UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Ground-based Upward Extrapolated Gravity Data for Use in Testing the Aerial Profiling of Terrain System (APTS)

by

Thomas G. Hildenbrand[1]
Robert P. Kucks[1]
William F. Hanna[2]

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[1]U.S. Geological Survey, Denver, Colorado
[2]U.S. Geological Survey, Reston, Virginia

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INTRODUCTION

In the fall, 1982, a ground-based gravity survey was conducted within and around a region immediately northwest of Cambridge, Massachusetts, designated for testing the Aerial Profiling of Terrain System (APTS), an airborne inertial surveying system designed, fabricated, and bench tested by the Charles Stark Draper Laboratory, Inc., under contract to the U.S. Geological Survey (R. H. Brown and C. E. Mongan, U.S. Geological Survey, 1974, written communication; Desai and others, 1976; Chapman and Brown, 1977; Chapman and Starr, 1979; Soltz and others, 1981). The APTS bears a relationship to the earth's gravity field in two remarkably contrasting ways: (1) APTS needs gravity data in the form of a gravity model in order for its inertial navigator to provide desired positional data for accurately locating the APTS-carrying aircraft, an essential requirement for profiling terrain using an auxiliary laser altimeter, and (2) APTS can independently provide gravity data, potentially useful not only for upgrading the needed gravity model but also, and perhaps more importantly, for assessing earth resources or hazards marked by lateral density contrasts of subsurface rock masses. Thus, one purpose of the ground-based survey was to provide a data base available for inclusion in a gravity model; a second purpose was to provide a data base with which to compare gravity data obtained directly by APTS. For both purposes the ground-based data are used for computing the gravity environment expected to be encountered by APTS at a flight height of 2,000 ft above ground.

This report deals in sequence with (1) a high-precision ground-based gravity survey conducted within the test region, (2) a regional data base of ground-based gravity values extending beyond the test region, synthesized from existing data with data acquired and processed specifically for the present investigation, and (3) an upward continuation of the regional data base to simulate the gravity field at the flight height of APTS, including results of a comparison of two contrasting techniques used for the analytical continuation. All ground-based data are in the form of magnitudes of observed gravity vectors; the scalar nature of these data must be kept in mind when compared to airborne vector gravity data.

High-precision Gravity Survey

High-precision gravity measurements were made at sites of ground-based retroreflectors in two areas of the test region: (1) Hanscom Air Field at Bedford, Massachusetts, and (2) the flight-testing range, an 11 by 32 mile rectangle elongate north-south. The high precision of the measurements refers to the fact that data were obtained using two LaCoste and Romberg geodetic gravity meters (G-550 and G-614) and that data were acquired in closed double loops, that is, a procedure in which a base station is first read, stations to be referenced to this base station are subsequently read, the base station is read for a second time, the stations to be referenced are read for a second time, and the base station is read for a third time, all within a period not exceeding several hours. Measurements were made at sites of retroreflectors because estimates of APTS-derived gravity data are made at points directly above the retroreflectors, at the flight height of APTS. These retroreflectors were sited and topographically surveyed by personnel of the National Mapping Division of the U.S. Geological Survey (S. H. Schroeder, W. H. Chapman, and E. J. Cyran, 1983, oral and written communication); this topographic control permits future processing of the gravity data to free-air, Bouquer, or isostatic gravity anomalies for geologic interpretation.

High-precision measurements at Hanscom Air Field were made at five sites on the field (labeled "Lab 1-5", fig. 1) and one site within the hangar (labeled "Lab 6", fig. 1); retroreflectors at these sites serve for calibration and alinement of APTS prior to takeoff for the flight-test range. Measurements were made at 15 sites within the flight-test range (labeled "533, 535-547, and 50118", fig. 2); although most of the retroreflectors were mounted on rooftops or elevated structures, each site was also topographically surveyed at ground level, providing a convenient and stable location for gravity measurements.

All high-precision data were referenced to a base station belonging to the International Gravity Standardization Net 1971 which fortuitously has been established in a building connected to the hangar (fig. 3). This base station was originally established on a concrete slab unattached to the building's floor; for safety reasons, concrete was later poured within the gaps between the floor and slab, thereby subjecting the site to floor vibration. Because it has been slightly altered, this base was recalibrated by referencing it to an absolute gravity station at the nearby U.S. Air Force Geophysics Laboratory (AFGL) where five time-integrated free-fall measurements had been made by AFGL personnel during the period 1978 through 1980 (table 1). The arithmetic mean of the five values (980,378.685±.009 mgal) was adopted for the AFGL station; based on this value, the base station in the hangar building was determined to be 980,380.368 mgal.

