R. Welch
University of Georgia
Athens, GA 30602

Skylab S-190B ETC Photo Quality

The Earth Terrain Camera had a ground resolution of 15 to 30 meters, and derived photomap products should be limited to scales of 1:50,000 to 1:100,000 or smaller.

Introduction

In a previous report the quality of photographs obtained on the Skylab-2 (SL-2) mission was evaluated, with emphasis placed on the determination of system modulation transfer functions (MTF's) and resolution values for second-generation S-190A Multispectral Photographic Facility (MPF) images (Welch, 1974). These evaluations have now been extended to include photographs recorded on the SL-3 and SL-4 missions with the S190B Earth Terrain Camera (ETC) manufactured by Actron (NASA, 1974b). As with the earlier work, the objectives of these image analyses have been to (a) assess camera system performance and (b) quantitatively evaluate the cartographic potential of the high-resolution photographs obtained on the Skylab missions. The quality and cartographic potential of the ETC photographs are of considerable interest to photogrammetrists, since they were recorded on high-resolution films normally reserved for reconnaissance missions.

Abstract: *Analyses of S190B photographs recorded on high-resolution reconnaissance films during the Skylab missions confirm the excellent performance of the ETC system. Low-contrast resolution values of 30 to 70 lpr/mm, corresponding to ground resolutions of 30 to 15 m, are estimated for second-generation photographs distributed to investigators, and maximum scales of 1:50,000 to 1:100,000 are recommended for photomap products prepared from ETC photographs.*

ETC System Characteristics

The S-190B ETC was developed from the basic designs of the KA-74 reconnaissance camera and the Lunar Topographic Camera to meet the objective of providing earth scientists and cartographers with relatively large-scale, high-resolution satellite photographs. Several unique features are incorporated in the ETC design, including an *f*/4 color-corrected lens of 460 mm focal length and a forward image motion compensation system which pivots the camera at the appropriate angular rate. These characteristics permitted Skylab photographs to be recorded on Eastman Kodak reconnaissance films such as types 3414, SO-242, and SO-131 at a scale of approximately 1:946,000 (Table 1). Of these films, 3414 and SO-242 are high-resolution panchromatic and color films, whereas SO-131 is a relatively new color-infrared film with greatly improved image structure properties as compared to the commercially available type 3443. Significantly, the duplicating films 2430 and 2447 are inferior to the original emulsions.

Photogrammetric Engineering and Remote Sensing,
Vol. 52, No. 8, August 1976, pp. 1057-1060.

TABLE 1. IMAGE STRUCTURE PROPERTIES OF EASTMAN KODAK FILMS (1973-75)

EK Film	Resolving Power (lpr/mm) TOC 1000:1	TOC 1.6:1	Granularity	Comments
3414	630	250	8	Panchromatic
SO-242	200	100	11	Color
SO-131	160	50	9	Color IR
3443	63	32	17	Color IR
2430	320	125	7	Duplicating film for 3414
2447	100	50	9	Duplicating film for SO-242 and SO-131

The resolving power capabilities of the ETC system under laboratory conditions are summarized in Table 2 for first-generation (original) photographs recorded on 3414, SO-242, and 3443 films (Gimlett, 1975a). Although these resolution values demonstrate the inherent capabilities of the camera system, they are not a realistic measure of the quality of the second-generation photographic products distributed to investigators.

SYSTEM PERFORMANCE AND IMAGE QALITY

System performance and second-generation photo quality were assessed using the MTF analysis techniques described in the following paragraphs. Referring to Figure 1, the appropriate component MTF's were cascaded to obtain the predicted system MTF's given in Figure 2. These predicted MTF's represent theoretical performance levels that might be achieved in a laboratory environment, and are indicative of optimum quality second-generation photographs. Uncompensated image motion, vacuum failure, incomplete contact between the original and duplicating materials during the reproduction process, or any of a number of other factors can degrade photographs recorded and duplicated under operational conditions.

MTF's for selected second-generation ETC photographs provided by NASA were next determined from microdensitometer edge traces performed across field boundaries and aircraft runway patterns with a Joyce Loebl Mark III CS microdensitometer ($2 \times 125\ \mu m$ effective slit). These edge traces were then converted to system MTF's using procedures previously described by Welch (1971). Sensitometric data for both the original and duplicating films were obtained from NASA (1973 a,b,; 1974a).

