MASTER

RELEASED FOR ANNOUNCEMENT
IN NUCLEAR SCIENCE ABSTRACTS

Development and Calibration Of The PR-3 Flowmeter

PREPARED FOR

**DIVISION OF BIOLOGY AND MEDICINE
U.S. ATOMIC ENERGY COMMISSION**

BY

**APPLIED SCIENCE DIVISION
LITTON SYSTEMS, INC.
LITTON INDUSTRIES**

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

ASD Report No.: 2723
Contract No.: AT(11-1)-401

COO-401-118

DEVELOPMENT AND CALIBRATION OF THE PR-3 FLOWMETER

Prepared for:

The Division of Biology and Medicine
U. S. Atomic Energy Commission

by

Rex C. Wood
Leonard R. Graf
Lawrence V. Nelson

August 1, 1965

TABLE OF CONTENTS

	<u>PAGE</u>
<u>INTRODUCTION</u>	1
<u>FLOWMETER DESIGN</u>	3
GENERAL DESIGN PHILOSOPHY	3
SYSTEM DESCRIPTION	4
General	4
Flow Sensor	5
Data Recorder	6
Frequency Calibrator	8
DESIGN DEVELOPMENT	9
Selection of Turbine Bearings	9
Selection of Output Transducer	13
Design of the Turbine Rotor	15
Frequency-to-dc Converter	18
<u>FLOWMETER CALIBRATION</u>	22
TEST APPARATUS	22
VOLUME FLOW MEASUREMENTS	23
PRESSURE DROP MEASUREMENTS	26
<u>OPERATION</u>	27
PRE-FLIGHT INSPECTION	27
Data Recorder	27
Flow Sensor	30
THE BASELINE CHECK	31
Determination of Data Cycling Rate	31
Frequency Calibration	32
Chart Entries	33

TABLE OF CONTENTS (Continued)

	<u>PAGE</u>
INSTALLATION AND POST-FLIGHT PROCEDURES	33
Identification of Components	33
Data Recorder Switch Settings	34
Handling and Disposition of the Chart Records	34
FLOW MEASUREMENT	35
Primary Output	35
Secondary Output	35
<u>MAINTENANCE</u>	39
FLOW SENSOR	39
Turbine Blades	39
Bearings	40
Reed Switches	40
DATA RECORDER	41
APPENDIX A. Analysis of Flowmeter Slip Phenomena	A-1
APPENDIX B. PR-3 Flowmeter System Wiring Diagrams	B-1
APPENDIX C. PR-3 Flowmeter System Engineering Drawings and Sketches	C-1

LIST OF ILLUSTRATIONS

<u>FIGURE</u>		<u>PAGE</u>
1	PR-2 flowmeter	1
2	PR-3 flowmeter system	2
3	Block diagram of PR-3 flowmeter system	4
4	Sectional view of PR-3 flow sensor	5
5	Block diagram of PR-3 flow recorder	7
6	Frequency calibrator	8
7	Nylon bearing test mount	10
8	Microtech S-0152 bearing assembly	11
9	Turbine rotor	16
10	Frequency-to-dc converter	19
11	Response characteristic of the converter circuit	19
12	Relationship between converter output and supply voltage	20
13	Relationship between converter output and battery temperature	21
14	Test setup for flowmeter calibration	22
15	Flowmeter output as a function of volume flow (60,000 to 100,000 feet)	24
16	Flowmeter output as a function of volume flow (100,000 to 150,000 feet)	25

LIST OF ILLUSTRATIONS (Continued)

<u>FIGURE</u>		<u>PAGE</u>
17	Observed pressure drop characteristics	26
18	Typical calibration baseline	28
19	Characteristics of temperature-measuring circuit	37
20	Procedure for checking turbine blade angle	39

APPENDIX A

A-1	Forces acting on blade of flowmeter
A-2	Theoretical aerodynamic slip effect (PR-2 flowmeter)

APPENDIX B

B-1	Data recorder circuit
B-2	Calibration unit for PR-3 flowmeter system

APPENDIX C

(Diagrams are arranged according to the sequence of numbers in the lower right corner of the title block.)

LIST OF TABLES

<u>TABLE</u>		<u>PAGE</u>
1	Characteristics of PR-3 Flow Sensor	6
2	Reed Switch Characteristics	14
3	Volume Error as a Function of Nominal Pitch	17
4	Displacement of Flowmeter Calibration Curve at the Higher Operating Altitudes	23

INTRODUCTION

One of the most difficult problems associated with the use of high-altitude samplers has been determination of volume flow. In the early years of the upper air sampling program there were no suitable methods for making direct measurements of flow rate; hence, an indirect approach utilizing blower performance data furnished by the manufacturer was used. This method assumed that a sampler of fixed geometry, operating at a given altitude, would have a flow rate expressible as a function of blower rpm.

In order to provide a better solution, this laboratory utilized a well-known approach to flow measurement and designed a high-altitude air flowmeter which could be mounted in the blower exhaust duct of air-sampling equipment. This was basically a low-drag, high-volume, turbine-type anemometer. Model PR-2, an operational version in use since 1961, is shown in Figure 1.

FIGURE 1. PR-2 Flowmeter

An attractive advantage of the turbine principle is that the signal output is a linear function of volume flow, largely independent of gas density. This is somewhat analogous to the operation of a wood screw, where penetration is a function of the number of turns, independent of the density of the medium through which it is driven.

The PR-3 Flowmeter illustrated in Figure 2 has been developed as an improved system with increased reliability, range, and accuracy. Although intended mainly for use with large volume, balloon-borne air sampling equipment, it has potential uses in other applications where measuring equipment must handle high gas flows (to 1500 cfm) with minimum pressure loss.

FIGURE 2. PR-3 Flowmeter System

FLOWMETER DESIGN

General Design Philosophy

For a number of practical reasons the PR-3 system has many of the fundamental characteristics of the PR-2 Flowmeter previously developed under this contract. Both are air turbines, and they share the following common advantages:

- 1) A true measure of volume flow is obtained. In contrast to other methods which relate pressure or temperature measurements to air velocity past a point probe, the turbine flowmeter gives an output in terms of volume flow, largely independent of local variations in velocity profile.
- 2) Output is essentially linear with respect to volume flow.
- 3) Calibration is independent of air density (altitude) over a wide range of operating conditions.
- 4) All flowmeters of the same type have nearly identical characteristics (± 2 percent), and do not require individual calibration.
- 5) Turbine flowmeters impose relatively small pressure losses on the flow system.

In developing the PR-3 system as an improved replacement for the PR-2, we have been guided by specific requirements, some of which are unique to balloon sampling. It is recognized, for example, that damage to instruments must be anticipated as a normal consequence of balloon operations. For this reason the flowmeter has been designed to allow easy replacement of damaged parts without the use of special tools or the skill of a watchmaker. We have also felt that the flowmeter should be compatible with existing samplers. Because of this, the diameter and mounting flange dimensions of the PR-3 and PR-2 Flowmeters are the same.

Finally, the most important design factors have been those associated with providing a degree of reliability consistent with operational requirements and the high cost of balloon sampling. The most obvious deficiencies associated with the PR-2 design have been corrected. The PR-3 is stronger, more resistant to vibration and shock, and the turbine blades are less vulnerable to accidental damage. Two separate and independent outputs provide access to flow data.

