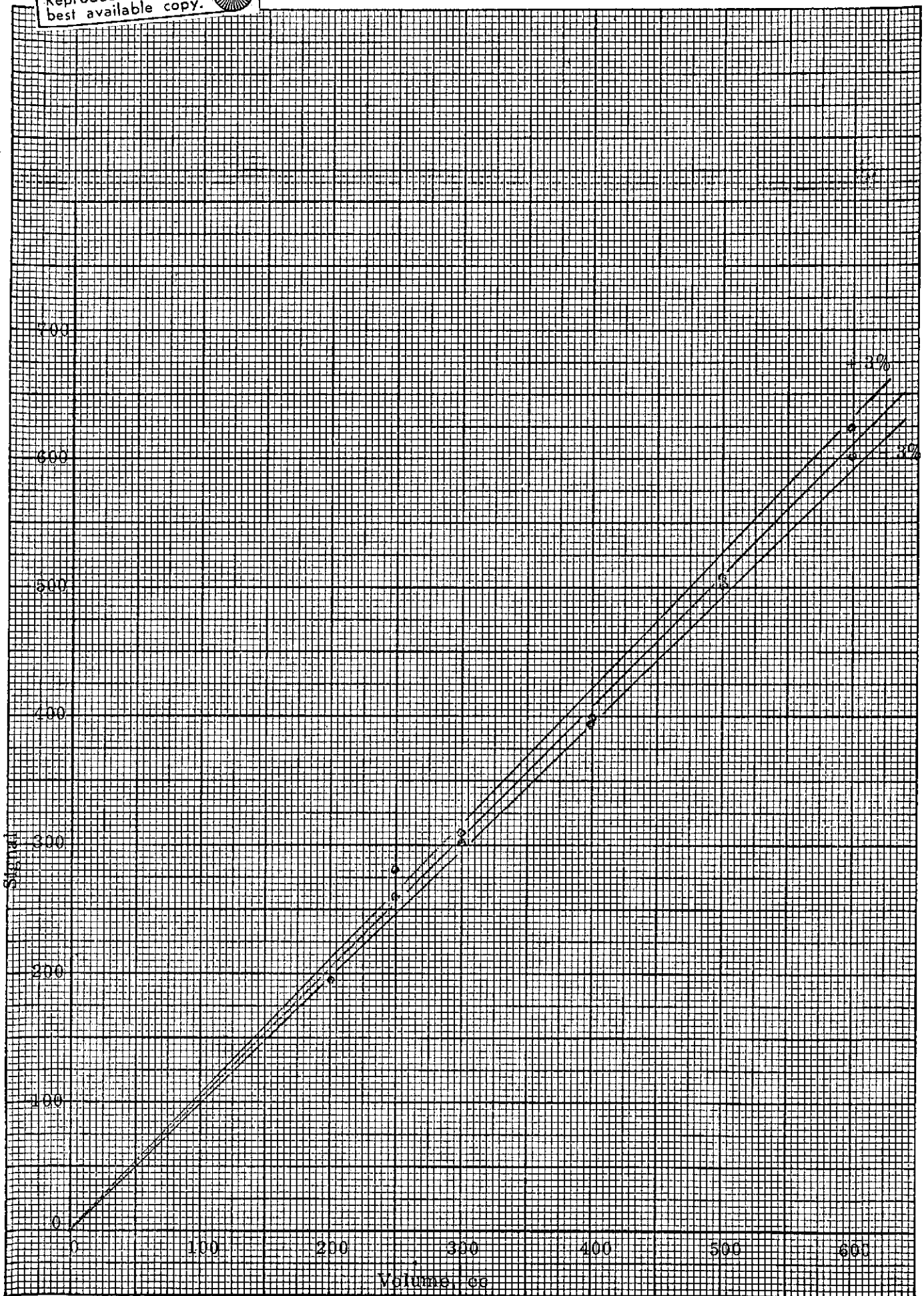


Figure 8. Early volume measurements with breadboard PEP (data set 2; July 1973).

E. Houston FVMS Breadboard Demonstration

In August of 1973, the General Electric Company and Geoscience assisted NASA staff members in making a presentation of the FVMS system to program directors, including a demonstration of the breadboard containing both the PEP and SEP systems. The system was successfully demonstrated to two groups at that time.

### III. MODIFIED PEP BREADBOARD APPARATUS

The breadboard fluid volume system was originally constructed with a circuit which actuated the flowmeter and integrator when 99°F water was introduced into the urine receptacle. This actuation system proved to be acceptably reliable and minimized difficulties with circuit adjustment. However, the requirements for accurately-controlled test water temperature and a flow switch temperature pickup located near the urine receptacle were both inconvenient. For this reason, GE requested an alternate switching method.

The alternate chosen and installed in the breadboard PEP in November, 1973, utilizes the inverter output signal to drive the integrator switches. With this circuit, the flowmeter input power is allowed to cycle on and off at the maximum temperature limit as set by the overtemperature cut-off circuit. When the liquid flow starts, the tube wall temperature drops below the maximum temperature set point so that the flowmeter power remains on until flow ceases. No other flowmeter power control is used. The integrator input starts when the flow grows to some threshold level, and ceases when the flow decreases below a second, independently adjustable threshold level. Test results showing the performance of the PEP system with this switching circuit are presented in Figure 9.

The average deviation from the mean line through the data is 1.6 percent for the 15 points above 30 cc, and seven percent for the five points at 30 cc.

Additional discussion of this switching circuit is included in Section IV. B.

