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Ohio State University

MODULATION TRANSFER FUNCTION AND THE ROLE OF FOCAL LENGTH OF A PHOTOGRAMMETRIC CAMERA IN IMAGE GENERATION

A Thesis

by

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MODULATION TRANSFER FUNCTION AND THE ROLE OF FOCAL LENGTH OF A PHOTOGRAMMETRIC CAMERA IN IMAGE GENERATION

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Presented in Partial Fulfillment of the Requirements for the Degree Master of Science

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Approved:

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SUMMARY

In order to determine where emphasis should be placed in future photogrammetric camera designs, all contributing factors in image generation must be qualitatively analyzed to obtain a precedence. This research investigates the role of focal length of a photogrammetric camera in image generation through the criterion of Modulation Transfer Function.

A comparative study is made of the MTF obtained from two lens cones under various aperture settings, detail size and light conditions. This includes an analysis by graphical methods.

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LIST OF ILLUSTRATIONS

1. INTRODUCTION

Which camera should be used?

What is the best aperture setting?

What should the exposure time be?

What will be the effect of this filter?

These are questions being continually asked by people in connection with the operation of photogrammetric cameras. Unfortunately, there is no single answer available, since each question is dependent on many variables. However, there is one basic question to which they are all related; namely, how is the image generation affected? In order to answer this question, much time has been spent in the development of sophisticated methods to evaluate the photogrammetric image generated. As a result, many specific quality criteria have been evolved. These criteria may be of importance in themselves or in relationship to each other.

Before evaluation of the image can begin, all factors affecting the image quality must be known. Some of the more important factors include: the lens, film, shutter efficiency, image motion, atmospheric and environmental conditions. Therefore, it is readily seen that an extremely complex problem is involved. Appreciation for this complexity is gained only with the realization that each of the above factors is composed of several contributing elements which, in turn, have varied effects on image quality. The lens, for example, has many elements, the most important of which are: focal length, aperture, aberrations, radial and tangential distortion, opacity and vignetting. In the research to date, practically all of the quality criteria developed for image

evaluation have been used for camera systems or the main factors which affect image quality. Very little research has been delegated to using the quality criteria to determine the individual effects, in image generation, of the above mentioned contributing elements of the quality factors.

1.1 Quality Criteria

As previously mentioned, investigation of image evaluation techniques brought about development of many quality criteria; some of the more important of which are

a) Resolving Power or Resolution Limit, both linear and angular,

b) Acutance: The mean squared density gradient divided by density difference (also called Edge Gradient),

c) Modulation Transfer Function (Relative and True): the ratio of contrast in the image to the contrast in the original subject,

d) Granularity and Graininess,

e) Spread Function.

Since none of the above criteria are accepted individually as the performance criteria for photogrammetric cameras, a detailed analysis must include several of these criterion. At present, selection of criteria is left to the researcher with no specific guide lines.

1.2 Objective and Scope

The objective of this research is to investigate the role of focal length of a photogrammetric camera in image generation, as determined by the quality criterion of Relative Modulation Transfer

Function. Merits of using this quality criterion are:

a) The Transfer Function is a physical property of the information link between the scene and the observer.

b) Transfer Function is adaptable to data obtained from a Micro Image Scanner or Microdensitometer.

c) Only relative studies need to be made in order to obtain perspective for equivalent systems.

d) Data acquisition is comparitively simpler.

e) It is of particular importance in mapping and photographic interpretation.

In order to determine the effect of focal length, all other contributing elements are made constants, with the exception of relative aperture. Aperture is left as a variable because of its close relationship with focal length. The development of test procedures and evaluation of the results are based on the viewpoints of aerial triangulation and photo interpretation.

2. EXPERIMENTATION AND ANALYSIS

2.1 Concepts of the Experiment

Basic concepts involved in the design of this investigation are:

a) A uniform target must be projected, under controlled conditions, to lens cones of varied focal length so as to form comparable images.

b) Intensity measurements are to be made at prescribed intervals, on each image generated, by a scanning system.

c) The scanning system output is to be recorded for evaluation.

2.2 The Target

Targets used in camera research are closely associated with the quality criterion sought in the investigation. As a result, four types have become predominate. These are the Bar target (historically used in determination of Resolving Power), Square-Wave, sinusoidal and aerial photographs. Recent prominence of the sinusoidal target is due to its ability to produce results which are adaptable to several quality criteria, especially those involving Fourier techniques. These targets are made by use of the sunburst or pie pattern (known in Europe as the "Siemens star").

A variation of the pie pattern was developed for this experiment. As seen in Figure 1, the target is a wedge consisting of four tonal variations and seven scanning positions which are indicated by double hatchures on the borders. Two different methods of construction were used to obtain the shades. The first was to use "CRAFTONE" tape, made by Craftone Mgf. Co. of Cleveland, Ohio. In this method, the different shades are obtained by use of different dot densities. When projected, this target produced density variations within the tonal zones and was, therefore, deemed unacceptable. The second method entailed the use of "ZIP-A-TONE" tape, manufactured by Para-Tone, Inc. of LaGrange, Illinois. This method provides a uniform shade through mixing of a fixed percentage of black and white. For the target constructed, the light gray zone is a 20% scale gray and the dark gray an 80% scale gray. This target when projected gave a completely acceptable uniform density throughout each zone.

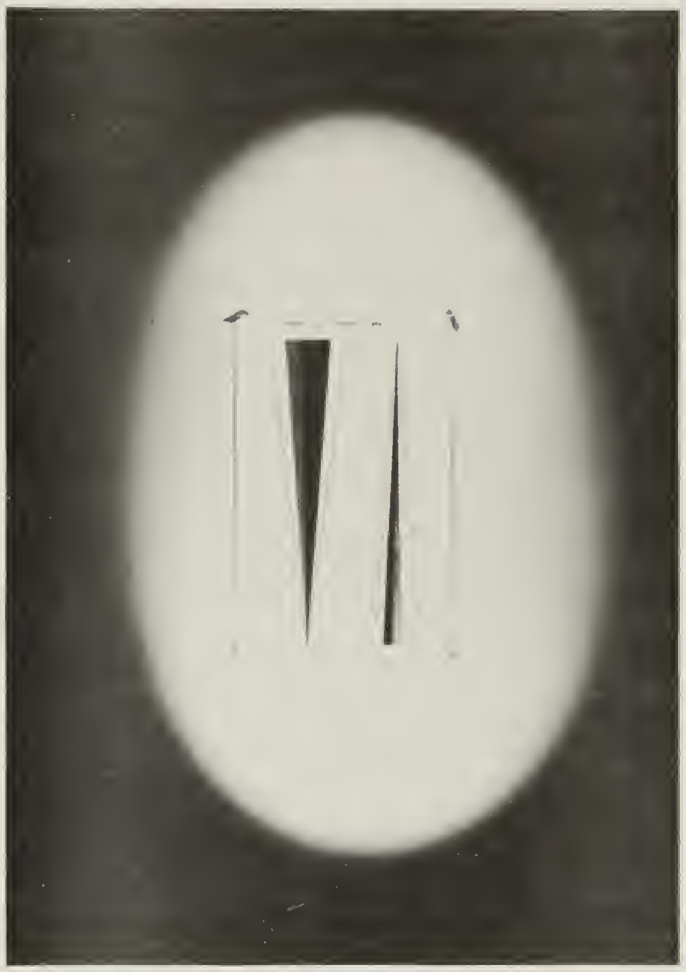


Figure 1. Target

The deciding factors involving the use of this target type were:

a) A sinusoidal trace is produced.

b) Image scan could be either circular or straight lines parallel to each other.

c) Similarity, in the densitometer traces along parallel sections, would be easily discernible.

d) Construction is easy and yet maintains considerable precision.

e) It provides observation data at any location that may be desired because of scale variations due to changing focal lengths.

f) Gray tones are represented, as opposed to only black and white.

The target was then photographed on DUPONT CRONAR ORTHO-S film by The Ohio State University, Department of Photography. The target was reduced 25 times during the photography, so that it would be usable with either a Micro Image Scanner or a Microdensitometer.

2.3 Lenses

For purposes of standardization, it was decided to use lenses made by one manufacturer only; in this case, Wild Heerbrugg, Ltd. of Heerbrugg, Switzerland. In this way, it was felt that consistency in the manufacturer's design and quality could be accepted as a constant factor. That is to say, the glass formula, grinding, polishing, and make-up of the lenses would be completed in basically the same manner. Unfortunately, only two lens cones were available for this experiment. The Ohio State University made available for the experiment both of the Wild RC-5a lens cones listed on the following page:

a) "AVIOTAR" f:4 Narrow angle lens
Focal length 21 cm
Format size 18 x 18 cm

b) "AVIOGON" f:5.6 Wide angle lens
Focal length 11.5 cm
Format size 18 x 18 cm

2.4 Optical Equipment

Experimentation was conducted at the U.S. Army Engineer, Geodesy, Intelligence and Mapping Research and Development Agency, Fort Belvoir, Virginia. The equipment listed below was made available by USAE/GIMRADA for the duration of the test.

a) Two Gaertner Optical Benches, 120 and 160 cm in length.

b) R/L Collimating fixture, designed by Arma Division of American Bosch Arma Corporation and manufactured by Mechanical Division of General Mills (see Figure 2). This fixture contained diffusion lenses, target receiver and the collimating lenses.

c) Micro Image Scanner, Serial No. 338, manufactured by Ansco-Division of General Aniline Corporation, Binghamton, New York (see Figure 3).

d) Ansco Model 4 Automatic Recording Microdensitometer, Serial No. 338, manufactured by Photographic Reporduction Division General Aniline and Film Corp., Binghamton, New York (see Figure 4).

e) Naren "Pro Spot" MOD N-103 rated at 1000 watts.

f) Green and Red pass filters, 571 and 649 millimicrons respectively.

Figure 5 gives a schematic diagram of the test set-up and the general flow of information.

