Apollo 16 Metric (Mapping) Camera and Panoramic Camera Ephemeris Data Description

Collection Overview

This collection contains comma-delimited ASCII tables of computed ephemeris data (spacecraft state vector, camera orientation, photograph position, and lighting data) for the Apollo 16 Metric (Mapping) and Panoramic photographic images taken on 20-24 April 1972 of the moon from lunar orbit. This collection also includes the original scans of the ephemeris data on microfilm in the form of PDF/A files.

Digitization of Apollo 16 Ephemeris Data

The Apollo 16 ephemeris support data, also known as state vector data, were originally computed for each Metric and Panoramic camera photograph and recorded to paper and then later recorded to microfilm, which are held at the NASA Space Science Data Coordinated Archive (NSSDCA, formerly NSSDC) as datasets PSPG-00572 and PSPG-00344. Due to the degradation of the paper copies, some of the records were never converted to microfilm. The NSSDCA scanned the microfilm records to Tagged Image File Format (TIFF) files, where the ephemeris data for a single observation (photograph) sometimes spans several pages. The Arizona State University (ASU) received these files and customized an Optical Character Recognition (OCR) algorithm to convert the raster TIFF images to text format for most of the ephemeris scans. ASU implemented manual methods to record values that failed OCR conversion, and then stored the final values of the OCR conversion, manual efforts, and subsequent validation as comma-separated values (CSV) ASCII files in the online ASU Apollo Image Archive, http://apollo.sese.asu.edu/EPHEMERIS/. Please note that ASU did not include several data values, such as the emission and phase angles, in the final CSV tables.

The NSSDCA downloaded the CSV files from the Apollo Image Archive in August 2016 but discovered additional OCR errors such as more than one decimal point in floating point numbers and underscore characters in numeric values. The NSSDCA corrected these conversion errors and reformatted several columns in the CSV files to conform to PDS standards, such as inserting a capital T for values in the UTC time column and inserting a capital E before the exponent for numeric values given in scientific notation. This collection contains these NSSDCA-inspected and -corrected CSV files.

The Apollo Image Archive states that these ephemeris files should be considered "historical" since more accurate and improved coordinate information is available for features on the Moon. The Apollo Image Archive also states that their CSV files are "first-run" and new versions will likely be uploaded in the future. However as of December 2017, the Apollo Image Archive files were identical to those downloaded in August 2016 as input for this collection.

Original ephemeris support data for Metric and Panoramic photographs acquired during the Apollo 15 and 17 missions were also restored from microfilm as part of this digitization effort and archived as:

Robinson, M.S., Cisneros, E., and Paris, C.N., "Apollo 15 Metric (Mapping) Camera and Panoramic Camera Orbital Support Data - Photographic Ephemeris", NASA Planetary Data System, id: urn:nasa:pds:a15photosupportdata:geom_orbital_photo_ephem, 2017.

Robinson, M.S., Cisneros, E., and Paris, C.N., "Apollo 17 Metric (Mapping) Camera and Panoramic Camera Orbital Support Data - Photographic Ephemeris", NASA Planetary Data System, id: urn:nasa:pds:a17photosupportdata:geom_orbital_photo_ephem, 2017.

Ephemeris Data Files

This collection contains two comma-delimited ASCII tables as CSV files. The first file, as16_metriccam_state_vectors.csv, contains one record of ephemeris data for one Metric Camera photograph, as extracted by OCR from scans of microfilm PSPG-00572. The second file, as16_pancam_state_vectors.csv, contains one record of ephemeris data for one Panoramic Camera photograph, as extracted by OCR from scans of microfilm PSPG-00344.

Both CSV files are identically formatted and contain the same 79 data fields (columns). The format of each file is defined by its detached metadata label, as16_metriccam_state_vectors.xml or as16_pancam_state_vectors.xml. Appendix A provides a detailed definition of each data field. Identical file format and fields are used for the archived ephemeris data for Apollo 15 and Apollo 17, identified above. One minor format difference is that the right ascension and declination columns are defined as ASCII strings for the Apollo 15 and 16 files; these columns are empty in the A17 files but are defined in that archive as ASCII_Real.

