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REPORT OF THE

PHOTO WORKING PANEL

ON THE C/M SYSTEM

8 FEBRUARY 1964

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Panel Members

Name	Affiliation	Signature
[redacted]	[redacted]	[redacted]

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I. Introduction

We were charged in essence with the problem "Is something wrong with C/M and if so, what?"

The first step in coming to grips with this question is to agree to methods for evaluating the system. Since the end result is a photographic image we must construct an objective quantitative measure of image quality. Against this standard the performance of the system must be measured and the observed image compared with the one to which the system is designed - including effects of atmosphere, image motion, and film processing and sensitivity in addition to the lens system. If all of these factors are fully understood and the design performance is achieved, then we conclude C/M is a satisfactory system in the sense that we have given it a test and it has passed. There is a big question of course: have we given the right test, i.e., the most useful one from the viewpoint of the mission we want C/M to accomplish?

In more specific terms we speak of the optical transfer function or the sine wave response curve t(k) as a function of spatial frequency k as the most convenient meeting ground between design and performance. In the engineering design of an optical system one seeks maximum resolution in lines/mm by keeping t(k) as large as possible in the region of high k. It has been a primary concern of this Committee to determine to what extent the design resolution is achieved by the system in practice. On the other hand, there are users' criteria of quality and one might benefit for intelligence purposes by trading off, for example, some resolution in order to achieve higher contrast - this is a human factor involving the PI's. This question of the optimum design of a transfer function for the intelligence community is a corollary and also vital problem.

The distinction between <u>users</u>' criteria and <u>engineering</u> criteria cannot be overstressed. In the first case one typically asks, "Is photographic sample A a better source of intelligence information than sample B and if so by how much?" In the second case one asks, "Is the equipment performing in actual use as it did under laboratory test and, if there is a difference, what is the magnitude of the difference?"

We discuss first in this report the questions of constructing and applying <u>objective measures of image quality</u> that are both useful and experimentally feasible. In practice, in the real world, there are many parameters affecting performance which cannot be specified precisely. The transfer function t(k) is a product of four components;

$$t(k) = \underset{(atmosphere)}{t(k)} \cdot \underset{(image\ motion)}{t(k)} \cdot \underset{(optics)}{t(k)} \cdot \underset{(film)}{t(k)} .$$

A characterization of performance by t(k) alone is incomplete since it does not take film granularity into account. However in these discussions we assume the slow, fine grained film 4404 (formerly SO 132) now in use is a fixed parameter of the system. Uncertainties in the individual factors of t(k) make it impossible for us at present to assess accurately the operational performance of the C/M system. We would like to sharpen up our knowledge of these factors and to determine what parameters in the C/M system or environment affect them sensitively. With this knowledge we will have a more complete understanding of the C/M system which will permit us better to assess and possibly to improve its operational performance.

This calls for a measurement program - which is the next main subject of discussion in this report. Engineering passes over known design targets in known weather conditions are one aspect. Another very important one is an in-flight measurement program to determine, for example, what the effect of the in-flight environment is on the optical focus - one area of particular concern being the possible focal errors introduced by thermal gradients and transients in the camera barrel and lens system. We do not here attempt a detailed design study but we indicate the types of measurements which are felt to be most desirable and which can be made on the ground or in orbit without substantially conflicting with the operational goals of the C/M missions.

As a general remark we add our very strong conviction of the need for instituting with great urgency a program of mission measurements and analyses to help identify the main causes degrading image quality - or to verify, by establishing a lack of correlation between the image quality and the monitored parameters, that the present quality is typical of what is to be expected. The measurement programs proposed in this report should be carefully prepared and not viewed as quick fixes.

In view of the extremely limited technical feedback as to the performance of components in flight to the systems designers, it is amazing to those of us on the "outside" how well C/M has done so far. Nevertheless, there are major quality variations during operation the causes of which are not yet understood. In its best moments C/M has performed very well, indicating that improvements to yield a higher level of performance consistently should be possible. The urgency of a measurement program and of timely systematic performance analyses to enable the designers to achieve possible improvements cannot, therefore, be overemphasized.

II. Summary and Recommendations

A. Measures of Image Quality

1. Edge measurement techniques for determining the optical transfer function. The aim here is to provide a reliable and reproducible "canonical" technique for accurately measuring t(k) particularly for high spatial frequencies (say 10 ft. ground resolution or 100 l/mm). We want to know t(k) so that by comparing the measured value with the value to which the system is designed we can answer whether the photography obtained is all that can be expected from C/M or whether there is a loss of resolution due to shortcomings of the system. Since the atmosphere's transfer function enters into this comparison it too must be measured or calculated in principle. As discussed further in Section D the only significant effect of atmospheric haze on the transfer function of C/M photography is a DC reduction of contrast, and t(k) is independent of this and therefore of the atmosphere.

The practicability of microdensitometric edge measurements for a routine evaluation of photography at high resolution in order to determine t(k) must still be established. As a relatively new technique it is still fraught with practical difficulties and potential dangers. It presents no theoretical problems, however. Suitable edges for the scale of C/M photography may be found e.g. in the form of certain large airfield landing strips, and for special tests can be conveniently provided by a target layout on the ground.

In order to demonstrate the practicability of edge measurements for 100 l/mm analysis a long-range industrial program is in progress and full support to continue and expand it is recommended. Its development goals should be to

a. Establish reliability by comparing recent measurements of t(k) from edge scans to results from sine wave targets. The resulting modulation transfer function should be combined with a film modulation threshold curve to predict the resolution in l/mm for direct experimental comparison.

b. Compare and standardize different microdensitometer slits, determining optimal dimensions and data handling methods.

c. Determine practicability of the method in terms of number of man-hours involved per edge for a reliable scan.

Toward these ends we recommend that there be

a. Initiated both at Westover and NPIC a program of selecting and measuring edges on new mission material (and on past material if warranted by success of the above program), both to advance the confidence in and reliability of edge measurements and to accumulate data on C/M performance. At this time the edge scan method is not ready for production use; and

b. Constituted a working group including representatives of the principal laboratories to carry out a standardization study on edge measurement techniques. This activity should not be bound by security restrictions but should operate as an industrial cooperation oriented by a work statement for such a study from this Committee; and

c. During the early stages of implementing a mission edge measurement program, there be formed an ad hoc group including members of this Committee to help orient and direct actual procedures and techniques.

2. Visual comparison of photography of unknown quality with photography of known quality as obtained by the same optical system. This technique of subjective quality comparators or "GEMS" (Graded Estimated Measuring Samples) for judging image quality is of interest and potential value because there are no standard resolution targets in operational photography and the edge scan measurements are still of uncertain merit. Moreover comparative analysis of properly prepared GEMS may provide some valuable input into a human equation for the optimum photography for use of the intelligence community. Both the flexibility and quantitative value of GEMS are uncertain at this moment and experience in working with them will be important in evaluating this technique.

The first use of such photographic comparators is for engineering evaluation. They will be designed with the aim of permitting the observer to identify the main characteristics of quality degradation in the actual picture - whether due to reduction of t(k) for high k leading to fuzzy edges of high contrast, or non-optimal processing to high or low average densities which affects graininess, or loss of contrast (due to the sum of the effects of corona discharge, light leaks, haze, and thin clouds) but with edges remaining sharp. The observer will identify these quality characteristics by comparison with a library series of GEMS that can be brought to adjacent positions in sequence by a comparison eyepiece. He can also rate the photography by a resolution level in 1/mm for 2:1 contrast targets as imaged in the GEMS.

The second use will be to determine the effects of the variables introduced into the GEMS on the value of photographic material for intelligence purposes. To reiterate an earlier point - our primary Committee concern is to determine how well the system produces its design transfer function, but the question of what is the transfer function to which the system is to be optimally designed is a longer-ranged and corollary question.

A comparison technique for assessing the photographic quality is presented and the basic elements of a GEM library are discussed in this report. As a first step in implementing this program a simple dual microscope system with a comparison eyepiece and a small library of GEMS with varying resolutions has been prepared.

We recommend support for continued developments and refinements of GEM techniques and for a program of applying GEMS to C/M mission material in order to determine their value. It is important that the original negatives of mission photography on engineering passes over domestic targets be available for this program.

3. First results of edge scan measurements and visual photographic comparators applied to operational photography. Edge scan measurements on mission photography have been made with the Eastman Kodak microdensitometer as summarized in Table 1 and Figures 1 and 2 where the limiting resolution in 1/mm is computed from the measured transfer function for 2:1 contrast targets. We feel that difficulties in selecting reliable edges and imperfections in the measurement technique may be effecting the resolution values obtained.

GEM measurements of the limiting resolutions were made and are shown for 76 frames of mission 9056 in Figure 3. The correlation of GEM measurements with edge scan results for scenes in the close vicinity of the edge scans made on missions 1001 and 9062 is shown in Figure 4. That no better than a moderate degree of correlation was found indicates the extreme caution with which these first results must be viewed. Indeed we feel that the set of GEMS used in this comparison was much too limited in range of contrast and illumination conditions to determine only the resolution in the scenes. Retaining this caution in mind we may view Table 2, which shows a rather good agreement between the resolutions measured by these two techniques.

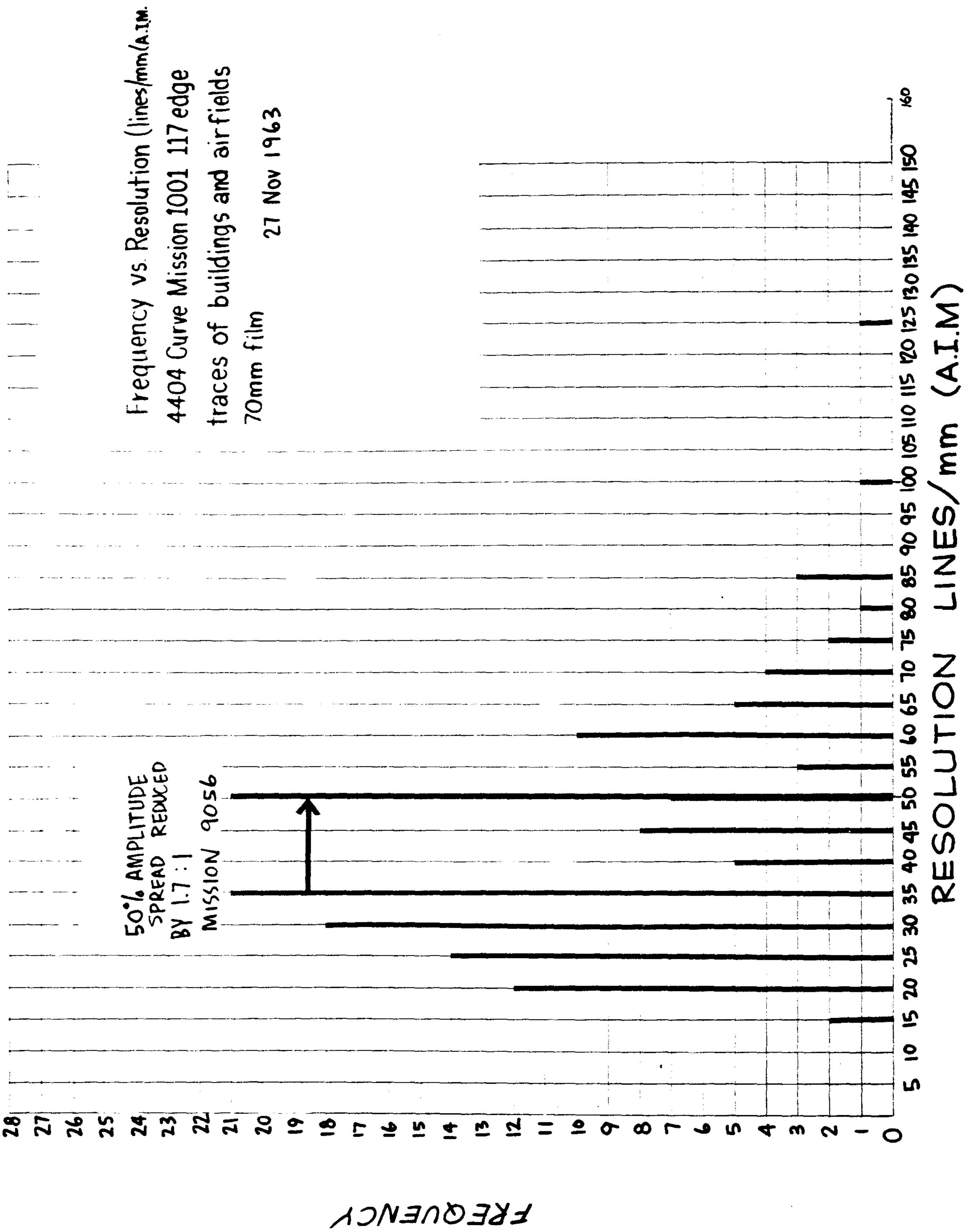
The 76 frames of Mission 9056 which were given subjective MIP (Mission Information Potential) ratings at NPIC and, as discussed and plotted by [redacted] and [redacted], caused very great concern, were compared with the GEMS as shown in Figure 5. A lack of correlation is evident - as it is also with the RES (Reciprocal Edge Spread) measurements made at Westover (Figure 6). Furthermore, these two different

[redacted]

Table I

Image Evaluation of Edges by Microdensitometer

Flight Number	Film Size	Number of Edges	Hand Calculation: Spread Function Width at 50% Amplitude in Microons			IBM Computer: Spread Function Width at 50% Amplitude in Microns			IBM Computer: Resolution in lines/mm from 4404 A.I.M. Curve		
			Arith. Mean (Microns)	Standard Deviation (Microns)	Coefficient of Dispersion	Arith. Mean (Microns)	Standard Deviation (Microns)	Coefficient of Dispersion	Arith. Mean 1/mm	Standard Deviation 1/mm	Coefficient of Dispersion
1001	70mm	117				26	11	44%	42	20	46%
8003	5"	12	65	21	33%						
9054	70mm	12	13	7.9	59%						
9056	70mm	15	17	6.6	38%						
9057	70mm	35	14	4.3	32%						
9057	70mm	21	18	14	78%	14	9.5	67%	67	27	40%
9062	70mm	69				12	4.5	37%	88	30	34%



Frequency vs. Resolution (lines/mm(A.I.M.
4404 Curve Mission 1001 117 edge
traces of buildings and airfields
70mm film
27 Nov 1963
50% AMPLITUDE
SPREAD REDUCED
BY 1.7:1
MISSION 9056
RESOLUTION LINES/mm (A.I.M)
FREQUENCY

FIG-1

[redacted]

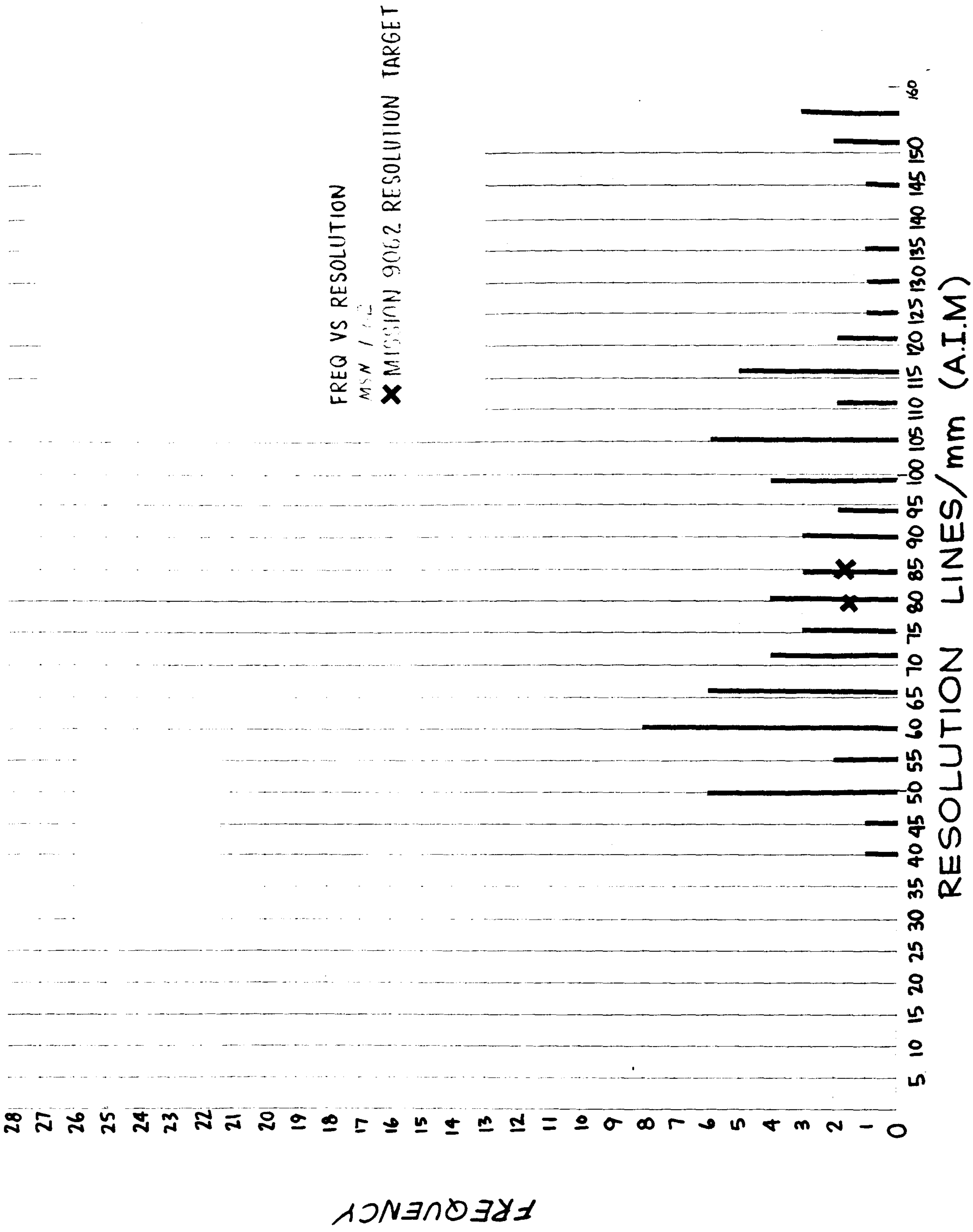


FIG - 2

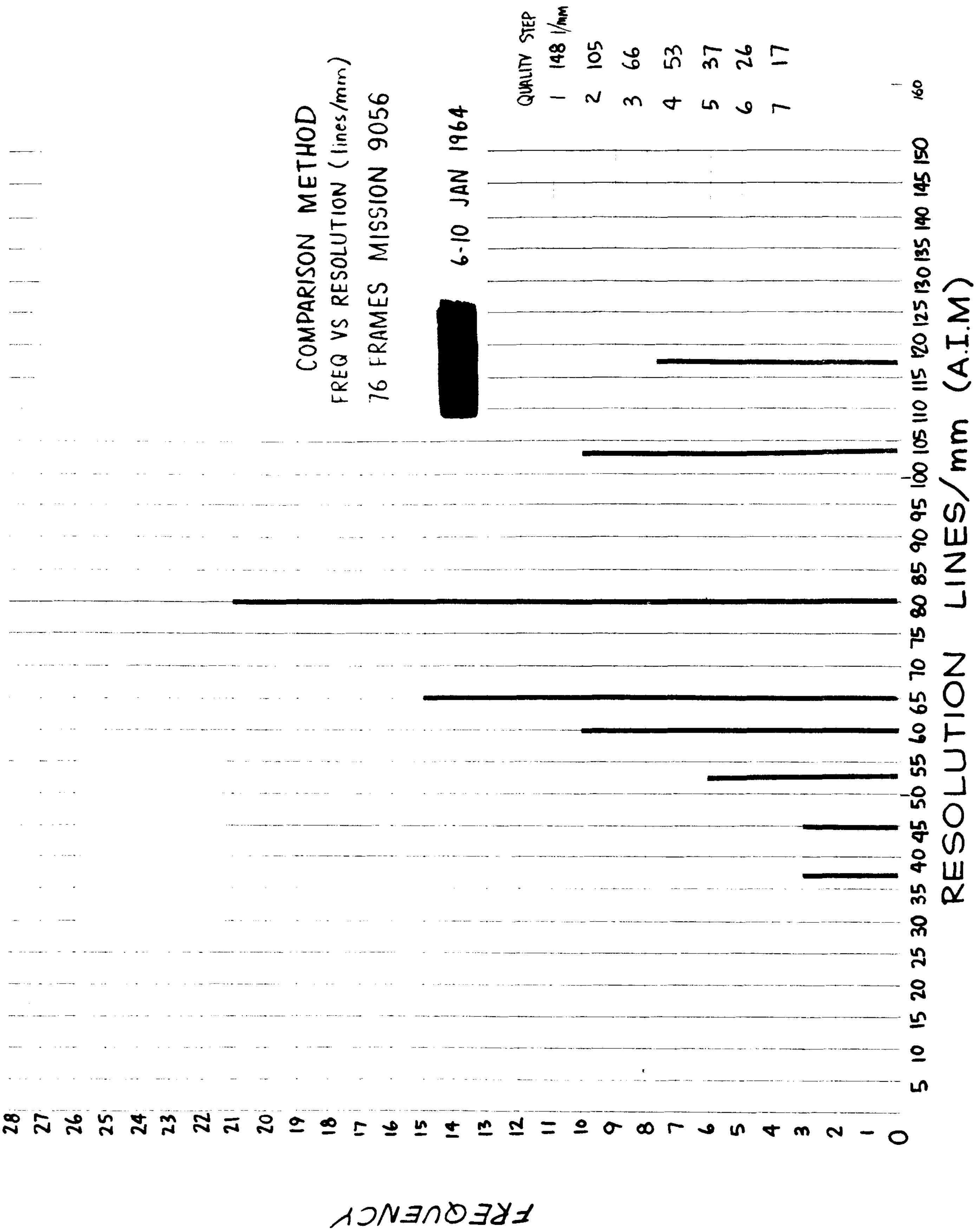

COMPARISON METHOD
FREQ VS RESOLUTION (lines/mm)
76 FRAMES MISSION 9056
[redacted] 6-10 JAN 1964
QUALITY STEP
1 148 l/mm
2 105
3 66
4 53
5 37
6 26
7 17
RESOLUTION LINES/mm (A.I.M)
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120 125 130 135 140 145 150 160
FREQUENCY
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28

FIG - 3

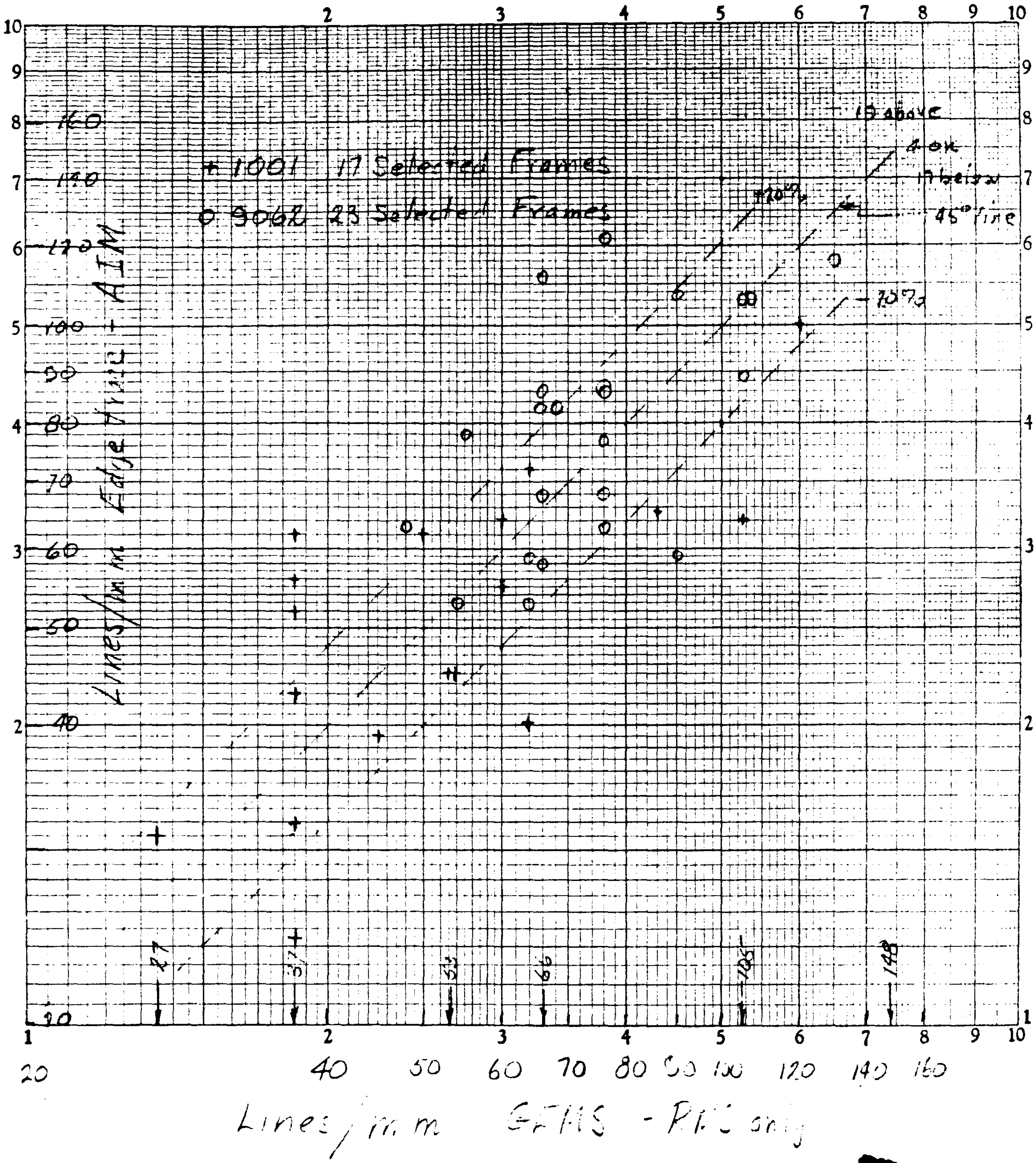


Figure 4

[redacted] 2/3

Table II

Comparison Between Edge Scan and GEM Analysis

Mission	Method	Resolution 1/mm Arith. Mean μ	Standard Deviation
1001	Edge Scan 117 Edges	42	20
	GEMS 23 Frames	50	26
9062	Edge Scan 69 Edges	88	30
	GEMS 23 Frames	88	25

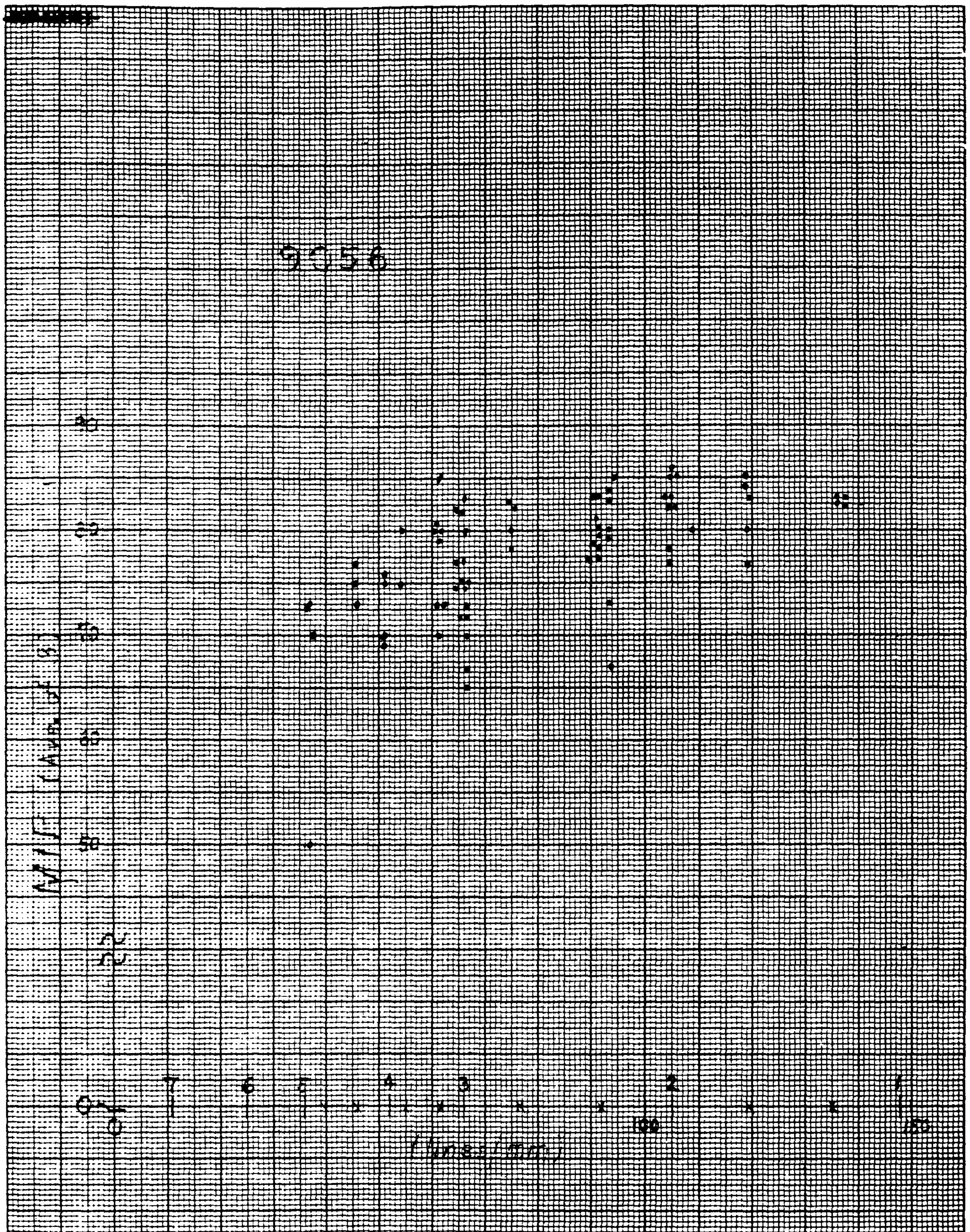
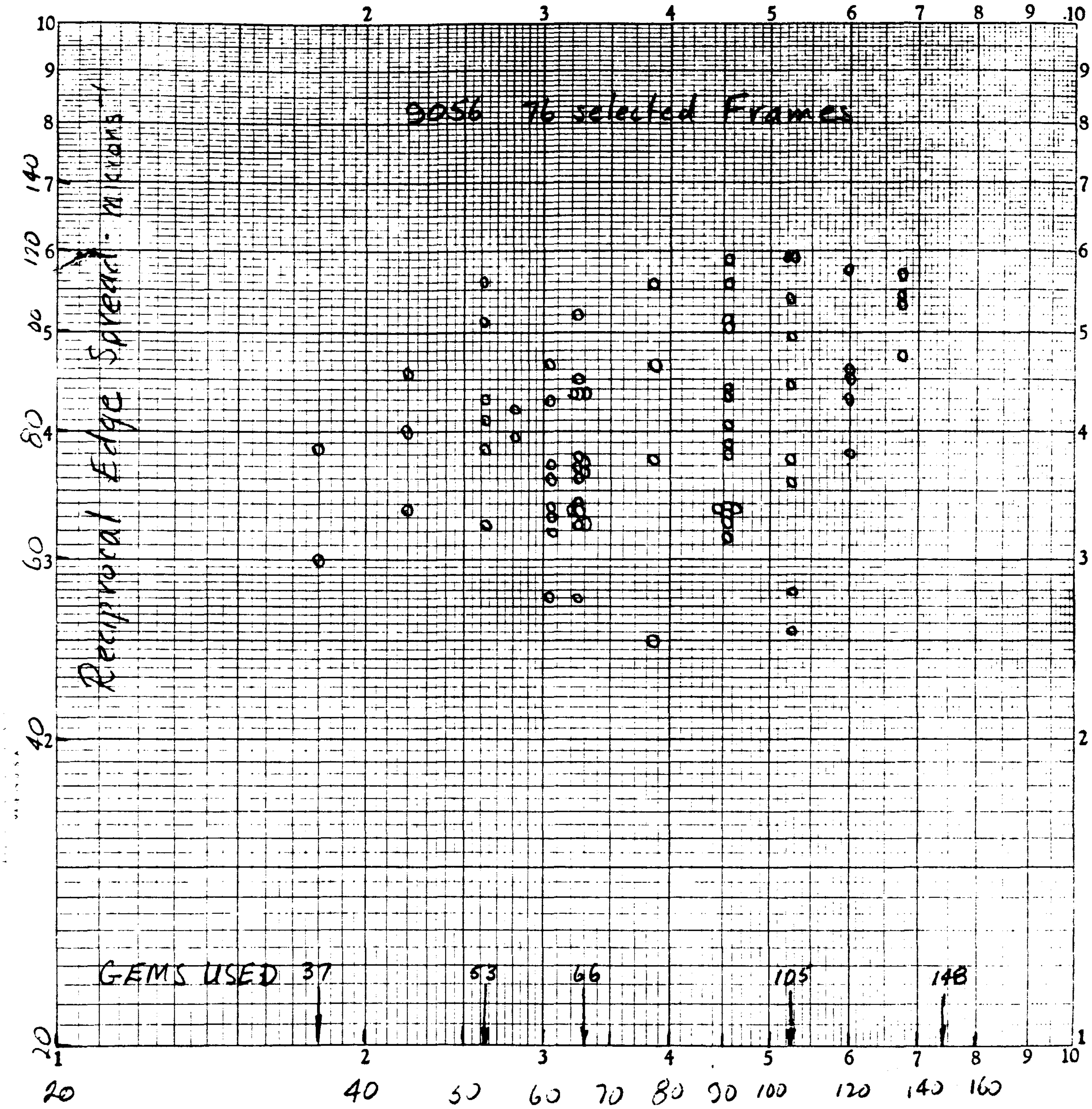


Fig. 5 - Attempted Correlation between MTF & GDMS

[redacted]



Lines/mm - GEMS

[redacted] 1/8/64

Figure 6

subjective measures of quality, RES and MIP, fail to correlate with each other as shown by Figure 7. The conclusion from this is that both MIP and RES measurements have a presently uncertain, if indeed any, quantitative value.

The lack of correlation of RES with edge scan measurements can in part be attributed to the sensitivity of the RES results to the average density of the edge. Although it is a rapid and convenient method of analysis it must be established that, taken together with a simple measure of the average density, RES can be reliably and accurately correlated with objective quality measures before one can justify a continuing program of measuring RES values. At this time RES appears to be of limited quantitative value.

In assessing image quality by subjective standards we believe that variations in the illumination conditions contribute significantly to the observed spread of quality although we have not assessed the significance of these variations quantitatively. Figures 8 and 9 show two striking examples of this effect in technically equivalent pairs of photographs. Only the angle of solar illumination is different in Figure 8 and the angle between viewing directions and illumination in Figure 9. The actual shadows are the same in both photographs in Figure 9 which show two successive frames 10 seconds apart along a flight line but the extent to which they may be seen depends strikingly on the camera's angle of view.

It is also clear that factors which reduce the relative brightness of the shadows such as haze and scattered clouds will tend to dilute the above effects, so as to make the photography generally drift in quality toward the low contrast of the subsolar point seen in Figure 9. Indeed moderate haze by scattering light into the shadows has a significant and often overlooked effect on overall quality in addition to the DC back-scattering of light into the lens. Clouds can produce a similar effect even though a ground target is directly illuminated by the sun and directly visible by the camera.

These factors which play an important role in subjective evaluations are not relevant in an engineering analysis of a system in terms of limiting resolution in l/mm. If one is to compare objective and subjective measures of image quality such as MIP values then a way must be found to take into account the effect of variability of subject matter.