System Description

● GENERAL

As shown by the block diagram, Figure 3, the PR-3 system consists of two basic units, a flow sensor and a data recorder.

FIGURE 3. Block Diagram of PR-3 Flowmeter System

● FLOW SENSOR

Important physical features of the flow sensor are identified in the sectional drawing, Figure 4. Dimensions, weight, and other details are given in Table 1.

FIGURE 4. Sectional View of PR-3 Flow Sensor

In operation, the turbine blades rotate at a speed essentially proportional to the volume rate of gas flow into the sensor. Two reed switches connected to separate information channels are actuated each revolution by a small (Alnico V) permanent magnet attached to the turbine hub. A rod thermistor mounted between the straightening vanes provides the temperature data required for subsequent conversions of volume flow to mass flow.

TABLE 1

Characteristics of PR-3 Flow Sensor	
Dimensions	
O.D. mounting flange	5.56 inches
I.D. duct casing	4.81 inches
Length	6.00 inches
Weight	2 pounds
Turbine Pitch (relative to plane of rotation)	60 degrees
Effective Free Area (at plane of turbine rotation) . . .	0.1 ft ²
RPM Transducer	Reed switch, magnetically actuated
Calibration Constant (60° turbine)	0.161 ft ³ /rev.

● DATA RECORDER

The PR-3 Data Recorder is housed in an aluminum case measuring 11" x 7" x 7" and weighs 9 lb with batteries. This unit performs the following functions:

- 1) It accepts a frequency analog of flow rate from the flow sensor and converts this frequency to a proportional dc signal which is displayed by a small, panel-mounted strip chart recorder.
- 2) It accepts a frequency analog of flow rate from the flow sensor, and produces a pulse rate output suitable for modulating a frequency-telemetering transmitter.

- 3) It accepts temperature information from one or more thermistor sensors and displays this data on a time-sharing basis on the strip chart recorder.
- 4) It monitors the voltage of the converter battery and displays this information on the strip chart recorder as high reference and low reference calibrating markers.

A block diagram of the data recorder is shown in Figure 5. The sequence and number of time-shared inputs to the recorder is arbitrary. It is possible, for example, to re-wire the cycling switch to provide fewer flow segments and substitute additional temperature inputs.

FIGURE 5. Block Diagram of PR-3 Data Recorder

The frequency converter accepts pulse rates from 0 to 200 cps and delivers a proportional dc voltage for display on the recorder. A small calibrating device operating from standard 60-cycle, 115-volt power lines may be attached to the input to provide 60 and 120 cycle calibrating frequencies.

A complete wiring diagram of the data recorder is presented in Appendix B.

● FREQUENCY CALIBRATOR

Although not a basic component of the flowmeter system, the frequency calibrator (Figure 6) offers a convenient and inexpensive means for rapid adjustment and calibration of the frequency-to-dc converter output. When connected to standard 115-volt, 60-cycle power, the calibrator will perform half-wave, or full-wave rectification to provide 60-cycle or 120-cycle calibrating frequencies. The calibrator can be furnished as a separate, optional item, or it can be assembled easily in the field from readily available components (see wiring diagram, Appendix B).

FIGURE 6. Frequency Calibrator

Design Development

● SELECTION OF TURBINE BEARINGS

In exploratory design work on the flowmeter two basic types of turbine bearings have been considered: sleeve bearings and miniature ball bearings.

Sleeve Bearings

The following materials were studied:

- 1) Porous metal
- 2) Sapphire
- 3) Nylon
- 4) Teflon
- 5) Other plastics.

In the initial investigation, materials capable of being used without lubrication have been of greatest interest. This stems from the need to minimize variations in bearing drag arising from changes in lubricant viscosity with temperature. For this reason, porous metal bearings are not considered as suitable for the application. Similarly, it has been found that sapphire bearings, unlubricated, are not suitable at the shaft speeds of interest. Experimental tests of a turbine assembly supported between 0.05-inch I. D. sapphire ring jewels (obtained from Aurele M. Gatti, Inc.) revealed excessive shaft wear after two operating hours.

The best unlubricated wear characteristics have been obtained with bearings machined from Nylon and Teflon. These bearings and the stainless steel shaft, mounted in the configuration shown in Figure 7, exhibited no significant wear after 24 hours of operation.

FIGURE 7. Nylon Bearing Test Mount

Based upon a qualitative comparison of the intervals required for the turbine rotors to coast to a full stop, Teflon shows less frictional drag than Nylon. This is consistent with published average frictional coefficients of 0.15 and 0.075 for Nylon and Teflon, respectively.

Two new plastics for bearings are the polycarbonate, Lexan, and the acetal, Delrin. Since both of these plastics can be injection-molded, bearings can be formed quite economically. They both have good physical properties, and Lexan is particularly stable in applications where Nylon has shown a tendency to cold flow.

Although far from complete, the investigation of sleeve bearings has been discontinued because of overriding advantages offered by a miniature ball bearing assembly being tested.

Ball Bearings

Shortly after the start of this program we were made aware of the availability of a line of miniature ball bearing assemblies offering potential design opportunities. One of these assemblies (Figure 8) manufactured by the Microtech Division of Federal-Mogul-Bower Bearings, Inc. has been selected for evaluation.

FIGURE 8. Microtech S-0152 Bearing Assembly

The bearings used in this assembly are of instrument quality meeting ABEC 7 tolerance classifications. As indicated by the sketch, the assembly design offers ideal protection from contamination. Because it is manufactured in quantity for another instrument application, it is available at low cost (under \$15.00).

Running Tests - Dry

One of the outstanding characteristics of the S-0152 assembly is the extremely low bearing drag. With the shaft held, while the 0.26-inch diameter case is spun with the fingers, a dry assembly will coast for well over one minute. In tests to determine if the assembly could be used without lubrication, a flowmeter turbine blade was attached and run at approximately 1000 rpm until bearing failure occurred. Three bearing assemblies have been tested in this manner with the following results:

Assembly 1 - Increased drag at two hours.

Assembly 2 - Increased drag at two hours.

Assembly 3 - Bearing seized during overnight operation.

Running Tests - Lubricated

On the advice of the manufacturer, five bearing assemblies were given a light oil plate calculated to alleviate bearing wear while introducing the least possible viscous drag. This was accomplished by immersing the bearing assemblies in a mixture consisting of 10 percent Dow-Corning 10 centistoke type, 200 silicon oil and 90 percent volatile solvent. Subsequent draining, followed by evaporation of the solvent, left bearing surfaces plated with a very thin oil film. To-date, none of these bearings have failed. Two flowmeter sensors mounted on a test stand have accumulated over 500 hours at 1200 rpm (36,000,000 revolutions).

Bearing Drag at Low Temperatures

Since the flowmeter will be required to operate in the stratospheric temperature environment, it is important that any increase in lubricant viscosity impose negligible added drag upon the turbine. As a test of the bearing system and the lubrication procedure outlined in the preceding section, we have attempted to determine the relative increase in bearing drag

after cold soaking an assembled flowmeter for two hours at -50°C . Although it is certain that bearing drag does increase as temperature decreases, the magnitude of this increase was found to be small. We could, for example, detect no difference in the time interval required for warm and cold turbine rotors to coast to a full stop. When removed from the environmental chamber and held in still air with the axis of rotation vertical, it was observed that the cold turbine would start to move and continue rotating for several minutes, actuated only by the downwash of dense, cold air from the chilled blades and walls of the instrument.