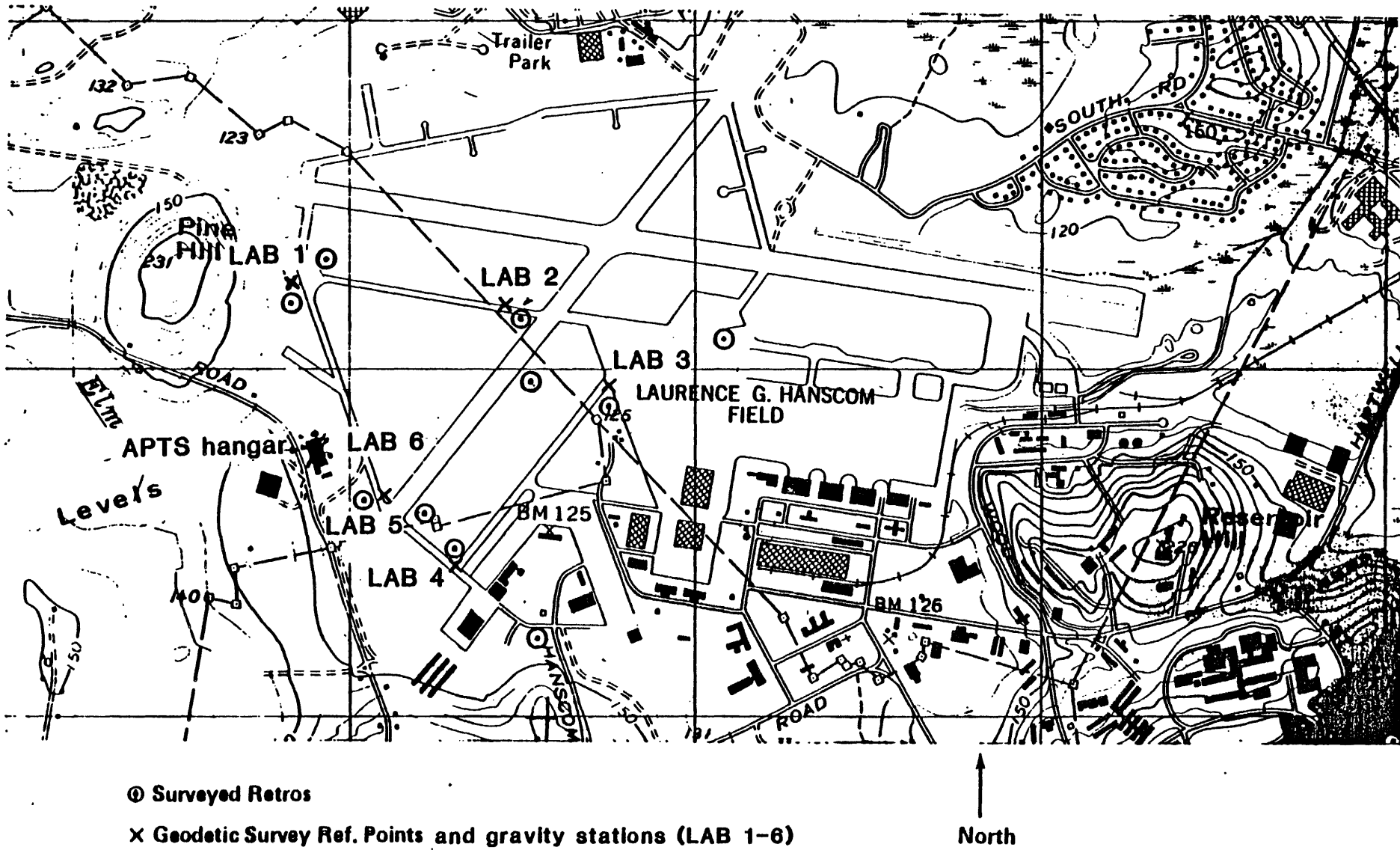

Figure 1 -- Hanscom Air Field showing approximate locations of high-precision stations.

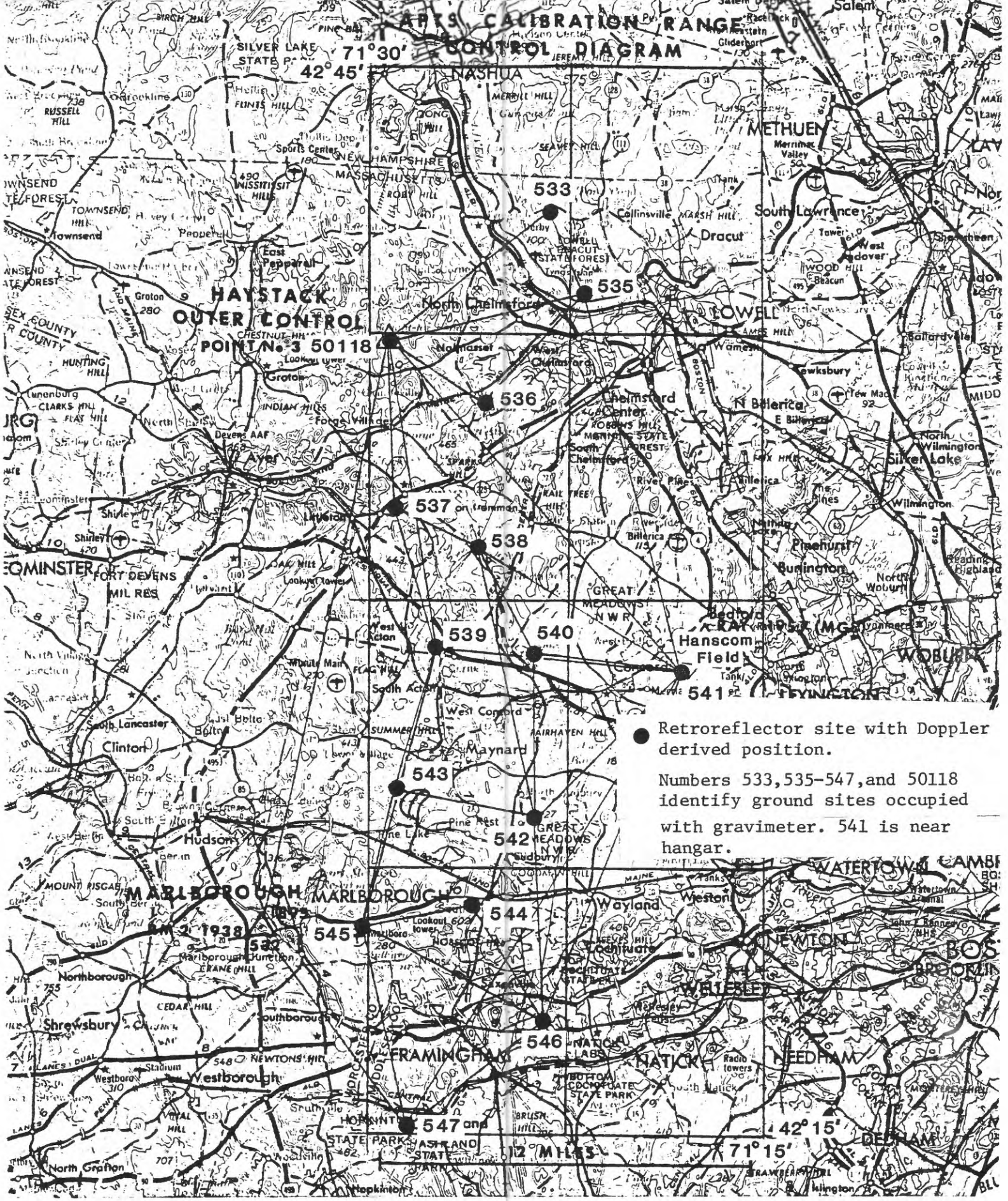

Figure 2 -- Flight test range showing approximate locations of high-precision stations

GRAVITY BASE STATION

LATITUDE: 42° 27.90' N (1)	STATION DESIGNATION: BOSTON
LONGITUDE: 71° 18.07' W (1)	
ELEVATION: 42.6 METERS (1)	COUNTRY/STATE: USA/Massachusetts

REFERENCE CODE NUMBERS	ADOPTED GRAVITY VALUE
ACIC 2188-1	g= 980 394.06 mgals (old datum)
IGC 15221B	

ESTIMATED ACCURACY	DATE
± 0.1 mgals	MONTH/YEAR: July/1967

DESCRIPTION AND/OR SKETCH

The station is located at the MIT Instrument Lab, west of Hanscom Field. Observations were made on concrete pad #7 which is the northeast pad in the lab building.

