60-26

Copy 2

AFCRL-TR-60-406
AD 250 567

WOODS HOLE OCEANOGRAPHIC INSTITUTION

Reference No. 60-26

Final Report

on

Gravity Program

WOODS HOLE, MASSACHUSETTS

Woods Hole Oceanographic Institution

Woods Hole, Massachusetts

Reference No. 60-26

Final Report on

Gravity Program

by

G. P. Woollard and J. C. Rose

FINAL REPORT

Work carried out under Contract AF19(604)2157
with the Geophysics Research Directorate
Air Force Cambridge Research Center
Air Research and Development Command

July 1960

APPROVED FOR DISTRIBUTION

Paul M. Fye, Director

PREFACE

The report presented is the final one under Air Force Cambridge Research Center Contract 19(604)-2157 with the Woods Hole Oceanographic Institution. The report covers a program of pendulum and gravimeter measurements conducted over the period 1950-1959.

The original objective of the program was to establish a series of reliable gravity control measurements through the use of pendulums over a sufficient range of gravity to permit the calibration of geodetic gravimeters with an accuracy of one part in 5000 over a range of 5000 mgals and thus assure a potential accuracy of 1 mgal or better with such gravimeters on any global series of measurements. With time this objective was modified to include the establishment of pendulum gravity measurements outside of North America as there appeared to be no unanimity of international opinion regarding a gravity standard.

A second objective of the program was to expand the gravity coverage and standardize existing gravity surveys within the United States so that reliable gravity anomaly maps could be prepared.

A third objective was to strengthen and expand the world network of airport gravity bases established earlier under the auspices of the Office of Naval Research so that data in all parts of the world could be integrated onto the same datum and gravity standard.

The report is subdivided on the basis of these objectives into three principal parts plus an introductory chapter giving the history of the program, and a final chapter presenting recommendations as to further work deemed desirable.

Dr. J. C. Rose, who has been in charge of the pendulum program since its inception, prepared the second portion of the report, which deals with the pendulum measurements, and the writer prepared the remainder.

G. P. Woollard
June 30, 1960

ACKNOWLEDGMENTS

To acknowledge the assistance and many courtesies extended by various individuals, institutions and governmental agencies over the past ten years in carrying out the pendulum and gravimeter programs covered by this report would read like a catalogue of international scientists and institutions. To present such an extensive list of all those who contributed so generously of their time and efforts to make this study as effective as possible would, because of its very length, defeat the purpose of the writers in acknowledging their appreciation for all of the help received. Therefore, the writers hope that no one will feel slighted or take umbrage at not having specific mention made of his individual contribution to the program.

The writers, however, do want to stress that the help of each and every person as well as the many institutions who cooperated was invaluable, and that without this help much of the work reported would not have been possible, and certainly in many cases the quality of the results would also have suffered.

In addition to the help of third parties, the writers are particularly indebted to the many individuals who as students at the University of Wisconsin participated at one time or another in the program as field observers. A list of these men, who did a major part of the field work and who should be identified with the program in addition to the writers are:

Pendulum Program

Wayne Ault (Columbia University)
W. E. Bonini
E. C. Carlson
R. M. Iverson
K. Koenen
R. P. Meyer
N. A. Ostenso
J. S. Steinhart
O. Strickholm
J. Watkins

Gravimeter Program

B. B. Adams
J. C. Behrendt
W. A. Black
W. E. Bonini
N. C. Harding
R. M. Iverson
T. S. Laudon
J. W. Mack
C. Muckenfuss
P. Moors
N. A. Ostenso

R. Pemberton
D. Plouff
J. Schallock
W. Sonntag
J. S. Sparkman
J. S. Sumner
E. C. Thiel
J. Weinman
P. Wolfe
M. Woollard

Acknowledgments (Cont'd)

Of equal importance to the program was the staff of people who assisted on the computations. In the early stages of the program there were Harriet Hayward and Phoebe Black né Pierce, but since 1955 the reductions and IBM programming has been entirely under the direction of Delia Lavin. It has been the unhappy lot of Mrs. Lavin to have to adjust all of the previous work twice for changes in calibration standard as well as take care of current results and the adjustment of oil company and other data. If any one of our group could be described as indispensable, she would certainly qualify.

Finally, the writers want to acknowledge the assistance of Alice Nilsson, who over the years has taken care of the "paper work", an aspect of the program which at times has assumed formidable proportions, as in the preparation of the present report. Without her and the able assistance of the various typists and draughtsmen, Mary Kirk, Miriam Galitz, Arden Scott and Dave Johnson, this report would never have been completed.

TABLE OF CONTENTS

PREFACE

PART I. Introduction and Development of Program.

PART II. Pendulum Program.

Part 2. Appendix of Tables.

PART III. Gravimeter Program.

Part 2. Appendix of Tables

PART IV. Cooperative Programs with other Groups of Observers.

1. Cambridge University in Africa.
2. Cambridge University in South America.
3. Cambridge University in Pacific Area.
4. Institute of Geophysics, University of Mexico.
5. California Exploration Company

Part 2. Appendix of Tables.

PART V. Conclusion and Recommendations.

PART I

Introduction and Development of Program

ERRATA SHEETS
FOR
AIR FORCE REPORT NO. AFCRL-TR-60-406

Page

Errata For Section I

- 1 Under Departure from Average change -6.3 to -3.7
- 10 Lisbon; column 3; line 7: Change -0.8 to -1.2
Fairbanks (Univ); column 2; line 9: Change .3462 to .2462

Errata For Section II

Note: No corrections were made in the text and tables for small errors in the pendulum gravity computations on the order of 0.1 mgal involving entire tables of weighted means.

- ii Paragraph 3; line 9: Change sties to sites
- 13 Line 1: Insert square-root sign over I/mgI
- 31 Table II-6; line 23: Change .7579 .7578 657.2
to .7589 .7588 658.2
- 35 Figure II-13: Change ICAIRO to CAIRO
- 37 Table II-11; Asmara: Change .8193 2549.9
to .8203 2548.9
- 50 Paragraph 1; line 13: Change 12.90 to 12.09
- 64 Equation (23): Change $2\Delta t$ to $4\Delta t$
- 73 Table II-27; line 7: Change .0353¹ to 979.0353¹
- 88 Table II-34; Copenhagen: Change +362.12 to +361.81
- 89 Table II-35: Change $+\bar{s}^2$ to $\bar{s}^2$
- 90 Table II-37; line 2; column 4: Delete -452.00
line 3; " ": Insert -452.07
line 6; " ": Delete -2892.97
line 7; " ": Insert -2892.97
- 102 Table II-52; line 4: Change 451.26 1.000 1.00 (assumed)
to 451.58 0.098 10.20
line 6: Change 33.33 to 42.53
- 105 Table II-53; line Ottawa: Insert II-47 after Table
line Lethbridge: Change 638.8 to 639.8

Errata For Section II (cont'd)

Page

- 106 Table II-53; line Madison: Insert II-45 after Table
line Lamont Obs: Change 0.0086 to 0.0095
116.27 to 105.26
- 107 Table II-53; line Charleston: Change -567.2 -568.03
0.927 to 0.345
1.08 2.90
- 111 Table II-54; Ottawa: Insert II-47 after Table
Lethbridge: Change 638.8 to 639.8
" 639.37 to 639.70
" mean column to read 640.18
0.47
0.220
- 112 Table II-54; Madison: Insert II-46 after Table
- 113 Table II-54; San Francisco: Change $\bar{s}$ 0.18 to 0.23
" v.m. 0.032 to 0.054
Tulsa : Change -353.39 to -353.90
- 117 Table II-56; Punta Arenas: Change 1149.9 to 1194.9
- 124 Table II-59; Station: Change 52CB to 49CB
Oslo : Change 730.53 730.81
(0.500) to 0.098
(2.00) 10.20
- 124 Table II-59; Edinburgh: Change 387.13 387.31
(0.500) to 0.098
(2.00) 10.20
Copenhagen: Change 362.47 362.30
(0.500) to 0.098
(2.00) 10.20
Bad Harzburg: Insert II-51 after Table
Paris : Change -255.57 -255.67
(0.500) to 0.098
(2.00) 10.20
Munich : Insert II-52 after Table
Edinburgh : Change CB 387.25 387.30
CB (0.500) to 0.248
CB (2.00) 4.03
Copenhagen : Change 361.89 to 361.57
- 125 Table II-60; Oslo: Change DGJF column to read

731.12 58 $\overline{-12}$
.15
0.12 58 $\overline{-34}$
.85
730.81 4

Errata For Section II (cont'd)

Page

125 Table II-60; Edinburgh: Change DGJF column to read

387.21 58 $\overline{-12}$

.71

.09 58 $\overline{-34}$

.21

381.37 4

Change All Mean column 387.19 to 387.30

" v.m. 0.0036 to 0.012

Copenhagen: Change DGJF column to read

363.09 58 $\overline{-12}$

2.95

1.55 58 $\overline{-34}$

.61

362.30 4

Change All Mean 361.83 to 361.97

125 Table II-60; Paris: Change DGJF column to read

-254.79 58 $\overline{-12}$

5.60

6.27 58 $\overline{-34}$

.01

-255.67 4

Munich: Change DGJF column to read

-451.49 58 $\overline{-12}$

.15

.71 58 $\overline{-34}$

.96

-451.58 4

Oslo: Change Cambridge column to read 730.68

.70

.39

1.22

.08

.20

730.88

127 Table II-61; Asmara: Change -3377.5 to -3376.5

129 Table II-62; Asmara: Change -3377.51 to -3376.51

130 Table II-63; Point Barrow: Change 2850.56 to 2580.56

Laredo : Change .07977 to .07985

Miami : Change .03502 to .03520

Key West : Change 978.9682⁸ to 978.9686⁹

132 Table II-64; La Paz: Change .4665¹ to read 977.4665¹

133 Table II-66; Edinburgh: Line should read
+387.31 .26 0.070 .5835¹
Copenhagen: Line should read
+361.70 .14 0.020 .5579⁰
Under Data Used column, delete 1952 Cambridge (Bullenwell)
Table II-67; Asmara: Change -3377.51 .8186⁹
to -3376.51 .8196⁹

134 Table II-68; Column headings: Change all +s to +̄s
Beloit : Change Weighted Mean Gulf from 979.9977
to 979.9979

135 Table II-68-cont.; Tulsa: Last column change .7653 to .7648
Key West: Change 978.9683 .9683
to 978.9687 .9686
Monterrey: Change .8051 to .8049
Mexico, D.F.: Change .9420 to .9418

136 Table II-69; La Paz: Insert 977 in first column

137 Table II-70; Christchurch: Under Simple Means under Gulf insert .5083
Under +̄s for Gulf insert .23
Chitose AFB : Under Simple Means under Gulf insert .4410
Under +̄s for Gulf insert (.47)
Honolulu : Insert 978 in first column

138 Table II-71; Oslo : Change column DGJF to .9270
Edinburgh : Change column DGJF to .5835
Copenhagen : Change column DGJF to .5585
Munich : Change column DGJF to .7446
Tripoli : Insert 979 in first column

139 Table II-72; Salisbury: Under Camb change .1482 to .1480
Asmara : Change .8187 to .8197

140 Table II-73; Darwin: Change -2882.0 to -2881.7
Washington: Change -1149.6 to -1149.9
Mowbray : Change -1121.3 to -1621.3
Johannesburg: Change -2119.2 -1118.8
to -2719.2 -2718.8

144 Ottawa; line 1: Change 1952-3 to 1952-4

145 Great Falls; line 4: Change 3rd Ave. W to 3rd Ave. N.
" 24th St. W. to 24th St. N.

154 Bogota; Title: Change Bogata to Bogota
line 1: Change Bodaga to Bodega

Errata For Section II (cont'd)

Page

154 Bogota; line 4: Change Bogata to Bogota

155 Ross Island; line 3: Change 12.9 to 12.09

160 Paris; line 2: Change Bretenil to Breteuil

170 Ref. 6: Change Mounet to Monnet
After Ref. 3 insert:

Browne, B. C., Cook, A. H., McCarthy, E. J. and Parsnis, D. S.,
Gravity measurements at York, Newcastle - Upon - Tyne, Edin-
burgh and Aberdeen, M.N.R.A.S., Geophys. Supp., Vol. 6, No. 2,
91-108, 1950

172 Ref. 1: Change vorlänfige to vorläufige

Ref. 2: Change Schweregrunduetz to Schwergrundnetz

Ref. 4: Should readEuropa, Estratto da: La Ricerce
Scientifica, Anno 28^o,

173 Ref. 9: Add (unpublished) at end

PART I

Introduction and Development of Program

In 1946 Morelli published a report on the uncertainty of the values of gravity at the international gravity reference stations. In this report Morelli attempted to redefine the values for the various international bases by giving differential weights to the observations made by different observers. This study focused attention on the fact that there were few gravity base values that could be regarded as having an accuracy of 1 mgal and that at least in one case the uncertainty was of the order of 25 mgals. In 1948, Hirvonen made a similar independent evaluation of the international network of base values. His results did not agree in detail with those of Morelli because of (a) the difference in weights the two attached to the same sets of observations, and (b) a difference in the mathematical handling of the data. The disagreement obtained by these two investigators for what can be regarded as a well established international gravity base can be illustrated by the data for Copenhagen, which on four different occasions had been tied directly to Potsdam with pendulums.

Year	Observer	Value at Copenhagen	Departure from Av.
1930	Schmehl	981.5556 <i>ENA.</i>	-6.3 mgals
1930	Andersen	981.5621	+2.8
1935	Andersen	981.5606	+1.3
1935	Brockamp	981.5577	-1.6
	Average	981.5593	

Year	Adjusted Values
1946	Morelli 981.5584
1948	Hirvonen 981.5575
1948	Hirvonen's evaluation using Morelli's weighted values 981.5586

If two investigators as competent as Morelli and Hirvonen could not agree on how to weight and average four gravity connections between two points made with first order equipment to better than one mgal, it appeared obvious that there was a need (a) for more precise gravity observations, and (b) a more objective method of handling the data and checking the international gravity base network.

Development of instrumentation for direct evaluation of world gravity network:

Prior to the above studies by Morelli and Hirvonen, the senior author, on the basis of war-time studies of factors limiting the accuracy of long range triangulation systems, and an evaluation of the accuracy of the pendulum network of the Coast and Geodetic Survey in the United States using a high range Humble X gravimeter, had entered into negotiations with the LaCoste-Romberg Company in 1945 to build a precision high range gravity meter suitable for geodetic work. One of the capabilities specified was that the instrument have sufficient range to tie all of the world's gravity bases together into a unified network with a precision of better than 0.5 mgals.

This appeared feasible on the basis of the writer's experience in using a high range Humble gravity meter to establish a series of gravity measurements at 10-mile intervals across the North American continent in 1940, and in establishing a network of stations over the Appalachian Mountains and eastern seaboard area from Newfoundland to the Gulf of Mexico in 1941. Although the instrumentation was regarded as feasible by the LaCoste-Romberg Company, other considerations, in part of a financial nature and in part related to how the instrument was to be used, led to negotiations breaking down. It was not until the fall of 1947 that the senior author found another gravity apparatus manufacturer (S. P. Worden) willing to undertake building a suitable instrument. Mr. Worden, on the basis of "no pay if it doesn't work", built the first of such instruments in 1948. Although quite a few other Worden geodetic gravimeters have been built subsequently, until the advent of the LaCoste-Romberg geodetic gravimeter in 1957, the original instrument was still the only one with sufficient range to read anywhere in the world. It was the Worden geodetic gravimeter that made it possible to carry out the first objective evaluation of the world's gravity control network. The use of this instrument, however, was not without its problems. The principal one recognized at the beginning was the establishment of the calibration and linearity of the instrument. In the first tests which were carried out in the United States, the pendulum bases of the United States Coast and Geodetic Survey along the Atlantic Coast were used as a standard. These bases were chosen because, on the basis of the earlier studies with the Humble X gravimeter, they appeared to have an accuracy of ± 1 mgal. Closed loops using Navy logistics air support were then run to points as far away as Panama and Guam to establish the drift and closure reliability. On the basis of these tests it was evident that here was an instrument for resolving which of the various gravity ties made previously with pendulums between the international gravity bases could be regarded as reliable and which should be totally rejected.

First operational tests:

On the first operational test, which was made under the auspices of the Office of Naval Research and which involved a loop around the world, the total closure error after taking out drift as evaluated on the ground and projected from station to station, was only 0.6 mgal. However, the calibration used did not give results in agreement with those in use for the national bases occupied, or those derived by Morelli and Hirvonen. The calibration was therefore adjusted to give the best fit to Morelli's and Hirvonen's adjusted values for the national gravity bases at Washington, London, Paris, Copenhagen, Stockholm, Helsinki, DeBilt, Rome, and Tokyo. As the total change in gravity between these points is less than 2000 mgals, and the average disagreement between Hirvonen and Morelli as to the value at each was about 1.0 mgal with no guarantee that either was correct, the resulting calibration resulted in values having an accuracy no better than 1 mgal for 1000 mgals change in gravity.

It was also found that the instrument's coarse spring reading dial screw was subject to systematic errors related to non-uniformity in the pitch of the threads and also irregularities in the graduations on the reading dial. By 1949 it also became obvious that the calibration was

subject to change with time, and possibly also to temperature. However, the biggest temperature effect appeared to be that of temperature gradient on the drift rate, particularly at certain temperature levels, and jumps in readings when the instrument was subject to sudden changes in ambient temperature of 50°F or more. Although it appeared possible to determine the idiosyncrasies of the instrument and operate at a constant temperature through the use of a thermostatically controlled heating jacket, the problem of an adequate calibration for world studies did not appear to be resolvable with existing facilities.

A first priority requirement therefore was the establishment of a gravity standardization range that would permit (a) an overall evaluation of the calibration and linearity of a gravimeter and (b) the response for small changes in gravity to be evaluated.

The gravity standardization program:

Comparisons with the Worden gravimeter against gravity intervals established with different sets of pendulum apparatus in different parts of the world indicated that the pendulums of Cambridge University in England came the closest to providing data of the requisite accuracy. In any one area values established with these pendulums appeared to be good to ± 0.4 mgal. By way of contrast, the Brown pendulum apparatus of the United States Coast and Geodetic Survey and the submarine pendulum apparatus of Vening Meinesz did not appear to have an accuracy greater than ± 3 to 5 mgals although there were some series of observations made in a single season by the United States Coast and Geodetic Survey with the Brown apparatus which appeared to be good to ± 1.0 mgal. On an interim basis the measurements made with Cambridge pendulums in England, Australia, New Zealand and Africa were adopted as a calibration standard. The range of measurements, however, was restricted in latitude and there were apparent datum discrepancies between the British, African and Australian series of measurements. Another set of pendulum observations, which were evaluated in a limited way in the United States, were those of the Gulf Research and Development Company. These appeared to be equal to the Cambridge pendulums in reliability, and in oil exploration work they had a history of being accurate to ± 0.2 mgal. One set of these pendulums (Set "C") had been released to Professor Maurice Ewing in 1938 for scientific studies, and in 1950 arrangements were made with Professor Ewing to borrow these pendulums for testing their use in establishing a gravity standardization range. The program proposed involved a series of observations at intervals of about 150 mgals between Mexico City and Fairbanks, Alaska following the principal air traffic lanes with auxiliary sites at each airport so that a gravimeter could be taken on commercial airlines over the whole range with a full complement of observations in a period not exceeding a week to ten days. This program was submitted for support to Air Force Cambridge Research Center and a contract was obtained through the Woods Hole Oceanographic Institution for field studies in 1950.

By coincidence, the United States Coast and Geodetic Survey also decided to establish a gravity standardization range in cooperation with the Dominion Observatory of Canada this same year. This range, now known as the mid-continent standardization range, was routed along a north-south line from north of Winnipeg, Canada to the Texas-Mexico border.

It was later extended by the Dominion Observatory southward to Mexico City and northward to Fairbanks, Alaska to coincide with the range established by the writers outside of the United States.

The first series of measurements on this range were made by the United States Coast and Geodetic Survey with the Brown pendulum apparatus in conjunction with gravimeters. The pendulums were used for establishing the overall control and the gravimeters to give more precision to the individual station interval values. The University of Wisconsin checked this range in 1951 with the Worden geodetic meter and a North American gravity meter calibrated against the Cambridge University pendulum standard, and a systematic difference of about 2.8 mgals per 1000 mgals change was found. This was later found to be related to the effect of the earth's magnetic field on the Invar pendulums of the Brown apparatus. It was at this juncture in the program that the Dominion Observatory borrowed the Cambridge University pendulums to repeat key stations over this range as well as occupy sites established under the AFCRC program with the Gulf pendulums in Canada, Mexico and Alaska.

The first extended series of measurements that were made with the Gulf "C" pendulums was in 1950 between Lamont Geological Observatory in New York and the University of Wisconsin. These were followed by a complete series of measurements from Fairbanks, Alaska to Mexico City in 1951. The results for these measurements also showed an apparent systematic departure from values established with gravimeters calibrated on the Cambridge pendulum standard. This departure was of opposite sign from that found with the Brown pendulums. The cause of this effect was not obvious and at first it was attributed to the change in length of the travel path for the WWV time signals which were used to trigger the timing mechanism as well as rate the chronometer. Further study, with the help of the National Physical Laboratory at Teddington, England showed it to be due to the level of the WWV signal marker pulses that were being used as a trigger mechanism on the timing device. At great distances the signal level did not reach the required intensity level to trigger a strobotron circuit until the third or fourth pulse arrival. Another problem associated with these first measurements was that the zero of the manometers used for recording the operating pressure was subject to frequent change and resulted in errors that could not always be pinned down. However, despite these defects, later measurements have shown that an accuracy of about ± 1 mgal was obtained on the original series with the "C" pendulums over a range of about 4500 mgals.

By 1952 the importance of the standardization program was generally recognized, and the Gulf Research and Development Company made two sets of their best pendulums (Sets "K" and "M") available for the program. Subsequently these pendulums have been given to the University of Wisconsin by the Gulf Research and Development Company and improvements have since been made on them which could not be undertaken while they were on a loan basis.

The first really definitive measurements were not made with the Gulf pendulums until 1953. That year both sets "M" and "K" were used to rerun the entire standardization range between Mexico and Alaska. However, about half of the way through the measurements on the back leg from

Alaska an unfortunate accident occurred to the "K" set. One of the heating jacket thermostat switches stuck while in transit and the instrument badly overheated. It is believed that the cement holding the knife edge plugs in the pendulum was softened and the cement apparently has never completely recovered its set since, as the period appears to be subject to a constant "creep" that is a function of use. It was also this year that the Dominion Observatory used the Cambridge University pendulums to occupy the bases set with the Gulf pendulums in Canada and Alaska.

This coordination of program by the Dominion Observatory that resulted in dual measurements with the Gulf and Cambridge pendulums, at many sites between Alaska and Mexico City, immeasurably strengthened the program. However, the fact that Dominion Observatory measurements were carried out as two separate operations based on Ottawa with no direct connection across the middle portion of the range in the United States, resulted in this portion being a weak link. The first (1952) series of Cambridge pendulum measurements were from Ottawa to Washington, and followed the United States Coast and Geodetic Survey range from Winnipeg, Canada to Houston, Texas and the University of Wisconsin range from there to Mexico City with a tie to Madison, Wisconsin on the way back to Ottawa. The second (1953) series of Cambridge pendulum measurements were from Ottawa to Edmonton and thence to Alaska along the University of Wisconsin range with no tie to any of the points established the year before. Hence there is no direct interval connection between Houston, Texas and Lethbridge, Alberta, the two points of nearest proximity. This was particularly unfortunate since it is this portion of the range where the "creep" induced in the "K" pendulum period by overheating is greatest and difficult to evaluate. It is not surprising therefore that although the Gulf and Cambridge pendulum results agree reasonably well (± 0.5 mgal) in Canada and Alaska, the results for the overall range from Mexico City to Alaska suggest either a systematic departure between the two or a step offset between the 1952 and 1953 Dominion Observatory measurements. The gravimeter comparisons run by the University of Wisconsin indicate no systematic error in the Gulf "M" pendulum results. They, however, do suggest a change with time in the "K" pendulum results, and either the same effect or a jump of about 1.5 mgals between the two series of Cambridge pendulum measurements. In an effort to resolve this discrepancy, the Edmonton-Houston interval was rerun with the Gulf "M" set of pendulums in 1954 and the Washington-Ottawa interval was also measured, as was that between Houston, Texas and Huron, South Dakota on the mid-continent range occupied with the Cambridge pendulums. These results support the conclusion from the gravimeter check that over this interval the Cambridge pendulums were also subject to troubles.

Through the courtesy of the Dominion Observatory of Canada a copy of the original Cambridge pendulum field data was later obtained for study. The data were reworked for each set of pendulums and it appeared that the results for both sets of Cambridge pendulums agreed with the Gulf pendulums for the 1953 season but departed systematically with latitude for the 1952 season. The comparisons over the United States Coast and Geodetic Survey range between Huron, South Dakota and Houston, Texas are in reasonable agreement although the interval involved is too small to give conclusive results concerning any systematic departure between the sets of pendulums. Subsequent direct comparisons between Teddington,

England, Madison, Wisconsin, Mexico City, Mexico and in Europe, Africa and South America indicate there is no systematic deviation between the Gulf and Cambridge pendulum results.

Foreign Standardization Program:

One factor brought out by the global gravimeter studies sponsored by the Office of Naval Research, which were being made concurrently with the above pendulum program, was that there was no unanimity on calibration standard. Each country had its own standard and milligal unit. In order to reconcile these differences it would be necessary to establish a series of standardization ranges similar to that established in North America. Therefore, upon the completion of the pendulum measurements in North America a program for foreign pendulum observations was submitted to AFCRC. The first proposal included check measurements at sites occupied earlier with the Cambridge pendulums in Africa and Europe and the establishment of a Euro-African standardization range. Incidental to these measurements it was proposed to set a world-girdling loop of bases for general control purposes. Both programs were approved and carried out in 1954 and 1955.

Because of an unfortunate accident in which the pendulum truck rolled down an embankment, the program was curtailed the following year. At this time the method of recording was changed from a photographic one to a direct read-out with the period time indicated on an electronic counter. The next series of measurements (1956) were carried out down the west coast of South America as an extension of the North American standardization range. In 1957 the program was shifted to the western Pacific area and a series of measurements made between the island of Hokkaido, Japan and McMurdo Sound, Antarctica. Because of uncertainties at some of the Australian stations, this portion of the series was repeated later during the same year. The 1958 program involved measurements down the east coast of South America which tied into and repeated some of the observations made the previous year. As the value of having duplicate independent data on these standardization ranges had been demonstrated on the North American range, the AFCRC agreed to underwrite the cost of having the Cambridge University pendulums used to occupy the bases set in 1957 with the Gulf pendulums in southern Europe and Africa. This resulted in two independent sets of measurements that agreed within 0.4 mgal throughout on an interval basis.

In 1959 the recording system of the "M" pendulums was again modified to permit permanent records to be obtained and also permit higher precision in determining the period of the pendulums. During this period, in view of the political unrest in Africa and the need for standardization measurements in West Africa, the "K" set of pendulums were used to establish a series of measurements from Teddington, England to Johannesburg, South Africa via Lisbon, Dakar and Leopoldville. In view of subsequent developments in the Congo, the decision to make these measurements at that time appears to have been a wise one.

The last pendulum measurements were made in the Fall of 1959 with the improved "M" set of pendulums and the "K" set between Ottawa, Canada and Key West, Florida. These measurements, on the basis of closures and

an independent evaluation with the LaCoste-Romberg geodetic gravimeter, indicate that the results obtained are good on the average to ± 0.2 mgal except for the Key West observation, which appears to be off from the gravimeter comparison by 0.5 mgal.

The parallel gravimeter program was devoted principally to (a) developing a national network of airport bases for general control purposes, (b) the establishment of regional gravity coverage (10- to 15-mile spacing) along principal highways in areas not covered by governmental or industrial gravity surveys, and (c) the strengthening and expansion of the international network of airport gravity surveys established earlier under the auspices of the Office of Naval Research. The last program as well as the pendulum program received support also from the United States National Committee for the International Geophysical Year and through that auspices was enabled to set up a gravity program in Antarctica that otherwise would not have been possible. The regional gravity program in the United States has received support from many sources. Originally it was supported by the Geological Society of America; under AFCRC auspices it was further expanded, and at this writing is receiving limited financial support from the National Science Foundation.

Through the cooperation of the oil industry, coverage involving several thousands of additional gravity observations have become available but until these have all been adjusted to a common datum and calibration these data can not be regarded as reliable except for defining local changes in the gravity field. The above material, coupled with that secured by the United States Geological Survey, the United States Coast and Geodetic Survey and various university groups throughout the country who have made their observational data available, has resulted in fairly comprehensive coverage over most of the country. Figure I-1 shows the present status of this coverage.

Although no attempt was made to develop a gravity observational program outside of the United States, the bases established have served as a nucleus for the development of comprehensive surveys in several areas,- a notable example being South Africa. In most areas the bases have been adopted as reference stations for oil company gravity exploration surveys, and even though the results from such surveys may not be available for some time it will be a simple matter later, when the material does become available, to integrate it into the world gravity coverage.

Remarks on Difference in Datums used for Pendulum and Gravimeter Work.

It will be noted that the Madison, Wisconsin base value as given from the pendulum measurements is 980.3686 gals whereas that used for the gravimeter measurements is 980.3689 gals. This difference is due to the fact that the pendulum measurements are related to Bad Harzburg as a primary base (981.1803 gals) with all other values based entirely on pendulum connections. The gravimeter base value for Madison was derived from the best mean fit of gravimeter values calibrated against the Gulf-Wisconsin pendulums to those national gravity sites that have been tied directly to Potsdam. Bad Harzburg, on this basis, has a value of 981.1808 gals. Although the value adopted for Bad Harzburg by the International Gravimetric Bureau is 981.1804, the indicated discrepancy of 0.4 mgals is not substantiated by ties to the other first order gravity bases established by the International Gravimetric Bureau. Reoccupations of 27 of the 28 first order sites show an average difference from the IGM 1959 values of 0.8 mgal without regard to sign with eight sites having discrepancies of from 1 to 4 mgals. See Table I-1. For the 19 sites having differences of 1 mgal or less, the average difference without regard to sign is only 0.34 mgal and +0.12 mgal with regard to sign. As the values for the first order world network are in the process of being readjusted, it was not felt that a change of 0.1 mgal in the base value in use was justified.

Once the first order network has been adjusted to give the best fit to all pendulum and gravimeter measurements, a corresponding datum adjustment should be made in both the pendulum and gravimeter values quoted in this report.

Where comparisons are made between gravimeter and pendulum results in this report an adjustment of 0.3 mgal has been made in order to have both sets of values on the same datum relative to the Madison base.

Table I-1

Data for Fundamental World Gravity Bases

	I.G.M. Adopted Values (1959)	Gravimeter Values based on Madison 980.3689	Diff.
Reykjavik	982.2785	.2800	+1.5
Bad Harzburg	981.1804	.1808	+0.4
Teddington	981.1960	.1966	+0.6
Helsinki	981.2152	.2155	+0.3
Paris	980.9410	.9409	-0.1
Rome	980.3617	.3619	+0.2
Lisbon	980.0915	.0903	-0.8
Madrid	979.9810	.9812	+0.2
Fairbanks (Univ.)	982.2452	.3462	+1.0
Ottawa	980.6220	.6208	-1.2
Washington	980.1190	.1188	-0.2
Mexico (Univ.)	977.9415	.9414	-0.1
Quito	977.2805	.2774	-3.1
Rio de Janeiro	978.8060	.8047	-1.3
Buenos Aires	979.7046	.7048	+0.2
Kyoto	979.7215	.7216	+0.1
New Delhi	979.1362	.1363	+0.1
Singapore (Raffles Mus.)	978.0820	.0808	-1.2
Beyrouth (Fac.Med.)	979.6910	.6910	0.0
Algiers (Obs.)	979.9120	.9112	-0.8
Dakar (M' Bour)	978.388	.3856	-2.4
Khartoum	979.3033	.3033	0.0
Leopoldville	977.9185	.9144	-4.1
Johannesburg	978.5495	.5495	0.0
Melbourne	979.9790	.9798	+0.8
Christchurch	980.5095	.5089	-0.6
Honolulu	978.9526	.9530	+0.4

Without regard to sign, all 27 sites: 0.8 mgals

Without regard to sign for 19 sites with differences of 1 mgal

or less: 0.34 mgals

With regard to sign: +0.12 mgals.

PART II

THE PENDULUM PROGRAM

FOREWORD

This report presents the results obtained with the Gulf-Wisconsin apparatus during the period 1950-1959. The program of measurements involved observations at 105 locations distributed around the world as shown in Figure II-1. The total range in gravity covered is in excess of 5400 mgals with an uncertainty of less than 0.5 mgal for eighty percent of the measurements. A companion gravimeter observation program that was carried out in conjunction with the pendulum program was of great value in improving the reliability of the observations which are ordinarily gauged only through trip or periodic closure observations with the pendulums. This procedure, however, is no true gauge of the reliability of the data as it can only detect permanent changes in pendulum period and may give rise to false conclusions because of a transient change in pendulum period.

The gravimeter observations were invaluable in determining the times at which changes in pendulum period occurred, and the magnitude of the effect. The use of these data along with that for the pendulum closure observations are the reason why such an extensive program could be carried out with such a high over-all degree of reliability.

Although the gravimeter observations also served as a means of evaluating the station to station accuracy of the pendulum observations, a true evaluation of the over-all reliability of the pendulum measurements only can be affected through comparisons with the results obtained with other pendulums. The writers were fortunate in that the Cambridge pendulum apparatus had also been used extensively on a global basis and that support could be obtained through their own study contract to have additional measurements made with these pendulums by independent observers in different parts of the world at the same sites used with the Gulf-Wisconsin pendulums.

At over half of the 105 locations shown in Figure II-1 that were occupied with the Gulf-Wisconsin pendulums there are comparative values obtained with other modern pendulums. In the present report the data obtained by the writers is compared with those obtained by these other observers, and an attempt is made to combine all of the observational data using a standard method of weighting based on the number of independent observations by each observer at each site and their internal consistency.

The final weighted mean gravity results are given relative to either the British fundamental station at the National Physical Laboratory, Teddington, England, or the floor of the gravity vault in the Commerce Building, Washington, D.C. To the nearest 0.1 milligals the gravity reference value at Washington (CF) is $980.1187 \pm 0.00015 \text{ cm/sec}^2$ relative to Teddington (NPL) as 981.1962 ± 0.0 . Taking into account the uncertainty in the connection to Potsdam, the errors become:

Potsdam Pendelsaal	981.2740 ± 0.0
Bad Harzburg	981.1803 ± 0.00018
Teddington (NPL)	981.1962 ± 0.00023
Washington, D.C. (CF)	980.1187 ± 0.00028

WORLD, CONTINENTS

No. 201HC

FIG. II-1

GOODE'S SERIES OF BASE MAPS
HENRY M. LEPPARD, EDITOR

Prepared by Henry M. Leppard
Published by the University of Chicago Press, Chicago, Illinois
Copyright 1933 and 1939 by the University of Chicago

Part II

Table of Contents

	<u>Page</u>
Foreword	ii
Introduction	II-1
List of Observers with the Gulf Pendulum	II-2
Description of the Gulf Pendulum Apparatus for 1953-56	II-3
Method of Computation 1953-56	II-6
Factors influencing the Accuracy of Pendulum Observations	II-7
Pendulum Design	II-7
Associated Mechanical Devices	II-9
The Pendulum Environment	II-10
Timing	II-10
External and Special Factors	II-10
Factors Related to Operational Procedure	II-11
Corrections to the Pendulum Period	II-12
Reduction to Zero Amplitude	II-12
Pressure Correction	II-13
Temperature Correction	II-14
Earth tide Correction	II-14
Sway and Deviation from Isochronism	II-16
Location of Observations in North America through 1954	II-16
Remarks Concerning Field Procedures and Observations in 1953 and 1954	II-16
Results and Error Discussion for the 1951-54 Observations	II-20
Remarks Concerning Instrument Errors	II-20
The Gulf K & M Observations in 1953	II-20
The 1954 Gulf M Observations in Western North America	II-27
The 1951 Gulf C Observations in North America	II-29
The 1954 Gulf M World Trip	II-32
The 1955 Gulf M Africa Trip	II-32
The 1956 Gulf M East Coast U.S.A. Trip	II-38
Modifications to the Apparatus in 1956	II-40
The 1956-57 Gulf M Pacific Trip	II-43
The 1957 Gulf M East Coast and South American Trips	II-50
The 1958 Gulf M Far East and Pacific Trip	II-56
The 1958 Gulf M South America Trip	II-56
Modifications to the Gulf Apparatus in 1958-59	II-56
The 1959 Gulf K Africa Trip	II-64
Modifications in the Gulf Recording System in 1959	II-69
The 1959 Gulf K and M East Coast Trip	II-70
Investigation of the Results of Other Observers	II-77
Introductory Remarks	II-77
The USC & GS Brown Invar Pendulums	II-77
The Cambridge Invar Pendulums	II-80
1948-49 Cambridge (Hales and Gough) Africa	II-83
1951 Cambridge (Cook) Europe	II-84
1952-53 Cambridge (Garland) North America	II-85
1953-54 Cambridge (Garland and Cook) NPL-DO-NBS	II-86
1955 Cambridge (Jelstrup) Europe	II-87
1956 Cambridge (Gough) Africa	II-89
1958 Cambridge (Jackson) South America	II-90
1958 Cambridge (Browne) Europe and Africa	II-90

	<u>Page</u>
1959 Cambridge (Jackson) Pacific	II-91
1952 GSI (Muto) Chiba-Kyoto	II-92
1955 GSI (Okuda, Inoue, Suzuki) Washington, D.C. to Japan	II-92
1957-58 GSI (Harada, Et Al) Malaya-Africa	II-93
Pendulum Ties Potsdam to Bad Harzburg	II-94
Combination and Comparison with the Results of Other Observers	II-96
Appendix II-1 Pendulum Station Descriptions for North America	II-141
Appendix II-2 Pendulum Station Descriptions for South America	II-153
Appendix II-3 Pendulum Station Descriptions for the Far East and Pacific	II-155
Appendix II-4 Pendulum Station Descriptions for Europe & North Africa	II-159
Appendix II-5 Pendulum Station Descriptions for Africa	II-162
Appendix II-6 Sketches of Pendulum Sites in North America	II-165
Appendix II-7 Sketches of Pendulum Sites in South America	II-166
Appendix II-8 Sketches of Pendulum Sites in the Far East and Pacific	II-167
Appendix II-9 Sketches of Pendulum Sites in Europe and North Africa	II-168
Appendix II-10 Sketches of Pendulum Sites in Africa	II-169
Bibliography	II-170

List of Figures

II-1 World Gravity Standardization Stations Established with the Gulf-Wisconsin Pendulums	iii
II-2 Size and Shape of the Gulf Pendulum (Fused Quartz) and Knife Edge Bearing Surface (Pyrex)	II-4
II-3 Gulf Pendulum Recording and Timing Principle	II-5
II-4 Enlarged Section of Pendulum Recording Showing Computation Procedure	II-8
II-5 Effect of Pressure on Pendulum Period (Silica Gel Dessicant)	II-15
II-6 Gulf Pendulum Bases in North America 1953-54	II-17
II-7 Sequence of Gulf Pendulum Observations in North America (1953-54)	II-18
II-8 1953 Gulf K & M Pendulum Gravity Results in North America Showing Closures and Comparison with Mean Gravimeter Results	II-25
II-9 1953 K & M Pendulum Intervals and Mean Gravimeter Intervals	II-26
II-10 1954 Gravity Intervals in North America with the Gulf M Pendulums	II-28
II-11 1951 Gravity Intervals in North America with the Gulf C Pendulums	II-33
II-12 1954 Gulf M World Station Sequence	II-34
II-13 Gulf M 1955 Africa Station Sequence	II-35
II-14 Electronic Recording System for the Gulf-Wisconsin Pendulums	II-41
II-15 Experimental Determinations of Gulf M-Set Amplitude Correction	II-44
II-16 Sequence of Gulf-Wisconsin Pendulum Sites 1956-57	II-45
II-17 1956-57 Gulf M Pacific Difference between Mean Periods of Pendulum Pair and No. 2 Pendulum	II-46

	<u>Page</u>
II-18 Christchurch II Anomalous Pressures	II-47
II-19 1957 Gulf M South America Station Sequence	II-53
II-20 Gulf M 1957 Anomalous Pressure at Punta Arenas	II-54
II-21 Gulf M 1957 Anomalous Pressure at Antofagasta	II-55
II-22 Sequence of Gulf-Wisconsin Pendulum Sites 1958	II-57
II-23 1958 Gulf M South America Station Sequence	II-60
II-24 Gulf K 1959 Africa Station Sequence	II-65
II-25 Gulf K 1959 Africa Period Closures	II-67
II-26 1959 East Coast Station Sequence	II-71
II-27 Period Closures K Set 1959 East Coast	II-74
II-28 1959 Gulf M Amplitude Damping Ratio as a Function of Pressure	II-75
II-29 1959 Gulf M Effect of Pressure on Period P_{205}	II-76
II-30 1959 Gulf K Effect of Amplitude on Period	II-78
II-31 1959 Gulf M Effect of Amplitude on Period	II-79
II-32 Comparisons of Pendulum Gravity Results in North America	II-81
II-33 Weighted Mean Gravity Intervals between Major Excenters	II-103

Introduction

All of the Gulf pendulum observations by the group at the University of Wisconsin are discussed. None of the tables of reductions to the periods are presented, as they are merely tedious and contribute nothing to the analysis. The policy adopted in this paper of removing tares and systematic effects from pendulum results will no doubt arouse controversy. Interpretations of results are kept as simple as possible. Sufficient Gulf data are presented to permit others to make their own interpretations.

List of Observers with the Gulf Pendulums

- 1951 Gulf C North America
J. C. Rose and W. U. Ault
- 1953 Gulf K and M North America
J. C. Rose and E. A. Carlson
- 1954 Gulf M Western North America and World
J. C. Rose and E. A. Carlson
- 1955 Gulf M Africa
J. C. Rose and K. H. Koenen
- 1956 Gulf M East Coast U.S.A.
J. S. Steinhart and R. M. Iverson
- 1956-57 Gulf M Pacific
J. C. Rose and R. M. Iverson
- 1957 Gulf M East Coast U.S.A.
J. C. Rose and R. A. Haubrich
- 1957 Gulf M South America
J. S. Watkins and R. M. Iverson
- 1958 Gulf M Far East and Pacific
R. M. Iverson and T. S. Laudon
- 1958 Gulf M South America
R. M. Iverson and T. S. Laudon
- 1959 Gulf K Africa
R. M. Iverson and N. A. Ostenso
- 1959 Gulf K and M East Coast
J. C. Rose and O. Strickholm

Description of the Gulf Pendulum Apparatus for 1953-56

The ensuing discussion is mainly concerned with the 1953-56 apparatus. Subsequent modifications will be taken up later. Three sets of the compound quartz pendulum apparatus of the Gulf Research and Development Company were used in carrying out the program; the C set on loan to Columbia University and the K and M sets on loan to Dr. G. P. Woollard of the Department of Geology, University of Wisconsin. The C set was used during the joint study carried out with Columbia University in 1950 and 1951, and the K and M sets for the subsequent observations. In 1959 the Gulf Research and Development Company very generously gave the K and M pendulums to the University of Wisconsin.

The Gulf pendulum apparatus consists of two compound fused quartz pendulums housed in a special aluminum alloy case. The case remains sealed throughout the field season. The pendulums are mechanically raised and lowered for an observation and mechanically clamped in transit. The size and shape of the pendulum and its bearing surface are shown in Figure II-2. The period is approximately 0.89 seconds and a pair of pendulums is generally isochronous to 2×10^{-6} or better. These are mounted on a common support and swing 180° apart in phase, so that induced motion in the support will tend to be nullified. The Gulf pendulums when used originally for prospecting purposes had an operational precision of ± 0.25 milligal and it was shown by Gay (1940) that an accuracy of ± 0.1 milligal could be obtained when sufficient care was employed.

The pressure of the dessicated air in the pendulum case was measured with a portable McLeod vacuum gage to ± 0.01 millimeter of mercury. The case is electrically heated and the temperature is read from an internally mounted thermometer to $\pm 0.02^\circ\text{C}$.

The recording and timing apparatus for the K and M sets was developed at the University of Wisconsin. Figure II-3 shows a block diagram of the recording and timing principle. The chronometer employed a 100 KC crystal clock. A 1000 cycle sine wave output was used to drive a non-selfstarting synchronous motor. For control of the rate of the chronometer, a harmonic of the oscillator is compared with the carrier wave frequency of radio station WWV. The oscillator is continuously adjusted to zero-beat. In principle the chronometer then has an accuracy comparable with the received carrier accuracy of WWV. In practice the accuracy obtained was between the optimum and one part in ten million because of poor radio reception and cycling of the crystal oven heater. The oven heater has since been rebuilt.

To record simultaneously the time generated by the chronometer and the pendulum oscillations, a light beam originated in the camera box, passed through a revolving slotted disk on the shaft of the synchronous motor, going into the pendulum optical system where it was reflected from the mirror face of the pendulum and then was sent back to the moving 35 millimeter film in the recording camera. Thus the pendulum oscillations were recorded continuously as a broken line trace. The advantage of this method was that the timing marks also comprise the pendulum trace. Moreover, the amplitude may easily be determined. In practice the procedure was to record for two and a half

FIG. II-2

**GULF PENDULUM
RECORDING AND TIMING
PRINCIPLE**

FIG. II - 3

minutes at the beginning and end of the one hour observation, with no recording during a fifty-eight minute interval. Each pendulum was recorded independently, one trace being offset slightly both horizontally and vertically from the other on the film.

The instrumentation used in 1950 and 1951 with the C set of pendulums differed from that used with the K and M sets. The rate of the chronometer was evaluated by energizing a strobtron from the one second pulses of WWV through a one thousand cycle tuned filter attached to the output of the radio receiver. The flashes onto the edge of the revolving shutter disc on the synchronous motor showed the change of position of suitably scribed marks on the disc relative to an associated fixed scale, as a function of time. Considerable error in the results resulted from erratic behavior of the strobtron circuit, generally because of poor radio reception.

Another factor adversely affecting the 1951 results with the C pendulums was the determination of the pressure in the pendulum case. This was measured with a U-tube mercury manometer and the poor reading accuracy (± 0.1 millimeter) in addition to changes in the "zero" of the manometer in the field resulted in appreciable errors in the results.

Method of Computation 1953-56

The shutter disc in the camera revolved with a period of 0.06 seconds. There were twelve apertures cut through it - ten of the same size and two slightly smaller. This resulted in a recorded pendulum trace consisting of black dashes (the exposed portions) and clear spaces (the unexposed portions). The time interval from corresponding ends of successive dashes (e.g., from the leading end of one dash to the leading end of the next dash) was 0.005 seconds, and the time interval between corresponding ends of the shorter dashes was 0.03 seconds. The short clear spaces and the short black dashes were of 0.00125 seconds duration. Figure II-4 shows an enlarged portion of a photographic record with the two independent traces of each pendulum. Only the center of the trace is recorded on the 35 millimeter film.

If the pendulum period had been exactly 0.9 seconds, the pendulum oscillations and the timing marks would remain exactly in phase and there would be no apparent advance of the timing marks with time. Since the pendulum period is approximately 0.89 seconds, the time dashes lag by about 0.01 seconds for each succeeding pendulum oscillation.

The mean pendulum period for an integral number of swings is

$$T = \frac{\text{total elapsed time}}{\text{number of swings}} = \frac{\Delta t}{N} \quad (1)$$

where N is the integral number of swings occurring during time interval Δt . The recording is not continuous, so N cannot be counted directly and must be computed using the approximate period determined from a recorded portion of the

trace. Then

$$N \doteq N_{\text{approximate}} \doteq \Delta t / T_{\text{approximate}}. \quad (2)$$

Since the time of passage of a particular recorded dash across the center line of the trace can be determined to within 0.0005 seconds, the approximate period will be accurate to 2×10^{-5} in twenty five seconds, or the uncertainty is ± 0.2 swings in one hour.

To facilitate determination of Δt , a relay actuated by an electrical contact cam system driven by the synchronous motor through a gear reduction of 100:1 interrupts the light beam for one-half second every six seconds. These are the major time breaks shown in Figure II-4. Breaks for which the instant of interruption occurs on the recorded center portion of the pendulum trace are used as time reference points. By the appropriate additions and subtractions of the time intervals represented by the dashes comprising the pendulum traces, the time of a passage of the center line by a particular dash is directly determined relative to the nearest six second "break". The six second breaks always occurred at the same timing mark of the shutter disc because of the direct gear relation with the synchronous motor. The time difference between particular passages of the center line at the end section and at the initial section of the recording gave a value of Δt corresponding to an integral number of swings of the pendulum. A sample calculation is given in Figure II-4.

The center line was determined from the symmetry of the phase-shift pattern of the short timing marks. The intersection of diagonal straight lines along "up" going and "down" going short dashes gave the center line position to sufficient accuracy.

Factors Influencing the Accuracy of Pendulum Observations

The discussion in this section is somewhat cursory and emphasizes the special features of the Gulf apparatus and the modifications made at the University of Wisconsin.

The accuracy of land pendulum observations is affected chiefly by the design of the pendulums and their associated recording and timing apparatus, external or special factors, operational procedure and the method of reduction.

Pendulum design

Concerning pendulum design the material used for the pendulum determines the length stability and the temperature effect. There is some difference of opinion as to whether quartz or invar is the more stable in its length. For temperature stability quartz has the advantage that its linear coefficient of thermal expansion is very small, about 1/50 that of bronze and about 1/2 that of invar. The relative disadvantages of quartz and invar are that quartz tends to develop electrostatic charges which strongly affect the period, and invar is magnetic, so its period could be affected by the earth's magnetic field, a magnetized object within or exterior to the pendulum case, or by its companion pendulum for the double pendulum apparatus. To dissipate the electrostatic charge, the Gulf pendulums utilize 100 micrograms of radium salt on suitably

PROCEDURE FOR DETERMINING
TRANSIT TIME OF T_1 ϕ BY T_1
TRACE AT POINT A:

- STEP 1: "BREAK" REFERENCE POINT
AT TIME t .
- STEP 1-2: -0.45 SEC.
- STEP 2-3: -0.9 SEC.
- STEP 3-4: -0.9 SEC.
- STEP 4-5: +0.03 SEC.
- STEP 5-6: -0.9 SEC.
- STEP 6-7: -0.9 SEC.
- STEP 7-8: -0.9 SEC.
- STEP 8-9: +0.02 SEC.

TRANSIT TIME AT A = t - 4.90 SECONDS.

ENLARGED SECTION OF PENDULUM RECORDING SHOWING
COMPUTATION PROCEDURE

FIG. II - 4

located metal plates within the pendulum case so that charges even as great as several hundred volts will be reduced to less than one volt in less than ten seconds. Since the maximum observed charges induced by the friction of the Gulf clamping and unclamping device are between twenty-five and thirty-five volts, it is seen from the empirical expression found by G. B. Lamb (1931) (unpublished) of the Gulf Research and Development Company, that the radium salts present in the case are more than adequate for control of the electrostatic potential problem. The relation obtained was

$$\frac{\Delta T}{T} = 0.9 \times 10^{-10} V^2 \quad (3)$$

where ΔT is the period change in seconds due to the potential in volts V of the pendulum with period T seconds. The Cambridge invar pendulums have been shielded from the earth's magnetic field with mumetal, and more recently Helmholtz coils have been employed with the Cambridge and with the Brown apparatus of the U.S. Coast and Geodetic Survey for compensating one component of the earth's field.

The Gulf pendulums are about thirty centimeters long and weigh about 590 grams. Since they are minimum pendulums, the effects of changes in knife edge conditions are minimized. Their weight is such that a horizontal acceleration of 300 centimeters per second (corresponding to 75,000 dynes) would be required to skid the pendulum on the knife edge.

The Gulf pendulum has a streamlined cross-section to minimize the large effect of air pressure on it.

The knife edge is made of ground and polished fused quartz at an included angle of 120° to minimize fracturing effects.

Associated mechanical devices

The bearing surface for each Gulf pendulum is a massive block of well annealed Pyrex glass, ground and polished to $1/4$ wave length of sodium light. These surfaces were reported by the Gulf Company never to have warped and never to have shown any wear. Therefore, they answer admirably to the two desired qualifications for a pendulum bearing: to remain flat and coplanar.

The main internal support is a rigid aluminum alloy frame. Each pair of pendulums for all field observations were cocked with very nearly the same amplitude (maximum difference 0.3 percent) and released within 5×10^{-3} seconds of each other. It was observed that each pair had the same periods within 4×10^{-6} seconds. Thus the maximum sway effect on the period was less than 10^{-7} seconds.

The starting device of the Gulf pendulums consists of bumper arms which contact the pendulums at their center of percussion so that the imparted motion is rotation about the knife edge without translation. This minimizes the tendency for knife edge skid during starting or arresting. The device functions sufficiently reliably so that the reduction to zero amplitude could be omitted without seriously affecting the accuracy of the results.

The raising and lowering device has a two-speed gear system. In the clamped position a formed leather-lined cup holds a pendulum rigidly up against a strong spring. This system has proven to be more than adequate for protection of the pendulums in transit. For example, the Gulf Company reports an instance in which a set of pendulums remained undamaged while strapped to the inside wall of a truck which rolled over. In 1956 the M set was tied down in a truck which rolled over and was completely demolished. The pendulums were not damaged. When lowering, the device first lowers the pendulum relatively rapidly onto two round-headed screws, each fitting into a conical hole at each end of the knife edge plug. Then the gear-ratio of the lowering device changes to give a very slow rate of lowering. When the knife edges reach the bearing surfaces the supporting screws are carried on down and out of the way of the pendulum assembly.

The only defect in the design of the lowering device is that the point of support for lowering is above the horizontal plane of the knife edge, so a lateral skidding effect is possible at the moment of contact or pickup. Great care is taken by the observers to avoid this.

The pendulum environment

The pressure effects on the period of the Gulf pendulums are considerably larger than for most other types, on the order of one microsecond per millimeter of mercury. The Gulf Company was able to maintain low pressures for periods of months. This proved to be difficult with the present observations. Nevertheless, the pressure leak observed was never larger than one millimeter per hour and this did not appear to affect the pendulum period if the mean pressure during an observation was used in determining the pressure correction. A McLeod gage was used for pressure measurement, apparently giving a reading precision of ± 0.01 millimeter.

The temperature effects on the Gulf pendulum period are very small, about 0.2×10^{-6} seconds per degree centigrade. The heated pendulum case would maintain constant temperature to a few tenths of a degree as indicated by the internal thermometer with its reading accuracy of $\pm 0.02^\circ\text{C}$ even when under adverse room temperature conditions. However, considerable time was necessary for the pendulums to reach temperature equilibrium. (See error discussion and remarks concerning observations.)

Timing

The desired stability for an electronic chronometer would be one part in 10^7 or better for an hour. This was not achieved with the present design. Therefore, continuous radio reception for continuous adjustment of the chronometer was necessary in order to maintain an effective zero-beat with the WWV carrier wave. Occasionally poor radio reception resulted in errors as large as five parts in 10^7 relative to the received carrier wave during an observation. Portable primary frequency standards stable to 10^{-9} sec per day are now available but are rather expensive.

External and special factors

Magnetic effects on the Gulf pendulums are believed to be negligible.

External temperature variations were seldom great enough to seriously affect the periods significantly provided temperature equilibrium within the pendulum case had already been achieved. However, external temperature variations influenced the ambient operating temperature of the crystal oven of the chronometer which could result in relatively large errors where poor radio reception was received.

Concerning apparent length changes, it is not known whether there is a thermal "hysteresis" effect or not, because this would be combined with knife edge effects. The observed period changes on reoccupations are both plus and minus and could be attributed either to length or to knife edge changes. Extreme care was taken in raising and lowering the pendulums to avoid knife edge fracturing.

There is some possibility of a molecular "creep" in pendulum length because of the presence of radioactive material in the pendulum case, but this effect would probably be too small to be observed.

Variations in moisture content of the air probably do not affect the periods because of the dessicant within the pendulum case. At least no effects of this sort have been observed. Silicagel was used as the dessicant from 1953 to 1956. Since 1956 P_2O_5 has been used.

That the system of swinging two very nearly isochronous pendulums on the same horizontal plane with a 180° phase difference nullifies most sway and horizontal seismic effects is well known. With the Gulf pendulums, the maximum period effect observed in the field for horizontal seismic disturbances was about 2×10^{-6} seconds. It can be shown that in order to eliminate effects of this magnitude the pendulums must be isochronous to 1.5×10^{-6} seconds, must be released at the same instant within 0.005 seconds, and the initial amplitudes must be the same within about one percent. The M set always satisfied all of these requirements but the K set at times exhibited period differences of 3×10^{-6} seconds or more. This means that relatively large horizontal seismic disturbances could have produced K set errors on the order of 0.1×10^{-6} seconds or 0.2 milligals.

To eliminate vertical seismic effects a four pendulum apparatus would be required with the proper phase and orientation relationships. However, for most land observations the vertical seismic effects are small enough to be ignored.

For an error of less than 10^{-7} in "g", a cross leveling accuracy of better than 1.5 minutes of arc is required. The level used had a sensitivity of forty-eight seconds of arc per division and the pendulum case was always leveled to 0.1 division. The maximum level change observed at a field station was 0.2 division, and the leveling bearing on top of the pendulum case has remained in agreement with the internal pendulum bearing surfaces to within 0.1 division. It is felt that leveling could not have contributed any significant error.

Factors Related to Operational Procedure

The M case required about six hours and the K case about eight hours before the internal thermometer indicated that the operating temperature had been

reached. It was customary to wait an additional two hours, or a total of ten hours, before beginning the observations. This was always sufficient for thermal equilibrium of the M set, but not always for the K set, as evidenced by the progressive period increases of the K pendulums for many of the observations in Mexico. It is suspected that the K set would have required twenty-four hours of heating to reach complete thermal equilibrium.

The change in period values for both sets at Houston in 1953 subsequent to opening the case indicates that a sealed case for the entire field season is highly desirable. The reasons for the period changes are not known. This will be discussed later in connection with the 1959 observations. Theoretical calculations of the effect of an adsorbed layer of gas on the period were undertaken by Muskat (1951) (unpublished) by the Gulf Company in an attempt to explain this peculiar behavior which they observed also. It was found that a period increase of one part in one hundred million was the maximum effect that could be expected. An adsorbed gas film therefore, could not possibly explain the period irregularity. The closed case operation also eliminates possibilities for damage or irregularities due to handling of the pendulums.

The observation time was standardized at one hour. The field procedure in 1953 was to lower the pendulums once and make three one hour swings, recocking each time. This procedure was modified in 1954 and three lowerings were made with two swings for each lowering. The latter method gave a better sample of conditions representative of the knife edge on its bearing surface, assuming that the knife edge might assume a slightly different position on the bearing surface each time it was lowered. Moreover, it was felt that this gave a three to one chance for possible knife edge fracture to occur during observations at a particular site rather than on the first lowering at a new site. It turned out that there was no great difference between results with either procedure. Present procedure is to lower independently for each observation.

Corrections to the Pendulum Period

The theory of the corrections for a two pendulum apparatus was developed by Vening Meinesz (1929), Anderson (1932), Swick (1942) and is well known. Lamb and others of the Gulf Research and Development Company developed a very direct mathematical approach to the pendulum theory and corrections in a series of technical reports and performed careful experiments to measure perturbing effects on the pendulum period. Unfortunately, these investigations have never been published. Part of the material in this section has been taken from the Gulf technical reports.

Reduction to zero amplitude

The period of a compound pendulum vibrating with a finite amplitude of α radians on a rigid support is given approximately by the well known relation

$$T \doteq 2\pi \sqrt{\frac{I}{mgl}} \left[1 + \frac{\alpha^2}{16} \right] \quad (4)$$

with an error less than 10^{-8} seconds for α on the order of $1/50$ radian. If

$T_0 = 2\pi I/mgl$ is the period for zero amplitude and exponential damping is assumed, T_0 is given by

$$T_0 = T_{ave} \left[1 - \frac{\alpha_1^2 - \alpha_2^2}{32 \ln \frac{\alpha_1}{\alpha_2}} \right] \quad (5)$$

where α_1 is the amplitude at initial time t_1 and α_2 is the amplitude at final time t_2 . The amplitude correction ΔT_A is

$$\Delta T_A = T_0 - T_{ave} = - \frac{\alpha_1^2 - \alpha_2^2}{32 \ln \frac{\alpha_1}{\alpha_2}} \quad (6)$$

wherefore N swings corresponding to time interval $t_2 - t_1$,

$$T_{ave} = \frac{t_2 - t_1}{N} = \frac{\Delta t}{N} \quad (7)$$

From the measured vertical displacements of A inches on the photographic trace corresponding to pendulum amplitudes of α radians, the amplitude corrections were found to be

$$\left[\Delta T_A \right]_M = - 0.1285 \frac{A_1^2 - A_2^2}{\log_{10} \frac{A_1}{A_2}} T_M \times 10^{-6} \quad (8a)$$

$$\left[\Delta T_A \right]_K = - 0.1004 \frac{A_1^2 - A_2^2}{\log_{10} \frac{A_1}{A_2}} T_K \times 10^{-6} \quad (8b)$$

It should be remarked that cocking amplitudes of both sets were adjusted in the laboratory to be approximately the same, but there was an optical path length difference between the K and M sets. The resulting corrections, however, were approximately the same for both sets. Relation (8a) was verified experimentally.

For ease of computation, a graph of the amplitude correction functions was constructed. The amplitude is determined from the relation

$$A_i = A \sin \frac{2\pi t}{T} \quad (9)$$

where A_i is the measured amplitude from the center line of timing marks for time interval t (usually 0.03 seconds).

Pressure corrections

The air surrounding the pendulum has two known effects on the period: buoyancy and hydrodynamic increase in mass. When viscosity is considered, the theory becomes mathematically complex, so the pressure correction was determined

empirically.

The experimentally determined pressure effect is shown in Figure II-5. With respect to pressure the conditions were ideal, because there was no pressure leak in either pendulum case at the time. The temperature of the pendulums had been stabilized for several days and the chronometer checks during the observations were good. The periods shown on the graphs are corrected for temperature and amplitude. The slopes of the lines, fitted by least-squares, were 0.9618×10^{-6} for the K set and 0.9463 for the M set, resulting in

$$\frac{1}{T_K} \left(\frac{\Delta T_K}{\Delta P} \right) = 1.081 \times 10^{-6} \text{ sec.} \quad (9)$$

$$\frac{1}{T_M} \left(\frac{\Delta T_M}{\Delta P} \right) = 1.061 \times 10^{-6} \text{ sec.} \quad (10)$$

or the mean experimental pressure correction is

$$\Delta T_P = -1.071 p T \times 10^{-6} \text{ sec.} \quad (11)$$

where p is the pressure in millimeters of mercury. Pressures were measured with a McLeod gage to ± 0.01 millimeters, and the air inside the pendulum case was dried by means of containers of silica gel.

Temperature correction

From the period relation,

$$T = 2\pi \sqrt{\frac{I}{mgl}} = C l^{1/2} \quad (12)$$

where C is a constant. The logarithmic differential is

$$\frac{dT}{T} = \frac{1}{2} \frac{dl}{l} = \frac{1}{2} (0.48 \times 10^{-6} \times \Delta \theta) \quad (13)$$

or

$$T_0 = T (1 - 0.24 \times 10^{-6} \times \Delta \theta) \quad (14)$$

where $\Delta \theta$ is the temperature difference above the normal operating temperature, and 0.48×10^{-6} is the thermal coefficient of linear expansion for fused quartz. Then the temperature correction is

$$\Delta T_\theta = -0.24 \times T \times \Delta \theta \times 10^{-6} \text{ sec.} \quad (15).$$

Earth tide correction

A small correction to g of an amount δg in terms of a pendulum period correction δT is given from the relation

$$\frac{T - \delta T}{T} = \left(\frac{g}{g + \delta g} \right)^{1/2} \quad (16)$$

or

$$\delta T \doteq - 1/2 \frac{T}{g} \delta g \text{ sec}, \quad (17)$$

but the period T is approximately 0.89 seconds and g is approximately 980 cm/sec² so the correction to the period is approximately

$$\delta T = -0.454 \delta g \text{ sec}. \quad (18)$$

This relation is useful for earth tide corrections and for local changes in observation sites.

The earth tide corrections were determined in part from the tables prepared by Damrel (1951) and in part from the graphs prepared by Morelli (1954).

Sway and deviation from isochronism

It appears unnecessary to correct for flexure of the support because the largest value observed in the field for this correction was about 10⁻⁸ seconds.

Location of Observations in North America Through 1954

A map showing the location of the sites occupied in 1953 and 1954 in North America with the Gulf pendulums is shown in Figure II-6, and a schematic drawing of the sequence of stations starting from Madison and using the M and K sets of pendulums is given in Figure II-7. Station descriptions for North America for all recent observers are listed in the order of the observed gravity value in Appendix II-1. Sketches and drawings of sites other than those occupied by Garland (1953) and (1955) are in Appendix II-6. The particular sites used were chosen on the following basis: 1) the gravity interval between sites is approximately 150 milligals; 2) the sites are readily accessible by airplane and by automobile; 3) many of the sites had been previously occupied with the Gulf C pendulums, by the U.S. Coast and Geodetic Survey, or by the Dominion Observatory with the Cambridge Pendulums. The sites which were occupied with the Cambridge pendulum apparatus by G. D. Garland for the Dominion Observatory include Ottawa, Washington, Madison, Fairbanks, Whitehorse, Fort St. John, Grande Prairie, Edmonton, Lethbridge, Huron, Beloit, Tulsa, Houston, Monterrey, and Mexico City. The U.S. Coast and Geodetic Survey has made observations with the Brown pendulum apparatus at Fairbanks, Huron, Beloit, Tulsa, and Houston. Stations previously occupied with the Gulf C pendulums in the cooperative program with Columbia University include Fairbanks, Whitehorse, Fort St. John, Grande Prairie, Edmonton, Calgary, Lethbridge, Cutbank, Great Falls, Billings, Sheridan, Casper, Cheyenne, Houston, Laredo, Monterrey, Tamazunchale, Mexico City, Madison, Washington, and the Lamont Observatory.

Remarks Concerning Field Procedures and Observations in 1953 and 1954

The pendulum equipment was transported in a half-ton Chevrolet carryall truck belonging to the U.S. Air Force modified for overload springs and over-size rear tires. The observers and their baggage plus the pendulum equipment weighed about 3000 pounds--three times the specified load capacity of the truck. The overload coupled with the Alaska Highway took a heavy toll of tires, and several wheel bearing and axle failures occurred.

FIG. II - 7

The pendulum cases were transported in boxes located near the center of gravity of the truck. In 1953 the pendulums were electrically heated from the truck battery while in transit, but in 1954 this procedure was abandoned because of the danger of overheating.

The pendulum observational procedure adopted in 1953 was to lower the pendulums once and make three one hour observations, recocking each time but not raising until the observations for the station had been completed. This procedure was modified in 1954 to include more lowerings of the pendulums and more observations in order to obtain a better sampling of possible knife edge irregularities in contacting the bearing surface.

Observations with a Worden Geodetic gravimeter were made at all stations and numerous local connections were established.

The interior of the truck was exceedingly warm during the drive from Lethbridge to Cutbank, and the pendulums were being electrically heated in transit. As a consequence, serious overheating was discovered upon arrival at Cutbank. The internal thermometers were at their limit of 50°C. Despite the removal of the top insulating jacket of the pendulum case for more rapid cooling, at least an hour elapsed before the thermometers were within their operating range.

The observation was made six hours after the thermometers indicated a normal operating temperature. The results indicate that the pendulum periods were greatly in error for that station with the K set, and were sufficiently altered with the M set so that a small systematic effect may have persisted until Houston.

Concerning temperature effects, the K set periods at Great Falls and often in Mexico show a progressive increase, most pronounced for T_2 . Apparently the practice of beginning the observations two hours after the operating temperature of the K set was reached allowed sufficient time for the M pendulums with their faster heating rate to achieve thermal equilibrium, but sometimes the K set apparently required more than two hours. The pendulums were arbitrarily designated as T_1 and T_2 for each of the sets, where T_1 was the pendulum on the end of the case away from the observation window, and T_2 the pendulum nearest the observation window. The latter end has apertures in the down insulating jacket and is covered by an additional insulating flap when temperature readings are not being taken. The much greater stability of the T_1 period with both sets is attributed to its more stable temperature environment.

Because of the increasing pressure leak throughout the field season in 1953 for both sets, the pendulum cases were opened and the vacuum seals repacked at Houston on returning from Mexico. This produced an obvious change in periods for both sets which as explained earlier cannot be accounted for on theoretical grounds. The pendulums were not touched in any manner in the process, and the air was let into the cases slowly through a dessicating bottle and filter arrangement. This period change effect apparently persisted for the subsequent Amarillo and Tulsa observations with the K set, but had disappeared at Beloit.

In Table II-1, some stations list only one or two observations instead of three. Although observations were made the records were not usable either because the recorded trace was too faint to be read, or because of mechanical or electrical failures in the recording and timing systems. In Mexico City at Tacubaya Observatory for example, only two observations were obtained out of six attempts. The unsuccessful observations all resulted from power line failures. For this reason the Mexico City observations subsequent to Paso de Cortes were made at the University of Mexico.

Results and Error Discussion for the 1951-4 Observations

Remarks concerning instrument errors

The error in picking the records results in a standard deviation of $\pm 0.02 \times 10^{-6}$ based on the period calculations for twenty stations. As the manometer was read to ± 0.01 millimeter, the standard deviation for the pressure correction error is $\pm 0.01 \times 10^{-6}$. All amplitudes were measured to ± 0.01 inches, or the standard deviation of the amplitude correction is $\pm 0.01 \times 10^{-6}$. The estimated maximum chronometer error on the period for good radio reception was $\pm 0.01 \times 10^{-6}$. The temperature of the pendulums when in thermal equilibrium can easily be read to $\pm 0.05^\circ\text{C}$. This results in a correction error with a standard deviation of $\pm 0.01 \times 10^{-6}$.

The net standard deviation for all of the above factors is $\pm 0.03 \times 10^{-6}$ seconds. Instrument errors, therefore, in the absence of abnormal conditions are considered to be small. For this reason, errors in the gravity results can best be determined from a comparison of the results obtained with the two sets of pendulums and from the closure errors for reoccupations at a particular site.

The Gulf K and M observations in 1953

The mean periods of each individual pendulum and each pair of pendulums and the corresponding standard error for the sequence of stations is given in Table II-1. The K and M periods are used for the gravity calculations. The relation used for these calculations was

$$g_{\text{field}} = g_{\text{base}} \left(\frac{T_{\text{base}}}{T_{\text{field}}} \right)^2. \quad (19)$$

For interpretation purposes all of the field gravity results were computed relative to the first Madison occupation as $980.3689 \text{ cm/sec}^2$. These unadjusted gravity results are given in Table II-2. Figure II-8 shows the closures in milligals at reoccupation sites. In the North the K-set closes satisfactorily at Whitehorse and Edmonton but fails to close by 1.8 mgals at Great Falls. In the South the K-set shows large closure errors; -2.1 mgals at Mexico City, +0.3 mgals at Monterrey and +1.4 mgals at Houston. As a result of repacking the vacuum seals at Houston, there is an obvious +3.5 mgal tare. There does not seem to be any significant closure error for the East Coast loop with the K-set. Because of the difficulty of deciding where the tares indicated by the closure errors had occurred, or whether the closures represented true tares at all or merely a large scatter in the results, additional comparison data were

TABLE II-1
1953 GULF K AND M (ROSE) NORTH AMERICA

Date	Station Sequence	Occup.	Seconds		Microseconds				n	Seconds		Microseconds				n
			K	K	K1-K2	$\bar{s}$ K1	$\bar{s}$ K2	$\bar{s}$ K		M	M	M1-M2	$\bar{s}$ M1	$\bar{s}$ M2	$\bar{s}$ M	
290753	Madison (25)	1	0.889	661 68	+1.3.	0.04	0.17	0.08	3	0.891	555 00	+1.87	0.19	0.22	0.20	3
	Equiv. (12)			661 65							554 97					
0108	Huron	1		623 22	+0.90	.06	0	.03	2		518 96	-1.44	.21	.20	.01	2
05	Great Falls	1		590 16	+1.19	.10	.08	.05	3		485 11	-0.17	.02	.08	.03	3
07	Edmonton (LAB)	1		299 15	+1.10	.04	.06	.06	2		193 94	+0.04	.13	.30	.10	3
12	Whitehorse (PUMP)	1		035 87	+1.68	.10	.08	.12	2	0.890	930 27	+0.22	.03	.12	.05	3
18	Fairbanks (LADD)	1	0.888	811 91	+1.24	.12	.06	.09	4		705 86	-0.05	.10	.04	.07	4
20	Northway			926 28	+2.05	--	--	--	1		820 52	+0.60	--	--	--	1
23	Whitehorse (PUMP)	2	0.889	035 88	+1.54	.12	.06	.03	3		930 46	-0.10	.09	.09	.01	3
28	Fort St. John (B)			191 24	+1.73	.18	.17	.18	2	0.891	086 17	-0.07	.01	.01	.01	2
29	Grande Prairie (PO)			231 21	+1.62	.12	.09	.06	3		126 08	+0.10	.05	.08	.06	3
0109	Edmonton (LAB)	2		299 12	+1.84	.32	.20	.20	3		194 41	+0.11	.24	.18	.20	3
02	Red Deer			376 53	+1.85	.06	.17	.10	3		271 82	+0.08	.12	.07	.09	3
04	Calgary (AIRPORT)			452 49	+2.29	.09	.03	.06	3		348 59	+0.05	.05	.08	.03	3
05	Lethbridge			484 14	+2.39	.15	.24	.06	3		380 05	-0.35	.03	.16	.07	3
06	Cutbank (TEMP BLDG)		REJECTED - OFF TEMPERATURE								448 50	-0.95	--	--	--	1
08	Great Falls	2		589 32	+2.60	.37	.33	.35	3		486 03	-1.04	--	--	--	1
09	Billings			659 73	+2.43	.10	.21	.16	3		556 67	-0.73	.03	.05	.03	3
12	Sheridan			724 82	+2.71	.05	.06	.05	3		622 44	-1.08	.16	.06	.11	3
13	Casper			847 63	+3.19	.05	.13	.05	3		745 58	-0.88	.06	.09	.08	3
14	Cheyenne			964 23	+2.03	.02	.04	.01	3		861 85	-0.78	.03	.08	.03	3
17	Denver		0.890	004 31	+2.66	.15	.11	.04	3		902 12	-0.52	.18	.23	.09	3
20	Houston	1		146 51	+3.23	.04	.10	.03	3	0.892	044 57	-0.05	.08	.16	.06	3
23	San Antonio			192 49	+3.13	.14	.18	.04	3		090 67	-0.04	.07	.02	.03	3
0510	Monterrey	1		370 41	+4.19	.13	.20	.04	2		269 18	-0.30	.08	.16	.13	2
10	Mexico, D.F. (TAC)	1		762 94	+4.44	.01	.20	.11	2		663 09	-0.32	.04	.06	.04	2
14	Paso de Cortes			931 47	+1.93	.20	.42	.32	3		832 35	-0.64	.02	.09	.06	3
17	Mexico, D.F. (UNIV)	2		763 48	+2.80	.16	.11	.12	3		662 91	-0.16	.10	.11	.09	3
	Equiv. (TAC)			763 25							662 68					
19	El Zarco			842 33	+3.31	.10	.02	.04	3		742 24	-0.32	.02	.02	0	2
21	Ixmiquilpan			660 15	+3.53	.24	.34	.34	3		559 57	-0.01	.06	.04	.04	3
23	Jacala			586 23	+4.26	.01	.04	.01	2		485 90	-0.06	.06	.05	.03	3
25	Chapulhuacan			516 04	+4.03	.07	.35	.20	3		415 36	+0.14	0	.04	.03	3
27	Tamazunchale			436 21	+4.32	.20	.34	.21	3		335 28	-0.09	.14	.27	.21	3
30	Monterrey	2		370 27	+3.29	.06	.10	.05	3		269 00	-0.14	.04	.06	.05	3
31	Laredo			245 06	+3.93	.10	.10	.10	3		143 97	-0.59	.10	.06	.05	3
0511	Houston	2A		145 87	+3.79	.02	.07	.05	3		044 36	-0.36	.08	.13	.03	3
08		2B		144 26	+1.64	.13	.16	.01	2		043 92	-0.39	.11	.30	.10	2
11	Amarillo			087 86	+2.05	.06	.06	.01	3	0.891	986 87	-0.47	.08	.02	.03	3

11-21

-41-

TABLE II-1
1953 GULF K AND M (ROSE) NORTH AMERICA (CONT.)

121153	Tulsa	0.889	952 53	+2.84	.03	.05	.03	3	831 17	-0.10	.08	.06	.10	3
14	Beloit		828 14	+2.29	.08	.32	.12	2	725 47	-0.30	.12	.17	.08	3
17	Huron	2	621 86	+2.22	.03	.07	.05	3	518 20	-0.04	.15	.06	.06	3
20	Madison (25)	2	660 15	+2.70	.08	.06	.06	2	557 19	-0.47	.12	.18	.04	2
	Equiv. (12)		660 12						557 16					
25	Washington, D.C. (GL)	1	781 65	+3.13	.05	.05	.02	3	679 32	-0.27	.06	.03	.04	3
30	Ottawa (D.O. FLOOR)	1	546 07	+2.23	.03	.07	.05	3	442 58	-0.23	.05	.04	.02	3
0912	Washington, D.C. (GL)	2	781 44	+2.69	.11	.03	.06	3	679 10	-0.41	.06	.05	.05	3
11	Lamont Observatory	1	709 61	+2.24	.10	.01	.04	2	606 84	-0.34	.04 0		.01	2
010154	Madison (25)	3A	659 99	+2.56	.04	.04	.03	8	557 00	-0.31	.09	.14	.11	8
	Equiv. (12)		659 96						556 97					

TABLE II-2
GRAVITY RESULTS

1953 GULF K AND M (ROSE) NORTH AMERICA

Station Sequence	K			M			KM		N	Intervals		(mgals) ² $\overline{s}^2$
	Un-corrected g gals	Tare Cor- rected g gals		Un-corrected g gals	Tare Cor- rected g gals		Mean Tare Corr. g gals	mgals Δg		mgals $\pm \overline{s}$		
Madison (12)	980.3689	.3689		.3689	Ma	.3690 ⁵	6	0	0	0		
Huron	.4536	.4536		.4489	.4544	.4537 ³	4 +	84.68	0.29	0.086		
Great Falls	.5265	.5265		.5226	.5281	.5267 ⁸	4 +	157.73	"	"		
Edmonton	981.1683	.1683		.1634	.1689	.1683 ⁵	4 +	799.30	"	"		
Whitehorse	.7495	.7495		.7442	.7497	.7495 ⁰	4 +	1380.45	"	"		
Fairbanks (L)	982.2443	.2443		.2390	.2445	.2444 ⁰	2 +	1875.35	.37	.137		
Northway	981.9916	.9916		.9861	.9916	.9916 ⁰	2 +	1622.55	"	"		
Whitehorse	.7495	.7495		.7438	.7493	--						
Fort St. John	.4065	.4065		.4007	.4062	.4063 ⁵	2 +	1037.30	"	"		
Grande Prairie	.3182	.3182		.3128	.3183	.3182 ⁵	2 +	949.20	"	"		
Edmonton	.1684	.1684		.1623	.1678	--						
Red Deer	980.9976	.9976	Ka	.9919	.9974	.9975	2 +	628.45	"	"		
Calgary	.8300	.8282		.8229	.8284	.8283	2 +	459.25	"	"		
Lethbridge	.7602	.7584		.7537	.7592	.7588	2 +	389.75	"	"		
Cutbank	(.6044)	N.G.	-1.8 mg1	.6031	.6086	+5.5 mg1	.6086	1 +	239.55	.49	.240	
Great Falls	.5283	.5265		.5205	.5260	--						
Billings	.3731	.3713	Kb	.3652	.3707	.3710	2 +	1.95	.37	.137		
Sheridan	.2297	.2263		.2205	.2260	.2261 ⁵	2 -	142.90	"	"		
Casper	979.9591	.9557		.9498	.9553	.9555	2 -	413.55	"	"		
Cheyenne	.7024	.6990		.6943	.6998	.6994	2 -	669.65	"	"		
Denver	.6141	.6107		.6059	.6114	.6110 ⁵	2 -	758.00	"	"		
Houston	.3012	.2978		.2930	.2985	.2984 ⁸	(4) -	1070.57	.29	.086		
San Antonio	.2000	.1966		.1918	.1973	.1969 ⁵	2 -	1172.10	.37	.137		
Monterrey	978.8087	.8053		.8001	.8056	.8054 ⁸	4 -	1563.57	.29	.086		
Mexico (Tac)	977.9463	.9429		.9364	.9419	.9422 ⁰	4 -	2426.85	"	"		
Paso de Cortes	.5750	.5716		.5657	.5712	Mb	.5714	2 -	2797.65	.37	.137	
Mexico (Tac)	.9442	.9418	-3.4 mgal	.9373	.9422	--						
El Zarco	.7720	.7686		.7630	.7679	.7682 ⁵	2 -	2600.80	"	"		
Ixmiquilpan	978.1706	.1672		.1633	.1682	.1677	2 -	2201.35	"	"		

II-23

employed. The pendulum results were tentatively adjusted for tares and used for calibration of a number of University of Wisconsin gravimeter trips over the North American Gravity Range. The mean gravimeter intervals were worked out by G. P. Woollard. The comparisons of the unadjusted pendulum results with these mean gravimeter results are shown in Figures II-8 and II-9.

It is evident that a major temporary tare occurred at Houston as a result of repacking the vacuum seals. The tare adjustments adopted are:

K-Set

- Ka = -1.8 mgals between Red Deer and Calgary
- Kb = -3.4 mgals total (Ka - 1.6 mgals) between Billings and Sheridan.
- Kc = -6.9 mgals total (Kb - 3.5 mgals) between Houston 2A and Houston 2B (the result of repacking the vacuum seals).
- Kd = -3.4 mgals total (Kc + 3.5 mgals) between Tulsa and Beloit (the recovery from the repacking tare)

M-Set

- Ma = +5.5 mgals between Madison 1 and Huron 1.
- Mb = +4.9 mgals total (Ma - 0.6 mgals) between Paso de Cortes and Mexico, D.F. 2.
- Mc = +3.9 mgals total (Mb - 1.0 mgals) between Houston 2A and Houston 2B (the result of repacking the vacuum seals.)
- Md = +4.9 mgals total (Mc + 1.0 mgals) between Huron 2 and Madison 2 (the recovery from the repacking tare.)