Ephemeris Data Scans

This collection also includes the original scans of the ephemeris data on microfilm in the form of PDF/A files: as16_metriccam_state_vectors_scans.pdf and as16_pancam_state_vectors_scans.pdf. These files were produced by merging the TIFF images of the scans into a PDF file, then converting that file to PDF/A format.

Appendix B provides one page of ephemerid data computed for Apollo 16 Metric Camera image 678 (page number 678, revolution 26). Although this page was scanned by the NSSDCA, it was not included in the associated PDF, as16_metriccam_state_vectors_scans.pdf, and the associated ephemeris file, as16_as16_metriccam_state_vectors.csv, does not have an entry for this image. It is assumed that this page was never OCR'd by ASU.

References

The first five publications pertain directly to this data collection.

Apollo 16 Photograph Evaluation (APE) Data Book, NASA MSC-07396, NASA Manned Spacecraft Center, Houston, Texas, January 1973. This publication reproduces the printouts of computed ephemeris support data for the first and last frames from each sequence of images acquired by the metric and panoramic cameras. It includes definitions for the computed ephemeris data variables.

Apollo Photograph Evaluation (APE) Programming Manual, NASA CR-134218, Contractor Report prepared by I.J. Kim, TRW Systems Group, NASA Johnson Space Center, Houston, Texas, February 1974. This publication describes the programming techniques used to implement the equations of the APE computer program. It includes definitions for the computed ephemeris data variables.

Cameron, W.S., F.J. Doyle, M.A. Niksch, K. Hug, L. Levenson, and K. Michlovitz, Data Users Note - Apollo 16 Lunar Photography, NSSDC-73-01, NSSDC 74-08, published by NASA Space Science Data Center (NSSDC), Greenbelt, Maryland, May 1973. This publication includes descriptions of service module, command module and lunar surface photography along with brief explanations of mission objectives, photographic equipment, and photographic coverage and quality. Included are samples of the photographic ephemeris support data.

Apollo 16 Index of Mapping Camera and Panoramic Camera Photographs, NASA MSC-072561, NASA Johnson Spacecraft Center, Mapping Sciences Branch, Houston, Texas, August 1972. This publication describes all photographs from the Apollo 16 Panoramic and Metric (Mapping) Cameras.

Apollo SIM Bay Photographic Equipment and Mission Summary - Apollo 16 Supplement, NASA Johnson Space Center, Mapping Sciences Branch, Unnumbered, Houston, Texas, September 1972. This publication summarizes the Spectral Imaging Module (SIM) Bay photographic experiments, in flight operations, and pre-launch calibrations for the Apollo 16 mission.

Apollo 16 Preliminary Science Report, NASA SP-315, published by NASA, Washington, D.C., 1972.

Apollo Scientific Experiments Data Handbook, NASA Technical Memorandum X-58131, JSC-09166, published by NASA Johnson Space Center, Houston, Texas, August 1974 (revised April 1976).

Robinson, M., "Apollo 16 Metric Camera 2 Scanned Images Version 1.0", NASA Planetary Data System, id. A16C-L-MC-2-SCANNED-IMAGES-V1.0, 2011.

Acknowledgements

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Source

The NSSDCA provided this collection description. Most of the text in the section above named Digitization of Apollo 16 Ephemeris Support Data was copied from the ASU Apollo Image Archive, http://apollo.sese.asu.edu/.

Appendix A

Description of the data fields (columns) in CSV files. Column descriptions were extracted from Section 2.0 of the Apollo 16 Photograph Evaluation Data Book and Tables 2-1 and 4-15 in the APE Programming Manual.

