The AFGL Absolute Gravity Program

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Abstract. A brief discussion of the AFGL's program in absolute gravity is presented. Support of outside work and in-house studies relating to gravity instrumentation are discussed. A description of the current transportable system is included and the latest results are presented. These results show good agreement with measurements at the AFGL site by an Italian system and with previous measurements by Hammond and Faller. The accuracy obtained by the transportable apparatus is better than 0.1 $\mu m/sec^2$ (10 μgal) and agreement with previous measurements is within the combined uncertainties of the measurements. The instrument will be used extensively for field measurements in 1979.

The Air Force Geophysics Laboratory's program in absolute gravity can be divided into three main areas: support of outside research into measurement techniques and of comparative measurements by other absolute instruments; the study of the physics of the measurement techniques and the development of new instrumentation; and measurements in the laboratory and at selected field sites with the AFGL transportable system. The predominant focal point of this paper is the work on current measurements, but in the interest of completeness we will also briefly discuss the first two areas.

The outside work supported by AFGL includes that of Dr. James Faller and Mr. Robert Rinker of the Joint Institute for Laboratory Astrophysics in Boulder, Colorado (JILA/NBS). AFGL has supported the development of a novel system for the isolation of a reference reflector in an interferometer type of absolute gravity instrument. This system, which uses an electro-mechanical feedback system to synthesize a very long period vertical mass-spring support, is being designed and built into a package which should be capable of directly supporting the reference reflector on a gravity instrument.

AFGL supported the visit to the U.S.A. of the transportable system developed by the Istituto di Metrologia "G. Colonetti" (IMGC) of Torino, Italy with the cooperation of the Bureau International de Poids et Mesures (BIPM). This work was supported by a grant to the IMGC administered through the European Office of Aerospace Research and Development as well as by in-house support from AFGL and the Defense Mapping Agency Geodetic Survey Squadron (DMA/GSS). The work involved transporting the equipment and two people to six sites (Hanscom AFB, MA; Denver, CO; Holloman AFB, NM; San Francisco, CA; Bismarck, ND; Miami, FL). The system had a mass of about 1500 kg when packaged for air transport and the entire operation required six weeks to complete (with a final remeasurement at Hanscom AFB, seven measurements were made). The uncertainty obtained was about .1 $\mu m/sec^2$ (10 μgal) at most sites. [Marson and Alasia, 1978]

In the area of studying the physics of measurement techniques we are planning to do accurate measurements of the effect of air resistance on the free fall type of measurement. The current data analysis method allows very small effects to be seen in the deviation of the fall of the reflector from a purely uniform acceleration.

Another concern is that the laser wavelength standard is reproducible and stable. Periodic measurement of the laser used in our system will be done to assure our wavelength standard is not perturbed by time or the effects of transporting the equipment.

AFGL is looking at new developments in electronics and other areas to solve some of the current problems with this kind of instrumentation. In particular, several techniques for making the system simple to operate are employed in the current AFGL system. The system is completely automated and data are analyzed and corrected for gravity tides in real time. Optical and mechanical alignment are simplified over previous systems and self-checks on timing accuracy can be performed independent of a gravity measurement. A new timing and data analysis system is being obtained that should have increased reliability over the current system.

Measurements are currently being made with a system that incorporates the mechanical parts from the first generation instrument [Hammond, 1970], and uses a control system and support base (with optics) built at AFGL. The timing and data analysis equipment were integrated by JILA. Figure 1 shows schematically the absolute gravity system. The laser length standard is a Lamb-dip stabilized He-Ne laser which is periodically compared with an Iodine stabilized laser in our laboratory. The oscillator is a Rubidium frequency standard and the timing electronics allow very precise (± 125 psec) measurement of a large number of time values during the fall of the reflector. The reference system in the current arrangement is simply a retroreflector mounted to the base with no seismic isolation.

