R. WELCH
University of Georgia
Athens, Georgia 30602

Skylab-2 Photo Evaluation*

Investigations of image quality demonstrate the applicability of MTF analysis techniques for predicting and evaluating the performance of high-resolution camera systems employed in satellites.

ABSTRACT: *Modulation transfer function (MTF) analyses of second-generation Skylab-2 photographs indicate that the S190A and S190B photographic systems are performing about as predicted. However, the quality of these second-generation materials is somewhat reduced from that of the original photographs. Resolution estimates, for example, indicate that the values for the black-and-white and color-infrared second-generation photographs are approximately 10 to 20 percent below the predicted values for the original photos. With respect to the second-generation color photos, resolution values appear to be reduced by about 40 percent due primarily to the properties of the duplicating film.*

INTRODUCTION

IN ORDER TO evaluate the suitability of Skylab 2 images for Cartographic tasks, and to determine the degree to which the levels of performance predicted for the S190A Multispectral Photographic Facility (MFP) and the S190B Earth Terrain Camera (ETC) have been attained (Table 1),[1,2,3] photographs taken with these cameras have been subjected to analyses of image quality. Using quantitative methods, modulation transfer functions (MTF's) and resolution estimates have been derived which, upon comparison to predicted values, provide a basis for assessing both sensor performance and the cartographic products that can be reasonably prepared from the Skylab photographs.[4] In addition to these data, the Skylab photographs have also provided one of the best opportunities to date to test the reliability of MTF image evaluation techniques as applied to satellite photography. The results of these analyses are considered in this paper.

ANALYSIS OF SKYLAB IMAGES

Modulation transfer functions (MTFs) were determined for a representative sample of second-generation S190A and S190B Skylab-2 photographs of scenes in California, South Dakota, Montana and Brazil.[5] All of these photographs contained images of sharp, natural boundaries such as coastlines or field patterns for which microdensitometer edge traces were produced. MTFs were then calculated from the edge traces using a graphical-digital technique.[6] Sensitometric data for both the original and duplicating films were provided by NASA, and the different camera/film/duplicating film combinations are listed in Table 2.[7]

With reference to the S190A system, only minor variations in MTFs were noted between spectral bands for which the same original/duplicating film combination was employed (such as the 0.7 to 0.8 μm and 0.8 to 0.9 μm infrared images on 2424/2420 and the 0.5 to 0.6 μm and 0.6 to 0.7 μm visible spec-

TABLE 1. SKYLAB CAMERA CHARACTERISTICS

Camera Characteristics	*S190A MPF*	*S190B ETC*
Focal length	152 mm	460 mm
Spectral Bands	6	1
Film Size	70 mm	125 mm
Nominal Image Scale	1:2,900,000	1:950,000

*Presented at the Annual Convention of the American Society of Photogrammetry on March 11, 1974 in St. Louis, Missouri.

TABLE 2. SKYLAB-2 FILM/DUPLICATING FILM COMBINATIONS

System	*EK Film/ Duplicating Film*[1,2]	*Spectral Band*
S190A	2424/2420	Infrared (0.7-0.8μm, 0.8-0.9 μm
	2443/S0-360	Color Infrared (0.5-0.9 μm)
	S0-356/S0-360	Color (0.4-0.7 μm)
	S0-22/2430	Green Red (0.5-0.6 μm, 0.6-0.7 μm)
S190B	S0-242/S0-360	Color (0.4-0.7 μm)
	3414/2430	Green-red (0.5-0.7 μm)

1. S0-22 and S0-356 are the same emulsions as 3400 and S0-242, but coated on a 4 mil base.
2. S0-360 has been redesignated as Kodak Aerochrome Duplicating Film 2447.

trum images on S0-22/2430). Consequently, it was possible to produce *average* measured MTFs (Figure 1) which correspond to the combination indicated in Table 2. In addition to the average measured MTFs, predicted MTFs were computed for the S190A system by cascading the lens, original film, and duplicating film MTFs obtained from manufacturers' data.[2,8] These predicted curves, shown in Figure 2, provide slightly higher response values but on the average correspond to within 6 percent of the measured values. This is very good agreement (particularly where differences between manufacturers' and user conditions, and the variabilities of the photographic process are considered) and confirms that S190A system performance in terms of both MTFs and resolution is about as predicted.[2, 3, 9, 10]

Average measured MTFs were also determined for the S190B 3414/2430 and S0-242/S0-360 combinations. These MTFs are given in Figure 3. The S0-243/S0-360 MTFs closely approximate the S0-356/S0-360 curves for the S190A system, indicating comparable performance. By contrast, the greatly reduced MTF for the 3414/2430 combination reflects the degradation introduced by the reported vacuum system problems and is not representative of expected S190B system performance. Visual examinations of high-quality S190B/3414/2430 photographs obtained on Skylab-3 confirm that the S190B system was not functioning (or operated) correctly when the first Skylab-2 black-and-white photographs were obtained.