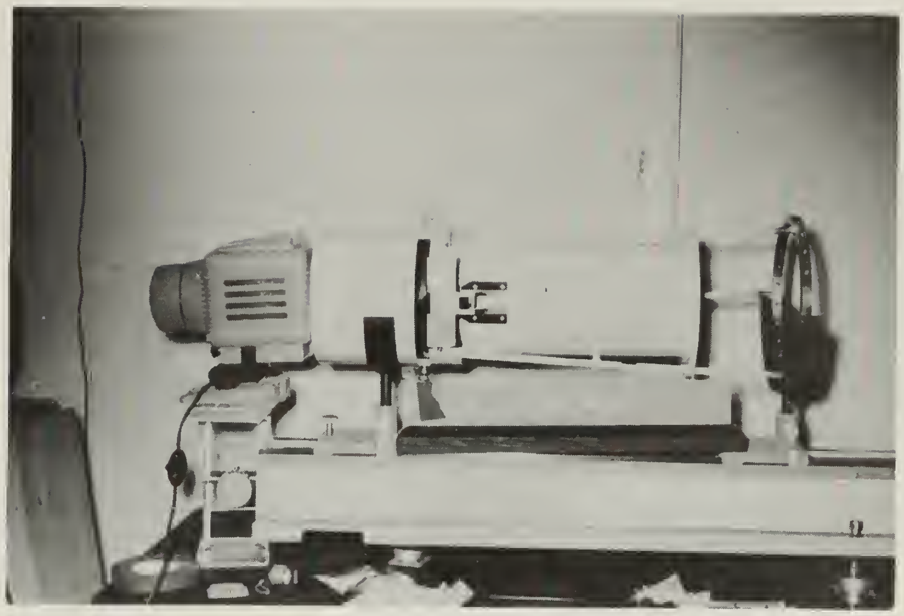


Figure 2. Arrangement of Light Source and Collimating Fixture on the Optical Bench

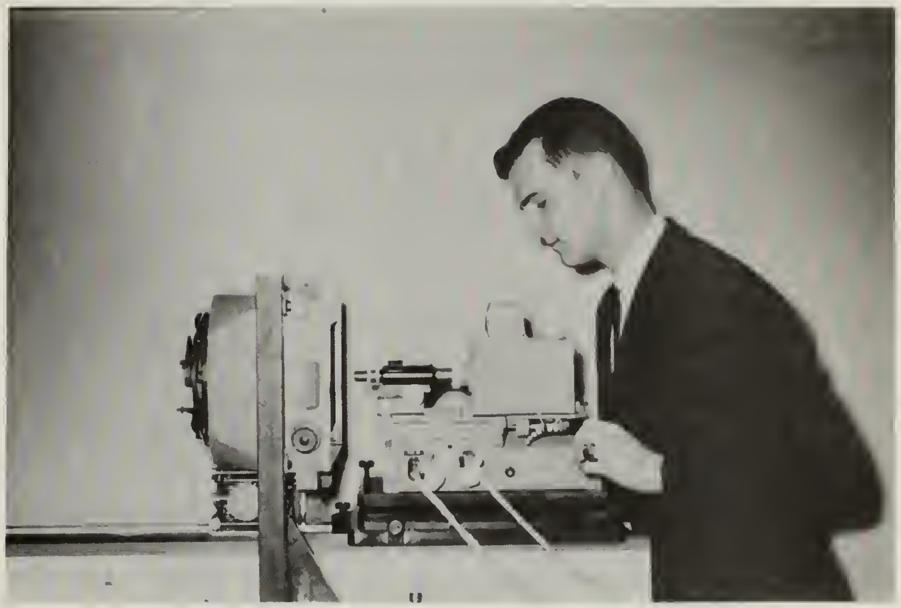


Figure 3. Relationship of Lens Cone and
Micro Image Scanner

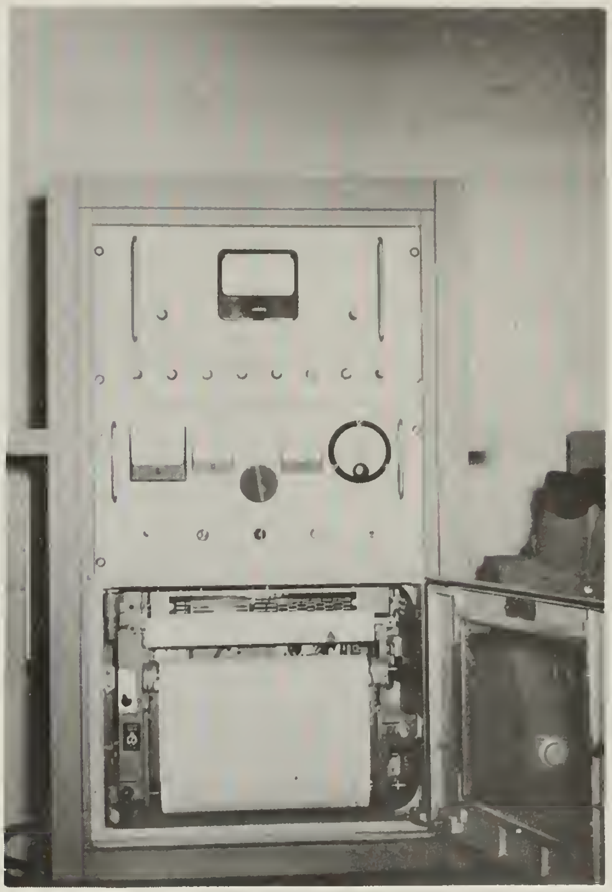


Figure 4. Ansco Model 4 Microdensitometer Recorder

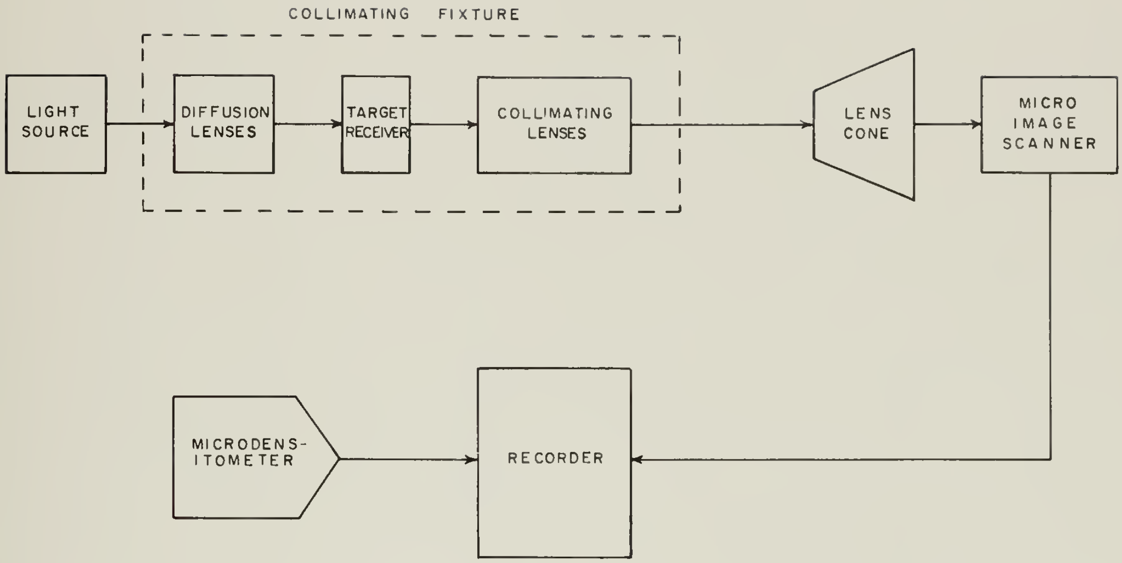


Figure 5. Schematic Diagram of Equipment and Information Flow

2.5 Test Procedure

The original procedure to be followed in obtaining the image traces was to use each lens cone with three types of generating light sources; white, white with a 571 mμ green pass-filter, and white with a 649 mμ red pass-filter. With each light source, positions one through seven would be scanned in parallel straight lines while varying the common relative apertures of the lens cones. Relative apertures that are common to both lens cones are 5.6, 8, 11, and 16. This procedure was to be done for an axial and off-axis position. Due to the extreme barrel distortion, prevalent in the collimator, this procedure was modified to use only the axial image. One other alteration to the test procedure was required by the red light source. When the white light with the 649 mμ red pass-filter was used, it was found that the reduced light reaching the Micro Image Scanner would not produce an acceptable Recorder Trace. Therefore, only white and green light sources were used in the experiment. Through this procedure 112 image traces were obtained. The advantage of using the Micro Image Scanner for these traces is that its output is a smooth curve which greatly reduces computation time.

The Microdensitometer was used to obtain traces of the object so that the initial contrast conditions could be found. The procedure followed was similar to that described above. Unfortunately, only traces for the first three positions with a white light source were obtained, due to technical difficulties.

The above mentioned traces were made under the following conditions:

	Micro Image Scanner	Microdensitometer
Scan Rate	1.25 mm/min	1 mm/min
Magnification	50 x	250 x
Effective Spot Diameter	30 μ	4.5 μ
Chart Speed	2, 4 and 8 inches/min (Varied with position as a matter of convenience)	8 inches/min

2.6 Constant Factors

Traces obtained under the afore mentioned investigation contain several unavoidable factors. These are

a) Non-linearity of the Micro Image Scanner and Microdensitometer.

b) Modulation Transfer Functions of the Micro Image Scanner and Microdensitometer; they are both less than unity.

c) Cut-off frequency of the Micro Image Scanner and Microdensitometer.

d) Radial lens distortion, which is given by the manufacturer as less than ±0.01 mm.

3) Barrel distortion of the collimator. This was particularly extreme and was reduced somewhat through the modified test procedure. (See Paragraph 2.5.)

f) Aberration, opacity and vignetting of the lens.

g) Knife-edge diffraction.

h) Differences in the conditions by which the traces were made with the Micro Image Scanner and the Microdensitometer.

Since all of these factors remained the same throughout the experiment, they are constants and as such will produce no effect on the computation of the relative MTF. If the true transfer function was desired, then these constants could be combined into one so that only a simple multiplication would be required to convert the relative transfer function.

2.7 Trace Characteristics

Recorder traces from the Micro Image Scanner are typified by Figure 6. All traces show a shift in the edge trace from the actual scan distance. This is primarily caused by scattering, distortion, and knife-edge diffraction. In traces of the first three positions, a dip or saddle frequently occurs. This is an interference pattern that is commonly associated with knife-edge diffraction. (Refer to: Born, M. and Wolf, E., "The Principles of Optics", New York, Pergamon Press, 1959.)