Figure 2 is a photo of the system as it looked at the time of this symposium. The vacuum chamber has been reduced in height by 45 cm so that the free fall path is now about 60 cm. A smaller vacuum pump is used (30 l/sec pumping speed) and the pump magnetic field is reduced considerably from the earlier system. An "old fashioned", simple free fall technique is used because several apparently inherent problems obtained with a "chamber-in-a-chamber" system, resulting in our setting that chamber aside, at least temporarily. This system has a total mass of about 700 kg when packed for air transport and it is contained in nine or ten boxes which can be handled by one or two people.

The first field measurements were made in June of 1978, approximately six months after the decision to convert the old vacuum chamber for use with the new system. At the time of that field trip we were using a computation technique that used 150

Proc. of the 9th GEOP Conference, *An International Symposium on the Applications of Geodesy to Geodynamics, October 2-5, 1978*, Dept. of Geodetic Science Rept. No. 280, The Ohio State Univ., Columbus, Ohio 43210.

time measurements from three different positions in the free fall path. This technique produced good statistics and fairly good repeatability at the AFGL site, but a systematic effect was known to exist prior to the June 1978 field trip.

In spite of this systematic effect, (which has since been eliminated) several important things were demonstrated by these field measurements at Denver, CO, Holloman AFB, NM, and San Francisco, CA:

1. Portability of the system, short operating time (three sites in ten days)
2. 10 μgal accuracy is possible at most sites
3. Sites must be chosen carefully.

The third result expresses a difficulty that proved to be very serious in San Francisco. The site chosen was the actual IGSN-71 site in a museum in Golden Gate Park. Preliminary measurements with a short period seismometer did not indicate such a serious noise problem, but it was so bad that we were only able to get a standard error of .15 μm/sec^2 (15 μgal) with about 2400 drops. The IMGC system didn't experience as much trouble because they use a seismometer for an inertial support of the reference retroreflector.

In August of 1978 a least-squares program was adopted for doing the data analysis. This is a program in which the positions (X_i) and the times (t_i) are fit to a constant acceleration formula:

$$X_i = 1/2\ g\ t_i^2 + v_o\ t_i + X_o$$

The results are: g, v_o, S_o (the last two are of no interest, except to fix the positions of the measurement), and a table of residuals for each drop. The residuals for each position in the path can be averaged and then plotted as in Figure 3. These residuals represent the deviation of the relative path difference between the reference reflector and the freely falling reflector from what it would be if the reference reflector were not accelerating at all, and the free falling reflector were accelerating uniformly at g. Thus, a vibration of the reference reflector at a constant frequency appears as a vibration whose frequency in space decreases as the falling reflector moves to the bottom. In Figure 3, then, the ordinate gives the magnitude of these average residuals in Angstroms and the abscissa gives the position of the object in the vacuum chamber measured from the start of the measurement (approximately 8 cm from the zero velocity position).

Even with the vibration shown in Figure 3 the g value obtained showed a much reduced bias when compared with the IMGC measurement and with the older measurement [Hammond and Faller, 1970]. The repeatability and the standard error of the g value were as good as before. A rough calculation showed that even this small vibration, initiated by the release of the falling body, could produce a systematic effect of the order of .60 μm/sec^2. In fact, the g value then obtained agreed with the IMGC to within the uncertainties of the measurements.

We decided to get rid of the vibration even though it didn't cause a large bias with the least squares analysis technique. To do this the chamber was isolated from the reference reflector and the rest of the optics by placing it on a separate vibration isolation system. The results of averaging 150 drops worth of data are shown in Figure 4. The solid line is the result of subjecting synthetic data, with a 3 μm/sec^2/m gradient included, to the same least squares analysis. Thus most of the systematic appearance, if not all, is caused by the vertical gradient. If one attempts to fit the

