air photographic and charting service
mats
orlando air force base
orlando, florida

Wood's Hole
Oceanographic Institution
Ref. 62-23
Work done under Contract
AF 08 (614)-2923

GRAVITY STANDARDIZATION
STUDIES
Final Report

WOODS HOLE OCEANOGRAPHIC INSTITUTION

WOODS HOLE, MASSACHUSETTS

Reference No. 62 - 23

Final Report on 1961 - 62

Gravity Standardization Studies

by

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FINAL REPORT

Work carried out under

Contract AF 08 (614) - 2923

with the Air Force 1381st Geodetic Squadron,

Air Photo and Charting Service, Orlando A.F.B., Florida

July 1962

Approved for distribution

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MBL/WHOI

0 0301 0092234 0

ACKNOWLEDGMENTS ON FIELD PROGRAM
AND PREPARATION OF REPORT

The following people worked or helped on the various aspects of the work reported.

Except where noted, all those mentioned are connected with the Geophysical and Polar Research Center of the Department of Geology at the University of Wisconsin.

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1. INTRODUCTION

1. a. General Remarks:

The successful promulgation of any regional gravity program carried out with gravimeters depends upon several factors. These can be described as (1) instrumental characteristics, (2) calibration standard, (3) method of survey, and (4) reduction procedure. It is assumed the instrument is reliable, has adequate range, and that the observer takes normal precautions to secure good data.

Although much research has been devoted to the study of the effect of slight imperfections in the pitch of the reading dial screw, reading dial graduation error, effect of pressure and temperature changes on instrumental drift rate and readings, linearity of response, and calibration stability, all that has been ascertained is that each instrument constitutes an individual problem, and that no two instruments have the same characteristics although in gross terms they may be identical. Therefore, in order for data obtained using several gravimeters, or data obtained by several unrelated groups to be integrated it is necessary that there be some standards for either evaluating the instruments used directly or the data obtained through spot check observations with a standardized instrument.

Although pendulum measurements of gravity still constitute the most reliable calibration standard over any extended range of gravity, it has been shown by Woollard and Rose (WHOI Tech. Report 60-26) that pendulum measurements also are beset by problems in the form of tares (jumps in period) and period creep. The only method of detecting these effects is through closure runs whereby an entire series of pendulum measurements is repeated in reverse order and through companion gravimeter measurements. Although gravity simulation by tilting a gravimeter and loading the beam are the common laboratory methods used to establish the overall calibration of gravimeters, these procedures are seldom accurate enough to provide a calibration reliable to better than 1 mgal for 2000 mgal change in gravity. These procedures, however, do provide a ready means for determining changes in calibration constant with time once a gravimeter has been calibrated against a series of good pendulum observations.

One part of the United States national program for the International Geophysical Year was the establishment of a series of pendulum observations by the University of Wisconsin in collaboration with Cambridge University as a part of an international effort to develop an international gravity standard and control network. This program actually was initiated much earlier and the writers' participation started in 1951 when a series of measurements with the Gulf "C" pendulums was established in North America between Alaska and Mexico under Air Force Cambridge Research Center auspices through the Woods Hole Oceanographic Institution. By the time of the International Geophysical Year the writers' program had been extended from North America to Africa, South America, Europe and the Far East.

As shown by Woollard and Rose (WHOI Tech. Report 60-26), comparative

gravimeter measurements indicate that the average reliability of these pendulum standardization measurements is about ± 0.3 mgal over a range of about 5000 mgals. Subsequent improvements in the Gulf pendulum apparatus by Dr. Rose however, have resulted in their degree of reliability being improved to better than 0.2 mgal.

To establish the screw and dial idiosyncrasies of a geodetic gravimeter whose reliability may vary in a sinusoidal manner by 1 mgal or more over a range varying usually between 150 to 750 mgals, the most feasible standard is a series of closely spaced observations made with another gravimeter having a low amplitude sinusoidal response covering a 1000 or more mgal range that can be adequately checked either through laboratory gravity simulation tests or comparisons with good pendulum measurements. The large LaCoste-Romberg geodetic gravimeter is such an instrument and also has the additional advantage of having a very low drift rate. The University of Wisconsin large LaCoste-Romberg geodetic gravimeter No. 1, for example, seldom drifts more than 0.2 mgal per month. A series of closely spaced (30-40 mgal interval) measurements with this instrument now that its characteristics have been established, provides a means for evaluating the screw curve and dial idiosyncrasies of other gravimeters.

The effect of external temperature, temperature gradient and pressure on gravimeter readings can be adequately tested in a laboratory. Not only is the effect of changes in ambient recording conditions on instrument readings important, but also the rate at which an instrument adjusts to changes in recording environment. The latter has been observed to be critical in using plane transportation where an instrument is subject to a rapid change in pressure on landing. Some instruments show no change in readings with time after landing other than that for normal drift and the earth tide effect; others may require half an hour to become stable. On a somewhat different scale, an instrument that is operated at constant temperature which has been stored off heat for several months may require a week or more to stabilize after being put back on heat. If at all possible such an instrument should be kept on heat all of the time.

Survey procedure as regards closures should determine the reduction procedure to be used in obtaining observed gravity values, and, as will be shown later, this factor can be significant in determining the reliability of the values obtained.

1. b. Objectives of Program:

In view of the accumulative importance of the various factors described above on the reliability of regional gravity work, the senior author entered into an agreement with the Air Force 1381st Geodetic Squadron, A.P.C.S., Orlando, to develop improved gravity standards and to set up gravimeter tests that could be used by the 1381st Geodetic Squadron to establish and maintain a program of high quality gravity work. Specifically, the program included the following:

1. Reoccupy key gravity bases on the North American western gravity standardization range between Pt. Barrow, Alaska, and Mexico City, Mexico, and to establish a tie from this line via Madison, Wisconsin, to the national absolute gravity site in Washington, D. C. The work to be done with an overall precision of ± 0.2 mgal or better using the Gulf-Wisconsin compound quartz pendulum apparatus and a large LaCoste-Romberg geodetic gravimeter No. 1.

2. Establish a gravimeter control line for the detection of gravimeter screw and dial idiosyncrasies between Miami, Florida, and Charleston, South Carolina, with the LaCoste-Romberg large geodetic gravimeter No. 1 observations to be made at approximately 30-40 mgal intervals.

3. Investigate the effect of changes in external pressure and temperature on the response of both Worden and LaCoste-Romberg geodetic gravimeters, particularly those being used by the 1381st Geodetic Squadron.

4. Have built a tilt-table gravity simulator to be used by the 1381st Geodetic Squadron for checking their Worden Geodetic gravimeters for changes in calibration.

1. c. Remarks on Program Carried Out:

It was possible to carry out the objectives cited under Items 1 and 2 above, but difficulties were encountered in meeting the directives given for Items 3 and 4.

As originally planned, the effect of changes in external pressure (Item 3) were to be established in the de-compression chamber at Chanute Air Force Base. However, upon arrival at Chanute Field for preliminary tests, it was found that the time required in the chamber for comprehensive tests could not be obtained because of other Air Force requirements. Rather than omit this phase of the study, the senior author authorized the expenditure of other funds to build a pressure chambers for these tests; one that would accommodate Worden gravimeters, and also others as the large LaCoste-Romberg gravimeters. The delay occasioned by the necessity for constructing this pressure chamber resulted in a more limited body of data than otherwise might have been obtained. The tests also had to be run in part on instruments other than those belonging to the Air Force. This was because instruments were not available for testing.

According to Item 4, a tilt-table gravity simulator was to be built for the 1381st Geodetic Squadron so that calibration tests of their Worden gravimeters could be carried out at the Orlando Air Force Base. Accordingly, an agreement was entered into with the Worden Laboratories of Houston, Texas, to build a tilt-table calibrator. However, during the middle of the contract period, Mr. C. Whelan, in charge of the 1381st Geodetic Squadron gravity program, advised that he was contemplating a change-over from Worden geodetic gravimeters to LaCoste-Romberg small geodetic gravimeters. As the LaCoste-Romberg gravimeters cannot be calibrated by tilting, the Air Force A.P.C.S. Headquarters was notified that the tilt-table which had been started by Worden Laboratories would be useless. As Mr. S. P. Worden of Worden Laboratories felt he might be able to develop a spin-table calibrator that would accommodate both Worden and LaCoste-Romberg gravimeters, it was recommended that Mr. Worden be authorized to undertake this development with some supplemental funding over and above that authorized for the tilt-table calibrator. As in all development work, many difficulties that could not be anticipated were encountered, and Mr. Worden not only invested personally very heavily in this development, but the senior author also felt it worthwhile to send two men to work with Mr. Worden for a period of five weeks in order to help with the development program.

By the middle of June, 1962, the principal problems associated with the spin calibrator appeared to have been solved, and it was possible to conduct some tests with a Worden gravimeter - the only gravimeter available - which were very encouraging. On the basis of these tests and a letter from Mr. Struhart, Procurement Officer for A.P.C.S. Headquarters, Orlando AFB, dated June 12, 1962, requesting delivery of the spin-table calibrator on the contract expiration date, July 1, 1962, it was decided to send the calibrator to Madison, Wisconsin, for whatever additional instrument tests that could be accomplished in the remaining period. The calibrator, however, did not reach Madison until June 28th, which left essentially no time for reassembly, the manufacture of a jig to accommodate a LaCoste gravimeter, and any testing.

As a prototype piece of apparatus, the spin calibrator appears to be a success, but several modifications are still desirable. As it stands, the apparatus requires a skilled technician to obtain satisfactory measurements. If at all possible, the design should be modified to facilitate measurements by unskilled personnel.

2. THE FIELD PROGRAM

2. a. The Pendulum Measurements:

As outlined in the Introduction, measurements were to be made with the Gulf-Wisconsin pendulums and the large LaCoste-Romberg geodetic gravimeter (LR-G-1) over the western North American gravity standardization range between Point Barrow, Alaska, and Mexico City, Mexico, with a tie to the absolute gravity base at the National Bureau of Standards in Washington, D.C. The field program proper was preceded by a test run from Madison, Wisconsin, to St. Louis, Missouri, and from Madison to Minneapolis, Minnesota, as the apparatus had not been in use for a period of nearly one year and during the interim some basic modifications in the recording system had been made. The results on the test runs which were carried out in September, 1961, by Dr. Rose, Mr. Longfield and Mr. Carlson showed that the pendulums were working in a satisfactory manner as indicated below:

Madison - St. Louis

Out leg	Back leg
-370.29 mgals	-370.29 mgals

Madison - Minneapolis

Out leg	Back leg
+228.94 mgals	+229.03 mgals

The above closures are among the best ever obtained with any set of pendulums, and the results agree to 0.1 mgal with the gravity intervals measured with the large LaCoste-Romberg geodetic gravimeter.

The pendulum program proper was carried out by Mr. Longfield and Mr. Carlson and took the form of three series of observations. The first two

series covered the western gravity standardization range, and the third series, the tie to Washington. The sites occupied on each series on the western gravity standardization range are given below:

Northern Series

Out leg

Madison, Wisconsin I
Huron, South Dakota I
Denver, Colorado I
Great Falls, Montana I
Edmonton, Alberta I
Whitehorse, Yukon I
Fairbanks, Alaska I
Point Barrow, Alaska I

Back leg

Point Barrow, Alaska II
Fairbanks, Alaska II
Whitehorse, Yukon II
Edmonton, Alberta II
Great Falls, Montana II
Denver Colorado II

Southern Series

Out leg

Denver, Colorado II
Houston, Texas I
Monterrey, Mexico I
San Luis Potosi, Mexico I
Mexico City, Mexico I

Back leg

Mexico City, Mexico II
San Luis Potosi, Mexico II
Monterrey, Mexico II
Houston, Texas II
Denver, Colorado III
Madison, Wisconsin II

Fig. 1 shows the geographic distribution of the sites occupied.

In making the connection from Madison, Wisconsin, to the western standardization range the Huron, South Dakota, gravity base on the mid-continent gravity standardization range was occupied on the way to Denver as a final check on the operation of the equipment.

In order to simulate independent observations at the two end points, Point Barrow and Mexico City, the pendulums were taken off heat after the first series of swings up, and then driven around for half a day to subject them to ordinary road vibration.

The pendulum tie from Madison to Washington was not made until the latter part of April after the western results were worked up. At the same time that the Washington connection was made, repeat pendulum and gravimeter measurements were made at the Charleston, Miami, and Key West pendulum bases established earlier.

2. b. The Gravimeter Measurements:

The LaCoste-Romberg gravimeter LR-G-1 was used to occupy all of the sites occupied with the pendulums on the western gravity standardization range, and in addition most of the earlier established intermediate pendulum bases which are described in WHOI Report 60-26. The sites occupied are listed below.

FIG. 1

Northern Series

Out leg	Back leg
Denver, Colorado	Point Barrow, Alaska
Cheyenne, Wyoming	Fairbanks, "
Casper, "	Whitehorse, Yukon
Sheridan, "	Watson Lake, "
Billings, Montana	Fort Nelson, British Columbia
Great Falls, "	Fort St. John, " "
Cut Bank, "	Grande Prairie, Alberta
Lethbridge, Alberta	Edmonton, "
Calgary, "	Red Deer, "
Red Deer, "	Calgary, "
Edmonton, "	Lethbridge, "
Grande Prairie, "	Great Falls, Montana
Fort St. John, British Columbia	Billings, "
Whitehorse, Yukon	Sheridan, Wyoming
Snag, "	Casper, "
Northway, Alaska	Cheyenne, "
Fairbanks, "	Denver, Colorado
Point Barrow, "	

Southern Series

Out leg	Back leg
Denver, Colorado	Paso de Cortes, Mexico
Amarillo, Texas	Mexico City, "
Houston, "	San Luis Potosi, "
Austin, "	Monterrey, "
Laredo, "	Laredo, Texas
Monterrey, Mexico	Houston, "
San Luis Potosi, Mexico	Austin, "
Mexico City, "	Amarillo, "
Paso de Cortes, "	Denver, Colorado
	Madison, Wisconsin

In addition to the above, a companion set of gravimeter measurements was made at the time of the pendulum tie from Madison, Wisconsin, to Washington with the large LaCoste geodetic gravimeter. This gravimeter was used also to establish a series of auxiliary bases at about 30 to 40 mgal intervals between Charleston, South Carolina, and Miami, Florida, in accordance with the requirement outlined in the Introduction for a series of observations that could be used by the 1381st Geodetic Squadron as a standard for evaluating screw and dial idiosyncracies of their gravimeters. The sites occupied on this series of measurements are listed below:

Charleston, South Carolina
 Pendulum Station
 Municipal Airport
 MATS Base
 Green Pond, S. C. (R.R. Station)
 Ridgeland, S. C. (R.R. Station)
 Savannah, Ga. (Municipal Airport)

Riceboro, Ga. (R.R. Station)
St. Simons Island, Ga. (Municipal Airport)
Kingsland, Ga. (R.R. Station)
Jacksonville, Fla (Municipal Airport)
St. Augustine, Fla. (Municipal Airport)
Bunnell, Fla. (R.R. Station)
Daytona Beach, Fla. (Municipal Airport)
Sanford, Fla. (R.R. Station)
Orlando, Fla.
 Municipal Airport
 McCoy Air Force Base
 Orlando Air Force Base
Cocoa, Fla. (R.R. Station)
Melbourne, Fla. (Municipal Airport)
Vero Beach, Fla. (Municipal Airport)
Stuart, Fla. (R.R. Station)
West Palm Beach, Fla. (Municipal Airport)
Pompano Beach, Fla. (Municipal Airport)
Miami, Fla.
 Municipal Airport (EAL)
 International Airport
 Pendulum Station

Fig. 2 shows the geographic location of the sites occupied.

Although not an official part of this study, cooperative measurements were also carried out with the 1381st Geodetic Squadron between Orlando, Florida, and Bogota, Colombia, via Panama; from Orlando, Florida, to Presque Isle, Maine, along the east coast, and from Orlando, Florida, to Japan and thence to Hong Kong. These measurements, however, are not included here, and will be reported separately.

2. c. Remarks on Field Program:

As the pendulum program did not get under way until October, much of the northern series of observations was carried out under sub-freezing conditions which necessitated heating the pendulum case for double the normal period of time in order to insure equilibrium at the normal operating temperature of 35°C. Even then, in several places it was necessary to employ auxiliary space heaters and additional insulation for the pendulum case in order to hold temperature.

As all travel was by truck except for the tie between Fairbanks and Point Barrow, Alaska, which was made by airplane, a serious problem encountered was icy road and blizzard conditions, which materially slowed down the operation. The significance of this factor is well illustrated by the fact that on two occasions less than 100 miles of travel was accomplished in the course of a 12-hour day. Even with careful driving the truck skidded off the road three times and the winch of the truck broken in trying to get back on the road the last time this happened. However, outside of blowing the head gasket on the engine 150 miles north of Whitehorse in the Yukon, which necessitated being towed back to Whitehorse for repairs, no major difficulties were encountered. This happy situation contrasts strongly with that experienced on the 1951 series of pendulum measurements to Alaska when three axles

were broken, the gas tank punctured and eight tires ruined. The explanation for this difference can be attributed to having a vehicle appropriate for the trip with armoured gas tank, heavy duty axle, four-speed drive, overload springs and high road clearance.

On the southern series of observations sub-freezing conditions were also encountered in Mexico. However, the only serious obstacle encountered on this series of measurements was a delay of nearly a week in getting across the Mexican border. The instruments had been cleared, but lacking full details on the truck, tire numbers, etc., a month in advance, the Mexican Customs refused entry. However, through the good graces of Ing. Julio Monges of the Instituto Geofisico, who made a special trip from Mexico City to facilitate entry, it was finally possible to post bond for the truck and carry out this portion of the program.

3. THE PENDULUM APPARATUS

3. a. General Remarks:

The pendulums used were the "M" set of compound quartz pendulums developed by the Gulf Research and Development Company of Pittsburgh, Pennsylvania, with modifications of the seals and recording system as made by Dr. John Rose of the University of Wisconsin. As these pendulums have been described in Woods Hole Oceanographic Institution Reports Nos. 53-36, 56-72, and 60-26, they will not be discussed further here. However, in view of the changes made in the recording system and temperature and pressure controls since the issue of WHOI Report No. 60-26, these modifications in the apparatus will be described.

3. b. Description of Pendulum Recording Apparatus:

Basically, recording is done by having a beam of light from an external light source reflected from the mirrored surface of the pendulums to an external recorder. In the present apparatus an external transducer box contains the incandescent light source and a photomultiplier transducer which is connected to an oscillograph recorder. There are four accurately located horizontal slits in the face of the box, and the box is located at an accurately measured distance of 93.8 cm in front of the window of the pendulum case. This distance corresponds to the focal length of the lens of the optical bench in the pendulum case. The light beam reflected from the mirror face of each pendulum is thus brought to a focus at the photomultiplier transducer after passing through the slit system which is located just in front of the photomultiplier. The four slits provide a center-line slit and an amplitude slit for each pendulum. Vertical adjustment of the transducer box is provided so that the reflected light beams from the two pendulums when lowered and at rest are focused on the respective center-line slits. Fig. 3-a shows the transducer box, and Fig. 3-b shows the relation of the transducer box to the pendulum case.

The photomultiplier consists of four Texas Instrument 2175 silicon photodiodes, and their outputs are applied to the galvanometers of a high speed, direct readout, fourteen-channel Honeywell-Heiland Model 906B Visicorder Oscillograph.

Figure 3-a

Transducer Box

Figure 3-b
Relation of Transducer
Box To Pendulum Case

Galvanometer recording with an oscillograph has many advantages in that in addition to the two pendulum traces, WWV radio time signals, and timing marks generated by an auxiliary secondary time standard are simultaneously recorded. With this system, instead of continuously beating a crystal oscillator against WWV and hoping that the frequency dividers function properly, a permanent and independent direct check of the timing system against WWV is recorded along with the pendulum traces. Another advantage of this recording system is that the records can be partially developed immediately under controlled incandescent light conditions which enables the observer to continuously evaluate the operation of the entire apparatus.

The WWV radio receiver employed is a Specific Products Model WWVT Receiver and the frequency standard used is a Model JK-Sulzer FS-1100T Frequency Standard built by the James Knights Company. As the frequency standard's accuracy is a few parts in a billion and exceeds the short term accuracy of the WWV signals received, WWV is only used to determine shifts of the frequency dividers.

3. c. Temperature Control:

With a single thermometer in the pendulum case, it can not be ascertained reliably when thermal equilibrium has been reached. To aid in determining the true thermal state within the case, three thermistor elements were installed within the case; two on the bearing plates and one on the thermometer.

In a room with constant temperature conditions, the three thermistors are read in the middle of each one-hour observation period, but if the room temperature is unstable they are checked more often. The thermometer within the case is used to calibrate the thermistors before and after a trip, as it has been established that they drift with aging.

3. d. Pressure Control:

Pressure is checked before and after each series of swings with a transistorized Hastings-Raydist thermocouple gauge. The leak rate of the "M" set on the western North American gravity standardization range from October through December, 1962 was approximately eight microns of mercury per day, necessitating pumping the case every two weeks. However, the leak rate increased rapidly toward the end of the trip between Monterrey and Denver to five microns per hour. By the time of the connection to Washington, D.C. in May, 1962, the "M" set leak rate had increased to eight microns per hour, so that pumping of the case was required at every station.

4. PENDULUM OPERATIONAL PROCEDURE

4. a. Description of Procedure:

The pendulum apparatus is put on heat immediately upon arrival at a station. Normally, a waiting period of twelve hours is usually sufficient time for the pendulums to reach thermal equilibrium, but under extreme cold ambient temperature conditions, twenty-four hours may be necessary.

Observations are made at pressures varying from 0.080 to 0.300 millimeters mercury. If the case has failed to maintain pressure within this range en route between stations, the vacuum pump is started at the same time that the pendulums are put on heat, as a waiting period is necessary to dissipate any possible electrostatic charges built up during pumping.

After the waiting period is completed and thermal equilibrium established, the pendulums are unclamped, lowered onto the flats, manually cocked, and then released two minutes prior to the recording time. Recordings are timed to synchronize with the WWV five-minute tone signal. An accurately rated mechanical clock is used, together with WWV, so that the oscillograph drive can be turned on one second before the tone. A continuous recording is made for three seconds at a paper speed of 50 inches (127 cm) per second. This ensures six center-line crossings for each pendulum, or three complete swings. The pendulums are allowed to swing undisturbed for one hour, and then another recording is made in the same manner as outlined above. Five one-hour runs are usually made, with the pendulums being raised off the flats and then lowered again before each run to obviate any skewness of knife-edge position upon the flats that might be obtained on a single lowering. Because of the sensitivity of the pendulum period to tilt, both lateral and longitudinal leveling of the set is checked at the beginning and end of each run.

One factor related to operations that was suspected earlier but verified in the present measurements is the effect of changes in heating procedure. Normally the pendulums are not heated while in transit, but on the back leg from Mexico City to Madison the pendulums were kept on heat. It is significant that only this portion of the trip is characterized by pendulum period creep. This is believed to have been caused by softening of the knife edge cement because of continuous heating and possibly at the same time vibration of the apparatus while in transit.

5. READING OF THE RECORDS

5. a. General Description:

The method of picking the records to determine the pendulum period consists of locating pendulum trace peaks and determining their time significance using the timing lines generated by the frequency standard. This is discussed further in Section 6. The Visicorder Oscillograph offers several improvements over the old photographic system. A major one is that the records can be partially developed right away by exposure to incandescent light and visually inspected as a check on the proper operation of all components. Latensification (latent image intensification) for record reading is done later, and to obtain good contrast an exposure time of ten to thirty minutes under incandescent light is required. However, ultra-violet or sunlight can not be allowed to strike the record, as under these conditions the record will be destroyed in a few seconds. Although permanent stability can be obtained with an acid fixer and then washing and drying the records, it has been found that the records are stable if stored in a closed file and only exposed to be read. This requires about an hour and is done under controlled light conditions.