The GEM and edge scan measures show some promise but conclusions at this time

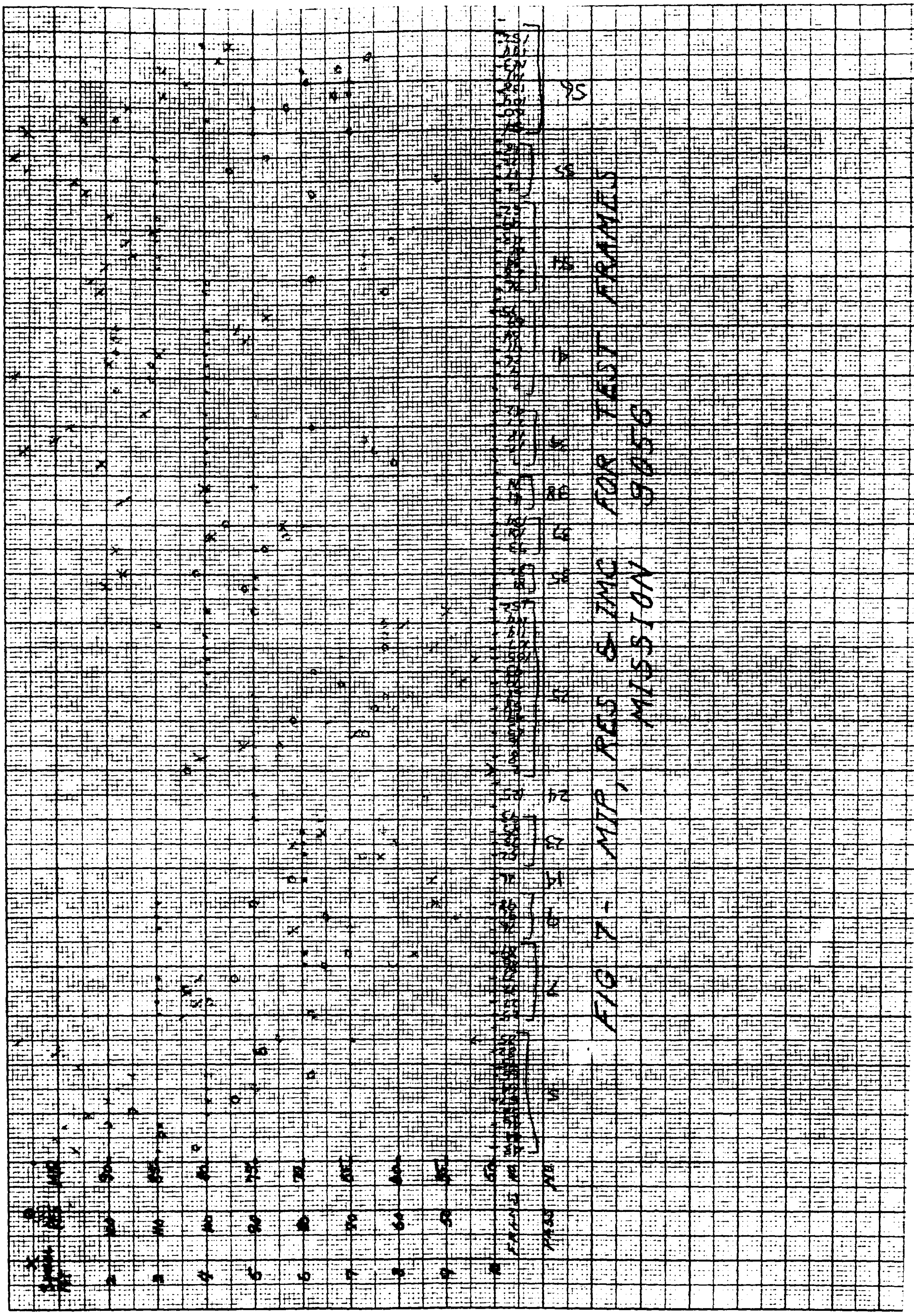


FIG 7 - MTP, RES & IMC FOR TEST FRAMES
MISSION 9056

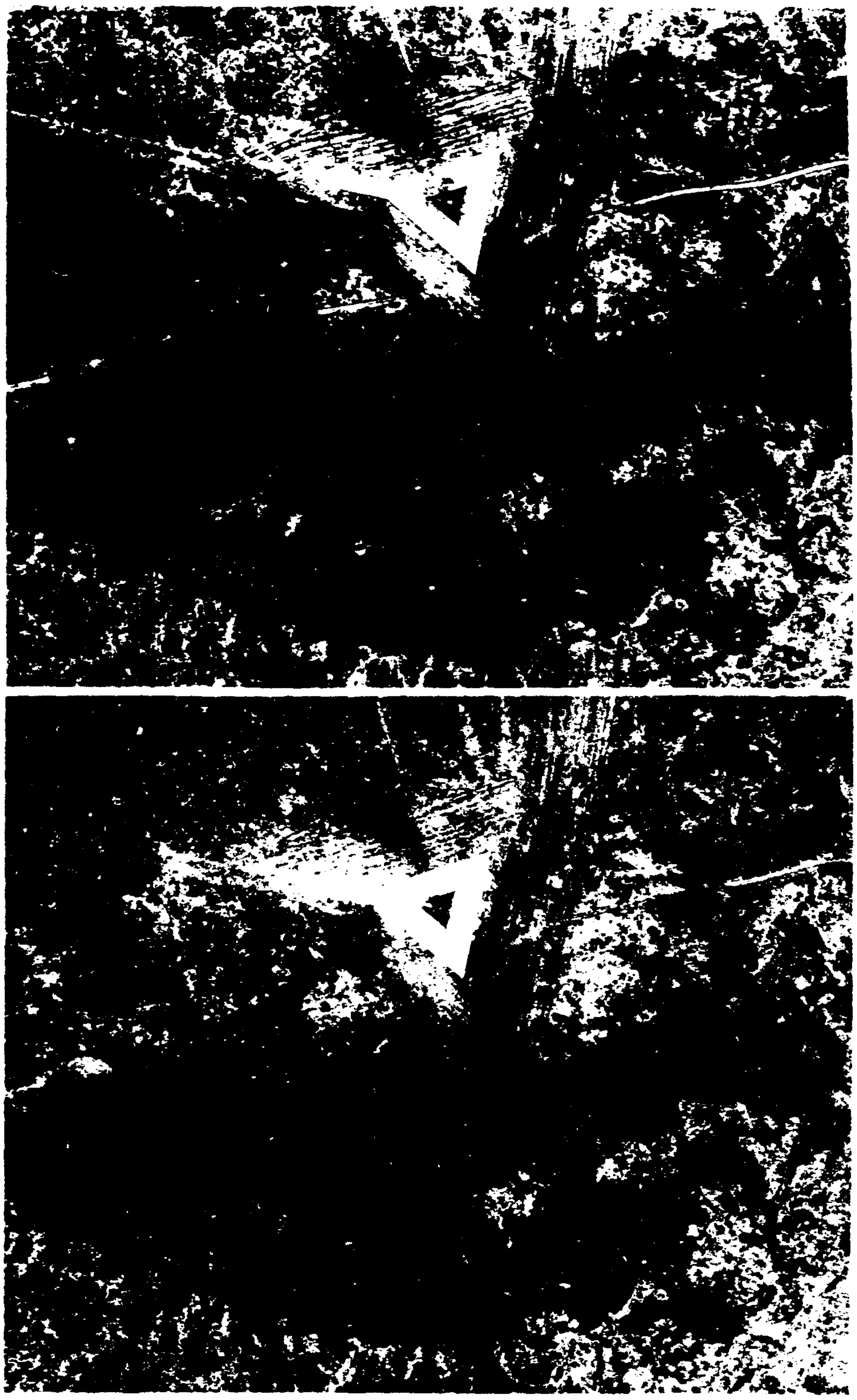


Fig. 8 - Effect of Solar Altitude on Visibility of Ground Details

El Adem: June 3rd 1958
6" F.49 Camera: [illegible] feet: Enlargement X [illegible].5
Upper: Time: [illegible]6.42. Solar Altitude: [illegible]°4'.
Lower: Time: 1[illegible].15. Solar Altitude: 7[illegible]°[illegible]4'.
Neg. Nos. 1[illegible] [illegible]7 and 6[illegible]

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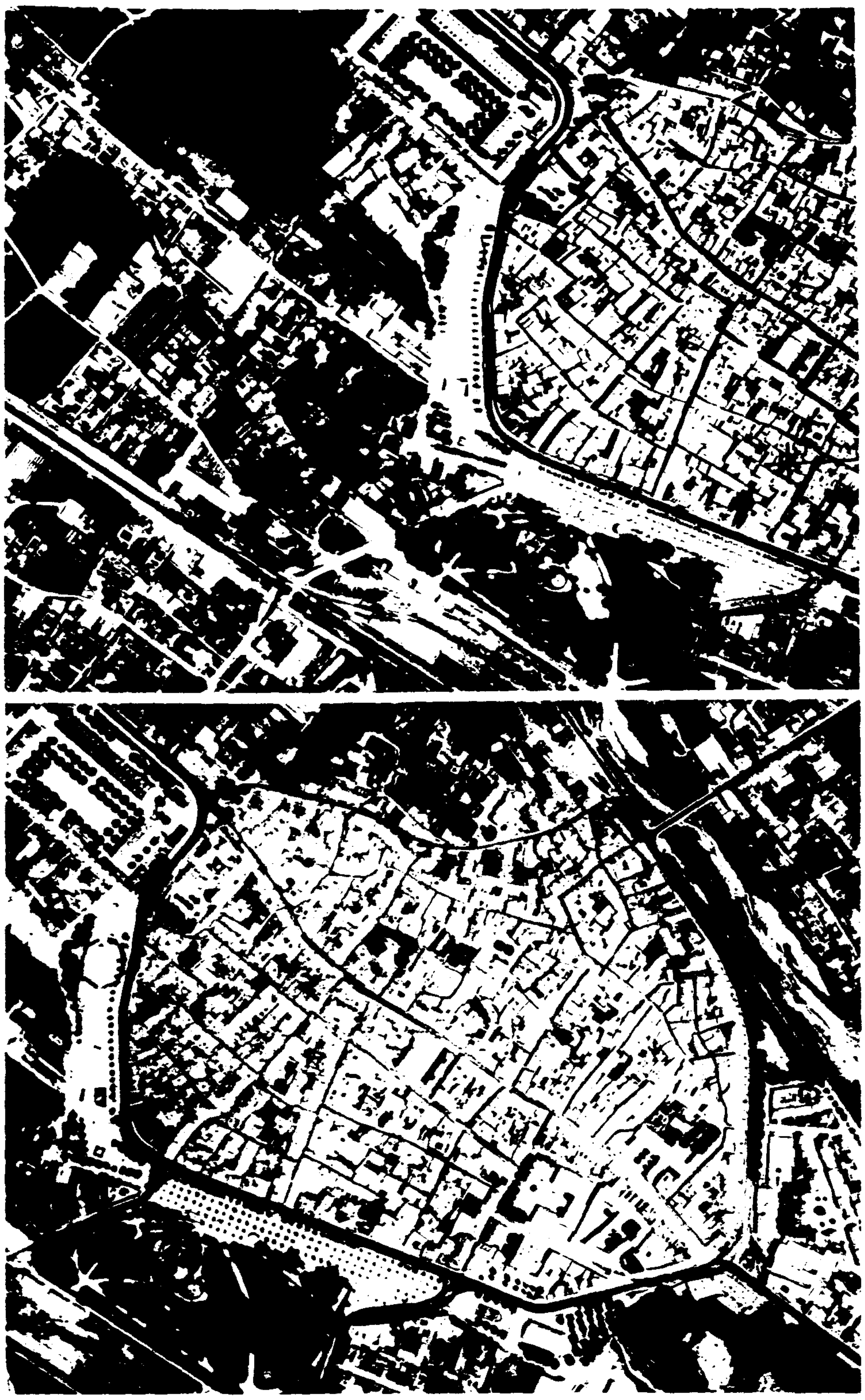

Fig 9. Showing Loss of Contrast when Co-Incidence of Angle of View and Angle of Illumination Eliminates Shadows

Montelimar: 31st May, 1958.
5" F.24 Camera: 5,000 feet: Enlargement X 2.35
Successive Photographs in a Line Overlap.
Same Solar Altitude.
Neg. Nos. 13[illegible]/1 and 3.

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would be premature and the question of C/M's performance is still to be decided by continued measurements by edge scans and GEMS.

Beyond determining a level of average performance in terms of limiting resolution in l/mm for 2:1 contrast targets we would like to determine a mean spread in performance about this average. Neither the edge scan nor GEM measurements have advanced yet to the level that we can with any certainty deduce this spread from observations. The observed distribution reflects both that of C/M performance and that of the measurement technique itself. Presently available data are presented in Tables 1 and 2, in Figures 1 and 2 for edge scans, and Figures 10, 11, and 12 for GEMS. We cannot answer why the system is apparently performing often at twice the resolution that it shows at other times. A statistical analysis of anticipated spread in resolution from image motion blur and design focal limits of uncertainty should be made. More confidence in computing an anticipated spread in performance will be possible once physical parameters in orbit are determined.

The potential values of GEMS for relating the physical characteristics of the photographic image with its intelligence value to the PI remains to be explored and further work in this direction is recommended. Table 3 below compares and summarizes various methods of measuring image quality.

B. Measurement Program

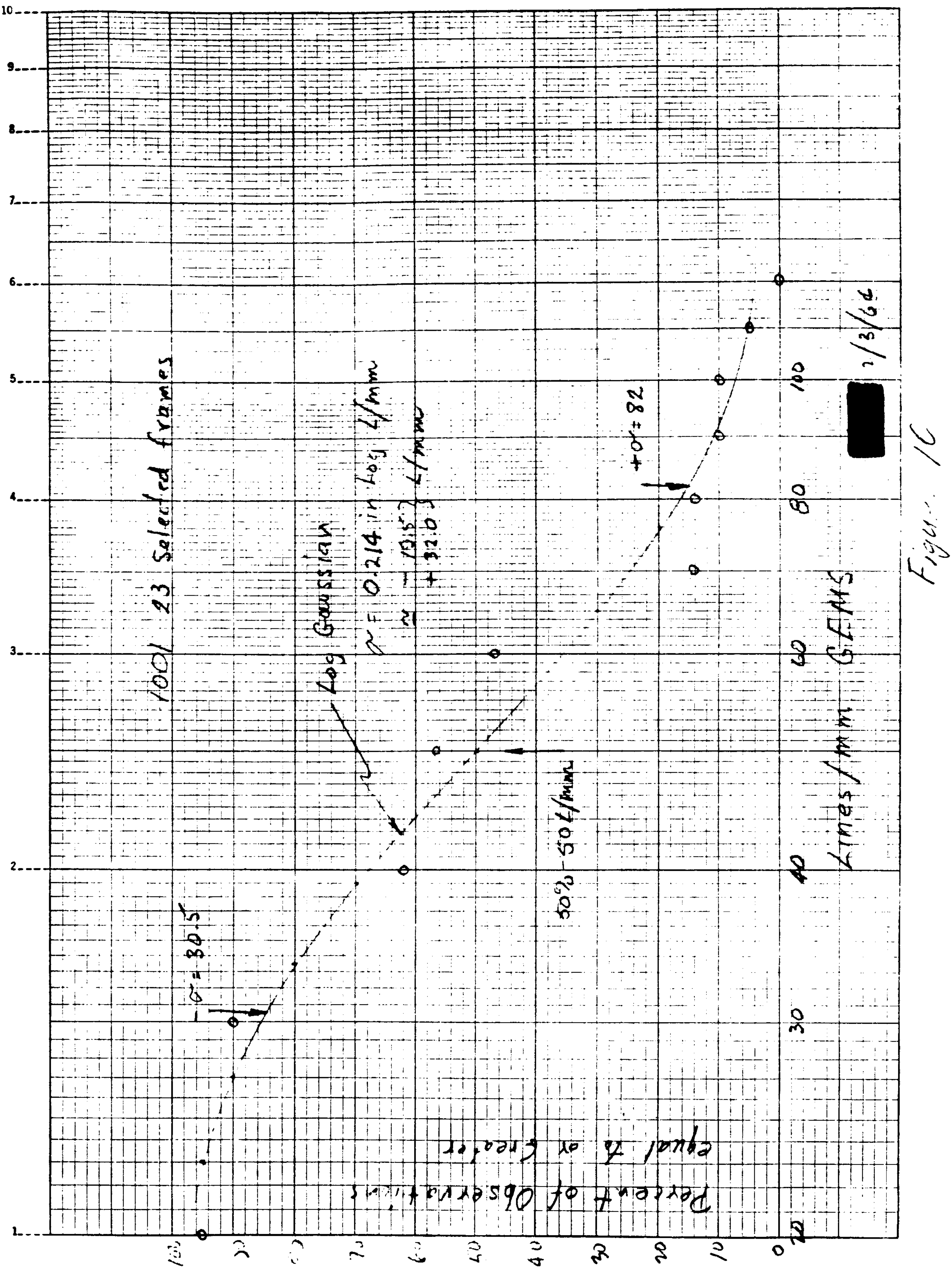
1. In-flight and ground measurements for obtaining engineering data to check on system performance in the operational environment and to correlate with image quality. The C/M system is subjected to extensive laboratory tests on the ground in Boston, Palo Alto, and Vandenberg to check its operation both before and after thermal and pressure changes, in different gravity orientations, and after vibrations. These tests are designed to cover the range of parameters anticipated during launch and orbital phases.

There are, however, several critical areas where orbital data are lacking and ground studies inconclusive. We do not now know, for example, whether thermal gradients and transients degrade actual system performance in flight. No in-flight measurement program exists for determining the temperature inhomogeneities during flight due to variable sun angles and camera barrel exposure to space, and furthermore, there is no in-flight verification that the focal point is at the film. Remedies for these deficiencies are proposed. They require a continuing in-flight measurement

Table III - Comparison of Various Method of Image Quality Measurement for C/M Photography

	Static Laboratory Test of Instrument	Dynamic Laboratory Test of Instrument	Operational Evaluation of Technical Performance	Operational Evaluation of Quality for Photo. Interpretation
1. Sine-wave Analysis	Ideal	Much more data compared to (3)	Targets too large	Limited value because relationship to PI usefulness requires more study.
2. Edge Scan	Less convenient and precise but related to (1) and (3)	Less convenient and precise but related to (1) and (3)	Good, more available than (3)	
3. Three Bar Targets	Suitable	Suitable	Suitable if large enough to produce edge trace	
4. RES	N. A.		Convenient but method and accuracy not validated	
5. Photographic comparitors (GEMS)			Possibly good. Precision not validated.	Expected to be of use as experience is gained.
6. MIP			Not intended for this purpose.	Subjective judgment includes scale, haze, subject matter, illumination, etc.

[redacted]


1001 23 Selected frames
Log Gaussian
$-\sigma = 30.5$
$+\sigma = 82$
50% - 50 L/mm
Lines/mm GEMS
Percent of Observations
equal to or Greater
1/3/66
[redacted]
Figure 1C

[redacted]

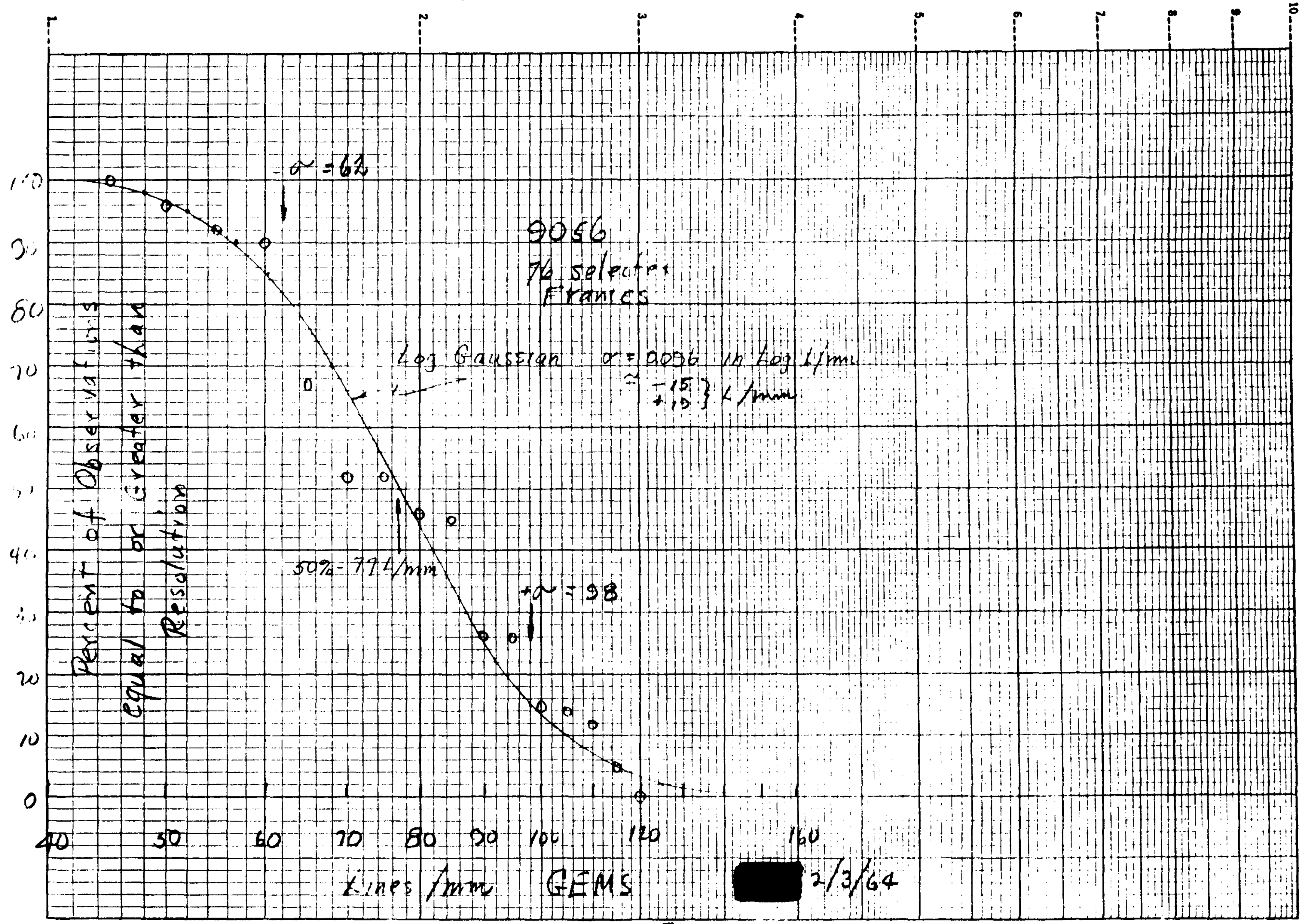


Figure 11

Handle Via [redacted] Control System Only

program not seriously interfering with operational activities and designed to:

a. determine if the camera stays in focus, and

b. measure local temperatures of the camera system.

Furthermore, a vigorous and more thorough laboratory study with a theoretical model is encouraged to complement this program, providing more details as to where to put temperature sensors on board and pointing the way toward improved thermal control.

Additional ground tests over a wider range of parameters for checking film flatness are suggested. These should include a broad temperature range and should be designed to test vibration during exposure.

Another recurring plague of C/M photography is corona discharge. Laboratory tests suggest that if the film were maintained at a pressure of 20μ to 100μ instead of at ambient this condition would be controlled. Work is in progress to develop a light weight pressure system and should be pressed with full support. In view of the recurring serious corona problem a suitable system for maintaining pressures above 20μ, even if not at optimal one, should be introduced in C/M as soon as possible, along with periodic pressure monitoring. A reexamination of the entire question of unwanted sources of light in C/M operation is suggested.

Direct tests on film properties and sensitometry are discussed in Section C. We recommend that the decision to avoid change of exposure in-flight be reexamined.

2. Engineering Passes Over Ground Targets. It is recommended that these be carried out over properly designed targets and the present program extended until one is driven to the conclusion that the system is working up to its design potential. Simultaneous recording of component performance in the measurement program described in the preceding section is necessary to permit degraded imagery to be correlated with physical causes. The resulting loss of operational coverage resulting from such a program is not significant and is a very worthy investment.

An aerial ground target of minimal size is designed which permits determination of the transfer function $t(k)$ from edge measurements on the scale of C/M photography as well as for any system of comparable or superior resolution. This determination is independent of any DC reductions of contrast such as may be caused by light leaks, corona fogging, or atmospheric haze. Deployment and use of standard resolution targets accompanying the edge gradient targets is also encouraged.

In order to determine the loss of contrast in C/M mission photography due to recurring serious corona difficulties and of other unwanted film exposure, it is desirable to remove the contrast reduction due to atmospheric haze alone. This could be done by flying a photometrically calibrated camera, using identical film and processing, in an aircraft at high altitudes over targets of known ground contrast at approximately the same time as the satellite engineering pass. This is not envisaged as a continuing test program but one to be terminated as confidence is gained that extraneous light is not fogging the film. Relative merits of different filters and slit widths could also be assessed by such a program once the airplane is flying.

C. Film Processing and Sensitometric Strips

1 & 2. Film Processing. No appreciable degradation of limiting resolution in the C/M photography was found to result from film processing. It does appear, however that the processing has frequently been to a fuller level than that to which the mission is designed.

The exposure criteria are based on two series of experimental data collected from aircraft and aerial reconnaissance cameras. These data are further reviewed in the light of analysis of current operational results. We recommend the resumption of a program to review exposure criteria and chemical processing, and the modification of procedures as found appropriate to maximize the final product quality. The exposure latitude of the film (higher D max) should be extended without introducing adverse effects.

3. Sensitometric strips. Sensitometric strips are controlled exposures which provide a calibration of the characteristic curve (density vs. log exposure) of the mission film. If desired as a monitor of film processing uniformity throughout a mission, sensitometric exposures should be placed frequently along the edges. This is done most conveniently after flight exposure and just prior to processing. They appear to be attractive as an adjunct for edge measurements since sensitometric step wedges on each frame can be used conveniently for calibrating the microdensitometer and film combination out of the edge trace. Trial evaluation of sensitometric strips is recommended.

D. Atmospherics

1. Calculation of weather effects. The transfer function of the atmosphere plays an important role in the considerations of each of the three preceding sections. For example, in designing to a transfer function there would be limited value in striving for a lens transfer function which achieved a resolution substantially

dulled by turbulence. Likewise if the haze attenuation presented only objects of low contrast to the lens it would be for such objects and not for high contrast ones that it would be desirable to optimize the resolution.

The effect of turbulence on the transfer function is negligible on the scale of 10 ft. ground resolution photography (2×10^{-5} rad angle). However, there is appreciable contrast, or modulation, reduction as a DC effect of haze. This is very sensitively dependent on local weather and its degree of predictability over hostile territory is undetermined. There are suggestions that it may be correlated usefully with atmospheric humidity, which can be predicted with a measure of reliability, and a study of the type recently concluded at Wright Field deserves renewed support and encouragement. Analysis of atmospheric parameters in conjunction with the overflights discussed in section B.2 will be useful in this study. Once it has been ascertained that the image contrast is determined primarily by haze and not by corona or light leaks, GEMS as discussed in section A.2 may be of value for measuring reduction of modulation resulting from haze.

2. Prediction of weather. The extent to which world-wide weather data as available from weather satellites can be integrated into the mission orbit selection was explored briefly. The enormous benefits to be gained by a substantial reduction in the present average of roughly 50% cloud cover in mission photography justifies further investigation.

E. Stereo

No one questions the desirability of having a stereo capability in the C/M system. The only question has to do with the relative value of trading off some stereo coverage in order to increase the total geographic coverage. Our inquiry into this question of trade offs was a very limited one and we offer no recommendations. However, we believe the present equipment at NPIC is inadequate for extensive viewing of stereo.

F. New Ideas

1. We looked into the possibility of using spatial filtering with coherent light. This does not appear to have practical application to the C/M system at this time because we are working too near the grain limit of the film.

2. The possibility of on-board sensors to provide the C/M camera with an in-orbit capability to decide to take or not to take pictures depending on cloud cover

deserves more study. With the present weather satellite program, a correlation of cloud cover and other sensor data with geophysical features can be measured and evaluated for suitability in this.

G. <u>Conclusion</u>

We have not answered the question posed in the first sentence of this report. Rather we have emphasized the fact that at this rather late date there still remains the need to construct an objective and quantitative measure of image quality that is both reliable and operationally practical. Although promising techniques were discussed and measurements were made toward filling this need, much continuing work is required.

In addition we have very strongly emphasized the urgency of a measurement program in order to identify sensitive parameters of the C/M system and orbital environmetn which limit the present performance level. Such a measurement program, as well as timely, systematic performance analyses are needed to close the loop back to the system designers who have thus far received extremely limited feedback on the performance of individual components.

While sympathizing with the priority of maintaining an operational schedule we recommend that an increased number of research and developmental tests be included in the C/M program. The potential value to be gained for this as well as other satellite reconnaissance programs is very high.

We also feel that the C/M program has been restricted and compartmentalized by security regulations to a detrimental degree. For example, photography taken on domestic engineering passes need not be kept behind the walls of Talent and Keyhole classification but should be made available to the much broader community with the Corona clearance since it is of great technical value for systems engineering analyses.

III. A.I. Edge Scan

Introduction

As an objective measure of image quality of operational photography, the analysis of microdensitometric traces of scene edges is recommended. There is a well understood relationship between a photographic edge and the transfer function of the instrument which imaged that edge. System specifications and pre-flight measurements can be related to this transfer function. However, the practicability of this measure for instrument evaluation has not been demonstrated. Continued refinement of techniques is required to improve the precision which can be achieved and to reduce the effort involved in making the measurements.

The limitations of edge trace measurements must be pointed out. The transfer function derived from an edge trace is, in principle, independent of contrast or density level, within the limits of experimental error. Hence, the edge trace measurement is not an indication of some instrument defects such as corona discharge, fogging, and veiling glare. Secondly, the measurement is sensitive to the accuracy of sensitometry and to the quality of and absence of stray light in the microdensitometer. These factors limit the precision of the measurement and demand careful technique. Finally, in dealing with an edge on the ground, one cannot be absolutely sure of its sharpness and straightness, a matter which is fundamental to the measurement. For example, a painted edge on a runway strip or a non-abrupt transition from pavement to grass may lead to errors. At the present time, for C/M photography, it is necessary to use long edges associated with very large objects which can be recognized well enough to give reasonable assurance of original sharpness. Panoramic distortion causes edges to curve and this may limit the location and orientation of edges which can be used. Careful examination under high magnification helps eliminate obviously improper edges.

Method

Only a very brief description of the method for deriving the transfer function will be given here. Details are still to be developed as techniques are improved.

The choice of an appropriate edge is discussed above. A microdensitometric trace of that edge is then made with an instrument which is as free from stray light as possible. The instrument must be calibrated against a sensitometric exposure on the same film with identical processing. With these calibration data, the edge trace is reduced to exposure versus distance across the edge. Smoothing to eliminate grain noise is essential and, at the present time, is done by hand. The resulting curve is normalized, thereby eliminating the effect of contrast change. There is now a direct mathematical transformation to the system transfer function which includes lens, image smear and film. The microdensitometric transfer function may be removed approximately by division, or more accurately by a procedure which takes into account the non-linearity.

Resolution at some specified contrast ratio can be inferred from the system transfer function, from the known transfer function of the film and from the film threshold modulation curve (aerial image modulation, or AIM curve). Most of the data presented in summary are in this form so that a single number can give an approximate description of the performance.

It is also possible to derive the line spread function of the system plus the microdensitometer by taking the derivative of the edge trace plotted as exposure versus distance. The line spread function is the distribution of light in the image of a very narrow line. Obviously, as the spread function widens, the quality of the image decreases. Therefore, it is also possible to describe image quality as the width of the line spread function at some appropriate level, such as half the height. In this case again, the normalization removes the effect of contrast and density level. Obviously, the transfer function of the microdensitometer must be near unity or it will overshadow the image quality of the system being studied.

As one would expect, there is a fairly good correlation between inferred resolution and half-width of the spread function. The correlation cannot apply consistently to each edge scan since line spread functions of the same half width but various shapes will have different transfer functions. However, both half width and inferred resolution can be used for single parameter evaluation and experience will have to dictate which is the more practical tool. Neither inferred resolution nor spread-function half width, being single parameter measures, contain as much information as the transfer function. At the present time, however, it is not certain that the transfer function derived from an edge trace contains meaningful detail because of grain noise and other instrumental effects.

<u>Refinement of Edge Scan Technique</u>

Since there is still a great deal of uncertainty in edge scan analysis, further refinement is required. Based on the present knowledge and understanding of edge scan analysis, it appears reasonable to establish the following immediate and long term goals.

1. Establish the reliability of measurements with laboratpry experiments.
2. Determine the most promising data handling technique.
3. Measure the variability of existing microdensitometers.
4. Determine the working practicality of any feasible methods developed.
5. Accumulate data from future missions.
6. Determine if extending the analysis to past material is warranted.

Some experimental work has been completed to establish the reliability of measurement. These laboratory experiments involved the use of edges, resolution charts, sine-wave targets and sensitometric strips, all photographed simultaneously on type 4404 film. Resolution was read directly and was compared to resolution inferred from the transfer functions derived from edge traces and sine-wave targets. The results of this study, Table Al-1, indicate that resolution can be predicted with reasonable accuracy and repeatability but that errors increase rapidly as resolution and lens aperture are increased.

Further laboratory tests are recommended to establish the effects of density level, density difference, microdensitometric technique, computational method, calibration procedures, etc. It is proposed that a working group, including representatives of principal laboratories, carry out this work. Because of the urgency of the situation, a short range goal must be established to develop a useable technique which can then be applied to operational photography. There should also be a longer range program with the purpose of continuing to improve and extend the utility of edge scan measurements. This program would be designed to provide definitive answers to the following questions:

1. What accuracy is possible in obtaining the transfer function from edge trace data?
2. How repeatable are the results?
3. To what extent can the techniques be used in a routine way outside the laboratory?
4. How can one reliably select an edge for measurement in operational photography and be confident it meets the necessary requirements?

TABLE A1-1 Summary of Laboratory Test of Edge Scan

Lens Aperture	Resolution Chart Reading	Resolution at 2:1 Contrast Ratio: Inferred from edge scan	Resolution at 2:1 Contrast Ratio: Inferred from sine-wave targets
f/5.6	115	93	117
f/8	99	100	114
f/11	87	87	91
f/16	71	74	72
f/22	53	50	47
One σ variation for a series of tests at f/8	7.9	14.9*	4.7*

*There is additional uncertainty from the resolution threshold curve.

Assuming that the results of the laboratory investigations are positive, namely that a useful determination of the transfer function is possible, it would then be desirable to consider the problem of working with edges in aerial photographs of man-made objects. The goal would be to determine a set of working rules for selection of edges which would give consistent measurements.

Edge Scan Measurements on Mission Material

A very limited number of measurements have been made on C/M photography. A modest number of these measurements will be made on future mission material under an existing contract to aid in developing the technique. If any large scale measurement program is to be performed, it should be done by NPIC or SPPL. However, no firm conclusions should be drawn from the measurements until the technique and its shortcomings are well understood and the decision has been made that it can serve a useful purpose.

Edge scan measurements which have been made are reported in Section III, A3. Because the data were obtained and analyzed during the same period that the edge scan technique was being refined, one should avoid drawing firm conclusions about the image quality. Individual data can have unexpectedly large variations; for example, two different sections of a runway image can yield different results. Consequently, the dispersion of indicated quality undoubtedly includes deficiencies of measuring technique as well as real quality variations. However, the mean values undoubtedly have some significance and correlate to a reasonable extent with other measures (Section III, A3). It is interesting that edges photographed during the engineering pass of 9062 yielded higher than average resolution, 136 lines/mm at 2:1 contrast ratio for an average of seven edges, but a ground target (Webster Field) indicated slightly less than 100 lines/mm at an estimated contrast ratio of 3:1 or possibly 4:1.

Conclusions

Significant strides have already been made in the use of edge traces to evaluate photographic image quality. Laboratory experiments indicate reasonable accuracy and repeatability. However, application to mission photography over a range of contrast and density is much more difficult and the uncertainty of the sharpness of the original edge must be considered. Further refinement of technique is necessary before this tool can be used with assurance.

III. A.2. Measurement of Image Quality by Comparison

Discussion

As the result of a search for a rapid and convenient method of evaluating image quality, it is suggested that a series of scenes of known quality be prepared which could be compared by eye with images whose quality is to be determined. The quality of an image is dependent on several attributes and, in some cases, on the use to be made of the image. For the purpose of gathering intelligence by photographic reconnaissance, the dependence on use may be removed by making the comparison between images of scenes of approximately the same type of subject material. Some variation of suitable material may well prove advantageous in order that image quality may be evaluated when only a limited variety of subject is available in the scene. It may be that a synthetic scene made up of various geometric shapes and contrasts would provide a more suitable basis of comparison than any natural scene and this should be studied as a part of the continuing program. Another alternative which should be the subject of eventual investigation is the use of a comparison scene generated by the combination of many parts of natural scenes containing a considerable variety of material.

Those attributes of quality which it would be desirable to simulate are:

1. Information Content

Here information is used in its generalized meaning having to do with the spatial frequencies present in the image. Such comparison scenes could be prepared from a single original by successive degradation of quality in known steps. It has been practical in the case of the comparison scenes prepared by ITEK to provide this degradation in quality by changing the focus of the copying camera by various amounts. These scenes are imaged on the same negative material and at the same scale as C/M photography. The resolution of the degraded copies has been judged from three-bar targets imaged with the scene. An alternate method used by [redacted] to prepare comparison scenes has been to make nearly contact prints in which the separation of original and print together with the shape of the light source provides a pre-selected transfer function between original and print. There is a well-known effect in the variation of image quality due to a variation in the shape of the transfer function even though the limiting resolution may be held constant. This effect has been discussed by Higgins[(1)]. System defects of the sort characterized by defect of focus or random image motion move the transfer function as a whole toward lower frequencies. Other types of defects such as optical errors producing small and random distortions of the wave front change the limiting resolution very little but have a stronger effect at intermediate contrasts. No attempt has been made as yet to separate these effects but it may be that after the method is refined some results will be observed permitting analysis of these differences.

The question of the size of resolution steps between samples best suited for comparison has been considered. The samples presently at hand were prepared with the aim of obtaining a $\sqrt{2}$ change in limiting resolution between each step. The observers who have used these samples agree that smaller steps should be used in the next set to be prepared and $\sqrt[3]{2}$ has been suggested.

2. Contrast Range

The apparent quality of an image of a scene is affected by the contrast of the image. In order to make the selection of a comparison scene of the same image quality as that of the sample in an information content sense as accurate as possible, other variations between the two must be matched as well. One of these is contrast, the range of brightness variation. It has not been established just how well this quality need be matched for optimum accuracy but the two grades of contrast available in the ITEK samples may be too few. The next set should have three or perhaps four such steps.

Since natural effects, haze, high thin clouds and natural variations of terrain as well as defects such as corona, light leaks, improper exposure or processing all reduce contrast, the grading of results on the basis of the contrast variable alone is expected to yield useful information.

(1) Ap. Optics, Vol. 3, 1, 1964

3. Graininess

The resolution of an optimized photographic system is often limited by the grain of the sensitive material. The appearance and thus the quality of the image is also strongly affected by the grain. For these reasons the comparison scenes should simulate or duplicate the grain of the scene in question quite closely. It is fortunate that the exposure and processing of the material used for most of the work under investigation are quite uniform and thus the graininess appears also to be uniform. If, however, other processing is to be considered or wide variations of graininess are encountered then the samples must reflect or encompass this variation as well.

Status of Current Work

The term GEMS (Graded Estimated Measuring Samples) has been coined for designating the comparison samples discussed in the foregoing. A first set has been prepared by ITEK for initial evaluation of the procedure. This set was prepared in the following way:

The GEMS were made in the laboratory to match the following characteristics of the operational photography:

a. Scene - Urban Area

b. Contrast - Medium

c. Scale - 1:325,000

d. Negative Material - Type 4404

e. Processing - Full

f. Positive Material - 8430

The Target Panel

High quality original 1:2000 vertical photography of a large urban area was used as a starting point.

Since this photography was made at low altitude without much haze, it had a somewhat larger brightness range than the same scene would have presented for a high altitude system. To decrease the brightness range the negatives were printed at about 0.6 gamma onto matrix material, producing a somewhat reduced contrast aerial scene. It must be recognized that this is not an accurate simulation since the effect on the contrast of shadow generated will be incorrect.

Two 9x9 transparencies were placed side by side on a light panel along with high and low (2:1) contrast resolving power charts, and sensitometric strips.

The Reduction System

This target panel was photographed at an object distance of 163 inches by a camera with a one inch focal length f/2.3 Baltar lens on Type 4404 film.

The Production of Various Quality Levels

To produce GEMS of differing quality a through-focus series of exposures was made thus producing pictures in sharp focus as well as others with varying degrees of sharpness.

The Processing

The 4404 material was processed fully in D-19 to produce a granularity similar to that of fully processed operational material.

The Resolution Levels

The resolutions obtained in the pictures were determined from the images of the 2:1 contrast targets. Negatives with the following resolution levels were selected for the "GEM" mosaic.

1	148 Lines/mm
2	105 Lines/mm
3	66 Lines/mm
4	53 Lines/mm
5	37 Lines/mm
6	26 Lines/mm
7	17 Lines/mm

The Positive "GEMS"

Positive transparencies of these "GEMS" were produced by contact printing the negatives onto 8430 positive material. The printing was accomplished with large printing pressure and a point light source.

The positives were developed in D-19 to printing gammas of 1.3 and 1.8. The series of 7 positive GEMS was mounted as a mosaic between 3¼" x 4" cover glasses for ease in handling. Figure A.2.1 shows a 4X enlargement of the GEM mosaic of the 1.8 gamma positives. Because of low magnification in the reproduction process it is difficult to detect the quality differences between successive steps.

The Optical Comparison Equipment

To compare the "GEMS" with operational material of unknown quality two monocular microscopes are employed, one for viewing the "GEMS" mosaic and the other for

~~TOP SECRET~~

148 LINES PER MILLIMETER

105

66

53

37

27

17

5X ENLARGEMENT, GEM MOSAIC
~~PRINTED ON FINE GRAIN AERIAL DUPLICATING FILM~~,
~~TYPE 8430; DEVELOPED TO GAMMA 1.8~~

~~TOP SECRET~~

the operational material. The fields of view of the two microscopes are brought together by a comparison eyepiece. Figure A.2.2 shows the equipment. The eye-piece, of the type used for bullet comparisons, presents a circular field of view with a vertical dividing line. On one side of the dividing line the image from the GEMS mosaic appears while on the other side is the image of the operational material.

With this simultaneous viewing the judgment of quality differences is simplified. Figure A.2.3 shows three separate comparisons as seen through the comparison eyepiece. View A shows operational material and a "GEM" that is two steps better in quality. View B shows the same operational material with a "GEM" that is about equal in quality. View C shows the same comparison with a GEM that is two steps poorer in quality than the operational material.

In making the judgment the brightnesses of the two halves of the split field must be approximately the same. To accomplish this a series of neutral density filters has been provided. In addition, a continuously variable transformer, VARIAC, has been supplied for fine adjustment. By using the appropriate neutral density filter and the variable transformer, minor color differences between the appearance of the GEMS and the operational material can be made negligible.

<u>Viewing Magnification</u>

The viewing magnification is critical only in the sense that it must be the same for both microscopes. However, it should also be sufficient to allow the observer to see the fine detail in each picture. For example, the quality steps in Figure A.2.1 do not appear to be very large. This is because insufficient magnification was used in making the reproduction (and, indeed, a loupe will probably not help much either since the print quality is a limiting factor.) Viewed at unit magnification the GEM mosaic shows little or no scale of quality.

Hence the magnification employed for the comparison must be high enough to allow the observer to "see the fine details" in the picture. One consequence of insufficient magnification is that the observer would use factors other than fine detail, such as contrast for finding quality.