● SELECTION OF OUTPUT TRANSDUCER

In selecting an rpm transducer for this application, two approaches are considered potentially suitable:

- 1) Photoelectric shutter
- 2) Magnetically operated reed switch.

The photoelectric shutter has a fundamental advantage in that it imposes no drag forces on the rotating shaft. It does, however, require a light source and some degree of signal amplification.

Because of its inherent simplicity and ease of application, the magnetically operated reed switch has been given first consideration. The principal question stemming from this choice has been the possible effect of magnetic drag on turbine speed. Characteristics of the reed switch chosen for this application are given in Table 2 (page 14).

To provide a high degree of reliability through redundancy, the transducer design uses two switches in the configuration shown in Figure 4. As the turbine rotates, the small permanent magnet mounted on the end of the bearing hub modulates the lines of magnetic force in a manner to alternately reinforce and oppose the field set up by the fixed bias magnet. The two reed conductors in each switch effectively become extensions of the nearest magnet, alternately repelling and attracting each other as the hub rotates.

TABLE 2

Reed Switch Characteristics	
<hr/>	
Manufacturer	Hamlin, Inc.
Type Number	MRS-5
Features	Glass envelope, hydrogen filled
Dimensions	0.125" dia. x 0.805" long
Contacts	Silver alloy
Maximum Current	0.01 amperes
Resonant Frequency	600 cps
Expected Life	10^8 operations

In this configuration, each reed switch is part of a separate flow information channel. One switch generates a frequency analog of turbine rpm which, after suitable conditioning, is telemetered to a ground receiving station. An identical frequency generated by the other switch is converted into an equivalent dc analog of flow rate which is logged by the strip chart recorder.

The signal generated by each switch is essentially a square wave, and ideally, the on-off times are equal. In actual practice, however, the on-off intervals will not be equal due to differences in the magnetic circuit from instrument to instrument. This is not a critical factor. The frequency-to-dc converter is substantially independent of the on-off ratio within relatively wide limits which we have tentatively established as 0.3 and 0.7.

Magnetic Drag

Since all magnetic materials possess some degree of hysteresis, the magnetic circuit must generate a force component tending to retard turbine rotation. To determine the general magnitude of this effect, the turbine has been operated in a high-altitude flow system at 120,000-foot equivalent pressures with the magnetic circuit installed and with the magnetic circuit removed. At test flows of 700 cfm as monitored by a PR-2 Flowmeter, no significant difference in rpm can be observed. Data from this test are recorded in Notebook No. 616.

Anticipated Reliability

Because of basic simplicity, small size, and low cost, reed switches are finding increased use as circuit elements in a wide spectrum of applications. The MRS-5 switch presently being evaluated in the flowmeter has been recommended by the manufacturer as a premium type offering maximum reliability. In this application these units are being operated well under the recommended current rating and life expectancies in excess of 10^8 operations are forecast.

● DESIGN OF THE TURBINE ROTOR

In designing the turbine rotor the following guidelines have been observed.

- 1) The rotor should have the lowest possible inertia to minimize response time.
- 2) It must be strong enough to withstand imposed centrifugal forces without blade distortion.
- 3) The method of fabrication should be aimed at achieving a high degree of uniformity from unit to unit without the need for tedious alignment or balancing procedures.

The present turbine design is generally consistent with these objectives. Each unit (Figure 9) is fabricated in one piece from a flat sheet of 2024-T3 aluminum alloy, approximately 0.04 inch thick. Individual blades are subsequently bent to the exact angle desired in a bending jig. Blades are flat, without camber or twist. This design permits 20 or 30 units to be stacked and machined to identical dimensions at one time on a dividing head.

FIGURE 9. Turbine Rotor

The configuration and dimensions of the turbine blank before bending are shown in Sketch PR-3-010-B, Appendix C.

Blade Pitch

In choosing an optimum blade angle for the turbine, one factor of importance is the effect of pitch errors on flowmeter accuracy. If the desired blade angle is 45° , but all blades are set incorrectly to an angle of 46° (with respect to the plane of rotation), the resulting error in turbine rpm and indicated volume will be,

$$\frac{\tan 46^\circ - \tan 45^\circ}{\tan 45^\circ} \times 100 = 3.5\% .$$

The magnitude of the error in the indicated volume flow arising out of a given small error in pitch angle depends upon the nominal pitch as shown in Table 3.

Table 3 shows that a given error in blade angle produces the least total error in flowmeter indication when the nominal blade angle is 45° . For this reason, 45° was selected as the blade angle for the Model PR-2 Flowmeter.

Experience with the PR-2 Flowmeter has shown, however, that a 45° pitch will produce undesirably high rotational speeds when measuring volume flow rates in excess of 1000 cfm. Because of this, the PR-3 system uses 60° blades. For a given flow rate this reduces turbine rpm by 40 percent and centrifugal forces on the blades by 64 percent.

TABLE 3

Volume Error as a Function of Nominal Pitch (Pitch Setting Error $(\Delta \phi) = 1$ deg.)			
Nominal Pitch (ϕ)	Tan (ϕ)	Tan ($\phi + \Delta \phi$)	Error in Indicated Volume
75°	3.372	4.011	7.9%
60°	1.732	1.804	4.2%
45°	1.000	1.035	3.5%
30°	0.577	0.601	4.2%
15°	0.268	0.288	7.5%

● FLOWMETER OUTPUT CIRCUIT FOR FREQUENCY TELEMETERING

As mentioned previously, the PR-3 Flowmeter system has two independent information channels for flow measurement. The primary, most accurate channel conveys flow information as a variable frequency, radio-telemetered to a ground-based recording station. The secondary backup channel utilizes frequency-to-dc conversion and on-board recording of volume flow rate. Both channels are actuated by separate reed switches within the flow sensor and have independent circuits and power sources. A failure of one channel should have no effect upon the other.

To provide a signal suitable for telemetering, the characteristic square wave output of the reed switch is modified by a pulse-shaping network (see Figure 5) and then fed directly into the audio input channel available in B-58 or T-13 altitude transmitters. Details of the pulse shaping network and transmitter connections are shown in Appendix B.

● FREQUENCY-TO-DC CONVERTER

The secondary (backup) output of the PR-3 system involves conversion of the flow sensor pulse rate to a dc voltage suitable for on-board recording.

The converter developed for this purpose is shown in Figure 10. It will accept variable pulse rates between 0 to 200 cycles per second, and produce a dc analog on the order of 0 to 100 microamperes through a load of 4600 ohms. Within rather wide limits this conversion is independent of pulse shape, amplitude, or duration. Figure 11, a plot of current output versus input frequency shows that response is essentially linear.

FIGURE 10. Frequency-to-dc Converter

FIGURE 11. Response Characteristic of the Converter Circuit

Effect of Changes in Battery Voltage

One 7-volt battery supplies power required to operate the converter. For a given input frequency, the dc output level is dependent upon the supply voltage. Figure 12 illustrates the relationship between converter output and battery voltage at constant input frequencies of 60 cycles and 120 cycles.