6. PENDULUM PERIOD REDUCTION PROCEDURE

6. a. Outline of Procedures:

The essential steps in determining the pendulum period are outlined below:

- 1 - WWV is used to assign precise time relations between zero-minute and the end of a sixty-minute run.
- 2 - Center-line slit crossings and amplitude slit crossings are identified on the records and picked to the nearest tenth of a millisecond, using the timing lines generated by the James Knights frequency standard.
- 3 - Compute paired center-line averages for both zero-minute and sixty-minute runs of both pendulums.
- 4 - Using the approximate period derived from one-minute runs at each station, determine the number of swings over an hour period.
- 5 - Correct for the drift rate of the frequency standard. This is established by beating the frequency standard against WWV during periods of good reception. This check is best made on ground wave reception of WWV, but frequent checks under varying ionospheric conditions during a trip also permit determination of the drift rate to within one part in 10^8 .
- 6 - Using the above information, determine the raw periods for the time represented by the center-line average of the zero-minute run subtracted from the center-line average of the sixty-minute run.

$$T = \frac{t}{N} \quad (1)$$

T = raw period

t = total time

N = number of swings

Example: (Washington I, No. 7)

$$\begin{array}{r} M_1 \\ 3601.148267 \text{ sec.} \\ -1.427717 \\ -0.000493 \text{ (freq. std. correc.)} \\ \hline t = 3599.720057 \end{array}$$

$$\begin{array}{r} M_2 \\ 3601.158167 \text{ sec.} \\ -1.428667 \\ -0.000493 \\ \hline t = 3599.729007 \end{array}$$

$$N = 4037$$

$$T_{M_1} = \frac{3599.720057}{4037} \text{ sec.}$$

$$= 0.891 \ 681 \ 96 \text{ sec.}$$

$$T_{M_2} = \frac{3599.729007}{4037} \text{ sec.}$$

$$= 0.891 \ 684 \ 17 \text{ sec.}$$

$$T_{\bar{M}} = 0.891 \ 683 \ 06 \text{ sec.}$$

7. CORRECTIONS TO THE PENDULUM PERIOD

7. a. General Statement:

The theory of the corrections for a two pendulum apparatus has been developed by Vening Meinesz (1929), Andersen (1932), Swick (1942), and others. A discussion of the reduction to zero amplitude, pressure corrections, temperature corrections, and earth tide corrections has been given in detail by Rose (WHOI Tech. Report No. 60-26, p. 12-16).

7. b. Amplitude Correction (ΔT_A):

Reduction to zero amplitude depends on the measured vertical displacements of the pendulums in A inches corresponding to α radians, according to the relationship:

$$\Delta T_A = -2.21 \frac{A_1^2 - A_2^2}{\log_{10} \frac{A_1}{A_2}} T \times 10^{-6} \quad (2)$$

where A_1 = amplitude at 0 min.

A_2 = amplitude at 60 min.

Tables have been derived for the determination of pendulum amplitude (A) from the time interval of the light beam to pass the pair of slits at the transducer on the basis of the following equations:

$$A = \frac{\Delta A}{\sin \omega \Delta t} \quad (3)$$

where A = linear amplitude in inches at the slit transducer

(1959-62 GULF K & M)

ΔA = distance between slits in inches

= 0.300 inch

Δt = time of passage between slits in seconds

$\omega = 2\pi/T$

where T = period of pendulum in seconds

It follows that
$$A = \frac{\Delta A}{\sin \omega \Delta t} = \frac{\Delta A}{\sin \frac{2\pi \Delta t}{T}} \quad (4)$$

$$= T \left[\frac{\Delta A}{2\pi} + \frac{1}{\Delta t} \cdot \frac{\Delta A \times 2\pi}{6 \times 0.794} \Delta t \right] \quad (5)$$

$$\dot{z} = T \left[\frac{0.04852}{\Delta t} + 0.3957 \Delta t \right] = T A' \quad (6)$$

A' = amplitude in inches for pendulum period of 1 sec. A' must be multiplied by T to get the proper amplitude.

Example: (Washington I, #7) using Equation 2

$$\Delta T_A = -2.21 \frac{(.963)^2 - (.663)^2}{\log_{10} \frac{.963}{.663}}$$

$$= -5.93 \times 10^{-6} \text{ sec.}$$

7. c. Pressure Correction, (ΔT_p):

The pressure correction for the "M" pendulums has been determined experimentally by Rose, (WHOI Tech. Report 60-26, p. 14). Observed pressures are first reduced to a common temperature (20°C) according to the following relationship:

$$P_{20} = \frac{293}{273 + \theta} P_{\theta}$$

where θ = observed temperature °C. (7)

The experimentally determined pressure effect is given by the expression:

$$\Delta T_p = -1.08 P_{20} T \times 10^{-6} \quad (8)$$

7. d. Temperature Correction (ΔT_{θ}):

The experimentally determined temperature correction is given by the expression:

$$\Delta T_{\theta} = -0.214 \Delta \theta \cdot T \times 10^{-6} \quad \text{where } \Delta \theta = \text{temperature variation from the standard value.} \quad (9)$$

As the pendulum case is thermostatically controlled to 35°C, this temperature is used as a standard. Corrections are necessary as drafts and variations in local room temperature conditions introduce some variations in operating temperature from the 35° standard.

7. e. Earth Tide Corrections (ΔT_{ET}):

The earth tide correction is determined from the tables published by the European Association of Exploration Geophysicists and applied in equivalent seconds of period on the basis that 1 mgal = 0.454 milliseconds with the Gulf-Wisconsin pendulums.

7. f. Corrections Obtained for Pendulum Measurements 1961-62:

In Table No. 1 of the Appendix the raw periods observed for each run are listed along with the operating temperature, pressure, the observed amplitudes, and derived period corrections for all stations occupied on the run from Madison, Wisconsin, to Pt. Barrow, Alaska, Mexico City, Mexico, and return to Madison.

In Table 1a similar information for the connection from Madison to Washington, D. C., is recorded and in Table 1b the data for the connection from Madison, St. Louis and Minneapolis.

8. CORRECTED PERIODS FOR PENDULUM MEASUREMENTS

The mean corrected periods for all runs of each sequence of observations at each observation site are listed in Table 1 along with differences between pendulum No. 1 and pendulum No. 2 ($M_1 - M_2$) and the standard errors for both pendulums and their mean value. The last column gives the number of swings included in the sequence.

9. THE PENDULUM RESULTS

9. a. The Pendulum Closures:

In Figure 4 the gravity intervals obtained with the pendulums on the outgoing leg from Madison, Wisconsin, to Denver, Colorado, via Huron, South Dakota, is compared with that obtained between Denver and Madison on the back leg. It is seen that the intervals agree to 0.01 mgal and this indication of reliability is substantiated to 0.1 mgal by gravimeter observations.

In Figure 5 the closure errors are shown for each site occupied. All values were computed relative to the Madison, Wisconsin, base. It is seen that the overall closure at Madison is +0.55 mgal; and that on the series of observations north of Denver, the loop closure is -0.5 mgal. On the series of observations south of Denver, the loop closure is +1.06 mgals. These closures suggest tares in both series of observations. On the northern series, one tare is indicated between Denver and Great Falls by the change in closure error from -0.5 mgal at Denver to +0.18 mgal at Great Falls. Another tare is suggested between Fairbanks and Point Barrow by the change in closure error from +0.18 mgal at Fairbanks, Alaska, to -0.11 mgal at Point Barrow, Alaska. On the series of observations south of Denver a tare between Denver and Houston is indicated by the change in closure error from +1.06 mgals at Denver to +0.57 mgal at Houston. Another tare is indicated between San Luis Potosi and Mexico City by the change in closure error from +0.48 mgal at San Luis Potosi, Mexico to -0.08 mgal at Mexico City.

In order to ascertain whether the tares indicated occurred on the going leg or the back leg of the respective series of observations, the measured gravity intervals between sites without tares are compared in Figure 6 with the intervals as determined with the large LaCoste-Romberg geodetic gravimeter. From these comparisons it is seen the tare between Denver and Great Falls must have occurred on the going leg, and that between Fairbanks and Point Barrow on the back leg. It also is to be noted from Figure 5 that there is a marked discrepancy between pendulum and gravimeter results for the intervals between Fairbanks and Point Barrow and Whitehorse and Fairbanks, which amounts to 0.3 mgal in each case. However, the interval values as determined with both the pendulums and the gravimeter are in substantial agreement between Whitehorse and Point Barrow as shown below.

TABLE 1

1961 GULF-WISCONSIN M NORTH AMERICA

Date	Station Sequence	Seconds M	Microseconds				n
			M1-M2	$\bar{s}$ M1	$\bar{s}$ M2	$\bar{s}$ M	
10-14-61	Madison (12)	0.891 555 22	-2.20	0.02	0.04	0.01	4
18	Huron	516 63	-2.31	0.03	0.04	0.02	4
21	Denver (U. Denv.)	899 40	-2.09	0.04	0.06	0.01	4
26	Great Falls	483 52	-2.61	0.03	0.02	0.02	4
29	Edmonton	192 41	-2.36	0.03	0.05	0.03	4
11-04-	Whitehorse	.890 928 01	-2.56				1
08	Fairbanks (GI)	702 85	-2.36	0.01	0.06	0.03	4
10	Pt. Barrow	497 37	-2.35	0.02	0.03	0.01	4
11	Pt. Barrow	497 42	-2.48	0.10	0.06	0.07	2
13	Fairbanks (GI)	702 78	-2.45	0.07	0.09	0.06	4
18	Whitehorse	927 92	-2.53	0.02	0.11	0.06	3
23	Edmonton	.891 192 39	-2.90	0.05	0.05	0.01	4
26	Great Falls	483 44	-2.31	0.14	0.16	0.05	4
30	Denver (U. Denv.)	889 63	-2.53	0.09	0.10	0.02	4
12-05	Houston (Rice)	.892 042 50	-2.70	0.18	0.18	0.04	4
14	Monterrey	267 03	-2.26	0.06	0.07	0.03	4
15	San Luis Potosi	538 75	-2.63	0.06	0.11	0.04	4
18	Mexico, DF	661 15	-2.59	0.02	0.11	0.05	4
20-21	Mexico, DF	661 18	-2.83	0.07	0.09	0.03	7
22	San Luis Potosi	538 53	-2.51	0.04	0.04	0.01	4
24	Monterrey	266 86	-2.64	0.02	0.03	0.01	4
26	Houston (Rice)	042 24	-2.85	0.07	0.11	0.03	4
29	Denver (U. Denv.)	.891 899 14	-2.34	0.08	0.19	0.09	4
1-04-62	Madison (12)	554 97	-2.51	0.04	0.03	0.04	4

TABLE 1 (Cont'd)

1961 GULF-WISCONSIN M MADISON-ST. LOUIS-MINNEAPOLIS

Date	Station Sequence	Seconds M	M1-M2	Microseconds			n
				$\bar{s}$ M1	$\bar{s}$ M2	$\bar{s}$ M	
8-29-61	Madison (12)	0.891 555 38	-2.50	0.02	0.05	0.04	2
9-01	St. Louis (Wilson Hall)	723 79	-2.30	0.05	0.09	0.02	3
9-02	St. Louis	723 75	-2.20	0.06	0.02	0.03	4
9-09	Madison (12)	555 34	-2.34	0.04	0.04	0.04	4
9-12	Minneapolis	451 25	-2.71	0.05	0.08	0.06	4
9-13	Minneapolis	451 22	-2.41	0.07	0.04	0.03	4
9-17	Madison (12)	555 34	-2.25	0.02	0.03	0.02	4

1962 GULF-WISCONSIN M MADISON-WASHINGTON

Date	Station Sequence	Seconds M	M1-M2	Microseconds			n
				$\bar{s}$ M1	$\bar{s}$ M2	$\bar{s}$ M	
4-30-62	Madison (12)	0.891 554 76	-2.37	0.01	0.04	0.03	4
5-05	Washington	676 65	-2.20	0.02	0.06	0.03	5
5-30	Washington	676 62	-2.19	0.04	0.02	0.03	3
6-07	Madison (12)	554 60	-2.44	0.16	0.09	0.03	4

1961 GULF-WISCONSIN PENDULUM INTERVALS (MGALS) TO THE WESTERN CALIBRATION LINE

FIG. 4

REOCCUPATION CLOSURES (MGALS)

FIG.5

1961 GULF WISCONSIN PENDULUM INTERVALS (MGALS) ON WESTERN LINE

[] = TARE

FIG. 6

Pendulums		Gravimeter
Whitehorse - Point Barrow		Whitehorse - Point Barrow
Going leg	Back leg	
949.76 mgals	949.46 mgals	949.7 mgals
	.29 (apparent tare)	
	949.75 mgals	

As the pendulum intervals on both legs for the connection between Whitehorse and Fairbanks agree to 0.01 mgal, it appears either the gravimeter or the pendulums were subject to some unknown local effect at Fairbanks.

9. b. Reduction of Values on Basis of Observed Station Closures:

On the basis of the closure values shown in Figure 5 and the pendulum interval comparisons shown in Figure 6, the tare between Point Barrow and Fairbanks on the back leg is +0.18 mgal. This is based on the closures for all sites between Great Falls and Fairbanks, which averages +0.18 mgal as shown in Figure 5. To reconcile these closures with the indicated interval difference of +0.29 mgal observed on the going and back leg between Fairbanks and Point Barrow, it has to be assumed that the second Point Barrow observation is in error by the observed difference of -0.11 mgal between the first and second occupation.

On the basis of the closure of -0.5 mgal at Denver and the above tare of +0.18 mgal, the tare between Denver and Great Falls is -0.68 mgal, which agrees with the difference in pendulum gravity interval observed between Denver and Great Falls on the going leg and back leg.

On the series of measurements south of Denver the comparison of interval measurements shown in Figure 6 indicates that both tares deduced from Figure 5 occurred on the back leg. The difference in interval values observed between Mexico City and San Luis Potosi on the going leg and back leg is 0.56 mgal. However, the average of the closure values for San Luis Potosi, Monterrey and Houston taken from Figure 5 is +0.48 mgal. It therefore appears that the difference of -0.8 mgal observed between the second and first occupation at Mexico City represents a poor value for the second occupation. On this basis the tare is +0.48 mgal, which agrees with the closure value.

If this tare is applied to the closure error observed for the Denver reoccupation (+1.06 mgals), the tare between Houston and Denver is +0.58 mgal. This checks closely the closure on Madison, which is shown in Figure 5 to be +0.55 mgal. As no tares are indicated in the connection between Denver and Madison, an average value of +0.57 mgal was adopted for this final tare between Houston and Denver.

A summary on tares therefore is as follows:

Madison-Denver

Going leg (no tares)	Back leg (no tares)
----------------------	---------------------

Denver-Point Barrow

Going leg

Denver-Great Falls -0.68 mgal

Great Falls-Point Barrow (no tares)

Back leg

Point Barrow-Fairbanks +0.18 mgal

Fairbanks-Denver (no tares)

Net tare on Denver closure: $-0.68 + 0.18 = -0.50$ mgal, which checks the closure value.

Denver-Mexico City

Going leg

Denver-Mexico City (no tares)

Mexico City-San Luis Potosi +0.48 mgal

San Luis Potosi-Houston (no tares)

Houston-Denver +0.57 mgal

Net tare on Denver closure = $+0.48 + 0.57 = +1.05$ mgals, which checks the Denver closure value to 0.01 mgal.

Net tare on Madison closure from Denver = $+1.05 - 0.50 = +0.55$ mgal, which checks the Madison closure value of +0.55 mgal.

9. c. The Pendulum Gravity Values on Basis of Station Closures:

In Table 2 the pendulum gravity values both without and with the tare corrections are tabulated.

9. d. Reduction of Values on Basis of Gravimeter Comparison:

In the procedure used above for establishing the magnitude of the tares present from the individual station closures, an inherent assumption in the procedure is that all the values are equally reliable and all good. A critical factor is the actual degree of reliability as contrasted to the decimal value cited.

On the basis of the station interval comparisons measured with the pendulums that do not appear to be affected by tares (See Fig. 6), the actual observational reliability is about ± 0.1 mgal. However, it is clear that a poor observation at any key closure base, as Denver, would seriously bias the results. Also it is evident that the closure method does not necessarily provide a unique solution when more than one tare is present.

A better procedure for determining the magnitude of tares and differentiating good from poor observations in the pendulum measurements is to use the gravimeter values as an independent reference standard. With this method a sequence plot is made of the difference between pendulum and gravimeter values at all sites. Tares are then defined by offsets in the graph defining the best fit between the two sets of data. The amount of offset defines the amount of the tare. In the present case, the gravimeter observations

Table 2

Pendulum Gravity Results Gulf-Wisconsin Pendulums 1961 On Basis of Station Closures					
Station		Uncorrected Value Gals	Tare Correction mgal	Corrected Value Gals	Average Value Gals
Madison (base)	I	980.36890			980.36890
Huron	I	980.45377			980.45377
Denver	I	979.61240			979.61240
Great Falls	I	980.52660	+0.68	980.52728	980.52728
Edmonton	I	981.16729	"	981.16797	981.16790
Whitehorse	I	981.74974	"	981.75042	981.75043
Fairbanks	I	982.24615	"	982.24683	982.24683
Pt. Barrow	I	982.69950	"	982.70018	982.70013
Pt. Barrow	II	982.69939	"	982.70007	
Fairbanks	II	982.24633	+0.68 - 0.18 = +0.50	982.24683	
Whitehorse	II	981.74993	"	981.75043	
Edmonton	II	981.16733	"	981.16783	
Great Falls	II	980.52678	"	980.52728	
Denver	II	979.61190	"	979.61240	
Houston	I	979.29813	"	979.29863	979.29868
Monterrey	I	978.80533	"	978.80583	978.80578
San Luis Potosi	I	978.20946	"	978.20996	978.20996
Mexico DF	I	977.94122	"	977.94172	977.94168
Mexico DF	II	977.94114	"	977.94164	
San Luis Potosi	II	978.20994	+0.50 - 0.48 = +0.02	978.20996	
Monterrey	II	978.80571	"	978.80573	
Houston	II	979.29870	"	979.29872	
Denver	III	979.61296	+0.02 - 0.57 = -0.55	979.61241	
Madison	II	980.36945	"	980.36890	

made during the course of the pendulum measurements, and the mean of gravimeter values established earlier during the period 1949-1960 were both used for reference purposes. The plot of the differences between the pendulum values with no tare corrections and these two sets of gravimeter results are shown in Figure 7. This plot bears out the tare between Denver and Great Falls on the going leg, and the one between Point Barrow and Fairbanks on the back leg of the series of measurements north of Denver, but shows that on the southern series of measurements the pendulums experienced no tares but were characterized by period creep on the back leg from Mexico City.

The magnitude of the tares was determined as follows. On the basis of the 1961 gravimeter measurements, the best graphical fit to the observations before and after Great Falls shows the Denver-Great Falls tare to be -0.42 mgal. Using the earlier gravimeter values as a standard, the tare is -0.35 mgal. A mean value of -0.39 mgal was adopted. Similarly the 1961 gravimeter measurements define the tare between Point Barrow and Fairbanks as being +0.14 mgal. The earlier gravimeter values define this tare as being +0.18 mgal. A mean value of +0.16 mgal was adopted. The creep which is seen to be linear from the gravimeter comparison and amounted to +0.78 mgal between Mexico City and Madison, Wisconsin, was distributed as shown in Figure 7.

From the standpoint of recognizing poor observational data, it is clear from Figure 7 that the second Denver occupation with the pendulums is in error by about 0.2 mgal, as is the second occupation at Edmonton, and the first occupation at San Luis Potosi. Except for these three observations and the effect of the two tares plus period creep, the pendulum measurements had a reliability of about ± 0.1 mgal. The quality of the gravimeter work appears to be about the same as that of the better portion of the pendulum work, but as seen from Figure 7, the 1961 Madison-Denver gravimeter connection is 0.1 mgal higher than the mean of the earlier gravimeter connections and the pendulum connection. That this difference is not a result of poor observations was verified by a repeat tie to Denver from Madison with gravimeter LR-G-1 using air transport. The closure was completed in one day, there were no tares, and no drift other than that for earth tide. The gravimeter closure was to less than 0.01 mgal; the pendulum intervals agree to 0.01 mgal; yet the difference in the two sets of values is 0.1 mgal. Discrepancies as this one and that for Fairbanks, Alaska, can not be explained by any known factors. Obviously there was some local factor at Fairbanks that influenced the pendulum period in the same manner on both occupations, but what it was is not known. That it was the pendulums that were affected rather than the gravimeters is indicated by the fact that the 1961 gravimeter values check to 0.01 mgal the mean of the earlier gravimeter values and to 0.02 mgal the mean of previous pendulum measurements.

In the case of Monterrey, Mexico, where the 1961 gravimeter value is 0.2 mgal lower than the pendulum value and the mean of earlier gravimeter values, it appears the gravimeter measurements were affected by some local factor.

9. e. Pendulum Gravity Values Reduced on Basis of Gravimeter Comparisons:

In Table 3 the pendulum values as obtained on the basis of the gravimeter comparisons as described above are tabulated.

SEQUENCE

DIFFERENCE IN UNCORRECTED PENDULUM VALUES & GRAVIMETER VALUES
POINT BARROW - MEXICO, D.F.

● GRAVIMETER LR-G-1 (1961)
X MEAN GRAVIMETER VALUE (1949-1960)

FIG. 7

Table 3

Pendulum Gravity Results on Basis of Gravimeter Comparisons

Station		Uncorrected Value	Tare Correction and Value	Creep Correction and Value	Average Value
Madison	I	980.36890			980.3689 0
Huron	I	980.45377			980.4537 7
Denver	I	979.61240			979.6123 1
Great Falls	I	980.52660	$\frac{+0.39}{.52699}$		980.5270 0
Edmonton	I	981.16729	.16768		981.1676 2
Whitehorse	I	981.74974	.75013		981.7501 5
Fairbanks	I	982.24615	.24654		982.2465 5
Pt. Barrow	I	982.69950	.69989		982.6998 4
Pt. Barrow	II	982.69939	$\frac{.69978}{+0.39 -0.16 =}$		
			$\frac{+0.23}{.24656}$		
Fairbanks	II	982.24633	.24656		
Whitehorse	II	981.74993	.75016		
Edmonton	II	981.16733	.16756		
Great Falls	II	980.52678	.52701		
Denver	II	979.61190	.61213		
Houston	I	979.29813	.29836		979.2983 5
Monterrey	I	978.80533	.80556		978.8055 5
San Luis Potosi	I	978.20946	.20969		978.2098 3
Mexico DF	I	977.94122	.94145		977.9414 1
Mexico DF	II	977.94114	.94137		
San Luis Potosi	II	978.20994	.21017	$\frac{-0.20}{.20997}$	
Monterrey	II	978.80571	.80594	$\frac{-0.40}{.80554}$	
Houston	II	979.29870	.29893	$\frac{-0.59}{.29834}$	
Denver	III	979.61296	.61319	$\frac{-0.78}{.61241}$	
Madison	II	980.36945	.36968	.36890	

9. f. Comparison of 1961 Pendulum Values with Other Data:

In Tables 4 and 5 the mean gravity values as obtained with the pendulums using the two methods of reduction are compared with the weighted mean values of earlier gravimeter measurements established during the period 1949-1960 and the 1961 gravimeter measurements. It is clear from the differences in values that the pendulum results obtained using the gravimeter comparison method for defining tares gives better agreement with the other data than those derived on the basis of individual station closures. These latter values therefore appear to be the less reliable of the two.

Another reason for rejecting the pendulum values based on station closures is brought out if the differences in pendulum values as derived by the two methods relative to the three sets of comparative values are plotted as a function of gravity. In Figure 8 the differences for the two sets of pendulum values from the mean of the earlier pendulum values are plotted, and it is seen that the values derived on the basis of station closures average about 0.3 mgal positive suggesting that the earlier work was off in datum by this amount, which is unlikely. The values reduced on the basis of the gravimeter comparisons, on the other hand, show no shift in datum and the differences average zero.