The station is not monumented. (1)

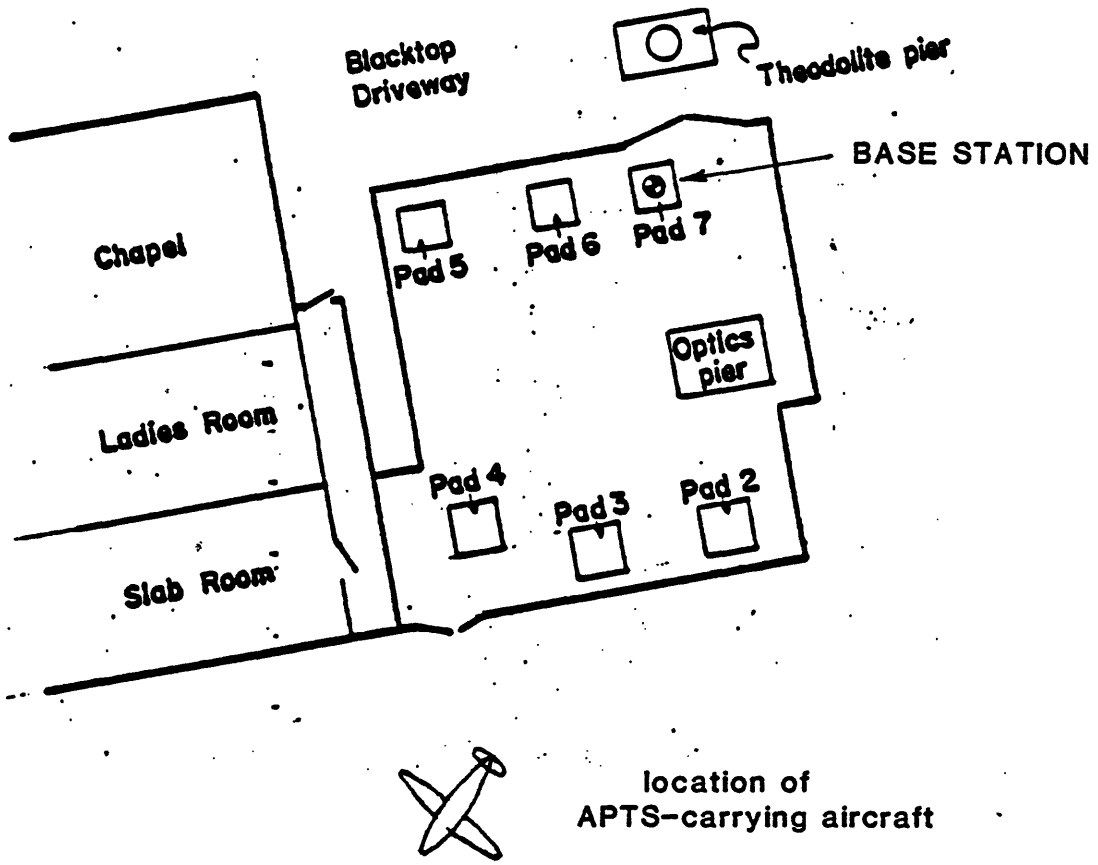

Figure 3 -- Original description and diagram for the gravity base station in building connected to hangar. The revised observed gravity value is 980,380.368 mgals.

Table 1. Absolute gravity measurements of AFGL.

Year	Dates	Mean Value (±standard deviation)
1978	9/27 to 10/6	980378.678 (± .007)
1979	8/14 to 9/7	980378.687 (± .010)
1979	11/20 to 12/6	980378.689 (± .010)
1980	5/5 to 5/6	980378.688 (± .010)
1980	7/7	980378.681 (± .010)
	Average =	980378.685 (± .009) mgal

Observed gravity values for all high-precision stations, corrected for instrumental drift as well as lunar and solar tidal effects using a computer program of R.C. Jachens (U.S. Geological Survey, 1983, written communication), are summarized in table 2. The total error in these values is difficult to estimate but can be approximately bracketed. Absolute values of observed gravity carry the ±0.009 mgal error of the AFGL absolute station; to this must be added an error of approximately ±0.010 mgal associated with meter readings, perhaps a little more where high winds or vehicular traffic induced significant ground vibrations. The total error of high-precision gravity values is estimated to be about 0.020 mgal at most of the retroreflector sites.

Table 2. Observed gravity values at the retroreflector sites.

Station identification[1]	Gravity value (mgal)
533	980391.069
535	980397.790
536	980380.988
537	980383.650
538	980379.565
539	980373.153
540	980374.194
541	980380.574
542	980367.476
543	980362.398
544	980365.562
545	980352.555
50118	980360.025
118	980373.294
547	980333.761
Lab1	980381.760
Lab2	980381.412
Lab3	980381.653
Lab4	980380.889
Lab5	980380.568
Lab6	980380.342

[1]Stations "Lab 1-5" are marked by nails on concrete runways of the air field; "Lab 6" is located near a water drain of the hangar, about 10 ft from a mark later established and topographically surveyed by the National Mapping Division of the U. S. Geological Survey.

Regional Data Base

A regional map of ground-based gravity data in the form of observed gravity values, corrected for instrument drift and tidal effects, was prepared (plate 1) to show true variations of observed gravity between the high-precision stations at retroreflector sites. The map represents 140 stations established by R. P. Kucks at an average spacing of about 1.5 mi using LaCoste and Romberg gravity meter G-550, interspersed among 185 stations extracted from the Department of Defense files, available through the National Geophysical and Solar Terrestrial Data Center of the National Oceanic and Atmospheric Administration, Boulder, Colorado. Principal facts for the data, which have been adjusted to conform to the International Standardization Net of 1971 (Morelli and others, 1974), are listed in the appendix. This regional data base was expanded to an area bounded by latitudes 42° N to 43° N and longitudes 71° W to $71^{\circ}45'$ W, using data from the Department of Defense files, to satisfy mathematical conditions for producing a map of upward continued values, corresponding to the area of plate 1, free of error-contaminated edge effects. The regional data base thus serves two useful purposes: First, it indicates how the actual gravity gradients between pairs of retroreflector sites would differ from inferred linear gradients sometimes estimated from airborne data, using only values above retroreflector sites obtained in post-survey Kalman (1960) filtering; second, it provides an areal distribution of data necessary for computing its extrapolation to the flight height of APTS.