FIGURE 12. Relationship Between Converter Output and Supply Voltage

To keep the battery current drain as low as possible, voltage regulation has not been included in the converter circuit; stable operating voltage is obtained by using mercury batteries. Average current drawn by the converter circuit is 4.5 milliamperes.

Effect of Temperature

Tests indicate that the converter is relatively unaffected by temperature changes in the environment (one percent drift through a temperature range from +25° to -60°C) if the supply voltage is held constant. Mercury batteries are, however, power-limited at low temperatures. Figure 13, a plot of system characteristics as a function of temperature, shows this limitation graphically in a comparison of batteries of different capacity.

FIGURE 13. Relationship Between Converter Output and Battery Temperature

In these tests the batteries were exposed to the chamber environment at atmospheric pressure with no protective insulation. Forced air was circulated within the chamber to bring all system components to temperature equilibrium in a minimum time interval.

Results of this test are consistent with published data indicating that the temperature-voltage characteristic is a function of the internal current density. For a given load, the current density in the larger battery is approximately one-half that of the smaller, and the larger unit exhibits less voltage drop. The battery finally selected for use with the converter is of slightly higher capacity (2200 milliamperes-hours) than the larger of the two cells tested.

A diagram of the converter circuit is included in Appendix B.

FLOWMETER CALIBRATION

Test Apparatus

The PR-3 Flowmeter has been calibrated using the test setup shown in Figure 14 and essentially the same procedure used in previous calibrations of the PR-2 Flowmeter.

FIGURE 14. Test setup for flowmeter calibration

The comparison standard is a diaphragm-type gas flowmeter calibrated by the local gas company to within ± 0.5 per cent. Air is admitted to the gas meter at atmospheric pressure and passes through at low velocities. Air expands to altitude pressure through the throttling valve (V_1) and passes through the test flowmeter at high velocities. Since measurements at the gas meter inlet and at the flowmeter show that air temperatures are equal at both stations, the volume flow rate (Q_2) at the flowmeter can be derived from the simple relationship:

$$Q_2 = Q_1 (p_1/p_2)$$

where:

- Q_1 = volume flow rate entering the gas meter
- p_1 = atmospheric pressure at gas meter inlet
- p_2 = measured pressure at the flowmeter inlet.

Volume Flow Measurements

Results of the calibration are summarized in Figures 15 and 16. All experimental data have been recorded in laboratory notebook No. 616. Volume flow rates on the order of 800 to 900 cfm were achieved, at density-equivalent test altitudes up to 150,000 feet. As indicated by Figure 15, the flowmeter calibration is substantially independent of altitude up to 100,000 feet. Data for higher altitudes plotted in Figure 16 show the same progressive shift noted in previous calibrations of the PR-2 Flowmeter except that the magnitude of the shift is somewhat less. Ignoring the fact that the calibration does not pass exactly through zero, the PR-3 Flowmeter calibration constant (R) for operating altitudes below 100,000 feet is 0.161 ft^3 per revolution of the propeller.

As operation is extended above 100,000 feet, the characteristic parallel shift of the calibration points produces a departure from this baseline as indicated by Table 4.

TABLE 4

Displacement of Flowmeter Calibration Curve at the Higher Operating Altitudes		
Altitude (ft)	Slip (ft^3/min)	Percent Slip (@ $800 \text{ ft}^3/\text{min}$)
100,000	0	0
110,000	10	1.25
120,000	24	3.0
130,000	40	5.0
140,000	62	7.75
150,000	90	11.25

FIGURE 15. Flowmeter output as a function of volume flow (60,000 ft to 100,000 ft)

FIGURE 16. Flowmeter output as a function of volume flow (100,000 ft to 150,000 ft)

In our previous work we have assumed that this shift (or slip) stems mainly from bearing drag. Current studies by Lee Torgeson, however, tend to indicate that a significant, and perhaps major, fraction of this slip is due to aerodynamic drag. This is discussed in detail in Appendix A.

Pressure Drop Measurements

Pressure drop characteristics of the PR-3 Flowmeter are shown in Figure 17. These data show that pressure drop across the flowmeter is relatively low and that in most circumstances it can be ignored. It may be desirable, however, to include the retarding effect of flowmeter pressure drop when making advance predictions of system performance at the higher operating altitudes.

FIGURE 17. Observed Pressure Drop Characteristics

OPERATION

Although there are many potential areas of flowmeter application, the following procedures are related specifically to use with operational stratospheric sampling equipment.

Pre-flight Inspection

● DATA RECORDER

- 1) Check and install new batteries before each flight:
 - a) Recorder — four Eveready #94, 1.5-volt alkaline cells
 - b) Converter — one #302642, 7-volt mercury battery.
- 2) Check amount of paper remaining in the recorder and install a new chart roll if necessary. Turn POWER and CYCLE switches on. Determine if the chart is being advanced evenly, and at the proper rate (approximately 12 inches per hour).
- 3) A frequency calibrator is furnished as auxiliary equipment. Connect the output of the calibrator to the input fitting on the side of the data recorder and plug the power cord into an available 115-volt, 60-cycle outlet. Set the calibrator switch at 120 cycles. With POWER and CYCLE switches on, and INPUT switch in position A, the data recorder should yield a trace similar to that shown in Figure 18. Eight channels of information are sampled every 5 minutes:

BASELINE CALIBRATION
PR-3 ON-BOARD RECORDING SYSTEM

Location LITTON FLIGHT CENTER - ST. PAUL, MINN.

Flight No. 3030

Date Launched 7/14/65

Sampler AES "A"

Flow Sensor No. 012

Data Recorder No. 002

1. Check data cycling speed: two data cycles in 594 seconds.
2. Recorder calibration:
 - a. High reference = 76.5 microamperes
 - b. 120 cps input = 78.5 microamperes
 - c. 60 cps input = 39.0 microamperes

Baseline performed by L. N.

Figure 18. Typical Calibration Baseline

- (1) Flow
- (2) High reference
- (3) Flow
- (4) Low reference
- (5) Flow
- (6) Temperature, flow sensor
- (7) Flow
- (8) Zero (spare).

It should be noted that with the calibrator plugged in, the temperature channel (6) will record zero.

- 4) Adjust recorder zero. To do this, wait until the recorder is on a vacant channel (channel 8), turn CYCLE switch off, remove the button on the recorder face, and adjust the recorder until it prints exactly on zero. Turn CYCLE switch on.
- 5) Adjust frequency. Wait until the recorder is on a flow channel, turn the CYCLE switch off, and remove the "adj" button located to the right of the recorder. Using a small screwdriver, adjust the multi-turn potentiometer for any desired recorder value between 50 and 85 microamperes. (Note: For the current operational flights adjust recorder to 80 microamperes at 120 cps input frequency.)
- 6) Test linearity. After adjusting 120 cycles to the desired recorder value, switch the calibrator to 60 cycles. The recorder should now read one-half the previous value, ± 2 microamperes.