In Figure 9 the differences of the two sets of pendulum values from the 1961 gravimeter values and the mean of the earlier gravimeter values are plotted. It is seen that the station closure method suggests not only that there is a shift in datum for the gravimeter observations but also that the gravimeter results incorporate both a pronounced screw effect, and a discrepancy in calibration of about 0.2 mgal in 4500 mgals. Any screw effect is unlikely as the mean of the early gravimeter values is based upon six different gravimeters having varying screw characteristics which had been allowed for. It is extremely unlikely that any error in these values should correspond so closely to a screw error associated with the large LaCoste-Romberg geodetic gravimeter used for the 1961 measurements.

The plot of the differences for the pendulum results based on gravimeter comparisons with the two sets of gravimeter values shows no calibration error or significant shift in datum level within 0.05 mgal, and if there is any screw effect present, it does not exceed 0.1 mgal. As indicated earlier, the Fairbanks value is anomalous and can not be reconciled with any known effect.

On the basis of the above comparisons, the pendulum values derived on the basis of station closures (Table 2) are rejected, and those based on gravimeter comparisons (Table 3) adopted.

10. PENDULUM CONNECTIONS TO ST. LOUIS, MINNEAPOLIS AND WASHINGTON

10. a. Pendulum Gravity Value for St. Louis and Minneapolis:

As indicated in the Introduction, the pendulum program was preceded by field tests of the equipment involving connections from Madison, Wisconsin, to St. Louis, Missouri, and Minneapolis, Minnesota. As at Point Barrow and Mexico City, double occupations were simulated by taking the pendulums off

Table 4

Comparison of Gulf-Wisconsin 1961 Pendulum Values
with Gravimeter and Older Pendulum Values
(Station Closure Method)

Station	1961 Pendulum Value Table 2	LR(G)-1 1961 Gm Value	mgal Diff	Mean 1949-60 Gm Value	mgal Diff	Mean 1951-58 Pend. Value	mgal Diff
Pt. Barrow							
1958 site	982.6999	.6996	+0.3	.6996	+0.3	.6996	+0.3
1961 site	.7001	.6998	+0.3	.6998	+0.3	.6998	+0.3
Fairbanks							
Ladd Field	982.2450	.2444	+0.6	.2444	+0.6	.2445	+0.5
Geophys. Inst.	.2468	.2462	+0.6	.2462	+0.6	.2463	+0.5
Whitehorse							
1953 site	981.7489	.7486	+0.3	.7486	+0.3	.7492	-0.3
1961 site	.7504	.7501	+0.3	.7501	+0.3	.7507	-0.3
Edmonton							
1953 site	981.1680	.1677	+0.3	.1678	+0.2	.1680	0.0
1961 site	.1679	.1676	+0.3	.1677	+0.2	.1679	0.0
Great Falls							
High School	980.5273	.5270	+0.3	.5269	+0.4	.5265	+0.8
Huron							
Airport	980.4538			.4536	+0.2	.4539	-0.1
Madison	(Base)						
University	980.3689	.3689	0.0	.3689	0.0	.3689	0.0
Denver							
1953 site	979.6118	.6117	+0.1	.6118	0.0	.6110	+0.8
1961 site	.6124	.6123	+0.1	.6124	0.0	.6116	+0.8
Houston							
Sears Lab.	979.2987	.2984	+0.3	.2983	+0.4	.2983	+0.4
Monterrey							
Tech. Inst.	978.8058	.8053	+0.5	.8055	+0.3	.8052	+0.6
San Luis Potosi							
	978.2100	.2099	+0.1				
Mexico City							
University	977.9417	.9414	+0.3	.9414	+0.3	.9416	+0.1
Tacubaya	.9422	.9419	+0.3	.9419	+0.3	.9421	+0.1

Mean 1949-60 values adjusted to 1961 sites through local 1961 gravimeter connections

Table 5

Comparison of Gulf-Wisconsin 1961 Pendulum Values
with Gravimeter and Older Pendulum Values
(Gravimeter Comparison Method)

Station	Pendulum Value Table 3	LR-G -1 1961 Gm Value	mgal Diff	Mean 1949-60 Gm Value	mgal Diff	Mean 1951-58 Pend. Value	mgal Diff
Pt. Barrow							
1958 site	982.6996	.6996	0.0	.6996	0.0	.6996	0.0
1961 site	.6998	.6998	0.0	.6998	0.0	.6998	0.0
Fairbanks							
Ladd Field	982.2448	.2444	+0.4	.2444	+0.4	.2445	+0.3
Geophys. Inst.	.2466	.2462	+0.4	.2462	+0.4	.2463	+0.3
Whitehorse							
1953 site	981.7487	.7486	+0.1	.7486	+0.1	.7492	-0.5
1961 site	.7502	.7501	+0.1	.7501	+0.1	.7507	-0.5
Edmonton							
1953 site	981.1677	.1677	0.0	.1678	-0.1	.1680	-0.3
1961 site	.1676	.1676	0.0	.1677	-0.1	.1679	-0.3
Great Falls							
High School	980.5270	.5270	0.0	.5269	+0.1	.5265	+0.5
Huron							
Airport	980.4538			.4536	+0.2	.4539	-0.1
Madison	(Base)						
University	980.3689	.3689	0.0	.3689	0.0	.3689	0.0
Denver							
1953 site	979.6117	.6117	0.0	.6118	-0.1	.6110	+0.7
1961 site	.6123	.6123	0.0	.6124	-0.1	.6116	+0.7
Houston							
Sears Lab.	979.2984	.2984	0.0	.2983	+0.1	.2983	+0.1
Monterrey							
Tech. Inst.	978.8056	.8053	+0.3	.8055	+0.1	.8052	+0.4
San Luis Potosi							
	978.2098	.2099	-0.1				
Mexico City							
University	977.9414	.9414	0.0	.9414	0.0	.9416	-0.2
Tacubaya	.9419	.9419	0.0	.9419	0.0	.9421	-0.2

Mean 1949-60 values adjusted to 1961 sites through local 1961 gravimeter connections

DIFFERENCE 1961 "M" PENDULUM VALUES (STATION CLOSURE METHOD) FROM WEIGHTED MEAN OF 1951-1958 PENDULUM VALUES

DIFFERENCE 1961 "M" PENDULUM VALUES (GRAVIMETER COMPARISON METHOD) FROM WEIGHTED MEAN OF 1951-1958 PENDULUM VALUES

FIG. 8

FIG. 9

heat and driving them around for a day before repeating the measurement. The results for these measurements are given in Table 6. The raw period values and corrections are given in Table 1-B of the Appendix and the corrected periods in Table 1 of the text (pages 18-19).

Table 6

Pendulum Gravity Values for
St. Louis, Mo. and Minneapolis, Minn.

	Gravity Interval Relative Madison mgals.	Ave. Interval mgals.	Gravity Value gals.
Madison (1)			980.36890
	370.27	370.27	
St. Louis (1)			979.99863
St. Louis (2)	370.27		
Madison (2)	228.96	228.99	
Minneapolis (1)			980.59789
Minneapolis (2)	229.02		
Madison (3)			

10. b. Pendulum Gravity Connection Madison to Washington:

The pendulum connection between Madison and Washington was made to the Carnegie Institution Geophysical Laboratory base after the completion of the measurements on the western gravity standardization range. The Washington measurement was made at the Geophysical Laboratory base rather than the Commerce Building national gravity base site because of the better geological environment and freedom from ground motion. The Commerce Building base is on river alluvium in an area with heavy traffic and the Geophysical Laboratory is on granite outcrop in a quiet residential area. However, gravimeter ties were affected from the observational site to both the Commerce Building and the National Bureau of Standards absolute gravity base. The raw period values and corrections are given in Table 1-A of the Appendix and the corrected period values are given in Table 1 (pages 18-19) of the text. In Table 7 the gravity intervals measured are listed, and it is seen that there is a difference of 0.29 mgal because of a tare on one leg. From the gravimeter comparisons and earlier connections with both pendulums and gravimeters, this tare occurred on the going leg. The results for this leg have, therefore, been rejected.

Table 7

Pendulum Gravity Interval
Madison, Wis. to Washington, D. C.

Station	Gravity Interval mgals.	Gravity Value Relative to Washington gals.
Madison (1)	(rejected be- 268.01 cause of tare)	
Washington (1)		
Washington (2)		980.10060
Madison (2)	268.30	980.36890

In Table 8 the present pendulum and gravimeter results are compared with those of earlier measurements for the connection between Washington and Madison. Comparative values are also given for other sites occupied.

Table 8

Gravity Values Based on Connections in Washington
and From Washington to Madison

Base: Department of Commerce National Gravity Base
Floor of Pendulum Vault = 980.1190 gals.

Station	Mean Gm. Value 1948-60	LR-G-1 1961 Value	Mean Pend. Value 1951-59	Gulf "M" Pend. 1961
Comm. Bldg.				
Gravity Vault (floor)	980.11900			
14th St. excenter	.11816	.11825		
Geophysical Lab.	980.10064	.10060*	.10060*	.10060*
Natl. Bu. Stds.				
Absolute site (floor)	980.09946	.09948		
New absolute site		.09947		
Rear entrance				
Excenter	980.09758	.09760		
Madison, Univ. Wis.				
Science Hall	980.36894	.36882	.36895	.36890

*Assumed base value.

From an inspection of Table 8 it is seen that the uncertainty in the Washington connection to either the national gravity base in the Commerce Building or the National Bureau of Standards absolute gravity site does not exceed ± 0.1 mgal.

11. DESCRIPTIONS OF PENDULUM AND GRAVIMETER BASES AND LOCAL GRAVIMETRIC TIES TO EXCENTERS

Descriptions and diagrams of the various bases occupied with the Gulf-Wisconsin "M" pendulums and gravimeter bases are given in Table 2 of the Appendix. Local gravimetric ties from the pendulum site occupied in 1961 and 1962 to pendulum sites used at the same stations in the past and excenter sites, as airports, are given in Table 3 of the Appendix.

12. REDUCTION OF GRAVIMETER OBSERVATIONS

12. a. General Considerations:

The procedures used for obtaining gravity values from gravimeter observations is fairly well standardized for local surveys where it is possible to establish closures at some common base. On an operation such as that over the North American gravity standardization range the reduction procedure is dictated by the field procedure. The observations can be made in leap-frog sequence A-B-A-B-C-B-C-D-C etc. as a repeat series A-B-C-D-D-C-B-A or as in closed loops A-B-C-D-A. The leap-frog series theoretically offers the most rigid control, particularly if the series is repeated as a straight run of stations back to the station of origin. However, the cost of this procedure on a survey such as the present one is usually prohibitive. The next best method is to repeat the series of observations in reverse order so that each interval is observed twice. The least reliable method is a loop closure. The factors that dictate this appraisal of methods are the common occurrence of tares and changes in instrument drift rate. Tares (jumps in instrument readings) are caused by minor as well as major jars, and temperature shock (sudden changes in temperature) such as are encountered on leaving a plane at 70°F in the winter and setting up for an observation at an ambient temperature of -15°F. Changes in drift rate are occasioned by changes in temperature, temperature gradient, pressure and vibration. With some instruments, even those maintained at constant temperature, the drift rate may vary in sign as well as rate with changes in ambient conditions, and most instruments have a different drift rate while sitting still from that experienced while in transit. It is therefore essential that the survey procedure provide a mechanism for recognizing both the magnitude of these effects and where they occur. The method of repeat measurements offers the most economical method of doing this, and was the procedure used in the measurements reported.

12. b. Outline of Reduction Procedure:

1. Convert all readings to milligals and apply the appropriate earth tide corrections.

2. Remove all sitting drift in order to obtain the running drift (changes in readings while in transit).

3. Plot a closure plot as a function of running time. If there are no tares or changes in drift rate, the plot will define a straight line whose slope is the drift rate. If this plot defines two parallel lines, a tare is indicated whose magnitude is the offset between the lines and whose location

is indicated by the stations between which the offset occurs. If there is a change in drift rate the slope of the closure plot curve will not be constant. Although it is not possible to tell from the closure plot whether the tare or change in drift rate occurred on the going or back leg of a trip, it is known that trouble exists, the magnitude of tares are indicated, and those observations which are critical for correcting the situation defined. In the present series of measurements the earlier measurements at the same sites help define the leg on which tares occurred.

4. Apply the appropriate drift rate, tares, etc. and determine the gravity differences from the primary gravity base that is being used as a reference datum.

5. Determine the final values on the basis of the difference in values from that of a reference base absolute gravity value.

The above procedure will result in a single value for each station occupied if there are no errors in readings. Any other procedure as a rule will give as many values as there are observations at a given site because of variations in drift rate and tares. Averaging the various values has no virtue other than reducing the magnitude of error.

12. c. Illustrative Example:

To illustrate the procedure used for determining tares assume a series of observations taken at different sites in the sequence A-B-C-D-E-F-E-D-C-B-A. Assume also that the observations are equally spaced in time, that the instrument does have a constant drift rate of 0.1 mgal between observations, but that there is a tare of 0.5 mgal between sites C and D on the back leg. The instrument readings will be as follows:

Time	Reading	Time	Reading
0	A	6	E + 0.6
1	B + 0.1	7	D + 0.7
2	C + 0.2		Tare of +0.5
3	D + 0.3	8	C + 0.8 + 0.5 = C + 1.3
4	E + 0.4	9	B + 0.9 + 0.5 = B + 1.4
5	F + 0.5	10	A + 1.0 + 0.5 = A + 1.5

Closures Data

Station	Time	Closure
A	10 - 0 = 10	(A + 1.5) - (A) = +1.5
B	9 - 1 = 8	(B + 1.4) - (B + 0.1) = +1.3
C	8 - 2 = 6	(C + 1.3) - (C + 0.2) = +1.1
D	7 - 3 = 4	(D + 0.7) - (D + 0.3) = +0.4
E	6 - 4 = 2	(E + 0.6) - (E + 0.4) = +0.2
F	5 - 5 = 0	(F + 0.5) - (F + 0.5) = 0

If the above closures are plotted as a function of closure time it is seen that the slope for stations D, E and F will be 0.1 mgal per unit of

time, and although the slope for stations A, B, C is the same, there is a positive offset between stations C and D at closure times 4 and 6 respectively which graphically would scale 0.5 mgal, the tare introduced.

If the total closure on A had been used and distributed as drift, only the initial site, A, would have had a single value. The drift would have been taken as 0.15 mgal per unit of time, and the corrections would have been as shown below with the average values only partially correct.

Time	Reading	Drift Corr.	Values	Average Value
0	A	0	A	A
1	B + 0.1	-0.15	B - 0.05	B
2	C + 0.2	-0.3	C - 0.1	C
3	D + 0.3	-0.45	D - 0.15	D - 0.25
4	E + 0.4	-0.6	E - 0.2	E - 0.25
5	F + 0.5	-0.75	F - 0.25	F - 0.25
6	E + 0.6	-0.9	E - 0.3	
7	D + 0.7	-1.05	D - 0.35	
8	C + 1.3	-1.20	C + 0.1	
9	B + 1.4	-1.35	B + 0.05	
10	A + 1.5	-1.50	A	

It is clear that if more than one tare plus a change in drift rate is present, the overall closure method can lead to inferior results.

13. GRAVIMETER RESULTS

13. a. Measurements on North American Western Standardization Range:

The gravimeter results obtained at the pendulum sites occupied have already been presented in connection with the evaluation of the pendulum values. Gravimeter measurements, however, were also made at several of the other pendulum sites established in 1951 and 1953 on the western gravity standardization range. In Table 9 these values are compared with the older pendulum values and the mean of previous gravimeter measurements. In Figure 10 the differences are plotted as a function of gravity for each group of comparative data.

If the comparison with the earlier gravimeter measurements is considered first, it is seen that except for two stations, Lethbridge and Casper, the agreement is within 0.2 mgal everywhere. However, when the values are compared with the mean of the earlier pendulum results a sinusoidal pattern is indicated which could be interpreted as evidence for a screw curve in the gravimeter. As shown earlier, the 1961 pendulum values reduced on the basis of closures also suggested such an effect, but if these results are plotted for comparison, it is seen the two curves are markedly different. As seen, there is no evidence for a screw curve in the comparisons with the mean of earlier gravimeter measurements and the present pendulum measurements corrected for tares and creep on the basis of the gravimeter comparisons. The comparisons in Figure 10, therefore, serve to further emphasize the importance of the reduction procedure used in obtaining the pendulum values.

TABLE 9

Comparison of 1961 Gravimeter Values with Pendulum Values
and the Mean of Previous Gravimeter Values

Station	1961 LR(G)1 Gm	1951-58 Pendulum	Diff.	1961 Pendulum	Diff	1949-60 Mean Gm	Diff
Pt. Barrow(Site II)	982.6998	.6998	0.0	.6998	-0.0	.6998	0.0
Fairbanks, Univ.	982.2462	.2463	-0.1	.2466	-0.4	.2462	0.0
Northway AP	981.9908	.9915	-0.7			.9907	+0.1
Snag AP	981.9323	.9328	-0.5				
Whitehorse (Site II)	981.7501	.7507	-0.6	.7502	-0.1	.7501	0.0
Watson Lake AP	981.7145	.7153	-0.8			.7146	-0.1
Ft. Nelson AP	981.6929	.6921	+0.8			.6930	-0.1
Ft. St. John	981.4058	.4063	-0.5			.4059	-0.1
Grande Prairie AP	981.3157	.3160	-0.3			.3158	-0.1
Edmonton (Site II)	981.1676	.1679	-0.3	.1676	0.0	.1677	-0.1
Red Deer Armory	980.9972	.9974	-0.2			.9973	-0.1
Calgary AP	980.8282	.8283	-0.1			.8281	+0.1
Lethbridge PO	980.7593	.7589	+0.4			.7589	+0.4
Cut Bank AP	980.6084	.6084	0.0			.6085	-0.1
Great Falls H. S.	980.5270	.5265	+0.5	.5270	0.0	.5269	+0.1
Billings AP	980.3710	.3708	+0.2			.3710	0.0
Sheridan AP	980.2268	.2259	+0.9			.2265	+0.3
Casper AP	979.9563	.9553	+1.0			.9558	+0.5
Cheyenne AP	979.7009	.6993	+1.6			.7008	+0.1
Denver (Site II)	979.6123	.6116	+0.7	.6123	0.0	.6124	-0.1
Amarillo AP	979.4237	.4234	+0.3			.4235	+0.2
Houston Lab.	979.2984	.2983	+0.1	.2984	0.0	.2983	+0.1
Laredo AP	979.0793					.0792	+0.1
Monterrey	978.8053	.8052	+0.1	.8056	-0.3	.8055	-0.2
San Luis Potosi	978.2099			.2098	+0.1		
Mexico D.F.(Univ)	977.9414	.9416	-0.2	.9414	0.0	.9414	0.0
Paso de Cortes T.V.	977.5711	.5713	-0.2			.5711	0.0

COMPARISONS 1961 LR-G-1 GRAVIMETER VALUES

FIG. 10

13. b. Measurements on East Coast:

13. b. 1. General Statement: In addition to the gravimeter observations made in connection with the pendulum observations over the North American western gravity standardization range, measurements were made also along the east coast between Charleston, South Carolina, and Miami, Florida.

The purpose of these measurements was to establish a series of gravity values reliable to ± 0.1 mgal over a range of about 500 mgals that could be used as a standard for checking gravimeters for screw and dial effects.

Two independent sets of measurements were made with LaCoste-Romberg gravimeter No. LR-G-1 between Charleston, South Carolina, and Miami, Florida, and one set of measurements with gravimeter No. LR-g-1 plus a set of measurements south of Orlando, Florida, with Worden gravimeter No. W-607. Additional control is provided by five series of observations made earlier by the University of Wisconsin connecting Charleston and Miami with intermediate observations at the principal airports. Five series of measurements also have been made by the 1381st Geodetic Squadron, Orlando A. F. B., at airports between Miami and Charleston and, in addition, there are numerous random measurements made by the University of Wisconsin at different times.

13. b. 2 Overall Control on East Coast: Although the area of present interest is confined to the region between Charleston, South Carolina, and Miami, Florida, it is necessary to consider a larger geographic area if it is to be demonstrated that there is no calibration effect present in the measurements under consideration. To test the calibration factor, which was established on the western gravity standardization range, the 1961 gravimeter measurements with meter No. LR-G-1 are compared with three other sets of data: (1) weighted mean pendulum values, (2) earlier observations with this same instrument, and (3) the mean of all earlier gravimeter measurements. The pendulum values used are those for the bases occupied with the Gulf-Wisconsin pendulums between Ottawa, Ontario, and Miami, Florida. The comparative values are tabulated in Table 10.

From the differences shown in Table 10 it is seen that there is no significant variation in the various sets of measurements made with gravimeter LR-G-1. If the difference in mean of the measurements with the large LaCoste-Romberg gravimeter (LR-G-1) and the weighted mean pendulum values are plotted as a function of gravity along with the difference between the pendulum values and the mean of all gravimeter measurements made from 1948-1960, as shown in Figure 11, it is seen there is no valid evidence for any screw effect or error in the calibration constant. However, there is evidence for an error of about 0.4 mgal in the pendulum values for the gravity interval between Charleston and Miami.

13. b. 3. Intermediate Control: In addition to the pendulum control between Charleston, South Carolina, and Miami, Florida, there are the various airport gravity bases that have been occupied several times prior to the 1961-62 measurements. These provide intermediate independent checks on the reliability of the present measurements. In the following tabulation, the gravity intervals observed with the large LaCoste-Romberg gravimeter (LR-G-1) are compared with those measured with other gravimeters by the University of Wisconsin and by the Air Force 1381st Geodetic Squadron.

TABLE 10

Comparison of LR-G-1 Gravimeter Measurements and Other Gravimeter Measurements
with Weighted Mean Pendulum Values on North American Eastern Standardization Range

Station	Mean Pendulum Values	Mean Gravimeter Values (1948-60)	Diff.	LR-G-1 (1961)	Diff.	LR-G-1 (1960)	Diff.	LR-G-1 (1959)	Diff.	LR-G-1 (1958)	Diff.
Ottawa Dom. Obsr.	980.6218	980.6217	-0.1	.6216	-0.2	.6216 .6217	-0.2 -0.1	.6216	-0.2		
Lamont Geol. Obsr.	980.2594	980.2596	+0.2	.2596	+0.2			.2595	+0.1	.2596	+0.2
Washington Geophys. Lab.	980.1006	980.1006	0.0	.1006	0.0	.1006	0.0	.1006	0.0	.1006	0.0
Charleston	979.5511	979.5509	-0.2	.5510	-0.1	(.5510)	-0.1	.5509	-0.2	(.5510)	-0.1
Miami	979.0355	979.0357	+0.2	.0358	+0.3	.0359	+0.4	.0356	+0.1	(.0358)	+0.3

*Bracketed values derived from local airport connection

DIFFERENCE GRAVIMETER VALUES AND WEIGHTED MEAN PENDULUM VALUES
NORTH AMERICAN EASTERN GRAVITY STANDARDIZATION RANGE

FIG. II

Charleston, South Carolina (MATS) - Jacksonville, Florida (Airport)

LR-G-1 values: -181.8, 181.9, 181.9, 182.0, 181.8	Average -181.88 mgals
Other U.W. gravimeters: 182.0, 182.0, 181.7, 181.7, 181.9, 181.9, 181.7	-181.84
1381st Geod. Sqdn: - 182.0, 181.9, 181.9, 181.9, 182.0, 181.7	-181.90

Jacksonville (Airport) - Orlando (Airport)

LR-G-1 values: -166.9, 167.0, 167.0	-166.97
Other U.W. gravimeters: -166.8, 167.0, 166.9, 166.8, 166.8, 166.7, 166.7, 166.9	-166.83
1381st Geod. Sqdr.: -166.8, 166.7, 166.8, 166.8, 166.7, 167.2* *rejected.	-166.76

Orlando (Airport) - Miami (Airport - E.A.L.)

