PHOTOGRAMMETRIC CONTROL AND MOSAICKING OF APOLLO 15 PANORAMIC CAMERA IMAGES. Kenneth L. Edmundson[1], J.A. Anderson[2], B.A. Archinal[1], T.L. Becker[1], A.V. Nefian[3], M.S. Robinson[4], and O.H. Thomas[5], [1]Astrogeology Science Center, United States Geological Survey, Flagstaff, AZ, USA, 86001 (kedmundson@usgs.gov), [2]USGS Retired, [3]NASA Ames Research Center, Moffett Field, CA, USA, 94035, [4]Arizona State University, Tempe, AZ, USA, 85287, [5]Cardinal Systems, LLC, Flagler Beach, FL, USA, 32136

Introduction: The U.S. Geological Survey Astrogeology Science Center (ASC) is photogrammetrically and geodetically controlling the ~1500 images acquired with the high-resolution Apollo 15 Panoramic Camera (PC). The PC, together with the Metric (mapping) Camera (MC), and a star camera and laser altimeter (to provide support data) formed the integrated photogrammetric mapping systems flown on the last three Apollo lunar missions (15, 16, and 17) [1]. We will accurately determine, for the first time, the proper geometry and location of the Apollo 15 PC images and produce a digital image mosaic (DIM) covering ~11% of the Moon at a pixel scale of ~2-5 m/pixel (Figure 1).

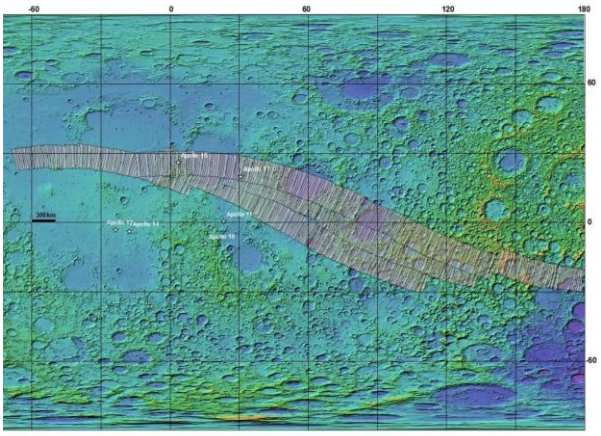

Figure 1: Apollo 15 panoramic image footprints covering ~11% of the lunar surface.

This effort is the most recent in an ongoing collaboration between the ASC, Arizona State University (ASU), and the Intelligent Robotics Group of the NASA Ames Research Center (ARC) to achieve the most complete cartographic development of Apollo mapping system data into versatile digital map products [e.g., 2-9]. The NASA Johnson Space Center and ASU recently completed digital scans of both the original MC and PC negatives at film-grain resolution and created a digital record of support data (available via the ASU Apollo Digital Image Archive; http://apollo.sese.asu.edu) [2,7]. Processing of the MC nadir digital images by the ARC resulted in a controlled, orthorectified digital image mosaic (DIM) and digital terrain model (DTM) covering ~18% of the Moon at a pixel scale of ~30 m/pixel [6]. The combined processing of nadir and oblique Apollo MC images is ongoing [10].

The 2-5 m pixel scale of the PC images approaches that of the Lunar Reconnaissance Orbiter (LRO) Narrow Angle Camera (NAC). Aside from a few Lunar Orbiter and Ranger images and images from landers, these are the highest resolution images acquired prior to LRO and therefore offer a unique and invaluable opportunity for the detection of the most subtle of changes in the lunar surface over a ~40 year window in time. Digital MC and PC data will be integrated easily with other digital lunar data and can be updated geodetically and cartographically as needed. This work will thus render this image dataset in a readily usable form, enabling a wide variety of scientific and engineering uses, such as planning and undertaking future missions, geologic mapping, geophysical process modeling, slope dependent correction of spectral data, and as mentioned above, detection of changes and assessment of the rate of formation of small impact craters.