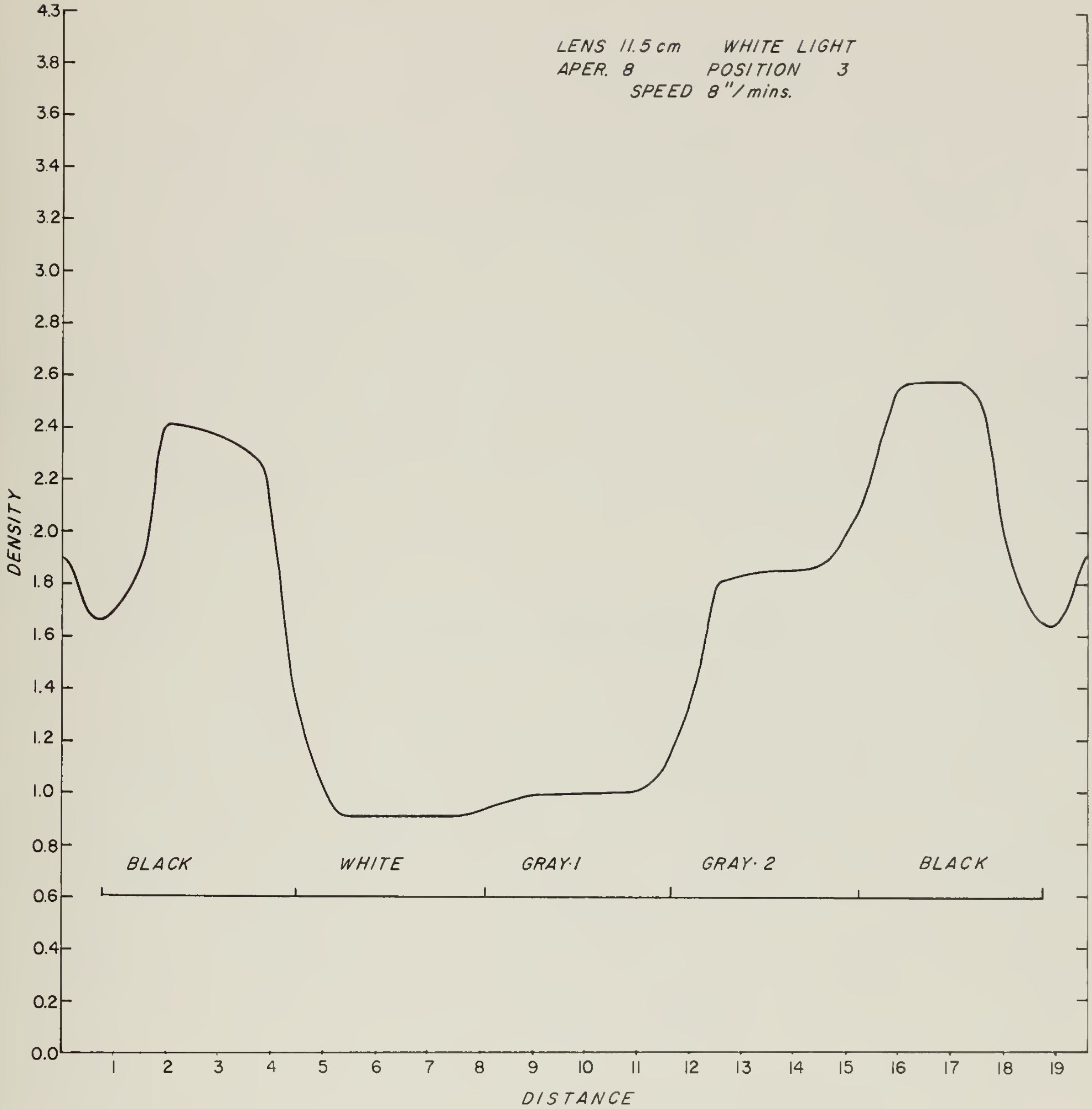


Figure 6. Representative Recorder Trace

2.8 Reduction of Data

By definition "Modulation Transfer Function" is the ratio of modulation at the output of a photo-optical system or component to the modulation at the input. This is synonymous with the term "Contrast Transfer Function" as used before 1961 (still used in France and Germany). In this instance output and input refer to the image generated and object respectively. Modulation is normally expressed as the ratio of $(I_{max} - I_{min})$ to $(I_{max} + I_{min})$ which is analogous to modulation in the field of electronics. With modulation values so determined, for the image and object, the transfer function is readily found from the basic definition.

$$\text{MTF } (\%) = \frac{\text{MOD. IMAGE}}{\text{MOD. OBJECT}} \times 100$$

Maximum and minimum intensity values for the image are directly available from the recorder output. However, in order to obtain the object values the rough microdensitometer traces must first be smoothed out. This was accomplished by two different methods. The first consisted of finding the mean of the individual peaks by

$$I = 1/2 \left(\frac{\Sigma P_{max}}{N} + \frac{\Sigma P_{min}}{N} \right)$$

where P refers to the individual peak value,

N is the total number of peaks (or troughs), and

I is the intensity value.

In the second method a Gaussian mean value was obtained by evaluating

the traces at 1 mm intervals. This takes the form

$$I = \frac{\Sigma R}{D}$$

where R refers to the value of the trace at a given interval,

and D is the total number of intervals.

Since only the first three target positions were scanned with the Microdensitometer, an average value for the object modulation was used. In order to reduce the Human Factor from values obtained by the above methods, each value is the result of three separate analyses. This information was then entered on data cards and submitted as a program to The Ohio State University IBM 7094 computer. The resultant output was Relative Modulation Transfer Function, in per cent, for edge gradients of Black to White, Gray 1 (light gray) to White, Gray 2 (dark gray) to Gray 1, and Black to Gray 2 for both methods of determining the object modulation. Comparison of these results showed less than a 1.0% difference between the two methods. Therefore, only the transfer functions obtained from the first method were used in a graphical analysis.

Graphical analysis was carried out in three ways.

1) Relative MTF was plotted against Position for both focal lengths with each relative aperture setting.

2) Average relative MTF was plotted against Relative Aperture.

3) Average relative MTF was plotted against Average Acutance.

Average relative MTF was obtained by meaning the transfer functions for each relative aperture. The average acutance values were obtained from the data of Ryan. (Refer to Ryan, R. M., "The Role of Focal Length of a Photogrammetric Camera in Acutance and Resolution", M.S. Thesis,

The Ohio State University, Columbus, Ohio, 1966.)

Since the object modulation for a green light source was not available, graphical analysis (1) above includes only four curves for the green source based on a fictitious relative MTF. This transfer function was obtained by using the image modulation with the green source and the average object modulation with the white source. Although this is an unacceptable method it was felt that it might be used to give an indication of the relationship between source wave length and scattering. By doing so, it would give some credibility to the acutance data obtained by Ryan.

2.9 Evaluation of the Graphical Analysis

Due to the fact that four edge gradients are involved, it is easier to view each graphical analysis separately. In the discussion below the following symbols are used to reference the different gradients; B/W (Black to White), G1/W (Gray 1 to White), G2/G1 (Gray 2 to Gray 1), and B/G2 (Black to Gray 2).

1) RELATIVE MTF vs POSITION (refer to Appendix I)

a) B/W: The transfer function increases rapidly between positions 1 and 2 and thereafter becomes approximately a constant value. Although the exact meaning of this break-point is not known, it is closely related to relative lens resolution and is probably a function of scattering, distortion, diffraction and detail size. As will be seen in the other gradients, this break shifts with the density of the tonal variations.

With respect to aperture settings the 11.5 cm focal length overall gives better transfer functions. Two notable exceptions occur to this statement. For apertures 8 and 11 the 21 cm focal length is initially better than the 11.5 cm focal length until between positions 1 and 2. The second occurs for aperture 16 where the 21 cm focal length gives higher MTF for all positions.

b) G1/W: Observable transfer functions have about the same value with the 11.5 cm focal length being slightly higher. A reversal of this is again present with relative aperture 16. It should be noted that image modulation was unobtainable for all of position 1 (and to a large extent the position 2 traces) for all aperture settings. This appears to be due to the small amount of contrast between the zones, shades involved, and the interference patterns presented by adjacent strips being more pronounced with decreased detail size. Further investigation in this area is definitely indicated.

c) G2/G1: The transfer functions show a moderate increase to position 4 and thereafter a slight linear increase. This is similar to the B/W but shifted toward the longer scan positions. In this investigation it must be remembered that longer scan is synonymous with

increased detail size. Again the 21 cm focal length gives higher transfer functions with relative aperture 16. As in (b) above image modulation was difficult to obtain and the resulting MTF should be treated lightly until further data are available.

d) B/G2: Transfer functions increase sharply to position 4 and then a gradual increase to position 7. Relative aperture 16 again gives higher transfer functions for the 21 cm focal length. As in the B/W condition slightly better initial MTF are obtained by the 21 cm focal length until between positions 1 and 2 with aperture 11.

Separation between the focal length curves follows the same general pattern for all gradients. The largest separation occurs with aperture 5.6 with a non-linear reduction to aperture 16. The sign of this separation changes somewhere between relative aperture 11 and 16. This trend is largely due to the reduction of scattering and effective light with increased relative aperture. An interesting aspect, of this separation, is observed in the fictitious MTF curves for a green light source. (Refer to Appendix I, B/W, Relative Apertures 5.6 and 8.) In these curves the separation is greatly reduced from those curves obtained by a white light source. This gives credibility to the idea that scattering is a function of wave length and focal length. However, until satisfactory data can be obtained this evidence must be considered inconclusive.

2) AVERAGE RELATIVE MTF vs. RELATIVE APERTURE

From Figure 7 (a) it is seen that for relative aperture 16 the 21 cm focal length gives higher transfer functions. This is in correlation with the results obtained from (1) above. Examination of Figure 7 (d) shows that for darker tones the 21 cm focal length gives better transfer functions from aperture 8 upwards. In contrast to this the lighter tones give the same transfer functions for both focal lengths. (See Figure 7 (b).) However, it must be kept in mind that the transfer functions obtained in the first two positions were not accurate. When Figure 7 (b), (c), and (d) are compared as a group it is apparent that, for photo interpretation work, it is better to have an underexposed photo versus an overexposed one. This observation has long been expounded by personnel connected with photo interpretation, but, to the extent of the author's knowledge, has never been qualitatively proven. It is entirely possible that emulsion effects will modify this increased MTF in underexposed photographs, and should, therefore, be included as a subject for further research.

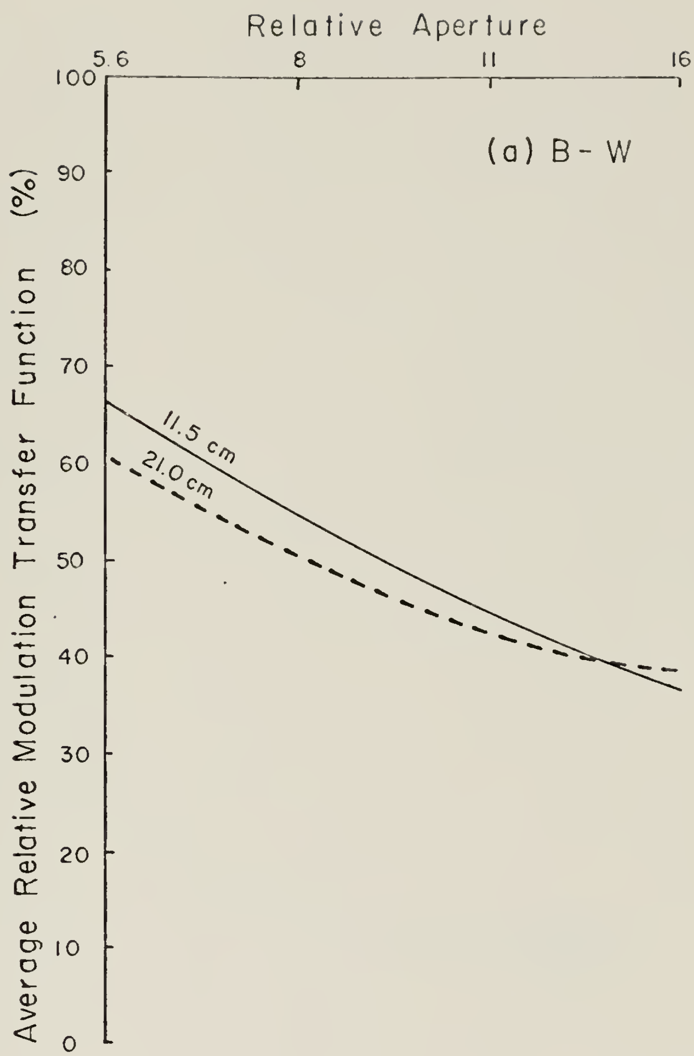


Figure 7. Average Relative MTF vs. Relative Aperture
(a)