The Skylab photographs, with the exception of the high-resolution color originals (S0-242 and S0-356), have been reproduced on duplicating films with imaging characteristics superior to those of the films utilized in the camera systems. Consequently, only the color duplicates (second generation) reproduced on S0-360 film appear to have suffered a significant loss of resolution. Analytical techniques indicate that low contrast (1.6:1) resolution values of approximately 35 lpr/mm are appropriate for the S0-242/S0-360

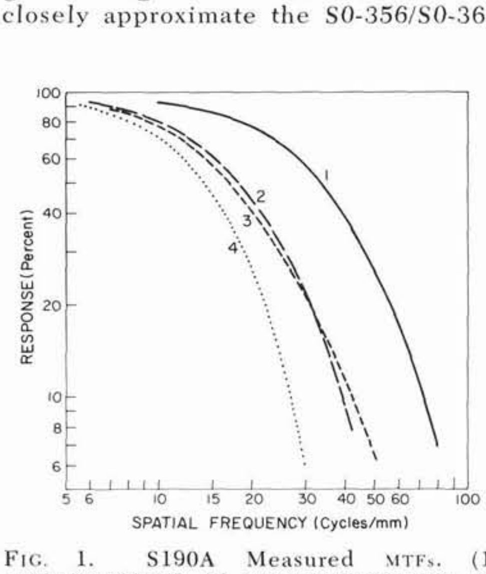

FIG. 1. S190A Measured MTFs. (1) S190A/S0-22/2430, (2) S190A/S0-356/S0-360, (3) S190A/2424/2420, (4) S190A/2443/S0-360.

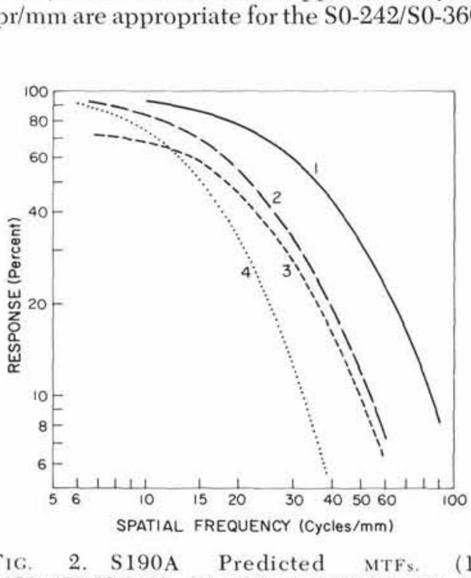

FIG. 2. S190A Predicted MTFs. (1) S190A/S0-22/2430, (2) S190A/S0-356/S0-360, (3) S190A/2424/2420, (4) S190A/2443/S0-360.

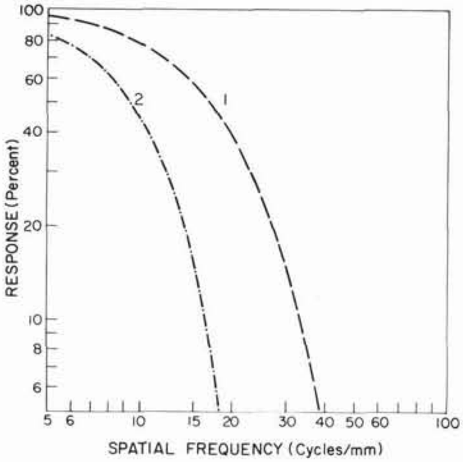

FIG. 3. S190B Measured MTFs. (1) S190B/S0-242/S0-360, (2) S190B/3414/2430. The abnormally low response for (2) is attributed to vacuum system problems.

and S0-356/S0-360 combinations, as compared to the predicted 60 to 70 lpr/mm for the original photos.

Resolution and ground resolution estimates derived from these analyses of the contact second-generation Skylab-2 photographs are summarized in Table 3. Other than the color reproductions and the S190B/3414/2430 images, these resolution estimates represent values approximately 10 to 20 percent below those predicted for the original photos.

Conclusion

Investigations of the image quality of second-generation Skylab photographs demonstrate the applicability of MTF analysis techniques for predicting and evaluating the performance of high-resolution camera systems employed in satellites. Based on these initial analyses the S190A and S190B systems are providing original photographs of near the expected quality. However, the resolution values of second-generation black-and-white and color-infrared materials appear to be reduced by approximately 10 to 20 percent from those predicted for the originals, and due primarily to the properties of the duplicating film the resolution of the color reproductions may be reduced by about 40 percent. It is hoped that these evaluations of Skylab systems performance and image quality will enable earth scientists and cartographers to determine the types and scales of products which can be realistically produced from the photographs.

Acknowledgements

The assistance and cooperation of Dr. R. B. McEwen, U. S. Geological Survey, is gratefully acknowledged. The views and conclusions are those of the author and do not necessarily represent those of U. S. Government agencies.