Upward Extrapolation of Data

A number of theoretical subtleties are of interest regarding the upward extrapolation of the ground-based data. In the discussions below, the term "normal" gravity is synonymous with "theoretical" gravity. First, the APTS-carrying aircraft remains earthbound and thus is subjected to the centrifugal (viewed from within the rotating earth coordinate system) component of the gravity vector, unlike orbiting satellites which experience only the gravitational component. Second, the gravitational part of the gravity potential is harmonic and thus may be analytically continued upward; in contrast, the centrifugal part is not harmonic and may not be analytically continued. Third, the extrapolation of the normal value of the combined gravitational and centrifugal accelerations may be accomplished using closed formulas or a height derivative of the normal gravity formula, termed the free-air gradient. Fourth, ground-based gravity anomalies (observed true value minus normal value when the latter is taken at a point where the normal potential--or spheropotential--has the same value as the true potential--or geopotential) and gravity disturbances (observed true value minus normal value when both are taken at the same point) are harmonic and thus may be analytically continued upward. Fifth, although anomalies are obtained at ground level, disturbances are obtained at the flight altitude. The most exact procedure to extrapolate the data, would involve computing gravity disturbances at ground level from free-air anomalies (observed gravity values, corrected for the free-air gradient) at ground level by applying formulas of Stokes or Poisson (Hirvonen and Moritz, 1963) and analytically continuing the disturbances upward to the flight heights recorded by APTS. Although this exact procedure was not used in this report, the anticipated errors are thought to be neglible (less than 0.1 mgal). The upward extrapolation problem for oribiting satellites is commonly solved in two parts: The normal field is computed using closed formulas, and gravity disturbances at ground level are

computed from free-air anomalies at ground level and analytically continued upward. The approach used in this report is somewhat similar: A mean value of observed gravities is used as a reference for the observed gravity values, rather than the normal reference field, and "anomalies" of observed gravity are upward continued; the normal reference field corresponding to the mean terrain height is subsequently extrapolated to the mean height of APTS using the free-air gradient.

In the present investigation, it was convenient to extrapolate the ground-based data in a sequence of procedures. First, the regional data set was gridded at an interval of 0.5 km using a computer program of Webring (1981) based on minimum curvature (Briggs 1974). Second, the observed gravity values on the irregular terrain were reduced to a common level--that of the mean terrain height--using a Taylor series truncated following the second-order term (Cordell and Grauch, 1982), justified because the topographic relief is much less than the grid interval. Third, the reduced data were analytically continued upward using a computer program of Hildenbrand (1983) to the mean flight height of APTS--mean terrain height plus 2,000 ft. Fourth, the upward continued data were reduced to a surface parallel to and 2,000 ft above the irregular terrain surface (Cordell and Grauch, 1982). Fifth, these reduced values were adjusted by subtracting a constant 188.12 mgal from all grid values, corresponding to the free-air gradient of -0.3086 mgal/m, valid for the normal gravity (gravitation plus centrifugal parts) field at moderate latitude, say, between 50^{o} and 60^{o}. (see, for example, Vanicek and Krakiwsky, 1982, p. 495). The resulting map of upward extrapolated values is shown as plate 2.

As an approximate check on the validity of using this continuation technique, the technique was compared to an equivalent source method of continuation (Bhattacharyya and Chan, 1977) by noting differences between the respectively continued results. Only data within the area of plate 1 were used for the equivalent source continuation; the resulting continued map therefore contained error-contaminated edge effects around the map's border. The algebraic difference of continued results, including the edge effects which should be ignored, is shown in plate 3. Inward from the map edges, where differences can be validly compared, the methods are shown to agree generally to within less than a milligal.

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Appendix

Principal facts for gravity stations obtained by the U.S. Geological Survey for this study and gravity stations in the Department of Defense nonproprietary data file. Elevations of most stations are inferred to be accurate to ±2 ft; geographic coordinates are inferred to be accurate to ±0.2 min.

STATION IDENTIFICATION proj	sta-id	LOCATIONS LATITUDE deg	min	LONGITUDE deg	min	ELE (in mt)	ST	GRAVITY OBSERVED	THEORETICAL
	:bed	42	29.64	-71	17.22	44.20		980383.96	980392.56
	:apts 1	42	33.82	-71	21.35	59.13		980386.77	980398.84
	:apts 2	42	35.52	-71	19.93	43.89		980393.68	980401.40
	:apts 3	42	35.45	-71	17.82	34.44		980395.26	980401.29
	:apts 4	42	36.72	-71	18.17	38.71		980397.79	980403.20
	:apts 5	42	35.67	-71	16.03	40.84		980394.65	980401.63
	:apts 6	42	37.27	-71	15.73	42.67		980397.75	980404.02
	:apts 7	42	38.77	-71	16.28	43.89		980401.58	980406.28
	:apts 8	42	38.73	-71	18.00	28.65		980405.68	980406.22
	:apts 9	42	34.47	-71	15.77	43.28		980390.83	980399.82
	:apts 10	42	33.65	-71	19.32	65.84		980385.12	980398.59
	:apts 11	42	34.97	-71	21.22	51.82		980390.86	980400.57
	:apts 12	42	37.03	-71	22.40	51.51		980397.07	980403.66
	:apts 13	42	36.75	-71	23.90	57.00		980392.30	980403.24
	:apts 14	42	37.55	-71	25.25	55.78		980384.97	980404.45
	:apts 15	42	38.10	-71	23.87	47.24		980389.02	980405.27
	:apts 16	42	39.68	-71	25.57	49.07		980391.66	980407.65
	:apts 17	42	40.75	-71	25.98	50.29		980393.83	980409.26
	:apts 18	42	42.33	-71	26.52	50.29		980396.41	980411.63
	:apts 19	42	42.48	-71	28.80	59.74		980393.33	980411.86
	:apts 20	42	43.40	-71	29.67	71.32		980392.85	980413.24
	:apts 21	42	40.48	-71	28.95	68.21		980389.36	980408.85
	:apts 22	42	38.88	-71	28.50	90.22		980382.83	980406.45
	:apts 23	42	36.58	-71	27.77	70.71		980378.99	980402.99
	:apts 24	42	36.25	-71	29.75	77.42		980379.51	980402.49
	:apts 25	42	30.57	-71	19.48	47.85		980383.70	980393.96
	:apts 26	42	32.40	-71	20.08	60.05		980384.44	980396.71
	:apts 27	42	30.77	-71	21.28	64.92		980380.14	980394.26
	:apts 28	42	31.17	-71	23.42	77.72		980377.90	980394.86
	:apts 29	42	32.88	-71	24.88	65.53		980383.29	980397.43
	:apts 30	42	33.60	-71	23.43	65.53		980385.31	980398.52
	:apts 31	42	35.13	-71	23.53	76.81		980386.96	980400.81
	:apts 32	42	34.20	-71	25.15	77.42		980384.54	980399.41
	:apts 33	42	33.63	-71	29.70	71.32		980382.43	980398.55
	:apts 34	42	31.28	-71	28.72	93.27		980375.31	980395.02
	:apts 35	42	30.03	-71	27.50	75.29		980375.86	980393.15
	:apts 36	42	29.62	-71	25.50	56.08		980378.75	980392.53
	:apts 37	42	29.57	-71	24.00	74.37		980375.61	980392.46
	:apts 38	42	28.27	-71	25.63	57.30		980375.96	980390.51
	:apts 39	42	26.97	-71	26.10	60.96		980373.00	980388.55