LR-G-1 values: -164.4, 164.2, 164.3	-164.30
Other U.W. gravimeters: -164.7, 164.7, 164.2,* 164.7, 164.6	-164.68
1381st Geod. Sqdn.: -164.5, 164.5, 164.1*, 164.5, 164.4 *rejected	-164.48

Intermediate control at airports between the above sites is as follows:

Charleston, South Carolina (MATS) - Savannah, Georgia (Airport)

LR-G-1 values: -69.7, 69.9, 69.9, 69.6	- 69.78
Other U.W. gravimeters: - 69.8, 69.8, 69.8, 69.7	- 69.76
1381st Geod. Sqdn.: -69.7, 69.8, 69.8, 69.9, 69.9, 69.6	- 69.78

Savannah, Georgia (Airport) - Jacksonville, Florida (Airport)

LR-G-1 values: -112.1, 112.0, 112.1, 112.2	-112.10
Other U.W. gravimeters: -112.2, 112.1, 111.9, 111.7*, 112.1, 112.0	-112.06
1381st Geod. Sqdn.: -112.3, 112.2, 112.1, 112.0, 112.1, 112.2 *rejected	-112.15

Jacksonville (Airport) - Daytona Beach (Airport)

LR-G-1 values: -108.5, 108.6, 108.4	-108.50
Other U.W. gravimeters: -108.4, 108.5, 108.5, 108.4, 108.2* 108.4	-108.44
1381st Geod. Sqdn.: -108.4, 108.3, 108.4, 108.5, 108.3, 108.9* *rejected	-108.38

Daytona Beach (Airport) - Orlando (Airport)		Average
LR-G-1 values:	-58.4, 58.4, 58.6	- 58.47
Other U.W. values:	-58.4, 58.5, 58.4, 58.5, 58.6	- 58.48
1381st Geod. Sqdn.:	-58.4, 58.4, 58.4, 58.4, 58.3	- 58.38
Daytona Beach (Airport) - West Palm Beach (Airport)		
LR-G-1 values:	-85.4, 85.4, 85.4, 85.2	- 85.35
Other U.W. values:	-85.4, 85.4, 85.6, 85.5	- 85.48
1381st Geod. Sqdn.:	-85.4, 85.4, 85.2, 85.4, 85.4	- 85.36
West Palm Beach (Airport) - Miami (Airport, E.A.L.)		
LR-G-1 values:	-79.0, 79.2, 78.8, 79.1	- 79.02
Other U.W. gravimeters:	-79.3, 78.8, 79.1, 79.1	- 79.08
1381st Geod. Sqdn.:	-79.1, 79.1, 78.9, 79.1, 79.0	- 79.04

From the above comparisons it is seen that the average of the interval measurements made with the large LaCoste-Romberg gravimeter agree to within 0.1 mgal with the averages derived from other measurements. There is, therefore, no reason to question the general reliability of the results obtained in 1961 and 1962 with LaCoste-Romberg gravimeter LR-G-1.

In Table 11 the interval measurements between sites to be used for evaluating screw effect are given along with absolute values of gravity based on a value of 980.1190 on the floor of the U. S. Coast and Geodetic Survey gravity vault in the basement of the Commerce Building in Washington, D. C.

As gravity values determined on the basis of the summation of interval values can accumulate errors, the above results are compared with those based on the intervals derived from the observations at Charleston, Jacksonville, Orlando and Miami in Table 12.

TABLE 12

Comparison of Values Based on Major Interval Measurements

Station	LR-G-1	Gravity	Other U. W. observations	Gravity	From Table 11
Charleston (MATS)		979.56750		.56750	.56750
Ave(5)	-181.88		Ave(7) -181.84		
Jacksonville (AP)		979.38562		.38566	.38558
Ave(3)	-166.97		Ave(8) -166.83		
Orlando (A)		979.21865		.21883	.21862
Ave(3)	-164.30		Ave(4) -164.68		
Miami (AP, EAL)		979.05435		.05415	.05423

Table 11

Gravity Intervals and Values for Sites Between
Charleston, South Carolina, and Miami, Florida,
in Milligals

Station		LR-G-1	LR-G-1	W-607	LR-g-1	Average Interval	Average Gravity Value Gals
South Carolina		Longfield (1961)	Mack (1960)	Woollard (1960)	Woollard (1960)		979.56750
Charleston	(MATS)	- 9.3	- 9.3		- 9.3	- 9.30	
Green Pond	(R.R.)	-39.6	-39.8		-39.8	-39.73	.55820
Ridgeland	(R.R.)						.51847
Georgia		-20.8	-20.9		-20.8	-20.83	
Savannah	(A.P.)						.49764
		-42.9	-42.9		-42.9	-42.90	
Riceboro	(R.R.)	- 5.6	- 5.5		- 5.5	- 5.53	.45474
St. Simons	(A.P.)	-42.4	-42.4		-42.5	-42.43	.44921
Kingsland	(R.R.)						.40678
Florida		-21.2	-21.2		-21.2	-21.20	
Jacksonville	(A.P.)						.38558
		-43.8	-43.8		-43.8	-43.80	
St. Augustine	(A.P.)	-42.8	-42.8		-42.8	-42.80	.34178
Bunnell	(R.R.)	-21.9	-22.0		-21.9	-21.93	.29898
Daytona	(A.P.)	-24.6	-24.7		-24.8	-24.70	.27705
Sanford	(R.R.)	-33.8	-33.7		-33.7	-33.73	.25235
Orlando	(A.P.)	- 1.8	- 1.9	- 1.9	- 1.9	- 1.87	.21862
Cocoa	(R.R.)	-28.5	-28.5	-28.5	-28.5	-28.50	.21675
Melbourne	(A.P.)	-14.7	-14.6	-14.7	-14.6	-14.65	.18825
Vero Beach	(A.P.)	-45.9	-45.8	-46.0	-45.9	-45.90	.17360
Stuart	(R.R.)	+ 5.5	+ 5.4	+ 5.7	+ 5.5	+ 5.52	.12770
West Palm Beach	(A.P.)	-47.0	-46.8	-47.1	-46.8	-46.92	.13322
Pompano Beach	(A.P.)	-32.1	-32.0	-32.2	-32.0	-32.07	.08630
Miami	(A.P., EAL)						.05423

The actual values observed with the large LaCoste gravimeter (LR-G-1) for these sites based on Washington and adjusted to the mean value for Charleston MATS are given below in Table 13.

TABLE 13

Comparative LR-G-1 Values Adjusted to Charleston 979.5675

Station	Longfield 1961	Mack 1960	Rose 1959	Sparkman 1958	Ave.
Charleston (MATS)	979.5675	.5675	.5675	.5675	.56750
Jacksonville (AP)	979.3857	.3856	.3856	.3856	.38563
Orlando (AP)	979.2188	.2186		.2186	.21867
Miami (AP, EAL)	979.0544	.0544	.0543	.0543	.05435

From Table 12 and Table 13 it is evident that there is an accumulative error in the values derived in Table 11. If the averages in Table 13 are taken as being the more reliable standard, a plot of the differences for the values in Table 11 (Fig. 12) shows that the creep is essentially linear. A linear correction was, therefore, applied to obtain the gravity values adopted for the station observations between Charleston and Miami. The revised values are given in Table 14 and rounded to the nearest 0.1 mgal as it is not believed any single measurement with a geodetic gravimeter has an actual observational reliability exceeding 0.1 mgal.

13. b. 4. Local Connections to Alternate Sites: As at Charleston, Orlando, and Miami, there are more than one site in use and the Miami EAL site can no longer be occupied, connections were made to alternate sites. The gravity values for these sites based on Table 14 values are as follows:

CHARLESTON

MATS	979.5675
Municipal Airport	.5669
Gulf-Wis. Pend. Sta.	.55095

ORLANDO

Municipal Airport	979.2187
Orlando A.F.B.	.22235
McCoy, A.F.B.	.2004

MIAMI

Airport (EAL)	979.0543
Intl. Airport	.0530
Gulf-Wis. Pend. Sta.	.0537

CREEP IN ACCUMULATIVE VALUES

CHARLESTON - MIAMI

FIG. 12

Table 14

Adopted Gravity Values
Charleston - Miami

Station		Table 11 Value	Creep Corr.	Final Value	Rounded Value
South Carolina					
Charleston	(MATS)	979.56750	0.0	.56750	.5675
Green Pond	(R.R.)	979.55820	+0.0	.55820	.5582
Ridgeland	(R.R.)	979.51847	+0.01	.51848	.5785
Georgia					
Savannah	(A.P.)	979.49764	+0.01	.49765	.4977
Riceboro	(R.R.)	979.45474	+0.02	.45476	.4548
St. Simons	(A.P.)	979.44921	+0.03	.44924	.4492
Kingsland	(R.R.)	979.40678	+0.03	.40681	.4068
Florida					
Jacksonville	(A.P.)	979.38558	+0.04	.38562	.3856
St. Augustine	(A.P.)	979.34178	+0.05	.34183	.3418
Bunnell	(R.R.)	979.29898	+0.06	.29904	.2990
Daytona	(A.P.)	979.27705	+0.06	.27711	.2771
Sanford	(R.R.)	979.25235	+0.07	.25242	.2524
Orlando	(A.P.)	979.21862	+0.07	.21869	.2187
Cocoa	(R.R.)	979.21675	+0.07	.21682	.2168
Melbourne	(A.P.)	979.18825	+0.08	.18833	.1883
Vero Beach	(A.P.)	979.17360	+0.08	.17368	.1737
Stuart	(R.R.)	979.12770	+0.09	.12779	.1278
West Palm Beach	(A.P.)	979.13322	+0.09	.13331	.1333
Pompano Beach	(A.P.)	979.08630	+0.10	.08640	.0864
Miami	(AP, EAL)	979.05423	+0.11	.05434	.0543

14. DESCRIPTIONS OF GRAVIMETER BASES

Station descriptions and diagrams for all sites occupied in the course of the 1960-61 gravimeter measurements along the East coast are given in Table 4 of the Appendix.

15. PRESSURE AND TEMPERATURE TESTS OF GRAVIMETERS

15. a. Remarks on Pressure Effects:

One of the factors associated with the use of gravimeters that can not be evaluated in the field as a rule is the effect of changes in external pressure on the gravimeter readings. The pressure change may be occasioned by changes in land elevation or through the use of aircraft in moving from one site to another. In the latter case an additional critical factor is the time response of the gravimeter in adjusting to marked changes in pressure.

With a hermetically sealed system such as is the case with a Worden gravimeter, changes in pressure on the case are transmitted to the interior and affect the readings through changes in operating pressure. With a compensated system such as is the case with a LaCoste-Romberg gravimeter, it is the response of the compensator that is important. In addition, any slight leak in the hermetical seal or compensator will result in the readings being directly related to changes in ambient pressure.

To establish the pressure response characteristics of a gravimeter as well as to check for any leaks in the system or compensator, it is desirable to have a pressure chamber in which to simulate variations in elevation likely to be encountered in field operations.

15. b. Remarks on Temperature Effects:

The response of different gravimeters to variations in ambient temperature vary from changes in drift rate to actual jumps in readings. The effect may also be expressed as a change in the sign of the drift. A knowledge of instrumental response to variations in external temperature is therefore important. As most instruments are now thermostatically controlled at a temperature level above that likely to be encountered under normal operating conditions, the range of temperatures that have to be considered lies between -20°F and 100°F; the critical range being that between -20°F and 70°F.

15. c. Test Equipment:

As explained earlier, it was not possible to use the decompression chamber at Chanute Field for the pressure tests as originally planned, and it was therefore necessary to build equipment for these tests. During the interim two pressure chambers were borrowed from the Texas Instrument Company to study design features. The chamber built was made large enough to accommodate all geodetic gravimeters now in use and has a pressure range equivalent to over 50,000 feet of altitude. The chamber is cylindrical with an "O" ring seal for a 1-inch plexiglass cover. By having a transparent cover,

the instruments being tested can be read through the top. Pressure is read with a standard Air Force airplane altimeter that was calibrated at the Truax Air Force Base aircraft instrument shop. As changes in pressure were found to distort the floor of the pressure chamber sufficiently to affect the leveling of the instrument, the chamber was mounted on a base plate equipped with leveling screws so that the instrument could be releveled, if necessary, during observations. There was no evidence that the gravimeter system itself was distorted by changes in pressure. This conclusion is based on the response of the LaCoste-Romberg pressure compensated instruments which showed no change in values for changes in pressure once the instrument was releveled.

The temperature tests were run in a standard, top door, deep-freeze unit, and although there is some error in the thermometer readings taken in the freezer during cooling and heating due to the influx of warm air, this discrepancy does not appear to have been serious.

15. d. Instruments Tested:

Tests of the effect of changes in pressure and temperature were run on five gravimeters: a LaCoste-Romberg large geodetic gravimeter (LR-G-1), LaCoste-Romberg small geodetic gravimeter (LR-g-1), Worden temperature compensated geodetic gravimeter (W-14), and two Worden temperature controlled, master geodetic gravimeters (W-616 and W-617).

15. e. Results of Pressure Tests on Worden Gravimeters:

15. e. 1. Worden Master Meter (W-617): Worden master geodetic gravimeter No. W-617 was run through two pressure tests. The results are shown in Figures 13, 14 and 15. In the first test the simulated elevation above sea level was increased by 5000 foot increments to 25,000 feet. Each intermediate elevation was maintained for approximately 15 minutes. The gravimeter was maintained at 25,000 feet for 1 hour and 20 minutes and then the simulated elevation was reduced to 1000 feet again by steps as indicated in Figure 14 over a period of 1 hour and 50 minutes. In the second test run on this meter the simulated elevation was increased from 1000 feet to 25,000 feet over a period of 7 minutes. The elevation of 25,000 feet was maintained for a period of 35 minutes and then returned to an elevation of 1000 feet over a period of 30 minutes.

From an examination of Figures 13, 14 and 15, the following conclusions can be drawn:

(1) Changes in pressure over the equivalent range of 1000 feet to 15,000 feet elevation produce a change in gravimeter readings of approximately $+.05$ mgal per 1000 feet. Changes in pressure over the range of 15,000 feet to 25,000 feet, however, produce a change in gravimeter readings of only about $+.02$ mgal per 1000 feet.

(2) As no time lag was noted in the response of the meter to changes in pressure, the experimental data indicates that this gravimeter adjusts immediately to changes in pressure.

(3) Examination of Figure 15 indicates that drift is greater during pressure changes than at other times.

PRESSURE TEST WORDEN MASTER W617

--- TEST NO. 1
— TEST NO. 2

FIG. 13

CHANGE IN METER READING (MGALS)

PRESSURE TEST WORDEN MASTER W-617

TEST No.1

FIG.14

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PRESSURE TEST WORDEN MASTER W-617

TEST No. 2

FIG. 15

15. e. 2. Worden Master Meter (W-616): Worden master geodetic gravimeter No. W-616 was run through one pressure test. The simulated elevation was raised from 1000 feet to 25,000 feet over a period of 8 minutes. Pressure conditions for 25,000 feet were maintained for 32 minutes and then lowered to 1000 feet over a period of 40 minutes. The results are shown in Figures 16 and 17. The same comments as applied to Worden geodetic gravimeter No. W-617 also apply here. The observed response was:

- (1) The pressure effect is $+0.12$ mgal per 1000 feet between 1000 and 15,000 feet but only $+0.06$ mgal per 1000 feet between 15,000 and 25,000 feet.
- (2) There is no time lag in the response of the gravimeter to changes in pressure.
- (3) Examination of Figure 17 indicates drift is greater during pressure changes than at other times.

15. e. 3. Worden Temperature Compensated Geodetic Gravimeter (W-14): Worden temperature compensated geodetic gravimeter No. W-14 was run through one pressure test and the results are given in Figures 18 and 19. In this test the simulated elevation was raised from 1000 feet to 23,000 feet over a period of 1 hour and 35 minutes; maintained at 23,000 feet for 2 hours and 20 minutes and then lowered to 1000 feet over a period of 15 minutes. The observed response was:

- (1) The pressure effect is $+0.0444$ mgal per 1000 feet between 1000 feet and 15,000 feet but only $+0.019$ mgal per 1000 feet between 15,000 and 23,000 feet.
- (2) There is no time lag in the response of the meter to changes in pressure.
- (3) Drift is greater during pressure changes than at other times. This is not indicated directly on Figure 19, but a reading taken 6 hours after the return to 1000 feet elevation showed only half as much drift following the return to 1000 feet.

15. f. Results of Pressure Tests on LaCoste-Romberg Gravimeters:

15. f. 1. LaCoste-Romberg Gravimeter No. LR-g-1: The LaCoste-Romberg small geodetic gravimeter (LR-g-1) was tested in the following manner. The simulated elevation was raised from 1000 feet to 30,000 feet over a period of 1 hour and 20 minutes, maintained at 30,000 feet for 1 hour and 25 minutes and then returned to 1000 feet over a period of 1 hour and 5 minutes. The results of this test are shown in Figure 20. A drift of about 0.1 mgal over the 4 hours and 30 minutes of the test has been removed. Although there is an indication of a slight effect (0.04 mgal) during the period of pressure change, suggesting a time lag in the compensator, this is probably a leveling effect due to distortion of the pressure chamber floor. It was necessary to relevel the gravimeter at 20,000 feet, and once this was done the readings returned to normal. It was also necessary to relevel as the gravim-

PRESSURE TEST WORDEN MASTER W-616

FIG. 16

FIG. 17

PRESSURE TEST WORDEN NO 14 - TEST NO.1

FIG. 18

PRESSURE TEST ON WORDEN METER W-14

FIG. 19

PRESSURE TEST SMALL LACOSTE GEODETIC GRAVIMETER (LR-g-1)

FIG. 20

CHANGE IN GRAVITY READING - MGALS
(DRIFT REMOVED)

PRESSURE TEST LARGE LACOSTE GEODETIC GRAVIMETER
(LR-G-1)

FIG. 21

eter was returned to ground conditions. This gravimeter, therefore, can be said to show no effect with change in elevation.

15. f. 2. LaCoste-Romberg Gravimeter No. LR-G-1: The LaCoste-Romberg large geodetic gravimeter (LR-G-1) was tested in the following manner. The simulated elevation was raised from 1000 feet to 25,000 feet over a period of 7 minutes, maintained at 25,000 feet for 1 hour and 20 minutes and then returned to 1000 feet over a period of 1 hour. The results are shown in Figure 21. The drift of .093 mgal over the 6-hour period of the test has been removed.

Although this meter was releveled during the test as with LR-g-1 above, the results show an elevation effect of -0.1 mgal for a change from 1000 feet to 25,000 feet, and a time lag of 3 hours in reaching stability. However, on the change from 25,000 feet to ground conditions with a gradual change in simulated elevation, the time lag in reaching stability and full recovery of the 0.1 mgal effect was only 27 minutes.

15. g. Results of Temperature Tests:

15. g. 1. LaCoste-Romberg Geodetic Gravimeter: The LaCoste-Romberg small geodetic meter (LR-g-1) was run through two temperature tests. In each test the instrument was read at room temperature and then placed in the freezer with the freezer temperature between 0°F and +5°F. Over the next 2 hours the freezer temperature was lowered to -14°F and the gravimeter read periodically during this time. The gravimeter was kept at approximately -14°F for an additional 1 to 2 hours and gravimeter readings taken periodically. The instrument was then returned to room temperature by removal from the freezer and readings recorded periodically for an additional hour.

The results are plotted in Figure 22, and it is seen that the change from room temperature (70°F) to freezer conditions (+5° to -15°F) causes a decrease in reading of 0.125 mgal. However, this change also can be related in large part to a decrease in gravimeter temperature of about 0.25°C. It is therefore difficult to assess the relationship between gravimeter readings and ambient temperature. It does appear though that there is an effect below -2°F of about .01 mgal per 1°F down to -8°F. At lower temperatures this correlation between gravimeter readings and temperature disappears and is replaced by a constant error which amounts to about 0.05 mgal within the range of the experiment (-15°F). The fact that there is about a 30-minute differential between the time the gravimeter reading shows a temperature effect and the thermometer in the gravimeter registers any change in gravimeter temperature with a falling temperature, and the same time lag is observed in reaching reading stability after the thermometer in the gravimeter indicates the normal operating temperature has been established, tends to support the reality of the temperature effect described.

15. g. 2. Large LaCoste-Romberg Geodetic Gravimeter (LR-G-1): The LaCoste-Romberg large geodetic gravimeter (LR-G-1) was run through one temperature test. In this test the gravimeter was read at room temperature and then placed in the freezer at +5°F. The temperature was allowed to rise to +27°F over a period of 10 minutes and then lowered to -7°F over a period of 3 hours. The gravimeter was then taken from the freezer, returned to room temperature, and read for another 3 hours. The results are shown in Figure 23.

The results of this test are difficult to assess. The most reasonable assumption appears to be that in the stages of slow cooling from +29°F to -7°F the gravimeter was little affected. If a linear drift of .01 mgal per hour is removed as shown in Figure 23, the maximum temperature effect during the period is .035 mgal. The sharp change in readings of .09 mgal immediately following removal of the instrument from the freezer could be interpreted as a transient effect due to the sudden temperature change or to a tare. The fact that the gravimeter value returned to normal during the ensuing hour and a half supports the idea that the sudden temperature change resulted in a transient change in values. It will be noted that unlike the small geodetic gravimeter (LR-g-1) the temperature for LR-G-1 held constant throughout the test.

15. g. 3. Worden Master Geodetic Gravimeter (W-617): Worden master geodetic gravimeter W-617 was run through one temperature test. The instrument was read under room conditions and placed in the freezer at a freezer temperature of +13°F. The freezer temperature was then lowered over a period of two hours to -2°F, after which the gravimeter was taken from the freezer and read for another hour under room conditions. The results are shown in Figure 24.

The temperature effects on this gravimeter, if a linear drift of .08 mgal per hour is removed, are negligible. The maximum deviation from the linear drift line over the period of the test was .03 mgal and the deviation did not show any systematic relation to temperature. The only temperature effect on this instrument appears to have been an increase in drift rate. This is indicated by the fact that immediately after the test the normal drift rate was observed over a period of 15 hours.

Although there was a change in gravimeter temperature of 0.5°F during the test, this had no effect on the readings. This is to be expected as the Worden gravimeters have internal temperature compensation.

15. g. 4. Worden Master Geodetic Gravimeter (W-616): Worden geodetic gravimeter W-616 was run through one temperature test. The meter was read for an hour at room temperature and then placed in the freezer, which was at a temperature of +15°F. The temperature was then lowered over a period of 2 hours to a temperature of -3°F during which time readings were periodically taken. The meter was then taken from the freezer and read for another 45 minutes at room conditions. The results are shown in Figure 25.

As will be noted, the temperature of this gravimeter varied rather widely, presumably because of a faulty thermostat. As can be seen from Figure 25, the changes in readings, ranging up to 0.5 mgal, can be related directly to the changes in gravimeter temperature. This test, therefore, gave little information on the effects of low temperature but did show that this gravimeter in contrast to W-617 is very sensitive to small temperature changes and that this instrument is poorly compensated for variations in temperature.

15. g. 5. Worden Compensated Gravimeter (W-14): Worden gravimeter W-14 is a single dial, high range (1750 mgal), temperature compensated instrument designed to be read under all normal ambient temperature conditions. The principal temperature effect noted with this gravimeter in the field has been that its drift rate varies significantly with changes in temperature gradient.

TEMPERATURE TEST ON SMALL LACOSTE ROMBERG GRAVIMETER LR-g-1

FIG 22

TEMPERATURE TEST LACOSTE-ROMBERG LARGE GRAVIMETER LR-G-1

FIG. 23

TEMPERATURE TEST WORDEN MASTER W-617

FIG. 24

TEMPERATURE TEST WORDEN MASTER W - 616

FIG. 25

TEMPERATURE TEST WORDEN W-14

FIG. 26

Two temperature tests were run on this gravimeter. On the first test the instrument was read for an hour at room temperature and then placed in the freezer, which was at a temperature of -8°F . The temperature of the freezer was raised to about -5°F over the next hour and a half and then lowered to -15°F over the next two hours. Temperature was held constant at this level for the next two hours, after which the gravimeter was removed from the freezer. The instrument readings were taken at approximately 15-minute intervals once a temperature of -15° had been established. The results are shown in Figure 26.