Col #	Name	Data type	Unit	Description
1	state_vector_id	ASCII_NonNegative_Integer		Unique ID for this ephemeris record.
2	image_name	ASCII_String		Apollo photograph (image) name given as ASnn-c-iiii where nn is the Apollo mission number (15, 16, or 17), c is set to M for metric (mapping) camera or P for panoramic camera, and iiii specifies the image number.
3	page_number	ASCII_NonNegative_Integer		Page number of printed output; same as the image number in column 2.
4	mission	ASCII_String		Apollo mission; values are AS15, AS16, or AS17.
5	camera	ASCII_String		Camera used; values are M for metric camera or P for panoramic camera.
6	orbit_number	ASCII_NonNegative_Integer		Lunar orbit number.
7	data_origin	ASCII_String		Month/year when this state vector and ephemeris data were computed.
8	utc_time_str	ASCII_String		UTC time of film exposure in format yyyy-mm-ddThh:mm:ss.{sss}. Note: The APE Data Book and the APE Programming Manual define this time as Greenwich Mean Time = Sidereal time of file exposure (year, month, day, hour, minute, second) - (UT1 - USNO).
9	cte_time	ASCII_String		Central clock time of film exposure which was recorded on the film in format dd-hh:mm:ss.{sss}.
10	x1950_x	ASCII_Real	km	1950 state vector: X component of the spacecraft position in mean 1950 moon centered, inertial, cartesian coordinates.
11	x1950_y	ASCII_Real	km	1950 state vector: Y component of the spacecraft position in mean 1950 moon centered, inertial, cartesian coordinates.
12	x1950_z	ASCII_Real	km	1950 state vector: Z component of the spacecraft position in mean 1950 moon centered, inertial, cartesian coordinates.
13	x1950_xdot	ASCII_Real	km/s	1950 state vector: X component of the spacecraft velocity in mean 1950 moon centered, inertial, cartesian coordinates.
14	x1950_ydot	ASCII_Real	km/s	1950 state vector: Y component of the spacecraft velocity in mean 1950 moon centered, inertial, cartesian coordinates.
15	x1950_zdot	ASCII_Real	km/s	1950 state vector: Z component of the spacecraft velocity in mean 1950 moon centered, inertial, cartesian coordinates.

16	selenographic_x	ASCII_Real	km	Selenographic state vector: X component of the spacecraft position in selenographic, instantaneous inertial, cartesian coordinates.
17	selenographic_y	ASCII_Real	km	Selenographic state vector: Y component of the spacecraft position in selenographic, instantaneous inertial, cartesian coordinates.
18	selenographic_z	ASCII_Real	km	Selenographic state vector: Z component of the spacecraft position in selenographic, instantaneous inertial, cartesian coordinates.
19	selenographic_xdot	ASCII_Real	km/s	Selenographic state vector: X component of the spacecraft position in selenographic, instantaneous inertial, cartesian coordinates.
20	selenographic_ydot	ASCII_Real	km/s	Selenographic state vector: Y component of the spacecraft position in selenographic, instantaneous inertial, cartesian coordinates.
21	selenographic_zdot	ASCII_Real	km/s	Selenographic state vector: Z component of the spacecraft position in selenographic, instantaneous inertial, cartesian coordinates.
22	sigma_x	ASCII_Real	km	First order uncertainty in X component of the spacecraft position.
23	sigma_y	ASCII_Real	km	First order uncertainty in Y component of the spacecraft position.
24	sigma_z	ASCII_Real	km	First order uncertainty in Z component of the spacecraft position.
25	sigma_xdot	ASCII_Real	km/s	First order uncertainty in X component of the spacecraft velocity.
26	sigma_ydot	ASCII_Real	km/s	First order uncertainty in Y component of the spacecraft velocity.
27	sigma_zdot	ASCII_Real	km/s	First order uncertainty in Z component of the spacecraft velocity.
28	nadir_point	ASCII_String	deg	Nadir_point given as (longitude,latitude); intersection with the mean lunar surface of the vector from the moon's center of mass to the spacecraft. Please note the outer and inner footprint corners in columns 69-72 and 76-79 are given in the order of (latitude, longitude).
29	camera_axis_intersect	ASCII_String	deg	Camera axis intersect (longitude,latitude): Position of principal intersection point; intersection of camera optical axis direction with mean lunar surface. Please note the outer and inner footprint corners in columns 69-72 and 76-79 are given in the order of (latitude, longitude).
30	spacecraft_radius	ASCII_Real	km	Vector from moon center of mass to spacecraft.
31	mean_altitude_rate	ASCII_Real	km/s	Rate of change in spacecraft altitude above the mean lunar surface.
32	spacecraft_altitude	ASCII_Real	km	Height of spacecraft above mean lunar surface.
33	phi	ASCII_Real	deg	Angles which rotate the camera axes coordinate system into the nadir point centered lunar local horizontal system, where phi is the primary right-handed rotation about the camera Y-axis.
34	sigma_phi	ASCII_Real	deg	First order uncertainty in phi.