- 7) Test pressure switches. All data recorders intended for operational use are equipped with automatic pressure switches that will turn the PR-3 system on as the balloon ascends through the 5000-foot level. This eliminates the need for additional wiring to an external switch and minimizes battery drain. The pre-flight inspection should verify the proper operation of these pressure switches. To do this, turn the POWER switch off, and turn the CYCLE switch on. Place the unit in a bell jar or altitude chamber and lower the pressure to 523 mm Hg (10,000 feet). Observe the data recorder through a viewing port. Operation of the pressure switches is indicated if the instrument turns on and records high and low reference markers as the chart paper advances.

- 8) Check telemetry output. Connect a spare T-13 transmitter at the 4-pin output receptacle through pins A (common) and B. Furnish a test signal by connecting the frequency calibrator at the INPUT receptacle. Turn POWER and CYCLE switches on. Set INPUT switch in B position.

Using a suitable 40-mc receiver and oscilloscope, monitor the signal transmitted by the T-13. A 60-cycle input frequency should produce approximately 100 percent modulation of the 40-mc carrier. At 120 cps the modulation should be approximately 40 percent.

● FLOW SENSOR

- 1) Check the flow sensor visually for evidence of damage. All straightening vanes should be aligned parallel to the flowmeter axis. Check for evidence of bearing friction by deflecting the turbine blades slightly from their rest position. When returning to the rest position, the turbine should undergo a number of slow oscillations caused by the restoring force of the sensor magnets. If inspection indicates the possibility of damage or misalignment of the turbine blades or excessive bearing friction, the unit should be replaced.

- 2) Using the cable furnished, attach the flow sensor at the data recorder input connector. The recorder should now respond to pulse rates from the reed relays as the turbine rotates. Check operation of the flow sensor by providing a suitable volume flow of air. Each flow sensor has two reed relay transducers operating independently. Check the operation of each relay by moving the INPUT switch back and forth from A to B. Aside from a transient switching pulse, there should be no difference in recorder reading with the INPUT switch in either position.
- 3) Check the temperature circuit. Turn CYCLE switch on. The flowmeter thermistor should now be in the circuit for a short interval each 5-minute cycle and at room temperatures register a value between 85 and 90 micro-amperes.

The Baseline Check

After the flowmeter inspection has been accomplished, a pre-flight baseline check will be performed. This is essentially a calibration of the on-board recording system to provide means for an accurate post-flight evaluation of flow and temperature information. The baseline check must be performed with the data recorder in the same orientation as flown (front panel horizontal, controls up).

● DETERMINATION OF DATA CYCLING RATE

Poor atmospheric conditions will occasionally make it difficult to determine the sampling interval from telemetered information. In this event, it will be necessary to refer to the on-board chart record. Since information is cycled sequentially into the data recorder at a constant, uniform rate (8 channels in 5 minutes), this furnishes a time base. The interval of sampling can be estimated by counting the number of data cycles from the time the flow sensor begins to operate until it stops.

In tests we have found that the Brailsford cycling motor provides a reasonably constant time base, largely independent of the voltage applied. The speed of any unit may, however, differ a few percent from the nominal value of one cycle every 5 minutes. For this reason it is necessary to verify the cycling rate of each data recorder prior to a flight. This will be accomplished in the following manner:

- 1) Turn the POWER and CYCLE switches on.
- 2) Record the time interval between three successive high or low reference calibrating markers (approximately 600 seconds).
- 3) Note this value on the recorder chart and enter on baseline check form, Figure 18.

● FREQUENCY CALIBRATION

The frequency calibration will be recorded in the following manner prior to each flight:

- 1) Connect the frequency calibrator at the recorder input. Turn POWER and CYCLE switches on. Set INPUT switch at position A. Set the input frequency at 120 cycles.
- 2) Make any necessary adjustments to the recorder zero and converter frequency response as outlined in instructions for PRE-FLIGHT INSTRUCTIONS
- 3) After all adjustments are complete, let the recorder operate through one or more data cycles (5 minutes) with a frequency input of 120 cycles.
- 4) Switch frequency input selector to 60 cps and repeat, letting the recorder operate again through one or more data cycles.

As shown in Figure 18, an acceptable baseline record will clearly show:

- 1) Position of high and low reference markers
- 2) Current level corresponding to a 120-cps input frequency (approximately 80 microamperes)
- 3) Current level corresponding to a 60-cps input frequency
- 4) Position of the recorder zero.

No adjustments of the converter frequency response should be made after the baseline check is recorded.

● CHART ENTRIES

On completion of the baseline check, the following entries will be made on the recorder chart (using the access window):

- 1) Data baseline check performed
- 2) Initials of operator
- 3) Serial number of data recorder.

Installation and Post-flight Procedures

● IDENTIFICATION OF COMPONENTS

When flying a dual sampler system, it is possible to interchange connections so that the input from the PR-3 flow sensor on sampler no. 1 can, for example, be connected to the recorder of sampler no. 2. Such a possibility should be avoided through positive identification of all connectors and system components. If possible, a person other than the installer should verify that the data recorders and flow sensors are properly identified and connected.

● DATA RECORDER SWITCH SETTINGS

All data recorders intended for operational use are equipped with automatic pressure switches that will turn the PR-3 system on as the balloon ascends through the 5000-foot level. This eliminates the need for additional wiring to an external switch and minimizes battery drain. As finally installed in the launch configuration, the switch positions of the data recorder panel must be as follows:

- 1) POWER OFF
- 2) CYCLE ON
- 3) INPUT A or B

These switch settings should be verified by another individual prior to flight.

● HANDLING AND DISPOSITION OF THE CHART RECORDS

After the completion of a sampling flight, the recorder charts will be removed. The baseline check portion should not be detached from the flight record. The chart should be folded accordion fashion in a manner leaving the baseline check portion on top. Under previous entries, the following will be noted:

- 1) Flight number assigned
- 2) Type and number of sampler
- 3) Date and time of launch
- 4) Serial number of data recorder unit
- 5) Serial number of flow sensor unit.

The chart record will be mailed with other flight forms to the office designated. Since the recorder tapes are pressure sensitive and easily marked by rough handling, they should be adequately protected from damage.

Flow Measurement

● PRIMARY OUTPUT

The primary, most accurate means for determining flow will involve the measurement of reed switch pulse rate. In laboratory applications, the square wave pulses from the reed switches may be fed into an oscilloscope or frequency counter from the red and black plug receptacles located on the front of the panel.

In transmitting frequency to a ground station during flight, the flowmeter is connected to a B-58 altitude transmitter (1.7 mc) or to a T-13 transmitter (40 mc). Connections are made through the four-terminal chassis connector. The input requirement for each transmitter is different; the B-58 being modulated by 2 to 6 volts (rms) through pins A and C, the T-13 transmitter being modulated by 8 to 12 volts (rms) through pins A and B (see Appendix B). Flow rate is determined from pulse rate measurements using the calibration data summarized in Figures 15 and 16.

● SECONDARY OUTPUT

The small strip chart recorder provides a convenient access to flow and temperature data. Although the baseline check establishes the relationship between the recorder reading and frequency, various environmental effects may contribute error producing drifts. Most of these may be compensated by the following appropriate corrections:

Zero Drift

If the zero drifts during recorder operation, all readings should be adjusted an appropriate, constant amount. If the drift is positive, an equal value must be subtracted from the readings. If the drift is negative, the correction is positive.