It is important to emphasize that the gravimeter intervals are used only for the location of the pendulum tares. The amounts of the pendulum tares are determined from the pendulum closure errors. Thus the Gulf pendulum apparatus is regarded as a kind of cumbersome gravity meter subject to tares but requiring no calibration. The tares are removed in order to make a valid estimate of the overall reliability of the trip from the reoccupation closures.

The last columns of Table II-2 give the mean gravity intervals relative to Madison. The K and M results are averaged to give a large number of degrees of freedom and a more homogeneous variance. If the tare corrected reoccupation closures of the K-set alone were to be used for estimating its variance, the result would be an unduly optimistic estimate that would not account for the relatively poor "signal-to-noise" ratio in Mexico as indicated by Figure II-8. The variability of the K-set in Mexico is partly the result of temperature instability and partly the result of a high pressure leak rate in the pendulum case.

For the combined K and M results the estimated variance of an individual occupation of a station based on 54 degrees of freedom is the measure of uncertainty at any station including the Madison base station, provided that the assumption of homogeneous variance for the entire trip is valid. The estimated standard error of any field station is the square root of the sum of the variance of the mean at the field station and the variance of the mean at the base station. This type of error evaluation procedure will be used in the discussion of the subsequent Gulf pendulum trips as well as in evaluation of results with

TABLE (Continued)
GRAVITY RESULTS
1953 GULF K AND M (ROSE) NORTH AMERICA

Jacala	978.3344	.3310		.3248	.3297	.3303 ⁵	2 -2038.70	"	"
Chapulhuacan	.4878	.4844		.4794	.4843 +4.9 mgl	.4843 ⁵	2 -1884.70	"	"
Tamazunchale	.6641	.6607		.6551	.6600	.6603 ⁵	2 -1708.70	"	"
Monterrey	.8090	.8056		.8005	.8054	--			
Laredo	979.0844	.0808		.0748	.0797	.0802 ⁵	2 -1288.80	"	"
Houston	.3026	.2992 Kc		.2935	.2984 Mc	--			
Houston	.3061	.2992		.2945	.2984	--			
Amarillo	.4302	.4233 -6.9 mgl		.4197	.4236	.4234 ⁵	2 -945.60	"	"
Tulsa	.7722	.7653 Kd		.7618	.7657 +3.9 mgl	.7655	2 - 603.55	"	"
Beloit	980.0021	.9987		.9940	.9979	.9983	2 - 370.75	"	"
Huron	.4566	.4532		.4498	.4537 Md	--			
Madison (12)	.3723	.3689		.3641	.3690	--			
Washington (GLF)	.1045	.1011 -3.4 mgl		.0955	.1004	.1009 ⁸	4 - 268.07	.29	.086
Ottawa (DOF)	.6237	.6203		.6161	.6210 +4.9 mgl	.6206 ⁵	2 + 251.60	.37	.137
Washington (GLF)	.1049	.1015		.0960	.1009	--			
Lamont Obs.	.2632	.2598		.2548	.2597	.2597 ⁵	2 - 109.30	"	"
Madison (12)	.3726	.3692		.3645	.3694	--			

Ka = -1.8 mgl
Kb = -1.6 mgl
Kc = -3.5 mgl
Kd = +3.5 mgl

Ma = +5.5 mgl
Mb = -0.6 mgl
Mc = -1.0 mgl
Md = +1.0 mgl

Combined $\overline{KM}$
DF = 54
 $s^2 = 0.206(\text{mgals})^2$
s = ±0.45 mgals

II-24A

the Brown apparatus of the U.S. Coast and Geodetic Survey, the Cambridge pendulums, the GSI pendulums and others.

The 1954 Gulf M observations in western North America

Subsequent to the 1953 observations it was apparent that the calibration line was strong north of Great Falls and south of Houston, but probably weak in the middle. To strengthen the center a special western loop with the Gulf M-set in 1954, tying Madison, Huron, Great Falls, Edmonton and Houston together as well as repeating Washington, D.C. and Ottawa was made. The trip sequence is shown on Figure II-7. Table II-3 gives the observed mean periods of the individual and paired pendulums per occupation. There apparently were no tares.

TABLE II-3
1954 GULF M (ROSE) WESTERN N. AMERICA

Date	Station Sequence	Occup.	Seconds		Microseconds				n
			$\bar{M}$		$\overline{M1-M2}$	$\frac{s}{M1}$	$\frac{s}{M2}$	$\frac{s}{\bar{M}}$	
280654	Madison (25)	3B	0.891	557 21	-0.25	0.06	0.11	0.09	5
	Equiv. (12)			557 18					
0307	Huron	3		518 65	-0.12	.10	.09	.07	6
06	Great Falls	3		485 60	-0.34	.04	.11	.05	6
09	Edmonton	3		194 16	-0.35	.10	.14	.06	7
11	Great Falls	4		485 49	-0.36	.02	.13	.06	6
17	Houston	3	0.892	044 10	-0.21	.09	.06	.05	8
22	Huron	4	0.891	518 29	-0.11	.04	.06	.03	6
30	Madison (25)	4		557 03	-0.06	.02	.05	.03	8
	Equiv. (12)			557 00					
0408	Washington, D.C.(GLF)	3		679 15	+0.11	.04	.06	.04	8
11	Ottawa (DOF)	2		442 22	+0.06	.05	.05	.03	8
18	Washington, D.C.(GLF)	4		678 89	+0.02	.02	.07	.04	6
23	Madison (25)	5		557 31	-0.04	.04	.07	.05	6
	Equiv. (12)			557 28					

The gravity results of the 1954 western trip are given in Table II-4 with mean intervals and estimated standard errors relative to Madison computed in the same manner as the 1953 results. The gravity intervals are shown in Figure II-10. The results are in excellent agreement with the 1953 results with the exception of the Ottawa to Washington interval. This may be related to relatively poor radio reception of WWV at Ottawa.

-b4-

28

TABLE II-4
GRAVITY RESULTS
1954 GULF M (ROSE) WESTERN NORTH AMERICA

Station Sequence	Occup.	Un-corrected g gals	Mean g gals	N	Intervals		
					mgals Δg	mgals $\pm \bar{s}$	(mgals) ² $\bar{s}^2$
Madison (25)	3B						
Equiv. (12)		980.3689	.3690	3	0	0	0
Huron	3	.4536	.4540	2	+ 85.0	0.35	0.123
Great Falls	3	.5263	.5264	2	+157.4	"	"
Edmonton	3	981.1678	.1678	1	+798.8	.44	.197
Great Falls	4	980.5266	--				
Houston	3	979.2989	.2989	1	-1070.1	"	"
Huron	4	980.4544	--				
Madison (25)	4						
Equiv. (12)		.3693	--				
Washington, D.C.(GLF)	3	.1007	.1010	2	-268.0	.35	.123
Ottawa (DOF)	2	.6218	.6218	1	+252.8	.44	.197
Washington, D.C.(GLF)	4	.1013	--				
Madison (25)	5						
Equiv. (12)		.3687	--				
D.F.			5				
s ² (mgals) ²			0.148				
s mgals			0.38				

The 1951 Gulf C observations in North America

Table II-5 is a summary of the mean pendulum periods for the Gulf C-set, with all temperature, pressure, amplitude and chronometer corrections, and shows the station sequence. The periods are the same as those given by Woollard, Rose, and Ault (1954). This work was first reported by Woollard, Bonini, Black, Rose and Ault (1953). The large closure errors at the Lamont Observatory, Washington, D.C., and Madison indicate the occurrence of one or more tares (offsets) in the pendulum periods during the field season. The tares could not be accurately located and evaluated until the Gulf K and M-set results had been obtained for comparison. The unadjusted gravity results relative to the second Washington occupation are given in Table II-6 with corrections to the 1953-4 Gulf sites as determined by the local gravimeter ties established in 1953.

The Lamont 2 and 3 closure error was 6.6 mgals and the Washington, D.C. 1 and 2 closure error was 6.1 mgals. The mean of these, or 6.4 $\pm$ 0.2 mgals was taken as the total tare. Comparison with the Gulf M-set results showed that 2.5 mgals of this occurred between Sheridan and Casper, as shown in Table II-7.

TABLE II-5
1951 GULF C (ROSE AND AULT) NORTH AMERICA

Station Sequence	Occup.	Seconds		Microsec.	
		<u>C</u>		<u>s</u>	<u>n</u>
Lamont Observatory	1	0.892	073 58	0.40	3
Washington D.C. (GLF)	1		144 92	(.59)	1
Lamont Observatory	2		072 31	.47	2
Madison (12)	1		024 25	(.59)	1
Great Falls	1	0.891	953 16	(.59)	1
Edmonton (SDWLK)	1		661 74	(.59)	1
Fairbanks (U)			171 94	(.59)	1
Whitehorse (HNCR)			398 43	(.59)	1
Watson Lake (OUT)			412 82	(.59)	1
Fort St. John (OUT)			553 40	(.59)	1
Grande Prairie (SCHOOL)			592 83	(.59)	1
Edmonton	2		661 74	(.59)	1
Calgary (SCHOOL)			817 80	(.59)	1
Lethbridge (MUN.)			847 77	(.59)	1
Cutbank (ADMN)			916 25	(.59)	1
Great Falls	2		953 18	(.59)	1
Billings (STATUE)		0.892	024 19	(.59)	1
Sheridan (AIRPORT)			090 30	(.59)	1
Casper (STORAGE)			214 44	(.59)	1
Cheyenne (HGHWY)			330 77	(.59)	1
Houston			513 63	(.59)	1
Mexico, D.F. (TAC)		0.893	132 06	(.59)	1
Tamazunchale (CHURCH)		0.892	801 99	(.59)	1
Monterrey			738 18	(.59)	1
Laredo (POLICE)			611 48	(.59)	1
Houston	2	REJECTED - OVERHEATED			
Chicago (MIDWAY)			062 98	(.59)	1
Madison (12)	2		026 19	(.59)	1
Washington, D.C. (GLF)	2		147 93	(.59)	1
Lamont Observatory	3		075 06	.13	7

Note: Estimated standard errors at stations with only one observation are based on the mean of the estimated variances at Lamont Observatory 1, 2, and 3.

TABLE II-6

GRAVITY RESULTS

1951 GULF C (ROSE AND AULT) NORTH AMERICA

Station Sequence		Un- corrected g gals	Tare Cor- rected g gals	Tare corrected mean g gals	N	Intervals mgals Δg	mgals $\pm \bar{s}$	(mgals) ² $\bar{s}^2$
Lamont Observatory	1	980.2640	.2576	.2596 ³	3	+ 159.0	1.02	1.05
Washington, D.C.(GLF)	1	.1072	.1008	Ca .1006	2	0	0	0
Lamont Observatory	2	.2668	.2604	--				
Madison (12)	1	.3724	.3698	.3688	2	+ 268.2	1.12	1.26
Great Falls	1	.5287	.5262	.5261	2	+ 425.5	"	"
Edmonton (Sdwlk)	1	981.1697						
Equiv. Physics Lab.		.1702	.1677	.1676	2	+1067.0	"	"
Fairbanks (Univ.)		982.2485						
Equiv. Ladd AFB		.2467	.2442	.2441	1	+2143.5	1.37	1.89
Whitehorse (Hngr)		981.7495						
Equiv. Pump House		.7496	.7471	.7470	1	+1646.4	"	"
Watson Lake (Out)		.7178						
Equiv. D.O. Site		.7182	.7157	.7156	1	+1615.0	"	"
Fort St. John (Out)		.4087						
Equiv. Basement		.4091	.4066	.4065	1	+1305.9	"	"
Grande Prairie (School)		.3214						
Equiv. Postoffice		.3219	.3194	.3193	1	+1218.7	"	"
Edmonton (Sdwlk)	2	.1697						
Equiv. Physics Lab.		.1702	.1677	--				
Calgary (School)		980.8264						
Equiv. Airport		.8316	.8291	.8290	1	+ 728.4	"	"
Lethbridge (Mun.)		.7604						
Equiv. Postoffice		.7614	.7579	.7578	1	+ 657.2	"	"
Cutbank (Admn)		.6098						
Equiv. Temp. Bldg.		.6100	.6075	.6074	1	+ 506.8	"	"
Great Falls	2	.5287	.5262	--				
Billings (Statue)		.3725						
Equiv. Hanger		.3718	.3693	.3692	1	+ 268.6	"	"
Sheridan (Airport Out)		.2272						
Equiv. Airport Hanger		.2270	.2245	.2244	1	+ 123.8	"	"
Casper (Storage)		979.9545						
Equiv. Pumphouse		.9543	.9543	.9542	1	- 146.4	"	"
Cheyenne (hghwy)		.6990						
Equiv. Rec. Hall		.6990	.6990	.6989	1	- 401.7	"	"
Houston	1	.2976	.2976	.2975	1	- 803.1	"	"
Mexico, D.F.(Tacubaya)		977.9419	.9419	.9418	1	-2158.8	"	"
Tamazunchale (Church)		978.6651						
Equiv. Tourist Court		.6603	.6603	.6602	1	-1440.4	"	"
Monterrey		.8050	.8050	.8049	1	-1295.7	"	"
Laredo (Police)		979.0829						
Equiv. A.F.B.		.0810	.0810	.0809	1	-1019.7	"	"
Houston	Rejected - Overheated							
Chicago		980.2873	.2873	.2872	1	+ 186.6	"	"
Madison (12)	2	.3681	.3680	--				
Washington, D.C.(GLF)	2	.1006	.1006					
Lamont Observatory	3	.2607	.2607					

*Tare corrections D.F. = 6
 Ca = -6.4 mgals $s^2 = 1.26$ (mgals)²
 Cb = -2.5 mgals $s = 1.12$ mgals

TABLE II-7
COMPARISON BETWEEN GULF C-SET AND GULF M-SET RESULTS
SHOWING 2.5 MGAL TARE WITH THE GULF C-SET
BETWEEN SHERIDAN AND CASPER

Stations	Gravity Differences in Milligals			
	C-set		M-set	C-M
	1951 C-site	1953 K and M site	1953 K and M site	Difference at same sites
Great Falls - Casper	574.2	574.4	571.7	+2.7
Billings - Cheyenne	673.5	672.8	670.7	+2.1
Sheridan - Houston	929.6	929.4	926.7	+2.7
Mean				+2.5 $\pm$ 0.2

The mean gravity intervals and estimated errors relative to Washington, D.C. are given in Table II-6. With only 6 degrees of freedom the estimate of the variance may not be very reliable; however, the large closure errors at the Lamont Observatory help to save the estimate from being biased optimistically. Comparison of the results with the 1953 results shows that despite only one one-hour swing at each field station with the C-set, the agreement is surprisingly good. Figure II-11 shows the gravity intervals diagrammatically.

The 1954 Gulf M World Trip

Figure II-12 shows the station sequence for the 1954 Gulf M world trip. The station descriptions are given in Appendix II-1 for North America, Appendix II-3 for the Far East and Pacific and Appendix II-4 for Europe and North Africa. Corresponding sketches of the sites are given in Appendices II-6, II-8, II-9 respectively.

Tables II-8 and II-9 list the observed mean periods and gravity results respectively.

The 1954 Western trip and World trip could actually be considered as a single combined trip, as there do not appear to be any significant tares during the entire sequence. On such a basis the estimated variance is approximately the same as the estimated variance of the Western trip alone; for this reason the estimated variance of the Western trip is assumed to apply to the World trip. It is felt that if only the Madison and Bad Harzburg reoccupation closures of the World trip are used, the estimated variance would be biased optimistically.

The 1955 Gulf M Africa Trip

The station sequence for the 1955 Gulf M Africa trip is shown in Figure II-13. The station descriptions are given in Appendices II-1, II-3 and II-5, with corresponding sketches in Appendices II-6, II-8 and II-10 respectively. Table II-10 gives the sequence of mean periods and Table II-11 gives the sequence of corresponding unadjusted gravity results computed relative to Washington, D.C.

FIG. II -12

11-34

1954 GULF M
WORLD
STATION SEQUENCE

FIG. II - 13

1955 GULF M
AFRICA
STATION SEQUENCE

TABLE II-8
1954 GULF M (ROSE) WORLD

1954 GOLF II (ROSE) WHEELUS									
Date	Station Sequence	Occup.	Seconds		$\bar{M1-M2}$	$\bar{s}$ $\bar{M1}$	$\bar{s}$ $\bar{M2}$	$\bar{s}$ $\bar{N}$	n
220854	Madison (25)	5	0.891	557 31	-0.04	0.04	0.07	0.05	6
	Equiv. (12)	5		557 28					
0809	San Francisco	1		731 52	+0.11	.10	.15	.12	6
14	Honolulu	1	0.892	202 62	+0.17	.09	.10	.04	6
25	Kyoto		0.891	852 28	-0.11	.04	.10	.04	6
30	Tokyo	1		815 77	+0.24	.29	.32	.11	6
0610	Manila (MUNTINLUPA)	1	0.892	471 22	+0.45	.10	.07	.04	5
	Equiv. (CLARK AFB)	1		455 56					
13	New Delhi			118 45	+0.44	.03	.06	.05	2
20	Tripoli (WHEELUS AFB)		0.891	913 00	-0.09	.07	.09	.07	6
26	Rome (I.N.G.)			559 55	0	.09	.07	.04	5
30	Frankfurt (SINDLINGEN)			242 68	+0.05	.09	.11	.03	5
0511	Bad Harzburg	1		188 51	+0.19	.06	.08	.04	6
09	Copenhagen (BUDD.FLOOR)	1		017 00	+0.45	.06	.14	.05	6
14	Oslo	1	0.890	849 37	-0.04	.05	.07	.06	6
21	Munich(NYMPHENBURG)	1	0.891	386 63	-0.16	.03	.09	.05	6
24	Bad Harzburg	2		188 57	+0.09	.04	.09	.04	6
0212	Teddington (NPL 11)	1		181 15	+0.65	.14	.16	.04	6
28	Washington, D.C. (GLF)	5		679 59	+0.54	.04	.05	.02	6
020155	Madison (25)	6A		557 32	+0.33	.02	.08	.04	5
	Equiv. (12)			557 29					
06	Madison (12)	6B		557 31	-0.29	.16	.07	.11	3

TABLE II-9
1954 GULF M (ROSE) WORLD

A variance corresponding to that of the 1954 Western North America loop will be assumed to apply to the 1954 World results.

Station Sequence	Occup.	g gals	Intervals				
			Mean g gals	N	mgals Δg	mgals $\pm \bar{s}$	(mgals) ² $\bar{s}^2$
Madison (12)	5	980.3689 ¹	.3689 ⁰	2	0	0	0
San Francisco	1	979.9858 ³	.9858 ³	1	-383.07	0.47	0.225
Honolulu	1	978.9512 ⁰	.9512 ⁰	1	-1417.70	"	"
Kyoto		979.7204 ⁶	.7204 ⁶	1	-648.44	"	"
Tokyo	1	.8006 ⁸	.8006 ⁸	1	-568.22	"	"
Manila (Muntinlupa)							
Equiv. Clark AFB	1	978.3963 ⁷	.3963 ⁷	1	-1972.53	"	"
New Delhi		979.1359 ³	.1359 ³	1	-1232.97	"	"
Tripoli (Wheelus AFB)		.5870 ⁷	.5870 ⁷	1	-781.83	"	"
Rome (I.N.G.)		980.3639 ²	.3639 ²	1	- 4.98	"	"
Frankfurt (Sindlingen)		981.0611 ⁵	.0611 ⁵	1	+692.25	"	"
Bad Harzburg	1	.1804 ²	.1803 ⁶	2	+811.46	.39	.150
Copenhagen (Budd,floor)		.5581 ⁹	.5581 ⁹	1	+1189.29	.47	.225
Oslo		.9276 ²	.9276 ²	1	+1558.72	"	"
Munich (Nymphenburg)		980.7443 ²	.7443 ²	1	+375.42	"	"
Bad Harzburg	2	981.1802 ⁹	--				
Teddington (NPL 11)	1	.1966 ³	.1966 ³	1	+827.73	"	"
Washington, D.C. (GLF)	5	980.0999 ⁸	.0999 ⁸	1	-268.92	"	"
Madison (12)	6A	.3688 ⁹	--				

s^2 0.150 (mgals)² Assumed
s 0.39 mgals

TABLE II-10
1955 GULF M (ROSE) - AFRICA

Date	Station	Occup.	Seconds			$\bar{s}$	$\bar{s}$	$\bar{s}$	n
	Sequence		M	M1-M2	M1	M2	M		
060555	Washington, D.C.(GLF)	6	0.891	680 25	-0.04	0.07	0.05	0.05	3
0507	Madison (12)	7		558 87	+0.23	.11	.10	.05	4
11	San Francisco	2		731 99	+0.51	.09	.10	.07	6
200755	Manila (CLARK AFB)	2	0.892	456 16	+1.74	.14	.02	.08	3
0408	Cairo (HELWAN OBS.)			047 99	+0.28	.13	.09	.09	4
06	Khartoum (COORD.RM.)			498 29	+0.29	.06	.14	.10	6
10	Nairobi (FLD SURV.)	1		845 98	+0.17	.05	.06	.04	6
14	Victoria Falls			530 49	+0.39	.05	.10	.05	5
19	Johannesburg	1		385 34	+0.08	.05	.07	.06	6
22	Mowbray (TRIG.SURV.)		0.891	885 01	+0.73	.08	.13	.06	6
28	Lusaka		0.892	611 31	+0.79	.08	.09	.01	6
31	Nairobi (FLD.SURV.)	2		845 78	+0.48	.02	.03	.00	5
0409	Asmara (KAGNEW)			718 22	+0.53	.02	.09	.04	6
17	Manila (CLARK AFB)	3		455 06	+1.31	.11	.10	.01	6
20	Honolulu	2		201 58	+1.06	.03	.06	.02	6
22	San Francisco	3	0.891	730 81	+1.06	.09	.15	.08	5
2212	Madison (12)	8A		556 98	+1.49	.06	.09	.06	6

TABLE II-11
1955 GULF M (ROSE) AFRICA

Station Sequence	Occup.	Uncor- rected		Tare cor- rected	Tare cor- rected	Tare cor- rected mean	N	Intervals		
		g gals	g gals		M gals	g gals		mgals Δg	mgals $\pm \bar{s}$	(mgals) ² s^2
Washington, D.C.(GLF)	5	980.1021				980.1013	2	- 267.9	0.88	0.769
Madison (12)	6	.3710				.3692	3	0	0	0
Washington, D.C.(GLF)	6	.1006				--				
Madison (12)	7	.3675				--				
San Francisco	2	979.9869				979.9869	2	- 382.3	.88	.769
Manila (Clark AFB)	2	978.3971				978.3970	2	-1972.2	"	"
Cairo (Helwan Obs.)		979.2927	.2919			979.2919	1	-1077.3	1.11	1.229
Khartoum (Coord.Rm.)	A	978.3043	.3035	-0.8 mgls		978.3035	1	-2065.7	"	"
" "	B	.3051	.3035	-1.6 "		--				
Nairobi (Fld.Surv.)	1	977.5430	.5405			977.5407	2	-2828.5	.88	0.769
Victoria Falls		978.2342	.2317			978.2317	1	-2137.5	1.11	1.229
Johannesburg	1	.5524	.5499			.5499	1	-1819.3	"	"
Mowbray (Trig.Surv.)		979.6506	.6481			979.6481	1	- 721.1	"	"
Lusaka		978.0570	.0545	-2.5 "		978.0545	1	-2314.7	"	"
Nairobi (Fld.Surv.)	2	977.5434	.5409			--				
Asmara (Kagnew)		.8228	.8193			977.8193	1	-2549.9	"	"
Manila (Clark AFB)	3	978.3995	.3970			--				
Honolulu	2	.9556	.9531			978.9531	1	-1416.1	"	"
San Francisco	3	979.9895	.9870							
Madison (12)	8A	980.3716	.3691							

D.F.
 s^2 (mgals)²
s

8
0.921
0.96

The results were difficult to interpret because the trip had a large scatter in periods as well as several tares during the trip. There was very little comparison data either from reoccupations or from other observers.

The mean of the San Francisco and Clark closures is 2.5 mgals. Madison was not considered suitable for evaluation of field tares, because the first Madison is regarded as erratic. The family Wash., D.C. 5, Madison 6, Washington, D.C. 6 and Madison 7 show erratic periods. All field stations were examined for period consistency. The Madison 7 to San Francisco interval is poor because Madison 7 is erratic. The closure on the Nairobi 1 - Nairobi 2 loop indicated the tare was not there. The San Francisco 2 - Clark 2 interval is 1589.8 mgals and the Clark 3 - San Francisco 3 interval is 1590.0 mgals, so the tare was not in either of these intervals. The interval Nairobi 2 - Clark 3 agrees within 0.5 mgals of gravimeter intervals, so the tare (or tares) was assumed to be between Clark 2 and Nairobi 1. The interval Clark 2 - Cairo is about 0.5 mgals higher than gravimeter intervals. Khartoum shows two characteristic periods, one for the first three swings and a different period for the second three swings. The resulting gravity result offset is 0.8 mgals. The gravity interval from Khartoum to Cairo for the first 3 Khartoum swings agrees with gravimeter intervals. For the interval Khartoum B - Nairobi 1 the gravity interval is about one mgal less than the gravimeter interval. All three of these intervals, i.e. Clark 2 - Cairo, Khartoum A - Khartoum B and Khartoum B - Nairobi indicate in a sense, progressive pendulum period decrease in a step-like fashion. Accordingly, the adopted corrections are 0.8 mgals for Clark 2 - Cairo, 0.8 mgals for Khartoum A - Khartoum B and 0.9 mgals for Khartoum B - Nairobi 1. It is felt that the resulting estimated variance after tare corrections is strongly affected by the Madison and Washington erratic periods near the beginning of the sequence, resulting in a pessimistically biased estimate of the error.

The 1956 Gulf M East Coast U.S.A. Trip

Station sequence, mean periods, and corresponding gravity results are listed in Tables II-12 and II-13 respectively. The original trip plan called for observations at Thule, Greenland but electronic timing system failures made successful observations virtually impossible. It was on this trip, between Madison 9 and Woods Hole that the truck containing the pendulums rolled over and was demolished. The agreement of the Madison 8B to Washington, D.C. 8 gravity interval with the 1953 and 1954 intervals indicates that the pendulums were not damaged.

The optical system was modified for this trip because of some difficulty in locating the spots of light at the recording camera.

CHANGE TO INVERTED CAMERA WITHOUT CYLINDER LENS

TABLE II-12

1956 GULF M (STEINHART) EAST COAST USA

Date	Station Sequence	Occup.	Seconds		$\overline{M1-M2}$	Microseconds			n
			$\overline{M}$			$\overline{s_{M1}}$	$\overline{s_{M2}}$	$\overline{s_M}$	
280456	Madison (12)	8B	0.891	556 58	-0.12	?	?	?	1
0105	Washington, D.C.(GLF)	7	POOR RECORDING						
1406	Madison (12)	9	DEFECTIVE MANOMETER						
27	Woods Hole		0.891	575 04	-0.13	0.39	0.61	0.13	4
0107	Washington, D.C.(GLF)	8		678 30	+0.08	.03	.04	.02	5
03	Princeton			642 78		.09	.04	.06	4

TABLE II-13

1956 GULF M (STEINHART) EAST COAST USA

Station	Sequence	Occup.	Uncor- rected g gals	Tare cor- rected g gals	Tare cor- rected M gals	Tare cor- rected mean g gals	Intervals		
							N	mgals Δg	mgals $\pm \overline{s}$
Madison (12)		8B	980.3683				1	+ 267.7	0.65
Washington, D.C.(GLF)		7	Poor recording						
Madison (12)		9	Defective manometer						
Woods Hole			.3276				1	+ 227.0	"
Washington, D.C.(GLF)		8	.1006				1	0	0
Princeton			.1787				1	+ 78.1	.65

s^2 (mgals)² 0.42 Estimated from known g at Madison and Washington.

Modifications to the Apparatus in 1956

Occasionally with the photographic recording scheme used prior to 1956 an anomalous period result was obtained. This could not be explained as it would occur as only one of a series of 3 or 4 observations at a particular site and the rest of the observations would be all right. From the beginning of the development of the photographic recording method in 1950 one of the principal weaknesses of the system was the reliance on the mechanical performance of the synchronous motor which ran the revolving shutter disc. If it were possible for the motor to skip a tooth occasionally, a serious error in the results could be obtained. The motor used had 60 teeth and was driven with a 1000 cycle precision signal. This gave a period of revolution of $60/1000$ sec. so a slip of one tooth would give $1/60$ of a revolution error or 0.01 seconds error in the timing of the pendulum period. Over a one hour swing this would be about 3 microseconds or 6 milligals error in the result.

Conversations with Dr. Gilbert of the Dominion Observatory, Ottawa, and the synchronous motor manufacturer indicated that such slips, even with non-self-starting motors, were indeed possible. Even if the motor did not slip it could have a "hunting" error.

Erratic behavior of the motor at Thule, Greenland during the summer of 1956 led to a series of tests of the motor stability by Steinhart and Iverson. The test results indicated that the motor hunted considerably, and the possibility of completely electronic recording was investigated. The author had considered the feasibility of use of an electronic start-stop counter chronograph in 1951 but at that time circuits that could be operated reliably under adverse field conditions were not available. In 1956 it was decided that the Berkeley EPUT timer would be a practical instrument for field use.

The primary drawbacks of an entirely electronic scheme were that the light beam would have to be very accurately centered on the slit, it would have to remain centered during the observation, and no permanent record of the observation would be obtained. The advantages were that the device gave a direct readout of the raw period and the mechanical device, the synchronous motor, had been eliminated. Photographic records required about one hour per observation to pick and calculate the raw period in addition to the necessity of carrying all the photographic materials in the field. The electronic system made it easily possible to do complicated tests such as period as a function of amplitude without acquiring the almost prohibitive volume of computations inherent in interpreting photographic recordings. The new system also permitted immediate evaluation of the period consistency of field results.

The 1956 revised recording scheme is shown diagrammatically in Figure II-14. A beam of light originates at the light source. Its distance from the lens in the pendulum case is equal to the focal length of the lens, hence the light reflected from the mirror face of the pendulum comes to a focus at the photomultiplier transducer after passing through the slit system just in front of the photomultiplier. Each complete swing of the pendulum produces two electrical events from the photomultiplier. The output pulses from the photomultiplier either directly or indirectly can trigger an electronic gate to start and stop the counting of one-microsecond pulses generated in the interval timer. The one-microsecond pulses come from a one megacycle

secondary crystal frequency standard incorporated in the interval timer (Berkeley Model 7360).

The interval timer can be made to reset to zero either manually with a push button or automatically. With automatic reset the timer resets itself to zero at an adjustable automatic repetition rate. When the gate is operated directly by the photomultiplier pulses, the first pulse after reset-to-zero opens the gate and the second pulse closes the gate. With automatic reset a number of samples of the pendulum half-period can thus be obtained. Of course, the light beam must be accurately centered on the slit initially while the pendulum is at rest, or it can be centered electronically on the slit while the pendulum is swinging by making the "up" and "down" half-periods equal. The Berkeley interval timer lends itself readily to this type measurement.

For measurement of a time interval corresponding to many photomultiplier pulses, i.e., a large number of swings of the pendulums, the period-times-ten function of the Berkeley timer is used. The photomultiplier pulses go into a decade divider circuit. The divider output triggers the timer gate on and off. The input divider normally resets to 9 when the timer unit resets to zero. After reset, the next photomultiplier pulse makes the input divider advance from 9 to 0. The resulting input divider output pulse opens the timing gate and microseconds are counted until the tenth photomultiplier pulse (counting the first as zero) causes the input divider to again go through the 9 to 0 cycle. This second input divider output pulse triggers the timer gate to "off" and the timing stops. Thus the time interval corresponding to 10 photomultiplier events or 5 pendulum periods has been counted. Obviously 5 pendulum periods do not give the required pendulum precision. Since the pendulum period is about 0.9 seconds, 5 swings take about 4.5 seconds. This is sufficient time for the observer to operate an extra switch on the timer unit which disconnects the output of the input divider circuit from the timer gate circuits. In this way any multiple of 5 pendulum periods may be timed. Most of the observations for the 1956-57 trip were for 2000 events of the photomultiplier or 1000 pendulum periods. This is about 15 minutes for each observation. Subsequent trips took one hour observations corresponding to 8000 swings because of the somewhat greater accuracy obtainable.

The double slit system in front of the photomultiplier permits accurate determination of the amplitude of the pendulum swing by measuring the time interval corresponding to passage of the light beam between the two slits. For slit spacing a_i and corresponding time interval δt_i and pendulum period T , the maximum instantaneous amplitude A_i can be calculated from the relation

$$a_i = A_i \sin \omega \delta t_i = A_i \sin \frac{2\pi}{T} \delta t_i \quad (20)$$

If the distance from the slit to the pendulum face is known the angular deflection of the pendulum may be calculated. In practice the amplitude correction was determined experimentally directly in terms of δt . Of course, the spacing between pendulum and slit must be the same for all stations or must be corrected to correspond to a "standard" spacing. At a distance L from the pendulum mirror face to the slits the vertical linear deflection A corresponding to the angular deflection α of the pendulums is given by the relation

$$A = L \tan 2\alpha \doteq 2 L \alpha. \quad (21)$$

An equation for reduction to zero amplitude corresponding to equation (6) but in terms of δt can be written:

$$\Delta T_A = -0.001293 \frac{\left(\frac{1}{\delta t_1}\right)^2 - \left(\frac{1}{\delta t_2}\right)^2}{\log_{10} \frac{\delta t_2}{\delta t_1}} \times 0.8915 \text{ microseconds} \quad (22)$$

where the constant 0.001293 was determined experimentally and 0.8915 is the Gulf M pendulum period at about 45° latitude. The slit width was 0.010 inches, the slit system center bar width was 0.253 inches, and the distance L was 30 cm. The data obtained for the experimental determination of ΔT_A are shown in Figure II-15.

The 1956-7 Gulf M Pacific Trip

The sequence of stations is shown in Figure II-16 and the corresponding periods and gravity results in Tables II-14 and II-15 respectively. The additional station descriptions and sketches are in Appendices II-3 and II-8 respectively. The mean of the reoccupation closure errors at Brisbane, Melbourne, Sydney, Christchurch, San Francisco and Madison is -1.3 ± 0.3 mgals. The results of the gravimeter (Worden 10f) used in conjunction with the trip show that the tare occurred between Brisbane 1 and Townsville 1. With this tare correction the mean gravity intervals and estimated standard errors were determined from the reoccupation closures.

By the nature of the electronic recording system, either the "fictitious" pendulum (the optical mean of the individual pendulums) or one of the "real" pendulums could be recorded at a particular time. To record each pendulum of a pair independently and simultaneously would have required two electronic interval timers. Nevertheless, a few recordings of one of the individual pendulums (M2) were usually made at each field station. The differences between the mean periods of the pair and the mean periods of the individual pendulum are tabulated in Table II-14 and shown graphically in Figure II-17. The effect of the tare between Brisbane and Townsville is indicated with the dashed line.

The reason for the rejection of Christchurch 2 is shown in Figure II-18. Apparently the McLeod vacuum gage was defective. This type of anomalous pressure reading has occurred occasionally, but Christchurch 2 was the only station of the 1956-7 trip for which it was definitely observed. It appears to be related to dirt in the gage and possibly to silicone grease blocking the glass valves in the vacuum line to the manometer. The same type of effect occurred in the 1957 Gulf M South America trip at Antofagasta and Punta Arenas. In 1959 the apparatus was completely overhauled and a thermocouple gage system for pressure measurement was installed. This was not possible in the earlier instrumentation because of the combination of pressure leak in the case and the limited range of a thermocouple gage.

Considerable difficulty was experienced at the Ross Island site because of the lack of a stable foundation for the pendulum equipment. Various schemes were attempted, including one-inch thick steel plates on top of alternating layers of volcanic ash and plaster of paris in the permafrost. The steel plate

FIG. II - 15

EXPERIMENTAL DETERMINATIONS OF
GULF M-SET AMPLITUDE CORRECTION

FIG. II-16

FIG. II-17

II-48

CHANGE TO ELECTRONIC RECORDING

TABLE II-14
1956-7 GULF M (ROSE) PACIFIC

Date	Station Sequence	Occup.	Seconds		Microseconds			μ sec.	
			$\overline{M}$		$\overline{M-M2}$	$\overline{s}$ $\overline{M2}$	$\overline{n_{M2}}$	$\overline{s}$ $\overline{M}$	$\overline{n_M}$
141156	Madison (12)	10	0.891	558 72	-1.44	0.32	4	0.09	4
21	San Francisco	4		731 96	-1.03	.11	2	.17	5
27	Christchurch	1		494 87	-1.95	.55	3	.19	5
0212	Hastings			685 30	-2.02	?	1	.18	3
03	Lower Hutt			592 53	-1.05	.43	2	.11	5
040157	Ross Island		0.890	367 96	-1.56	?	1	.11	7
28	Melbourne (FOOTSCRAY)	1	0.891	735 63			0	.13	6
31	Christchurch	2		496 34	-1.57	.73	3	.08	7
0802	Sydney	1		869 44	-1.78	.29	3	.14	6
11	Brisbane	1	0.892	104 58	-0.94	.63	3	.18	6
15	Townsville	1		354 15	-0.53	.23	2	.14	6
16	Cairns	1		410 87	-1.30	.02	2	.06	4
21	Brisbane	2		105 59	-0.45	.41	3	.12	7
26	Melbourne	2	0.891	736 22	-0.62	.04	2	.12	8
0103	Darwin (BMR)	1	0.892	495 06	-0.95	.62	3	.04	4
05	Sydney	2	0.891	869 59	-0.33	?	1	.06	5
07	Christchurch	3		495 29	-0.80	.24	3	.08	5
10	Dunedin			388 97	-1.80	.33	3	.19	5
12	Christchurch	4		495 28	-2.41	?	1	.24	4
19	Honolulu	3	0.892	203 96	-0.61	.05	2	.05	5
22	San Francisco	5	0.891	732 81			0	.13	4
31	Madison (12)	11		559 16	-0.83	1.37	4	.10	19

TABLE II-15

1956-57 GULF M (ROSE) PACIFIC

Station Sequence	Occup.	Uncor- rected g gals	mgals T.C.	Tare cor- rected g gals	Mean tare cor- rected g gals	N	mgals Δg	mgals $\pm s$	(mgals) ² s^2
Madison (12)	10	980.3689			980.3689	2	0	0	0
San Francisco	4	979.9880			979.9875	2	- 381.4	0.46	0.212
Christchurch	1	980.5093			980.5094	(3)	+ 140.5	.53	.281
Hastings		.0906			.0904	1	- 278.3	.56	.315
Lower Hutt		.2945			.2943	1	- 74.6	"	"
Ross Island		982.9929			982.9927	1	+2623.8	"	"
Melbourne (Ftscry)	1	979.9799			979.9798	2	- 389.1	.46	.212
Christchurch	2	(980.5061)	Rejected						
Sydney	1	979.6859			.6862	2	- 682.7	"	"
Brisbane	1	.1695			.1689	2	-1200.0	"	"
Townsville	1	978.6219		.6232	978.6230	1	-1745.9	.56	.315
Cairns	1	.4975		.4988	.4986	1	-1870.3	"	"
Brisbane	2	979.1673		.1686	--				
Melbourne	2	.9787		.9800	--				
Darwin (BMR)	1	978.3129		.3142	.3140	1	-2054.9	"	"
Sydney	2	979.6856		.6869	--				
Christchurch	3	980.5084		.5097	--				
Dunedin		.7423		.7436	980.7434	1	+ 374.5	"	"
Christchurch	4	.5084		.5097	--				
Honolulu	3	978.9514		.9527	978.9525	1	-1416.4	"	"
San Francisco	5	979.9861		.9874	--				
Madison (12)	11	980.3679		.3692	--				

D.F.
 s^2 (mgals)²
s mgals

6
0.21
0.46

scheme did not work because the foundation would slowly sink differentially into the permafrost. In addition, the surrounding air in the building was too cold to permit the pendulum case to be heated to its normal operating temperature. The problem was eventually solved when several bags of cement were obtained from the U.S. Navy and a different and isolated building was made available. Permission was granted to remove a section of the plywood floor, and a concrete pier was poured. Insulation was packed around the concrete to prevent it from freezing while setting. The aggregate used was volcanic rock material selected for its appearance of durability. A 4 by 6 inch brass plate was set in the concrete with blind retaining bolts underneath. The pier was examined by Dr. Edward Thiel in 1959 and found to be in good condition. At that time he and an associate measured the elevation of the top of the pier above their determination of mean sea level as 12.90 meters. At the time of the observation in 1956-7 the elevation was measured as 9.33 meters relative to the "HUT" bench mark on Hut Point taken at that time as 7.62 meters (25 feet) arbitrarily. The tide was said to have a total amplitude of 2.5 feet but mean sea level was not known because the tide gage had frozen during the winter.

The 1957 Gulf M East Coast and South America Trips

New station descriptions and sketches are in Appendices II-1, II-2, II-6 and II-7 respectively. Mean periods are listed in Tables II-16 and II-17 and gravity results are listed in Tables II-18 and II-19. The station sequence for South America is shown in Figure II-19.

The 1957 South America observations represent a saga of assorted difficulties in the field. By Panama 1 the vacuum pump developed trouble and there were several power failures as well as erratic counting of the interval timer. The power was 25 cycles per second causing the interval timer to blow fuses. Lima 1 was relatively routine with only occasional power failures. At Quito the power was exceptionally erratic and observations had to be made at night because of the excessive ground motion during the day. One night five unsuccessful attempts were made to get a period determination, all failures due to power failures. At La Paz 1 there was an attempt to keep trucks away from the site because of ground motion problems. An auxiliary gasoline generator was used for power. The floor was tile rather than concrete. At Santiago 1 the room was too cold to maintain the normal 35°C. operating temperature, so it was reduced to 25°C. by installing a 25°C thermostat. By Punta Arenas the 25°C. thermostat failed and some transformers of the heater control circuit had shaken loose. The anomalous pressure reading shown in Figure II-20 resulted from an electric heater being too close to the McLeod gage. Observations then appeared to be getting routine until the Antofagasta, where a small earthquake occurred during the observations, the thermostat failed, the anomalous pressures shown in Figure II-21 were observed as the result of a contaminated mercury column, and local photographers taking flash pictures made new observations necessary. At La Paz 2 the interval timer was erratic and the high-voltage power supply for the photomultiplier developed an arcing and a battery supply had to be improvised. Aluminum filings and a loose screw were found in the interval timer circuitry. The pressure and timing problems persisted for the remainder of the trip.

The 1957 trip could not be satisfactorily evaluated until 1960 when adequate comparison data were finally available. The unadjusted gravity results computed

TABLE II-16
1957 GULF M (ROSE) EAST COAST USA

Date	Station Sequence	Occup.	Seconds $\bar{M}$	μ Sec. $\bar{s}$	n
310357	Madison (12)	11	0.891 559 16	0.10	19
2704	Washington, D.C.(GLF)	9	681 01	.15	7
0305	Charleston	1	930 90	.17	7
0306	Madison (12)	12	559 13	.14	10
0307	"		559 48	.21	10

TABLE II-17
1957 GULF M (WATKINS) SOUTH AMERICA

030757	Madison (12)	12	0.891 559 48	0.21	10
05	Minneapolis	1	454 86	.16	3
08	Madison (12)	13	559 02	.07	7
13	Charleston	2	931 88	.05	6
15	Washington, D.C.(GLF)	10	682 36	.07	4
18	Charleston	3	931 97	.07	4
21	Panama	1	0.892 527 87	.14	4
24	Lima	1	508 20	.11	4
28	Quito	1	966 76	.15	2
31	La Paz	1	880 86	.15	5
0408	Santiago	1	0.891 986 04	.05	3
13	Punta Arenas		128 92	.06	4
17	Santiago	2	986 39	.14	4
20	Buenos Aires	1	861 16	.06	4
26	Antofagasta		0.892 226 27	.17	5
30	La Paz	2	880 99	.27	4
0209	Lima	2	509 70		1
05	Panama	2	529 38	.17	10
12	Charleston	4	0.891 933 36	.18	4
14	Washington, D.C.(GLF)	11	682 13	.19	5
19	Madison (12)	14A	560 03	.05	3

TABLE II-18
1957 GULF M (ROSE) EAST COAST USA

Station Sequence	Occup.	Uncorrected		Mean	Intervals		(mgals) ²
		g gals	mgals 57M-59KM		mgals Δg	mgals $\pm s$	
Madison (12)	11	980.3689	0	.3689	+ 268.0	0.83	0.69
Washington, D.C. (GLF)	9	.1010	+0.4	.1009	0	0	0
Charleston	1	979.5519	+1.0	.5518	- 549.1	0.96	0.92
Madison (12)	12A	980.3690	+0.1	--			
D.F. s ² (mgals) ²			3 0.46				

Note: Error estimated by comparison with 1959 KM results.

TABLE II-19
1957 GULF M (WATKINS) SOUTH AMERICA

	Occup.	Uncor- rected	G-C	G-G58	G-G59	G-WM	mgals T.C.	Tare cor- rected	Mean tare cor- rected	Intervals N	mgals Δg	mgals $\pm s$	(mgals) ²
		g gals						g gals	g gals		g gals		
Madison (12)	12B	980.3689	0	0	0	0		.3689	.3694	3	0	0	0
Minneapolis	1	.5990						.5990	.5990	1	+ 229.6	0.94	0.883
Madison (12)	13	.3697	+0.8	+0.8	+0.8	+0.8		.3697	--				
Charleston	2	979.5504			-0.5	-0.5		.5504	.5499	3	(- 819.5)	(.66)	(.442)
Washington, D.C. (GLF)	10	980.0987			-1.9	-1.9		.0987	.0999	2	- 269.5	.74	.552
Charleston	3	979.5502			-0.7	-0.7		.5502	--				
Panama	1	978.2427	+1.0	+0.8		+0.9		.2427	.2420	2	-2127.4	"	"
Lima	1	.2858	+2.8	+2.1		+2.6		.2837	.2841	2	-2085.3	"	"
Quito	1	977.2813	+3.1	+1.9		+2.7		.2792	.2792	1	-3090.2	.94	.883
La Paz	1	.4693	+2.5			+2.5		.4672	.4671	2	-2902.3	.74	.552
Santiago	1	979.4315	+2.5			+2.5		.4294	.4290	2	- 940.4	"	"
Punta Arenas	1	981.3165						.3144	.3144	1	+ 945.0	.94	.883
Santiago	2	979.4307	+1.7			+1.7		.4286	--				
Buenos Aires	1	.7060	+0.9	-0.2		+0.8		.7039	.7039	1	- 665.5	"	"
Antofagasta	1	978.9041						.9020	.9020	1	-1467.4	"	"
LaPaz	2	977.4691	+2.3			+2.3		.4670	--				
Lima (poor)	2	978.2825	-0.5	-1.2		-0.7		.2844	--				
Panama	2	.2393	-2.4	-2.6		-2.5		.2412	--				
Charleston	4	979.5472			-3.7	-3.7		.5491	--				
Washington, D.C. (GLF)	11	980.0992			-1.4	-1.4		.1011	--				
Madison (12)	14A	.3677	-1.2	-1.2	-1.2	-1.2		.3696	--				

D.F.
s² (mgals)²

9
0.662

Charleston
Washington, D.C. (GLF)

3 - 550.0 0.74 0.552
2 0 0 0

G-C = 1957 Gulf (Watkins) - 1958 Cambridge (Jackson)
G-58G = " " " - 1958 Gulf (Iverson)
G-59KM = " " " - 1959 Gulf KM (Rose and Strickholm)

FIG. II-19

1957 GULF M
SOUTH AMERICA
STATION SEQUENCE

FIG. II-21

relative to Madison 12B were compared with the 1958 Cambridge-Pendulum results of Jackson, the tare corrected 1958 Gulf M Pendulum results of Iverson and, for Charleston, with the 1959 Gulf K and M results of Rose and Strickholm. Comparison of the 1957 results with the weighted mean of the more recent results indicated that the simplest interpretation was a tare of $+2.1 \pm 0.1$ mgals between Panama 1 and Lima 1 and another tare of -4.0 ± 0.3 mgals between La Paz 2 and Lima 2. These adjustments were made and the mean gravity intervals computed. It is felt that the estimated variance of 0.662 (mgals)^2 for each station occupation is probably valid. The error for Antofagasta and Punta Arenas may be as much as several milligals because of the necessity for estimating the pressure.

The 1958 Gulf M Far East and Pacific Trip

Figure II-22 shows the station sequence. New station descriptions and sketches are given in Appendices II-3 and II-8 respectively. Mean periods and gravity results are given in Tables II-20 and II-21 respectively.

The trip had two tares as indicated by the closure errors at reoccupation stations. Reoccupation stations including tare No. 1 were San Francisco, Tokyo, Okinawa, Manila and Hong Kong with closure errors of -1.3, -1.2, -1.1, -0.9 and -2.1 mgals respectively. These give a mean tare of -1.3 ± 0.21 mgals. This was adopted as tare No. 1, occurring between Hong Kong 1 and Singapore. Tare No. 2 was taken as 1.8 mgals. Madison was the only closure including both tares, and fails to close by -3.1 mgals. Tare No. 2 occurred between San Francisco 2 and Seattle 1.

The stations with particular field difficulties were Hong Kong 1 and Tokyo 2. At Hong Kong 1 the clamped pendulums were knocked off from their base blocks by a janitor. A second set of observations were made following the accident, giving a mean period 0.4 microseconds lower than before the accident. This was not regarded as a permanent period change. At Tokyo 2 there was difficulty with erratic behavior of the electronic interval timer.

The 1958 Gulf M South America Trip

Figure II-23 gives the sequence of stations and Tables II-22 and II-23 give the mean periods and gravity results respectively. The pendulum reoccupation closures indicated two tares. Tare No. 1 was between Bogota and Caracas 1 and Tare No. 2 was between Belém and Rio de Janeiro 1. The mean total tare based on closures at Madison, Mexico, D.F., and Panama was -2.9 ± 0.3 mgals. Tare No. 2 based on closures at Caracas and Panama 2 and 3 was -1.3 ± 0.35 mgals. Tare No. 1 was the difference between these or -1.6 mgals. The tare corrections were applied and mean gravity intervals computed, as listed in Table II-23.

Modifications to the Gulf Apparatus in 1958-9

A three stage program of instrument refinements was begun late in 1958. The first stage was to improve the vacuum system, temperature control, and optical system. The second stage was to improve the recording system. The third stage has not yet been undertaken, i.e., the improvement of the pendulum itself.

TABLE II-20
1958 GULF M (IVERSON) FAR EAST AND PACIFIC

1958 GOLF II (IVERSON) FAR EAST AND PACIFIC							u Sec.	n
Date	Station Sequence	Occup.	Seconds			$\bar{s}$		
			$\bar{M}$					
070158	Madison (28)	14B	0.891	557	36	0.03	7	
	Equiv. (12)			557	31			
18	San Francisco	6		731	20	.10	5	
20	Honolulu	4	0.892	201	76	.04	5	
25	Tokyo	2	0.891	815	18	.16	3	
28	Okinawa (KADENA AFB)	1	0.892	122	77	.05	6	
30	Manila (CLARK AFB)	4		455	70	.11	5	
0202	Hong Kong	1		286	51	.09	8	
05	Singapore			599	60	.07	6	
14	Darwin (BMR)	2		493	31	.12	5	
16	Brisbane	3		103	38	.08	5	
17	Cairns	2		408	40	.04	5	
20	Sydney	3	0.891	868	18	.08	4	
210258	Christchurch	5	0.891	494	29	0.05	4	
22	Sydney	4		868	58	.01	4	
24	Brisbane	4	0.892	103	73	.04	6	
25	Cairns	3		408	76	.05	4	
26	Townsville	2		352	25	.08	4	
0203	Brisbane	5		103	49	.12	9	
05	Darwin (BMR)	3		493	48	.03	4	
14	Manila (CLARK AFB)	5		455	91	.08	7	
14	Hong Kong	2		287	44	.06	4	
27	Manila (CLARK AFB)	6		456	13	.04	4	
30	Okinawa (KADENA AFB)	2		123	29	.04	3	
0304	Tokyo	3	0.891	815	74	.17	2	
08	Chitose AFB			524	96	.06	4	
13	San Francisco	7		731	80	.07	8	
20	Seattle	1		390	08	.09	6	
23	Fairbanks (LADD AFB)	2	0.890	706	89	.06	5	
28	Point Barrow			500	91	.06	3	
0205	Fairbanks (LADD AFB)	3		707	02	.17	4	
05	Seattle	2	0.891	390	32	.01	4	
10	Madison (28A)	15A		558	77	.03	5	
	Equiv. (12)			558	72			

TABLE II-21

1958 GULF M (IVERSON) FAR EAST AND PACIFIC

Station Sequence	Occup.	Un- corrected g gals	Tare cor- rected g gals	Mean Tare corrected g gals	N	Intervals		(mgals) ² <u>s</u>
						mgals <u>Δg</u>	mgals <u>+ s</u>	
Madison (28)	14B							
Equiv. (12)		980.3689		.3689	2	0	0	0
San Francisco	6	979.9866		.9866	2	- 382.3	0.38	0.141
Honolulu	4	978.9531		.9531	1	-1415.8	.46	.212
Tokyo	2	979.8020		.8020	2	- 566.9	.38	.141
Okinawa (Kadena AFB)	1	.1265		.1266	2	-1242.3	.38	.141
Manila (Clark AFB)	4	978.3961		.3965	3	-1972.4	.34	.118
Hong Kong	1	.7672		.7668	2	-1602.1	.38	.141
Singapore		.0807	.0820	.0820	1	-2286.9	.46	.212
Darwin (BMR)	2	.3137	.3150	.3148	2	-2054.1	.38	.141
Brisbane	3	979.1690	.1703	.1700	3	-1198.9	.34	.118
Cairns	2	978.4998	.5011	.5007	2	-1868.2	.38	.141
Sydney	3	979.6856	.6869	.6864	2	- 682.5	.38	.141
Christchurch	5	980.5075	.5088	.5088	1	+ 139.9	.46	.212
Sydney	4	979.6847	.6860	--				
Brisbane	4	.1683	.1696	--				
Cairns	3	978.4990	.5003	--				
Townsville	2	.6230	.6243	.6243	1	-1744.6	.46	.212
Brisbane	5	979.1688	.1701	--				
Darwin (BMR)	3	978.3133	.3146	--				
Manila (Clark AFB)	5	.3957	.3970	--				
Hong Kong	2	.7651	.7664	--				
Manila (Clark AFB)	6	.3952	.3965	--				
Okinawa (Kadena AFB)	2	979.1254	.1267	--				
Tokyo	3	.8008	.8021	--				
Chitose AFB		980.4400	.4413	.4413	1	+ 72.4	.46	.212
San Francisco	7	979.9853	.9866	--				
Seattle	1	980.7368	.7399	.7396	2	+ 370.7	.38	.141
Fairbanks (Ladd AFB)	2	982.2418	.2449	.2448	2	+1875.9	.38	.141
Point Barrow		.6963	.6994	.6994	1	+2330.5	.46	.212
Fairbanks (Ladd AFB)	3	.2416	.2447	--				
Seattle	2	980.7363	.7394	--				
Madison (28A)	15A	---						
Equiv. (12)		.3658	.3689	--				

D.F.
s² (mgals)²

14
0.141

FIG. II-23

1958 GULF M
SOUTH AMERICA
STATION SEQUENCE

TABLE II-22
1958 GULF M (IVERSON) SOUTH AMERICA

Date	Station Sequence	Occup.	Seconds		u Sec.	n
			M			
150758	Madison (12)	15B	0.891	558 63	0.06	7
19	Mexico, D.F. (U.FLOOR)	3	0.892	664 35	.06	4
	Equiv. (TAC.FLOOR)			664 21		
20	Panama (FT.CLAYTON)	3		527 50	.04	7
25	Bogota			909 56	.07	4
30	Caracas	1		620 33	.13	5
0408	Panama (FT.CLAYTON)	4		528 18	.05	12
06	Belem			621 77	.10	6
08	Rio de Janeiro	1		271 89	.11	6
12	Buenos Aires	2	0.891	861 58	.03	6
18	Rio de Janeiro	2	0.892	272 43	.15	8
21	Caracas	2		621 11	.05	5
24	Panama (FT.CLAYTON)	5		528 63	.03	7
28	Quito	2		968 24	.07	5
30	Lima	3		509 76	.06	4
0209	Panama (FORT CLAYTON)	6		529 16	.01	4
06	Mexico, D.F. (U.FLOOR)	4		665 56	.01	4
	Equiv. (TAC.FLOOR)			665 42		
08	Madison (12)	16A	0.891	560 22	.05	4

TABLE II-23

1958 GULF M (IVERSON) SOUTH AMERICA

Station Sequence	Occup.	Uncor- rected g gals	Tare cor- rected mgals	Tare cor- rected g gals	Mean Tare cor- rected g gals	N	Intervals		
							mgals Δg	mgals $+\bar{s}$	(mgals) ² $\bar{s}^2$
Madison (12)	15B	980.3689			980.3689	2	0	0	0
Mexico, D.F. (U.floor)	3								
Equiv. (Tac.floor)		977.9420			977.9424	2	-2426.5	0.49	0.237
Panama (Ft.Clayton)	3	978.2416			978.2419	4	-2127.0	.42	.178
Bogota		977.4046			977.4049	1	-2964.0	.60	.356
Caracas	1	978.0381			978.0398	2	-2329.1	.49	.237
Panama (Ft.Clayton)	4	.2401	+1.6	.0397	--				
Belem		.0350		.0366	.0369	1	-2332.0	.60	.356
Rio de Janeiro	1	.8022		.8051	.8048	2	-1564.1	.49	.237
Buenos Aires	2	979.7030		.7059	979.7062	1	- 662.7	.60	.356
Rio de Janeiro	2	978.8010		.8039	--				
Caracas	2	.0364		.0393	--				
Panama (Ft.Clayton)	5	.2391		.2420	--				
Quito	2	977.2762	+2.9	.2790	977.2794	1	-3089.5	"	"
Lima	3	978.2805		.2834	978.2837	1	-2085.2	"	"
Panama (Ft.Clayton)	6	.2380		.2409	--				
Mexico, D.F. (U.floor)	4				--				
Equiv. (Tac.floor)		977.9393		.9422	--				
Madison (12)	16A	980.3654		.3683	--				

D.F.
s² (mgals)²

7
0.237

The Gulf apparatus had long been plagued with the problem of pressure leaks in the case. It was felt that the 25 year old design of the vacuum system left much to be desired. The main case seal consisted of mating lapped surfaces on which silicone stopcock grease was applied. The windows were sealed with neoprene gaskets, and the control shafts were compression cotton packing glands. Invariably the case would hold a vacuum well for a while after repacking, and then over a period of months would gradually develop an ever-increasing leak rate. Tests with a Helium leak-chaser indicated that most of the leak was through the main case seal. The K-set was modified in the winter of 1958-9 and the M-set was modified in the summer of 1959. The sets were disassembled and the castings and framework thoroughly cleaned with inhibited trichloroethane followed by acetone followed by petroleum ether. The main seal, shaft seals and window seals were modified to accommodate neoprene O-rings. The bronze shaft seal housings formerly had been threaded into the aluminum alloy case casting and vacuum sealed with lead washers. The lead washers were replaced with Teflon O-rings. The McLeod gage measuring system was replaced with a very rugged type of thermocouple gage clamped close to the outside of the casting so that it could be at the same temperature as the pendulum case. Formerly, corrections for ambient room temperature were necessary with the McLeod gage, leading to rather large pressure effects at room temperature extremes. The external vacuum plumbing was arranged to permit convenient periodic checks of the thermocouple gage calibration. A kovar-sealed electrical connector with an O-ring seal was fitted to each case.

The original cork sleeves on the bumper arm shafts of the cocking mechanism were replaced by nylon. For each case, an aged thermistor was cemented into the slot in each pyrex bearing block and an additional aged thermistor was affixed to the base of the internal thermometer as a check on the possible drift of the thermistors. Formerly it was never certain that the internal thermometer accurately represented the temperature of the pendulums. The pyrex blocks should have thermal lag effects similar to the quartz of the pendulums, so measurement of the pyrex block temperature should give a reasonable representation of the pendulum temperature.

New optical benches with a black anodized aluminum framework and utilizing first-surface mirrors exclusively were made. They can be adjusted by removing the front and rear windows of the case.

With the foregoing modifications it became possible to leave the flap of the temperature insulating down cover closed during the observations, thereby improving the period stability of the No. 2 pendulum of the pair. The final step regarding the vacuum was to coat the case castings. The K-case under slight vacuum was coated with several layers of clear glyptal varnish, each baked on, and finally with a heavy coat of gray glyptal. The M-case was coated with an anerobic setting epoxy resin ("Permafill").

There was insufficient time to complete the new recording system for the 1959 Africa trip with the K-set, so the photomultiplier and slit system with the electronic interval timer was used. Eighty cm. focal length lenses as well as a slit spacing identical to that used since 1956 were employed so that the period reductions would be the same as in 1956, 7 and 8.

The 1959 Gulf K Africa Trip

Figure II-24 shows the station sequence. New station descriptions and sketches are in Appendices II-4, II-5, II-9 and II-10. The observed sequence of reduced mean periods is given in Table II-24 and the gravity computations in Table II-24. The number of observations at each station occupation was greater than the number of times lowered indicated by L in Table II-24. The total numbers of observations for each occupation are listed below:

	<u>Occup. 1</u>	<u>Occup. 2</u>	<u>Occup. 3</u>
Madison	23	9(A); 9(B)	6
Minneapolis	9		
Teddington	5	13	
Lisbon	8	17	
M'bour	9	10	
Accra	5	13	
Leopoldville	8	14	
Johannesburg	18	22	
Paris	23		

A correction for possible off-centering of the light beam on the slit was derived:

$$\Delta T_{oc} = \frac{T}{2\Delta t} [S_{u1} - S_{d1} - S_{u2} + S_{d2}] \quad (23)$$

in which

- ΔT_{oc} = correction in microseconds to be added to the pendulum period.
- T = observed pendulum period in seconds.
- Δt = duration of the individual observation in minutes.
- S_{u1} = mean half-period of up-swings at the beginning of the observation.
- S_{u2} = mean half-period of up-swings at the end of the observation.
- S_{d1} = mean half-period of down-swings at the beginning of the observation.
- S_{d2} = mean half-period of down-swings at the end of the observation.

The mean half-periods could be very easily measured with the electronic interval timer. The recording box was not touched during the entire observation except for the instantaneous amplitude determinations before and after the observation.

The reason for the means grouped by lowerings is apparent from Figure II-25. The large period closure errors at reoccupation sites were found to be remarkably systematic, plotted as a function of the number of times the pendulums were lowered. It is felt that the effect may also be a function of time, but predominantly it is related to lowering. Examination of Figure II-8 suggests that the same phenomenon was affecting the K-set in 1953 subsequent to the overheating at Cutbank. This effect is believed to be directly related to the physical condition of the cement holding the knife edge plug in the pendulum. There are presently two obvious differences between the K and M pendulum sets. The K-set has a great number of large air bubbles in the cement of the knife edge plug (the cement is above the plug) while the M-set has only a few small air bubbles in the cement. It is suspected that the bubbles developed as the result of the overheating at Cutbank in 1953. The cementing material appears to be

II-65

GULF K 1959 AFRICA
STATION SEQUENCE

FIG. II-24

TABLE II-24
1959 GULF K (IVERSON) AFRICA

Date	Station Sequence	Occup.	Seconds Grouped $\bar{K}$	$\bar{L}$	$\bar{s}^2$ (μ sec) ²	ΔL	ΔT_L	ΔT_T	Corr. Grouped $\bar{K}$ Seconds
140759	Madison (12)	1	0.889 658 59	3	0.031				
18	Minneapolis		555 07	3	0.0032				
19	Madison (12)	2A	658 80	3	0.0010				
20	Madison (12)	2B	659 07	3	0.0020	0	0		0.889 659 07
24	Teddington	1	283 66	2	0.0073	2.5	0.11		283 77
29	Lisbon	1	785 34	6	0.0079	6.5	0.28		785 62
0308	Mbour	1	0.890 560 56	5	0.0279	12	0.52		0.890 561 08
07	Accra	1	687 30	4	0.0027	16.5	0.72		688 02
09	Leopoldville	1	773 98	5	0.0127	21	0.91		774 89
13	Johannesburg	1	484 45	9	0.0025	28	1.21		485 66
16	Leopoldville	2	773 50	9	0.0027	37	1.60	-0.18	774 92
21	Johannesburg	2	483 85	12	0.0053	47.5	2.06	"	485 73
24	Accra	2	685 67	7	0.0026	57	2.47	"	687 96
28	Mbour	2	558 42	5	0.0026	63	2.73	"	560 97
29	Lisbon	2	0.889 782 78	8	0.0110	73.5	3.19	"	0.889 785 79
0109	Paris		396 41	10	0.0060	82.5	3.58	"	399 81
04	Teddington	2	280 39	4	0.0030	89.5	3.88	"	284 09
13	Madison (12)	3	655 36	2	0.0090	92.5	4.01	"	659 19

Symbols:

Occup.	Occupation
Grouped $\bar{K}$	Mean of mean reduced periods per lowering
$\bar{L}$	Number of times the pendulums were lowered at the station
$\bar{s}^2$	Variance of the grouped mean period
ΔL	Number of intervening lowerings between grouped means
ΔT_L	Creep correction to period
ΔT_T	Tare " " "

TABLE II-25

1959 GULF K (IVERSON) AFRICA

Station Sequence	Occup.	g gals	Mean g gals	N	mgals Δg	mgals $+\bar{s}$	(mgals) ² $\frac{\bar{s}}{s}$
Madison (12)	1	980.3689 ⁰	980.3686 ⁷	2	0	0	0
Minneapolis		.5970 ⁹	.5970 ⁹	1	+ 228.42	0.29	0.085
Madison (12)	2A	.3684 ⁴	--				
Madison (12)	2B	980.3689 ⁰	980.3687 ⁷	2	- 827.43	0.24	0.057
Teddington	1	981.1965 ⁵	981.1962 ⁰	2	0	0	0
Lisbon	1	980.0900 ⁵	980.0898 ⁷	2	-1106.33	.24	.057
Mbour	1	978.3839 ⁶	978.3840 ⁸	2	-2812.12	"	"
Accra	1	.1051 ⁰	.1051 ⁷	2	-3091.03	"	"
Leopoldville	1	977.9143 ⁴	977.9143 ¹	2	-3281.89	"	"
Johannesburg	1	978.5497 ⁰	978.5496 ²	2	-2646.58	"	"
Leopoldville	2	977.9142 ⁷	--				
Johannesburg	2	978.5495 ⁴	--				
Accra	2	.1052 ³	--				
Mbour	2	.3842 ⁰	--				
Lisbon	2	980.0896 ⁸	--				
Paris		.9405 ⁴	980.9405 ⁴	1	- 255.66	.29	.085
Teddington	2	981.1958 ⁵	--				
Madison (12)	3	980.3686 ⁴	--				

D.F.
s² (mgals)²

7
0.057

white shellac. The other difference is that the K-set lowering device and clamping arrangement are out of adjustment. If the poor mechanical adjustments were causing excessive knife edge wear, the periods would be expected to increase. It is concluded that the air bubbles tend to increase in size every time the pendulum knife edge plugs are subjected to the weight of the pendulum and then raised and clamped and the load removed. This would slowly shorten the effective length of the pendulum. It is expected that this effect would continue but at a much slower rate while sitting for months in a clamped position. The total K-set period decrease between August 20 1959 and June 1960 has been about 11 microseconds. Both pendulums of the pair are affected. From the equation for the period of a simple pendulum the logarithmic differential is

$$\frac{dT}{T} = \frac{1}{2} \frac{dl}{l} \quad (24)$$

so for an effective pendulum length of about 20 cm. the length change was approximately 0.004 millimeters or 0.0002 inches! It will be seen in the 1959 East Coast trip that the M-set periods do not show the period decrease effect, suggesting that the K pendulums would be alright if the knife edge plugs were to be re-cemented. This would not be difficult.

On the basis of the least-square fit to the points in Figure II-25 a "Creep" correction was applied to the mean periods. Also, a tare correction of 0.18 microseconds was applied for all stations subsequent to Johannesburg. The gravity results and intervals relative to Madison and Teddington are given in Table II-25.

Modifications in the Gulf Recording System in 1959

Subsequent to the Gulf K 1959 Africa trip a new transducer box with high precision slits, a strong light source and tiny silicon photodiodes (Texas Instruments IN2175) was employed. The output of the photodiodes was applied to a high-speed direct-readout 14 channel galvanometer oscillograph (Honeywell-Heiland Model 906 A-1). The galvanometer system has a number of advantages. With an ordinary photographic system it is difficult to record more than two pendulums simultaneously. The galvanometer camera can easily record 8 or 10. In addition it records WWV directly, simultaneously with timing marks generated by an auxiliary secondary time standard. This means that in addition to the usual scheme of tuning the "head" end of the timing system to WWV and hoping that the frequency dividers function properly, an independent direct check of the timing system against WWV is recorded at the "tail" end along with the pendulum pulses. It would also be possible to record temperature and pressure but it was felt there was no particular advantage in this.

One of the chief drawbacks with the direct use of an electronic interval timer and slit system was that the interval timer could only trigger on the leading or trailing edge of a pulse. This introduced an error into the observed period because of the slower rise time of pulses at the end of an observation due to the reduced amplitude of the pendulums. Also, any change in intensity of the light source would change the rise time of the pulses. The pendulum amplitude damping effect would introduce a constant period error at all stations. The change in light intensity error would be different for each station.

All of these problems including that of off-centering of the light beam on the slit disappear with the use of the galvanometer recorder. Another advantage is that intermediate period samples at 15 minutes, 30 minutes, etc. can be taken without disturbing the one hour observation. The paper drive speed used is 50 inches per second. Of course, only a few seconds can be sampled at any one time unless one desires to fill up the room with paper. Each of the five cycles of the WWV seconds tick is very easy to see on the recording, and any shift relative to the millisecond timing lines from the crystal clock system is easy to evaluate.

For the 1960 observations a transistorized crystal clock will be used, making the timing system independent of local power.

The 1959 Gulf K and M East Coast Trip

It was desirable to have a gravimeter calibration line on the East Coast. Considerable gravimeter work had already been done by the University of Wisconsin group, U.S. Coast and Geodetic Survey and the Dominion Observatory. It was felt that the trip would also serve as a field test to determine the amount of improvement in the results effected by the extensive modifications. The station sequence is shown in Figure II-26 and the new station descriptions and sketches are given in Appendices II-1 and II-6 respectively. Table II-26 lists the mean period data and Table II-27 lists the gravity results corrected for earth tides.

The creep effect in the K-set periods observed in Africa was still present, as shown in Figure II-27, and a correction determined from the least-square straight line fit of the reoccupation closures was applied. The M-set did not show any period change in the field. The very close agreement of the gravity results with the two sets implies that the method of handling the K-set creep effect is valid. The East Coast results are the best ever obtained with the Gulf pendulums and possibly with any other pendulums.

An attempt was made to see if the pendulums could be used as a kind of giant Langmuir gage to measure the pressure in the case. Figure II-28 shows the amplitude damping ratio as a function of the case pressure in microns for observations made in Madison. The data above 1000 microns (1 mm) are taken from the 1953-4 results. The results indicate that the amplitude damping ratio can act as an independent check on the calibration of the thermocouple gage below 300 microns. This has little significance because the correction to the period is small below 300 microns.

Two attempts were made to determine the pressure correction below one millimeter. The results in Figure II-29 show a puzzling phenomenon. The pressure effect on the period appears to have a different slope when the pressure is decreased from that when the pressure is increased. Air was admitted to the case from a dessicating bottle closed to the outside air. The effect could be an outgassing phenomenon, or it could be related to much slower dissipation of electric charge at low pressures. It is planned to make further investigations. The pressure correction adopted for the Africa and East Coast trips was

$$\Delta T_p = -1.325 P_{20} \times 10^{-6} \text{ seconds} \quad (25)$$

1959 EAST COAST
STATION SEQUENCE

FIG. II-26

TABLE II-26
1959 GULF K AND M (ROSE AND STRICKHOLM) EAST COAST USA

Date	Station Sequence	Seconds		μ sec.		Microseconds			ΔL	μ sec.		Seconds
		$\bar{K}$		$\overline{K1-K2}$	$\bar{n}$	$\bar{s}(\bar{K1})$	$\bar{s}(\bar{K2})$	$\bar{s}(\bar{K})$		ΔT_L	"Creep"	Corr. $\bar{K}$
261059	Madison (12)	0.889	652 47	+3.71	3	0.081	0.124	0.088	0	0		652 47
0211	Lamont Obs.		702 07	3.60	3	.117	.050	.059	3	0.17		702 24
03	Washington, D.C. (GLF)		773 87	3.67	4	.021	.075	.045	6.5	.36		774 23
05	Charleston	0.890	023 25	3.64	4	.072	.121	.050	10.5	.58		023 83
07	Miami (M.L.)		257 36	3.50	4	.089	.093	.028	14.5	.80		258 16
10	Key West		287 48	2.64	4	.233	.229	.017	18.5	1.03		288 51
11	Miami (M.L.)		256 94	2.97	4	.089	.106	.014	22.5	1.25		258 19
14	Charleston		022 43	3.23	4	.057	.104	.026	26.5	1.47		023 90
16	Washington, D.C. (GLF)	0.889	772 55	3.20	4	.072	.079	.025	30.5	1.69		774 24
18	Ottawa (GLF)		535 87	2.34	(3)	.032	.233	.101	35	1.94		537 81
21	Lamont Obs.		700 13	2.41	4	.063	.033	.016	38.5	2.14		702 27
24	Madison (12)		650 15	2.68	4	.086	.168	.109	42.5	2.36		652 51

Date	Station Sequence	$\bar{M}$		$\overline{M1-M2}$		$\bar{n}$	$\bar{s}(\bar{M1})$	$\bar{s}(\bar{M2})$	$\bar{s}(\bar{M})$
261059	Madison (12)	0.891	555 58	-2.38	3	.063	.066	.054	
0211	Lamont Obs.		605 34	-2.14	3	.037	.030	.032	
03	Washington, D.C. (GLF)		677 69	-2.24	4	.055	.066	.044	
05	Charleston		927 73	-2.29	4	.103	.049	.033	
07	Miami (M.L.)	0.892	162 46	-2.18	4	.060	.084	.044	
10	Key West		192 81	-2.06	4	.089	.069	.029	
11	Miami (M.L.)		162 55	-1.53	4	.128	.067	.033	
14	Charleston	0.891	927 83	-2.06	4	.050	.088	.056	
16	Washington, D.C. (GLF)		677 64	-2.08	4	.110	.046	.066	
18	Ottawa (GLF)		440 66	-2.01	(3)	.071	.077	.070	
21	Lamont Obs.		605 26	-1.85	4	.059	.035	.036	
24	Madison (12)		555 66	-1.87	4	.069	.040	.020	

II-72

TABLE II-27
1959 GULF K AND M (ROSE AND STRICKHOLM) EAST COAST USA

	Gals K	Gals M	Gals KM	n	Mgals Δg	Mgals $\pm \bar{s}$	(Mgals) ² $\bar{s}^2$
Madison(12)	980.3689 ²	.3690 ⁴	.3689 ¹	4	268.31	0.093	0.0086
Lamont Obs.	2592 ³	.2596 ¹	.2594 ⁵	4	158.85	"	"
Washington, D.C.(GLF)	.1006 ²	.1005 ⁵	.1006 ⁰	4	0	0	0
Charleston	979.5509 ⁸	.5511 ¹	.5509 ⁵	4	-549.65	0.093	0.0086
Miami(M.L.)	.0353 ⁵	.0357 ³	.0354 ⁸	4	-1065.12	"	"
Key West	978.9686 ³	.9691 ²	.9688 ⁸	2	-1131.72	.16	.0259
Miami(M.L.)	.0353 ¹	.0355 ³	--				
Charleston	.5508 ²	.5508 ⁸	--				
Washington, D.C.(GLF)	980.1005 ⁷	.1006 ⁵	--				
Ottawa(GLF)	.6216 ⁵	.6218 ²	.6217 ⁴	2	521.14	"	"
Lamont Obs.	.2591 ⁸	.2597 ⁹	--				
Madison(12)	.3688 ³	.3688 ⁶	--				

D.F. 17

s^2 0.0345 (mgals)²

where

ΔT_p = correction in microseconds to be added to the pendulum period.
 P_{20} = pressure in mm Hg at 20°C.

The reduction to zero amplitude constant was redetermined for the 100 cm focal length lenses used in the optical benches. The results are shown in Figures II-30 and II-31.

Investigation of the Results of Other Observers

Introductory remarks

With the objective of valid comparison of the results obtained by the group at the University of Wisconsin using the Gulf pendulums with the results of other observers with other types of modern pendulums, it was necessary to see if tares and systematic effects were present in the other results. The author feels that the tares and systematic effects should be removed from the results of other observers in order to obtain a valid estimate of error.

Investigations have been made by the author of the results with the magnetically compensated Brown invar pendulums of the U.S. Coast and Geodetic Survey, the Cambridge invar pendulums, the GSI quartz pendulums and the Dominion Observatory bronze pendulum apparatus developed by Thompson (1959).

The USC and GS Brown Invar Pendulums

Rice (1958) comments that after the 1952 observations in Alaska, the pendulums were examined, and a fine crack was found in the agate plane of Apparatus 2. Rice implies that the crack occurred between the pre-season swing at Washington and the swing at Umiat, but does not incorporate the results of Apparatus 2 based only on the post-season Washington swing into the adopted results. For purposes of estimating the error the gravity results of Apparatus 2 based only on the post-season swing at Washington are included by the present author with the Apparatus 3 results and listed in Table II-28. The Point Barrow and Fairbanks values are in excellent agreement with the Gulf results.

For the 1953 results an assumption that the closures for reoccupations at Beloit and Washington were random seems to be as reasonable as any other. Rather than using Beloit as a satellite base the present author has computed the gravity results of App. 2 and App. 3 relative to the first Washington swings and averaged the results, permitting a valid estimate of the error. The results computed in this fashion are virtually identical with the results adopted by Rice except for a 0.1 mgal difference at Winnipeg and at Tulsa. The standard error of the intervals is approximately the same as that estimated by Rice. The agreement between the USC and GS and Gulf results is excellent, the maximum difference being 0.3 mgals.

FIG. II-30

FIG. II-31

II-80

TABLE II-28
1952-53 USCGS NORTH AMERICA

	n	Δg mgals Means	Mgals $\bar{s}$	$\bar{s}^2(\text{mgals})^2$	$\bar{g}$ Means
Point Barrow	2	+2580.7	+0.46	0.201	982.6997
Umiat	2	+2425.1	"	"	.5441
Fairbanks (LADD)	2	+2125.2	"	"	.2442
Anchorage	2	+1820.5	"	"	981.9395
Kodiak	2	+1627.7	"	"	.7467
Washington, D.C.(CF)	3	0	(0)	(0)	980.1190
D.F.	7				
$s^2(\text{mgals})^2$		0.251			
Winnipeg	2	+ 874.3	+0.48	0.227	980.9933
Huron	2	+ 335.2	+ "	"	.4542
Washington, D.C.(CF)	4	0	0	0	.1190
Beloit	6	- 121.0	+0.35	0.126	979.9980
Tulsa	2	- 353.5	+0.48	"	.7655
Houston	2	- 821.2	"	"	.2978
Brownsville	2	-1079.5	"	"	.0395
D.F.	13				
$s^2(\text{mgals})^2$		0.302			

The Cambridge Invar Pendulums

Only the data closely related to the Gulf observations were investigated. It was decided to defer comparisons with the Cambridge results in Australia and New Zealand pending their publication in the near future.

For the Hales and Gough's (1950) results the large scatter in reoccupation closures is regarded as random. Minor modifications were made in the method of interpretation of the results obtained by Cook (1952). The results of Garland (1953), (1955) were examined in detail. It was concluded that none of the Washington periods should be rejected. Dr. Innes of the Dominion Observatory supplied a copy of all of the original reduced periods including the unpublished ones for the spring of 1953 loop from Ottawa to Winnipeg to Edmonton to Ottawa. The gravity results for each field season were computed by the present author using the station sequence scheme adopted for the Gulf results, and means determined. Results are tabulated in Table II-30. Mexico City was considered as only one data sample because very few swings were made there. The gravity intervals listed in Table II-30 are very nearly the same as those given by Garland.

Comparison of the Cambridge results with the Gulf results in Figure II-32 suggests that there was a magnetic effect present in the 1952 Cambridge observations. Subsequent modifications to the Cambridge results seem to have removed the cause, as evidenced by the results of Jackson (1959) at Mexico City.

There has been a considerable amount of discussion regarding Garland's results; see Gilbert (1957) and (1958).

The results of Garland and Cook (1955) appear to be subject to uncertainty

COMPARISONS OF PENDULUM GRAVITY RESULTS
IN NORTH AMERICA

FIG. II - 32

at Ottawa.

In the observations by Jelstrup (1957) with the Cambridge apparatus the pendulums appear to have changed period in a systematic fashion during the field season.

There is insufficient evidence of systematic error to justify adjustment of the results obtained by Gough (1958), although there is a strong suggestion that all pendulums except VIB increased their periods in a remarkably similar fashion as a linear function of time from Teddington 1 until Mowbray 2 and then partially recovered by Teddington 2.

The subsequent results of Jackson (1959), (1960) and Browne (1960) indicate that the Cambridge pendulums were reasonably well behaved. Perhaps the most puzzling phenomenon of the recent work is the tendency of pendulum VIB to show no period change during the field season when on one of the agates, but to show a progressive period change on the other agate. Browne (1960) remarks about this effect.