The mean MTF's derived from these analyses are shown in Figure 3, and a comparison of these measured operational MTF's with the predicted curves in Figure 2 indicates correspondence (in response) to within approximately 10 per cent for 3414/2430; 25 per cent for SO-242/2447; and 2 per cent for SO-131/2447. In each of these comparisons the measured MTF's are reduced from the predicted curves by the given percentages, a pattern also noted in the earlier analyses of the S-190A MPF photographs. With the exception of the SO-242/2447 photographs, the correspondence between measured and predicted MTF's is excellent and confirms that ETC operational system performance was about as expected.

The quality of the second-generation photographs specified in terms of low-

TABLE 2. MEASURED AWAR RESOLUTION (LPR/MM) FOR THE ETC (GIMLETT, 1975a)

EK Film	Filter	1000:1 TOC	2:1 TOC
3414	Wratten 12	206	143
SO-242	None	137	127
3443	Wratten 12	56	33

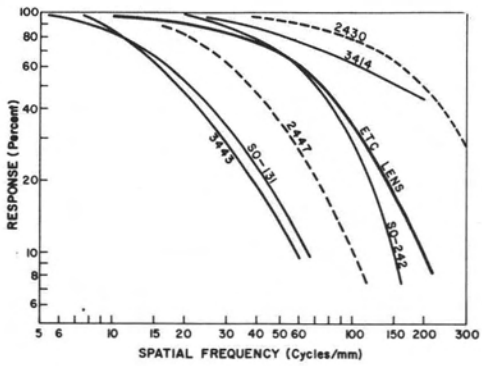

FIG. 1. MTF's for the ETC lens (Gimlett, 1975b) and the Eastman Kodak films employed to record and duplicate ETC photographs.

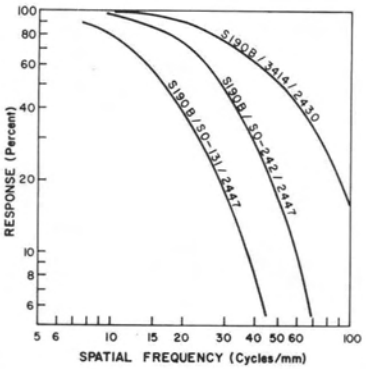

FIG. 2. Predicted MTF's for second-generation ETC photographs obtained by cascading the lens MTF with the appropriate MTF's for the original and duplicating films.

contrast resolution values is of particular interest to photogrammetrists. In the absence of imaged targets, resolution estimates for a target contrast ratio of 1.6:1 at the camera lens were obtained by translating the measured MTF's to a response of 23 per cent (which is equivalent to a contrast ratio of 1.6:1) on the log-log paper and accepting the indicated maximum spatial frequency in the threshold modulation range of 5 to 10 per cent. A small upward adjustment was made for the color photographs because color differences as well as modulations contribute to the recorded resolution. The general procedure is illustrated in Figure 4, and the estimated resolution values for the ETC photographs are given in Table 3. Based on the estimated resolution values, ground resolutions of 15 to 30 m are representative for ETC photographs, as compared to 60 to 145 m for MPF (S-190A) images.

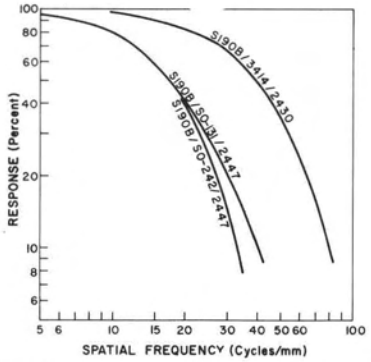

FIG. 3. Average measured MTF's for properly exposed second-generation ETC photographs.

CARTOGRAPHIC POTENTIAL

Suitable scales for photomaps produced from the Skylab ETC photographs were objectively estimated, again with the aid of the MTF's (Welch, 1972). In Figure 5 the measured image MTF's and the MTF of the human eye are plotted. Based on this figure, the measured MTF's for the panchromatic and color/color infrared photographs must be translated to the left by factors of approximately 20× and 10 × respectively in order to correspond to the MTF for the eye. Since these translation factors may be regarded as enlargement ratios at which the image will begin to appear blurred, maximum scales for "sharp" photomaps are limited to *approximately* 1:50,000 scale for products prepared from the black-and-white photographs and 1:100,000 scale if the color/color infrared photographs are employed. These objectively determined enlargement ratios generally have been confirmed by U.S. Geological Survey experiments involving the production of photomaps from ETC photographs.