35	kappa	ASCII_Real	deg	Angles which rotate the camera axes coordinate system into the nadir point centered lunar local horizontal system, where kappa is the secondary right-handed rotation about the intermediate X-axis.
36	sigma_kappa	ASCII_Real	deg	First order uncertainty in kappa.
37	omega	ASCII_Real	deg	Angles which rotate the camera axes coordinate system into the nadir point centered lunar local horizontal system, where omega is the final right-handed rotation about the local vertical (local horizontal Z-axis).
38	sigma_omega	ASCII_Real	deg	First order uncertainty in omega.
39	x_tilt	ASCII_Real	deg	(Lateral tilt) Angle from the local horizontal plane at the nadir point to the camera Y-axis.
40	sigma_x_tilt	ASCII_Real	deg	First order uncertainty in x_tilt.
41	y_tilt	ASCII_Real	deg	(Longitudinal tilt) Angle from the local horizontal plane at the nadir point to the camera X-axis
42	sigma_y_tilt	ASCII_Real	deg	First order uncertainty in y_tilt.
43	heading	ASCII_Real	deg	Angle, measured positive clockwise in the lunar local horizontal plane at the nadir point, from north to the projection of the camera X-axis onto that plane.
44	sigma_heading	ASCII_Real	deg	First order uncertainty in heading.
45	laser_spacecraft_altitude	ASCII_Real	km	Vertical component of laser altimeter slant range based on the assumption that the laser altimeter was aligned along the three-inch mapping camera optical axis.
46	laser_slant_range	ASCII_Real	km	Telemetered laser altimeter readout.
47	selenographic_cos_x	ASCII_Real		Selenographic direction cosines, cos X: Direction definition of the vector from the spacecraft to the principal intersection point in the instantaneous inertial selenographic coordinate system.
48	selenographic_cos_y	ASCII_Real		Selenographic direction cosines, cos Y: Direction definition of the vector from the spacecraft to the principal intersection point in the instantaneous inertial selenographic coordinate system.
49	selenographic_cos_z	ASCII_Real		Selenographic direction cosines, cos Z: Direction definition of the vector from the spacecraft to the principal intersection point in the instantaneous inertial selenographic coordinate system.
50	selenographic_magnitude	ASCII_Real	km	Magnitude of the selenographic direction vector.
51	selenocentric_matrix_tl	ASCII_Real		Selenocentric coordinate system to camera axes coordinate system transformation matrix: element in top row, left column.
52	selenocentric_matrix_tm	ASCII_Real		Selenocentric coordinate system to camera axes coordinate system transformation matrix: element in top row, middle column.

