FINAL REPORT

Apollo Laser Altimeter Analysis

S-246

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APOLLO LASER ALTIMETER ANALYSIS

S-216

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Final Report: Laser Altimeter Experiment (S-216)

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The objective of this laser altimeter data analysis was 1) to extract some farside gravity anomalies and 2) to determine global geometric parameters. The attempt to obtain some farside gravity variations was not successful, for our reductions always met with inconsistencies and high correlations that made any proposed model invalid. There was only a small subset of the data which lent itself to the analysis, so extensive trials were not possible. However the analysis for global shape parameters was very fruitful and significant determinations have been made that have led to inferences concerning lunar structure and history. The primary results are the 1) size of the basic ellipsoid, 2) the displacement of the optical center from the center of gravity, 3) the global shape of the ringed maria surface having a 2+ km bulge toward the earth, 4) the large farside depression at 180° longitude, 5) the average elevation difference between highland and maria, 6) the smoothness of the maria over 1000 km and 7) the consistency of the laser data with other observations made from seven independent experiments.

We have analysed the laser altimeter data from Apollos 15, 16 and 17 missions. The Apollo 15 data was rather short due to hardware failure. As a result there were only 2 complete profiles (orbits 15 and 21) obtained. Prior to these orbits some data was obtained during orbits 3-9 when the spacecraft altitudes were above 40 nautical miles (a hardware constraint for valid data). These data are on the farside of the moon from 130E to 270E longitude. There was also some partial coverage during orbits 25 and 33 before total failure occurred. The sampling of the data was approximately every 20 seconds which provided an observation every 30 km or 1 degree along the orbit track. For Apollo 16 the sampling rate was reduced to approximately 1/min. to avoid the Apollo 15 failure situation. Five complete profiles were obtained from orbits 17, 28, 37, 47 and 59. For Apollo 17 the coverage was increased over both Apollo 15 and 16 providing data on orbits 13, 15, 23, 27, 28, 37, 49, 52, 65-71 and 74. The data quality was excellent, although we did not really use the data to its ultimate accuracy. We used the raw observations uncorrected for camera orientation and therefore errors on the order of 5-10 meters have been neglected. These data are published in reference 7.

The uncertainty in Apollo laser altimetry profiling comes from the inability to precisely determine the spacecraft positions at the observation time. The spacecraft position is determined independent of the laser measurement using Doppler radio tracking. Since the farside gravity field is unknown, the total gravity field used for modeling the perturbing forces is poor. The net result is that spacecraft positions in orbit can only be determined to 300-400 meters in the altimeter observation direction. This is a low frequency bias effect, so nearly adjacent altimeter data still preserve valid high frequency variations. Once the spacecraft orbit was established, it was a simple matter of subtracting the laser reading from the spacecraft selenocentric radius vector to produce the lunar topographic profiles. For the profiles presented in the literature another subtraction has been made to remove a basic lunar figure. The usual figure is a 1738. km sphere having its center at the center of gravity, but other models have been used including offset ellipsoids and spheres.

The agreement of the laser data with previous independent spacecraft topography measurements is excellent. There is no one article which covers the comparisons, so a short summary of these measurements in five surface areas will be made here. The different experiments are 1) Ranger Mission Impact Times, 2) Surveyor Lander Tracking data, 3) Lunar Orbiter V/H data, 4) Earth-based laser ranging to retro reflectors, 5) Apollo Command Module landmark tracking, 6) Lunar Orbiter Photogrammetry, 7) Apollo 17 Sounder Experiment. A comparison of elevation estimates is shown in Table I. The consistency of the estimates is very good, for the points of comparison are not precisely at the same latitude and longitude and local variations contribute to the differences. Another result which also shows excellent agreement with these laser data are the Ortho-Photo maps made from the Apollo metric camera photography.

Attached to this report are reprints of articles that have resulted from our analysis. As specific items are mentioned, these articles will be referenced from the publications list where one can obtain a more detailed description of the effort. Many of the items are discussed in several articles, for the increased data sets from the following missions provided a larger base for stronger interpretations.

The first topographic profiles from the Apollo 15 laser observations are probably the most dramatic set of data in the whole laser altimeter data bank. The striking ringed basins of Mare Serenitatis, Mare Crisium, and Mare

Smythii were clearly seen with the deepest region on the Moon being at Mare Smythii, some 4 1/2 km below a reference sphere of 1738 km centered about the center of gravity. These mare including Oceanus Procellarum were very flat. A large farside depression was discovered. If one assumes that it is a circular feature, it would be centered at approximately 45°S and 181°E with a 1900 km diameter. Also in evidence were the farside highlands that rose some 3 to 4 km above the 1738 km reference sphere. (see publication list 1, 4, 5, 8). The Apollo 17 profiles which were near the Apollo 15 region show many of the same features and verify the earlier results (see 3).