1948-9 CAMBRIDGE (HALES AND GOUGH) AFRICA

The gravity interval from Teddington (NPL 11) to the Cambridge Pendulum House will be taken from Cook (1953) as 72.17 $\pm$ 0.08 mgals. The gravity intervals are:

TABLE II-29
GRAVITY INTERVALS RELATIVE TO TEDDINGTON (NPL 11)

	$\frac{IA}{0}$	$\frac{IB}{0}$	$\frac{IC}{0}$	$\frac{VIA}{0}$	$\frac{VIB}{0}$	$\frac{VIC}{0}$
Equiv. NPL 11						
Mowbray	-1549.3	46.7	48.5	50.0	48.3	50.0
Capetown(ROY.OBS.)	-1541.5	43.8	38.3	40.1	38.1	41.7
9 Stations						
Johannesburg	-2647.5	44.8	46.4	47.6	47.0	47.3
Pretoria	-2567.9	67.5	66.5	66.6	65.8	67.5
Johannesburg	Above is mean pre- and post-Pretoria					
7 Stations						
Mowbray				-1549.8	49.7	49.5
7 Stations						
Johannesburg	-2645.3	46.1	43.5	46.0	44.9	46.4
2 Stations						
Salisbury				-3048.6		48.1
Bulawayo				-2903.4		05.8
Victoria Falls				-2964.6		66.6
Bulawayo				-2904.1		05.6
2 Stations						
Johannesburg	-2646.5	46.2	46.1	47.6	48.6	48.2
4 Stations						
Johannesburg	-2645.1	46.2	45.3	47.6	48.1	48.6
8 Stations						
Mowbray	-1547.3	47.9	48.0	49.5	47.3	49.7
Mowbray	-1548.0	49.9	48.2	50.2	48.1	51.9
Equiv. NPL 11	0	0	0	0	0	0
Means						
Equiv. NPL 11	0	0	0	0	0	0
Mowbray	-1548.23	48.23	48.23	49.93	48.43	50.33
Capetown (ROY.OBS.)	-1541.5	43.8	38.3	40.1	38.1	41.7
Johannesburg	-2646.13	45.83	45.33	47.43	47.23	47.63
Pretoria	-2567.9	67.5	66.5	66.6	65.8	67.5
Salisbury				-3048.6		48.1
Bulawayo				-2903.75		05.70
Victoria Falls				-2964.6		66.6
Means	All	Mgals		(Mgals) ²		
	I and VI	$\pm s$		$\frac{s}{s}$		
Equiv. NPL 11	0	0		0		
Mowbray	-1548.90	0.29		0.086		
Capetown(ROY.OBS.)	-1540.58	.55		.301		
Johannesburg	-2646.60	.27		.075		
Pretoria	-2566.97	.55		.301		
Salisbury	-3048.35	.95		.902		
Bulawayo	-2904.73	.67		.451		
Victoria Falls	-2965.60	.95		.902		

D.F.
 $s^2(\text{mgals})^2$

58

1.804

1951 CAMBRIDGE (COOK) EUROPE

In 1951 Cook used the Cambridge apparatus for connections between absolute sites in Europe. Examination of his Table 2. of mean periods shows that pendulum VI A was anomalous for the NPL 2 to 4 July 1951 observations. This is obvious from the VI(A-B) and VI(A-C) period differences. All the other pendulums appear to have been reasonably well behaved for the sequence of observations. For the present computations, only the VI A period for the first NPL occupation will be rejected. As in Cook's paper, the gravity intervals are calculated relative to the most closely associated NPL occupations. Minor computation errors in the paper, e.g. NPL - BIPM are corrected.

Milligals	IA	IB	IC	VIA	VIB	VIC
<u>Mean NPL(1,2) - BIPM</u>	257.34	255.79	256.54	249.08	257.12	256.23

Mean 255.35 $\pm$ 1.28 mgals

$$\bar{s}^2 = 1.63 \text{ (mgals)}^2$$

$$DF = 5$$

Mean NPL(2,3) - PTB	-68.13	-70.63	-69.11	-64.02	-67.40	-68.12
---------------------	--------	--------	--------	--------	--------	--------

Mean -67.90 $\pm$ 0.90 mgals

$$\bar{s}^2 = 0.81 \text{ (mgals)}^2$$

$$\bar{s} = 0.90$$

$$DF = 5$$

Mean NPL(2,3) - BH	17.46	15.39	14.50	16.11	16.46	14.62
--------------------	-------	-------	-------	-------	-------	-------

Mean 15.76 $\pm$ 0.47 mgals

$$\bar{s}^2 = 0.218 \text{ (mgals)}^2$$

$$\bar{s} = 0.47$$

$$DF = 5$$

1952-53 CAMBRIDGE (GARLAND) - NORTH AMERICA

The unpublished periods were used and the 1 ABAC and 6 BC results were averaged. Results were separated by trips. None of the Washington periods are rejected.

TABLE II-30

Station Sequence	Mean g gals		n	Mgals Δg	Mgals $+\bar{s}$	(Mgals) ² $\bar{s}^2$
	1ABAC, 6BC					
Ottawa (DOF)	980.6207		4	0	0	0
Washington, D.C. (CF)	.1186		4	-502.1	0.53	0.284
Beloit	979.9976		6	-623.1	0.49	0.237
Houston	.2976		2	-1323.1	0.65	0.426
Monterrey	978.8041		2	-1816.6	"	"
Mexico (TAC)	977.9400	(1)		-2680.7	0.84	0.709
Tulsa	979.7650		2	-855.7	0.65	0.426
Beloit	---					
Huron	980.4540		2	-166.7	"	"
Winnipeg	.9938		2	+373.1	"	"
Beloit	---					
Madison (25)	---					
Equiv. (12)	.3685		2	-252.2	"	"
Washington, D.C. (CF)	---					
Ottawa (DOF)	---					

D.F. 18
 s^2 0.567 (mgals)²
 s 0.75 mgals

Ottawa (DOF)	980.6207	8	0	0	0
Winnipeg	.9928	2	+372.1	0.99	0.971
Edmonton	981.1675	8	+546.8	0.62	0.388
Ottawa (DOF)	---				
Ottawa (DOF)	---				
Edmonton	---				
Grande Prairie	.3179	2	+697.2	0.99	0.971
Fort St. John	.4062	2	+785.5	"	"
Fort Nelson	.6816	2	+1060.9	"	"
Watson Lake	.7149	2	+1094.2	"	"
Whitehorse	.7485	2	+1127.8	"	"
Fairbanks (U)	982.2461	2	+1625.4	"	"
Equiv. (LADD)	.2443	2	+1623.6	"	"
Snag	981.9325	2	+1311.8	"	"
Edmonton	---				
Red Deer	980.9974	2	+ 376.7	"	"
Lethbridge	.7598	2	+ 139.1	"	"
Edmonton	---				
Ottawa (DOF)	---				

D.F. 24
 s^2 1.554 (mgals)²
 s 1.25 mgals

Weighted Mean Winnipeg - Ottawa (DOF) = 372.8 $\pm$ 0.54 $\bar{s}_{WM}^2$ = 0.296
 Ordinary Mean Madison (12) - WDC (CF) = 249.9 $\pm$ 0.65 $\bar{s}^2$ = 0.426

II-86

1953-54 CAMBRIDGE (GARLAND AND COOK) - NPL-DO-NBS

Garland and Cook's method of interpretation appears to be best.

TABLE II-31

	Mgals Δg	Mgals $\bar{s}$	(Mgals) ² $\bar{s}^2$
Ottawa (DOF) - Teddington (B11F) =	-576.95	+0.32	0.102
Washington (NBSSSBF) - Teddington =	-1096.59	+0.46	0.212
Ottawa - Washington =	+ 519.64	+0.42	0.176

1955 CAMBRIDGE (JELSTRUP) EUROPE

The Cambridge apparatus used by Jelstrup and Jackson in 1955 shows a consistent period increase in the field as indicated by the table below:

TABLE II-32

		Period Change in Microseconds Relative to First Occupation			
		I AB	I AC	VI AB	VI BC
Teddington	1	0	0	0	0
Oslo	1	0	0	0	0
Bodo	1			0	0
Hammerfest					
Bodo	2			+0.16	+0.39
Oslo	2	+0.01	+0.07	+0.19	+0.17
Copenhagen	1	0	0	0	0
Bad Harzburg	1	0	0	0	0
Munich					
Bad Harzburg	2	+0.34	+0.27	+0.19	-0.01
Copenhagen	2	+0.19	+0.17	-0.18	+0.11
Oslo	3	+0.43	+0.36	+0.38	+0.33
Teddington	2	+0.38	+0.46	+0.30	+0.33

Assuming that Teddington and Oslo represent the most stable conditions, the mean rate of change in period using only Teddington and Oslo is:

Pendulum Pair	I AB	+0.05	microseconds per sta. interval			
" "	I AC	+0.043	"	"	"	"
" "	VI AB	+0.035	"	"	"	"
" "	VI BC	+0.034	"	"	"	"

The gravity results after correcting the periods for drift are given in the following table:

Drift corrected results:

TABLE II-33

		1AB	1AC	6AB	6BC
Teddington	1	981.1961 ⁰	.1961 ⁰	.1961 ⁰	.1961 ⁰
	2	.1963 ⁷	.1958 ³	.1965 ⁷	.1964 ¹
Mean		981.1962 ⁹ -	.1959 ⁷ -	.1963 ³ +	.1962 ⁵ +
Oslo	1	981.9268 ⁵	.9267 ³	.9276 ⁰	.9274 ⁴
	2	.9269 ⁶	.9266 ⁶	.9274 ⁰	.9273 ⁶
	3	.9265 ⁰	.9265 ⁰	.9274 ⁸	.9275 ²
Mean		981.9267 ⁷	.9266 ³	.9274 ⁹	.9274 ⁴
Bodo	1			982.3873 ²	.3869 ³
	2			.3869 ⁷	.3856 ⁹
Mean				982.3871 ⁴ +	.3863 ¹
Hammerfest				982.6321 ³	.6312 ⁴
Copenhagen	1	981.5577 ⁵	.5572 ⁸	.5587 ⁰	.5585 ⁸
	2	.5577 ⁸	.5572 ⁸	.5599 ⁴	.5587 ⁰
		981.5577 ⁷ -	.5572 ⁸	.5593 ²	.5586 ⁴

II-88

CAMBRIDGE - JELSTRUP - EUROPE - CONT.

Bad Harzburg	1	981.1807 ⁵	.1802 ⁸	.1811 ⁹	.1804 ⁹	
	2	.1798 ²	.1795 ⁹	.1807 ²	.1808 ⁰	
		<u>981.1802⁹</u>	<u>.1799⁴⁻</u>	<u>.1809⁵⁺</u>	<u>.1806⁴⁺</u>	
Munich		980.7442 ⁰	.7437 ⁷	.7453 ⁶	.7458 ²	
s ²		0.115	0.061	0.179	0.148	(mgals) ²
D.F.		5	5	6	6	

Weighted mean gravity intervals are computed using the inverse of the estimated variance of the mean of a particular pendulum pair as the weight for that pair. The estimated variance of the weighted mean is the inverse of the sum of the weights. The estimated variance of the mean gravity interval for a particular pair is the sum of the estimated variances of the mean at the base station and at the field station.

TABLE II-34

	Weighted Mean	Mgals	(Mgals) ²
	Δg mgals	$+\bar{s}$	$\bar{s}^2$
Hammerfest	+1435.40	0.37	0.136
Bodo	+1190.40	.28	.081
Oslo	+ 730.79	.15	.022
Copenhagen (Budd.Pier)	+ 362.12	.16	.027
Teddington (NPL 11)	0	0	0
Bad Harzburg	- 15.85	.16	.027
Munich (Nymphenburg)	- 451.67	.20	.040

II-89

1956 CAMBRIDGE (GOUGH) AFRICA

Gough's Table 5 is the basis of the table below:

TABLE II-35
GRAVITY INTERVALS RELATIVE TO TEDDINGTON (NPL 11)

	<u>IA</u>	<u>IB</u>	<u>IC</u>	<u>VIA</u>	<u>VIB</u>	<u>VIC</u>
Teddington(NPL 11)	0	0	0	0	0	0
Mowbray	-1549.4	49.4	49.5	49.8	48.5	48.7
Johannesburg	-2647.6	46.8	47.1	47.5	46.2	46.6
Pretoria	-2567.3	66.9	66.9	67.8	66.3	67.0
		Mgals	(Mgals) ²			
<u>Means</u>	<u>All I, VI</u>	<u>$\bar{s}$</u>	<u>$\bar{s}^2$</u>			
Teddington(NPL 11)	0	0	0			
Mowbray	-1549.2	0.21	0.044			
Johannesburg	-2647.0	.21	.044			
Pretoria	-2567.0	.21	.044			
D.F.			15			
s^2 (mgals) ²			0.265			

1958 CAMBRIDGE (JACKSON) - SOUTH AMERICA

The mean gravity results of pendulum pairs IAB, IAC, VIAB, and VIBC relative to Madison (12) are given below:

TABLE II-36

	Gals <u>g</u>	n	Mgals <u>Δg</u>	Mgals <u>$\frac{g}{s}$</u>	(Mgals) ² <u>$\frac{s^2}{s^2}$</u>
Teddington (B17)	981.1967 ⁴	8			
(Equiv. B11)	.1966 ⁹		+827.79	0.34	0.116
Madison (12)	980.3689 ⁰	8	0	0	0
Mexico (UNIV.FLOOR)	977.9415 ⁹	8			
(Equiv. TAC.FLOOR)	.9420 ⁶		-2426.84	0.30	0.089
Panama	978.2416 ⁷	12	-2127.23	0.30	0.092
Quito	977.2782 ⁴	8	-3090.66	0.30	0.090
Lima	978.2829 ⁵	8	-2085.95	0.31	0.099
Lapaz	977.4668 ³	8	-2902.07	0.33	0.106
Santiago	979.4289 ⁹	8	- 939.91	0.33	0.106
Buenos Aires	.7051 ⁴	8	- 663.76	0.31	0.096
Rio de Janeiro	978.8047 ⁵	4	-1564.15	0.31	0.098
Caracas	.0397 ³	4	-2329.17	0.30	0.091

1958 CAMBRIDGE (BROWNE) EUROPE AND AFRICA

The results from a personal communication are:

TABLE II-37

				<u>Δg mgals</u>
Teddington (NPL)	981 196.0 ⁷	+0	mgals	0
Munich (Residenz)	980 737.6	+0.7	"	-452.00
Equiv. Nymphenburg	980 744.0			
Rome (I.N.G.)	364.0	+0.5	"	-832.07
Catania (Observatory)	046.7	+0.9	"	-1149.37
Khartoum (Physics Dept.)	978 302.9	+0.4	"	-2892.97
Equiv. Coord. Rm.	303.1			
Nairobi (Fld. Surv.)	977 540.5	+0.3	"	-3655.57
Salisbury (Met.Sta.)	978 148.1	+0.4	"	-3047.97
Johannesburg	549.8	+0.2	"	-2646.27

1959 CAMBRIDGE (JACKSON) - PACIFIC

There does not appear to be any consistent period change during the trip.
Weighted means of individual intervals were taken.

TABLE II-38

	Weighted Means	Mgals			
	<u>Mgals</u>	<u>$\bar{s}_{WM}$</u>	<u>$\bar{s}_{WM}^2$</u>	<u>$\bar{s}_{WM}(\text{Mgals})^2$</u>	<u>DF</u>
Teddington - Singapore	3114.31	+0.14		0.021	8
" - Darwin	2881.66	"		"	"
" - Melbourne	1216.97	"		"	"

$$\begin{aligned}
 s^2 = \bar{s}_{\Delta g}^2 &= 0.221 \text{ mgals}^2 \text{ (1AB)} \\
 &= 0.099 \text{ " (1AC)} \\
 &= 0.067 \text{ " (6AB)} \\
 &= 0.052 \text{ " (6BC)}
 \end{aligned}$$

There were two occupations at each site.

II-92

1952 GSI (MUTO) CHIBA - KYOTO

The gravity interval computed by Muto between Chiba and Kyoto was 68.2 ± 0.2 mgals. The results are re-evaluated below:

TABLE II-39

Sta. Seq.	Periods in Seconds		Gravity in Gals		
	No. 1	No. 2	No. 1	No. 2	Means
Chiba	1.017 246 02	1.017 247 16	979.7900 ^o	.7900 ^o	.78997
Kyoto	281 62	282 55	.7213 ¹	.7218 ³	.7215 ⁷
Chiba	246 06	247 18	.7899 ²	.7899 ⁶	---
D.F.					4
$s^2(\text{mgals})^2$					0.035

$$\begin{aligned} \text{Chiba} - \text{Kyoto} &= 68.40 \pm 0.16 \text{ mgals} \\ \bar{s}^2 &= 0.027 (\text{mgals})^2 \end{aligned}$$

1955 GSI (OKUDA, INOUE, SUZUKI) - WASHINGTON, D.C. TO JAPAN

Results are re-evaluated by Rose using "external" errors rather than internal. Weights equal to the inverse of the variance of the mean for Pendulum No. 1, Pendulum No. 3 and Mean Pendulums 1 and 2 (series b) are used to obtain a weighted mean interval. The weighted mean gravimeter interval between Commerce Pier and NBS sub-basement floor is taken as 19.39 ± 0.03 mgals to give the GSI results the equivalent of 3 USCGS occupations to aid in error evaluation.

TABLE II-40
GRAVITY RESULTS

Δg			$s^2(\text{mgals})^2$	$\bar{W}$	DF
C and GS - GSI = (No. 1)	329.33		0.010	100.0	3
= (No. 3)	330.70		0.108	9.3	3
= (No. 1, 2)	329.07		0.691	1.4	2

$$\begin{aligned} \text{W.M. C and GS (CP) - GSI} &= 329.45 \pm 0.095 \\ \bar{s}_{\text{WM}}^2 &= 0.0090 \quad \text{DF} = 8 \\ \bar{s}_{\text{WM}} &= \pm 0.095 \end{aligned}$$

Quoted intervals:

Sta. "Tokyo" (One meter base bar room) - GSI = $+11.2$ mgal
Sta. "Kyoto" (Laboratory of theoretical geology of Kyoto Univ.) - GSI = -68.3 ± 0.3 mgal

Note Recalc. 1952 (JCR) w/Feb-Mar 1955 68.4 ± 0.3 gives W.M. = -68.40 ± 0.14
 $\bar{s}_{\text{WM}}^2 = .021$

Sta. "Tokyo" = $139^\circ 45.6'$ E = $35^\circ 42.6'$ N H = 18 m.
Sta. "Kyoto" = $135^\circ 47.2'$ E = $35^\circ 01.6'$ N H = 60.8 m.
Sta. "Tokyo, old" = $139^\circ 45' 45''$ E = $35^\circ 42' 24''$ N H = 15 m.
(cellar of former Physical Institute of the Tokyo University)
GSI, Chiba = $140^\circ 06.5'$ E = $35^\circ 38.0'$ N H = 20.9 m

II-93

1957-58 GSI (HARADA, ET AL) MALAYA - AFRICA

TABLE II-41

	Mean Periods in Seconds		g gals		Means
	No. 3	No. 2	No. 3	No. 2	
1957					
Chiba	1.017 224 80	1.017 226 70	979.7900 ⁰	.7900 ⁰	.7900 ⁰
Singapore	.018 113 44	.018 114 36	978.0803 ⁶	.0822 ⁵	.0813 ¹
Capetown	.017 298 77	.017 300 44	979.6475 ²	.6479 ⁶	.6477 ⁴
1958					
Capetown	.017 298 79	.017 300 09	.6474 ⁸	.6486 ⁴	.6480 ⁶
Singapore	.018 113 17	.018 114 34	978.0808 ⁸	.0822 ⁹	.0815 ⁹
Chiba	.017 224 35	.017 225 69	979.7908 ⁷	.7919 ⁴	.7914 ¹

Comparisons with the Cambridge pendulum results of Hales and Gough (1948-49), and Jackson (1959) as well as with the Gulf pendulum results of Rose (1955) and Iverson (1958) indicate a tare in the GSI periods for both pendulums, between Singapore 2 and Chiba 2. Omitting the Chiba reoccupation, the mean gravity results are:

TABLE II-42

	Δg mgals	Mgals $\pm \bar{s}$	(Mgals) ² $\bar{s}^2$
Chiba	0	0	0
Singapore	-1708.55	0.24	0.058
Capetown	- 142.10	"	"
D.F.	2		
$s^2(\text{mgals})^2$	0.045		
s mgals	0.21		

The error is determined from the Singapore and Capetown closures of the mean results.

PENDULUM TIES
POTSDAM TO BAD HARZBURG

It is unlikely in the near future that many new pendulum connections will be made from Potsdam to Bad Harzburg. A best estimate of the Potsdam system must be made from the existing data. The most valid data appear to be those reported by Weiken (1950) for measurements made from 1937 through 1942. Ten trips were made. The mean value for Bad Harzburg obtained by Weiken was 981.1804 ± 0.00013 cm/sec² by giving equal weight to all Bad Harzburg results from all the ten trips. Cook (1952) pointed out that the separate results of any particular trip are not independent since they all depend on the same base observation at Potsdam. Cook re-evaluated the connection giving the mean value of each trip the same weight. Cook's result is 981.18027 ± 0.00022 cm/sec² for Bad Harzburg.

Using the same data, the author has pooled the estimated variances of the Bad Harzburg values for each trip relative to the mean for that particular trip, giving an overall estimated variance characteristic of any particular occupation of either Potsdam or Bad Harzburg. From this the variance of each mean interval was calculated and the weighted mean result is 93.68 ± 0.18 mgals. The weight assigned each mean interval is the inverse of the variance of that interval. The standard error of the weighted mean result is the square root of the inverse of the sum of the weights. The author's result for Bad Harzburg is 981.18032 ± 0.00018 cm/sec². This agrees very well with Cook's result. The adopted value for Bad Harzburg is 981.1803 ± 0.00018 cm/sec².

The author assumes that there were two Potsdam observations per trip.

TABLE II-43
GERMAN PENDULUM OBSERVATIONS AT BAD HARZBURG
(FROM COOK 1952 AFTER WEIKEN 1950)

Value of Gravity					
<u>g, Potsdam Pendelsaal = 981274.0 Mgal</u>					
<u>Observer</u>	<u>Year</u>	<u>Mgal</u>		<u>Δg mgal</u>	<u>Std. Error</u>
Weiken	1937a	981180.1	981180.45	93.55	+0.46
		.3			
		.6			
		1.4			
		0.4			
		179.9			
Jung	1937a	981180.2	981180.60	93.40	+0.46
		1.2			
		0.0			
		0.0			
		1.0			
		1.2			
Weiken	1937b	981180.1	981180.80	93.20	+0.56
		1.6			
Jung	1937b	981181.4	981180.95	93.05	+0.56
		0.5			
Weiken	1938	981180.1	981180.1	93.90	+0.69
Jung	1938	981178.9	981178.9	95.10	+0.69
Weiken	1942	981180.0	981180.20	93.80	+0.56
		.4			

PENDULUM TIES POTSDAM - BAD HARZBURG - CONT.

Weiken	1942	981179.8 .6 .3	981179.63	94.37	<u>+0.51</u>
Reicheneder	1942	981180.5	981180.5	93.50	<u>+0.69</u>
Reicheneder	1942	981180.5 .6	981180.55	93.45	<u>+0.56</u>

Mean Values	981180.4 <u>+0.13</u>	Weiken	$\bar{s}^2 = 0.315 \text{ (mgals)}^2$
	981180.27 <u>+0.22</u>	Cook	$\bar{s} = 0.56 \text{ mgals}$
	981180.32 <u>+0.18</u>	Rose	D.F. = 16

Adopted Value 981180.3 +0.18 mgals

Combination and Comparison with the Results of Other Observers

In the pages to follow, an attempt is made by the author to combine the results of the various recent gravity observations with several different kinds of pendulum apparatus. The author is not attempting to incorporate all possible results of observations by all observers. This is extra labor without significant improvement in the accuracy of the result. Unless no other observations were available, no results of work done with mechanical chronometers were used. No results with bronze pendulums were used except those of Thompson (1959) in North America. Concerning the D. O. Bronze apparatus, with the exception of Bad Harzburg, the 1959 observations of Winter and Valiant resulted in gravity differences significantly different from those obtained by other observers. The D.O. interval from Teddington to Paris was -256.9 mgals in contrast to -255.7 (Gulf 1959), -255.4 (Cambridge 1951) and -255.6 (DGJF 1958) mgals. The D. O. interval from Teddington to Rome ING was -833.5 mgals in contrast to -832.3 (Gulf 1954), -832.1 (Cambridge 1958) and -832.8 (CGI 1958) mgals. The D.O. interval from Teddington to Ottawa (GLF) was -575.8 mgals in contrast to the weighted mean Gulf interval via Washington D.C. and Madison of -574.8 mgals. One plausible explanation would be that Room 11 at Teddington was considerably colder than the other D.O. observation sites. The fact that the gravity room in the Commerce Building in Washington was cooler than the Ottawa site could also explain the fact that Thompson (1959) gets a gravity interval of 502.25 ± 0.09 to Ottawa in contrast to the weighted mean Gulf interval of 502.66 ± 0.16 mgals. Another connection between Ottawa and Washington with the Gulf M pendulums will be made in 1960, as well as a direct tie from Washington to Teddington.

For Askania invar pendulum work, the uncompensated results were used for Potsdam to Bad Harzburg because they seem to be the only data available. Of the many other Askania apparatus observations in the European gravity network, only the 1958 results with Helmholtz coil compensation were used.

The Cambridge invar pendulum results used were either corrected for magnetic effects, e.g., Browne and Bullard (1940) with the correction given by Garland and Cook (1955), or compensated with mu-metal or Helmholtz coils.

For data not available to the author in the original form, i.e., with mean periods and station sequence, a variance of 0.500 (mgals)^2 was assumed.

Two methods of synthesis were used. With the first method, a homogeneous variance throughout each observer's trip was assumed, and the weight assigned to the observer's mean gravity result at a particular station was the inverse of the variance of the mean at that station. This is the method used by Jeffreys (1948). Obvious tares and/or systematic effects were removed from each observer's trip, if possible, in order to strengthen the assumption of homogeneous variance. Of course, the assumption of homogeneous variance and its estimation from reoccupation closures loses validity if external magnetic or temperature effects, for example, can systematically influence the results, because the apparatus would then measure gravity plus the perturbing effect without affecting the closures. The estimate of the variance improves with the number of reoccupations.

The estimated variance of the weighted mean result is taken as the inverse

of the sum of the weights.

The second method of synthesis used was to take simple means of all the interval samples and estimate the variance for a particular station from the departures of the individual intervals from the mean interval.

The resulting weighted means based on Washington, D.C. are listed in Tables II-63, II-64, and II-65, and those based on Teddington are listed in Tables II-66 and II-67.

Comparison between weighted means and simple means is made in Tables II-68 through II-72. There is virtually no difference between the weighted means and ordinary means. A comparison of the weighted mean results with those obtained by Cook (1957) is made in Table II-73. Within the standard errors, the agreement is very good. No comparison is made with Cook's weighted means for North America because very few data were available to him at that time, so the comparison would have little significance.

TABLE II-44
LOCAL TIES IN WASHINGTON, D.C.

Site		Gravity Intervals in Mgals		
		Adopted This Report	USCGS Adopted	Woollard June 1960
Commerce Floor	= CF	0	0	0
" Pier	= CP	-0.18	-0.18	-0.14
Geophysical Lab. Floor	= GLF	-18.37 +0.02	-18.36	-18.34
NBS Sub-Sub-Basement Floor	= NBS	-19.57 +0.03	-19.54	-19.57

TABLE II-45
TIES BETWEEN MADISON AND WASHINGTON D.C.

			Mgals (Mgals) ²		W
		Mgals	$\bar{s}$	$\bar{s}^2$	
1951 Gulf C (Rose)	Madison (12) - WDC(GLF)	268.2	+1.12	1.26	
	- WDC(CF)	249.8			0.79
1953 Gulf KM (Rose)	- WDC(GLF)	268.1	+0.29	0.086	
	- WDC(CF)	249.7			11.63
1954a Gulf M (Rose)	- WDC(GLF)	268.0	+0.36	0.130	
	- WDC(CF)	249.6			7.69
1954b Gulf M (Rose)	- WDC(GLF)	268.92	+0.47	0.225	
	- WDC(CF)	250.55			4.44
1956 Gulf M (Steinhart)	- WDC(GLF)	267.7	+0.65	0.42	
	- WDC(CF)	249.3			2.38
1957a Gulf M (Rose)	- WDC(GLF)	268.0	+0.83	0.69	
	- WDC(CF)	249.6			1.45
1957b Gulf M (Watkins)	- WDC(GLF)	269.5	+0.74	0.552	
	- WDC(CF)	251.1			1.81
1959 Gulf KM (Rose and Strickholm)	- WDC(GLF)	268.31	+0.093	0.0086	
	- WDC(GLF)	249.94			116.27
1952 Cambridge (Garland)	- WDC(CF)	249.9	+0.65	0.426	2.35

$\Sigma W = 148.81$

Weighted Mean

	$\bar{s}_{WM}$	$\bar{s}_{WM}^2$
Madison (12) - WDC (CF)	249.92 +0.08	0.0067
	+0.09	.0076 w/local error

TABLE II-46
MEAN PENDULUM GRAVITY INTERVAL BETWEEN
MADISON (12) AND WASHINGTON, D.C. COMMERCE FLOOR

						Mgals
1951	Gulf C (Rose)	Madison (12)	-	Wash., D.C.(GLF)		269.0
"	"	"	"	"	"	7.4
1953	"	K	"	"	"	7.8
"	"	"	"	"	"	7.7
"	"	M	"	"	"	8.6
"	"	"	"	"	"	8.5
1954	"	"	"	"	"	8.6
"	"	"	"	"	"	7.4
"	"	"	"	"	"	8.9
1955	"	"	"	"	"	8.9
"	"	"	"	"	"	6.9
1956	"	"	"	"	"	7.7
1957	"	"	"	"	"	8.0
"	"	"	"	"	"	71.0
"	"	"	"	"	"	68.5
1959	"	K	"	"	"	8.30
"	"	"	"	"	"	8.26
"	"	M	"	"	"	8.49
"	"	"	"	"	"	8.21
Mean						268.32
1952	Cambridge I					
	(Garland)	"		"		7.07
"	"	"		"		8.47
Mean Gulf and Cambridge						268.27 ± 0.19
"	"	"	"	to Commerce Floor		<u>249.90 ± 0.19</u>
D.F.	20					
$\bar{s}^2$	0.036 (mgals) ²					

II-100

TABLE II-47
MEAN PENDULUM GRAVITY INTERVALS BETWEEN
OTTAWA (GLF) AND WASHINGTON, D.C. (CF)
Weighted Means Ordinary Means

(mgals) ²							
Gulf	Ngals	$\bar{s}^2$	n	Gulf	Ngals		
1953 KM (Rose)	502.1	0.156	6.41	1953 K(Rose)	501.43		
1954 M (Rose)	503.23	0.59	1.69	1953 M "	502.78		
1959 Kb(Rose and Strickholm)	502.71	0.069	14.49	1954 M "	503.23		
1959 M "	502.80	0.069	14.49	1959 Kb(Rose and Strickholm)	502.71		
				1959 M "	502.80		
Weighted Mean	502.66	mgals		Mean	502.59	mgals	
$\bar{s}_{WM}$	± 0.16	mgals		$\bar{s}$	± 0.31	mgals	
$\bar{s}_{WM}^2$	0.027	(mgals) ²		$\bar{s}^2$	0.094	(mgals) ²	
Cambridge				Cambridge			
1952 I VI (Garland)	502.9	0.284	3.52	1952 I(Garland)	504.0		
1954 I VI "	500.87	0.176	5.68	" " "	501.6		
				" VI "	502.9		
				" " "	503.2		
				1954 I "	500.24		
				" VI "	501.98		
Weighted Mean	501.65	mgals		Mean	502.32		
$\bar{s}_{WM}$	± 0.33	mgals		$\bar{s}$	± 0.54	mgals	
$\bar{s}_{WM}^2$	0.109	(mgals) ²		$\bar{s}^2$	0.296	(mgals) ²	
D.O. Bronze				D.O. Bronze			
1957 4,5,6(Thompson)	502.25	0.0081	123.46	1957 4-6(Thompson)	502.56	I	
				" 5-6 "	501.97	I	
				" 4-5 "	502.52	II	
				" 4-6 "	502.42	II	
				" 5-6 "	502.07	II	
				" 4-5 "	502.39	III	
				" 5-6 "	501.91	III	
				" 4-6 "	502.13	III	
Combined							
Weighted Mean	502.41	mgals		Mean	502.25	mgals	
$\bar{s}_{WM}$	0.077	mgals		$\bar{s}$	± 0.09	mgals	
$\bar{s}_{WM}^2$	0.0059	(mgals) ²		Combined Mean	502.36	mgals	
				$\bar{s}$	± 0.18	mgals	

II-101
TABLE II-48
TIES BETWEEN TEDDINGTON AND WASHINGTON

1939 Cambridge (Browne and Bullard)	Tedd(B11) - NBSSSBF	=1097.1*	0.33	0.112	8.93
1953-4 " (Garland and Cook)	" - "	=1096.59	0.46	0.212	4.72
1954 Gulf M (Rose)	" - GLF	=1096.65	0.55	0.300	
	" - NBSSSBF	=1097.85			3.33

*With Garland and Cook (1955) magnetic correction 16.98

Weighted Mean

Teddington (B11) - WDC (NBS-SSBF)	= 1097.11	+0.24	0.059
" - WDC (CF)	= 1077.54	+0.24	0.060

TABLE II-49
TIES BETWEEN MADISON AND TEDDINGTON

		Δg	$\bar{s}$	$\bar{s}^2$	$\bar{W}$
1954 Gulf M (Rose)	Teddington(B11) - Mad(12)	827.73	+0.48	0.230	4.35
1959 Gulf K (Iverson)	" "	827.43	+0.24	0.057	17.54
1958 Cambridge (Jackson)	" "	827.79	+0.34	0.116	8.62
					30.51

Weighted Mean

	Δg	$\bar{s}_{WM}$	$\bar{s}_{WM}^2$
Teddington (B11) - Madison (12)	827.57	+0.18	0.033

TABLE II-50
RECENT PENDULUM CONNECTIONS BETWEEN
WASHINGTON, D.C., TEDDINGTON, AND MADISON (12).

Teddington(NPL 11) - Madison (12)	827.73	1954 Gulf M (Rose)
	.65	1959 " K (Iverson)
	.21	" " " "
	.89	1958 Cambridge I (Jackson)
	.87	" " " "
	.36	" " VI "
	.27	" " " "
Mean	827.57	mgals
$\bar{s}$	0.11	
$\bar{s}^2$	0.012	(mgals) ²

Teddington(NPL 11) - Wash., D.C. (1097.1)	1939 Cambridge (Browne and Bullard)
(NBS)	(with Garland and Cook's(1955)
	magnetic correction)
1096.59	1954 Cambridge (Garland and Cook)
(1097.85)	1954 Gulf (Rose) - Equivalent N.B.S.
Mean	1097.18 mgals
$\bar{s}$	0.37 mgals
$\bar{s}^2$	0.134 (mgals) ²

Equivalent NPL - CF 1077.61 +0.37 mgals

Via Madison NPL - CF 1077.47 +0.23 "

Weighted Mean Direct and
via Madison NPL - CF

From Table II-50
1077.51 +0.19 mgals

From Tables II-45, 48, 49
1077.51 +0.15 mgals

$\bar{s}^2$

0.037 (mgals)²

0.024 (mgals)²

TABLE II-51
TIES FROM TEDDINGTON TO BAD HARZBURG

	Mgals	(Mgals) ²
1951 Cambridge (Cook)	15.76 $\pm$ 0.47	0.218
1955 " (Jelstrup)	15.85 $\pm$ 0.16	0.027
1954 Gulf (Rose)	16.27 $\pm$ 0.48	0.230
Weighted Mean	15.88 $\pm$ 0.15	0.022

TABLE II-52
TIES BETWEEN TEDDINGTON AND MUNICH (NYMPHENBURG)

		Mgals	$\bar{s}^2$	W	(Mgals) ²
1954 Gulf M (Rose)	Teddington - Munich	452.31	0.300	3.33	
1955 Cambridge (Jelstrup)	" "	451.67	0.040	25.00	
1959 " (Browne)	" "	452.14	0.500	2.00	
1958 DGJF (Marzahn)	" "	451.26	1.000	1.00(assumed)	
1958 Italian (Mazzon)	" "	451.58	0.500	2.00(assumed via Bad Harzburg)	
			Σ	33.33	
Weighted Mean	" "	<u>451.74 $\pm$0.17</u>			$\bar{s}^2(\text{mgals})^2$ 0.030

WEIGHTED MEAN GRAVITY INTERVALS BETWEEN
MAJOR EXCENTERS

FIG. II-33

11-107

TABLE II-53
DATA FOR WEIGHTED MEAN PENDULUM GRAVITY IN NORTH AMERICA

Station	Gulf											Cambridge		USCGS	Bronze	
	51 C	53 KM	54 Ma	54 Mb	55 M	56 M	56-7 M	57 Ma	57 Mb	58 M	59 K	59 KM	52-3CB	58 CB	52-3U	57D.O.
Point Barrow										2580.4					2580.7	
v.m.										0.220					0.201	
W										4.55					4.98	
Umiat															2425.1	
															0.201	
															4.98	
Fairbanks(LADD)	2125.1	2125.3								2125.8			2125.5		2125.2	
v.m.	1.878	0.145								0.149			0.998		0.201	
W	0.53	6.90								6.71			1.00		4.98	
Northway		1872.5														
v.m.		0.145														
W		6.90														
Anchorage															1820.5	
v.m.															0.201	
W															4.98	
Snag													1813.7			
v.m.													0.998			
W													1.00			
Whitehorse(PUMP)	1628.0	1630.4											1629.7			
v.m.	1.878	0.094											0.998			
W	0.53	10.64											1.00			
Kodiak															1627.7	
v.m.															0.201	
W															4.98	
Watson L.(D.O.)	1596.6												1596.1			
v.m.	1.878												0.998			
W	0.53												1.00			
Fort Nelson													1562.8			
v.m.													0.998			
W													1.00			
Fort St. John	1287.5	1287.2											1287.4			
v.m.	1.878	0.145											0.998			
W	0.53	6.90											1.00			
Grande Prairie	1200.3	1199.1											1199.1			
(P.O.)v.m.	1.878	0.145											0.998			
W	0.53	6.90											1.00			

II-104

II-104

-125-

TABLE II-53
DATA FOR WEIGHTED MEAN PENDULUM GRAVITY IN NORTH AMERICA - CONT.

Edmonton(LAB)	1048.6	1049.2	1048.7				1048.7	
v.m.	1.255	0.094	0.357				0.416	
W	0.80	10.64	2.80				2.40	
Red Deer		878.4					878.6	
v.m.		0.145					0.998	
W		6.90					1.00	
Winnipeg							874.7	874.3 874.55
v.m.							0.647	0.227 0.090
W							1.55	4.41 11.11
Vancouver								816.48
v.m.								0.046
W								2174
Calgary(APT)	710.0	709.2						
v.m.	1.878	0.145						
W	0.53	6.90						
Lethbridge(P.O.)	638.8	639.8					641.0	
v.m.	1.878	0.145					0.998	
W	0.53	6.90					1.00	
Seattle						620.6		
v.m.						0.149		
W						6.71		
Ottawa(GLF)	See Table	; Weighted Mean	502.52 $\pm$ 0.06 mgals			$\bar{s}_{WM}^2 = 0.0038$ (mgals) ²		
Cutbank (T.B.)	488.4	489.4						
v.m.	1.878	0.248						
W	0.53	4.03						
Minneapolis						479.5	478.3	
v.m.						0.891	0.351	
W						1.12	2.85	
Prescott								446.69
v.m.								0.044
W								
Great Falls	407.2	407.6	407.3					
v.m.	1.255	0.094	0.263					
W	0.80	10.64	3.80					
Huron		334.6	334.9				335.2	335.2
v.m.		0.094	0.263				0.505	0.227
W		10.64	3.80				1.98	4.41

II-105

TABLE II-53
DATA FOR WEIGHTED MEAN PENDULUM GRAVITY IN NORTH AMERICA - CONT.

Billings(HNGR)	250.2	251.8															
v.m.	1.878	0.145															
W	0.53	6.90															
Madison (12)	See Table ; Weighted Mean 249.92 $\pm$ 0.08 mgals $s_{WM}^2 = 0.0076$ (mgals) ²																
Woods Hole (BSMT)			208.6														
v.m.			0.430														
W			2.33														
Cornell																181.33	
v.m.																0.094	
W																	
Chicago	168.2																
v.m.	1.878																
W	0.53																
Lamont Obs.	140.5	140.6											140.48				
v.m.	1.041	0.145											0.0086				
W	0.96	6.90											116.27				
Sheridan(HNGR)	105.4	107.0															
v.m.	1.878	0.145															
W	0.53	6.90															
Princeton			59.7														
v.m.			0.430														
W			2.33														
Washington,D.C.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
(C.F.)v.m.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
W																	
Beloit		-121.0											-121.2		-121.0		
v.m.		0.145											0.316		0.126		
W		6.90											3.16		7.94		
San Francisco			-133.2	-132.4		-131.5		-132.4									
v.m.			0.233	0.777		0.220		0.149									
W			4.29	1.29		4.55		6.71									
Casper(PUMP)	-164.8	-163.6															
v.m.	1.878	0.145															
W	0.53	6.90															
Tulsa		-353.6											-353.8		-353.5		
v.m.		0.145											0.505		0.126		
W		6.90											1.98		4.98		

II-106

TABLE II-53
DATA FOR WEIGHTED MEAN PENDULUM GRAVITY IN NORTH AMERICA - CONT.

Cheyenne(REC.)	-420.1	-419.7				
v.m.	1.878	0.145				
W	0.53	6.90				
Denver		-508.1				
v.m.		0.145				
W		6.90				
Charleston			-567.2		-568.02	
v.m.			0.927		0.0095	
W			1.08		105.26	
Amarillo		-695.7				
v.m.		0.145				
W		6.90				
Houston	-821.5	-820.7	-820.2		-821.2	-821.2
v.m.	1.878	0.094	0.357		0.505	0.126
W	0.53	10.64	2.80		1.98	7.94
San Antonio		-922.2				
v.m.		0.145				
W		6.90				
Laredo(AFB)	-1038.1	-1038.9				
v.m.	1.878	0.145				
W	0.53	6.90				
Brownsville						-1079.5
v.m.						0.126
W						
Miami(M.L.)					-1083.49	
v.m.					0.0095	
W					105.26	
Key West					-1150.09	
v.m.					0.0268	
W					37.31	
Monterrey	-1314.1	-1313.7			-1314.7	
v.m.	1.878	0.094			0.505	
W	0.53	10.64			1.98	
Tamazunchale	-1458.8	-1458.8				
(TOURIST v.m.)	1.878	0.145				
(COURT) W	0.53	6.90				

II-107

-828-

TABLE II-53
DATA FOR WEIGHTED MEAN PENDULUM GRAVITY IN NORTH AMERICA - CONT.

Chapulhuacan	-1634.8				
v.m.	0.145				
W	6.90				
(Jacala)	(-1788.8)				
v.m.	0.145				
W	6.90				
Ixmiquilpan	-1951.4				
v.m.	0.145				
W	6.90				
Mexico, D.F.	-2177.2	-2176.9	-2176.6	-2178.8	-2176.92
(TAC.FLOOR) v.m.	1.878	0.094	0.245	(0.788)	0.097
W	0.53	10.64	4.08	1.27	10.31
El Zarco	-2350.9				
v.m.	0.145				
W	6.90				
Paso de Cortes	-2547.8				
v.m.	0.145				
W	6.90				

II-109

TABLE II-54
MEAN PENDULUM INTERVALS IN NORTH AMERICA
RELATIVE TO WASHINGTON, D.C. COMMERCE FLOOR

	Intervals in Milligals						All Mean
	Gulf		USC and CS		Cambridge	D.O. Bronze	
Point Barrow	2580.4	58M	2580.2	52-2			
			2581.0	52-3			
$\bar{s}$	2580.4	1	2580.6	2			2580.53
v.m.							0.24
Umiat			2425.0	52-2			0.058
			.1	52-3			
$\bar{s}$			2425.05				2425.05
v.m.							(0.45)
Fairbanks (Ladd)	2125.1	51C	2125.0	52-2	2126.3	53I	(0.201)
	.2	53K	.3	52-3	2124.4	53VI	
	.3	53M					
	.9	58M					
	.7						
$\bar{s}$	2125.44	5	2125.15	2	2125.35	2	2125.48
v.m.							0.19
Northway	1872.5	53K					0.036
	.4	53M					
$\bar{s}$	1872.45						1872.45
v.m.							(0.38)
Anchorage			1820.6	52-2			(0.145)
			.4	52-3			
$\bar{s}$			1820.50				1820.50
v.m.							0.10
Snag					1813.8	53I	0.010
					.4	53VI	
$\bar{s}$					1813.60		1813.60
v.m.							0.20
Whitehorse(Pump)	1628.0	51C			1630.0	53I	0.040
	30.4	53K			29.2	53VI	
	.4						
	.5	53M					
	.1						
$\bar{s}$	1629.88	5			1629.60	2	1629.80
v.m.							0.34
Kodiak			1627.7	52-2			0.118
			.7	52-3			
$\bar{s}$			1627.70	2			1627.70
v.m.							(0.45)
Watson Lake (D.O.)	1596.6	51C			1596.5	53I	(0.201)
					5.5	53VI	
$\bar{s}$	1596.6	1			1596.00	2	1596.20
v.m.							0.35
							0.123

TABLE II-54
MEAN PENDULUM INTERVALS IN NORTH AMERICA
RELATIVE TO WASHINGTON, D.C. COMMERCE FLOOR - CONT.

Fort Nelson			1562.8 53I		
			.6 53VI		
			<u>1562.70</u>		1562.70
$\bar{s}$					0.10
v.m.					0.010
Fort St. John(BSMNT)	1287.5 51C		1287.3 53I		
	.4 53K		.2 53VI		
	.0 53M				
	<u>1287.30 3</u>		<u>1287.25 2</u>		1287.35
$\bar{s}$					0.09
v.m.					0.009
Grande Prairie(P.O.)	1200.3 51C		1199.3 53I		
	1199.1 53K		8.7 53VI		
	.1 53M				
	<u>1199.50 3</u>		<u>1199.00 2</u>		1199.30
$\bar{s}$					0.27
v.m.					0.072
Edmonton (LAB.)	1048.6 51C		1048.4 53I		
	.6		.7		
	9.2 53K		9.1		
	.3		.3		
	.7 53M		8.5 53VI		
	8.6		.3		
	.7 54M		.3		
			.4		
	<u>1048.96 7</u>		<u>1048.63 8</u>		1048.78
$\bar{s}$					0.11
v.m.					0.012
Red Deer	878.5 53K		878.7 53I		
	.2 53M		.3 53VI		
	<u>878.35 2</u>		<u>878.50 2</u>		878.43
$\bar{s}$					0.11
v.m.					0.012
Winnipeg	874.60 53-2	875.5 52I	874.18 57-45		
	3.99 53-3	4.3 52VI	.60 57-46		
		5.0 53I	.63 57-56		
		2.9 53VI			
	<u>874.30 2</u>	<u>874.43 4</u>	<u>874.45 3</u>		874.41
$\bar{s}$					0.24
v.m.					0.058
Vancouver			816.26 57-45		
			.54 57-46		
			.40 57-56		
			<u>816.40 3</u>		816.40
$\bar{s}$					0.08
v.m.					0.007
Calgary(APT.)	710.0 51C				
	709.1 53K				
	.2 53M				
	<u>709.43 3</u>				709.43
$\bar{s}$					0.28
v.m.					0.081

II-111

TABLE II-54
MEAN PENDULUM INTERVALS IN NORTH AMERICA
RELATIVE TO WASHINGTON, D.C. COMMERCE FLOOR - CONT.

Lethbridge(P.O.)	638.8	51C	642.0	53I		
	9.3	53K	639.8	53VI		
	40.0	53M				
	639.37	3	640.90	2	639.98	
$\bar{s}$					0.55	
v.m.					0.298	
Seattle	620.9	58M				
	.4					
	620.65	2			620.65	
$\bar{s}$					0.25	
v.m.					0.063	
Ottawa (GLF)	Special Case - See Table		502.59	adopted.		
Cutbank(TEMP,BLDG)	488.4	51C				
	9.4	53M				
	488.90	2			488.90	
$\bar{s}$					0.50	
v.m.					0.250	
Minneapolis	479.5	57Mb				
	8.3	59Ka				
	478.90	2			478.90	
$\bar{s}$					0.60	
v.m.					0.360	
Prescott			446.12	57-45		
			.28	-46		
			7.26	-56		
			6.63	-45		
			.73	-46		
			.54	-56		
			446.59	6	446.59	
$\bar{s}$					0.16	
v.m.					0.026	
Great Falls(SCH)	407.2	51C				
	.2					
	.4	53K				
	.4					
	8.9	53M				
	6.8					
	7.2	54M				
	.5					
	407.45	8			407.45	
$\bar{s}$					0.22	
v.m.					0.049	
Huron	334.5	53K	335.19	53-2	335.8	52I
	.1		.24	-3	4.4	52VI
	5.2	53M				
	4.5					
	.5	54M				
	5.3					
	334.68	6	335.21	2	335.10	2
$\bar{s}$						
v.m.						334.87
						0.18
						0.032

II-113

TABLE II-54
MEAN PENDULUM INTERVALS IN NORTH AMERICA
RELATIVE TO WASHINGTON, D.C. COMMERCE FLOOR - CONT.

San Francisco	-133.2	54Mb							
	2.4	55M							
	.3								
	1.2	56-7M							
	.8								
	2.4	58M							
	.4								
	-132.24	7							-132.24
$\bar{s}$									0.18
v.m.									0.032
Casper(PUMP)	-164.8	51C							
	3.4	53K							
	.9	53M							
	-164.03	3							-164.03
$\bar{s}$									0.41
v.m.									0.168
Tulsa	-353.8	53K	-353.66	53-2	-353.7	52I			
	.5		.30	53-3	4.1	52VI			
	-353.65	2	-353.48	2	-353.39	2			-353.68
$\bar{s}$									0.11
v.m.									0.012
Cheyenne(REC.)	-420.1	51C							
	.1	53K							
	419.4	53M							
	-419.87	3							-419.87
$\bar{s}$									0.23
v.m.									0.054
Denver	-508.4	53K							
	7.8	53M							
	-508.10	2							-508.10
$\bar{s}$									0.30
v.m.									0.090
Charleston	-567.5	57Ma							
	.9	57Mb							
	8.1								
	9.2								
	7.99	59Kb							
	8.15								
	7.86	59M							
	8.09								
	-568.10	8							-568.10
$\bar{s}$									0.17
v.m.									0.030
Amarillo	-695.8	53K							
	.6	53M							
	-695.70								-695.70
$\bar{s}$									0.10
v.m.									0.010

II-114

TABLE II-54
MEAN PENDULUM INTERVALS IN NORTH AMERICA
RELATIVE TO WASHINGTON, D.C. COMMERCE FLOOR - CONT.

Houston	-821.5	51C	-821.05	53-2	-821.4	52I	
	.3	53K	.33	53-3	.2	52VI	
	819.9						
	20.7	53M					
	.8						
	.2	54M					
	-820.73	6	-821.19	2	-821.30	2	-820.94
$\bar{s}$							0.17
v.m.							0.029
San Antonio	-922.5	53K					
	1.9	53M					
	-922.20	2					-922.20
$\bar{s}$							0.30
v.m.							0.090
Laredo	-1038.1	51C					
	.3	53K					
	9.5	53M					
	-1038.63	3					-1038.63
$\bar{s}$							0.44
v.m.							0.191
Brownsville			-1080.51	53-2			
			78.54	53-3			
			-1079.53	2			-1079.53
$\bar{s}$							0.98
v.m.							0.970
Miami(M.L.)	-1083.62	59Kb					
	.66						
	.24	59M					
	.44						
	-1083.49	4					-1083.49
$\bar{s}$							0.10
v.m.							0.0092
Key West	-1150.34	59Kb					
	49.85	59M					
	-1150.10	2					-1150.10
$\bar{s}$							0.24
v.m.							0.060
Monterrey	-1314.1	51C			-1314.8	52I	
	3.8	53K			.9		
	.5						
	.6	53M					
	.8						
	-1313.76	5			-1314.85	2	-1314.07
$\bar{s}$							0.21
v.m.							0.046
Tamazunchale(TC)	-1458.8	51C					
	.4	53K					
	9.2	53M					
	-1458.80	3					-1458.80
$\bar{s}$							0.23
v.m.							0.053

II-115

TABLE II-54
MEAN PENDULUM INTERVALS IN NORTH AMERICA
RELATIVE TO WASHINGTON, D.C. COMMERCE FLOOR - CONT.

Chapulhuacan	-1634.7	53K		
	.9	53M		
	-1634.80	2		-1634.80
$\bar{s}$				0.10
v.m.				0.010
Jacala	(-1788.1)	53K		
	(.9.5)	53M		
	(-1788.80)	2		(-1788.80)
$\bar{s}$				
v.m.				
Ixmiquilpan	-1951.9	53K		
	.0	53M		
	-1951.45	2		-1951.45
$\bar{s}$				0.45
v.m.				0.203
Mexico, D.F.	-2177.2	51C	-2178.9	52
	6.2	53K		
	7.3			
	.3	53M	6.91	58I
	.0		.83	
	6.8	58M	7.04	58VI
	.5		6.98	
	-2176.90	7	-2177.33	5
$\bar{s}$				-2177.08
v.m.				0.19
				0.036
El Zarco	-2350.5	53K		
	1.3	53M		
	-2350.90	2		-2350.90
$\bar{s}$				0.40
v.m.				0.160
Paso de Cortes	-2547.5	53K		
	8.0	53M		
	-2547.75	2		-2547.75
$\bar{s}$				0.25
v.m.				0.063

TABLE II-55
DATA FOR WEIGHTED MEAN PENDULUM GRAVITY IN SOUTH AMERICA

Station	Gulf		Camb.
	57 Mb	58 M	58 CB
Punta Arenas	1194.9		
v.m.	0.891		
W	1.12		
Washington, D.C.(GLF)	0	0	0
v.m.	0	0	0
W			
Buenos Aires	-415.6	-412.8	-413.83
v.m.	0.891	0.364	.104
W	1.12	2.75	9.62
Santiago	-690.5		-689.98
v.m.	.560		.114
W	1.79		8.77
Antofagasta	-1217.5		
v.m.	.891		
W	1.12		
Rio de Janeiro		-1314.2	-1314.22
v.m.		0.245	.106
W		4.08	9.43
Lima	-1835.4	-1835.3	-1836.02
v.m.	.560	0.364	.107
W	1.79	2.75	9.35
Panama	-1877.5	-1877.1	-1877.30
v.m.	.560	0.186	.100
W	1.79	5.41	10.00
Caracas		-2079.2	-2079.24
v.m.		0.245	.099
W		4.08	10.10
Belem		-2082.1	
v.m.		0.364	
W		2.75	
La Paz	-2652.4		-2652.14
v.m.	.560		.114
W	1.79		8.77
Bogata		-2714.1	
v.m.		0.364	
W		2.75	
Quito	-2840.3	-2839.6	-2840.73
v.m.	.891	0.364	0.098
W	1.12	2.75	10.20

II-117

TABLE II-56
MEAN PENDULUM INTERVALS IN SOUTH AMERICA
RELATIVE TO WASHINGTON, D.C. COMMERCE FLOOR

	Gulf		Cambridge		All Mean
Punta Arenas	1149.9	57M			1149.9
$\bar{s}$					(0.94)
v.m.					(0.891)
Washington, D.C.(CF)	(0)		(0)		0
Buenos Aires	-415.6	57M	-413.66	58I	
	-412.8	58M	.76		
			4.21	58VI	
			3.78		
	-414.20	2	-413.85	4	-413.97
$\bar{s}$					0.38
v.m.					0.143
Santiago	-690.1	57M	-690.21	58I	
	.9		.11		
			.10	58VI	
			689.62		
	-690.50	2	-690.01	4	-690.17
$\bar{s}$					0.17
v.m.					0.028
Antofagasta	-1217.5				-1217.5
$\bar{s}$					(0.94)
v.m.					(0.891)
Rio de Janeiro	-1313.6	58M	-1313.92	58I	
	4.8		4.58	58VI	
	-1314.25	2	-1314.25	2	-1314.25
$\bar{s}$					0.30
v.m.					0.089
Lima	-1835.8	57M	-1835.93	58I	
	.1		6.28		
	.3	58M	5.90	58VI	
			6.06		
	-1835.40	3	-1836.04	4	-1835.77
$\bar{s}$					0.16
v.m.					0.025
Panama	-1876.8	57M	-1877.28	58I	
	8.3		6.80		
	7.1	58M	7.13		
	.0		.78	58VI	
	6.7		.70		
	7.8		.26		
	-1877.28	6	-1877.33	6	-1877.31
$\bar{s}$					0.14
v.m.					0.020
Caracas	-2079.0	58M	-2079.09	58I	
	.4		.45	58VI	
	-2079.20	2	-2079.27	2	-2079.24
$\bar{s}$					0.11
v.m.					0.012
Belem	-2082.1	58M			-2082.1
$\bar{s}$					(0.60)
v.m.					(0.364)

TABLE II-56
 MEAN PENDULUM INTERVALS IN SOUTH AMERICA
 RELATIVE TO WASHINGTON, D.C. COMMERCE FLOOR - CONT.

La Paz	-2652.3	57M	-2652.05	58I	
	.5		.45		
			1.88	58VI	
			2.28		
	-2652.40	2	-2652.17	4	-2652.25
$\bar{s}$					0.09
v.m.					0.009
Bogota	-2714.1	58M			-2714.1
$\bar{s}$					(0.60)
v.m.					(0.364)
Quito	-2840.3	57M	-2841.18	58I	
	39.6	58M	.02		
			0.82	58VI	
			.85		
	-2839.95	2	-2840.97	4	-2840.63
$\bar{s}$					0.24
v.m.					0.057

TABLE II-57
DATA FOR WEIGHTED MEAN PENDULUM GRAVITY IN THE FAR EAST AND PACIFIC

Station	Gulf				Japanese		Camb.
	54 M	55 M	56-7 M	58 M	55 GSI	57-8GSI	59 CB
Ross Island			2873.7				
v.m.			.323				
W			3.10				
Dunedin			624.4				
v.m.			.323				
W			3.10				
Christchurch			390.4	389.8			
v.m.			(0.289)	.220			
W			3.46	4.55			
Chitose(AFB)				322.3			
v.m.				.220			
W				4.55			
Lower Hutt			175.3				
v.m.			.323				
W			3.10				
Washington,D.C.(CF)	0	0	0	0	0	0	0
v.m.	0	0	0	0	0	0	0
W							
Hastings			-28.6				
v.m.			.323				
W			3.10				
Melbourne(FTSCRY)			-139.2				-139.46
v.m.			.220				0.047
W			4.55				21.28
Tokyo	-318.30			-317.0		-318.43	
v.m.	.233			.149		(0.019)	
W	4.29			6.71		52.63	
Chiba					-329.63		
v.m.					0.0090		
W					111.11		
Kyoto	-398.52				-398.03		
v.m.	.233				0.030		
W	4.29				33.33		
Sydney			-432.8	-432.6			
v.m.			.220	.149			
W			4.55	6.71			
Brisbane			-950.1	-949.0			
v.m.			.220	.126			
W			4.55	7.94			
New Delhi	-983.05						
v.m.	.233						
W	4.29						
Okinawa(Kadena)				-992.4			
v.m.				.149			
W				6.71			
Honolulu	-1167.78	-1166.2	-1166.5	-1165.9			
v.m.	.233	1.237	.323	.220			
W	4.29	0.81	3.10	4.55			
Hong Kong				-1352.2			
v.m.				.149			
W				6.71			

TABLE II-57

DATA FOR WEIGHTED MEAN PENDULUM GRAVITY IN THE FAR EAST AND PACIFIC - CONT.

Townsville		-1496.0	-1494.7	
v.m.		.323	.220	
W		3.10	4.55	
Cairns		-1620.4	-1618.3	
v.m.		.323	.149	
W		3.10	6.71	
Manila(Clark AFB)	-1722.61-1722.3		-1722.5	
v.m.	.233 .777		.126	
W	4.29 1.29		.794	
Darwin (BMR)		-1805.0	-1804.2	-1804.15
v.m.		.323	.149	0.047
W		3.10	6.71	21.28
Singapore		-2037.0		-2038.18-2036.8
v.m.		.220		0.067 0.047
W		4.55		14.93 21.28

TABLE II-58
MEAN PENDULUM INTERVALS IN THE FAR EAST AND PACIFIC
RELATIVE TO WASHINGTON, D.C. COMMERCE FLOOR

		<u>Gulf</u>	<u>Cambridge</u>	<u>GSI</u>	All Mean
Ross Island	2873.7	56-7M			2873.7
$\bar{s}$					(0.57)
v.m.					(0.323)
Dunedin	624.4	56-7M			624.4
$\bar{s}$					(0.57)
v.m.					(0.323)
Christchurch	390.1	56-7M			
Rejected	(386.9)				
	389.2				
	.2				
	.8	58M			
	<u>389.57</u>	<u>(4)</u>			389.57
$\bar{s}$					0.23
v.m.					0.051
Chitose AFB	322.3	58M			322.3
$\bar{s}$					0.47
v.m.					(0.220)
Lower Hutt	175.3	56-7M			175.3
$\bar{s}$					(0.57)
v.m.					(0.323)
Washington, D.C.(C.F.)	(0)	(249.90 to Mad.)			0
Hastings	-28.6	56-7M			-28.6
$\bar{s}$					(0.57)
v.m.					(0.323)
Melbourne(FTSCRY)	-139.3	56-7M	-139.55	59I	
	.2		.72		
			.47	59VI	
			.34		
	<u>-139.25</u>	<u>2</u>	<u>-139.52</u>	<u>4</u>	-139.43
$\bar{s}$					0.08
v.m.					0.006
Tokyo	-318.32	54M		(-317.98)	55-1
	7.0	58M		(.79)	
	6.9			(9.55)	55-3
				(.84)	
				(8.53)	55-12
				(7.57)	
	<u>-317.41</u>	<u>3</u>		<u>-318.54</u>	<u>6</u>
$\bar{s}$					-318.16
v.m.					0.34
Chiba				-329.18	55-1
				8.99	
				330.75	55-3
				1.04	
				329.73	55-12
				8.77	
				<u>-329.74</u>	<u>6</u>
$\bar{s}$					-329.74
v.m.					0.39
					0.151

II-122

TABLE II-58
MEAN PENDULUM INTERVALS IN THE FAR EAST AND PACIFIC
RELATIVE TO WASHINGTON, D.C. COMMERCE FLOOR - CONT.

Kyoto	-398.52	54M	(-397.58)	55-1	
			(.39)		
			(9.15)	55-3	
			(.44)		
			(8.13)	55-12	
			(7.17)		
	-398.52	1	(-398.14)	6	-398.19
$\bar{s}$					0.33
v.m.					0.110
Sydney	-433.3	56-7M			
	2.3				
	.1	58M			
	3.0				
	-432.68	4			-432.68
$\bar{s}$					0.28
v.m.					0.081
Brisbane	-949.7	56-7M			
	950.6				
	948.7	58M			
	9.4				
	8.9				
	-949.46	5			-949.46
$\bar{s}$					0.34
v.m.					0.113
New Delhi	-983.05	54M			-983.05
$\bar{s}$					(0.48)
v.m.					(0.233)
Okinawa(KADENA)	-992.5	58M			
	.3				
	-992.40	2			-992.40
$\bar{s}$					0.10
v.m.					0.010
Honolulu	-1167.8	54M			
	6.2	55M			
	.5	56-7M			
	5.9	58M			
	-1166.60	4			-1166.60
$\bar{s}$					0.42
v.m.					0.175
Hong Kong	-1351.8	58M			
	2.6				
	-1352.20	2			-1352.20
$\bar{s}$					0.40
v.m.					0.160
Townsville	-1496.0	56-7M			
	4.7	58M			
	-1495.35	2			-1495.35
$\bar{s}$					0.65
v.m.					0.423

TABLE II-58
MEAN PENDULUM INTERVALS IN THE FAR EAST AND PACIFIC
RELATIVE TO WASHINGTON, D.C. COMMERCE FLOOR - CONT.

Cairns	-1620.4	56-7M							
	17.9	58M							
	18.7								
	-1619.00	3						-1619.00	
$\bar{s}$								0.74	
v.m.								0.543	
Manila(CLARK AFB)	(-1722.6)	54M							
	.2	55M							
	.3								
	.9	58M							
	.0								
	.5								
	-1722.42	6						-1722.42	
$\bar{s}$								0.13	
v.m.								0.017	
Darwin(BMR)	-1805.0	56-7M	-1804.26	59I					
	4.0	58M	.61						
	.4		.14	59VI					
			.05						
	-1804.47	3	-1804.27	4				-1804.35	
$\bar{s}$								0.13	
v.m.								0.017	
Singapore	-2037.0	58M	-2037.09	59I	-2037.49	57-8-3			
			6.50		.45				
			.74	59VI	8.43	57-8-2			
			.93		.15				
	-2037.0	1	-2036.82	4	-2037.88	4		-2037.31	
$\bar{s}$								0.21	
v.m.								0.046	

TABLE II-59 II-124

DATA FOR WEIGHTED MEAN PENDULUM GRAVITY IN EUROPE AND N. AFRICA

Station	Gulf		Cambridge				DGK	Italian
	54 M	59 K	51 CB	52 CB	55 CB	58 CB	58 DGJF	58 CGI
Hammerfest					1435.40			
v.m.					0.136			
W					7.35			
Bodo					1190.40			
v.m.					0.081			
W					12.35			
Oslo	730.99				730.79		730.53	
v.m.	0.300				0.022		(0.500)	
W	3.33				45.45		(2.00)	
Edinburgh				387.25			387.13	
v.m.				(0.500)			(0.500)	
W				(2.00)			(2.00)	
Copenhagen	361.32				361.89		362.47	
(BUDD. PIER) v.m.	0.300				0.027		(0.500)	
W	3.33				37.04		(2.00)	
Teddington	0	0	0	0	0	0	0	0
(NPL 11) v.m.	0	0	0	0	0	0	0	0
W								
Bad Harzburg	See Table ;							
v.m.	Weighted Mean -15.88 ± 0.15 mgals							
W					$\bar{s}_{WM}^2 = 0.022$ (mgals) ²			
Frankfurt	-135.48							
(SINDLINGEN)								
v.m.	0.300							
W	3.33							
Paris(SEVRES A)		-255.66	-255.35				-255.57	
v.m.		0.085	1.63				(0.500)	
W		11.76	0.61				(2.00)	
Munich(NYMPH.)	See Table ;							
v.m.	Weighted Mean -451.74 ± 0.17 mgals							
W					$\bar{s}_{WM}^2 = 0.030$ (mgals) ²			
Rome(I.N.G.)	-832.71					-832.07		-832.79
v.m.	0.300					0.250		(0.529)
W	3.33					4.00		(1.89)
Lisbon(EGN 1)		-1106.33						
v.m.		0.057						
W								
Catania						-1149.37		-1150.17
v.m.						0.810		(1.029)
W						1.23		(0.97)
Tripoli	-1609.56							
(WHEELUS) v.m.	0.300							
W	3.33							

II-125

TABLE II-60
MEAN PENDULUM INTERVALS IN EUROPE
RELATIVE TO TEDDINGTON (NPL 11)

	<u>Gulf</u>		<u>Cambridge</u>		<u>DGJF</u>	<u>CGI</u>	All Mean
Hammerfest			1435.39	55VI			1435.39
$\bar{s}$							0.37
v.m.							(0.136)
Bodo			1190.83	55VI			
$\bar{s}$			.03				
v.m.			1190.43	2			1190.43
Oslo	731.38	54M	730.66	55I	730.53	58	0.40
$\bar{s}$			.68				0.160
v.m.			.37				
			1.22	VI			
			.08				
			.20				
	731.38	1	730.87	6	730.53	1	730.89
$\bar{s}$							0.15
v.m.							0.024
Edinburgh			387.25	52	387.13	58	387.19
$\bar{s}$							0.06
v.m.							0.0036
Copenhagen(PIER)	361.32	54M	361.15	55I	362.47	58	
$\bar{s}$			.15				
v.m.			2.10	55VI			
			.78				
	361.32	1	361.80	4	362.47	1	361.83
$\bar{s}$							0.29
v.m.							0.086
Teddington	0		0		0	0	0
Bad Harzburg	-16.27	55M	-15.78	51I			
$\bar{s}$			.73	VI			
v.m.			.61	55I			
			16.42				
			15.46	VI			
			.54				
	-16.27	1	-15.76	6			-15.83
$\bar{s}$							0.14
v.m.							0.020
Frankfurt	-135.48	55M					-135.48
(SINDLINGEN)							
$\bar{s}$							(0.48)
v.m.							(0.233)
Paris(SEVRES A)	-255.66	59K	-256.56	51I	-255.57	58	
$\bar{s}$			4.14	VI			
v.m.	-255.66	1	-255.35	2	-255.57	1	-255.48
							0.50
							0.250
Munich(NYMPH)	-452.31	54M	-452.14	55I	-451.26	58	-451.53
$\bar{s}$			0.71	VI			58
v.m.			2.14)	58			via B.H.
			2.14)				15.83
	-452.31	1	-451.78	4	-451.26	1	-451.75
$\bar{s}$							0.23
v.m.							0.051

II-126

TABLE II-60
MEAN PENDULUM INTERVALS IN EUROPE
RELATIVE TO TEDDINGTON (NPL 11) - CONT.

Rome(ING)	-832.71	54M	-832.07)	58	-832.61	58	
			.07)			via B.H.	
	-832.71	1	-832.07	2	-832.61	1	-832.37
$\bar{s}$							0.17
v.m.							0.029
Lisbon(EGN 1)	-1106.15	59K					
	.52						
	-1106.34	2					-1106.34
$\bar{s}$							0.18
v.m.							0.032
Catania			-1149.37)	58	-1149.99	58	
			.37)				
			-1149.37	2	-1149.99	1	-1149.58
$\bar{s}$							0.21
v.m.							0.043
Tripoli(WHEELUS)	-1609.56	54M					-1609.56
$\bar{s}$							0.55
v.m.							(0.300)

TABLE II-61
DATA FOR WEIGHTED MEAN PENDULUM GRAVITY IN AFRICA

Station	Cambridge			Gulf		Japanese
	48-9 CB	56 CB	58 CB	55 M	59 K	57-8 GSI
Teddington	0	0	0	0	0	0
v.m.	0	0	0	0	0	0
W						
Capetown(Roy.OBS)	-1540.6					
v.m.	0.301					
W	3.32					
Mowbray(TRIG.SURV.)	-1548.90	-1549.2		-1548.71		-1549.24
v.m.	.086	0.044		1.263		0.093
W	11.63	22.73		0.79		10.75
Cairo(HELWAN OBS.)				-1904.91		
v.m.				1.263		
W				0.79		
Pretoria	-2566.97	-2567.0				
v.m.	0.301	0.044				
W	3.32	22.73				
Johannesburg	-2646.60	-2647.0	-2646.29	-2646.91	-2646.58	
v.m.	0.075	0.044	0.040	1.260	0.057	
W	13.33	22.73	25.00	.79	17.54	
Mbour					-2812.12	
v.m.					0.057	
W					17.54	
Khartoum(COORD)			-2892.97	-2893.31		
v.m.			0.160	1.263		
W			6.25	0.79		
Bulawayo	-2904.73					
v.m.	0.451					
W	2.22					
Victoria Falls	-2965.60			-2965.1		
v.m.	0.902			1.263		
W	1.11			0.79		
Salisbury	-3048.35		-3047.97			
v.m.	0.902		0.160			
W	1.11		6.25			
Accra					-3091.03	
v.m.					0.057	
W					17.54	
Lusaka				-3142.3		
v.m.				1.263		
W				0.79		
Leopoldville					-3281.89	
v.m.					0.057	
W					17.54	
Asmara(KAGNEW)				-3377.5		
v.m.				1.263		
W						
Nairobi(FLD.SURV.)			-3655.57	-3656.11		
v.m.			0.090	.803		
W			11.11	1.25		

II-128

TABLE II-62
MEAN PENDULUM INTERVALS IN AFRICA
RELATIVE TO TEDDINGTON (NPL 11)

	Gulf		Intervals in Milligals		GSI		All
	0		Cambridge		0		Mean
Teddington(NPL 11)							0
Capetown(ROY.OBS.)			-1541.5	48IA			
			3.8	B			
			38.3	C			
			40.1	VIA			
			38.1	B			
			41.7	C			
			-1540.58	6			-1540.58
$\bar{s}$							0.90
v.m.							0.802
Mowbray	-1548.71	55M	-1548.23	48IA	-1548.95	57-8-3	
			.23	B	.35	-2	
			.23	C			
			9.93	VIA			
			8.43	B			
			50.33	C			
	-1548.71	1	-1548.90	6	-1548.65	2	-1548.82
$\bar{s}$							0.26
v.m.							0.069
Cairo(HELWAN)	-1904.91	55M					-1904.91
$\bar{s}$							(1.12)
v.m.							(1.263)
Pretoria			-2567.9	48IA			
			.5	B			
			6.5	C			
			.6	VIA			
			5.8	B			
			7.5	C			
			.3	56IA			
			6.9	IB			
			.9	C			
			7.8	VIA			
			6.3	B			
			7.0	C			
			-2567.00	12			-2567.00
$\bar{s}$							0.18
v.m.							0.033
Johannesburg(BPI)	-2646.91	55M	-2646.13	48IA			
	.50	59K	5.83	IB			
	.66		5.33	IC			
			7.43	VIA			
			.23	VIB			
			.63	VIC			
			.6	56IA			
			6.8	IB			
			7.1	IC			
			.5	VIA			
			6.2	VIB			
			.6	VIC			
			.20	58I			
			.37				

TABLE II-62
MEAN PENDULUM INTERVALS IN AFRICA
RELATIVE TO TEDDINGTON (NPL 11) - CONT.

Johannesburg -cont.			.27	58VI	
			.20		
$\bar{s}$	-2646.69	3	-2646.65	16	-2646.66
v.m.					0.15
M'Bour	-2812.24	59K			0.022
	.00				
$\bar{s}$	-2812.12	2			-2812.12
v.m.					0.12
Khartoum(COORD.)	-2893.31	55M	-2892.97)	58	0.014
			.97)		
$\bar{s}$	-2893.31	1	-2892.97	2	-2893.08
v.m.					0.28
Bulawayo			-2903.75	48VIA	0.077
			5.70	C	
$\bar{s}$			-2904.73	2	-2904.73
v.m.					0.98
Victoria Falls	-2965.1	55M	-2964.6	48VIA	0.960
			6.6	C	
$\bar{s}$	-2965.1	1	-2965.6	2	-2965.43
v.m.					0.60
Salisbury			-3048.6	48VIA	0.361
			.1	C	
$\bar{s}$			7.97)	58	
v.m.			7.97)		
Accra	-3091.20	59K	-3048.16	4	-3048.16
	0.97				0.15
$\bar{s}$	-3091.09	2			0.022
v.m.					
Lusaka	-3142.31	55M			-3091.09
$\bar{s}$					0.12
v.m.					0.144
Leopoldville	-3281.86	59K			-3142.31
	.93				0.
$\bar{s}$	-3281.90	2			0.
v.m.					
Asmara	-3377.51	55M			-3281.90
$\bar{s}$					0.04
v.m.					0.002
Nairobi(FLD.SURV.)	-3656.3	55M	-3655.57)	58	-3377.51
	5.9		.57)		(1.12)
$\bar{s}$	-3656.10	2	-3655.57	2	(1.263)
v.m.					

TABLE II-63
PENDULUM WEIGHTED MEANS - NORTH AMERICA

	Δg	$\pm \bar{s}_{WM}$	$\bar{s}_{WM}^2$	g
Point Barrow	2850.56	0.32	0.105	982.6992 ⁵
Umiat (USCGS)	2425.1	.45	.201	.5438
Fairbanks (LADD)	2125.45	.22	.050	.2441 ⁴
Northway	1872.5	.38	.145	981.9912
Anchorage (USCGS)	1820.5	.45	.201	.9392
Snag	1813.7	1.00	.998	.9324
Whitehorse (PUMP)	1630.24	.29	.082	.7489 ³
Kodiak (USCGS)	1627.7	.45	.201	.7464
Watson Lake (D.O.)	1596.27	.81	.654	.7149 ⁶
Fort Nelson	1562.8	1.00	.998	.6815
Fort St. John (BSMNT)	1287.24	.34	.119	.4059 ³
Grande Prairie (P.O.)	1199.18	"	.119	.3178 ⁷
Edmonton (LAB)	1049.01	.24	.060	.1677 ⁰
Red Deer	878.43	.36	.127	980.9971 ²
Winnipeg	874.50	.24	.059	.9931 ⁹
Vancouver	816.48	.21	.046	.9351 ⁷
Calgary (APT)	709.26	.37	.135	.8279 ⁵
Lethbridge (P.O.)	639.88	.34	.119	.7585 ⁷
Seattle	620.6	.39	.149	.7393
Ottawa (GLF)	502.66	.16	.027	.6213 ⁵
Cutbank (TB)	489.28	.47	.219	.6079 ⁷
Minneapolis	478.64	.50	.252	.5973 ³
Prescott	446.69	.21	.044	.5653 ⁸
Great Falls (SCH)	407.50	.26	.066	.5261 ⁹
Huron	334.84	.22	.048	.4535 ³
Billings (HNGR)	251.69	.37	.135	.3703 ⁸
Madison (12)	249.92	.09	.0076	.3686 ¹
Woods Hole (BSMNT)	208.6	.66	.430	.3273
Cornell	181.33	.31	.094	.3000 ²
Chicago	168.2	1.37	1.878	.2869
Lamont Obs.	140.49	.09	.008	.2591 ⁸
Sheridan (HNGR)	106.89	.37	.135	.2255 ⁸
Princeton	59.7	.66	.430	.1784
Washington, D.C. (CF)	0	0	0	.1186 ⁹
Beloit	-121.04	.24	.056	979.9976 ⁷
San Francisco	-132.36	.24	.059	.9863 ³
Casper (PUMP)	-163.69	.37	.135	.9550 ²
Tulsa	-353.59	.27	.072	.7651 ⁰
Cheyenne (REC.)	-419.73	.37	.135	.6989 ⁶
Denver	-508.1	.38	.145	.6106
Charleston	-568.01	.10	.0094	.5506 ⁴
Amarillo	-695.7	.38	.145	.4230
Houston	-820.87	.20	.042	.2978 ²
San Antonio	-922.2	.38	.145	.1965
Laredo	-1038.84	.37	.135	.0797 ⁷
Brownsville	-1079.5	.35	.126	.0391 ⁹
Miami (M.L.)	-1083.49	.10	.0095	.0350 ²
Key West	-1150.09	.16	.027	978.9682 ⁸
Monterrey	-1313.87	.28	.076	.8048 ²

TABLE II-63
PENDULUM WEIGHTED MEANS - NORTH AMERICA - CONT.

Tamazunchale(T.C.)	-1458.80	0.37	0.135	978.65989
Chapulhuacan	-1634.8	.38	.145	.4839
(Jacala	-1788.8	"	"	.3299)
Ixmiquilpan	-1951.4	"	"	.1673
Mexico, D.F. (TAC)	-2176.96	.19	.037	977.94173
El Zarco	-2350.9	.38	.145	.7678
Paso de Cortes	-2547.8	"	"	.5709

Data Used for These Results:

1951 Gulf C (Rose)
 1952-3 USCGS
 1952-3 Cambridge (Garland)
 1953 Gulf KM (Rose)
 1954a Gulf M (Rose)
 1954b " M "
 1954 Cambridge (Garland and Cook)
 1955 Gulf M (Rose)
 1956 " M (Steinhart)
 1956-7 " M (Rose)
 1957a " M (Rose)
 1957b " M (Watkins)
 1957 D.O. (Thompson)
 1958a Gulf M (Iverson)
 1958b " M (Iverson)
 1958 Cambridge (Jackson)
 1959 Gulf KM (Rose and Strickholm)

The Washington base value is based on the weighted mean interval to Teddington of 1077.51 $\pm$ 0.15 mgals. Teddington is taken as 981.1962⁰.

Jacala should not be used.