53	selenocentric_matrix_tr	ASCII_Real		Selenocentric coordinate system to camera axes coordinate system transformation matrix: element in top row, right column.
54	selenocentric_matrix_ml	ASCII_Real		Selenocentric coordinate system to camera axes coordinate system transformation matrix: element in middle row, left column.
55	selenocentric_matrix_mm	ASCII_Real		Selenocentric coordinate system to camera axes coordinate system transformation matrix: element in middle row, middle column.
56	selenocentric_matrix_mr	ASCII_Real		Selenocentric coordinate system to camera axes coordinate system transformation matrix: element in middle row, right column.
57	selenocentric_matrix_bl	ASCII_Real		Selenocentric coordinate system to camera axes coordinate system transformation matrix: element in bottom row, left column.
58	selenocentric_matrix_bm	ASCII_Real		Selenocentric coordinate system to camera axes coordinate system transformation matrix: element in bottom row, middle column.
59	selenocentric_matrix_br	ASCII_Real		Selenocentric coordinate system to camera axes coordinate system transformation matrix: element in bottom row, right column.
60	local_horizontal_matrix_tl	ASCII_Real		Local horizontal coordinate system to camera axes coordinate system transformation matrix: element in top row, left column.
61	local_horizontal_matrix_tm	ASCII_Real		Local horizontal coordinate system to camera axes coordinate system transformation matrix: element in top row, middle column.
62	local_horizontal_matrix_tr	ASCII_Real		Local horizontal coordinate system to camera axes coordinate system transformation matrix: element in top row, right column.
63	local_horizontal_matrix_ml	ASCII_Real		Local horizontal coordinate system to camera axes coordinate system transformation matrix: element in middle row, left column.
64	local_horizontal_matrix_mm	ASCII_Real		Local horizontal coordinate system to camera axes coordinate system transformation matrix: element in middle row, middle column.
65	local_horizontal_matrix_mr	ASCII_Real		Local horizontal coordinate system to camera axes coordinate system transformation matrix: element in middle row, right column.
66	local_horizontal_matrix_bl	ASCII_Real		Local horizontal coordinate system to camera axes coordinate system transformation matrix: element in bottom row, middle column.
67	local_horizontal_matrix_bm	ASCII_Real		Local horizontal coordinate system to camera axes coordinate system transformation matrix: element in bottom row, left column.
68	local_horizontal_matrix_br	ASCII_Real		Local horizontal coordinate system to camera axes coordinate system transformation matrix: element in bottom row, right column.
69	photo_footprint1	ASCII_String	deg	Photographic footprint, corner 1: latitude and longitude of full field of view corner point projections onto the lunar surface, formatted as "(latitude,longitude)".

70	photo_footprint2	ASCII_String	deg	Photographic footprint, corner 2: latitude and longitude of full field of view corner point projections onto the lunar surface, formatted as "(latitude,longitude)".
71	photo_footprint3	ASCII_String	deg	Photographic footprint, corner 3: latitude and longitude of full field of view corner point projections onto the lunar surface, formatted as "(latitude,longitude)".
72	photo_footprint4	ASCII_String	deg	Photographic footprint, corner 3: latitude and longitude of full field of view corner point projections onto the lunar surface, formatted as "(latitude,longitude)".
73	right_ascension	ASCII_String		Right ascension of direction to stellar photo center; for mapping camera only, formatted as {-}hh:mm:ss.s.
74	declination	ASCII_String		Declination of direction to stellar photo center; for mapping camera only, formatted as {-}deg:mm:ss.s.
75	file_catalog_id	ASCII_NonNegative_Integer		An internal identifier assigned by ASU during the OCR effort.
76	inner_photo_footprint1	ASCII_String	deg	Inner photographic footprint of the undistorted area of image, corner 1: latitude and longitude of inner field of view corner point projections onto the lunar surface, formatted as "(latitude,longitude)"; available only for panoramic camera.
77	inner_photo_footprint2	ASCII_String	deg	Inner photographic footprint of the undistorted area of image, corner 2: latitude and longitude of inner field of view corner point projections onto the lunar surface, formatted as "(latitude,longitude)"; available only for panoramic camera.
78	inner_photo_footprint3	ASCII_String	deg	Inner photographic footprint of the undistorted area of image, corner 3: latitude and longitude of inner field of view corner point projections onto the lunar surface, formatted as "(latitude,longitude)"; available only for panoramic camera.
79	inner_photo_footprint4	ASCII_String	deg	Inner photographic footprint of the undistorted area of image, corner 4: latitude and longitude of inner field of view corner point projections onto the lunar surface, formatted as "(latitude,longitude)"; available only for panoramic camera.

Appendix B

Ephemeris data computed for Apollo 16 Metric Camera image 678 (page number 678, revolution 26). Although this page was scanned by the NSSDCA, it was not included in the associated PDF, as16_metriccam_state_vectors_scans.pdf, and the associated ephemeris file, as16_as16_metriccam_state_vectors.csv, does not have an entry for this image.