The Apollo 15 Panoramic Camera: The PC (Figure 2), modified from the Itek KA-80A "optical bar" camera used by the Air Force [11], used a moving lens of 610 mm focal length to capture a 114x1140 mm image. Panoramic images (Figure 3) were acquired either simultaneously or interleaved with the MC images (Figure 4). A PC image covers a 339 (across-track) by 22 km "bowtie" shaped area (Figure 5). Stereo convergence was accomplished by pitching

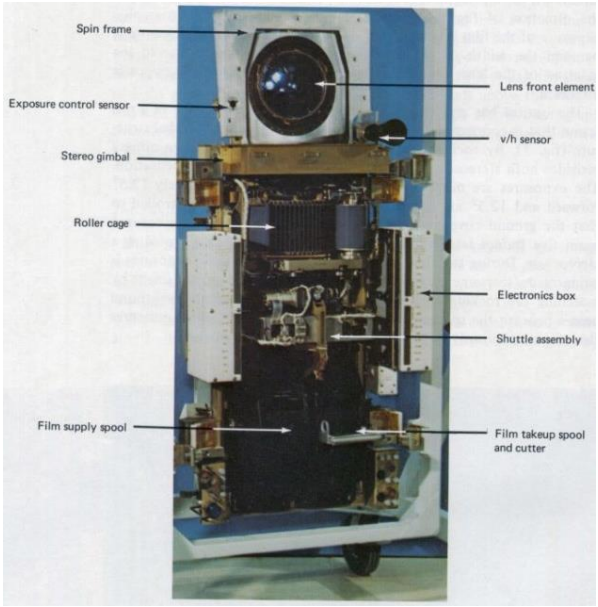

Figure 2: Apollo Panoramic Camera with cover removed (NASA).

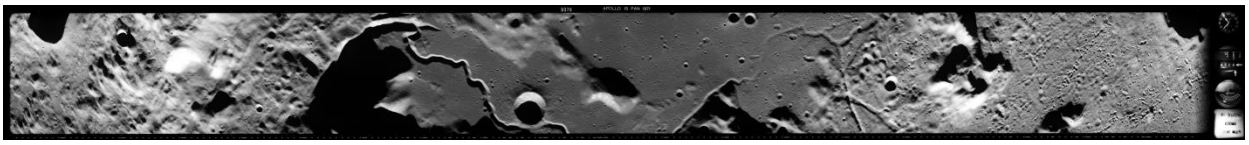

Figure 3: Apollo 15 PC image #9379 of Rima Hadley (NASA/JSC/ASU).

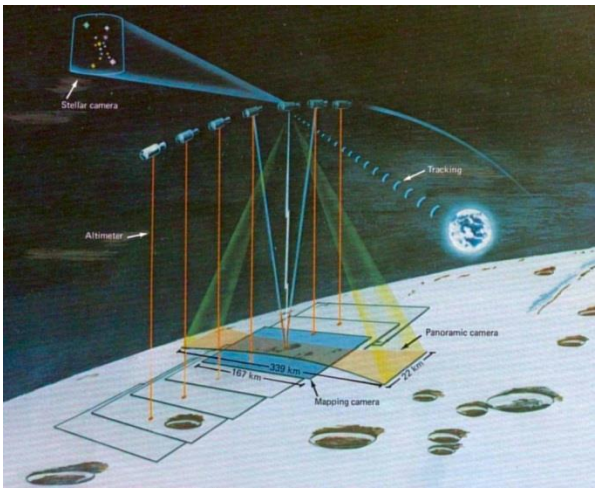

Figure 4: Relationship between Apollo MC and PC image coverage (from [12]).