From Figure 26 it is seen that there was an abrupt change in drift rate on putting the gravimeter in the freezer and that this drift rate continued during the period the freezer temperature was being raised. The gravimeter experienced what could be a tare of 1.6 mgals at this point, but, as seen from the results of Test 2, this change could be a legitimate change in readings. Following this drastic change in readings, the drift rate was essentially zero for nearly two hours. This corresponds to the period in which the freezer temperature was being lowered. Once the freezer temperature had stabilized at -15°F though, the high drift rate was reassumed, and this continued for at least an hour and a half after the instrument had been removed from the freezer. Ten hours later, after the instrument had had ample time to reach equilibrium conditions with the ambient room temperature of 70° , the drift rate was back to a rate of about .05 mgal per hour. On the second temperature test, the freezer temperature was lowered continuously from -2°F to -14°F and then allowed to vary over 5° to see if there was any noticeable effect on the readings.

As seen from Figure 26, the response of the instrument to cooling was noticeably different from that observed on the first test, but after the first two hours, the values and response pattern were very much the same on both tests. However, as seen, the temperature effect differed after about 4 hours with a much larger departure occurring on the first test than was observed on the second test.

These tests therefore only show that changes in temperature do markedly affect the drift rate of the temperature compensated Worden gravimeters.

16. SPIN-TABLE CALIBRATOR

16. a. General Remarks on Feasibility of Method:

In theory it should be possible to calibrate a gravimeter upon a table rotating about a vertical axis if the gravimeter is tilted and placed on the table so that the hinged beam is directed perpendicular to the radius of rotation. Under these conditions there will be a component of centrifugal force tending to elongate the spring when the table is rotated. Tilting the gravimeter is necessary as theoretically there should be no centrifugal effect on an untilted rotating gravimeter. With a tilted system, it is obvious that any change in radius from the axis of rotation will produce a change in the centrifugal force acting on the beam of the instrument. By equating known changes in force for different radii to changes in meter readings of the tilted gravimeter, the calibration constant of the gravimeter can be obtained.

Possible complications can be envisioned from the horizontal components of a force applied to the gravimeter system, and from the fact that the gravimeter is in motion with respect to the earth. Results obtained so far, however, indicate that although a few questions remain unanswered, the method is feasible. Three runs, made with a Worden geodetic gravimeter, using different angles of tilt over the same variations in radii at constant rotational speed, yielded a calibration constant that differed only slightly from that obtained using a tilt-table calibrator. The mean value for the three runs gave a calibration constant for the meter of 0.694 mgal per scale division. The calibration constant determined by the Texas Instrument Company using a regular tilt-table calibration was 0.696 mgal per scale division.

16. b. Theory of Spin-table Calibrator:

The theory involved in the use of a spin table as a gravimeter calibration device can best be understood from the point of view of a mass suspended from a spring and hinged as shown in Figure 27. Although the actual spring system in a gravimeter is more complicated, the primary relations are the same. In the untilted position, Figure 27-a, the force of gravity is vertical and creates a torque about the hinge. This is resisted by the spring so that the mass reaches a stable position when the gravitational force (G) is numerically equal to the restoring force (F_1) exerted by the spring, which is then the effective force (G_{eff}) acting in opposition to the spring. Thus, in this case,

$$G_{eff} = G. \quad (1)$$

Now consider Figure 27-b. Here the view is looking directly toward the hinge rather than perpendicular to it as in Figure 27-a. The spring is no longer parallel to the direction in which G acts. In this case G can be broken up into two perpendicular components. Only the component $G \cos \theta$ tends to rotate the mass about the hinge and must be opposed by the spring force F_2 . Therefore, for the mass at rest the effective force acting on the gravimeter and balanced by the spring force is

$$G_{eff} = G \cos \theta \quad (2)$$

This depicts what takes place when a gravimeter is tilted.

Now consider a tilted gravimeter, as shown in Figures 28 and 29, which is being rotated on a spinning table. In addition to the gravitational force G there will be a centrifugal force A directed along the line drawn through the center of the mass on the beam and the axis about which the rotation is taking place. It will be directed away from the rotation axis. As shown by Figure 28, there are now two forces acting to produce rotation about the hinge which must be opposed by the spring. These are $A \sin \theta$ and $G \cos \theta$. For the mass at rest, the effective force balanced by the spring force F_3 now becomes

$$G_{eff} = G \cos \theta + A \sin \theta \quad (3)$$

From the laws of physics we also have

$$A = \omega^2 r \quad (4)$$

(A) METER NOT TILTED

(B) METER TILTED

FIG. 27

FIG. 28

SIDE VIEW OF SPINNING METER

TOP VIEW OF SPINNING METER

FIG. 29

where ω = angular frequency (velocity)

r = distance from center of rotation

and since $\omega = \frac{2\pi}{T}$,

where T is the period, we can write equation (4) as

$$A = \frac{4\pi^2 r}{T^2} \quad (5)$$

From equations (3) and (5) we get for the spinning meter

$$G_{\text{eff}} = G \cos \theta + \frac{4\pi^2 r}{T^2} \sin \theta. \quad (6)$$

As what is actually recorded when reading a gravimeter is a quantity proportional to G_{eff} which we shall call $G_{\text{m.u.}}$, it follows that

$$G_{\text{eff}} = k G_{\text{m.u.}}$$

where k is a constant of proportionality. The units of G_{eff} are milligals. The units of $G_{\text{m.u.}}$ are the gravimeter scale units. Thus the units of k are milligals per gravimeter unit.

The proportionality constant k theoretically could be determined with a spin table by using equation (6) in the form

$$G_{\text{eff}} = k G_{\text{m.u.}} = G \cos \theta + \frac{4\pi^2 r}{T^2} \sin \theta \quad (7)$$

$$\text{or } k = \frac{1}{G_{\text{m.u.}}} \left[G \cos \theta + \frac{4\pi^2 r}{T^2} \sin \theta \right] \quad (8)$$

as all the quantities on the right hand side of equation (8) appear to be measurable.

Actually, it is not possible to measure r as this is the distance from the axis of spin to the center of mass of the mass element in the gravimeter. However, the center of mass is fixed with respect to other physical points on the gravimeter. Therefore, if we measure two successive radii from the axis of rotation to any point on the gravimeter the difference in radius experienced by this point on the gravimeter will also be equal to the difference in radius experienced by the center of mass of the mass element. Therefore, we need to put equation (7) in a form requiring only knowledge of a radius change (Δr) and not absolute radius.

Consider now the terms in equation (7) for two different radii, r_1 and r_2 . With G being held constant,

$$K G_{\text{m.u.}} \quad 1 = G \cos \theta + \frac{4\pi^2 r_1}{T^2} \sin \theta$$

$$K G_{\text{m.u.}} \quad 2 = G \cos \theta + \frac{4\pi^2 r_2}{T^2} \sin \theta.$$

Since the changes in r in practice will be only a few inches, this is permissible. Subtract one from the other.

$$k G_{m.u. 2} - k G_{m.u. 1} = G \cos \theta + \frac{4\pi^2 r_2}{T^2} \sin \theta - G \cos \theta - \frac{4\pi^2 r_1}{T^2} \sin \theta$$

$$\text{or } k = \frac{4\pi^2}{T^2} \frac{\Delta r}{\Delta G} \sin \theta \quad (9)$$

$$\text{where } \Delta r = r_2 - r_1,$$

$$\Delta G = (G_{m.u.})_2 - (G_{m.u.})_1$$

The quantities on the right hand side of equation (9) are now measurable and k may be computed. Equation (9) as written gives k in gals per gravimeter scale unit when r is in cm and T in seconds. To get k in mgals per gravimeter scale unit one must multiply the results of equation (9) by 10^3 .

An additional advantage of proceeding as described above is that knowledge of the absolute value of gravity at the location of the spin table is not necessary for the calibration.

16. c. The Eotvos Effect:

Thus far no mention has been made of the Eotvos effect to be expected on the moving gravimeter. Equation 10 gives the forces to be expected on a moving gravimeter as

$$E = \frac{R \phi + h}{R \phi^2} (2V \phi V_e + V^2)^* \quad (10)$$

where E = vertical force on the gravimeter element caused by motion with respect to the earth's surface

$R \phi$ = radius of earth at the latitude of measurement

h = elevation above earth's surface

$V \phi$ = linear speed of earth's surface at latitude ϕ due to the earth's rotation

V_e = east-west component of gravimeter's motion (positive when gravimeter is moving east)

V = total linear velocity of gravity meter

For a gravimeter rotating in a circle we see that the Eotvos effect can be broken into two parts.

* See: Nettleton, L. L., LaCoste, Lucien, and Harrison, J. C., 1960, Tests of An Airborne Gravity Meter; Geophysics, vol. XXV, No. 1, p. 181-202.

A gravimeter rotating at a particular angular velocity at a particular distance from the axis of rotation will have a constant magnitude linear velocity, V , so that the part of the Eotvos effect given by

$$E_c = \frac{R\phi + h}{R\phi^2} V^2 \quad (11)$$

is a constant force acting on the gravimeter and is always positive. The other portion of the Eotvos effect given by

$$E_v = \frac{R\phi + h}{R\phi^2} 2V\phi V_e \quad (12)$$

is variable with time since the eastward velocity V_e is given by $V_e = V \cos \varphi$ where φ is the angle between north and the direction of the instantaneous velocity V . But if we consider the gravimeter to be directly north of the axis of rotation at time $t = 0$ and to start rotating toward the east at an angular velocity ω so that it has a period T , we get

$$\varphi = \frac{2\pi t}{T}$$

$$\text{and } V_e = V \cos \frac{2\pi t}{T},$$

$$\text{therefore } E_v = \frac{R\phi + h}{R\phi^2} 2V\phi V \cos \frac{2\pi t}{T} \quad (13)$$

Thus, there should be an Eotvos effect which varies sinusoidally with a period equal to the period of rotation of the spinning platform.

As we shall see, the Eotvos effect does not enter directly into the computations of k , although E_v is not negligible.

16. d. Description of Spin-Table Calibrator:

Basically the spin-table calibrator can be described as follows:

1. An external housing that can be leveled, and having center bearings in its floor plate and roof to take the shaft of an inner rotating cage.

2. An inner cage, the spin table proper, which is rotated about a vertical axis by a belt drive from an external motor through a speed reduction gear box. As all observations are made in this cage it is provided with both a mount for the gravimeter and a stool for the observer.

3. The instrument mount consists of: (A) a fixed horizontal bracket in which is inserted a 2-inch plane-surfaced slab of "granite", actually diabase; (b) a metal plate having three ball feet and side flanges which fits over the sides of the "granite" slab and thus roughly positions the plate laterally; (c) a jig for holding the instrument which can be positioned for changes in radius with a micrometer screw on the metal plate. Tilting is accomplished through use of a Johansen block which is inserted between the "granite block" and the center ball foot of the plate holding the jig.

Figure 30-a shows a general view of the spin-table calibrator and Figure 30-b the location of the instrument and observer while making a reading.

16. e. Problems Observed with the Spin-table Calibrator:

The following problems were encountered in developing the spin-table calibrator.

1. With the drive motor connected directly to the reduction gear box considerable vibration was transmitted from the motor to the spin table. This was in large measure rectified by having a flexible drive shaft between the motor and the reduction gear box and having each unit on an independent shock mount separate from that of the spin table frame.

2. Although the speed of rotation used for the spin table is only 1 revolution in 4.5 seconds, this was sufficient to induce vertigo in the observer. By putting side panels on the outer frame it was found that this tendency was lessened. However, on the basis of tests at Pensacola Naval Air Station Air Medicine Center, it may be necessary to use operators with punctured ear drums to really overcome this problem.

3. Leveling of the gravimeter in its case was not satisfactory as there is sufficient play between the inner working element case and the outer case of the instrument for the inner case to get out of level when rotated. It was, therefore, necessary to remove the inner case and mount it in a special jig for observations. As the inner, working element case has no provision for leveling, it was necessary to use the restraining screws as leveling screws. Leveling is thus provided by horizontal thrust from the sides of the jig. This system is very sensitive but the adjustments are time-consuming. To help compensate for the loss of insulation about the working element case, it was necessary to insulate the jig with a styrofoam jacket.

16. f. Calibration Procedure:

The procedure used in carrying out a gravimeter calibration on the spin table can be divided into two parts -- orientation of the gravimeter and measurements while spinning.

The procedure for correct orientation of the meter, carried out with the spin table stationary are:

1. The gravimeter is leveled in the jig and read.
2. The gravimeter is tilted through an angle θ and read.
3. The beam sensitivity is checked with the gravimeter tilted.
4. The gravimeter is tilted the same amount in the opposite direction and read.
5. The sensitivity is checked again.

The gravimeter reading at opposite tilts is done to check the level bubbles. The gravimeter readings, tilted in opposite directions through the same angle, should be identical. If they are not, the level bubbles are out

FIGURE 30 a

OVERALL VIEW OF SPIN TABLE

FIGURE 30 b

VIEW OF INSTRUMENT MOUNT

of adjustment. The leveling can be corrected by adjusting the level bubbles on the gravimeter or by adjusting the gravimeter in the holder on the spin table.

In tilting a Worden gravimeter, care must be taken to orient the instrument so that the beam supporting the mass is perpendicular to the direction of tilt (thus the torsion fiber to which the beam is attached is parallel to the direction of tilt). This is necessary to assure that the gravimeter does not become unstable. The beam sensitivity is an indication of how well the beam is oriented with respect to the direction of tilt. If the beam is perfectly aligned perpendicular to the direction of tilt, the beam sensitivity should be the same in both directions. To prevent instability while spinning, the direction of tilt must also be along a radius from the axis of rotation. Once leveling and orientation are correct, the actual test can be started. The procedure is as outlined below.

1. The gravimeter is leveled and read.
2. The gravimeter is tilted and read without spinning.
3. The spin table is started in rotation and the tilted gravimeter is read for a number of values of spin radii.
4. Steps 2 and 3 are repeated for as many different tilt angles as desired.
5. The gravimeter is leveled and read again to check for any drift in readings.
6. Leveling and beam sensitivity are again checked.

In making readings with the gravimeter spinning it was necessary to null the gravimeter by having the reading line oscillate equal amounts on both sides of the null point. Stable readings are impossible because the Eotvos effect keeps the element from coming to rest. As reading under these conditions is considerably more difficult than reading when the element is at rest, small errors are to be expected. No doubt this explains why the results obtained using small incremental changes of force are less accurate than those with larger increments as the error represents a larger percentage of the change in value.

16. g. Example of Calibration Test Measurement:

The results for one of the test calibrations made are given below. The gravimeter used for these tests was Worden gravimeter No. W-616. Throughout the runs, the period of revolution was kept at $T = 4.521$ sec.

TABLE 15

Spin Table Results

<u>Meter Reading</u>	<u>Change in Meter Reading</u>	<u>Change in radius between readings</u>	<u>Cumulative change in radius</u>	
$G_{m.u.}$	$G_{m.u.}$	Δr	$\sum \Delta r$	$\Delta G / \Delta r$
(meter units)	(meter units)	(inches)	(inches)	m.u./in.
<u>Meter tilted at $1^{\circ}25'57''$</u>				
1114.6				
	+35.5	+0.200	0.200	177.5
1150.1				
	+ 4.1	+0.025	0.225	164.0
1154.2				

TABLE 15 (Contd)

<u>Meter Reading</u>	<u>Change in Meter Reading</u>	<u>Change in radius between readings</u>	<u>Cumulative change in radius</u>	
<u>Meter tilted at 2°17'33"</u>				
885.9				
	+141.8	+0.5	+0.500	283.6
1027.7				
	+ 57.0	+0.2	+0.700	285.0
1084.7				
	+ 83.9	+0.3	+1.000	279.7
1168.6				
	- 29.3	-0.1	+0.900	293.0
1139.3				
	+ 14.6	+0.05	+0.950	292.0
1153.9				
<u>Meter tilted at 2°52'00"</u>				
1099.8				
	17.5	+0.050	0.0500	350.0
1117.3				
	22.4	+0.0625	0.1125	358.4
1139.7				
	13.8	+0.0375	0.1500	341.3
1153.5				

The evaluation of this data was made in two ways. First, we note that by rearranging equation (9) it can be written in the form

$$\frac{\Delta G}{\Delta r} = \frac{4 \pi^2}{T^2 k} \sin \theta \quad (14)$$

$$\text{or in the form } \Delta G = \frac{4 \pi^2}{T^2 k} \sin \theta \Delta r. \quad (15)$$

As T was constant throughout the test, equation (14) implies that for any angle θ , the quantity $\Delta G / \Delta r$ should be a constant assuming k remains constant over the gravimeter range used. The last column in Table 15 gives the observed values of $\Delta G / \Delta r$. It is also possible to compute the $\Delta G / \Delta r$ values to be expected from the observed values of T, k, and θ using equation (14). In Table 16 the computed values of $\Delta G / \Delta r$ for the values of θ used are tabulated.

TABLE 16

<u>θ</u>	<u>$\Delta G / \Delta r$</u>
1°25'57"	176.2
2°17'33"	282.0
2°52'00"	352.3

The agreement of these values with those in Table 15 on the whole is good. There is, of course, some scatter, as would be expected for reasons given earlier. As expected, the deviation is greatest where ΔG and Δr

are the smallest and the percentage error in reading the vibrating beam is at a maximum. It should also be pointed out that all of the scatter may not represent experimental error as it is known that the gravimeter "constant" is not actually constant over the complete range of the instrument.

To get the best value of $\Delta G / \Delta r$ for use in evaluating k from equation (9) we will make use of the form of equation (11) which states that a plot of the absolute value of ΔG vs absolute value of Δr should be a straight line. In Figure 31 values of $|\Delta G|$ vs $|\Delta r|$ are plotted for the three different values of θ given in Table 15. A best fitting straight line was drawn through each set of values and the origin. The slopes of these lines were then used to determine the $\Delta G / \Delta r$ values to be substituted in equation (9). The results of the k computations are as follows.

Table 17

θ	k (mgal/meter unit)
$1^{\circ}25'57''$	0.697
$2^{\circ}17'33''$	0.695
$2^{\circ}52'00''$	0.691

Mean value of $K = 0.694$

The Texas Instrument Company tilt-table calibration value = 0.696 mgal/unit.

16. h. The Calculated Eotvos Effect:

It is of interest to evaluate the Eotvos effect to be expected and compare these with experimental observations. For present purposes it is sufficient to make approximate calculations. In the latitude of Houston, Texas, where the tests were conducted, the Eotvos corrections to a first approximation are:

$$E_c \approx 43.6 \times 10^{-7} V^2$$

$$\text{and } E_v \approx 87.2 \times 10^{-7} V \phi V \cos \frac{2\pi t}{T}.$$

The linear velocity of the gravimeter element squared, V^2 , is given by the following equation in the rotational case,

$$V^2 = rA = \left(\frac{2\pi r}{T}\right)^2.$$

Since $T = 4.521$ and $\text{sec} = .07535$ min.

$$V^2 \approx 7000 r^2.$$

In the experiment, r varied from 10 cm = 0.1 m to 20 cm = 0.2 m, so that V^2 is in the range of 70 to 280 m^2/min^2 . Also, we note that $V\phi \approx 48,000$ m/min. Substituting these values gives

SPIN TABLE RESULTS ON WORDEN GRAVIMETER
 θ = ANGLE OF TILT

FIG. 31

$$E_c \approx 0.0003 \text{ mgal to } 0.0012 \text{ mgal}$$

$$\text{and } E_v \approx 4.0 \cos \frac{2\pi t}{T} \text{ mgal to } 8.0 \cos \frac{2\pi t}{T} \text{ mgal}$$

$$= 5 \text{ mgals to } 10 \text{ mgals.}$$

Thus we see that the value of the constant Eotvos effect (E_c) was negligible for the tests under consideration. The value of E_v , on the other hand, was not negligible and amounted to between +5 and +10 mgals. This was taken care of in the course of reading the gravimeter through the nulling procedure used whereby the beam was adjusted with the gravimeter dial to swing equally to both sides of the zero point and this dial setting used for the reading value. This procedure was equivalent to reading the average value over a complete rotation of the spin table which eliminates E_v as (E_v) avg. = 0.

Two points are worth noting in connection with E_v :

1. The value of E_v as estimated by the amplitude of the swing of the beam (in this case ± 5 to ± 10 mgals) checks with that estimated from the approximate computations.

2. The Eotvos effect puts a limit on the amount of centrifugal force which can be applied to a gravimeter on a spin table as the swing of the beam due to E_v will at some point become too large to permit reliable readings to be obtained. A final limit, of course, is imposed by the beam hitting the stops.

Contrary to theoretical expectation, it was found that if the meter were leveled and rotated without tilt, an effect was noted on the meter readings. Experiment showed that the amount of this effect is independent of the radius at which the gravimeter is placed. This would seem to indicate that the effect is independent of the magnitude of the centrifugal force or linear velocity over the ranges encountered in the experiment. No explanation for this force was found. At first it might seem surprising that the calibration results were accurate with this force present. However, as the force is constant, the effect is to add a constant to the right hand side of equation (7); then, in carrying out the subtraction indicated in computing equation (9), this force, as does the constant force, $G \cos \theta$, cancels out. The question, however, remains as to the source of this effect and whether it might not change at some values of centrifugal force not encountered as yet in tests.

