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FORCE GEOPHYSICS LAB HANSCOM AFB MA   J A HAMMOND ET AL.
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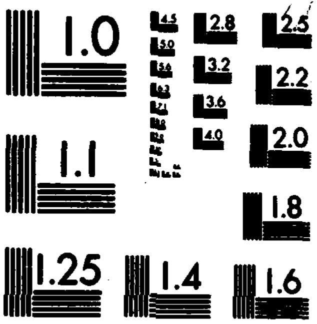

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This technical report has been reviewed and is approved for publication.

DR. [illegible] JR.
Chief Scientist

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Contents

Illustrations

New Techniques for Absolute Gravity Measurements

1. INTRODUCTION

Since the international conference on precision measurement and fundamental constants,[1] a number of new techniques have been put into practice at the Air Force Geophysics Laboratory (AFGL) in a transportable system for measuring the acceleration of gravity. The system in use at the present incorporates an earlier vacuum chamber with some modifications and includes new electronics, data analysis, and optical subsystems. Along the way new techniques have been incorporated which have resulted in several improvements to the overall operation of the system. The electronics now produce time measurements at a large number of points (500) during the free fall of the object. These time values are analyzed with a least squares fit to a second-order polynomial to obtain the average acceleration. The correction for air resistance is now made by monitoring the pressure and making a correction based on extrapolation from near atmospheric pressure (7×10^{-2} Pa) to the low operating pressure (3×10^{-5} Pa). The use of an Iodine-stabilized laser as a reference for the length measurement has significantly reduced the uncertainty due to the wavelength of the Lamb-dip stabilized laser.

(Received for publication 6 January 1983)

[1] Langenburg, D.N., and Taylor, B.N., Editors (1970) International Conference on Precision Measurement and Fundamental Constants, held at the NBS Gaithersburg, Maryland, Aug 3-7, 1970, NBS Special Publication 343.

2. HISTORY

The Air Force Geophysics Laboratory (formerly known as the Air Force Cambridge Research Laboratories) has long been involved in development and support of instruments for the absolute measurement of gravity, and supported the development of the first transportable absolute gravity system (see Figure 1) which contributed greatly to the establishment of a new international gravity standardization network. This instrument and the results obtained have been discussed in the literature.[2, 3, 4, 5]

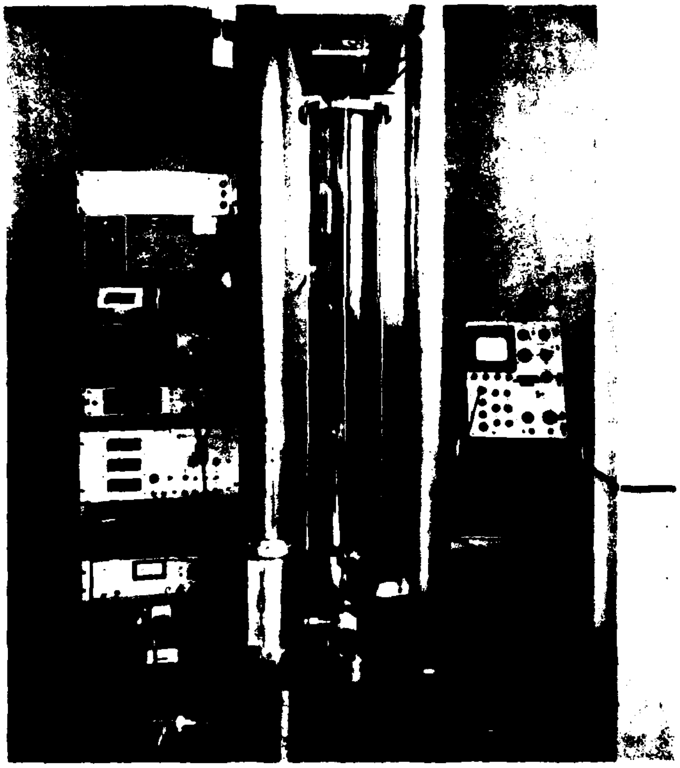

Figure 1. AFCRL Absolute Gravity System, 1968

(Due to the number of references cited above, they will not be listed here. See References, page 13.)