The magnification required for reading resolving power charts is normally equal to about $\frac{1}{2}$ the number of lines per millimeter which the picture resolves. More magnification than this decreases the edge gradients seen by the eye and thus makes the picture bigger and less sharp without revealing more significant

COMPARISON MICROSCOPE ARRANGEMENT

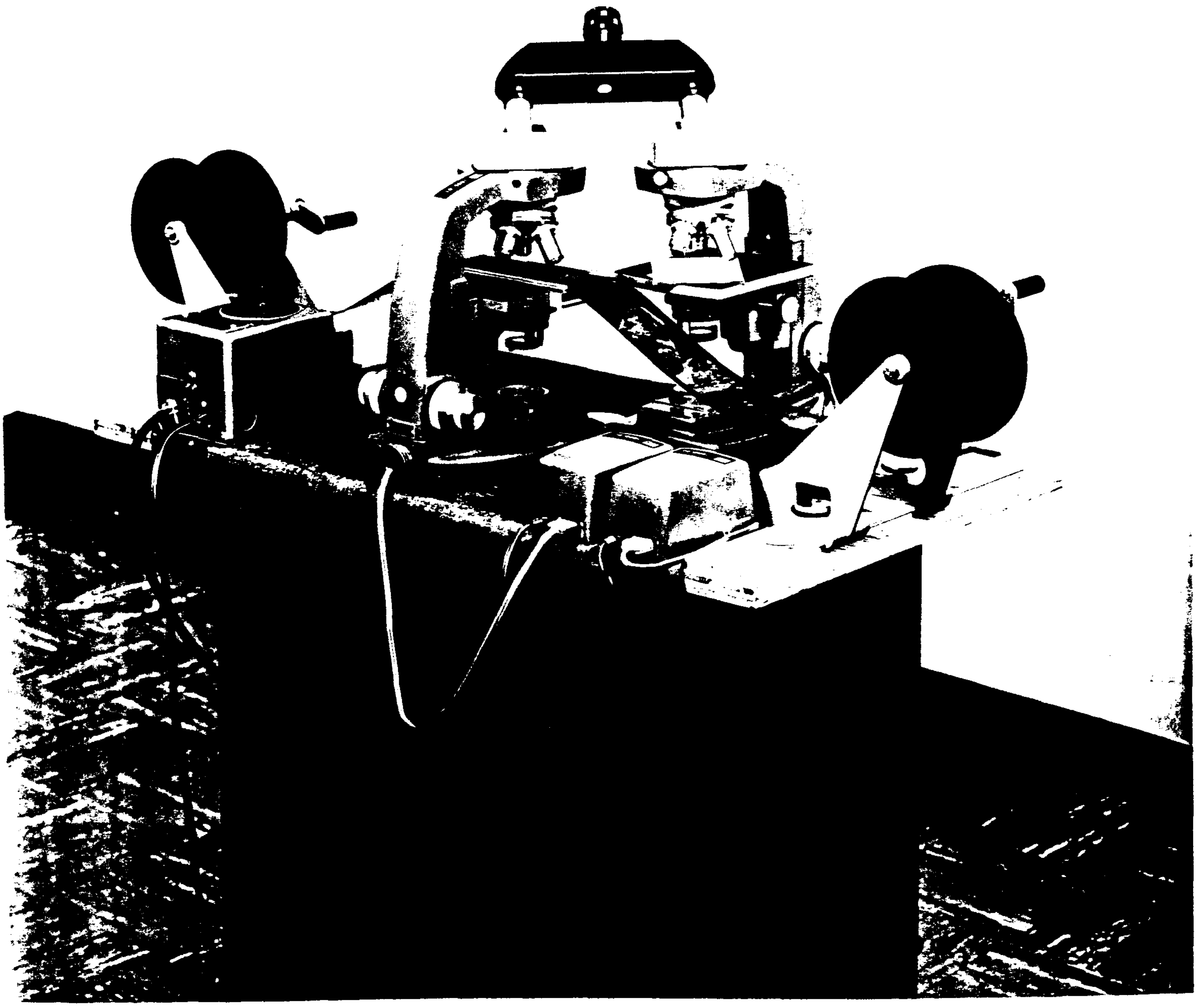


FIGURE 2

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CONTROL SYSTEM

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TYPICAL IMAGE COMPARISON 50X

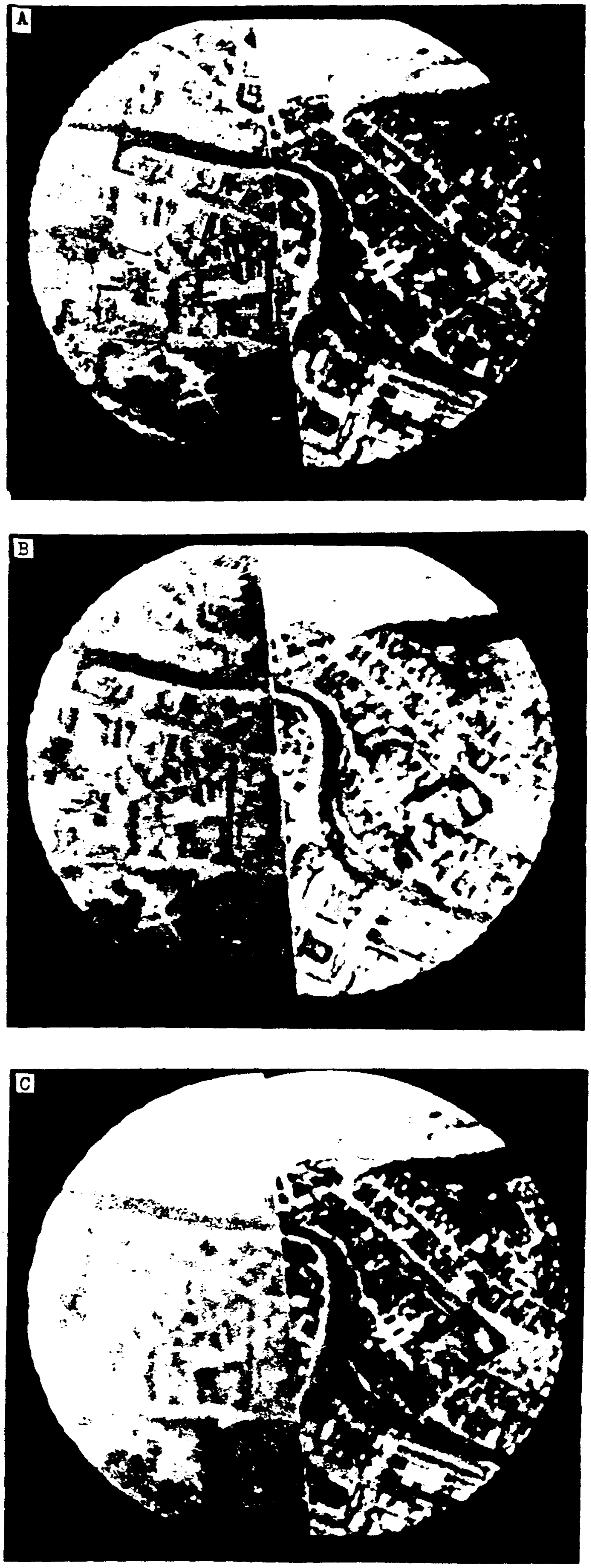


FIGURE 3

detail. On the other hand, the use of considerably less magnification, say a factor of 4 smaller than $\frac{1}{2}$ unit per line per millimeter, would mean that the limitations of the eye itself would be important. In other words the transfer function of the eye related back through the viewing system to the target material becomes an appreciable limitation on the reading of detail. For comparing differences one might expect lower power to be required than for reading targets.

In general, because of differences in visual acuity, the observer should use the lowest power with which he can see all or most of the available detail.

The comparison microscopes are provided with 5X eyepieces 10X eyepieces and $3\frac{1}{2}$X, 10X and 21X objectives. The comparison eyepiece is unit power.

We have found that 50X seems sufficient magnification for judging differences in quality. In many cases 17X appears satisfactory. However, it should be noted again that although differences in quality can be seen with lower power it appears that differences in contrast will affect judgment to a great extent when low power viewing is employed.

With proper magnification small contrast differences can be disregarded. In the end, we compared quality on 76 frames mentioned in the [redacted] study only with the "GEMS" printed at a γ of 1.8. In a few cases low contrast detail on the operational material made it difficult to obtain a consistent rating value.

In a repeat comparison rating of the 76 frames it was found that the individual readings in the second set differed from those in the first set by no more than one scale unit. A distribution of the differences is shown in Table A.2-I.

Table A.2-I

Distribution of Second Readings of 76 Frames with Respect to First Readings:

	Number
Second Reading 1 Unit Higher	7
Second Reading $\frac{1}{2}$ Unit Higher	20
Second Reading Same	24
Second Reading $\frac{1}{2}$ Unit Lower	15
Second Reading 1 Unit Lower	9
Second Reading $1\frac{1}{2}$ Unit Lower	1*

*Checking back on this frame showed it to be extremely low contrast with negligible man-made details for comparison.

In making a comparison judgment the procedure was to record the number of the comparison sample which most nearly approximated in resolution of edges or of fine detail that of the operational material. When it was felt that the operational material was about ½ way between two steps this fact was so recorded with the number of both steps shown. In this way half steps were estimated.

The averaged values of the two readings of the 76 frames from 9056 are tabulated with their frequencies of occurrence in Table A.2-II.

Table A.2-II

2:1 Contrast Resolution Levels	No. of Frames
148 Lines/mm	0
105/148 Lines/mm	1
105 Lines/mm	15
66/105 Lines/mm	19
66 Lines/mm	13
53/66 Lines/mm	12
53 Lines/mm	12
37/53 Lines/mm	2
37 Lines/mm	1
26/37 Lines/mm	1
26 Lines/mm	0
17/26 Lines/mm	0
17 Lines/mm	0

It is interesting to note that the variation in resolution shown by these figures is only 4 to 1 when one considers the extreme tails of the distribution. And, indeed, it appears that 93% of the data fall within the 2 to 1 resolution range of 53 Lines/mm to 105 Lines/mm.

Now while these readings appear to be indicative of the camera performance from frame to frame, there may be a subtle bias or spread in these values caused by the appearance of the "GEMS" which are used. Many factors could cause such effects.

1. The original scene, a crowded city area, from which the reduced scale GEMS were made had detail much more closely packed than most of the detail available for comparison in the operational material.

2. The contrast in the target scene appears to be slightly lower than the average as seen by the operational system.

3. The GEMS as currently used do not simulate change of illuminating conditions, relationship of viewing and illumination angles nor the change in ratio of shadow density to mean density.

4. A white light point source was employed for the printing, whereas the C/M material is usually printed with a blue, line source.

5. The degradation in GEM quality was produced by throwing a high quality f/2.3 lens out of focus. This may not adequately simulate focal shifts of the actual C/M f/3.5 lens.

It may be that when the appropriate GEMS have been constructed so that the image characteristics of the GEMS are more nearly similar to the image characteristics of the GEMS are more nearly similar to the image characteristics of the C/M material there will be even less quality variation evident.

One other fact should be pointed out. All studies so far have been done on the 2nd generation positives. This is one step removed from the system performance as recorded on the original negative and provides possibility for additional quality variation. The system evaluation can be much better accomplished by comparing GEM negatives to the ON's of the C/M missions.

III. A.3. <u>Comparison With Other Measures of Image Quality</u>

Reciprocal Edge Spread measurements and Mission Information Potentials are available for 76 frames from Mission 9056. These same frames have been examined by comparison with the first set of GEMS. The results appear in Figures A.3.1 and A.3.2. Because of the dependence of RES values on the average density of the edge (see section on RES) the lack of correlation between such results and the GEMS results is to be expected. The reason for the low correlation with MIP estimates, however, is not so obvious and a program is here suggested to provide input for a better understanding of the usefulness of photographic material of varying quality. This point will be treated further in a subsequent section.

Many frames of the original negatives of Mission 1001 and 9056 have been selected for edge profile measurement. (See section on edge measurements) The limiting resolution of these scenes in the close vicinity of those edges measured has been determined by comparison with GEMS on duplicate positive material. When the transfer function based on the edge trace is used to predict the limiting resolution and this value plotted against the GEMS results, a reasonable correlation appears. Figure A.3.3 is such a plot.

Three missions, 1001, 9056 and 9062, have been examined by GEMS comparisons. In the case of 1001 and 9062, some frames had been selected for edge measurement and it was these same frames, areas close to the edges, which were used in the GEMS measurements. The two missions together yielded resolutions ranging from a low of 27 lines/mm up to 148 lines/mm. These are the points which appear in Figure A.3.10. A line at 45° is drawn on the figure as a reference but there has been no attempt to position this line from the data. In addition, lines of 20% differences in results by the two methods are shown. The correlation would appear to be remarkably good when it is remembered that different traces of the same edge may yield results differing by as much as 50% and two independent GEMS measurements of the same area will differ by 1/2 unit or more 70% of the time and by one unit or more 20% of the time.

The distribution of GEMS measurements for the three missions are presented in Figures A.3.4, A.3.5 and A.3.6. It will be noticed that the resolution scales are logarithmic. These distributions were plotted directly on linear probability paper, on log-probability paper and the reciprocals of resolution plotted on

[redacted]

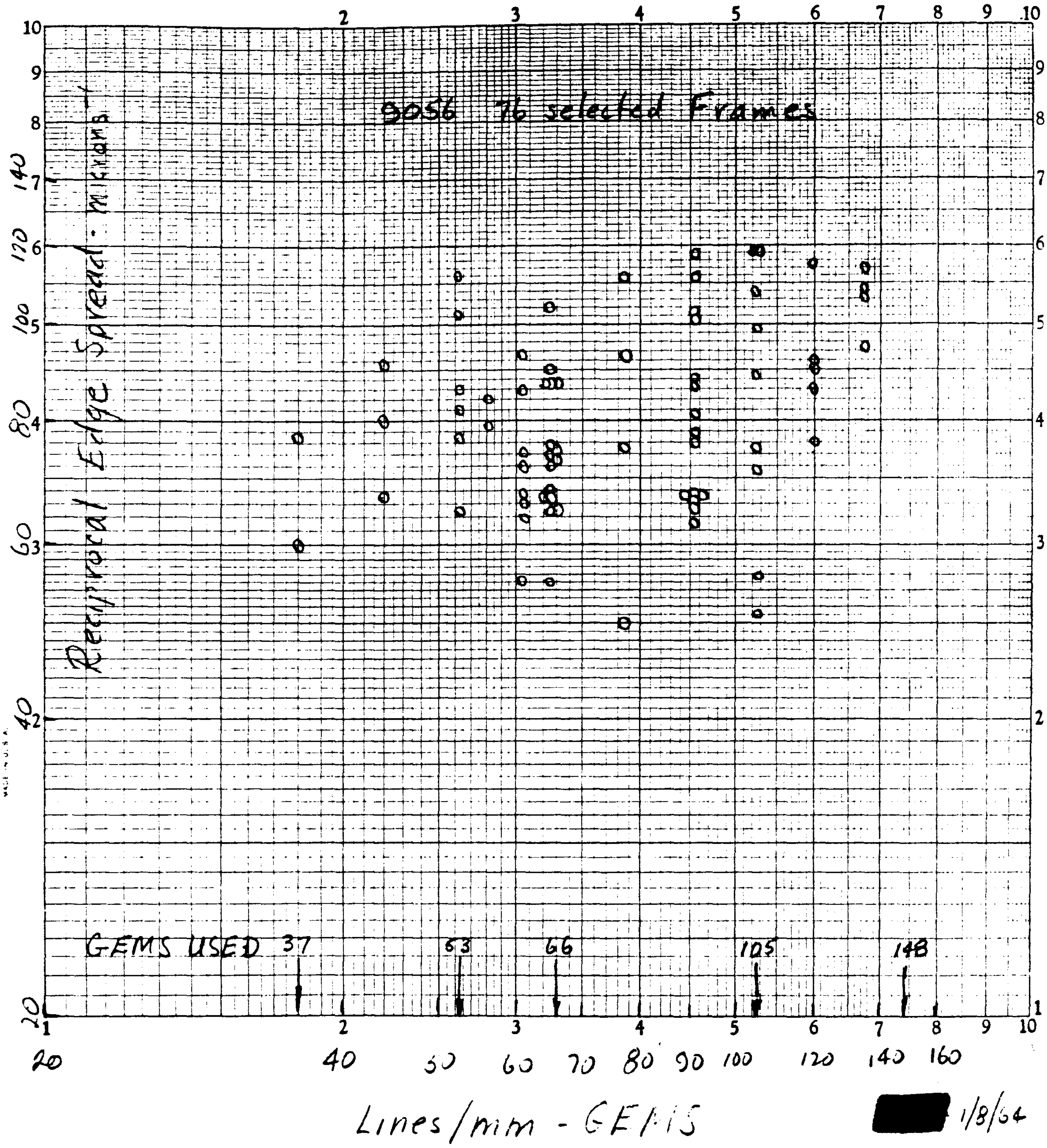
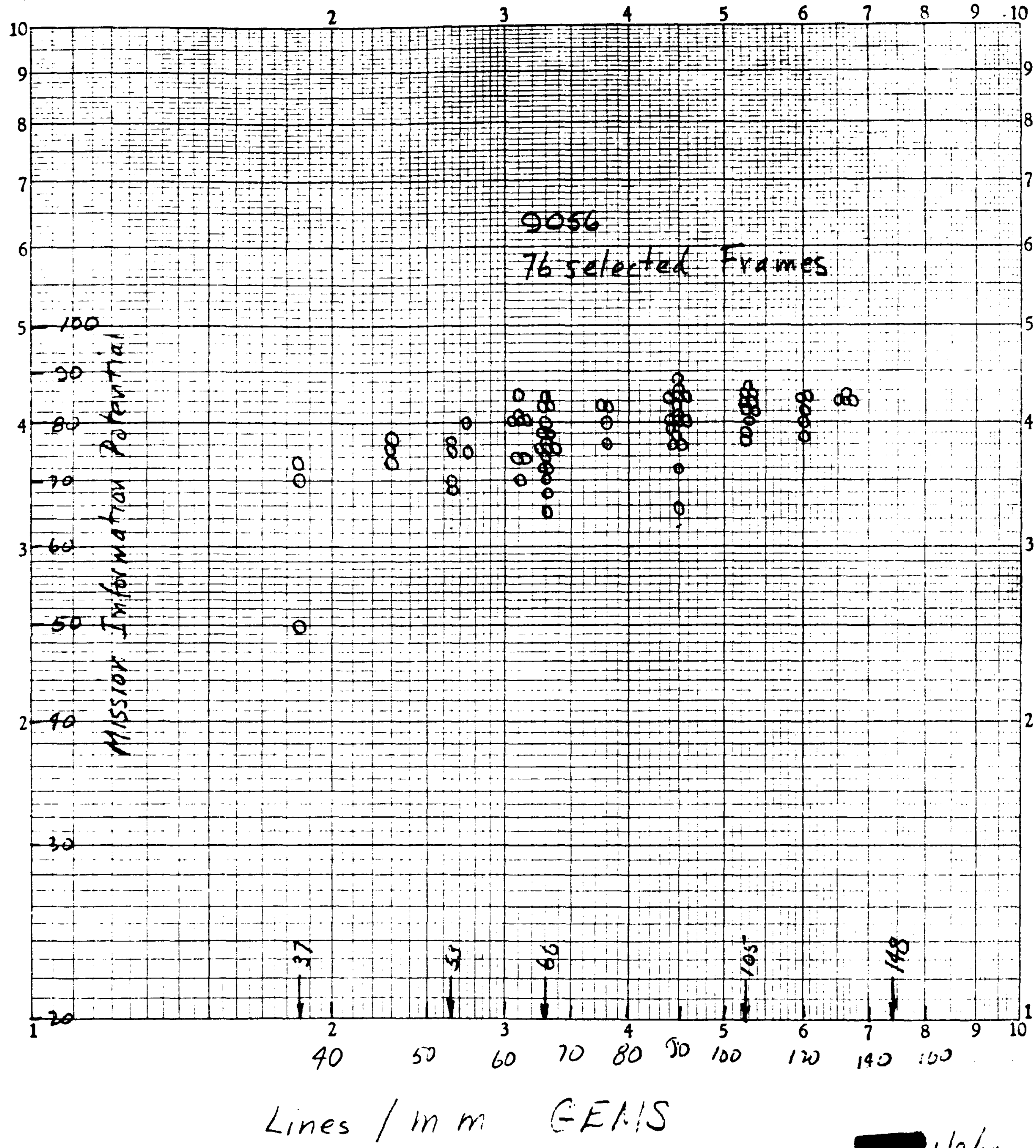


Figure A-3-1

[redacted]



[redacted] 1/8/64

Figure A-3-2

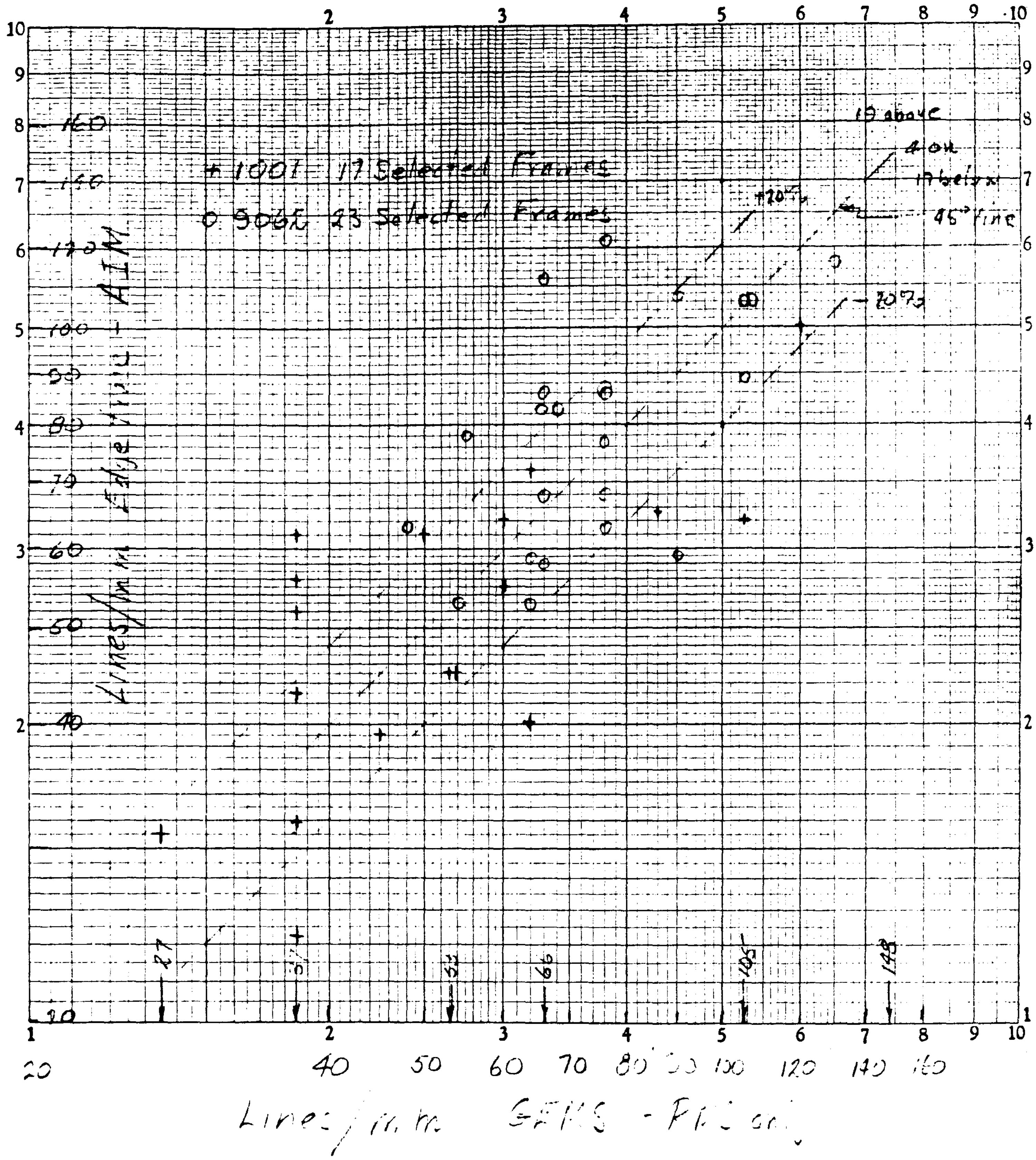


Figure A-3-3 [redacted] /2 -

[redacted]

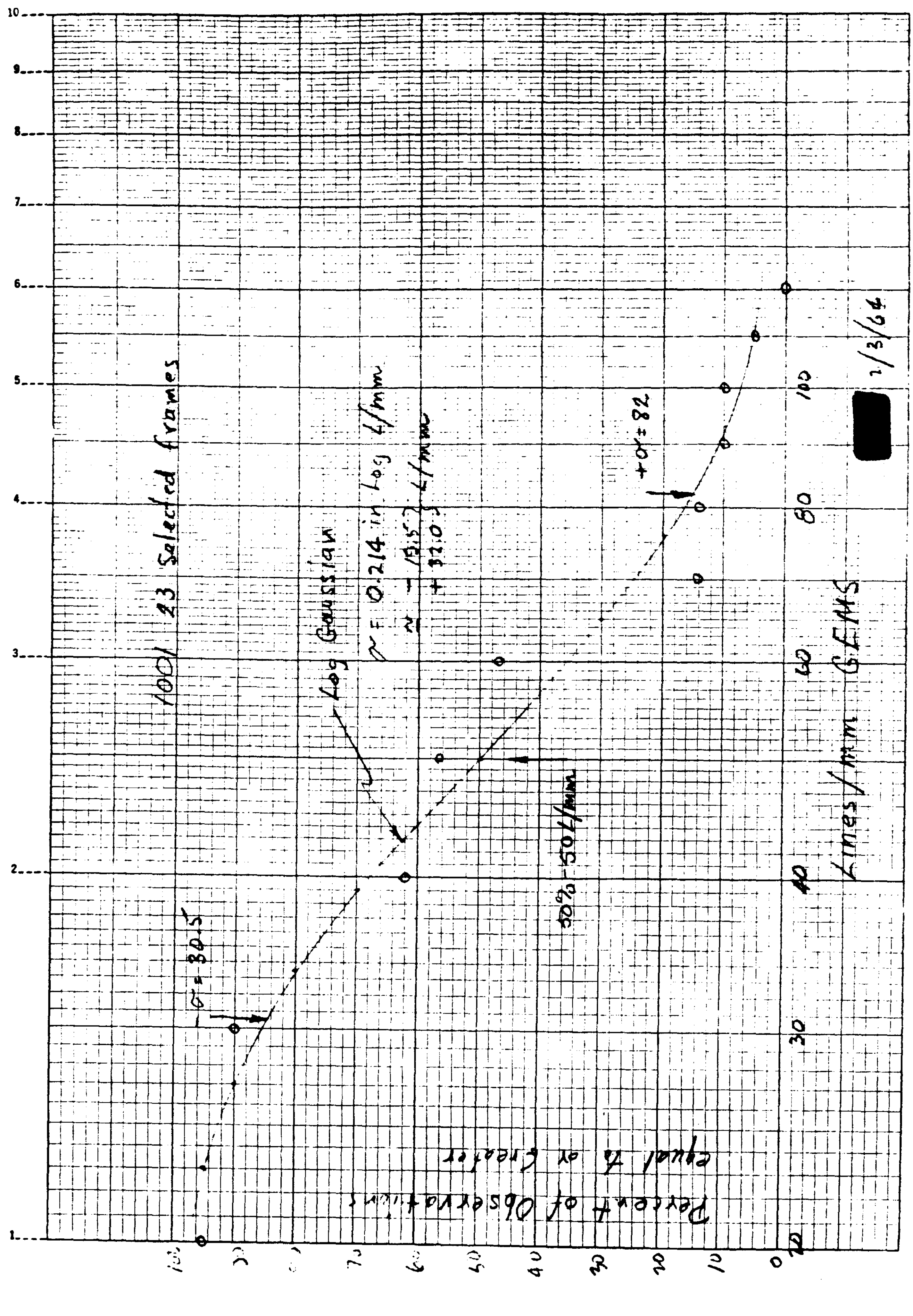


Fig A-3-4

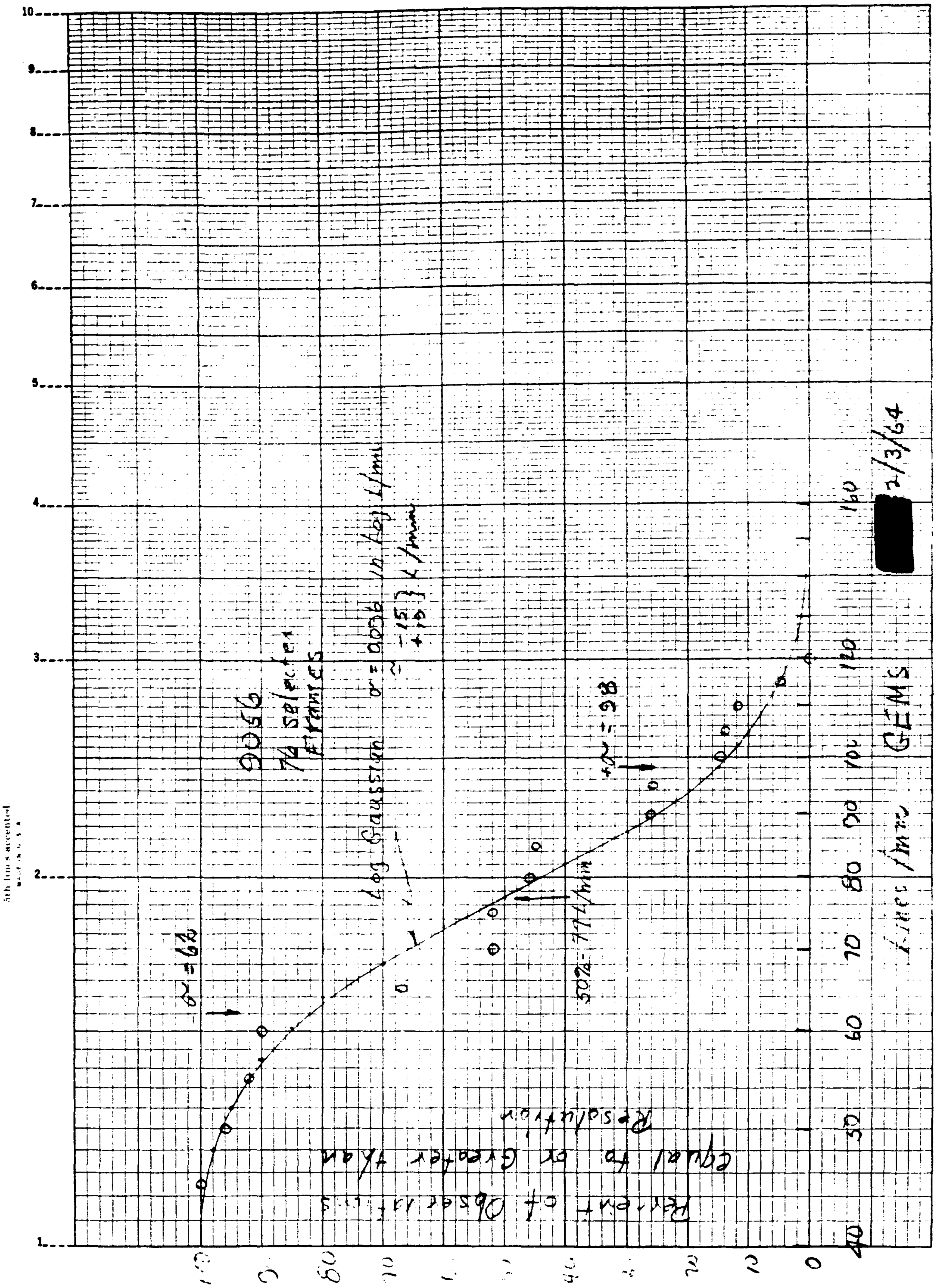

0056
76 selected frames
Log Gaussian
50% - 77 L/mm
Lines/mm
GEMS
2/3/64
Percent of Observations equal to or Greater than Resolution

Figure A-3-5

[redacted]

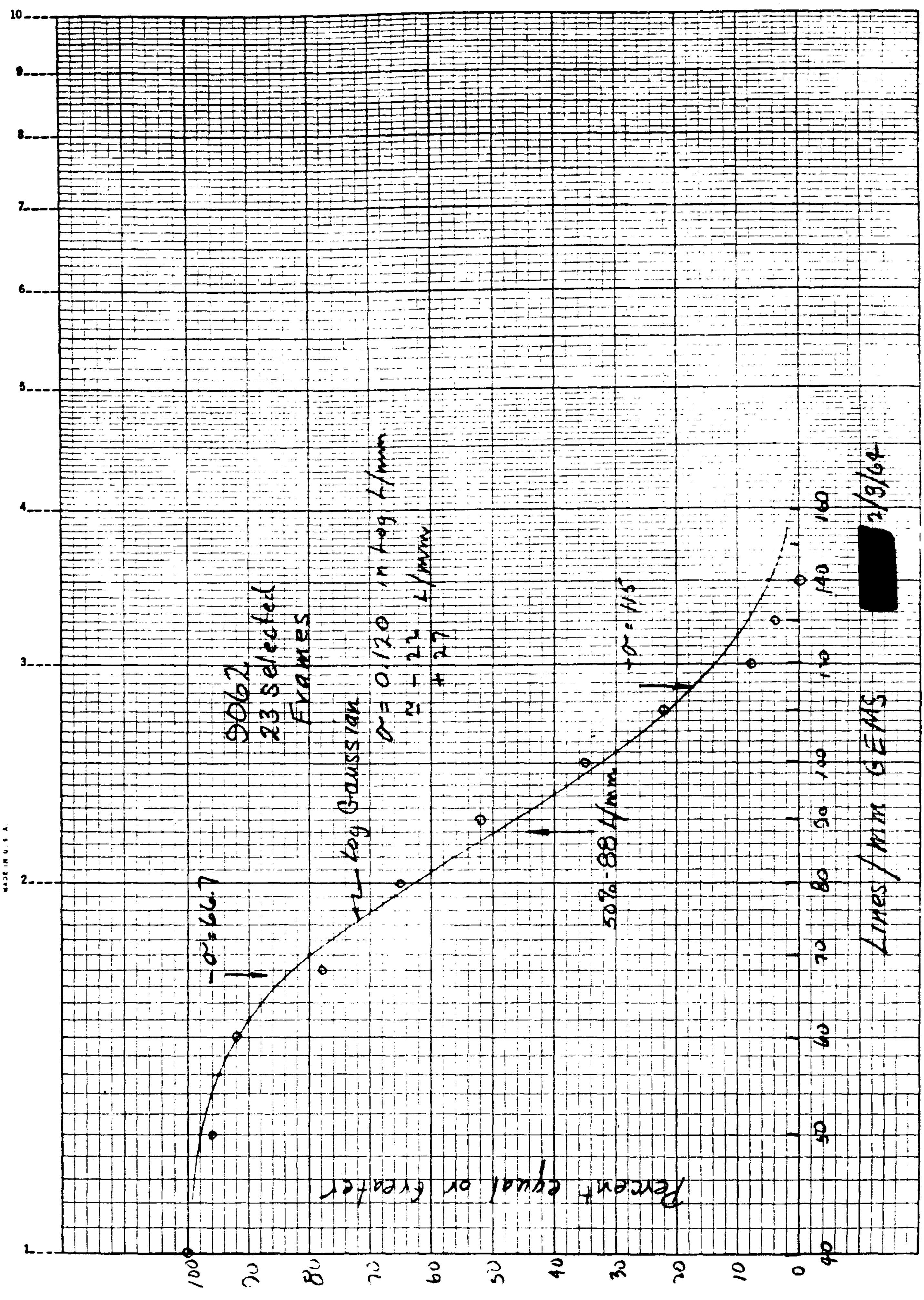


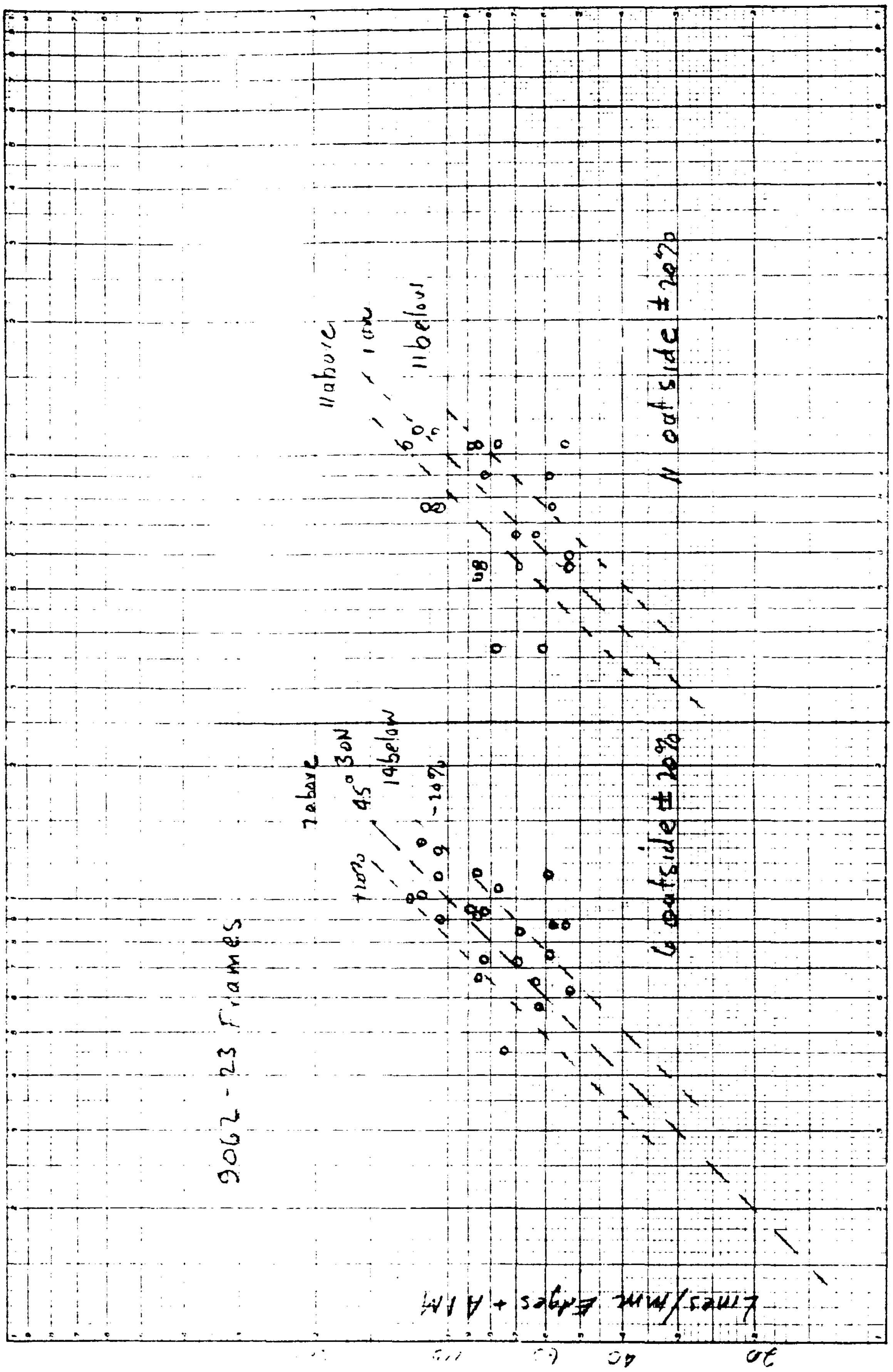
Figure A-3-6

probability paper. In all three cases, the plots were most nearly linear on the log paper. Thus the distribution would appear to be best represented as Gaussian when plotted against log resolution. It would not seem that any important conclusion could be derived from this observational fact, but it is a matter of some convenience.

The three missions have mean resolutions of 50, 77 and 88 lines/mm respectively, indicating a considerable improvement in resolution performance of the system over the period of these missions. The dispersion in log resolution of the three missions is 0.214, 0.096 and 0.120. Thus while the last mission, 9062, had a better mean resolution value, its dispersion is a bit greater than the earlier mission, 9056. Both were much better than the earlier one. While the data is limited in number of readings on the 9062 mission and considerable selection was applied to the frames to be measured, if the results were unchanged by the inclusion of more measurements, one might reason that the factors controlling resolution in 9062 changed over a larger range than they did in 9056. The fraction of low resolution results in the two missions is about the same and it is only the more frequent occurrence of the higher values that makes the average better in the later one.

A series of small figures is included to illustrate some interesting results from comparisons of GEMS results for various observers. The first Figure A.3.7, correlates the mean of four observers with results from edge measurements. The next four Figures A.3.8, A.3.9, A.3.10 and A.3.11 show the relation for the individual observers. The correlation is best for the mean of the four. [redacted] results are symmetrical about the 45° line but show greater spread as is also the case with [redacted] These observers are not trained PIs but have made a large number, 100 or so, of GEMS measurements. The GEMS readings by [redacted] a trained PI but with no previous experience with GEMS, give higher resolutions than were obtained from edge traces. This result was even more pronounced with the measures of [redacted] who is also a trained PI. In looking into this unexpected effect, it was determined that the specialties of these two individuals were industrial complexes and shipping respectively. Thus the latter observer was looking for very small detail and finding it often. The other PI was also looking for detail, but perhaps not so fine, while [redacted] and [redacted] were concerned more with larger structure edges, etc.