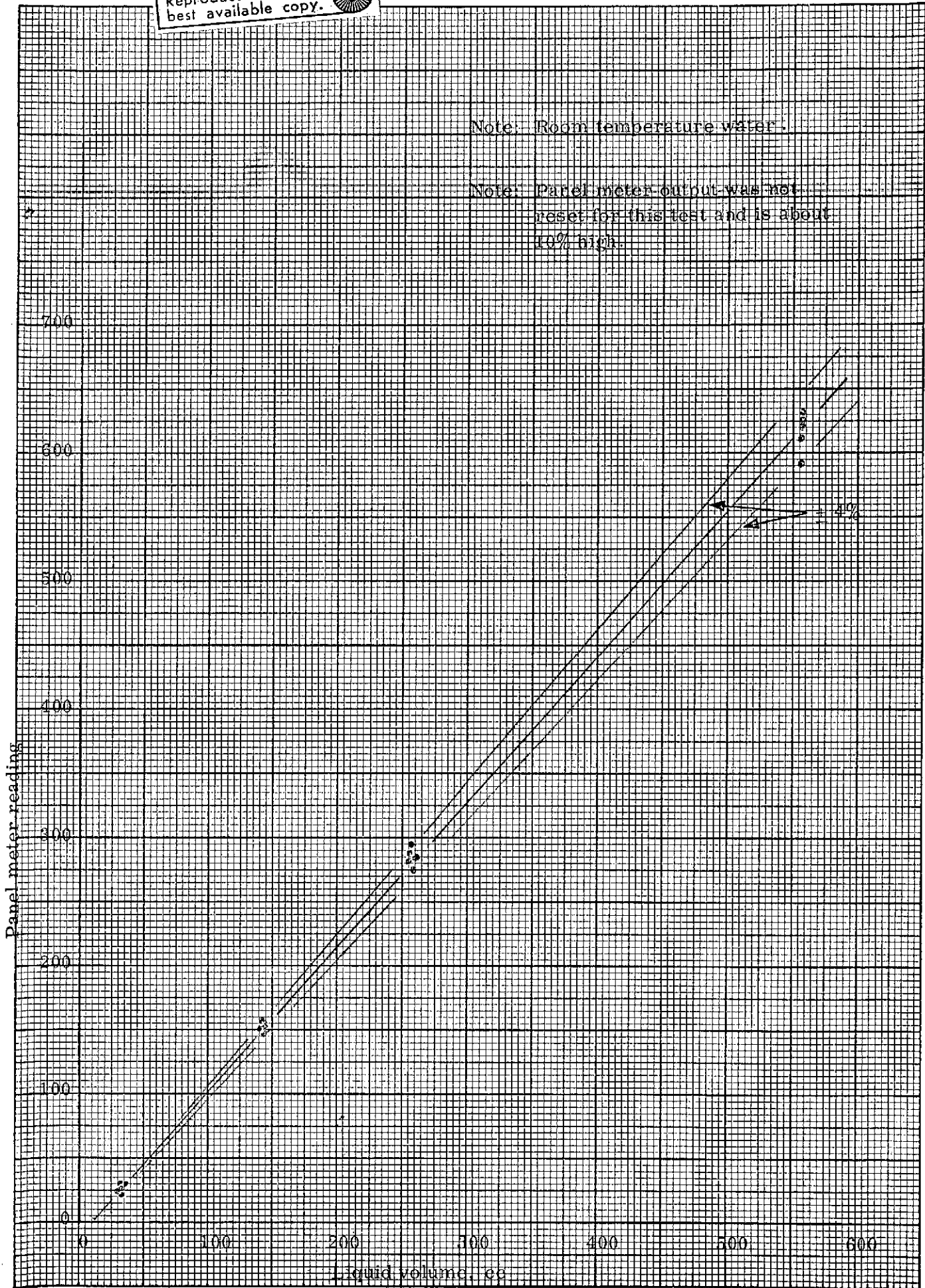


Figure 9. PEP volume measurement system using flowmeter signal driven integrator switches.

#### IV. REVIEW AND SUMMARY OF THE CONCEPTS EVALUATED DURING THE MEASUREMENT SYSTEM OPTIMIZATION

##### A. Flowmeter

The principles upon which the Geoscience flowmeter is based (outlined previously in this report) were used to design a prototype flowmeter. The prototype differed from the breadboard system only in that the air flow rates were somewhat higher (0.5 to 1.5 cfm).

The major design consideration for the thermal two-phase flow flowmeter is that the flow state must be turbulent. If it is not, then the length of the entrance region becomes excessive, thereby requiring undesirable tube lengths. The increased air flow requirement for the prototype system guarantees turbulent flow.

It was also requested by program monitors that greater compactness of the FVMS be achieved. By changing the straight tube geometry to curved tubes, greater compactness was achieved. Results of this optimization are discussed in the next section.

##### B. Electronics Control Equipment

The alternate switching system utilizing the flowmeter signal for integrator control has replaced the original thermally sensing flow switch. It is described in Section III.

This method of operation is acceptable, but has some significant disadvantages, several of which are listed below.

1. There must be a flow established through the flowmeter before the integrator will start so that a "starting" quantity of fluid passes through the system without being measured.
2. The liquid flow must be above some minimum level before the threshold level is attained and the integrator can start, and it has been found experimentally that other system requirements prevent this threshold from being set so that unmeasured flows are always negligible.
3. The flowmeter signal is not a smoothly varying function because of the two phase flow (see, for example, the chart record in Figure 4), and triggering does not occur in an identical manner each time.
4. A relatively high maximum tube wall temperature limit setting is required to keep the integrator from triggering on signal variations during thermal transients not related to liquid flow, such as vacuum pump startup and tube wall dry out.
5. The vacuum pump must be started before electrical signals can be reset.
6. Once the flow has been interrupted, the integrator switches must be reset before more liquid volume will be recorded.

These features place too many unnecessary restrictions upon PEP operations.