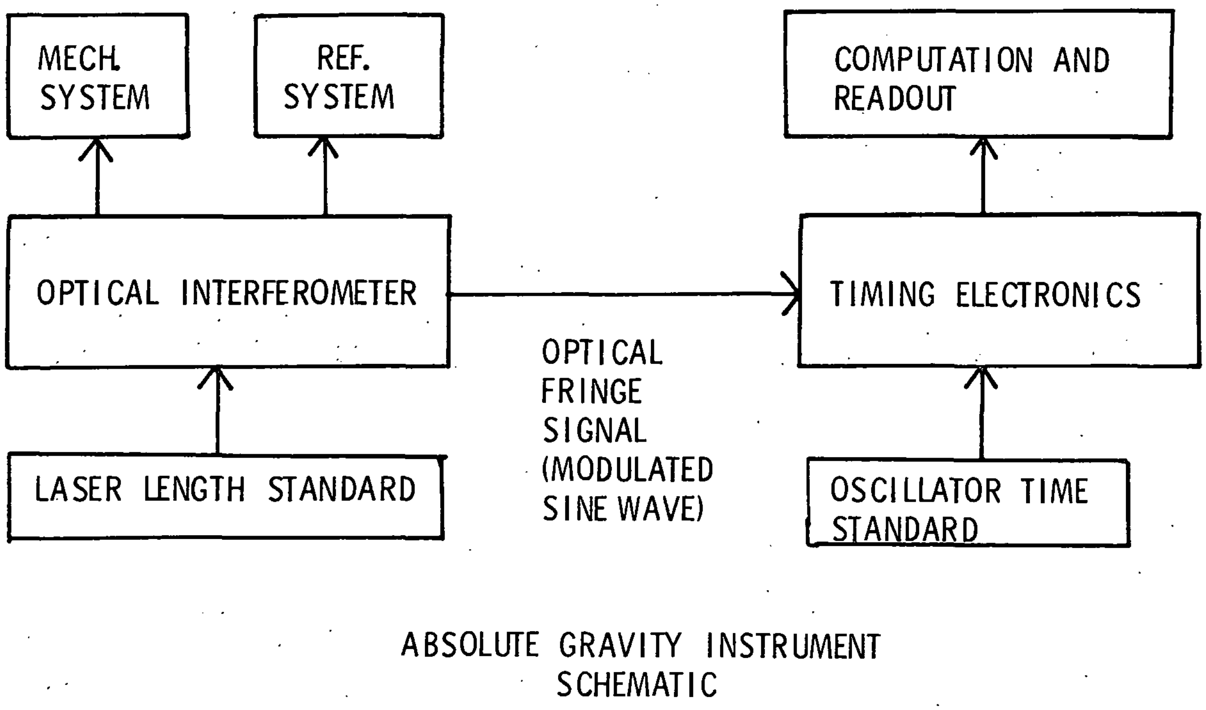

Fig. 1. Schematic diagram of a system for measuring absolute gravity.