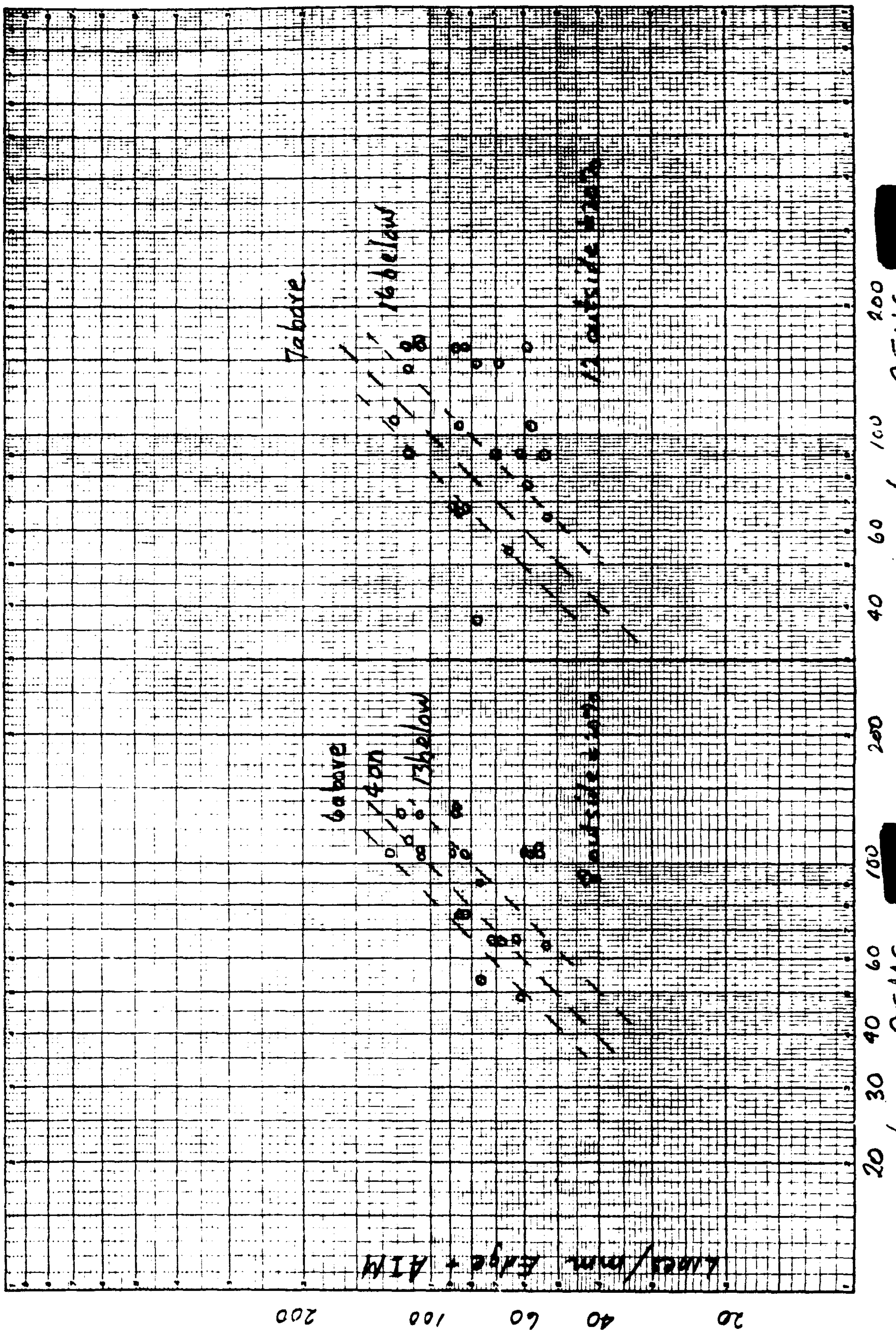
[redacted]



FigA-3-7 Lines/mm - CEMS - Means

Lines/mm [redacted]

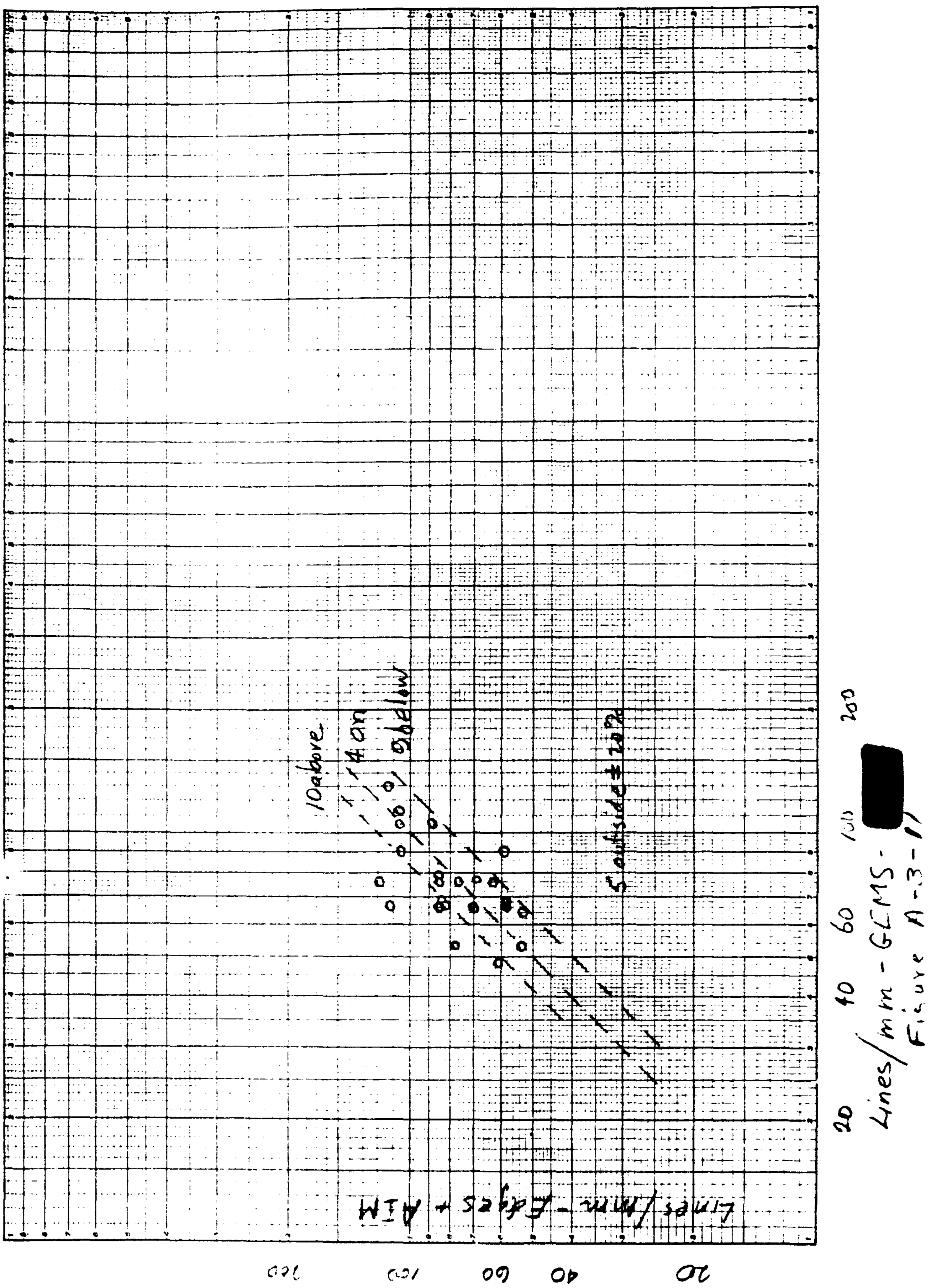
Figure A-3-8



Lines/mm GEMS-[redacted]
Figure A-3-10

Lines/mm GEMS-[redacted]
Figure A-3-9

[redacted]



Handle Via [redacted] Control System Only

Recommendation

These results are sufficiently encouraging to lead to the recommendation that additional work be done with GEMS. A new set should be prepared with closer steps in resolution and more samples of contrast. Each scene should contain a greater variety of subject material than the ones previously used. This set should be prepared for use on original negative material and the comparison made with such scenes. The additional step of duplication to a positive adds new and undesirable variables.

When the GEMS are available, it is recommended that they be used in a program of mission evaluation. Comparisons should always be made with scenes on the original negative. Since it is recommended elsewhere that a program of edge measurement be undertaken, continued GEMS comparisons with areas near the edge measurement should also be made. In addition, on those engineering passes over resolution targets or special edge targets, GEMS comparisons should always be reported. The primary function of these measurements is to provide data for cross correlation of the results of the various methods of image quality measurement.

A regular program of comparisons should be instituted. The most desirable program would be one in which the center plus several other positions of every frame are measured, but the magnitude of such a job would not be justified. Every tenth or twentieth frame would be almost as good. For this statistical study, any pre-selection on the basis of quality should be avoided except for the rejection of start-up or slow-down frames, frames completely covered by clouds or frames not showing any useful detail. As a start, the center of at least 50 frames per mission might be measured. A plot of the cumulative distribution of resolution and, separately, contrast would show the performance of the two cameras in a useful and meaningful way. The 50% point for a succession of these curves would then yield a time record of the improvement of the system. A second useful characteristic of such distributions would be the standard deviations since these indicate consistency of performance during a mission.

The measurement by GEMS of a larger number of frames per mission would permit the study of variations of quality within a single mission or even within a single frame. However, the accuracy of such single measurements is yet to be determined. The average of several measurements by different observers or by the same observer of different small areas closely spaced should be a great deal more trustworthy than a single measurement.

Evaluation of Usefulness of Material

Once a set of GEMS variable both in resolution and contrast is available in negative form, it seems highly desirable to make positive prints of these under a variety of printing conditions. Such prints should then be graded on an MIP or any other basis to evaluate the variables of the entire process in their effect on usefulness and value for intelligence purposes. To this end it would seem that a variety of subject material would be desirable.

III. A.4. Reciprocal Edge Spread Measurements

Because of the fact that a great number of measurements of the apparent width of nominally sharp edges have been made and the intuitive feeling that these widths are related to the resolution, sharpness or acuteness of the pictures in which they appear, it would seem worthwhile to examine in a systematic way the relations and effects to be expected. The observer, looking through a microscope sees a region in which the intensity of the light transmitted by the negative grades from a low value in the more heavily exposed side of the edge to a higher value on the less exposed side. A typical plot of such an edge, freed of the effect of the ever present grain, is shown in Figure A4-1. Along a pair of lines parallel to the edge, there appears to be a transition from the edge itself to the uniform exposures on each side. The separation of these lines is the edge spread. The observer sets a cross wire along these lines in succession and measures their separation. He attempts to set the wire so as to separate the region of uniform intensity from the region where the intensity of the transmitted light is increasing or decreasing.

The first question to be answered is, "How is the decision made as to where to put the line?" Several pertinent attributes of the eye are known and understood. In the first place, the eye can detect a change in intensity across a sharp division of about 3%. In addition, it would appear that under favorable conditions of light intensity and adaptation, the eye is just able to detect an intensity gradient of 3% per minute of arc provided such a gradient extends for at least a minute of arc. While there are undoubtedly more subtle effects in the eye which should be considered, these will permit some understanding of the variables of the problem.

If we now plot the gradient required for detection of the presence of a gradient, as a function of the intensity, a curve something like Figure A4-2 will be obtained. Three regions of interest are shown. In the first region we know that at very low intensity, tending toward zero, a larger and larger gradient will be required for detection. In region 2 the 3% gradient as the threshold of detectability holds, while at very high intensities a saturation effect is bound to set in increasing the detectability limit.

Let us now return to Figure A4-1 and compute the slope as a function of displacement. In Figure A4-3, the distance coordinate x has been replaced by an angular coordinate θ, the angular subtence as seen by the eye. The relation between x and θ

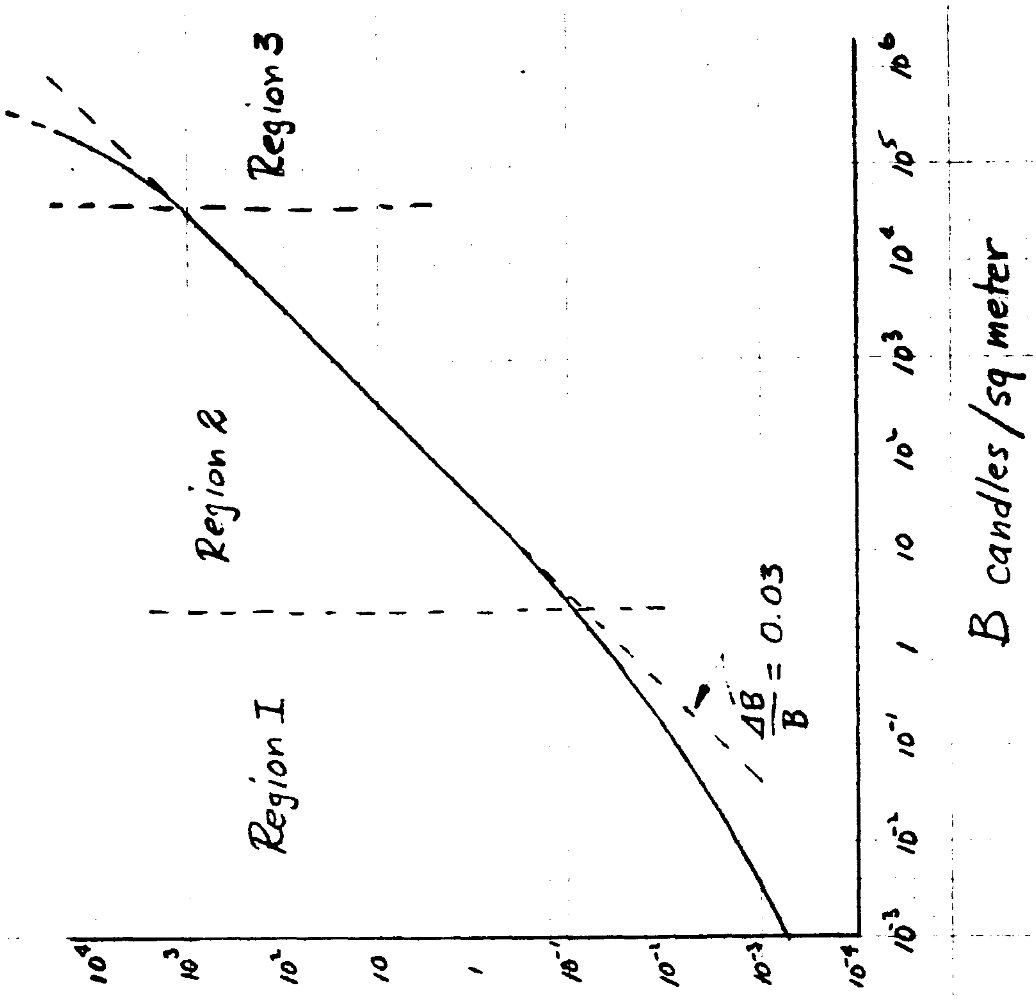


Figure A4-3

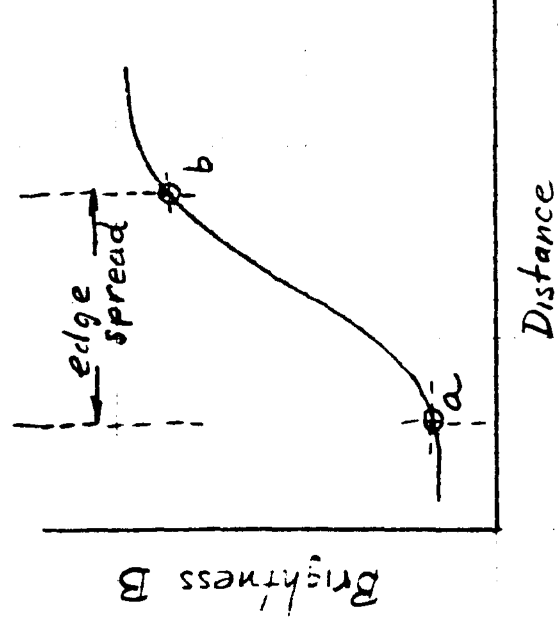


Figure A4-1

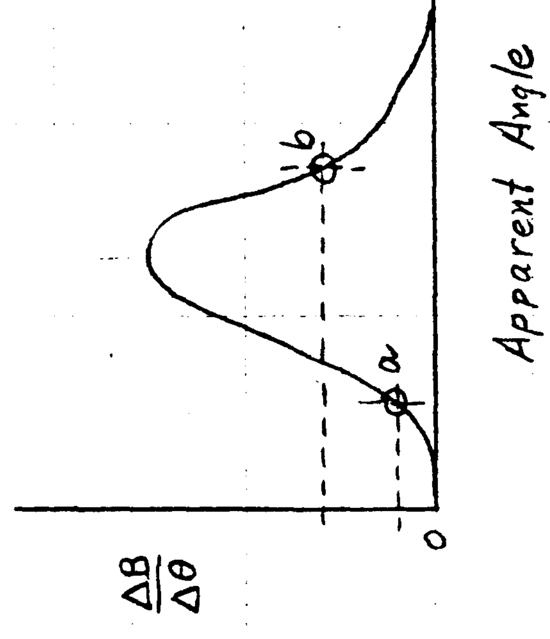


Figure A4-2

[redacted] 12/8/63

is determined by the magnification of the microscope. As one proceeds from left to right in the lower part of Figure A4-3, the value of dB/dΘ increases to some value where the eye can detect it, point a for example. The location of this point will be determined from Figure A4-2 as the point a there as well. On the other side of the edge the intensity is higher and the first detectable gradient might well be higher also, as shown by point b in both Figure A4-2 and A4-3.

The magnification of the observing microscope determines the conversion from distance on the plate to angular distance as seen by the eye. It also determines the apparent brightness of the field. It can be shown that if the microscope is properly designed so that the exit pupil of the instrument coincides with the pupil of the eye, both in position and size, the eye will see a field of the same brightness as would be seen viewing the scene directly, except for transmission losses in the optics. We will neglect such losses, although they could be of some importance and should be considered in a later discussion.

On the other hand, the apparent gradient in brightness is reduced by the magnification since two points of a given difference in transmitted intensity appear farther apart as the magnification is increased. We might well assume 100x. Then the first detectable logarithmic gradient is 90/rad and is equivalent to 3.55×10^{-2} per micron.

The actual spread of an edge, sharp in the scene, will be determined by the transfer function of the optical system and film, the exposure level on the two sides of the edge and the effective H&D curve. Let us assume that the processing is such that there is no Eberhard effect so that the H&D curve determined from large areas holds in detail across the edge to be measured. Figure A4-4 shows a typical curve for the material in question.

Because the material which has been measured was obtained under conditions where many effects were probably combined to yield the equipment transfer function, there seems no better assumption than to assume it to be Gaussian. The exposure of an edge will then be integral of the Guassian curve. It is now possible to investigate the apparent edge spread for a group of typical cases. The process will be to assume that the edge spread will be measured between points which have a gradient of 3% per minute of arc. The exposure gradient will be computed for a number of cases by the first set of equations and from this the distance x will be found from the spread functions for various resolutions. Since the resolution variable leads to a smaller number of cases, it will be considered first.

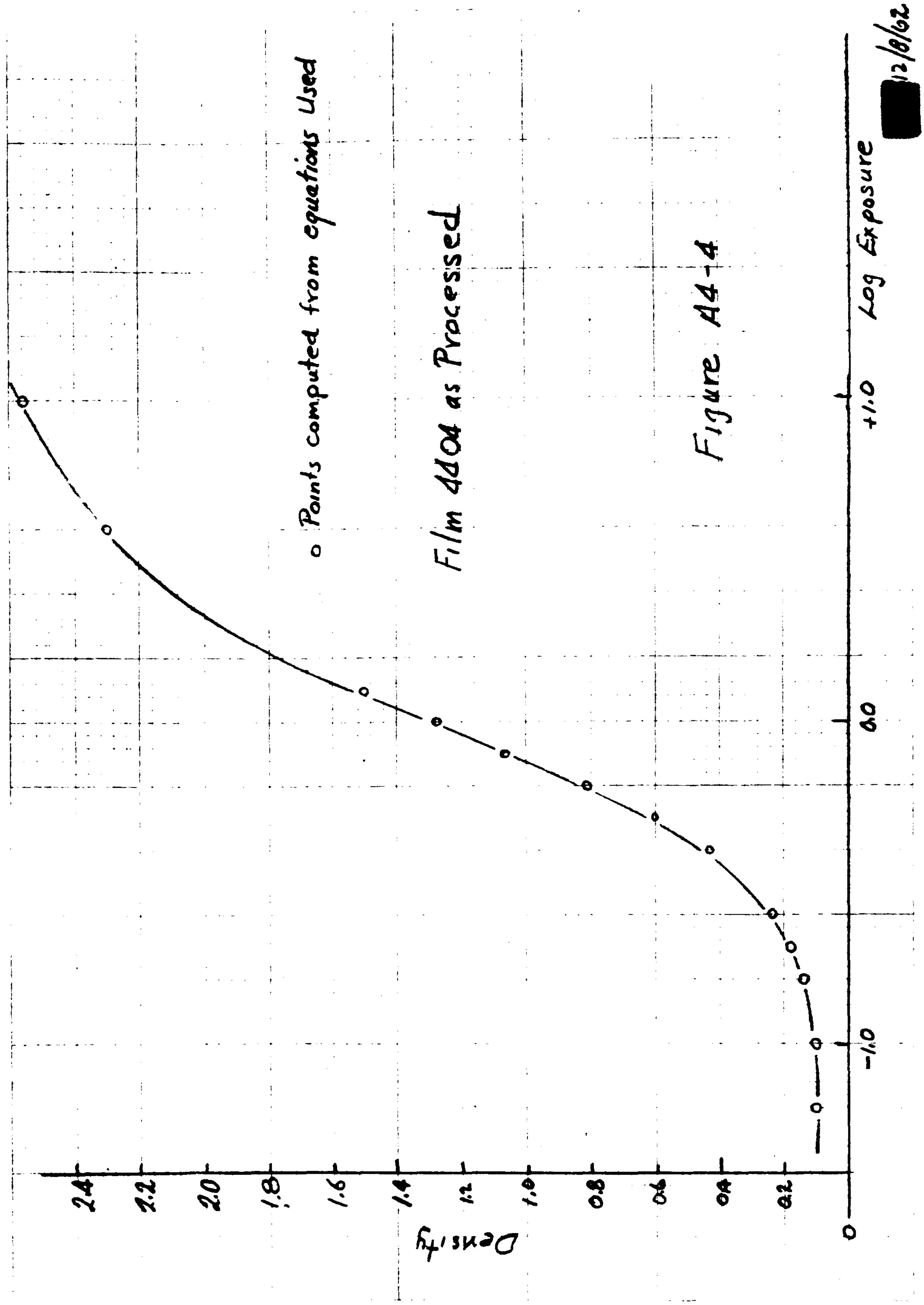

o Points computed from equations Used
Film 4404 as Processed
Log Exposure
+1.0
0.0
-1.0
Density
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
[redacted] 12/18/62

Figure A4-4

The assumed Gaussian transfer function for the system may be slid along the resolution axis to represent systems in different states of perfection. The parametric variable is the high contrast three-bar target, limiting resolution. Figure A4-5 shows the curves used. Table A4-I shows the results.

Table A4-I

Case	Limiting Resolution	RMS Spread, a
1	50 l/mm	0.0091 mm
2	70	.0056
3	100	.0039
4	120	.0029
5	150	.0021

The lower resolution cases are more doubtful than the ones of higher value because of the variability of the eye contrast threshold.

The density difference across the edge and the mean density are variables of the problem. Table A4-II illustrates the cases considered.

Table A4-II

Case	D min	E min	D max	E max	$\bar{D}$	$\bar{E}$	ΔD	$\frac{\Delta G}{\Delta x}$ min	$\frac{\Delta G}{\Delta x}$ max
A	1.1	0.83	1.3	1.00	1.2	0.91	0.2	0.157	0.304
B	1.0	0.76	1.4	1.13	1.2	0.91	0.4	0.115	0.431
C	0.9	0.68	1.5	1.26	1.2	0.91	0.6	0.082	0.600
D	0.8	0.63	1.6	1.38	1.2	0.91	0.8	0.060	0.850
E	0.4	0.37	0.8	0.63	0.6	0.50	0.4	0.0254	0.060
F	0.1	0.30	0.5	0.44	0.3	0.30	0.4	0.0140	0.031
G	2.0	2.34	2.4	5.00	2.2	3.24	0.4	5.2	50.0

Conclusions

The results of the computations are shown in Figure A4-6. First, it would appear that the RES values predicted are somewhat smaller than those actually encountered in practice. There may be many reasons for this, but among those to be considered are the magnification of microscope and the fact that it may not be possible in practice for the observer to detect a gradient as small as 3% per minute of arc especially in the presence of grain. It has been assumed that the illumination level is sufficiently high to insure that all measurements are made on the linear part of the eye response curve. The results reported for the detection

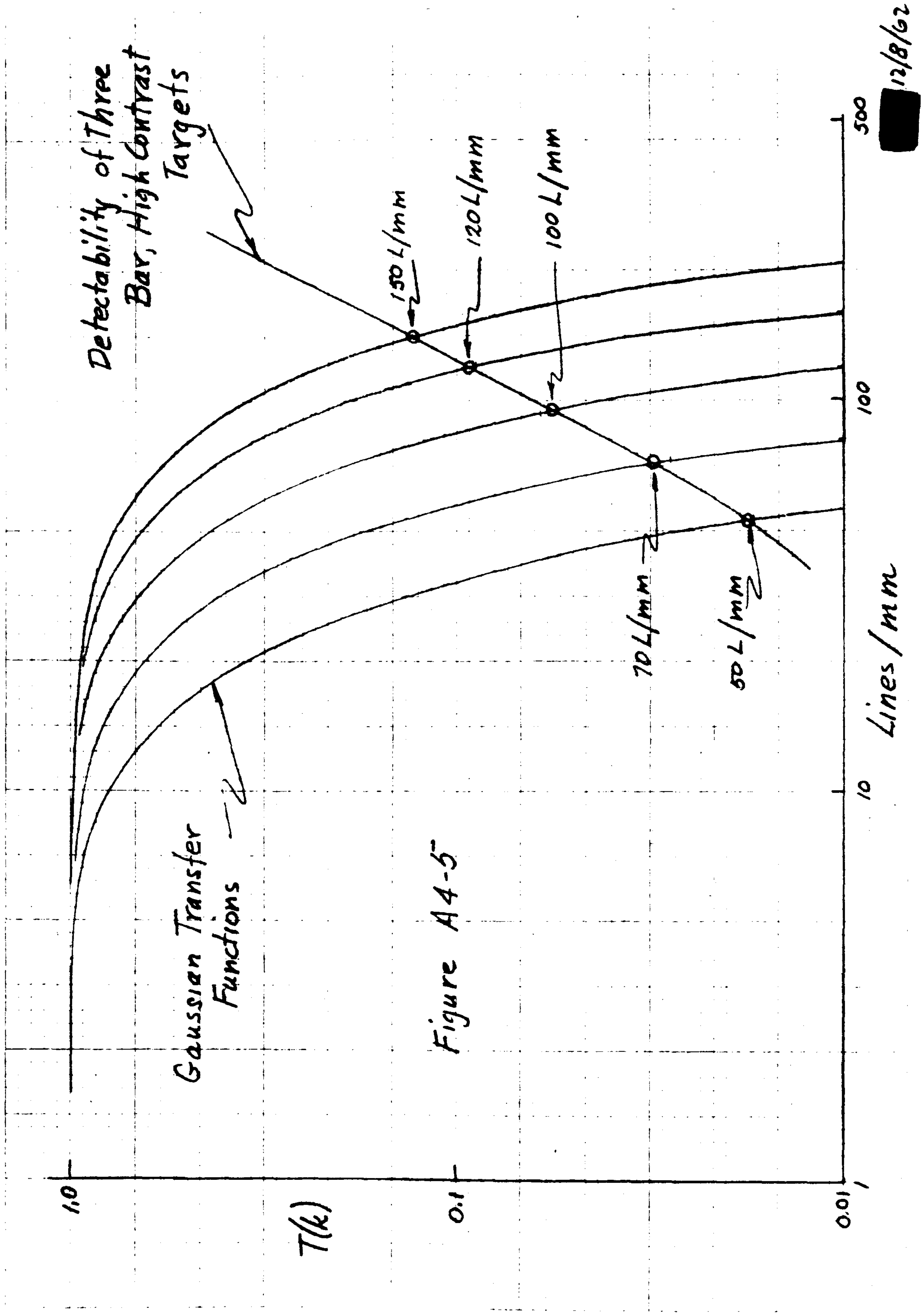

Detectability of Three Bar, High Contrast Targets
150 L/mm
120 L/mm
100 L/mm
70 L/mm
50 L/mm
Gaussian Transfer Functions
T(k)
1.0
0.1
0.01
1
10
100
500
Lines/mm
[redacted] 12/8/62

Figure A4-5

[redacted]

12/8/62 [redacted]

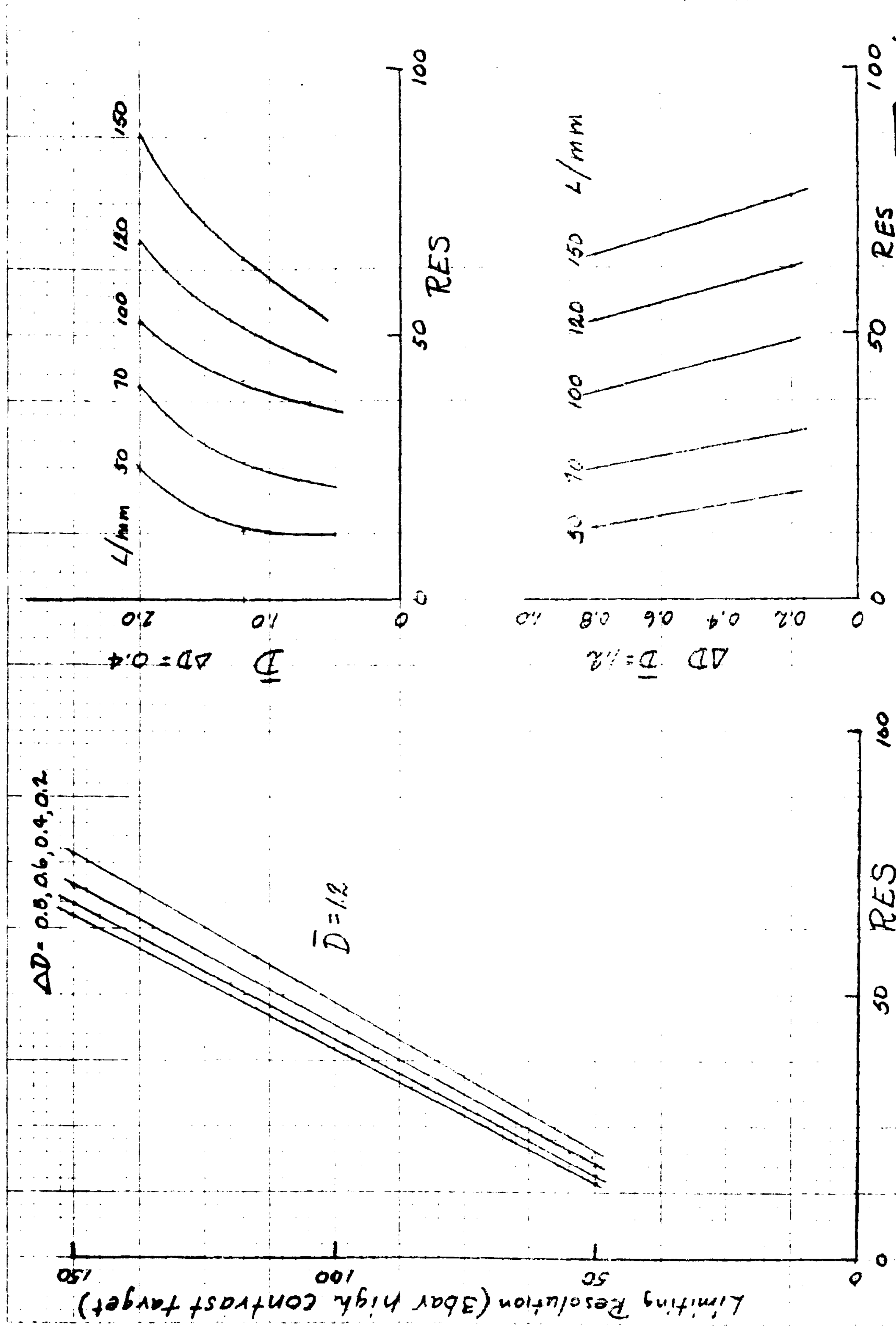


Figure A4-6

of a brightness difference between two large uniform areas may not apply directly to the case of the detection of the start of a gradually increasing gradient. All of these effects would influence the observer to measure the width of an edge as somewhat smaller than has been assumed in these computations and thus the RES result would be larger. Nevertheless, considerable information may be obtained from a study of the curves of Figure A4-6. The simple relationship between RES values and the limiting resolution of a three-bar target in lines per millimeter for a particular density difference and average density is quite impressively linear. The variation of the position of the line for different density differences is rather small and is an unexpected result. On the other hand, the RES measurement for an edge of given density difference appears to increase rather strongly as the average density is increased. In spite of these encouraging results, it does not seem possible to deduce an equivalent limiting resolution for the optical system from RES measurements unless a good deal is known about the average density of the edge. The density difference across the edge appears to have a small enough effect to be negligible.

Recommendation

It is recommended that consideration be given to the development of a quick and simple visual method of determining the average density of edges. If such a method is developed a program of density and edge spread measurements should be undertaken to discover the validity of the density correction to RES values. These corrected values should be correlated with actual edge traces and other measures of performance before using RES for system evaluation.

III. A.5. Image Quality and Interpreter Performance

The ultimate criterion of the effectiveness of a photographic reconnaissance system is the amount and validity of the information obtained from the photography by professional PIs.[1] Although transfer functions can be written describing the effects of such factors as the lens system and the film, no equation can presently be written describing the final link: an equation that relates the physical characteristics of the final photographic image to the exploitation performance that can be expected from the PI.

The value of determining the relations among objective measures of PI performance, subjective assessments of image quality, and physical measures of image quality, and of having a summary measure of image quality that would permit the accurate prediction of PI performance, has not been ignored by the Air Force and the Army. A study being conducted by [redacted], under contract with Rome Air Development Center, has as its goal the analysis and, eventually, the prediction of PI performance as a function of ground resolution and contrast. PI performance will be measured in terms of accuracy, speed, and completeness of target identification. Twenty-nine different types of targets will be identified in both real and simulated aerial photography, ranging in scale from 1/5000 to 1/100,000. Ground resolution will range from 1' to 64' in six steps, and contrast from 2/1 to 30/1 in three steps. This study is still in progress.

Other studies of a similar nature into effects of contrast, smear, and noise on PI interpretability are also in progress

The results of this work may have implications for NPIC. However, the photography must be adequately specified in terms of transfer functions if the results of research on interpreter behavior are to be of value to the designers of collection systems or viewing devices.

Research on psychological factors in image interpretation has suffered universally from the inability of the investigators to specify the stimulus conditions in terms that are meaningful to equipment designers. Much of the research has been naive, and the results are not relevant to NPIC operations. No one known what

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1The amount of time required to obtain the information might be considered an additional criterion of system effectiveness.

really contributes to interpretability or what constitutes a good PI. But with the tools available today for specifying the characteristics of photography, worthwhile research could be done. It should be done, however, in NPIC and should be designed in light of NPIC operations.

III.B.1. Cm Measurement Program

1.0. Introduction

1.1. Causes of Quality Loss

In approaching the subject of a measurement program aimed at a better definition of system performance and better estimates of the magnitudes of various degrading factors, it is appropriate to review, qualitatively at least, what appears to be the principal causes for image quality variation in the system. That there are variations in quality of the photographic product is an observation based on subjective impressions as well as MIP, RES, and edge trace measurements. Some of these yard sticks, particularly MIP, are undoubtedly affected by the uncontrollable factors of haze, subject contrast, and scale changes, but others, notably edge traces, do indicate a sizable change in sharpness of detail. Furthermore, there are obvious losses in contrast due to instrument-induced fogging.

It is clear that a better measure of the variables which affect on-orbit photographic quality is necessary in order to define precisely the variations which have been noted. Furthermore, the availability of a quantitative measure of image quality is critical in monitoring the measurement program results and in assessing improvements. This subject is treated extensively elsewhere in the report and for purposes of the present section it is assumed that adequate standards are feasible and will be developed.

1.1.1. Corona

One of the more serious defects is that of corona discharge which has been observed to fog the film, reducing the contrast and information content. It is notable in Mission 9062 that the affected area correlates with frame spacing, indicating that the discharge is related to the film motion in the intermittent portion of its travel through the instrument. That the problem has been observed several times indicates that it is under poor control.

1.1.2. Light Leaks

Fogging has occasionally been so severe that complete frames were severely exposed. Some returns show a small but noticeable contrast change across the width of the frame as indicated by comparing the small overlap areas of two adjacent frames. One also wonders about the over-all scene contrast which at times seems low, possibly indicating veiling glare. Incidentally, veiling glare will not be detected by the usual measure of base fog in the frame borders nor by edge movement.

1.1.3. Focus

Changes in focus may be one of the more serious causes for loss in image quality, as examples 9050 and 100. Sharpness of detail appears to change gradually throughout the mission. This is most easily detected by comparing the same object photographed in the fore and aft cameras. The differences can be quite substantial, even when small changes in gross contrast are taken into account, and can hardly be blamed on any other cause. The loss in quality seems to occur over the entire frame and for many frames in a row. Therefore, the drift of focus is gradual as one might expect from temperature changes resulting in thermal gradients. There is no assurance that this is typical of missions for which temperatures are within tolerance since temperature telemetry has not been adequate for detailed analysis.

1.1.4. Soft Spots

Occasionally there are localized areas of very unsharp images that persist from frame to frame. This is, apparently, a bad focus error. Perhaps the film is being raised above the rail out of reach of the focus rollers. This may be caused by accumulated gelatin being scratched off the film as the film is advanced.

1.1.5. Scratches

Scratches persist along the edges of film approximately in line with the edges of the rails which support the film. Since the film is advanced by drawing it across the rails, it seems likely that gelatin is being scraped off the film at this place. Tests performed at Eastman Kodak indicate that a hard deposit of gelatin can accumulate and tenaciously adhere to such a metal surface; however, under vacuum conditions the buildup is less likely.

1.1.6. Smear

Smear is seldom obvious and when it is noticeable it can usually be associated with badly out-of-tolerance vehicle attitude. Seldom does an unsharp image, as described in 1.1.3 under focus, have any noticeable directionality which might indicate smear. However, smear at about the same dimensions as ground resolution can have a definite effect on quality without being obvious.

1.2. Goal of Measurement Program

In addition to the detailed study of the photographic product, the analytical model used to evaluate Cm performance, the ground test and launch preparation procedures employed at Itek in Boston, at LMSC in Palo Alto and at the launch site at Vandenberg and the in-flight instrumentation records were reviewed. There exist several critical areas where available data is inconclusive or incomplete, where analytical studies have not been performed in sufficient detail, or where adequate precision is not possible to permit definite conclusions to be drawn. It is recommended that activity in the measurement program be concentrated in these areas of suspicion and that adequate analytical studies be undertaken to properly support the measurement program . A prime objective of the measurement program is the acquisition of sufficient data so that the expected distribution of performance can be calculated. When calculated, it should be compared with the observed distribution.

Much of the necessary data can be obtained by ground testing in the laboratory or in thermal/altitude chambers, and wherever possible this course should be pursued in preference to on-orbit measurements and tests. It is obvious, however, that laboratory simulations are not exact and in some cases (e.g. zero "g" environment) impossible. For this reason, it is necessary to support and verify the results of ground tests by satellite testing.

Measurements of this nature have been considered only in cases where they can be obtained with little or no effect on the operational employment of the system. The role of aircraft tests (possibly using the [redacted] system) as an alternate to satellite measurements has been considered but in view of the radically different operating conditions (camera cycling rates, thermal environment, stability of platform, vibration environment), it is felt that little useful data can be obtained in this manner. It is likely that data concerning slit widths, film/filter combinations, effects of haze, etc., can be obtained, however, and such a test program is described in a later section.

1.3. Assumptions and Preliminary Conclusions

In order to identify and segregate those areas where additional work is indicated, it is useful to review a number of preliminary conclusions reached on the basis of data presented to the committee and as the result of detailed study of Cm photography.

1.3.1. Vehicle Motion

Precise data describing vehicle orientation and vehicle rates in roll, pitch and yaw are available during photographic passes from the horizon cameras and from the stellar/index camera carried on Cm flights. In addition telemetered data relating to guidance system performance are available during each pass over tracking stations, and on a few flights where a tape recorder was carried, during photographic passes as well. The data contains some inconsistencies which have not been explained, but in general good agreement exists. Although in isolated instances large attitude errors and vehicle rates have been observed and measured, these instances in general have been related to malfunctions or failures in the attitude control system and should not be employed to describe guidance system performance under nominal conditions.

Attitude data have been examined in detail during photographic passes for a number of Cm flights and in general vehicle angular rates are well under 50°/hr. about each axis. Angular excursions are generally well within the specified dead-band limit (this limit varies somewhat from flight to flight, has been decreased to $+0.5^{o}$ recently, but in no case is larger than + 3^{o}). Converting these angles and rates into equivalent image smear at ground scale is straight forward and the maximum smear contribution from this source is on the order of one foot or less (one foot of image motion results from approximately 70^{o}/hr. pitch rate, for instance.) On this basis, it has been concluded that vehicle attitude and rates are not a problem of existing Cm photography and that confirmation by means of special experiments or measurements is not necessary. It is recommended that existing measurements and evaluations be continued, and that additional tape recorded telemetry data be obtained to support the evaluation and to explain inconsistencies and biases remaining in the data.

1.3.2. V/h Mismatch

In the Cm system along track image motion resulting from vehicle velocity over the earth's surface is compensated by translation of the camera lens in a direction which tends to hold the image fixed with respect to the film during the exposure interval. Since slightly elliptical orbits are flown, velocity and altitude over the ground vary from point to point on the orbit. A small V/h programmer is used to provide means for selecting a given V/h variation (ramp) over a photographic pass. The desired variation for perfect match is generally sinusoidal. Early Cm payloads used a system of linear ramps; more recent flights have employed a system of sinusoidal ramps capable of closer match to the desired V/h profile. Selection of the desired ramp is by ground command.

In some flights V/h mismatch has been larger than desirable as a result of thermal effects and inaccurate ephemeris early in the flight. Available data indicates that during normal vehicle operations it has been possible to match V/h over the complete photographic pass to better than 3% and during most passes to within 1%. (3% mismatch contributes approximately four feet of image motion under nominal exposure conditions).

On the basis of existing evaluations the committee has concluded that V/h error contributions to system degradation are well understood; straight-forward analytical techniques are available to predict effects of such errors and no additional testing or measurement program is necessary in this area.