II-132

TABLE II-64
PENDULUM WEIGHTED MEANS - SOUTH AMERICA

	Δg	$\pm \bar{s}_{WM}$	$\bar{s}_{WM}^2$	g
Punta Arenas	+1194.9	0.94	0.891	981.3136
Washington, D.C. (CF)	0	0	0	980.1186 ⁹
Buenos Aires	-413.77	0.27	0.074	979.7049 ²
Santiago	-690.01	.31	.095	.4286 ⁸
Antofagasta	-1217.5	.94	.891	978.9012
Rio de Janeiro	-1314.21	.27	.074	.8044 ⁸
Lima	-1835.80	.27	.072	.2828 ⁹
Panama	-1877.26	.24	.058	.2414 ³
Caracas	-2079.23	.27	.071	.0394 ⁶
Belem	-2082.1	.60	.364	.0366
La Paz	-2652.18	.31	.095	.4665 ¹
Bogata	-2714.1	.60	.364	977.4046
Quito	-2840.47	.27	.071	.2782 ²

Data Used:

1957 Gulf M (Watkins)
1958 " M (Iverson)
1958 Cambridge (Jackson)

TABLE II-65
PENDULUM WEIGHTED MEANS - FAR EAST AND PACIFIC

Ross Island	+2873.70	0.57	0.323	982.9923 ⁹
Dunedin	+624.40	.57	.323	980.7430 ⁹
Christchurch	+390.06	.35	.125	.5087 ⁵
Chitose (AFB)	+322.30	.47	.220	.4409 ⁹
Lower Hutt	+175.30	.57	.323	.2939 ⁹
Washington, D.C. (CF)	0	0	0	980.1186 ⁹
Hastings	-28.60	.57	.323	.0900 ⁹
Melbourne (Footscray)	-139.41	.20	.039	979.9792 ⁸
Tokyo	-318.27	.13	.016	.8004 ²
Chiba	-329.63	.09	.009	.7890 ⁶
Kyoto	-398.09	.16	.027	.7206 ⁰
Sydney	-432.68	.30	.089	.6860 ¹
Brisbane	-949.40	.28	.080	.1692 ⁹
New Delhi	-983.05	.48	.233	.1356 ⁴
Okinawa (KADENA)	-992.40	.39	.149	.1262 ⁹
Honolulu	-1166.70	.28	.078	978.9519 ⁹
Hong Kong	-1352.20	.39	.149	.7664 ⁹
Townsville	-1495.23	.36	.131	.6234 ⁶
Cairns	-1618.96	.32	.102	.4997 ³
Manila (CLARK AFB)	-1722.52	.27	.074	.3961 ⁷
Darwin (BMR)	-1804.19	.18	.032	.3145 ⁰
Singapore	-2037.04	.15	.024	.0816 ⁵

Data Used:

1952 GSI (Muto)	1955 Gulf M (Rose)	1958 Gulf M (Iverson)
1954 Gulf M (Rose)	1956-7 " M (Rose)	1959 Cambridge (Jackson)
1955 GSI (Okuda)	1957 GSI (Harada)	

TABLE II-66
PENDULUM WEIGHTED MEANS - EUROPE AND NORTH AFRICA

	Δg	$\pm \bar{s}_{WM}$	$\bar{s}_{WM}^2$	g
Hammerfest	+1435.40	0.37	0.136	982.6316 ⁰
Bodo	+1190.40	.28	0.081	.3866 ⁰
Oslo	+730.79	.14	0.020	981.9269 ⁹
Edinburgh	+387.19	.50	0.250	.5833 ⁹
Copenhagen (Pier)	+361.87	.15	0.023	.5580 ⁷
Teddington (NPL B11)	0	0	0	981.1962 ⁰
Bad Harzburg	-15.88	.15	0.023	.1803 ²
Frankfurt (SINDLINGEN)	-135.48	.55	0.300	.0607 ²
Paris (SEVRÈS A)	-255.63	.26	0.070	980.9405 ⁷
Munich (NYMPHENBURG)	-451.74	.17	0.030	.7444 ⁶
Equiv. (RESIDENZ)	-458.10	.17	0.029	.7381 ⁰
Rome (I.N.G.)	-832.45	.33	0.108	.3637 ⁵
Lisbon (EGN 1)	-1106.33	.24	0.057	.0898 ⁷
Catania	-1149.72	.67	0.455	.0464 ⁸
Tripoli	-1609.56	.55	0.300	979.5866 ⁴

Data Used:

1951 Cambridge (Cook)
 1952 " (Bullerwell)
 1954 Gulf M (Rose)
 1955 Cambridge (Jelstrup)
 1958 " (Browne)
 1958 Askania (Marzahn)
 1958 CGI (Mazzon)
 1959 Gulf K (Iverson)

TABLE II-67
PENDULUM WEIGHTED MEANS - AFRICA

Teddington (NPL B11)	0			981.1692 ⁰
Capetown (ROY.OBS.)	-1540.6	0.55	0.301	979.6556 ⁰
Mowbray (TRIG.SURV.)	-1549.12	0.15	0.022	.6470 ⁸
Cairo (HELWAN OBS. SEIS.)	-1904.91	1.12	1.263	.29129
Pretoria	-2567.0	0.19	0.038	978.6292 ⁰
Johannesburg	-2646.62	.11	0.013	.5495 ⁸
M'Bour	-2812.12	.24	.057	.38408
Khartoum	-2893.01	.38	.142	.30319
Bulawayo	-2904.73	.67	.451	.2914 ⁷
Victoria Falls	-2965.31	.72	.524	.2308 ⁹
Salisbury	-3048.03	.37	.136	.1481 ⁷
Accra	-3091.03	.24	.057	.10517
Lusaka	-3142.31	1.12	1.263	.05389
Leopoldville	-3281.89	0.24	0.057	977.91431
Asmara	-3377.51	1.12	1.256	.81869
Nairobi (FIELD SURVEY)	-3655.63	0.28	0.081	.54057

Data Used:

1948-9 Cambridge (Hales and Gough) 1957-8 GSI (Harada)
 1955 Gulf M (Rose) 1958 Cambridge (Browne)
 1956 Cambridge (Gough) 1959 Gulf K (Iverson)

TABLE II-68
MEAN PENDULUM GRAVITY IN CM/SEC² FOR NORTH AMERICA

	Weighted Means				Simple Means						
	Gulf	$\pm s$	All	$\pm s$	Gulf	$\pm s$	All	$\pm s$	USCGS	Camb.	D.O.
Point Barrow	982.6991	0.47	.6993	0.32	.6991	0.47	.6992	0.24	.6993		
Umiat(USCGS)			.5438	.45			.5438	.45	.5438		
Fairbanks(LADD)	.2442	.27	.2441	.22	.2441	.15	.2442	.19	.2439	.2441	
Northway	981.9912	.38			.9912	.38					
Anchorage(USCGS)			.9392	.45			.9392	.10	.9392		
Snag			.9324	1.00			.9323	.20		.9323	
Whitehorse(PUMP)	.7490	.30	.7489	.29	.7486	.48	.7485	.34		.7483	
Kodiak(USCGS)			.7464	.45			.7464	.45	.7464		
Watson Lake(D.O.)	.7153	1.37	.7150	.81	.7153	1.37	.7149	.35		.7147	
Fort Nelson			.6815	1.00			.6814	.10		.6814	
Fort St. John(BSMNT)	.4059	0.37	.4059	.34	.4060	.15	.4061	.09		.4060	
Grande Prairie(P.O.)	.3179	.37	.3178	.34	.3182	.40	.3180	.27		.3177	
Edmonton(LAB)	.1678	.26	.1677	.24	.1678	.17	.1676	.11		.1674	
Red Deer	980.9971	.38	.9971	.36	.9971	.15	.9971	.11		.9972	
Winnipeg			.9932	.24			.9931	.24	.9930	.9931	.9932
Vancouver			.9352	.21			.9351	.08			.9351
Calgary(APT)	.8280	.37			.8281	.28					
Lethbridge(P.O.)	.7584	.37	.7586	.34	.7579	.35	.7587	.55		.7596	
Seattle	.7393	.39			.7393	.25					
Ottawa(GLF)	.6214	.16			.6213	.31				.6213	.6213
Cutbank(TB)	.6080	.47			.6076	.50					
Minneapolis	.5973	.50			.5976	.60					
Prescott			.5654	.21			.5653	.16			.5653
Great Falls(SCH)	.5262	.26			.5262	.22					
Huron	.4534	.26	.4535	.22	.4533		.4535	.18	.4538	.4537	
Billings(HNGR)	.3704	.37			.3700	.59					
Madison(12)	.3686	.08	.3686	.09			.3686	.20		.3689	
→ Woods Hole(BSMNT)	.3273	.66			.3273	.66					
Cornell			.3000	.31			.2998	.33			.2998
Chicago	.2869	1.37			.2869	1.37					
Lamont Obs.	.2592	.09			.2592	.29					
Sheridan(HNGR)	.2256	.37			.2252	.55					
Princeton	.1784	.66			.1784	.66					
Washington,D.C.(CF)	.1187	0	.1187	0	.1187	0	.1187	0	.1187	.1190	.1190
Beloit	979.9977	.38	.9977	.24	.9978	.45	.9976	.12	.9977	.9974	

TABLE II-68
MEAN PENDULUM GRAVITY IN CM/SEC² FOR NORTH AMERICA - CONT.

San Francisco	979.9863	0.24			.9865	0.18			
Casper(PUMP)	.9550	.37			.9547	.41			
Tulsa	.7651	.38	.7651	.27	.7650	.15	.7650	.11	.7652 .7653
Cheyenne (REC.)	.6990	.37			.6988	.23			
Denver	.6106	.38			.6106	.30			
Charleston	.5506	.10			.5505	.17			
Amarillo	.4230	.38			.4230	.10			
Houston	.2981	.27	.2978	.20	.2983	.25	.2978	.17	.2975 .2974
San Antonio	.1965	.38			.1965	.30			
Laredo	.0798	.37			.0800	.44			
Brownsville			.0392	.35			.0392	.98	.0392
Miami (M.L.)	.0350	.10			.0350	.10			
Key West	978.9683	.16			.9683	.24			
Monterrey	.8050	.30	.8048	.28	.8051	.10	.8046	.21	.8038
Tamazunchale(T.C.)	.6599	.37			.6599	.23			
Chapulhuacan	.4839	.38			.4839	.10			
Jacala	(.3299)	?			(.3299)	?			
Ixmiquilpan	.1673	.38			.1673	.45			
Mexico, D.F.(TAC)	977.9419	.26	.9417	.19	.9420	.16	.9416	.19	.9414
El Zarco	.7678	.38			.7678	.40			
Paso de Cortes	.5709	.38			.5709	.25			

II-135

TABLE II-69
MEAN PENDULUM GRAVITY IN CM/SEC² FOR SOUTH AMERICA

	Weighted Means				Simple Means					
	<u>Gulf</u>	<u>+s</u>	<u>All</u>	<u>+s</u>	<u>Gulf</u>	<u>+s</u>	<u>All</u>	<u>+s</u>	<u>Camb</u>	<u>+s</u>
Punta Arenas	981.3136	0.94			.3136	0.94				
Washington, D.C.(CF)	980.1187	0	.1187	0	.1187	0	.1187	0	.1187	0
Buenos Aires	979.7051	.51	.7049	.27	.7045	1.40	.7047	.38	.7048	0.13
Santiago	.4282	.75	.4287	.31	.4282	0.40	.4285	.17	.4287	.13
Antofagasta	978.9012	.94			.9012	.94				
Rio de Janeiro	.8045	.49	.8045	.27	.8045	.55	.8045	.30	.8045	.33
Lima	.2834	.47	.2829	.27	.2833	.21	.2829	.16	.2827	.07
Panama	.2415	.37	.2414	.24	.2414	.26	.2414	.14	.2414	.16
Caracas	.0395	.49	.0395	.27	.0395	.20	.0395	.11	.0394	.18
Belem	.0366	.60			.0366	.60				
La Paz	.4663	.75	.4665	.31	.4663	.10	.4664	.09	.4665	.13
Bogota	.4046	.60			.4046	.60				
Quito	.2789	.51	.2782	.27	.2787	.35	.2781	.24	.2777	.08

TABLE II-70
MEAN PENDULUM GRAVITY IN CM/SEC FOR FAR EAST AND PACIFIC

	Weighted Means				Simple Means							
	<u>Gulf</u>	<u>$\pm s$</u>	<u>All</u>	<u>$\pm s$</u>	<u>Gulf</u>	<u>$\pm s$</u>	<u>All</u>	<u>$\pm s$</u>	<u>Camb</u>	<u>$\pm s$</u>	<u>GSI</u>	<u>$\pm s$</u>
Ross Island	982.9924	0.57			.9924	0.57						
Dunedin	980.7431	.57			.7431	.57						
Christchurch	.5088	.35										
Chitose AFB	.4410	.47										
Lower Hutt	.2940	.57			.2940	.57						
Washington, D.C. (CF)	.1187	0	.1187	0	.1187	0	.1187	0	.1187	0	.1187	0
Hastings	.0901	.57			.0901	.57						
Melbourne	979.9795	.47	.9793	.20	.9795	.05	.9793	.08	.9792	.21		
Tokyo	.8012	.30	.8004	.13	.8013	.46	.8005	.34			.8002	.39
Chiba			.7891	.09			.7890	.39			.7890	.39
Kyoto	.7202	.48	.7206	.16	.7202	.48	.7205	.33			.7206	.45
Sydney	.6860	.30			.6860	.28						
Brisbane	.1693	.28			.1692	.34						
New Delhi	.1357	.48			.1357	.48						
Okinawa (KADENA)	.1263	.39			.1263	.10						
Honolulu	.9520	.28			.9521	.42						
Hong Kong	.7665	.39			.7665	.40						
Townsville	.6235	.36			.6233	.65						
Cairns	.4997	.32			.4997	.74						
Manila	.3962	.27			.3963	.13						
Darwin (BMR)	.3142	.32	.3145	.18	.3142	.29	.3143	.13	.3144	.22		
Singapore	.0817	.47	.0817	.15	.0817	.47	.0814	.21	.0819	.23	.0808	.46

II-137

TABLE II-71
MEAN PENDULUM GRAVITY IN CM/SEC² FOR EUROPE AND NORTH AFRICA

	<u>Gulf</u>	<u>+s</u>	<u>A11</u>	<u>+s</u>	<u>A11</u>	<u>+s</u>	<u>Camb.</u>	<u>+s</u>	<u>DGJF</u>	<u>+s</u>	<u>CGI</u>	<u>+s</u>
Hammerfest	982.		.6316	0.37			.6316	(0.37)				
Bodo			.3866	.28			.3866	.40				
Oslo	981.9272	0.55	.9270	(.14)	.9271	(0.15)	.9271	.14	.9267	(0.70)		
Edinburgh			.5834	(.50)	.5834	(.06)	.5835	(.70)	.5833	(.70)		
Copenhagen(PIER)	.5575	.55	.5581	(.15)	.5580	(.29)	.5580	.40	.5587	(.70)		
Teddington(NPL 11)	<u>.1962</u>	0	<u>.1962</u>	0	<u>.1962</u>	0	<u>.1962</u>	0	<u>.1962</u>	0	<u>.1962</u>	0
Bad Harzburg	.1799	.48	.1803	.15	.1804	.14	.1804	.14				
Frankfurt(SIND)	.0607	.55										
Paris(SEVRES A)	980.9405	.29	.9406	(.26)	.9407	(.50)	.9408	1.21	.9406	(.70)		
Munich(NYMPH.)	.7439	.55	.7445	(.17)	.7444	(.23)	.7444	(.36)	.7449	(.70)	.7447	(.72)
Rome(ING)	.3635	.55	.3638	(.33)	.3638	(.17)	.3641	.50			.3636	(.72)
Lisbon(EGN 1)	.0899	.24										
Catania			.0465	.67	.0466	(.21)	.0468	.90			.0462	(.72)
Tripoli(WHEELUS)	.5866	.55										

Remark: 1959 D.O. Bronze obtained .1804 at Bad Harzburg, .9393 at Paris and .3626 at Rome.

TABLE II-72
MEAN PENDULUM GRAVITY IN CM/SEC² FOR AFRICA

	Weighted Means				Simple Means				
	Gulf	$\pm s$	All	$\pm s$	Gulf	$\pm s$	Camb	$\pm s$	GSI $\pm s$
Teddington(NPL 11)	981.1962	0	.1962	0	.1962	0	.1962	0	
Capetown(ROY.OBS.)	979		.6556	.55			.6556	.90	
Mowbray	.6475	1.12	.6471	.15	.6475	1.16	.6473	.39	.6475 .44
Cairo(HELWAN)	.2913	1.12			.2913	1.16			
Pretoria	978		.6292	.19			.6292	.20	
Johannesburg(BPI)	.5496	0.23	.5496	.11	.5495	0.16	.5495	.16	
M'Bour	.3841	.24			.3841	.12			
Khartoum(COORD.)	.3029	1.12	.3032	.38	.3029	1.16	.3032	.40	
Bulawayo			.2915	.67			.2915	.31	
Victoria Falls	.2311	1.12	.2309	.72	.2311	1.16	.2306	1.01	
Salisbury			.1482	.37			.1482	.15	
Accra	.1052	.24			.1052	0.12			
Lusaka	.0539	1.12			.0539	1.16			
Leopoldville	977.9143	0.24			.9143	0.04			
Asmara	.8187	1.12			.8187	1.16			
Nairobi(FLD.SURV.)	.5401	0.90	.5406	.28	.5401	0.32	.5406	.30	

Remark: Standard errors of simple means are approximate, obtained from summing the variances of the means for the series of legs required to arrive at the station via Teddington.

TABLE II-73
COMPARISON OF WEIGHTED MEAN RESULTS IN THIS PAPER
WITH THE WEIGHTED MEANS OBTAINED BY COOK (1957); UNITS IN MILLIGALS

	Cook	$\pm\bar{s}$	This Paper	$\pm\bar{s}$
Teddington(NPL-11)	0	0	0	0
Washington(CP)	-1077.9	0.31	-1077.7	0.15
Dunedin	-455.0	0.63	-453.1	0.59
Christchurch(NEW)	-688.2	0.50	-687.4	0.38
Melbourne	-1217.2	0.46	-1216.9	0.25
Sydney	-1510.5	0.41	-1510.2	0.34
Darwin(BMR)	-2881.6	0.69	-2882.0	0.23
Cambridge (P.H.)	0	0	0	0
Washington(CP)	-1149.4	0.33	-1149.6	0.15
Mowbray	-1621.3	0.26	-1121.3	0.15
Johannesburg	-2119.2	0.28	-1118.8	0.11
Salisbury	-3120.9	0.45	-3120.2	0.37
Pretoria	-2638.8	0.38	-2639.2	0.19

APPENDIX II-1

PENDULUM STATION DESCRIPTIONS FOR NORTH AMERICA

Point Barrow, Alaska

Gulf M 1958; USC and GS 1952: Site is in Building 353, a Butler Building. The Gulf site is in the West corner and the USC and GS site is in the South corner. The building was being used by the Arctic Research Laboratory as a machine and carpenter shop in 1958. The building is supported on pilings steamed into the permafrost. The floor is about 3 feet above ground level. The Gulf site is approximately 1125 feet S. 7°E. of the center of the large commercial hangar at the landing strip. The pendulum site is marked by a standard USC and GS gravity disk stamped PT BARROW 1952, in the southwest corner of the concrete floor.

Latitude 71°19.6'; longitude 156°40.6'; elevation 3.4 meters.

Umiat, Alaska

USC and GS 1952: At Umiat, Alaska, in the southwest corner of the dravo (heater) room of Building 20, about 200 yards southwest of the airstrip and west of the road leading from the airstrip to the camp. Pendulum site is marked by a standard USC and GS gravity disk (unstamped), set in a drill hole.

Latitude 69°22.1'; longitude 152°08.7'; elevation 107.3 meters.

Fairbanks, Alaska

Gulf KM 1953, 1958; USC and GS 1952: At Ladd Air Force Base, Fairbanks, Alaska, in the basement of building 1157 (BOQ No. 10), in the washroom at the Southwest corner of the basement. Pendulum site is marked by a standard USC and GS gravity disk cemented in the concrete floor, stamped FAIRBANKS 1952.

Latitude 64°50.7'; longitude 147°36.2'; elevation 135.2 meters.

Cambridge 1953: In the small telephone terminal room in the basement of the Geophysical Institute of the University of Alaska, at College, 3 miles north of Fairbanks.

Latitude 64°51.5'; longitude 147°49.4'; elevation 157.0 meters.

Gulf C 1951: Station is on a concrete loading platform at the SW corner of the Geophysical Institute of the University of Alaska, approximately 6 miles from Fairbanks. The pendulums were located 8 feet SW of the W. entrance to the building, 6 feet west of a bench mark stamped USCGS F 53 1951. The loading platform level is 31 inches above the level of the gravel parking lot. Elevation 157.0 meters.

Northway, Alaska

Gulf K and M 1953: 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 pendulums were 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 feet 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.

Latitude 62°57.4'N.; longitude 141°57.1'W.; elevation 522.1 meters.

PENDULUM STATION DESCRIPTIONS FOR NORTH AMERICA - CONT.

Anchorage, Alaska

USC and GS 1952: At Elmendorf Air Force Base, Anchorage, Alaska, in the basement and mechanical room (boiler room) of VOQ Building 10-430, in the southeast corner of the concrete floor. Pendulum site is marked by a standard USC and GS gravity disk set in the floor.

Latitude $61^{\circ}15.2'$; longitude $149^{\circ}49.4'$; elevation 48.1 meters.

Snag, Yukon Territory

Cambridge 1953: Basement of the administration building at Snag Airport 14 miles from the Northwest Highway.

Latitude $62^{\circ}21.3'$; longitude $140^{\circ}24.5'$; elevation 578.5 meters.

Whitehorse, Yukon Territory

(Gulf C 1951); Gulf K and M 1953; Cambridge 1953: On the concrete floor in the northeast corner of the Department of Transport pumphouse at the civil airport on the bluff above the city. The pumphouse is about 200 feet east of the southeast corner of the Canadian Pacific Airlines hangar. The floor of the pumphouse is about 6 feet below the outside ground level. The 1951 Gulf C observation was in the hangar.

Latitude $60^{\circ}42.8'N.$; longitude $135^{\circ}03.5'W.$; elevation 695.2 meters.

Kodiak, Alaska

USC and GS 1952: At the Kodiak Naval Base, about 6 miles southwest of the town of Kodiak, Alaska. Station is in Building 17 (old engine test building), in a room between the two engine test sites, in the north end of the room at the foot of a concrete stairway. Pendulum site is marked by a standard USC and GS gravity disk stamped KODIAK 1952, set in the concrete floor.

Latitude $57^{\circ}44.5'$; longitude $152^{\circ}30.3'$; elevation 11.4 meters.

Watson Lake, Yukon Territory

Cambridge 1953: In the north-west corner of the one-room basement of the dwelling of the officer-in-charge of the radio range station at the R.C.A.F. airport. The building is about 700 ft. south-east of the control tower of the airport.

Latitude $60^{\circ}07.0'$; longitude $128^{\circ}49.1'$; elevation 682.8 meters.

Gulf C 1951: Station is at the SE corner of the control tower building of the RCAF Airport, 8 miles from the Alcan Highway junction.

Fort Nelson, British Columbia

Cambridge 1953: Basement of the Fort Nelson Hotel, which is located in the settlement of Maska on the Northwest Highway, 9 miles from the airport.

Latitude $58^{\circ}48.3'$; longitude $122^{\circ}41.7'$; elevation 414.5 meters.

Fort St. John, British Columbia

Gulf K and M 1953; Cambridge 1953: Basement of the administration building of the Department of Transport airport, 3 miles east of the town. The apparatus was set up in a small room at the north-east corner of the building.

Latitude $56^{\circ}14.3'$; longitude $120^{\circ}44.1'$; elevation 693.1 meters.

PENDULUM STATION DESCRIPTIONS FOR NORTH AMERICA - CONT.

Fort St. John, British Columbia (cont.)

Gulf C 1951: Station is 30 feet due S. of the control tower at the airport, 10 feet N. of an asphalt taxi ramp and 50 feet due SW of Canadian Geodetic Service bench mark BM 898 J. Posted airport elevation is 2276 feet.

Grande Prairie, Alberta

Cambridge 1953: Basement of the post office (erected 1952) in a small room near the middle of the south side of the building.

Latitude $55^{\circ}10.4'$; longitude $118^{\circ}47.7'$; elevation 655.0 meters.

Gulf K and M 1953: In the center of the floor of the basement room of the new Postoffice. The basement room is on the south side of the building, immediately east of the boiler room.

Gulf C 1951: The station is at the SW corner of the Montrose public school, 10 feet E. and 6 feet S. of the SW corner of the building. There is a Canadian Geodetic Service bench mark BM 393 H set in the E. wall of the SE corner of the school.

Edmonton, Alberta

Gulf K and M 1953; Cambridge 1953: Basement laboratory No. 1 of the Physics Department in the arts Building of the University of Alberta, in the southeast corner of the laboratory in the southeast corner of the building. The pendulums were 6 feet east of the west wall and 6 feet north of the south wall. The University of Alberta is in South Edmonton at 89th and 112th streets.

Latitude $53^{\circ}31.3'N$.; longitude $113^{\circ}31.3'W$; elevation 669.6 meters.

Gulf C 1951: Station is 10 feet S. of extreme SE corner of the Arts building of the University of Alberta, on a concrete sidewalk. The next building to the W. of the Arts building is the "Carnot" building.

Red Deer, Alberta

Gulf K and M 1953: One block west of the Armory in the boiler room on the east side of the basement of the new Postoffice building. The floor is about 8 feet below outside ground level. The pendulums were 5 feet west of the east wall and about midway between the north and south walls.

Cambridge 1953: Basement of the Dominion Public Building (erected 1951), in the boiler room near the south-east corner of the building.

Latitude $52^{\circ}16.1'$; longitude $113^{\circ}48.8'$; elevation 856.2 meters.

Winnipeg, Manitoba

USC and GS 1952; Cambridge 1952-3: Room 2 in the basement of the Dominion Public Building, 6 ft. from the northerly wall of the room and 5 ft. from the westerly wall. The site is within 10 ft. of that used by Innes for observations with the bronze pendulums of the Dominion Observatory in 1946.

Latitude $49^{\circ}53.4'$; longitude $97^{\circ}08.3'$; elevation 229.5 meters.

PENDULUM STATION DESCRIPTIONS FOR NORTH AMERICA - CONT.

Vancouver, British Columbia

D.O. 1957: University of British Columbia, Physics Bldg., Room 120 (basement, Optics laboratory); site is on concrete floor 10 feet 6 inches from north wall, 9 feet from east wall, 3 feet 7 inches north of pillar in center of room, and marked by a bronze tablet.

Latitude 49°16.0'N.; longitude 123°15.1'W.; elevation 84.4 meters.

Calgary, Alberta

Gulf K and M 1953: In the one-story stucco transformer and auxiliary electric generator building at the Calgary Municipal Airport about 2 miles north of the city. The building is about 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 pendulums were in the southwest room of the building.

Latitude 51°06.6'N.; longitude 114°31.0'W.; elevation 1083.6 meters.

Gulf C 1951: Station is on the E. side of the Crescent Heights High School on a concrete sidewalk, 20 feet E. of the most southerly of 3 green doors of an entrance which is 75 feet N. of the main entrance to the high school.

Lethbridge, Alberta

Cambridge 1953: In the basement of the post office (erected 1913) in the small room on the north side of the building previously occupied by Miller(1929).

Latitude 49°41.4'; longitude 112°50.2'; elevation 905.6meters.

Gulf K and M 1953: In a basement room in the northeast corner of the Post-office building. The room is just west of the elevator generator room and about 30 feet northwest of the elevator shaft.

Gulf C 1951: Station is in back of a red brick municipal building marked "City of Lethbridge" on the corner 2 blocks E. of the post office. The pendulums were on a concrete sidewalk leading to a double door rear entrance, and about 15 feet E. of the driveway that goes down into the basement garage, at the foot of the steps to the rear entrance.

Seattle, Washington

Gulf M 1958: University of Washington, Geology Department (Johnson Hall) Room B3. This room is a seismograph laboratory.

Latitude 47°40'N.; longitude 122°18'W. approx. Elevation

Ottawa, Ontario

Cambridge 1952-3; Gulf K and M 1953; Gulf M 1954: Basement of the Dominion Observatory, about 100 ft. west of the gravity pier and 2 ft. below it. By gravimeter measurements, gravity at this site was found to be 0.2 mgal greater than at the pier.

Latitude 45°23'39.0"N.; longitude 75°42'55.9"W.; elevation 82.0 meters.

PENDULUM STATION DESCRIPTIONS FOR NORTH AMERICA - CONT.

Ottawa, Ontario - cont.

D.O. 1957; Gulf K and M 1959: On the pier flush with the floor in room 8 of the Geophysical Laboratory Building at the Dominion Observatory.

Latitude $45^{\circ}23'41.8''\text{N}$; longitude $75^{\circ}42'52.9''\text{W}$.; elevation 78.38 meters.

Cutbank, Montana

Gulf K and M 1953: In a one-story frame building at the Cutbank Municipal Airport. The pendulums were 30 feet south of the north end and 6 feet east of the west wall of the building. The site is about 300 feet east of the control tower on the Administration Building and about 150 feet south of the southwest corner of a large hangar. Floor level is about 1 foot below the field elevation.

Latitude $48^{\circ}37.0'\text{N}$.; longitude $112^{\circ}22.5'\text{W}$.; elevation 1188.4 meters.

Gulf C 1951: Station is on the S. side of the Western Airlines administration building on a 4.5 X 7 foot concrete slab at the rear (S.) entrance to the SW wing of the building. The building is new, made of red brick, and has a control tower on top of it. The concrete slab is approximately at the surrounding ground level.

Minneapolis, Minnesota

Gulf M 1957; Gulf K 1959: University of Minnesota, Dept. of Geology in Pillsbury Hall on the concrete floor of room 14 of the basement. The room is now used as a storeroom. The pendulums were 6 feet N. of the S. wall of the basement, even with a window. The floor is about 3 feet below the surface of the ground surrounding the building. The site is approximately equivalent to USC and GS No. 74 (1910).

Latitude $44^{\circ}58.7'\text{N}$.; longitude $93^{\circ}13.9'\text{W}$.; elevation 256.1 meters.

Prescott, Ontario

D.O. 1957: R.C.A. Victor plant, employee training room immediately north of main entrance hall; site is on concrete floor 6 feet 9 inches from west wall, 1 foot 4 inches from north wall.

Latitude ; longitude ; elevation 94.2 meters.

Graat Falls, Montana

Gulf K and M 1953: South end of the south hallway of the Roosevelt School, 20 feet north of the double doors on the south side of the building nearest to 2nd Ave. N. The school occupies the entire city block between 2nd Ave N. and 3rd Ave. W., and between 24th St. W. and 26th St. N.

Latitude $47^{\circ}30.7'\text{N}$.; longitude $111^{\circ}15.7'\text{W}$.; elevation 1050.0 meters.

Gulf C 1951: Station is in the entryway to the gymnasium of the Roosevelt School. The entryway has a concrete floor, the level of which is 39 inches above the level of the ground outside the building. The gymnasium is in the NE corner of the building. Gravimeter ties give the same gravity at both sites.

Huron, South Dakota

Cambridge 1952; USC and GS 1953; Gulf K and M 1953; Gulf M 1954: At Huron Airport, about 1.2 miles north of the railroad station at Huron, S. Dak., in

PENDULUM STATION DESCRIPTIONS FOR NORTH AMERICA - CONT.

Huron, South Dakota - cont.

the basement furnace room of the Administration Building. The pendulum site is near the south wall of the building and about 20 feet from the east wall. A standard USC and GS gravity reference disk, set in the concrete step to east door of hangar, is approximately 220 feet east of the pendulum site. The gravity meter difference from pendulum site to reference disk is minus 0.53 milligal.

Latitude $44^{\circ}23.0'$; longitude $98^{\circ}13.4'$; elevation 389.6 meters.

Billings, Montana

Gulf K and M 1953: 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 the cliff north of the city.

Latitude $45^{\circ}48.2'N$.; longitude $108^{\circ}32.5'W$.; elevation 1101.5 meters.

Gulf C 1951: Station is at the municipal airport, 20 feet NE of most eastern red and white wooden antenna pole, 150 feet S $10^{\circ}E$ of bronze statue "A Range Rider and his Horse on the Yellowstone," 175 feet due S. of an 8 inch diameter pine tree that is 50 feet E. of the statue. The ground level at the station is approximately 6 feet lower than the level of the roadway around the statue. The airport is on the cliff N. of the city.

Madison, Wisconsin

Gulf C 1951: Station is in the basement of Science Hall at the corner of Park Street and Langdon Street, at the University of Wisconsin. Station is 30 feet E. of the elevator shaft, in front of the door to room No. 7 (now room 40).

Cambridge 1952: At the University of Wisconsin, in Room 26 (now room 5) of the basement of Science Hall, 13 ft. from the north (outside) wall of the room, and 8 ft. east of the partition between this room and the cadaver storage.

Latitude $43^{\circ}04.6'$; longitude $89^{\circ}24.0'$; elevation 270.1 meters.

Gulf K and M 1953-4: Science Hall basement Room 27 (now room 4). Equivalent to room 26. The gravity is 0.06 mgals less than at room 12 (now room 70D) by gravimeter tie. Elevation is the same as the room 26 site.

Gulf M 1954-9: Science Hall room 12A (now room 70D) in the S.E. portion of the basement. Floor level is the same as the Gulf C 1951 site but two feet below the room 26, 27 and 28 sites. Elevation is 270.0 meters.

Gulf M 1958: Science Hall basement room 28 (now room 6). The gravity is 0.11 mgals less than at the room 12A site. Elevation is the same as the room 26 site.

Remark: The adopted reference site is room 12A.

Woods Hole, Massachusetts

Gulf M 1956: Basement Room G9B in the NE corner of the Main Building of the Woods Hole Oceanographic Institution.

Latitude $41^{\circ}31.48'N$; longitude $70^{\circ}40.32'W$.; elevation 1.0 meters.

PENDULUM STATION DESCRIPTIONS FOR NORTH AMERICA - CONT.

Ithaca, New York

D.O. 1957: Cornell University, Rockefeller Hall, room 5 (basement); site is on concrete floor 3 feet from east wall, 4 feet from north wall, and marked by a bronze tablet.

elevation 258.5 meters.

Chicago, Illinois

Gulf C 1951: The station is in the Eastern Airlines hangar at the Chicago Midway (Municipal) Airport, at the corner of S. Cicero Street and W. 55th Street. The pendulums were on the concrete floor of the hangar, 10 feet in from the hangar door on the NW side and 10 feet NE of the SW wall inside the hangar. The S. corner of the hangar is about 300 or 400 feet due NW of the extreme N. end of the long low red brick main administration building for the airport. Station is about 250 feet due S. of the centerline of W. 55th Street, and about 500 feet due W. of the centerline of S. Cicero Street.

Latitude $41^{\circ}47'N.$; longitude $87^{\circ}45'W.$; elevation 184.5 meters approx.

Lamont Observatory, New York

(Gulf C 1951); Gulf K and M 1953; Gulf K and M 1959: Floor of the large basement room south of the gravity room, at the same level as the floor of the gravity room, in the main building at the Lamont Geological Observatory, Torrey Cliff. The Gulf C 1951 observations were in the gravity room.

Latitude $41^{\circ}00.6'N.$; longitude $73^{\circ}54.5'W.$; elevation 104.12 meters.

Sheridan, Wyoming

Gulf K and M 1953: In a storeroom on the northwest side of the smaller of two 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.

Latitude $44^{\circ}46.3'N.$; longitude $106^{\circ}58.1'W.$; elevation 1225.9 meters.

Gulf C 1951: Station is at the Municipal Airport (county) 150 feet due E. of new administration building, midway between power line poles with radio antenna strung between them. Ground elevation posted as 4021 feet.

Princeton, New Jersey

Gulf M 1956: Directly beneath the geophysics laboratory on the concrete floor of the sub-basement of Guyot Hall at Princeton University. The sub-basement floor is about 12 feet below the level of the surface of the ground surrounding the building.

Latitude $40^{\circ}20.75'N.$; longitude $74^{\circ}39.25'W.$; elevation 42.1 meters.

Washington, D.C.

Gulf C 1951; Gulf K and M 1953-59: Basement compressor room of the Geophysical Laboratory of the Carnegie Institute of Washington, 2801 Upton Street, N.W. Site is 12 feet north and 6 feet west of the U.S. Coast and Geodetic Survey marker for their pendulum station No. 338. The marker is on top of a concrete pier.

Latitude $38^{\circ}56.6'N.$; longitude $77^{\circ}03.4'W.$; elevation 87.5 meters

PENDULUM STATION DESCRIPTIONS FOR NORTH AMERICA - CONT.

Washington, D.C. - cont.

USC and GS 1952-3; Cambridge 1952; D.O. 1957: Flush piers at floor level, in the gravity room of the Commerce Building between Fourteenth and Fifteenth Streets NW. The gravity on the flush piers is taken as 0.18 mgals greater than on the elevated piers.

Latitude $38^{\circ}53.6'N.$; longitude $77^{\circ}02.0'$; elevation 0.2 meters.

GSI 1955: Commerce Building basement gravity room on an elevated pier (2.0 feet high).

Cambridge 1939; Cambridge 1954; GSI 1955: On the concrete floor of the National Bureau of Standards sub-sub-basement in the small room adjoining the site of the absolute determination of P. R. Heyl and G. S. Cook. Site is USC and GS No. 84A (E. J. Brown 1932).

Latitude $38^{\circ}56.5'N.$; longitude $77^{\circ}03.9'W.$; elevation 94.75 meters.

Beloit, Kansas

Cambridge 1952; USC and GS 1953; Gulf K and M 1953: At Beloit, Kans., in the basement of a service station operated by Mr. J. Sault, at the northeast corner of South Brooklyn Street and Asherville Road. The pendulum site is on the east side of the westerly basement room. A standard USC and GS gravity reference disk, set in a circular concrete post 10 inches in diameter and stamped BELOIT 1950, is in a north-south fence line about 230 feet north-northeast of the pendulum site. The gravity meter difference from pendulum site to reference disk is minus 0.56 milligal.

Latitude $39^{\circ}27.3'$; longitude $98^{\circ}06.2'$; elevation 418.2 meters.

San Francisco, California

Gulf M 1954, 1955, 1956-7, 1958: Natural History Museum Building of the Academy of Science in Golden Gate Park. Station is on the first floor in the Paleontological Laboratory which is the room just east of the most westerly rear door of the building, across the corridor from the men's wash room. Station is 10 feet from the north wall in front of bench along corridor (west) wall at floor level which is approximately 4 feet above outside ground level.

Latitude $37^{\circ}46'N.$; longitude $122^{\circ}28'W.$; elevation

Casper Wyoming

Gulf K and M 1953: At the Natrona County Airport on the floor of the red brick pumping building next to the reservoir, in the west corner of the building. The building, No. 950, is approximately 0.65 miles southeast and 0.1 miles north-east of the Administration Building.

Latitude $42^{\circ}54.7'N.$; longitude $106^{\circ}27.9'W.$; elevation 1628.5 meters.

Gulf C 1951: Station is at the Natrona County Airport, 90 paces SW of the SW corner of a control tower, on a lane leading SW off from the main E-W road past the terminal building, 100 feet due S. from the center line of a red concrete blockhouse (center one of three) of dimensions 16 X 16 feet with a sign indicating that "Not More Than 500 Gallons of Oil or Dope May Be Stored".

PENDULUM STATION DESCRIPTIONS FOR NORTH AMERICA - CONT.

Tulsa, Oklahoma

Cambridge 1952; USC and GS 1953; Gulf K and M 1953: Room 4 of the basement of the Waite Phillips Engineering Building at the University of Tulsa, 28 feet from the front wall and 8 feet from the east end wall.

Latitude $36^{\circ}09.1'N.$; longitude $95^{\circ}56.5'W.$; elevation 234.3 meters.

Cheyenne, Wyoming

Gulf K and M 1953: Cheyenne Municipal Airport in the old cafe building 100 feet southwest of the Administration Building. The old cafe building is now used as a recreation hall. The pendulums were 4 feet north of the south wall and 20 feet west of the east wall of the building.

Latitude $41^{\circ}10.2'N.$; longitude $104^{\circ}48.6'W.$; elevation 1878.5 meters.

Gulf C 1951: The station is just off the air base N. of the city, 175 feet W. of the centerline of US 87, 235 feet N. of the centerline of a road going W. from the junction of US 87 and the boulevard entrance road to the airport. The station is due W. of a large red brick building marked WYOMING SKYWAYS INC. This building is the most southerly of four adjoining low red brick buildings. There are two gravel roads (part of a turnaround) going diagonally NW from the junction. The station is 30 feet SW of the centerline of the northernmost of the two gravel roads, and is approximately 800 feet E. of a ballpark or fairgrounds with lights for night games.

Denver, Colorado

Gulf K and M 1953: Chamberlin Observatory basement on the north side of the large telescope pier, on Iliff Avenue on the campus of Denver University.

Latitude $39^{\circ}40.6'N.$; longitude $104^{\circ}57.1'W.$; elevation 1639.5 meters.

USC and GS 1894: University Park, University of Denver, in Chamberlin Observatory in the basement south of the equatorial foundation. Station Number 44.

Charleston, South Carolina

Gulf M 1957; Gulf K and M 1959: On the concrete floor of the Physics Laboratory balance room, in the S.E. corner of the E. wing of Bond Hall, the Citadel University, Room 149.

Latitude $32^{\circ}47.8'N.$; longitude $79^{\circ}57.8'W.$; elevation 5.2 meters.

Amarillo, Texas

Gulf K and M 1953: At English Field in the southwest corner room of the hangar 200 feet northwest of the Administration Building. The pendulums were 25 feet north of the south wall and 15 feet east of the west wall of the room. English field is east of Amarillo on highway U.S. 60.

Latitude $35^{\circ}13.7'N.$; longitude $101^{\circ}41.5'W.$; elevation 1098.2 meters.

Houston, Texas

Gulf C 1951; Cambridge 1952; Gulf K and M 1953; Gulf M 1954: In Houston, Tex., in storeroom of the building at 2424 Branard Street occupied in 1953 by Houston Technical Laboratory but now occupied by Electro-Tech International Company. The pendulum site is about 5 feet from the east wall and 20 feet

PENDULUM STATION DESCRIPTIONS FOR NORTH AMERICA - CONT.

Houston, Texas - cont.

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, one foot south of the northwest corner and one foot above ground. The gravity meter difference from pendulum site to station disk is minus 0.08 milligal.

Latitude $29^{\circ}44.2'$; longitude $95^{\circ}25.1'$; elevation 18.4 meters.

San Antonio, Texas

Gulf K and M 1953: San Antonio International Airport in small wooden shack farthest west of the terminal buildings. Site was about 400 feet west of the control tower and 400 feet east of large Alamo Aviation (Beechcraft) hangar. Floor was about 1 foot above field elevation.

Latitude $29^{\circ}31.8'N.$; longitude $98^{\circ}28.1'W.$; elevation 244.1 meters.

Laredo, Texas

Gulf K and M 1953: Laredo Air Force Base in building No. T 255 (a one-story barracks) in the northwest corner of the area of buildings and barracks. The front (street side) of the building is 950 feet west and 350 feet south of the control tower, and 625 feet west and 350 feet south of the brick hangar. The floor level is about 5 feet below the air strip elevation.

Latitude $27^{\circ}32.4'N.$; longitude $99^{\circ}27.8'N.$; elevation 154.5 meters.

Gulf C 1951: Station is 15 feet N $20^{\circ}E$ of the N. entrance to the Police Station, at the SW corner of a low white brick building (Webb Co. Health Unit). The station is 60 feet S. of the centerline of Hidalgo Street, 100 feet E. of the centerline of Flores Avenue 500, 700 or 800 feet SW of the Plaza Hotel, 100 feet S. of the front of the Plaza movie theatre. The pendulums were set up on a concrete slab 2.5 feet due W. of the SW corner of the Health building.

Brownsville, Texas

USC and GS 1953: In Brownsville, Tex., in Room B-10 of the basement of the U.S. Post Office. The basement floor is 11.0 feet below USC and GS bench mark K 678 at the front entrance of the Post Office. The gravity meter difference from pendulum site to bench mark K 678 is minus 0.78 milligal.

Latitude $25^{\circ}54.1'$; longitude $97^{\circ}30.0'$; elevation 8.1 meters.

Miami, Florida

Gulf K and M 1959: At the University of Miami Marine Biological Laboratory on Virginia Key, on the concrete floor of the laboratory used by the assistant director. The room is in the SW corner of the older portion of the building, adjacent to the new wing under construction. The floor elevation is about 1 feet above the level of the ground surrounding the outside,

Latitude $25^{\circ}44.0'N.$; longitude $80^{\circ}10.0'W.$; elevation 1.5 meters (approx.)

Key West, Florida

Gulf K and M 1959: Reoccupation of USC and GS pendulum station No. 1 (1896) in what is now Building 91 on the U.S. Naval Station. The building is constructed of red brick, and is about 100 feet west of the intersection of Whitehead Street and Greene Street. In 1896 it was the postoffice and custom

PENDULUM STATION DESCRIPTIONS FOR NORTH AMERICA - CONT.

Key West, Florida - cont.

house building. The site is on the concrete floor of the southeast basement room.

Latitude $24^{\circ}33.6'N.$; longitude $81^{\circ}48.4'W.$; elevation 0.5 meters.

Monterrey, Nuevo Leon, Mexico

Gulf C 1951; Cambridge 1952; Gulf K and M 1953: Automobile shop of the Instituto Tecnológica y Estudios Superiores, 10 ft. from the north (outside) wall of the room, and 3 ft. from the east wall.

Latitude $25^{\circ}38'$; longitude $100^{\circ}17'$; elevation 566.9 meters.

Tamazunchale, San Luis Potosi, Mexico

Gulf K and M 1953: In the garage adjoining the back of the main building of the Quinta Chilla Tourist Courts at Km.356, about 4 Km. south of the bridge at Tamazunchale.

Latitude $21^{\circ}15.8'N.$; longitude $98^{\circ}49.5'W.$; elevation 160 meters approx.

Gulf C 1951: Station is at the St. John Baptist Church on the NW corner of the concrete platform in front of the main door to the church. The main door of the church is on the N. side of the church. The platform is 2 feet above the ground level of the church yard.

Latitude $21^{\circ}16.0'N.$; longitude $98^{\circ}46.5'W.$; elevation 120 meters approx.

Chapulhuacan, Hidalgo, Mexico

Gulf K and M 1953: In the old Postoffice, now the Campamento S.C.O.P., in the small room next to the garage of the main building.

Latitude $21^{\circ}09.8'N.$; longitude $98^{\circ}54.3'W.$; elevation 840 meters approx.

Jacala, Hidalgo, Mexico

Gulf K and M 1953: In the east corner of the sacristia at the west corner of the parroquia de San Antonio. (The sacristy room of the church.)

Latitude $21^{\circ}0.9'W.$; longitude $99^{\circ}12.1'W.$; elevation 1390 meters approx.

Ixmiquilpan, Hidalgo, Mexico

Gulf K and M 1953: In a large room near the back of the hotel next to the Palacio Municipal, 115 feet back from the front of the hotel. The large room was across from room No. 15 of the hotel.

Latitude $20^{\circ}29'N.$; longitude $99^{\circ}13.4'W.$; elevation 1691.5 meters approx.

Mexico, D.F., Mexico

Cambridge 1952; Gulf K and M 1953: Photogrammetry room of the Oficina de Geografia, 192 Observatory Ave., Tacubaya, 6 feet west of the No. 1 pendulum pier. The surface of the pier is 0.4 meters above the floor level. The pendulums were 7 feet east of the west wall and 12 feet south of the north wall of the room.

Latitude $19^{\circ}24.3'N.$; longitude $99^{\circ}11.7'W.$; elevation 2297.9 meters

PENDULUM STATION DESCRIPTIONS FOR NORTH AMERICA - CONT.

Mexico, D.F., Mexico - cont.

Gulf C 1951: The station is at the Dept. of Geography and Meteorology of the Ministry of Agriculture, 192 Observatory Avenue, Tacubaya, in the main floor buildings patio, facing the Salon of Photogrammetry in which the No. 1 gravity station pier is located. The elevation of the No. 1 base is 2298.3 meters. Pendulum site is 0.9 meters lower than the top of pier No. 1.

Gulf K and M 1953; Gulf M 1958: 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.

Latitude 19°20'N.; longitude 99°11'W.; elevation 2268.5 meters.

Gulf M 1958: Universidad Nacional de Mexico in the gravity room on the floor next to the pier.

Cambridge 1958: Universidad Nacional de Mexico on the floor in a room adjoining the south-east corner of the large room containing the square concrete piers; elevation 2267.9 m.

El Zarco, D.F., Mexico

Gulf K and M 1953: In a small round house used as an eating place for visitors at the Navy Department fish hatchery and park. The round house is about 150 feet uphill from a main large building adjacent to circular water tanks, and about 350 feet downhill from a large fountain.

Latitude 19°17.0'N.; longitude 99°20.0'W.; elevation 3120 meters approx.

Paso de Cortes, Mexico

Gulf K and M 1953: At Paso de Cortes between the mountains Popocatepetal and Ixtacchuatl in the transmitter room of the television relay station. The pendulums were 10 feet north of the south wall and 15 feet west of the east wall of the room. The station elevation is approximately 13,000 feet.

Latitude 19°07.2'N.; longitude 98°38.0'W.; elevation 3974.6 meters approx.

APPENDIX II-2

PENDULUM STATION DESCRIPTIONS FOR SOUTH AMERICA

Punta Arenas, Chile

Gulf M 1957: Chlorination Room in the Filtration Plant.

Latitude $53^{\circ}09'S$; longitude $70^{\circ}55'W$; elevation ?

Buenos Aires, Argentina

Gulf M 1957; Gulf M 1958; Cambridge 1958: In the lower basement of the building known as "Instalaciones Sargento Major Ingeniero Jose Antonio de Condarco", in the suburb of San Martin, on the floor of the western corner of the passage-way which surrounds the inner laboratory in which is installed the pendulum apparatus for absolute determination of gravity. Site 2a in the diagram in RGI 1959.

Latitude $34^{\circ}34.4'S$; longitude $58^{\circ}31.1'W$; elevation 8.8 meters?

Santiago, Chile

USC and GS 1948; Gulf M 1957; Cambridge 1958: In the basement of a building of the Instituto Geografico Militar on Calle Castro in a room used by the IAGS as a paper store, on the floor about a meter south of the concrete wing walls. The building is called Pabellion A and the room is designated as No. 5. This is the site of Cdr. G. R. Shelton's 1948 USC and GS observation.

Latitude $33^{\circ}27'05.5''S$; longitude $70^{\circ}39'49.3''W$; elevation 541.33 meters.

Antofagasta, Chile

Gulf M 1957: At the Colegio San Luis at 14 Febrero and Calle Baquedano, in a small room in the north-west corner of the school.

Latitude $23^{\circ}38.6'S$; longitude $70^{\circ}24.0'W$; elevation 18 meters approx.

Rio de Janeiro, Brazil

USC and GS 1948; Cambridge 1958; Gulf M 1958: In a room adjoining the seismograph room on the ground floor of the main building of the Observatorio Nacional, 586 General Bruce Street. The site is an isolated section of the floor specially provided to serve as a gravity reference station. Site 2 on the diagram in RGI 1959. This is the site of Cdr. G. R. Shelton's 1948 USC and GS observation.

Latitude $22^{\circ}53'42.2''S$; longitude $43^{\circ}13'22.5''W$; elevation 29.0 meters.

Lima, Peru

Gulf M 1957; Gulf M 1958: In the printing annex of the Instituto Geografico Militar, No. 310 Avenida Arequipa.

Latitude $12^{\circ}08'S$; longitude $77^{\circ}01'W$; elevation 131.2 meters.

Cambridge 1958: In the basement of the I.G.M. in a room normally used as a canteen, close to the new photogrammetry building and the Gulf M site. The gravity difference is estimated to be negligible by Jackson, the observer.

Panama

Gulf M 1957; Gulf M 1958; Cambridge 1958: In building 1019 on the Pacific Air Depot occupied by the I.A.G.S. Logistics Division, on the ground floor

PENDULUM STATION DESCRIPTIONS FOR SOUTH AMERICA - CONT.

Panama - Cont.

in a small room adjoining the radio-shop and containing a Multiplex instrument, a level calibrator and an altimeter testing table: there is a brass plug in the floor.

Latitude $8^{\circ}58'N.$; longitude $79^{\circ}34'W.$; elevation 7 meters.

Caracas, Venezuela

Gulf M 1958; Cambridge 1958: In the new Cagigal Seismological Observatory, at the end of a passage-way in the basement, on the floor outside of the seismograph room.

Latitude $10^{\circ}30'N.$; longitude $66^{\circ}56'W.$; elevation 1042 meters.

Belém, Para, Brazil

Gulf M 1958: SNAPP water filter plant about 1/4 mile towards Belém from the airport.

Latitude $1^{\circ}23'S.$; longitude $48^{\circ}29'W.$; elevation 10.7 meters approx.

La Paz, Bolivia

USC and GS 1948; Gulf M 1957; Cambridge 1958: On the ground floor of the Instituto Geografico Militar, in a room used by the IAGS as a store and fitted with cupboards, on the floor about three meters from the window. The room adjoins the IAGS radio room. This is the site of Cdr. G. R. Shelton's 1948 USC and GS observation.

Latitude $16^{\circ}30'40.4"S.$; longitude $68^{\circ}07'31.7"W.$; elevation 3518.9 meters.

Bogata, Colombia

Gulf M 1958: Instituto Geografico Militar, IAGS Bodaga, in the surveyed material room. This is believed to be the same site as Cl. Aslakson USC and GS 1941.

USC and GS 1941: Station is in Bogata at the Instituto Geografico Militar y Catastral, in the eastern-most building which extends north and south, faces west, and is used for clerical offices and warehouse. The station is in a small room at the extreme south end of the building, 7 meters from the principal entrance, in the southwest corner of the room.

Latitude $4^{\circ}38.5'N.$; longitude $74^{\circ}03.9'W.$; elevation 2591.8 meters.

Quito, Ecuador

USC and GS 1948; Gulf M 1957; Gulf M 1958; Cambridge 1958: In the basement of the National Astronomical Observatory in the city, on the floor of the seismograph, as described in RGI 1959.

Latitude $00^{\circ}12'58"S.$; longitude $78^{\circ}29'57"W.$ elevation 2815.05 meters.

APPENDIX II-3

PENDULUM STATION DESCRIPTIONS FOR THE FAR EAST AND PACIFIC

Ross Island, McMurdo Sound, Antarctica

Gulf M 1956-7: The site is on a concrete pier set in permafrost, beneath the floor of temporary building No. 30 now used as a GCA building.

Latitude $77^{\circ}53'6.856''$ S.; longitude $166^{\circ}45'18.122''$ E.; elevation 12.9 meters above m.s.l.

Dunedin, New Zealand

Cambridge 1947-8; Gulf M 1956-7: The site is in the basement furnace room of the Geology Department of Otago University. This is also a D.S.I.R. Cambridge pendulum site.

Latitude $45^{\circ}52.2'$ S.; longitude $170^{\circ}31.0'$ E.; elevation 8 meters approx.

Christchurch, New Zealand

Cambridge 1947-8; Gulf M 1956-7; Gulf M 1958: The site is on the floor of the workshop building of the Magnetic Observatory in the Botanical Gardens. This is also a D.S.I.R. pendulum station established with the Cambridge pendulums.

Latitude $43^{\circ}31.77'$ S.; longitude $172^{\circ}37.18'$ E.; elevation 6.7 meters.

Chitose AFB, Hokkaido, Japan

Gulf M 1958: Station at field elevation on the concrete floor of the hangar just north of the Japan Air Line terminal.

Latitude $42^{\circ}47'$ N.; longitude $141^{\circ}41'$ E.; elevation 22 meters approx.

Lower Hutt, New Zealand

Cambridge 1947-8; Gulf M 1956-7: The site is at the Dominion Physical Laboratory (Gracefield) in the Electrical Standards laboratory. This is also a D.S.I.R. Cambridge pendulum station.

Latitude $41^{\circ}14'12''$ S.; longitude $174^{\circ}55'02''$ E.; elevation 3 meters.

Hastings, New Zealand

Cambridge 1947-8; Gulf M 1956-7: The site is on the floor of the Beechcraft Mapping Company hangar at the Hastings airport. This is also a D.S.I.R. pendulum station established with the Cambridge pendulums.

Latitude $39^{\circ}39'09''$ S.; longitude $176^{\circ}45'58''$ E.; elevation 19.5 meters.

Melbourne (Footscray), Victoria, Australia

Cambridge 1947-8; Cambridge 1958: A small room on the ground floor just inside the central entrance of the Geophysical Laboratory at Footscray. (The local magnetic field here is disturbed by the passage of electric trams on the road outside: the usual tests of pendulum magnetization could not be carried out till after the trams stopped running at 1 a.m.) The same site was occupied by the Japanese party.

Latitude $37^{\circ}47.2'$ S.; longitude $144^{\circ}53.5'$ E.; elevation 34.7 meters.

PENDULUM STATION DESCRIPTIONS FOR THE FAR EAST AND PACIFIC - CONT.

Melbourne (Footscray), Victoria, Australia - cont.

Gulf M 1956-7: The site is in the machine shop of the Geophysical Laboratory on Gordon Street in Footscray. The site is about 30 ft. S. and 8 ft. E. of the gravity pier in Room 102 (gravity room). The gravity pier is the site of the BMR Cambridge pendulum station No. 1.

Tokyo, Japan

Gulf M 1954; Gulf M 1958: Earthquake Research Institute, Tokyo University, Bunkyo-ku, Tokyo. Observation was made on long pier in the Base Apparatus Room on the south side of the Earthquake Research Institute Building. The pier stands 0.75 meters above the floor level.

Latitude $35^{\circ}42.6'N$.; longitude $139^{\circ}46.0'E$.; elevation 17.99 meters.

Chiba, Japan

GSI 1952; GSI 1955: Laboratory of the former Geographical Survey Institute, Chiba, located about 30 kilometers east of Tokyo. Station is in the "gravity room" laboratory of the GSI. This station was used for pendulum and gravimeter observations until August 1958.

Latitude $35^{\circ}38.0'N$.; $140^{\circ}06.5'E$.; elevation 20.9 meters.

Kyoto, Japan

GSI 1952; GSI 1955; Gulf M 1954: Kyoto University. Pendulum room in basement of "Geological and Mineralogical Institute." Room is also known as "second laboratory of theoretical geology," and site is referred to as the "Kyoto Secondary Difference Station." Station is in the north basement wing, 48 feet west of the foot of the stairs to the ground floor, 6 feet south of the north wall and 36 feet east of the west wall of adjoining laboratory at the end (west) of corridor. Observations were made on the pier flush with the floor, 4 feet north of 28 inch high columnar piers. Floor level is 6 feet below outside ground level.

Latitude $35^{\circ}01.6'N$.; longitude $135^{\circ}47.2'E$.; elevation 60.82 meters.

Sydney, N.S.W., Australia

Cambridge 1947-8; Gulf 1956-7; Gulf 1958: The site is in basement room No. 37 of the National Standards Laboratory at the University of Sydney. This is also the BMR Cambridge pendulum station No. 5.

Latitude $33^{\circ}53.4'S$.; longitude $151^{\circ}11.4'E$.; elevation 29.6 meters.

Brisbane, Queensland, Australia

(Cambridge 1947-8); Gulf 1956-7: The site is in the Collections Room of the Geology Building of the University of Queensland, and is 10 ft. N. of the S. wall and 3 ft. W. of the E. Wall near a large double door on the E. wall. The BMR Cambridge pendulum station No. 47 is nearby but at a lower elevation, in the seismograph vault.

Latitude $27^{\circ}30.0'S$.; longitude $153^{\circ}00.8'E$.; elevation 25 meters approx.

New Delhi, India

Gulf M 1954: Surveyor General's Office. Station is in the east corner of the southeast end of the old Surveyor General's Office in the map sales wing

PENDULUM STATION DESCRIPTIONS FOR THE FAR EAST AND PACIFIC - CONT.

New Delhi, India - cont.

(Block No. 9, Room 347) of the old Supply Department Building on the Shahjahan road, New Delhi. The station is 1170 yards (map scale) along the Shahjahan road, then 210 yards southeast along the Humayan road, as measured from the King George V statue near the India gate. On the map the latter is located in the Princes Park, and the India gate is called the War Memorial Arch. About one-third the way from the George V statue, along Shahjahan road, is survey of India BM 686. Station is at ground level and about the same elevation as center line of Humayan Road, which is about 30 yards southwest of the station.

Latitude $28^{\circ}37'N.$; longitude $77^{\circ}13'E.$; elevation ?
Location approximate

Okinawa (Kadena AFB)

Gulf M 1958: Room 62 of Building 604 on the floor at ground elevation.

Latitude $26^{\circ}22'N.$; longitude $127^{\circ}41'E.$; elevation ?
Location approximate

Honolulu, Hawaii

Gulf M 1954; Gulf M 1955; Gulf M 1956-7; Gulf M 1958: Bishop Museum. Station is in Room 2 on ground floor of the Administrative and Research Annex Building (northeast annex building at the rear of the museum). Station is in the north corner of room 2 at floor level which is about 3 feet below the level of the ground immediately outside and located 40 feet southeast of the rear (northwest building wall) and 3 feet southwest of the northeast side wall of building.

Latitude $22^{\circ}20.2'N.$; longitude $157^{\circ}52.4'W.G.$; elevation ?

Hong Kong

Gulf M 1958: Basement room B10 of the United States Consulate Building.

Latitude $22^{\circ}16'N.$; longitude $114^{\circ}11'E.$; elevation ?
Location approximate

Townsville, Queensland, Australia

Gulf M 1956-7; Gulf M 1958: The site is on the floor of building No. 73, the supply-storeroom, of the Garbutt RAAF Aerodrome.

Latitude $19^{\circ}15'44''S.$; longitude $146^{\circ}46'04''E.$; elevation 4.9 meters.

Cairns, Queensland, Australia

Cambridge 1947-8; Gulf M 1956-7; Gulf M 1958: The site is on the floor of the A.N.A. hangar in the office section, 6 ft. N. of the S. wall of the building and 12 ft. W. of the compressor room wall. This is also the BMR Cambridge pendulum site No. 52.

Latitude $16^{\circ}53.0'S.$; longitude $145^{\circ}45.0'E.$; elevation 2.7 meters.

Manila (Clark AFB) Phillipine Islands

Gulf M 1954: At the Magnetic Observatory, Muntinlupa, Rizal Province, Luzon, Republic of the Philippines. Muntinlupa is 32 kilometers south of Manila and the station is in the office building of the Coast and Geodetic Survey Magnetic Observatory located at New Bilibid Prison. This building is on the

PENDULUM STATION DESCRIPTIONS FOR THE FAR EAST AND PACIFIC - CONT.

Manila (Clark AFB) Phillipine Islands - cont.

south side of the entry gate inside the observatory area. The prison is 4.7 kilometers from Muntinlupa. The observation was made in the north corner of the office building at floor level (elevation is approximately 65 meters). Relative to the absolute magnetic pier whose coordinates are: Latitude, $14^{\circ}22'28''$; Longitude $121^{\circ}00'56''$, the office is about 200 meters northeast of the pier. The office floor level is about 1 foot above outside ground.

Gulf M 1955; Gulf M 1958: Clark Air Force Base, Luzon, on the concrete floor of building T-6648, a one-story H-shaped quonsot building. The site is 500 feet N. 67° E. of the center of the Kelly theater, 4360 ft. N 87.5° W. of the front porch of the passenger terminal building, and is along the south side of the triangle of roads formed by Bong Highway, Maratt Highway, and Dau Avenue. The pendulums were along the E. wall of the E. wing of the building at the center. The site elevation is approximately 559 feet and the elevation of the front porch of the passenger terminal building is approximately 500 feet.

In 1955 the E. wing was used for Link Trainer instruction and the W. wing was a photographic laboratory. There was observable ground vibration from an electrical generating plant 1500 feet to the E. of the site.

Latitude $15^{\circ}11.0'N.$; longitude $120^{\circ}32.9'E$; elevation 170.4 meters.

Darwin, Northern Territory, Australia

Gulf M 1956-7; Gulf M 1958; Cambridge 1958: The site is in the Bureau of Mineral Resources building on the corner of Daly Street and Wood Street, in the Assay laboratory of the Darwin Uranium Group.

Latitude $12^{\circ}20'S.$; longitude $130^{\circ}50'E.$; elevation 22.7 meters.

Singapore, Malaya

GSI 1957; Gulf M 1958; Cambridge 1958: Map room on the ground floor of the Department of Geography, University of Malaya.

Latitude $1^{\circ}19.1'N.$; longitude $103^{\circ}49.1'E.$; elevation 19.2 meters.

APPENDIX II-4

PENDULUM STATION DESCRIPTIONS FOR EUROPE AND NORTH AFRICA

Hammerfest, Norway

Cambridge 1955: The apparatus was placed on the concrete floor of the workshop room in cellar of the Fire Station, Kirkegata 21. The station is marked with a brass ring on the concrete floor.

Latitude $70^{\circ}39'43''$ N.; longitude $23^{\circ}41'6''$ E.; elevation 15.60 meters.

Bodø, Norway

Cambridge 1955: The apparatus was placed on the concrete floor of the washing room in the cellar of the Bodø elementary school, Silvert Nilsensget. The station is marked with a brass ring on the concrete floor.

Latitude $67^{\circ}16'47''$ N.; longitude $14^{\circ}23'43''$ E.; elevation 13.37 meters.

Oslo, Norway

Gulf M 1954; Cambridge 1955: Geologisk Museum, Trondheims Vei. Station is on the floor of Room 030 in the cellar of "Geologisk Museum" marked with brass bolt BM No. G35KIT. Fundamental station.

Latitude $59^{\circ}55'7''$ N.; longitude $10^{\circ}46'37''$ E.; elevation 30.59 meters.

Edinburgh, Scotland

Cambridge 1936; Cambridge 1952; DGJF 1958: Royal Observatory, in the clock room which is in the basement of the Eastern Tower. The pendulums stood between the two Shortt clocks, 12.5 ft. (3.81 m) south of the centre of the tower. The floor is concrete.

Latitude $55^{\circ}55'24.5''$ N.; longitude $3^{\circ}07'36''$ W.; elevation 129.4 meters.

Copenhagen, Denmark

Gulf M 1954; Cambridge 1955; DGJF 1958: Buddinge Fortification. Station is on the floor of the "watch cellar" next to pillar No. 1. This is the location of the Danish national reference station. Height of pillar is 0.80 meters.

Latitude $55^{\circ}44'35''$ N.; longitude $12^{\circ}30'12''$ E.; elevation 43.97 (floor) meters.

Teddington, England

All observers unless otherwise noted: National Physical Laboratory. On the pier flush with the floor in Room 11 of the Metrology Division Building. This is the site of Clark's absolute determination. Cambridge 1958 (Jackson) used basement room B17 in nearby Bushy house and DGJF 1958 (Marzahn) used room B14 in nearby Bushy house. The gravity in the basement of Bushy house in room B14 is 0.05 mgals higher than on the pier in Room 11 of the Metrology Building.

Latitude $51^{\circ}25'13.6''$ N.; longitude $0^{\circ}20'21.4''$ W.; elevation 9.24 meters.

Bad Harzburg, Germany

All observers: Evangelisches Gemeindehaus, Kirchstrasse 6. Observation was made on the floor of the cellar in a room which is east of the room formerly used as a kitchen.

Latitude $51^{\circ}52.91'$ N.; longitude $10^{\circ}34.07'$ E.; elevation 215.19 meters.

PENDULUM STATION DESCRIPTIONS FOR EUROPE AND NORTH AFRICA - CONT.

Frankfurt A.M. (Sindlingen), Germany

Gulf M 1954: Institut für Angewandte Geodäsie. Frankfurt am Main Sindlingen, Weinbergstrasse 9. Observation was made on the floor in the cellar of Science Branch Building in the northeast corner of gravity room (south-east corner room of building).

Latitude $50^{\circ}04.75'N.$; longitude $8^{\circ}31.28'E.$; elevation 95.73 meters.

Paris, France

Cambridge 1951; DGFJ 1958; Gulf K 1959; D.O. 1959: Bureau International des Poids et Mesures, Pavillon de Bretenil, Sèvres (Seine and Oise), about 13 km. southwest of Paris. The station is designated as "Sèvres, Point A" and is in Room 1 in the basement on a flush independent pier at floor elevation. This is near the site of the absolute determinations of M. Volet.

Latitude $48^{\circ}49'45"N.$; longitude $2^{\circ}13'14"E.$; elevation 65.93 meters.

Munich, Germany

Gulf M 1954; Cambridge 1955: Landesamt für Mass und Gewicht, Franz-Schranckstrasse, Nymphenburg, Munich. Station is at floor level in the Wassermess room of the cellar.

Latitude $48^{\circ}10'00"N.$; longitude $11^{\circ}30'20"E.$; elevation 511.00 meters.

CGI 1958; Cambridge 1958; DGFJ 1958: Munich-Residenz in the new measuring cave of the German Geodetic Research Institute. This site is 6.36 mgals less than the Nymphenburg site by multiple gravimeter ties.

Latitude $48^{\circ}08.5'N.$; longitude $11^{\circ}34.9'E.$; elevation 510 meters?

Rome, Italy

Gulf M 1954; Cambridge 1958; CGI 1958; D.O. 1959: City University of Rome.. The station is located in the basement seismic room in the Physics Section of the National Geophysical Institute and Physics Building of the City University of Rome. Observations were made with the Gulf and Cambridge apparatus on the most westerly of 3 flush piers. This pier is in the northwest corner of the room, and the pendulums were set 6 feet from the north wall and 6 feet from the west wall. The D.O. apparatus was on the center pier.

Latitude $41^{\circ}54.2'N.$; longitude $12^{\circ}30.8'E.$; elevation 45 meters.

Lisbon, Portugal

Gulf M 1959: Instituto Geográfico e Cadastral, Praça da Estrela in the inner corridor on the ground floor in the southwest corner of the building. Site is marked with a square bronze bench mark EGN 1.

Latitude $38^{\circ}42'41.58"N.$; longitude $9^{\circ}09'35.75"W.$; elevation 75.10 meters.

Catania, Italy

CGI 1958; Cambridge 1958: Basement room of the Astrophysical Observatory.

Latitude $37^{\circ}30.3'N.$; longitude $15^{\circ}04.8'E.$; elevation 42.1 meters.

PENDULUM STATION DESCRIPTIONS FOR EUROPE AND NORTH AFRICA - CONT.

Tripoli, Libya

Gulf M 1954: Wheelus Air Force Base. Station is 62 feet west and 82 feet north of the octagonal shape stone control tower, building T-102, on the flight line in the old PX room of building T-101. The station elevation is the same as that of the passenger waiting room and about 6 inches above the flight line. This building is immediately south of the M.A.T.S. passenger terminal waiting room. The observation was made at floor level 3 feet east of the west (roadway) wall and about 8 feet north of the door leading to the roadway.

Latitude 32°54.4'N.; longitude 13°15.9'E.; elevation 5.2 meters.

APPENDIX II-5

PENDULUM STATION DESCRIPTIONS FOR AFRICA

Capetown, South Africa

Cambridge 1948-9: Royal Observatory.

Latitude $33^{\circ}56.1'S.$; longitude $18^{\circ}28.7'E.$; elevation 16 meters.

Mowbray, Capetown, South Africa

Cambridge 1948-9; Cambridge 1956; Gulf M 1955; GSI 1957-8: In room No. 14 of the Trigonometrical Survey building on Rhodes Avenue, Mowbray. This is also a 1948 BPI Cambridge pendulum site. The wooden plates on the floor must be removed so the apparatus rests on concrete.

Latitude $33^{\circ}57.1'S.$; longitude $18^{\circ}28.1'E.$; elevation 38.4 meters.

Cairo, Egypt

Gulf M 1955: On the tile floor at the southeast wall of the spare room in the west corner of the seismic vault building at the Helwan Observatory 15 miles south of Cairo.

Latitude $29^{\circ}53'N.$; longitude $31^{\circ}20'E.$; elevation ?
Location approximate

Pretoria, South Africa

Cambridge 1948-9; Cambridge 1956: Transvaal Museum.

Latitude $25^{\circ}45.1'S.$; longitude $28^{\circ}11.4'E.$; elevation 1337.1 meters.

Johannesburg, South Africa

Cambridge 1948-9; Gulf M 1955; Cambridge 1956; Cambridge 1958; Gulf K 1959: On the seismometer block in the seismograph room in the Bernard Price Institute of the University of Witwatersrand.

Latitude $26^{\circ}11.5'S.$; longitude $28^{\circ}01.8'E.$; elevation 1755.0 meters above m.s.l.

M'Bour, Sngal, French West Africa

Gulf K 1959: "Centre de Gophysique" in an office in the center of the building at the back (west?).

Latitude $14^{\circ}23.5'N.$; longitude $16^{\circ}57.7'W.$; elevation 5.10 meters.

Khartoum, Sudan

Gulf M 1955: On the concrete floor of the second room north of the Coordinatograph room in the Survey Department of the Sudan Survey, Ministry of Mineral Resources, in Block No. 2 River Front East.

Latitude $15^{\circ}36.5'N.$; longitude $32^{\circ}31.8'E.$; elevation 379.9 meters above
m.s.l. Alexandria.

Cambridge 1958: University of Khartoum, formerly known as Gordon College, in the Physics Department south room of Seismography, on the concrete floor.

Latitude $15^{\circ}36.7'N.$; longitude $32^{\circ}32.5'E.$; elevation 381.3 meters above
m.s.l. Alexandria.

Note: The small building called the Seismography building by Curry (1912) and also used by Munsey (1935-6) is now used as a chemical store by the University College of Khartoum.

PENDULUM STATION DESCRIPTIONS FOR AFRICA - CONT.

Bulawayo, S. Rhodesia

Cambridge 1948-9:

Latitude $20^{\circ}08.7'S$.; longitude $28^{\circ}36.8'E$.; elevation 1341.7 meters.Victoria Falls, S. Rhodesia

Cambridge 1948-9; Gulf M 1955: On the concrete floor of the radio building twenty feet S. of the superintendent's office at the Native Village Settlement on Wankie Road, 4545 English feet southwest of the Victoria Falls hotel. The site was about 40 feet south of the 1948 BPI Cambridge pendulum site, which was in another small building used as the main office of the Urban settlement. The gravimeter ties gave the difference as 0.00 mgals.

Latitude $17^{\circ}56.6'S$.; longitude $25^{\circ}51.0'E$.; elevation 955.5 meters.Salisbury, S. Rhodesia

Cambridge 1948-9; Cambridge 1958: On the floor of the main building of the Meteorological Station.

Latitude $17^{\circ}50.0'S$.; longitude $31^{\circ}01.0'E$.; elevation 1471.6 meters.Accra, Ghana

Gulf K 1959: At the new University College on the floor of Room 31 of the Geology Building, in the far left corner of the room beneath a window and near a work bench.

Latitude $5^{\circ}37'N$.; longitude $0^{\circ}12'W$.; elevation ?Lusaka, N. Rhodesia

Gulf M 1955: At the Lusaka airport 2 1/2 miles E. of the center of Lusaka on Rosemary Rd. The site was in the center of the W. room of the quonset radio building, 84 feet True North of the center of the dining room in the passenger terminal building.

Latitude $15^{\circ}24.9'S$.; longitude $28^{\circ}20.1'E$.; elevation 1270 meters approx.Leopoldville, Belgian Congo

Gulf K 1959: On the floor of the basement gravity and instrument cave of the Service Météorologique de Binza. The site is marked with a brass bench mark.

Latitude $4^{\circ}22.1'S$.; longitude $15^{\circ}15.3'E$.; elevation 450 meters.Asmara, Ethiopia

Gulf M 1955: At the W. wall of the southwest corner room of the headquarters building of the Kagnev station on Via R. Giuliani site; this is 0.69 miles S $20^{\circ}W$. (relative to True North) of the cathedral in the center of Asmara.

Latitude $15^{\circ}19'43''N$.; longitude $38^{\circ}56'05''E$.; elevation ?Nairobi, Kenya

Gulf M 1955; Cambridge 1958: On the floor in the alcove near the 100 ft.

PENDULUM STATION DESCRIPTIONS FOR AFRICA - CONT.

Nairobi, Kenya - cont.

pillar in the tape calibration chamber at the Field Survey Headquarters of the Survey of Kenya, on Thika Road, approximately 4 miles N.E. of the center of Nairobi.

Latitude $1^{\circ}14'55''$ S.; longitude $36^{\circ}51'24''$ E.; elevation 1636.1 meters.

II-165

APPENDIX II-6

SKETCHES OF PENDULUM SITES IN NORTH AMERICA

II-165a
APPENDIX II-6

SKETCHES OF PENDULUM SITES IN NORTH AMERICA

CHARLESTON, SOUTH CAROLINA

MADISON, WISCONSIN
 DEPT. OF GEOLOGY - SCIENCE HALL
 UNIVERSITY OF WISCONSIN

11-1654

-191-

IL-165e

II-165F

-193-

11-165g

WASHINGTON, D. C.

CARNEGIE INSTITUTION OF WASHINGTON, 2801 UPTON ST., N.W.
GEOPHYSICAL LABORATORY BASEMENT COMPRESSOR ROOM

11-1651

-196-

11-165j

WOODS HOLE OCEANOGRAPHIC INSTITUTION
WOODS HOLE, MASSACHUSETTS

SKETCHES OF PENDULUM SITES IN SOUTH AMERICA

-204-

1-1668

APPENDIX II-8

SKETCHES OF PENDULUM SITES IN THE FAR EAST AND PACIFIC

DOMINION PHYSICAL LABORATORY
LOWER HUTT
NEW ZEALAND

"Fortress Rocks"
Lat. $77^{\circ}52'52.320''$ S.
Long. $166^{\circ}47'10.994''$ E.

Pendulum Site In Building No. 30

Lat. $77^{\circ}53'6.856''$ S.
Long. $166^{\circ}45'18.122''$ E.
Elevation 12.09 Meters
above m.s.l. to top
of pier

Distance 3961.49 Bearing $78^{\circ}49'00''$ E.

Distance 1668.32
Bearing $N.71^{\circ}56'00''$ W.

"Hut"
Distance 2618.32
Bearing $S.54^{\circ}24'00''$ E.
Lat. $77^{\circ}52'59.990''$ S.
Long. $166^{\circ}43'59.993''$ E.

Church

Building No. 30

Distance 2896.14 Bearing $S.46^{\circ}30'24''$ W.

Scale
0 feet 500

"South"
Lat. $77^{\circ}53'15.014''$ S.
Long. $166^{\circ}45'44.700''$ E.

WILLIAMS AIROPFAC
ROSS ISLAND
MCMURDO SOUND
ANTARCTICA

11-1670

SKETCHES OF PENDULUM SITES IN EUROPE AND NORTH AFRICA

BAD HARZBURG, GERMANY

BUREAU INTERNATIONAL DES POIDS ET MESURES
PAVILLON DE BRETEUIL, SÈVRES
PARIS, FRANCE

L' INSTITUTO GEOGRAFICO e CADASTRAL

● PENDULUM

LISBON, PORTUGAL

NATIONAL PHYSICAL LABORATORY
TEDDINGTON, ENGLAND

WHEELUS A.F.B.
TRIPOLI, LIBYA

APPENDIX II-10

SKETCHES OF PENDULUM SITES IN AFRICA

II-169b

Main Basement

Service Météorologique de Binza
LEOPOLDVILLE, BELGIAN CONGO

BIBLIOGRAPHY

- Anderson, E., Beitrag zur Mitschwingungstheorie der relativen Pendelmessungen mit 2- und 4-Pendel apparaten, Kopenhagen: Bianco Lunos Bogtrykkeri, 65 pp., 1932.
- Aslakson, C. I. and Swick, C. H., Gravity observations in Peru and Colombia, USC and GS Spec. Pub. No. 233, 18 pp., 1943.
- Browne, B. C. and Bullard, E. C., Comparison of the acceleration due to gravity at the National Physical Laboratory, Teddington, and the Bureau of Standards, Washington, D.C., Proc. Roy. Soc., A, Vol. 175, 110-120, 1940.
- Browne, B. C., African trip with the Cambridge pendulums, personal communication, 1960.
- Bullard, E. C., Gravity measurements in East Africa, Phil. Trans. Roy. Soc. London, A, Vol. 235, 445-531, 1936.
- Coron, S. and Mounet, F., Réseau Gravimétrique Internationale de Ire Ordre, Bureau Gravimétrique Internationale, 176 pp., 1959.
- Cook, A. H., Comparison of the acceleration due to gravity at the National Physical Laboratory, Teddington, the Bureau International des Poids et Mesures, Sèvres, the Physikalisch-Technische Bundesanstalt, Brunswick, and the Geodetic Institute, Potsdam, Proc. Roy. Soc., A, Vol. 213, 408-424, 1952.
- Cook, A. H., Adjustment of the principal gravity observations in Great Britain, M.N.R.A.S., Geophys. Supp., Vol. 6, No. 8, 494-534, 1953.
- Cook, A. H., Comparisons between relative gravity measurements with the Cambridge pendulum apparatus and Worden gravity meters in North America, South Africa, Australia, New Zealand, and Great Britain, M.N.R.A.S., Geophys. Supp., Vol. 7, No. 5, 228-255, 1957.
- Damrel, J. B., Tidal gravity effect tables, Pub. of the Houston Technical Laboratories, 71 pp., 1951.
- Duerksen, J. A., Pendulum gravity data in the United States, USC and GS Spec. Pub. No. 244, 218 pp., 1949.
-, Deutscher Landesbericht (West Deutschland) zur Sitzung der Internationalen Gravimetrischen Kommission in September 1959 in Paris, D.G.K., Bayer.-Akad. Wissensch., 99 pp., Sept. 1959.
- Garland, G. D., Gravity measurements in North America with the Cambridge pendulums (I), Proc. Roy. Soc., A, Vol. 219, 215-233, 1953.
- Garland, G. D., Gravity measurements in North America with the Cambridge pendulums (II), Proc. Roy. Soc., A, Vol. 233, 203-213, 1955.

- Garland, G. D. and Cook, A. H., A determination of the differences in gravity between the National Physical Laboratory, Teddington, the Dominion Observatory, Ottawa, and the National Bureau of Standards, Washington, Proc. Roy. Soc., A, Vol. 229, 445-458, 1955.
- Gay, M. W., Relative gravity measurements using precision pendulum equipment, Geophysics, Vol. 5, No. 2, 176-191, 1940.
- Gilbert, R. L. G., Some comments on the results obtained with the Cambridge pendulum apparatus in North America, Trans. A.G.U., Vol. 38, No. 4, 457-461, 1957.
- Gilbert, R. L. G., Discussion of "Some comments on the results obtained with the Cambridge pendulum apparatus in North America", Trans. A.G.U., Vol. 39, No. 4, 729-730, 1958.
- Gough, D. I., A new determination of the differences in gravity between the N.P.L. Teddington and the South African Fundamental and Secondary Stations, Geophys. Jour., Vol. 3, No. 20, 298-307, 1958.
- Hales, A. L. and Gough, D. I., Measurements of gravity in Southern Africa, Govt. Printer, Pretoria, 56 pp., 1950.
- Harada, Y., Suzuki, H., Ohashi, S. and Kakinuma, S., Report on the gravity measurements by the Japanese Antarctic Research Expedition, 11 pp., 1958, (unpublished).
- Heyl, P. R. and Cook, G.S., The value of gravity at Washington, J. Res. Nat. Bur. Stand., Vol. 17, 805, 1936.
- Innes, M. J. S., The establishment of a calibration standard for gravimeters in Eastern Canada and the United States, Trans. Am. Geophys. Un., Vol. 39, No. 2, 195-207, 1958.
- Jackson, J. E., Observations with the Cambridge pendulum apparatus in North, Central and South America in 1958, Geophys. Jour. R.A.S., Vol. 2, No. 4, 337-347, 1959.
- Jackson, J. E., Pendulum observations at Teddington, Singapore, Darwin and Melbourne in 1959, Geophys. Jour. R.A.S., Vol. 3, No. 1, 78-82, 1960.
- Jeffreys, H., Theory of probability, 2nd edition, Oxford, at the Clarendon Press, 1948.
- Jelstrup, G., Observations on the gravimetric calibration base Hammerfest-Munich with the Cambridge pendulum apparatus, Norges Geografiske Oppmaling, Geod. Pub. No. 7, 42 pp., 1957.
- Kneissl, M., Der deutsche Anteil an der Europäischen Gravimeter-Eichlinie Hammerfest-Rom, Bayer.-Akad. Wissensch., Math.-Naturw. Kl Abh. NF Heft 78, Munchen, 52 pp., 1956.