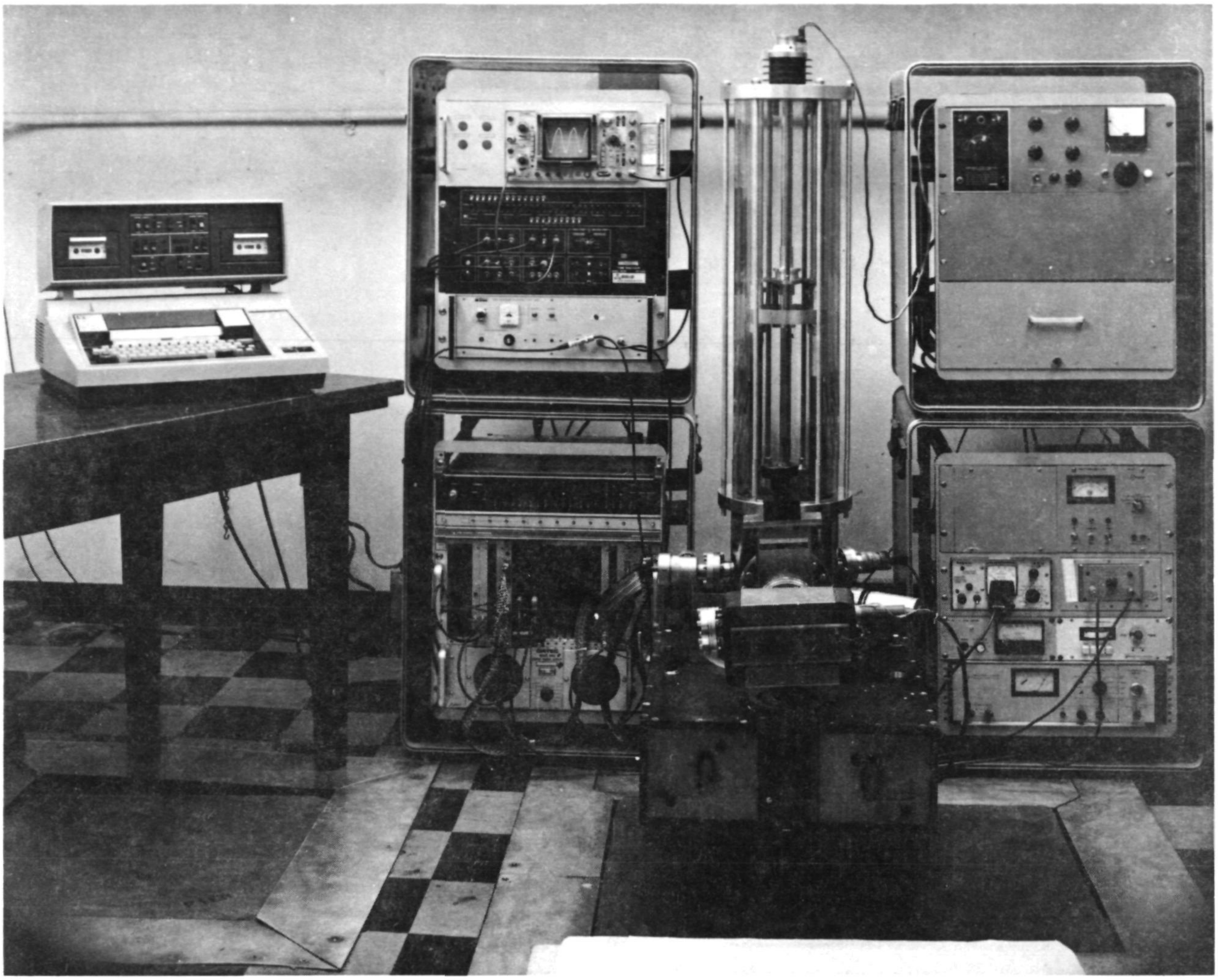

Fig. 2. The AFGL Transportable Absolute Gravity Instrument.

gradient as an additional parameter, the least squares fit becomes poorly determined and the g values have a higher scatter.

The most recent value obtained at AFGL on pier 1, Haskell Observatory is:

Measured Value	9803783.21	± 0.03 μm/sec^2
Gradient Correction	+ 3.77	± 0.03 μm/sec^2
Velocity of Light Correction	- .25	± 0.01 μm/sec^2
Wavelength Uncertainty		± 0.03 μm/sec^2
Estimated Uncertainty for Atmospheric Pressure and Other Possible Systematic Effects		± 0.05 μm/sec^2
Value at Floor Level	9803786.73	± 0.07 μm/sec^2

This can be compared with the IMGC 1978 measurements and the 1970 Hammond-Faller value at this site.

Marson and Alasia (1978)	9803786.59	± 0.10 μm/sec^2
Hammond and Faller (1971)	9803786.71	± 0.42 μm/sec^2

There is a discrepancy at close to a significant level between the AFGL and IMGC values. Effects such as water table level and air pressure could contribute to the difference. Pressure changes could result in as much as 0.10 μm/sec^2 full swing. Those who use these data will have to do the best they can (weighted means) to incorporate all possible measurements at any site. Future operators of these types of instruments must make it a rule to make some notation about the barometric pressure. Discrepancies in gravity tide effects could also contribute to these differences. It is possible to perform corrections for tides which fully include the effects of ocean loading.