1.3.3. Exposure

Exposure of the film in the Cm camera is accomplished by moving a slit over the format area; exposure time is thus a function of the slit width and its velocity over the format. No capability for varying slit width in flight exists; the width to be used on a given flight (generally 0.20 or 0.25 in.) is selected prior to launch on the basis of illumination predictions. These predictions are made on the basis of time of year, orbital parameters, time of day predicted for launch. Exposure time in orbit thus depends only upon velocity of the slit, which is a function of camera cycle time and which in turn is tied to the V/h program being used for proper image motion compensation. Thus, actual exposure times vary somewhat in orbit, and in a manner which is not optimum, since exposure time is proportional to V/h and is not directly related to illumination levels. A compromise has been reached wherein non-optimum exposures are compensated in the development process (three levels of development are available) in order to retain the advantages of simplicity and reliability in the airborne hardware. It has been generally concluded within the committee that no significant degradation results from this compromise under average illumination conditions.

Under some operational conditions (strong desire to attempt coverage of a high priority target under marginal illumination) it is clear that capability for varying exposure time in flight would be beneficial. It is felt that the exposure situation in general requires no additional in-flight measurements to explore degrading effects. However, it is strongly recommended that the decision to avoid in flight exposure control be re-examined. Aircraft tests under varying illumination conditions would be helpful in determining the level of sophistication necessary in such a device; these tests are described in a larger section of this report.

1.3.4. Uniformity of Quality

As a result of examining large quantities of Cm photography the following general observation has been made and is stated here as an assumption in evaluating a measurement program. There seems to be no significant variation of quality within given frames of Cm photography; with specific exceptions, quality tends to be quite uniform within a frame. Exceptions have been related to tolerance build up in the data block area under abnormal thermal conditions and possible emulsion accumulation on the rail surface. (See 1.1.4 above) Pre-flight measurements in the laboratory (Aschenbrenner Test) are used to verify flatness within tolerances which are tighter than depth of focus.

1.3.5. Focus Shifts

A second observation which has been made as a result of examination of large quantities of Cm photography is that a general "softening" of the image exists in areas where effects of weather and illumination cannot be quantitatively assessed and the quality is below that observed in other portions of the mission. Inaccurate focus could be the cause of such degradation. Of immediate concern when pursuing focal shift problems are the areas of (a) thermal environment in orbit (its predictability, how well it has been measured, and its effects on lens distortions and/or focal shifts) and (b) vibration encountered within the exposure interval. In examining the analytical and experimental results which have been presented in both of these areas, the committee feels that the data are inconclusive, at best, and that a thorough measurement program should be undertaken in order to explore in detail the extent to which these factors are degrading the photography. The bulk of the measurement program being recommended bears on these areas.

1.3.6. Corona

It is obvious that the corona problem is a very serious one in Cm and that high priority must be placed on a program leading to a solution to this problem. It is highly probable that a larger proportion of photography is affected than that which is obviously "corona marked" and this factor should be considered in arriving at a solution.

Film fogging as a result of corona discharge has been observed on a sporadic basis on a number of Cm flights. The film is almost never entirely corona free; even the best flights exhibit so-called "start up" corona which degrades the first frame or two. It has been true, however, that good correlation exists between altitude chamber tests of the system and orbital results; when a full four-day-test cycle has been performed prior to launch with acceptable results, orbital performance has been satisfactory. Careful selection of rubber roller material (on the basis of conductivity) has been used to control corona discharge on a flight-to-flight basis; however, the problem is not well understood, no great degree of predictability exists, and, hence, no great confidence exists that the situation is under control. As the result of a large amount of testing, the presence of corona discharge appears to be well correlated to the pressure regime of one to ten microns. Raising the internal pressure is an effective technique for extinguishing the discharge. The amount of increase varies somewhat from system to system but in general 30 to 50 microns is sufficient. The committee feels that development of a pressure make up system capable of providing such an environment should be given high priority. The system should be incorporated immediately into flight payloads and be used until more fundamental approaches indicate the problem is understood and can be controlled without increasing the pressure.

1.3.7. Non-image Forming Light

An impression that a fairly high percentage of Cm photography is affected by light leaks has been expressed by committee members.

In most cases these light leaks are related to malfunctions (horizon shutter failure, light-tight hoods failing). However, a significant number of frames in a normal mission are light struck as a result of film sitting between photographic passes in an area where it receives stray light within the payload. Furthermore, photographic contrast can be reduced by veiling glare especially in the presence of extensive cloud cover. Since the possibility for some system improvement exists, this situation should be re-examined.

2.0. Recommended Measurement Program

The various factors where additional data are necessary before conclusions can be reached tend to be grouped in three areas: (a) behavior of the film as it is lifted from the rails by the scan arm (under range of environmental conditions encountered in orbit); (b) thermal environment of the camera, especially the optical system proper under orbital conditions; (3) vibration environment and characteristics of the camera system. In each of these cases it is recommended that sufficient testing and measurements be accomplished to confirm or discount them as a source of severe photographic degradation.

2.1 Film Behavior During Exposure

During its testing cycle in Boston, each camera is subjected to a test for film flatness during the exposure interval. The testing technique (Aschenbrenner test) employs a pair of small lamps mounted near the end of the scan arm and a series of fine slits mounted in the scan arm at the position of the exposure slit (the fine slits are parallel to the direction of scan). Each slit thus produces a pair of parallel lines (one line from each lamp) on the film during the scan; the distance between the lines at any point is a measure of distance from the slit plate to the film surface at that instant. From this data contours are plotted. The test is thus an accurate relative measure of film flatness with respect to the slit plate. It gives no measure, however, of focal shifts or of dimensional changes in the scan arm.

The Aschenbrenner test has been employed to measure improvements achieved in evolving the presently used four roller scan head from the two roller head previously employed. The test has been run only at room temperature and it is felt that a series of runs should be made, at least in a representative system, over a range of temperatures. In addition, measurements should be made over the range of film tensions likely to be encountered in orbit.

The possibility of in flight Aschenbrenner Tests was considered, but in view of the difficulty of implementing such a test, the probable effect on operational coverage, and the lack of a specific justification, it is not recommended at this time.

A second test technique described by Itek employed a grid on the film itself. This grid was photographed using a fast exposure time ($\frac{1}{5000}$ sec.) at the moment the scan arm passed and was used to study the dynamic behavior of the film (including longitudinal and lateral motion). The test was used in the past with the two roller scan head and it is felt that it should now be repeated with the four roller head to be certain that no change has occurred in this area.

2.2 Thermal Environment

The equilibrium temperature of the Cm payload on orbit is controlled by passive techniques which involve careful selection and application of surface finishes. In general two surface coatings of known characteristics are applied in an alternating pattern which varies from flight to flight depending primarily on the angle between the orbital plane and the earth sun line (solar angle). In this manner the average payload temperature is held within 70 $\pm$ 10° although skin temperatures vary over wider ranges. No active temperature control devices such as heaters or shutters are employed in the existing system, and it has been suggested in committee discussions that such devices might be necessary for more precise control. More data is needed before definite conclusions can be reached on this point, however.

The precise thermal environment encountered in orbit by the camera optical system is dependent to a large extent upon the geometrical relationships within the system. A short description of the camera operating cycle is necessary to appreciate the significance of these relationships. While the scan arm executes a back and forth motion in the "scan and return" cycle, the lens rotates continuously, being mechanically locked to the scan arm drum and barrel during the active portion of the scan. During this active scan the lens "sees" the ground through an opening in the drum. Once uncovered by blowing off a door during ascent into orbit this opening is uncovered throughout orbital operation and, of course, is always located in line with the scan arm (the lens is aligned only during the active portion of the scan in general). A command for camera system shut-down can be accepted at any time during a cycle, and once commanded the camera coasts to a stop; no braking is applied and no specific "rest" position is defined for the lens or scan arm. The "rest" configuration varies depending primarily upon the cycle rate prior to shutdown command (which is a function of V/h). In the rest position the lens is not aligned with the scan arm or with the opening but lies generally horizontal. Glass elements can be seen through the opening only at grazing incidence. In this configuration one side of the lens barrel "sees" the earth through the opening and thus tends to cool off during "rest" period and the other side "sees" the 70-degree interior of the barrel and scan arm. The rest position of the scan arm is generally near the end of scan, and since the two cameras are rotating asychronously in opposite directions, typically one scan arm comes to rest near one side of the payload skin the other scan arm near the other side. In general (other than noon orbit) one side of the payload is hot (exposed to the sun) the other cold (exposed to space).

2.2.1. Analytical Treatment

In the past rather rudimentary thermal models have been employed in selecting thermal patterns; a more sophisticated model is being generated at present using techniques which have been proven in various Agena programs. The method is a nodal analysis using electrical network analogies in which items of hardware (black boxes) acting as sources or sinks form nodes and are coupled to adjacent nodes. To verify the results of such an analysis in a test program, it is important that the location of instrumentation be selected on the basis of this nodal model.

The thermal model being generated for the Cm system tends to treat the critical camera components in a somewhat superficial fashion, i.e., the lens is treated as a single element, as are several related components. It is felt by the committee that the thermal analytical work needs to be extended into much more depth in the camera system proper to support and extend the results obtained by thermal testing. An analytical model is needed which will permit estimates of longitudinal, radial and peripheral gradients within the lens assembly itself, for example, under varying orbital conditions and under the various conditions of system geometry which are encountered in operation. This is especially significant in view of the unpredictability of the "rest" geometry.

2.2.2. Altitude Chamber Testing

Each Cm payload undergoes a fairly comprehensive series of tests prior to launch under simulated orbital conditions in a thermal/altitude chamber. As presently performed these tests are not primarily diagnostic but serve the function of certifying the flight worthiness of the payload. No attempt is made to monitor focal shifts during tests nor is the camera system adequately instrumented for detailed diagnostic results. Camera focus is set at Itek as a result of thru focus measurements on each individual lens. Focus is adjusted to optimum at 70° F. and thermal variations are undesirable. In recent cameras a Titanium drum and Invar scan arm has reduced the sensitivity to thermal shifts substantially. (A variation of ±15°F. now produces a focal shift of ±.001 in., whereas formerly a ±15° F. variation shifted focus ±.004 in. Depth of focus is approximately .004 in.)

Because of the lack of detailed analytical work and test data, it is strongly recommended that a comprehensive thermal measurement program be pursued on Cm, concentrating on thermal response of the optical system under a range of orbital conditions. It is desired to correlate these thermal effects with system photographic performance, either by means of a collimator used in conjunction with the thermal/altitude chamber or by means of auxiliary devices capable of monitoring focal shifts and similar effects.

To support and correlate the results of system thermal testing, it is recommended that a separate thermal test program be established for the lens as a component separate from the rest of the system. Effects of temperature shifts and of transients and gradients need to be explored as they affect both focus and image quality.

Since the instrumentation accuracy available in flight probably precludes measurements of thermal gradients within the lens assembly, careful ground testing and simulation work must furnish the bulk of this data. In flight measurements can only serve as check points in the analysis.

To provide adequate data for exploring the desired goals of the program, thermal/altitude chamber tests should satisfy a number of criteria, most of which are not being met by present procedures for thermal testing. These criteria are enumerated below:

(a) Tests should be run under the best available simulated orbital conditions and over a range of orbital conditions likely to be encountered by future Cm flights. Present testing restricts individual payloads to the nominal condition predicted for that particular payload.

(b) The test specimen should be representative of the flight article and should be sufficiently complete in terms of auxiliary and related hardware items that the camera is exposed to as precise a simulation as possible. All camera doors should be removed and/or proper simulation of this aspect of the environment be provided.

(c) The orbital operations of the camera system should be programmed fairly precisely. As an example a typical range of cycle rates should be employed to be certain that measurements are obtained over a representative range of camera "rest" configurations.

(d) Additional temperature sensors need to be provided, especially in areas critical to optical performance and in particular on the lens assembly proper. Attention should be paid to accuracy of the instrumentation and proper calibration procedures should be developed to provide confidence in the data. It has been reported that self-heating effects degrade the accuracy of existing instrumentation, particularly on the thin metal of the scan arm; this situation should be rectified. Since it is important that thermal test efforts be correlated with the analytical model and these two efforts tend to be complementary, care should be taken to install sensors at or very near to points corresponding to nodes in the analytical model. Finally, since confirmation of both analytical and measurement efforts requires special thermal instrumentation on a representative sample of orbital flights, the instrumentation system developed for the altitude chamber program should be qualified for use on operational flights.

(e) As mentioned previously, it is highly recommended that camera focal shifts be monitored during the thermal testing, since this is the area of primary concern. Ideally such monitoring would be accomplished by testing in a facility where combined collimator altitude/thermal chamber programs can be accommodated. Since very few such facilities exist, since they are not completely operational and need to be modified to accept the Cm system, and since attendant problems such as scheduling, cost and security are very severe, it is felt that the use of such complex facilities should be avoided if other techniques can be substituted. Several techniques for monitoring focal shifts without the use of collimators were discussed by the members of the committee, some of which would apply only to chamber testing and some of which could be extended to orbital measurements as well. (One possible technique on orbit is simply to tilt the roller head, causing only a narrow band of the photograph to be in good focus; the position of the band being a measure of focus shift.)

(f) To define the situation more completely, the possibility of running Aschenbrenner tests concurrently on representative frames should be examined. With this combination (film flatness and focal shift determination) it should be possible to fully analyze the focus situation.

2.2.3. On Orbit Measurements

Since ground test work represents, at best, a good simulation of the orbital environment, it is important that sufficient measurements of a diagnostic nature be obtained from operational satellites to support and confirm the results of ground testing. A technique for monitoring focal shifts in flight should be developed and employed to directly correlate orbital performance with ground test results.

A limited amount of thermal data is available at present from each flight, including some tape recorded data; by expanding this existing instrumentation system, the desired data should be obtainable.

In evolving an in-flight program, the following points should be emphasized:

(a) Properly calibrated thermal sensors are required in locations consistent with the analytical model.

(b) Sensor accuracy should be selected on the basis of the desired diagnostic results.

(c) Attention should be devoted to good installation practice and self-heating effects; special techniques may be required for sensor application to glass surfaces.

(d) The lens assembly including glass elements must be adequately instrum ented to obtain information on radial, peripheral and longitudinal gradients.

(e) Tape recorded telemetry programming should be extended to provide better coverage of operational camera passes.

(f) To relate temperature profile to the camera "rest" configuration between various operational cycles, it may be appropriate to monitor by some means the precise position of the scan arm and lens between camera passes.

(g) Great importance is attached to monitoring focal shifts in flight even though this may lead to a partial degradation of the mission photography from one camera. Techniques such as tilted focal plane or stepped field flattener are cited as feasible approaches.

2.3 Vibration Environment

Insufficient data exists at present to permit definite conclusions to be drawn concerning the role of vibration in Cm performance and the extent to which resolution is degraded (if at all) by vibration under orbital conditions. Such vibrations are present to some extent, being excited by camera operation and/or by vehicle moving parts; no precise measurements of the magnitude of this effect have been made. A difference of opinion (whether or not resolution is degraded by vibration) exists in this area partly on an intuitive basis and partly on the basis of limited and somewhat ambiguous data.

The most straightforward approach for removing doubts and clarifying the role of vibration appears to be a direct comparison of the static and dynamic resolution of the camera under closely simulated orbit conditions and over a representative range of operational programs. Such comparisons have been attempted on one or two occasions in the past but results are inconclusive. Two major problems appear to exist in running such a test on existing equipment. First, the collimator normally used for resolution measurements has no provisions for static resolution, nor does the camera system provide a straightforward means for such measurements. Second, and probably more fundamental is susceptibility of the collimator itself to vibration effects and the difficulty in distinguishing between camera and collimator degradations. A third shortcoming, related to these two, is the inability to obtain measurements while the orbital vehicle is completely assembled, i.e., resolution tests are "payload only" tests with the payload rigidly fastened to the collimator base. No tests have been made with payload mounted on the Agena vehicle or a simulation of this configuration, nor have any resolution measurements have obtained while attempting to simulate vehicle induced vibrations. (It should be noted that such excitations are quite small, probably the most severe being attitude control system gas valve firings on the aft rack approximately twenty feet from the camera. A single valve provides 0.5 lb. thrust, is open for 20-30 m.sec., firing rate varies over a range of 5 to 15 pulses per second and typical operation of the system involves periods of fairly intense gas valve activity separated by varyiing period, i.e., up to several minutes, of little or no activity.) Little consideration either analytical or experimental has been given the role of these excitations in past vibration studies.

A further factor which tends to make existing data inconclusive is the standard method of obtaining resolution measurements with the Cm system on the collimator. In test runs only the lowest camera cycling rate is used, and this is almost certainly the least severe mode so far as camera-induced vibrations are concerned. This cycle rate is less than half that typically encountered in orbit. In addition, a special test slit is used (.062" wide in contrast to the 0.20" to 0.25" typically used operationally) which has the effect of shortening exposure times, even at the slow cycling rate, to approximately 1/3 to 1/4 that typically encountered in orbital operation. (Collimator resolution tests are typically made at 1/500th to 1/600th sec.)

2.3.1. Vibration Measurements

It is recommended that emphasis be placed on developing a technique which can be used with confidence to obtain a direct measure of static vs. dynamic resolution. The technique should, so far as feasible, meet the following criteria:

(a) The camera system should be mounted in a manner which closely simulates the orbital configuration.

(b) Camera cycling rates and exposure times should be varied over the range likely to be encountered in orbit.

(c) Tests should be run with those excitations present which are likely to be experienced on orbit (or a reasonable simulation).

(d) Wherever feasible, collimator effects should be determined and factored out.

If, as a result of the static dynamic comparison, a significant degradation is shown to exist, it is obvious that more detailed analytical work and additional instrumentation are necessary to explore the modes of vibration, the critical frequencies and to identify the sources of excitation.

2.3 2. <u>In-flight Measurements</u>

To support and substantiate results of collimator measurements, the mounting of sensitive accelerometers at critical points in the camera system should be considered. It is unreasonable to expect tape-recorded data of this sort, but real time transmission during a limited number of engineering passes over tracking stations is probably adequate. Also, during engineering passes, it should be possible to correlate gas valve firings from telemetry data with individual camera frames and attempt to compare photographic quality during periods of intense gas valve activity with that during periods of no activity. To obtain a similar correlation during operational passes requires some technique for recording the valve firings. Again tape recording appears unreasonable because of the frequency response requirements; however, it would appear feasible to record directly on a film data block if preliminary testing indicates that this is a critical area.

<u>CONCLUSIONS</u>

The program described above represents a very extensive and lengthy effort, and furthermore no guarantee can be made at the outset that serious photographic degradation exists as a result of these factors or that it can be identified and corrected as a part of such effort. Additional emphasis on more and better instrumentation on operational flights might be used as an alternate approach to piece together the total picture over a longer period of time, assuming that a usable measure of operational image quality will be available and that other degrading effects can be measured and factored out. The cost of the test effort must be weighed against the desirability of determining objectively the extent to which these particular factors degrade the photographic output of the Cm system, recognizing that some degradation almost certainly is present and that existing data is inadequate and inconclusive in terms of establishing the magnitude of such degradation.

III. B. 2. Engineering Passes and Aerial Targets

Introduction

In this section, detailed attention is given to the use of aerial targets. First, in order to justify the use of aerial targets, we answer the dual question, "What can be done with target photography that cannot be done otherwise and why is this useful?" Second, we discuss the role of atmospheric scattering (haze), as this is central to the choice of a target form. While atmospheric turbulence ("seeing" or refractive index inhomogeneity) is not germane to the C/M system and is therefore not discussed, it must not be ignored for higher resolution systems (e.g., [redacted]. Third, specific types of targets are described and the implications of using these are explained. Fourth, target fabrication and location are discussed. Fifth, and last, recommendations are made.

The Need for Aerial Targets

The quality of an aerial photograph is primarily determined by the nature of the object, the illumination, the nature of the atmosphere, the ability of the lens to resolve detail, the stillness and focus of the image impinging on the film, and the processing and granularity of the film. Each of these independent contributions to overall quality can be separately measured - and should be, when relevant, during camera development and test - but the only complete test of an aerial camera is an aerial photograph of an object sufficiently well known so that uncertainties about the object are negligible compared to other parameters of interest.

As can readily be imagined, the instrumentation required to accurately measure each independent variable simultaneously is overwhelming, so, as a practical matter, such a program is intelligently approximated, at best. For instance, temperature of the lens and barrel are measured, and perhaps film flatness is measured, but the location of the true aerial image relative to the film is very difficult to check other than by the photography itself. Similarly, the relevant properties of the atmosphere could be measured - if they ever become well known - but the effect of the atmosphere can be subtracted out of the quality equation for certain target forms without any measurement of the atmosphere. Thus, the answer to the question, "What can be done with target photography that cannot be done otherwise?" is - nothing, in theory; but, in practice, target photography provides the simplest, cheapest, most accurate measure of camera performance without a weight or space penalty in the airborne package.

Is this useful? The answer here depends on the intentions of the measurer. If the target photography is merely recorded and no improvements are to be attempted, then there is no point in making any measurement or in conducting engineering passes, either of a component or the complete system. However, if improvements are to be attempted, and we presume this to be the case, then an accurate measurement is needed beforehand to assist in diagnosis, and is needed afterwards as a test of success.

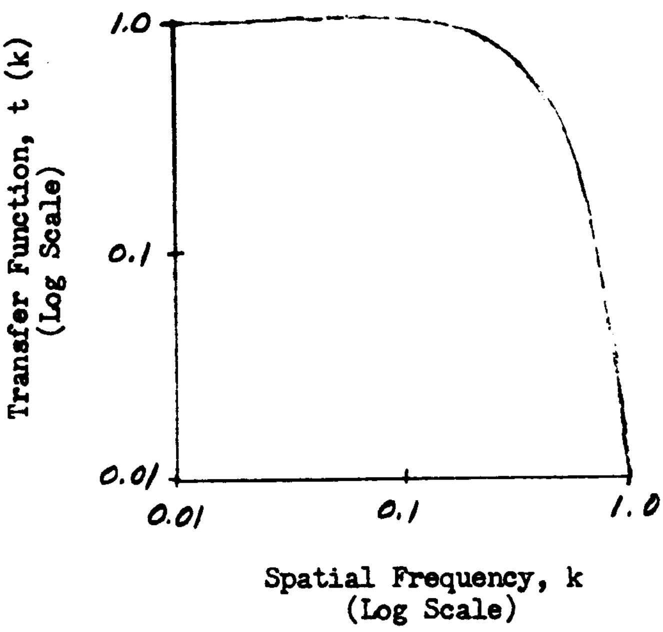
Target photography can assure good ground truth and the ambiguities can easily be made negligible for any aerial camera of interest. Similarly, appropriate ground targets will be immune to the effect of atmospheric scattering on photographic quality.

However, target photography cannot pinpoint a faulty component, although it may well identify the nature of a deficiency, so target photography should be conducted concurrently with carefully instrumented component measurements during engineering passes. The concurrency of photography and instrumentation provides a necessary consistency check on both outputs, and is the standard and most valuable test for conventional aerial cameras. Also, target photography reveals nothing about the usefulness of the photography to the photointerpreter, and this must be investigated by other means.

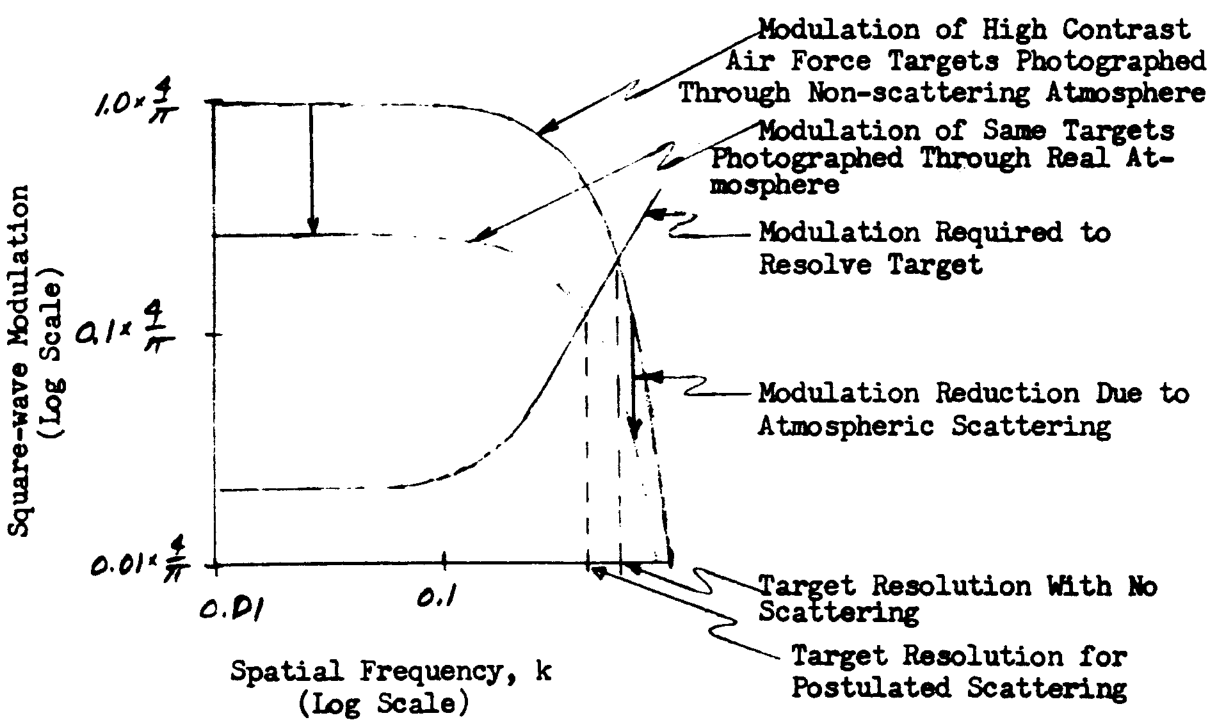
The Role of Atmospheric Scattering (Haze)

Atmospheric scattering (or haze) lowers the brightness modulation (or contrast) of an aerial photograph, primarily by adding non-image forming brightness, analogously to the addition of an extraneous D. C. voltage to a mixed A. C. and D. C. signal voltage. A reduction of signal (brightness) modulation means that the resolution of a three-bar or other target form will be lowered in a predictable way, as illustrated in Figure B.2.1. Further, the haze alters shadow contrast. Both target resolution and information will be lower in a hazy atmosphere. The important aspect is that camera deficiencies can produce similar losses, as illustrated in Figure B.2.2, and it is thus important to distinguish those losses due to atmospheric scattering from those due to camera deficiencies. In fact, because of atmospheric scattering, it is possible to obtain poorer resolution photographs with a superior camera, as illustrated in Figure B.2.3. There is no value in modifying an operational camera system if its quality

Figure __(1)__ Effect of Modulation Reduction on Resolution

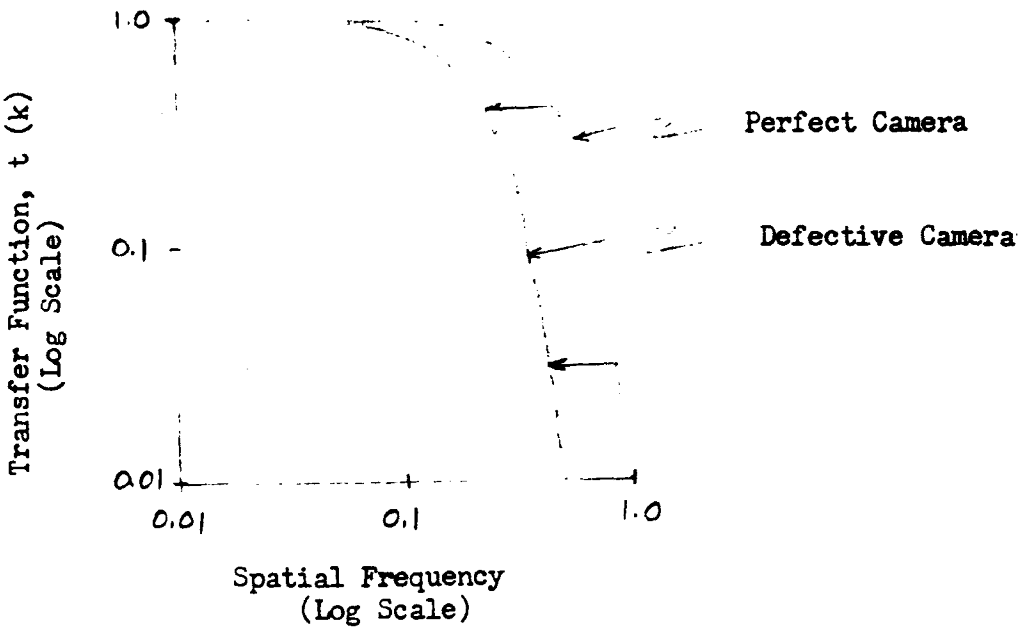


A - Transfer Function of Aerial Camera

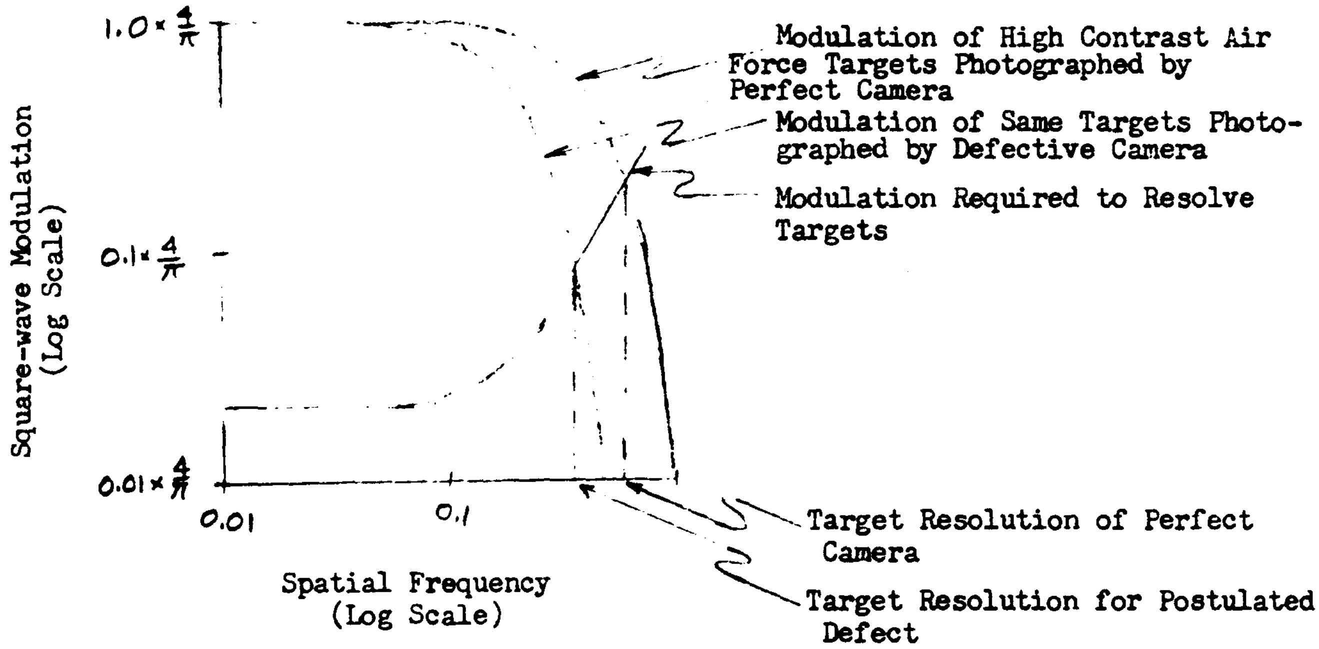


B - Modulation Reduction and Resolution

Figure __(2)__ Effect of Camera Defect on Resolution

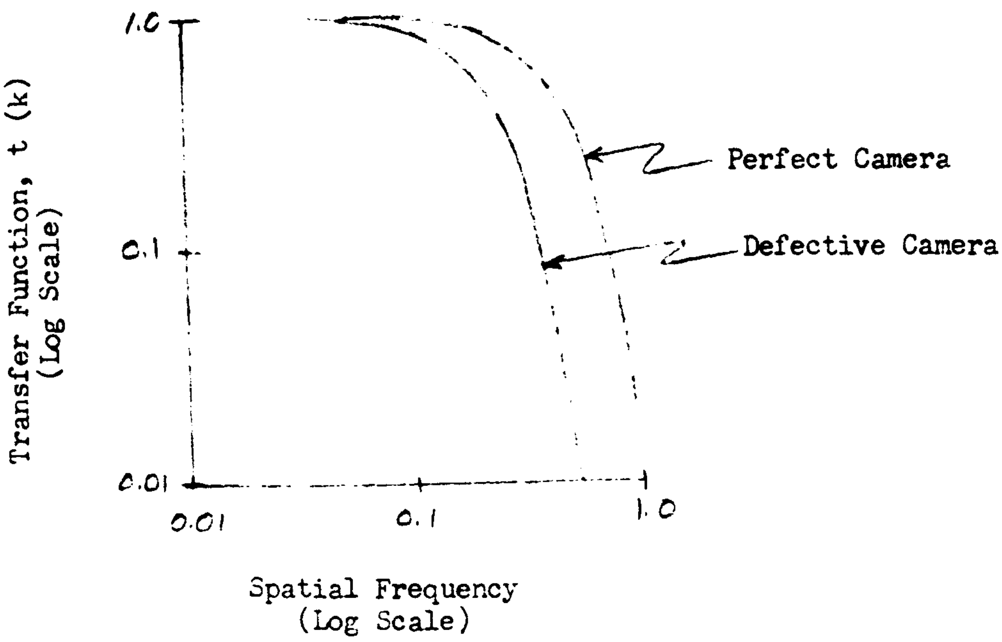


A - Transfer Functions of Aerial Camera

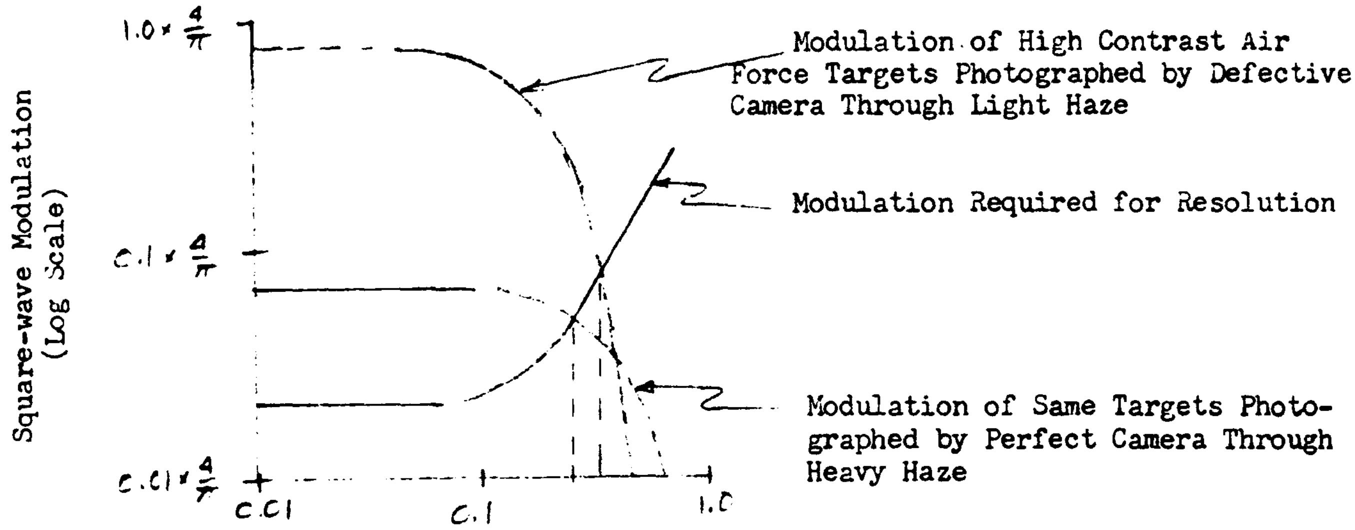


B - Resolution Change Due to Transfer Function Change

Figure __(3)__ Illustration that Camera Resolution is not a Reliable Measure of Camera Performance



A - Transfer Functions of Aerial Camera



B - Illustration of Higher Resolution Result Obtained by Poorer Camera Because of the Modulation Reduction Due to Atmospheric Scattering variations (in terms of interpretability, for instance) are caused solely by atmospheric scattering variations, so it is very important to assess atmospheric scattering, or to choose a target form which is immune to modulation reduction.

The effect of atmospheric scattering is indistinguishable from other D. C. reductions of modulation such as veiling glare or light leak. Thus, a target form immune to the effect of atmospheric scattering will not, by itself, help reveal the magnitude of veiling glare in the camera. However, this determination can be accomplished by comparative photography of ground targets.

Because atmospheric scattering reduces the target modulation and thus requires consideration in data reduction of target photography, thought has been given to installing targets above the atmosphere (or, at least, most of the atmosphere) where the target modulation would not be influenced by atmospheric effects. Assuming that the targets can be made as motionless as ground based targets, this is still a very expensive alternative to proper data reduction of the images of ground based targets and leads to torturous logistic complexities that are unwarranted.

Types of Targets and Their Associated Requirements

The most satisfactory basis for predicting and explaining the behavior of an aerial camera is by the use of optical transfer functions to characterize the imaging system. An optimum target would thus be one which permits the transfer function to be determined. Three targets which do this are edge gradient, sine-wave, and long line. Resolution targets give one point on the transfer function. Each of these forms is discussed below.

Edge Gradient

Edge gradient targets are composed of two adjacent (relatively large) areas of differing brightness, where the brightness discontinuity occurs sharply at a (relatively long) straight line. Thus, edge gradient targets occur naturally in many cases (e.g., the edge of a runway, the shadow of a building, etc.) and they are a most valuable artificial target form because of this similarity. The use of natural edge gradients in denied areas for which ground truth can only be assumed, as an approximate camera performance monitor, assures that both good techniques and convenient instrumentation will be available to reduce data from targets of this form. Furthermore, the camera performance as determined from edge gradient targets provides the only direct verification of the validity of using naturally occurring edge gradients as a further performance measure.

Since the brightness discontinuity rather than relative or absolute brightness level of the target is the critical property, this target form is immune to the effect of atmospheric scattering. The contrast reduction caused by haze lowers the relative size of the brightness step presented to the camera, but the sharpness is maintained. In fact, it is this very immunity to haze variation which makes the use of natural edge gradients valuable. If the absolute brightnesses of the edge gradient target are known, then a direct measure of modulation reduction due to atmospheric scattering is available.

The required size of edge gradient objects is determined by the magnitude of the image spread. An estimate of required dimensions can easily be made after doing the arithmetic for some nicely behaved functions.

Assuming the optical transfer function is even (i.e., no phase shift) and Gaussian, then the line spread function is also Gaussian, and the edge gradient is the error integral. For this case, Figures B.2.4, B.2.5 and B.2.6 reveal that the image of a sharp edge object is "enlarged" to slightly more than twice the reciprocal of the limiting spatial frequency. Figure B.2.7 illustrates the effect of this edge "enlargement" on the image of an edge-gradient target. Figure B.2.8 relates patch size to microdensitometry requirements.

In Figure B.2.9, a four-patch target is illustrated. It contains the four long edges and sufficient area adequately remote from edges to give reliable brightness data. Table B.2-I gives ground dimensions, based on a Gaussian transfer function, for two systems for current interest and also for a hypothetical system. Allowing for non-nadir viewing and other pessimistic factors, the table contains suggested dimensions for four-patch targets of the form illustrated in Figure B.2.9.