- Kneissl, M., Die internationalen europäischen Gravimeter-Eichbasen, Beschreibung und vorläufige Messungsergebnisse 1954-1956, Abhandl. d. Bayer. Akad. d. Wiss., Math. - nat. Klasse, Neue Folge, Heft 79, München, 80 pp., 1956.
- Kneissl, M., Das deutsche Schweregrundnetz, Pendelmessungen 1958, bearbeitet von K. Marzahn, Veröff. d. DGK., Reihe B, Heft Nr. 23, Teil VII.
- Kumagai, N., Results of measurements of gravity in Japan and her vicinity, Report of the Japanese Geod. Comm., New Series, No. IV, 53 pp., Kyoto 1953.
- Mazzon, C. and Pieri, L., Relazione preliminare sulle Misure Pendolari Italiane per la base gravimetrica Europea, Estrattoda: La Ricerche Scientifica, Scientifica, Anno 28^o, n. 11, 9 pp., 1958.
- Miller, A. H., A determination of the relative values of gravity at Potsdam, Greenwich, Ottawa, and Washington, Publ. Dom. Obs. Ottawa, 11, 61-75, 1931.
- Morelli, C., Tidal gravity corrections for 1954, Geophys. Prosp., Vol. II, Supp., 32-42, 1954.
- Munsey, D. F. and Bullard, E. C., Gravity measurements in the Anglo Egyptian Sudan, M.N.R.A.S., Geophys. Supp., Vol. 4, No.1, 114-121, 1937.
- Muto, K., A GSI pendulum apparatus for gravity measurements, Proc. Jap. Acad., Vol. 29, No. 8, 439-445, 1953.
- Okuda, T., Inoue, E., and Suzuki, H., Determination of the differences in gravity values at the Coast and Geodetic Survey (C and GS), the National Bureau of Standards (N.B.S.), Washington, D.C., and the Geophysical Survey Institute (GSI), Chiba, Japan, Bull. Geog. Surv. Inst., Vol. V, Parts 1-2, 1-12, March 1957.
- Rice, D. A., Gravity control measurements in North America, USC and GS Pub. 63-1, 23 pp., 1958.
- Rose, J. C., and Woollard, G. P., 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).
- Rose, J. C. and Woollard, G. P., 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)
- Swick, C. H., Modern methods for measuring the intensity of gravity, USC and GS Spec. Pub. No. 69, 96 pp., 1921.
- Swick, C. H., Pendulum gravity measurements and isostatic reductions, USC and GS Spec. Pub. No. 232, 82 pp., 1942.

-, The British Fundamental Gravity Station, Nature, Vol. 173, p. 794, 1954.
- Thompson, L. G. D., An improved bronze pendulum apparatus for relative gravity determinations, Pub. of Dom. Obs., Dept. Mines and Tech. Surv., 143-176, 1959.
- 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.
- Weiken, K., Ergebnisse der Pendelmessungen der Jahre 1934 bis 1943, Veröff. d. Geod. Inst. Potsdam Nr. 3, 31 pp., Berlin 1950.
- Winter, P. J., Valliant, H. D. and Hamilton, A. C., Pendulum observations at Ottawa, Gander, Teddington, Paris, Rome and Bad Harzburg, Bull. Geod., 1960 (In Press).
- Woollard, G. P., The gravity meter as a geodetic instrument, Geophys., Vol. 15, 1-29, 1949.
- Woollard, G. P., Bonini, W. E., Black, W. A., Rose, J. C. and Ault, W., A study of methods for measuring large changes in gravity on an inter-continental basis, Woods Hole Ocean. Inst. Tech. Rept., Ref. 53-36, 92 pp., 1953 (unpublished).
- Woollard, G. P., Rose, J. C. and Ault, W., A study of methods for measuring large changes in gravity on an intercontinental basis (supplement), Woods Hole Ocean. Inst. Tech. Rept., Ref. 54-84, 18 pp., 1954 (unpublished).
- Woollard, G. P. and Rose, J. C., Preliminary values and station descriptions world pendulum gravity bases established 1954, Woods Hole Ocean. Inst. Tech. Rept., Ref. No. 55-49, 18 pp., 1955.
- Woollard, G. P., Harding, N. C. and Rose, J. C., The problem of calibrating high-range Geodetic-type gravimeters, Trans. Amer. Geophys. Un., Vol. 36, 12-24, 1955.
- Woollard, G. P., Rose, J. C. and Bonini, W. E., The establishment of an International Gravity Standard, Trans. Amer. Geophys. Un., Vol. 37, 143-155, 1956.
- Woollard, G. P. Standardization of the world's gravity data, Trans. Amer. Geophys. Un., Vol. 37, 669-675, 1956.

PART III

Gravimeter Program

Errata For Section III

Note: The results quoted in this report were determined on the basis of individual trip closures. The data have also been examined from the standpoint of geographic loop closures. Where discrepancies in excess of 0.3 mgal were apparent the original data were restudied to see if tares or variations in drift rate could have been handled differently. In some cases restudy resulted in changes of 0.3 mgal or more, and the following tabulation of corrections include these revised values plus typographical errors discovered after the report had been printed. Pendulum comparisons given were for data available in 1959. The addition of new (1960) pendulum data will modify these comparisons somewhat.

Page

- 1A Graph 1: Change Punta Arena to Punta Arenas
Change Antofogasta to Antofagasta
- 2 Footnotes; line 2: Change VXXIII to XXIII
- 4 Eastern Range; Charleston, S.C.: Change 5003 5009
to 5508 5509
- 5 Pacific Range; Sydney, Australia: Change 979.6868 .6863 -0.5
to 979.6863 .6863 0.0
- 6 Survey and Reduction Procedure on Evaluation Study; paragraph 2;
line 1: Change Table III A-1 to Table III-A-0
- 8 Butte, Mont.: Change 980.1740 .1740 .1740 .0000
to " .1744 " -.0004
Syracuse, N.Y.: Change 980.3965 .3964 .3968 +.0004
to " .3968 " .0000
Burlington, Vt.: Change 980.5188 .5181 .5187 +.0006
to .5273 " .5172 +.0091
- 9 Raleigh-Durham, N. C.; column 3: Change +0.2 to -0.2
Kansas City, Mo.; column 3: Change +0.2 to +0.1
- 10 Oceanside, Calif.; column 3: Change -5.3 to -5.5
Indianapolis, Ind.; column 2: Change .0898 to .0890
Philadelphia, Pa.; column 3: Change -4.0 to -0.4
Bellingham, Wash.; columns 2 and 3: Change .8843 -2.7
to .8847 -2.3
- 11c Change W106 to W10b
- 13 Evaluation of World Network Through Measurements by Other Groups;
paragraph 2; line 6: Change +0.03 to +0.3
- 14 Line 1: Add (old pillar) after Paris Observatory
Line 3; column 4: Change .9459 to .9159

Errata For Section III (cont'd)

Page

- 14 Line 8: Change Edinborough to Edinburgh
 Line 12: Change Belegrade to Belgrade
 Line 32: Change Dar es Sallaan to Dar es Salaam
 Line 33: Change Mombassa to Mombasa
- 15 Line 17; column 5: Change +0.3 to -0.7
- 16 Paragraph 5; line 2: Change Idelwild to Idlewild
 line 7: " " " "
- 16A Figure II-20: Change Africa to Arica
- 17 Line 2: Change Sallel to Salle No. 1
 Line 7: Change (Ciampino E) to (Ciampino Est)
- 18 La Paz, Bolivia; Airport (Panagra: Change 977.348 to 977.3487
- 19 Paragraph 2; line 6: Change Buenos Aires (GM) to Buenos Aires (IGM)

Table of Contents

Part III Program of Gravimeter Measurements

	<u>Page</u>
General Statement	III-1
Evaluation of Pendulum Results	III-1
United States Network of Control Bases	III-2
Evaluation of United States Network	III-2
Standardization of Evaluation Gravimeter	III-6
Survey and Reduction Procedure	III-6
Results of Evaluation Study	III-7
Evaluation by U.S. Coast and Geodetic Survey	III-7
Results at Harbor and University Sites	III-9
World Network of Gravimeter Bases	III-11
Remarks on Adjustment of International Airport Values	III-13
Evaluation of World Network by Other Groups	III-13
Expeditions Polaires Francaises	III-13
Inter-American Geodetic Survey	III-16
Morelli Program of Intercontinental Connections	III-16

PART III

Gravimeter Program

General Statement:

The gravimeter program, as mentioned in the Introduction, served three purposes: (1) a check on the reliability of the pendulum measurements; (2) the development of gravity coverage in the United States, and (3) the refinement and expansion of the world network of airport bases that could be used as an extended secondary system of reference bases.

Evaluation of Pendulum Results:

In Table III-1 the general agreement obtained between pendulum and gravimeter values over the North American gravity standardization ranges was obtained with a series of Worden geodetic gravimeters and with LaCoste-Romberg geodetic gravimeters calibrated so as to give a best mean square fit to all the pendulum values. It is to be noted (a) that with two exceptions (Whitehorse and Tulsa) the gravimeters agree very well with each other and (b) both sets of gravimeter comparisons indicate similar departures in the pendulum values. The difference in values obtained with the Worden and LaCoste-Romberg meters averages less than 0.2 mgal if the large discrepancy at Whitehorse of 0.9 mgal is disregarded. The cause of this discrepancy is not known, but may be related to a misreading on the one occupation here with a LaCoste-Romberg meter.

The average reliability indicated by the data of Table III-1 for the pendulum measurements in North America from these comparisons is 0.27 mgals. Intercontinental comparisons at pendulum sites in Europe, Africa, Australia and South America made with LaCoste-Romberg geodetic gravimeters calibrated at the North American pendulum sites indicate that this standard is maintained on a global basis and Table III-2 lists the comparative values obtained on such an evaluation study made in 1959. It is seen that the average degree of agreement outside of North America does not differ significantly from that given in Table III-1 for the pendulum measurements in North America (± 0.35 mgal vs. ± 0.27 mgal).

If results adjusted to the same standard obtained on earlier trips outside North America are examined in a similar manner the agreement is equally as good, as is shown graphically in Figures III-0 and Figure III-1. It therefore appears that the pendulum values have an average reliability of from 0.3 to 0.4 mgal throughout the world. The gravimeter comparisons, however, do indicate that some of the pendulum bases do not have this reliability. Those pendulum bases that appear to be in error by over 0.5 mgal are as follows:

NORTH AMERICA

Northway, Alaska	0.7 to 0.8 mgal high
Whitehorse, Y.T.	0.6 to 0.7 mgal high
Grand Prairie, Alb.	0.5 to 0.6 mgal high

III-1A

FIG. III - O

III-1B

FIG. III - 1

III-2

NORTH AMERICA (Cont'd)

Sheridan, Wyo.	0.6 to 0.7 mgal low
Casper, Wyo.	0.5 to 0.6 mgal low
Cheyenne, Wyo	1.1 to 1.3 mgal low
Seattle, Wash.	0.7 to 0.9 mgal high

EUROPE

Copenhagen, Den.	1.0 to 1.2 mgal high
Frankfurt, Ger.	0.7 to 0.8 mgal high

AFRICA

Dakar	0.6 to 0.8 mgal low
-------	---------------------

AUSTRALIA-NEW ZEALAND

Dunedin, N. Z.	0.9 to 1.1 mgal high
Darwin, Aust.	0.8 to 1.0 mgal high
Singapore	0.5 to 1.0 mgal high
Hong Kong	0.8 to 1.0 mgal low
Tokyo, Japan	0.8 to 1.0 mgal low
Kyoto, Japan	0.8 to 1.0 mgal low

SOUTH AMERICA

Punta Arenas	0.9 to 2.5 mgals low
--------------	----------------------

Although the above list of seventeen apparently sub-reliable values appears high, it actually represents only 16% of the one hundred and five pendulum bases established under the program.

United States Network of Control Bases:

As part of the gravity program carried out in part under the cognizance of this contract, a network of gravity control bases was established at airports throughout the United States. See Figure III-2. The results for this network and base descriptions were published in 1958*. This work was done almost entirely with Worden gravimeters and was believed to have an accuracy of 0.3 mgal on the basis of closure intervals.

Evaluation of United States Network of Gravimeter Bases:

The accuracy of the airport network of bases in the United States could not be reliably evaluated until this past year. This was possible through the development of the LaCoste-Romberg high range geodetic gravimeter, which has a reliability of approximately 0.1 mgal. This instrument, although it requires an external power supply and must be maintained at constant temperature and is not as portable as the Worden meters, does have a very low, nearly constant drift rate, few tares, a 6000 mgal range without resetting and a reading sensitivity of ± 5 micro-gals. For any study in which precision is the first requisite, the advantages of the LaCoste-Romberg instrument far outweigh its disadvantages.

*Woollard, G. P. 1958 Results for a Gravity Control Network at Airports in the United States. Geophysics VXXIII, 3, pp. 520-535.

FIG. III-2

Table III-1

Evaluation of Gravity Standardization Ranges in North America
Base University of Wisconsin, Madison, 980.3689

Western Range

<u>Station</u>	<u>Pendulum Value</u> <u>Weighted Mean</u>	<u>Worden Meters</u> <u>(averages)</u>	<u>Diff.</u>	<u>LaCoste Meter</u> <u>G-1</u>	<u>Diff.</u>	<u>Diff. in</u> <u>Meters</u>
ALASKA						
Pt. Barrow	982.6998	.7000 (2)	+0.2	.6997	-0.1	0.3
Fairbanks (Ladd AFB)	982.2445	.2445 (5)	0.0	.2444	-0.1	0.1
Anchorage	981.9396	.9394 (5)	-0.2			
Northway	981.9915	.9913 (1)	-0.2			
CANADA						
Whitehorse, Y.T.	981.7493	.7495 (5)	+0.2	.7486	-0.7	0.9
Fort St John, B.C.	981.4063	.4062 (7)	-0.1	.4059	-0.4	0.3
Grand Prairie, Alb.	981.3182	.3184 (3)	+0.2			
Edmonton, Alb.	981.1681	.1682 (7)	+0.1	.1678	-0.3	0.4
Red Deer, Alb.	980.9975	.9976 (4)	+0.1			
Calgary, Alb.	980.8283	.8282 (6)	-0.1	.8281	-0.2	0.1
Lethbridge	980.7589	.7590 (6)	+0.1			
UNITED STATES						
Cutbank, Mont.	980.6083	.6086 (8)	+0.3	.6085	+0.2	0.1
Great Falls, Mont.	980.5265	.5268 (8)	+0.3	.5270	+0.5	0.2
Billings, Mont.	980.3707	.3711 (11)	+0.4	.3710	+0.3	0.1
Sheridan, Wyo.	980.2257	.2263 (9)	+0.6	.2264	+0.7	0.1
Casper, Wyo.	979.9553	.9556 (9)	+0.3	.9558	+0.5	0.2
Cheyenne, Wyo.	979.6993	.7003 (9)	+1.0	.7006	+1.3	0.3
Denver, Colo.	979.6109	.6111 (9)	+0.2	.6114	+0.5	0.3
Amarillo, Tex.	979.4231	.4230 (8)	-0.1			
Houston, Tex.	979.2982	.2984 (8)	+0.2	.2985	+0.3	0.1
San Antonio, Tex	979.1968	.1976 (8)	+0.8	.1976	+0.8	0.0
MEXICO						
Monterrey, N.L.	978.8052	.8056 (3)	+0.4	.8055(2)	+0.3	0.1
Tamazunchale, S.L.P.	978.6602	.6598 (2)	-0.4			
Chapulhuacan, Hid.	978.4842	.4843 (4)	+0.1			
Ixmiquilipan, Hid.	978.1676	.1680 (4)	+0.4			
Mexico, D.F.	977.9421	.9418 (8)	-0.3	.9419	-0.2	0.1
(Tacubaya)						
El Zarco, D.F.	977.7681	.7675 (2)	-0.6			
Paso Cortes, D.F.	977.5712	.5709 (8)	-0.3	.5711	-0.1	0.2

Mid-Continent Range

<u>Station</u>	<u>Pendulum</u> <u>Weighted Mean</u>	<u>Worden Meters</u> <u>(averages)</u>	<u>Diff.</u>	<u>LaCoste-Romberg</u> <u>(averages)</u>	<u>Diff.</u>	<u>Diff. in</u> <u>Meters</u>
Huron, S.D.	980.4539	.4535 (6)	-0.4			
Madison, Wis. (Base)	980.3689	.3689 (6)	0.0	.3689	0.0	0.0
Beloit, Kansas	979.9981	.9980 (6)	-0.1	.9978 (2)	-0.3	0.2
Tulsa, Okla.	979.7655	.7659 (6)	+0.4	.7661 (2)	+0.6	0.2

Table III-1 (Cont'd)

Evaluation of Gravity Standardization Ranges in North America
Base University of Wisconsin, Madison, 980.3689

Mid-Continent Range (cont.)

Houston, Tex.	979.2982	.2984 (6)	+0.2	.2985 (2) +0.3	0.1
Brownsville, Tex.	979.0395	.0399 (2)	+0.4		

Eastern Range

<u>Station</u>	<u>Pendulum Value</u> <u>Weighted Mean</u>	<u>Worden Meters</u> <u>(averages) Diff.</u>	<u>LaCoste-Romberg</u> <u>(averages) Diff.</u>	<u>Diff. in</u> <u>Meters</u>
Ottawa, Ontario				
Dominion Observ.	980.6215	.6218 (4) +0.3	.6219 +0.4	0.1
Palisades, N.Y.				
Lamont Geol. Obs. (Geophysics Lab)	980.2593	.2598 (1) +0.5	.2596 (2) +0.3	0.2
Washington, D.C.				
(Geophysics Lab)	980.1006	.1006 (12) 0.0	.1006 (4) 0.0	0.0
(Commerce, Floor)	980.1188	.1188 0.0	.1188 0.0	0.0
Charleston, S.C.	979.5510	.5008 (2) -0.2	.5009 (2) -0.1	0.1
Miami, Fla.	979.0354	.0358 (1) +0.4	.0356 (2) +0.2	0.2
Key West, Fla.	978.9687		.9692 (1) +0.5	

III- 5

Table III-2

<u>Pendulum Site</u>	<u>Weighted Mean Pendulum Value</u>	<u>Gravimeter Value L-R G-1</u>	<u>Diff.</u>
NORTH AMERICAN RANGE			
Pt. Barrow, Alaska	982.6998	.6997	-0.1
Fairbanks, Alaska (Ladd AFB)	982.2445	.2444	-0.1
Whitehorse, Y.T.	981.7493	.7486	-0.7
Edmonton, Alberta	981.1681	.1678	-0.3
Madison, Wisconsin (Base)	980.3689	.3689(Base)	0.0
Washington, D.C.(Geophys.Lab.)	980.1006	.1006	0.0
Houston, Texas	979.2982	.2985	+0.3
Mexico City, Mexico (Tacubaya)	977.9421	.9419	-0.2
San Francisco, Calif.	979.9866	.9868	+0.2
PACIFIC RANGE			
Honolulu, Hawaii	978.9525	.9529	+0.4
Christchurch, N.Z.	980.5091	.5091	0.0
Sydney, Australia	979.6868	.6863	-0.5
Brisbane, Australia	979.1696	.1698	+0.2
Darwin, Australia	978.3148	.3139	-0.9
Singapore	978.0820	.0817	-0.3
EURO-AFRICAN RANGE			
Cairo, Egypt	979.2916	.2912	-0.4
Rome, Italy	980.3642	.3642	0.0
Paris, France	980.9409	.9410	+0.1
Dakar, French West Africa	978.3844	.3852	+0.8
SOUTH AMERICAN RANGE			
Rio de Janerio, Brazil	978.8048	.8046	-0.2
Buenos Aires, Argentina	979.7052	.7048	-0.4

Standardization of LaCoste-Romberg Geodetic Gravimeter:

The calibration of LaCoste-Romberg Geodetic Meter No. 1 was established by reoccupying key pendulum stations on the North American gravity standardization range between Paso de Cortes, Mexico and Fairbanks, Alaska and on the mid-continent and eastern series of pendulum measurements. Observations were made as a series of closed loops. The gravity values used for these standardization stations were based upon the weighted means of the observations made with the United States Coast and Geodetic Survey, Cambridge University (England) and Gulf-University of Wisconsin sets of pendulum apparatus, as explained in Part II on the pendulum observations. Although any one set of observations made by the various groups could be the most accurate, the use of the weighted mean values for all three groups is the least subjective approach in establishing the value for these bases. As the response curve of the LaCoste-Romberg instrument had been determined in the laboratory by the manufacturer, the observations could be fitted to the pendulum values as a linear function. The LaCoste-Romberg meter results presented in Table III-1 give the comparison between the gravimeter and the pendulum results for the stations occupied. Figure III-3 is a plot of the difference in gravimeter and pendulum values. Zero ordinate defines the calibration factor that gives the best fit and is based upon a least square adjustment between the gravimeter values and the weighted means of the pendulum results. The average agreement with the pendulum values is about 0.27 mgal, which is within the limits of confidence for most of the pendulum measurements. The standard deviation for the gravimeter observations used in establishing the calibration factor for the meter is 0.08 mgal. The 95% confidence limits for any one of the stations based on 16 degrees of freedom is ± 0.14 mgal.

Survey and Reduction Procedure on Evaluation Study:

For general control over the country on the evaluation study, a network of stations was established by air travel at forty sites. These bases served as control for stations occupied using ground transport and each was occupied from two to nine times. Earth tide corrections were made using the tables prepared by the European Association of Exploration Geophysicists. The correction for instrument drift after allowing for earth tide effects averaged about one-tenth of a milligal per week. The values of gravity for each site were based upon the observed differences from the pendulum base station at the University of Wisconsin (980.3689 gals) as based upon the ties made by Woollard (1948) to seven international gravity bases tied directly to Potsdam.

Table III A-1 of the Appendix presents the results and descriptions for the network of forty control stations. These were occupied on several different "trips" but owing to the high repeatability of the meter could be analyzed together statistically. The estimated standard deviation for the group is 0.08 mgal. The 95% confidence limits for any one of the stations in the control group is ± 0.13 mgal based on 14 degrees of freedom.

Table III A-2 presents the principal facts, latitude, longitude, elevation, observed gravity, Free Air anomaly and Bouguer anomaly for

CALIBRATION DATA for LRG-1

○ PENDULUM VALUES WITH GREATEST WEIGHT
 MULTIPLE OCCUPATIONS GULF WIS. & CAMB
 and/or U.S.C. & G.S.

FIG. III - 3

FIG. III - 4

a density of 2.67 gm/cc for all sites where reliable location and elevation data are available.

In addition to occupying the airport network of bases, Mr. J.C. Behrendt of the University of Wisconsin, who carried out the evaluation study, established new bases at several airport sites not previously occupied and in addition established bases at various universities known to have gravity studies underway and also at port sites likely to be used on future marine gravimetric programs. A spot check was also made of a number of the pendulum gravity bases established earlier by the United States Coast and Geodetic Survey.

A breakdown on the observations in terms of locations is as follows:

- 111 Airport Stations
- 50 Universities and Institution Stations
- 61 Pendulum Stations
- 32 Harbor Stations (Great Lakes, Atlantic,
Pacific, and Arctic Coasts)

Results of Evaluation Study:

In Table III-3 the values obtained on the present study are compared with those established at the same airports by Woollard (1958) using Worden gravimeters, and in Figure III-4 the difference in values is plotted as a function of the absolute gravity value. As seen in Figure III-4, the values appear to differ in a systematic manner with change in gravity indicating a difference in calibration standard. This can be accounted for by the fact that the calibration used by Woollard was based upon the preliminary values for the Gulf-University of Wisconsin pendulum results only on the North American standardization range. If Woollard's results are adjusted for the apparent difference in calibration of 0.35 mgal per 1000 mgals change, the two sets of values are brought into substantial agreement. Except for two sites, Burlington, Vermont and Medford, Oregon, the two sets of data agree on the average to 0.2 mgal, which is within the limit of ± 0.3 mgal originally claimed by Woollard. The discrepancy at Burlington, Vermont appears to have been a poor reading by Woollard, and at Medford, Oregon there is some question as to whether identical sites were used, as the airport terminal had been rebuilt during the intervening period.

In Table III A-2 of the Appendix revised values and the principal facts are given for all of the airport network bases originally reported by Woollard (1959) that were not reoccupied in the present study. This table and Tables III A-1 and III A-3 of the Appendix, which give the principal facts for the airports occupied on this study, are believed to provide reliable control on an absolute basis at airports throughout the United States and parts of Canada and Mexico.

Evaluation of Airport Network by the United States Coast and Geodetic Survey:

An evaluation of the airport network in the United States was also made by the United States Coast and Geodetic Survey. This consisted of a series of measurements along the East Coast with some spot checks in

III-8

Table III-3 Airports

Comparison of L & R Geodetic #1 with Adjusted 1958 Values

Station	A	B	C	Difference C - B
	Unadjusted Woollard (58)	L & R Geodetic #1	Adjusted Woollard (58)	
Birmingham, Ala.	979.5389	.5390	.5392	+.0002
Los Angeles, Calif.	979.5944	.5946	.5947	+.0001
San Diego, Calif.	979.5366	.5369	.5369	.0000
San Francisco, Calif.	979.9880	.9883	.9881	-.0002
Denver, Colo.	979.6330	.6335	.6333	-.0002
Washington, D.C. (Comm. Outside)	980.1182	.1182	.1182	.0000
Jacksonville, Fla.	979.3855	.3856	.3859	+.0003
Pensacola, Fla.	979.3626	.3630	.3630	.0000
Atlanta, Ga.	979.5203	.5205	.5206	+.0001
Savannah, Ga.	979.4977	.4980	.4980	.0000
Indianapolis, Ind.	980.0933	.0933	.0934	+.0001
Lafayette, Ind.	980.1468	.1469	.1468	-.0001
New Orleans, La.	979.3294	.3298	.3298	.0000
Detroit, Mich.	980.3187	.3188	.3187	-.0001
Minneapolis, Minn.	980.5951	.5950	.5950	.0000
Kansas City, Mo.	979.9997	.9998	.9998	.0000
Butte, Mont.	980.1740	.1740	.1740	.0000
Missoula, Mont.	980.4438	.4440	.4437	-.0003
Las Vegas, Nev.	979.6047	.6050	.6049	-.0001
Santa Fe, N.M.	979.1970	.1974	.1975	+.0001
New York (LaGuardia), N.Y.	980.2827	.2825	.2825	.0000
Syracuse, N.Y.	980.3965	.3964	.3968	+.0004
Cincinnati, O.	979.9929	.9931	.9930	-.0001
Cleveland, O.	980.2325	.2322	.2325	+.0003
Tulsa, Okla.	979.7762	.7766	.7764	-.0002
Eugene, Ore.	980.5150	.5148	.5149	+.0001
Medford, Ore.	980.2363	.2375	.2363	(Poss. not same site)
Pittsburgh, Pa.	980.0994	.0993	.0995	+.0002
Charleston, S.C.	979.5664	.5668	.5667	-.0001
Brownsville, Tex.	979.0505	.0509	.0511	+.0002
El Paso, Tex.	979.0811	.0814	.0817	+.0003
San Antonio, Tex.	979.1971	.1975	.1976	+.0001
Burlington, Vt.	980.5188	.5181	.5187	+.0006
Seattle, Wash.	980.7769	.7765	.7767	+.0002
Spokane, Wash.	980.6463	.6463	.6461	-.0002
Charleston, W.Va.	979.9256	.9259	.9257	-.0002
Madison, Wis. (Base)	980.3689	.3689	.3689	.0000
Milwaukee, Wis.	980.3597	.3597	.3597	.0000
Casper, Wyo.	979.9560	.9562	.9561	-.0001

the mid-continent area. The results of this evaluation are shown in Table III-4. This evaluation shows agreement to within ± 0.2 mgal, which checks that made with the LaCoste-Romberg gravimeter.

Table III-4

Evaluation by United States Coast and Geodetic Survey of
Airport Gravity Network in the United States

	USC&GS	U.Wis.	Diff.
Washington Commerce Base (Pier)	980.1180	.1180	0.0
U. S. national datum			
Richmond, Va.	979.9525	.9526	+0.1
Raleigh-Durham, N. C.	979.8012	.8010	+0.2
Greensboro, N. C.	979.7647	.7650	+0.3
New Bern, N. C.	979.7280	.7278	-0.2
Charlotte, N. C.	979.7272	.7275	+0.3
Florence, S.C.	979.6842	.6843	+0.1
Wilmington, N. C.	979.6767	.6764	-0.3
Greenville, S.C.	979.6219	.6224	+0.5
Charleston, S.C.	979.5663	.5659	-0.4
Orlando, Fla.	979.2181	.2183	+0.2
Kansas City, Mo.	979.9989	.9990	+0.2
Tulsa, Okla.	979.7754	.7756	+0.2
Dallas, Tex.	979.5121	.5121	0.0
Houston, Tex.	979.2923	.2925	+0.2
Av. Diff. with regard to sign 0.1 mgal.			
Av. Diff. without regard to sign 0.2 mgal.			

Results for Harbor and other Sites Occupied in North America other than
Airports on Evaluation Study:

The descriptions and values of gravity at sites other than airports occupied on the airport network evaluation study are listed in the Appendix under the following designations:

- Table III A-4 Harbor Gravity Bases
- Table III A-5 University Gravity Bases
- Table III A-6 Pendulum Gravity Bases

In the last (Table III A-6), the designation GW refers to sites occupied with the Gulf-Wisconsin pendulums. The designation U refers to sites occupied originally by the United States Coast and Geodetic Survey, and the number designation is that given by Duerksen (1949) in Pendulum Gravity Data in the United States, United States Coast and Geodetic Survey Special Publication No. 244. In each case the description of the site occupied refers to that used in making the gravimeter observation and represents as close a reoccupation of the original pendulum site as could be achieved.

As many of the pendulum bases established by the United States Coast and Geodetic Survey have been used as reference datums for oil company surveys, Table III-5 was prepared to show their relative

III-10

Table III-5

Comparison of Values at United States Coast and Geodetic
Survey Pendulum Bases

Base U. S. National Datum (Commerce 980.1180)

	<u>Station</u>	<u>Reported Value</u>	<u>Observed</u>	<u>Diff.</u>
U1119	Tuscaloosa, Ala.	979.562	.5590	-3.0
238	Eureka, Calif.	980.223	.2211	-1.9
241	Oceanside, Calif.	979.571	.5655	-5.8
239	Santa Rosa, Calif.	980.024	.0195	-4.5
1078	Colorado Sprgs, Colo.	979.494	.4923	-1.7
1164	Craig, Colo.	979.622	.6194	-2.6
337a	Washington, D.C.	980.1176	.1174	- .2
890	Crestview, Fla.	979.377	.3807	+3.7
869	Lake City, Fla.	979.334	.3332	- .8
399	Mariana, Fla.	979.367	.3657	-1.3
164	Pensacola, Fla.	979.363	.3623	- .7
15	Atlanta, Ga.	979.527	.5230	-4.0
36	Chicago, Ill.	980.281	.2850	+4.0
137	Indianapolis, Ind.	980.093	.0898	-4.0
23A	Baltimore, Md.	980.114	.1156	+1.6
29	Boston, Mass.	980.399	.3959	-3.1
30	Cambridge, Mass.	980.401	.4003	- .7
145	Laurel, Miss.	979.468	.4689	+ .9
584	Forsythe, Mont.	980.514	.5081	-5.9
764	Albuquerque, N.M.	979.221	.2224	+1.4
149	Wilmington, N.C.	979.668	.6695	+1.5
136	Columbus, Ohio	980.092	.0856	-6.4
232	Eugene, Ore.	980.493	.4902	-2.8
229	Portland, Ore.	980.649	.6466	-2.4
957	Philadelphia, Pa.	980.197	.1966	-4.0
17	Charleston, S.C.	979.549	.5493	+ .3
186	Aberdeen, S.D.	980.553	.5455	-7.5
153	Cleveland, Tenn.	979.652	.6509	-1.1
98	Alpine, Tex.	978.994	.9902	-3.8
727	Corpus Christi, Tex.	979.145	.1481	+3.1
723	Del Rio, Tex.	979.193	.1912	-1.8
73A	Denison, Tex.	979.569	.5704	+1.4
63	El Paso, Tex.	979.127	.1249	-2.1
7	Galveston, Tex.	979.276	.2745	-1.5
730	Rosenburg, Tex.	979.279	.2780	-1.0
49	Salt Lake City, Utah	979.806	.8030	-3.0
1175	Vernal, Utah	979.671	.6678	-3.2
175	Lexington, Va.	979.862	.8633	+1.3
220	Bellingham, Wash.	980.887	.8843	-2.7
226	Bremerton, Wash.	980.813	.8109	-2.1
221	Everett, Wash.	980.784	.7799	-4.1
222	Issaquah, Wash.	980.766	.7646	-1.4
112	Olympia, Wash.	980.828	.8162	-11.8
223	Port Angeles, Wash.	980.378	.3744	-3.6
37	Madison, Wis.	980.368	.3681	+ .1

reliability. The datum used was that of the U.S.C. & G.S. gravity pier in the basement of the Department of Commerce building, which is 0.8 mgal lower than that adopted for the world program of measurements on the basis of inter-comparisons between national bases tied directly to Potsdam.

The comparison of results, which represents a random spot check across the country, indicates that the pendulum values are characterized by random errors in the amount of ± 3 to 4 mgals with a mean error with regard to sign of about +2.0 mgals. From a plot of the differences it might be concluded that there is evidence for a systematic deviation with change in gravity of about 5 mgals per 1000 mgals change. This is believed to be fortuitous for Woollard et al (1955) have shown that there is good evidence for datum shifts in the United States Coast and Geodetic Survey pendulum stations results that can be correlated with different operational seasons. For example, Table III-6 lists the changes observed at 36 pendulum sites previously occupied by Woollard in the Mid-West area as a function of the year of observation. The agreement between Tables III-6 and III-7 is striking and substantiates the earlier conclusion that there are datum shifts associated with periods of operation. Although there were several changes in instrumentation in the period 1891 to 1931, it is significant that the apparent changes in datum are not noticeable until the year 1932, which coincides with the establishment of the Commerce Building base as the national reference site. Unpublished studies by D. A. Rice of the U. S. Coast and Geodetic Survey in recent years show that these apparent datum shifts probably were related to undetected induced resonance in the pier in use at the time. Measurements made since 1955 with the pendulums on the floor rather than on the pier have shown no such effect.

World Network of Airport Gravimeter Bases:

The world network of gravity bases at airports that have been interconnected with gravimeters is shown in Figure III-A. Geographic coverage is good in most areas that are politically accessible and where transportation facilities exist. In some areas, as Canada, the program was limited to the standardization range and ties to the national gravity base, as the Dominion Observatory had a comprehensive gravity study under way in that country. Details on connections made on some of the more extensive series of measurements are shown in Figure III-5 through Figure III-16 and the observers and trips are listed in the Appendix.

Mean values of gravity at each principal airport site with an operational description, coordinates and elevation are listed in Table III A-7 of the Appendix. The descriptions are necessarily brief as most observations were made during the ten- to twenty-minute interval the plane was on the ground. In some instances, where new terminal facilities have been constructed since the observations were made, the original sites can no longer be recovered. However, in most instances it is believed that a reoccupation reliable to about 0.2 mgal can be achieved. This potential error, coupled with an average uncertainty in the original measurements of ± 0.3 mgal results in a possible discrepancy of about 0.5 mgal on reoccupations between sites.

FIG. III-17

III-12

Table III-6

Average Error USC&GS Pendulum Stations in Midwest Area

<u>Year of Pendulum Work</u>	<u>No. of Observations</u>	<u>Average Deviation Rel. Gravimeter</u>
1890-1930	11	+2.3 mgals
1932	5	-3.5
1934	6	+3.3
1936-1939	5	-0.3
1940-1941	5	+0.1
1948	4	+2.1

If the present comparison involving a different sampling of the pendulum stations is studied in the same manner, the results are as shown in Table III-7.

Table III-7

Comparison of values at United States Coast and Geodetic Survey pendulum stations occupied on an evaluation study.

<u>Year of Pendulum Work</u>	<u>No. of Observations</u>	<u>Average Deviation Rel. Gravimeter</u>
1890-1930	26	+2.5 mgals
1936-1939	13	-0.6
1948	3	+2.8

Remarks on Adjustment of International Airport Values:

As the world network of airport gravity bases had been established in large measure prior to the development of the pendulum standardization range in North America, all of the values published prior to now require adjustment. One such adjustment had been made earlier on the basis of the preliminary results obtained with the Gulf-Wisconsin "M" set of pendulums. As additional pendulum measurements have been made during the interim at key sites, such as Fairbanks, Alaska and Mexico City, and it has also been possible to evaluate and weight the original Cambridge pendulum measurements in North America, the standardization values have undergone some revision which requires a further adjustment in the calibration used. That used is based upon the weighted mean values of all observations, as was discussed in Part I on the pendulum measurements. Actually the straight mean would have given identical results as far as establishing the calibration for the gravimeters is concerned since over a range of nearly 5000 mgals with twenty-odd control points the difference between the weighted means and average means results in no systematic change in values.

Evaluation of World Network Through Measurements by Other Groups:

The results for the international network of airport gravity bases can be evaluated on an independent basis through comparisons with the results obtained on international connections made by other groups, particularly the measurements made by The Expéditiones Polaires Françaises. This group has occupied many of the base sites established by the University of Wisconsin. M. J. Martin, for example, has occupied an extensive series of University of Wisconsin sites in Europe and Africa and M. P. Stahl many of the bases between Europe and Antarctica. Table III-8 presents a comparison of values at sites occupied by Martin. From a casual inspection one might conclude that the differences which range from 0.1 to 4.4 mgals indicate very poor agreement. However, if the comparisons are arranged so as to conform to the change in gravity it is seen that these differences vary in a systematic manner. This is brought out by Figure III-18. The best mean fit to this difference plot indicates that the calibration standard used by Martin differs by 1.1 mgals per 1000 mgals change from that of the University of Wisconsin. If the values by Martin are corrected for this difference in calibration standard, the agreement is well within ± 0.2 mgal throughout Europe and Africa, as shown by Table III-8 and graphically in Figure III-18. The fit would be even better if there had not been an apparent difference in calibration for the work done by Martin in Africa and that in western Europe and Iceland. The various reports available to the writer for the measurements in Iceland and Great Britain in particular show notable difference in values at these stations, and the ones used were those that appeared to conform most closely to the calibration used on the African program.

A similar comparison can be made with the values obtained by Stahl in Australia and the Middle East. Again it is found that a similar systematic difference in values exists that can be related to the difference in the calibration standard used. See Table III-9 and Figure III-19. A correction for this difference in calibration standard brings the two sets of data into good agreement (± 0.03 mgal) except for two sites in the Middle East area which were closed out twice by both groups of observers.

III-13A

FIG. III - 18

FIG. III - 19

III-14

Table III-8

COMPARISON
VALUES OF GRAVITY DETERMINED
BY J. MARTIN WITH THOSE BY UNIVERSITY OF WISCONSIN
EUROPE - AFRICA - ATLANTIC AREA

	<u>Reported</u>	<u>Calbr.Adj.</u>	<u>Adjusted</u>	<u>U. Wis.</u>	<u>Diff.</u>
Paris Observatory	980.9430	+0.1	.9431	.9431	0.0
Paris (LeBourget AP)	980.9501	+0.1	.9502	.9502	+0.0
Paris (Orly, Salle No. 1)AP	980.9157	+0.1	.9158	.9459	-0.1
London (North)AP	981.2015	+0.4	.2019	.2018	+0.1
Teddington (NPL)	981.1962	+0.4	.1966	.1966	0.0
Prestwick AP	981.5776	+0.8	.5785	.5784	+0.1
Glasgow Univ.	981.5944	+0.9	.5953	.5953	0.0
Edinburgh Obs.	981.5832	+0.9	.5841	.5839	+0.2
Stockholm (Bromma) AP	981.8445	+1.3	.8458	.8459	-0.1
Copenhagen (Kastrup)AP	981.5567	+0.9	.5576	.5572	+0.4
Brussels (Melsbroeck)AP	981.1602	+0.4	.1606	.1608	-0.2
Belegarde (Zemun)AP	980.6077	-0.3	.6074	.6071	+0.3
Rhein Main(USAF) AP	981.0570	+0.2	.0572	.9572	0.0
Gander AP	980.9590	+0.1	.9591	.9593	-0.2
Keflavik AP	982.2728	+1.8	.2746	.2743	+0.3
Reykjavik, Long Quay (Harbor)	982.2797	+1.8	.2815	.2817	-0.2
Algiers (Maison-Blanche) AP	979.9075	-1.3	.9062	.9058	+0.4
Casablanca (Cases) AP	979.6441	-1.6	.6425	.6428	-0.3
Ber Rechid Obs.	979.5593	-1.7	.5576	.5578	-0.2
Port Lyautey NAS	979.6533	-1.6	.6517	.6518	-0.1
Livingstone AP	978.2236	-3.5	.2201	.2200	+0.1
Tananarive AP	978.2204	-3.5	.2169	.2165	+0.4
Leopoldville AP	977.9555	-3.9	.9516	.9517	-0.1
N'Dola AP	977.9167	-4.0	.9127	.9125	+0.2
Abercorn AP	977.6753	-4.3	.6710	.6708	+0.2
Tabora AP	977.6886	-4.3	.6843	.6845	-0.2
Nairobi (Eastleigh) AP	977.5476	-4.4	.5432	.5430	+0.2
Nairobi (West) AP	977.5387	-4.4	.5343	.5340	+0.3
Bullard PS No. 1	977.5326	-4.4	.5281	.5279	+0.2
Kasama AP	977.7921	-4.1	.7880	.7877	+0.3
Entebbe AP	977.7284	-4.2	.7242	.7241	+0.1
Dar es Salaan AP	978.1205	-3.7	.1168	.1168	-0.0
Mombassa AP	978.0528	-3.8	.0490	.0489	+0.1

III-15

Table III-9

COMPARISON
VALUES OF GRAVITY DETERMINED
BY P. STAHL WITH THOSE BY UNIVERSITY OF WISCONSIN
EUROPE - ASIA - AUSTRALIA - PACIFIC AREA

	<u>Reported</u>	<u>Cal. Adj.</u>	<u>Adjusted</u>	<u>U. Wis.</u>	<u>Diff.</u>
Paris Observatory "C"	980.9437	+0.2	.9439	.9439	0.0
Paris (Orly Salle No. 1) AP	980.9157	+0.2	.9159	.9159	0.0
Stockholm (Bromma) AP	981.8447	+1.2	.8459	.8459	0.0
Rome (Ciampino) Est AP	980.3498	-0.5	.3493	.3489	+0.4
Rome (Ciampino) USAF	980.3486	-0.5	.3481	.3477	+0.4
Rome Obs.	980.3647	-0.5	.3642	.3639	+0.3
Athens (Ellinikon) AP	980.0602	-0.8	.0594	.0592	+0.2
Beyrouth (Bir Hassan) AP	979.6882	-1.3	.6869	.6865	+0.4
University Faculty Med.	979.6927	-1.3	.6914	.6910	+0.4
Basrah AP	979.3267	-1.6	.3251	.3241	+1.0
Tripoli (Kleiat) AP	979.7263	-1.2	.7251	.7241	+1.0
Karachi AP	978.9637	-2.0	.9617	.9619	-0.2
Calcutta (Dum Dum) AP	978.8098	-2.2	.8076	.8077	-0.1
Saigon (Tan Son Nhut) AP	978.2327	-2.9	.2298	.2302	-0.4
Singapore (Kallang) AP	978.0843	-3.1	.0812	.0816	-0.4
Banque Indo China, Singapore	978.0827	-3.1	.0796	.0799	-0.3
Djakarta (Kemajoran) AP	978.1667	-3.0	.1637	.1644	+0.3
Darwin AP	978.3181	-2.8	.3153	.3153	0.0
Brisbane (Eagle Farm) AP	979.1619	-1.8	.1601	.1598	+0.3
Sydney (Mascot) AP	979.7006	-1.2	.6994	.6992	+0.2
Melbourne (Essendon) AP	979.9639	-0.9	.9630	.9629	+0.1
Hobart (Cambridge) AP	980.4430	-0.4	.4426	.4432	-0.6
Noumea, IFO	978.8823	-2.1	.8802	.8800	+0.2

There is no ready explanation for the discrepancy at these sites of about 1.2 mgal or of that of 0.6 mgal at Hobart in Tasmania.

As the French calibration was based upon a relatively short base line covering a change in gravity only about one-eighth the range encompassed in the North American range, the indicated difference in calibration is understandable. If the calibration adjusted values of Martin and Stahl are corrected through local connections to Gulf-Wisconsin pendulum sites in the same towns and compared with the mean pendulum values, the agreement is of the same order (± 0.4 mgal) as has been obtained with the University of Wisconsin gravimeters. (See Table III-10), and if the difference in values is plotted as a function of change in gravity it is seen that the calibration adjustment applied on the basis of the gravimeter comparisons was correct to within 0.2 mgal per 5000 mgals change.

The above comparisons therefore indicate that the principal world networks of gravimeter bases established by different groups can be satisfactorily adjusted and brought into substantial agreement with very few exceptions.

Evaluation Through Measurements of the Inter-American Geodetic Survey:

In South America an evaluation of the reliability of the measurements in that area can be obtained through a comparison with the measurements made by the Inter-American Geodetic Survey. Table III-11 lists values for common sites in Peru, Bolivia and Chile. As in the case of the French measurements, and as indicated in Figure III-20, there is a substantial difference in the calibration factor used. An adjustment for this difference of 3.5 mgals per 1000 mgals change results in agreement to ± 0.1 mgal except for Santa Cruz, Bolivia, which shows a discrepancy of 0.7 mgal.

Evaluation Through Multiple Inter-continental Connection Links:

A more definitive evaluation than is provided by the above comparisons is afforded by the multiple direct connections affected by Morelli between Rome and distant sites having approximately the same value of gravity. Because of the small gravity interval, the calibration error factor is negligible and the use of multiple runs and rapid air transport minimizes errors related to drift or tares.

For example: Morelli and Rice determined the gravity interval between the Rocca di Poppa base in Rome and Idelwild airport in New York to be 6.16 ± 0.02 mgal. This is based upon the mean value for three sets of round trip measurements made with each of four Worden gravimeters. This interval, as determined from mean values for the same two sites using the airport network is as follows:

Idelwild Airport, N.Y.	980.2273	
(old terminal)		
Ciampino Airport (Est)Rome	980.3488	
Diff.	+1215	
Ciampino AP Est-Rocca di Poppa	-1277	
Diff.	- 6.2	vs. -6.16 ± 0.02

The agreement to less than 0.1 mgal is fortuitous, but is an indication that no serious error exists in the network connecting Europe and North America.

FIG. III -20

Table III-10

ADJUSTED FRENCH GRAVIMETER VALUES
VS
PENDULUM VALUES

	Reported	Adjusted for Calibration	Weighted Pend.	Diff.	Ave. Pend.	Diff.	Gulf Wis.	Diff.
Base Teddington NPL	981.1962	.1966	.1965	+0.1	.1965	+0.1	.1965	+0.1
Paris(Orly Sallel)	980.9157	.9159						
PS conn.	+24.9	.9408	.9409	-0.1	.9410	-0.2	.9408	0.0
Copenhagen PS	981.5571	.5580	.5584	-0.4	.5583	-0.3	.5578	+0.2
Rhein Main USAF	981.0570	.0572						
PS conn.	+3.4	.0606	.0610	-0.4	.0610	-0.4	.0610	-0.4
Rome(Ciampino E)	980.3498	.3493						
PS conn.	+15.4	.3647	.3642	+0.5	.3641	+0.6	.3638	+0.9
Leopoldville AP	977.9555	.9516						
PS conn.	-37.2	.9144	.9146	-0.2	.9146	-0.2	.9146	-0.2
Nairobi (Eastleigh)	977.5476	.5432						
PS conn.	-2.7	.5405	.5409	-0.4	.5407	-0.2	.5404	+0.1
Livingstone AP	978.2236	.2201						
Salisbury PS conn.	-72.2	.1479	.1485	-0.6	.1483	-0.4	--	--
Victoria Falls PS conn.	+11.3	.2314	.2312	+0.2	.2311	+0.3	.2314	0.0
Singapore(Kallang)	978.0843	.0812						
PS conn.	-0.2	.0810	.0820	-1.0	.0817	-0.7	.0820	-1.0
Darwin AP	978.3181	.3153						
PS conn.	-1.4	.3139	.3148	-0.9	.3147	-0.8	.3145	-0.6
Brisbane AP	979.1619	.1601						
PS conn.	+9.7	.1698	.1696	+0.2	.1695	+0.3	.1695	+0.3
Sydney AP	979.7006	.6994						
PS conn.	-13.0	.6864	.6863	+0.1	.6863	+0.1	.6863	+0.1
Melbourne	979.9639	.9630						
PS conn.	+16.9	.9799	.9796	+0.3	.9796	+0.3	.9798	+0.1

III-17

- 279 -

Table III-11

Comparison of Values with those by Inter-American Geodetic Survey
in South America

	<u>IAGS</u>	<u>U.Wis.</u>	<u>Diff.</u>
Santiago, Chile - IGM Pend.base	979.4290	.4290	0.0
Arica, Chile AP	978.5105	.5120	+1.5
Santa Cruz, Bolivia	978.3633	.3644	+1.1
La Paz, Bolivia			
Airport (Panagra)	977.3452	.3488	+3.6
(Braniff)	977.3492	.3527	+3.5
IGM Pend. Base	977.4636	.4671	+3.5

Adjusted Values

	<u>Original</u>	<u>Calibr.</u> <u>Adj.</u>	<u>Adjusted</u>	<u>U.Wis.</u>	<u>Diff.</u>
Santiago, Chile	979.4290	0.0	979.4290	.4290	0.0
Arica, Chile	978.5105	+1.6	978.5121	.5120	-0.1
Santa Cruz, Bolivia	978.3633	+1.8	978.3651	.3644	-0.7
La Paz, Bolivia					
Airport (Panagra)	977.3452	+3.5	977.348	.3488	+0.1
(Braniff)	977.3492	+3.5	977.3527	.3527	0.0
IGM Pend. Base	977.4636	+3.5	977.4671	.4671	0.0

A similar comparison is possible in Argentina where Morelli and Baglietto achieved a connection in the same manner between Rome and Buenos Aires. The difference measured by direct connection would give an interval of 657.2 mgals between the Italian fundamental station in Rome at the Faculta di Ingeneria and the Argentine fundamental station at the Instituto Geografico Militar. Using the airport network values and local ties to the fundamental stations involved, the results are:

Faculta di Ingeneria Base-Rome		
to Ciampino (Est) AP	- 12.9 mgal	
Ciampino AP (Est)Rome	980.3488	
Ezeiza AP Buenos Aires	979.7317	
	<u>-0.6171</u>	-617.1
Ezeiza AP - IGM		<u>- 26.9</u>
		-656.9 mgal vs. 657.2

The difference of 0.3 mgals is within the probable error believed to be associated with the international network of airport bases, and lends strength to the other airport base values in South America.

If the triangle Washington-Rome-Buenos Aires, as defined by Morelli's cooperative gravimeter ties, is compared with that determined from the airport network values the agreement can only be regarded as excellent.

<u>Morelli</u>		<u>Univ. of Wisconsin</u>
Washington (Comm.)-Rome (Fac.Ing.)	+243.0	+243.0
Rome (Fac.Ing.)-Buenos Aires(IGM)	<u>-657.2</u>	<u>-656.9</u>
Buenos Aires (GM)-Washington(Comm.)	+414.2(cal.)	+414.1(measured)

Although the above independent appraisals of the reliability of the airport gravity bases established are impressive, self-evaluations made through repeat measurements on a spot check basis have brought out that some of the work done under this study do not have the above reliability. This applies particularly to the early measurements and those carried out under adverse conditions. For example, most of the measurements made in the continental interior of Brazil do not appear to be reliable to better than ± 1.0 mgal. The same error applies to the measurements made in southern Chile, Argentina, Antarctica and in the Arctic Islands north of Canada. The cause of these discrepancies varies but is related principally to defects in the instrument, particularly changes in drift rate and sign with changes in temperature and to irregularities in reading dial increments on the first Worden geodetic gravimeters.

Fortunately, all key points on the world network have been occupied a sufficient number of times that these uncertainties do not pertain to these bases. The weakest values are those associated with sites occupied only once or on extended trips into hinterland areas.

Local Gravimeter Connections to Pendulum Sites:

In order to effectively utilize the pendulum network for the calibration of gravimeters, it is necessary to have auxiliary sites at the airports so that they can be occupied in lieu of the actual pendulum site. The principal difficulty experienced with such auxiliary sites,

which are excellent in principle, is that airport terminal facilities are constantly being expanded and revised with new terminal facilities frequently being constructed a mile or more away from the sites originally occupied. During the course of the measurements presented terminal locations were changed in the United States at Milwaukee, Wis., Dallas, Texas, San Francisco, Calif., Houston, Texas, Richmond, Va., Charlotte, N. C., St. Louis, Mo., Idlewild, N. Y., O'Hare Field, Chicago, Ill., Wayne Airport, Detroit, Mich., Pittsburgh, Pa., Cleveland, Ohio and Raleigh-Durham, N. C. At the moment a new terminal is nearing completion at Atlanta, Ga., and a new terminal is planned at New Orleans, La. These changes result in confusion in trying to occupy sites described earlier as in most cases no change in name of the airport is involved. The descriptions and local ties to pendulum bases from airports listed in the Appendix have been corrected insofar as is possible to conform to terminal locations currently in use. Table III A-8 of the Appendix gives the local connections from the airports to the pendulum sites.

Bibliography

- Duclaux, Francoise and Jean Martin. 1951 Contribution a l'establissement des bases du reseau gravimetrique africain, Comptes rendus des seances de l'Academie des Sciences, t. 233, p. 847-849.
- Duerksen, J. A. 1949 Pendulum Gravity Data in the United States. U. S. Coast and Geodetic Survey, Spec. Pub. 244, 218 pp.
- Einarsson, T., Sigurgeirsson, Th. and G. Bðdvarsson 1951 Report on the French-Icelandic gravity measurements in southern Iceland in 1950, Soc. Sci. Isl.,
- Martin, Jean 1949 Liaisons Gravimetrique Internationales, Comptes rendus des seances de l'Academie des Sciences, t. 228, p. 658-660.
- Martin, Jean 1951 Unpublished report. Liaisons Gravimetriques Internationales 1947-1951.
- Morelli, Carlo and D. A. Rice. 1955 Gravimetric Ties, Europe-America, Bull. Geod. Geo., N. 38, p. 35-41.
- Stahl, Pierre 1958 Liaison Gravimetrique France-Terre Adelis, Exp. Polaires Francaises, Resultats Sci., No. S III-3, 271 pp.
- Woollard, G. P. 1950 The Gravity Meter as a Geodetic Instrument. Geophysics 15, No. 1.
- Woollard, G. P. 1958 Results for a Gravity Control Network at Airports in the United States. Geophysics 23, No. 3, pp. 520-535.
- Woollard, G. P., N. C. Harding and J. C. Rose. 1955 The Problem of Calibrating High-Range Geodetic Type Gravimeters. Trans. Am. Geophys. Un., v. 36, No. 1, pp. 12-24.

Errata for Appendix

Table III-A-1

Change Watson Lake, TT, Can. to Watson Lake, YT, Can.

Table III-A-2

File III-A-2								
Columbus, Ga.:	Change	32°27.1'	84°58.6'	240'	979.5125	+1.6	-6.6	
	to	32 30.5	84 56.6	397	"	+11.7	-1.9	
Macon Ga.:	Change	32 49.5	83 34.0	463	979.5323	+11.8	-4.0	
	to	32 42.0	83 38.5	354	"	"	-0.3	
Columbus, Ohio:	Change	40 04.4	83 04.0	900	980.0774	-24.9	-55.6	
	to	40 00.0	82 52.2	830	"	-25.0	-53.3	
Change Montpelier, Va. to Montpelier, Vt.								
Richmond, Va.:	Change	37°33.5'	77°23.9'	172'	979.9534	+4.1	-1.8	
	to	37 30.5	77 19.2	167	"	+7.9	+2.2	

Table II-A-3

Columbus, Ohio: Change	40	4.4	83	4.0	900	980.0791	-23.2	-53.9
to	40	00.4	82	52.2	816	"	-25.1	-53.0

Table III-A-4

San Diego, Cal.: Delete USC and GS No. 5107

Table III-A-7

South America; line 3: Change Iverson, R. M. 1956 W326
to " " W32B

Table III-A-7.1 (African Area)

Algeria, Algiers; line 2: Change department to "departure"
Egypt, Cairo; line 2: Insert counter after bank
Change Ethiopia, Asmara to Eritrea, Asmara
Union of South Africa, Tsumeb: Change 427' to 4270'

Table III-A-7.2 (Antarctica Area)

Add Table III-A-7.2 above title

Table III-A-7.3 (Asiatic Area)

Ceylon, Colombo: Change 980.1323 to 978.1323
India, New Delhi: Change Palam Airport description to:
" " - on porch to left of entrance to
terminal from field.
India, Srinagar: Change description to read: At entrance to runway at
cement block (wing tab hold).
Iraq; line 18: Change hang . to hangar.
Japan, Honshu Island, Tokyo: Change (formerly Haneda) to (Haneda MATS terminal)
Lebanon, Beirut: Change 979.6922 to 979.6933
Phillipines, Republic of, Clark Field: Change 978.3905 to 978.3965
Manila : Change (Nicols Field) to(Pan American
Terminal)
Singapore, Changi: After Changi add RAF Base
Turkey, Izmir: Change central to control

Table III-A-7.4 (Atlantic Ocean Area)

Change Table III-A-7.2 to Table III-A-7.4

Table III-A-7.5 (Australian Area)

Change Table III-A-7.4 to Table III-A-7.5

Australia, Adelaide: Change Parafield Airport description to:

- on left side of bottom step of field entrance to terminal.

Australia, Canberra: Change Fairbairn Airport description to read:

- at right hand corner of civil TAA terminal when entering from field at ground level.

Errata For Appendix (cont'd)

Table III-A-7.5 (Australian Area)

Australia, Carnarvon: Change description to read:

- To right of gate in fence directly in front of entrance to first-aid room in passenger lounge building.

Australia, Melbourne: Change 979.9729 to 979.9629; Change Essenden to Essendon

Australia, Rockhampton: Change 978.9737 to 978.8737

Australia, Sydney: Change description to read: at Mascot Field outside of and to right of street entrance to overseas departure waiting room.

New Zealand, Auckland, Mechanics Bay Flying Boat Base: Change 79.9632 to 979.9632

New Zealand, Hastings: Change 979.0881 to 980.0881

Table III-A-7.6 (Central American Area)

Change Table III-A-7.5 to Table III-A-7.6

Add at end of list: Mexico

Canal Zone; add Coco Solo

U.S. Navy Base - at street entrance to Building 152 which is now deserted, but last used as Operations Aerology Photo Laboratory.

09° 22.5' N 79° 53.2' W 00' 978.2559

Costa Rica, San Jose: Change San Jose Airfield to El Coco Airport

Costa Rica, San Jose: Add Sabana Airport - Pan American Airways terminal at steps leading to office.

09° 57.0' N 84° 06.0' W 3716' 977.9453

Puerto Rico, San Juan: Delete Air Force terminal room right of door

Mexico, Ensenada: Change 31° 52.8' N to 31° 42.8' N

Mexico, Tamin: Change Mexican to Mexican

Table III-A-7.7 (European Area)

Change Table III-A-7.6 to Table III-A-7.7

England, London: Change Airport Central description to read:

- street side of terminal at foot of Channel 9 down escalator.

Finland, Helsinki: Change Sentala to Seutula

Germany, Frankfurt: Change AF to MATS

Scotland, Prestwick: After Prestwick Airfield add new MATS terminal

Yugoslavia, Belgrade: Change on airport to at airport

Table III-A-7.8 (North American Area)

Add Table III-A-7.8 above title

Alaska, Juneau: Change 981.7686 to 981.7680

British Columbia; add Vancouver

Vancouver International Airport - at terminal across from TCA desk against wall at electrical outlet.

49° 11.1' N 123° 10.0' W 9' 981.9299

British Columbia, Victoria: Change 980.9454 to 980.9448

Newfoundland, Goose Bay: Add Labrador after Goose Bay

Newfoundland, Gander: Change description to read: Old terminal, field exit "B" from passenger waiting room.

Northwest Territory, Cape Perry: Change Perry to Parry

Arizona, Prescott: Change 979.2376 to 979.2406

Errata For Appendix (cont'd)

Table III-A-7.9 (Pacific Ocean Area)

Change Table III-A-7.7 to Table III-A-7.9

Midway Islands, Sand Island: Change 978.4993 to 979.4993

Table III-A-7.10 (South American Area)

Add Table III-A-7.10 above title

Argentina, Comodoro Rivadavia, Comodoro Rivadavia: Change Comodoro Rivadavia, Comodoro Rivadavia to Comodoro Rivadavia, Chubut

Argentina, Puerto Deseado, Comodoro Rivadavia: Change Puerto Deseado, Comodoro Rivadavia to Puerto Deseado, Santa Cruz

Argentina, Trelew, Chubut: Change description to read: In front of terminal on sidewalk leading to runway.

Brazil, Recife, Pernambuco: Change 978.1667 to 978.1663

Chile, Antofagasta, Antofagasta: Change description to read: - Hangar No. 3 at front right-hand wall facing field.

Chile, Santiago, Santiago: After Los Cerrillos Airport add in old terminal Change 979.4500 to 979.4487

Uruguay, Montevideo: Change description to read: - in bus parking lot in corner between covered walk and main terminal building.

Table III-A-8

North American Western Standardization Range

Alaska

Umiat

Change Pendulum Station = 982.2535 to 982.5435

" a) = 982.2544 to a) = 982.5444

Canada

Yukon Territory

Watson Lake

Change c) -0.6 mgls to c) -0.4 mgls

Alberta

Edmonton

Change c) (Gulf "C" side) to (Gulf "C" site)

United States

Texas

San Antonio

b) Change +0.4 mgls to -0.2 mgls.

b) Change b)=979.1979 to b) = 979.1973

Mexico

Mexico City

c) Change Taculouga (Photogrammetry room) to Tacubaya (Photogrammetry Room)

North American Eastern Standardization Range

United States

Florida

Miami

Change b) +17.1 to +18.4

" b) = 979.0527 to b) = 979.0540

Errata For Appendix (cont'd)

Table III-A-8

Pacific Standardization Range

Phillipine Republic

Manila

Change c) (domestic terminal) to (PAL terminal)

Australia

Queensland

Brisbane

Change a) -9.1 mgls. to -9.7 mgls.

Victoria

Melbourne

Change a) Essenden Airport to Essendon Airport

" -6.9 mgls to -16.9 mgls

" a) = 979.9729 to a) = 979.9629

New Zealand

Wellington

Pendulum Station = 980.2936 add (Lower Hutt)

European Standardization Range

England

Teddington

a) Change Channel Gescalator to Channel 9 down escalator

Portugal

Lisbon

Change a) Martin-Gonzalves Airport to Lisbon Airport

West African Standardization Range

Dakar

Change Pendulum Station = 978.3856 to 978.3852

" a) +91.6 mgls to +92.0 mgls

Ghana

Accra

Change Pendulum Station = 978.1159 to 978.1059

" a) -0.6 mgls to +9.4 mgls

Congo Republic

Leopoldville

Change a) parking lot to parking spot

South American Western Standardization Range

Chile

Punta Arenas

Change a) right of entrance to left of entrance

Additional Standardization Station

India

New Delhi

Change b) -1.4 mgls to +1.4 mgls

APPENDIX

Table of Contents

Table III-A-0	Gravity Results at Main Control Stations
Table III-A-1	Values and Descriptions at Airport Gravity Base Stations Established With L-R Geodetic Meter No. 1
Table III-A-2	Principal Facts Woollard 1958 (Adjusted) Airport Stations
Table III-A-3	Principal Facts for Airport Stations Occupied With L-R Geodetic Meter No. 1
Table III-A-4	Descriptions and Values at Harbor Gravity Base Stations
Table III-A-5	Descriptions and Values at University Gravity Base Stations
Table III-A-6	Gravimeter Values at Pendulum Stations
Table III-A-7	Descriptions and Values at Airport Gravity Bases
	III-A-7.1 African Area
	III-A-7.2 Antarctic Area
	III-A-7.3 Asiatic Area
	III-A-7.4 Atlantic Ocean Area
	III-A-7.5 Australian Area
	III-A-7.6 Central American Area
	III-A-7.7 European Area
	III-A-7.8 North American Area
	III-A-7.9 Pacific Ocean Area
	III-A-7.10 South American Area
	Part 2. Foreign Harbor Sites
Table III-A-8	Local Gravimeter Connections to Pendulum Sites

TABLE III-A-0

GRAVITY RESULTS AT MAIN CONTROL STATIONS

<u>Location</u>	<u>$\bar{G}$</u>	<u>n</u>	<u>Estimated Standard Error</u>
Fairbanks AP	982.2464 gal	5	0.06 mgl
Fairbanks PS	982.2444	2	0.05
Edmonton AP	981.1729	5	0.05
Port Angeles AP	980.8640	2	0.05
Everett PS	980.7807	5	0.00
Seattle AP	980.7765	6	0.00
Great Falls AP	980.5137	3	0.01
Great Falls PS	980.5270	2	0.05
Billings PS	980.3710	2	0.05
Madison PS	980.3689	Base station	
Cambridge PS	980.4011	2	0.00
AFCRC (Bedford)	980.3942	2	0.00
New York (Col. U.)	980.2689	2	0.00
New York (LaGuardia)	980.2825	2	0.00
Chicago (Midway)	980.2864	9	0.01
Chicago (U.C.)	980.2858	2	0.05
Washington, D.C. AP	980.1088	2	0.00
Pittsburgh AP	980.0993	3	0.00
Beloit, Kansas PS	979.9978	2	0.05
Kansas City, Mo., AP	979.9998	2	0.05
Tulsa AP	979.7766	2	0.05
Tulsa PS	979.7663	4	0.05
San Francisco AP	979.9883	2	0.05
Salt Lake City AP	979.8070	2	0.00
Blacksburg VPI	979.7324	2	0.00
Knoxville AP	979.7032	2	0.10
Chattanooga AP	979.6505	2	0.00
Casper AP	979.9562	2	0.05
Golden CSM	979.5842	2	0.05
Ft. Worth AP	979.4934	4	0.05
Atlanta AP	979.5205	3	0.00
Dallas AP	979.5131	5	0.04
Austin L&R	979.2849	2	0.00
Austin AP	979.2889	2	0.00
Denver AP	979.6335	4	0.01
San Antonio AP	979.1973	2	0.05
Houston PS	979.2983	2	0.05
Houston AP	979.2932	2	0.00
Monterrey AP	978.8617	3	0.06
Mexico City AP	977.9701	2	0.00
Mexico City (Tac)	977.9419	3	0.01

$\bar{G}$ Mean value corrected for earth tide.

n Number of observations.

Table III-A-1

Values at Airport Gravity Base Stations Established
with L-R Geodetic Meter No. 1

L&R Geodetic #1 Airport Gravity Base Stations

<u>Station</u>	<u>Station Description</u>	<u>Obs. Gravity</u>
Birmingham, Ala.	Barrier Gate 5.	979.5390
Mobile, Ala.	Barrier Gate 2.	979.3396
Fairbanks, Alaska	Lobby at E. I beam	982.2464
Pt. Barrow, Alaska	In front of entrance to terminal.	982.6997
Umiat, Alaska	On runway at edge of field.	982.5444
Los Angeles, Cal.	United terminal at street exit in lobby, left of door.	979.5946
Monterrey, Cal.	Sidewalk curb in front of E. front entrance to terminal.	979.8692
San Diego, Cal.	Inside terminal lobby at middle door to street, at right side (facing out).	979.5369
San Francisco, Cal.	Gate 23	979.9883
San Francisco, Cal.	Curb ground level, main entrance to terminal opposite 2nd pillar from south.	979.9885
Santa Barbara, Cal.	At street curb in front of right hand arch to terminal facing terminal.	979.6407
Denver, Colo.	Gate 2	979.6335
Denver, Colo.	Gate 6	979.6327
Kremling, Colo.	SW. corner at hangar, at BM K297 USC&GS	979.4903
New Haven, Conn.	Exit to field at barrier	980.3125
Wilmington, Dela.	On curb in front of east exit to street.	980.1757
Washington, D.C.	Field level, field side of terminal, EAL air freight entrance, at baggage gate 6.	980.1098
Washington, D.C.	Upper street level, northern doors, center on sidewalk.	980.1088
Jacksonville, Fla.	Gate 6 and 7.	979.3856
Pensacola, Fla.	Barrier, Gate 3	979.3630
Tallahassee, Fla.	End of left hand (facing field) concourse, under arcade.	979.3544

Table III-A-1 (Cont'd)

L&R Geodetic #1 Airport Gravity Base Stations

<u>Station</u>	<u>Station Description</u>	<u>Obs. Gravity</u>
Atlanta, Ga.	East Concourse, gate 1, (old terminal).	979.5205
Atlanta, Ga.	West Concourse, gate 1, (old terminal).	979.5203
Savannah, Ga.	Gate 2, field level.	979.4980
Coeur d'Alene, Idaho	On concrete platform in front of street entrance to terminal lobby.	980.6387
Chicago, Ill.	Midway, North Central Airlines terminal at water cooler.	980.2864
Indianapolis, Ind.	Gate 5.	980.0933
W. Lafayette, Ind.	Purdue Univ. Airport, terminal, waiting room, in corner, opposite door to field.	980.1469
Beloit, Kans.	In front of aluminum hangar at Phillips gas pump on concrete base of pump.	980.0000
Kansas City, Kans.	At street entrance to terminal on sidewalk, next to steps.	980.0010
Wichita, Kans.	Gate 3.	979.8404
Lexington, Ky.	Gate 3.	979.8988
Baton Rouge, La.	Gate 1.	979.3637
New Orleans, La.	On sidewalk at curb in front of entrance to terminal.	979.3312
New Orleans, La.	Moisant Airport, Gate 5 at barrier.	979.3298
Portland, Me.	Inside terminal against N. wall E. of insurance machine.	980.5126
Baltimore, Md.	Terminal street entrance, lower level, on curb against W. wall.	980.1104
Bedford, Mass.	Hanscom Field, at Gate 2 to base, bldg. 1101, outside door to Provost Marshall's Office, next to phone booth.	980.3942
Boston, Mass.	Near gate 17, in AA outbound baggage room.	980.4036
Boston, Mass.	Gate 19.	980.4036
Detroit, Mich.	Willow Run Airport, Gate 17, Blue Concourse.	980.3188
Lansing, Mich.	Transient gate, field level (gate at NE. corner of barrier).	980.3518

Table III-A-1 (Cont'd)

L&R Geodetic #1 Airport Gravity Base Stations

<u>Station</u>	<u>Station Description</u>	<u>Obs. Gravity</u>
Minneapolis, Minn.	Gate 1.	980.5950
Meridian, Miss.	New Terminal airport, at Sewer N. end of barrier on field.	979.4840
Kansas City, Mo.	Street entrance to terminal against building on sidewalk.	979.9998
St. Louis, Mo.	Gate 17.	980.0043
Billings, Mont.	West wall of Hangar No. 2, 7 feet N. of door end. (Pend. Sta.)	980.3710
Billings, Mont.	Barrier, Gate 6, New Terminal.	980.3717
Butte, Mont.	At barrier gate to terminal.	980.1744
Great Falls, Mont.	Western Air Lines desk in terminal.	980.5137
Cutbank, Mont.	Field door of customs inspection room.	980.6085
Lewistown, Mont.	50 feet out on apron from barrier.	980.4510
Missoula, Mont.	Inside terminal lobby at right of exit to field.	980.4440
Las Vegas, Nev.	Center point in terminal lobby.	979.6049
Reno, Nev.	N. field entrance to U.S. Weather Bureau building at foot of steps.	979.6873
Albuquerque, N.M.	Barrier, Gate 2.	979.2081
Santa Fe, N.M.	At right of terminal entrance from field.	979.1974
New York, LaGuardia	Lower lobby at P.O. counter.	980.2825
New York, Idlewild	Opposite entrance to customs in new terminal.	980.2261
Syracuse, N.Y.	Barrier, Gate 2.	980.3968
Cincinnati, Ohio	In front of terminal, 4 feet from N. end of walk on flag circle, in road.	979.9935
Cincinnati, Ohio	Gate 3.	979.9931
Cleveland, Ohio	Gate 6 to field.	980.2322
Columbus, Ohio	New Terminal, Gate B1, field level.	980.0791
Tulsa, Okla.	Gate 3.	979.7766

Table III-A-1 (Cont'd)

L&R Geodetic #1 Airport Gravity Base Stations

<u>Station</u>	<u>Station Description</u>	<u>Obs. Gravity</u>
Eugene, Ore.	Beneath marquee at terminal lobby entrance.	980.5148
Medford, Ore.	Under marquee opposite Gate 3 at left of door.	980.2375
Portland, Ore.	In lower lobby at right of doors to street at wall.	980.6483
Portland, Ore.	Old terminal. Under marquee at NE. corner of curb.	980.6477
Philadelphia, Pa.	Main entrance, at curb, opposite eastern most of doors.	980.1976
Pittsburgh, Pa.	Gate 9.	980.0993
Providence, R.I.	Gate 3 at barrier.	980.3139
Charleston, S.C.	MATS terminal, processing room, against window wall, 2 ft. from counter. Same bldg. as U.S. Customs.	979.5674
Charleston, S.C.	Municipal airport at USC&GS BM, on porch field side of terminal.	979.5668
Chattanooga, Tenn.	Street entrance to terminal on sidewalk at curb.	979.6505
Knoxville, Tenn.	Gate 1 at barrier (southern-most).	979.7032
Austin, Tex.	Next to terminal on concrete at Gate 1.	979.2889
Brownsville, Tex.	Barrier, Gate 1 (on concrete).	979.0509
Corpus Christi, Tex.	Barrier, Gate 2.	979.1430
Dallas, Tex.	Gate 11.	979.5131
El Paso, Tex.	Terminal lobby entrance at pillar beneath marquee.	979.0814
Fort Worth, Tex.	Gate 11, on sidewalk by sewer.	979.4934
Galveston, Tex.	Gate 2.	979.2696
Houston, Tex.	Gate 9, inside terminal.	979.2933
Houston, Tex.	Gate 7.	979.2932
Laredo, Tex.	Terminal street entrance, field level.	979.0792
San Antonio, Tex.	American Airlines street exit.	979.1973

Table III-A-1 (Cont'd)

L&R Geodetic #1 Airport Gravity Base Stations

<u>Station</u>	<u>Station Description</u>	<u>Obs. Gravity</u>
San Antonio, Tex.	Gate 8.	979.1975
Salt Lake City, Utah	Inside terminal at door to S. Concourse against E. wall.	979.8070
Vernal, Utah	225 feet E. of entrance to field and 90 feet S. of section line rd., in open field.	979.6686
Burlington, Vt.	Gate 2, barrier.	980.5181
Norfolk, Va.	New terminal, street entrance to terminal on sidewalk at curb opposite center of main door.	979.8789
Norfolk, Va.	Old station at eastern edge of 2 Piedmont hangars.	979.8788
Roanoke, Va.	On sidewalk in front of terminal, NW. end of walk at curb.	979.8076
Port Angeles, Wash.	At 6 feet N. of NE. corner of base of control tower.	980.8640
Seattle, Wash.	Gate 5.	980.7765
Seattle, Wash.	Gate 3. Inside entrance against N. wall.	980.7765
Seattle, Wash.	At curb E. end of walk from flag.	980.7765
Spokane, Wash.	Terminal lobby in front of fireplace.	980.6463
Charleston, W.Va.	Barrier, gate 6.	979.9259
Janesville-Beloit, Wis.	Rock County Airport at gate.	980.3303
Milwaukee, Wis.	Gate 16, field level.	980.3597
Casper, Wyo.	Gate 3.	979.9562
Cheyenne, Wyo.	At gate to terminal.	979.7008
Sheridan, Wyo.	Passenger gate to barrier.	980.2266
Calgary, Alberta, Can.	At entrance to parking lot inside both doors.	980.8288
Edmonton, Alberta, Can.	Against radiator at CPA counter.	981.1729
Ft. Nelson, BC, Can.	Next to entrance of terminal at field.	981.6930
Ft. St. John, BC, Can.	Center basement room of terminal, in SE. corner (in pend. sta.).	981.4059

Table III-A-1 (Cont'd)

L&R Geodetic #1 Airport Gravity Base Stations

<u>Station</u>	<u>Station Description</u>	<u>Obs. Gravity</u>
Grand Prairie, Can.	At edge of concrete in front of terminal.	981.3158
Lethbridge, Alberta, Canada	At foot of ladder to control tower on hangar E. of customs.	980.7538
Quebec, Que., Can.	On apron at edge of field opposite S. end of terminal building (about 50 ft. S. of S. field entrance to terminal) field level.	980.7405
Vancouver, BC, Can.	Terminal across from TCA desk, against wall (street side) at electrical outlet.	980.9299
Watson Lake, TT, Can.	Inside passenger waiting room, SE. corner.	981.7141
Whitehorse, YT, Can.	PAA desk next to radiator.	981.7487
Mexico City, D.F., Mex.	In corner of waiting room for incoming pas- sengers against glass outside wall and glass partition.	977.9701
Monterrey, N.L., Mex.	On curb at entrance to AA Terminal at Inst. Geofisica Mark.	978.8617

Table III-A-2

Principal Facts Woollard 1958 (Adjusted)
Airport Stations

<u>Station</u>	<u>Lat.</u>	<u>Long.</u>	<u>Elev.</u>	<u>Observed Gravity</u>	<u>Free Air Anomaly</u>	<u>Bouguer Anomaly</u>
Muscle Shoals, Ala.	34 45.0	87 37.0	548	979.6914	+18.5	-0.1
Phoenix, Ariz.	33 26.0	112 1.1	1120	979.4918	-17.1	-55.3
Tucson, Ariz.	32 7.5	110 57.0	2595	979.2277	-35.1	-123.6
Little Rock, Ark.	34 44.0	92 14.0	260	979.7245	+26.0	+17.1
Fresno, Cal.	36 46.5	119 42.5	331	979.8328	-33.6	-44.8
Colorado Springs, Colo.	38 48.5	104 42.7	6172	979.4833	-11.2	-221.5
Washington, D.C. (Field level, Nat'l. Apt.)	38 51.1	77 1.8	16	980.1100	+32.6	+32.1
Washington, D.C. (Street side, Nat'l. Apt.)	38 51.1	77 1.8	30	980.1090	+33.0	+31.9
Daytona Beach, Fla.	29 11.1	81 3.0	34	979.2782	+6.7	+5.5
Gainesville, Fla.	29 41.5	82 16.5	155	979.3064	+7.2	+1.9
Miami, Fla.	25 47.8	80 17.0	9	979.0540	+29.9	+29.5
Ocala, Fla.	29 10.0	82 9.4	84	979.2618	-3.6	-6.5
Orlando, Fla.	28 33.0	81 19.4	115	979.2191	+3.6	-0.4
Sarasota, Fla.	27 23.4	82 32.9	24	979.1444	+6.8	+6.0
St. Petersburg, Fla.	27 54.5	82 41.4	12	979.1974	+20.3	+19.9
Tampa, Fla.	27 58.5	82 31.4	26	979.2047	+24.0	+23.1
West Palm Beach, Fla.	26 41.2	80 5.5	15	979.1332	+46.1	+45.6

Table III-A-2 (Cont'd)
Principal Facts Woollard 1958 (Adjusted)
Airport Stations

<u>Station</u>	<u>Lat.</u>	<u>Long.</u>	<u>Elev.</u>	<u>Observed Gravity</u>	<u>Free Air Anomaly</u>	<u>Bouguer Anomaly</u>
Brunswick, Ga.	31 11.4	81 29.4	14	979.4498	+19.4	+19.0
Columbus, Ga.	32 27.1	84 58.6	240	979.5125	+1.6	-6.6
Macon, Ga.	32 49.5	83 34.0	463	979.5323	+11.8	-4.0
Boise, Idaho	43 34.0	116 13.4	2858	980.2082	-23.0	-120.4
Chicago, Ill.	41 59.6	87 54.0	666	980.2894	-6.5	-29.2
Springfield, Ill.	39 45.1	89 41.6	606	980.0821	-19.3	-40.0
Cedar Rapids, Iowa	41 53.5	91 43.3	863	980.2519	-16.3	-45.7
Des Moines, Iowa	41 31.8	93 38.8	957	980.1984	-28.6	-61.2
Louisville, Ky.	38 11.1	85 44.4	497	979.9586	-14.9	-31.9
Shreveport, La.	32 32.5	93 44.8	179	979.5305	+6.5	+0.4
Mankato, Minn.	44 8.9	93 58.6	1005	980.4666	+8.6	-25.6
Rochester, Minn.	44 0.0	92 27.0	1041	980.4311	-10.1	-45.6
Jackson, Miss.	32 20.1	90 13.4	343	979.5270	+35.3	+23.6
Helena, Mont.	46 36.5	111 59.5	3882	980.3778	-31.6	-163.8
Kalispell, Mont.	48 18.8	114 15.8	2971	980.5818	-66.7	-167.9
Alliance, Nebr.	42 3.2	102 48.7	3930	980.0105	+16.2	-117.6
Grande Island, Nebr.	40 58.1	98 18.5	1846	980.0957	+2.6	-60.3
Lincoln, Nebr.	40 51.5	96 46.2	1191	980.1756	+30.7	-9.9