Considerably more flexibility is achievable in a modified thermal flow switch arrangement tested with one of the spare flowmeter tubes returned for repair. In this arrangement, the flow switch is incorporated directly in the flowmeter tube, and will actuate on water of any temperature. These features eliminate the two principal objections to the former flow switch arrangement.

The flow switch consists of a thermocouple added to the flowmeter tube wall within the first portion of the heated region. The flowmeter tube at the location of this thermocouple is maintained above water temperature. When the water is introduced, the tube wall temperature falls rapidly to a level near the inlet water temperature, passing through a set point temperature which actuates the integrator. The water temperature can be any value below the set point temperature, and the tube wall temperature maximum need only be set a few degrees above the maximum expected water temperature.

A typical trace of the output from a thermocouple on the tube wall which could be used for this function is shown in Figure 10.

The sharp decrease in wall temperature during liquid flow is apparent. Two other features of this trace, unrelated to the flow switch application, deserve some explanation. The temperature excursions during temperature control cycling with air flow only appear quite large. The temperature control hysteresis band is only 2°F wide. However, the particular power relay used to control the flowmeter power in the breadboard PEP is relatively slow, and lags behind the controller signal. The other feature is the change in temperature level with air

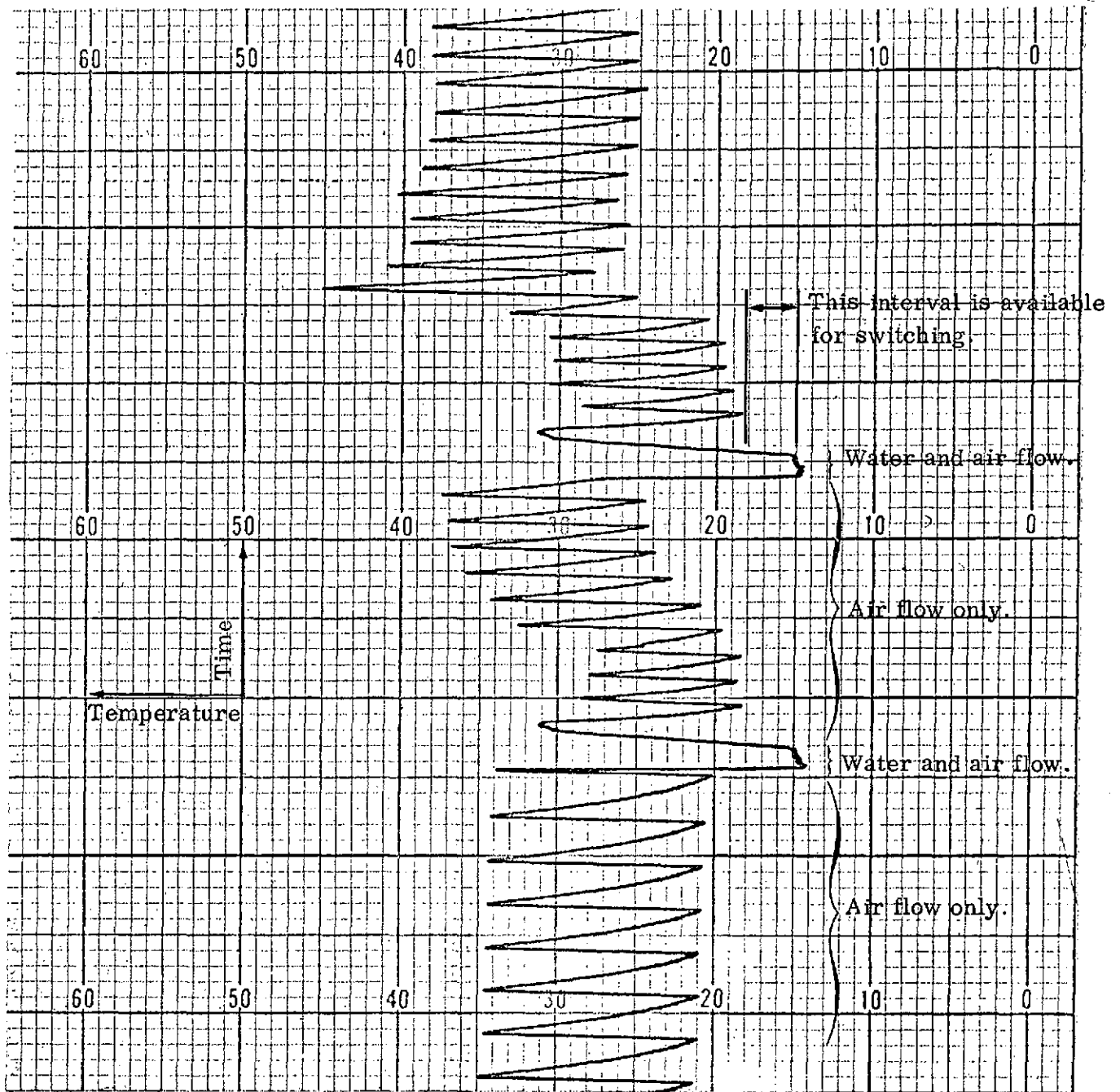


Figure 10. Output of thermocouple on flowmeter tube wall.



flow only, after the liquid flow has ceased. This is caused by water still remaining on the wall of the tube. The power control thermocouple maintains its axial location between the same two temperature levels whether a liquid film remains on the tube wall or not. However, the thermocouple displayed is, for these tests only, farther downstream than the control thermocouple and its location remains wet and cooled somewhat longer than does the location of the power control thermocouple.