To get a better feeling for the reasonableness of the suggested safety factor, the dependence of the suggested size on the Gaussian transfer function assumption is next considered. An exponential transfer function produces an inverse tangent edge gradient. This gradient approaches the patch brightness asymptote very slowly and thus would require a patch nearly fifty times larger than the reciprocal of the limiting spatial frequency. (See Figure B.2.10, B.2.11 and B.2.12) If, however, the patch is the previously suggested four or five times the reciprocal of the limiting spatial frequency, the brightness gradient would be within 11% of the

[redacted]

FIG. B2-4 - BRIGHTNESS DISTRIBUTION OF EDGE

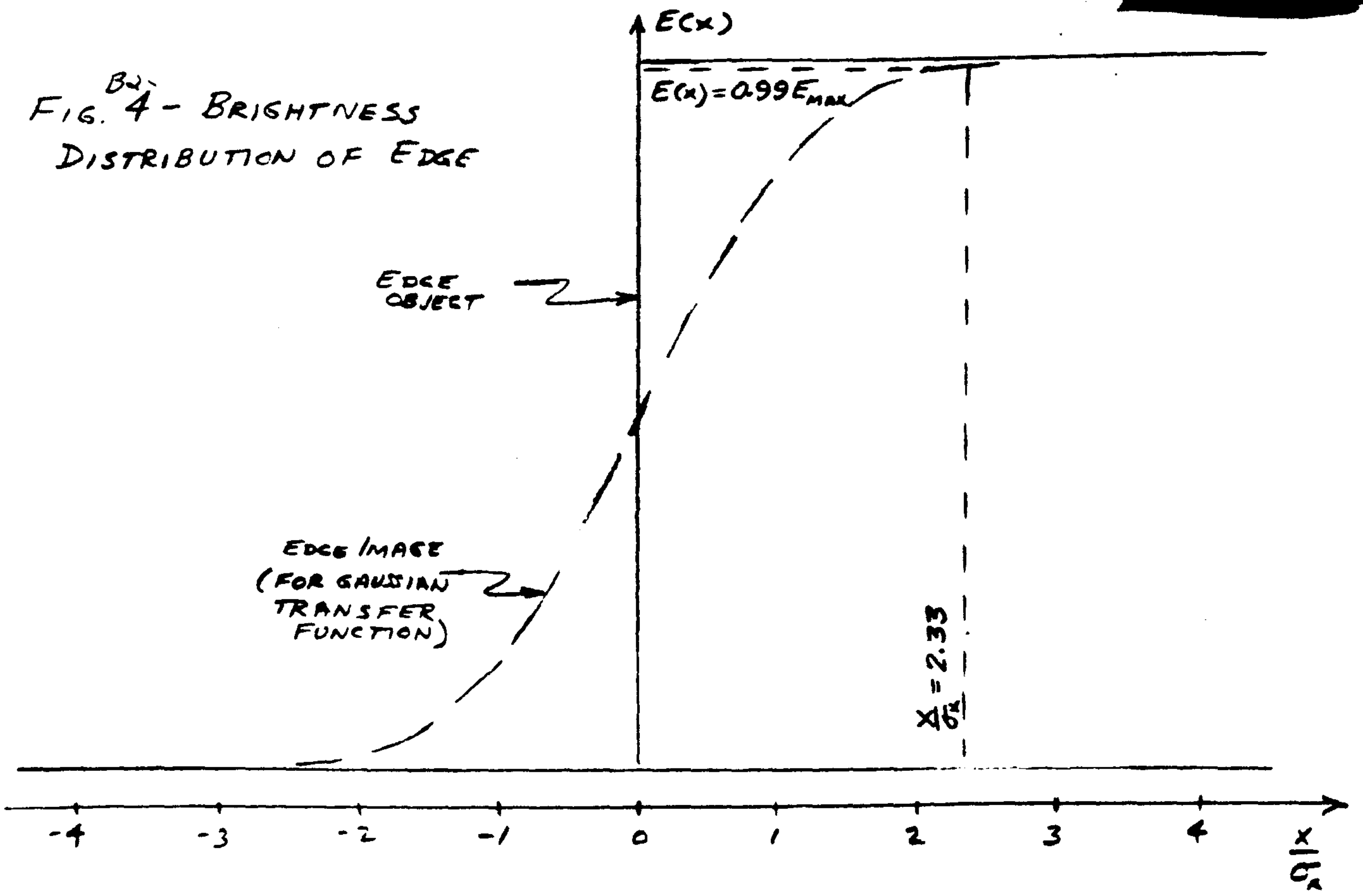
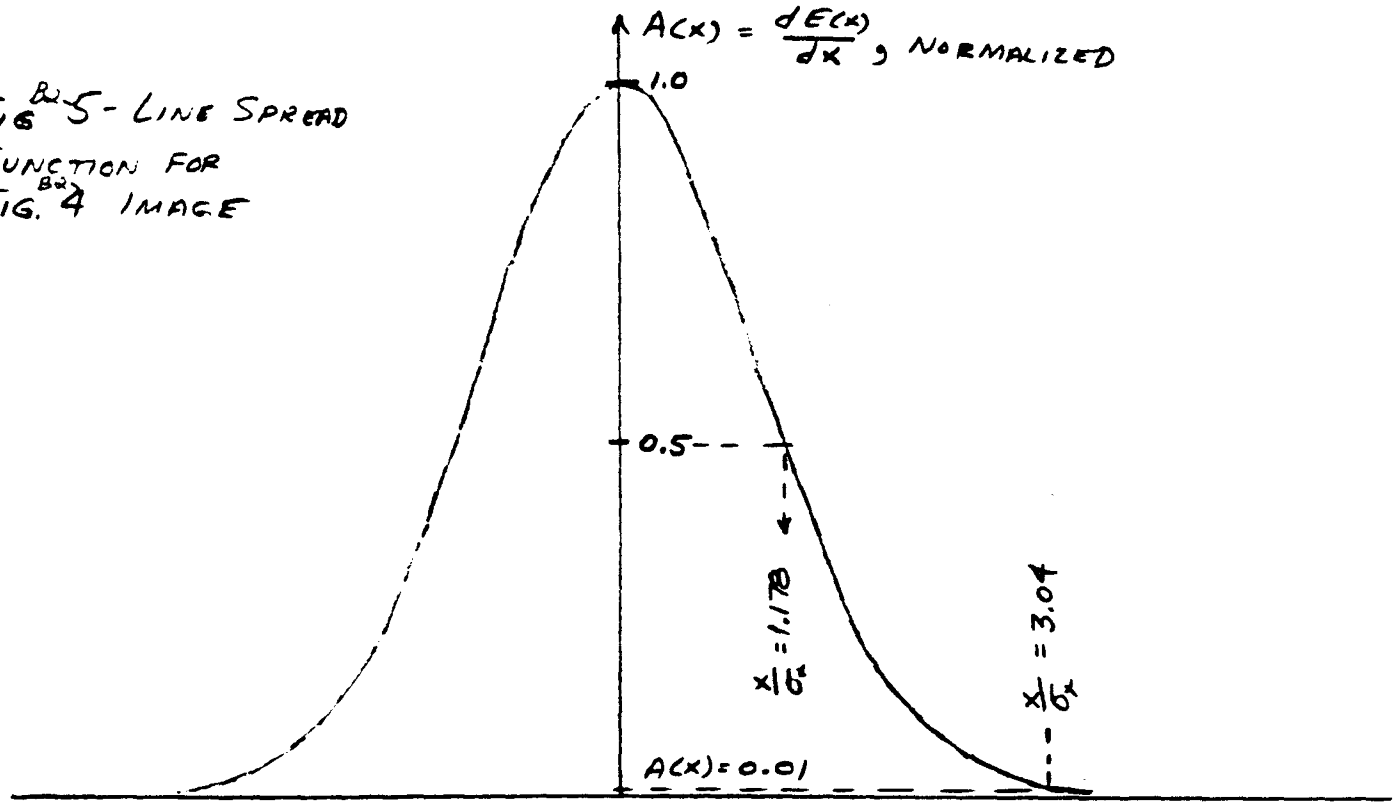
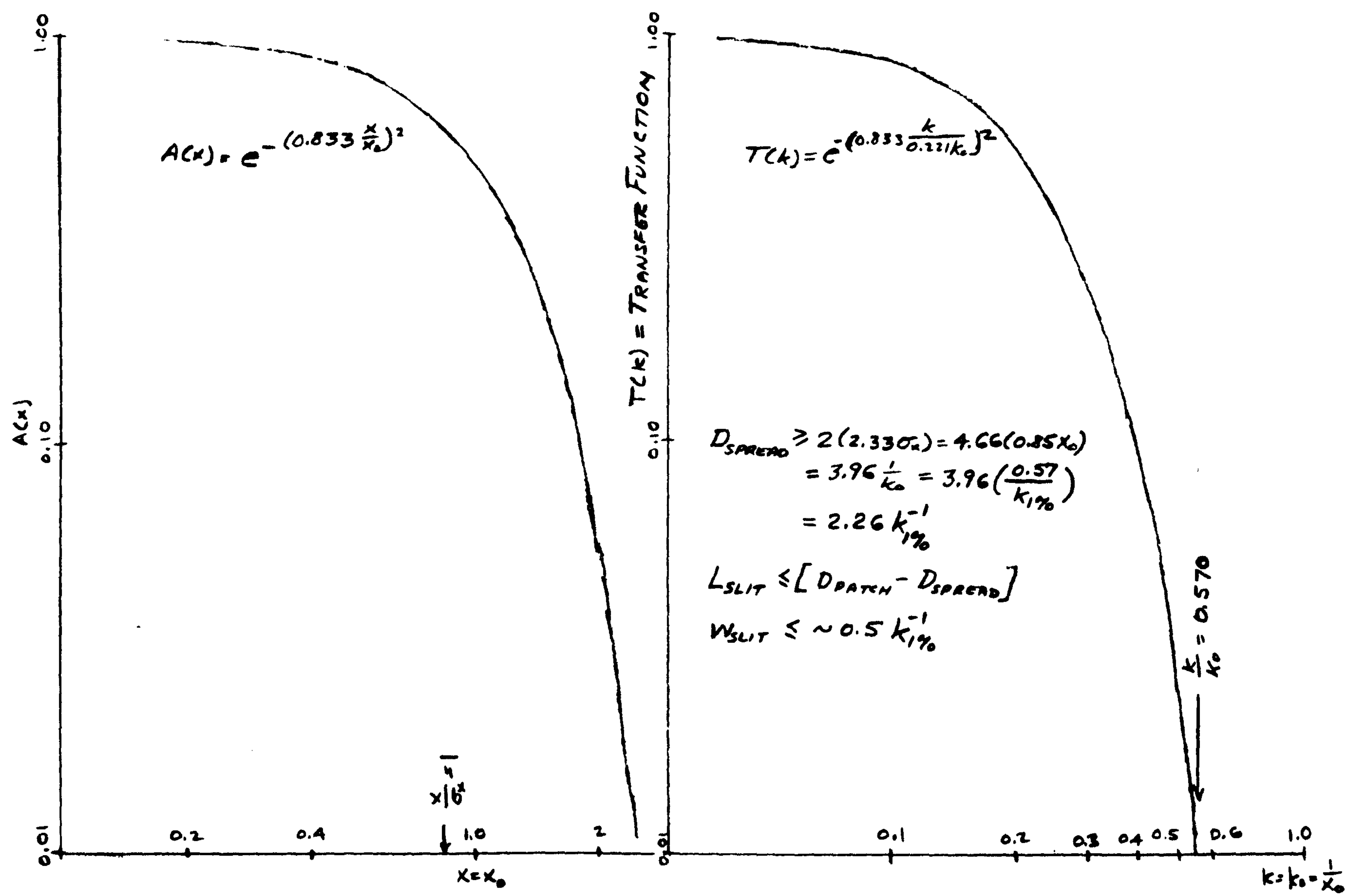


FIG B2-5 - LINE SPREAD FUNCTION FOR FIG. B2-4 IMAGE

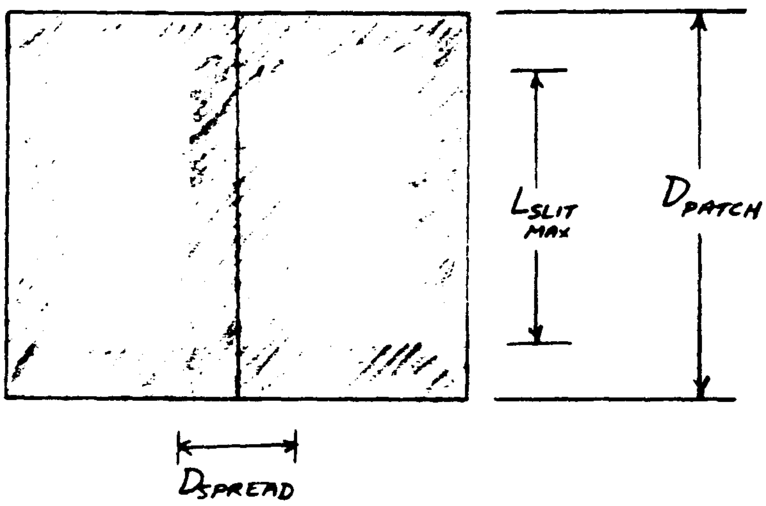


[redacted]

FIG. B2-6 — LINE SPREAD & TRANSFER FUNCTION FOR FIG. 4 IMAGE



Handle Via [redacted] Control System Only



$$D_{PATCH} \geq [L_{SLIT} + 2.26\, k_{1\%}^{-1}]$$

Fig. 7 - Image of Edge Gradient Target

[redacted]

FIG. B2-8- MICRODENSITOMETRY CONSIDERATIONS

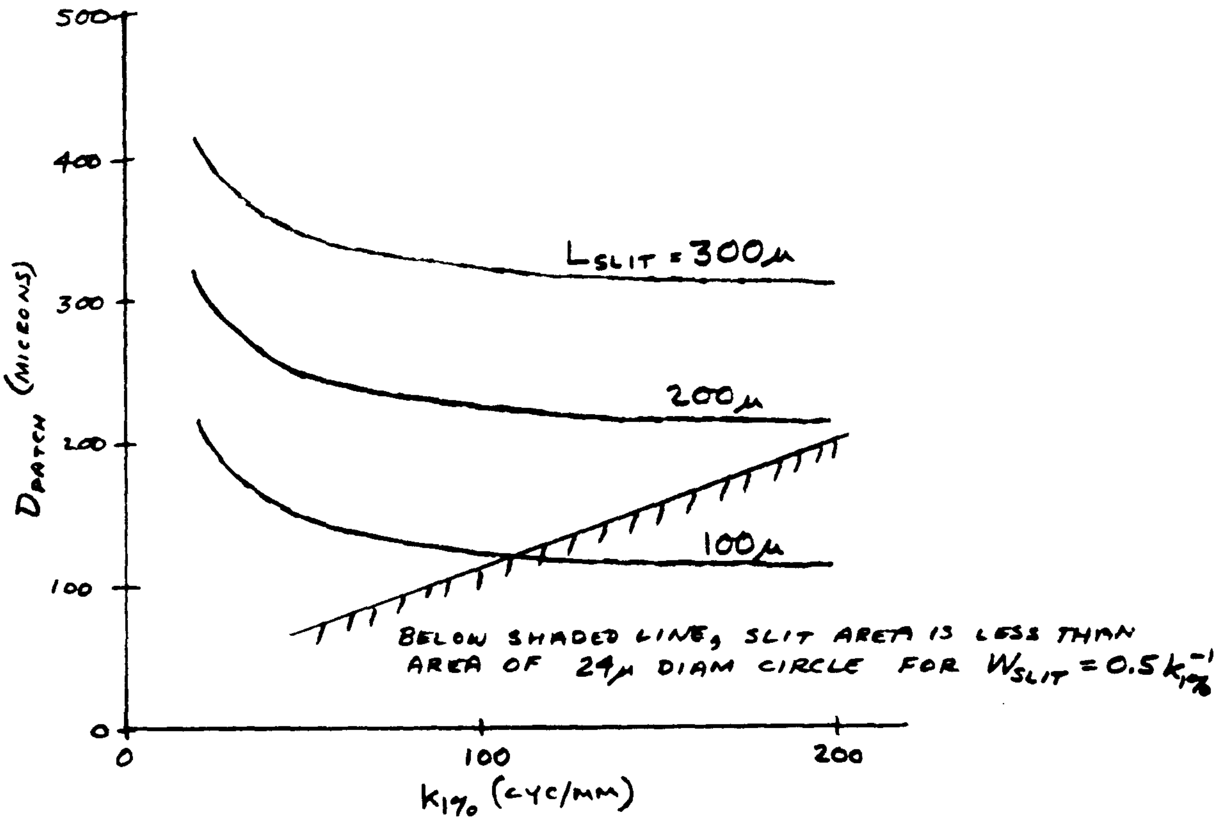
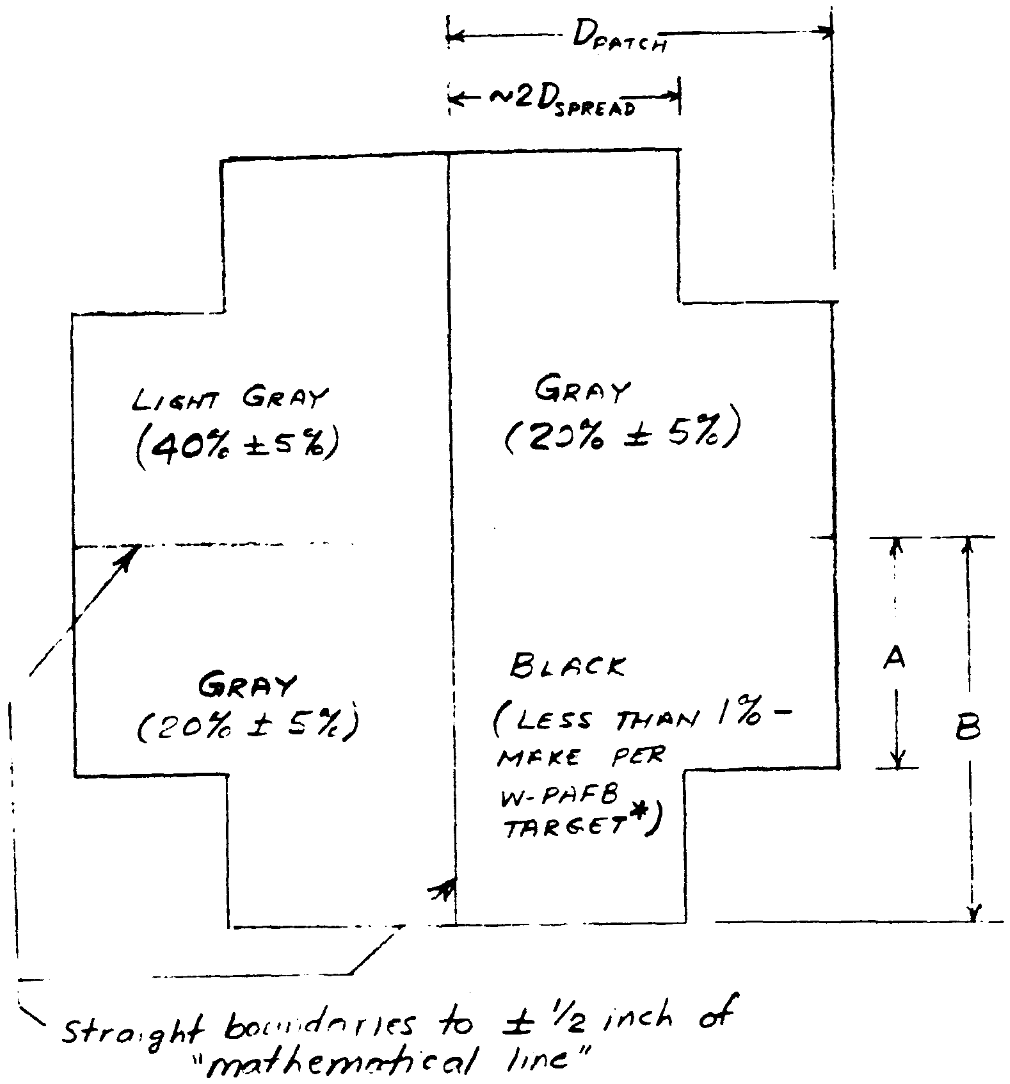


FIG 9 TWO-DIRECTION FOUR-EDGE GRADIENT TARGET AND GRAY SCALE

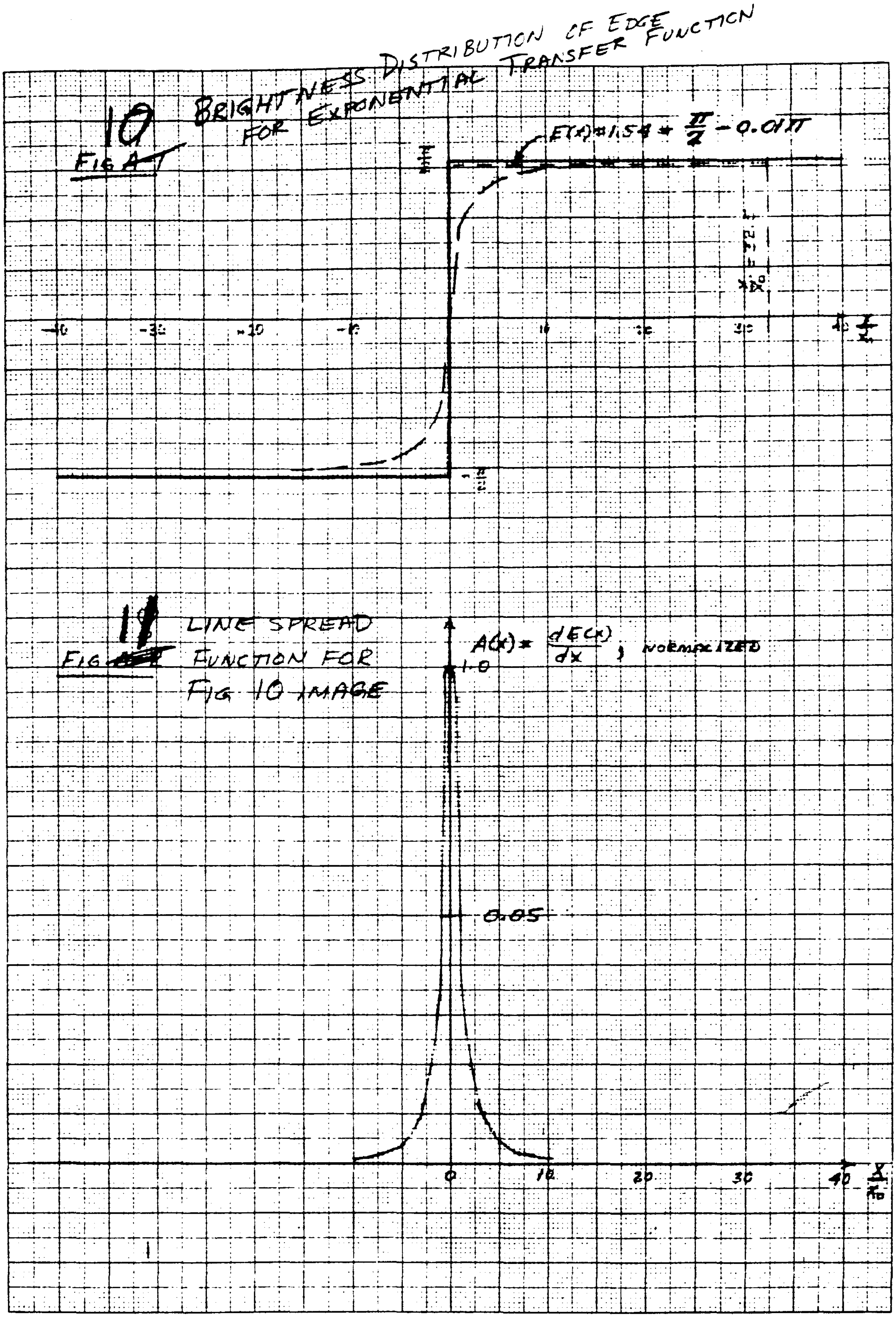


* L. Bogdan, "Instrumentation for Aerial Photographic Experiments", Cornell Aeronautical Laboratory Report VF-1478-P-1 prepared for ASD Reconnaissance Laboratory at Wright-Patterson AFB under [redacted], Project No. [redacted], Task No. [redacted] July 1961. See pages 5-10.

Table B.2.-I

Edge Gradient Target Dimensions

System	Assumed K1% (L/mm)	D_{spread} (μ)	A (=2 $D_s h/f$) (F+)	Assumed L_s (μ)	B (=[D_s + L_s]h/f) (F+)
C/M	100	22.6	54	100	148
	50	45.2	108	50	114
[redacted]	100	22.6	17	100	46
	50	45.2	34	50	36
Hypo-thetical 120" Focal Length	200	11.3	5	200	51
	100	22.6	11	100	30
	50	45.2	22	50	23
Recommended Sizes (Incl. Contingency)			120		200



[redacted]
25 Dec 6.

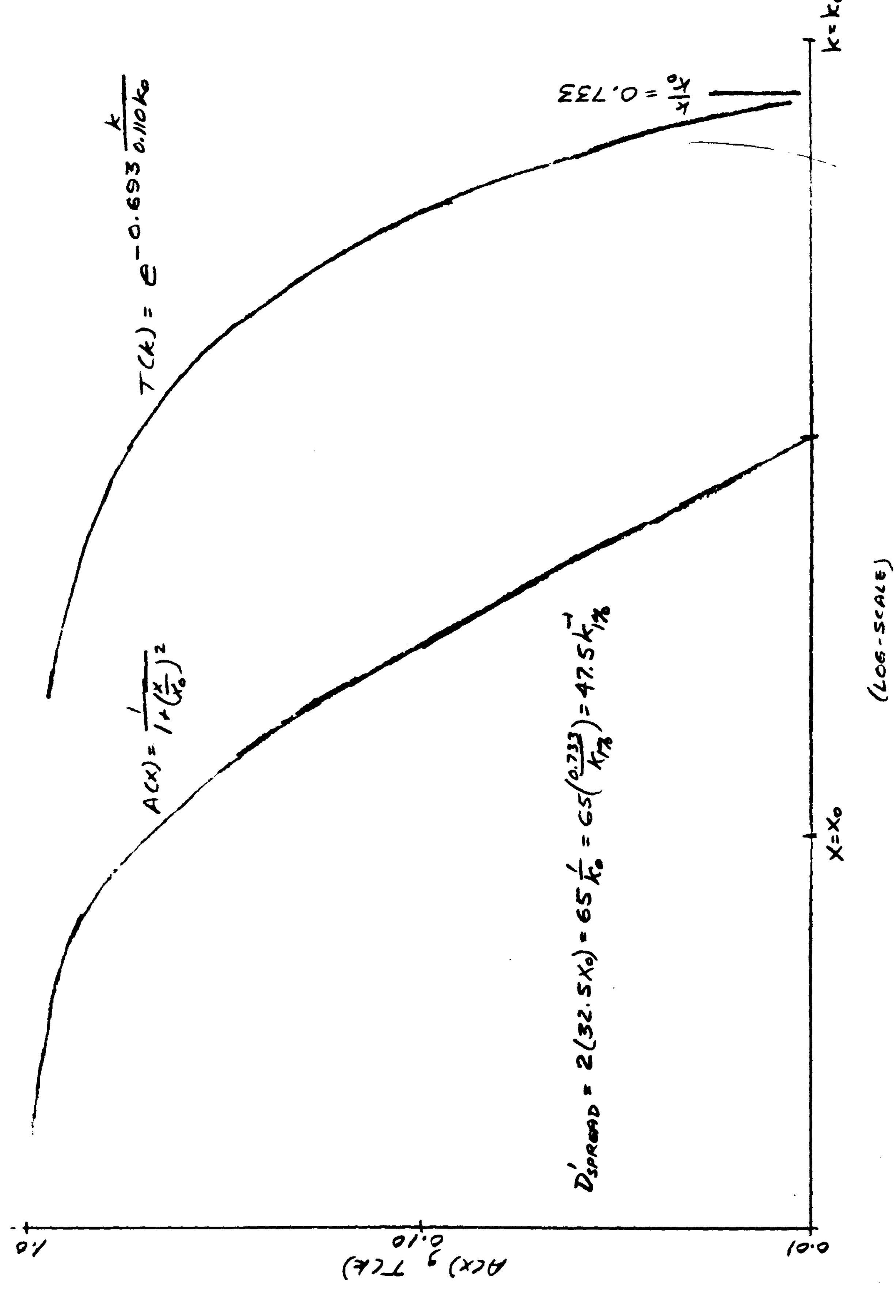


Fig. 12 - Line Spread & Transfer Function for Fig. 10 Image

asymptotic value rather than the 1% difference for a Gaussian transfer function. Conversely, linear image motion gives a linear-ramp gradient and only produces a spread equal to the reciprocal of the limiting spatial frequency. (See Figures B.2.13, B.2.14 and B.2.15.)

Instead of the four-edge target form illustrated in Figure B.2.9, some economy of space is achieved by using a two-edge target as illustrated in Figure B.2.16.

The transfer function is obtained from a Fourier Transform of the exposure gradient on the film. Thus, sensitometric data and a microdensitometer trace of the edge are required, and it is convenient (but not necessary) to obtain the Fourier Transform with a digital computer.

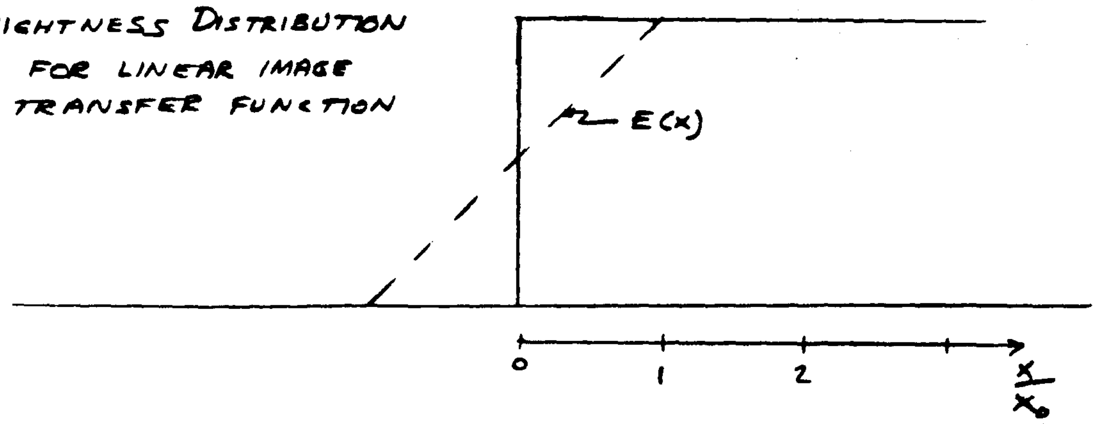
<u>Line</u>

In principle, line targets are comparable to edge gradient targets. They must be of the same size but they lack two virtues of the edge gradient form: (1) No gray scale is available "free"; and (2) A very high resolution camera might not be able to use the same line target as the C/M cameras. These targets thus have no clear advantage over edge gradient targets and are not recommended.

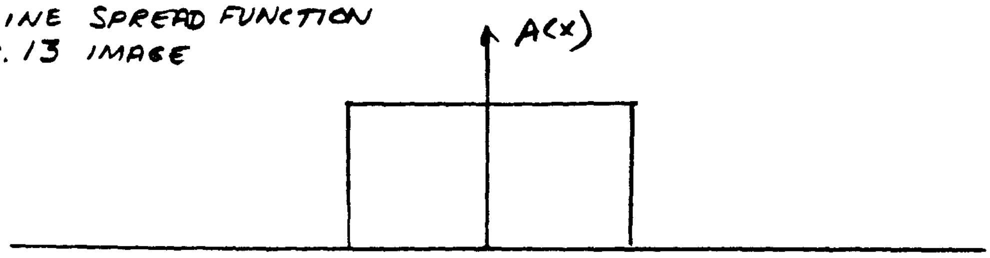
<u>Sine-wave</u>

These targets consist of paint patterns arranged so that the integrated brightness along a line element varies sinusoidally as the line is displaced perpendicular to its length. Each target provides one spatial frequency in one direction, and it is thus necessary to have several (e.g., four to six) targets aligned in each of two perpendicular directions. The transfer function is thus approximated by a curve drawn through the several determined points. The conceptual and arithmetic simplicity of this approach is attractive, but the target area is very large (approximately 200 feet by 240 feet for the lowest spatial frequency, and then proportionately smaller for the several higher frequencies) and the targets must be accompanied by a gray scale on the ground. Since this gray scale could take the form of an edge gradient target, the sine-wave target form can be viewed as a trade in which greater ground target area is substituted for the computation of the Fourier Transform of the edge gradient. The sine-wave target requires the same kind of sensitometric data and microdensitometer trace as the edge gradient.

Br.
FIG. 13 - BRIGHTNESS DISTRIBUTION OF EDGE FOR LINEAR IMAGE MOTION TRANSFER FUNCTION

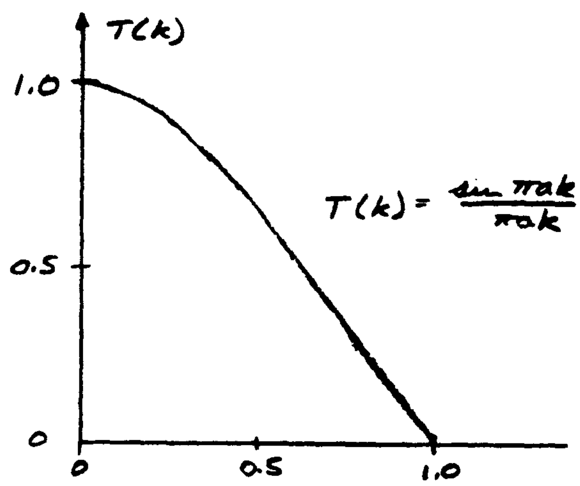


Br.
FIG. 14 - LINE SPREAD FUNCTION FOR FIG. 13 IMAGE



Br.
FIG. 15 - TRANSFER FUNCTION FOR FIG. 13 IMAGE

$D''_{SPREAD} \cong K^{-1}_{1\%}$



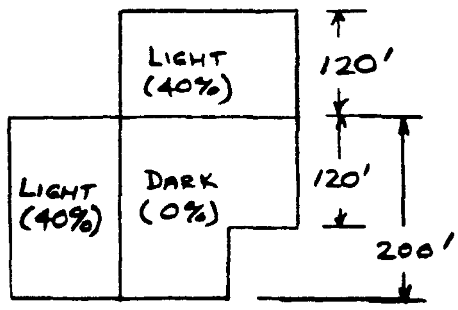


FIG. 76 - TWO DIRECTION TWO-EDGE GRADIENT TARGET

Sine-wave targets must be made for each spatial frequency of interest, and, thus, other cameras of higher resolution require further targets (which would be smaller). The size of the targets can reveal resolution dimensions of the using cameras, and this should be considered.

Resolution Types

Over the years, many resolution test patterns have been proposed for cameras (e.g., National Bureau of Standards, Ross, Siemens, Sayce, Cobb, comb, and others), but recently it has been conventional to employ Air Force three-bar patterns. The "resolution limit" on any of these patterns is the spatial frequency at which the modulation transfer function (i.e., the modulus of the optical transfer function) multiplied by the target modulation intersects the modulation detectability function for the target. Modulation detectability curves currently exist only for the Air Force three-bar pattern. The use of such targets can give only one point on the optical transfer function, but these Air Force targets are worthy of consideration, particularly because of their tie to recent practice in the Reconnaissance Community and because of familiarity.

Figure B.2.17 illustrates a single frequency pattern, useful in two directions. Figure B.2.18 shows a normal array of six frequency steps. Figure B.2.19 is a possible layout of four groups which would decrease from a pattern of 24 feet per line pair to 1.7 feet per line pair, thus covering the range of C/M, and, with the smaller groups, also covering the range of realistic higher resolution systems. The overall size of the array is controlled almost entirely by the coarsest spatial frequency of interest; as shown in Figure B.2.20, the 24 foot dimension implies that the array in Figure B.2.19 would be 192 by 386 feet. To this area, it is necessary to add a gray scale, which could take the form of an edge gradient target. As with the sine-wave target form, this extra ground area is a trade to reduce data reduction. Unfortunately, only one point on the transfer function is obtained, so these targets are not very useful in this regard unless the shape of the transfer function is invariant.

In common with sine-wave targets, the size of these targets reveals the resolution dimensions of interest.

FIG. 17 - SINGLE FREQUENCY (K) TARGET

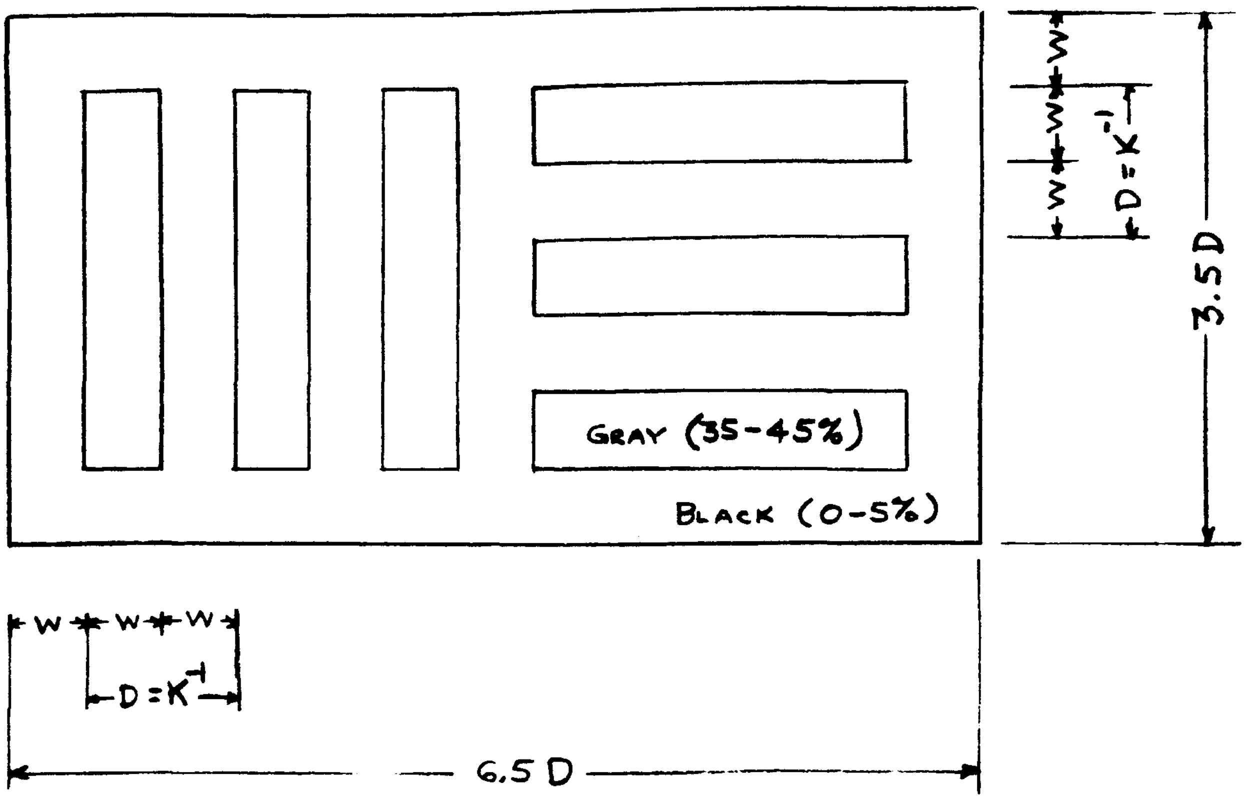
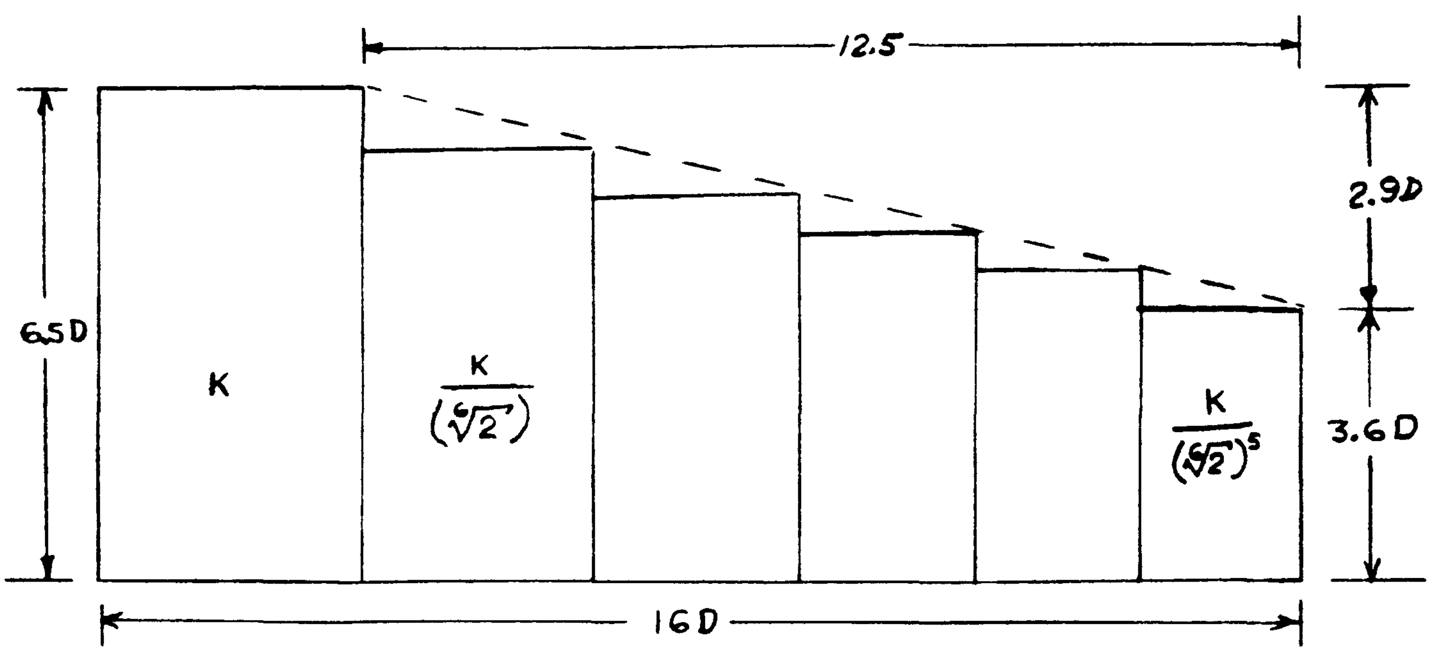