BIBLIOGRAPHY

- Andersen, E., Beitrag zur Mitschwingungstheorie der Relativen Pendelmessungen mit 2- und 4- Pendel Apparaten, Kopenhagen: Bianco Lunos Bogtrykkeri, 65 pp., 1932.
- Rose, J. C., Final Report on Gravity Program, Part II, The Pendulum Program, of Woollard, G. P. and Rose, J. C., Woods Hole Ocean. Inst. Tech. Rept., Ref. No. 60-26, 173 pp., 1960. (unpublished)
- Swick, C. H., Pendulum Gravity Measurements and Isostatic Reductions, USC and CS Spec. Pub. No. 232, 82 pp., 1942.
- Vening Meinesz, F. A., Theory and Practice of Pendulum Observations at Sea, Part I, Pub. of the Netherlands Geodetic Commission, 95 pp., Waltman, Delft, 1929.
- Woollard, G. P., Bonini, W. E., Black, W. A., Rose, J. C. and Ault, Wayne, A Study of Methods for Measuring Large Changes in Gravity on an Inter-Continental Basis. Woods Hole Ocean. Inst. Tech. Rept. Ref. No. 53-36, 138 pp., 1953. (unpublished)
- Woollard, G. P. and Rose, J. C., Gravity Values Obtained with the Gulf Quartz Pendulums over the North American Gravity Range, Woods Hole Ocean. Inst. Tech. Rept., Ref. No. 55-44, 75 pp., 1955. (unpublished)
- Woollard, G. P., and Rose, J. C., Report on Gravity Measurements Carried out with the Gulf "M" and "K" Sets of Pendulums (1953-55), Woods Hole Ocean. Inst. Tech. Rept., Ref. No. 56-72, 50 pp., 1956. (unpublished)

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TABLE 1

RAW PENDULUM PERIOD VALUES AND CORRECTIONS

TABLE I

GULF-WISCONSIN PENDULUM CORRECTIONS

Run No.	Uncorrected Period In Seconds	Temp. In °C	Mean Press. MM. Hg.	Amplitude In Inches		Corrections In Sec x 10 ⁻⁶			
				A1	A2	Temp.	Press.	Ampl.	E. T.
Madison I, October 14, 1961									
1	0.891 560 49	35.8	0.179	.966	.672	-0.17	-0.19	-6.02	+0.02
	562 72			.972	.664			-6.00	
2	0.891 560 53	35.8	0.181	.964	.674	-0.17	-0.19	-6.02	+0.01
	562 59			.974	.668			-6.04	
3	0.891 560 43	35.8	0.184	.965	.672	-0.17	-0.20	-6.01	+0.01
	562 72			.973	.665			-6.01	
4	0.891 560 49	35.9	0.186	.965	.670	-0.19	-0.20	-6.00	+0.02
	562 70			.971	.664			-5.99	
Huron I, October 18, 1961									
5	0.891 521 77	35.8	0.221	.962	.668	-0.17	-0.24	-5.96	+0.04
	524 06			.974	.660			-5.98	
6	0.891 521 69	35.7	0.222	.961	.644	-0.15	-0.24	-5.77	+0.04
	524 05			.982	.642			-5.89	
7	0.891 521 78	35.8	0.223	.959	.672	-0.17	-0.24	-5.97	+0.02
	524 32			.974	.667			-6.04	
8	0.891 521 79	35.6	0.224	.964	.669	-0.13	-0.24	-5.98	+0.01
	524 14			.973	.662			-5.99	
Denver I, October 21, 1961									
9	0.891 904 66	35.7	0.132	.960	.677	-0.15	-0.14	-6.02	+0.03
	906 75			.978	.676			-6.14	
10	0.891 904 45	35.6	0.132	.959	.648	-0.13	-0.14	-5.79	+0.05
	906 62			.981	.658			-6.02	
11	0.891 904 60	35.8	0.133	.964	.682	-0.17	-0.14	-6.09	+0.04
	906 89			.969	.668			-6.01	
12	0.891 904 80	35.8	0.133	.967	.686	-0.17	-0.14	-6.14	+0.03
	906 79			.974	.669			-6.06	

Run No.	Uncorrected Period In Seconds	Temp. In °C	Mean Press. MM. Hg.	Amplitude In Inches		Corrections In Sec x 10 ⁻⁶			
				A1	A2	Temp.	Press	Ampl.	E. T.
Great Falls I, October 26, 1961									
13	0.891 488 51 491 37	36.1	0.153	.961 .978	.668 .677	-0.24	-0.17	-5.95 -6.14	+0.03
14	0.891 488 42 491 35	36.0	0.153	.953 .978	.662 .679	-0.21	-0.17	-5.85 -6.16	+0.02
15	0.891 488 36 491 27	35.9	0.153	.950 .981	.664 .676	-0.19	-0.17	-5.85 -6.16	+0.02
16	0.891 488 44 491 10	35.9	0.154	.957 .978	.652 .649	-0.19	-0.17	-5.80 -5.92	+0.03
Edmonton I, October 29, 1961									
17	0.891 197 52 200 06	35.8	0.161	.955 .978	.669 .673	-0.17	-0.17	-5.92 -6.11	+0.03
18	0.891 197 35 199 98	35.6	0.162	.952 .970	.667 .667	-0.13	-0.17	-5.88 -6.01	+0.03
19	0.891 197 51 199 98	35.7	0.162	.957 .975	.673 .673	-0.15	-0.17	-5.96 -6.09	+0.03
20	0.891 197 48 199 69	35.6	0.163	.960 .963	.681 .666	-0.13	-0.18	-6.05 -5.95	+0.03
Whitehorse I, November 4, 1961									
21	0.890 933 11 933 54	35.9	0.197	.966 .965	.673 .661	-0.19	-0.21	-6.02 -5.92	+0.02
22	0.890 933 19 933 62	35.9	0.198	.968 .968	.673 .667	-0.19	-0.21	-6.04 -5.99	+0.03
23	0.890 933 12 933 88	35.6	0.198	.962 .973	.671 .664	-0.13	-0.21	-5.98 -6.00	+0.04
24	0.890 933 13 935 71	35.9	0.199	.967 .971	.674 .673	-0.19	-0.21	-6.04 -6.06	+0.04

Run No.	Uncorrected Period In Seconds	Temp. In °C	Mean Press. MM. Hg.	Amplitude In Inches		Corrections In Sec x 10 ⁻⁶			
				A1	A2	Temp.	Press	Ampl.	E. T.
Fairbanks I, November 8, 1961									
25	0.890 707 99	35.7	0.155	.963	.675	-0.15	-0.17	-6.02	+0.04
	710 16			.974	.668			-6.04	
26	0.890 707 95	35.8	0.155	.963	.673	-0.17	-0.17	-6.00	+0.04
	710 39			.973	.664			-6.00	
27	0.890 707 92	35.7	0.156	.963	.672	-0.15	-0.17	-5.99	+0.04
	710 39			.974	.666			-6.02	
28	0.890 708 10	35.8	0.156	.971	.681	-0.17	-0.17	-6.12	+0.04
	710 28			.956	.664			-5.88	
Barrow I, November 10, 1961									
29	0.890 502 41	34.5	0.167	.972	.683	+0.11	-0.18	-6.14	+0.05
	504 35			.955	.660			-5.84	
30	0.890 502 33	34.4	0.169	.971	.680	+0.13	-0.18	-6.11	+0.04
	504 37			.960	.656			-5.85	
31	0.890 501 89	33.1	0.170	.961	.676	+0.41	-0.18	-6.01	+0.03
	504 32			.966	.663			-5.94	
32	0.890 501 93	32.8	0.172	.962	.676	+0.47	-0.19	-6.02	+0.02
	504 23			.965	.667			-5.97	
Barrow II, November 11, 1961									
33	0.890 501 75	32.2	0.174	.956	.667	+0.60	-0.19	-5.90	+0.03
	504 29			.976	.663			-6.01	
34	0.890 501 64	32.8	0.173	.956	.664	+0.47	-0.19	-5.88	+0.04
	504 14			.959	.657			-5.85	

Run No.	Uncorrected Period In Seconds	Temp. In °C	Mean Press. MM. Hg.	Amplitude In Inches		Corrections In Sec x 10 ⁻⁶			
				A1	A2	Temp.	Press	Ampl.	E. T.
Fairbanks II, November 13, 1961									
35	0.890 708 07	35.8	0.188	.967	.674	-0.17	-0.20	-6.04	+0.05
	710 16			.954	.659			-5.83	
36	0.890 708 01	35.7	0.189	.974	.681	-0.15	-0.20	-6.14	+0.04
	710 44			.961	.661			-5.89	
37	0.890 707 95	35.8	0.189	.973	.676	-0.17	-0.20	-6.10	+0.04
	710 13			.966	.661			-5.93	
38	0.890 707 81	35.6	0.190	.972	.676	-0.13	-0.21	-6.09	+0.03
	710 12			.966	.664			-5.95	
Whitehorse II, November 18, 1961									
39	0.890 932 91	35.8	0.207	.961	.666	-0.17	-0.22	-5.93	+0.04
	935 18			.960	.657			-5.86	
40	0.890 933 04	35.8	0.207	.961	.672	-0.17	-0.22	-5.98	+0.02
	935 52			.962	.658			-5.88	
41	0.890 933 00	35.8	0.208	.968	.667	-0.17	-0.22	-5.99	+0.01
	935 56			.960	.659			-5.87	
Edmonton II, November 23, 1961									
43	0.891 197 10	35.9	0.112	.957	.668	-0.19	-0.12	-5.92	+0.03
	200 10			.957	.663			-5.88	
44	0.891 197 26	35.8	0.113	.955	.670	-0.17	-0.12	-5.93	+0.03
	199 96			.963	.667			-5.96	
45	0.891 197 09	35.8	0.114	.960	.674	-0.17	-0.12	-5.99	+0.04
	200 09			.962	.663			-5.92	
46	0.891 197 19	35.8	0.115	.960	.673	-0.17	-0.12	-5.98	+0.04
	199 96			.962	.664			-5.93	

Run No.	Uncorrected Period In Seconds	Temp. In °C	Mean Press. MM. Hg.	Amplitude In Inches		Corrections In Sec x 10 ⁻⁶				
				A1	A2	Temp.	Press	Ampl.	E. T.	
Great Falls II, November 26, 1961										
47	0.891 488 88	35.6	0.122	.964	.675	-0.13	-0.13	-6.03	+0.03	
	490 43			.968	.670			-6.02		
48	0.891 488 24	35.8	0.123	.965	.672	-0.17	-0.13	-6.01	+0.03	
	491 13			.975	.667			-6.04		
49	0.891 488 56	35.8	0.124	.967	.682	-0.17	-0.13	-6.11	+0.02	
	490 72			.966	.664			-5.96		
50	0.891 488 73	35.9	0.125	.965	.680	-0.19	-0.14	-6.08	+0.01	
	490 93			.949	.656			-5.78		
Denver II, November 30, 1961										
51	0.891 904 69	35.9	0.166	.956	.667	-0.19	-0.18	-5.91	+0.03	
	907 04			.966	.663			-5.95		
52	0.891 904 57	35.9	0.167	.965	.652	-0.19	-0.18	-5.86	+0.02	
	906 91			.962	.640			-5.74		
53	0.891 904 86	35.9	0.168	.961	.671	-0.19	-0.18	-5.98	+0.02	
	907 03			.961	.660			-5.89		
54	0.891 904 41	35.9	0.169	.962	.664	-0.19	-0.18	-5.93	+0.02	
	907 43			.961	.658			-5.88		
Houston (Rice) I, December 5, 1961										
55	0.892 047 15	35.9	0.180	.969	.671	-0.19	-0.19	-6.04	+0.02	
	050 59			.963	.667			-5.96		
56	0.892 047 97	35.9	0.181	.963	.669	-0.19	-0.20	-5.98	+0.04	
	049 76			.963	.665			-5.95		
57	0.892 047 50	35.9	0.182	.963	.675	-0.19	-0.20	-6.03	+0.04	
	050 29			.963	.667			-5.96		
58	0.892 047 56	35.9	0.183	.970	.676	-0.19	-0.20	-6.08	+0.02	
	049 99			.963	.663			-5.93		

Run No.	Uncorrected Period In Seconds	Temp. In °C	Mean Press. MM. Hg.	Amplitude In Inches		Corrections In Sec x 10 ⁻⁶			
				A1	A2	Temp.	Press	Ampl.	E. T.
Monterrey I, December 14, 1961									
59	0.892 272 25	35.1	0.169	.968	.676	-0.02	-0.18	-6.07	+0.03
	274 14			.963	.668			-5.97	
60	0.892 272 28	35.2	0.170	.967	.682	-0.04	-0.18	-6.11	+0.03
	274 21			.960	.663			-5.91	
61	0.892 272 25	35.4	0.170	.968	.682	-0.08	-0.18	-6.12	+0.02
	274 43			.956	.661			-5.87	
62	0.892 272 11	35.6	0.171	.967	.677	-0.13	-0.18	-6.07	+0.01
	274 41			.961	.660			-5.90	
San Luis Potosi I, December 15, 1961									
63	0.892 543 80	35.7	0.178	.976	.685	-0.15	-0.19	-6.20	+0.02
	546 35			.926	.660			-5.66	
64	0.892 543 95	35.6	0.179	.967	.682	-0.13	-0.19	-6.11	0.00
	546 10			.958	.653			-5.82	
65	0.892 543 69	35.0	0.180	.955	.669	-0.00	-0.19	-5.93	-0.02
	546 18			.963	.664			-5.94	
66	0.892 543 56	35.2	0.181	.954	.668	-0.04	-0.20	-5.91	-0.03
	546 08			.959	.664			-5.91	
Mexico, D. F. I, December 18, 1961									
67	0.892 666 22	35.8	0.204	.959	.669	-0.17	-0.22	-5.96	-0.03
	668 95			.968	.668			-6.01	
68	0.892 666 19	35.8	0.205	.961	.669	-0.17	-0.22	-5.97	-0.01
	669 05			.963	.663			-5.94	
69	0.892 666 34	35.8	0.207	.965	.674	-0.17	-0.22	-6.04	+0.01
	668 74			.968	.665			-5.99	
70	0.892 666 34	35.8	0.209	.969	.684	-0.17	-0.23	-6.15	+0.03
	668 50			.963	.662			-5.93	

Run No.	Uncorrected Period In Seconds	Temp. In °C	Mean Press. MM. Hg.	Amplitude In Inches		Corrections In Sec x 10 ⁻⁶			
				A1	A2	Temp.	Press	Ampl.	E. T.
Mexico, D. F. IIa, December 20, 1961									
71	0.892 666 44	35.8	0.133	.969	.687	-0.17	-0.14	-6.18	-0.03
	668 57			.949	.661			-5.82	
72	0.892 666 25	35.8	0.133	.972	.686	-0.17	-0.14	-6.18	-0.03
	668 94			.944	.661			-5.79	
73	0.892 665 99	35.7	0.133	.963	.683	-0.15	-0.14	-6.09	0.00
	669 05			.984	.667			-6.11	
74	0.892 666 11	35.8	0.133	.959	.677	-0.17	-0.14	-6.01	+0.02
	668 94			.978	.669			-6.09	
Mexico, D. F. IIb, December 21, 1961									
75	0.892 666 20	35.9	0.140	.949	.669	-0.19	-0.15	-5.89	-0.02
	668 80			.957	.661			-5.88	
76	0.892 666 09	35.9	0.141	.946	.671	-0.19	-0.15	-5.88	-0.02
	668 69			.953	.662			-5.86	
77	0.892 665 90	35.8	0.142	.944	.668	-0.17	-0.15	-5.84	-0.03
	668 81			.953	.661			-5.85	
San Luis Potosi II, December 22, 1961									
78	0.892 543 57	35.7	0.153	.961	.677	-0.15	-0.16	-6.03	-0.02
	546 13			.963	.666			-5.96	
79	0.892 543 57	35.7	0.154	.957	.673	-0.15	-0.16	-5.97	-0.01
	546 11			.963	.668			-5.97	
80	0.892 543 69	35.8	0.154	.956	.673	-0.17	-0.17	-5.97	+0.01
	545 94			.961	.665			-5.94	
81	0.892 543 45	35.7	0.155	.958	.669	-0.15	-0.17	-5.95	+0.03
	546 08			.968	.665			-5.99	

Run No.	Uncorrected Period In Seconds	Temp. In °C	Mean Press. MM. Hg.	Amplitude In Inches		Corrections In Sec x 10 ⁻⁶			
				A1	A2	Temp.	Press	Ampl.	E. T.
Monterrey II, December 24, 1961									
82	0.892 271 88 274 44	35.9	0.178	.959	.675	-0.19	-0.19	-6.00	-0.01
				.957	.653			-5.81	
83	0.892 271 99 274 49	35.9	0.179	.965	.675	-0.19	-0.19	-6.04	-0.02
				.954	.659			-5.84	
84	0.892 272 04 274 32	35.9	0.181	.964	.681	-0.19	-0.20	-6.08	-0.02
				.948	.657			-5.78	
85	0.892 272 02 274 30	35.9	0.182	.965	.675	-0.19	-0.20	-6.04	0.00
				.953	.652			-5.78	
Houston (Rice) II, December 26, 1961									
86	0.892 047 16 050 30	35.9	0.286	.959	.665	-0.19	-0.31	-5.92	-0.01
				.963	.658			-5.89	
87	0.892 047 51 049 80	35.9	0.287	.961	.673	-0.19	-0.31	-6.00	0.00
				.961	.650			-5.82	
88	0.892 047 28 049 82	35.9	0.288	.958	.668	-0.19	-0.31	-5.94	0.00
				.963	.652			-5.85	
89	0.892 047 09 050 19	35.9	0.290	.961	.665	-0.19	-0.31	-5.93	+0.01
				.964	.658			-5.90	
Denver III, December 29, 1961									
90	0.891 904 53 906 79	36.0	0.432	.948	.647	-0.21	-0.47	-5.70	+0.02
				.951	.639			-5.66	
91	0.891 904 23 906 18	36.0	0.437	.953	.647	-0.21	-0.47	-5.74	+0.03
				.962	.647			-5.80	
92	0.891 904 28 906 95	36.0	0.443	.957	.654	-0.21	-0.48	-5.82	+0.03
				.961	.647			-5.79	
93	0.891 904 44 906 93	35.9	0.448	.954	.658	-0.19	-0.48	-5.83	+0.03
				.962	.652			-5.84	

Run No.	Uncorrected Period In Seconds	Temp. In °C	Mean Press. MM. Hg.	Amplitude In Inches		Corrections In Sec x 10 ⁻⁶			
				A1	A2	Temp.	Press	Ampl.	E. T.
Madison II, January 4, 1962									
94	0.891 560 13	35.9	0.266	.964	.668	-0.19	-0.29	-5.97	+0.04
				562 57	.963			.654	
95	0.891 560 11	35.8	0.271	.967	.665	-0.17	-0.29	-5.97	+0.05
				562 65	.967			.658	
96	0.891 560 14	35.9	0.279	.971	.669	-0.19	-0.30	-6.03	+0.04
				562 53	.968			.658	
97	0.891 560 10	36.0	0.287	.966	.663	-0.21	-0.31	-5.95	+0.01
				562 60	.966			.652	

Run No.	Uncorrected Period In Seconds	Temp. In °C	Mean Press. MM. Hg.	Amplitude In Inches		Corrections In Sec x 10 ⁻⁶			
				A1	A2	Temp.	Press.	Ampl.	E. T.
Madison IV, June 7, 1962									
50	0.891 559 82	36.0	0.178	.970	.667	-0.21	-0.19	-6.01	+0.02
	561 95			.964	.652			-5.85	
51	0.891 559 92	35.9	0.185	.968	.664	-0.19	-0.20	-5.97	+0.01
	561 96			.964	.651			-5.84	
52	0.891 560 00	35.9	0.193	.973	.665	-0.19	-0.21	-6.01	0.00
	562 00			.968	.652			-5.88	
55	0.891 559 31	36.0	0.218	.966	.658	-0.21	-0.24	-5.91	-0.04
	562 31			.956	.642			-5.72	

TABLE Ia

GULF-WISCONSIN PENDULUM CORRECTIONS

Run No.	Uncorrected Period In Seconds	Temp. In °C	Mean Press. MM. Hg.	Amplitude In Inches		Corrections In Sec x 10 ⁻⁶			
				A1	A2	Temp.	Press.	Ampl.	E. T.
Madison III, April 30, 1962									
1	0.891 559 91 562 32	36.0	0.245	.958 .972	.657 .655	-0.21	-0.26	-5.85 -5.93	-0.02
2	0.891 559 91 562 48	36.0	0.255	.959 .973	.654 .658	-0.21	-0.28	-5.83 -5.96	-0.01
3	0.891 559 89 562 22	36.0	0.268	.960 .968	.657 .653	-0.21	-0.29	-5.86 -5.88	0.00
4	0.891 559 95 562 41	35.9	0.278	.965 .973	.656 .654	-0.19	-0.30	-5.89 -5.93	+0.02
Washington I, May 5, 1962									
7	0.891 681 96 684 17	36.0	0.171	.963 .977	.663 .665	-0.21	-0.18	-5.93 -6.04	-0.03
8	0.891 681 87 684 41	36.0	0.180	.966 .973	.658 .661	-0.21	-0.19	-5.91 -5.98	-0.06
9	0.891 681 90 684 17	36.0	0.190	.961 .981	.662 .663	-0.21	-0.21	-5.91 -6.06	-0.06
10	0.891 681 93 684 23	36.0	0.203	.964 .977	.660 .663	-0.21	-0.22	-5.91 -6.03	-0.05
11	0.891 681 91 684 13	35.9	0.213	.959 .970	.658 .657	-0.19	-0.23	-5.86 -5.93	-0.02
Washington II, May 30, 1962									
45	0.891 682 18 684 22	35.9	0.180	.983 .982	.677 .661	-0.19	-0.19	-6.18 -6.05	-0.04
47	0.891 681 76 684 01	35.8	0.197	.964 .974	.662 .654	-0.17	-0.21	-5.93 -5.93	0.00
49	0.891 681 87 683 97	35.9	0.212	.965 .971	.662 .652	-0.19	-0.23	-5.94 -5.90	+0.04

TABLE 1b

GULF-WISCONSIN PENDULUM CORRECTIONS

Run No.	Uncorrected Period In Seconds	Temp. In °C	Mean Press. MM. Hg.	Amplitude In Inches		Corrections In Sec x 10 ⁻⁶			
				A1	A2	Temp.	Press.	Ampl.	E. T.
Madison I, August 29, 1961									
1	0.891 560 60 563 11	36.0	0.169	.987 .982	.686 .671	-0.21	-0.18	-6.28 -6.12	-0.01
2	0.891 560 19 562 90	36.0	0.169	.972 .968	.680 .667	-0.21	-0.18	-6.12 -5.99	+0.01
3	0.891 560 61 562 90	36.0	0.169	.972 .964	.682 .667	-0.21	-0.18	-6.14 -5.97	+0.03
4	0.891 560 54 562 95	35.9	0.169	.967 .964	.676 .664	-0.19	-0.18	-6.06 -5.94	+0.03
St. Louis I, September 1, 1961									
5	0.891 729 37 731 36	36.0	0.188	.978 .948	.681 .651	-0.21	-0.20	-6.18 -5.73	+0.02
7	0.891 729 34 731 24	36.0	0.195	.984 .955	.690 .655	-0.21	-0.21	-6.29 -5.81	+0.01
8	0.891 729 33 731 10	36.0	0.199	.985 .952	.689 .652	-0.21	-0.21	-6.29 -5.77	+0.02
9	0.891 729 32 731 19	36.1	0.199	.968 .971	.680 .671	-0.23	-0.21	-6.10 -6.05	+0.02
St. Louis II, September 2, 1961									
10	0.891 729 10 731 35	36.0	0.204	.977 .972	.681 .667	-0.21	-0.22	-6.17 -6.02	+0.01
11	0.891 729 11 731 20	36.0	0.204	.968 .971	.679 .664	-0.21	-0.22	-6.09 -5.99	+0.02
12	0.891 729 27 731 31	36.0	0.206	.971 .968	.682 .663	-0.21	-0.22	-6.14 -6.07	+0.02
13	0.891 729 23 731 32	36.0	0.209	.972 .972	.680 .667	-0.21	-0.23	-6.13 -6.02	+0.02

Run No.	Uncorrected Period In Seconds	Temp. In °C	Mean Press. MM. Hg.	Amplitude In Inches		Corrections In Sec x 10 ⁻⁶			
				A1	A2	Temp.	Press.	Ampl.	E. T.
Madison II, September 9, 1961									
14	0.891 560 65	36.0	0.209	.964	.667	-0.21	-0.23	-5.97	-0.02
	562 92			.967	.657			-5.91	
15	0.891 560 53	36.0	0.213	.967	.672	-0.21	-0.23	-6.03	+0.01
	562 86			.967	.658			-5.92	
16	0.891 560 51	35.9	0.218	.962	.670	-0.19	-0.24	-5.98	+0.02
	562 68			.964	.654			-5.87	
17	0.891 560 60	35.9	0.221	.964	.664	-0.19	-0.24	-5.94	+0.03
	562 90			.965	.662			-5.93	
Minneapolis I, September 12, 1961									
18	0.891 456 35	35.8	0.162	.979	.674	-0.17	-0.17	-6.13	-0.02
	458 89			.973	.662			-5.99	
19	0.891 456 39	35.9	0.163	.975	.670	-0.19	-0.18	-6.07	-0.01
	459 13			.969	.660			-5.95	
20	0.891 456 21	35.9	0.163	.973	.674	-0.19	-0.18	-6.08	+0.01
	458 72			.966	.660			-5.93	
21	0.891 456 30	35.9	0.164	.961	.669	-0.19	-0.18	-5.96	+0.03
	458 86			.965	.656			-5.89	
Minneapolis II, September 13, 1961									
22	0.891 456 63	36.0	0.173	.971	.677	-0.21	-0.19	-6.09	0.00
	458 69			.964	.656			-5.88	
23	0.891 456 19	35.9	0.173	.966	.667	-0.19	-0.19	-5.98	-0.01
	458 70			.962	.654			-5.85	
24	0.891 456 49	35.9	0.173	.967	.676	-0.19	-0.19	-6.06	0.00
	458 62			.967	.657			-5.91	
25	0.891 456 49	35.9	0.173	.968	.675	-0.19	-0.19	-6.06	+0.01
	458 80			.965	.660			-5.92	

Run No.	Uncorrected Period In Seconds	Temp. In °C	Mean Press. MM. Hg.	Amplitude In Inches		Corrections In Sec x 10 ⁻⁶			
				A1	A2	Temp.	Press.	Ampl.	E. T.
Madison III, September 17, 1961									
26	0.891 560 66	35.9	0.199	.966	.677	-0.19	-0.21	-6.06	+0.01
	562 75			.960	.654			-5.84	
27	0.891 560 72	35.9	0.200	.970	.673	-0.19	-0.22	-6.06	+0.02
	562 73			.960	.652			-5.82	
28	0.891 560 61	35.9	0.202	.966	.670	-0.19	-0.22	-6.00	+0.02
	562 58			.958	.650			-5.79	
29	0.891 560 68	35.9	0.204	.972	.680	-0.19	-0.22	-6.13	+0.02
	562 77			.968	.662			-5.96	

The pendulum station is located on the floor of the furnace room of the Arctic Research Laboratory, Building 750-121. The furnace room proper is located from the southeast wall of building 750.