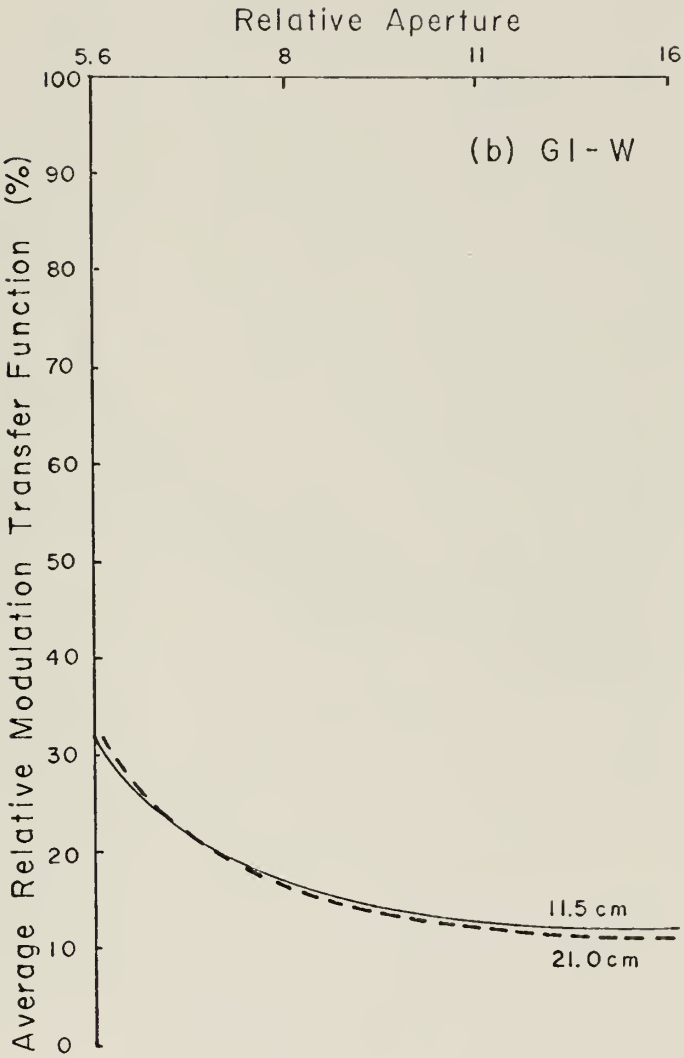


Figure 7. Average Relative MTF vs. Relative Aperture
(b)

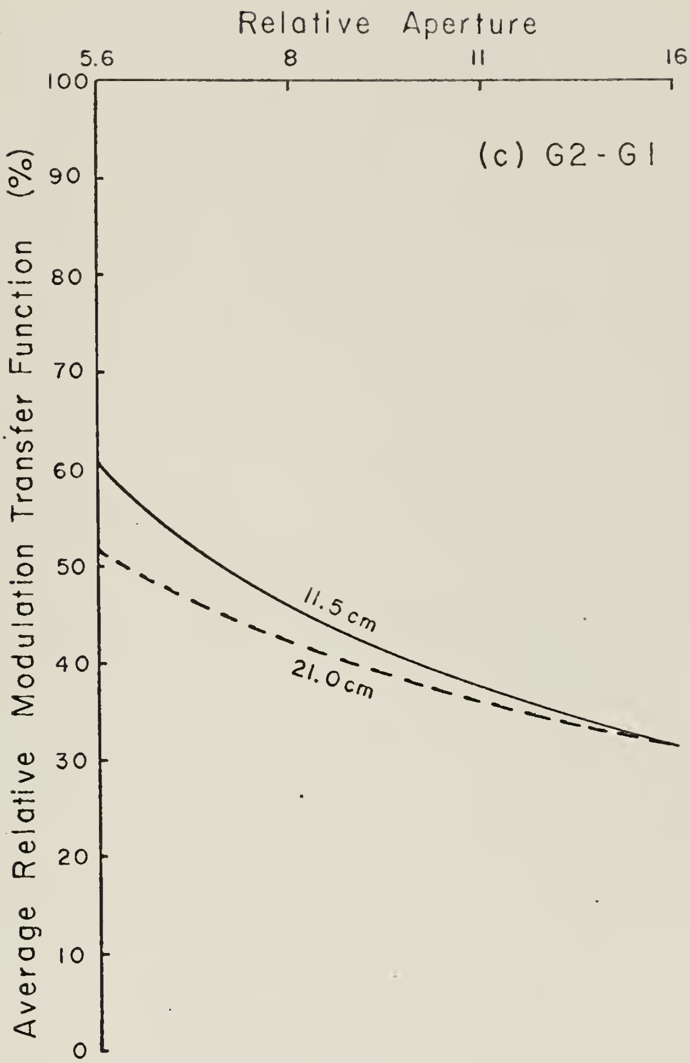


Figure 7. Average Relative MTF vs. Relative Aperture
(c)

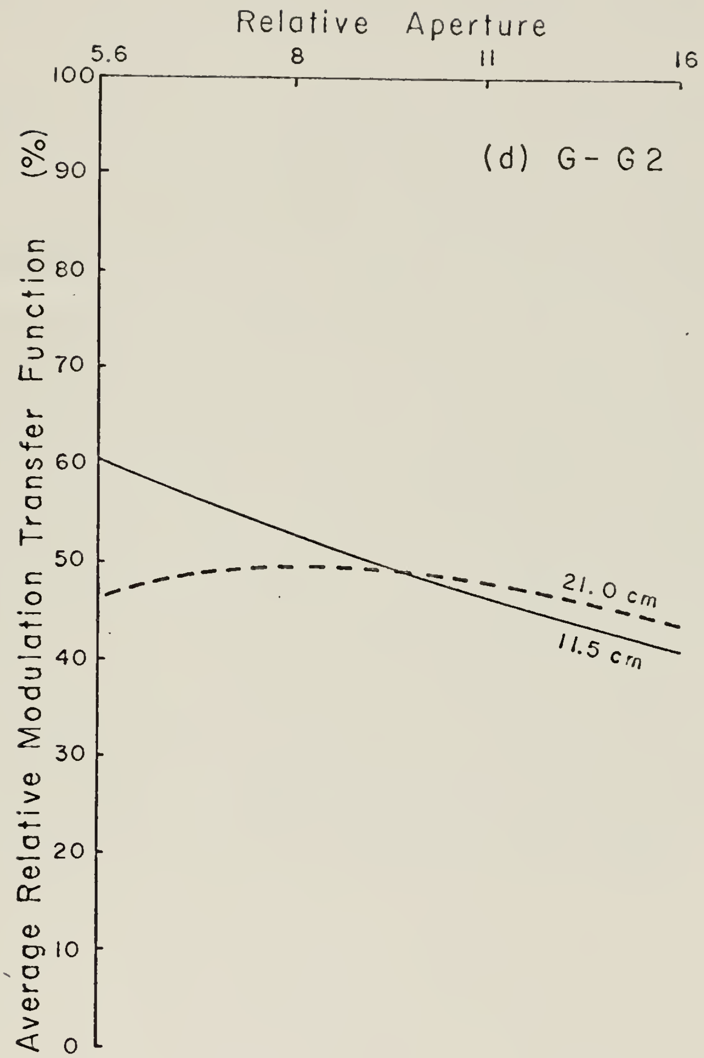
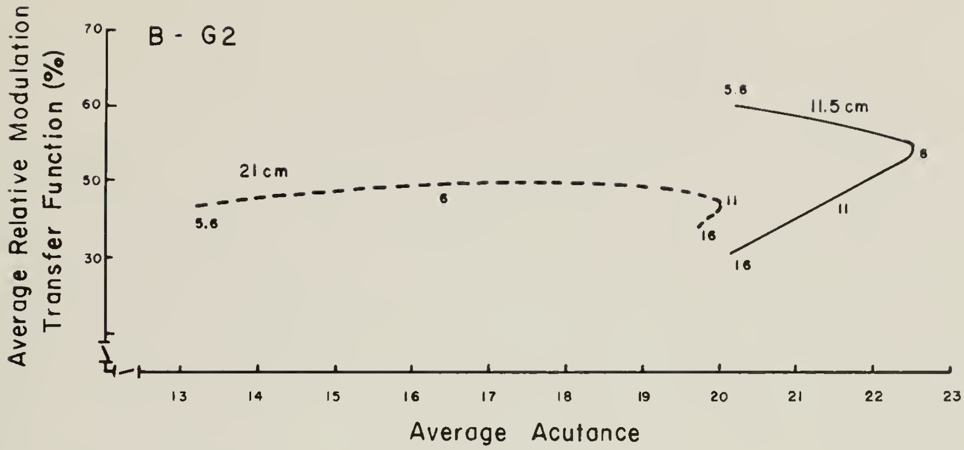


Figure 7. Average Relative MTF vs. Relative Aperture
(d)

3) AVERAGE RELATIVE MTF vs. AVERAGE ACUTANCE

In Figure 8 the 11.5 cm focal length curves show a well defined break. This break represents the maximum sharpness and its associated contrast for the lens. Furthermore, it shows that maximum contrast and sharpness do not occur at the same relative aperture settings. In fact, these break points do not, as a rule, occur on specific standard apertures, but vary with the tonal variations. For the 21 cm focal length only the B/G2 gradient exhibits a break. Reasons for not having this in other cases with the 21 cm focal length could be in sufficient data, a function of lens design, or a combination of both. Further research is necessary to determine the actual reason. The G1/W breaks are opposite from that expected from the above data and are believed to be a result of some reason not yet known to the author. Further research is necessary to determine the cause.