In summary, the AFGL program in absolute gravity, which contributed so significantly to the IGSN-71 with absolute gravity measurements at eight sites, will continue to produce significant results and advances in the future. There are several important ways for absolute measurements of gravity to help in solving problems in geodynamics. The necessity for accurate calibration lines for relative instruments, as well as for the absolute values for networks and at sites of special significance, should be obvious enough that looking at instrument acquisition as a long term goal would appear more important than making patchwork measurements with prototype instruments. The agencies

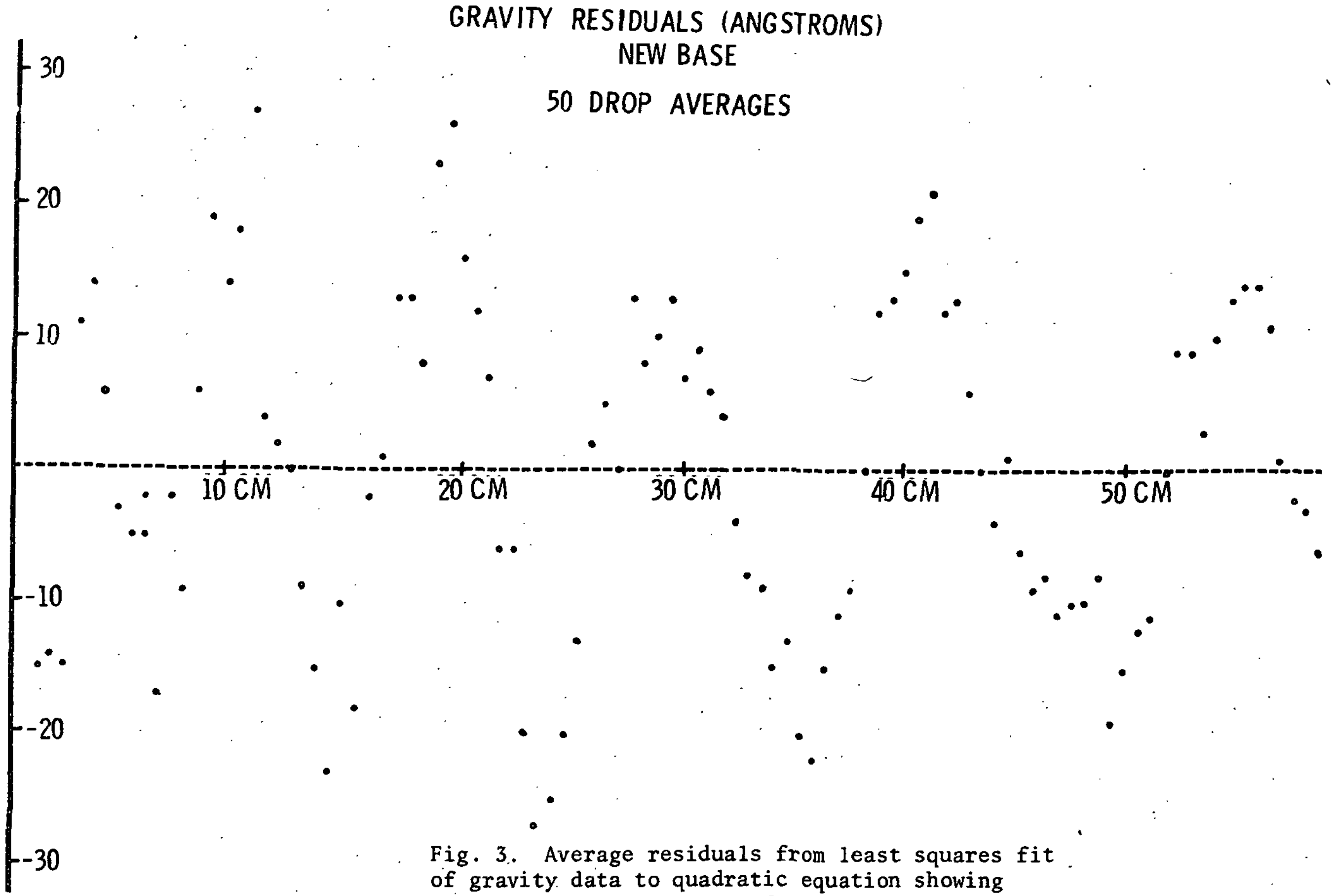

Fig. 3. Average residuals from least squares fit of gravity data to quadratic equation showing systematic vibration of reference reflector.