References

1. NASA, 1973 *EREP Investigators Information Book*, Lyndon B. Johnson Space Center, Houston, Texas.
2. Forkey, R. E. and Wombie, D. A., 1972, "Unique Lens Design for Multispectral Photographic Cameras," Presented Paper, International Society of Photogrammetry, XII Congress, Ottawa, Canada.
3. McLaurin, J. D., 1972, "The Skylab S190B Earth Terrain Camera," Presented Paper, International Society of Photogrammetry, XII Congress, Ottawa, Canada.
4. Welch, R., 1972, "Photomap Image Quality," *The Cartographic Journal*, Vol. 9, No. 2, pp. 87-92.

TABLE 3. RESOLUTION ESTIMATES FOR SECOND-GENERATION SKYLAB-2 PHOTOS.

EK Film/ Duplicating Film Combinations	*Resolution Estimates, lpr/mm at 1.6:1 Contrast (to nearest 5 lpr/mm)*	*Nominal Photo Scale*	*Ground Resolution, Meters (to nearest 5 m)*
S190A			
2424/2420	20	1:2,900,000	145
2443/S0-360	20		145
S0-22/2430	50		60
S0-356/S0-360	35		85
S190B			
S0-242/S0-360	35	1:950,000	25
3414/2430	10[1]		95[1]

1. Due to vacuum failure.

5. McEwen, R. B., 1973, Memorandum for the Record (EC-1-Skylab), U. S. Geological Survey, 14 November.
6. Welch, R., 1971, "Modulation Transfer Functions," *Photogrammetric Engineering*, 37(3):247-259.
7. NASA, 1973, SL/2 *Sensitometric Data Package*, July, 490 pages.
8. Eastman Kodak, 1972, "Kodak Aerial Films and Photographic Plates," *Publication No. M-61*.
9. Welch, R., 1971, "Earth Satellite Camera Systems: Resolution Estimates and Mapping Applications," *The Photogrammetric Record*, 7(38):237-246.
10. Colvocoresses, A. P., 1972, "Image Resolutions for ERTS, Skylab and Gemini/Apollo," *Photogrammetric Engineering*, 38(1):33-35.

BOOK REVIEW

Multispectral Photography for Earth Resources. By Sondra Wenderoth, Edward Yost, Rajender Kalia, and Robert Anderson. Published by Science Engineering Research Group C. W. Post Center, Long Island University, Greenvale, New York, 8¾ × 11½ inches, Table of Contents, 258 pages, plus a 4 page Glossary, and a 2 page reference, 82 black-and-white illustrations, and an additional 37 in full color, plus numerous charts and graphs. Hardback, 1972. (Price not stated).

DESTINED to be regarded a classic in the field of multispectral investigation. *Multispectral Photography for Earth Resources* has combined under one cover all of the techniques required to plan and execute the collecting of meaningful multispectral data.

The book includes the following chapters. *1*. Introduction. 2. Capabilities and Limitations of Color and Color Infrared Films. *3*. Image Color Measurements. *4*. Methods of Relating Ground Phenomena to Film Density and Color Measurement. *5*. Sensitometry. *6*. Sensitometric Data Handling. 7. Negative Exposure and Processing of Multispectral Black-and-White Photography. *8*. Positive Duplication of Black-and-White Multispectral Negatives. *9*. Additive Color Presentations and Their Measurement. *10*. Considerations in the Selection of Multispectral Cameras and Components. *11*. Photographic Materials for Color and Black-and-White Photography. *12*. Applications Including Isoluminous Techniques. *13*. Mission Planning. Glossary. Reference.

The purpose of the manual as set forth by the authors is two-fold: "1. A guide to producing accurate multispectral photography, and 2. To eliminate unnecessary research". They have fulfilled both objectives extremely well.

The black-and-white half-tone reproductions included leave something to be desired; the color illustrations are beautiful. As with any work of this magnitude, some errors are bound to creep in. On page 2-6 the statement is made, "deviations between one half and one stop for optimum exposure are sufficient to cause noticeable color quality losses". Yet on page 2-9 it is pointed out that the manufacturer is unable to produce a constant product with ½ stop of the published value. Such statements demand that to obtain good multispectral photography one must use as much care as for obtaining good reversal normal-color or false-color aerial photographs, and that the work must be performed by competent people, which is a requirement in any situation.

Page 5-6, Figure 53: this reviewer would never consent to a laboratory arrangement such as the one shown where film and chemistry is stored in the same room. Page 10-8: "An altitude will be reached at which the images are as small as the lens is capable of producing them. With increasing altitude, then, the image size will remain the same." This, of course, is not a fact.

As one can see by the foregone criticism, one has to dig deep to find fault with this book. Everyone involved in photogrammetry or photo interpretation from laboratory technicians to program planning personnel needs a copy to read and to retain as a reference on multispectral photography.

—*John T. Smith*