Since that time support has been given to the development of a second generation instrument which used a chamber-in-a-chamber technique. This system produced reasonably good data,[6,7] but several effects presented problems which encouraged us to reevaluate the previous system. We decided to modify the first generation system to use the superior electronics which were developed for the second generation system. Thus, at the beginning of 1978 the assembly of the current system was started. Most of the "New Techniques" which we will discuss in this report are the result of innovations first put into operation with the second generation system. The electronics system developed by the Joint Institute for Laboratory Astrophysics (JILA) with AFGL support performed multiple time measurements during the fall of the object, and these time measurements were used to compute gravity 'g'. This is in contrast to the three-position technique used in the first generation systems.[3]

When the decision to use the mechanical parts of the first generation system was made, it was concluded that the reduction of the height of the chamber by about 0.5 m would not only simplify the transportation and operation of the system but would not reduce the precision. The first data obtained with this new system has been described earlier.[8] There was reasonably good agreement between the new measurements and previous measurements at the AFGL site.

3. DESCRIPTION OF EXPERIMENT

The instrument, shown in Figure 2, was used in 1979 for a series of measurements along a calibration line from Great Falls, Montana to Ft. Davis, Texas. Data with an estimated accuracy of 0.010 mgal (one mgal = 10^{-5} m/sec^2) were obtained at most sites, and the operation time required for seven sites was 28 days. At this time and until early in 1980 the timing electronics made a direct measurement of the time of occurrence of 350 fringes during the drop. Then a least squares fit of the time and distance values to the second order equation describing the distance as a function of time was made. The resulting 'g' value was the measurement of the drop. The data were acquired with an on-line computer, and a 'g' value was calculated for each drop. Data were averaged together for up to 24 hours

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6. Faller, J.E., and Hammond, J.A. (1974) A New Portable Absolute Gravity Instrument, Bulletin D'Information, International Gravimetric Bureau, No. 35:I-43.

7. Hammond, J.A. (1978) Bollettino Di Geofisica Teorica ed Applicata Vol. XX.

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of total operating time at each site. The appropriate corrections made to arrive at the final value are: gravity gradient, velocity of light, laser wavelength, pressure, and earth tides. Other effects which have been considered or are under investigation are: electrostatic and magnetic effects,[3] constant gravity gradients and coriolis forces.[9]

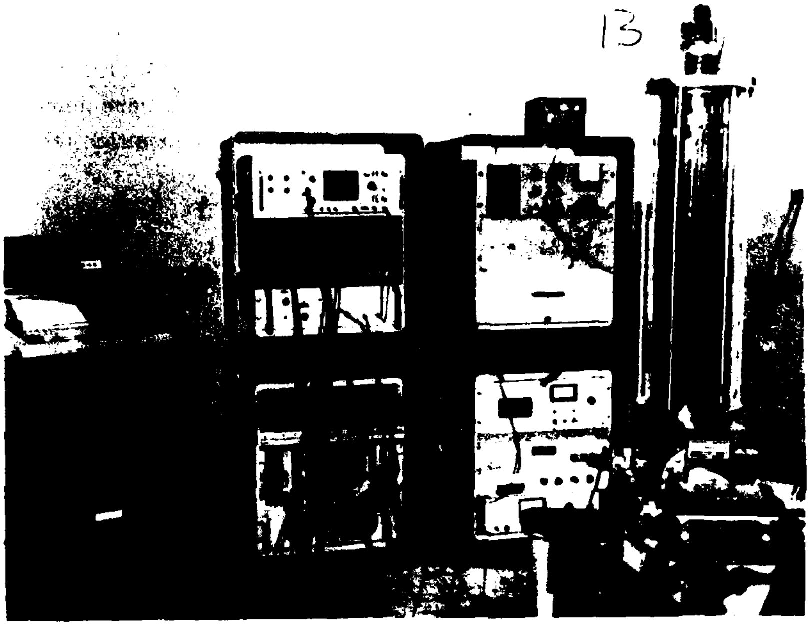

Figure 2. AFGL Absolute Gravity System, 1980

This measurement technique enables a unique method to determine the value of the corrections required because of two phenomena which are important in this kind of measurement. These two phenomena are the vertical gradient of gravity and the finitude of the velocity of light.