STATION IDENTIFICATION proj sta-id	LOCATIONS LATITUDE deg min	LONGITUDE deg min	ELE (in mt)	GRAVITY ST OBSERVED	THEORETICAL
:apts 40	42 27.45	-71 27.67	60.96	980375.15	980389.27
:apts 41	42 26.88	-71 29.00	67.67	980373.41	980388.41
:apts 42	42 26.07	-71 29.60	64.01	980372.46	980387.20
:apts 43	42 25.53	-71 27.57	62.79	980369.98	980386.39
:apts 44	42 24.42	-71 26.57	58.83	980371.54	980384.73
:apts 45	42 22.73	-71 27.17	55.47	980363.78	980382.19
:apts 46	42 23.52	-71 29.25	61.57	980366.14	980383.37
:apts 47	42 23.62	-71 25.52	63.40	980364.95	980383.52
:apts 48	42 22.68	-71 24.23	71.63	980363.13	980382.11
:apts 49	42 25.07	-71 24.43	60.05	980369.71	980385.70
:apts 50	42 26.08	-71 24.33	64.01	980369.80	980387.22
:apts 51	42 26.30	-71 22.73	53.04	980372.56	980387.55
:apts 52	42 15.18	-71 19.93	43.89	980359.45	980370.85
:apts 53	42 16.28	-71 21.33	61.87	980357.36	980372.50
:apts 54	42 16.63	-71 19.48	68.88	980358.60	980373.02
:apts 55	42 15.22	-71 17.83	43.28	980357.77	980370.91
:apts 56	42 15.18	-71 15.05	36.27	980362.87	980370.85
:apts 57	42 17.30	-71 15.82	45.72	980364.38	980374.03
:apts 58	42 17.20	-71 17.40	49.38	980364.53	980373.88
:apts 59	42 16.15	-71 18.02	33.53	980363.13	980372.30
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:apts 61	42 19.03	-71 19.03	51.51	980368.92	980376.63
:apts 62	42 17.82	-71 20.92	67.67	980359.53	980374.81
:apts 63	42 19.47	-71 20.72	52.12	980368.00	980377.29
:apts 64	42 19.27	-71 21.90	52.43	980365.22	980376.99
:apts 65	42 20.90	-71 21.58	64.92	980366.39	980379.44
:apts 66	42 21.80	-71 19.68	61.57	980373.42	980380.79
:apts 67	42 20.58	-71 19.18	82.91	980366.29	980378.95
:apts 68	42 21.60	-71 17.65	65.23	980372.31	980380.48
:apts 69	42 20.88	-71 16.93	64.92	980371.76	980379.41
:apts 70	42 20.77	-71 15.08	23.16	980380.83	980379.24
:apts 71	42 21.73	-71 15.45	26.24	980380.50	980380.68
:apts 72	42 31.13	-71 18.12	42.98	980385.88	980394.80
:apts 73	42 32.18	-71 17.17	63.09	980384.59	980396.38
:apts 74	42 41.37	-71 27.88	70.41	980390.46	980410.19
:apts 75	42 40.15	-71 27.05	52.43	980392.92	980408.35
:apts 76	42 38.92	-71 26.67	48.16	980390.78	980406.51
:apts 77	42 41.68	-71 24.93	42.98	980397.00	980410.66
:apts 78	42 43.15	-71 25.15	43.59	980399.71	980412.87
:apts 79	42 44.13	-71 24.35	76.50	980395.29	980414.34

STATION IDENTIFICATION proj sta-id	LOCATIONS LATITUDE deg min	LONGITUDE deg min	ELE (in mt)	ST	GRAVITY OBSERVED	THEORETICAL
:apts 80	42 42.68	-71 23.93	72.24		980393.06	980412.16
:apts 81	42 16.98	-71 29.80	99.67		980334.88	980373.55
:apts 82	42 16.37	-71 27.85	82.91		980336.12	980372.63
:apts 83	42 15.65	-71 26.27	56.08		980344.98	980371.55
:apts 84	42 17.65	-71 25.95	51.51		980353.83	980374.55
:apts 85	42 16.75	-71 25.05	51.15		980352.82	980373.20
:apts 86	42 15.17	-71 24.52	57.30		980350.12	980370.84
:apts 87	42 16.15	-71 22.97	45.11		980360.49	980372.30
:apts 88	42 17.68	-71 22.65	52.12		980358.63	980374.60
:apts 89	42 18.50	-71 28.80	64.62		980347.96	980375.84
:apts 90	42 18.60	-71 26.98	61.57		980351.77	980375.98
:apts 91	42 17.65	-71 19.77	52.12		980363.44	980374.55
:apts 92	42 18.82	-71 17.55	69.19		980363.50	980376.31
:apts 93	42 22.05	-71 29.78	83.21		980358.59	980381.16
:apts 94	42 20.92	-71 28.83	83.52		980355.09	980379.47
:apts 95	42 19.78	-71 29.32	106.98		980345.69	980377.76
:apts 96	42 19.82	-71 27.77	87.78		980350.30	980377.81
:apts 97	42 19.10	-71 25.78	59.44		980357.26	980376.73
:apts 98	42 19.57	-71 24.43	54.56		980361.86	980377.44
:apts 99	42 18.53	-71 24.73	53.64		980358.71	980375.88
:apts100	42 19.93	-71 22.82	58.52		980364.06	980377.98
:apts101	42 21.12	-71 24.15	42.67		980366.08	980379.77
:apts102	42 20.10	-71 25.88	58.83		980359.49	980378.23
:apts103	42 21.93	-71 27.40	57.91		980363.03	980380.98
:apts104	42 20.75	-71 26.97	183.49		980335.55	980379.21
:apts105	42 23.53	-71 27.02	60.35		980367.01	980383.38
:apts106	42 21.87	-71 21.72	38.71		980372.96	980380.89
:apts107	42 40.08	-71 15.50	42.98		980406.76	980408.25
:apts108	42 43.55	-71 15.18	56.39		980397.92	980413.47
:apts109	42 44.67	-71 17.57	45.72		980401.31	980415.15
:apts110	42 44.03	-71 19.38	46.33		980399.57	980414.19
:apts111	42 43.17	-71 18.20	63.40		980394.27	980412.89
:apts112	42 42.95	-71 16.55	56.08		980396.60	980412.56
:apts113	42 42.13	-71 17.37	51.82		980400.07	980411.33
:apts114	42 41.93	-71 19.03	45.72		980399.09	980411.03
:apts115	42 43.65	-71 20.95	51.21		980399.29	980413.62
:apts116	42 44.58	-71 22.20	129.24		980385.88	980415.02
:apts117	42 42.23	-71 21.98	56.08		980394.59	980411.48
:apts118	42 40.33	-71 21.43	53.64		980394.39	980408.63
:apts119	42 39.52	-71 22.27	58.83		980390.90	980407.41