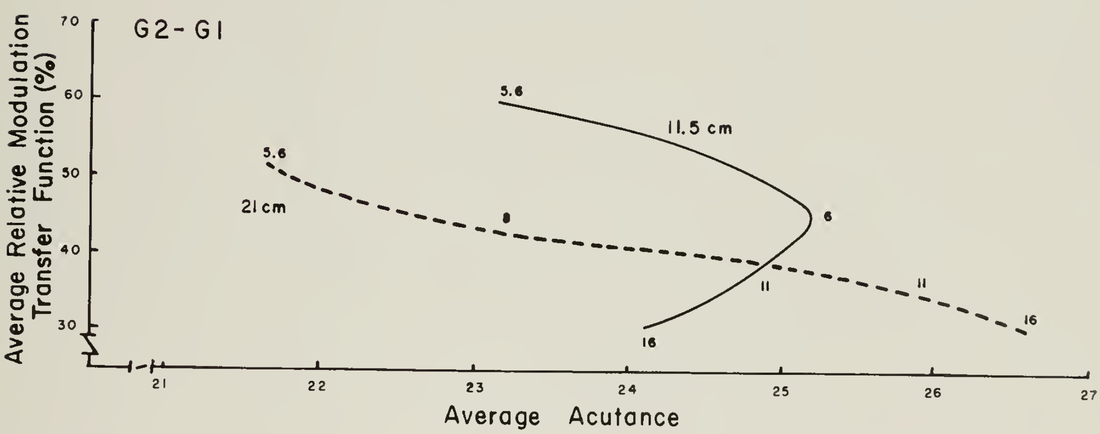


Figure 8. Average Relative MTF vs. Average Acutance
(a) and (b)

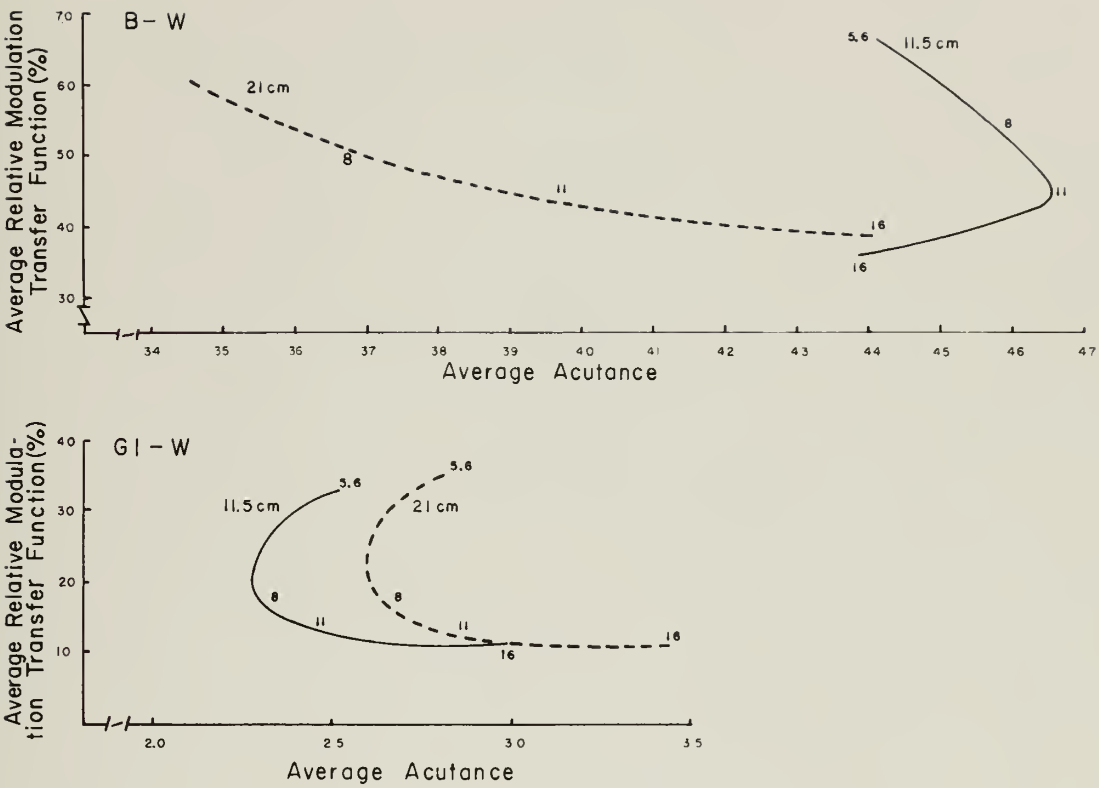


Figure 8. Average Relative MTF vs. Average Acutance
(c) and (d)

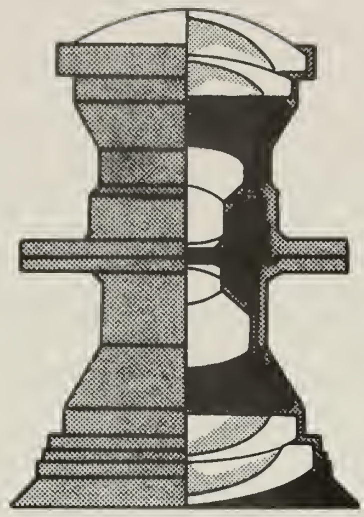
3. CONCLUSIONS AND RECOMMENDATIONS

3.1 Conclusions

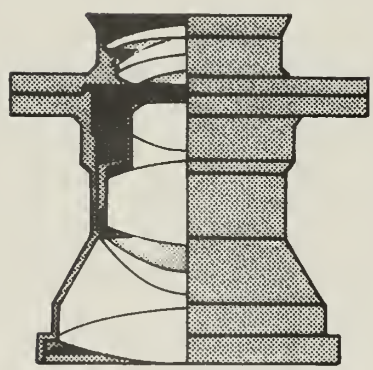
On the basis of the investigations reported in this paper it is concluded that:

1) Shorter focal lengths give higher transfer functions for a majority of the aperture range of a lens. This result is directly associated with the better geometrical image characteristics of the shorter focal lengths.

2) With maximum relative aperture settings, the longer focal lengths will result in higher transfer functions. This can most likely be attributed to a direct function of lens construction, especially that of lens thickness. Figure 9 gives a good schematic view of the construction of the two lenses involved. There is also evidence of this occurring, to a limited extent, for minimum relative aperture setting with small detail size. However, further research in this area is needed to substantiate this conclusion.



WILD AVIOTAR f:4



WILD AVIOGON f:5.6

Figure 9. Cutaway View of Lenses

3) There is a maximum detail size for each focal length, after which any increase in contrast is negligible. Furthermore, this detail size is directly related to the tonal variation.

4) Quality criterion for camera evaluation should no longer be based solely on the ideal contrast gradient of black to white. They should instead be based on a representative series of tonal variations that cover the most typical gradients found in aerial photography.

5) There is a need for further research with various light sources. Although the evidence is slight in this investigation, there is an apparent connection between source wave length, focal length variation, and the combined effects of scattering, distortion, and diffraction. Proof of this could greatly alter present ideas on aerial photography.

6) In all cases where doubt exists as to the camera settings required to give a properly exposed photograph, the setting selection should favor slightly underexposed photos rather than allowing any overexposed portions.

7) Longer focal lengths will give better results in areas of low contrast and darker tonal variations.

8) There is a need for a larger selection of relative aperture settings. This need is clearly pointed out in the graphical analysis of the Average Relative MTF vs. Average Acutance. Without additional aperture settings full advantage of camera characteristics cannot be taken.

9) From a practical point of view focal length alone, for equivalent systems, is of minor importance in image generation. The true role of focal length in image generation can only be realized through studies of its combined effects with the other influencing factors.

10) The data resulting from this investigation are not sufficient in extent to make final conclusions. Even if these data were sufficient in extent, final conclusions should be based on investigations by all accepted quality criteria. In this regard, further research is required along these lines.

3.2 Recommendations for Future Research

Looking in retrospect at the procedures used in this investigation, several improvements are deemed necessary to obtain sufficient data. These improvements are listed below in hopes they will be of assistance to future researchers in this field.

1) A series of sunburst patterns should be used in place of the wedge shaped target. Each pattern in the series should be comprised of only one gradient. These gradients should be selected on the basis of tonal variations present in aerial photographs. Such a target allows investigation by several quality criteria from one set of observations.

2) With a sunburst pattern provisions must be made for rotating the target.

3) A minimum of three lens cones should be used, since a lesser number does not really establish a trend, particularly if it is nonlinear.

4) Red, Blue, Green, and Yellow monochromatic light sources should be used in order to determine chromatic and wave lengths effects.

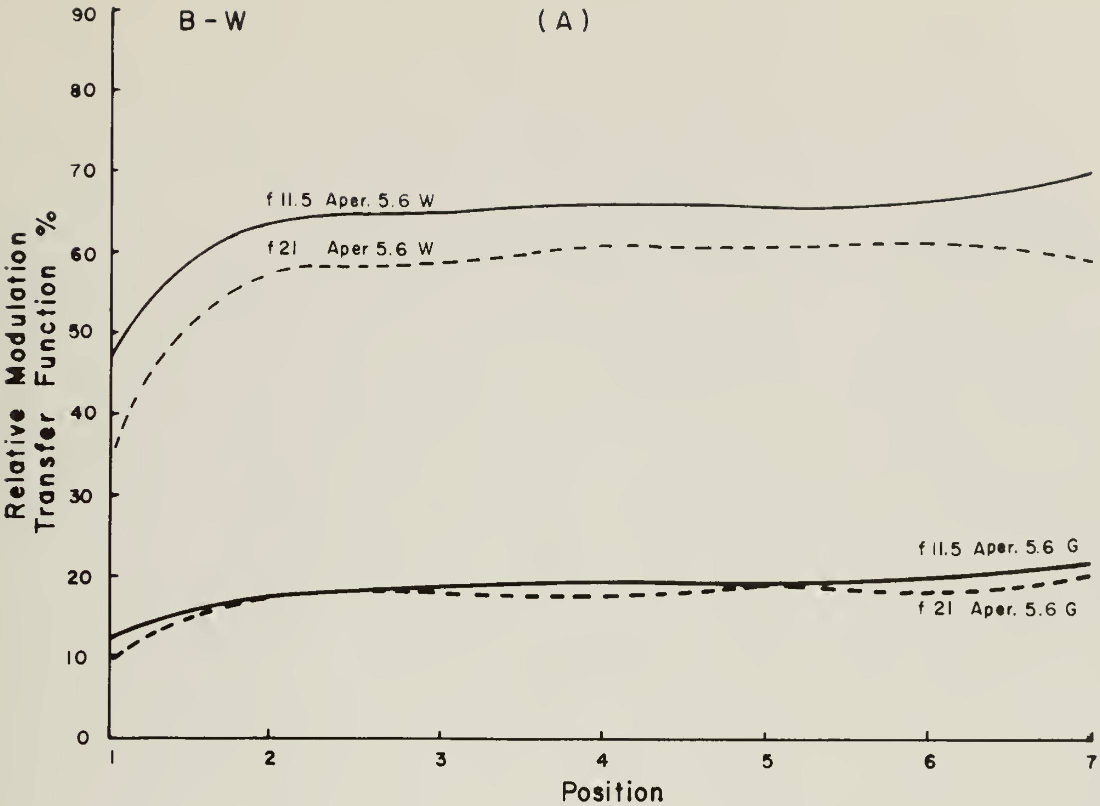
5) It is necsssary to use a collimator of high quality so that off-axis images can be investigated. The off-axis images should be investigated above, below, right, and left of the lens axis.