Reference Drift

The high and low reference markers provide means for correcting temperature and flow readings for drifts in battery voltage. The high reference precision resistor (82,500 ohms) in series with the recorder resistance (4600 ohms) yields a reference current near 75 microamperes. The low reference resistor (604,000 ohms) in series with recorder yields a current near 10 microamperes.

Temperature Readings

After the recorder zero corrections have been applied, any drift of the reference readings from a high reference value of 75 or a low reference value of 10 is indicative of a similar proportional drift in battery voltage and a similar proportional drift in thermistor current. Before obtaining temperature values from the calibration curve, Figure 19, the thermistor current must be adjusted by applying appropriate corrections, for example:

Observed Values:

Zero Reading	-1 microampere
High Reference	72 microamperes
Thermistor Current	40 microamperes

Application of the constant-value zero correction will raise high reference and thermistor values 1 microampere to 73 and 41, respectively. This corrected high reference value indicates that battery voltage has dropped 2.7 percent below the value for which the thermistor calibration is valid. An appropriate correction ($0.027 \times 41 = 1.1$ microamperes) adjusts the thermistor current for this drop in battery voltage:

$$\begin{aligned} \text{thermistor current} + \text{zero corr.} + \text{battery corr.} &= \\ 40 + 1 + 1.1 &= 42.1 \text{ microamperes.} \end{aligned}$$

From the chart, Figure 19, this corresponds to a temperature of -23°C .

FIGURE 19. Characteristics of temperature-measuring circuit

Flow Rate

As shown in Figure 12, the relationship between high reference current and converter output is linear over the range of interest. Analysis of these data shows that these lines fit an equation of the form:

$$y = ax + b$$

and that converter output is proportional to the high reference current plus a constant (-11).

To illustrate how an observed drift in high reference can be used to correct converter output (flow rate) for a drift in battery voltage during flight, the following example is offered:

Assume initially, that the high reference current during the pre-flight calibration adjustment was 75 microamperes. During flight, battery voltage dropped as indicated by a high reference reading of 73 microamperes. To correct for this, all flow readings must be multiplied by the ratio:

$$\frac{\text{high reference reading at calibration} + \text{constant}}{\text{high reference reading at time of measurement} + \text{constant}}$$

or

$$\frac{75 + (-11)}{73 + (-11)} = 1.03.$$

MAINTENANCE

The PR-3 Flowmeter System has been designed for ease of disassembly, and we anticipate that maintenance procedures will involve mainly the replacement of damaged or wornout components.

Flow Sensor

● TURBINE BLADES

Since the turbine is protected by straightening vanes fore and aft, it should not be susceptible to damage arising out of normal handling and use, but if damage or misalignment is suspected this can be verified readily. To inspect the turbine, dismount the flanged ring on the bearing end of the flow sensor (see Figure 4) and remove the straightening vane assembly, and turbine.

Check blade angle on a flat surface as shown in Figure 20.

FIGURE 20. Procedure for checking turbine blade angle

The blade angle should be 60 degrees $\pm 1/4$ degree. If carefully performed, small adjustments to blade angle may be performed in the field. In addition to having the correct pitch, all blades must be equally spaced around the plane of rotation and when resting on a flat surface, the corners of all blades must lie within 1/32-inch of the surface plane. Turbine replacement is effected easily by removing the four small hub screws. After installing a new turbine, a small drop of enamel should be applied to each screwhead to prevent the screw from working loose.

● BEARINGS

No attempt should be made to lubricate the bearings in the field. If the test described under PRE-FLIGHT INSPECTION (Par. 1), page 30) indicates the presence of bearing drag, or if any defect in the bearing is suspected, it should be replaced. To do this, disassemble the flow sensor as indicated in the previous section, loosen the small setscrew nearest the turbine and remove the bearing clamp. Immerse the bearing clamp in solvent to soften the locking enamel and push the bearing assembly out of the clamp. Unscrew the defective assembly from the turbine hub. Apply a small drop of enamel to the threads of the replacement bearing and attach the new bearing assembly to the hub.

Insert the bearing into the bearing clamp until the back of the bearing protrudes 1/32 inch. Apply locking enamel along the bearing clamp slots and let dry.

Apply a few drops of locking enamel around the edge of the bearing clamp, insert into the vane hub and tighten the locking setscrew. Recheck turbine blade angle and reassemble.

● REED SWITCHES

If the test performed under PRE-FLIGHT INSPECTION (Par. 2), page 31) indicates that a reed switch is defective, the entire flow sensor should be returned to the manufacturer for replacement.

Data Recorder

Other than replacement of batteries and chart paper, the data recording unit requires no field maintenance. The small strip chart recorder mounted in the box may be replaced as a unit in the field. Repair or replacement of other components will be performed by the manufacturer.

APPENDIX A

ANALYSIS OF FLOWMETER SLIP PHENOMENA

by

W. L. Torgeson

ANALYSIS OF FLOWMETER SLIP PHENOMENA

Calibrations of the PR-2 and PR-3 Flowmeters for low-density conditions have disclosed characteristic shifts of the calibration curve with increasing altitude. These effects have frequently been attributed to bearing friction. However, recent test results with the improved PR-3 Flowmeter, which has lower bearing friction than the PR-2 Series Flowmeters, suggest that bearing friction is not the primary reason for the observed slip effects.

The following analysis shows that slip effects at low densities and low speeds may in large part be caused by purely aerodynamic phenomena. The basic cause of aerodynamic slip can be seen from Figure A-1, showing forces acting on a blade of the flowmeter.

FIGURE A-1. Forces Acting on Blade of Flowmeter

Suppose that the slip is very slight so that the resultant velocity vector seen by the blade is inclined slightly with respect to the plane of the blade. The resultant airflow velocity, as seen by the blade, is then very nearly:

$$U = U \sec \theta \quad (1)$$

where U is the mean axial stream velocity and θ is the blade pitch (see Figure A-1). As a result of the flow past the blades of the flowmeter, a drag force D , acting in the plane of the blade, is applied to each blade. Defining ℓ as the effective mean radius, these drag forces produce a moment about the rotational axis:

$$T = n D \ell \sin \theta, \quad (2)$$

for n blades (assuming zero slip). Therefore, in the absence of slip, a torque must be applied to overcome the moment due to blade drag. This torque is supplied by lift forces developed by the blades, at the expense of some retardation of rotational speed. Ordinarily the rpm is only slightly reduced; however, it will be shown that the degree of slip (i. e., the angle of attack) required for equilibrium, increases with decreasing density, becoming significant at density altitudes above 100,000 feet.