FIG. 18 - GROUP OF SIX TARGETS, VARYING BY $2^{-1/6}$



[redacted]
12 JAN 64

[redacted] 12 JAN 64

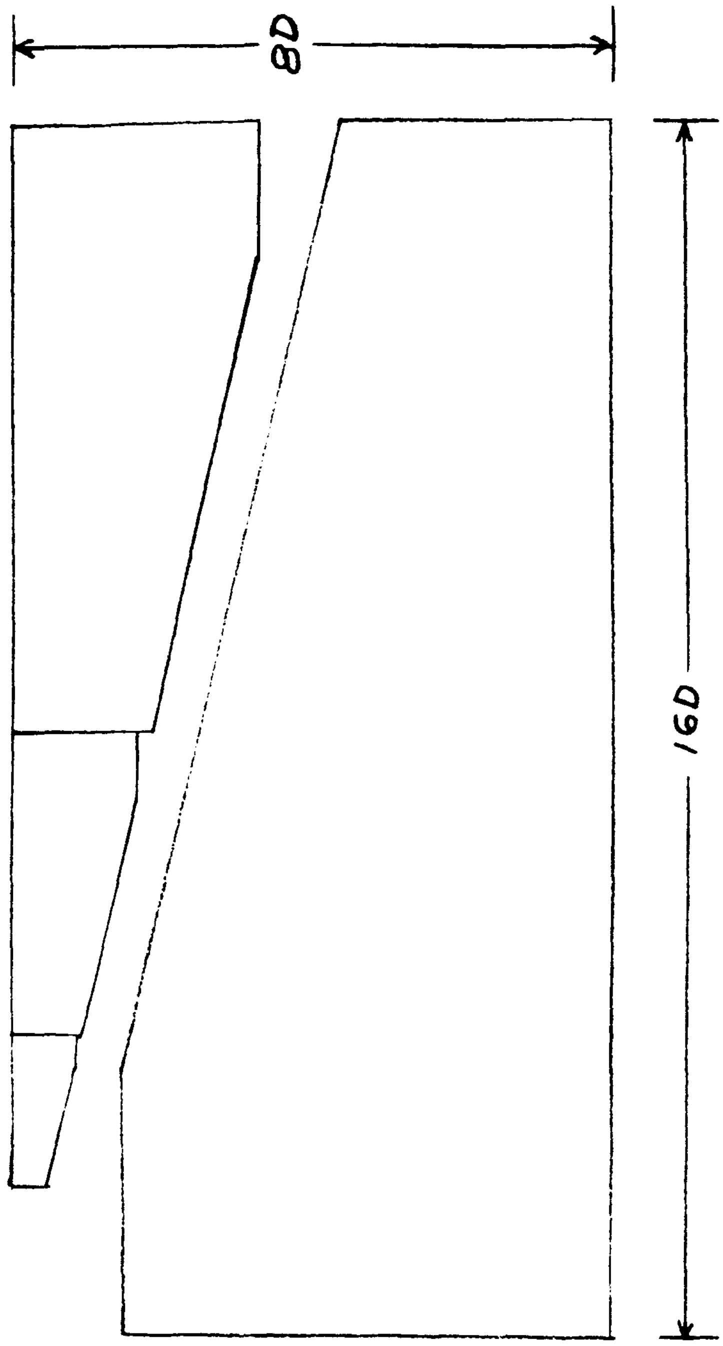
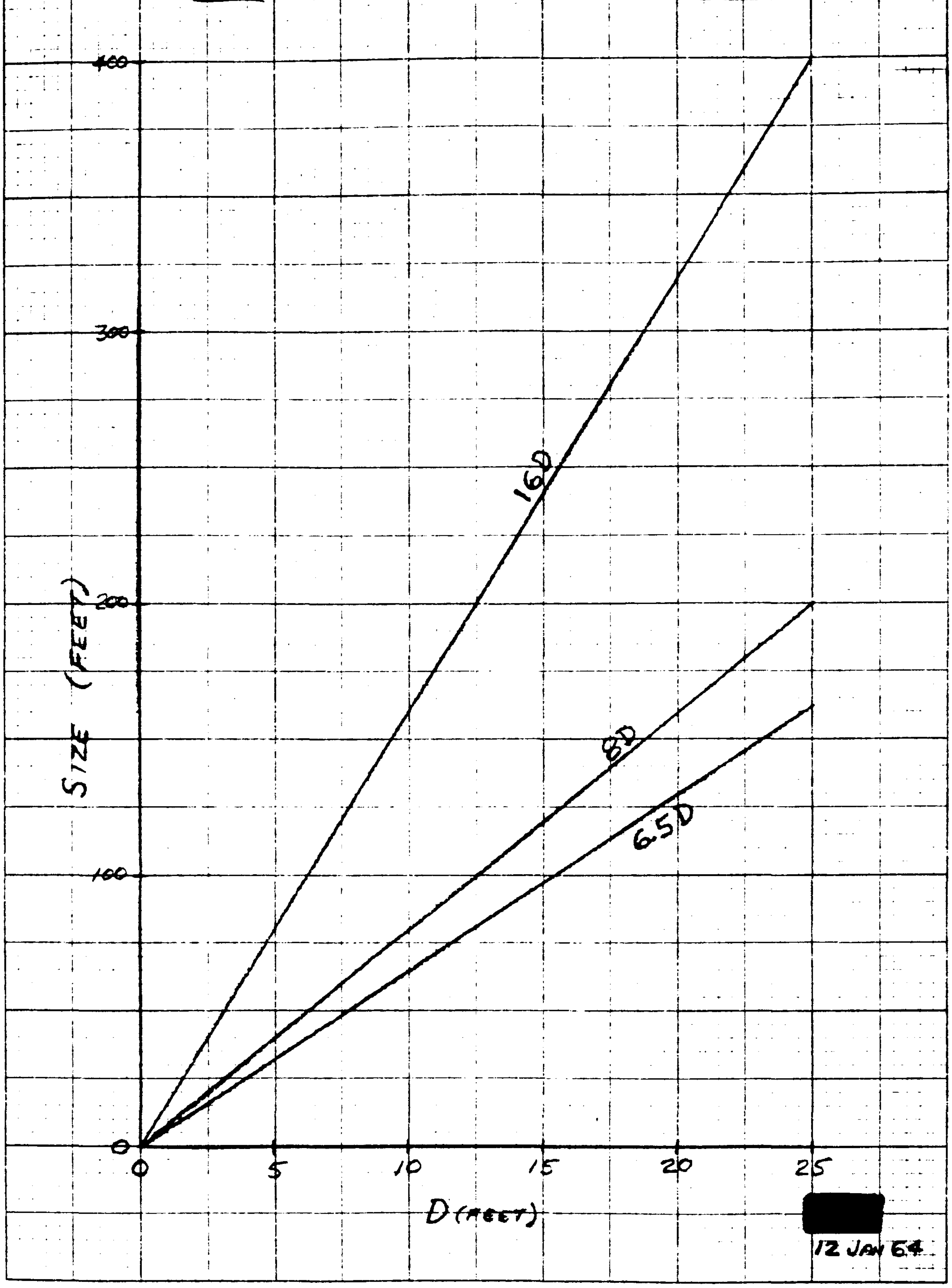


FIG. 19 - FOUR GROUPS OF SIX TARGETS

[redacted]

FIG. 20 - OVERALL SIZE OF AF TRI-BAR TARGETS



Handle Via [redacted] Control System Only

Target Fabrication and Location

Conventionally, aerial targets are made with very black and very white paints and thus have an average reflectance close to fifty per cent. However, the average albedo (reflectance) of the earth is about twenty per cent. As the camera is normally programmed for exposure based on this earth value, the average reflectance of aerial targets should also be close to twenty per cent, thus assuring near optimum exposure.

Geographically, the targets should be located south of the normal snow limit to simplify maintenance, but it may be desirable to place some targets farther north to more closely match operational latitudes. To further increase the optical accessibility, daytime cloud and fog cover should be minimized by proper site selection. Obviously the targets should be distributed close to habitual satellite tracks, preferably early orbits.

Finally, if ground brightness readings can be made of the targets and meteorological data obtained, both nearly simultaneous with the photography then it is possible to experimentally confirm postulated relations of modulation reduction and meteorological conditions. A time leeway of from five to fifteen minutes would seem reasonable, depending on how rapidly conditions changed, but the target site must be quite accessible if this measurement program is to be attempted.

Recommendations

As an absolute minimum, three edge gradient targets of the form shown in Figure B.2.16 should be constructed and maintained. This work is underway. This gives a fair probability of obtaining target photography on each mission. C/M photography of these targets should be obtained as frequently as possible. Diagnostic on-board instrumentation should be operated simultaneously with the target photography whenever it is available. The reduction of operational coverage resulting from these engineering passes is an investment to improve future operational coverage and is probably so insignificant that it will never be missed.

More extensive targets are very desirable, since these will increase the probability of obtaining target photography. Money and space permitting, about six edge gradient targets of the form shown in Figure B.2.9 should be constructed and maintained. Of lower priority, Air Force targets of the form shown in Figures B.2.17, B.2.18 and B.2.19 could be added if still further money and space were available.

Because non-image forming exposure (corona, radiation, light leak, etc.) is at times a very serious problem with C/M photography, it is valuable to capitalize upon these targets and CORN overflights of these targets until the extraneous exposure problem is under control. Specifically, nearly simultaneous overflights (say within fifteen minutes either way) of the targets should be made at a high enough altitude so that a camera with negligible light leaks can obtain photographs of the same targets as seen with all of the significant atmospheric modulation reduction. When this camera has the same film-filter combination as C/M and views the targets from the same angle and with the same illumination as C/M, then the difference in modulation reduction perceived by the two cameras is a measure of the unwanted exposure in C/M.

III. C.1. Subcommittee Report of Type 4404 Film with the Corona Camera

Purpose

Subcommittee was constituted to examine the film/camera characteristics (Type 4404/Corona) as can be determined from the existing knowledge of the film data and results of the mission test and operational data.

Subcommittee met at [redacted] 6 January 1964 and a one day review was presented. Following personnel were in attendance:

[redacted]

Observers

Mr. E. Kiefer — DDNRO

[redacted] — [redacted]

Eastman Kodak

[redacted]

Mr. E. Green

[redacted]

[redacted]

Mr. D. Schoessler

Procedure

[redacted] welcomed the group to the facility and presented a full day agenda for consideration. The discussion and presentations included the following items:

1. Historical Background
   a. Interrupted Processing
   b. Exposure Criteria
2. Characteristics of Kodak High Definition Aerial Film (Estar Thin Base) Type 4404.
3. Typical Mission Procedures
   a. Preliminary Prediction
   b. Detailed Processing Plan
   c. O. N. Processing Machine
   d. Film Preparation
   e. Control Procedures
   f. Post-processing Evaluation
   g. Printing

4. Data on past C/M/J Missions

   D $_{Max} \cong$ 1.35 2 σ variation .6 to 2.5

   D $_{Min} \cong$ 0.8 2 σ variation .2 to 1.5

5. Tour of Facility

<u>Summary</u>

1. Interrupted Processing. Historical review covering former and subject systems indicated that the film and chemical processing is well understood; pressure of continued heavy workload has slowed the pace of development of equipment and chemical processing. Steady progress in image measurement and equipment refinement is evident in the processing of the original negatives from MSN 9009 to MSN 9062.

2. Exposure Criteria. Criteria are based on early aircraft flight test program and aircraft reconnaissance systems. Data obtained result in a minimum scene luminance between 350-2000 foot lamberts with peak at 890 foot lamberts. The Type 4404 exposure curves used for CORONA and provided by Eastman Kodak are based on a speed point at 675 foot lamberts. The [redacted] mission exposures are based on a minimum scene luminance of 890 foot lamberts. The log E difference between the two is 0.12. This difference in minimum scene luminance is the main reason for the variation in D min, D max, $\bar{D}$ and Δ D between CM and [redacted] photography. These exposure values may not be appropriate for all space systems.

3. Typical Mission Procedures. A review by Eastman Kodak of the mission exposure data selected by Project Resident Officer is made to determine if existing standards are adequate. The processing stage to be used for start of mission photography is selected and determination is made as to where changes in chemical processing are likely to be required as a function of solar angle. Machine preparation, including tests strips to verify processing state, for beginning and periodic chemical analyses, are accomplished. Processing is viewed by infrared viewer and with a scanning infrared densitometer having a line of cells. Each cell is .080" x .080" (.3 x .3 N. Mile on ground). These two devices are used for determining processing state after the first stage.

Extreme effort is essential to correlate measured image parameters [redacted] with procedures for Trenton Processor control to preserve the maximum imagery in the peak performance of the Type 4404 characteristic curves.

4. Characteristics of Type 4404 Film. Physical and sensitometric charac[redacted]istics of Type 4404 film indicated that this film is generally unsurpassed in

quality and performance. However, improvements to provide a higher D_{max} without loss of quality or speed are desirable for C/M photography.

5. Image Measurements. Equipment and procedural differences in the measurement by different laboratories provide various statements of image quality. It is necessary to continue the exchange system for standardization of all measurement techniques and development of objective systems to replace subjective procedures where possible.

6. Lens Flare. SPPL is to make density measurements on the original negatives from CM and [redacted] using apertures in densitometers ratioed in size to cover the same ground area to attempt to determine the flare of the CM lens.

7. Physical Characteristics. It was concluded that degradations to the image quality as a result of relative humidity changes, low ambient pressure, tensile strength properties, thermal effects, and optical response are negligible with the exception of the contribution to the static discharge phenomenon.

<u>Conclusions</u>

1. Exposure Programming and Chemical Processing have contributed no appreciable degradation of limiting resolution in the CM photography; however, exposure criteria should be immediately reviewed and revised as appropriate. Positive steps must be taken to insure adequate communications and use of common exposure criteria between system designers, operators, and film processors.

2. The emulsion should be changed to yield greater exposure latitude (higher D_{max}) without causing MTF, grain size, or layer thickness to change adversely. In addition, the Pelloid back coating should be modified to eliminate interference (noise) contribution in image reproduction and subsequent measurements.

3. Immediate standardization of measurement techniques is required for density, microdensitometer measurements and data reduction and reporting by NPIC, SPPL, and [redacted]

4. D_{max} and D_{min} data should be analyzed to determine optimized techniques for processor control to keep off the toe and shoulder of the curve and develop objective density criteria suitable for CM original negative development in the Trenton processor.

III C 2 Some Comments on Cloud Cover, Processing and Exposure

An examination of the processing data (1) for the film from the Panoramic cameras in Missions 9056, 9057, 1001 and 9062 yields the results indicated in Table C2:

Table C2-I

Approximate % of Film Processed Under Conditions Noted

Mission No.	Primary	Intermediate	Full
9056	--	44*	56
9057	--	7	93
1001	--	--	100
1002	M	S	S
9062	--	27	73

* 69% Master film was processed intermediate. Much of this film was fogged, apparently due to light leak. 19% Slave film was processed intermediate.

M Majority of Master Film processed primary; high level of fog was present, apparently due to light leak.

S Slave film processed either intermediate or full; no percentages available.

Comparison of Processing with Cloud Cover

Some correlation between cloud cover and processing level might be expected. This correlation was explored, particularly for those missions employing more than one processing level.

The average cloud cover data (2) during all the operational passes of a particular mission are compared in Table C2-II with the approximate average cloud cover for those passes in that mission processed intermediate.

Table C2-II

	% of Cloud Cover					Average Cloud Cover %/pass
Mission No. 9057	=10	10-25	26-50	51-99	100	
Mission Average	17.0	7.2	13.1	50.0	12.7	57.3
Average for Int. Processing	18.8	4.4	7.5	53.0	16.4	60.5
Mission No. 9062						
Mission Average	41.9	9.2	9.3	26.2	13.4	40.3
Average for Int. Processing	32.5	10.6	7.3	33.2	16.5	47.6

Appropriate data for the other missions are not available. Since that film from Missions 9057 and 9062 not processed intermediate was processed full, there is an obvious lack of correlation between heavier than average cloud cover and full processing.

This conclusion is reinforced by individual passes with minimum cloud cover (5%) which were processed full (e.g., 9057 - 24A, 57D; 9062 - 25D).

Discussion

The above data clearly indicate a tendency toward full processing. This in no way implies that substantial amounts of intelligence information of value are being lost by "overprocessing". Indeed, a compilation of density data presented during the Users' Subcommittee visit to [redacted] (3) indicated that the shoulder or toe of the characteristic curve was reached in relatively few cases.

The disturbing factor is this. Exposure determination is made by the mission planners on the basis of an intermediate processing curve (4). A tentative conclusion is that less exposure, on the average, is ordinarily obtained than expected. This might be due to the use of too large a value for the average luminance of an aerial scene on which the Exposure Value Number - Solar Altitude curve is based.

The experimental determinations of the variation of apparent scene luminance with solar altitude involved a limited series of aircraft tests (Spokane, 1955; Red Dot 12/56-6/58) over a restricted geographical area.

It would appear that a re-examination of exposure criteria based upon operational results is in order. If consistently less than expected average exposure is being obtained, less margin for error is left before intelligence is lost. To this end it is recommended that more communication and closer liaison be promoted between the mission planners and the processors.

REFERENCES

(1) "Processing Summary for Mission ________".

(2) "Cloud Cover Information" for appropriate Mission.

(3) "Subcommittee Report of Type 4404 Film with the Corona Camera" (see previous Sect.)

(4) "Current Method for M & J Systems Exposure Determination".

III C 3 Mission Sensitometry

Definition:

Sensitometry refers to the technique (s) of applying a series of known, controlled exposures to photosensitive material such that, after subsequent processing and density measurement, a calibration curve of output (density) versus input (exposure) may be generated. This curve is the "characteristic curve" of the material and is usually plotted as density versus log exposure as suggested by Hurter and Driffield.

Present Practice:

It is normal practice with mission film to attach a sensitometric strip exposure at the head and tail of each roll before processing. These sensitometric exposures are on the same type film as the mission and comparison of the H & D curves from head and tail with the specified standard curves provides a measure of machine stability for the over-all mission.

A piece of film from the actual mission roll is also taken off before final loading in the flight vehicle and returned to the processing sites for a third check of mission sensitometry. This provides data on the characteristics of the mission film before it undergoes flight environment.

Proposal:

It has been proposed that sensitometric exposures be placed frequently along the edge of the mission film. Such exposures could be applied at one of three possible times:

1. Prior to or during spooling at the film manufacturer's plant.
2. During flight in the vehicle, or
3. On the ground just prior to processing.

These are the three times when the film is being spooled (or unspooled) and all of the edge would be accessible.

Analysis of Point of Application:

1. Application at the manufacturing plant.

   This location has both technical and economic disadvantages. On the technical side, the film is being transported faster here than anywhere else in the system. For many reasons it would be ideal to make the controlled exposures on stationary or slowly moving film and to accomplish exposures at the maximum transport speed reduces the reliability and accuracy of the result.

Furthermore, to attempt to vary the speed or stop the film in the spooling operation would jeopardize the uniformity of winding tensions in the roll. This greatly reduces the reliability of film handling and tracking in the camera, and has been known to contribute to serious camera malfunction.

The costs would also be increased out of proportion. The exposures would have to be applied to all material, yet only a small portion would become flight material. The balance of the material would be raised in cost without serving any useful purpose.

2. Application in-flight.

This has the real advantage of being applied at the same time and under the same environmental conditions as the scene image exposure. However, it would violate the general principle of keeping complexity on the ground and simplifying the airborne equipment whenever possible. The need for "controlled" exposures dictates accurate light source intensities, stable power supplies, and constant exposure conditions. These are not easily compatible with vehicle environments and with the variable transport speeds required for operational (IMC) reasons. Since the feedback from an airborne sensitometer is possibly inadequate to certify the "control" of the exposures and since post mission return of the device is normally impossible, it may be unsatisfactory to attempt to rely on in-flight exposures for monitoring ground operations such as processing. However, in-flight exposures would serve the useful purpose of providing data on the film sensitometry at the time of scene image exposure.

3. Application on returned flight material.

The most logical place for applying such exposures would be at the head end of the processing machine, just prior to processing. Here the film is moving slowly, at a constant speed. The equipment could be as bulky as necessary for stability and the edge exposures would be added only to actual flight material.

On the basis of these considerations, it appears most reasonable to add edge exposures on the ground just prior to processing, if the exposures can be shown to serve a useful purpose. This is the next question to explore.

Purpose of Edge Exposures:

The reasons for proposing edge exposures generally fall into three categories:

a. To check on the processing (or film) variations throughout the mission roll.

b. To facilitate post processing measurements such as edge traces, haze measurement, etc., by having local density patches available for reading by the same microdensitometer, and

c. To check on possible variations in film sensitometry due to actual flight environment of temperature, pressure, humidity, etc.

Analysis of Purpose:

Purpose (a) sounds like a reasonable goal on the surface and there is no doubt that more frequent sensitometric data would aid in confirming the mission processing profile. However, the type of variation most frequently encountered in deep tank machines or spray machines not designed and maintained for high quality processing is mottle or streaking. If such processing variations occur, they appear as density variations in both directions on the film surface. Sensitometric exposures along one edge (perhaps every 18 inches) would show only long trends along the edge and would have no use in monitoring across the web variations.

In actual fact such short term variations seldom exist in a high quality processing lab unless some component malfunction occurs, and if they did exist, edge exposures would be of questionable value in monitoring the fault.

Long term trends during a mission roll are checked now by sampling and photographically testing developer solutions for every 1,500 feet or less of mission material. These results, plus the head and tail tests give a good long term picture of trends throughout the mission. Typical results from head to tail show little variation in output. In addition, a tape record of processing level and IR densitometer reading versus mission footage is automatically recorded as a permanent record of the mission processing profile. The only footage not well monitored is that in transition when changing from one processing level to another.

Thus if processing data were the only reason for edge exposures, there would exist a serious question of whether the additional data gained would be worth the added complexity.

Reason (b), to aid in post processing measurements has been brought forward only recently as the result of the interest expressed by the committee in the general technique of edge traces for quality measurement. These traces require calibration of the micro-densitometer used to measure the edge density profiles and it is convenient and accurate to have a gray scale of known sensitometry available near the scene edge being measured. It is also possible that other useful measurements of scene haze, or system flare can be assisted by such edge exposures. These edge exposures, of course, could not be analyzed should there be some extraneous source of exposure present such as static, fog, or radiation.

Present day mission material is not routinely analyzed for such data. If it is felt that time, man power, and justification for such data will all be available in the future, then sensitometric edge exposures may be a useful adjunct to the data collection and analysis.

Reason (c), to provide information on effects of flight environment, can only be accomplished by in-flight exposures. The existing ground test data on sensitometry at varying temperatures and pressures, would not lead to a serious concern over changes in film sensitivity compared with ground data. Our present knowledge of actual temperature, pressure and humidity of the film at the time of exposure is inadequate. As a result we cannot say conclusively that ground tests have been made under flight conditions, because "flight conditions" are not really defined.

However, ground tests have bracketed flight conditions and show no reason for concern at low pressures and changing temperatures.[1] Neither has operational mission film shown symptoms that would lead to the suspicion of changing sensitivity with environment.

Thus reason (c) raises a question that is not considered very serious on the basis of ground test data. To answer the question requires adding complexity to the airborne equipment and it is not recommended until such time as ground or flight data indicate that a problem exists.

[1]Manual of Physical Properties, Section 16, Practical Behavior, p. 6:
"The low humidity, the reduced pressure or the cold temperature at the time of exposure had no significant photographic effects. At the higher temperature slight speed losses amounting to less than half a lens stop were observed. ...."

Summary:

The discussion above has presented a rational position on sensitometric edge exposures on mission material from the standpoint of film manufacturer, camera designer, processor, and user.

It appears that applying exposures on the ground before processing accomplishes the most important purposes with relatively low complexity.

It is the consensus of the committee that a trial evaluation be made using exposures made on the ground prior to processing. Such exposures would have the following advantages and disadvantages.

Advantages

1. Provide more frequent sensitometric data.
2. Aid in confirmation of mission processing profile
3. Aid in establishing ground rules for scene luminance calculations for particular sections of mission record.
4. Provide convenient calibration for edge scan measurements.

Disadvantages

1. Increase risk of fogging material (during edge print).
2. Complicates ground equipment without providing additional sensitometric process control, i.e., all information is post facto to processing.
3. Slight edge fog from other sources could shift sensitometric results and provide misleading data.
4. Could conceivably obliterate edge data (timing track, fiducials, etc.) if any of the exposures in question were misoriented.
5. Uniformity in processing is most difficult to control near the extreme edge. Currently this is of little consequence, however, if edge printing were used, uniformity at the edge would become important and could produce misleading results.

The type and size of exposures contemplated for this purpose would consist of three or four steps each occupying an area approximately 2 millimeters square.

The use of such sensitometry should be evaluated after several trial missions and the technique should be continued only if significant beneficial results are obtained.

III. D. Atmospherics

Introduction

In reconnaissance photography from satellites, the quality of the result vitally depends on four different aspects of the atmosphere: (1) extent of cloud cover which completely obscures the ground; (2) atmospheric turbulence which makes the atmosphere optically inhomogeneous; (3) illuminating conditions, which depend on the object reflectivity ratio of direct color illumination to integrated sky-light and solar elevation; and (4) atmospheric scattering which reduces the modulation (contrast) of the scene. These points are discussed separately below and the section concludes with specific recommendations.

Clouds

Clouds obscure the ground completely and it is, therefore, highly desirable to operate cameras when there is minimal cloud cover. Presently, about 50% cloud cover is normally experienced in C/M operation. The percentage target coverage of the C/M program is directly related to the product of target density per pass and the percentage of the ground viewed. It is inescapable that higher coverages are related to lower cloud cover. For its mission C/M is film limited because of re-entry package size, weather forecasts with any significant skill level may increase the useful coverage.

The gainful use of weather forecasts is limited to the degree of freedom in camera program selection. When target priorities are extremely high, this freedom is removed and, thus, no use is made of weather forecasts. But, when the freedom of selection exists, the optimum use of the weather forecasts should be employed to increase useful coverage.

Atmospheric Turbulence

Atmospheric turbulence causes the index of refraction to vary irregularly along the optical path. Hufnagel, by making assumptions similar to those in the upward looking case[1], has estimated the average magnitude of this effect, as shown in Figure D.1. In this case, the modulation reduction is a function of the size of the ground detail, unlike the case of atmospheric scattering. For C/M photography, atmospheric turbulence is not expected to be important. (For [redacted] photography, the effect may be of importance, but there is no obvious way to distinguish it from other random image degradations.)

1-Hufnagel and Stanley, J. Opt. Soc. Am., Jan. 1964

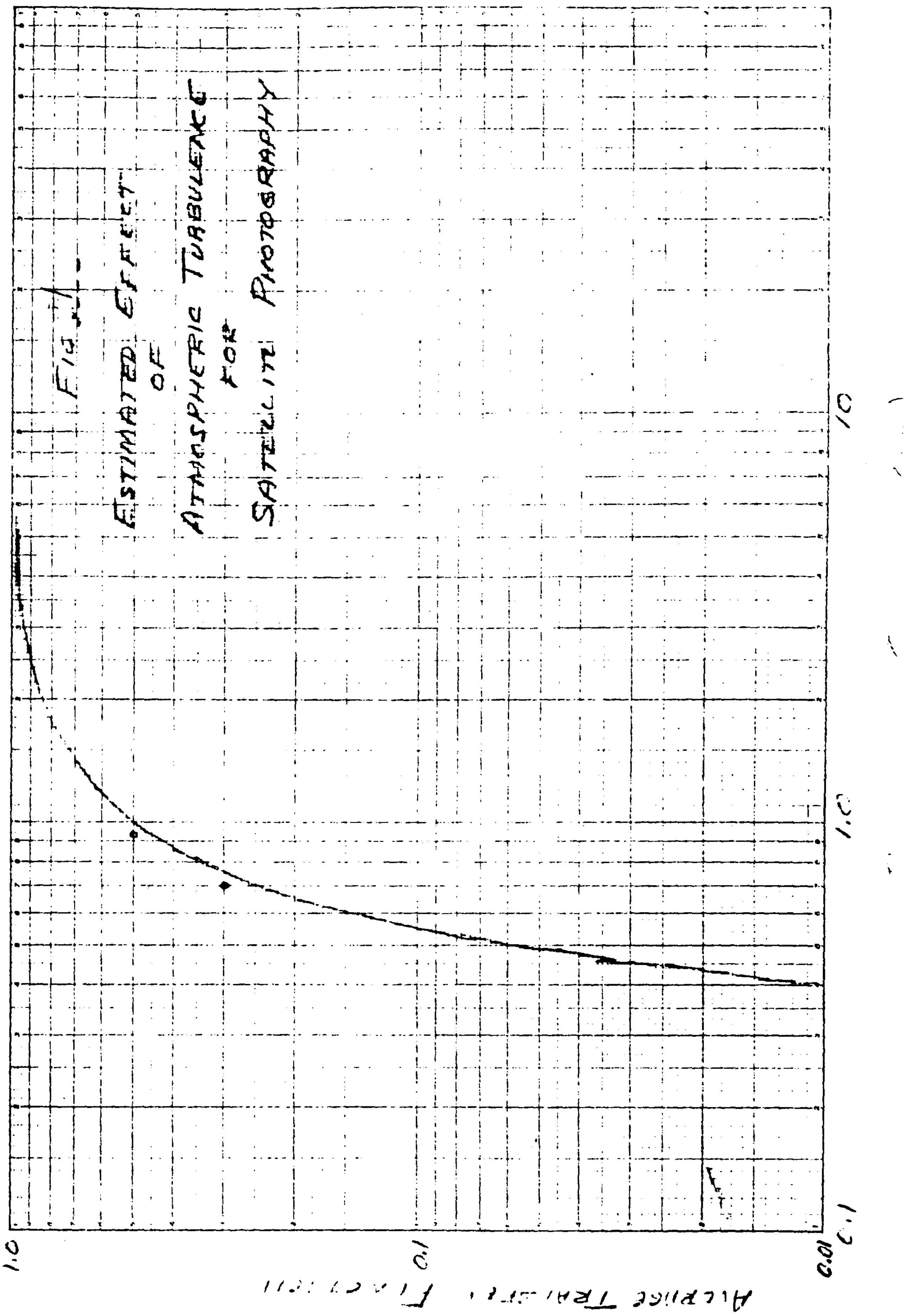


FIG 1
ESTIMATED EFFECT
OF
ATMOSPHERIC TURBULENCE
FOR
SATELLITE PHOTOGRAPHY
10
1.0
0.1
1.0
0.1
0.01

It is easy to confirm the resonableness of Figure D.1 by the following direct argument.

The index of refraction irregularity leads to two effects degrading the quality of the image impinging on a camera:

a. Quiver or shimmer due to fluctuations in the angle of arrival of the light.

b. Twinkling or brightness scintillation in the light intensity.

These two effects are both caused by phase fluctuations of the incident wave and may be estimated in terms of known astronomical viewing conditions and shown to be negligible on the scale of C/M photography.

a. From astronomical viewing of an object at zenith, it is found that the root mean square fluctuation of the angle of arrival of the light might be as large as $\sqrt{\overline{(\Delta\alpha)^2}} \cong 3$ arc-sec for daytime viewing. This shimmering effect is the consequence of refraction of light rays through turbulent elements of the atmosphere and varies with zenith angle according to $\overline{(\Delta\alpha)^2} = A^2 \sec\theta$; $A = 3$ arc-sec

The predominant contribution to this angle fluctuation arises at an altitude of comparable to the atmospheric scale height ($H_o = 8$ km = 5 miles), and corresponds to a ground image dispacement as seen from the C/M camera for vertical viewing of roughly (3 arc-sec) X (25,000 ft.) $\leq$ 0.5 ft. which is completely negligible.

b. Light fluctuations in stellar and planetary images provide a useful calibration of brightness scintillations for the C/M system. The relevant parameters are as follows: viewing a point source, a telescope with an aperture of $\geq$ 30 inches sees a percentage fluctuation of less than 20% in the amplitude relative to the mean light level. The effective aperture of C/M is determined by computing how big a slice of atmosphere is sampled as it moves during its 1/200 second viewing interval. It moves 140 ft. during this time and thus integrates the contribution from approximately 6 ft. of linear extent of atmosphere at 20,000 ft. altitude during this time. Since the diameter of the C/M lens is 7", this means an area of effective atmosphere of 7" x 72" = 500 sq. in. per look, which is comparable with a telescope of 25" aperture. This means a scintillation effect of approximately 20% will exist for point sources. To understand this small result, we note that the aperture D is much larger than $\sqrt{2 H_o} \cong 3$ inches where $H_o \cong 5$ miles is the scale height and 2 the wavelength, indicating that there is a considerable averaging of this diffraction effect. Broad areas will not show this effect, and indeed intensity fluctuations when viewing Venus are less than 10%. Venus is seen through a 3 foot slice of atmosphere at the reduced scale height and the C/M camera views through a 6 foot slice at this altitude so fluctuations are correspondingly smaller.

Illuminating Conditions

In assessing the overall quality of photography, it is of the greatest importance to make appropriate allowance for illuminating conditions. Changes in illumination which at first glance may appear small or even overlooked can have a large effect, often localized, on the quality of the photography.

The most dramatic effects occur when variation in illumination causes a change in effective scene contrast. Under ideal clear-day conditions, the contrast of ground objects is greatly enhanced by shadows which delineate edges and provide texture at scales both above and below the resolution limit. For example, a peaked roof top may look flat when the illumination is relatively diffuse, but show clearly the contours of its true shape when illuminated suitably by direct sunlight. Even detail below the resolution limit of the system can have an effect. Badly curled shingles on the roof, for example, cause shadows which, integrated with the illuminated portions of the shingles, affect significantly the overall brightness of the roof as seen by the camera. Thus, there is an effect on the gross contrast between that roof top and some differently illuminated adjacent area. Moreover, this effect on contrast is a strong function of the illuminating and viewing angles. Generally speaking, it is at a minimum when the sun is directly behind the camera.

The same effect is well known as it affects overall exposure. Most natural objects and terrain look brighter when the sun is directly behind the camera since the shadows cannot be seen from that angle. These exposure differences, which can be substantial, show up consistently in the actual operational photography, both between the ends of any given frame and between simultaneous frames from the two C/M cameras (because of the 30 degree angular separation).

This explains why two photographs of the same area, taken with properly operating equipment but at different times, may appear quite different and why given objects may be visible or not visible in a somewhat random fashion.

Atmospheric haze, therefore, plays a role not only because light is scattered back into the camera lens (thus degrading contrast), but because the ratio of brightness is changed between shadow areas and directly illuminated areas. The phenomenon is well known to all amateur photographers who take pictures under conditions described on the film exposure data sheet as "hazy sky, soft shadows". Pictures (particularly black and white) show much inferior quality under these conditions, including a loss of resolution for much of the finer detail.

It is quite possible for this effect to occur when objects are in direct sunlight and with very little actual haze: Scattered clouds which are outside the field of view cause illumination of the shadows which reduce contrast.

Indeed, in our examination of Mission 9056 photography, we have found that frames scoring low on resolution correlate with illumination conditions producing very little shadow.

It is difficult to quantitatively predict the results of these effects on subjective image quality. It should be noted that one effect of low contrast due to poor illumination will be a reduction in the number of "targets" per unit area of film. Objects whose contrast is an inherent property of reflectance alone will, if perfectly diffuse, be unaffected in contrast by illumination conditions. Objects in nature are always partially specular, however, so that the direction of illumination will be important. More significantly, objects whose contrast is illumination generated through shadows may effectively disappear; this affecting the richness, that is, the amount of detail in the photograph. The photograph will thus appear to be of poorer quality even if there is no deterioration in a purely technical sense. Figures D.8 and D.9 in the summary of this report illustrate this effect.

Atmospheric Scattering

The modulation reduction caused by atmospheric scattering (haze) is extremely variable in magnitude. If the distribution were well known, allowance could be made for it in the design performance predictions for every camera system. It would then be possible to more accurately compare different systems and operational programs on a basis of both probability of target resolution and interpretability.

In this sub-section, the magnitude of modulation reduction is first estimated. Next, an approach to improve the estimate of the distribution of modulation reduction is outlined. Finally, a suspected relationship between modulation reduction and meteorological conditions is described.

Magnitude of Modulation Reduction

The magnitude of modulation reduction can be estimated from Project Photorek[2] flights at 50,000 feet, which is over most of the atmosphere. Figure D.2 shows the ogive of modulation reduction of a high contrast target in "fair" weather for the spectral region of interest. The modulation reduction will be more severe when integrated over the broader sample of meteorological conditions experienced by the C/M system and, also, more severe for typical scenes since these have a lower albedo than a high contrast target, as shown in Figure D.3. The data in Figure D.2 are reasonably consistent with the prediction made by a radiated energy balance model of the atmosphere. From the limited photorek data and the radiative energy balance a judicious estimate of the average modulation reduction factor is .5.

Prediction of Modulation Reduction from Previous Samples

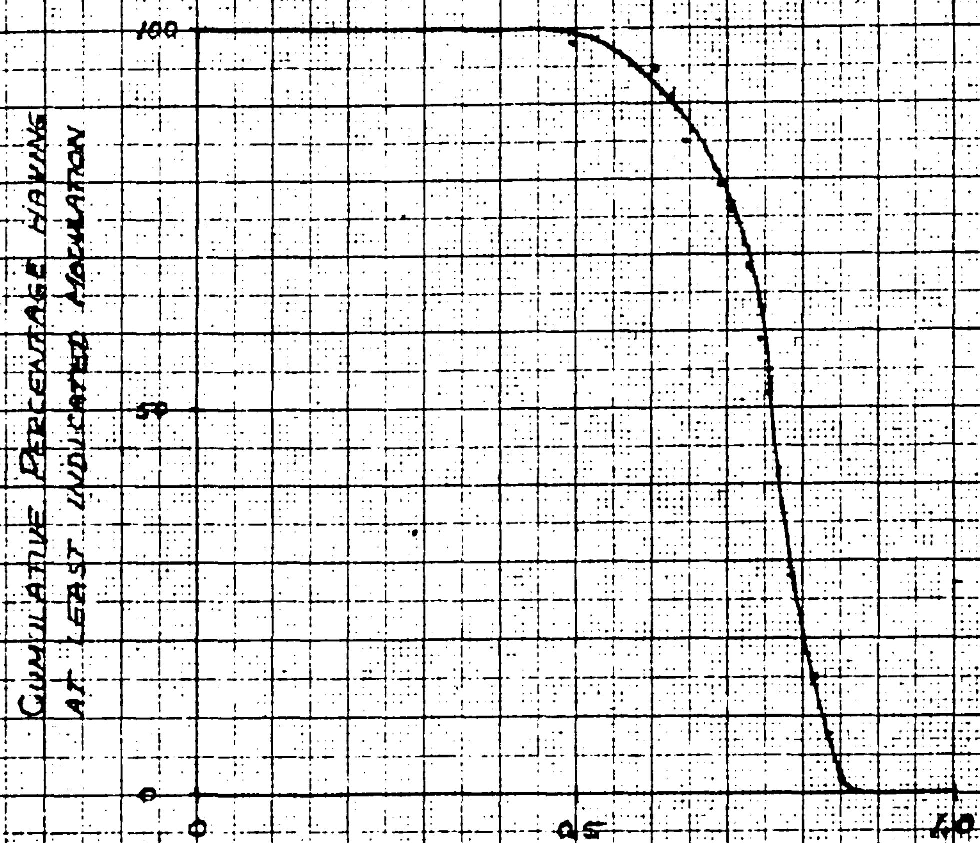
The probability distribution of modulation reduction due to haze is of primary concern to us and, fortunately, detailed physics of atmospheric scattering and meteorological parameters can be bypassed. There are two ways for determining the probability of modulation reduction. First, targets of known reflectance can be photographed and the distribution of results will yield the desired probability distribution. To be meaningful, this is likely to be a program similar to, but more extensive than, Project Photorek, carried out at Wright-Patterson AFB, and results must be extrapolated to other geographical regions and seasons. The second approach is possibly less accurate, but the comparison of operational photography with carefully prepared GEMS will, at least, roughly sort the distribution of modulation reduction into broad categories; in this approach, the distribution obtained applies for the operational area of interest. A combination of both approaches provides a valuable consistency check.