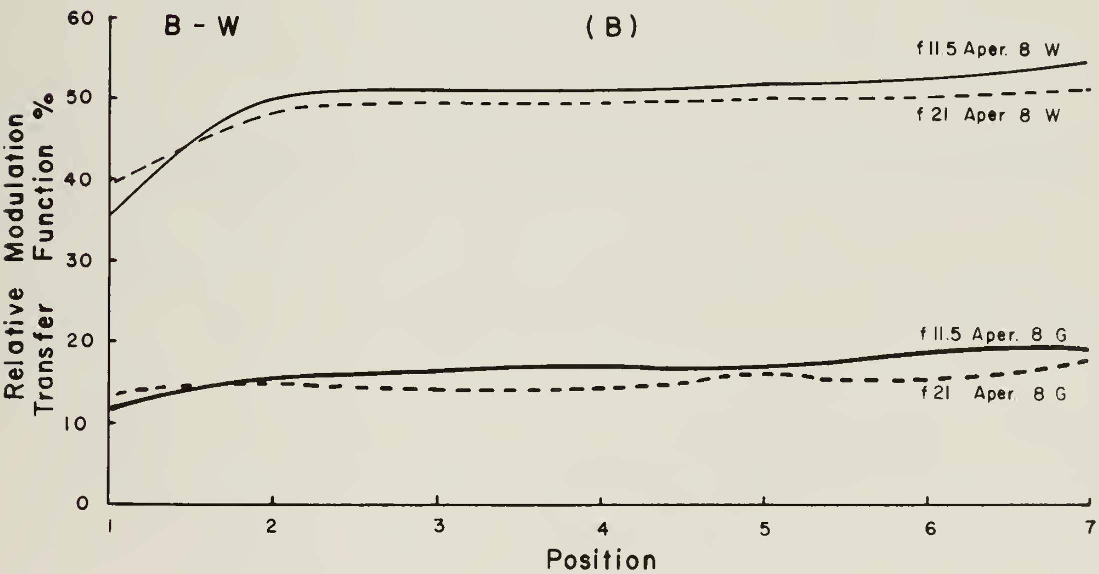
6) Additional scanning positions are needed between the detail size in positions 0 to 2 of this experiment.

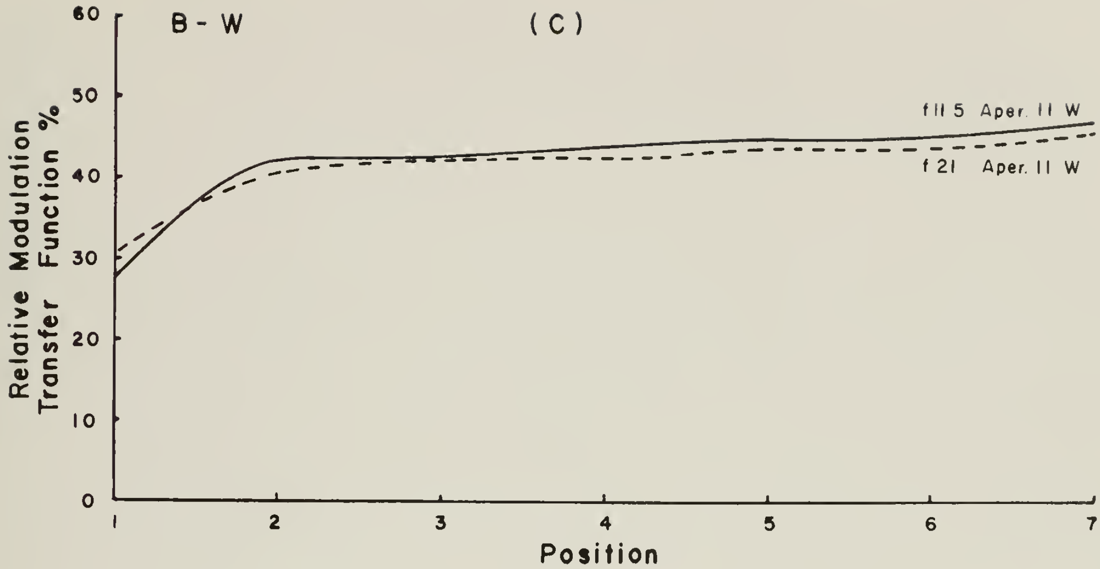
7) It is imperative to obtain the initial modulation measurements for the object with all light sources and in all positions.

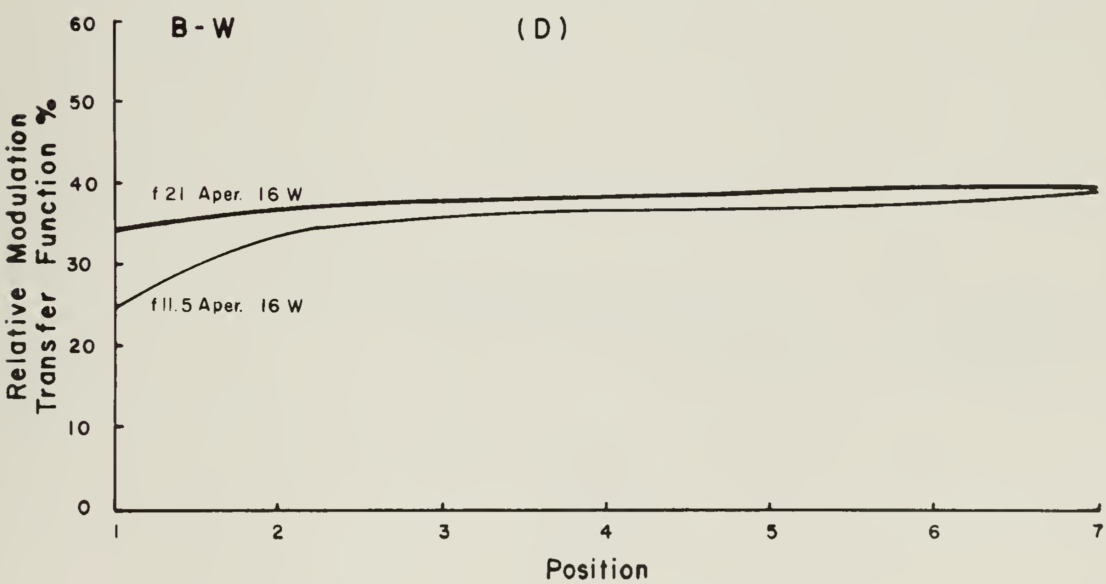
8) If possible, the effects of Infrared and Ultra-Violet light should also be studied.

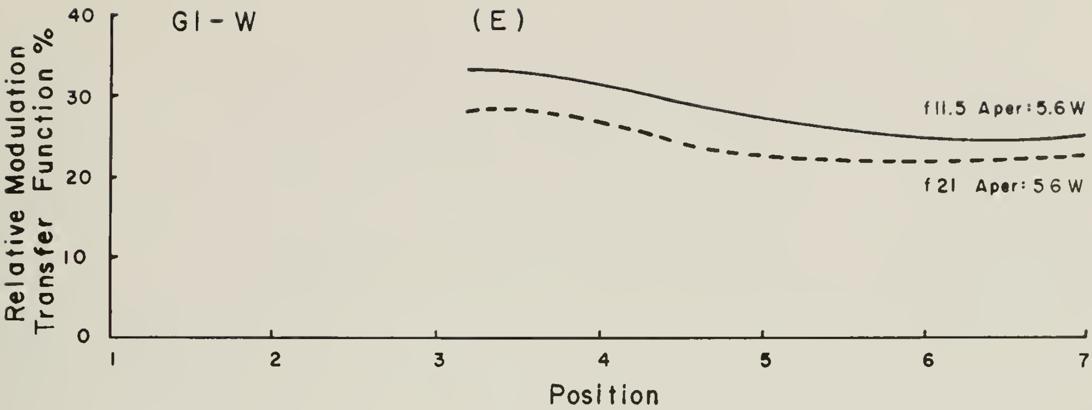
APPENDIX I

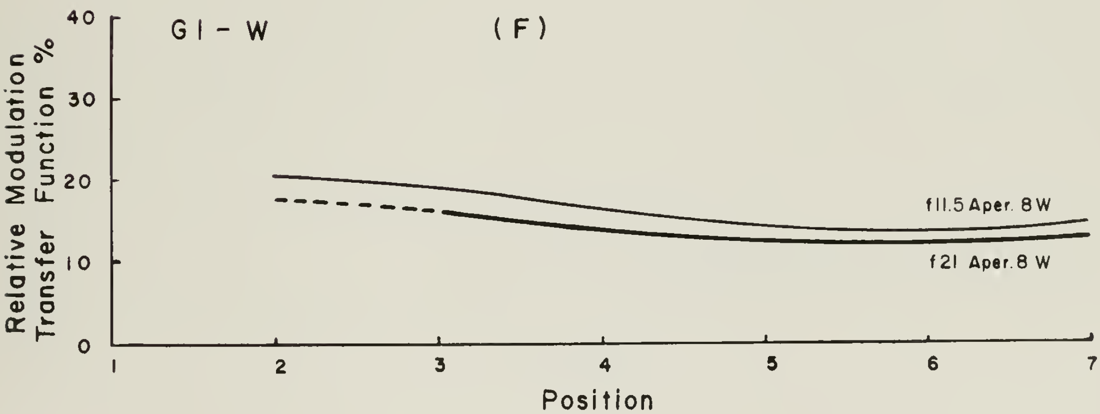

B - W
(A)
Relative Modulation Transfer Function %
f 11.5 Aper. 5.6 W
f 21 Aper 5.6 W
f 11.5 Aper. 5.6 G
f 21 Aper. 5.6 G
Position

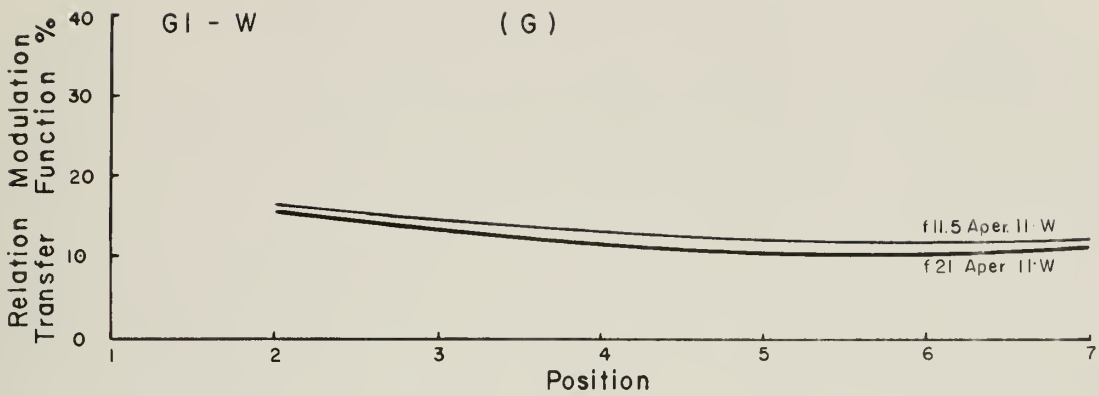

B - W
(B)
Relative Modulation Transfer Function %
f 11.5 Aper. 8 W
f 21 Aper 8 W
f 11.5 Aper. 8 G
f 21 Aper. 8 G
Position