## V. RESULTS OF THE PRELIMINARY CHECKOUT FOR THE OPTIMIZED PROTOTYPE SYSTEM

It is desirable to reduce the size and weight of all components in a fluid transfer measurement system for use in a spacecraft. Therefore, Geoscience has spent time on an optimized PEP system. In particular, the flowmeter has been made more compact by replacing the straight flow tube by helical or curved tubes. Two specific configurations have been assembled and tested and the results of this work are presented below:

### A. Compact Models

#### 1. Helical Tube Flowmeter

One way of reducing the size of the flowmeter is to arrange the flow tube in the form of a helix with a number of turns. The flow tube is then contained in a short cylindrical enclosure. In this way, the previous sixteen-inch long straight-tube breadboard flowmeter can be reduced to a length of about six inches. A comparison of a helical tube model with an early straight tube model is shown in Figure 11.

#### 2. Curved Tube Flowmeter

A second way of reducing the flowmeter size is to arrange the flow tube in a curved or single loop; the tube can then be housed in a flat box or cylinder. Figure 12 shows a 3 inch x 5 inch x 5 inch enclosure

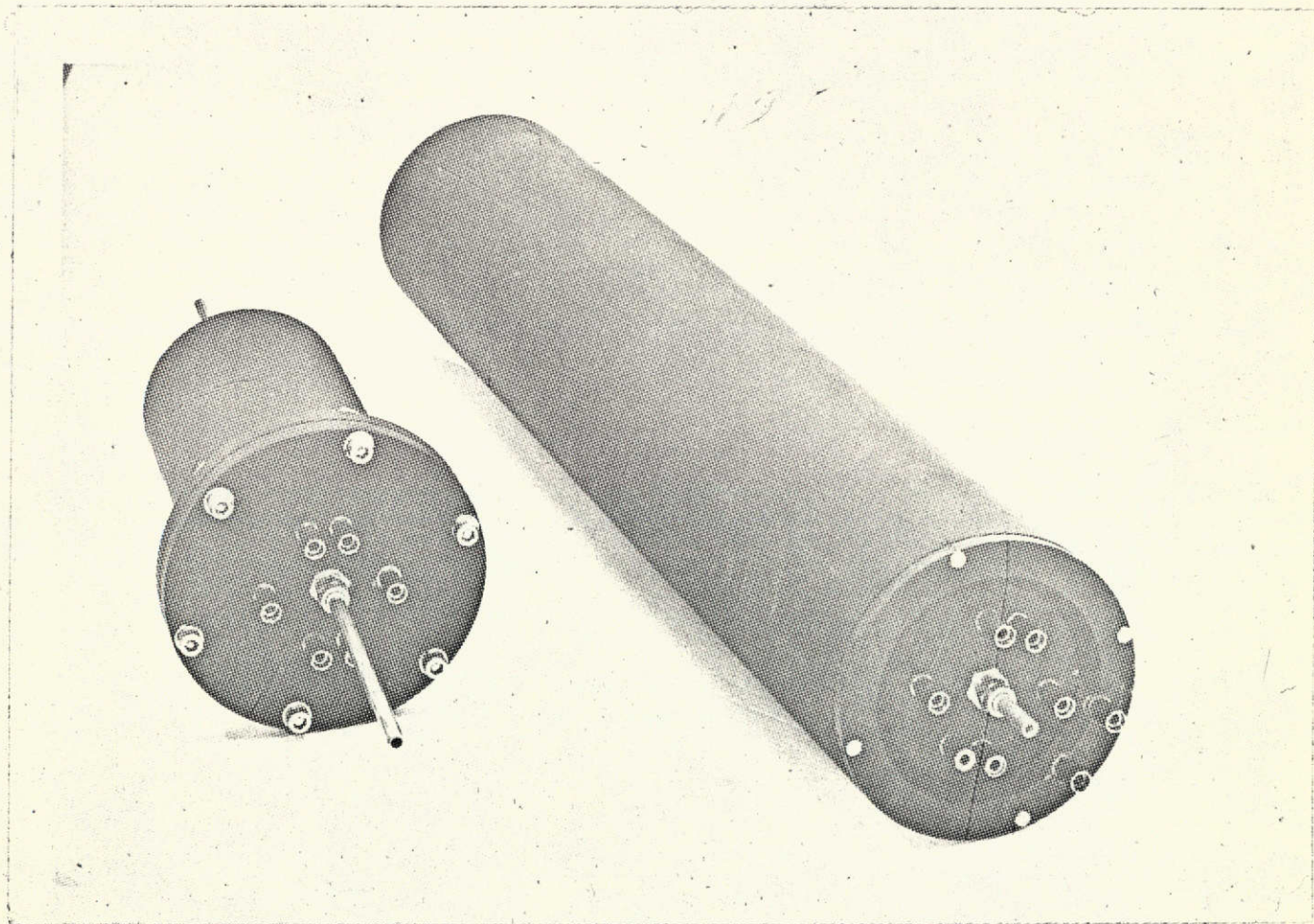


Figure 11. Photograph showing a comparison of a helical tube flowmeter model with an early straight tube flowmeter model.