STATION IDENTIFICATION proj	sta-id	LOCATIONS LATITUDE deg	min	LONGITUDE deg	min	ELE (in mt)	GRAVITY ST OBSERVED	THEORETICAL
	:apts120	42	39.88	-71	23.73	50.60	980389.28	980407.95
	:apts121	42	39.37	-71	20.48	43.89	980398.39	980407.18
	:apts122	42	40.73	-71	19.42	50.60	980399.56	980409.23
	:apts123	42	40.58	-71	17.67	52.43	980403.90	980409.00
	:apts124	42	37.92	-71	17.22	47.24	980399.17	980405.00
	:apts125	42	37.55	-71	21.07	46.33	980398.94	980404.45
	:apts126	42	37.13	-71	19.50	42.06	980398.92	980403.81
	:apts127	42	32.90	-71	15.65	60.05	980386.49	980397.46
	:apts128	42	30.28	-71	16.62	55.47	980383.27	980393.52
	:apts129	42	34.10	-71	26.97	102.41	980380.76	980399.27
	:apts130	42	37.10	-71	26.18	63.09	980382.86	980403.77
	:apts131	42	29.62	-71	29.18	66.75	980377.33	980392.53
	:apts132	42	28.25	-71	28.90	67.06	980374.34	980390.48
	:apts133	42	29.08	-71	22.33	53.95	980378.06	980391.72
	:apts134	42	25.02	-71	17.28	62.48	980381.77	980385.63
	:apts135	42	24.25	-71	19.23	56.08	980375.57	980384.47
	:apts136	42	23.73	-71	21.97	36.88	980372.92	980383.69
	:apts137	42	22.68	-71	21.78	46.72	980372.13	980382.11
	:apts138	42	26.82	-71	21.62	42.37	980374.07	980388.33
	:apts139	42	26.53	-71	16.47	58.83	980380.89	980387.89
	:bed	42	29.64	-71	17.22	44.20	980383.96	980392.56
	: r69540	42	28.38	-71	23.98	59.95	980374.20	980390.67
	: r69539	42	28.52	-71	27.40	75.17	980373.16	980390.88
	: r69538	42	31.35	-71	26.05	71.25	980379.57	980395.13
	: r69541	42	27.93	-71	17.97	39.15	980380.58	980389.99
	: r69535	42	38.38	-71	21.89	32.13	980397.79	980405.70
	: r69533	42	40.95	-71	23.30	57.73	980391.07	980409.55
	: r50118	42	37.36	-71	29.32	120.56	980373.30	980404.16
	: r69536	42	35.24	-71	25.94	109.62	980380.99	980400.98
	: r69537	42	32.65	-71	29.01	68.48	980383.65	980397.09
	: r69542	42	23.79	-71	24.10	52.90	980367.48	980383.77
	: r69544	42	21.56	-71	25.56	42.72	980365.56	980380.43
	: r69546	42	18.06	-71	23.82	54.37	980360.03	980375.17
	: r69547	42	15.10	-71	28.48	75.99	980333.76	980370.73
	: r69545	42	20.94	-71	30.23	96.87	980352.56	980379.50
	: r69543	42	24.79	-71	29.16	92.52	980362.40	980385.28
	:20000116	42	15.10	-71	29.69	90.20	980330.15	980370.73
	:20000108	42	15.50	-71	22.49	55.20	980356.25	980371.33
	:22090589	42	15.59	-71	28.30	59.40	980338.07	980371.47
	:20000090	42	16.19	-71	16.00	50.60	980361.45	980372.37

STATION IDENTIFICATION proj sta-id	LOCATIONS LATITUDE deg min	LONGITUDE deg min	ELE (in mt)	ST	GRAVITY OBSERVED	THEORETICAL
:20000098	42 16.19	-71 17.99	33.50		980363.15	980372.37
:22090588	42 16.49	-71 26.20	60.70		980345.13	980372.82
:22090590	42 16.70	-71 27.70	80.50		980338.39	980373.13
:20000107	42 16.79	-71 25.00	51.20		980352.85	980373.27
:22090587	42 18.89	-71 20.50	48.50		980366.35	980376.42
:22090586	42 19.19	-71 20.69	52.10		980367.81	980376.87
:20000088	42 19.40	-71 16.30	36.00		980372.65	980377.19
:20000097	42 19.79	-71 19.70	60.70		980368.45	980377.77
:20000106	42 20.09	-71 25.90	58.80		980359.45	980378.22
:22090585	42 20.60	-71 18.29	69.50		980368.99	980378.98
:35030599	42 21.40	-71 28.10	66.40		980357.02	980380.19
:20000105	42 21.80	-71 22.90	41.10		980368.35	980380.79
:20000086	42 22.30	-71 17.60	49.10		980377.55	980381.54
:22090142	42 22.60	-71 15.29	38.10		980383.04	980381.99
:22090141	42 22.60	-71 15.80	38.10		980381.38	980381.99
:22090136	42 22.60	-71 18.70	51.50		980378.50	980381.99
:22090140	42 22.70	-71 16.49	44.20		980380.36	980382.14
:22090110	42 22.70	-71 20.39	54.60		980375.57	980382.14
:22090139	42 22.90	-71 17.00	41.10		980381.09	980382.44
:22090135	42 23.00	-71 18.50	48.20		980380.26	980382.59
:22090138	42 23.20	-71 17.30	40.20		980382.55	980382.89
:22090111	42 23.20	-71 20.69	54.90		980374.01	980382.89
:22090143	42 23.39	-71 16.49	47.90		980380.85	980383.17
:20000096	42 23.39	-71 21.10	41.10		980373.65	980383.17
:22090112	42 23.50	-71 21.10	41.10		980373.48	980383.34
:22090137	42 23.60	-71 17.50	40.20		980383.68	980383.49
:22090113	42 23.80	-71 21.10	44.80		980372.60	980383.79
:35030598	42 23.80	-71 21.20	50.30		980369.02	980383.79
:22090134	42 23.99	-71 17.99	42.40		980383.33	980384.08
:22090145	42 24.10	-71 19.00	56.40		980377.19	980384.24
:22090146	42 24.20	-71 19.19	56.10		980375.53	980384.39
:22090114	42 24.40	-71 21.20	55.80		980369.72	980384.70
:22090147	42 24.50	-71 19.49	62.80		980373.28	980384.84
:22090148	42 24.70	-71 20.00	62.50		980371.91	980385.14
:22090133	42 24.89	-71 17.90	58.80		980379.48	980385.43
:22090115	42 24.89	-71 20.50	52.40		980373.53	980385.43
:22090150	42 25.00	-71 21.20	38.40		980373.96	980385.59
:22090151	42 25.19	-71 21.89	38.10		980374.84	980385.88
:22090152	42 25.30	-71 22.30	38.70		980373.28	980386.05
:22090180	42 25.40	-71 15.10	69.80		980382.89	980386.20