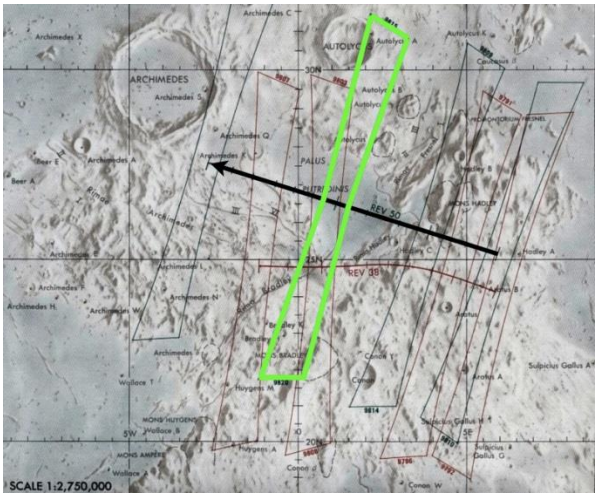

Figure 5: Example Apollo 15 PC "bowtie" footprint highlighted in green. Black arrow indicates flight direction (NASA).

the PC alternately 12.5° fore and aft of nadir.

Controlling Apollo 15 PC Images: This project utilizes the Integrated Software for Imagers and Spectrometers (ISIS) planetary cartography package developed by the USGS [13]. We will register the Apollo 15 PC images to each other and to the Apollo 15 MC image dataset by measuring a large number of features (or tie points) common between overlapping images. Radius values for tie points will come from either the Apollo Zone DTM created by the ARC or, for points falling outside of that region, from the most recent LRO Wide Angle Camera DTM (GLD100 [14]). The MC images and Apollo Zone and GLD100 DTMs are tied to the Lunar Orbiter Laser Altimeter (LOLA) reference frame [15]. The PC images will therefore be tied to this reference frame as well. The position and attitude parameters of the PC images will be refined via the ISIS least-squares bundle adjustment module *jigsaw* [16]. Finally, we will generate a geodetically controlled, orthorectified DIM of the useable Apollo 15 PC images (excluding dark and overexposed images). The PC images will be projected onto either the Apollo Zone or GLD100 DTMs.

Currently, our work is focused on refining the existing ISIS Apollo PC model and validating *a priori* support data for the Apollo 15 PC image dataset. Long term plans are to control the entire Apollo PC image dataset (including images from Apollo 16 and 17) which we hope to accomplish under a future proposal.

Products: In addition to the Apollo 15 PC DIM, products will include updated NAIF (Navigation and Ancillary Information Facility [17]) format image position and pointing kernels (*a priori* and updated from control network solutions), a database of MC and PC tie-points and their adjusted 3D coordinates, and any improvements to the publicly available ISIS software.

Acknowledgements: This work is funded by the NASA Lunar Advanced Science and Exploration Research program under contract #NNH14AY48I.

References: [1] Livingston, R.G., et al. (1980) *Aerial Cameras*, In *Manual of Photogrammetry, 4th Ed.*, ASP, 187-278. [2] Robinson, M.S., et al. (2008) *LPS XXXIX*, Abstract #1515. [3] Broxton, M.J., et al. (2009) *Proceedings ISVC09*. [4] Kim, T., et al. (2010) *IEEE Electron Letters* 46(9), 631-633. [5] Nefian, A.V., et al. (2010) *Proc. Conf. Intelligent Data Understanding*. [6] Nefian, A.V., et al. (2012) *LPS XLIII*, Abstract #2184. [7] Paris, K.N., et al. (2012) *LPS XLIII*, Abstract #2273. [8] Nefian, A.V., et al. (2013) *LPS XLIV*, Abstract #1649. [9] Rosiek, M.R., et al. (2010) *LPS XLI*, Abstract #2506. [10] Edmundson, K.L., et al. (2014) *LPS XLV*, Abstract #1915. [11] McCash, D.K. (1973) *Photogramm. Eng.*, 39(1), 65-72. [12] Light, D.L. (1972) *Photogramm. Eng.*, 38(6), 339-346. [13] Keszthelyi, L., et al. (2014) LPS XLV, Abstract #1686. [14] Scholten, F., et al. (2012) *J. Geophys. Res-Planet*, 117(E3). [15] Mazarico, E., et al. (2010) *JGeod*, 84(6), 343-354. [16] Edmundson, K.L., et al. (2012) *ISPRS Annals, I-4*, 203-208. [17] Acton, C.H., et al. (1996) *Planet. Space Sci.*, 44(1), 65-70.