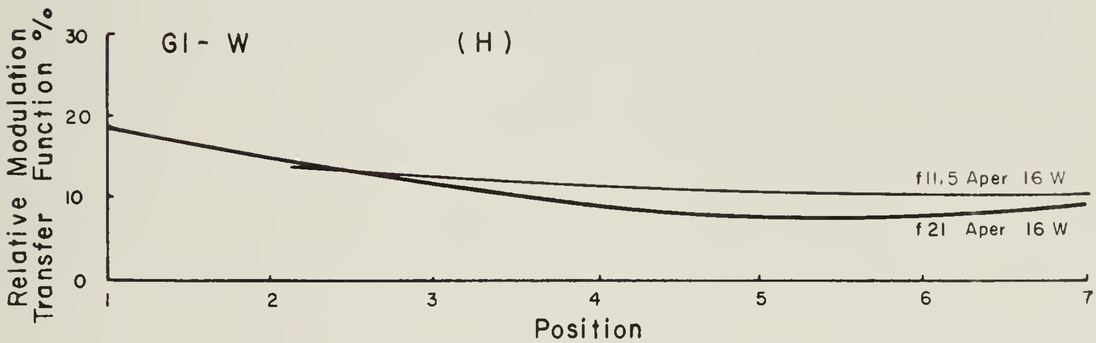

B - W
(C)
Relative Modulation Transfer Function %
60
50
40
30
20
10
0
f 11.5 Aper. 11 W
f 21 Aper. 11 W
1
2
3
4
5
6
7
Position

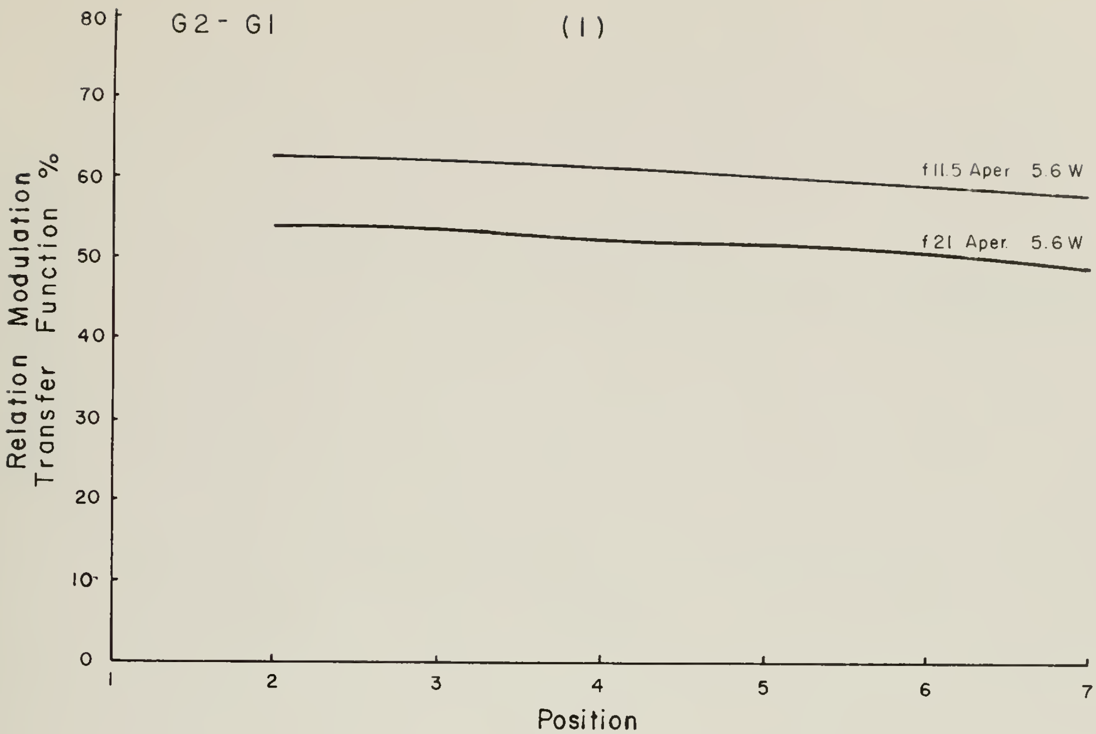

B - W
(D)
Relative Modulation Transfer Function %
60
50
40
30
20
10
0
f 21 Aper. 16 W
f 11.5 Aper. 16 W
1
2
3
4
5
6
7
Position

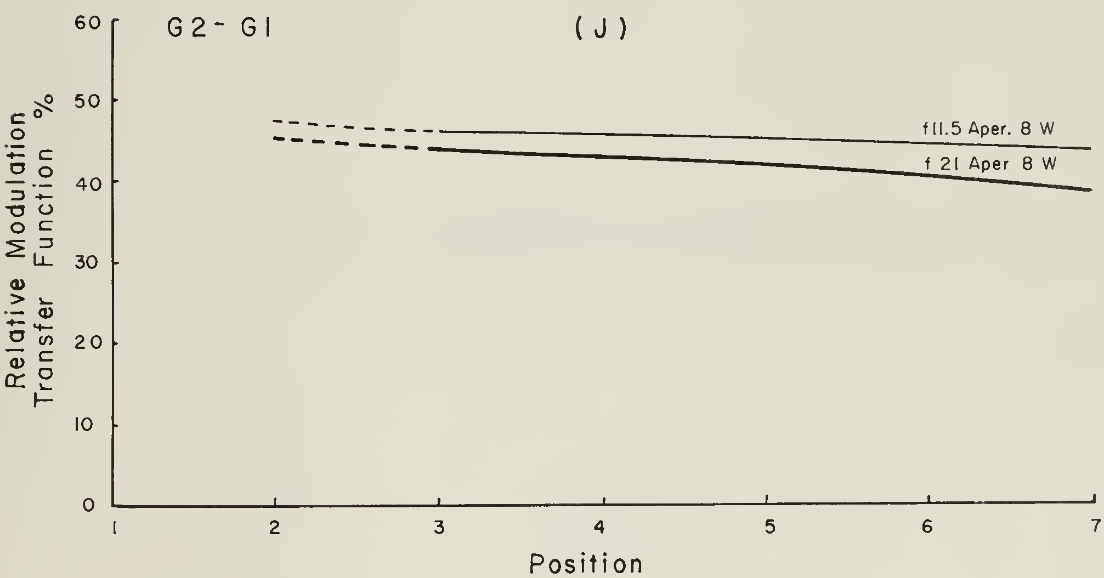

G1 - W
(E)
f11.5 Aper: 5.6 W
f21 Aper: 5.6 W
Relative Modulation Transfer Function %
40
30
20
10
0
1
2
3
4
5
6
7
Position

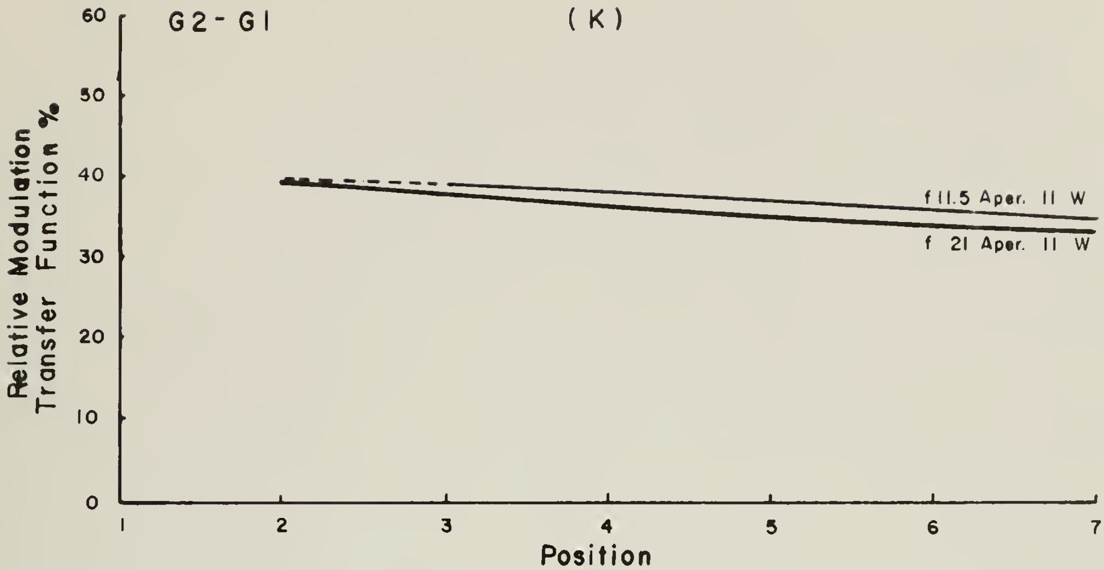

G1 - W
(F)
f11.5 Aper. 8 W
f21 Aper. 8 W
Relative Modulation Transfer Function %
40
30
20
10
0
1
2
3
4
5
6
7
Position

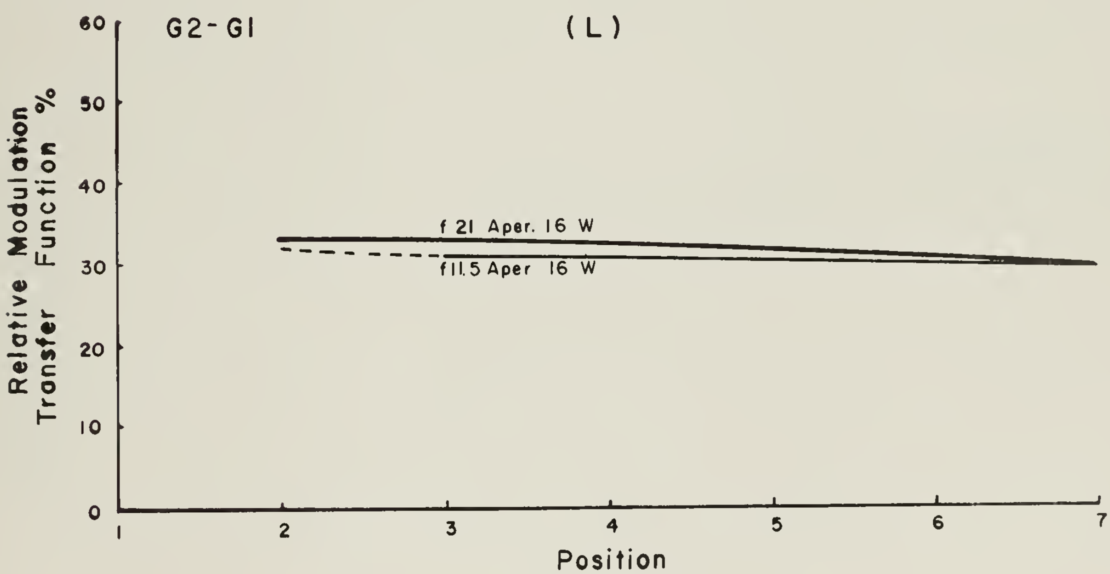

GI - W
(G)
Relation Modulation Transfer Function %
40
30
20
10
0
1
2
3
4
5
6
7
Position
f11.5 Aper. 11·W
f21 Aper 11·W