Table III-A-2 (Cont'd)
Principal Facts Woollard 1958 (Adjusted)
Airport Stations

<u>Station</u>	<u>Lat.</u>	<u>Long.</u>	<u>Elev.</u>	<u>Observed Gravity</u>	<u>Free Air Anomaly</u>	<u>Bouguer Anomaly</u>
North Platte, Nebr.	41 8.5	100 42.0	2779	980.0295	+8.7	-86.0
Omaha, Nebr.	41 18.0	95 53.5	982	980.2143	+10.3	-23.2
Scotts Bluff, Nebr.	41 52.2	103 36.2	3965	979.9482	-26.3	-161.4
Ely, Nev.	39 17.8	114 50.8	6258	979.4946	-34.9	-248.1
Tonopah, Nev.	38 3.5	117 5.2	5426	979.4767	-22.1	-207.0
Lebanon, N.H.	43 38.0	72 18.6	579	980.4412	-10.4	-30.1
Wrightstown, N.J.	40 1.6	74 35.8	120	980.2127	+41.1	+37.1
Alamagordo, N.M.	32 51.5	106 6.0	4092	979.1484	-33.5	-172.9
Charlotte, N.C.	35 12.8	80 56.2.	748	979.7283	+35.0	+9.5
Greensboro, N.C.	36 5.6	79 56.0	913	979.7658	+12.9	-18.2
New Bern, N.C.	35 4.9	77 2.5	18	979.7286	-22.2	-22.8
Raleigh-Durham, N.C.	35 52.2	78 47.0	435	979.8018	+23.1	+8.3
Wilmington, N.C.	34 16.6	77 54.6	31	979.6772	-4.5	-5.5
Bismarck, N.D.	46 46.8	100 45.5	1653	980.6274	-7.1	-63.4
Fargo, N.D.	46 54.9	96 48.9	900	980.7270	+9.5	-21.2
Jamestown, N.D.	46 56.0	98 41.0	1498	980.6540	-8.9	-59.9
Columbus, Ohio	40 4.4	83 4.0	900	980.0774	-24.9	-55.6
McAlester, Okla.	34 55.0	95 45.2	750	979.6274	-40.5	-66.1

Table III-A-2 (Cont'd)

Principal Facts Woollard 1958 (Adjusted)
Airport Stations

<u>Station</u>	<u>Lat.</u>	<u>Long.</u>	<u>Elev.</u>	<u>Observed Gravity</u>	<u>Free Air Anomaly</u>	<u>Bouguer Anomaly</u>
Oklahoma City, Okla.	35 23.5	97 36.9	1283	979.6656	+7.5	-36.2
Pendleton, Ore.	45 41.5	118 50.4	1493	980.5117	-39.7	-90.6
Salem, Ore.	44 54.7	123. 0.0	207	980.5837	-18.2	-25.3
Florence, S.C.	34 11.4	79 43.9	146	979.6851	+21.5	+16.6
Greenville, S.C.	34 51.0	82 21.0	1049	979.6232	-11.0	-46.7
Aberdeen, S.D.	45 27.3	98 26.0	1300	980.5438	-4.4	-48.7
Brookings, S.D.	44 18.1	96 48.6	1626	980.4302	+16.8	-38.6
Hot Springs, S.D.	43 21.5	103 24.8	3075	980.1954	+3.3	-101.4
Huron, S.D.	44 23.0	98 13.3	1287	980.4527		-43.8
Rapid City, S.D.	44 3.0	103 3.6	3172	980.2510	+5.7	-102.4
Spearfish, S.D.	44 28.7	103 47.1	3929	980.2521	+39.4	-94.5
Memphis, Tenn.	35 3.5	89 58.9	291	979.7257	+2.6	-7.3
Nashville, Tenn.	36 7.0	86 41.0	606	979.7796	-4.2	-24.8
Amarillo, Tex.	35 13.8	101 42.0	3604	979.4234	-2.7	-125.4
Lubbock, Tex.	33 39.3	101 48.9	3256	979.3228	-3.6	-114.5
Tyler, Tex.	32 21.0	95 24.1	544	979.4782	+4.1	-14.4
Wichita Falls, Tex.	33 59.0	98 30.5	1029	979.5483	-14.9	-50.0
Ogden, Utah	41 12.2	112 0.9	4455	979.8178	-50.9	-202.7

Table III-A-2 (Cont'd)

Principal Facts Woollard 1958 (Adjusted)
Airport Stations

<u>Station</u>	<u>Lat.</u>	<u>Long.</u>	<u>Elev.</u>	<u>Observed Gravity</u>	<u>Free Air Anomaly</u>	<u>Bouguer Anomaly</u>
Montpelier, Va.	44 12.5	72 34.1	1100	980.4629	+8.4	-29.0
Richmond, Va.	37 33.5	77 23.9	172	979.9534	+4.1	-1.8
Walla Walla, Wash.	46 5.9	118 17.0	1205	980.5740	-41.2	-82.2
LaCrosse, Wis.	43 53.0	91 16.0	653	980.4567	-10.5	-32.7
Madison, Wis.	43 8.7	89 20.0	859	980.3725	-8.8	-38.0
Montreal, Canada	45 27.0	73 45.0	103	980.6439	-16.4	-19.9
Ottawa, Canada	45 20.1	75 41.2	357	980.6215	-4.5	-16.7
Toronto, Canada	43 41.5	79 38.1	557	980.4298	-29.1	-48.1
Winnipeg, Canada	49 54.2	97 14.5	775	980.9924	-4.7	-31.1

Table III-A-3

L&R Geodetic #1 Airport Stations

<u>Station</u>	<u>Lat.</u>	<u>Long.</u>	<u>Elev.</u>	<u>Observed Gravity</u>	<u>Free Air Anomaly</u>	<u>Bouguer Anomaly</u>
Birmingham, Ala.	33 34.1	86 45.0	643	979.5390	-26.0	-47.9
Mobile, Ala.	30 41.3	88 14.2	217	979.3396	-31.8	-39.2
Los Angeles, Calif.	33 56.1	118 23.0	109	979.5946	-51.1	-54.8
Monterrey, Calif.	36 35.5	121 50.5	220	979.8692	+8.2	+0.7
San Diego, Calif.	32 44.0	117 11.0	14	979.5369	-18.3	-18.8
San Francisco, Calif. (Gate 23)	37 37.0	122 22.8	10	979.9883	+18.6	+18.3
San Francisco, Calif. (Main entrance)	37 37.0	122 22.8	10	979.9885	+18.8	+18.5
Santa Barbara, Calif.	34 26.0	119 49.5	14	979.6407	-55.7	-56.2
Denver, Colo. (Gate 2)	39 45.6	104 53.0	5325	979.6335	-24.8	-206.2
Denver, Colo. (Gate 6)	39 45.6	104 53.0	5325	979.6327	-25.6	-207.0
Kremling, Colo.	40 3.5	106 22.6	7411	979.4903	+1.7	-250.8
New Haven, Conn.	41 16.0	72 53.3	4	980.3125	+19.5	+19.3
Wilmington, Del.	39 45.9	75 36.5	135	980.1757	+28.8	+24.2
Washington, D.C. (Field level)	38 51.0	77 1.3	10	980.1098	+32.0	+31.7
Washington, D.C. (Upper street level)	38 51.1	77 1.8	16	980.1088	+31.4	+30.9
Jacksonville, Fla.	30 25.5	81 38.5	52	979.3856	+19.4	+17.7
Pensacola, Fla.	30 28.8	87 11.2	121	979.3630	-1.0	-5.1
Tallahassee, Fla.	30 26.3	84 20.0	70	979.3544	-11.1	-13.5

Table III-A-3 (Cont'd)

L&R Geodetic #1 Airport Stations

<u>Station</u>	<u>Lat.</u>	<u>Long.</u>	<u>Elev.</u>	<u>Observed Gravity</u>	<u>Free Air Anomaly</u>	<u>Bouguer Anomaly</u>
Atlanta, Ga. (East Concourse)	33 39.1	84 25.3	1005	979.5205	-17.3	-51.6
Atlanta, Ga. (West Concourse)	33 39.1	84 25.3	1005	979.5203	-17.5	-51.8
Savannah, Ga.	32 1.7	81 8.0	40	979.4980	+2.7	+1.3
Coeur d'Alene, Idaho	47 46.2	116 49.0	2310	980.6387	-23.1	-101.8
Chicago, Ill.	41 47.7	87 45.1	618	980.2864	+3.8	-17.3
Indianapolis, Ind.	39 43.6	86 16.0	792	980.0933	+11.6	-15.4
W. Lafayette, Ind.	40 25.0	86 56.0	605	980.1469	-13.7	-34.3
Beloit, Kans.	39 28.2	98 8.0	1416	980.0000	-0.3	-48.5
Kansas City, Kans.	39 8.7	94 36.0	746	980.0010	-33.6	-59.0
Wichita, Kans.	37 37.7	97 16.0	1372	979.8404	-2.2	-48.9
Lexington, Ky.	38 6.6	84 28.0	910	979.8988	-29.3	-60.3
Baton Rouge, La.	30 31.8	91 9.3	70	979.3637	-9.0	-11.4
New Orleans, La. (Entrance to term.)	30 2.3	90 2.0	8	979.3312	-8.8	-9.1
New Orleans, La. (Moisant Airport)	29 59.6	90 15.7	3	979.3298	-7.1	-7.3
Portland, Maine	43 38.8	70 18.4	60	980.5126	-11.0	+8.9
Baltimore, Md.	39 15.0	76 30.9	10	980.1104	-2.7	-3.0
Bedford, Mass.	42 28.2	71 17.0	135	980.3942	+5.6	+1.0
Boston, Mass. (Gate 17)	42 22.0	71 1.1	12	980.4036	+12.7	+12.3

Table III-A-3 (Cont'd)

L&R Geodetic #1 Airport Stations

<u>Station</u>	<u>Lat.</u>	<u>Long.</u>	<u>Elev.</u>	<u>Observed Gravity</u>	<u>Free Air Anomaly</u>	<u>Bouguer Anomaly</u>
Boston, Mass. (Gate 19)	42 22.0	71 1.1	12	980.4036	+12.7	+12.3
Detroit, Mich.	42 14.0	83 32.0	715	980.3188	+6.0	-18.4
Lansing, Mich.	42 46.5	84 35.8	858	980.3518	+3.7	-25.5
Minneapolis, Minn.	44 53.2	93 13.2	840	980.5950	+54.9	+26.2
Meridian, Miss.	32 20.4	88 44.8	297	979.4840	-12.5	-22.6
Kansas City, Mo.	39 7.2	94 35.6	744	979.9998	-32.8	-58.1
St. Louis, Mo.	38 45.0	90 22.0	567	980.0043	-12.3	-31.6
Billings, Mont.	45 48.0	108 32.2	3612	980.3717	+9.8	-113.2
Butte, Mont.	45 57.2	112 29.2	5554	980.1744	-18.6	-207.8
Great Falls, Mont.	47 29.0	111 22.0	3671	980.5137	+5.7	-119.4
Cutbank, Mont.	48 36.0	112 22.0	3900	980.6085	+21.7	-111.1
Lewistown, Mont.	47 2.5	109 28.9	4209	980.4510	+33.3	-110.1
Missoula, Mont.	46 55.0	114 5.4	3203	980.4440	-57.0	-166.2
Las Vegas, Nev.	36 4.2	115 10.0	2171	979.6049	-27.7	-101.6
Reno, Nev.	39 29.5	119 45.5	4404	979.6873	-33.9	-183.9
Albuquerque, N.M.	35 2.5	106 36.9	5330	979.2081	-39.6	-221.2
Santa Fe, N.M.	35 37.4	106 5.2	6344	979.1974	-4.4	-220.6
New York, N.Y. (LaGuardia)	40 46.7	73 52.8	19	980.2825	+34.5	+33.9

-30.2-

Table III-A-3 (Cont'd)

L&R Geodetic #1 Airport Stations

<u>Station</u>	<u>Lat.</u>	<u>Long.</u>	<u>Elev.</u>	<u>Observed Gravity</u>	<u>Free Air Anomaly</u>	<u>Bouguer Anomaly</u>
New York, N.Y. (Idlewild)	40 38.6	73 47.0	15	980.2261	-10.2	-10.7
Syracuse, N.Y.	43 4.4	76 15.5	396	980.3968	-21.6	-35.1
Cincinnati, Ohio (Front of terminal)	39 3.3	84 39.7	890	979.9935	-19.6	-49.9
Cincinnati, Ohio (Gate 3)	39 3.3	84 39.7	896	979.9931	-19.4	-49.9
Cleveland, Ohio	41 24.5	81 50.7	789	980.2322	+0.3	-26.6
Columbus, Ohio	40 4.4	83 4.0	900	980.0791	-23.2	-53.9
Tulsa, Okla.	36 12.2	95 54.1	674	979.7766	-8.2	-31.2
Eugene, Ore.	44 7.2	123 13.2	365	980.5148	-0.8	-13.3
Medford, Ore.	42 22.2	122 52.2	1330	980.2375	-29.7	-75.1
Portland, Ore. (Lower lobby)	45 35.0	122 36.0	23	980.6483	-31.6	-32.4
Portland, Ore. (Old Terminal)	45 35.0	122 36.0	30	980.6477	-31.5	-32.5
Philadelphia, Pa.	39 53.6	75 10.0	12	980.1976	+27.7	+27.3
Pittsburgh, Pa.	40 29.5	80 13.8	1168	980.0993	-15.1	-54.9
Providence, R.I.	41 43.7	71 25.5	53	980.3139	-15.9	-17.7
Charleston, S.C. (MATS Terminal)	32 54.0	80 2.4	45	979.5674	+1.4	-0.1
Charleston, S.C. (Municipal Airport)	32 53.9	80 2.4	40	979.5668	+0.5	-0.9
Chattanooga, Tenn.	35 2.3	85 12.5	682	979.6505	-34.1	-57.4
Knoxville, Tenn.	35 48.9	83 59.0	989	979.7032	-18.7	-52.4

Table III-A-3 (Cont'd)

L&R Geodetic #1 Airport Stations

<u>Station</u>	<u>Lat.</u>	<u>Long.</u>	<u>Elev.</u>	<u>Observed Gravity</u>	<u>Free Air Anomaly</u>	<u>Bouguer Anomaly</u>
Austin, Texas	30 17.8	97 42.3	631	979.2889	-12.7	-34.2
Brownsville, Texas	25 54.8	97 25.3	22	979.0509	+19.7	+19.0
Corpus Christi, Texas	27 46.0	97 26.2	42	979.1430	-20.7	-22.1
Dallas, Texas	32 51.0	96 51.3	477	979.5131	-8.2	-24.4
El Paso, Texas	31 48.2	106 23.8	3936	979.0814	-29.3	-163.4
Ft. Worth, Texas	32 48.8	97 22.1	692	979.4934	-4.6	-28.2
Galveston, Texas	29 16.0	94 51.6	7	979.2696	-10.7	-11.0
Houston, Texas (Gate 9)	29 39.0	95 16.7	50	979.2933	-12.5	-14.2
Houston, Texas (Gate 7)	29 39.0	95 16.7	50	979.2932	-12.6	-14.3
Laredo, Texas	27 32.2	99 27.4	512	979.0792	-23.3	-40.7
San Antonio, Texas (American Airlines)	29 32.0	98 28.0	800	979.1973	-29.0	-56.2
San Antonio, Texas (Gate 8)	29 32.0	98 28.0	797	979.1975	-29.1	-56.2
Salt Lake City, Utah	40 46.8	111 58.3	4220	979.8070	-46.0	-189.8
Vernal, Utah	40 26.3	109 31.4	5277	979.6686	-54.5	-234.3
Burlington, Vt.	44 28.1	73 9.2	333	980.5181	-32.0	-43.3
Norfolk, Va. (New Terminal)	36 53.5	76 12.0	26	979.8789	-26.3	-27.1
Norfolk, Va. (Old Station)	36 53.5	76 12.0	26	979.8788	-26.4	-27.2
Roanoke, Va.	37 19.3	79 58.0	1174	979.8076	-26.9	-66.9

Table III-A-3 (Cont'd)

L&R Geodetic #1 Airport Stations

<u>Station</u>	<u>Lat.</u>	<u>Long.</u>	<u>Elev.</u>	<u>Observed Gravity</u>	<u>Free Air Anomaly</u>	<u>Bouguer Anomaly</u>
Port Angeles, Wash.	48 7.4	123 29.6	290	980.8640	-19.6	-29.5
Seattle, Wash. (Gate 5)	47 26.5	122 18.0	416	980.7765	-34.0	-48.1
Seattle, Wash. (Gate 3)	47 26.5	122 18.0	416	980.7765	-34.0	-48.1
Seattle, Wash. (At curb)	47 26.5	122 18.0	416	980.7765	-34.0	-48.1
Spokane, Wash.	47 37.2	117 31.9	2372	980.6463	+3.8	-77.0
Charleston, W.Va.	38 22.3	81 35.4	981	979.9259	-18.5	-51.9
Janesville, Beloit, Wis.	42 37.1	89 2.0	807	980.3303	-8.5	-36.0
Milwaukee, Wis.	42 57.2	87 54.0	675	980.3597	-21.6	-44.6
Casper, Wyo.	42 54.5	106 28.0	5347	979.9562	+18.4	-163.8
Cheyenne, Wyo.	41 9.5	104 48.5	6156	979.7008	-3.9	-213.6
Sheridan, Wyo.	44 46.5	106 58.0	4021	980.2266	-4.3	-141.3
Calgary, Alberta, Canada	51 6.2	114 1.0	3540	980.8288	-14.7	-135.3
Edmonton, Alberta, Canada	53 34.4	113 31.8	2185	981.1729	-13.9	-88.4
Ft. Nelson, B.C., Canada	58 50.5	122 36.0	1247	981.6930	-21.8	-64.3
Grand Prairie, Canada	55 10.8	118 53.0	2200	981.3158	-7.1	-82.1
Lethbridge, Canada	49 37.8	112 48.0	3030	980.7538	-6.9	-110.1
Quebec, Canada	46 47.4	71 23.0	235	980.7405	-28.3	-36.3
Vancouver, B.C., Canada	49 11.2	123 11.0	6	980.9299	-75.6	-75.9

Table III-A-3 (Cont'd)

L&R Geodetic #1 Airport Stations

<u>Station</u>	<u>Lat.</u>	<u>Long.</u>	<u>Elev.</u>	<u>Observed Gravity</u>	<u>Free Air Anomaly</u>	<u>Bouguer Anomaly</u>
Watson Lake, Canada	60 7.2	128 48.0	2230	981.7141	-9.4	-85.4
Whitehorse, Canada	60 42.0	135 5.0	2297	981.7487	-13.6	-91.9
Mexico City, Mex.	19 25.5	99 6.0	7347	977.9701	+42.3	-208.0
Monterrey, Mex.	25 53.0	100 14.0	1474	978.8617	-30.8	-81.0

Table III-A-4

Harbor Gravity Base Stations

<u>Station</u>	<u>Station Description</u>	<u>Obs. Gravity</u>
Milwaukee, Wis.	Milwaukee dock area, Clipper ferry landing bldg. at water's edge, in parking area, about 30 ft. east of bldg. and about 80 ft. east of car loading ramp to ferry. (Wis.-Mich. SS Co.)	980.3697
Chicago, Ill.	Chicago sanitary causeway (approx. 100 yds. north Columbia Yacht Club) at entrance to causeway, at rear of Chicago Naval Armoury, about 7 ft. above lake level, about 25 ft. west of gate to causeway and 25 ft. south of north edge of pier. Navy Pier.	980.2941
Toledo, Ohio	Toledo, USCG Sta., at pier, at south-east corner, about 40 ft. from end and 20 ft. N. of S. side, about 5 ft. above water.	980.2528
Cleveland, Ohio	USCG Sta., (end of 9th St.) at NE. corner of pier about 5 ft. from each edge, about 7 ft. above lake, next to ring buoy on light pole.	980.2502
Quebec, Canada	Pier of Canada SS Lines, west end of pier, 75 ft. out from 40 Dalhousie Rue. Hy. 2 runs into driveway.	980.7476
Portland, Me.	U.S. Naval Res. Training Center, at concrete base of Naval Reserve pier.	980.5216
Portsmouth, N.H.	Navy base, berth no. 5. SE. corner, about 20 ft. from S. edge of pier, about 10 ft. from W. edge.	980.4727
Boston, Mass.	Boston Naval Base, pier no. 7, sea end, about 40 ft. from end and 30 ft. from west side.	980.4040
Woods Hole, Mass.	Woods Hole USCG pier, SE. corner, about 35 ft. N. of S. edge and 35 ft. W. of E. edge.	980.3276
Woods Hole, Mass.	Woods Hole, WHOI, pier, on concrete 30 ft. SE. of tide station.	980.3270
Davisville, R.I.	Pier no. 1 at sea end, 6 ft. from end, on center line of pier.	980.3123
Quonset Pt., R.I.	NAS, On curb in front of BOQ on center line.	980.3111

Table III-A-4 (Cont'd)

Harbor Gravity Base Stations

<u>Station</u>	<u>Station Description</u>	<u>Obs. Gravity</u>
New London, Conn.	Submarine Base, pier no. 7, north (land) end, at base of light post on E. side.	980.2964
New York	New York Naval Yard, pier J, NE. corner (sea end) 15 ft. S. of N. end, against wood beam at E. side, berth 16.	980.2721
Philadelphia, Pa.	Philadelphia Navy Yard, pier no. 5, center of pier about 25 ft. from south (sea) end.	980.1999
Baltimore, Md.	USCG Depot, sea end, pier no. 3, about 30 ft. N. of S. end and 25 ft. E. of W. side.	980.1046
Norfolk, Va.	Norfolk Naval Base, pier 5, sea end, 5 ft. in (NE.) from end on center line of pier.	979.8843
Wilmington, N.C.	USCG Station, at pier on concrete center of main entrance from street, 3 ft. from land edge of wood pier.	979.6708
Charleston, S.C.	Naval Base, pier F at outer end, 30 ft. N. of end and 10 ft. W. of outer side.	979.5650
Savannah, Ga.	USCG station, about 30 ft. E. of wire fence barrier gate and 10 ft. in from edge.	979.4932
Jacksonville, Fla.	Mayport Naval Base, north pier, berth C-1, S. side of pier, on concrete 20 ft. N. of asphalt at indentation in pier.	979.3758
Pensacola, Fla.	NAS, Alleghany Pier, NE. corner, 5 ft. S. of N. edge and 10 ft. W. of E. edge.	979.3560
Mobile, Ala.	USCG pier, 25 ft. N. of S. side and 100 ft. from sea end.	979.3576
New Orleans, La.	USCG New Carol Light Station, sea end of pier 20 ft. S. of bell.	979.3310
Galveston, Tex.	USCG station, McKenzie (Hopper Dredge Dock) on road to dock, 10 ft. in from land edge of pier.	979.2789
Corpus Christi, Tex.	City dock, S. end, 21 ft. N. of tank and about 40 ft. E. of street edge.	979.1490

Table III-A-4 (Cont'd)

Harbor Gravity Base Stations

<u>Station</u>	<u>Station Description</u>	<u>Obs. Gravity</u>
San Diego, Cal.	USN Sonar School, at junction of pier no. 5 and 6 on concrete next to man hole cover. EL. 10.97 ft. Reoc. Columbia 1948 No. 553, USC&GS No. 5107.	979.5423
LaJolla, Cal.	Scripps Inst. of Oceanography, Naval Electronics Lab, Marine Physical Lab, Post No. 5 gate house, outside at NW. corner of bldg. on concrete at edge of asphalt street.	979.5502
Port of Los Angeles, Cal.	San Pedro, Port of Los Angeles, Berth 57, at SW. side of pier, land end, next to large green mooring cleat.	979.6495
Monterrey, Cal.	USCG pier, sea end, at base of steel tower.	979.8917
San Francisco, Cal.	USN shipyard, Berth No. 3, NE. end of berth at edge and corner marked "O".	979.9906
Bremerton, Wash.	Puget Sound Naval Shipyard, pier 5, sea end, 6 ft. N. of S. end, 10 ft. E. of W. side.	980.8239

Table III-A-5

University* Gravity Base Stations

<u>Station</u>	<u>Station Description</u>	<u>Obs. Gravity</u>
Tuscaloosa, Ala.	<u>Univ. of Alabama</u> , U 1119, at USC&GS mark in open area, 186 ft. N., 85 W. from NW. corner of Chemistry Bldg.	979.5598
Fairbanks, Alaska	<u>Univ. of Alaska</u> , Geophysical Inst. At rear of bldg. just inside door from loading platform.	982.2462
Berkeley, Calif.	<u>Univ. of California</u> , Sather Tower, E. side of street, next to sidewalk against S. abutment of wall around square.	979.9704
Los Angeles, Calif.	<u>U.C.L.A.</u> , Chemistry-Geology Bldg., at center of doors to Room 1275.	979.5292
Palo Alto, Calif.	<u>Stanford Univ.</u> , Lloyd Noble Laboratory for Geophysics, at rear entrance to N. wing of bldg., at door stop for W. door.	979.9489
Pasadena, Calif.	<u>California Institute of Technology</u> , Mudd Hall, SW. corner at top of steps.	979.5785
San Diego, Calif.	<u>Institute of Oceanography</u> , (Scripps) Naval Electronics Laboratory, Marine Physical Lab, Post No. 5, gate house, outside of NW. corner of bldg. on concrete at edge of asphalt street.	979.5502
Boulder, Colo.	<u>Univ. of Colorado</u> , E. entrance to geology bldg., on sidewalk at curb.	979.6193
Colorado Springs, Colo.	<u>Colorado College</u> , Washburn Athletic Field, 160 ft. N. along road from NW. gate.	979.4931
Denver, Colo.	<u>Chamberlain Observatory</u> , N. entrance to basement, at foot of steps.	979.6113
Golden, Colo.	<u>Colorado School of Mines</u> , on curb in front of geology-geophysics science bldg., Berthoud Hall, in line with center of front door, Illinois Street entrance.	979.5842
New Haven, Conn.	<u>Yale Univ.</u> , Sloan Physics Laboratory, western most of two entrances on north side, on walk at edge of drive.	980.3163
Atlanta, Ga.	<u>Georgia School of Technology</u> , Mechanical Engineering Bldg., N. end in drive on sidewalk next to manhole E. side of bldg.	979.5286

*Some research institutions other than universities are included.

Table III-A-5 (Cont'd)

University Gravity Base Stations

<u>Station</u>	<u>Station Description</u>	<u>Obs. Gravity</u>
Chicago, Ill.	<u>Univ. of Chicago</u> , 40 ft. NE. of NE. corner Ryerson Physical Lab. on sidewalk next to curb of street. About 4 ft. lower than 1st floor.	980.2858
South Bend, Ind.	<u>Notre Dame Univ.</u> , in parking area south of engineering bldg., at sidewalk leading to E. end bldg., about 20 ft. S. of line of posts.	980.2547
West Lafayette, Ind.	<u>Purdue Univ.</u> , airport, terminal waiting room, in corner opposite door to field.	980.1469
West Lafayette, Ind.	<u>Purdue Univ.</u> , Chemistry and Meteorology Bld., entrance to Room 4.	980.1456
Orono, Me.	<u>Univ. of Maine</u> , N. side entrance to Boardman Hall (Engineering) 2 ft. N. of center of doors on step about 6 in. above ground level.	980.6063
Bedford, Mass.	<u>Air Force Cambridge Research Center</u> , Hanscom Field, at gate 2 to base, Bldg. 1101, outside Provost Marshall's Office, next to phone booth.	980.3942
Boston, Mass.	<u>Massachusetts Institute of Technology</u> , Bldg. 24, SE. corner of sidewalk at curb of N-S St.	980.4002
Cambridge, Mass.	<u>Harvard Univ. Observatory</u> , (Garden Street) on flagstone terrace at south entrance against E. end of steps to door.	980.4003
→ Woods Hole, Mass.	<u>Woods Hole Oceanographic Institute</u> , at street entrance.	980.3271
Ann Arbor, Mich.	<u>Univ. of Michigan</u> , at south end of parking lot just east of Natural Science Bldg., at base of flag mast, at BM (USC&GS 1934).	980.3131
East Lansing, Mich.	<u>Michigan State Univ.</u> , Physics and Math Bldg., at curb in front of main entrance.	980.3498
Chapel Hill, N.C.	<u>Univ. of North Carolina</u> , New (geology) East Hall main (south) entrance, on lower of two steps.	979.8184
Princeton, N.J.	<u>Princeton Univ.</u> , Guyot Hall, Room 14.	980.1776
Albuquerque, N.M.	<u>Univ. of New Mexico</u> , Administration Bldg., 52 ft. N. of S. wall and 40 ft. E. of E. wall.	979.2232
Socorro, N.M.	<u>New Mexico Institute of Mining & Technology</u> , NW. corner of Geophysical Research Lab, at inside corner of two sidewalks, at BM R222.	979.1856

Table III-A-5 (Cont'd)

University Gravity Base Stations

<u>Station</u>	<u>Station Description</u>	<u>Obs. Gravity</u>
New York, N.Y.	<u>Columbia Univ.</u> , Schermerhorn Hall, sidewalk outside of hall by large green door on Amsterdam Avenue across from 118th Street corner.	980.2689
Palisades, N.Y.	<u>Lamont Geological Observatory</u> , gravity room in basement.	980.2596
Syracuse, N.Y.	<u>Syracuse Univ.</u> , at corner about 100 ft. N. of Steele Hall, on sidewalk, at curb, 10 ft. N. of boulder marking tree commemorating birth of Mme. Marie Sklodowska Curie.	980.3817
Columbus, Ohio	<u>Ohio State Univ.</u> , Research Center, main gate on sidewalk beside guard-house.	980.0961
Columbus, Ohio	<u>Ohio State Univ.</u> , Bldg. 24, Hardin Road, wash room under S. window.	980.0993
Tulsa, Okla.	<u>Tulsa Univ.</u> , Phillips Engineering Bldg., Room 7A, back wall against radiator, 28 ft. from front of bldg. and 8 ft. W. of E. wall. (Pend. sta.)	979.7663
Tulsa, Okla.	<u>Tulsa Univ.</u> , at E. front entrance to Phillips Engineering Bldg.	979.7660
Philadelphia, Pa.	<u>Univ. of Pennsylvania</u> , Franklin Stadium, at brass disk in brick wall at N. corner of field. (Pend. sta.)	980.1974
State College, Pa.	<u>Pa. State Univ.</u> , State College, at curb (street level) in front of main entrance to Mineral Sciences Bldg.	980.1282
Knoxville, Tenn.	<u>Univ. of Tennessee</u> , Ayers Hall, main entrance on flagpole side, on concrete center of entrance.	979.7120
Houston, Texas.	<u>Rice Univ.</u> , Physics Bldg., parking lot, on concrete platform (ground level) for nitrogen generator. 6 ft. E. of W. edge of concrete at edge of asphalt.	979.2988
Salt Lake City, Utah	<u>Univ. of Utah</u> , Mines Building, center entrance on E. side of sidewalk at road.	979.7851
Salt Lake City, Utah	<u>Liberty Park</u> , under large tree used as base station by Univ. of Utah Geophysics Dept.	979.8001
Burlington, Vt.	<u>Univ. of Vermont</u> , Williams Science Hall, at main entrance to bldg., on walk at center of entrance against lower step.	980.5155

Table III-A-5 (Cont'd)

University Gravity Base Stations

<u>Station</u>	<u>Station Description</u>	<u>Obs. Gravity</u>
Blacksburg, Va.	<u>Virginia Polytech. Institute, Holden Hall (geology) on curb of walk to main entrance three short flights of steps below main entrance, about 100 ft. SE. of and on centerline of main entrance.</u>	979.7324
Seattle, Wash.	<u>Univ. of Washington, Johnson Hall, Room B1.</u>	980.7389
Madison, Wis.	<u>Univ. of Wisconsin, Science Hall, entrance to Room 40.</u>	980.3689
Madison, Wis.	<u>Univ. of Wisconsin, Geophysics Research Center, 2544 University Ave., at front door.</u>	980.3661
Lawrence, Kansas	<u>University of Kansas, Lindley Hall on first step outside northeast entrance on left end of step facing door.</u>	979.9845
	<u>University of Kansas, Hoch Auditorium, on sidewalk in front of main entrance.</u>	979.9849
Emory, Georgia	<u>Emory University, pier in basement of Physics Building.</u>	979.5375
	<u>Emory University, East rear entrance to Geology Building on concrete slab outside door.</u>	979.5390
Knoxville, Tenn.	<u>University of Tennessee, at Bench Mark Z189 at entrance to Physics-Geology Building.</u>	979.7120
Edmonton, Alberta, Can.	<u>Univ. of Alberta, Physics Lab (Room 19) pend. sta. in SW. corner of lab.</u>	981.1678
México City, Mex.	<u>Univ. of Mexico, in the gravity room at the Universidal Nacional de Mexico, about 50 ft. N. of the building housing the Van de Graaf generator of the Physics Department. On 1st pier to rt.</u>	977.9414
Mexico City, Mex.	<u>Tacubaya, Photogrammetry room of the Oficina de Geografia, 192 Observatory Ave., 6 ft. W. of the No. 1 pend. pier.</u>	977.9419
Monterrey, N.L., Mex.	<u>Institute Tecnológico y de Estudios Superiores, Classroom for Auto Shop repairs, 10 ft. from the N. (outside) wall and 3 ft. from the E. wall of the room.</u>	978.8055

Table III-A-6

Gravimeter Occupations of Pendulum Stations

<u>Station</u>	<u>Pend. Sta.</u>	<u>Station Description</u>	<u>Obs. Gravity</u>
Tuscaloosa, Ala.	U 1119	Univ. of Alabama at USC&GS mark in open area. 186 ft. N. 85 W. from NW. corner of Chemistry Bldg.	979.5598
Fairbanks, Alaska	GW 27	Ladd AFB, BOQ 10, Bldg. 1157, SW. corner of bldg. in basement at foot of stairs.	982.2444
Pt. Barrow, Alaska	GW 105	Butler Bldg. No. 353, SW. corner.	982.6997
Eureka, Calif.	U 238	On N. corner (P.O.) of H & 5th Streets at traffic signal, 6 ft. above pend. sta.	980.2219
Oceanside, Calif.	U 241	E. corner of 1st & Horne Streets, at high school, on curb next to hydrant.	979.5663
San Francisco, Calif.	GW 54	Academy of Science, Golden Gate Park, Paleo Lab,	979.9867
Santa Rosa, Calif.	U 239	Post Office, N. corner of 5th & A Streets, next to fire alarm box, 25 ft. S. of BM V106.	980.0203
Ventura, Calif.	U 250	Courthouse, NE. corner, on landing at top of steps to basement.	979.5600
Colorado Springs, Colo.	U 1078	Washburn Athletic Field of Colorado College, 160 ft. N. along dirt road from NW. gate.	979.4931
Craig, Colo.	U 1164	Rodeo grounds, .19 miles S. US 40 and 43 yds. W. of gravity mark on E. fence line.	979.6202
Denver, Colo.	GW 39	Chamberlain Observatory, N. entrance to basement, at foot of steps.	979.6114
Washington, D.C.	U 337	Department of Commerce Building, 14th Street side, N. arch of parking area, at bench mark, on curb.	980.1182
Crestview, Fla.	U 890	1.0 miles W. of courthouse, at Mar Camp tourist court. On left (S) side of US 90, 370 ft. S. of center US 90 and 91 ft. E. of blacktop road. Std. grav. mark.	979.3815

Table III-A-6 (Cont'd)

Gravimeter Occupations of Pendulum Stations

<u>Station</u>	<u>Pend. Sta.</u>	<u>Station Description</u>	<u>Obs. Gravity</u>
Lake City, Fla.	U 869	Duval Tourist Court, .9 miles E. center of town on US 90. About 30 ft. N. of S. prop. line and 121 ft. W. of USC&GS mark on E. prop. line.	979.3340
Mariana, Fla.	U 399	High school, NE. corner of grounds, 12 ft. W. of USGS mark on W. curb of Daniel Street.	979.3665
Pensacola, Fla.	U 164	NE. corner of courthouse in drive, about 20 ft. N. of bldg. 5 ft. above U 164 level.	979.3631
Atlanta, Ga.	U 15	Service entrance to capitol on main sidewalk.	979.5238
Chicago, Ill.	U 36	Univ. of Chicago, 40 ft. NE. of NE. corner Ryerson Physical Lab, on sidewalk next to curb of street. About 4 ft. lower than 1st floor.	980.2858
Indianapolis, Ind.	U 137	Sidewalk of court house on Meridian Street opposite SW. corner of bldg. at same level as basement.	980.0898
Beloit, Kans.	GW 52	Saults Service Station, on concrete platform in front of bldg. at right edge (facing in) of platform, 2 ft. from door. About 7 ft. above and 25 ft. SE. of basement station.	979.9978
Baltimore, Md.	U 23A	Corner of Monument and Linden, NW. corner of parking lot about 30 ft. E. bldg. and against brick wall. Mark in corner.	980.1164
Boston, Mass.	U 29	Annex to state house, in NE. corner of basement, in vault.	980.3967
Cambridge, Mass.	U 30	Harvard Observatory (Garden St.) in basement room, 2 ft. N. foundation of telescope.	980.4011
Laurel, Miss.	U 145	Corner of 5th Street and 4th Avenue. At 4th Ave. entrance to school on sidewalk at curb.	979.4697
Billings, Mont.		Airport, W. wall of hangar No. 2, 7 ft. N. of door.	980.3710
Cutbank, Mont.		Airport, field door of customs inspection room.	980.6085

Table III-A-6 (Cont'd)

Gravimeter Occupations of Pendulum Stations

<u>Station</u>	<u>Pend. Sta.</u>	<u>Station Description</u>	<u>Obs. Gravity</u>
Forsyth, Mont.	U 584	At courthouse, at top of stairs to NW. basement entrance at ground level 8 ft. above pend. sta.	980.5089
Great Falls, Mont.	GC 4	Roosevelt School, 20 ft. N. of S. entrance of S. hall in hall.	980.5270
Albuquerque, N.M.	U 764	Univ. of N.M., Administration Bldg., 52 ft. N. of S. wall and 40 ft. E. of E. wall.	979.2232
Wilmington, N.C.	U 149	In parking lot back of court house at Princess & 3rd Street. 30 ft. N. of brick wall at edge of drive and 40 ft. W. of SW. corner of new addition to court house.	979.6703
Columbus, Ohio	U 136	Old Memorial Hall on Broad Street, N. end of bldg. under archway in center. About 11 ft. above pend. sta.	980.0864
Tulsa, Okla.	GW 51	Phillips Engineering Bldg. Rm. 7A, back wall against radiator. 28 ft. from front of bldg. and 8 ft. W. of E. wall.	979.7663
Eugene, Ore.	U 232	Public library, on Olive Street curb 40 ft. S. of W. 13th Street curb, about 100 ft. N. and 1 ft. below pend. sta.	980.4910
Portland, Ore.	U 229	US Customs House, near NW. corner, on Everett Street sidewalk 40 ft. W. of 8th Street curb, 5 ft. above pend. sta.	980.6474
Philadelphia, Pa.	U 957	Inside Franklin Stadium, Univ. of Pa., at brass disk in brick wall at N. corner of field.	980.1974
Charleston, S.C.	U 17	Old Citadel, SW. corner on sidewalk. Probably 3 ft. below level of pend. sta.	979.5501
Aberdeen, S.D.	U 186	At SE. corner of 4th Street and Main, at curb, on sidewalk, at J.C. Penny Co. (site of old post office).	980.5463
Cleveland, Tenn.	U 153	P.O. on sidewalk at curb opposite SW. corner of bldg. about 1 ft. below basement floor.	979.6517

Table III-A-6 (Cont'd)

Gravimeter Occupations of Pendulum Stations

<u>Station</u>	<u>Pend. Sta.</u>	<u>Station Description</u>	<u>Obs. Gravity</u>
Alpine, Tex.	U 98	Public School at N. end of 6th Street. 3 ft. from edge of sidewalk at W. entrance.	978.9910
Corpus Christi, Tex.	U 727	3314 Hamilton Road, on sidewalk at property line next to pole, SW. corner of property.	979.1489
Del Rio, Tex.	U 723	Camp Del Rio, sidewalk at entrance to cabin No. 23.	979.1920
Denison, Tex.	U 73A	NE. corner of Armstrong and Main Sts., on curb of Armstrong 30 ft. N. of curb of Main.	979.5712
El Paso, Tex.	U 63	School at N. Kansas & Arizona, on sidewalk curb Kansas St. entrance.	979.1257
Galveston, Tex.	U 7	On curb of parking lot on sidewalk to rear entrance of West and South Life Insurance Co. between 22nd and 21st Streets and G & H Avenues.	979.2753
Houston, Tex.	GW 18	Hall-Sears, 2424 Branard Street at car shelter.	979.2985
Rosenberg, Tex.	U 730	Fairview Tourist Court, Hy. US 59 and US 90A. On sidewalk to SW. most cabin, at mark.	979.2788
Salt Lake City, Utah	U 49	Inside Temple Square, SE. corner of grounds on top of sandstone block engraved: United States Meridian Line, about 50 ft. N. of and midway between log cabin and museum.	979.8038
Vernal, Utah	U 1175	Airport, 225 ft. E. of entrance to field and 90 ft. S. of section line road, in open field.	979.6686
Lexington, Va.	U 175	On sidewalk at Nelson Street entrance to P.O. at bottom of steps,	979.8641
Bellingham, Wash.	U 220	Corner of W. Magnolia & Cornwall, at post office, on Magnolia Street curb, 20 ft. from S. corner of bldg.	980.8855
Bremerton, Wash.	U 226	Smith School, at SW. corner of bldg. next to window, ground level.	980.8117
Everett, Wash.	U 221	P.O. at Wall & Colby Street, NW. corner of bldg. on sidewalk, about 6 ft. above pend. sta.	980.7807

Table III-A-6 (Cont'd)

Gravimeter Occupations of Pendulum Stations

<u>Station</u>	<u>Pend. Sta.</u>	<u>Station Description</u>	<u>Obs. Gravity</u>
Issaquah, Wash.	U 222	At junior high school on sidewalk at rear of building opposite top of steps to basement.	980.7654
Olympia, Wash.	U 112	SE. corner Quince & 5th St., on curb.	980.8170
Port Angeles, Wash.	U 223	Courthouse, at E. wall, 10 ft. S. of N. wall, on concrete drive, approx. 5 ft. above pend. sta.	980.8752
Madison, Wis.	U 37	Science Hall, University of Wisconsin, entrance to Room 40.	980.3689
Calgary, Canada	GW 32	Airport, Aux. Gen. Bldg. approx. 100 ft. S. Chinook hangar SW. rooms.	980.8281
Edmonton, Canada	GW 25	Univ. of Alberta, Physics Lab. (Rm. 19) pend. sta. in SW. corner of lab.	981.1678
Ft. St. John, BC, Canada	GW 29	Airport, in center basement room of terminal in SE. corner.	981.4059
Watson Lake, YT, Canada	GC 8	Airport, inside passenger waiting room, SE. corner.	981.7141
Whitehorse, YT, Canada	GW 26	In pumphouse approx. 100 ft. E. SE. corner of hangar at foot of steps.	981.7486
Mexico City, D.F., Mex.	GW 43	In gravity room at Universidad Nacional de Mexico, about 50 ft. N. of bldg. housing the Van de Graaf generator of the Physics Department.	977.9414
Mexico City, D.F., Mex.	GW 41	Photogrammetry room of the Oficina de Geografia, 192 Observatory Ave., Tacubaya, about 20 ft. W. of pier, floor level.	977.9419
Monterrey, N.L., Mex.	GW 21	Institute Technology, auto shop classroom, at mark in floor: Instituto Geofisica Estacion UNAM about 15 ft. S. of N. wall door center of room.	978.8055
Paso de Cortes, Mex.	GW 42	TV relay station on floor in center of bldg. between banks of equipment.	977.5711

U Stations U.S. Coast & Geodetic Survey Pendulum Network.

GW Stations North American Standardization Range Pendulum Station.

Table III A-7

Airport Gravity Base Values

Gravimetric Connections by the University of Wisconsin used in establishing World Airport Network Values, surveys and observers.

World Loops

Woollard, G. P.	1948	W10b
Muckenfuss, C. M.	1950	W10e
Bonini, W. E.	1951	W10e
Bonini, W. E.	1954	W10e and W147
Rose, J. C.	1955	W147
Sparkman, J.	1957	LR Gd-1
Sparkman, J.	1958	LR Gd-1
Behrendt, J.	1959	LR G-1

Europe

Woollard, G. P.	1951	W10e
Woollard, G. P.	1952	Frost
Bonini, W. E.	1952	W126
Woollard, G. P.	1953	W10e
Woollard, G. P.	1954	W147 and W10f
Woollard, G. P.	1955	W147
Woollard, G. P.	1958	W14
Woollard, G. P.	1959	W14

Africa

Harding, N. C.	1950	W41
Ostenso, N.	1959	W147

Also ties by
Bonini in 1954 and Rose in 1955

South America

Harding, N. C.	1949	W10e
Black, W. E.	1952	W10e
Iverson, R. M.	1956	W326
Iverson, R. M.	1957	W10f
Laudon, T. L.	1958	W10g

Also ties by Bonini in 1951, Weiman 1957,
Sparkman 1958 and Behrendt 1958 and 1959

Australia-New Zealand

Muckenfuss, C. M.	1950	W10e
Rose, J. C.	1956	W10g
Laudon, T.	1958	W10g

Also ties by Bonini in 1954, Sparkman 1957
and Behrendt in 1959

Antarctica

Weiman, J.	1957	LR Gd-1
Iverson, R. M.	1956	W10g
Sparkman, J.	1957	LR Gd-1

Also ties by Behrendt 1958 and Thiel 1960

Table III A- (Cont'd)

Airport Gravity Base Values

North Pacific and Alaska

Muckenfuss, C. M.	1950	W10e
Bonini, W. E.	1950	No.Am.113
Black, W. E.	1952	W10e
Black, W. E.	1953	W10e
Harding, N. C.	1953	W10e and W147
Thiel, E. C.	1954	W14
Ostenso, N.	1955	W14
Iverson, R. M.	1960	LR Gd-1 and G-1
Thiel, E. C.	1956	W147

Also ties by Rose in 1953, Sparkman 1957, Adams 1957,
Iverson 1957, Laudon 1958 and Behrendt 1959

Arctic-Greenland

Rose, J. C.	1954	W147 and 10f
Iverson, R. M.	1957	W14

Also ties by Rose in 1956, Adams 1957,
and Sparkman 1958

Mexico and Central America

Harding, N. C.	1949	W10e
Black, W. A.	1951	W14
Bonini, W. E.	1951	No.Am.113
Black, W. A.	1952	W10e
Harding, N. C.	1954	W147
Monges, J.	1954	W32
Bonini, W. E.	1955	W10f
Woollard, G. P.	1955	W10f
Monges, J.	1956	W32
Laudon, T. S.	1958	W10g

Also numerous ties by various observers in
connection with calibration runs to Mexico City.

No attempt is made to list the numerous observers participating in the measurements within the United States.

Table III-A-7.1

AFRICAN AREA

Algeria
Egypt
Ethiopia
French West Africa
Gambia
Ghana
Ivory Coast
Kenya
Liberia
Libya
Madagascar
Morocco
Mozambique
Nigeria
Northern Rhodesia
Nyasaland
Portuguese Guinea
Republic of Congo
Sierra Leone
Somalia
Southern Rhodesia
Sudan
Tanganyika Territory
Tunisia
Uganda
Union of South Africa

ALGERIA

Algiers

Maison Blanche Airport - Holweck-Lejay pendulum station on east side of Salle-D'Attente department room just east of exit to runway.

36° 42.5' N 3° 13.0' E 82' 979.9058

EGYPT

Cairo

Cairo International Airport (formerly Farouk Field) - in waiting room just opposite bank by drinking fountain.

30° 07.9' N 31° 24.4' E 311' 979.3160

Alexandria

BOAC boat base - by doorway to customs office.

31° 11.5' N 29° 57.2' E -11' 979.4318

Alexandria Harbor

Coal quays - base of control tower.

31° 11.0' N 29° 52.5' E 4' 979.4333

Port Said

Civil Airport - right of front entrance to terminal.

31° 16.8' N 32° 14.3' E 3' 979.4528

ETHIOPIA

Addis Ababa

Field side of terminal at foot of steps; apron elevation. 2' below passenger terminal floor level.

09° 00.1' N 38° 44.4' E 7750' 977.4783

Asmara

Municipal Airport - street entrance to terminal at base of front steps.

15° 17.5' N 38° 54.5' E 7628' 977.8224

Debra Marcous

1' in front of terminal (field side); ground level at center of front of terminal.

10° 20.6' N 37° 45.1' E 8100' 977.5107

Gondar

Field side of terminal; front edge of stone porch. 2' above ground level.

12° 30.7' N 37° 25.1' E 6700' 977.5080

ETHIOPIA (cont.)

Tessenei

Northwest end of strip, 500 yards Azimuth 235° from long low terminal building; site is about 1' below runway strip.

15° 06.0' N 36° 38.5' E . --- 978.1902

FRENCH WEST AFRICA

Dakar

Yof Airport - in front of center pillar at Dakar air terminal entrance.

14° 44.0' N 17° 29.5' W 75' 978.4772

GAMBIA

Bathurst

Yundum Airport - in front of terminal's passenger reception door.

13° 20.5' N 16° 40.0' W 86' 978.3536

GHANA

Accra

Southeast end of terminal at entrance from field side at immigration and baggage entrance. Ground level.

05° 36.0' N 00° 10.2' W 221' 978.1153

IVORY COAST

Abidjon

At airport in corner of patio outside of departure waiting room on field side of terminal and next to a driveway in "arrivee".

05° 15.5' N 03° 56.0' W 17' 978.1007

KENYA

Nairobi

Eastleigh Airport - at sign on field side of terminal outside passenger waiting room.

01° 15.8' S 36° 51.3' E 5371' 977.5432

West Civil Aerodrome Terminal. At flagpole, field side, outside waiting room.

01° 19.3' S 36° 48.6' E 5500' 977.5357

Mombasa

Southeast corner of terminal waiting room.

04° 01.5' S 39° 35.5' E 186' 978.0489

LIBERIA

Roberts Field - in terminal building at far wall opposite main entrance approximately 6" above field level.

06° 14.8' N 10° 21.5' W 25' 978.1080

LIBYA

Benghazi

At right side of patio and restaurant entrance under transient restaurant sign.

32° 05.9' N 20° 17.0' E 411' 979.5265

Tripoli

Wheelus AFB - on floor in center of terminal building waiting room.

32° 53.5' N 13° 17.1' E 36' 979.5876

Idris Airport (formerly Castel Benito) - at entrance to passenger lounge, which is next to airport commandant's office. Terminal is at one end of large hangar.

32° 39.5' N 13° 08.5' E 263' 979.5379

MADAGASCAR

Tananarive

Arivonimamo Airport terminal - lower stone entrance, right of taxi stand entrance to customs and passenger waiting room.

19° 00.5' S 47° 10.5' E 4757' 978.2165

MOROCCO

Casablanca

Cazes Airport - by square column nearest field entrance and incoming customs counter.

33° 34.5' N 07° 40.0' W 203' 979.6428

Port Lyautey

Field entrance to V-24-MATS passenger terminal, right from door of blue canopy.

34° 18.5' N 06° 35.5' W 16' 979.6520

Tangier

Beside baggage gangway in small alcove just left of field entrance to terminal.

35° 44.0' N 05° 55.4' E 46' 979.7491

MOZAMBIQUE

Beira

On semi-circular cement sidewalk to right of DETA operations doorway.

19° 49.5' S 34° 51.0' E 0' 978.6254

MOZAMBIQUE (cont.)

Lourenco Marques

On concrete platform to left of main street entrance.

25° 55.0' S 32° 32.2' E 164' 979.0530

NIGERIA

Kano

Field side of terminal on sidewalk outside door to passenger terminal (beneath flagpole) and directly beneath a small bell marked W.A.A.C.

12° 03.5' N 08° 32.0' E 1563' 978.1357

NORTHERN RHODESIA

Abercorn

30-40 yards out on taxiway from new red brick building B.

08° 50.4' S 31° 20.8' E 5415' 977.6708

Kasama

Beneath southeast corner of control tower.

10° 12.2' S 31° 09.0' E 4550' 977.7877

Livingstone

On north side of passenger terminal, field side, on small porch 11" above tar sidewalk on right side facing terminal from field.

17° 52.5' S 25° 51.0' E 2961' 978.2202

Lusaka

On field side of terminal on sidewalk from passenger waiting room to ramp; about 2' below field elevation and about 4" below floor of passenger waiting room.

15° 24.9' S 28° 20.0' E 4170' 978.0534

Ndola

Field side of terminal on blacktop; 10' from entry door.

12° 59.0' S 28° 40.0' E 4160' 977.9127

NYASALAND

Blantyre

Chiloka Airport - right of porch to "passenger's entrance" in small concrete gully (4' below field elevation).

15° 41.2' S 34° 57.4' E 2400' 978.2171

PORTUGUESE GUINEA

Conakry

Conakry International Airport - in transient waiting room across room from field entrance at middle of back wall, under a clock.

09° 34.7' N 13° 37.5' W 85' 978.2264

REPUBLIC OF CONGO (formerly Belgian Congo)

Leopoldville

Left front entrance to air terminal at foot of round pillar to right of entrance.

04° 19.9' S 15° 18.1' E 961' 977.9519

Ndjili Airport - main entrance to new terminal building, 18" from center column on porch approximately 2' above runway level on field side of terminal.

04° 23.0' S 15° 26.0' E 1014' 977.9426

SIERRA LEONE

Freetown

Lungi Airport - on cement floor of porch outside passenger entrance to terminal.

08° 37.0' N 13° 12.2' W 81' 978.2001

SOMALIA (includes Italian and British Somaliland)

Hargeisa

At base of windsock.

09° 29.3' N 44° 06.2' E 4300' 978.4041

Mogadiscio

At base of flagpole on runway side of terminal.

02° 01.0' N 45° 19.5' E 27' 978.0779

SOUTHERN RHODESIA

Bulawayo

Field side of terminal in center of small concrete porch; 9" above ground level.

20° 07.7' S 28° 37.0' E 4480' 978.2921

Salisbury

Belvedere Airport - right of main street entrance to terminal.

17° 50.4' S 31° 04.5' E 4900' 978.1484

SUDAN

Kassala

On cement floor of porch on right side facing building of passenger waiting room.

15° 28.0' N 36° 24.4' E - 1650' 978.2651

Khartoum

Khartoum Airport - to right inside main street entrance.

15° 36.0' N 32° 33.5' E 1250' 978.3034

Gordon's Tree (Formerly BOAC) - in center of general office of Fisher's section, Sudan government.

15° 33.0' N 32° 30.0' E 1240' 978.2951

Port Sudan

Field side of passenger terminal on concrete porch in center.

19° 35.3' N 37° 12.9' E 10' 978.6404

TANGANYIKA TERRITORY

Dar-es-Salaam

Kurasini Airport - on concrete platform at front of street entrance to terminal.

06° 50.1' S 39° 16.0' E 105' 978.11⁶/₄

Dodoma

Southeast corner of terminal building, field elevation.

06° 09.5' S 35° 46.5' E 3670' 977.7535

Mbeya

Center of concrete porch on field side of passenger terminal.

08° 54.9' S 33° 28.9' E 5600' 977.6840

Moshi

On concrete porch on field side of passenger terminal. About 1' below field elevation.

03° 21.3' S 37° 19.8' E 2700' 977.7720

Tabora

Under control tower.

05° 04.5' S 32° 49.6' E 3875' 977.6845

TUNISIA

Tunis

El Aouina Airport - north entrance to lobby south of east doorway.

36° 51.3' N 10° 14.0' E 16' 979.9061

UGANDA

Entebbe

Against west wall of main briefing room, which is directly beneath control tower.

00° 03.2' N 32° 27.4' E 3789' 977.7241

UNION OF SOUTH AFRICA (including Southwest Africa)

Bloemfontein

Bloemspruit Field. On the N painted on cement wind tee platform.

29° 05.0' S 26° 18.9' E 4424' 978.8536

Capetown

Wingfield Airport - left rear of entrance way to terminal from car.

33° 54.0' S 18° 32.0' E 50' 979.6494

D.F. Malan - new terminal under construction at left of center doors to passenger waiting room from field on concrete porch about 1' above ramp elevation.

--- --- --- 979.6462

Ysterplaat Airport - at base of control tower.

33° 53.0' S 18° 30.0' E 36' 979.6488

Durban

National Airport - on car side of terminal beneath fire extinguisher between rest rooms and on long porch.

29° 53.2' S 31° 00.7' E 0' 979.3677

Stamford Hill - southeast corner of hangar T-2.

29° 49.5' S 31° 02.0' E 10' 979.3605

East London

Colondale Airport - at rear of small covered visitor's waiting pavilion next to a "Welcome to East London" sign at gate to planes.

33° 01.5' S 27° 49.0' E 400' 979.5463

UNION OF SOUTH AFRICA (cont.)

Johannesburg

Jan Smuts Airport - left side main entrance to terminal from bus parking spot.

26° 08.0' S 28° 15.1' E 5559' 978.5503

Kimberley

At right hand side of S.A.A. "Traffic Office" door on a porch (near gate to planes).

28° 48.5' S 24° 46.0' E 3940' 978.8881

Langebaan

Military Airport - on sidewalk leading from front entrance to auto parking lot.

32° 58.0' S 18° 10.0' E 100' 979.5646

Ohopoho (Southwest Africa)

At base of windsock at new landing strip.

18° 02.2' S 13° 52.5' E 3475' 978.2135

Oudtshoorn

On taxi ramp beside entrance drive to field. (Military airport).

33° 36.1' S 22° 11.4' E 1060' 979.5115

Port Elizabeth

Port Elizabeth Airport - at door to tea room lounge on porch on field side of terminal.

33° 59.5' S 25° 36.9' E 150' 979.6514

Pretoria

Zwartkop Airport - at exit to runway outside of Movement Control room.

25° 49.0' S 28° 10.2' E 4770' 978.5993

Rooikop

Beneath windsock beside a cement platform.

23° 00.0' S 14° 37.5' E 500' 978.8052

Tsumeb (Southwest Africa)

On cement platform beside southeast corner of metal hangar.

19° 13.0' S 17° 43.8' E 427' 978.2209

Upington

Aerodrome parking ramp about 80' east of operations shack.

28° 25.3' S 21° 15.9' E 2711' 978.9850

UNION OF SOUTH AFRICA (cont.)

Windhoek (Southwest Africa)

At entrance to air traffic control.

22° 35.8' S

17° 06.0' E

5543'

978.3209

ANTARCTICA

Beardmore Station (LIV Station)

January 5, 1957 - Outside of the door leading into the living, eating and communications tent.

85° 02.0' S 164° 40.0' W 700' 983.0705

November 11, 1957 - 10' from the end of a quonset hut, 7' from the side of a second quonset hut. The antenna farm is on the opposite side of the second quonset hut.

83° 21.7' S 174° 52.5' E 187' 983.1181

Belgrano

At base of red and white steel antenna, 197 ft. east of entrance to base.

77° 56.8' S 38° 29.4' W 131' 982.9507

Byrd

At front entrance to Science Building.

79° 59.0' S 120° 01.0' W 4969' 982.5952

Ellsworth

Science Building library, northwest corner of room.

77° 42.6' S 41° 08.0' W 138' 982.9263

Hallett

Entrance to Magnetic Observatory.

72° 18' S 170° 18' E --- 982.7049

Little America

On gravity pier in Building 12.

78° 11.0' S 162° 10.0' W 141' 982.9816

Kiel Field - maintenance building in the office, just inside the door and adjacent to the desk, over an aluminum plate in the floor stamped "Kiel Field Gravity Station".

78° 12.0' S 162° 08.0' W 144' 982.9817

Marble Point

Bench mark JAYB (iron rod set in concrete) at summit of hill approximately 3936 feet east of ice cliff, 1968 feet east of camp site, 984' from coast. The hill, composed of coarse-grained marble, is highest hill between ice cliff and bay.

77° 24.9' S 163° 42.0' E 226' 982.9511

Mirny

At the gravity site outside the Cosmic Ray Building.

66° 33.0' S 93° 00.0' E 72' 982.4074

Roi Baudouin

Science Building, Ionosphere Lab, next to workbench midway between ionosphere sounder and clock.

70° 25.9' S 24° 18.6' E 125' 982.7806

Ross Island

McMurdo

Entrance to Air Operations Building 27 at ground level.

77° 53.1' S 166° 45.3' E --- 982.9891

Helicopter hangar - building 34A

--- --- --- 982.9911

Gulf Pendulum Site - in Building 30 on a concrete slab beneath the wooden floor boards, over a brass plaque stamped "Gulf Pendulum Station, McMurdo Sound."

77° 53.1' S 166° 45.3' E 40' 982.9919

Shackleton

At base of metal meteorology tower.

77° 57.0' S 37° 16.0' W 190'

February 7, 1956 982.9379

February 1, 1959 982.9363

Scott Base

On concrete pier in Seismograph Hut.

77° 51.0' S 166° 47.0' E 98' 982.9882

South Pole

On wooden boardwalk at corner of Byrd Boulevard and Waldron Avenue adjacent to the Science Building.

90 S 9184' 982.3261 ± 1.5

Wilkes

Between the Seismograph Building and the Geomagnetism Building 3' from the wall of the Seismograph Building.

66° 15.0' S 110° 31.0' E 33' 982.3996

At the foot of weather mast near air strip, 6 miles from station.
Top of mast is above snow surface.

66° 15.0' S 110° 36.0' E 843' 982.3310

Table III-A-7.3

ASIATIC AREA

Aden	Lebanon
Bahrein Island	North Borneo
Cambodia	Okinawa
Ceylon	Pakistan
China	Phillipines
Formosa	Qatar
Hong Kong	Sarawak
India	Saudi Arabia
Iran	Singapore
Iraq	Thailand
Japan	Trucial Oman
Kamaran Island	Turkey
Korea	Viet Nam
Kuwayt	

ADEN

Aden RAF Airport - right of passenger entrance to terminal.

12° 49.5' N 45° 01.5' E 10' 978.3180

BAHREIN ISLAND

BOAC terminal - at side door to customs.

26° 16.2' N 50° 38.5' E 6' 979.0147

CAMBODIA

Phnom Penh

Airfield - on concrete drive at new airport just outside of door to control tower at field elevation.

11° 32.5' N 104° 50.5' E 39' 978.2390

CEYLON

Colombo

Ratmalana Airport - on porch field side next to center post of customs entrance.

06° 49.0' N 79° 53.1' E 22' 980.1323

CHINA

Shanghai

Chang-Wau Airport - on runway level at foot of steps leading into waiting room of terminal.

31° 20.7' N 121° 30.1' E 15' 978.7556

Tsingtao

Tsangkau Airport - on floor in middle of terminal waiting room opposite door to runway.

36° 09.5' N 120° 22.9' E 25' 978.8344

FORMOSA

Taipei

Taipei International Airport - at field side and level, at foot of steps leading to base operations door.

25° 04.5' N 121° 32.8' E 21' 978.9735

HONG KONG

Kowloon

Kai-Tak Airport - next to fire hose in covered walkway outside passenger lounge.

22° 20.5' N 114° 12.5' E 15' 978.7730

INDIA

Allahabad, United Provinces

Bamrambi Airport - on lower step of portico leading to lounge of terminal building from runway.

25° 26.6' N 81° 44.1' E 319' 978.9484

Amritsar, Punjab

Amritsar Airdrome - on ground in front of the center of passenger lounge building.

31° 43.0' N 74° 46.5' E 760' 979.3484

Bangalore, Mysore

Inside door of Deccan Airways on field side 2' above field elevation.

12° 57.8' N 77° 40.4' E 2914' 978.0387

Bombay, Bombay

Santa Cruz Airport - by door to restaurant near phone booths in in large quonset terminal.

19° 04.5' N 72° 52.1' E 35' 978.6557

Calcutta, Bengal

Dum Dum Airport - field side, outside of terminal on porch against wall between doors to two lounges, 5" above single step, 8" above level of field around building.

22° 38.5' N 88° 26.1' E 13' 978.8077

Cawnpore, United Provinces

Chakeri Airport - on ground off runway beneath isolated group of large shade trees used as terminal by Bharat Airways.

26° 29.1' N 80° 25.1' E 405' 978.9799

Gaya, Bihar

On concrete step outside entrance to meteorological office from runway.

24° 44.9' N 84° 57.1' E 371' 978.8850

Hyderabad, Hyderabad

Hakimpet Airport - corner of porch on restaurant, nearest center of terminal.

17° 33.0' N 78° 31.0' E 2027' 978.3347

INDIA (continued)

Jammu, Jammu

Jammu Airdrome - to left and on first step to door to passenger lounge.

32° 43.0' N 74° 52.0' E 1029' 979.3041

Madras, Madras

Saint Thomas Mount Airport - to right of Main Street door to terminal building, 3' above field elevation.

12° 59.6' N 80° 10.9' E 51' 978.2804

New Delhi, Punjab

Palam Airport - road at junction of Station Road and Gurgaon Road, at center of Police Pedistos, above street level by 15".

28° 34.5' N 77° 07.2' E 755' 979.1341

Willington Airport - at north field entrance to terminal on cement at base of steps at field elevation.

28° 36.5' N 77° 12.8' E 695' 979.1377

Srinagar, Kashmir

By cement block (wing tab hold) at airfield.

33° 59.0' N 74° 48.0' E 5458' 979.0443

Trichinopoly, Madras

Tiruchirappalli Airport - on porch of customs building, field level next to door with iron fence near it, furthest from control tower.

10° 45.8' N 78° 43.0' E 292' 978.1606

IRAN

Tehran

Mehrabad Airport - the customs building on west side of field (brick building among tin and brick hangars) beneath "Exchange Control" window.

35° 41.0' N 51° 18.5' E 3937' 978.4491

IRAQ

Ain Zalah

Mosul Petroleum Company Air Field - to left of door to airport rest room.

36° 41.1' N 42° 36.1' E 1229' 979.7840

Baghdad

Baghdad Airport - 4' above field in large central room, off to left of traffic door beneath BOAC sign.

33° 19.3' N 45° 22.6' E 112' 979.5469

Basrah

Margil Airport - to right base of steps field entrance to airport terminal.

30° 34.0' N 47° 46.6' E 8' 979.3240

Kirkuk

Iraq Petroleum Company landing ground K-1 - inside waiting room to left as you enter.

35° 30.6' N 44° 18.3' E 1008' 979.6574

I.P.

K-3 Pumping Station - Iraq Petroleum Company Station, in lounge of hang .

I.P.

34° 04.3' N 42° 20.8' E 475' 979.6205

I.P.

T-1 Pumping Station - Iraq Petroleum Company Station, in corner of waiting room.

34° 14.0' N 41° 20.0' E 1043' 979.5991

JAPAN

Hokkaido Island

Chitose AFB

JAL terminal - field side of building in corner to left of entrance as you face building, field level.

42° 48.0' N 141° 40.0' E 82' 980.4405

Honshu Island

Atsugi Naval Air Station - on top step to right of concrete ramp in front of terminal building operations tower.

35° 27.7' N 139° 26.4' E 195' 979.7643

JAPAN (continued)
Honshu Island (continued)

Itami

United States Air Force Base, Japan Air Wing Air Terminal,
building 345.

34° 47.0' N 135° 26.9' E 50' 979.7171

Iwakuni

United States Air Force Base - top of operations building 64.

34° 09.0' N 132° 13.1' E 10' 979.6522

Misawa

United States Air Force Base - beneath window in field side of
base operations. Building 998.

40° 42.5' N 141° 23.0' E 119' 980.3200

Tachikawa

Air Force Base - at foot of steps outside Gate 2 to planes,
(Sign "Passenger terminal, Tachikawa AB" over door.) out-
side enclosure on right facing building.

35° 42.8' N 139° 24.2' E 316' 979.7880

Tokyo

Tokyo International Airport (formerly Haneda) - by pillar
between Gates 1 and 2.

35° 32.8' N 139° 45.9' E 7' 979.7733

Yokosuka

United States Navy Base - at dry dock 5 just next to building
A61, 5' from edge of dry dock.

35° 17.3' N 139° 39.6' E 00' 979.7803

Kyushu Island

Ashiya

United States Air Force Base - at outside entrance to hut
between hangars C and D.

33° 53.0' N 130° 38.4' E 106' 979.6779

Brady Air Force Base - to left of door to operations.

979.6739

JAPAN (continued)

Kyushu Island (continued)

Itazuke

United States Air Force Base - just inside Base Operations door on right looking out at flag poles.

33° 34.6' N 130° 27.1' E 30' 979.6481

KAMARAN ISLAND

Red Sea Area

Kameran Island Airport - information sign board outside operations building.

15° 22.8' N 42° 36.8' E 50' 978.3820

KOREA, REPUBLIC OF

Chinhae

Chinhae Airstrip - just inside base operations door on concrete floor.

35° 06.1' N 128° 45.0' E 10' 979.7833

Chunchon

Chunchon Airstrip - entrance to operations on concrete porch (stuccoed concrete building).

37° 52.0' N 127° 44.0' E 250' 979.9655

Pohang

Yongil-Man Airstrip - inside clearance at southwest corner of building.

35° 57.0' N 129° 24.0' E 55' 979.8612

Pusan

Pusan, East(Tongnae) Airstrip - to right of door to "Base Operations" 452nd Bomber Wing.

35° 10.0' N 129° 08.5' E 6' 979.7892

Pusan, West Airstrip - southwest end of operations building (control tower building).

35° 09.5' N 129° 08.0' E 12' 979.7780

Seoul

Kimpo Airfield - to right of West entrance from field of Quonset hut used as Base Operations. This hut is located 100 feet east of gutted former concrete terminal building.

37° 33.2' N 126° 46.5' E 64' 979.9722

KOREA, REPUBLIC OF (continued)

Taegu

Taegu Airfield - to left of door to "Base Operations".

35° 54.5' N 128° 39.0' E 103' 979.8329

KUWAYT

Al Kuwayt

Kuwayt Airport - in the terminal next to door on sitting porch on side of terminal away from field.

29° 21.7' N 48° 00.0' E 20' 979.2688

LEBANON

Beirut

Khalde International Airport - in sub-basement of new control tower building at brass plate on floor between rooms 518 and 519.

33° 50.5' N 35° 29.6' E 85' 979.6922

Bir-Hassan Airport - (now out of use) - at base of steps, car side of terminal; street level.

33° 52.0' N 35° 29.6' E 196' 979.6864

Tripoli

Kleiat Airport - Lebanon terminal to left of door to ladies room.

34° 35.1' N 35° 59.8' E 25' 979.7242

NORTH BORNEO

Jesselton

Jesselton Airport - inside meteorological enclosure in field side of terminal on north train-catcher base, 1" above ground level.

05° 57.0' N 116° 03.5' E 07' 978.1279

Labuan Island

International Airport - to right of steps leading to customs and immigration from field, 6" below field level.

05° 18.2' N 115° 15.2' E 98' 978.0960

Sandakan

Sandakan Air terminal - at base of washbowl in "Gentlemen's Lavatory."

05° 54.1' N 118° 04.0' E 38' 978.0914

OKINAWA

Kadena

Kadena Air Force Base - MATS terminal inside both sets of doors of exit to planes, below light switches on right facing field.

26° 21.5' N 127° 46.5' E 142' 979.1343

Naha

Naha Air Force Base - in corner to left of street entrance to base operations building.

26° 12.0' N 127° 39.1' E 14' 979.1224

PAKISTAN

Karachi

Karachi Commercial Airport - in terminal building at field entrance to main passenger lounge, a semi-circular building with control tower, 30" above surrounding sidewalk.

24° 54.1' N 67° 09.6' E 81' 978.9620

Mauripur Airport - on strip at walk to Health and Immigration building marked "RAF Staging Post-Mauripur".

24° 54.0' N 66° 56.8' E 35' 978.9583

PHILLIPINES, REPUBLIC OF

Clark Field

United States Air Force Base - just to left of field side entrance to MATS terminal.

15° 11.0' N 120° 33.0' E 475' 978.3905

Manila

International Airport (Nicols Field) - on field side of building below north end of long (14 m) cement step.

14° 31.5' N 121° 00.5' E 67' 978.3767

QATAR

Dukhan Airstrip - to left of door to control tower building, Petroleum Development Ltd., airstrip.

25° 23.4' N 50° 49.0' E 00' 978.9528

SARAWAK

Kuching

Kuching Airport - air terminal immediately inside folding door to "Immigration" waiting room, 3' above Tarmac level.

01° 29.0' N 110° 20.5' E 80' 978.0763

Sibu

Sibu Airport - control tower building at outside door to building near step to tower on building apron.

02° 18.0' N 111° 49.9' E 18' 978.0790

SAUDI ARABIA

Abu Hadriyah

At base of wind sock mast on runway level.

27° 19.7' N 48° 59.3' E 80' 979.1084

Dhahran

Dhahran Air Force Base - on front top step, right side from field, just outside lobby entrance.

26° 16.4' N 50° 10.0' E 70' 978.9990

Jidda

Field side (east) of passenger terminal about 35' east of field entrance doors at north gate of 2 gates in concrete wall, about 6" below passenger terminal floor elevation and about 1' below strip elevation; about 40' fieldwards from center of control tower.

21° 29.7' N 39° 12.4' E 50' 978.7556

Ras Al Mishab

Ras Al Mishab Airstrip - on runway at fence opposite customs office shed.

28° 01.4' N 48° 51.8' E 20' 979.1696

SINGAPORE

Changi

Air movements office on veranda, outside money changing booth.

01° 22.0' N 103° 59.0' E 10' 978.0801

SINGAPORE (continued)

Kallang Airport (now Singapore Youth Sports Center) - to right of front entrance beneath building directory sign.

01° 18.4' N 103° 53.9' E 10' 978.0817

Paya Lebar Airport (Singapore International Airport) - passageway to planes beneath bronze tablet commemorating opening of the airport.

01° 20.5' N 103° 53.5' E 59' 978.0804

THAILAND

Bangkok

Don Muang Airport - field side of terminal in front of terminal.

13° 54.7' N 100° 36.5' E 12' 978.3297

TRUCIAL OMAN

Sharjah

RAF Airfield - just inside large doors at the Fort.

25° 21.1' N 55° 24.2' E 6' 978.9026

TURKEY

Ankara

Etimesut Civil Airport (Sivil Hava Alani) - in lowest level basement room at center post in terminal building (room is beneath restaurant kitchen). (Turkish secondary base.)

39° 57.0' N 32° 40.0' E 2660' 979.9500

Izmir

Cuma Ovasi Airport - at base of central tower on concrete paving at center of curved field-side wall of tower.

38° 15.1' N 27° 10.5' E 312' 980.0231

VIET NAM

Hanoi

Hanoi Airport - just inside terminal field side, next to "arrivee" counter, in rotunda, 2' above field elevation.

21° 02.0' N 105° 53.0' E 10' 978.6888

VIET NAM (continued)

Hue

Hue Airport - on flight strip nearest control tower at center of strip on concrete walk.

16° 23.2' N 107° 43.0' E 49' 978.4367

Nha-Trang

Nha-Trang Airport - on porch of terminal building, field side just outside "Meteorologie" door, 2' above field elevation.

12° 13.9' N 109° 11.5' E 10' 978.2624

Saigon

Tan Son Nhut Airport - at base of spiral staircase on field side of terminal.

10° 49.1' N 106° 38.5' E 33' 978.2300

Table III-A-7.2

ATLANTIC OCEAN AREA

Ascension Island

Azores

Bermuda

Iceland

ASCENSION ISLAND

At Weather Station in Operations Room in center of floor.

07° 58.5' S 14° 24.4' W 264' 978.2960

AZORES

Terceira Island

Lajes Airport - on right side of wooden terminal.

38° 45.2' N 27° 05.6' W 180' 980.1761

Santa Maria Island

Santa Maria Airport - at opening in customs counter near entrance by wall.

36° 57.7' N 25° 09.9' W 305' 980.1167

BERMUDA

Kindley AFB - under arcade which is parallel to taxi stand at rear corner of customs; in terminal reception room.

32° 21.7' N 64° 40.1' W 11' 979.8093

Mongus Island - Naval Operations Base control tower; sea plane base.

32° 16.1' N 64° 50.9' W 8' 979.8735

FERNANDO DO NORONHA ISLAND

Aircraft parking ramp - by barrier fence at sign "STAY BEHIND BARRIER".

03° 58' S 32° 30' W 168' 978.2989

ICELAND

Keflavik Airport - on floor of new terminal building by radiator to right of exit door to field, at east end of lobby.

63° 58.9' N 22° 36.0' W 169' 982.2744

Reykjavik Airport - at entrance to terminal.

64 08.0' N 21 56.5' W 45' 982.2784

Table III-A-7.4

AUSTRALIAN AREA

Australia

Indonesia

New Guinea

New Zealand

AUSTRALIA

Adelaide, South Australia

Adelaide Airport - at foot of steel steps in passenger waiting room of new terminal with control tower on top.

34° 57.0' S 138° 31.5' E 20' 979.7196

Parafield Airport - at foot of steel steps in new terminal, this is now a wood floor.

34° 47.1' S 138° 38.2' E 60' 979.7054

Alice Springs, Northern Territory

About 600' from waiting room in a small building.

23° 48.4' S 133° 53.5' E 1792' 978.6544

Brisbane, Queensland

Brisbane Airport (formerly Eagle Farm Airport) - to right of field entrance to TAA terminal waiting room.

27° 24.6' S 153° 05.0' E 18' 979.1598

Broome, Western Australia

Left of stairs leading to porch and entrance on south side of air radio building.

17° 56.6' S 122° 13.4' E 56' 978.5387

Cairns, Queensland

On first step to QEA office at field.

16° 53.0' S 145° 45.3' E 7' 978.5005

Camooweal, Queensland

At right front corner of small metal building at airfield.

19° 54.5' S 138° 07.5' E 792' 978.5665

Canberra, Commonwealth Territory

Fairbairn Airport - civil TAA terminal building at corner on field.

35° 18.0' S 149° 10.8' E 1886' 979.6210

Carnarvon, Western Australia

Left of gate in fence leading to waiting rooms.

24° 53.0' S 113° 40.2' E 15' 978.9448

Ceduna, South Australia

At left front corner of ANA building from field.

32° 08.0' S 133° 42.0' E 74' 979.4535

AUSTRALIA (continued)

Charters Towers, Queensland

Left of entrance to waiting room in building from field.

20° 02.6' S 146° 16.8' E 1000' 978.5954

Cloncurry, Queensland

Right of stairs leading to porch at passenger lounge.

20° 40.2' S 140° 30.0' E 623' 978.6517

Daly Waters, Northern Territory

Left side of hangar, looking at side nearest airport waiting room.

16° 15.5' S 133° 22.0' E 694' 978.3894

Darwin, Northern Territory

On sidewalk inside fence right of gate outside Inter-state Passenger Lounge.

12° 24.5' S 130° 52.2' E 101' 978.3153

Derby, Western Australia

At the left front corner of the hangar.

17° 21.0' S 123° 40.6' E 4' 978.5208

Forrest, Western Australia

Center of hangar door directly beneath a weather vane.

30° 50.2' S 128° 06.4' E 512' 979.3069

Geraldton, Western Australia

Left of gate in fence leading to waiting rooms.

28° 47.5' S 114° 42.6' E 120' 979.2697

Hobart, Tasmania

Right of gate at field and by window in TAA building.

42° 49.6' S 147° 29.1' E 30' 980.4432

Hughendon, Queensland

Beneath box at fence near gate.

20° 50.0' S 144° 12.8' E 1000' 978.6110

Ipswich, Queensland

Amberley RAAF Base - 30 miles west of Brisbane, front door of building 114 (Transient Personnel office)

27° 39.0' S 152° 43.5' E 80' 979.1557

AUSTRALIA (continued)

Julia Creek, Queensland

At right front corner of shed at airfield.

20° 41.3' S 141° 44.4' E 400' 978.6543

Kalgoorlie, Western Australia

On ground at right front corner of porch in front of ANA building at field (corner nearest air radio building).

30° 46.1' S 121° 27.6' E 1188' 979.2913

Katherine, Northern Territory

At base of lamp post at outer field side of terminal building.

14° 26.5' S 132° 16.5' E 351' 978.3453

Launceston, Tasmania

Right of and in front of a series of windows in front of passenger lounge at airdrome.

41° 33.2' S 147° 12.8' E 562' 980.2775

Leigh Creek, South Australia

In men's room of airport waiting room building.

30° 27.6' S 138° 26.5' E 640' 979.3207

Mackay, Queensland

On ground at left corner (as viewed from field) of air radio building and tower.

21° 11.0' S 149° 11.6' E 16' 979.7340

Maryborough, Queensland

Cambridge pendulum site in hangar.

25° 32.5' S 152° 42.4' E 34' 979.0219

Melbourne, Victoria

Essenden Airport - field side TAA terminal on asphalt apron between Gates 2 and 3.

37° 43.5' S 144° 53.5' E 283' 979.9729

Laverton RAAF Base - at base of steel control tower on apron.

37° 21.5' S 144° 45.6' E 52' 979.9911

Mount Eba, South Australia

On left side of concrete porch of small green hut on field.

30° 09.8' S 135° 40.7' E 700' 979.2991

AUSTRALIA (continued)

Mount Isa, Queensland

Southwest corner of passenger terminal building (outside)
at field elevation.

20° 44.5' S 139° 31.0' E 1113' 978.6191

Nhill, Victoria

At front left corner of ANA building at airdrome viewed
from field.

36° 18.0' S 141° 39.0' E 430' 979.8217

Oodnadatta, South Australia

On ground to right of right entrance to radio shack of airfield.

27° 34.5' S 135° 27.5' E 383' 979.1012

Onslow, Western Australia

At front left corner of the right of two small motel huts
(storage for Vacuum Air Service) as viewed from field.

21° 41.0' S 115° 06.0' E 2' 978.7750

Perth, Western Australia

Right of entrance to TAA passenger lounge.

31° 55.5' S 115° 57.5' E 62' 979.4011

Port Hedland, Western Australia

Left of gate in fence by a warning sign on a fence.

20° 22.5' S 118° 37.0' E 26' 978.6458

Richmond, New South Wales

Base of old steel frame control tower at ground level across
ramp from row of five hangars.

33° 35.8' S 150° 46.9' E 50' 979.6460

Rockhampton, Queensland

Right of entrance to TAA building from field.

23° 23.1' S 150° 28.5' E 32' 978.9737

Roebourne, Western Australia

Southeast corner of the southern-most runway marker at south
end of airstrip.

20° 46.7' S 117° 07.1' E 50' 978.6795

AUSTRALIA (continued)

Sydney, New South Wales

Kingsford-Smith Airport - at Mascot field right of entrance
outside to overseas waiting room, "Departures" entrance.

33° 56.0' S 151° 11.0' E 20' 979.6993

Rose Bay, Flying Boat Base - on sidewalk to right of steps
to entrance.

33° 51.6' S 151° 16.0' E 00' 979.6965

Tennant Creek, Northern Territory

Northwest corner of air radio building.

19° 38.3' S 134° 10.9' E 1235' 978.5292

Townsville, Queensland

Northwest corner of passenger lounge building.

19° 15.1' S 146° 46.0' E 13' 978.6240

Wyndham, Western Australia

10' east of southwest corner of air radio building (along
front of building from the field)

15° 31.0' S 128° 08.6' E 14' 978.4151

INDONESIA

Djakarta

Kemajoran Airport - on porch of restaurant field side next
to a quarter circle bar.