With the addition of the Apollo 16 laser profiles, there was a 38° latitude separation in the coverage and one could analyse global shape parameters. It was found that the best fitting ellipsoid was nearly a sphere with radius 1737.7 km. The old astronomers did a fairly good job, for their value was 1738.0 ± 1 km. However what was strongly determined from the data and which the old astronomers could not determine was the center of gravity (c.g.) shift from the optical center. The shift of the c.g. is 2 km toward earth and 1 km eastward. The polar direction was not well determined. (See 5, 9) The implication of such a shift in centers has led to models having an offset core or thickening of the farside crust. There have also been interior density models generated using constraints from other discipline observations. (see 5, 8, 9, 10).

Apollo 15 and 16 data provided statistics on the mean levels of highlands and maria, showing a 3 km difference. Comparison of these data with the Aeronautical Chart and Information Center (ACIC) Lunar chart elevations (scale 1:1,000,000) revealed large discrepancies over relatively small regions, making some old geological interpretations erroneous. (see 2, 5)

Analysis of the maria surface elevations has shown that the ringed maria sampled, plus Grimaldi and Tsiolkovsky all lie very close to an ellipsoid surface having a 2+ km bulge toward the earth. The irregular mare of Tranquillitatis and Fecunditatis are elevated above this reference by 1 km. Implications on this are covered in publication 6.

For those interested in analysing the raw observations or reduced profile values, the complete data set has been compiled in publication 7.

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TABLE 1: COMPARISON OF LUNAR ELEVATIONS DETERMINED BY EIGHT INDEPENDENT EXPERIMENTS

GROUP	EXPERIMENT	ELEVATION (KM)	LOCATION		UNCERTAINTY 1-σ (KM)	REMARKS	REFERENCE
			LAT, DEG	LONG, DEG			
1 MARE COGNITUM	RANGER VII	1735.5	-10.6	-20.6	0.3	IMPACT TIME	1
	LASER ALTIMETER	1735.4	- 9.0	-20.6	0.4	APOLLO 16	2
2 MARE TRAN-QUILLITATIS	RANGER VI	1735.3	9.3	21.5	0.3	IMPACT TIME	1
	RANGER VIII	1735.2	2.7	24.7	0.3	IMPACT TIME	1
	LUNAR ORBITER V/H	1735.4	1.0	23.2	0.7	SET III	3
	PHOTOGRAMMETRY	1735.4	1.7	24.0	0.2	LUNAR ORBITER SITE II P636	4
	RETROREFLECTOR	1735.6	0.7	23.5	0.05	APOLLO 11	5
	LANDMARK TRACKING	1735.3	1.3	23.7	0.4	APOLLO 11	6
3 OCEANUS PROCELLARUM	SURVEYOR I	1735.5	-2.5	-43.3	1.3	LANDER TRACK-ING	7
	LUNAR ORBITER V/H	1735.6	-2.1	-43.8	0.7	SET IXa	3
	PHOTOGRAMMETRY	1735.7	-2.1	-43.8	0.2	LUNAR ORBITER SITE P-9.2AB	4
	LASER ALTIMETRY	1735.3	-5.2	-43.3	0.4	APOLLO 16	2
4 MARE SERENITATIS	PHOTOGRAMMETRY	1734.6	21.3	27.6	0.2	LUNAR ORBITER SITE V-24	4
	SOUNDER	1734.2	20.0	27.6	0.4	APOLLO 17	8
	LASER ALTIMETRY	1734.2	23.9	27.0	0.4	APOLLO 15	2
5 PALUS PUTREDINIS	LANDMARK TRACKING	1735.6	3.7	26.1	0.4	APOLLO 15	6
	RETROREFLECTOR	1735.6	3.6	26.1	0.05	APOLLO 15	5
	LASER ALTIMETRY	1735.7	3.4	26.0	0.4	APOLLO 15	2

Publications

1. Roberson, F. I. and W. M. Kaula. Apollo 15 Preliminary Science Report, Laser Altimetry, NASA SP-289, pp. 25-48 to 25-50, 1972.

2. Wollenhaupt, W. R. and W. L. Sjogren. Apollo 16 Preliminary Science Report, Laser Altimetry, NASA SP-315, pp. 30-1 to 30-5, 1972.

3. Wollenhaupt, W. R., W. L. Sjogren, R. E. Lingenfelter, G. Schubert and W. M. Kaula, Apollo 17 Preliminary Science Report, Laser Altimetry NASA SP-330, pp. 33-41 to 33-43, 1973.

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Appendix I

Publication List ~~and the Publications~~

Publications

1. Roberson, F. I. and W. M. Kaula. Apollo 15 Preliminary Science Report, Laser Altimetry, NASA SP-289, pp. 25-48 to 25-50, 1972. B25740

2. Wollenhaupt, W. R. and W. L. Sjogren. Apollo 16 Preliminary Science Report, Laser Altimetry, NASA SP-315, pp. 30-1 to 30-5, 1972. B25 74

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