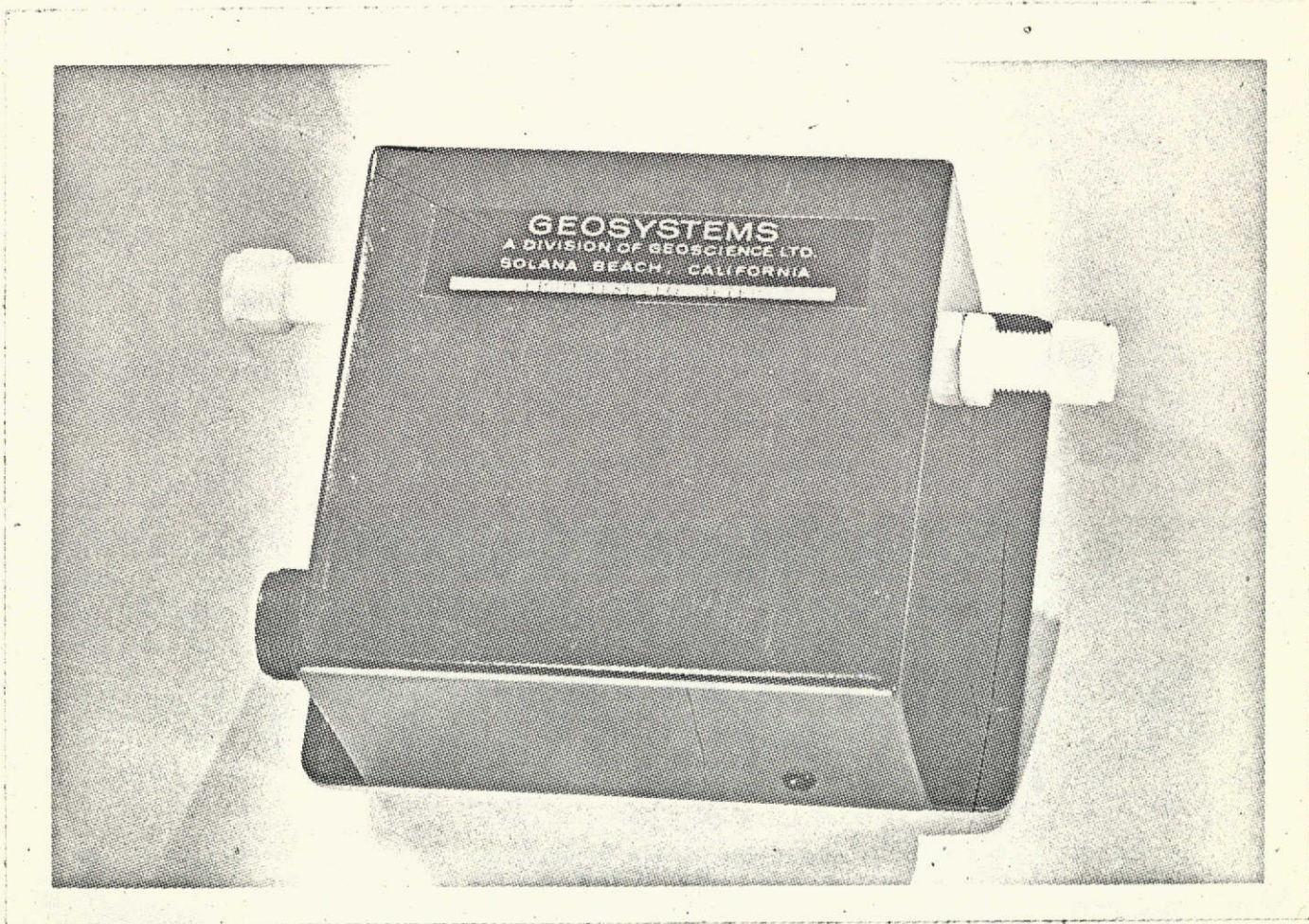


Figure 12. Photograph of a curved tube flowmeter model with a 3 inch x 5 inch x 5 inch enclosure.

that contains such a curved tube. This geometry closely satisfies the space requirement stipulated by General Electric for the proposed flight prototype fluid volume measurement system.

## B. Flowmeter Test Results

### 1. Helical Tube Flowmeter

A helical tube flowmeter was operated on the flow test stand and a typical calibration curve of water flow rate versus output signal is shown in Figure 13. Note that the theoretical 45° curve on a log-log plot is again obtained.

### 2. Curved Tube Flowmeter

The curved tube flowmeter model was tested extensively in the laboratory and excellent flow-output voltage curves were obtained; typical results are shown in Figure 14. The experimental curve shown in Figure 14 deviates from the predicted curve (based on the flowmeter theory) by only two percent.