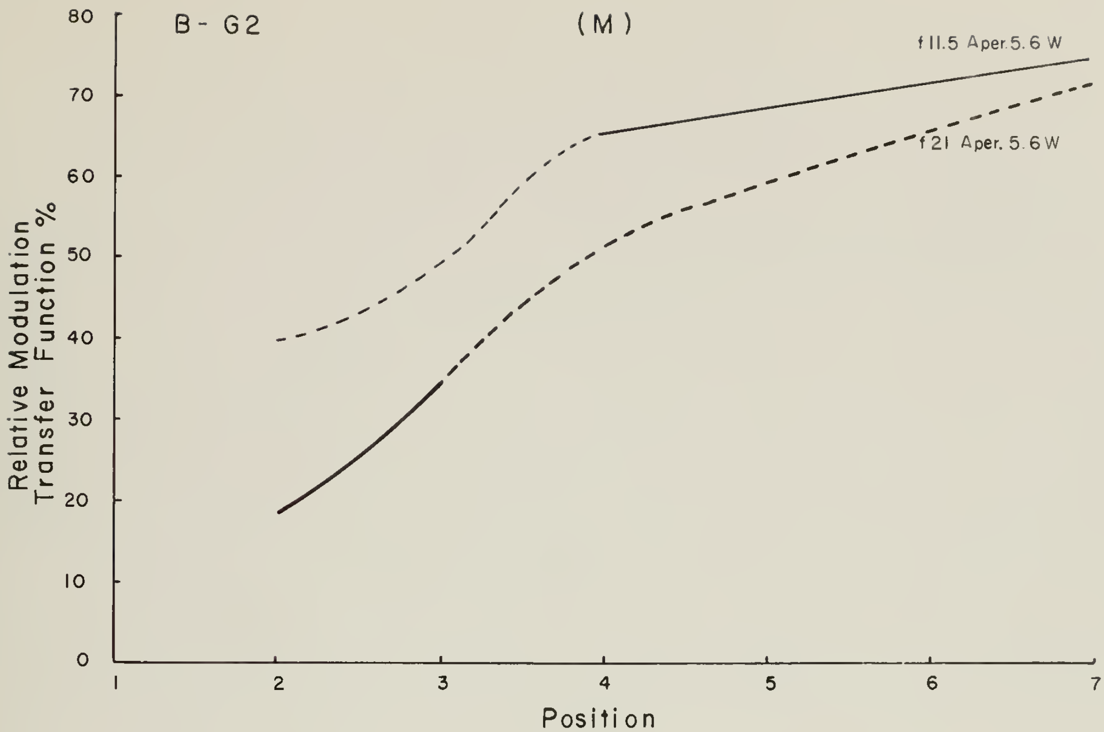

GI- W
(H)
Relative Modulation Transfer Function %
30
20
10
0
1
2
3
4
5
6
7
Position
f11.5 Aper 16 W
f21 Aper 16 W

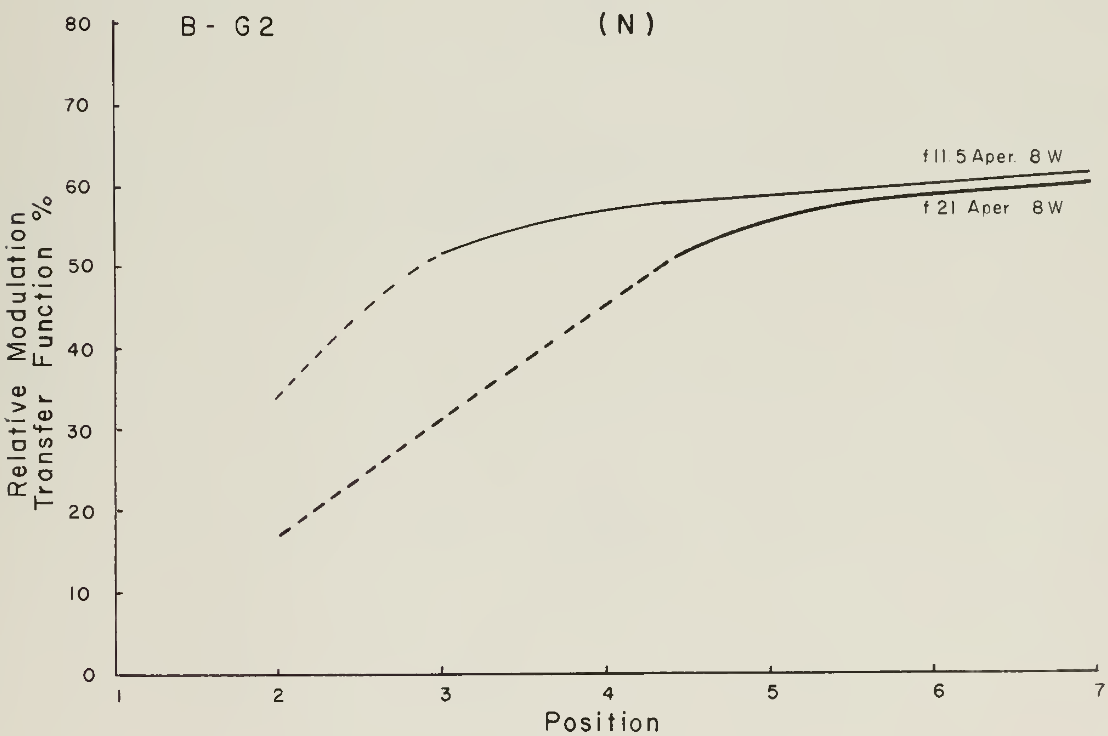

G2 - G1
(I)
Relation Modulation Transfer Function %
80
70
60
50
40
30
20
10
0
f11.5 Aper 5.6 W
f21 Aper. 5.6 W
1
2
3
4
5
6
7
Position

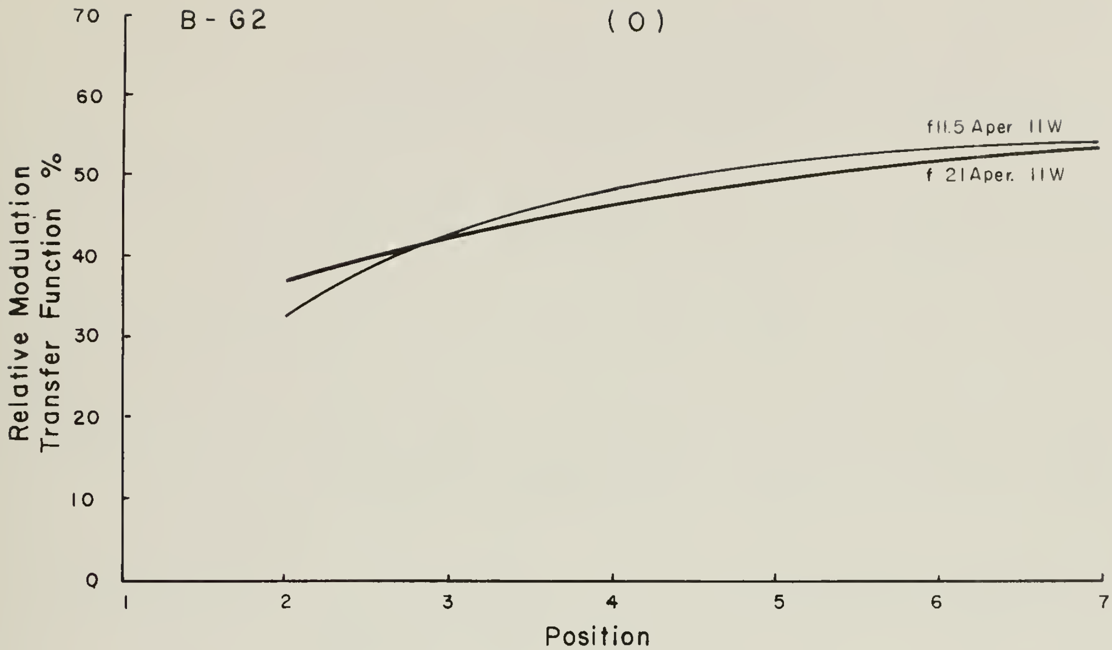

G2 - G1
(J)
Relative Modulation Transfer Function %
60
50
40
30
20
10
0
f11.5 Aper. 8 W
f 21 Aper 8 W
1
2
3
4
5
6
7
Position

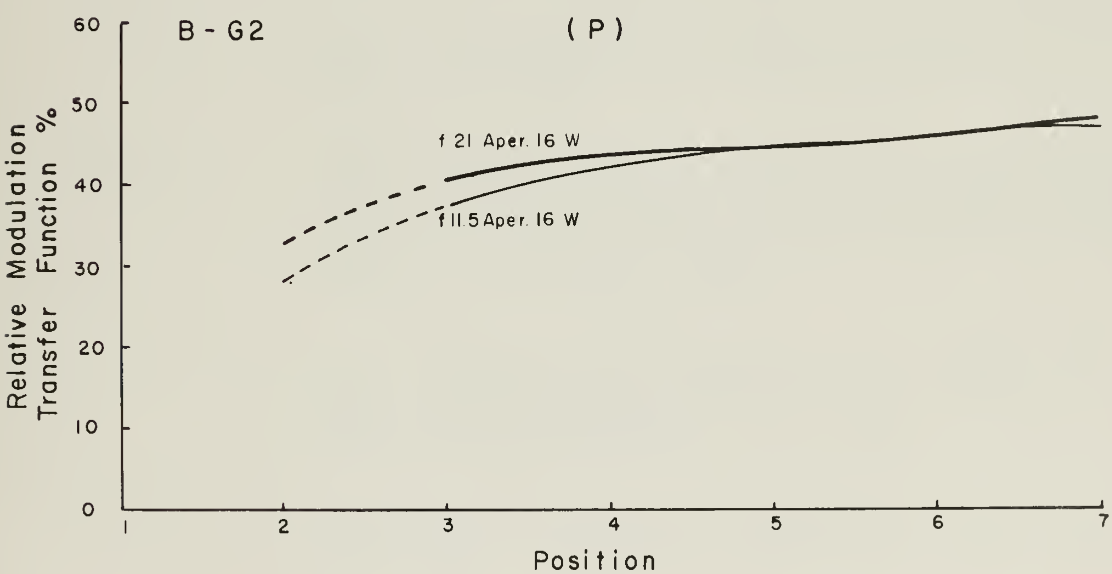

G2 - G1
(K)
Relative Modulation Transfer Function %
60
50
40
30
20
10
0
f 11.5 Aper. 11 W
f 21 Aper. 11 W
1
2
3
4
5
6
7
Position


G2 - G1
(L)
Relative Modulation Transfer Function %
60
50
40
30
20
10
0
f 21 Aper. 16 W
f 11.5 Aper 16 W
1
2
3
4
5
6
7
Position


B - G2
(M)
f 11.5 Aper. 5.6 W
f 21 Aper. 5.6 W
Relative Modulation Transfer Function %
Position


B - G2
(N)
f 11.5 Aper. 8 W
f 21 Aper 8 W
Relative Modulation Transfer Function %
Position


B - G2
(O)
Relative Modulation Transfer Function %
f11.5 Aper. 11W
f 21 Aper. 11W
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
Position


B - G2
(P)
Relative Modulation Transfer Function %
f 21 Aper. 16 W
f 11.5 Aper. 16 W
60
50
40
30
20
10
0
1
2
3
4
5
6
7
Position

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