	YEAR	MONTH	DAY	HOUR	MINUTE	SECOND
GMT	1972	4	21	21	55	13.176
CTE			5	4	1	13.808

STATE VECTOR	X (KM)	Y (KM)	Z (KM)	XDOT (KM/S)	YDOT (KM/S)	ZDOT (KM/S)
1950.0	1833.5998046	3.6400828	-269.4421890	-.1260858	-1.4188841	-.7759672
SELENOGRAPHIC	1289.7395414	1315.9552569	-225.1931431	1.1327182	-1.1484096	-.1713462

LONGITUDE OF NADIR POINT	45.5764294 DEG	LATITUDE OF NADIR POINT	-6.9678510 DEG
	45 DEG, 34 MIN, 35.1457214 SEC		-6 DEG, 58 MIN, 4.2635250 SEC
LONG OF CAMERA AXIS INTERSECT	45.9708867 DEG	LATI OF CAMERA AXIS INTERSECT	-10.3207165 DEG
	45 DEG, 58 MIN, 15.1921463 SEC		-10 DEG, 19 MIN, 14.5794010 SEC
SPACECRAFT RADIUS	1856.3076993 KM	SPACECRAFT ALTITUDE	118.2177030 KM
SCALE FACTOR	.0004803 M/KM	AZIMUTH OF VELOCITY VECTOR	263.8636182 DEG
MEAN ALTITUDE RATE	-.0063341 KM/SEC	HORIZONTAL VELOCITY	1.6220724 KM/SEC
TILT AZIMUTH	173.3943462 DEG	TILT ANGLE	40.1668572 DEG
SIGMA TILT AZIMUTH	.0003101 DEG	SIGMA TILT ANGLE	.0002000 DEG
SUN ELEVATION AT PRIN GRND PNT	53.7549210 DEG	SUN AZIMUTH AT PRINCIPAL GRND PNT	72.8581448 DEG
LONGITUDE OF SUBSOLAR POINT	80.3857893 DEG	LATITUDE OF SUBSOLAR POINT	1.5444075 DEG
	80 DEG, 23 MIN, 8.8415337 SEC		1 DEG, 32 MIN, 39.8671246 SEC
ALPHA	-31.1028116 DEG	SWING ANGLE	179.8542840 DEG
EMISSION ANGLE	43.5423173 DEG	SIGMA SWING ANGLE	.0003101 DEG
PHASE ANGLE	48.8019514 DEG	NORTH DEVIATION ANGLE	188.4714550 DEG
PHI	-.1229948 DEG	A-TILT	-40.1666975 DEG
SIGMA PHI	.0002617 DEG	SIGMA A-TILT	.0002000 DEG
KAPPA	173.5850258 DEG	Y-TILT	.0939891 DEG
SIGMA KAPPA	.0002617 DEG	SIGMA Y-TILT	.0002000 DEG
OMEGA	-40.1666970 DEG	HEADING	-96.4943049 DEG
SIGMA OMEGA	.0002000 DEG	SIGMA HEADING	.0002000 DEG
SPACECRAFT ALTITUDE (LASER)	.0000000 KM	LASER SLANT RANGE	.0000000 KM

SELENOGRAPHIC DIRECTION COSINES OF CAMERA AXIS	A	Y	Z	MAGNITUDE (KM)
	-.63833442	-.54530368	-.54329832	158.646284

TRANSFORMATION MATRIX FROM SELENOCENTRIC TO CAMERA

-.76349441-01	-.87166931+00	-.48411100+00
.53245734+00	.37485805+00	-.75892728+00
.84300645+00	-.31571208+00	.43550653+00

TRANSFORMATION MATRIX FROM LOCAL HORIZONTAL TO CAMERA

-.99358181+00	-.11310431+00	-.16404179-02
.85379797-01	-.75938640+00	.64501363+00
-.74199486-01	.64073373+00	.76416926+00

PHOTOGRAPH FOOTPRINT

LATITUDE	LONGITUDE
-6.909	47.996
********	.000
********	.000
-7.447	43.226

DIRECTION TO STELLAR PHOTO CENTER

RIGHT ASCENSION -9 HR, 10 MIN, 17.8 SEC DECLINATION 53 DEG, 14 MIN, 38.9 SEC