CONCLUSION

Evaluations of second-generation photographs indicate that the operational performance of the Skylab S-190B ETC system was about as predicted, and further confirm the validity of employing MTF analysis techniques to assess operational camera system performance. Estimated low contrast resolution values of 30 to 70 lpr/mm for the ETC photographs convert to ground resolutions of 15 to 30 m; as compared to 60 to 145 m for the MPF photographs and 200 to 250 m for LANDSAT images. Objective assessments indicate that photomaps should be limited to scales smaller than 1:50,000 and 1:100,000 for products derived from the pan-

TABLE 3. RESOLUTION ESTIMATES FOR SECOND-GENERATION ETC PHOTOGRAPHS

Film/Duplicating Film	Resolution Estimates (lpr/mm) for 1.6:1 Target Contrast	Ground Resolution, m
3414/2430	60-70	15
SO-242/2447	35	25
SO-131/2447	30	30

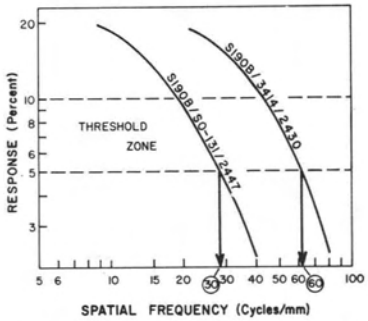

FIG. 4. Resolution prediction for low-contrast (1.6:1) targets.

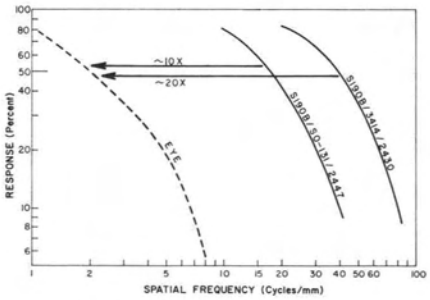

FIG. 5. MTF analyses indicate that ETC high-resolution panchromatic and color/color infrared photographs may be enalrged by factors of approximately 20× and 10× before they will appear blurred.

chromatic and color/color infrared photographs respectively.

ACKNOWLEDGMENTS

This work was undertaken in conjunction with the U.S. Geological Survey. However, the views and conclusions expressed are the author's and do not necessarily represent those of U.S. Government agencies. The assistance of Dr. R.B. McEwen, U.S. Geological Survey, is gratefully acknowledged.

REFERENCES

Eastman Kodak, 1973-75, Data Sheets for 3414, SO-242, SO-131, 2430 and 2447.

Gimlett, J.I., 1975a, Lens for the Skylab S-190B Camera, *MDC U0055*, Actron, Monrovia, California.

———, J.I., 1975b, Personal correspondence, 24 September.

NASA, 1973a, *SL/2 Sensitometric Data Package*, July.

———, 1973b, *SL/3 Sensitometric Data Package*, November.

———, 1974a, *SL/4 Sensitometric Data Package*, June.

———, 1974b, Skylab Earth Resources Data Catalog, *JSC 09016*, U.S. Government Printing Office, Washington, D.C. 20402.

Welch, R., 1971, Modulation Transfer Functions, *Photogrammetric Engineering*, 37(3): 247-259.

———, R., 1972, Photomap Image Quality, *The Cartographic Journal*, 9(2): 87-92.

———, R., 1974, Skylab-2 Photo Evaluation, *Photogrammetric Engineering*, 40(10): 1221-1224.

Notice to Contributors

1. Manuscripts should be typed, double-spaced on $8\frac{1}{2} \times 11$ or $8 \times 10\frac{1}{2}$ white bond, on *one* side only. References, footnotes, captions—everything should be double-spaced. Margins should be $1\frac{1}{2}$ inches.
2. Ordinarily *two* copies of the manuscript and two sets of illustrations should be submitted where the second set of illustrations need not be prime quality; EXCEPT that *five* copies of papers on Remote Sensing and Photointerpretation are needed, all with prime quality illustrations to facilitate the review process.
3. Each article should include an abstract, which is a *digest* of the article. An abstract should be 100 to 150 words in length.
4. Tables should be designed to fit into a width no more than five inches.
5. Illustrations should not be more than twice the final print size: *glossy* prints of photos should be submitted. Lettering should be neat, and designed for the reduction anticipated. Please include a separate list of captions.
6. Formulas should be expressed as simply as possible, keeping in mind the difficulties and limitations encountered in setting type.