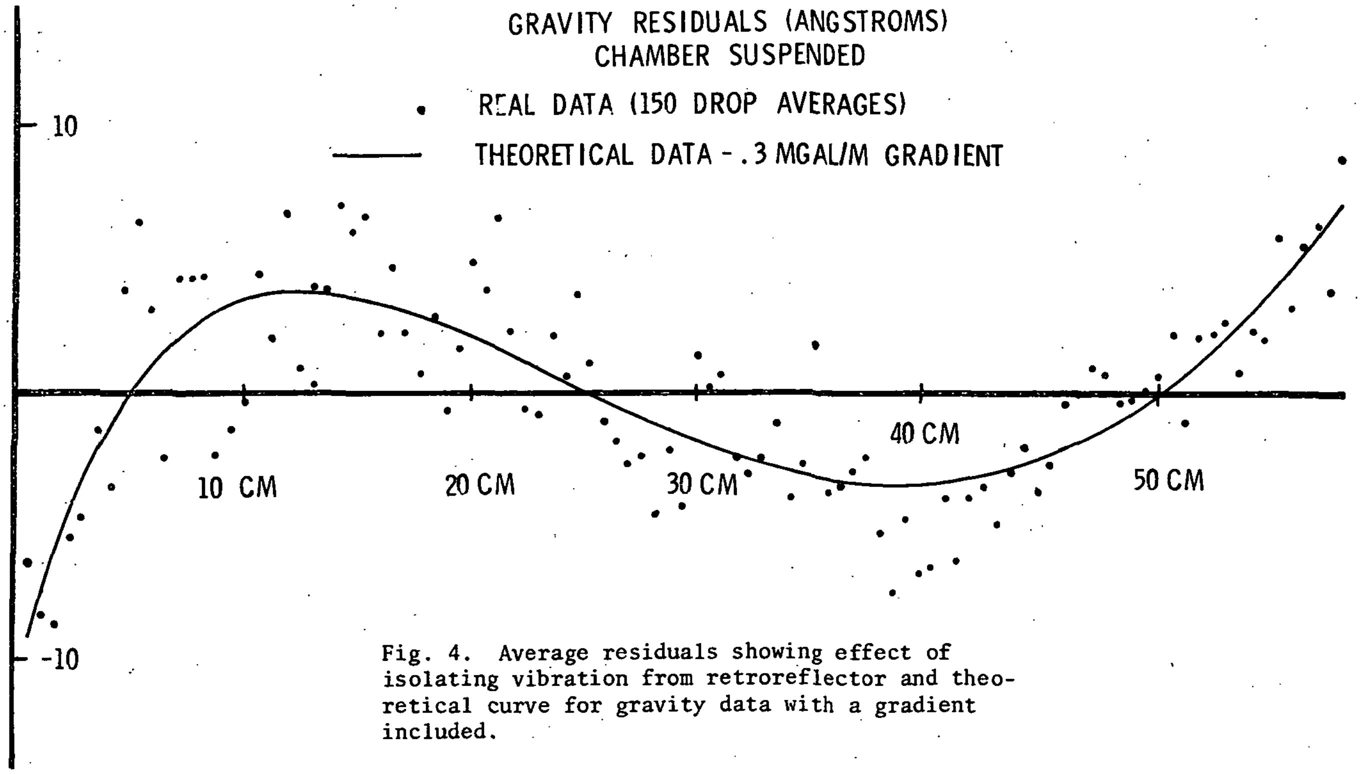

Fig. 4. Average residuals showing effect of isolating vibration from retroreflector and theoretical curve for gravity data with a gradient included.

interested should be looking at more than just the numbers describing the results. They should look at the systems with an eye to seeing them become operational instruments rather than specialized systems which only a Ph.D. physicist can operate.

References

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