STATION IDENTIFICATION		LOCATIONS					GRAVITY	
		LATITUDE		LONGITUDE		ELE	ST OBSERVED	THEORETICAL
proj	sta-id	deg	min	deg	min	(in mt)		
	:22090132	42	25.40	-71	17.50	72.50	980377.87	980386.20
	:22090153	42	25.40	-71	20.30	51.20	980374.89	980386.20
	:22090179	42	25.49	-71	15.20	74.40	980382.07	980386.33
	:22090178	42	25.49	-71	15.29	73.20	980382.36	980386.33
	:22090177	42	25.60	-71	15.40	73.20	980382.89	980386.49
	:22090176	42	25.70	-71	15.50	66.80	980383.29	980386.65
	:22090175	42	25.70	-71	15.59	53.60	980385.73	980386.65
	:22090174	42	25.79	-71	15.70	54.60	980385.58	980386.78
	:22090808	42	25.79	-71	15.80	53.00	980385.36	980386.78
	:22090807	42	25.79	-71	16.00	53.60	980384.52	980386.78
	:22090806	42	25.90	-71	16.00	55.50	980384.18	980386.95
	:22090131	42	25.90	-71	17.39	65.80	980377.82	980386.95
	:22090805	42	26.00	-71	16.10	54.30	980383.73	980387.09
	:22090804	42	26.00	-71	16.19	61.00	980382.98	980387.09
	:22090116	42	26.00	-71	20.09	56.70	980374.31	980387.09
	:22090803	42	26.09	-71	16.40	69.20	980381.18	980387.23
	:22090802	42	26.09	-71	16.49	70.10	980380.41	980387.23
	:22090801	42	26.09	-71	16.60	67.40	980379.93	980387.23
	:22090130	42	26.20	-71	15.50	66.40	980384.80	980387.40
	:22090800	42	26.20	-71	16.79	57.60	980380.46	980387.40
	:22090799	42	26.20	-71	16.90	61.30	980379.46	980387.40
	:22090798	42	26.20	-71	17.09	59.10	980379.63	980387.40
	:22090797	42	26.20	-71	17.20	58.50	980379.78	980387.40
	:22090796	42	26.20	-71	17.30	59.10	980379.13	980387.40
	:22090795	42	26.20	-71	17.50	61.00	980379.09	980387.40
	:22090794	42	26.30	-71	17.60	70.10	980377.59	980387.55
	:22090793	42	26.30	-71	17.69	72.80	980377.17	980387.55
	:22090792	42	26.39	-71	17.80	70.40	980377.54	980387.68
	:22090791	42	26.39	-71	17.90	75.00	980376.62	980387.68
	:22090154	42	26.39	-71	20.09	48.20	980374.89	980387.68
	:22090790	42	26.50	-71	17.99	82.00	980375.88	980387.84
	:22090789	42	26.50	-71	18.10	81.70	980377.08	980387.84
	:22090129	42	26.60	-71	16.40	58.80	980381.04	980388.00
	:22090788	42	26.60	-71	18.20	82.30	980377.49	980388.00
	:22090787	42	26.60	-71	18.29	80.20	980375.84	980388.00
	:22090786	42	26.69	-71	18.40	75.00	980374.09	980388.13
	:22090785	42	26.69	-71	18.50	69.80	980373.94	980388.13
	:22090784	42	26.80	-71	18.70	68.90	980372.46	980388.30
	:22090783	42	26.80	-71	18.80	66.40	980372.20	980388.30
	:22090782	42	26.90	-71	18.89	61.00	980373.76	980388.45

STATION IDENTIFICATION		LOCATIONS					GRAVITY	
		LATITUDE		LONGITUDE		ELE	ST OBSERVED	THEORETICAL
proj	sta-id	deg	min	deg	min	(in mt)		
	:22090781	42	26.90	-71	19.00	55.50	980374.00	980388.45
	:22090117	42	26.90	-71	20.60	45.40	980374.31	980388.45
	:22090780	42	26.99	-71	19.19	50.00	980375.82	980388.59
	:22090779	42	26.99	-71	19.30	48.80	980376.78	980388.59
	:22090160	42	27.10	-71	19.49	41.80	980377.62	980388.75
	:22090159	42	27.10	-71	19.79	48.50	980375.72	980388.75
	:20000084	42	27.20	-71	16.40	65.20	980379.55	980388.90
	:22090158	42	27.20	-71	20.09	38.70	980377.19	980388.90
	:22090182	42	27.29	-71	19.00	43.00	980378.31	980389.03
	:20000103	42	27.29	-71	24.29	45.10	980373.65	980389.03
	:22090157	42	27.40	-71	20.50	39.00	980376.84	980389.20
	:22090155	42	27.40	-71	20.80	39.00	980377.23	980389.20
	:22090162	42	27.40	-71	21.50	40.80	980376.11	980389.20
	:22090183	42	27.50	-71	19.49	41.10	980378.55	980389.35
	:22090156	42	27.50	-71	20.69	40.80	980376.79	980389.35
	:27330027	42	27.55	-71	18.04	42.60	980380.36	980389.42
	:22090161	42	27.59	-71	21.59	38.10	980376.99	980389.48
	:22090163	42	27.70	-71	22.19	43.90	980376.45	980389.65
	:22090184	42	27.89	-71	19.40	41.80	980379.97	980389.94
	:22090123	42	27.89	-71	20.90	41.50	980377.97	980389.94
	:2752V021	42	27.92	-71	18.07	42.60	980380.33	980389.98
	:27330030	42	28.00	-71	17.00	42.00	980382.02	980390.10
	:2752V022	42	28.00	-71	17.00	42.90	980381.99	980390.10
	:20000095	42	28.00	-71	20.80	42.40	980376.75	980390.10
	:22090173	42	28.19	-71	19.49	41.10	980380.75	980390.38
	:35820724	42	28.30	-71	24.10	9.10	980377.50	980390.55
	:22090171	42	28.49	-71	15.10	38.10	980386.85	980390.84
	:22090122	42	28.49	-71	21.10	42.10	980379.58	980390.84
	:22090170	42	28.70	-71	15.20	50.30	980383.53	980391.15
	:22090128	42	28.70	-71	16.19	36.00	980384.51	980391.15
	:22090169	42	28.79	-71	15.40	49.10	980383.29	980391.29
	:22090127	42	28.79	-71	17.00	37.80	980384.55	980391.29
	:22090121	42	28.79	-71	20.30	62.50	980376.06	980391.29
	:22090168	42	28.90	-71	15.50	41.10	980384.31	980391.45
	:22090172	42	28.90	-71	18.70	42.40	980382.26	980391.45
	:22090167	42	29.00	-71	15.59	37.80	980384.70	980391.60
	:22090126	42	29.00	-71	16.60	36.00	980385.33	980391.60
	:22090166	42	29.20	-71	15.70	33.50	980385.14	980391.90
	:22090120	42	29.20	-71	20.20	48.20	980380.60	980391.90
	:22090165	42	29.30	-71	16.19	44.20	980383.82	980392.05