Both effects produce errors in the measured value when the calculation assumes uniform acceleration. Since the least squares method is an averaging process, the result is some kind of average value of gravity. A spatial gradient becomes a time dependent value of 'g' because the falling body is moving in space and the least squares process will obtain this time-averaged value. If the variation

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[9] Jeudy, Luc M. A., and Iliff, R. L. Spectral Analysis of Free Fall Measurements and Determination of Absolute Gravity, to be published.

in 'g' is small compared with its magnitude, the effective point at which the acceleration is measured is then the time-averaged position of the falling body. That point can be determined analytically in a straightforward manner by computing a relatively simple integral.

Alternatively, an essentially numerical method has been used by us to determine this effective measuring point. We calculate a set of synthesized times using the formula:

$$t = (2X/g_o)^{1/2} - 5/12\,A\,(2A/g_o)^{3/2}$$

where A is the gravity gradient, X is the distance the object has fallen and g_o is the value of gravity at the top of the chamber. This expression may be derived by solving the differential equation describing the motion of a body in a gradient field and expanding the result assuming the gradient is small compared with 'g'. The result of fitting these time values is to produce a measured value of gravity, g_m, which is different from g_o. The difference between g_m and g_o can be used to calculate the effective measuring point X_m,

$$X_m = (g_m - g_o)/A\ .$$

In our case (0.075 m fall before the 0.575 m measurement interval begins) the result is an effective measurement position of about 0.32 m from the top of the chamber.

The effect of the velocity of light being finite requires corrections to the time values which depend upon where the falling body is in the chamber. A set of corrected time values can be calculated and then analyzed by the least squares technique and the effect on the measured 'g' value thereby determined. The result of such an exercise is a correction of 0.024 mgal.

The residuals obtained from our least squares fit would be expected to show effects which could indicate how well the system is operating. The residuals should show the fact that the gradient is not included in the curve fitting. Thus, in plots of residuals we show a more or less smooth line which results from the fit of the synthetic data described above with an assumed gradient of 0.3 mgal/m. The actual residuals should more or less track that smooth curve (shown in Figure 3) and the extent that it deviates from the smooth curve is an indication that there are vibrations or other effects that are influencing the measurement. The earliest such data showed a strong vibration (Figure 4) which was removed by isolating the dropping chamber above the optics chamber. This was done by placing the evacuated chamber which contains the dropped object on its own tripod above the optics chamber containing the laser and the reference reflector and isolating it from the pier (reference point) by shock mounts. The data plotted in Figure 3 is the result of this isolation.