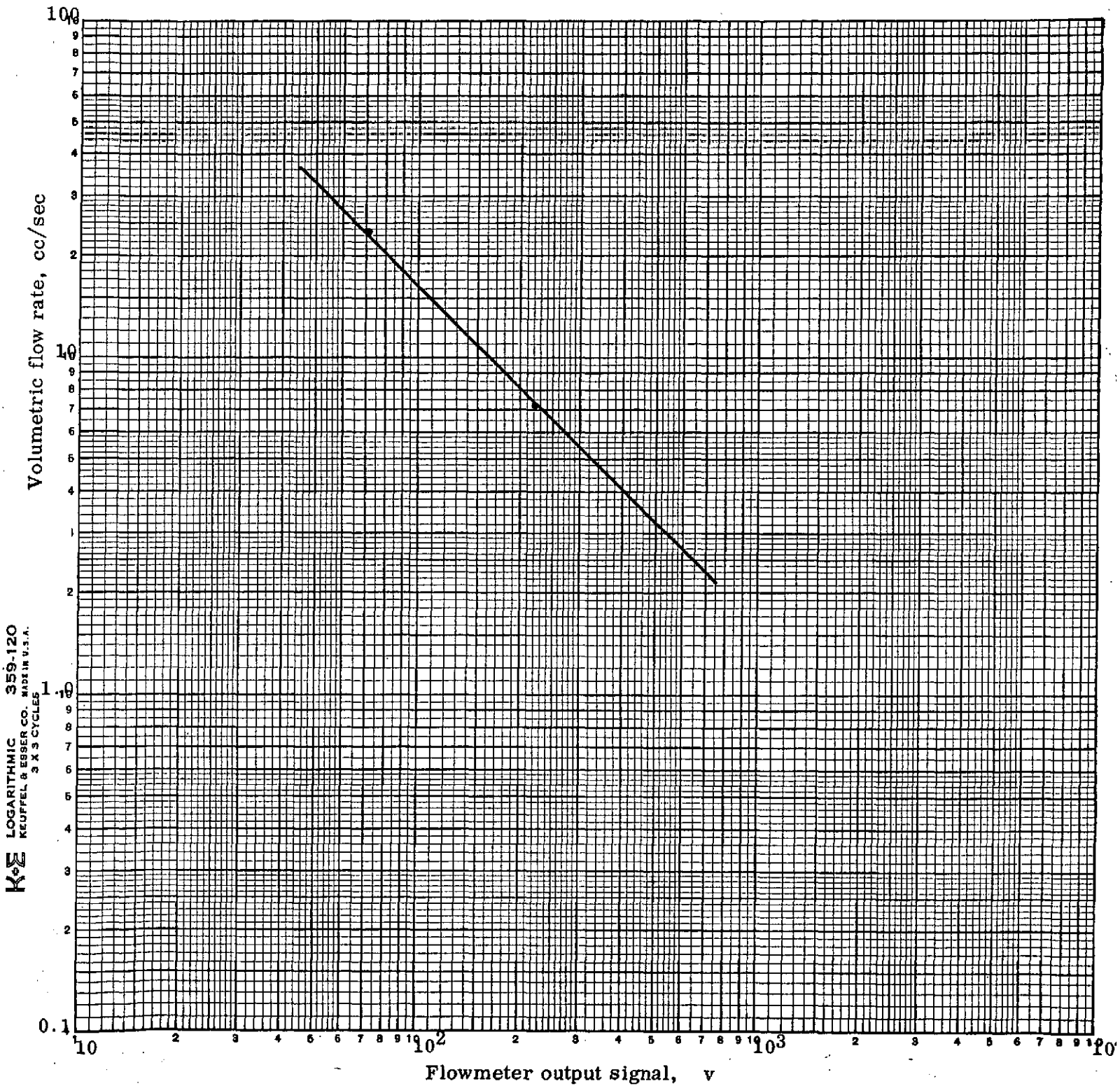


Figure 13. A calibration curve for a helical tube flowmeter model (constant airflow rate and a heater power of 15 watts).

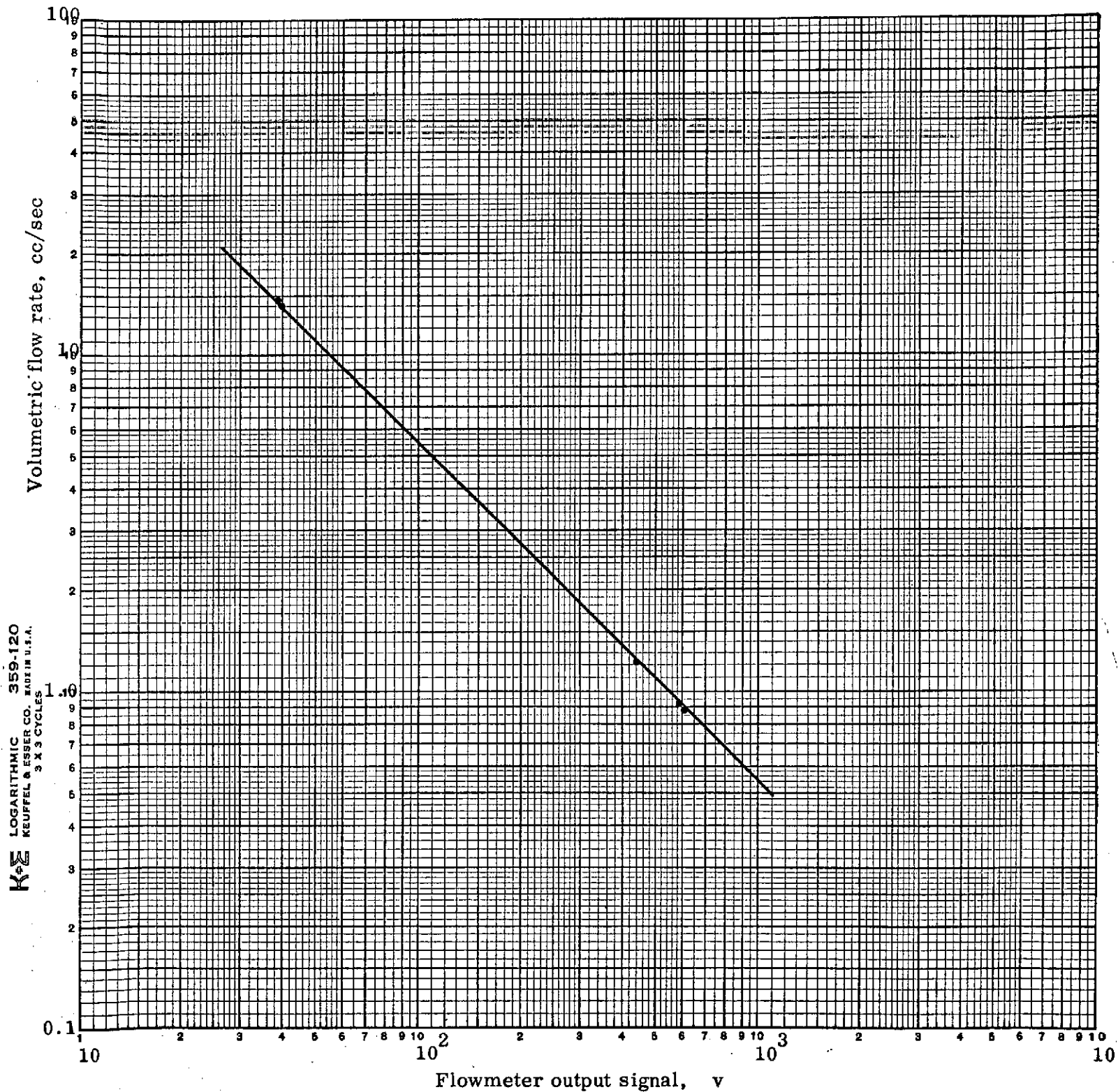


Figure 14. A calibration curve for a curved tube flowmeter model (3 inch x 5 inch x 5 inch enclosure). The airflow rate was 0.5 cfm and the heater power was 22 watts.