06° 09.3' S 106° 50.9' E 16' 978.1644

NEW GUINEA

Port Moresby, Papua

To right (on ground) of entrance to airdrome waiting room.

09° 26.4' S 147° 12.4' E 100' 978.2142

NEW ZEALAND

Auckland

Whenuapai Airport - on field side of passenger terminal to
right of door to wood building, on porch 3' high.

36° 47.5' S 174° 38.2' E 100' 979.9408

NEW ZEALAND (continued)
Auckland (continued)

Mechanics Bay Flying Boat Base - northeast corner of customs building on concrete, water side of building.

36° 50.0' S 174° 47.1' E 00' 79.9632

Christchurch

Harewood Airport - northwest corner on large asphalt square flush with ground of wind indicator, south of terminal about 25'.

43° 28.6' S 172° 31.5' E 113' 980.4962

Wigram Airport - on field side of Administration building at apron elevation control tower on top of building.

43° 32.4' S 172° 33.0' E 70' 980.5101

Dunedin

Taireri Airport - on 1st step of field side of terminal entrance.

45° 51.6' S 170° 22.0' E 85' 980.7367

Gisborne

Under canopy by waiting room door.

38° 39.5' S 177° 58.5' E 17' 980.0422

Hastings

Hastings Airport - at Cambridge pendulum station in mapping service hangar.

39° 38.3' S 176° 46.6' E 72' 979.0881

Napier

Northwest corner of tower.

39° 28.1' S 176° 51.5' E 3' 980.0431

Palmerston North

At southwest corner of administration building.

40° 19.4' S 175° 37.2' E 146' 980.0999

Paraparaumu

Paraparaumu Airport - (35 miles north of Wellington) on street side of terminal to right of ramp to waiting room, outside.

40° 54.1' S 174° 59.4' E 22' 980.2097

NEW ZEALAND (continued)

Tauranga

Northeast corner of hangar by rain spout.

37° 40.0' S

176° 12.0' E

12'

980.0162

Table III-A-7.5

CENTRAL AMERICAN AREA

British West Indies

Canal zone

Costa Rica

Cuba

El Salvador

Guatemala

Honduras

Nicaragua

Panama

Puerto Rico

Virgin Islands

BRITISH WEST INDIES

Antigua

Coolidge Airport - in passenger waiting room just left of information window.

17° 06.8' N 61° 47.0' W 25' 978.6538

St. Lucia

Beane Field - on cross walk between crew and passenger walks to parking ramp.

13° 44.8' N 60° 57.0' W 10' 978.5327

Trinidad

Piarco Airport - at H.M. Customs door in waiting room.

10° 35.8' N 61° 20.8' W 38' 978.1622

CANAL ZONE

Balboa

Albrook Air Force Base - MATS terminal passenger field entrance under the open porch between two supporting pillars in line with flower boxes.

08° 58.5' N 79° 33.0' W 31' 978.2426

Howard Air Force Base - by first door at hangar 1.

08° 55.0' N 79° 36.1' W 30' 978.2316

COSTA RICA

San Jose

San Jose Airfield - at steps leading to office.

09° 59.0' N 84° 12.2' W 3021' 977.9792

CUBA

Guantanamo Bay

Naval Air Station - hangar to which control tower is affixed outside terminal and waiting room on strip at canopy.

19° 53.5' N 75° 09.6' W 51' 978.7452

EL SALVADOR

San Salvador

Ilopango Airport - at doorway to men's room on second balcony.

13° 41.7' N 89° 06.4' W 2044' 978.1866

GUATEMALA

Guatemala City

La Aurora Airport - at middle of wall inside customs room
beneath mural map of Guatemala.

14° 33.5' N 90° 31.5' W 4925' 977.9816

HONDURAS

Tegucigalpa

Toncontin Airport - in front of gate 5, 15' south of door at
12' pillar.

14° 03.0' N 87° 13.0' W 3094' 978.0856

NICARAGUA

Managua

In waiting room to right (facing field) of exit door to
planes.

12° 06.5' N 86° 10.8' W 190' 978.2859

PANAMA

Panama

Tocumen Airport - IAGS gravity station BM in front of Marcos A.
Gelabert statue in between gate 1 and field, 9" above
field level.

09° 04.5' N 79° 22.6' W 135' 978.2665

PUERTO RICO

Aguadilla

Ramey Air Force Base - street entrance to MATS terminal.

18° 30.0' N 67° 08.5' W 237' 978.6601

San Juan

Pan American Airport - just inside and to left of exit gate
from customs and baggage room, ~~Air Force terminal room~~
~~right of door.~~

18° 27.6' N 66° 05.3' W 15' 978.6838

errata

VIRGIN ISLANDS

St. Croix Island

Alexander Hamilton Field - on lower step, left side, of
incoming and transient passenger entrance.

17° 42.0' N

64° 47.6' W

62'

978.6609

St. Thomas Island

Bourne Field - to right of incoming passenger door on hangar
floor.

18° 20.8' N

64° 57.2' W

8'

978.6807

MEXICO

checked ones not plotted

- 1 Campeche, Campeche
20' north of sidewalk to waiting room.
19° 50.0' N 90° 33.5' W 25' 978.6519
- 2 Casas Grandes, Chihuahua
At entrance to Administration Building.
30° 23.0' N 107° 53.0' W 4850' 978.9105
- 3 Chihuahua, Chihuahua
LAMSA Airport - 10' west of sign at gate to Administration Building.
28° 40.0' N 106° 06.5' W 4690' 978.7588
- 4 Ciudad del Carmen, Campeche
At field end of walk from terminal.
18° 40.0' N 91° 48.0' W 5' 978.5676
- 5 Ciudad Victoria, Tamaulipas
Airport, at entrance gate to path leading to terminal building (10' north and 10' west); 20' south of center line of road.
23° 43.0' N 98° 55.0' W 770' 978.7862
- 6 Culiacan, Sinaloa
6' west of northernmost gate to Administration Building.
24° 47.0' N 107° 24.5' W 144' 978.9315
- 7 Ensenada, Baja California
West corner of airport terminal terrace.
31° 52.8' N 116° 35.9' W 50' 979.4383
- 8 Guadalajara, Jalisco
Intersection of runway and sidewalk that goes to main door of terminal.
20° 37.7' N 103° 20.6' W 5200' 978.2203
- 9 Guasave, Sinaloa
At field end of sidewalk from Administration Building.
25° 35.0' N 108° 29.3' W 57' 978.9843
- 10 Guaymas, Sonora
50' west of NO SMOKING sign on east side of Administration Building, 25' north.
27° 58.0' N 110° 52.5' W 5' 979.1785

MEXICO (cont.)

- 11 Hermosillo, Sonora
Airstrip at sidewalk to terminal.

29° 06.5' N 110° 57.0' W 750' 979.1872

- 12 Juarez, Chihuahua
LAMS Base, 1' north and 2' east of gate to field in front of Administration Building.

31° 40.0' N 106° 25.0' W 3740' 979.0697

- 13 La Paz, Baja California
On airstrip between two sidewalks leading from terminal.

24° 09.9' N 110° 16.4' W 50' 978.9192

- 14 Loreto, Baja California
In front of semi-destroyed hangar on a mound of dirt.

26° 01.2' N 111° 21.2' W 10' 979.0181

- 15 Los Mochis, Sinaloa
At end of sidewalk to field.

25° 48.5' N 108° 59.0' W 27' 979.0199

- 16 Mazatlan, Sinaloa
At field end of sidewalk from terminal.

23° 15.0' N 106° 25.7' W 20' 978.8507

- 17 Minatitlan, Veracruz
At southeast corner of Sanitary Kiosk.

18° 00.9' N 94° 32.2' W 83' 978.4926

- 18 Merida, Yucatan
At end of sidewalk leading to Administration Building from field.

20° 55.5' N 89° 39.0' W 30' 978.6990

- 19 Mexico City, Distrito Federal
Central Airport - Customs (old terminal); 5' east and 2' north of outside door for visitors.

19° 25.5' N 99° 06.0' W 7347' 977.9669

- 20 New Airport - in corner of waiting room for incoming passengers, corner formed by wall on field side and glass partition of exit room from Customs.

--- --- --- 977.9701

MEXICO (cont.)

- 21 Monterrey, Nuevo Leon
At gravity marker on curb on street side of terminal opposite entrance.
25° 53.0' N 100° 14.0' W 1474' 978.8618
- 22 Navojoa, Sonora
On sidewalk outside terminal entrance.
27° 03.8' N 109° 26.2' W 10' 979.0967
- 23 Nuevo Laredo, Tamaulipas
Municipal Airport - 20' west of gate at highway.
27° 26.0' N 99° 31.0' W 420' 979.0770
- 24 Oaxaca, Oaxaco
Runway end of sidewalk.
17° 06.0' N 96° 42.0' W 5158' 978.0218
- 25 Obregon, Sonora
At field end of walk from terminal.
27° 31.0' N 109° 55.0' W 120' 979.1297
- 26 Parral, Chihuahua
Aeropuerto - 6' south of runway on east side of walk.
26° 52.0' N 105° 47.0' W 5990' 978.5372
- 27 Saltillo, Coahuila
At airport - at street at center line of door of entrance.
25° 27.3' N 101° 01.2' W 4801' 978.5785
- 28 San Luis Potosi, San Luis Potosi
LAMSA, at NO SMOKING sign on field side of terminal.
22° 11.5' N 100° 59.5' W 6158' 978.2079
- 29 Santa Rosalia, Baja California
Concrete platform between terminal and airstrip, next to gasoline tanks.
27° 20.1' N 112° 16.9' W 150' 978.1079
- 30 Tamuin, San Luis Potosi
American Airlines and CIA Mexican Airport - 20' north of gate in
fence around Radio Shack and main office.
22° 03.0' N 98° 48.5' W 164' 978.7589

MEXICO (cont.)

31 Tapachula, Chiapas

At field end of sidewalk from terminal.

14° 52.8' N 92° 18.0' W 356' 978.3186

32 Tehuantepec, Tehuantepec

At field end of sidewalk from terminal.

16° 28.0' N 95° 06.0' W 83' 978.4190

33 Tepic, Nayarit

At south corner of junction of sidewalk to Administration Building and runway.

21° 30.0' N 104° 51.5' W 3123' 978.4682

34 Tijuana, Baja California

Northwest corner of terminal lobby.

32° 34.4' N 117° 07.3' W 250' 979.4760

35 Torreon, Coahuila

LAMSA; on sidewalk at NO SMOKING sign. Just east of gate 2.

25° 36.0' N 103° 23.5' W 3735' 978.6399

36 Tuxtla Gutierrez, Chiapas

At field end of sidewalk from terminal.

16° 44.8' N 98° 05.5' W 1805' 978.2951

37 Veracruz, Veracruz

On pavement 10' south of NO SMOKING sign.

19° 09.0' N 96° 12.0' W 70' 978.5613

38 Villahermosa, Tabasco

At gate to Administration Building.

17° 59.5' N 92° 56.2' W 45' 978.5278

Table III-A-7.6

EUROPEAN AREA

Belgium

Cyprus

Denmark

Eire (Ireland)

England

Finland

France

Germany

Greece

Italy

Malta

Netherlands

Norway

Portugal

Scotland

Spain

Sweden

Switzerland

Yugoslavia

BELGIUM

Brussels-Melsbroek

National Airport - center of new terminal building on field side, at field level, under overhang on tile roadway outside baggage room. This site is underneath field side of transit passenger room.

50° 53.7' N 04° 29.4' E 127' 981.1567

CYPRUS

Nicosia

At fence by outside door next to men's room in the restaurant.

35° 08.9' N 33° 16.6' E 734' 979.8353

DENMARK

Copenhagen

Kastrup Airport left of entrance (revolving door) to "waiting room for transit passengers"; sign on roof above.

55° 37.2' N 12° 39.9' E 16' 981.5572

EIRE (IRELAND)

Belfast

Nutts Corner Airport - at corner of control tower on manhole plate.

54° 38.5' N 06° 08.8' W 359' 981.4790

Dublin

Dublin Airfield (formerly Collinstown Airfield) - on ramp on side of terminal.

53° 25.8' N 06° 14.7' W 223' 981.3989

Limerick

Shannon Airport - just inside of terminal at transit passenger's door.

52° 41.7' N 08° 54.5' W 15' 981.3424

ENGLAND

Blackbushe

RAF base. At entrance to quonset hut (old terminal) which is to right-rear (behind a waiting room) looking at new terminal from field.

51° 19.3' N 00° 51.0' W 320' 981.1554

Bovingdon

Airfield inside customs building just outside door marked "H. M. Customs" in room with long baggage tables.

51° 43.7' N 00° 33.4' W 535' 981.1935

ENGLAND (cont.)

Downham Market

Marham Field - RAF base at edge of runway directly in front of room for incoming baggage and mail for U.S. personnel.

52° 39.0' N 00° 33.8' E 80' 981.3134

Liverpool

Burtonwood Airfield - on wall at right rear corner of control tower building facing the MATS terminal building.

53° 25.2' N 02° 38.1' W 60' 981.3918

London

Airport Central - on covered pavement one foot from retaining wall in line with wall of basement building opposite. (Outside V. K. Customs Barrier).

51° 28.1' N 00° 27.0' W 74' 981.2003

Airport North - opposite PAA - TWA counter in center of lobby.

--- --- --- 981.2017

Hendon Field - RAF base at door marked "passenger reception" in building with control tower on RAF side of field.

51° 36.0' N 00° 13.1' W 160' 981.2072

Northolt Field - RAF side of terminal on concrete base of flagpole at plane parking outside "RAF command" door and VIP lounge.

51° 31.9' N 00° 25.0' W 112' 981.2074

Lympne

Lympne Field - outside entrance to right in hall. Right side of door on sidewalk.

51° 04.7' N 01° 00.2' E 340' 981.1515

Lyneham

RAF base on floor in far corner of reception room for incoming passengers diagonally across from runway entrance.

51° 30.9' N 01° 58.6' W 513' 981.1705

Mildenhall

Lakenheath RAF base - gate No. 2 entrance to customs PAX terminal building on left outside door, entering.

52° 24.1' N 00° 33.2' E 50' 981.2954

FINLAND

Helsinki

Helsinki Airfield - (Sentala Field) - in front of temporary terminal on flagstones to right of baggage entry, facing field.

60° 19.0' N 24° 58.0' E 167' 981.9249

Malmi Field - floor in rotunda of terminal building directly opposite entrance to passport inspection office for departing passengers.

60° 15.7' N 25° 02.6' E 49' 981.9206

FRANCE

Beauvais

Tille Field - outside customs door on field side of terminal.

49° 27.5' N 02° 07.4' E 344' 980.9966

Bordeaux

Merignac Airfield - on ground at edge of runway about 50' from control tower and on line between control tower and entrance to terminal building across the runway.

44° 50.0' N 00° 42.5' W 161' 980.5816

Marseilles

Marignane Field - in corner of waiting room about 1 foot from library - tobacco counter which serves both this and the transit waiting room.

43° 25.9' N 05° 13.9' E 65' 980.4880

Paris

Le Bourget Airport - at foot of stairs on street side of main lobby left of departure entrance.

48° 57.3' N 02° 26.9' E 180' 980.9502

Orly Airfield - field side entrance to MATS - USAF terminal.

48° 43.3' N 02° 23.2' E 295' 980.9166

Orly Airfield - gate 5, civilian terminal.

48° 43.3' N 02° 23.2' E 295' 980.9149

GERMANY

Frankfurt

Rhein/Main AFB - at right entrance to AF terminal from field.

50° 02.1' N 08° 34.0' E 368' 981.0559

GERMANY (cont.)

Wiesbaden

Wiesbaden AFB - at left pillar to field entrance to "Base Operations" on granite porch. Small control tower over porch.

50° 03.3' N 08° 20.9' E 460' 981.0610

GREECE

Athens

Ellinikon Airport - In corner of waiting room of 7206th USAF air base squadron passenger terminal at door from waiting room to restaurant.

37° 54.5' N 23° 43.7' E 62' 980.0592

ITALY

Naples

Capodichina Airport - civilian terminal, in front of telegraph office in customs entrance of terminal building.

40° 53.6' N 14° 17.5' E 303' 980.2559

Capodichina NAS - side of field in northeast corner of western of two hangars, close to Navy terminal.

--- --- --- 980.2568

Rome

Ciampino EST Terminal - to north of "arriving passengers" entrance to busses.

41° 47.9' N 12° 36.0' E 423' 980.3488

Ciampino OVEST Terminal - on sidewalk to left of field entrance to USAF terminal.

41° 47.9' N 12° 36.0' E 423' 980.3478

MALTA

Luqa Civil Air Terminal - baggage port for incoming passengers, second door east of buffet room, north side of terminal, 2' above field.

35° 51.5' N 14° 29.0' E 297' 979.8654

NETHERLANDS

Amsterdam

Schiphol Airport - on floor to left of inner door entering new terminal from runway.

52° 18.7' N 04° 47.0' E -13' 981.2871

NORWAY

Bodo

Bodo Airport - control building (with control tower on it) on ground floor in a small store room behind reception desk.

67° 16.3' N 14° 22.5' E 31' 982.3870

Oslo

Fornebu Airport - inside terminal building at 2nd circular pillar to right (on entering passenger entrance from cars). Pillar is between BEA and PAA offices, 5 meters from Cashier and 10 meters from "Bank" windows.

59° 54.5' N 10° 37.5' E 56' 981.9306

Tromso

Sea plane base - 1' back and 3" above N.G.O. reference mark which is on Tromso side of terminal building near top of a bank.

69° 40.2' N 19° 58.3' E 0' 982.5710

Trondheim

Vaernes Airport - 20 miles west of Trondheim, on field outside hangar No. 1. At post for center door closest to passenger terminal.

63° 27.5' N 10° 56.0' E 61' 982.1529

PORTUGAL

Lisbon

Martin-Gonzales station at bolt in floor outside SITA Office on lowest level of terminal. Also near exit of baggage customs.

38° 46.6' N 09° 08.2' W 361' 980.0796

SCOTLAND

Aberdeen

Dyce Airfield - on concrete square at base of flagpole outside terminal waiting room.

57° 12.0' N 02° 12.0' W 200' 981.6920

Glasgow

Renfrew Field - below control tower just outside and to right of field entrance to terminal building.

55° 51.3' N 04° 23.2' W 35' 981.6022

Orkney Islands

Grimsetter Airfield - near Kirkwell, at base of old control tower on concrete slab to left of entrance steps. Five feet above runway level.

58° 56.8' N 02° 54.5' W 40' 981.8708

SCOTLAND (cont.)

Prestwick

Prestwick Airfield - in foyer of new passenger lounge building, in corner away from field door, left side as you enter and against wall and window.

55° 30.1' N 04° 34.5' W 64' 981.5758

Shetland Islands

Sunburgh Airfield - on concrete floor inside luggage shed about halfway to terminal from field. 4' above field level.

59° 52.9' N 01° 17.4' W 29' 981.9482

SPAIN

Madrid

Barajas Airport - at secondary G base on porch of "Lazoreto" (Quarantine) at northeast corner (building to be destroyed).

40° 28.2' N 03° 34.0' W 1985' 979.9988

Getafe AFB - on porch at center of curved porch at door directly beneath control tower.

40° 17.2' N 03° 43.8' W 2030' 979.9917

Torrejon AFB - Base operations building on field side of porch about 1 foot left of hinge of left door when entering. 30' from control tower.

40° 29.4' N 03° 28.5' W 1991' 980.0072

SWEDEN

Goteborg

Torslanda Airport - field side of terminal at right base of steps to main entrance to terminal, 2' below top of steps and about 2 1/2 ' above piste level (next to large flower pot).

57° 43.0' N 11° 46.5' E 13' 981.7443

Stockholm

Bromma Airport - right of entrance from runway to immigration office for incoming passengers.

59° 21.0' N 17° 56.8' E 46' 981.8458

SWITZERLAND

Geneva

Cointrin Airport - on field side of terminal directly beneath control tower, 3 feet towards field from door marked "Pilatus Air Service" and 5 1/2 feet from large grill work on ground.

46° 14.0' N 06° 06.5' E 1411' 980.5888

Zurich

Kloten Airport - 2 feet parallel to building at post with telephone on it, outside a door to the terminal on field side to right of control tower looking at it.

47° 27.0' N 08° 33.3' E 1414' 980.6864

YUGOSLAVIA

Belgrade

Zemun Airport - on pier on airport.

44° 48.9' N 20° 25.2' E 243' 980.6071

NORTH AMERICAN AREA

Alaska

Canada and Arctic Area

United States

ALASKA

Adak

On ground 8 feet from door of Reeve Aleutian Airlines Office.

51° 52.8' N	176° 38.8'	21'	981.4420
-------------	------------	-----	----------

Allakaket

Northwest end of the northwest-southeast landing strip, 30 feet from top of bank of river.

66° 34.1'	152° 35.5'	475'	982.3583
-----------	------------	------	----------

Anchorage

Anchorage International Airport - on blacktop at passenger entrance from Gates 3 and 4, 4 feet from building.

61° 10.1'	149° 58.5'	117'	981.9204
-----------	------------	------	----------

Annette Island

Pan-American Airport - just inside main entrance to Administration Building.

55° 02.9'	131° 34.0'	119'	981.5266
-----------	------------	------	----------

Barrow Airfield

On the ground before the entrance to the passenger terminal.

71° 20.1'	156° 38.5'	9'	982.6993
-----------	------------	----	----------

Barter Island

125 feet toward village from end of runway, in center of road which runs from village to runway and skirts its seaward side.

70° 08.1'	143° 36.8'	4'	982.5954
-----------	------------	----	----------

Bear Creek

Landing strip runs north-south. Station is south of the center of the strip on its west side, where a road joins the strip.

63° 34.4'	156° 09.0'	600'	982.1482
-----------	------------	------	----------

Beaver

West of the center of east-west landing strip, on south side of strip where a road from the village joins the strip.

66° 21.8'	147° 25.0'	600'	982.3315
-----------	------------	------	----------

Big Delta

30 feet west of southwest corner of hangar on which control tower is affixed.

63° 59.7' 145° 42.6' 1266 982.1020

Battles Field

East end of east-west runway, opposite Wien Alaska Airlines Building, 3 feet from a white gas tank.

66° 55.0' 151° 30.5' 665' 982.3842

Boundary

End of landing strip, 15 feet from door of the "Bunk House".

64° 04.5' 141° 07.4' 2700 981.9850

Cape Lisburne

Center of the apron at south end of runway.

68° 52.7' 166° 09.4' 6' 982.5304

Cape Newenham

Center of runway, 50 feet from its extreme easternmost (highest) end.

58° 38.3' 162° 05.3' 600' 981.8247

Caribou

In center of airfield.

64° 39.6' 145° 43.7' 1150 982.1635

Chena Hot Springs

Opposite the center of the airfield at its south edge.

65° 03.9' 146° 05.0' 1500 982.1711

Chicken

On north side of airfield at junction of access road.

64° 04.5' 141° 56.0' 1800 982.0554

Chisana

At end of landing strip, where path from cabins meets strip, 15 feet from a wind sock.

62° 04.3' 142° 02.6' 3300 981.7941

Chitina

In center of airplane apron at north end of old 1800 foot landing strip.

61° 35.0' 144° 26.5' 620' 981.9492

Circle

South end of the north-south landing strip in a road which runs along the east side of a strip 150 feet west of the "Do Drop Inn".

65° 50.7' 144° 04.6' 598' 982.3049

Demarcation Point

DEW line radar station, in the center of the runway at its west end.

69° 39.4' 141° 13.2' 1' 982.5672

Dillingham

Landing field 2 miles west of town, at apron on east side of runway near its center, on south side of apron, 3 feet from door of the 8 x 12 foot orange Bristol Bay Airlines Building.

59° 02.6' 158° 31.1' 83' 981.8658

Dutch Harbor

Airport Waiting Room and Weather Station, on the concrete walk immediately outside field entrance. The number "115" appears above the door.

53° 53.9' 166° 32.5' 10' 981.5530

Eagle

At junction of two dirt roads near center of airstrip North of town.

64° 47.4' 141° 13.0' 791' 982.1821

Eielson AFB

At southeast corner of hangar #116 (control tower hangar), inside hangar beneath control tower.

64° 39.3' 147° 04.8' 544' 982.2165

Ekwok

Landing strip on a sandbar forming an island in the Nushagak River, on the extreme downstream end of island.

59° 22.8' 157° 28.2' 120' 981.8971

Elim

Center of landing strip, 30 feet from its extreme north end.

64° 36.8' 161° 08.4' 100' 982.2739

Fairbanks

Fairbanks International Airport - Passenger Terminal, on the concrete floor at the north corner of the porch to the Customs and Immigration Office. This porch is at the east corner of the terminal and faces the runway.

64° 50.5' 147° 44.0' 434 982.2463

Fire Island

Runway is on south end of island and runs east-west. Station is on north side of runway near its center, at base of a sign reading, "Fire Island -- Transient Operations - Restricted Location".

61° 07.6' 150° 15.6' 40' 981.8880

Flat

West of center of landing strip, on south side of strip, opposite a fork in the road which parallels the south side of strip.

62° 27.1' 157° 59.5' 309' 982.0936

Fort Greeley

Opposite the center of the north wall of the main hangar, 5 feet north of an entrance.

63° 59.4' 145° 42.6' 1266' 982.1028

Fort Yukon

West end of east-west runway, 150 feet north of a spotlight on a wooden tower.

66° 34.2' 145° 16.2' 420' 982.3580

Gakona

At the Gakona Airport - at the southwest end of the old (small) hangar building now used as a school and residence.

62° 18.1' 145° 17.2' 1550' 981.9421

Galena

Military Airfield - 200 yards east of main hangar with a control tower on its southeast corner, at bush plane refueling point.

64° 44.3' 156° 55.9' 120' 982.2706

Gambell

Center of apron at north end of runway.

63° 45.6' 171° 44.5' 30' 982.2132

Gulkana Landing Field

100 yards northeast of beacon tower, at the CAA Airways Communication Station, 7.5 feet south of northeast corner of the building, at USCGS benchmark D 27.

62° 09.5' 145° 27.6' 1573' 981.9314

Gustavus

On airplane apron to right of CAA building (as one faces the runway), 200 feet from point where access road joins apron.

58° 25.5' 135° 42.5' 28' 981.7902

Homer

Airfield - at foot of steps to CAA control building.

59° 38.5' 151° 29.6' 66' 981.8824

Hughes

North end of the north-south landing strip, in center of strip directly in front of Post Office

66° 02.7' 154° 15.5' 350' 982.3341

Humphrey Point

DEW line radar station, at the east end of the runway.

69° 59.0' 142° 32.5' 7' 982.5702

Huslia

75 yards from southwest end of the northeast-southwest landing strip, in center of strip.

65° 39.4' 156° 22.5' 200' 982.3213

Iliamna

Airfield - on concrete slab at foot of steps to CAA Control Building.

59° 45.2' 154° 54.6' 186' 981.9030

Jack Wade

In the center of the hangar on the east side of the airfield.

64° 07.3'	141° 32.1'	1800'	982.0379
-----------	------------	-------	----------

Juneau

In Concourse to field at first windows out from terminal entrance.

58° 21.7'	134° 35.3'	26'	981.7686
-----------	------------	-----	----------

Kenai

Pacific Northern Airlines Terminal, on ground 40 feet from field entrance.

60° 33.5'	151° 15.2'	93'	981.8378
-----------	------------	-----	----------

King Salmon

Bristol Bay Airlines Office located near west end of the 110°-290° runway and between the Northern Pacific Airlines Office and the Northern Consolidated Airlines Office, on the ground at northeast corner of this office.

58° 40.8'	156° 38.9'	52'	981.8426
-----------	------------	-----	----------

Kivalina

Extreme south end of landing strip.

67° 44.1'	164° 33.9'	6'	982.4621
-----------	------------	----	----------

Kodiak Naval Station

Pacific Northern Airlines Terminal, at foot of steps to field entrance.

57° 45.0'	152° 29.5'	77'	981.7458
-----------	------------	-----	----------

Kotzebue

West or seaward side of CAA Control Building on a concrete slab at former entrance to building (now boarded up).

66° 53.4'	162° 37.8'	11'	982.4141
-----------	------------	-----	----------

Koyuk

Center of landing strip at its extreme south end.

64° 56.2'	162° 15.1'	30'	982.2929
-----------	------------	-----	----------

Koyukuk

Landing strip downstream from village, in center of strip at its extreme northwest end.

64° 52.7' 158° 43.0' 115' 982.2801

Levelock

Extreme east end of east-west landing strip, in center of strip, at a point where a road from town joins the strip.

59° 07.2' 156° 52.0' 50' 981.8769

Livengood

South end of landing strip, in a road running perpendicular to the strip, on the projection of the center line of the strip.

65° 32.3' 148° 33.0' 645' 982.2725

Mallard Springs

On the southwest corner of the landing strip which parallels a "cat" trail.

68° 11.5' 141° 02.6' 1117' 982.4372

May Creek

On ground, 5 feet from door of log cabin Post Office at end of landing strip.

61° 19.9' 142° 43.5' 1550' 981.8421

McGrath

20 feet north of the door of the quonset housing the Post Office and Alaska Airline Office.

62° 57.5' 155° 37.5' 346' 982.1284

Medfra

Center of landing strip, opposite point where road from town joins strip.

63° 06.8' 154° 43.5' 453' 982.1202

Middleton Island

Edge of runway, in the vicinity of about 20 quonset huts, on line with roadway which leads past the doors of the first row of quonsets to the large brown building behind them.

59° 26.9' 146° 27.1' 87' 981.9707

Munchumina

South end of runway, near where a road joins the runway, 30 feet east of a CAA signboard reading "Minchumina".

63° 52.8' 152° 18.2' 687 982.1545

Mt. Edgecumbe

On concrete at foot of control tower, 2 feet from northeast corner of large silver hangar.

57° 03.0' 135° 20.9' 9' 981.7080

Nome

Major Airfield, at foot of steps to Pan American Airlines Terminal.

64° 30.9' 165° 23.9' 37' 982.2749

Ophir

Southeast end of landing strip, at a corner of the strip, where a road from town joins the strip.

63° 08.5' 156° 32.4' 525' 982.1199

Palmer

South end of airport, west side of single plane hangar.

61° 34.9' 149° 05.1' 214' 981.9816

Point Hope

8 feet south of building at west end of landing strip.

68° 20.8' 166° 44.5' 20' 982.5222

Port Heiden

300 yards from northwest end of runway, on northeast side of runway, beside the 7th beacon from northwest of runway.

56° 57.9' 158° 09.2' 95' 981.6875

Ruby

Landing strip on a hill beyond village, near center of strip and in a road on its west side, 75 yards north of a small sheet metal building owned by Northern Commercial Company.

64° 43.9' 155° 27.9' 635' 982.2376

St. Paul

Center of airplane parking lot located between south end of runway and Weather Station.

57° 09.5' 170° 13.5' 9' 981.7267

Shemya Island

Shemya Air Force Base, in front of Operations Building.

52° 43.5' 174° 24.9' 95' 981.5088

Skagway

Airstrip, where access road meets strip, beneath a "Welcome to Skagway" sign.

59° 28.0' 135° 24.0' 41' 981.7736

Solomon

Apron near center of landing strip and on its east side, in center of apron.

64° 37.0' 164° 22.3' 100' 982.2711

Stevens Village

East of center point of east-west landing strip, on the north side of the strip where a footpath crosses strip.

66° 01.0' 149° 06.3' 500' 982.3244

Takotna

Landing strip runs east-west. Station is near center of strip on its south side, where a road from the village joins the strip.

62° 59.8' 156° 04.5' 1405' 982.0928

Tannacross Airfield

On apron beneath the control tower and 15 feet east of entrance to Operations Room.

63° 22.2' 143° 20.0' 1545' 982.0087

Tanana

Airfield, on concrete sidewalk at foot of steps to CAA Control Building.

65° 10.5' 152° 06.5' 236' 982.2782

Tatalina

Runway runs north-south. Station is north of center of runway and on its west side, 50 feet east of a building on the west side of runway.

62° 52.3'	155° 58.5'	950'	982.0835
-----------	------------	------	----------

Teller

Landing strip on peninsula north of town, in center of the apron to east of strip, 30 feet from center line of strip.

65° 16.4'	166° 21.0'	6'	982.3119
-----------	------------	----	----------

Tin City

Center of apron at north (higher) end of runway.

65° 33.5'	167° 54.9'	219'	982.3141
-----------	------------	------	----------

Umiat

On runway in front of Operations Building.

69° 22.4'	152° 09.0'	352'	982.5443
-----------	------------	------	----------

Umnak Island

South end of the 30°-210° runway, in center of runway on the projection of the taxiway to hangar.

53° 22.4'	167° 53.9'	127'	981.5176
-----------	------------	------	----------

Unalakleet

South end of runway, in middle of road from runway to CAA Control Building, 50 feet east of CAA Control Building and 20 feet south of a flagpole.

63° 53.3'	160° 47.9'	19'	982.2178
-----------	------------	-----	----------

Utopia

West end of the east-west runway, at south end of the apron at head of runway, 75 yards from a building at edge of apron.

66° 01.8'	154° 15.1'	1000'	982.2740
-----------	------------	-------	----------

Valdez

Airplane unloading point near end of runway, 8 feet from door of a red 12 x 10 foot building.

61° 07.7'	146° 16.8'	80'	981.9993
-----------	------------	-----	----------

White Mountain

Landing strip on a hill behind village, on northeast side of cemetery, on south side of a 6 x 6 foot wooden shack with a wind sock mounted on the roof.

64° 41.1' 163° 24.4' 300' 982.2661

Wiseman

Northeast end of landing strip, where a road from the town joins the strip.

67° 24.5' 150° 06.8' 1600' 982.3341

Woodchopper

Edge of airstrip, at point where mail is unloaded, 15 feet from door of a 12 x 20 foot white building.

65° 18.8' 143° 28.9' 1200' 982.2164

Yakataga

Extreme northwest corner of runway.

60° 05.0' 142° 30.2' 12' 981.9037

Yakutat

On yellow line opposite center of hangar on apron.

59° 30.6' 139° 40.0' 37' 981.8373

CANADA AND ARCTIC

ALBERTA

Edmonton

RCAF NAMAQ - in corner of air movements passenger waiting room beneath pay telephone.

53° 40.0' N 113° 27.5' W 2256' 981.1806

BRITISH COLUMBIA

Dawson Creek

Airstrip, at base of wind sock at east end of air strip.

55° 45.0' N 120° 14.0' W 2196' 981.3655

Liard River

In front of building marked "office" at end of row of quonset huts, between milepost 507 - 508.

58° 30.8' N 126° 20.9' W 1400' 981.7041

Prophet River

Airstrip, 50' north of milepost 223.29 at wind sock, 30' north of hut. Flight strip No. 3.

57° 57.9' N 122° 46.1' W 1954' 981.5615

Sikanni Chief

West door of tar-paper house (cookhouse) on edge of flight strip No. 2. Wind sock is on north side of shack.

57° 05.4' N 122° 35.1' W 3258' 981.3941

Vancouver

RCAF Sea Island, in movements section of passenger waiting room by pillar near men's room.

--- --- --- 980.9313

Victoria

Patricia Bay airport on field at end of sidewalk to Customs and Immigrations.

48° 39.0' N 123° 25.5' W 63' 980.9454

MANITOBA

Churchill

Inside passenger waiting room and to right of door to field.

58° 45.2' N 94° 04.1' W 100' 981.7675

NEWFOUNDLAND

Argentia

Argentia NAS-(old terminal) inside hangar formerly used as passenger terminal and now housing Air-Sea rescue service, by fire hydrant.

47° 18.5' N 54° 00.0' W 51' 980.8548

Argentia - inside new passenger terminal and to left of door to street.

--- --- --- 980.8539

Gander

International Airport - in center of passenger waiting room.

48° 56.9' N 54° 34.8' W 496' 980.9590

Goose Bay

Field entrance to base operations at field elevation.

53° 18.6' N 60° 25.0' W 150' 981.3078

St. John's

Pepperrell USAF - officer's quarters, Building 309 on concrete porch on west side of main entrance door, southeast corner of building.

--- --- --- 980.8369

Stephenville

Ernest Harmon AFB - at ground level just inside of entrance to terminal building from field.

48° 31.8' N 58° 32.5' W 86' 980.9318

Torbay

Torbay USAF - east corner of passenger waiting room.

47° 37.0' N 52° 45.0' W 484' 980.8256

Torbay USAF - to left of field entrance to TCA passenger waiting room, on outside sidewalk, 30" above field level.

47° 36.2' N 52° 45.0' W 490' 980.8223

NORTHWEST TERRITORY

Aklavik

On the Mackenzie River at ski-plane terminal, at extreme south tip of the town.

68° 13.2 N 135° 00.0' W 9' 982.4902

NORTHWEST TERRITORY (Cont'd)

Cape Perry

DEW Line site pin C-8 in hangar by CO₂ tanks in furnace room.

70° 10.1' N 124° 41.0' W 50' 982.6220

Cornwallis Island

Resolute Bay - transient quarters just north of mess hall on wooden floor, barrack block No. 2.

74° 43.2' N 94° 58.0' W 210' 982.8624

Ellesmere Island

Alert - southwest end of runway at edge of runway.

82° 30.1' N 62° 20.0' W 205' 983.1417

Eureka - on garage floor approximately 5 ft. above sea level and about 250 ft. below air strip.

79° 59.9' N 85° 55.0' W 5' 983.0275

Ellef Rignes Island

Isachsen - 100 yards west of unloading ramp at edge of shore.

78° 47.0' N 103° 37.0' W 90' 983.0597

Prince Patrick Island

Mould Bay - inside operations building on floor of the northwest corner of entryway at south end of building, 45' east of the instrument shelter and about 1' above ground level at base of instrument shelter.

76° 17.0' N 119° 28.0' W 48' 982.9333

Yellowknife

At foot of basement stairs in radio building.

62° 27.6' N 114° 26.5' W 672' 982.0248

Victoria Island

Cambridge Bay - DEW Line site CAM C-18 in hangar in furnace room in corner of transformer cage, beneath fire extinguisher.

69° 07.2' N 105° 07.0' W 90' 982.5182

ONTARIO

Ottawa, new municipal airport (1960) at Gate No. 2.

45° 20.1' N 75° 41.2' W 357' 980.6186

YUKON TERRITORY

Burwash Landing - Airport emergency strip No. 8 directly in front of airport at side door of shack by large rotating beacon.

61° 22.8' N 139° 03.0' W 2640' 981.7543

Dawson - at boat and seaplane landing, immediately outside entrance to government ferry building: 20 ft. above river.

64° 03.6' N 139° 26.0' W 1050' 982.5223

Shingle Point - at DEW Line radar station in center of runway; this is a temporary runway built out of the sea ice.

68° 59.9' N 137° 26.0' W 0' 982.5223

Stokes Point - at DEW Line radar station in center of runway approximately 15 miles southeast of Herschel Island.

69° 20.0' N 138° 43.0' W 0' 982.5702

Teslin Lake - RCAF airstrip at northeast corner of building on airstrip. Seal of RCAF over door and RCAF sign on side.

60° 10.8' N 132° 44.6' W 2313' 981.7270

GREENLAND

Narsarssuak (BW-1) - on the south side of the front steps of main entrance to building No. 358, the passenger waiting room. Station is about 2' above elevation of field. Entrance is the west entrance at the north end of building.

61° 09.2' N 45° 24.1' W 136' 981.9387

Site I - on top of platform leading to underground quarters near weather station kiosk.

--- --- 4200' 982.7308

Site II - on iron catwalk in terminal in front of heater room just opposite dispensary, about 22.5' below outside snow level.

--- --- --- 982.3465

Sondre Stromfjord

Sondrestrop AFB - at foot of control tower, in back of passenger terminal.

67° 01.5' N 50° 41.9' W 160' 982.3843

Thule

Thule AFB - southeast corner of hangar No. 3 housing new passenger terminal (1958), about 300' west of control tower and at field elevation. The hangar is the second west of control tower.

76° 32.2' N 68° 45.3' W 251' 982.9280

ARCTIC OCEAN

Ice Island Alpha - On floor of Science Hut.

April 23, 1957					983.0900
November 13, 1957					983.1692
April 27, 1958	84° 02.0' N	152° 24' W	0'		983.1823
May 14, 1958	83° 45.3' N	152° 10' W	0'		983.1669

T-3 - On floor of AFCRC Cambridge trailer.

April 17, 1957					983.1609
September 26, 1958	78° 28' N	122° 12' W	0'		983.0087

UNITED STATES

ALABAMA

Huntsville

At entrance to terminal building on right side facing field.

34° 41.4' N 86° 36.0' W 619' 979.6362

Mobile

Brookley Field - MATS terminal at baggage room door.

30° 38.1' N 88° 04.1' W 26' 979.3543

Montgomery

Municipal Airport - at instrument shack for battery charger of EAL.

32° 18.5' N 86° 16.8' W 175' 979.5094

ARIZONA

Douglas

International Airport - Gate 2, between field platform and sidewalk to terminal.

31° 28.0' N 109° 36.2' W 4158' 979.0579

Flagstaff

Street side of terminal at right hand end of porch.

35° 08.0' N 111° 40.3' W 7010' 979.1427

Nogales

International Airport - at main entrance to terminal.

31° 24.6' N 110° 51.3' W 3938' 979.0701

Prescott

Airport is 8 miles north of Prescott, on roadside porch, midway between doors.

34° 38.8' N 112° 25.7' W 5042' 979.2376

Winslow

Municipal Airport - on fieldside porch, 5 feet from terminal exit to field.

35° 01.5' N 110° 43.5' W 4937' 979.2777

CALIFORNIA

Alameda

NAS - at foot of rear stairs from waiting room; Building 106.

37° 46.8' N 122° 18.8' W 15' 979.9859

CALIFORNIA (cont.)

Burbank

At gate 1 of barrier.

34	12.1' N	118	21.2' W	763'	979.5818
----	---------	-----	---------	------	----------

Chico

50' east of entrance to hangar.

39°	47.0' N	121°	52.0' W	237'	980.1315
-----	---------	------	---------	------	----------

Fairfield

Travis AFB - inside terminal at gate 2 to field.

38°	15.8' N	121°	55.7' W	62'	979.9898
-----	---------	------	---------	-----	----------

Modesto

Municipal Airport - 5' south of center gate to terminal building.

37°	37.5' N	120°	58.0' W	96'	979.9310
-----	---------	------	---------	-----	----------

Mountain View

Moffett NAS - inside hangar No. 2 at entrance to passenger lounge.

37°	25.3' N	122°	02.9' W	40'	979.9454
-----	---------	------	---------	-----	----------

Oakland

Oakland NAS - at field entrance to terminal building near corner of building in which operations is located.

37°	43.2' N	122°	12.6' W	5'	979.9741
-----	---------	------	---------	----	----------

Orville

50' north of entrance to terminal.

39°	29.1' N	121°	37.9' W	199'	980.0810
-----	---------	------	---------	------	----------

Red Bluff

On field about 2' from north side of passenger gate.

40°	09.3' N	122°	15.0' W	354'	980.1046
-----	---------	------	---------	------	----------

Redding

50' east of entrance to hangar.

40°	30.5' N	122°	17.5' W	500'	980.1292
-----	---------	------	---------	------	----------

Sacramento

Municipal Airport - to left of gate leading to South West Airlines offices.

38°	31.0' N	121°	29.5' W	21'	980.0146
-----	---------	------	---------	-----	----------

CALIFORNIA (cont.)

San Diego

Montgomery Field - at entrance to administration building.

32° 48.9' N 117° 08.6' W 417' 979.5281

Santa Ana

El Toro MCAS - 1' north of corner of Base Operations Building.

33° 40.5' N 117° 44.2' W 383' 979.6142

Yuba

Yuba County Airport - at field end of sidewalk from terminal.

39° 05.9' N 121° 34.9' W 63' 980.0400

COLORADO

Denver

Lowry AFB - southeast corner of Hangar 2.

39° 43.0' N 104° 53.2' W 5420' 980.6181

Pueblo

New Memorial Airport - on right hand side of porch facing parking lot.

38° 17.3' N 104° 29.5' W 4725' 979.5637

Saguache

At base of wind sock pole.

38° 05.9' N 106° 10.5' W 7700' 979.2896

CONNECTICUT

Hartford - Springfield

Bradley Field - inside terminal to left of stairs to dining room.

41° 56.3' N 72° 41.4' W 173' 980.3488

FLORIDA

Jacksonville

Jacksonville NAS - at top of steps to lounge in control tower building.

30° 14.3' N 81° 40.8' W 20' 979.3666

IDAHO

Pocatello

Municipal Airport - at passenger gate to waiting room from field.

42° 54.8' N 112° 36.0' W 4446' 980.0271

IOWA

Belmond

Municipal Airport - 200 yards east of southeast corner of hangar.

42° 51.8' N 93° 37.7' W 1150' 980.3751

Boone

Municipal Airport - 100' south of control tower.

42° 02.8' N 93° 50.8' W 1143' 980.3226

Clearmont

Municipal Airport - at northeast corner of southernmost hangar.

42° 55.9' N 91° 31.5' W 800' 980.3787

Davenport

Cram Airport - at northeast base of old beacon tower.

41° 33.5' N 90° 37.0' W 646' 980.2521

De Witt

Municipal Airport at northwest corner of first building south of US 30.

41° 49.2' N 90° 31.3' W 710' 980.2749

Dubuque

Municipal Airport - at northeast corner of Administration Building,
on passenger side.

42° 24.8' N 90° 42.4' W 1080' 980.3014

Goldfield

Eagle Grove Airport - at northeast corner of hangar.

42° 43.0' N 93° 55.5' W 1131' 980.3416

Mt. Joy

Davenport Municipal Airport - on sidewalk leading to Administration
Building, on auto side.

41° 37.0' N 90° 36.0' W 753' 980.2509

Riceville

Mosher Airport - 20' south of center line.

43° 22.0' N 92° 34.5' W 1263' 980.3483

Sioux City

Municipal Airport - at north end of terminal by gate to field.

42° 24.3' N 96° 23.0' W 1097' 980.3073

KANSAS

Olathe

Olathe NAS - in corner by field entrance to operations office.

38° 50.1' N 94° 53.6' W 1086' 979.9602

LOUISIANA

Lake Charles

To left of walk to passenger operations on taxi ramp.

30° 12.3' N 93° 09.5' W 17' 979.3324

MAINE

Augusta

Augusta State Airport - at end of concrete sidewalk to administration building from field.

44° 19.2' N 69° 47.8' W 355' 980.5372

Greenville

Folsom Air Service hangar, one foot southeast from southeast corner of hangar.

45° 27.7' N 69° 35.5' W 1028' 980.5895

Old Town

At entrance to lobby of administration building on airstrip side, on walk in front of door.

44° 57.2' N 68° 40.2' W 126' 980.6124

MARYLAND

Patuxent River

Patuxent River NAS - on porch on field side of terminal by passenger entrance.

38° 16.9' N 76° 25.0' W 38' 980.0258

MASSACHUSETTS

Chicopee Falls

Westover AFB - next to door to terminal from cafeteria just off concrete rampway.

42° 12.1' N 72° 32.0' W 245' 980.3555

Falmouth

Otis Airfield - on field side of base operations building on walk in front of steps to main entrance.

41° 39.3' N 70° 31.7' W 126' 980.3434

MINNESOTA

Austin

At northeast corner of wind sock hangar.

43° 40.0' N 92° 56.0' W 1237' 980.4222

Blooming Prairie

At southeast corner of hangar.

43° 53.3' N 93° 03.0' W 1200' 980.4457

Fairmont

At base of wind sock hangar.

43° 38.7' N 94° 25.5' W 1161' 980.4141

Jackson

Municipal Airport - at rear of wind sock hangar.

43° 39.2' N 94° 59.0' W 1445' 980.3903

MISSOURI

Joplin

50' out from field in front of terminal.

37° 09.0' N 94° 29.9' W 980' 979.8433

MONTANA

Glendive

At west end of "The Runway" building at base of east pole.

47° 07.7' N 104° 40.7' W 2128' 980.6371

Great Falls

Malmstrom AFB - at base of ladder on main control tower.

47° 30.5' N 111° 11.5' W 3525' 980.5277

Miles City

At passenger entrance to Frontier Airlines lobby from field.

46° 25.9' N 105° 52.5' W 2628' 980.5230

Stanford

150' north of northeast corner of hangar.

47° 08.5' N 110° 14.0' W 4285' 980.4369

Wolf Point

At northeast corner of Frontier Airlines terminal.

48° 05.4' N 105° 34.2' W 1980' 980.7252

NEBRASKA

Norfolk

15' east of front entrance to terminal, on sidewalk.

41° 59.4' N 97° 26.2' W 1562' 980.2298

NEW JERSEY

Newark

New airport, right side of field entrance at Gate 6.

40° 42.3' N 74° 09.7' W 18' 980.2706

NEW MEXICO

Carlsbad

New airport terminal on street side of porch, to left of door as entering.

32° 20.5' N 104° 15.8' W 3276' 979.1811

Raton

Raton-Hebron Airport - 2' south of southeast corner of beacon tower.

36° 44.4' N 104° 30.0' W 6379' 979.3135

NEW YORK

Albany

10' north from waiting room doors on field side entrance.

42° 33.8' N 71° 35.0' W 215' 980.3546

New York City

Idlewild Old International Terminal - now Domestic Terminal for Northwest Airlines; Delta and Braniff Airlines; station located in corridor (alongside Brass Rail restaurant) leading to street from TWA ticket counter, at end of telephone booth opposite large air conditioner. This corridor is one nearest to new TWA terminal building.

40° 38.6' N 73° 47.0' W 15' 980.2273

OHIO

Dayton

Patterson Field - 2' to right of MATS passenger entrance about 5' above ground.

39° 48.3' N 84° 03.4' W 819' 980.0918

OKLAHOMA

Oklahoma City

Tinker AFB - in front of terminal by gate.

35° 25.0' N	97° 23.8' W	1291'	979.6759
-------------	-------------	-------	----------

OREGON

Corvallis

To right of first gate in barrier.

44° 30.0' N	123° 17.0' W	245'	980.5701
-------------	--------------	------	----------

North Bend

At field end of sidewalk from terminal.

43° 24.0' N	124° 15.4' W	4'	980.4935
-------------	--------------	----	----------

Roseburg

20' north of airline shack.

43° 13.6' N	123° 22.0' W	500'	980.4294
-------------	--------------	------	----------

PENNSYLVANIA

Erie

Port Erie Airport - outside terminal on walk leading to flight strip.

42° 05.3' N	80° 11.3' W	732'	980.2706
-------------	-------------	------	----------

Scranton

Wilkes-Barre - Scranton Airport - on east side of terminal in front of flagpole.

41° 20.2' N	75° 43.5' W	956'	980.2257
-------------	-------------	------	----------

RHODE ISLAND

Quonset Point

Quonset Point NAS - northwest corner of control tower building.

41° 36.2' N	71° 24.6' W	22'	980.3122
-------------	-------------	-----	----------

SOUTH DAKOTA

Sioux Falls

Foss Airport - at northeast corner of terminal building.

43° 34.8' N	96° 44.6' W	1426'	980.3616
-------------	-------------	-------	----------

TEXAS

Beaumont

To right of steps into terminal from field.

30° 04.5' N 94° 12.8' W 31' 979.3149

Childress

At CAA weather hut.

34° 26.3' N 100° 17.4' W 1952' 979.4881

Corsicana

Corsicana 75 Airport - northeast corner of Hodge Flying Service building at level of concrete floor.

32° 07.0' N 96° 28.0' W 480' 979.4879

Dalhart

Municipal Airport - south of door into U.S. Weather Bureau station at north edge of ramp.

36° 01.2' N 102° 33.2' W 3989 979.4402

Huntsville

Entrance to Municipal Airport on US 75.

30° 44.9' N 95° 35.3' W 366' 979.3512

Paris

Cox Field - 100' from front of terminal.

33° 38.1' N 95° 26.8' W 546' 979.6039

UTAH

Ogden

Hill AFB - at entrance to operations building.

41° 07.8' N 111° 58.3' W 4788' 979.8005

VIRGINIA

Norfolk

Norfolk NAS - to left of steps of control tower building from field, at opposite end of building from control tower.

36° 55.8' N 76° 17.7' W 15' 979.8847

WASHINGTON

Olympia

To left of northwest gate, 50' north of main entrance.

46° 58.2' N 122° 55.0' W 190' 980.8198

WASHINGTON (cont.)

Seattle

Boeing Airfield - at Gate 4 of barrier.

47° 32.2' N 122° 18.0' W 17' 980.7654

Tacoma

McChord AFB - in terminal to left of Gate 1 exit.

47° 08.8' N 122° 29.0' W 320' 980.7487

WEST VIRGINIA

Huntington

Tri State Airport - next to fence at Gate 1.

38° 25.2' N 82° 29.4' W 826' 979.9515

WISCONSIN

Eau Claire

To right inside of barrier gate.

44° 52.0' N 91° 29.3' W 887' 980.5297

WYOMING

Douglas

Southwest corner of walk on pavement by CAA office.

42° 45.0' N 105° 21.1' W 4865' 979.9533

Wheatland

Beside beacon tower No. 10458.

42° 06.2' N 104° 58.6' W 4648' 979.9443

Table III-A-7.7

PACIFIC OCEAN AREA

Cook Islands

Fiji Islands

Guam

Hawaiian Islands

Johnston Island

Kwajalein Island

Midway Island

New Caledonia

Phoenix Islands

Samoa Islands

Society Islands

Tonga Islands

Wake Island

Wallis Islands

COOK ISLANDS

Aitutaki Island

Teal Flying Boat Base - near Akaiami, at the head of the stone pier, where the pier meets the beach, 2' above sea level.

--- --- 2' 978.8407

FIJI ISLANDS (Viti Levu Island)

Suva

Nasourie Airport - on concrete abutment over ditch.

18° 02.5' S 178° 34.2' E 19' 978.6242

Nandi

Nadi Airport - on concrete walk from air strip to aerodrome building.

17° 45.5' S 177° 26.7' E 63' 978.5471

GUAM

Marianna Islands

Agana Naval Air Station - in passenger waiting room to right of Gate 1 leading to runway.

13° 28.7' N 144° 47.1 E 280' 978.5240

Harmon Air Force Base - on floor in terminal building to right of Gate 1 to runway.

13° 30.2' N 144° 48.6' E 159' 978.5282

HAWAIIAN ISLANDS (Oahu Island)

Barbers Point Naval Air Station - to left of door to Fleet Logistics Air Terminal, entrance 2.

21° 18.9' N 158° 04.5' W 21' 978.9720

Hickam Air Force Base - beside customs door on field side of waiting room. (MATS base terminal)

21° 20.5' N 157° 57.5' W 21' 978.9337

Honolulu International Airport - at base of flagpole by Gate 4A - near Medical Inspection Building.

21° 19.5' N 157° 55.6' W 13' 978.9325

John Rodgers Naval Air Station - to left of door to Fleet Logistics Air Terminal.

21° 19.2' N 157° 55.2' W 6' 978.9290

Wheeler Air Force Base - at runway 150' out in front of hangar 2.

21° 29.4' N 158° 02.2' W 824' 978.9247

JOHNSTON ISLAND

Johnston Island Air Force Base - 12' to left of terminal building door.

16° 44.2' N 169° 30.9' W 7' 978.7198

KWAJALEIN, MARSHALL ISLANDS

Naval Air Station Operations Building - at field entrance door of terminal on small concrete porch 9" above field level.
There is a small walled-in stone enclosure between door and field.

08° 42.5' N 167° 43.6' E 7' 978.3668

MIDWAY ISLANDS

Sand Island

Sand Field - at foot of concrete steps to operations and terminal.

28° 12.0' N 177° 23.0' W 13' 978.4993

NEW CALEDONIA

Tontouta

Tontouta Airport - at southwest corner of hangar.

22° 01.7' S 166° 12.2' E 15' 978.8590

PHOENIX ISLANDS

Canton Island

Topham Airport - at entrance to terminal from air strip.

02° 46.0' S 171° 43.0' W 9' 978.2932

SAMOA ISLANDS

Faleolo (British Samoa; Upolu Island)

Faleolo Airport - by entrance to building from field

13° 49.9' S 171° 58.5' W 7' 978.6061

Pago Pago (American Samoa; Tutuila Island)

Tafuna Air Field - at entrance to operations at Naval Air Transport Service 21 building.

14° 20.0' S 170° 43.1' W 6' 978.6407

SOCIETY ISLANDS

Bora Bora Island

Airstrip, 3 feet from the wall of the passenger terminal, near the center of the building on the side facing the airstrip.

16° 26.4' S 151° 45.0' W 8' 978.6703

Fly Boat Base - on opposite side of island from airstrip at foot of rock pier to flying boats dock between the road and a bamboo hut, 16' from the water and 26' to the right of the road as one faces the water.

16° 26.8' S 151° 44.9' W 00' 978.6753

Tahiti Island

Fly Boat Base - in customs building to left of the counters as one faces the water, near the center of the lobby, adjacent to a bamboo divan.

17° 34.2' S 149° 37.2' W 5' 978.7086

TONGA ISLAND (Tongatuba Island)

Fua-Amotu Airport - on ground at entrance to NAC hut.

21° 14.0' S 175° 07.5' W 105' 978.8722

WAKE ISLAND

Wake Island Airport - by flagpole on terminal side of fence.

19° 17.2' N 166° 39.0' E 13' 978.8814

WALLIS ISLANDS

Wallis Island Airstrip - in center of strip directly opposite the flag pole in front of a bamboo building.

--- --- --- 978.5215

SOUTH AMERICAN AREA

Argentina

Bolivia

Brazil

British Guiana

Chile

Colombia

Ecuador

French Guiana

Paraguay

Peru

Surinam (Dutch Guiana)

Uruguay

Venezuela

ARGENTINA

Bahia Blanca, Buenos Aires

Harding Green Airport - southwest corner of airlines building. (10 meters west and 2 meters north of base of Antenna Tower).

38° 43.8' S 62° 10.8' W 82' 980.0696

Buenos Aires, Buenos Aires

Ezeiza International Airport (formerly Pistarini) - on top of I.G.M.
BM between first and second pillars of main administration building, on left when facing building.

34° 49.0' S 58° 33.0' W 68' 979.7317

Morón Airport - at base of radio antenna.

34° 39.8' S 58° 37.2' W 98' 979.7043

Cordoba, Cordoba

Field level, northeast corner of building.

31° 19.1' S 64° 12.7' W 1598' 979.3274

Comodoro Rivadavia, Comodoro Rivadavia

Southeast corner of main building on sidewalk.

45° 47.5' S 67° 27.8' W 204' 980.6640

Jujuy, Jujuy

Entrance to Aerolines Argentinas office.

24° 16.2' S 65° 14.9' W 4139' 978.4638

Mar del Plata, Buenos Aires

Passenger entrance at door under parapet leading to car stop.

37° 56.2' S 57° 35.0' W 66' 980.0191

Oran, Salta

Southeast corner of main building on checkered walk.

23° 10.0' S 64° 19.8' W 1187' 978.6380

Puerto Deseado, Comodoro Rivadavia

At door to rest room at airport.

47° 44.3' S 65° 54.5' W 43' 980.8597

Rio Gallegos, Santa Cruz

Argentina AF base at southeast corner of radio shack.

51° 39.1' S 69° 14.9' W 82' 981.2075

ARGENTINA (cont.)

Rio Grande, Tierra del Fuego

Aeropuerto de Marina - Southeast corner of waiting room.

53° 48.0' S	67° 40.5' W	16'	981.4362
-------------	-------------	-----	----------

Salta, Salta

Southwest corner of airport building at patio.

24° 43.6' S	65° 26.5' W	4137'	978.4991
-------------	-------------	-------	----------

San Julian, Santa Cruz

Southwest corner of Aero Club shack.

49° 18.7' S	67° 45.0' W	133'	981.0147
-------------	-------------	------	----------

Santa Cruz, Santa Cruz

Northeast corner of airlines shack.

50° 01.5' S	68° 35.8' W	440'	981.0474
-------------	-------------	------	----------

Santiago del Estero, Santiago del Estero

Southeast corner of main building.

27° 46.1' S	64° 17.5' W	610'	979.0996
-------------	-------------	------	----------

Tartagal, Salta

Southwest corner of Meteorology House on walk at airport.

22° 32.0' S	63° 50.8' W	---	978.5938
-------------	-------------	-----	----------

Trelew, Chubut

Airport - center line of west side on sidewalk.

43° 14.0' S	65° 18.8' W	125'	980.4547
-------------	-------------	------	----------

Tucuman, Tucuman

Southwest corner of building at car shelter.

26° 49.5' S	65° 11.5' W	1384'	978.9062
-------------	-------------	-------	----------

Ushuaia, Tierra del Fuego

Baglietto's station at airport.

54° 48.5' S	68° 19.5' W	33'	981.4864
-------------	-------------	-----	----------

BOLIVIA

La Paz, La Paz

El Alto Airport - Panagra terminal at runway and sidewalk.

16° 30.2' S	68° 12.2' W	13420'	977.3487
-------------	-------------	--------	----------

BOLIVIA (cont.)

Santa Cruz, Santa Cruz

El Trompillo Airport - at gate leading to Braniff Airlines shack.

17° 47.5' S 63° 10.8' W 1433' 978.3646

BRAZIL

Acu, Rio Grande do Norte

Twenty yards south of southwest corner of terminal.

05° 33.8' S 36° 54.6' W 223' 978.0844

Alegrete, Rio Grande do Sul

At fence and sidewalk.

29° 48.1' S 55° 43.0' W 315' 979.2938

Anapolis, Goias

Airport at VASP terminal; at base of large stone JK monument. About 2' above field level. About 400 yards from REAL terminal.

16° 20.9' S 48° 58.5' W 3080' 978.1489

Aracaju, Sergipe

At wind sox.

10° 54.1' S 37° 04.4' W 40' 978.2129

Aracati, Ceara

30 yards north of wind sox.

04° 33.2' S 37° 48.0' W 99' 978.5809

Aracatuba, Sao Paulo

Airport at baggage ramp at southeast corner of main building.

21° 13.0' S 50° 24.0' W 1312' 978.0985

Aragarcas, Goias

At airport at parapet shelter on left side at Arbor.

15° 54.5' S 52° 15.0' W 1000' 978.3215

Araguaia, Goias

At gate leading to first tower Aerea Radio.

08° 14.1' S 49° 18.1' W 500' 978.0456

Araguari, Goias

On veranda behind southern pillar of south end arch. (Rotary Club plaque on front of pillar.)

18° 38.5' S 48° 12.0' W 3050' 978.2767

BRAZIL (cont.)

Bage, Rio Grande do Sul

Entrance to Administration Building at ground level.

31° 19.2' S 54° 07.5' W 690' 979.4135

Belem, Para

Val de Caes Airport - new terminal building under construction 1958.

On parking ramp side at center of 4th concrete arch from west side
or 5th arch from east side beneath light.

01° 23.0' S 48° 28.5' W 42' 978.0341

Belo Horizonte, Minas Gerais

Pampulha Airport - At southwest corner of west sidewalk and ramp.

19° 51.7' S 43° 57.0' W 2575' 978.4021

Brasileia, Acre

At parking ramp, field level.

--- --- --- 978.1578

Brasilia, D.F.

Airport at junction of veranda walk with westernmost sidewalk leading
to field.

15° 51.1' S 47° 55.9' W 3474' 978.1013

Caceres, Mato Grosso

Field side of warehouse, centerline of shack.

--- --- --- 978.3983

Campo Grande, Mato Grosso

Campo Grande Air Base - at base of west steps to administration building
from field side.

20° 28.2' S 54° 40.8' W 1847' 978.5076

Municipal Airport - at entrance to gasoline pump.

20° 26.0' S 54° 39.0' W 2000' 978.5009

Campos, Rio de Janeiro

40 meters due south of southwest corner of hangar.

21° 49.7' S 41° 20.2' W 66' 978.7321

Canavieras, Bahia

20 yards north of northeast corner of house. F.A.B.

15° 39.2' S 38° 57.2' W 16' 978.4216

BRAZIL (cont.)

Caravelas, Bahia

On veranda between doors to main waiting room on ramp side (west side of terminal) Note: East side of terminal is dirt road.

17° 39.0' S 39° 14.6' W 33' 978.5262

Carolina, Goias

At radio shack.

07° 20.6' S 47° 25.3' W 600' 978.0466

Cruz Alta, Rio Grande do Sul

At base of highest radio antenna.

28° 37.9' S 53° 35.8' W 1502' 979.1225

Cruzeiro do Sul, Acre

At parking ramp, field level.

07° 36.9' S 72° 41.2' W --- 978.1092

Cuiaba, Mato Grosso

At northeast corner of small hangar at gas pump.

15° 34.6' S 56° 08.0' W 640' 978.3608

Curitiba, Parana

Bacachery Airport - on porch at entrance, 3' higher than ground and 15 yards from Gate A.

25° 25.0' S 49° 14.0' W 3050' 978.7894

Esplanada, Bahia

10 yards north of gate to administration building.

11° 46.2' S 37° 56.9' W 624' 978.2629

Fazenda San Juan de Piquiri, Mato Grosso

At gate leading to house from runway.

17° 20.0' S 56° 25.0' W --- 978.4828

Fernando de Noronha Island

At weather station, in center of operations room.

03° 51.4' S 32° 26.1' W 148' 978.3013

Florianopolis, Santa Catarina

At south corner of administration building 8' south of door to weather room.

27° 11.4' S 48° 33.5' W 5' 979.1354

BRAZIL (cont.)

Formosa, Minas Gerais

Northeast corner of storage shack 120 meters south of main building.

15° 32.2' S 47° 17.0' W 2988' 978.1145

Fortaleza, Ceara

Pinto Martins Airport - in corner between Forca Aerea check-in desk
in waiting room by stairs to lunch room and curio counter.

03° 47.5' S 38° 32.5' W 82' 978.0824

Forte Principe, Guapore

At concrete well for gasoline with steel top at north end of runway.

--- --- --- 978.2996

Goiania, Goias

At intersection of sidewalk and ramp.

16° 40.2' S 49° 16.0' W 2160' 978.2406

Grajau, Maranhao

At ramp and road to shacks.

05° 49.4' S 46° 08.2' W --- 977.9852

Guajara Mirim, Guapore

At Cruzeiro do Sul airlines house at steps.

10° 47.1' S 65° 22.7' W 600' 978.2190

Iguassu Falls, Parana

At end of hedge leading to plane ramp at field side.

25° 41.0' S 54° 28.2' W 590' 978.9193

Ilheus, Bahia

20 yards north of northeast corner of house.

14° 51.0' S 39° 02.5' W 10' 978.4627

Imparatiz, Maranhao

At wind sox.

05° 31.1' S 47° 29.3' W 300' 978.0198

Joao Pessoa, Paraiba

Santa Rita Airport - at center of terminal, edge of parking ramp.

07° 09.5' S 34° 57.4' W 217' 978.1442

BRAZIL (cont.)**Livramento, Rio Grande do Sul**

West gate leading to administration building.

30° 46.4' S	55° 33.7' W	670'	979.3368
-------------	-------------	------	----------

Maceio, Alagoas

Palmares Airport - at steps leading to operations building; 10 yards west of Meteorology shack.

09° 31.1' S	35° 47.5' W	377'	978.1439
-------------	-------------	------	----------

Manaus, Amazonas

At north end of operations building on cement walk.

03° 09.0' S	59° 59.0' W	272'	978.0211
-------------	-------------	------	----------

Maraba, Para

Fuersas Aereas de Brazil at radio station.

05° 22.2' S	49° 09.5' W	300'	978.0370
-------------	-------------	------	----------

Mossoro, Rio Grande do Norte

Aeroporto Dix Sept. Rosado - on concrete flagpole base.

05° 11.9' S	37° 22.3' W	99'	978.0927
-------------	-------------	-----	----------

Natal, Rio Grande do Norte

In civilian terminal over Cuiaba in Mosaic map of Brazil on waiting room floor.

05° 54.0' S	35° 15.1' W	161'	978.1155
-------------	-------------	------	----------

Paracutu, Minas Gerais

Northwest corner of hangar.

17° 13.5' S	46° 52.5' W	2329'	978.2615
-------------	-------------	-------	----------

Parana, Goias

At wind sox.

12° 32.1' S	47° 48.6' W	853'	978.1716
-------------	-------------	------	----------

Parnaiba, Piaui

In thatch-roofed terminal building by left hand pillar (palm tree) as entering from field.

02° 53.8' S	41° 44.5' W	12'	978.0374
-------------	-------------	-----	----------

Pedro Alfonso, Goias

At northeast corner of storage shack.

08° 57.2' S	48° 11.8' W	540'	978.0961
-------------	-------------	------	----------

BRAZIL (cont.)

Peixe, Goiás

At gate to road leading to road storage house.

12° 02.9' S 48° 33.4' W 492' 978.1999

Penedo, Alagoas

40 yards north of gate to administration building.

10° 14.1' S 36° 35.8' W 180' 978.1807

Porto Alegre, Rio Grande do Sul

Salgado Filho beneath bronze opening plaque dated April 19, 1953,
at foot of steps to bar and restaurant.

29° 59.5' S 51° 10.5' W 10' 979.3158

Porto Nacional, Goiás

At gate of F.A.B. gas pump.

10° 43.0' S 48° 25.0' W 777' 978.1621

Porto Seguro, Bahia

20 yards west of center line of building.

16° 29.5' S 39° 04.0' W 130' 978.4671

Porto Velho, Guapore

At concrete well for gasoline with steel cover.

08° 45.0' S 63° 55.0' W 300' 978.1458

Quarai, Rio Grande do Sul

20 yards west of administration building.

30° 23.2' S 56° 27.0' W --- 979.3332

Recife, Pernambuco

Guararapes Airport - beneath bronze inauguration plaque, right of
street entrance to main international departure section. At right
end of stone bench.

08° 08.0' S 34° 55.5' W 33' 978.1667

Rio Branco, Acre

At cargo shelter.

09° 59.1' S 67° 49.3' W 590' 978.1599

Rio de Janeiro, Rio de Janeiro

Santos Dumont Airport - 6th pillar from control tower on north end.

22° 54.4' S 43° 10.2' W 10' 978.8082

BRAZIL (cont.)

Rio de Janeiro, Rio de Janeiro (cont.)

Galeao Airport - at field exit to cab stand from baggage and customs room for arriving passengers.

22° 49.2' S 43° 14.2' W 10' 978.7977

Salvador, Bahia

Ipitanga Airport - at parking ramp end of walk leading to small building, northeast of terminal.

12° 54.5' S 38° 21.0' W 20' 978.3445

Santa Maria, Rio Grande do Sul

Southeast corner of control tower.

29° 42.5' S 53° 52.0' W 175' 979.2783

Santos, Sao Paulo

Basaer Airport - under arch of front (facing water) entrance; against left wall.

23° 56.4' S 46° 17.5' W 10' 978.8418

Sao Borja, Rio Grande do Sul

20' west of gate to administration building.

28° 39.8' S 56° 02.3' W 330' 979.2055

Sao Luis, Maranhao

Tirirical Airport - at left east end of bottom step of center flight of steps leading from field to veranda of airport, about 9" above field.

02° 37.0' S 44° 14.0' W 174' 977.9923

Sao Mateus, Espirito Santo

100 yards north of southeast corner of landing strip.

18° 43.1' S 39° 52.7' W 150' 978.5723

Sao Paulo, Sao Paulo

Campo de Marte Airport - at southeast corner of hangar No. 1.

23° 31.0' S 46° 38.2' W 2475' 978.6544

Sao Paulo International Airport (Congonhas) - at Gate No. 8. At 3rd concrete V from field supporting sun canopy, east side of walk.

23° 38.2' S 46° 39.1' W 2608' 978.6508

Sena Madureira, Acre

On runway at ramp plus or minus 50 yards east of west end of runway.

09° 05.0' S 68° 40.0' W 400' 978.1586

BRAZIL (cont.)

Tarauaca, Acre

At parking ramp, field level.

08° 21.5' S 70° 44.9' W --- 978.1418

Teresina, Piaui

On veranda on field side of terminal by first pillar left of center (northeast) with rotary club sign. Field level.

05° 03.0' S 42° 49.3' W 165' 978.0323

Tocantinapolis, Goias

At wind sox.

06° 21.0' S 47° 23.8' W 430' 978.0447

Tocantinia, Goias

At wind sox.

09° 35.1' S 48° 25.0' W 558' 978.1102

Tres Lagoas, Mato Grosso

At base of radio tower 100' south of radio shack.

20° 48.0' S 51° 43.0' W 1027' 978.5724

Uberaba, Minas Gerais

Airport at old terminal (now D.A.C.) building on concrete block at center of field side of building; 3' above field level.

19° 45.5' S 47° 54.5' W 2500' 978.3610

Uberlandia, Minas Gerais

Just south (left) of north (right hand) entrance to waiting room from field side.

18° 55.4' S 48° 18.2' W 2800' 978.2947

Uruguiana, Rio Grande do Sul

At entrance to administration building, field side.

29° 46.6' S 57° 02.9' W 250' 979.3087

Villa Bella, Mato Grosso

20 yards east of gas pump at end of runway.

15° 00' 0 S 59° 57.5' W 820' 978.3425

Vitoria, Espirito Santo

Airport at junction of sidewalk and plane parking ramp.

20° 16.0' S 40° 17.5' W 10' 978.6536

BRAZIL (cont.)

Xabantina, Mato Grosso

At airport at "A" frame for cars.

14° 40.4' S	52° 21.2' W	---	978.2857
-------------	-------------	-----	----------

Xapuri, Acre

At parking ramp, field level.

10° 39.1' S	68° 27.3' W	535'	978.1916
-------------	-------------	------	----------

BRITISH GUIANA

Georgetown

Atkinson Field - on first yellow line in front of passenger entrance gate on taxi ramp.

06° 30.0' N	58° 14.8' W	95'	978.0909
-------------	-------------	-----	----------

CHILE

Antofagasta, Antofagasta

Cerro Moreno Airport - to right of fence leading to terminal and runway at sign on fence, "Crew only".

23° 27.0' S	70° 27.1' W	442'	978.8820
-------------	-------------	------	----------

Arica, Parapaca

Chacalluta International Airport - 15' south of gate leading to Panagra waiting room at corner of fence.

18° 21.4' S	70° 22.0' W	114'	978.5120
-------------	-------------	------	----------

Punta Arenas, Magallanes

Old Punta Arenas Airport - near the town, at passenger terminal of Aerolineas Argentinas and Linea Area Nacional on concrete sidewalk just outside door into terminal building, at head of sidewalk leading to field and beneath a roofed porchway.

53° 07.3' S	70° 53.5' W	03'	981.3310
-------------	-------------	-----	----------

New Punta Arenas Airport - on sidewalk to left of entrance to temporary terminal facing field.

---	---	---	981.3126
-----	-----	-----	----------

Santiago, Santiago

Los Cerrillos Airport - in waiting room lobby by exit, between exit and stairway door.

33° 29.9' S	70° 42.4' W	1675'	979.4500
-------------	-------------	-------	----------

COLOMBIA

Barranquilla, Atlantico

Soledad Airport - in front of Avianca information booth.

10° 54.5' N	74° 47.0' W	47'	978.2265
-------------	-------------	-----	----------

Columbia (Cont'd)

Bogota, Cundinamarca

International airport - about 12' east southeast of departure gates 1 and 2. IAGS gravimeter station.

04° 42.0' N	74° 09.0' W	8355'	977.4018
-------------	-------------	-------	----------

Cali, Val del Cauca

Calpuerto Airport - right end (east) of Avianca information counter.
Approximately 2 paces southeast of control tower section of building.

03° 24.4' N	76° 23.9' W	3139'	977.8198
-------------	-------------	-------	----------

Cartagena, Bolivar

At Avianca information booth; left end of counter.

10° 23.2' N	75° 31.5' W	10'	978.1966
-------------	-------------	-----	----------

Ibaque, Tolima

Perales Airport - northwest corner of fence.

04° 25.1' N	75° 09.2' W	3050'	977.7753
-------------	-------------	-------	----------

Ipiiales, Narino

San Luis Airport - on veranda on field side in corner to right of door to administration offices.

00° 51.8' N	77° 40.5' W	9680'	977.2532
-------------	-------------	-------	----------

Medellin, Antioquia

Olaya Henara Airport - at bench mark A186CW5.

06° 13.5' N	75° 35.2' W	4929'	977.7576
-------------	-------------	-------	----------

Pereira, Caldas

Matecana Airport - at control tower, BM 170W.

04° 47.5' N	75° 45.5' W	4426'	977.7734
-------------	-------------	-------	----------

Popayan, Cauca

By pillar in waiting room.

02° 27.5' N	76° 37.5' W	---	977.5999
-------------	-------------	-----	----------

ECUADOR

Guayaquil

North of Panagra operations door on north ramp to runway.

02° 10.1' S	79° 52.5' W	13'	978.1387
-------------	-------------	-----	----------

Quito

Mariscal Sucre Airport - beside north door of terminal on runway side on Panagra luggage platform.

00° 08.0' S	78° 28.3' W	9220'	977.2860
-------------	-------------	-------	----------

FRENCH GUIANA

Cayenne

At junction of walk to waiting station with parking ramp; left side of walk facing station.

04° 49.5' N 52° 22.5' W 25' 978.0375

PARAGUAY

Asuncion

Southeast corner of building at passenger entrance.

25° 15.0' S 57° 33.0' W 330' 978.9578

PERU

Arequipa, Peru

Chachani Airfield - at corner of building housing control tower on the same side as the main entrance and the same end as the control tower. Three feet towards main entrance along wall from corner and one foot out from wall.

16° 21.0' S 71° 33.7' W 8150' 977.7165

Iquitos, Loreto

On cement walk on street side of building by steps.

03° 44.0' S 73° 12.5' W 384' 978.0870

Lima, Peru

Lima International Airport - just inside passenger entrance for incoming passengers, 20' north of stairway leading to main lobby for customs.

12° 06.0' S 77° 01.0' W 483' 978.2796

Talara, Piura

Capitan Montes Airport - at intersection of runway and sidewalk to administration building.

04° 34.0' S 81° 15.5' W 287' 978.1332

SURINAM (DUTCH GUIANA)

Parimaribo

Zandrey Field - junction with runway of first walk south of operations tower.

05° 27.0' N 55° 11.6' W 81' 978.0471

URAGUAY

Montevideo

Carrasco Field - in corner on side of Main bus between Arcade and bus.

34° 51.0' S 56° 02.5' W 79' 979.7462

VENEZUELA

Barcelona, Anzoategui

About 200 ft. west of operations building at junction of concrete parking and blacktop taxi-ramp; about 100' south of end of concrete ramp.

10° 06.8' N 64° 41.0' W * 15' 978.1505

Caracas, Federal District

Maiquetia Airport - at Cartografia Nacional B.M. In garden area in front of airport postoffice. Near eastern edge of grassy area.

11° 35.4' N 66° 58.5' W 160' 978.2456

Maracaibo, Zulia

On plane parking ramp on 11th concrete square out from the second inclined ramp to the left of the main field entrance to the terminal building and fenced spectator area.

10° 40.0' N 71° 39.0' W 144' 978.2000

Maturin, Monagas

PAA garage north of customs and operation building in northeast corner of garage.