Observations were made at a point about 13 feet from the foot of the outside wall 16 inches northeast of the southeast wall of the furnace room. A University of Wisconsin International Gravity Base is located in the floor.

The 1961 Gulf-Wisconsin pendulum site is located approximately 170 feet north and 60 feet west of the 1958 Gulf-Wisconsin pendulum site which was located in Building 322, the J. Carpenter Shop.

TABLE 2A

The gravity value at the 1961 pendulum site is $+0.17$ mgal relative to the 1958 Gulf-Wisconsin pendulum site.

DESCRIPTIONS OF PENDULUM BASES

Latitude	Longitude	Elevation
71° 19' 01" N	156° 40' 00" W	3.0 meters

Point Barrow, Alaska

Gulf M 1961

The pendulum station is located on the floor of the furnace room of the Arctic Research Laboratory, Building 250-251. The furnace room protrudes from the southwest wall of Building 251.

Observations were made at a point about 13 feet from the door to the outside and 18 inches northeast of the southwest wall of the furnace room. A University of Wisconsin International Gravity Disk is installed in the floor.

The 1961 Gulf-Wisconsin pendulum site is located approximately 170 feet north and 40 feet west of the 1958 Gulf-Wisconsin pendulum site which was located in Building 353, the former A.R.L. Carpenter Shop.

The gravity value at the 1961 pendulum site is + 0.17 mgal relative to the 1958 Gulf-Wisconsin pendulum site.

<u>Latitude</u>	<u>Longitude</u>	<u>Elevation</u>
71° 19.6' N	156° 40.6' W	3.0 meters

POINT BARROW, ALASKA

Fairbanks, Alaska

Cambridge 1953 Gulf M 1961

The pendulum station is located at the Geophysical Institute of the University of Alaska, at College, (3 miles north of Fairbanks) on the floor of a small telephone terminal room on the first floor of the Institute, which is on the same level as the concrete loading platform at the west end of the building. The telephone terminal room is located approximately midway along the length of the first floor corridor and on the north side of the corridor. A University of Wisconsin International Gravity Disk is installed. This is the same as the 1953 Cambridge pendulum site established by the Dominion Observatory. The loading platform was the 1951 Gulf-Columbia pendulum site.

Latitude

64° 51.5' N

Longitude

147° 49.4' W

Elevation

157.0 meters

GEOPHYSICAL INSTITUTE , COLLEGE, ALASKA

Whitehorse, Yukon Territory

Gulf M 1961

The pendulum station is located in the "Equipment Room" of "A" Hangar, which lies on the east side of the RCAF Base, which is on the west side of the runway of the Whitehorse Airport. The civilian airline terminal is situated east of the runway. Observations were made about midway along the north wall of the "Equipment Room" and 18 inches south of the north wall midway between two concrete piers, one 40 inches and one 6 inches in height. A University of Wisconsin International Gravity Disk is installed.

(The airport Manager states that in the future commercial flight operations will be moved to "A" Hangar and that there will be some remodeling, however, the "Equipment Room" will remain unchanged.)

The "Equipment Room" of "A" Hangar is located approximately one mile northwest of the Gulf 1953 pendulum site which was destroyed in 1961.

Latitude

60° 43' N

Longitude

135° 04.5' W

Elevation

701.9 meters

WHITEHORSE, Y.T. R.C.A.F. BASE - "A" HANGAR

Edmonton, Alberta

Gulf M 1961

The pendulum station is located in the Geophysics Laboratory (Room Number 17) in the basement of the new Physics-Math. Building of the University of Alberta. Observations were made on the westernmost of two 4' x 4' concrete piers set in flush with the floor. The other pier is used for seismometers.

A University of Wisconsin International Gravity Disk is installed approximately 10 feet north of the pendulum pier.

The 1961 Gulf-Wisconsin pendulum site is located approximately $\frac{1}{4}$ mile northwest of Gulf-Wisconsin 1953 pendulum site.

The 1953 Gulf-Wisconsin site has been remodeled and is now a classroom located in the Arts Building of the University of Alberta.

The gravity value at the 1961 Gulf-Wisconsin site is -0.10 milligal relative to the 1953 Gulf-Wisconsin site.

Latitude

Longitude

Elevation

53° 31' 42.8" N

113° 31' 29.0" W

669.9 meters

EDMONTON, CANADA
BASEMENT OF NEW PHYSICS-MATHEMATICS BUILDING

Great Falls, Montana

Gulf K and M 1953

Gulf M 1961

The pendulum station is located at the south end of the south hallway of the Roosevelt School, 49 feet north of the double doors on the south side of the building nearest to 2nd Avenue North. The school occupied the entire city block between 2nd Avenue North and 3rd Avenue North and between 25th Street North and 26th Street North.

A University of Wisconsin International Gravity Disk is installed outside on the top step up to the double doors at the south end of the south hallway. This disk is the site of a gravimeter reference station. The gravity value is the same at both sites.

Latitude

Longitude

Elevation

47° 30.7' N

111° 15.7' W

1050.0 meters

GREAT FALLS - ROOSEVELT SCHOOL

Huron, South Dakota

Gulf K & M 1953

Gulf M 1954

Gulf M 1961

The pendulums were located in the large room in the basement of the Administration Building of the Huron Airport. At the time of the 1953 and 1954 observations this was the furnace room, but the furnace has since been moved into a small room immediately west of the main room.

The old pendulum site was near the south wall of the building and twenty feet from the east wall. Cracks in the floor necessitated moving the site fifteen feet northwest to a location next to the north wall of the Airport Managers Office and seven feet from the east wall. The gravity is the same.

Latitude

Longitude

Elevation

44° 23.0' N

98° 13.4' W

389.6 meters

HURON, S. DAKOTA, BASEMENT OF AIRPORT ADMINISTRATION BUILDING

Madison, Wisconsin

1. Gulf M pendulum 1954-1959, 1961-1962

Station is in the basement of Science Hall at the intersection of Langdon and Park Streets on the campus of the University of Wisconsin. The observations were made in Laboratory Room 70-D (formerly Room 12-A) located in the southeast corner of the basement.

Latitude 43 04.6'N Longitude 89 24.0'W Elevations 70.0 meters

Earlier sites used:

2. Gulf "C" pendulum 1951

Basement of Science Hall in hallway in front of Room 40 (formerly Room 7). Elevation is same as Room 70-D.

3. Cambridge pendulum 1952

Basement of Science Hall in Room 5 (formerly Room 26).
Elevation 270.1 m

4. Gulf "K" and "M" pendulum 1953-54

Basement of Science Hall in Room 4 (formerly Room 27)
Elevation 270.1 m

5. Gulf "M" pendulums 1958

Basement of Science Hall in Room 4 (formerly Room 27)
Elevation 270.1 m

Difference in gravity for sites 3, 4 and 5 from site 1 = -0.06 mgal.
Difference in gravity sites 2 and 1 = 0.01 mgal.

Denver, Colorado

Gulf 1961

The pendulum station is located in Room Number 8 (Electronics - Physics Lab) in the basement of Science Hall at the University of Denver. Observations were made at the northwest corner of the room. A University of Wisconsin International Gravity Disk is installed 18 inches north of the observation site.

A gravimeter reference station is located outside the south basement door on the concrete landing at the bottom of the steps leading up to the parking lot. The gravity value at the reference station is -0.02 mgal, relative to the pendulum station.

The gravity value at the 1961 Gulf-Wisconsin pendulum site is +0.56 milligal relative to the 1953 Gulf-Wisconsin site which is located at Chamberlin Observatory, University of Denver.

<u>Latitude</u>	<u>Longitude</u>	<u>Elevation</u>
39° 40.7' N	104° 57.7' W	1635.5 meters

UNIVERSITY OF DENVER - SCIENCE HALL

Houston, Texas

Gulf 1961

The pendulum station is located in the northeast corner of Room Number 104, a mineralogy store room, in the Geology Building at Rice University. The site is twenty-three feet six inches west and fourteen feet six inches north of the center of the western of two piers. The site is thirty-two feet north of the elevator. A University of Wisconsin International Gravity Disk is installed on the floor at the site.

The gravity at the new site is the same as at the old site.

Latitude

Longitude

Elevation

29° 43' 08" N

95° 24' 08" W

Coordinates were surveyed in from a nearby bench mark.

HOUSTON, TEXAS GEOLOGY BUILDING, RICE UNIVERSITY

Monterrey, Nuevo Leon, Mexico

Gulf C 1951

Gulf K and M 1953

Gulf M 1961

The pendulum station is located in the automobile shop of the Instituto Tecnológico y estudios Superiores, on a line 15 feet south of the sliding overhead door installed in the north (outside) wall, and about 24 feet east of the west wall of the room. An Instituto de Geofísica Gravity Disk is installed at the site of observations. This is the site of all former Gulf pendulum observations.

Latitude

25° 38' N

Longitude

100° 17' W

Elevation

566.9 meters

MONTERREY, MEXICO
INSTITUTO TECNOLÓGICO
AUTOMOBILE SHOP

San Luis Potosi, San Luis Potosi, Mexico

Gulf M 1961

The pendulum station is located on a 2 1/2" platform in front of the east window of a classroom called "Aula Lic. C. Garcia" located in the northeast corner of the main courtyard of the "Instituto Cientifico" on Calle ALVARO OBREGON, which forms the east one-half of the north side of Plaza De Juarez.

A University of Wisconsin International Gravity Disk is located on the platform. At a later date an Instituto de Geofisica marker will be installed at the site.

<u>Latitude</u>	<u>Longitude</u>	<u>Elevation</u>
22° 09.2' N	100° 58.5' W	1865.0 meters

Coordinates and Elevation supplied by:

Ing. Julio Monges **Caldera**
Instituto de Geofisica
Universidad Nacional
De Mexico

SAN LUIS POTOSI, MEXICO INSTITUTO CIENTIFICO

Mexico D.F., Mexico

Gulf K and M 1953

Gulf M 1958

Gulf M 1961

The pendulum station is located in the gravity room at the Universidad Nacional de Mexico, about 50 feet north of the building housing the Van de Graaf generator of the Physics Department. The pendulums were on the most southeasterly of six similar 7 1/2 foot square concrete piers. The surface of the pier is 27 inches above floor level. An Instituto de Geofisica Gravity Disk is installed in the pier.

Latitude

Longitude

Elevation

19° 20' N

99° 11' W

2268.5 meters

GRAVITY ROOM, INSTITUTO DE GEOFISICA
UNIVERSIDAD NACIONAL DE MEXICO
MEXICO D.F. - MEXICO

Washington, D.C.

Gulf M and K 1959

The pendulum station is located in the basement compressor room of the Geophysical Laboratory of the Carnegie Institute of Washington, 2801 Upton Street, N.W. The station is approximately 15 feet west of the metal screen mesh separating the two air compressors and locker area of this section of the basement.

Latitude

38° 56.6' N

Longitude

77° 03.4' W

Elevation

87.5 meters

WASHINGTON, D.C.
CARNEGIE INSTUTION OF WASHINGTON, 2801 UPTON ST. N.W.
GEOPHYSICAL LABORATORY BASEMENT COMPRESSOR ROOM

St. Louis, Missouri

Gulf M 1961

The pendulum station is in Room No. 2 (Historical Geology room) in the southeast corner of Wilson Hall on the campus of Washington University. Wilson Hall is approximately 400 feet north of Forsyth Blvd., and 1/4 mile west of Skinker Blvd. The pendulum case was located on the concrete floor 90 inches east of the west wall of the room, and 75 inches north of the south wall of the room. The concrete floor is approximately one foot above ground level.

There is an auxiliary gravimeter site outside at the east entrance. The gravity is the same as at the pendulum station.

Latitude

38° 38.85' N

Longitude

90° 18.32' W

Elevation

162.1 meters

ST. LOUIS, MISSOURI
WASHINGTON UNIV.-WILSON HALL

Minneapolis, Minnesota

Gulf M 1957

Gulf K 1959

Gulf 1961

The pendulum station is located on the concrete floor of Room 14 in the basement of Pillsbury Hall (Geology Building) on the campus of the University of Minnesota. The room is now used as a storeroom. The pendulums were six feet north of the south wall of the basement, in line with a large window in the center of the south wall of the room. The floor is about 3 feet below the surface of the ground surrounding the building. The site is approximately equivalent to USC & GS No. 74 (1910).

Latitude

Longitude

Elevation

44° 58.7' N

93° 58.7' W

256.1 meters

ROOM 14, DEPT. OF GEOLOGY, PILLSBURY
HALL, UNIVERSITY OF MINNESOTA
MINNEAPOLIS, MINNESOTA

TABLE 2B

**DESCRIPTIONS OF GRAVIMETER BASES
(Western Standardization Range)**

SURVEY STATION DESCRIPTION			
COUNTRY U. S.	STATION DESIGNATION Gulf K and M 1953 P.S.	STATE OR PROVINCE Alaska	
Gravity Base	NEAREST CITY Northway	LATITUDE 62° 57.4' N	LONGITUDE 141° 57.1' W
STATION ELEVATION FT/MTR 522.1 Meters		ESTIMATED ACCURACY ± Unknown	
SOURCE OF INFORMATION FOR :			
LATITUDE & LONGITUDE WHOI Ref. No. 60-26. II-141		ELEVATION same	DATUM
OBSERVED BY Longfield	MONTH & YEAR Nov. 1961	CHIEF OF TEAM	
DESCRIPTION Observations were made at the Northway Airport on the floor of Building No. 65 now used as a truck maintenance garage. The floor of the building is at the same elevation as the airport runway. The station is 2 feet from the northwest wall at the center of the wall. The site is 775 feet southwest of a control tower not being used, about 650 north of the weather shack, and about 1000 feet north-northeast of a steel framework beacon light tower located 400 feet northwest of the runway.			
<div style="display: flex; justify-content: space-between;"> <div style="width: 45%;"> <p>SKETCH</p> </div> <div style="width: 50%; text-align: right;"> <p>BLDG. 65</p> <p>BEACON TOWER</p> </div> </div>			

SURVEY STATION DESCRIPTION			
COUNTRY U. S.	STATION DESIGNATION Gulf M 1958 P.S.	STATE OR PROVINCE Alaska	
Gravity Base	NEAREST CITY Pt. Barrow	LATITUDE 71° 19.6' N	LONGITUDE 156° 40.6' W
STATION ELEVATION FT/MTR 3.4 Meters		ESTIMATED ACCURACY± Unknown	
SOURCE OF INFORMATION FOR :			
LATITUDE & LONGITUDE WHOI Ref. No. 60-26. II-141		ELEVATION same	DATUM
OBSERVED BY Longfield	MONTH & YEAR Nov. 1961	CHIEF OF TEAM	
DESCRIPTION Observations were made on the northwest corner of the concrete foundation of Butler Bldg. 353, which has been destroyed by fire. This station is approximately 1125 feet south and 7° east of the large commercial hangar at the landing strip. This station is located approximately 170 feet south of the 1961 Gulf - Wisconsin pendulum site, which is in Bldg. No. 250-251.			
A standard USC and GS gravity disk stamped PT BARROW 1952, is set in the southwest corner of the foundation of Bldg. 353.			
SKETCH			
<p style="text-align: center; margin-top: 100px;">BLDG. 250 - 251</p> <p style="text-align: center; margin-top: 50px;">BLDG. 253</p> <p style="text-align: right; margin-top: 50px;">FOUNDATION, BLDG. 353</p>			

SURVEY STATION DESCRIPTION

[illegible]

SKETCH

SURVEY STATION DESCRIPTION			
COUNTRY U. S.	STATION DESIGNATION Stapleton Airport	STATE OR PROVINCE Colorado	
Gravity Base	NEAREST CITY In Denver	LATITUDE 39° 45.6' N	LONGITUDE 104° 53.0' W
STATION ELEVATION FT/MTR 5325 Feet		ESTIMATED ACCURACY ± Unknown	
SOURCE OF INFORMATION FOR :			
LATITUDE & LONGITUDE WHOI Ref. No. 60-26, Table III-A-3		ELEVATION same	DATUM
OBSERVED BY Longfield	MONTH & YEAR Oct. 1961	CHIEF OF TEAM	
DESCRIPTION At Gate 2, on the field side of terminal, approximately 75 feet east of the steps leading up to the cocktail lounge located inside the terminal. Observations were made approximately 4 feet south of the telephone booth located at Gate 2.			
SKETCH			

SKETCH

SURVEY STATION DESCRIPTION

SURVEY STATION DESCRIPTION			
COUNTRY U. S.	STATION DESIGNATION Gulf K and M 1953 P.S.		STATE OR PROVINCE Montana
Gravity Base	NEAREST CITY Billings	LATITUDE 45° 48.2' N	LONGITUDE 108° 32.5' W
STATION ELEVATION FT/MTR 1101.5 Meters		ESTIMATED ACCURACY ± Unknown	
SOURCE OF INFORMATION FOR :			
LATITUDE & LONGITUDE 26° II-146		ELEVATION same	DATUM
OBSERVED BY Longfield	MONTH & YEAR Oct. 1961	CHIEF OF TEAM	
DESCRIPTION Observations were made in Hangar No. 2 at the Billings Municipal Airport, 7 feet east of the west wall and midway along the wall. The site is about 200 feet west and 100 feet north of the main beacon, an orange and white checkered water tower at the side of the road past the airport, and about 400 feet northwest of the bronze statue, "A Range Rider and his Horse on the Yellowstone." The airport is on a cliff north of the city.			

SKETCH

SURVEY STATION DESCRIPTION			
COUNTRY U. S.	STATION DESIGNATION Great Falls Municipal A.P.	STATE OR PROVINCE Montana	
Gravity Base	NEAREST CITY Great Falls	LATITUDE 47° 29.0' N	LONGITUDE 111° 22.0' W
STATION ELEVATION FT/MTR 3671 Feet		ESTIMATED ACCURACY ± Unknown	
SOURCE OF INFORMATION FOR :			
LATITUDE & LONGITUDE Stand. of Intl. Gravity Values Appendix II		ELEVATION same	DATUM
OBSERVED BY Longfield	MONTH & YEAR Oct. 1961	CHIEF OF TEAM	
DESCRIPTION Observations were made 2 feet east of the center of the Western Air Lines ticket counter in the terminal. There are doors leading to the street and parking lot approximately 15 feet east of the station. A cocktail lounge is located approximately 100 feet southwest of the station. The airport is on a cliff west of the city.			
SKETCH <div style="text-align: center; margin-top: 20px;"> </div>			

SURVEY STATION DESCRIPTION			
COUNTRY U. S.	STATION DESIGNATION Malmstrom AFB	STATE OR PROVINCE Montana	
Gravity Base	NEAREST CITY Great Falls	LATITUDE 47° 30.5' N	LONGITUDE 111° 11.5' W
STATION ELEVATION FT/MTR 3525 Feet		ESTIMATED ACCURACY ± Unknown	
SOURCE OF INFORMATION FOR :			
LATITUDE & LONGITUDE 26. Table III A-7		ELEVATION same	DATUM
OBSERVED BY Longfield	MONTH & YEAR Oct. 1961	CHIEF OF TEAM	
DESCRIPTION Observations were made at a point beneath the ladder up to the control tower, which is located on top of the Base Operations Bldg. The ladder is approximately 15 feet northeast of the steps up to the entrance to Base Operations and 15 feet southeast of the parking lot. There are Electric Transformers approximately 20 feet northeast of the station.			
SKETCH

SURVEY STATION DESCRIPTION

COUNTRY U. S.	STATION DESIGNATION Houston Intl. A.P.	STATE OR PROVINCE Texas	
Gravity Base	NEAREST CITY Houston	LATITUDE 29° 39.0' N	LONGITUDE 95° 16.7' W
STATION ELEVATION FT/MTR 50 Feet	ESTIMATED ACCURACY± Unknown		
SOURCE OF INFORMATION FOR :			
LATITUDE & LONGITUDE WHOI Ref. No. 60- 26. Table III-A-3		ELEVATION same	DATUM
OBSERVED BY Longfield	MONTH & YEAR Dec. 1961	CHIEF OF TEAM	
DESCRIPTION Observations were made on the floor inside the concourse at Gate No. 9 at the Houston International Airport.			

SKETCH

SURVEY STATION DESCRIPTION			
COUNTRY U. S.	STATION DESIGNATION Gulf M P.S. 1954	STATE OR PROVINCE Texas	
Gravity Base	NEAREST CITY In Houston	LATITUDE 29° 44.2' N	LONGITUDE 95° 25.1' W
STATION ELEVATION FT/MTR 18.4 Meters		ESTIMATED ACCURACY ± Unknown	
SOURCE OF INFORMATION FOR :			
LATITUDE & LONGITUDE WHOI Ref. No. 60-26		ELEVATION same	DATUM
OBSERVED BY Longfield	MONTH & YEAR Dec. 1961	CHIEF OF TEAM	
DESCRIPTION Observations were made in the lunchroom of the building at 2424 Brannard Street occupied now by the Hall-Sears Co. (Formerly Houston Technical Laboratory and later Electro Tech International Co.). The station is approximately 5 feet from the west wall and 20 feet from the south wall of the storeroom. A standard USC and GS gravity station disk, stamped HOUSTON 1950, is set vertically in the wall of the building, 1 foot south of the north-west corner and 1 foot above ground. The gravity difference from the pendulum site to the disk is minus 0.08 milligal.			
<div style="display: flex; align-items: center;"> <div style="margin-right: 10px;"> <p>SKETCH</p> </div> </div>			

[illegible]

SURVEY STATION DESCRIPTION

COUNTRY U. S.	STATION DESIGNATION Gulf K and M 1953 P.S.	STATE OR PROVINCE Wyoming
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Gravity Base	NEAREST CITY Casper	LATITUDE 42° 57.7' N	LONGITUDE 106° 27.9' W
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STATION ELEVATION FT/MTR 418.2 Meters	ESTIMATED ACCURACY± Unknown
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SOURCE OF INFORMATION FOR :

LATITUDE & LONGITUDE 26. II-148	WHOI Ref. No. 60-	ELEVATION same	DATUM
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OBSERVED BY Longfield	MONTH & YEAR Oct. 1961	CHIEF OF TEAM
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DESCRIPTION Observations were made at the Gulf K and M 1953 pendulum station located at the Natrona County Airport on the floor of the red brick pumping building next to the reservoir, in the northwest corner of the building. The building, No. 950, is approximately 0.7 miles southeast of the Administration Building.