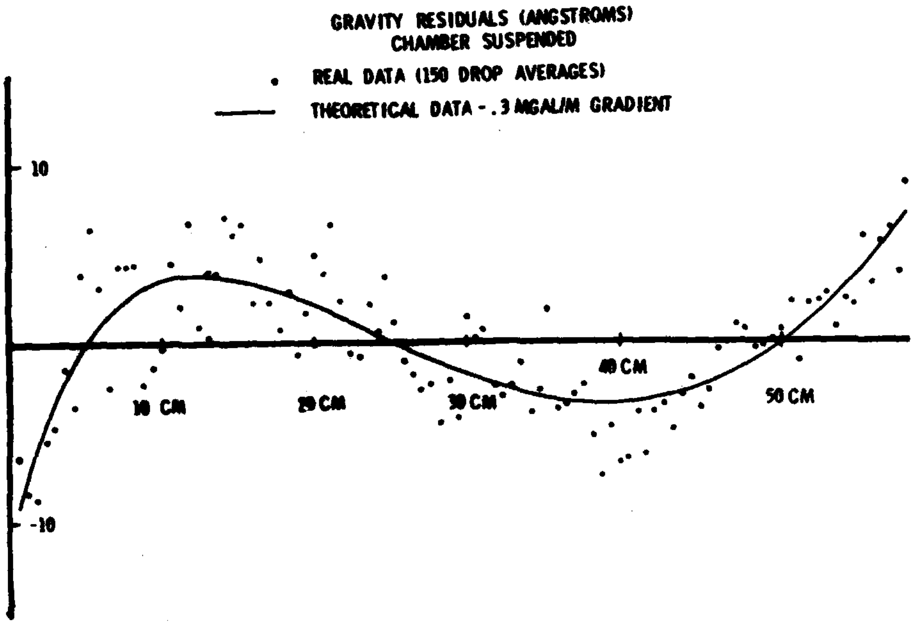

Figure 3. Residuals in Position for Least Squares Fit of Real and Synthesized Data

Other corrections must be made for the effect of air resistance on the falling body and for the difference between the manufacturer's given value of wavelength (for the purposes of computation) of the stabilized laser light used as the length standard and its actual value. Air resistance corrections are made by periodically determining the 'g' value in the pressure range of about 30×10^{-6} to about 70×10^{-3} Pa and extrapolating to zero pressure. We periodically check the wavelength of our laser against Iodine-stabilized lasers built by the National Bureau of Standards. We have been using the same Lamp-dip stabilized laser for almost three years and we have observed the rather typical drift of the wavelength of about one part in 10^8 per year. A considerable number of absolute measurements of gravity have been made over the last few years and they have generally corroborated previous measurements. It is hoped that this system will continue to contribute to establishing and maintaining gravity standards for geodesy and geophysics.

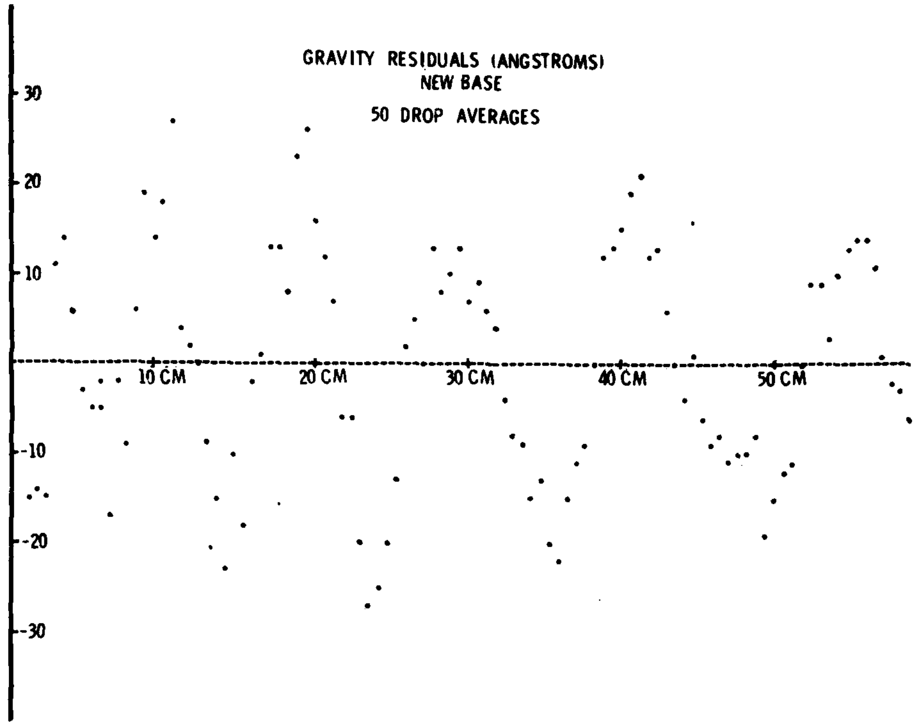

Figure 4. Residuals Showing Systematic Vibration of Reference Reflector

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