## VI. REFERENCES

1. Poppendiek, H. F., Mouritzen, G.; Sabin, C. M.; Final Report on "A Urine Volume Measurement System," Geoscience Ltd GLR-113, for NASA-MSD, Contract NAS 9-11612, December 1972.



**VII. APPENDIX**

**Statement of Work**

EXHIBIT "A"

## STATEMENT OF WORK

DEVELOPMENT OF PROTOTYPE  
FLUID VOLUME MEASUREMENT SYSTEM (FVMS)

April 1, 1973

**1.0** INTRODUCTION & SCOPE OF WORK

There will be a continuing requirement to measure the volume of urine produced in flight in future spaceflight missions. The method of choice for urine collection incorporates air entrainment of the urine stream as it is expelled from the crewmen. The measurement of the fluid volume in the resultant fluid-gas mixture presents a unique problem. The effort required by this Statement of Work will result in:

- a. Delivery of a breadboard urine volume measurement system.
- b. Design, fabrication, and check-out of an optimized prototype urine volume measurement system.
- c. Preparation of a final report describing the breadboard system as well as the optimized prototype system.

**2.0** BACKGROUND

Under previous NASA contract a working laboratory model of a system which is capable of accurately determining the volume of fluid (urine) in a fluid-gas mixture has been successfully developed and tested. This concept permits volume determination without the accompanying requirement of phase separation. The concept is compatible with both pneumatic collection and null gravity and is highly accurate in determining the volume of fluid in a fluid-gas mixture. The concept is based on the thermo flowmeter principle which basically permits volume determination through the precise measurement of the heat content (enthalpy change) of a fluid flowing through a tube. This heat content can be directly related to fluid volume and is not impacted by entrained air. The ability of the breadboard model, developed under previous effort to accurately measure fluid volumes with a high degree of automation and conversely a minimum of crewtime impact, has been demonstrated. This concept of urine collection and volume measurement is being proposed for ASTP and it is anticipated that, if flown, it will be used as the primary flight system. In addition, continued development work is required to broaden the range of the urine volume measurement system so that it will interface with a wide range of operating parameters. Broadening the range of the system will make it compatible with future projects such as Shuttle.

### 3.0 JUSTIFICATION

A continuing requirement exists to measure urine volumes in flight with a high degree of accuracy ( $\pm 2\%$ ) to support medical experiments and operational monitoring. This requirement has proven to be an extremely difficult one to meet. The problem is intensified by the method of choice of providing urine collection through pneumatic entrainment of the urine stream and thereby eliminating direct contact (man-machine) devices. The pneumatic collection model, in combination with the null gravity of space, requires either that phase separation be accomplished before volumetric measurement can be made or that alternate measurement schemes be developed. Several concepts for phase separation based on centrifugal action have been developed and successfully demonstrated. However, a concept for the volumetric measurement of fluid volumes which meets the accuracy requirements is not available.

### 4.0 TECHNICAL OBJECTIVE

- a. To provide a breadboard system to demonstrate the urine collection and volume measuring concept and to support development of an integrated system which will interface with the ASTP command module.
- b. To broaden the range of the urine volume measurement system to make it compatible with future projects such as Shuttle.
- c. To develop and fully test a flight prototype subsystem which will provide an accurate measurement of the volume of urine in a mixture of fluid and gas as would exist with desired urine collection schemes (pneumatic entrainment).

### 5.0 CONTRACTOR EFFORT

- 5.1 The contractor shall design, fabricate, test, and deliver a breadboard Fluid Volume Measurement System (FVMS) as depicted within the Prototype Equipment Package (PEP) of Figure 1. The system shall consist of inlet cone and flexible tubing, thermal flowmeter with supporting electronics and digital readout.
- 5.2 The contractor shall design, fabricate, and checkout an optimized prototype Fluid Volume Measurement System with an expanded operating range. The total system shall be as depicted in Figure 1 and shall consist of two parts: (1) The Prototype Equipment Package (PEP) consisting of inlet cone and flexible tubing, thermal flowmeter with supporting electronics and digital readout, and (2) the Supporting Equipment Package (SEP) consisting of collection container and blower with odor control filter.

The prototype equipment package shall be flight configured. The supporting equipment package is not required to be flight configured.

- 5.3 The contractor shall conduct this effort following submission of the preliminary program plan which will be submitted with the proposal. Changes to this program plan will require NASA approval. A Design Review for the systems shall be scheduled at NASA JSC by the contractor a minimum of 10 working days prior to the date of each review.
- 5.4 Both the breadboard and the optimized prototype system shall be capable of complete independent operation except for electrical energy. The 28 VDC power source shall not be a deliverable item.