09° 34.4' N 63° 10.8' W 237' 978.0112

FOREIGN HARBOR SITES

HARBOR GRAVITY BASE STATIONS

ADEN

Prince of Wales pier near middle of pier. 977.3227

Postoffice pier - near middle of pier. 977.3227

ARGENTINA

Ushuaia

Gravity station at the Office of the Chief of Police
off Calle 6 in line with long pier. 981.4856

AUSTRALIA

Brisbane, Queensland

Eagle Street Wharf - Lamont station No. 664, about 15
ft. above low water mark, and about 18 ft. from west
end of pier. 979.1705

200 feet downstream from upstream end of Eagle Street
Wharf on wharf edge. 979.1698

BERMUDA

Aquarium - in level stretch of Flats Road west of
Aquarium. 979.8262

Bermuda Biological Station - at Bench Mark No. 3 at tide
gauge station on Ferry Reach. 979.8232

Devonshire Dock - at entrance gate. 979.8490

Hamilton Dock - at east end of docks on Front Street. 979.8551

Ordnance Island - on town sea wall dock opposite Ordnance
Island in St. Georges. 979.8244

BRAZIL

Belem

Belem City Pier, south end, by third steel "I" beams
nearest water. 978.0383

Tide Gauge House - at north end of Belem City pier
northeast corner, inside house, 8 ft. northeast of
Consuelo Nacional de Geografia Bench Mark No. 1, 1948. 978.0396

CANAL ZONE

Balboa

Pier 18 at post No. 3 close to Ladies' Room on shore
end, 10 ft. above sea level. 978.2390

Pier 15C 978.2386

CANAL ZONE (Cont'd)

Balboa (Cont'd)

Rodman Naval Base -- at shore end of center of 3
piers next to large valve block painted black and
yellow. 978.2383

Cerro Gordo (Hill)

In station Building No. 1 near Pedro Miguel locks. 978.1838

Coco Solo

Southwest corner of Building No. 92 near end of
old Pier No. 1. 978.2557

CHILE

Punta Arenas

Magellanes Port Authority, at foot of main pier;
at base of steps. 981.3351

Valpariso

Waterfront, Pier No. 1 under archway opposite slid-
ing steel door to storehouse No. 11. 979.6355

CUBA

Guantanamo Bay

Wharf (Pier) Baker, underneath sign "62" on Building
62 (smoke stack building) at center of wharf, 100 ft.
from edge of wharf and 10 ft. above sea level. 978.7487

EGYPT

Alexandria Harbor

On main street opposite Port No. 14 Customs Office. 979.4331

Coal quays at base of control tower (Vening Meinesz
station). 979.4324

Cairo

Cairo base - River Nile park at Anglo-Egyptian oil
Company marker. 979.3173

Port Said

North end of Suez Canal, northwest corner of base
of Ferdinand de Lesseps statue site. 979.4473

Suez

South end of Suez Canal, on cement ledge against
north base of Indian Monument near Vening Meinesz
station. 979.3066

Little Bitter Lake, S.O.M.E.D. station B539 on
south end of lake. 979.3378

FRENCH WEST AFRICA**Dakar Harbor**

Seaward end of Mole No. 1.	978.4833
Seaward end of Mole No. 2.	978.4826
Seaward end of Mole No. 3.	978.4822

GUAM

Road junction to Naval Operations Base area and Cabras Island.	978.5417
--	----------

Naval Operations Base - main gate - 20 ft. north of sentry house.	978.5402
---	----------

HAWAIIAN ISLANDS**Oahu**

Pearl Harbor Naval Base - Land end of Sail 2.	978.9386
Land end of Sail 6.	978.9391
Next to Sail 11 sign.	978.9398
Fort Armstrong - boat house by Pier #1 on rip rap wall side nearest pier #1, 3 feet above water.	978.9398

ICELAND**Reykjavik**

Harbor, on deck at center of seaward end of concrete on LONG PIER.	982.2817
--	----------

JAPAN**Yokosuka**

OPPAMA sea plane base in office.	979.7769
----------------------------------	----------

MALTA

Dock No. 3 - about 6 ft. above Cooper's Submarine pendulum station.	979.8870
---	----------

Manuel Island

Opposite point where HMS Forth is tied, about 4 ft. above water near Cooper's Submarine pendulum station.	979.8859
---	----------

St. Paul's Bay

50 ft. west of mole at base of hill.	979.8881
--------------------------------------	----------

NEW ZEALAND**Wellington**

Gate to floating dry dock at right concrete post.	980.2829
---	----------

NORTH BORNEO**Labuan Island**

B.M.P. Base 4152 at B.M.P. wharf area.	978.0994
--	----------

OKINAWA

Naha Port

Northeast corner of Warehouse 307. 979.1169

PHILLIPINE Islands

Manila

On Pier No. 9 (formerly No. 6) in between Warehouse A and D on roadway next to abutment (Vening Meinesz). 978.3570

At edge of pier just out from Door No. 4, Warehouse C, 15 ft. above water. 978.3562

Pier 11 - Vening Meinesz station. 978.3580

SINGAPORE

East Wharf - at edge of pier directly out from south-east corner of large warehouse building No. 114, about 10 ft. above water. Vening Meinesz station. 978.0802

Royal Navy Base - main gate of H.M. dockyard on concrete sidewalk on right facing gate from outside. 978.0837

TUNISIA

Tunis

Tunis Harbor - at end in center of pier south of Basin de Voiliers; near Vening Meinesz Submarine pendulum station. 979.9152

Tunis Port - at entrance gate to Club Nautique, across causeway; northeast of Basin de Voiliers. 979.9144

Sfax

Sfax Harbor - Compagne Africaine Geophysique Station B17. 979.7263

UNITED STATES

California

San Diego

Alongside northernmost pier of U. S. Naval Sonar school. This is a reserve pier and not on Sonar school section. 979.5412

Northeast side of southernmost pier, U. S. Naval Sonar School. 979.5417

On center finger pier at Berth 3, 85 ft. from junction of main pier. 979.5482

On concrete pier head, 3 ft. west and 2 ft. north of south junction of wooden pier to land. About 12 ft. above sea level. 979.5423

UNITED STATES (Cont'd)

California (Cont'd)

San Francisco

Fort Mason - on cement pier at the head of Slip
No. 1, by the westernmost lamp post near Building
317, which is the westernmost pier. 979.9980

Mare Island

Naval Ship Yard - 20 ft. west of north
gate Sentry Post. 979.9909

Florida

Key West

At southeast junction of Thomas Street and South-
ard Street. Site is on sidewalk and is 20 ft.
north and 20 ft. east of gate guards' booth at
Southard Street gate of U. S. Naval Station. 978.9684

Land end of Pier No. 4 on north side of pier,
U. S. Naval Base. 978.9684

Lamont Geological Observatory site on long
angling pier at Key West Naval Base, on concrete
edge of pier at 14' x 33' one-story concrete
Building No. 185. The pier is called the "MOLE". 978.9686

LOCAL GRAVIMETER CONNECTIONS
TO PENDULUM SITESNORTH AMERICAN WESTERN STANDARDIZATION RANGE

ALASKA

Point Barrow

Pendulum Station = 932.6996

a) Airstrip at east entrance to terminal waiting room. +0.2 mgal

a) = 932.6998

Umiat

Pendulum Station = 932.2535

a) Airstrip opposite road leading to camp. +0.9 mgls.

a) = 932.2544

Fairbanks (Ladd AFB)

Pendulum Station = 932.2444 (BOQ 10)

a) Ladd AFB - base of control tower. -0.5 mgls.

b) Ladd AFB - outside entrance to terminal from field. +0.3 mgls.

c) Municipal AP terminal in lobby at East "I" beam pillar.
+2.0 mgls.d) University of Alaska, Geophysical Institute ground floor
Cambridge & Gulf "C" sites. +1.8 mgls.

a) = 932.2439 b) = 932.2441 c) = 932.2464 d) = 932.2462

Anchorage

Pendulum Station = 931.9397

a) Elmendorff AFB outside field entrance to passenger lobby (MATS)
-0.7 mgls.b) International A.P. at field entrance to terminal from Gates 3
and 4. -19.3 mgls.

c) Merrill Field, base of control tower. +0.6 mgls.

a) = 931.9380 b) = 931.9204 c) = 931.9403

CANADA

Yukon Territory

Watson Lake

Pendulum Station = 981.7150 (Manager's house)

a) Road side of Air terminal, 5 feet from end of terminal and
fence enclosing grass plot. -0.7 mgls.

b) Air Terminal waiting room in southeast corner. -0.9 mgls.

c) Gulf "C" (tower) site. -0.6 mgls.

a) = 981.7143 b) = 981.7141 c) = 981.7146

NORTH AMERICAN WESTERN STANDARDIZATION RANGE (Cont'd)

CANADA(Cont'd.)

Yukon Territory

Whitehorse

Pendulum Station = 981.7486 (pump house)

- a) Center of vehicle turn-around outside street entrance to Air Terminal. +0.1 mgls.
- b) In Air terminal lobby next to radiator at Pan American Airways counter. +0.1 mgls.
- c) Gulf "C" (hangar) site. -0.2 mgls.

a) = 981.7487 b) = 981.7487 c) = 981.7484

British Columbia

Fort Nelson

Pendulum Station = 981.6829

- a) 14 ft. in front of field entrance to Air terminal. +10.1 mgls.

a) = 981.6930

Fort St. John

Pendulum Station = 981.4059 (basement of Administration Building)

- a) On tarmac field side of Air terminal. -0.4 mgls.
- b) Inside and at right side of doorway into Canadian Pacific Hangar on field side of passenger Air Terminal. -0.4 mgls.
- c) Fireplace in passenger lounge. -0.5 mgls.
- d) Gulf "C" site. -0.3 mgls.

a) = 981.4055 b) = 981.4055 c) = 981.4054 d) = 981.4056

Alberta

Grand Prairie

Pendulum Station = 981.3180 (Post Office)

- a) At foot of beacon tower on street side of Air Terminal building. -2.2 mgls.
- b) Gulf "C" site (school). -0.5 mgls.

a) = 981.3158 b) = 981.3175

Edmonton

Pendulum Station=981.1678 (basement Physics Building)

- a) Air Terminal lobby by radiator and Canadian Pacific counter +5.1 mgls.
- b) To left of terminal entrance from field by fence at Gate 3. +5.3 mgls.
- c) Sidewalk outside Physics Building (Gulf "C" side). -0.6 mgls.
- d) RCAF Base, on north side Hangar 2 at STOP sign. +6.0 mgls.

a) = 981.1729 b) = 981.1731 c) = 981.1672 d) = 981.1738

NORTH AMERICAN WESTERN STANDARDIZATION RANGE (Cont'd)

CANADA (Cont'd.)

Alberta

Calgary

Pendulum Station = 980.8281 (hangar)

- a) Air terminal inside southernmost set of doors leading to parking lot. +0.7 mgls.
- b) Gulf "C" (school) site. -5.3 mgls.

a) = 980.8288 b) = 980.8228

Lethbridge

Pendulum Station = 980.7595 (Post Office)

- a) At field end of sidewalk leading from loading area into Air terminal. -5.7 mgls.
- b) Gulf "C" (Municipal Building) site. -1.0 mgls.

a) = 980.7538 b) = 980.7585

UNITED STATES

Montana

Cutbank

Pendulum Station = 980.6085

- a) ~~Outside~~ field entrance to airport customs inspection room. 0.0 mgls.
- b) ~~Gulf "C"~~ site. -0.2 mgls.

a) = 980.6085 b) = 980.6083

Great Falls

Pendulum Station = 980.5270 (Roosevelt School)

- a) At Gate 1 of barrier on field side of air terminal. -13.2 mgls.
- b) Inside air terminal at Western Airlines counter. -13.3 mgls.
- c) USAF Base at foot of ladder on control tower. +1.2 mgls.

a) = 980.5138 b) = 980.5137 c) = 980.5282

Billings

Pendulum Station = 980.3710 (Hangar)

- a) New Air Terminal, at Gate 6 of barrier leading to field. +0.7 mgls.
- b) Gulf "C" (Statue) site. +0.6 mgls.

a) = 980.3717 b) = 980.3716

Wyoming

Sheridan

Pendulum Station = 980.2267 (Hangar)

- a) Central gate in field barrier. 0.0 mgls.

a) = 980.2267

NORTH AMERICAN WESTERN STANDARDIZATION RANGE (Cont'd)

UNITED STATES (Cont'd)

Wyoming

Casper.

Pendulum Station = 979.9558

- a) Gate 3 of field barrier. +0.4 mgls.
- b) Gulf "C" (Storage Building) site. +0.2 mgls.

a) = 979.9562 b) = 979.9560

Cheyenne

Pendulum Station = 979.7007 (cafe)

- a) Central gate of barrier. +0.1 mgls.
- b) Gulf "C" (airstrip) site. +0.1 mgls.

a) = 979.7008 b) = 979.7008

Colorado

Denver

Pendulum Station = 979.6115

- a) Stapleton Field, Gate 2 of barrier. +21.9 mgls.
- b) Stapleton Field, Gate 6 of barrier. +21.1 mgls.
- c) Chamberlin Observatory at foot of basement steps leading into building. -0.3 mgls.

a) = 979.6334 b) = 979.6326 c) = 979.6112

Texas

Amarillo

Pendulum Station = 979.4235

- a) Outside Air terminal entrance from field to right of door. -0.1mgls.
- b) Barrier Gate 4 to field. 0.0 mgls.

a) = 979.4234 b) = 979.4235

Houston

Pendulum Station = 979.2983

- a) New Air terminal inside concourse at Gate 7. -5.1 mgls.
- b) On field side of new terminal at fire plug located beneath center of restaurant bay. -5.0 mgls.

a) = 979.2932 b) = 979.2933

San Antonio

Pendulum Station = 979.1975 (Storeroom)

- a) Barrier Gate 8, field level, the entry to U.S. Customs room. +0.1 mgls.
- b) Barrier Gate 3 opposite main entrance to air terminal from field. +0.4 mgls.

a) = 979.1976 b) = 979.1979

NORTH AMERICAN WESTERN STANDARDIZATION RANGE (Cont'd)

Texas

Laredo

Pendulum Station = 979.0799 (Bldg 204 Laredo AFB)

- a) Gulf "C" (Jail Site). +1.8 mgls.
- b) San Antonio Air terminal, Barrier Gate 8. +117.7 mgls.

a) = 979.0817 b) = 979.1976

MEXICO

Nuevo Leon

Monterrey

Pendulum Station = 978.8055

- a) At Inst. Geofisia marker on curb outside street entrance to lobby of Air terminal. +56.2 mgls.

a) = 978.8617

District Federal

Mexico City

Pendulum Station = 977.9414 (Univ. Nac)

- a) New International air terminal on field side of incoming passenger barge at glass partition on exit side from customs and immigration. +28.7 mgls.
- b) At bronze plaque in concourse running along street side of terminal. +29.1 mgls.
- c) Taculouga (Photogrametry room) 6 ft. west of pier No. 1. +0.5 mgls.

a) = 977.9701 b) = 977.9705 c) = 977.9419

Paso de Cortes

Pendulum Station = 977.5711 (TV Sta.)

- a) Mexico City International terminal, incoming passenger barge site (see Mexico City). +398.9 mgls.
- b) Television station garage. +0.8 mgls.
- c) Base of Paso Cortes monument. +82.5 mgls.

a) = 977.9701 b) = 977.5719 c) = 977.6536

NORTH AMERICAN PACIFIC COAST STANDARDIZATION RANGE

UNITED STATES

Washington

Seattle

Pendulum Station = 980.7388 (Univ. Wash)

- a) Seattle-Tacoma International air terminal in field level lobby at Gate 5. +37.7 mgls.
- b) McChord AF base, MATS terminal, inside and to left of Gate 1 exit to field. +9.7 mgls.

a) = 980.7765 b) = 980.7485

NORTH AMERICAN PACIFIC COAST STANDARDIZATION RANGE (Cont'd)

UNITED STATES (Cont'd.)

California

San Francisco

Pendulum Station = 979.9867 (Golden Gate Park)

- a) New International Air terminal inside field lobby at Gate 23 of Concourse "C". +1.6 mgls.
- b) International terminal on street side of United Air Lines main lobby. +1.5 mgls.
- c) Travis AFB at field entrance to terminal. +3.1 mgls.
- d) Moffet Field NAS - at field entrance to main hangar housing Fleet Logistics Terminal. -41.3 mgls.

a) = 979.9883 b) = 979.9882 c) = 979.9898 d) = 979.9454

NORTH AMERICAN MID-CONTINENT STANDARDIZATION RANGE

UNITED STATES

South Dakota

Huron

Pendulum Station = 980.4536 (basement Air terminal)

- a) At USC&GS marker on concrete step to east door of hangar, 220 ft. east of air terminal. -0.5 mgls.
- b) At west corner of air terminal building, ground level. -0.9 mgls.

a) = 980.4531 b) = 980.4527

Wisconsin

Madison

Pendulum Station = 980.3689 (Room 12, Science Hall)

- a) Truax Field inside air terminal by show case opposite street entrance. +3.6 mgls.
- b) Milwaukee, Mitchell Field, inside South Concourse at Gate 16. -9.3 mgls.
- c) Mitchell Field, West Concourse, Gate 9. -9.0 mgls.

a) = 980.3725 b) = 980.3596 c) = 980.3599

Illinois

Chicago

Pendulum Station 980.2873 (E.A.L. Hangar)

- a) Midway Airport, in lounge of North Central Airways at left-hand wall facing ticket counter and 12 ft. from counter. -0.9 mgls.
- b) O'Hare International Airport, N.W. Airlines field lobby, Gate 6, in corner to right of entry from Concourse. +2.0 mgls.

a) = 980.2864 b) = 980.2893

207

NORTH AMERICAN MID-CONTINENT STANDARDIZATION RANGE (Cont'd)

UNITED STATES (Cont'd)

Kansas

Beloit

Pendulum Station = 979.9981 (basement of Gas Station)

- a) Kansas City Air Terminal, on sidewalk between entry doors into terminal lobby. +1.7 mgls.
- b) Ground level outside Phillips gasoline station housing Pendulum Site. -0.4 mgls.

a) = 979.9998 b) = 979.9977

Oklahoma

Tulsa

Pendulum Station = 979.7663 (Rm. 4)

- a) Air Terminal, Barrier Gate 3. +10.3 mgls.
- b) Outside University Station at USC&GS marker. -0.2 mgls.

a) = 979.7766 b) = 979.7661

NORTH AMERICAN EASTERN STANDARDIZATION RANGE

CANADA

Ontario

Ottawa

Pendulum Station = 980.6217 (Geophysics Lab)

- a) Outside Field entrance to old airport terminal. -0.4 mgls.
- b) New air terminal, Gate 2. -3.1 mgls.
- c) Dominion Observatory pier. -0.9 mgls.
- d) N.R.C. absolute gravity site, floor. +7.0 mgls.

a) = 980.6213 b) = 980.6186 c) = 980.6208 d) = 980.6287

UNITED STATES

Massachusetts

Woods Hole

Pendulum Station = 980.3273 (W.H.O.I. basement)

- a) Boston, Logan AP at American Airlines lobby exits, Gate 19 or 17. +76.3 mgls.

a) = 980.4036

NORTH AMERICAN EASTERN STANDARDIZATION RANGE (Cont'd)

UNITED STATES(Cont'd)

New York

Palisades (Lamont Geol. Observatory)

Pendulum Station = 980.2596 (Lamont Observatory, Gravity room)

- a) Idlewild International Air Terminal, opposite entrance to Customs. -33.5 mgls.
- b) Idlewild (old) Domestic Terminal, in corridor opposite TWA advance registrations counter. -32.3 mgls.
- c) LaGuardia Air Terminal Bldg., Post Office. +22.9 mgls.
- d) Newark Air Terminal, Gate 6 to field. +11.0 mgls.

a) = 980.2261 b) = 980.2273 c) = 980.2825 d) = 980.2706

New Jersey

Princeton

Pendulum Station = 980.1781 (Guyot Hall sub-basement)

- a) Guyot Hall, room 14. -0.5 mgls.
- b) McGuire AFB, MATS Terminal, exit from lobby to field. +34.8 mgls.
- c) Philadelphia, main entrance to Air Terminal at curb opposite easternmost door. +19.5 mgls.

a) = 980.1776 b) = 980.2129 c) = 980.1976

District of Columbia

Washington

Pendulum Station = 980.1006 (Geophysics Lab Compressor room)

- a) Washington Airport, under portico on street side of terminal at base of column with letter "W" of word WASHINGTON. +8.3 mgls.
- b) Dept. of Commerce gravity pier. +18.2
- c) Dept. of Commerce, 14th St. side at USC&GS marker at arch leading into parking area. +17.5 mgls.
- d) National Bureau Standards, East Bldg. absolute gravity site. -1.2 mgls.

a) = 980.1089 b) = 980.1188 c) = 980.1181 d) = 980.0994

South Carolina

Charleston

Pendulum Station = 980.5507 (Citadel)

- a) Charleston AFB, MATS processing room by counter. +16.7 mgls.
- b) Municipal Airport, at USC&GS Bench Mark on porch on field of terminal. +16.0 mgls.
- c) Municipal Airport, barrier, Gate 5. +16.1 mgls.

a) = 979.5674 b) = 979.5667 c) = 979.5668

207

NORTH AMERICAN EASTERN STANDARDIZATION RANGE (Cont'd)

UNITED STATES(Cont'd)

Florida

Miami

Pendulum Station = 979.0356 (Univ. Biological Sta.)

- a) International Airport at plaque in lobby. +17.2 mgls.
- b) Eastern Airlines Terminal, East Concourse at Gate 1 to field.

+17.1 mgls
+18.4

a) = 979.0528 b) = 979.0527

errata

PACIFIC STANDARDIZATION RANGE

JAPAN

Hokkaido

Chitose

Pendulum Station = 980.4406

- a) Chitose, Japanese Airlines Terminal, left of field entrance to terminal at field level. -0.1 mgls.

a) = 980.4405

Honshu

Tokyo

Pendulum Station = 979.8016 (Tokyo Univ.)

- a) Haneda Air terminal at Gate 3. -28.0 mgls.
- b) Kyoto Fundamental Gravity base. -80.0 mgls.

a) = 979.7736 b) = 979.7216

HAWAIIAN ISLANDS

Oahu

Honolulu

Pendulum Station = 978.9530 (Bishop Museum)

- a) Hickam AFB, MATS terminal lobby next to wall map of Pacific Ocean. -19.3 mgls.
- b) International Airport at base of flag pole at Gate 4. -20.5

a) = 978.9337 b) = 978.9325

PACIFIC STANDARDIZATION RANGE (Cont'd).

OKINAWA

Kadena

Pendulum Station = 979.1265

- a) Kadena AFB, MATS terminal, right hand side of exit from lobby to field. +7.8 mgls.

a) = 979.1343

PHILLIPINE REPUBLIC

Manila

Pendulum Station = 978.3969

- a) Clark AFB, MATS terminal, left of field entrance into terminal. -0.4 mgls.
- b) Manila International Airport, at base of long cement step (North end) of Pan American field entrance into terminal. -20.2 mgls.
- c) Nichols Field (domestic terminal) at P.C.&G.S. gravity marker between Gates 6 and 7. -26.8 mgls.

a) = 978.3965 b) = 978.3767 c) = 978.3701

HONG KONG

Pendulum Station = 978.7677

- a) Kai-Tak Airport, terminal building next to fire hose near covered driveway. +5.3 mgls.
- b) Kai-Tak RAF Base, outside entrance to passenger lounge (Bldg. 188). +3.4 mgls.

a) = 978.7730 b) = 978.7711

SINGAPORE

Pendulum Station = 978.0815 (Univ. Malaya)

- a) Paya Lebar Airport (International Terminal) passageway to planes beneath brass plaque. -1.1 mgls.
- b) Changi Creek RAF Base, on veranda of air movement office at money exchange booth. -1.4 mgls.
- c) Kallang Airport (now Youth Sport Center) to right of front entrance. +0.2 mgls.

a) = 978.0804 b) = 978.0801 c) = 978.0817

AUSTRALIA

Northern Territory

Darwin

Pendulum Station = 978.3139 (Bu. Mineral Resources Bldg.)

PACIFIC STANDARDIZATION RANGE (Cont'd)

AUSTRALIA(Cont'd)

Northern Territory(Cont'd)

Darwin(Cont'd)

- a) International Airport, inside right hand door to International Passenger Lounge. +1.4 mgls.
- b) RAAF Base, Officers Club in room beneath bar with two refrigerator motors (BMR pendulum site.) +2.3 mgls.

a) = 978.3153 b) = 978.3162

Queensland

Townsville

Pendulum Station = 978.6247 (Garbutt RAAF)

- a) Air terminal, in northwest corner of passenger lounge. -0.7 mgls.

a) = 978.6240

Cairns

Pendulum Station = 978.5006

- a) Air terminal, on first step of field entrance into terminal building. -0.1 mgls.

a) = 978.5005

Brisbane

Pendulum Station = 979.1695

- a) Old Airport - (Eagle Farm) to right of field entrance to passenger lounge. -9.7 mgls.
- b) Univ. Queensland seismic vault. +0.6 mgls.

a) = 979.1598 b) = 979.1701

New South Wales

Sydney

Pendulum Station = 979.6863 (Nat. Stds. Lab.)

- a) Mascot Field, Kingsford-Smith Airport, to right of entrance to overseas passenger waiting room, marked "Departures". +13.0 mgls.
- b) Rose Bay Flying Boat Base, on sidewalk to right of street entrance to terminal. +10.2 mgls.

a) = 979.6993 b) = 979.6965

PACIFIC STANDARDIZATION RANGE (Cont'd)

AUSTRALIA (Cont'd)

Victoria

Melbourne

Pendulum Station = 979.9798

- a) Essenden Airport, east side of western pair of double doors leading from passenger lounge to field. -6.9 mgls.
- b) Laverton RAAF Base, at base of control tower. +11.3 mgls.

a) = 979.9729 b) = 979.9911

NEW ZEALAND

Wellington

Pendulum Station = 980.2936

- a) Paraparaumu Airport, to right of ramp entering terminal from street. -83.9 mgls.

a) = 980.2097

Christchurch

Pendulum Station = 980.5089

- a) Harewood Airport, 25 ft. south of terminal building on asphalt pavement at wind indicator. -12.7 mgls.
- b) Wigram Airport, field side of control tower building at field level. +1.2 mgls.

a) = 980.4962 b) = 980.5101

Dunedin

Pendulum Station = 980.7425 (Otago Univ.)

- a) Taieri Airport, on first step leading into terminal from field. -5.8 mgls.

a) = 980.7367

ANTARCTICA

McMurdo

Pendulum Station = 982.9919 (Bldg. 30)

- a) Air Operations Building, at entrance. -2.8 mgls.
- b) Scott Base, Seismic Hut on concrete pier. -3.7 mgls.

a) = 982.9891 b) = 982.9882

EUROPEAN STANDARDIZATION RANGE

NORWAY

Oslo

Pendulum Station = 981.9270 (Geol. Museum)

- a) Fornebu Airport, in terminal lobby to right of passenger entrance from car port, at base of second circular pillar. +3.6 mgls.

a) = 981.9306

DENMARK

Copenhagen

Pendulum Station = 981.5576 (floor of gravity vault)

- a) Kastrup Airport, to left of field entrance to lounge for transient passengers. -0.4 mgls.

a) = 981.5572

ENGLAND

Teddington, N.P.L.

Pendulum Station = 981.1966

- a) London Central Airport, street side of terminal at foot of Channel Gescalator. +3.7 mgls.
b) London North Airport, main lobby leading to restaurant between center columns opposite T.W.A. counter. +5.1 mgls.

a) = 981.2003 b) = 981.2017

GERMANY

Bad Harzburg

Pendulum Station = 981.1808

- a) Frankfurt Main Airport, in main terminal lobby at Lufthansa counter next to street exit. -123.7 mgls.
b) Braunschweig absolute gravity site, on floor at base of tower. +86.6 mgls.

a) = 981.0571 b) = 981.2674

GERMANY (WEST)

Frankfurt

Pendulum Station = 981.0608

- a) Frankfurt Main Airport, in main terminal lobby at Lufthansa counter next to street exit. -3.7 mgls.

a) = 981.0571

EUROPEAN STANDARDIZATION RANGE (Cont'd)

FRANCE

Paris

Pendulum Station = 930.9409 (Sevres)

- a) Orly Airport, at end wall of Room No. 1 for arriving passengers. -24.9 mgls.
- b) Orly Airport, USAF MATS terminal, to right of main door leading to field from terminal waiting room. -24.3 mgls.
- c) Le Bourget Airport, on street side of "Hall Central" in alcove formed by narrow stairs leading up from ground floor. +9.3 mgls.

a) = 930.9160 b) = 980.9166 c) = 980.9502

ITALY

Rome

Pendulum Station = 980.3639 (Nat. Geophy. Inst.)

- a) Ciampino Airport, EST Terminal in corner at door into restaurant. -15.1 mgls.
- b) Ciampino Airport, OVEST, USAF Terminal on sidewalk to left of field entrance into terminal. -16.1 mgls.
- c) Faculty of Engineering Fundamental Gravity Base. -2.1 mgls.

a) = 980.3488 b) = 980.3478 c) = 980.3618

PORTUGAL

Lisbon

Pendulum Station = 980.0903 (Observatory)

- a) Martin-Gonzalves Airport, at bolt in floor outside SITA office and across from Customs Baggage exit on ground floor. -10.7 mgls.

a) = 980.0796

EAST AFRICAN STANDARDIZATION RANGE

LYBIA

Tripoli

Pendulum Station = 979.5876 (Wheeler USAF Base)

- a) Idris (Castel Benito) Airport, at entrance to passenger lounge in hangar. -49.7 mgls.

a) = 979.5379

EAST AFRICAN STANDARDIZATION RANGE (Cont'd)

EGYPT

Cairo

Pendulum Station = 979.2915 (Helwan)

- a) Cairo International (Farouk) Airport, in waiting room by drinking fountain opposite Bank counter. +24.5 mgls.
- b) Port Said Air terminal, directly in front of front (street) entrance. +161.3 mgls.

a) = 979.3160 b) = 979.4528

SUDAN

Khartoum

Pendulum Station = 978.303⁴~~4~~

- a) Airport terminal, in lobby on right-hand side of main entrance from street. +0.⁴~~0~~ mgls.
- b) University College at door to "Store A", Faculty of Science Building. ~~+0.3~~ mgls.
-0.1

a) = 978.3034 b) = 978.3033

ERITREA

Asmara

Pendulum Station = 977.8194 (Kagnew)

- a) Municipal Airport terminal, at base of steps leading into terminal building from street. +3.0 mgls.

a) = 977.8224

KENYA

Nairobi

Pendulum Station = 977.5401

- a) Eastleigh Airport, outside passenger waiting room on field side of terminal at sign. +3.1 mgls.
- b) West Civil Airport, outside waiting room at flag pole on field side of terminal. -4.4 mgls.

a) = 977.5432 b) = 977.5357

EAST AFRICAN STANDARDIZATION RANGE (Cont'd)

NORTHERN RHODESIA

Lusaka

Pendulum Station = 978.0536

- a) Air terminal, on sidewalk and just outside door leading from passenger waiting room to field. -0.2 mgls.

a) = 978.0534

SOUTHERN RHODESIA

Victoria Falls

Pendulum Station = 978.2315

- a) Salisbury, Belvedere Airport, to right of main entrance to terminal from street. -83.1 mgls.
 b) Livingstone, Northern Rhodesia Airport, on right-hand side of porch facing field located outside field entrance to terminal. -11.3 mgls.
 c) Victoria Falls, Hales & Gough pendulum site. -0.1 mgls.
 d) Salisbury, Browne pendulum site. -83.4 mgls.

a) = 978.1484 b) = 978.2202 c) = 978.2314 d) = 978.1481

UNION SOUTH AFRICA

Johannesburg

Pendulum Station = 978.5495 (Bernard Price Inst.)

- a) Jan Smuts Airport, left side of main entrance to terminal from bus parking lot. +0.8 mgls.

a) = 978.5503

WEST AFRICAN STANDARDIZATION RANGE

FRENCH WEST AFRICA

Dakar

Pendulum Station = 978.3856

- a) Yof Airport, at base of center pillar in front of main (street) entrance to terminal. +91.6 mgls.

a) = 978.4772

WEST AFRICAN STANDARDIZATION RANGE (Cont'd)

GHANA

Accra

Pendulum Station = 978.1159 (University)

- a) Airport - outside Customs and Immigration entrance to terminal from field located at southeast end of terminal building. -0.6 mgls.

a) = 978.1153

CONGO REPUBLIC

Leopoldville

Pendulum Station = 977.9144

- a) Leopoldville Air Terminal, 50 feet toward field from restaurant steps; restaurant is located on an elevated ledge between terminal and adjacent building. +37.5 mgls.
b) Nigli Airport, two feet from center column on porch at entrance to terminal from field. +28.2 mgls.

a) = 977.9519 b) = 977.9426

UNION SOUTH AFRICA

Capetown

Pendulum Station = 979.6473 (Mowbray)

- a) D.F. Malan Airport, on concrete porch to left of center doors from field to passenger waiting room. -1.1 mgls.
b) Wingfield Airport, left side of rear entrance to terminal from driveway. +2.1 mgls.

a) = 979.6462 b) = 979.6494

SOUTH AMERICAN WESTERN STANDARDIZATION RANGE

PANAMA CANAL ZONE

Balboa

Pendulum Station = 978.2417 (IAGS)

- a) Tocumen Airport, at IAGS gravity marker at base of statue between Gate 1 and field. +24.8 mgls.
b) Albrook Air Force Base, MATS terminal, on porch of entrance to terminal from field between pillars. +0.9 mgls.
c) U.S.C.&G.S. pendulum site (YMCA) -2.4 mgls.

a) = 978.2665 b) = 978.2426 c) = 978.2393

SOUTH AMERICAN WESTERN STANDARDIZATION RANGE (Cont'd)

COLUMBIA

Bogota

Pendulum Station = 977.4048

- a) International Airport, between exit gates 1 and 2 to field.
-3.0 mgls.
 - b) U.S.C.&G.S. Pendulum Site. -1.0 mgls.
- a) = 977.4018 b) = 977.4038

ECUADOR

Quito

Pendulum Station = 977.2774

- a) Airport terminal on PANAGRA baggage platform on field side of terminal beside north door. +8.6 mgls.
- a) = 977.2850

PERU

Lima

Pendulum Station = 978.2836

- a) Airport terminal on field side at entrance for arriving passengers; 20 feet north of stairway leading to main lobby. -4.0 mgls.
- a) = 978.2796

BOLIVIA

La Paz

Pendulum Station = 977.4672

- a) Braniff Airways terminal, at field end of sidewalk leading to terminal. -114.4 mgls.
 - b) Panagra airways terminal. At field end of sidewalk leading to terminal. -118.5 mgls.
- a) = 977.3528 b) = 977.3487

CHILE

Antofagasta

Pendulum Station = 978.9017

- a) Airport, Hangar No. 3 at front right-hand wall facing field.
-19.7 mgls.
- a) = 978.8820

SOUTH AMERICAN WESTERN STANDARDIZATION RANGE (Cont'd)

CHILE (Cont'd)

Santiago

Pendulum Station = 979.4289

- a) Street side of temporary PANAGRA terminal building (1957) at telephone sign located at left end of terminal facing entrance. +21.1 mgls.

a) = 979.4500

Punta Arenas

Pendulum Station = 981.3162 (Filter Plant)

- a) Temporary terminal (1957) at new airport on sidewalk to right of entrance to terminal from field. -3.6 mgls.
- b) Old Airport used by Aerolineas Argentinas on covered sidewalk from field at terminal entrance. +14.8 mgls.

a) = 981.3126 b) = 981.3310

SOUTH AMERICAN EASTERN STANDARDIZATION RANGE

VENZUELA

Caracas

Pendulum Station = 978.0395 (Cagigal)

- a) Maiquetia Airport at entrance to terminal from parking lot beneath bronze elevation plaque "47.9 Meters". +206.1 mgls.
- b) USC&GS pendulum site. +26.9 mgls.

a) = 978.2456 b) = 978.0664

BRAZIL

Belem

Pendulum Station = 978.0373

- a) Val de Caes Airport PAN AMERICAN Terminal, at passageway between waiting room and restaurant on field side of terminal. -4.3 mgls.
- b) Val de Caes Airport, Control Tower Terminal Building lobby at airport director's desk. -3.9 mgls.

a) = 978.0330 b) = 978.0334

SOUTH AMERICAN EASTERN RANGE (Cont'd)

BRAZIL

Rio de Janerio

Pendulum Station = 978.8047 (Observatory Nacional)

- a) Galeao Airport - at field exit to taxi stand from Customs
-room for incoming passengers. -7.0 mgls.
- b) Santos Dumont Airport, on porch at 6th pillar to the north
from the Control Tower. +3.5 mgls.

a) = 978.7977 b) = 978.8082

ARGENTINA

Buenos Aires

Pendulum Station = 979.7053

- a) Ezeiza (Pistarini) Airport at gravity marker at southwest
corner of terminal outside restaurant. +26.4 mgls.
- b) IGM Fundamental Gravity Base. -0.5 mgls.

a) = 979.7317 b) = 979.7048

ADDITIONAL STANDARDIZATION STATION

INDIA

New Delhi

Pendulum Station = 979.1363

- a) Palam Airport - on porch to left of entrance to terminal
from field. -2.2 mgls.
- b) Willingdon Airport, at base of steps at North entrance
into terminal from field. -1.4 mgls.

a) = 979.1341 b) = 979.1377

PART IV

Cooperative Programs

Errata For Section IV

Page

- 2 Paragraph 3; line 2: Change numerous to numerous
- 8 Paragraph 4; line 6: Change organisation to organization
- 10 Paragraph 7; line 2: Change floow ro floor
- 12 Column 4; line 6: Change 2.1 to 2.5
- 18 Paragraph 2; line 3: Change Nueva Laredo to Nuevo Laredo
- 27 Ecuador, Guayaquil: Change 978.1286 to 978.1386
- 28 Colombia, Cali: Observed gravity of 977.8294 appears to be a
typographical error of cooperator and probably
should be 977.8194

PART IV

Cooperative Programs

As indicated in the previous sections of this report, the value of the study presented is immeasurably enhanced by both pendulum and gravimeter observations made by independent observers at the same sites occupied by the writers and their colleagues. These duplicate measurements initiated in North America by the writers in collaboration with the Dominion Observatory of Canada and the United States Coast and Geodetic Survey permit a more precise value of gravity to be determined for each pendulum site than would otherwise have been possible. It was the success of this program in North America that won both scientific and financial support for having similar duplicate measurements made with the Cambridge pendulums at sites occupied with the Gulf-Wisconsin pendulums in Europe, Africa, South America and the South Pacific area.

The following reports cover three sets of independent measurements made with the Cambridge pendulums by Professor B. C. Browne and Mr. J. E. Jackson of Cambridge University, England. A fourth report deals with the gravimeter program in Mexico which was carried out as a cooperative study with Instituto Geofisica of the Universidad Nacional de Mexico through Ing. Prof. Ricardo Monges Lopez. This program was also integrated with that of the Inter-American Geodetic Survey, which covers a large portion of both South America and Central America.

A fifth report deals with the cooperative program carried out in Central and South America in conjunction with the California Exploration Company.

Gravity Measurements with the Cambridge Pendulums in Europe and Africa in 1958

by

B. C. Browne

Introduction

The idea of making a series of duplicate measurements with the Cambridge pendulum apparatus at sites in Europe and Africa occupied with the Gulf-Wisconsin pendulums, and not previously occupied with the magnetically compensated Cambridge pendulums, as a contribution to the gravity program of the International Geophysical Year was first proposed to the writer by Professor G. P. Woollard during the I.U.G.G. meetings in Toronto in September of 1957. Although there were no funds available at that time for this program, Professor Woollard felt he might be able to secure the necessary financial backing in view of the excellent agreement found in North America between measurements made with the Gulf-Wisconsin pendulums by the University of Wisconsin group and those made with the Cambridge pendulums by the Dominion Observatory of Canada. The degree of agreement, approximating 0.5 mgals over various gravity intervals ranging from 200 mgals to over 4000 mgals, obtained with these two very dissimilar types of pendulum apparatus argued strongly that both sets of pendulum equipment were giving reliable measurements to ± 0.3 mgal of changes in the earth's gravitational field. It therefore was with pleasure that I learned during the winter of 1957 that the Air Force Cambridge Research Center, who had been supporting Dr. Woollard's gravity studies, had agreed to also support through his program a series of measurements by myself using the Cambridge pendulums in Europe and Africa.

The program of observations reported were carried out during the period February through May of 1958 and involved measurements at the following sites:

Teddington, National Physical Laboratory
Munich, Residenz
Rome, University, Faculty of Engineering
Catania, Astronomical Observatory
Khartoum, University, Physics Department
Nairobi, Field Survey Headquarters
Salisbury, Meteorological Station
Johannesburg, Bernard Price Institute

As observations were made at each site on both the outward and return journey, there are two sets of measurements at each site except Catania, which was not occupied on the return journey. However, there are three sets of observations of Rome as one was taken both before and after the Catania observation on the outward journey.

In carrying out the above program the writer is greatly indebted to many people too numerous to mention whose help contributed greatly to the success of the venture, and in particular the writer wishes to acknowledge the help of his wife, Marjorie, who accompanied him through-

out the trip and not only aided in the measurements but also took care of the many time-consuming details and errands required in connection with the operation.

Computation of Results:

The records were measured, and the pendulum periods computed, in the manner described by Jelstrup* using the same coefficients for the temperature, pressure and are corrections. The crystal controlled frequency standard retained a very nearly constant rate throughout the survey, which was fortunate because the reception of radio time signals was very difficult in Khartoum and Nairobi owing to severe interference caused by atmospherics. It was noticeable, however, that the rates observed in Nairobi, Salisbury and Johannesburg, were consistently lower by .011 sec/day than the rates at the European stations. This effect was probably due to the systematic difference in barometric pressure. The results are unaffected, since at all stations except Khartoum and Nairobi I the rate was checked against radio time signals.

An examination of the results shows at once that in general they are satisfactory. The differences in the period between the opening and closing swings at the N.P.L. Teddington were:-

	1A	1B	1C	VIA	VIB	VIC
N.P.L. I	+1.8	+2.1	+0.1	-1.2	+1.3	+0.9
- N.P.L. II						

the mean value is $+0.83 \times 10^{-7}$ sec.

It will be noticed that all except one of the pendulums shortened slightly during the survey. At first sight this seems surprising, since during both the 1955 survey in Europe and the 1956/57 swings in South Africa, the pendulum periods increased and during the year preceding the survey, the periods had been decreasing at approximately the same rate.

Considering now the behaviour of the pendulums at other stations, it is interesting to see how the differences vary. Considerable changes occurred, particularly at Catania, Khartoum and Rome III. The very large change in VIB at Rome III is so great that it seems probable that a mistake was made and that pendulum VIC was accidentally swung instead of VIB. In view of this possibility, these swings have not been used in computing the results. The fact remains, however, that considerable variations did occur and it is important to try and find out the cause of these changes.

To investigate this matter in more detail, the variations in the periods at the different stations were analyzed. One of the most noticeable effects is that, whereas the period of 1A does not seem to depend on whether it is swung with 1B or 1C, the period of VIB is consistently greater by $3.5 \pm 1.6 \times 10^{-7}$ sec. when swung with VIC. At

*Jelstrup, G. 1957 Observations on the gravimetric calibration base Hammerfest-Munich with the Cambridge Pendulum Apparatus. Norg. Geogr. Oppm. Geod. Arb., n. 7.

first sight one might attribute this to sway but as the mean values of of the differences are similar for both sets of pendulums, this seems unlikely.

1A - 1B	1A - 1C	VIA - VIB	VIB - VIC
- 21.5 $\pm$ 2.3	7.1 $\pm$ 2.3	- 6.2 $\pm$ 2.2	19.8 $\pm$ 1.9

This is confirmed by calculation which shows that even under the worst conditions, the effect of the difference in period would only have a second order effect. The first order effect is to produce a small difference in amplitude which also has a negligible effect.

We are forced to the conclusion, therefore, that the cause of the systematic change in the period of VIB when swung with VIA and VIC is due to the fact that in the former case it was swung on the right hand agate and in the latter case on the left hand agate. This effect has been known for some time although its cause is by no means certain. This is a matter which might well repay further investigation.

The question now arises as to what extent microseismic motions of the ground affected the observations. Some groups of observations (as for example VIB and VIC at Catania and Khartoum and 1A and 1C at Rome III) strongly suggest such an effect because the means of the two sets of observations agree well, whereas the difference in the differences of the periods are considerable. We can make a rough quantitative estimate of the magnitude of this effect in the following way.

Assume that at any one station, the error in determining the period of a pendulum arises from two independent random causes. The first of these, d , is assumed to arise from microseismic disturbances of the ground and will affect the periods of pendulums swinging in anti-phase by equal and opposite amounts. The second error, e , is assumed to account for all the other errors of observation. It follows that the r m s error in the determination of the mean period of two pendulums is $\frac{1}{2}(2e^2)^{\frac{1}{2}}$ whereas the r m s error in determining the difference will be $\frac{1}{2}(2e^2 + (2d)^2)^{\frac{1}{2}}$

by comparing the differences between the means of pairs of observations made with the same pendulums at the same station, we can evaluate

$$e = \pm 0.7 \times 10^{-7} \text{ sec. (r m s)}$$

Now comparing the differences in the differences we obtain

$$2(2e^2 + (2d)^2)^{\frac{1}{2}} = 1.7 \times 10^{-7} \text{ sec.}$$

$$\text{whence } d = \pm 0.33 \times 10^{-7} \text{ sec. (r m s)}$$

This result implies that at the average station the effect of ground motion causes less errors than other random sources. The question still remains, however, as to whether ground motion may not occasionally prove serious. To check this we can examine the distribution of the residuals. For the differences of the differences, these are as follows:

IV-5

Range	0 - 1	1 - 2	2 - 3	3 - 4	4 - 5	5 - 6	Over 6
Number	21	17	8	4	2	2	1
Theory	24	18	8	4	1	0	0

It will be seen that there are considerably more large errors than we should expect owing to pure chance and this confirms the opinion that at a few stations ground motion may cause quite serious effects on the periods of the pendulums.

Bearing this in mind, it is considered prudent to calculate the gravity differences between the various stations from the ratios of the squares of the mean periods of pairs of pendulums. Gough has pointed out that this method introduces a small error since the pendulums are not all given equal weight and he prefers to calculate the gravity differences from the individual pendulum periods. Actually the differences between the two methods hardly affects the results. As an example, the figures for the connexion

Teddington I - Johannesburg I and Johannesburg II - Teddington I are shown below based upon N.P.L. = 981.19607. (See Table IV-1)

Table IV-1

Value of Gravity at Johannesburg

Individual Pendulums

	1A	1B	1C	VIA	VIB	VIC
OUT	978.5498	.5506	.5492	.5494	.5501	.5499
HOME	978.5490	.5502	.5499	.5496	.5496	.5504
	Mean 978.5498					

Means of Periods

	1A and 1B	1A and 1C	VIA and VIB	VIB and VIC
OUT	978.5502	.5495	.5502	.5496
HOME	.5497	.5495	.5495	.5500
	Mean 978.5498			

Results:

Values of gravity based on g at N.P.L. = 981.19607 at each of the sites occupied computed as described are given in Table IV-2.

Table IV-2

Gravity Values Obtained with Cambridge Pendulum Apparatus

		Difference from N.P.L.
N.P.L., Teddington	981.19607	0
Residenz, Munich	980.7376 + .0007	-.4585 gals
I N G, Rome	980.3640 + .0005	-.8321
Observatory, Catania	980.0467 + .0009	-1.1494
Physics Department, Khartoum	978.3029 + .0004	-2.8932
Field Survey H.Q., Nairobi	977.5405 + .0003	-3.6556
Meteorological Station, Salisbury	978.1481 + .0004	-3.0480
B.P.I. Johannesburg	978.5498 + .0002	-2.7463

Comparative values with those obtained with the Gulf-Wisconsin pendulums at the same sites* on the same datum (NPL = 981.1961) are listed in Table IV-3.

Table IV-3

Comparison of Gulf and Cambridge Pendulums
Based on N.P.L. 981.1961

	<u>Gulf-Wis.</u>	<u>Cambridge</u>	<u>Observer</u>	<u>Difference</u>	<u>G.W.-C.(m)</u>
Oslo	.9271	.9270	J		+0.1
Copenhagen	.5574	.5582	J		-0.8
Bad Harzburg	.1798	.1804	J		-0.6
Munich (Ny)	.7438	.7447	J		-0.4
		.7440	B		
Rome, I N G	.3634	.3640	B		-0.6
Khartoum	.3028	.3029	G		-0.1
Nairobi	.5400	.5405	B		-0.5
Johannesburg		.5498	B		
B.P.I.	.5495	.5489	G		+0.2
		.5493	H		
Mowbray	.6474	.6466	G		+0.4
		.6473	H		
				Av. difference	0.4 mgal

Observers: J. = Jelstrup
B. = Browne
G. = Gough
H. = Hales and Gough

*There are actually some differences in sites occupied. At Munich the Cambridge pendulum measurements were made at the Residenz base while the Gulf-Wisconsin measurements were made at the Nymphenburg base. The gravity difference between sites is 6.38 mgals (from gravimeter connections), and this adjustment has been applied in Table IV-3. At Khartoum the sites were not identical, but from University of Wisconsin gravimeter connections it does not appear that the difference in site causes a discrepancy of more than 0.2 mgal.

OBSERVATIONS WITH THE CAMBRIDGE PENDULUM APPARATUS
IN NORTH, CENTRAL AND SOUTH AMERICA IN 1958

by

J. E. Jackson

Introduction:

The observations, which were made in the period August 13th to December 23rd, 1958 with the Cambridge pendulum apparatus, are reported in this paper.

The stations occupied were Teddington (National Physical Laboratory), Madison (University of Wisconsin), Mexico City (National University), Panama (Pacific Air Depot), Quito (National Observatory), Lima (Military Geographical Institute), La Paz (Military Geographical Institute), Santiago de Chile (Military Geographical Institute), Buenos Aires (Geophysics Laboratory), Rio de Janeiro (National Observatory), and Caracas (Seismological Observatory Cagigal).

Traveling was done entirely by commercial aeroplane services, a total distance of about 28,000 miles, and the apparatus travelled as excess personal baggage. The two boxes of pendulum; and a package containing manometers, quartz crystals and magnetometer, were carried in hand.

The route was traversed in both directions, so that two visits were made to each station except Rio de Janeiro and Caracas, and three visits were made to Panama. Twenty-one sets of observations were completed.

With slight modifications, the apparatus and the observational procedure were those used by G. Jelstrup for his observations at North European stations,¹ and by B. C. Browne in his work in Europe and Africa.² A new Helmholtz Coil designed and constructed by L. Flavill at the Department of Geodesy and Geophysics, Cambridge, was taken to America: the frame of this coil could be separated into three 120° sections, and the coils themselves were made from very flexible wire, so that this piece of apparatus could be packed into a box more easily portable than the one previously used.

For finding the true rate of the crystal-controlled time-marking mechanism, the pulses transmitted at one-second intervals by station WWV were used, except at Teddington where a local signal was available on a wire, and at Buenos Aires where the transmission LOL was received. At the first visit to Quito, the WWV signals were very weak: otherwise the signals used were received quite easily, though at some places they could not be heard at all times of the day.

A vacuum pump operated by a 110 volt electric motor was borrowed from the University of Wisconsin: this compact lightweight instrument proved to be very useful. Several other small pieces of apparatus were borrowed from the same source.

A manometer tube broke during the journey from Madison to Mexico, and the spare manometer was used for the rest of the observations. This was tested at Buenos Aires and at Teddington, and the appropriate corrections were applied. At Mexico City, Professor Ricardo Monges Lopez very kindly arranged for two new manometers to be provided.

Local power mains, generally 110 v 60 cycle, were used to operate the crystal oscillator, radio receiver and pump at all stations except Quito, where a petrol-electric generator set was provided by the Inter-American Geodetic Survey: on this account, the observations at Quito were done in a continuous session of 24 hours, while the generator, standing in the grounds of the Observatory, was protected by a military guard.

At all stations south of Madison, the Helmholtz Coils and the lamp for the recording camera were operated from batteries of three or four large dry cells: one supply of such cells, in fresh condition, just sufficed for each session of work. Accumulators were used to supply the larger currents required for the coils in the high magnetic latitudes of Madison and Teddington.

On arrival in Mexico City, Ingeniero Julio Monges Caldera joined the writer and accompanied him thereafter until the departure from the second visit to that city. Ing. Monges Caldera contributed much to the success of the project, not only through his knowledge of Spanish, but also by assisting with the observations and by attending to many details of travel and organisation. The writer is happy to have this opportunity to acknowledge his gratitude to Julio Monges for his pleasant companionship and co-operation, without which the work would certainly have been more irksome and less expeditious. Julio Monges carried with him a Worden Gravimeter with which he made observations at the airports, the pendulum stations, and many other points in the vicinity of the places visited.

The program and most of the financial support for this work was arranged for by Professor G. P. Woollard of the University of Wisconsin and the Woods Hole Oceanographic Institution. In close co-operation with him was Prof. Ing. Ricardo Monges Lopez, Executive Vice-President of the Pan-American Institute for Geography and History, who secured the co-operation of other Latin-American countries by consultation with the Heads of the national organisations interested in Geodesy and I.G.Y. work. To these gentlemen, Col. J. Tate, Head of the Inter-American Geodetic Survey, Ing. Col. Bolivar Zurita P. Director of the Instituto Geografico Militar in Quito, Col. Guillermo Barriga Meneses, Director of the Instituto Geografico Militar in Lima, Prof. Ismael Escobar, President of the Bolivian National Committee for the I.G.Y., Gen. Gregorio Rodriques, President of the Executive Committee for the I.G.Y. in Santiago, Gen. de Brigada Victor H. J. Hoskings, Director General of the Instituto Geografico Militar in Buenos Aires, Prof. Allyrio H. de Mattos, Director of the Division of Cartography in Rio de Janeiro, and Dr. A. C. Romero, President of the National Committee for the I.G.Y. in Venezuela, we express our thanks for their support and for the personal interest they took in the work.

We are also much indebted to many other officials of the I.A.G.S. and of the various national institutions, for providing transport, and other facilities, arranging accommodation, and cheerfully spending much of their own time in helping our technical activities to proceed smoothly, and in attending to various matters connected with import and export of the apparatus. We would also particularly like to thank Dr. A. H. Cook of the National Physical Laboratory, Teddington, Dr. John C. Rose of the University of Wisconsin, Professor H. Maldonado-Kehrdall, Secretary of the Pan-American Committee for the I.G.Y., Dr. Julian Adem of the National University of Mexico, Mr. J. Koslosky of the I.A.G.S. Canal Zone, Dr. Luis Eduardo Mena A, Director of the Astronomical Observatory in Quito, Dr. Jorge A. Broggi, President of the Peruvian Geophysical Committee for the I.G.Y., Maj. Ing. Reynaldo Salgueiro and Capt. Salvador del Pozo of the Instituto Geografico Militar in La Paz, Mr. Hank Hook of the I.A.G.S. in Santiago, Prof. Ing. Eduardo E. Baglietto and Ing. Angel A. Cerrato of the Faculty of Engineering of the University of Buenos Aires, and Dr. Lelio J. Gama, Director of the National Observatory in Rio de Janeiro.

The crystal oscillator suffered some damage on the journey from Santiago to La Paz, and Prof. Escobar kindly arranged for it to be repaired by a member of his staff, to whom we are deeply indebted.

Some financial support for the project was provided by grants from the Conselho Nacional de Geografia and from the Conselho Nacional de Pesquisas in Rio de Janeiro. The visit to Caracas was not at first included in the programme but it became evident in October that time would be available for this connexion, and additional funds for the purpose were provided by the Venezuelan National Committee for the I.G.Y.

Full descriptions of the stations occupied are given below. The letters RGI refer to the publication "Reseau Gravimetrique International" of the International Gravimetric Bureau. At all sites an attempt was made to occupy the exact locations used with the Gulf-Wisconsin pendulums.

TEDDINGTON. Room B.17, adjoining dark room, in the basement of Bushy House on the floor about the middle of the room (The National Gravity Station in Room 11 of the Metrology Building could not be used. The value of g in room B.17 is practically the same as at the national station).

MADISON. Room 12A of the Geology Department, adjoining lecture room at the southern end of the basement of the Science Hall, on the floor.

MEXICO CITY. In the new Gravitation Laboratory of the National University of Mexico, on the floor in a room adjoining the south-east corner of the large room containing concrete platforms for instruments. (The concrete platforms could not be occupied as they contain iron reinforcement and the magnetic field immediately above them is highly distorted. The value of g on the platform is about 0.1 mgal less than at the station actually occupied.) The room is shown on the diagram in RGI.

PANAMA. In building 1019 on the Pacific Air Depot occupied by the I.G.A.S. Logistics Division, on the floor in a small room adjoining the

radio-shop and containing a Multiplex instrument, a level calibrator and an altimeter testing table: there is a brass plug in the floor.

CARACAS. In the new Cagigal Seismological Observatory, at the end of a passage-way in the basement, on the floor outside the seismograph room.

QUITO. In the basement of the National Observatory in the city, on the floor of the seismograph room, as described in RGI.

LIMA. In the basement of the Instituto Geografico Militar, on the floor of a room normally used as a canteen, and close to the new photogrammetry building. (The station occupied by Iverson with the Gulf-Wisconsin pendulums is in the adjoining printing shop and the difference of g between the two places is inappreciable).

LA PAZ. On the ground floor of the Instituto Geografico Militar, in a room used by the I.A.G.S. as a store and fitted with cupboards, on the floor about three metres from the window.

SANTIAGO (CHILE). In the basement of a building of the Instituto Geografico Militar, in a room used by the I.A.G.S. as a paper store, on the floor about a metre south of the concrete wing-walls.

BUENOS AIRES. In the lower basement of the building known as "Instalaciones Sargento Major Ingeniero Jose Antonio de Condarco", in the suburb of San Martin, on the floor in the western corner of the passage way which surrounds the inner laboratory in which is installed the pendulum apparatus for absolute determination of gravity. Site 2a on the diagram in RGI.

RIO DE JANEIRO. In a room adjoining the seismograph room on the ground floor of the National Observatory, on an isolated section of the floor specially provided to serve as a gravity reference station. Site 2 on the diagram in RGI.

Remarks on Observations and Computations:

Each set of observations consisted of two runs lasting about seventy minutes with each of four pairs of pendulums -- I.A with I.B, I.A with I.C, VI.A with VI.B, and VI.B with VI.C. The plane of swing was perpendicular to the magnetic meridian, and the vertical component of local magnetic field was neutralised by the use of the Helmholtz Coils. Before each set of observations, the pendulums were tested for magnetism: in fact, they picked up very little magnetism on their travels and degaussing was only occasionally necessary. A primary objective was to keep a fixed routine of observational procedure, and to have conditions, as far as possible, the same at each station. The working temperature of the pendulums varied from 14°C at Santiago (first visit) to 26°C at Madison (second visit). All stations were very satisfactory as regards the steadiness of the ambient temperature.

The reputed seismic activity at Santiago had obvious effects on the periods of individual pendulums there, but the means of pairs of pendulums were as consistent as at other stations.

Differences of acceleration of gravity were computed from changes of period between successive stations. It is not proposed to embark on an elaborate discussion of errors and accuracy because it seems more appropriate to defer any such discussion till the time comes for consideration of these results in conjunction with other contributions to the world network of gravity base stations. However, some simple indicators of internal precision may be of immediate interest. Firstly, the difference of the two determinations of mean period of a pendulum pair does not exceed 20×10^{-8} second, except in one case which is referred to below: the r.m.s. value of these differences, eighty-three of them after excluding the exceptional one, is 8×10^{-8} sec. (25×10^{-8} is equivalent to a milligal). Secondly, there were changes of mean period, from first to second occupation of the same station, as tabulated below in Table IV-B-1, in units of 10^{-8} second.

Table IV B-1

Changes of mean periods of pendulum pairs, from first to second occupations at repeat stations: unit 10^{-8} sec.

	PENDULUM PAIR			
	I.AB	I.AC	VI.AB	VI.BC
Buenos Aires	+ 5	+ 20	- 12	- 10
Santiago	0	- 5	- 3	- 22
La Paz	+ 11	+ 10	+ 12	+ 9
Lima	+ 10	+ 6	+ 2	+ 6
Quito	- 5	- 2	+ 3	- 2
Panama	- 20	- 5	- 2	- 1
Panama*	+ 10	+ 7	- 11	- 12
Mexico City	0	- 5	+ 1	- 4
Madison	+ 10	+ 22	+ 45	+ 59
Teddington	+ 14	+ 20	+ 32	+ 26

*second to third occupation.

Briefly, the repeat values are very satisfactory at all stations except at Madison where they are poor, and at Teddington where they are not as good as at the other nine stations. No reason for the bad repeats at Madison can be given.

The computed differences of gravity, in milligals, are given in Table IV B-2.

Discrepancies, arising mainly from the poor repeat values at Madison, show in the section Teddington - Madison - Mexico City, but mean values of outward and return results are seen to have remarkable consistency.

Table IV B-2

Computed gravity differences; in milligals

Upper figure - outward journey

Lower figure - return journey

	Pendulum Pair			
	I.AB	I.AC	VI.AB	VI.BC
Teddington	- 827.9 827.8 Diff. 0.1	- 827.9 828.0 0.1	- 827.5 828.0 0.5	- 827.3 828.5 1.2
Madison	-2427.5 2427.1 Diff. 0.4	-2427.6 2426.6 1.0	-2428.2 2426.5 1.7	-2428.6 2426.1 2.1
Mexico City	+ 300.0 300.3 Diff. 0.3	+ 300.2 300.0 0.2	+ 299.7 300.3 0.6	+ 299.8 300.1 0.3
Panama	- 963.4 964.0 Diff. 0.6	- 963.7 963.8 0.1	- 963.1 963.2 0.1	- 963.0 963.0 0.0
Quito	+1005.0 1004.4 Diff. 0.6	+1004.8 1004.5 0.3	+1004.9 1004.9 0.0	+1004.9 1004.6 0.3
Lima	- 816.2 816.3 Diff. 0.1	- 815.9 816.1 0.2	- 815.9 816.2 0.3	- 816.0 816.2 0.2
La Paz	+1961.9 1962.3 Diff. 0.4	+1961.7 1962.2 0.5	+1961.8 1962.4 0.6	+1961.7 1962.9 1.2
Santiago	+ 276.5 276.4 Diff. 0.1	+ 276.5 276.3 0.2	+ 275.9 276.2 0.3	+ 275.9 275.5 0.4
Buenos Aires	- 900.2 900.1 Diff. 0.1	- 900.2 900.2 0.0	- 900.5 901.0 0.5	- 900.2 900.6 0.4
Rio de Janeiro				
Panama	- 202.4 202.0 Diff. 0.4	- 202.2 201.9 0.3	- 201.8 202.2 0.4	- 201.7 202.2 0.5
Caracas				

The other results are much more satisfactory. Repeat values are good, particularly at Mexico City, and there is little sign of any systematic change in the pendulums. Mention must be made, however, of the observations with pendulum pair VI.AB at Buenos Aires on the second visit: in this case the difference of the two measures of mean period had the exceptionally large value of 38×10^{-8} sec., referred to above. It may be advisable to ignore this observation and regard the sum of the affected gravity differences, -624.8, as a measure of the difference of gravity between Rio de Janeiro and Santiago.

In conclusion, I would like to express my indebtedness to Mr. B. C. Browne for much help and encouragement in carrying out this work.

References

1. Jelstrup, G. 1957 Observations on the gravimetric calibration base. Norges geografiske oppmåling. Oslo.
2. Browne, B. C. 1958 Gravity Observations in Europe and Africa. Unpublished.

Gravity Measurements with the Cambridge Pendulum Apparatus in South Pacific Area - 1959

by

J. E. Jackson

Introduction

The measurements reported are a continuation of the series started by Professor B. C. Browne in 1958 with the Cambridge pendulum apparatus at sites occupied with the Gulf-Wisconsin pendulums. As in the previous measurements made by the writer in North America, Central America and South America, the program was planned and financed through Professor G. P. Woollard of the University of Wisconsin and the Woods Hole Oceanographic Institution.

Observations were made at Teddington (N.P.L.), Singapore, and Darwin and Melbourne in Australia. Although it had been hoped that a connection could also be established between Singapore and Tokyo, Japan, time did not permit the latter measurement to be made. The period of the observations was from 10th August to 2nd October 1959, and, as in the previous measurements reported by the writer, two sets of observations were made at each site; one on the outward journey and one on the return journey.

Traveling was done on commercial airlines throughout. The writer was accompanied by Mr. J. A. Paterson, a student of geodesy in Cambridge University who contributed a great deal to the success of the program.

At Singapore, we had the valuable cooperation of Mr. M. N. Menon, Chief Surveyor of the Survey Department, and his staff: at the stations in Australia the arrangements were very efficiently made by officials of the Bureau of Mineral Resources.

The apparatus and procedure were the same as in the series of observations in South America last year. A description of the stations is as follows:

- Teddington: The British National Gravity Station at the National Physical Laboratory, Standards Division, Room 11.
- Singapore:* Map Room on the ground floor of the Department of Geography in the University of Malaya. (site recently occupied by Japanese pendulum party and with Gulf-Wisconsin pendulums.)
- Darwin: Assay room in the radioactivity section of the office of the Bureau of Mineral Resources. Site used with Gulf-Wisconsin pendulums.
- Melbourne: A small store-room on the ground floor of the workshop of the Bureau of Mineral Resources in Gordon Street. (site occupied by Japanese pendulum party but not identical with that used with Gulf-Wisconsin pendulums, which was in an adjacent room.)

*It was not possible on the return journey to occupy the original Singapore site and the observation was made in the hallway immediately outside the room described.

GRAVITY OBSERVATIONS
IN
CENTRAL AMERICA

(Established by C. H. G. Oldham, 1957)

The Base is for the following Program in Central America is the Guatemala City Airport value established by the University of Wisconsin: 977.9816.

GUATEMALA

Guatemala City (Airport)

14° 33.5' N 90° 32.7' W 4900 ft. 977.9816

Chahal (Airport)

To left of entry to hut from landing strip.

15° 47.0' N 89° 35.0' W 984 ft. 978.3723

Poptun (Airport)

On field side of terminal at right hand (from field) corner of room at porch projecting toward landing strip from front of building.

16° 19.7' N 89° 25.3' W 1804 ft. 978.3594

Santo Torbido (Airport)

At post 4 ft. out from center of terminal on opposite side from wind sock.

16° 36.5' N 89° 30.0' W 1214 ft. 978.4026

Dos Lagunas (Airport)

At base of wind sock, (16 meters from corner of terminal building).

17° 41.6' N 89° 93.1' W 678 ft. 978.4829

Paso Caballos (Airport)

At gravity marker "Gravity Base G" between concrete block and terminal, 14 ft. off runway and 12 ft. from concrete block.

17° 15.6' N 90° 14.5' W 148 ft. 978.4946

Sojio (Airport)

Right side of Barrier gate, (facing field) in front of terminal building.

16° 43.2' N 90° 05.8' W 299 ft. 978.4391

GUATEMALA (Continued)
 Fallabon (Airport)

Robert Ray Company Gravity Base.

17° 03.4' N 89° 09.1' W 348 ft. 978.4486

Uaxactun (Airport)

Robert Ray Company Gravity Base.

17° 23.4' N 89° 38.3' W 499 ft 978.4595

EL SALVADOR
 San Salvador (Airport)

Professor Woollard's station described as "Incoming customs waiting room in corner near men's room".

13° 42.0' N 89° 06.5' W 2044 ft. 978.1883

BRITISH HONDURAS
 Belize (Stanley Airfield)

In Customs Room for incoming passengers 3 ft. from communicating door into main waiting room.

17° 32.3' N 88° 18.2' W 16 ft. 978.5450

HONDURAS
 Tegucigalpa (Airport)

In front of gate #5, 15 feet south of door at D pillar.

14° 03.2' N 87° 13.5' W 3271 ft. 978.3527

San Pedro Sula (Airport)

On field side of terminal at left hand corner facing runway.

15° 29.0' N 88° 01.0' W 204 ft. 978.4129

Puerto Cortes (Airport)

Station is field side of terminal on concrete slab under a porch, in front of entrance to the terminal building.

15° 49.3' N 87° 55.3' W 5 ft. 978.4517

Tela (Airport)

Station is on street side of terminal waiting room, opposite counter and in left-hand corner facing street.

15° 45.7' N 87° 27.7' W 10 ft. 978.4787

HONDURAS (Cont'd).

The following stations are situated approximately midway along the runway.

Marcala (Airport)

14° 11.6' N	87° 57.6' W	4080 ft.	978.0167
-------------	-------------	----------	----------

La Esperanza (Airport)

14° 19.0' N	88° 18.6' W	5300 ft.	977.9430
-------------	-------------	----------	----------

Gracias (Airport)

14° 34.5' N	88° 31.3' W	2300 ft.	978.1240
-------------	-------------	----------	----------

Ruinas de Capan (Airport)

14° 51.3' N	89° 09.6' W	1900 ft.	978.2147
-------------	-------------	----------	----------

Ocatepeque (Airport)

14° 25.2' N	89° 11.9' W	2570 ft.	978.1204
-------------	-------------	----------	----------

NICARAUGA

Managua (Las Mercedes Airport)

To left of entrance to passenger waiting room from field.

12° 07.0' N	86° 10.9' W	195 ft.	978.2859
-------------	-------------	---------	----------

San Juan Del Sur (Airport)

On the third concrete step to J. Vassalli's store, on the water front near the freight sheds.

11° 15.4' N	85° 53.2' W	16 ft.	978.2608
-------------	-------------	--------	----------

Siuna (Airport)

Five feet off right side of walkway from field to terminal and 15 feet from terminal entrance.

13° 41.4' N	84° 34.7' W	480 ft.	978.3258
-------------	-------------	---------	----------

Alimicambi (Airport)

Three feet toward runway from crane platform.

13° 25.8' N	84° 05.4' W	65 ft.	978.3514
-------------	-------------	--------	----------

Bonanza (Airport)

Fifteen feet beyond corner formed by fence to cafe and rails from terminal building.

13° 55.7' N	84° 26.7' W	520 ft.	978.3239
-------------	-------------	---------	----------

NICARAUGA (Cont'd).

Puerto Cabezas (Airport)

At runway to left of sidewalk leading from runway to terminal.

14	02.1'	N	83	23.7'	W	65 ft.	978.3750
----	-------	---	----	-------	---	--------	----------

COSTA RICA

San Jose: (Sabana Airport)

At base of steps leading from field into terminal.

09°	56.2'	N	84°	05.6'	W	3724 ft.	977.9456
-----	-------	---	-----	-------	---	----------	----------

El Coco (Airport)

At base of steps leading from field into terminal.

10°	00.0'	N	84°	11.0'	W	3018 ft.	977.9792
-----	-------	---	-----	-------	---	----------	----------

The following Airport Observations are assumed to have been at field level and in front of terminal.

Puntarenas Airport

09°	58.0'	N	84°	46.7'	W	10 ft.	978.2170
-----	-------	---	-----	-------	---	--------	----------

Canas Airport

10°	25.7'	N	85°	06.1'	W	266 ft.	978.1946
-----	-------	---	-----	-------	---	---------	----------

Liberia Airport

10°	38.2'	N	85°	26.3'	W	466 ft.	978.1968
-----	-------	---	-----	-------	---	---------	----------

Santa Cruz Airport

10°	15.4'	N	85°	35.1'	W	177 ft.	978.2875
-----	-------	---	-----	-------	---	---------	----------

Nicoya Airport

10°	08.5'	N	86°	26.7'	W	404 ft.	978.2730
-----	-------	---	-----	-------	---	---------	----------

Las Chiles Airport

11°	02.3'	N	84°	43.2'	W	120 ft.	978.2444
-----	-------	---	-----	-------	---	---------	----------

Parrita Airport

09°	31.0'	N	84°	19.3'	W	16 ft.	978.1677
-----	-------	---	-----	-------	---	--------	----------

Palmar Airport

08°	56.1'	N	83°	28.3'	W	39 ft.	978.1500
-----	-------	---	-----	-------	---	--------	----------

Golfito Airport

08°	38.5'	N	83°	10.6'	W	10 ft.	978.2389
-----	-------	---	-----	-------	---	--------	----------

CANAL ZONE

Panama

Panama City (Tocumen Airport)

In front of, and on field side of the statue which is in front of the main doors to the terminal waiting room.

09° 06.0' N 79° 21.9' W 150 ft. 978.2665

David (Airport)

Station is on the pathway immediately below the first window to the left (facing the waiting room) of the terminal doorway from the field.

08° 22.8' N 82° 27.9' W 73 ft. 978.1618

COLOMBIA

Barranquilla (Airport)

In front of Avianca information booth.

10° 53.5' N 74° 47.0' W 84 ft. 978.2265

Cartegena (Airport)

In front of Avianca information booth.

10° 23.0' N 75° 32.0' W 10 ft. 978.1960

PART V

Conclusions and Recommendations

PART V

Conclusions and Recommendations

The results of the program of pendulum and gravimeter measurements of gravity presented indicate that the original objectives of the study were obtained. The overall reliability of the results as evaluated through comparisons with data obtained by other observational groups at the same sites show that the pendulum measurements on the whole have an average reliability of ± 0.4 mgal, and that the gravimeter values have a comparable absolute accuracy on a world wide basis and a relative reliability on a more restricted basis of ± 0.2 to ± 0.3 mgal.

From the interval comparisons between pendulum sites with the gravimeters, it appears that the values at only seventeen of the one hundred and five sites occupied with the pendulums are in error in excess of 0.5 mgal. A majority of these sub-standard measurements are in the United States and are located on the western standardization range. In view of the importance of having a continuous series of reliable measurements that can be readily utilized by air transport, these, or equivalent sites on this range should be reoccupied with the pendulums, or the gravimeter values established accepted as an alternate standard.

Although in principle it should suffice to have two well established end points to control the calibration of gravimeters, in practice this is not the case. This study has shown that every gravimeter is non-linear to some extent; that on a trip of 3000-4000 miles tares in the readings are apt to occur, and that changes in climatic conditions involving over 100°F change in temperature can be encountered in occupying the standardization range which, with certain gravity meters, will markedly affect their drift rate and response. The need for reliable check points throughout the standardization range therefore can not be over-emphasized. In the light of the experience gained from this study, it is believed that an interval of 500 mgals or 500 miles should constitute the maximum spacing between control points on the standardization ranges, and also in general there is no real benefit to be gained from having a much closer spacing of control points.

Inasmuch as the pendulum measurements along the East Coast in 1959 with the improved Gulf-Wisconsin pendulum apparatus showed that an accuracy of 0.2 mgals is now being obtained, it is recommended that key sites on the Mexico City-Point Barrow range be reoccupied with these pendulums. It is further recommended that a minimum of one key site, and preferably two sites, should be reoccupied on each of the standardization ranges outside of North America established under this program. Selection of these sites should be governed by (1) the desirability of having at least one site on each standardization range at near the same value of gravity so that all can be accurately tied together by multiple connections with a high sensitivity exploration type gravity meter such as Morelli has effected between Rome and Washington and Rome and Buenos

Aires; (2) the desirability of having an interval of at least 500 mgals and preferably 1000 mgals between the two well controlled sites; (3) local scientific interest and facilities for carrying out reliable pendulum measurements; (4) accessibility by air transport.

Most of the key airport base values are fairly well established, but there is a need at these sites as well as at the pendulum sites to have marker plates set to mark the observation site so that reliable reoccupations can be achieved. A marked auxiliary site such as has been established by the United States Coast and Geodetic Survey at most of their recent pendulum observation sites should also be established if the full benefit of this program is to be realized. Similarly, ties should be made to new airport facilities that have been developed since the original measurements were made.

The program of measurements at harbor and dock-side sites that might serve as reference bases for marine gravimetric studies should be expanded on a global basis in view of the increasing number of vessels that are conducting gravity measurements at sea.

In areas such as parts of South America, where the gravimeter measurements are sub-standard, these measurements should be repeated.

It is urged that effective liaison be maintained with the oil industry so that (a) the bases established under this program will be used as reference points in carrying out regional and local exploration surveys, (b) exploration surveys on a floating datum can be tied to the world network of control bases and (c) the existing program and arrangement for the release of regional gravity data for scientific purposes be maintained.

Finally, it is urged that the high degree of domestic and international cooperation developed during the period of this program be maintained for without such cooperation there is little hope of effectively gathering and integrating the world's gravity data into a unified whole.

DISTRIBUTION LIST FOR AFCRL-TR-60-406

Copies

- 5 Armed Services Technical Information Agency, Document Service Center, Arlington Hall Station, Arlington 12, Virginia. ATTN: DSC-SD
- 1 Air Force Secretary, General Sciences Coordinating Committee, Office of the Asst. Secretary of Defense (RandE), Washington 25, D.C.
- 1 Office, Assistant Secretary of Defense, Research and Engineering, Washington 25, D.C. ATTN: Mr. Willis B. Foster
- 1 Chief, Armed Forces Special Weapons Project, P.O. Box 2610, Washington 73, D.C. ATTN: Technical Library
- 1 Joint Chiefs of Staff, J-2, Photo Survey Branch, Washington 25, D.C. ATTN: Col. B. B. Hunkspillar
- 1 Wright Air Development Division, Wright-Patterson AFB, Ohio. ATTN: WCLRFC
- 1 Air Force Missile Test Center, Patrick AFB, Florida. ATTN: Col. E. Wynn, MTL
- 1 Air Proving Ground Center, Elgin AFB, Florida. ATTN: PGEEI
- 1 Air Force Missile Development Center, Holloman AFB, New Mexico. ATTN: MDWTD
- 1 Air Force Special Weapons Center, Kirtland AFB, New Mexico. ATTN: Chief, Technical Library
- 1 Rome Air Development Center, Griffis AFB, New York. ATTN: RCWIC
- 1 Rome Air Development Center, Griffis AFB, New York. ATTN: RCLSR
- 1 Director of Operations, Headquarters, USAF, Washington 25, D.C. ATTN: AFOCP-SV-PC
- 1 Directorate of Research and Technology, Headquarters, USAF, Washington 25, D.C. ATTN: Mr. S. Greenfield
- 1 Chief Scientist, Headquarters, USAF, Washington 25, D.C.
- 1 Directorate of Research and Technology, Headquarters, USAF, Washington 25, D.C. ATTN: AFDRT-RD
- 1 Assistant Chief of Staff, Intelligence, Headquarters, USAF, Washington 25, D.C. ATTN: AFCIN 3T3
- 1 Operations Analysis Office, Headquarters, USAF, Washington 25, D.C. ATTN: AFCOA

AFCRL-TR-60-406 Cont'd.

Copies

- 1 United States Air Force in Europe, APO 633, c/o Postmaster, New York, N.Y. ATTN: ATL Office, Operational Analysis Section
- 1 Far Eastern Air Force, APO 925, c/o Postmaster, San Francisco, California. ATTN: Operational Analysis Section
- 1 Commander, 497th Recon. Tech. Squadron, APO 633, c/o Postmaster, New York, New York. ATTN: Technical Advisor
- 1 Alaskan Air Command, APO 942, c/o Postmaster, Seattle, Washington. ATTN: Operational Analysis Section
- 1 Strategic Air Command, Offutt AFB, Omaha, Nebraska. ATTN: DIMR
- 1 Commander, Strategic Air Command, Offutt AFB, Omaha, Nebraska. ATTN: DIGM
- 1 AF Ballistic Missile Division, Air Force Unit Post Office, Los Angeles 45, California. ATTN: WDTGQ
- 1 Air Research and Development Command, Andrews AFB, Washington 25, D.C. ATTN: RDRR
- 2 Air Force Research Division, Washington 25, D.C. ATTN: RRRO
- 1 Commander, European Office, ARDC, c/o American Embassy, Brussels, Belgium, Department of State, Washington 25, D.C.
- 20 Air Force Cambridge Research Laboratories, L.G. Hanscom Field, Bedford, Massachusetts. ATTN: CROTLS
- 15 Air Force Cambridge Research Laboratories, Geophysics Research Directorate, Laurence G. Hanscom Field, Bedford, Massachusetts. ATTN: CRZEG
- 1 Air Photographic and Charting Service, Orlando AFB, Florida. ATTN: APOAS
- 2 Air Photographic and Charting Service, Orlando AFB, Florida. ATTN: APDDP
- 1 Aeronautical Chart and Information Center, Second and Arsenal Streets, St. Louis 18, Missouri. ATTN: ACOC
- 2 Aeronautical Chart and Information Center, Second and Arsenal Streets, St. Louis 18, Missouri. ATTN: ACDEG
- 5 Aeronautical Chart and Information Center, Second and Arsenal Streets, St. Louis 18, Missouri. ATTN: ACDEL
- 1 Washington Office, Aeronautical Chart and Information Center, Washington 25, D.C. ATTN: ACRS-G-1

Copies

- 2 Commander, 1381st Geodetic Survey Sqn. (Missile), Gravity Section, Orlando AFB, Florida.
- 1 Director, Air University Library, Maxwell AFB, Alabama. ATTN: C. R. 4582
- 1 Office, Chief of Engineers, Department of the Army, Washington 25, D.C. ATTN: ENG RD-T
- 1 Director, US Army Engineer Research and Development Laboratories, Fort Belvoir, Virginia. ATTN: Topographic Engineering Dept.
- 5 Commanding Officer, Army Map Service, Washington 25, D.C. ATTN: Chief, Department of Geodesy
- 1 ACS/Intelligence, Department of the Army, Washington 25, D.C. ATTN: Maj. H. Chippeaux
- 2 Director, Inter-American Geodetic Survey, Box 2031, Balboa Heights, Canal Zone, Panama
- 1 Office of the Chief of Naval Operations, Department of the Navy, Washington 25, D.C. ATTN: OP-07T21
- 1 Chief of Naval Research, Department of the Navy, Washington 25, D.C. ATTN: Geophysics, Code N-416
- 1 Commanding Officer and Director, U.S. Navy Electronics Laboratory (Library), San Diego 52, California
- 2 The Hydrographer, U.S. Navy Hydrographic Office, Washington 25, D.C. ATTN: Code 5672
- 1 Commander, U.S. Naval Observatory, Washington 25, D.C.
- 1 Commander, U.S. Naval Post Graduate School, Monterey, California. ATTN: Technical Reports Division
- 2 Director, U.S. Coast and Geodetic Survey, Department of Commerce, Washington 25, D.C. ATTN: Donald A. Rice, Chief, Gravity and Astronomy Branch
- 2 Director, U.S. Geological Survey, Department of Interior, Washington 25, D.C.
- 1 National Aeronautics and Space Administration, Goddard Space Flight Center, 8719 Colesville Road, Silver Springs, Maryland. ATTN: Theoretical Division
- 2 Dr. W. A. Heiskanen, Director, Institute of Geodesy, Mapping and Photogrammetry, Ohio State University Research Foundation, Columbus 12, Ohio

AFCRL-TR-60-406 Cont'd.

Copies

- 1 Father Francis J. Heyden, S.J., Director, Georgetown College Observatory, Washington 7, D.C.
- 1 Mr. R. F. Thyer, Chief Geophysicist, Bureau of Mineral Resources, Geology and Geophysics, 203 Collins Street, Melbourne, Australia.
- 1 Mr. David Barnes, Geophysics Branch, U.S. Geological Survey, Menlo Park, California.
- 1 American Geophysical Union, 1515 Massachusetts Avenue, N.W., Washington 5, D.C.
- 1 General Secretary, International Association of Geodesy, 10 Rue Auber, Paris 9, France.
- 1 Dr. M. Kneissl, Deutsche Geodatische Kommission, Areisstrasse 21, Munchen 2, Germany.
- 1 J. DeGraaff Hunter, West View, Lodge Lane, Keymor, Sussex, England.
- 1 Bureau Gravimetrique International, 35 Rue de Sevres, Paris (6⁰), France.
- 1 Dr. J. Tuzo Wilson, Department of Geophysics, University of Toronto, Toronto, Ontario, Canada.
- 1 Dr. F. A. Vening-Meinesz, Potgieterlaan 5, Amersfoort, Holland.
- 1 Department of Geophysics, University of California at Los Angeles, Los Angeles, California. ATTN: L. B. Slichter, Director
- 1 Dr. C. S. Beals, Office of the Director, Dominion Observatory, Ottawa, Canada.
- 1 Dr. E. C. Bullard, Director, National Physical Laboratory, Teddington, Middlesex, England.
- 1 Dr. James A. Peoples, Jr., Department of Geology, University of Kansas, Lawrence, Kansas.
- 1 Lamont Geological Observatory, Torrey Cliff, Palisades, New York. ATTN: J. Lamar Worzel
- 1 Professor Kenneth S. Curtis, School of Civil Engineering, Purdue University, Lafayette, Indiana.
- 1 Professor Ralph M. Berry, Department of Civil Engineering, University of Michigan, Ann Arbor, Michigan.
- 1 Dr. Bernhard Haurwitz, Department of Meteorology, New York University, University Heights, New York, N.Y.

Copies

- 1 Dr. Chuji Tsuboi, Geophysics Institute, Tokyo University, Tokyo, Japan.
- 1 Dr. C. T. Elvey, Director, Geophysical Institute, University of Alaska, College, Alaska.
- 1 Dr. Eric Tengstrom, Geodetic Institute, University of Uppsala, Uppsala, Sweden.
- 1 Dr. R. J. Uffen, Department of Geophysics, University of Western Ontario, London, Ontario, Canada.
- 1 Mr. Sam P. Worden, 695 Rocky River Road, Houston 27, Texas.