

Revised coordinates for Apollo Lunar Modules and ALSEPs

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The Narrow Angle Camera (NAC) on the Lunar Reconnaissance Orbiter (LRO) provides direct imaging, at pixel scales of 0.5 to 1.0 meter, of robotic and crewed mission hardware left on the surface of the Moon. We identified the descent stages of the lunar modules, central stations of the Apollo lunar surface experiments package (ALSEP), and laser ranging retroreflectors (LRRRs) in NAC images of the Apollo landing sites. The pixel coordinates of those objects were then converted to latitude and longitude coordinates using SPICE routines in the U.S. Geological Survey Integrated System for Imagers and Spectrometers (ISIS) software package. The resulting sets of map coordinates were averaged to precisely determine the location of each object.

Images included in coordinate determination were those acquired in the 50 km polar orbit for which there existed corrected ephemeris information (acquired between 15 September 2009 and 31 January 2011) derived from cross-over analysis provided by LRO laser altimeter team. This criteria restricted the image selection to approximately twelve images per site. For each image at the sites that contained a LRRR (Apollo 11, 14, and 15), we additionally used an ISIS routine to adjust the camera pointing to place the LRRR at the correct coordinates in each image. This adjustment further reduced the number of images used at those sites, as the LRRRs are not identifiable in all NAC images. However, this shift resulted in much lower uncertainties in the coordinates of the LM and ALSEP at these sites. For the remaining Apollo sites (12, 16, and 17), we used a temperature- and slew-corrected pointing model for the NAC cameras. The pointing model was derived from the positions of the LRRRs and can pinpoint the coordinates of the retroreflectors at Apollo and Lunokhod sites to within 15m ($\sim 0.0005^\circ$). For these sites, the images with the furthest outlying coordinates for the object of interest were dropped. Our LRO NAC analysis allows us to refine the locations of objects at the LRRR sites to within 2 m and for the other sites to within 12 meters.

The results of this process are summarized in the table, which provides both the new coordinates and the change from a previous compilation of coordinates of objects at the Apollo landing sites (Davies 1999).

References: Davies, M., 2000. Lunar coordinates in the regions of the Apollo landers. *Journal of Geophysical Research*, 105(8), pp 20277-20280

Site	LM Latitude	LM Longitude	Delta Davies (m)	ALSEP Latitude	ALSEP Longitude	Delta Davies (m)	# Images
Apollo 11	0.674158	23.473146	5.83				5
Apollo 12	-3.012499	336.578158	8.86	-3.009439	336.575314	3.25	12
Apollo 14	-3.645890	342.528050	25.28	-3.644185	342.522295	9.23	7
Apollo 15	26.132379	3.633303	17.54	26.134064	3.629920	3.33	5
Apollo 16	-8.973476	15.501019	28.83	-8.975951	15.498479	20.71	9

Apollo 17	20.190850	30.772247	17.27	20.19234	30.765569	21.09	5
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