ANALYSIS OF LUNAR ORBITER IMAGES RECOVERED FROM ANALOG TAPE.

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Introduction: The Lunar Orbiter Image Recovery Project (LOIRP) was founded in 2008 with funding from NASA ESMD to recover Lunar Orbiter images from the original 2" analog magnetic tapes that had been held in protective storage by the National Archives and NASA for 40 years.

Of the three central questions that had to be answered for project success, (can the tape drives be brought back to life, are the tapes any good, what is the quality of the data the best available), the final question, whether or not the analog image data on the tapes was superior in quality to the existing film was the ultimate criterion for success.

The results of an extensive search of the literature as well as the results of our digitization efforts indicate that while the resolution of the images are largely unaffected, the dynamic range has been markedly improved over the existing film, which provides in most cases, a dramatic improvement in overall image quality. Additionally, the capture of the entire analog signal allows for a more accurate alignment, processing, and reproduction of the images.

Original Reconstruction of LO Images: All Lunar Orbiter (LO) images, whether resident on the 2" magnetic tapes, or on the original 35mm Ground Reconstruction Equipment (GRE), are derived from images recorded on 70mm SO 243 film processed on board the spacecraft[1]. This 70mm film was then scanned with a 5 micron light beam which intensity modulated a photomultiplier, which then converted the intensity into electrical signals that were combined with digital telemetry data and transmitted to the Earth.

These signals were received and recorded on 2" magnetic tape in predetection format (before demodulation), and in parallel, the analog image information was demodulated and displayed on an RCA C24031 long persistence phosphor kinescope[2]. These images were then photographed by a 35mm (SO-349 film) GRE camera. The processed 35mm film with the raw LO framelets were assembled into a medium resolution frame (28 framelets), or into a high resolution frame of three subframes (96 framelets) 35mm film strips that were then rephotographed with identical 35mm film, which created the negative which was then printed into a photographic positive for initial analysis. The 2" magnetic tapes retained the original scanned data from the spacecraft, without any GRE film process steps.

Dynamic Range Reduction in the GRE: The dynamic range of the GRE reconstructed 35mm film and prints never matched the dynamic range of the 70mm spacecraft film. The clipping of the whiter whites and darker darks (corresponding with grey step chart numbers 1-2, and 8-9) was never adequately explained in any of the LO documentation. Our evaluation is that the dynamic range reduction came from the use of the RCA C24031 kinescope phosphor. This dynamic range clipping is revealed in table 1[3].

Gray Step No.	SO-243 R/O Density Range	Reassembled Record Density Range
1	0.21 - 0.29	Clipped by GRE
2	0.26 - 0.34	1.89 - 2.11 (clipped if R/O density below 0.30)
3	0.34 - 0.42	1.64 - 1.82
4	0.45 - 0.57	1.33 - 1.49
5	0.61 - 0.73	0.99 - 1.13
6	0.82 - 0.94	0.66 - 0.80
7	1.05 - 1.21	0.50 - 0.60
8	1.32 - 1.48	0.42 - 0.50 (may be clipped)
9	1.40 - 1.56	Clipped by GRE

Figure 1: LO GRE Film Dynamic Range Clipping.

We have observed similar dynamic range clipping from Nimbus AVCS images[4].

The Gray Step numbers on the left most column are from the pre-exposed Gray Step chart on each LO framelet. This provided analysts with an ongoing means to optimize the GRE film within the technological limitations of the era. The range and center values of the clipping was not consistent from frame to frame as adjustments were made to the GRE.

Documents indicate that the FR-900 recorded magnetic tapes were duplicated, and sent to NASA centers such as JSC for digitization and display of potential Apollo landing sites for safety certification and selection decisions.

LOIRP Image Assessment: After the FR-900 tape drives were returned to operational status and the digitization and image reconstruction system optimized, detailed image traces were taken and compared to the original modulation transfer function (MTF) of the 70mm film. The results are shown in figure 1.