STATION IDENTIFICATION proj	sta-id	LOCATIONS LATITUDE deg	min	LONGITUDE deg	min	ELE (in mt)	ST	GRAVITY OBSERVED	THEORETICAL
	:22090118	42	29.30	-71	20.09	52.40		980380.50	980392.05
	:22090164	42	29.50	-71	18.59	38.40		980383.77	980392.35
	:22090124	42	29.60	-71	17.09	50.90		980382.80	980392.50
	:22090119	42	29.69	-71	20.00	58.50		980379.77	980392.64
	:22090125	42	29.90	-71	16.49	44.50		980384.60	980392.95
	:22090240	42	30.10	-71	25.19	79.20		980380.89	980393.25
	:22090241	42	30.80	-71	25.49	69.50		980378.50	980394.30
	: 360	42	31.12	-71	24.29	52.70		980382.16	980394.79
	: 360	42	31.28	-71	17.27	54.60		980383.96	980395.02
	: 360	42	31.30	-71	20.99	56.10		980383.36	980395.05
	:22090242	42	31.30	-71	26.09	69.80		980379.67	980395.05
	: 360	42	31.42	-71	27.62	92.40		980375.26	980395.23
	:20000006	42	31.60	-71	15.50	56.70		980385.65	980395.51
	:20000008	42	31.70	-71	20.99	66.80		980382.05	980395.66
	:22090243	42	32.00	-71	26.90	70.70		980380.85	980396.11
	:20000007	42	32.09	-71	17.99	37.20		980388.05	980396.24
	:20000009	42	32.30	-71	23.80	64.00		980382.45	980396.56
	:22090244	42	33.10	-71	26.30	72.20		980382.99	980397.76
	: 360	42	33.41	-71	20.81	53.60		980386.86	980398.23
	:22090245	42	33.70	-71	27.50	81.70		980384.02	980398.66
	: 360	42	34.07	-71	23.96	66.10		980385.86	980399.22
	: 360	42	34.12	-71	27.88	71.30		980385.56	980399.30
	:22090246	42	34.19	-71	27.89	71.30		980385.87	980399.40
	: 360	42	34.25	-71	16.63	38.10		980391.86	980399.49
	:22090247	42	35.00	-71	27.80	70.10		980381.92	980400.62
	:22090248	42	35.50	-71	27.59	65.20		980382.07	980401.37
	:20000091	42	36.20	-71	21.29	48.50		980396.25	980402.42
	:20000099	42	36.20	-71	25.19	48.20		980391.65	980402.42
	: 360	42	36.29	-71	23.63	68.60		980392.06	980402.55
	: 360	42	36.38	-71	20.57	34.40		980398.66	980402.69
	: 360	42	36.65	-71	16.12	50.60		980395.06	980403.09
	:22090251	42	37.70	-71	27.80	61.30		980385.87	980404.67
	:22090252	42	38.30	-71	28.60	114.00		980377.28	980405.57
	: 360	42	38.84	-71	23.80	33.20		980391.46	980406.38
	: 360	42	38.87	-71	28.52	90.20		980382.86	980406.43
	:22090262	42	38.90	-71	23.80	33.20		980391.63	980406.48
	:22090259	42	38.90	-71	27.10	64.30		980387.97	980406.48
	:22090254	42	38.90	-71	28.49	90.20		980382.94	980406.48
	:22090253	42	38.99	-71	29.50	56.40		980388.56	980406.61
	:22090261	42	39.10	-71	25.19	48.50		980388.99	980406.77

STATION IDENTIFICATION		L O C A T I O N S					G R A V I T Y	
		LATITUDE		LONGITUDE		ELE	ST OBSERVED	THEORETICAL
proj	sta-id	deg	min	deg	min	(in mt)		
	:22090260	42	39.10	-71	26.09	59.40	980387.97	980406.77
	: 360	42	39.38	-71	20.48	43.90	980398.56	980407.20
	:22090255	42	39.59	-71	28.49	74.70	980386.95	980407.52
	: 360	42	39.71	-71	17.03	44.20	980406.36	980407.70
	:22090256	42	40.40	-71	27.89	57.90	980392.02	980408.73
	: 360	42	40.43	-71	27.92	57.90	980391.86	980408.77
	:20000100	42	40.49	-71	26.69	61.60	980391.95	980408.87
	:20000081	42	41.09	-71	16.19	47.20	980407.95	980409.77
	:22090257	42	41.20	-71	28.30	89.90	980386.41	980409.93
	: 360	42	41.36	-71	24.10	53.30	980394.16	980410.17
	:20000092	42	41.90	-71	21.10	47.90	980395.65	980410.98
	:22090258	42	41.99	-71	28.10	77.10	980390.17	980411.12
	: 360	42	42.02	-71	15.59	43.00	980404.66	980411.16
	: 360	42	42.17	-71	21.17	42.10	980396.26	980411.39
	:20000101	42	43.90	-71	25.49	58.80	980397.85	980413.99
	: 360	42	43.91	-71	28.57	50.00	980396.46	980414.01
	: 360	42	44.12	-71	24.32	76.50	980395.26	980414.32
	: 360	42	44.36	-71	15.67	60.00	980397.36	980414.68
	:20000082	42	44.39	-71	15.70	60.00	980397.55	980414.73
	: 360	42	44.72	-71	20.66	61.00	980398.76	980415.23
	:20000093	42	44.80	-71	21.50	175.30	980376.55	980415.34