Referring again to Figure A-1, the net torque about the axis of rotation for an angle of attack α is:

$$T = n \ell \left[L \cos (\theta - \alpha) - D \sin (\theta - \alpha) \right] \quad (3)$$

where L and D denote, respectively, the lift and drag acting on each blade. By definition, the lift force acts normal to the relative wind direction as seen by the blade while the drag acts in the direction of the relative wind. If the angle of attack is small, the lift and drag can be expressed as:

$$L = K_1 \alpha \quad (4a)$$

$$D = K_2 \quad (4b)$$

where K_1 and K_2 are constants. At equilibrium, we have (assuming zero bearing friction):

$$L \cos (\theta - \alpha) - D \sin (\theta - \alpha) = 0 \quad (5)$$

or, using Equations (4a) and (4b), and expressing the (small) angle α in radians, we obtain the following quadratic equation for α :

$$\alpha^2 + \left[\left(1 + \frac{K_2}{K_1} \right) \cot \theta \right] \alpha - \frac{K_2}{K_1} = 0 \quad (6)$$

If α is small, the drag is almost entirely due to skin friction. The drag of a flat plate for laminar flow is:*

$$D = 1.328 \bar{U}^{3/2} \sqrt{\rho \mu b} \cdot s \approx K_2 \quad (7)$$

where $\bar{U}$ is the resultant stream velocity, b is the blade chord and s is the blade span. The density and viscosity of the air-stream are denoted by ρ and μ , respectively. For perfect fluid flow (i. e., no flow separation from the blade surface), the lift is given by the equation:

$$L = \frac{1}{2} \rho \bar{U}^2 b s C_L = \pi \rho \bar{U}^2 b s \alpha \quad (8)$$

*Schlichting, H. Boundary layer theory. McGraw-Hill, 1955.

Thus, we have $K_1 = \pi \rho U^2 b s$ and the ratio K_2/K_1 is:

$$\left(\frac{K_2}{K_1} \right)_p = \frac{0.424}{\sqrt{Re}} \quad (9)$$

where the blade Reynolds number Re is defined by:

$$Re = \frac{\rho U b}{\mu} \quad (10)$$

If separation occurs, the lift curve slope K_1 is smaller by a factor of 4 (Birkhoff*) and the ratio K_2/K_1 is:

$$\left(\frac{K_2}{K_1} \right)_s = \frac{1.696}{\sqrt{Re}} \quad (11)$$

From Equation (6) the angle of attack is found to be (setting $z = K_2/K_1$):

$$\alpha = \frac{(1+z) \cot \theta}{2} \left\{ \sqrt{1 + \frac{4z \tan^2 \theta}{(1+z)^2}} - 1 \right\} \quad (12)$$

which, for small values of z , becomes:

$$\alpha \cong \frac{z}{\cot \theta} \quad (\text{small } z) \quad (13)$$

* Birkhoff, G. and E. H. Farantonello. Jets, wakes and cavities. N.Y., Academic Press, 1957.

Now for small values of α , the actual rpm N is related to the "ideal" speed N_0 by the equation:

$$N = N_0 \left(1 - \frac{2\alpha}{\sin 2\theta} \right) = N_0 (1 - S) \quad (14)$$

where $S = \frac{2\alpha}{\sin 2\theta}$ is a slip factor.

If z is not too large the slip factor can be expressed as:

$$S = \frac{z}{\cos^2 \theta} \quad (\text{small } z) \quad (15)$$

This equation shows that S increases with increasing pitch; e.g., at $\theta = 30^\circ$, $S = 1.33 z$ while for $\theta = 45^\circ$, $S = 2 z$.

In order to illustrate the effect of aerodynamic slip, calculations have been carried out for the PR-2 Flowmeter at altitudes of 100,000, 120,000, and 140,000 feet with z defined by Equation (11), i. e., assuming separated flow. The results are shown in Figure A-2.

It is apparent that the theory describes a slip effect very similar to that observed experimentally, although the slip is somewhat underestimated at low flow rates. This may in part be due to bearing friction, which will be most significant at low speeds.

This analysis shows that the observed slip of the PR Series Flowmeters can be ascribed to fundamental fluid dynamic processes rather than to bearing friction. This is of importance with regard to reproducibility of flowmeter calibration characteristics.

FIGURE A-2. Theoretical aerodynamic slip effect (PR-2 flowmeter)

APPENDIX B

PR-3 FLOWMETER SYSTEM
WIRING DIAGRAMS

DIAGRAM 1. Data recorder circuit

DIAGRAM 2. Calibration unit for PR-3 flowmeter system

APPENDIX C

PR-3 FLOWMETER SYSTEM ENGINEERING DRAWINGS AND SKETCHES

REVISIONS				
SYM	ECO NO	DESCRIPTION	DATE	APPROVAL

OUTSIDE SURFACE:
REMOVE SCRATCHES -
SMOOTH MATTE FINISH -

#30 DRILL (.125) TWO LOCATIONS
180° APART

ADDITIVE FINISH BLUE ANODIZE	UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES FRACTIONS DECIMALS ANGLES RADI $\pm \frac{1}{16}$ 3.005	DR <i>Raw</i> CHKD ORIGINAL DATE OF DRAWING <i>4/20/64</i> APPLICABLE SPECIFICATIONS	DESG <i>Raw</i> APPD NAME HEMISPHERICAL COVER	APPLIED SCIENCE SYSTEMS LITTON SYSTEMS, INC. LITTON INDUSTRIES
MATERIAL ALUM ALLOY SUITED TO SPINNING	HEAT TREATMENT	SCALE <i>X 1</i> UNIT WT	QWS SIZE A	PR-3-001 SHEET OF

SHEET OF																
<table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <th colspan="5" style="text-align: center;">REVISIONS</th> </tr> <tr> <th style="width: 10%;">SYM</th> <th style="width: 10%;">ECO NO</th> <th style="width: 40%;">DESCRIPTION</th> <th style="width: 15%;">DATE</th> <th style="width: 25%;">APPROVAL</th> </tr> <tr> <td> </td> <td> </td> <td> </td> <td> </td> <td> </td> </tr> </table>		REVISIONS					SYM	ECO NO	DESCRIPTION	DATE	APPROVAL					
REVISIONS																
SYM	ECO NO	DESCRIPTION	DATE	APPROVAL												
<p style="position: absolute; top: 330px; left: 660px;">NOTE (±5°) ① → 60° BEVEL ON EDGES INDICATED - SEE INSET BELOW: .015 MAX, .000 MIN</p> <p style="position: absolute; top: 610px; left: 170px;">TWO SLITS .050 WIDE (MAX) 3/32" DEEP.</p>																
ADDITIVE FINISH <p style="font-size: 1.2em;">GOLD ANODIZE</p>	UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES FRACTIONS DECIMALS ANGLES RADI $\pm \frac{1}{64}$ $\pm .005$	OR RCW CHKD APPD ORIGINAL DATE OF DRAWING APPLICABLE SPECIFICATIONS	NAME <p style="font-size: 1.2em;">STRAIGHTENING VANE</p>													
MATERIAL <p style="font-size: 1.2em;">2024 OR SIMILAR HARD ALUM ALLOY</p>	HEAT TREATMENT	APPLIED SCIENCES DIVISION LITTON INDUSTRIES														
SCALE X 1		DWG SIZE <p style="font-size: 2em;">A</p>														
UNIT WT		PR-3-003 C SHEET OF

SYN		ECO NO		DESCRIPTION		DATE		APPROVAL	
<p>4-40 NC-2A THD</p> <p>0-80 NF, 4 HOLES ON .750 DIA BC, 90° SPACING</p> <p>.062</p> <p>.125</p> <p>.005 MAX R.</p> <p>.385</p> <p>.020</p> <p>1.000</p> <p>.312</p> <p>BREAK ALL SHARP EDGES</p> <p>PROPELLER HUB</p> <p>2024 OR SIMILAR HARD ALUM ALLOY</p> <p>SCALE X 2</p> <p>UNIT WT</p> <p>OWN SIZE</p> <p>PR-3-009-B</p> <p>SHEET OF</p>