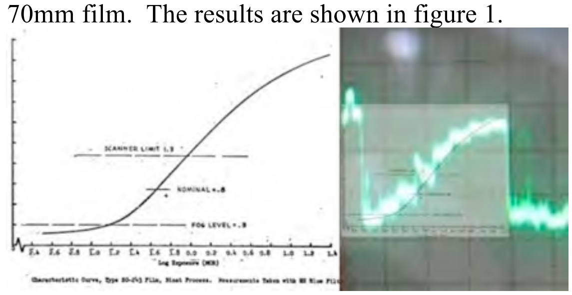

Figure 1: SO243 Modulation Transfer Function Vs Recorded Step Chart Trace from FR-900 Tape Replay

Improved Dynamic Range. For the particular framelet from LOII-070-H3, the match between the SO243 70mm Film and the electronic replay of the step chart is almost exact. This indicates that, at the detail level, the full MTF and step chart dynamic range is preserved. This is shown in large scale in Figure 2 and 3 following:

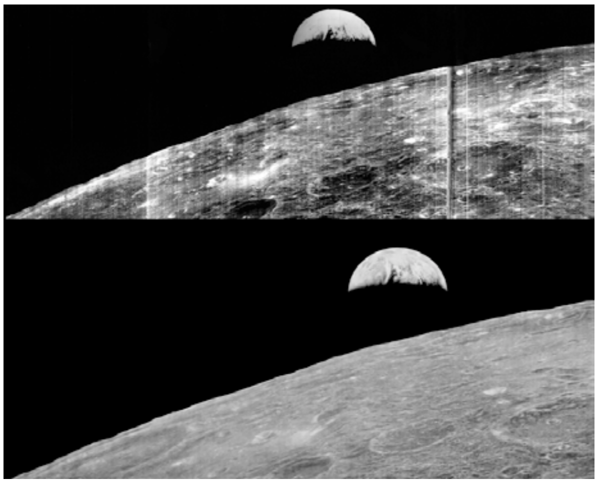

Figure 2: Original GRE Film (Above), and LOIRP Reproduction (Below)

Figure 3: Reproduction of the Detail of the Central Uplift of Copernicus, GRE (Above), LOIRP Reproduction (Below)

A detailed examination of the GRE film and LOIRP reproductions indicate that the LOIRP magnetic tape reproductions make the most difference in high contrast scenes as one might expect. However, this is also the case for low contrast scenes with small details with high contrast such as boulder shadows and small craters originally photographed at low solar angles.

Improved Reconstruction. Author Byrne has been involved in an effort to analyze the best scans of the GRE 35mm film, scanned into electronic form by the USGS. Samples of our LOIRP images were provided for comparison purposes[5]. Due to the retention in the magnetic tape recorded images of the full image trace, including synchronization pulses, back porch level, and full range output signal, an improved reconstruction of the individual framelets is possible, improving the line by line registration, and total x and y linearity. Also, any artifacts introduced by the 35mm film and GRE equipment are eliminated. The fully linear transfer function between transmission of the spacecraft negative and the LOIRP digitized image is confirmed by successful removal of the spacecraft CRT signature (variation of luminosity with distance across each framelet), independently of scene brightness. This provides for a more accurate reconstruction of the entire LO medium and high resolution frames to allow for a more effective removal of the well known line striping artifacts of the LO images.

Testing of the LOIRP magnetic tape derived images reveal that the system is not noise limited. This was accomplished by recording the same set of framelets multiple times and running comparisons at the individual word level. The FR-900 tape machine has been restored to better than original condition due to some design updates and replacement of noisy germanium transitors with silicon equivalents. The analog signals were digitized at a 10x rate in the frequency domain, as well as at a 65,535 to one dynamic range, far in excess of the 1000 to 1 (10 bit) dynamic range of the original analog signal.

Conclusions: After assessing hundreds of tapes, and after suggestions for improvement from author Byrne for our image reproduction process, we have developed an efficient means whereby to mass record the rest of the LO magnetic tapes. Further funding is being sought for this effort. The improvement in dynamic range and image reproduction fully justifies the effort and the resulting images are fully comparable with the LROC NAC image set coming from LRO.

Our long range plan is that the LOIRP raw processed data would become the base layer for a future fully interactive Google Moon type scientific visualization system for n layers of lunar remote sensing information.

References: [1] The Boeing Company (1967) *NASA CR-847,* 1-–6. [2] Eastman Kodak Company. (1966) *Photographic Subsystem Reference Handbook, Lunar Orbiter Program., 8.12* [3] Ibid, 7.48 [4] ARACON Geophysics Company, (1966) *Nimbus II User Guide*., 17 [5] C. J. Byrne, A. C. Crotts (2011) *Restoration of Very High Resolution Lunar Orbiter Images* , 42nd LPSC.