SKETCH

SURVEY STATION DESCRIPTION			
COUNTRY U. S.	STATION DESIGNATION Cheyenne Municipal A.P.	STATE OR PROVINCE Wyoming	
Gravity Base	NEAREST CITY In Cheyenne	LATITUDE 41° 9.5' N	LONGITUDE 104° 48.5' W
STATION ELEVATION FT/MTR 6156 Feet		ESTIMATED ACCURACY ± Unknown	
SOURCE OF INFORMATION FOR :			
LATITUDE & LONGITUDE WHOI Ref. No. 60-26. Table III-A-3		ELEVATION same	DATUM
OBSERVED BY Longfield	MONTH & YEAR Oct. 1961	CHIEF OF TEAM	
DESCRIPTION Observations were made just inside the gate separating the parking lot and the old terminal (approximately 200 yards west of the new terminal) which is now used as an office building. The parking lot north of the gate and old terminal was formerly the aircraft parking ramp.			
SKETCH			

SURVEY STATION DESCRIPTION			
COUNTRY U. S.	STATION DESIGNATION Gulf K and M 1953 P.S.	STATE OR PROVINCE Wyoming	
Gravity Base	NEAREST CITY In Cheyenne	LATITUDE 41° 10.2' N	LONGITUDE 104° 48.6' W
STATION ELEVATION FT/MTR 1878.5 Meters		ESTIMATED ACCURACY ± Unknown	
SOURCE OF INFORMATION FOR :			
LATITUDE & LONGITUDE WHOI Ref. No. 60-26, II-149 Appendix II-1		ELEVATION same	DATUM
OBSERVED BY Longfield	MONTH & YEAR Oct. 1961	CHIEF OF TEAM	
DESCRIPTION Observations were made at the east door of the "Street-Alley Weld Shop", (formerly a cafe, and later a recreation hall) located 100 feet south-west of the old Administration Building. The east door of the "Street-Alley Weld Shop" is apparently at the same elevation as the Gulf K and M 1953 pendulum station which is 25 feet west (inside the building) of this gravimeter site. The tie to the pendulum station could not be made at the time of this gravimeter observation.			
SKETCH 			

SURVEY STATION DESCRIPTION			
COUNTRY U. S.	STATION DESIGNATION Gulf K and M 1953 P.S.		STATE OR PROVINCE Wyoming
Gravity Base	NEAREST CITY Sheridan	LATITUDE 44° 46.3' N	LONGITUDE 106° 58.1' W
STATION ELEVATION FT/MTR 1225.9 Meters		ESTIMATED ACCURACY± Unknown	
SOURCE OF INFORMATION FOR :			
LATITUDE & LONGITUDE WHOI Ref. No. 60- 26. II-147		ELEVATION same	DATUM
OBSERVED BY Longfield	MONTH & YEAR Oct. 1961	CHIEF OF TEAM	
DESCRIPTION Observations were made at the Gulf 1953 K and M pendulum station located in a storeroom on the northwest side of the smaller of 2 hangars at the Sheridan Municipal Airport, 4 feet from the northwest (outside) wall and 50 feet southwest of the northwest corner of the hangar building. The hangar is about 300 feet southeast of the Administration Building. The floor level is about 1 foot above field elevation.			
SKETCH			

SURVEY STATION DESCRIPTION			
COUNTRY Canada	STATION DESIGNATION Gulf K and M 1953 P.S.	STATE OR PROVINCE Alberta	
Gravity Base	NEAREST CITY Calgary	LATITUDE 51° 06.6' N	LONGITUDE 114° 31.0' W
STATION ELEVATION FT/MTR 1083.6 Meters		ESTIMATED ACCURACY ± Unknown	
SOURCE OF INFORMATION FOR :			
LATITUDE & LONGITUDE WHOI Ref. No. 60-26, II-144		ELEVATION same	DATUM
OBSERVED BY Longfield	MONTH & YEAR Oct. 1961	CHIEF OF TEAM	
DESCRIPTION Observations were made in the one-story transformer and auxiliary electric generator building at the Calgary Municipal Airport about 2 miles north of the city. The building is 200 feet south of the south corner of the Chinook Flying Service Ltd. hangar or about 400 feet south of the control tower. The floor level is about 1 foot above the elevation of the runway.			
The station is on the opposite side of the runway from the new terminal building, a distance of approximately 0.6 mile.			
<div style="display: flex; justify-content: space-between; align-items: flex-start;"> <div style="width: 15%;"> <p>SKETCH</p> </div> </div>			

SURVEY STATION DESCRIPTION			
COUNTRY Canada	STATION DESIGNATION Edmonton Intl. A.P.	STATE OR PROVINCE Alberta	
Gravity Base	NEAREST CITY Edmonton	LATITUDE 53° 19.0' N	LONGITUDE 113° 34.9' W
STATION ELEVATION FT/MTR 2373 feet		ESTIMATED ACCURACY±	
SOURCE OF INFORMATION FOR :			
LATITUDE & LONGITUDE WAG		ELEVATION Air force Flight Info Pub.	DATUM
OBSERVED BY Longfield	MONTH & YEAR Nov. 1961	CHIEF OF TEAM	
DESCRIPTION Observations were made about 50 feet southeast of Gates 1, 2, and 3 leading to planes in the corridor on the right as you face Gates 1, 2, and 3, midway between doors leading to mens and ladies restrooms.			
This terminal is temporary and will be a maintenance hangar in the future. The airport is called Jubilee International Airport and is located south of Edmonton.			
SKETCH			

SURVEY STATION DESCRIPTION

COUNTRY Canada		STATION DESIGNATION Edmonton Municipal A.P.		STATE OR PROVINCE Alberta	
Gravity Base		NEAREST CITY In Edmonton	LATITUDE 53° 34.4' N		LONGITUDE 113° 31.8' W
STATION ELEVATION FT/MTR 2185 Feet		ESTIMATED ACCURACY± Unknown			
SOURCE OF INFORMATION FOR :					
LATITUDE & LONGITUDE WHOI Ref. No. 60-26. Table III-A-3			ELEVATION same		DATUM
OBSERVED BY Longfield		MONTH & YEAR Oct. 1961		CHIEF OF TEAM	
DESCRIPTION Observations were made at the Canadian Pacific Airlines counter, in the northwest corner of the terminal, about 30 feet west of the doors leading to planes and 20 feet south of the north wall. There is an inlaid design in the center of the terminal floor. The terminal is on the north edge of Edmonton.					

SKETCH

SURVEY STATION DESCRIPTION			
COUNTRY Canada	STATION DESIGNATION Gulf K and M 1953 P.S.	STATE OR PROVINCE Alberta	
Gravity Base	NEAREST CITY In Edmonton	LATITUDE 53° 31.3' N	LONGITUDE 113° 31.3' W
STATION ELEVATION FT/MTR 669.6 Meters		ESTIMATED ACCURACY ± Unknown	
SOURCE OF INFORMATION FOR :			
LATITUDE & LONGITUDE WHOI Ref. No. 60-26. II-143		ELEVATION same	DATUM
OBSERVED BY Longfield	MONTH & YEAR Oct. 1961	CHIEF OF TEAM	
DESCRIPTION Observations were made in basement Room 1 of the Arts Building on the campus of the University of Alberta. The station is 2 feet south of the north wall of the room and midway along the same wall. The Women's Staff Lounge is just south of Room 1. There has been extensive remodeling of this section of the Arts Building since 1953. The marker has been covered by linoleum, but the site was located with the aid of Dr. George Garland of the University of Alberta. The University of Alberta is in South Edmonton at 89th and 112th Streets.			
SKETCH <p style="text-align: center; margin-top: 20px;">WOMEN'S STAFF LOUNGE</p>			

SURVEY STATION DESCRIPTION

COUNTRY Canada		STATION DESIGNATION Ft. Nelson Municipal A.P.		STATE OR PROVINCE British Columbia	
GRAVITY BASE Gravity Base		NEAREST CITY Ft. Nelson		LATITUDE 58° 50.5' N	
STATION ELEVATION FT/MTR 1247 Feet		ESTIMATED ACCURACY ± Unknown			
SOURCE OF INFORMATION FOR :					
LATITUDE & LONGITUDE WHOI Ref. No. 60-26, Table III-A-3			ELEVATION same		DATUM
OBSERVED BY Longfield		MONTH & YEAR Nov. 1961		CHIEF OF TEAM	
DESCRIPTION Observations were made on a walkway 14 feet east of the field entrance to the terminal at Ft. Nelson Municipal Airport.					
The edge of the aircraft parking ramp is approximately 200 feet south of the gravimeter station.					

SKETCH

SURVEY STATION DESCRIPTION

COUNTRY	Canada	STATION DESIGNATION	Gulf K and M 1953 P.S.	STATE OR PROVINCE	British Columbia		
Gravity Base		NEAREST CITY	Ft. St. John	LATITUDE	56° 14.3' N	LONGITUDE	120° 44.1' W
STATION ELEVATION FT/MTR	693.1 Meters	ESTIMATED ACCURACY ±	Unknown				
SOURCE OF INFORMATION FOR :							
LATITUDE & LONGITUDE	WHOI Ref. No. 60- 26. II-142	ELEVATION	same		DATUM		
OBSERVED BY	Longfield	MONTH & YEAR	Oct. 1961		CHIEF OF TEAM		
DESCRIPTION	Observations were made in a storeroom located in the northeast corner of the basement of the Department of Transport Airport terminal building, 3 miles east of town. The station is in the center room of three on the left as you walk east through the basement corridor.						

SKETCH

PARKING

SKETCH

SURVEY STATION DESCRIPTION			
COUNTRY Canada	STATION DESIGNATION Gulf K and M 1953 P.S.	STATE OR PROVINCE Alberta	
Gravity Base	NEAREST CITY In Lethbridge	LATITUDE 49° 41.4' N	LONGITUDE 112° 50.2' W
STATION ELEVATION FT/MTR 905.6 meters		ESTIMATED ACCURACY ±	
SOURCE OF INFORMATION FOR :			
LATITUDE & LONGITUDE WHOI Ref. 60-26		ELEVATION Same	DATUM
OBSERVED BY Longfield	MONTH & YEAR Oct. 1961	CHIEF OF TEAM	
DESCRIPTION Observations were made in the basement of the new Lethbridge Post Office at 4th Ave. and 7th St. in a room 30 feet northwest of the elevator shaft. This station has a Dominion Observatory Reference Disk installed in the floor 2 feet from the north wall and 5 feet from the west wall of the room.			
SKETCH			

SURVEY STATION DESCRIPTION			
COUNTRY Canada	STATION DESIGNATION Gulf K and M 1953 P.S.	STATE OR PROVINCE Alberta	
Gravity Base	NEAREST CITY In Red Deer	LATITUDE 52° 16.1' N	LONGITUDE 113° 48.8' W
STATION ELEVATION FT/MTR 856-2 METERS		ESTIMATED ACCURACY ±	
SOURCE OF INFORMATION FOR :			
LATITUDE & LONGITUDE WHOL REF NO 60-26 II-143		ELEVATION Same	DATUM
OBSERVED BY Longfield	MONTH & YEAR Oct. 1961	CHIEF OF TEAM	
DESCRIPTION Observations were made in the furnace room on the east side of the basement of the new Red Deer Post Office Building. The floor of the room is about 8 feet below outside ground level. The station is about 5 feet west of the east wall and midway between the north and south walls of the furnace room.			
SKETCH <div style="text-align: center; margin-top: 50px;"> </div>			

SURVEY STATION DESCRIPTION

COUNTRY	Canada	STATION DESIGNATION	Whitehorse A.P.	STATE OR PROVINCE	Yukon Territory
Gravity Base	NEAREST CITY	Whitehorse	LATITUDE	60° 42.0' N	LONGITUDE 135° 5.0' W
STATION ELEVATION FT/MTR	2297 Feet	ESTIMATED ACCURACY± Unknown			
SOURCE OF INFORMATION FOR :					
LATITUDE & LONGITUDE WHOI Ref. No. 60-26. Table III-A-3	ELEVATION same	DATUM			
OBSERVED BY	MONTH & YEAR	CHIEF OF TEAM			
Longfield	Nov. 1961				
DESCRIPTION	Observations were made at the Pan American Airlines Counter next to radiator in the southwest corner of the terminal building, just south of the exit to planes. The 1961 Pendulum station is across the field and northwest of this gravimeter station.				

SKETCH

SKETCH

SURVEY STATION DESCRIPTION

COUNTRY	Mexico	STATION DESIGNATION	Aero puerto (Aeronaves de Mexico)	STATE OR PROVINCE	San Luis Potosi
Gravity Base		NEAREST CITY	San Luis Potosi	LATITUDE	22° 11.7' N
				LONGITUDE	100° 59.6' W
STATION ELEVATION FT/MTR	6158 feet	ESTIMATED ACCURACY±	10 feet		
SOURCE OF INFORMATION FOR :					
LATITUDE & LONGITUDE	WAC	ELEVATION	Same		DATUM
OBSERVED BY	Longfield	MONTH & YEAR	Dec. 1961		
CHIEF OF TEAM					
DESCRIPTION	Observations were made at the streetside entrance of the terminal on a concrete walkway approximately 50 feet north of a flagpole and dedication plaque. A gravity marker stamped "INSTITUTO DE GEOFISICA U.N.A.M. ESTACION, +" is to be installed by Ing. Julio Monges C. of the University of Mexico.				
This station is approximately 1/4 mile northwest of the old "Lamsa" Airport station.					

SKETCH

TABLE 3

LOCAL EXCENTER GRAVITY TIES TO PENDULUM BASES

Table 3

Local Connections to Pendulum Stations
on the North American Standardization Range

Point Barrow, Alaska

Gulf M 1961, Arctic Research Laboratory
furnace room Building 250-251. 982.6998

- (a) Gulf M 1958, Arctic Research Laboratory
Carpenter Shop, Building 353. -0.2
(a) = 982.6996

Fairbanks, Alaska

Gulf M 1961, Cambridge 1953, Geophysical Institute
telephone terminal room. 982.2462

- (a) Gulf K & M 1953, M 1958, Fort Wainwright
(Formerly Ladd AFB) Building 1157. -1.8
(b) Fairbanks Airport at East "I" Beam. +0.3
(a) = 982.2444
(b) = 982.2465

Whitehorse, Yukon Territory

Gulf M 1961, in the "Equipment Room" of "A" Hangar. 981.7501

- (a) Gulf K & M 1953, in Department of
Transport Pumphouse. -1.5
(b) Whitehorse Airport Terminal at P.A.A.
Desk, next to Radiator -1.4
(a) = 981.7486
(b) = 981.7487

Edmonton, Alberta

Gulf M 1961, Geophysics Laboratory in the new
Physics-Mathematics Building. 981.1676

- (a) Gulf K & M 1953, Basement of Arts
Building. +0.1
(b) Municipal Airport Terminal Building at
C.P.A. counter. +5.3
(c) Jubilee International Airport in concourse
leading to aircraft parking ramp at wall
between Mens' and Womens' rest-rooms. -33.6
(a) = 981.1677
(b) = 981.1729
(c) = 981.1340

Table 3 (cont.)

Great Falls, Montana

Gulf K & M 1953, M 1961 Roosevelt School. 980.5270

(a) Airport Terminal Building at Western
Airlines desk. -13.3

(b) Malmstrom AFB at ladder to control tower,
Base Operations. +2.2

(a) = 980.5137

(b) = 980.5292

Denver, Colorado

Gulf M 1961, basement, Science Hall. 979.6123

(a) Gulf K & M 1953, Chamberlin Observatory.
-0.6

(b) Science Hall Gravimeter Auxiliary Station
rear door to basement. 0.0

(c) Gate 2, Stapleton Air Field. +21.2

(a) = 979.6117

(b) = 979.6123

(c) = 979.6335

Houston, Texas

Gulf M 1961, Rice University. 979.2984

(a) Gulf K & M 1953, M 1954, Hall-Sears
Building. 0.0

(b) Houston Airport, Gate 7. -5.1

(a) = 979.2984

(b) = 979.2933

Monterrey, Nuevo Leon

Gulf K & M 1953, M 1961 Instituto Tecnologico
Automobile Shop. 978.8053

(a) Monterrey Airport, 20 feet north of
Customs, field side. +56.4

(a) = 978.8617

Table 3 (cont.)

San Luis Potosi, San Luis Potosi

Gulf M 1961, Instituto Cientifico. 978.2099

(a) Old "Lamsa" Airport. -0.4

(b) New "Aeronaves" Airport. -0.3

(a) = 978.2095

(b) = 978.2096

Mexico D. F., Mexico

Gulf K & M 1953, M 1958, M 1961 University Pier. 977.9414

(a) University floor. +0.1

(b) Mexico City International Airport. +28.8

(c) Paso de Cortes, T. V. relay station.
-370.3

(a) = 977.9415

(b) = 977.9702

(c) = 977.5711

The University of Wisconsin group was accompanied by Ing. Julio Monges of the University of Mexico while making the connections to the Mexico City Airport and Paso de Cortes. Ing. Monges observed with La Coste-Romberg G-11, an Army MAP Service instrument. Below are his results.

Mexico D.F., Mexico

Gulf K & M 1953, M 1961 University Pier. 977.9416

(a) Mexico City International Airport. +28.8

(b) Paso de Cortes T. V. relay station. -370.3

(a) = 977.9704

(b) = 977.5713

TABLE 4

DESCRIPTIONS OF GRAVIMETER BASES ON EAST COAST

GRAVITY STATION DESCRIPTION

COUNTRY USA		STATION DESIGNATION Cocoa R.R. Gravity Station, Florida		STATE OR PROVINCE Florida	
☐ REFERENCE ☐ DETAIL		NEAREST CITY Cocoa	LATITUDE 80° 44' 0" N	LONGITUDE 28° 21' 15" W	
STATION ELEVATION FT/MTR 25 ft.			PROBABLE ACCURACY		
SOURCE OF INFORMATION FOR:					
LATITUDE & LONGITUDE WAC Sectional			ELEVATION USGS Bull 274		
OBSERVED BY Longfield		MONTH & YEAR May, 1962	CHIEF OF TEAM		
DESCRIPTION Observations were made on the asphalt at the south end of a wooden shed located approximately 50 feet north of the Cocoa-Rockledge Railroad Station.					

SKETCH

GRAVITY STATION DESCRIPTION

COUNTRY USA		STATION DESIGNATION Daytona Beach A.P.		STATE OR PROVINCE Florida	
☐ REFERENCE ☐ DETAIL		NEAREST CITY Daytona Beach		LATITUDE 29° 11.1' N	
				LONGITUDE 81° 03' 0" W	
STATION ELEVATION FT/MTR 34 feet			PROBABLE ACCURACY 10 feet		
SOURCE OF INFORMATION FOR:					
LATITUDE & LONGITUDE WHOI Ref. No. 60-26			ELEVATION Same		
OBSERVED BY Longfield		MONTH & YEAR May, 1962		CHIEF OF TEAM	
DESCRIPTION Observations were made at the Daytona Beach Municipal Airport terminal, on the terminal side of the field barrier at Gate 2, on the concrete walkway.					

SKETCH

GRAVITY STATION DESCRIPTION

COUNTRY USA	STATION DESIGNATION Jacksonville	STATE OR PROVINCE Florida
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☐ REFERENCE ☐ DETAIL	NEAREST CITY Jacksonville	LATITUDE 30° 25' 30" N	LONGITUDE 81° 39' 0" W
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STATION ELEVATION FT/MTR 52 ft.	PROBABLE ACCURACY
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SOURCE OF INFORMATION FOR:

LATITUDE & LONGITUDE WAC Sectional	ELEVATION Same
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OBSERVED BY Longfield	MONTH & YEAR May, 1962	CHIEF OF TEAM
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DESCRIPTION Observations were made in the Imerson Airport terminal building at the center of the glass wall which faces the field, on the floor.

SKETCH

GRAVITY STATION DESCRIPTION

COUNTRY USA		STATION DESIGNATION Miami International A.P.		STATE OR PROVINCE Florida	
☐ REFERENCE ☐ DETAIL		NEAREST CITY Miami	LATITUDE 25 ° 48 ' 1 " N	LONGITUDE 80 ° 17 ' 0 " N	
STATION ELEVATION FT/MTR 9 ft.			PROBABLE ACCURACY		
SOURCE OF INFORMATION FOR:					
LATITUDE & LONGITUDE USAF US Navy F.I.P.			ELEVATION Same		
OBSERVED BY Longfield		MONTH & YEAR May, 1962	CHIEF OF TEAM		
DESCRIPTION Observations were made on the sidewalk on the street side of the airport post office approximately 20' north of a flagpole and 2-1/2 feet south of the post office building. It is 30 feet east and west of the two post office entrances. The site is directly under the Number 59 in the legend "US Post Office Airport Mail Facility, Miami 59, Florida."					

SKETCH

SKETCH

GRAVITY STATION DESCRIPTION

COUNTRY USA		STATION DESIGNATION Gulf K & M 1959 P.S.		STATE OR PROVINCE Florida	
☐ REFERENCE ☐ DETAIL		NEAREST CITY Miami		LATITUDE 25 24.0 N	
				LONGITUDE 80 10.0 W	
STATION ELEVATION FT/MTR 1.5 meters			PROBABLE ACCURACY Unknown		
SOURCE OF INFORMATION FOR:					
LATITUDE & LONGITUDE WHOI Ref. No. 60-26 II-150			ELEVATION Same		
OBSERVED BY Longfield		MONTH & YEAR May, 1962		CHIEF OF TEAM	
DESCRIPTION Observations were made at the University of Miami Marine Biological Laboratory on Virginia Key, on the floor (now tile) of the office of the Business Offices. The room is in the southwest corner of the older portion of the building. The new pendulum station is approximately 100 feet west of this storm.					

SKETCH

SKETCH

GRAVITY STATION DESCRIPTION

COUNTRY U.S.A.		STATION DESIGNATION Orlando A.P.		STATE OR PROVINCE Florida	
☐ REFERENCE ☐ DETAIL		NEAREST CITY Orlando		LATITUDE 28° 32' 46" N	
				LONGITUDE 81° 20' 16" W	
STATION ELEVATION FT/MTR 110 feet			PROBABLE ACCURACY 5 feet		
SOURCE OF INFORMATION FOR:					
LATITUDE & LONGITUDE 1:24,000 Quad Sheet			ELEVATION Same		
OBSERVED BY Longfield		MONTH & YEAR May, 1962		CHIEF OF TEAM	
DESCRIPTION Observations were made at Herndon Airport on the aircraft ramp					
side of the terminal in the outside passenger waiting area at the Gate 3					
exit to aircraft, on the concrete floor at ground level.					

SKETCH

GRAVITY STATION DESCRIPTION

COUNTRY USA		STATION DESIGNATION Fairchild-St. Augustine		STATE OR PROVINCE A. P. , Florida	
☐ REFERENCE ☐ DETAIL		NEAREST CITY St. Augustine	LATITUDE 29° 57 ' N	LONGITUDE 81° 20 ' W	
STATION ELEVATION FT/MTR 10Ft.			PROBABLE ACCURACY		
SOURCE OF INFORMATION FOR:					
LATITUDE & LONGITUDE 1381st Geodetic Survey Sqn. USAF			ELEVATION Same		
OBSERVED BY Longfield		MONTH & YEAR May, 1962	CHIEF OF TEAM		
DESCRIPTION Observations were made at the Air Force, Navy and employment office building at St. Augustine Airport (formerly St. Augustine Municipal) on the concrete floor of the reception foyer near the entrance door.					

SKETCH

SKETCH

GRAVITY STATION DESCRIPTION

COUNTRY USA		STATION DESIGNATION West Palm Beach		STATE OR PROVINCE Florida	
☐ REFERENCE ☐ DETAIL		NEAREST CITY West Palm Beach	LATITUDE 26° 41.2' N	LONGITUDE 80° 05.5' W	
STATION ELEVATION FT/MTR 15 feet			PROBABLE ACCURACY 10 feet		
SOURCE OF INFORMATION FOR:					
LATITUDE & LONGITUDE WHOI Ref. 60-26			ELEVATION Same		
OBSERVED BY Longfield		MONTH & YEAR May, 1962	CHIEF OF TEAM		
DESCRIPTION Observations were made at the north (outside) corner of the Palm Beach International Airport terminal, on the asphalt at the terminal side of Gate 2, against the barrier.					

SKETCH

SKETCH

SKETCH

GRAVITY STATION DESCRIPTION

[illegible]

SKETCH

GRAVITY STATION DESCRIPTION			
COUNTRY USA	STATION DESIGNATION Bureau of Standards Aux. Station	STATE OR PROVINCE Washington D. C.	
☐ REFERENCE ☐ DETAIL	NEAREST CITY Washington D. C.	LATITUDE 38 ° 56.5' N	LONGITUDE 77 ° 03.9' W
STATION ELEVATION FT/MTR 103.3 meters		PROBABLE ACCURACY	
SOURCE OF INFORMATION FOR:			
LATITUDE & LONGITUDE WHOI. Ref. No. 60-26 II-148		ELEVATION Extrapolation by gravity diff. from Abs. site	
OBSERVED BY Longfield	MONTH & YEAR May, 1962	CHIEF OF TEAM	
DESCRIPTION Observations were made at street level to the south of four steps leading up to the west entrance of the National Bureau of Standards "East Bldg".			
SKETCH			
<div style="position: relative; width: 100%; height: 100%;"> <div style="position: absolute; top: 10%; left: 40%; font-weight: bold;">EAST BUILDING</div> <div style="position: absolute; top: 55%; right: 10%; transform: rotate(90deg); font-weight: bold;">PARKING</div> <div style="position: absolute; top: 65%; left: 15%;"> <div style="text-align: center;"> GRAVITY STATION </div> <div style="position: absolute; top: 10px; left: 10px;"> </div> </div> </div>