[illegible]

NOTE: - WHEN GOVERNMENT SPECIFICATIONS OR OTHER DATA ARE USED FOR ANY PARTS OTHER THAN IN CONNECTION WITH A SPECIFICALLY RELATED GOVERNMENT PROCUREMENT SPECIFICATION THE UNITED STATES GOVERNMENT TAKES NO RESPONSIBILITY FOR ANY DEFICIENCY OR INADEQUACY, AND THE FACT THAT THE GOVERNMENT MAY HAVE FORMULATED, FURNISHED OR IN ANY WAY SUPPLIED THE SAID DRAWING SPECIFICATIONS OR OTHER DATA IS NOT TO BE REGARDED AS IMPLICATION OR OTHERWISE AS IN ANY MANNER, EXPLICITLY OR IMPLICITLY OR IN ANY OTHER MANNER OR OTHERWISE OR OTHERWISE ANY RIGHTS OR PRIVILEGES TO INVENTION, PATENT, OR ANY OTHER INVENTION THAT MAY BE IN ANY WAY BE RELATED THEREBY.

THIS DRAWING CONTAINS INFORMATION PERTINENT TO THE APPLIED SCIENCE SYSTEM LETTER SYSTEMS INC. AND INFORMATION CONTAINED OR USE OF THIS DRAWING IS EXPRESSLY PROHIBITED EXCEPT AS THE APPLIED SCIENCE SYSTEM LETTER SYSTEMS INC. MAY OTHERWISE AGREE IN WRITING.

NOTE:

1. FABRICATE FROM TYPE H33 MAGNET AS SUPPLIED BY HAMLIN, INC.

MAGNET DATA	
PART NO.	DIM. A
PR-3-014-001	11/32
PR-3-014-002	15/32

		UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ON		BY <i>Hamlin</i> 4-18-65		APPLIED SCIENCE DIVISION		19
		FINISH		DATE		17140 SYSTEMS DIV.		
		X1 ± .005		X2 ± .005		DESIGN		MAGNET
		X3 ± .005		X4 ± .005		VALUE SPS		
		MATERIAL		TAPES				
		ALNICO 8						
		MAGNET STOCK						
NEXT ASSY		USED ON				SIZE		
						CODE IDENT NO		
						B 17788		PR-3-014
APPLICATION						SCALE		NONE
						SHEET		OF

Engineering or Machine Shop/Manufacture: **APPROVED** by _____
 Date: _____
 This drawing is the property of the Applied Science Division and is to be used only for the purpose for which it was prepared. It is not to be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, recording, or by any information storage and retrieval system, without prior written permission of the Applied Science Division.

NOTES
 1. REMOVE BURRS & BREAK SHARP EDGES

ITEM NO.	DESCRIPTION	QTY
1	BLACK ANODIZE	
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		
20		
21		
22		
23		
24		
25		
26		
27		
28		
29		
30		
31		
32		
33		
34		
35		
36		
37		
38		
39		
40		
41		
42		
43		
44		
45		
46		
47		
48		
49		
50		
51		
52		
53		
54		
55		
56		
57		
58		
59		
60		
61		
62		
63		
64		
65		
66		
67		
68		
69		
70		
71		
72		
73		
74		
75		
76		
77		
78		
79		
80		
81		
82		
83		
84		
85		
86		
87		
88		
89		
90		
91		
92		
93		
94		
95		
96		
97		
98		
99		
100		

ITEM NO.		DESCRIPTION		QTY	
1		BLACK ANODIZE			
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					
21					
22					
23					
24					
25					
26					
27					
28					
29					
30					
31					
32					
33					
34					
35					
36					
37					
38					
39					
40					
41					
42					
43					
44					
45					
46					
47					
48					
49					
50					
51					
52					
53					
54					
55					
56					
57					
58					
59					
60					
61					
62					
63					
64					
65					
66					
67					
68					
69					
70					
71					
72					
73					
74					
75					
76					
77					
78					
79					
80					
81					
82					
83					
84					
85					
86					
87					
88					
89					
90					
91					
92					
93					
94					
95					
96					
97					
98					
99					
100					

ITEM NO.		DESCRIPTION		QTY	
1		BLACK ANODIZE			
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					
21					
22					
23					
24					
25					
26					
27					
28					
29					
30					
31					
32					
33					
34					
35					
36					
37					
38					
39					
40					
41					
42					
43					
44					
45					
46					
47					
48					
49					
50					
51					
52					
53					
54					
55					
56					
57					
58					
59					
60					
61					
62					
63					
64					
65					
66					
67					
68					
69					
70					
71					
72					
73					
74					
75					
76					
77					
78					
79					
80					
81					
82					
83					
84					
85					
86					
87					
88					
89					
90					
91					
92					
93					
94					
95					
96					
97					
98					
99					
100					

[illegible]

Technical drawing of a mechanical part, likely a bracket or support, showing front and side views with dimensions and material specifications.

Front View (Left):

- Overall height: $2\frac{1}{8}$
- Overall width: $\frac{1}{8}$
- Top flange thickness: $\frac{1}{8}$
- Bottom flange thickness: $\frac{1}{8}$
- Internal vertical dimension: $Y = 2.00$

Side View (Right):

- Overall height: $2\frac{1}{8}$
- Overall width: $\frac{1}{8}$
- Top flange thickness: $\frac{1}{8}$
- Bottom flange thickness: $\frac{1}{8}$
- Internal vertical dimension: $Y = 2.00$
- Internal horizontal dimension: $X = 2.00$
- Material specification: $\frac{1}{2}$ 40 UNC-2B THRU
- Material specification: $\frac{1}{2}$ 30 UNC-2B THRU

TABULATION		
DASH NO	X	Y
-1	250	1,500
-2	175	1,650

[illegible]

DATE	TIME	LOCATION	ACTIVITY	BY	REMARKS
10/10/2018	08:00	...	...	...	...

2550 MANUFACTURERS RD
SUNBURY, CALIFORNIA

4		$\text{AMG} = \frac{1}{2} \times 14 \times 2 \times 10 = 140 \text{ cm}^2$		
5		$\text{AMG} = \frac{1}{2} \times 14 \times 2 \times 10 = 140 \text{ cm}^2$		
6	140 cm ²	$\frac{1}{2} \times 14 \times 2 \times 10 = 140 \text{ cm}^2$		
7	140 cm ²	$\frac{1}{2} \times 14 \times 2 \times 10 = 140 \text{ cm}^2$		

[illegible]

NEGATIVE
UP

RECORDER
BATTERY

ON

OFF

POWER

ON

OFF

CYCLE

A

B

INPUT

POSITIVE
UP

CONVERTER
BATTERY

FREQUENCY

MONITOR

CONVERTER OUTPUT

ADJUSTMENT

DATA RECORDER

PR3 FLOWMETER SYSTEM

SERIAL NO.

APPLIED SCIENCE DIVISION
LITTON SYSTEMS, INC.
LITTON INDUSTRIES