### 5.5 Design Requirements

The design requirements of the breadboard system and the optimized prototype system to be developed under this effort are as follows:

#### 5.5.1 Breadboard System

- 5.5.1.1 Volume determination accuracy will be + 2% or better.
- 5.5.1.2 Size and weight of the Prototype Equipment Package shall be minimized.
- 5.5.1.3 The overall configuration of the system shall be such to insure ease of operation.
- 5.5.1.4 Materials and components to be used in the system shall be compatible with manned chamber requirements.
- 5.5.1.5 The PEP portion of the system shall be gravity independent. It shall be capable of being operated in all orientations.
- 5.5.1.6 Maintenance requirements shall be minimized.
- 5.5.1.7 Power requirements shall be 28 VDC.
- 5.5.1.8 Minimum void volume 50 ml.
- 5.5.1.9 Maximum void volume 800 ml: Maximum urine flow - 30 ml/sec.
- 5.5.1.10 Average micturitions - 7 per man-day.
- 5.5.1.11 Air flow design: 0.25 to 0.5 cfm.

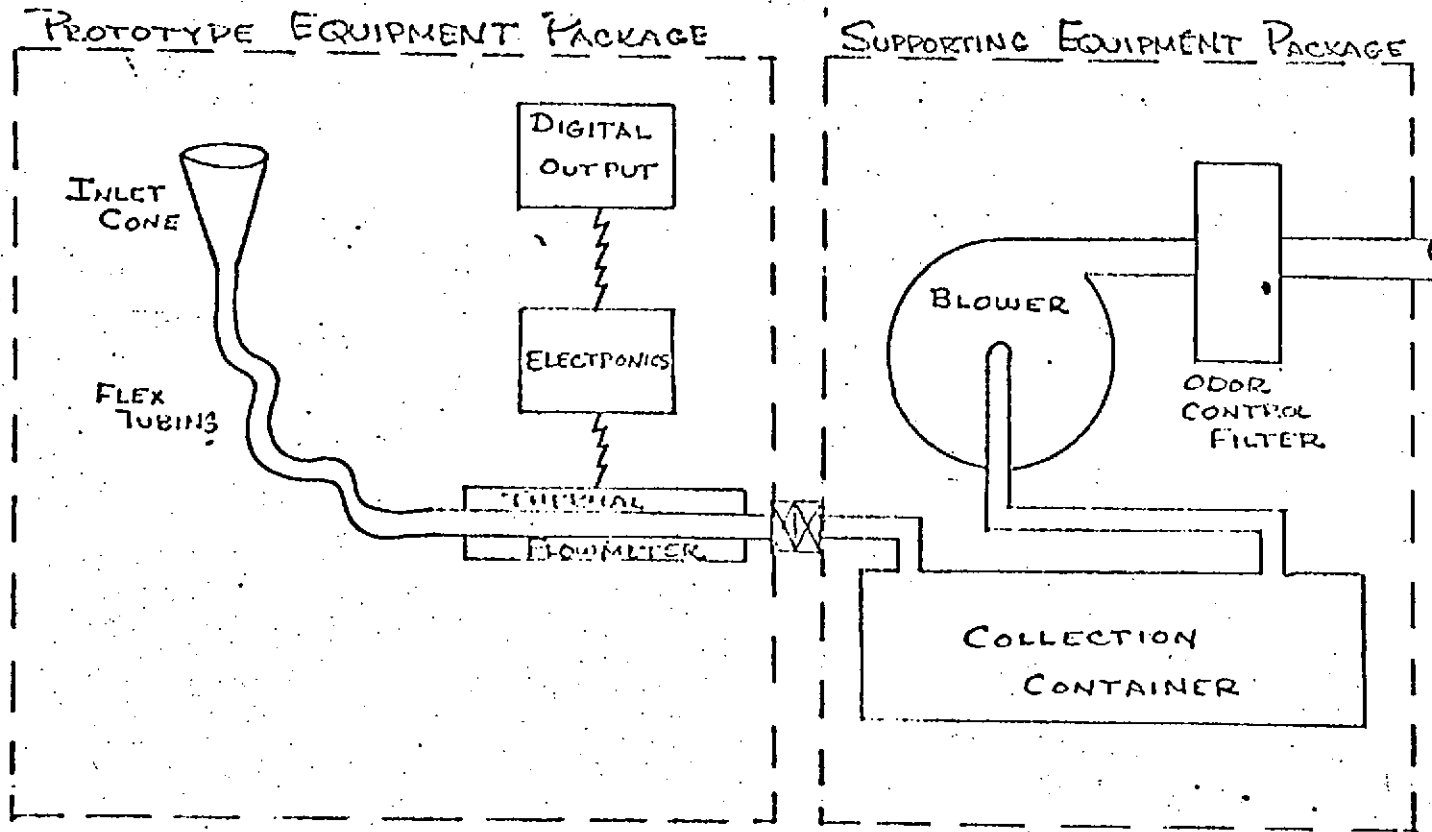
### 5.5.2 Optimized Prototype System

The design requirements for the Optimized Prototype System shall be the same as for the breadboard system except that the air flow design range shall be from 0.5 to 1.5 cfm.

## 5.6 Deliverable End Items

- 5.6.1 A breadboard fluid volume measurement system shall be the deliverable end item to be delivered within 6 weeks of initiation of this effort. Prior to shipment the system shall be cleaned and refurbished. Operating and maintenance procedures will be provided with the system and shall define the requirements for supporting equipment.
- 5.6.2 A complete set of drawings shall be furnished, one each for the breadboard system and the optimized prototype system. Included with the drawings shall be a materials list to include a listing of vendor items.
- 5.6.3 A final report shall be delivered at the completion of this effort. The final report shall contain but not be limited to the following:
- (a) All the results of the breadboard system development and checkout tests.
  - (b) A review and summary of the concepts evaluated during the process of optimizing the measurement system.
  - (c) Results of the preliminary check-out tests for the optimized prototype system.

# FLUID VOLUME MEASUREMENT SYSTEM Schematic



ELECTRICAL INTERFACE: 28VDC

FIGURE 1