Prediction of Atmospheric Scattering from Meteorological Conditions

The most desirable basis for predicting the probability distribution of haze is an accurate physical model. This would be expected to relate modulation

2-A study of Photographic Contrast Attenuation by the Atmosphere, ASD-TDR-63-541 (Sept. 1963)

FIG 2



APPARENT MODULATION OF
HIGH CONTRAST USAF
TRI-BAR TARGETS FROM
50,000 FT IN "FAIR" WEATHER
USING YELLOW FILTER

[redacted]

[redacted]

[redacted]

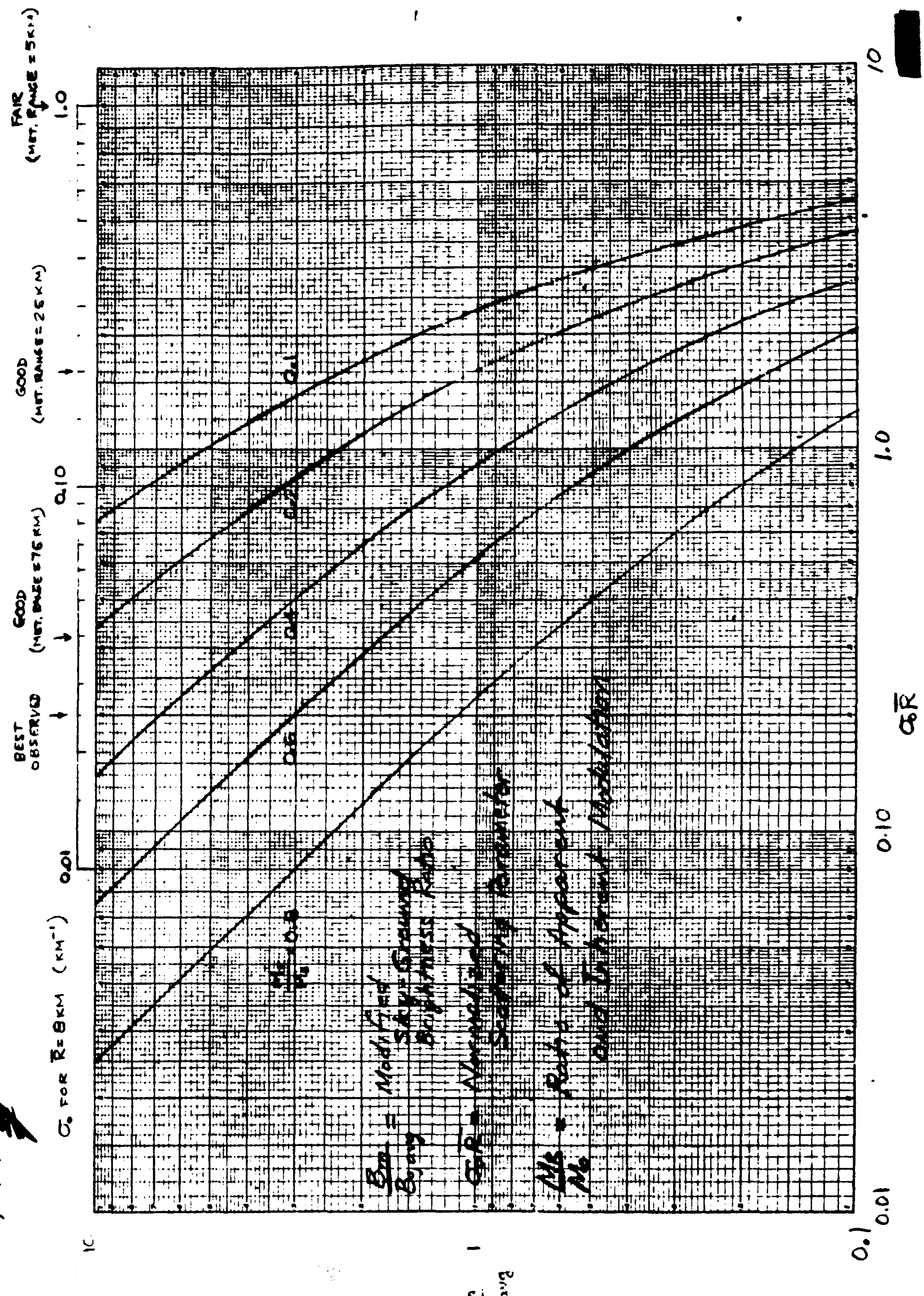


FIG 3

reduction to meteorological conditions. While it is not now clear that this can be done in a completely satisfactory way, if for no other reason than the atmosphere's lack of isotropy, a promising approach is discussed below.

Attenuation and scatter of light is a function of the particulate suspensoids (aerosols), their hygroscopicity and their spatial distribution along with the spatial distribution of atmospheric humidity. The primary sources of these particles are:

a. Combustion (both natural and industrial). These "combustion" aerosols consist of tars, oils, soot, as well as hygroscopic substances such as sulfuric and nitrous acid.

b. Turbulent upward dispersion of surface dust, the most abundant constituent of dust particles being silicon-dioxide.

c. Evaporation of sea-spray and subsequent upward dispersion. These "maritime" aerosols have about the same constituency distribution as sea water.

The absorption of water by the maritime salts and acid products of the combustion processes markedly intensify the attenuation effect in higher relative humidity environments. In general, the range of radii of solid particulate matter in the atmosphere is so small that only the shorter wavelengths of the visible spectrum are affected significantly in the "dry state". The increase in particle radii through the absorption of water from the atmosphere constitutes the dominant avenue of increasing atmospheric turbidity. Analytic relationships between the droplet size and humidity have been established both theoretically and verified experimentally. For instance, the differences between the physical nature and characteristic sizes of combustion nuclei and sea-salt nuclei result in quite different behavior patterns of particle growth with respect to changes in relative humidity. Figure D.4 portrays these relationships for combustion and sea-salt nuclei. Notice that the sea-salt nuclei reach droplet sizes of Mie scattering significance when the relative humidity exceeds 60%; whereas the combustion nuclei do not reach this critical range until nearly 100% relative humidity, where its radius grows very rapidly with increasing relative humidity.

In an atmosphere of combusion aerosols with characteristically high particle concentration, the time and space variations of attenuation coefficients would be rather abrupt, producing very little modulation reduction until the relative

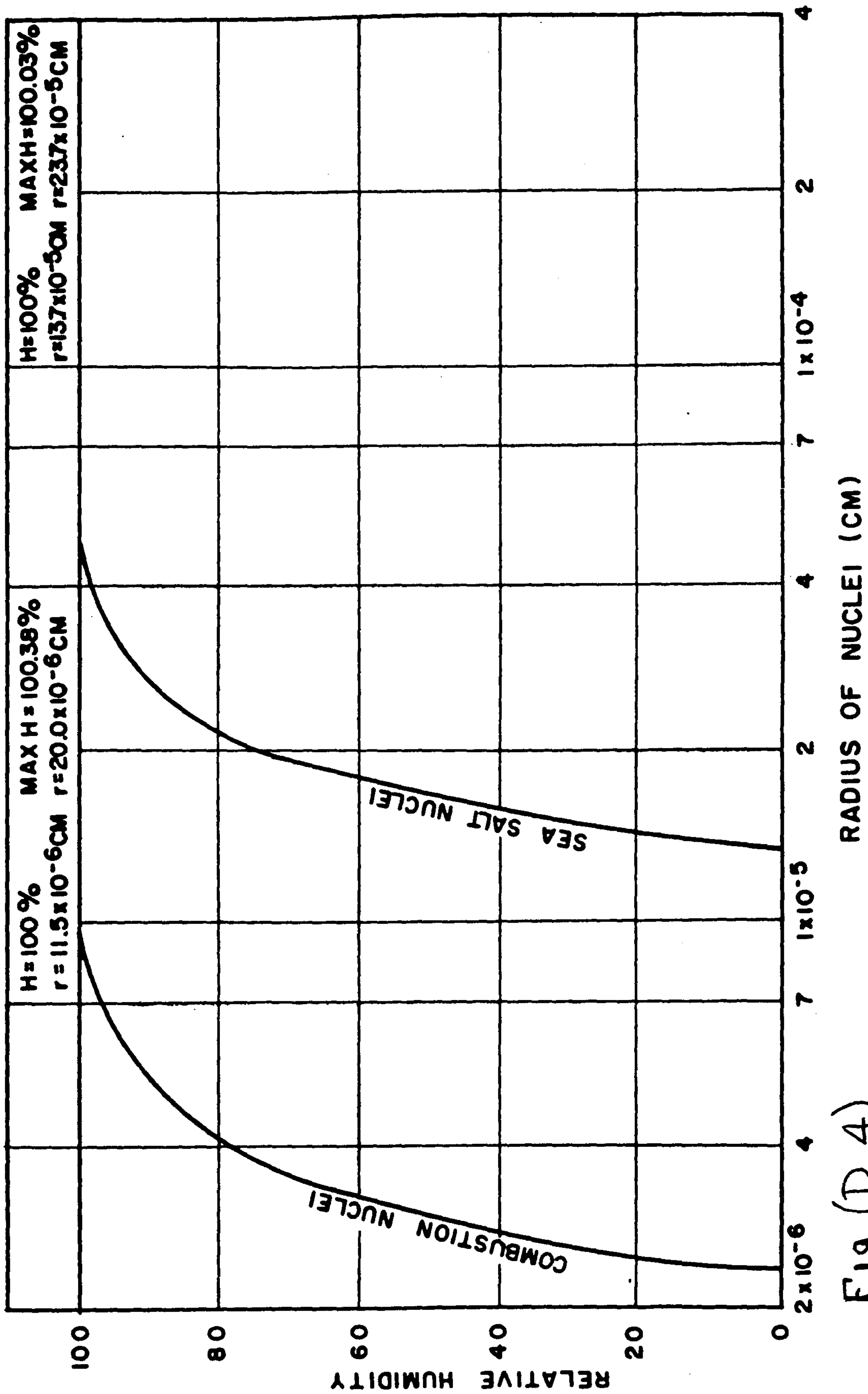

H=100%
r=11.5x10-6CM
MAX H=100.38%
r=20.0x10-6CM
H=100%
r=137x10-5CM
MAXH=100.03%
r=237x10-5CM
SEA SALT NUCLEI
COMBUSTION NUCLEI
RELATIVE HUMIDITY
100
80
60
40
20
0
2x10-6
4
7
1x10-5
2
4
7
1x10-4
2
4
RADIUS OF NUCLEI (CM)

Fig. (D 4)

humidity reaches 90 - 100%, at which point the modulation reduction would increase markedly. On the other hand, in an atmosphere of sea-salt nuclei, attenuation coefficients would vary more continuously as the relative humidity increased above 60%. If we consider a continental air mass (with a history of passage through industrial areas) to be an atmosphere dominated by combustion nuclei, and if we consider a maritime air mass (with a long water history) to be an atmosphere dominated by sea-salt nuclei, then a check on the foregoing hypothesis may be accomplished by checking the data observed at Wright-Patterson AFB in Project Photorek. The experiment was biased in selecting only "fair" weather conditions for flights. However, by stratifying the data as to the type of nuclei presumed to be present, relationships between modulation reduction and relative humidity are revealed. In Figure D.5, for the maritime air masses, the average relative humidity (up to 20,000 ft.) is plotted with the dashed curve, and the modulation reduction of the black and white targets is shown by the solid curve. The similarity of the curves is striking.

From the foregoing hypothesis, the continental air masses should show a different correlation. Figure D.6 portrays this for the continental polar cold air masses, which show three striking points of non-correlation. In combustion nuclei dominated atmospheres, one would expect the modulation reduction to be great if anywhere within the vertical column the relative humidity was near 90%, even for a thin layer, regardless of the average humidity through the entire layer. Conversely, if the average relative humidity were rather high, but no values near 90%, one would expect a rather small modulation reduction. Figures D.7, D.8 and D.9 show the vertical variations of relative humidity and modulation of the black and white targets for the flights of 1 August 1962, 7 September 1962 and 12 September 1962. On these dates the modulation reduction and average relative humidity values show departures from the normal pattern. On 1 August and 12 September the average humidity was high, whereas the modulation was low, conversely on 7 September the modulation reduction was high and the average humidity was low. Figures D.7 and D.9 (the 1 August and 12 September flights), show that, although the average relative humidity was high, no nearly saturated relative humidities existed, and, as would be expected with combustion aerosols, little modulation reduction occurred. The converse of this can be seen in Figure D.8 (7 September flight), where the average humidity was low but very high values

MT

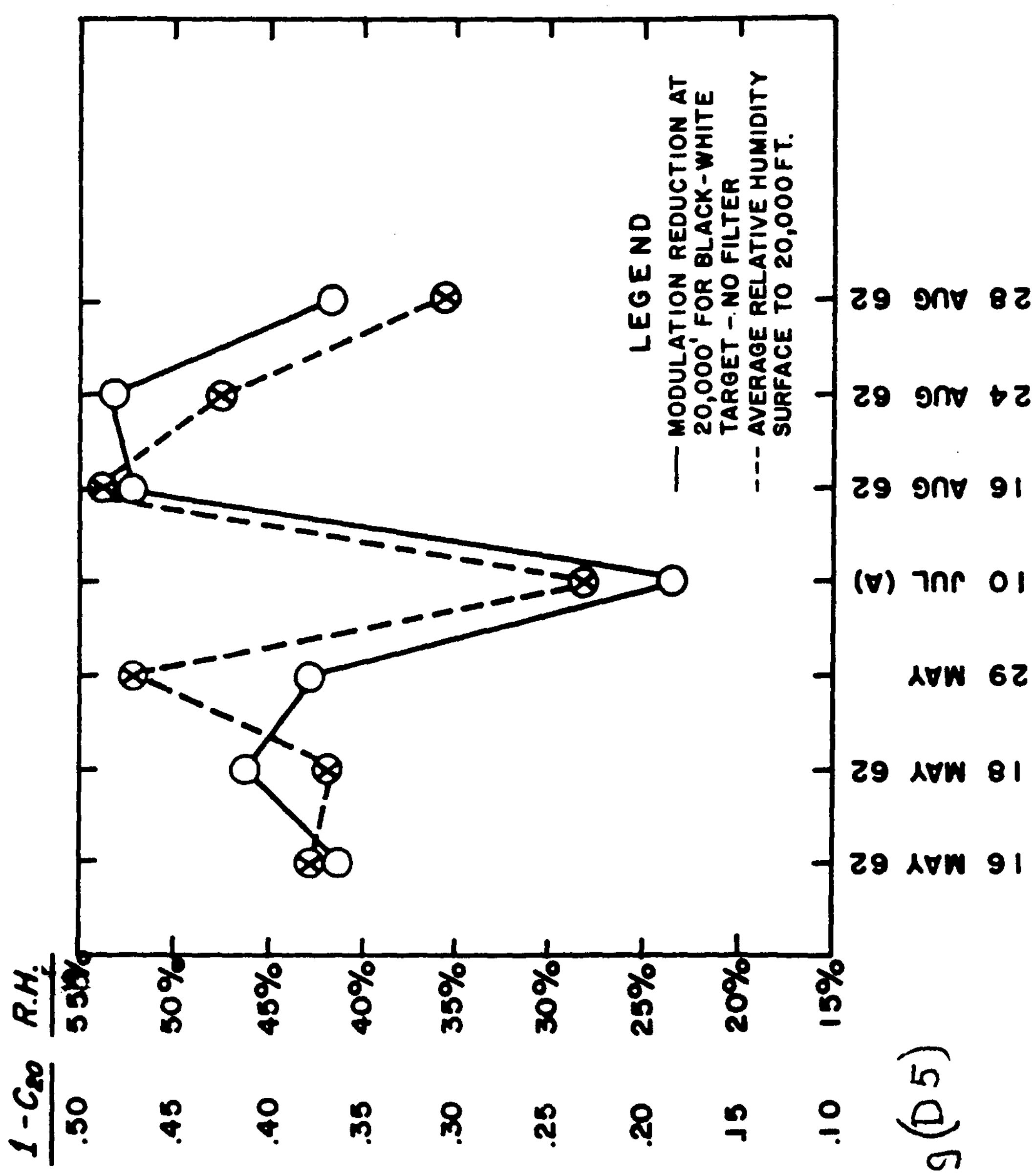

1 - C_{20}
R.H.
.50
.45
.40
.35
.30
.25
.20
.15
.10
55%
50%
45%
40%
35%
30%
25%
20%
15%
16 MAY 62
18 MAY 62
29 MAY
10 JUL (A)
16 AUG 62
24 AUG 62
28 AUG 62
LEGEND
— MODULATION REDUCTION AT 20,000' FOR BLACK-WHITE TARGET - NO FILTER
--- AVERAGE RELATIVE HUMIDITY SURFACE TO 20,000 FT.

Fig (D5)

cPK AIR MASSES

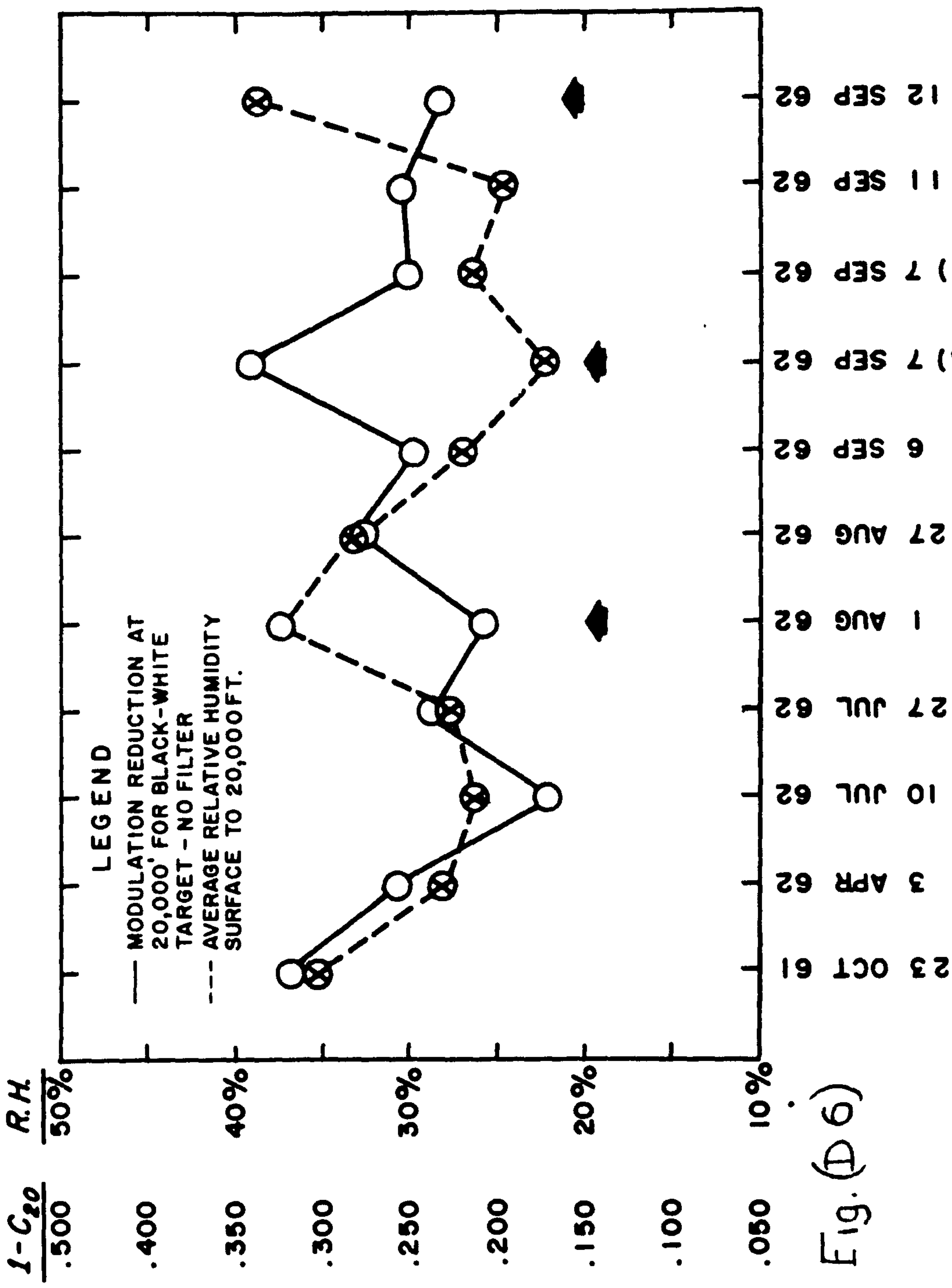


Fig. (D6)

[redacted]

1 AUGUST 1962 – 1230 (PM)

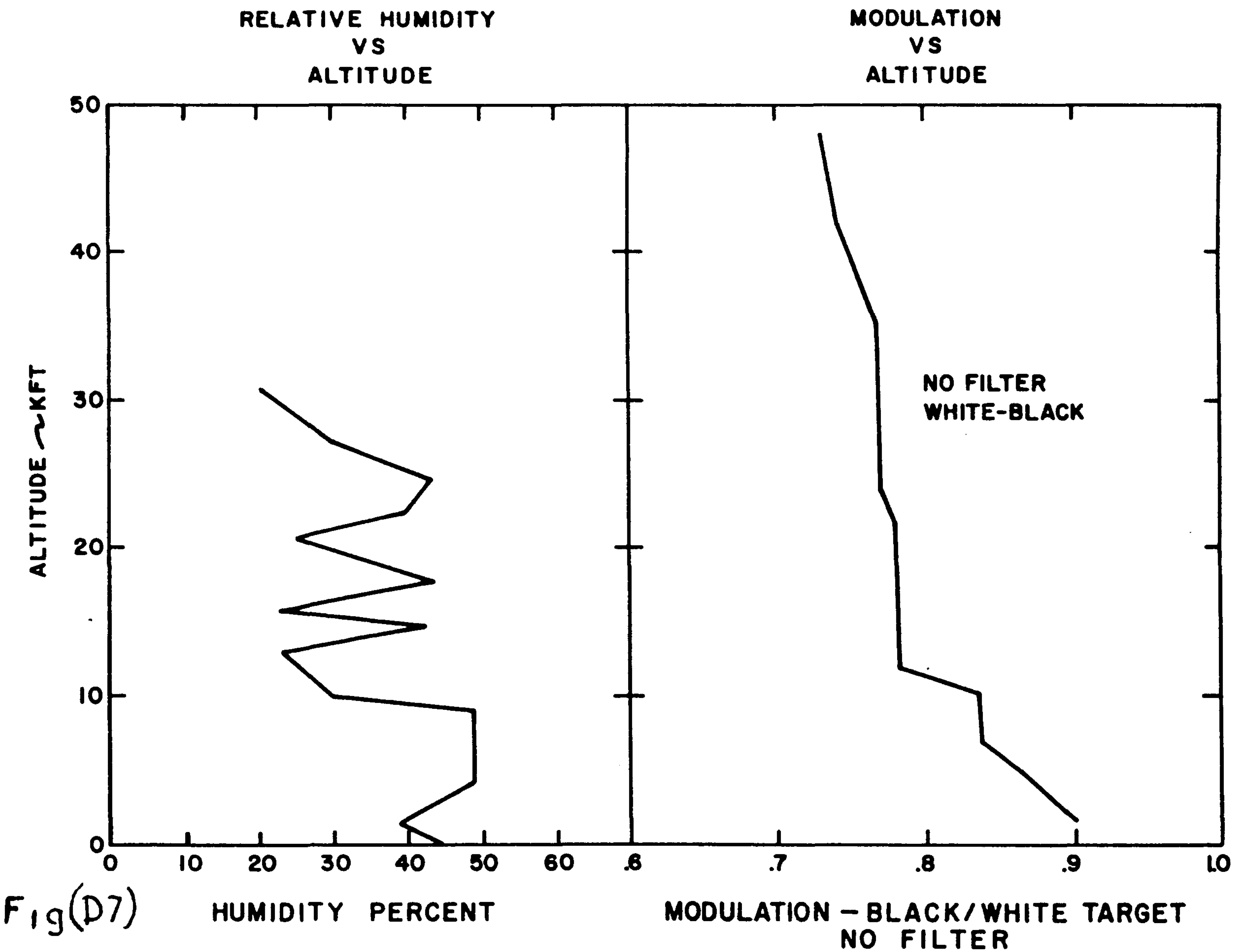


Fig (D7)

7 SEPTEMBER 1962 - 0630 (AM)

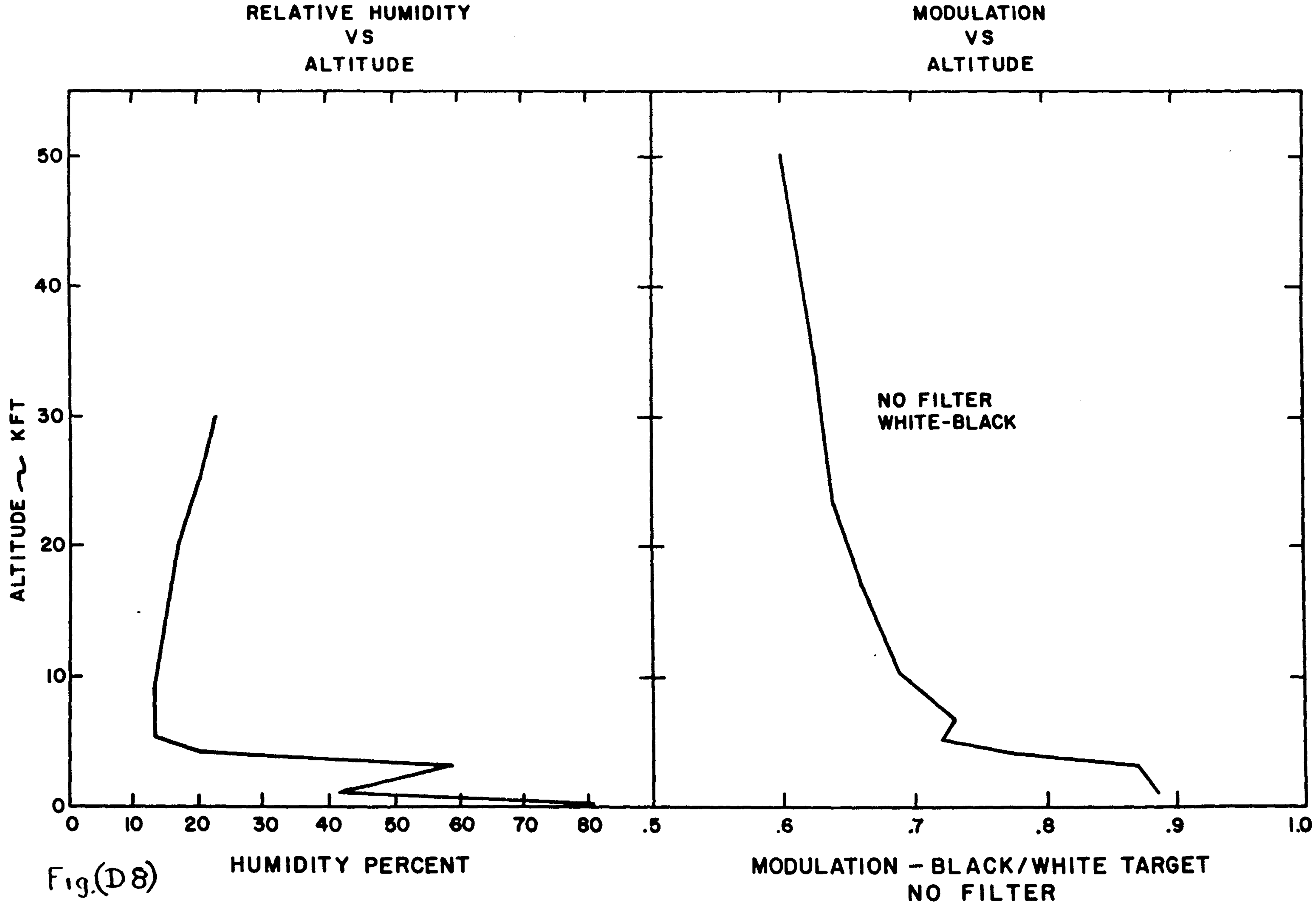


Fig.(D8)

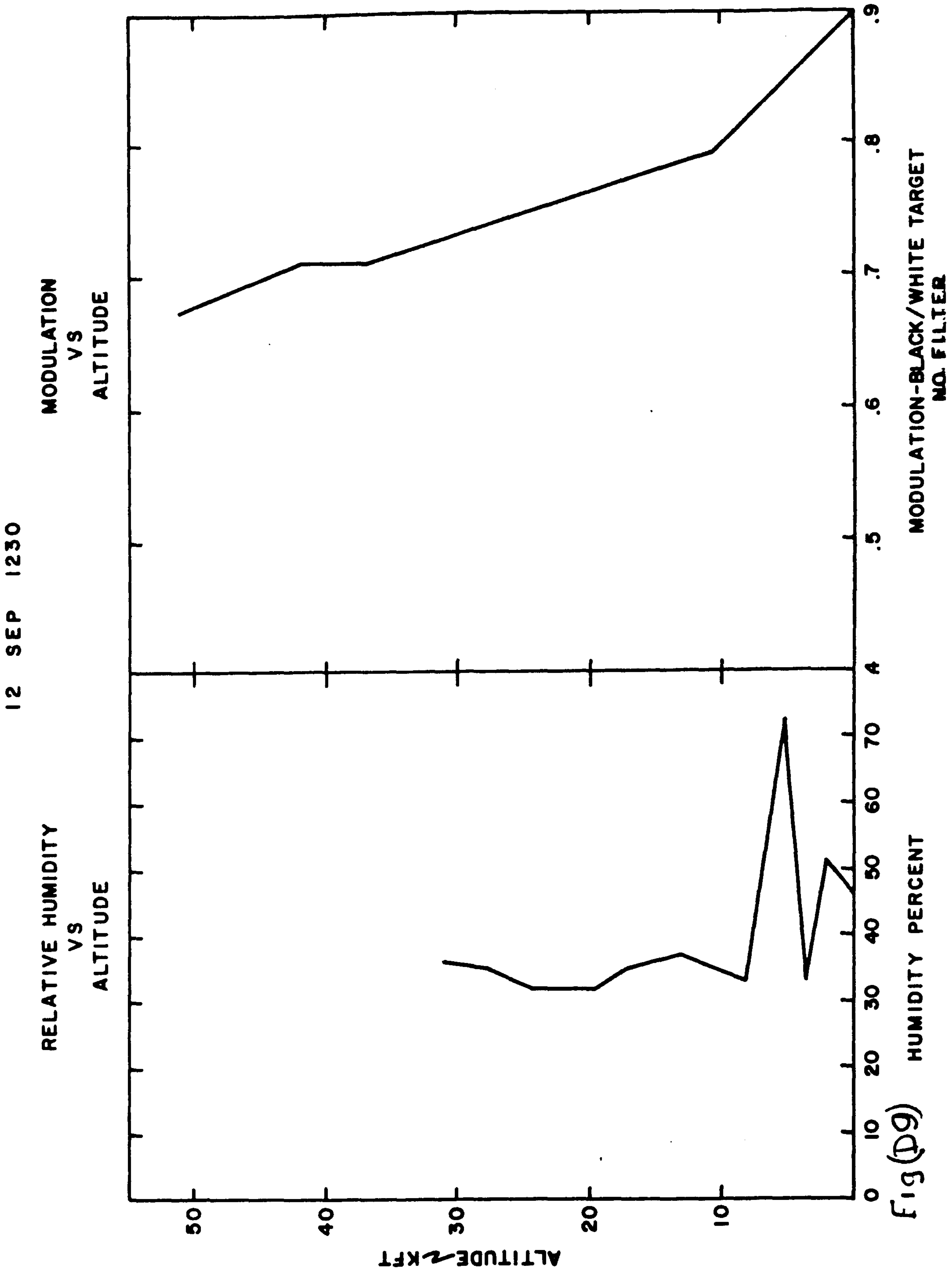


Fig (D9)

Handle Via [redacted] Control System Only

were observed in a shallow layer near the surface and the modulation reduction was relatively large.

Contrasting the data of Figure D.7 with Figure D.10, which portrays the vertical variability of humidity and modulation reduction in a maritime air mass during the 29 May flight, we see a case of relatively high average humidities without singular extremely high values. In this maritime air mass, the modulation reduction was large, consistent with the high average relative humidity.

It should be pointed out that both the sea-salt nuclei and combustion nuclei concepts do not enjoy universal acceptance among all researchers in atmospheric optics; and, in fact, Simpson concludes that the chief condensation nuclei are composed of naturally formed nitrous acid and that combustion nuclei, although much more numerous, take little part in cloud formation. It is more than likely that a great deal of the diversity of opinion is related to the regions and circulation patterns prevailing during individual experiments.

Having accepted that atmospheric humidity and concentration of aerosol types are primary factors in atmospheric contrast reduction, the time and space variability of these properties becomes an essential feature of the diagnosis. For instance, as a result of strong vertical gradients, the character of the aerosol will be dependent on the level from which air has been recently displaced, as well as its oceanic or continental history. That is, in regions of sinking air, where the air has descended from great heights, the air should be dry and contain relatively few maritime aerosols. On the other hand, in regions of disturbed weather, the upward transport of moisture and aerosols would contribute to a thicker, denser scattering medium and hence a much greater attenuation of contrast.

Superimposed over larger scale processes are the small-scale processes that may range over a large size spectrum. Vertical atmospheric motion is the prime process, since the effect of small-scale horizontal motion is to produce a relatively uniform lateral dispersion. However, the small scale vertical motion is very significant because of the strong vertical gradients and the critical way in which adiabatic cooling and heating affect relative humidity. In regions where the vertical velocities vary moderately in small horizontal distances, one may expect to find sizable differences in the attenuation coefficients. For example, in regions of scattered to broken cumulus clouds with moderate vertical development, sizable variations in vertical components must exist and one would expect

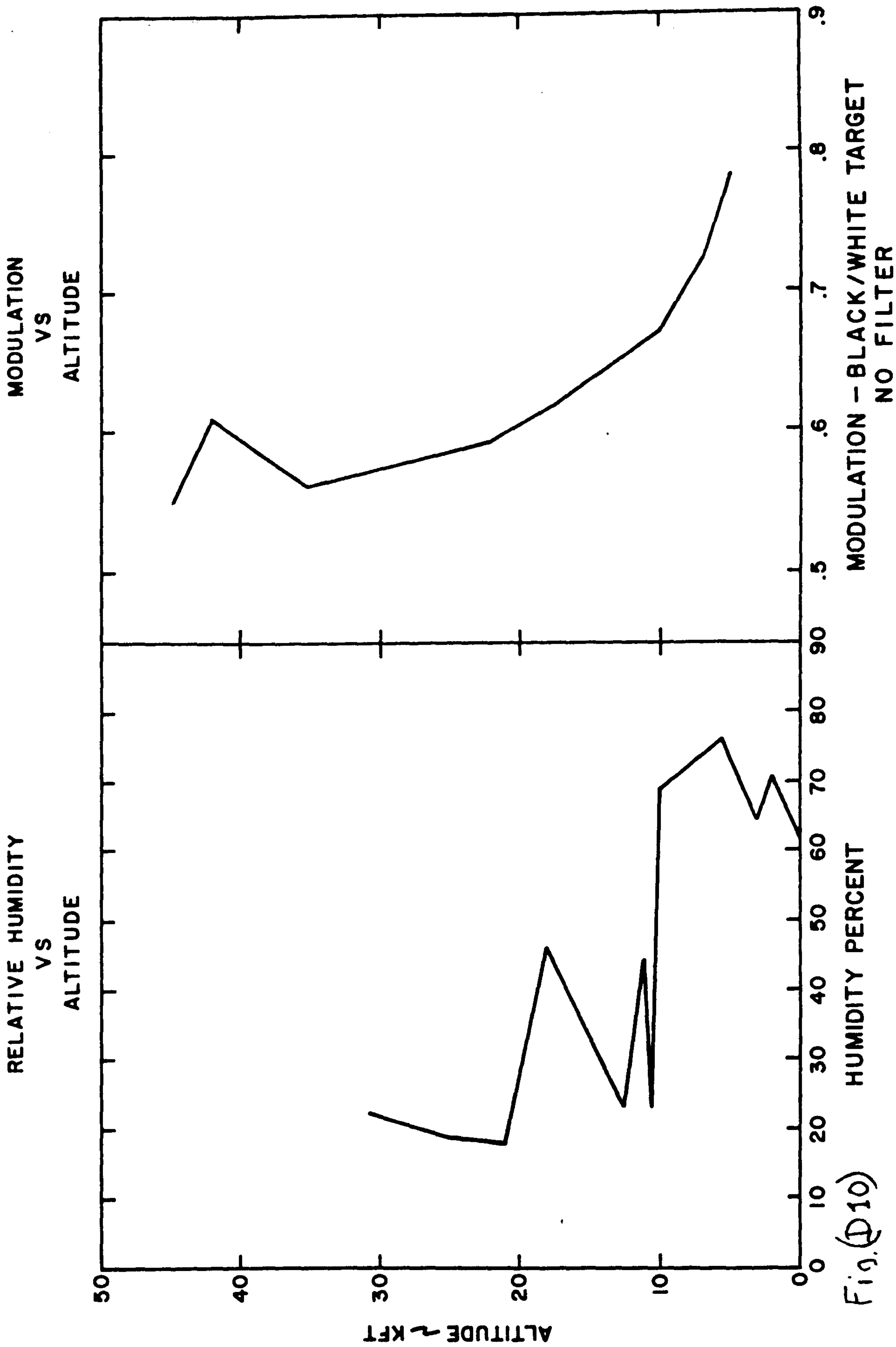

29 MAY 1230
RELATIVE HUMIDITY VS ALTITUDE
MODULATION VS ALTITUDE
ALTITUDE ~ KFT
0
10
20
30
40
50
HUMIDITY PERCENT
0
10
20
30
40
50
60
70
80
90
MODULATION – BLACK/WHITE TARGET
NO FILTER
.5
.6
.7
.8
.9

Fig. (D10)

to find the cloudless spots highly transparent. This is largely a function of the large-scale static stability of the atmosphere, which is predictable. However, where the vertical development is limited (more stable atmospheric conditions) and maritime aerosols prevail, cloud holes will not be so clear.

Although the prediction of these individual cells at particular spots will remain beyond the state of the prediction art for many years to come, we should be able to predict the conditions and extent of these cellular structures as a statistical property of a large region. While the problem of light scattering and attenuation by the atmosphere is by no means resolved and there remain many unexplained variations, one can envision the prediction of an average turbidity plus the standard deviation or some other distribution function over a large area.

Recommendations

The Committee feels that it is very important to improve knowledge of the probability distribution of modulation reduction due to atmospheric scattering. The reporting of contrast level as determined from GEMS will provide a posteriori estimate of the distribution and this data collection is strongly recommended. Further experimental and theoretical efforts are also justified.

While it is very attractive to exploit the existence of edge gradient targets and their photography obtained during C/M engineering passes to explore the relationship of modulation reduction and meterological conditions, this is ancilliary to the improvement of the C/M system. The Committee feels that the logistic complexity of obtaining brightness readings and meterological data simultaneous with satellite passes is sufficiently great that we recommend divorcing the operational C/M Program from these scientific investigations.

However, it is recommended that additional experimental target photography be obtained with airplanes above 40,000 - 50,000 feet. This could be an extension of the Project Photorek work, with flights being carried out over the targets proposed elsewhere in this report as well as over the Wright-Patterson targets. The flights elsewhere recommended to check upon extraneous light in the C/M camera provide one other, but limited, opportunity to obtain modulation reduction data with negligible cost.

As the relation of direct and diffuse illumination is very important, we further recommend that concurrent brightness measurements of a white card be made with the card fully illuminated and in shadow.

Finally, we believe that additional study of the relation between modulation reduction and predictable meteorological conditions is warranted. This study should be frequently checked against available experimental data.

III. E. <u>Stereoscopic Satellite Photography</u>

A question has been asked concerning the desirability of a trade off in favor of increased total coverage at the cost of reduced stereoscopic coverage.

Conditions to be considered in attempting to provide an answer include the following:

1. Type coverage concerned
    a. Search
    b. Surveillance
    c. Technical intelligence
2. Function to be performed
    a. Immediate reporting (OAK)
    b. Indexing (MCI)
    c. Detailed reporting
    d. Mensuration
3. Equipment available for accommodating stereoscopic photography
    a. Screening
    b. Interpretation
    c. Mensuration
4. Type benefits to be gained from stereo
    a. Height discrimination
    b. Height measurement
    c. Image improvement (S/N increase)
5. Benefits from two-camera usage, in addition to stereo
    a. Different angles of view allow looking under clouds
    b. Increased reliability thru redundancy

<u>Search Photography</u>

This category of coverage is described as that which provides a first look at a segment of geography. Its purpose is to confirm suspected target locations, discover previously unknown areas of interest, and permit description of such to the degree possible as allowed by the quality of the coverage.

The emphasis of such photography is directed primarily toward area coverage. The C/M System falls in this category. Because this system embodies a mix of both large area coverage and good resolution it has been used as a source of imagery which permits a reasonable degree of detailed interpretation. (This has been a high order requirement on this system particularly as it succeeded the U-2 and preceeded the [redacted]).

In immediate reporting on search coverage stereoscopic examination is only rarely used. Time requirements and equipment limitations preclude much more use of stereo in this operation. However, stereo must be and is used where monoscopic examinations provide inconclusive interpretation. Also, time constraints preclude a significant amount of mensuration during this operation.

During indexing or cataloging operations where all items of possible intelligence interest are listed, stereoscopic examination is performed when necessary to insure proper identification.

Detailed interpretation requires the ultimate in use of stereoscopic photography. Examination is made stereoscopically in all instances where such coverage is available. Stereo is considered absolutely necessary in such work, especially since questions are asked the interpreters which challenge the capability of the coverage to provide adequate answers. The history of the requirements imposed upon photo interpreters shows that the intelligence needed is often just beyond the capability to interpret it.

Mensuration support to the interpretation operation is at its highest level in the detailed reporting. Verification of small objects is often possible only through measurement. Differences between similar objects is often small and can be detected only by accurate dimensioning. Stereoscopic photography is used for measurement at this phase of reporting to allow accurate pointing of instrument reference marks for horizontal as well as vertical measurements. Vertical measurements are possible only through the use of stereo since shadows over terrain of unknown slope are unreliable as height determinators. The extremely small scales used make measurement errors more significant with relation to object size. Accurate pointing to the order of microns is necessary and only stereoscopic viewing allows this to be done within the tolerances required. Without stereo the photogrammetrist cannot determine the exact edges of the objects to be measured. This measurement function is equipment limited at the present. There is nothing standard available today which will accommodate the various formats, high resolution, and small scales to the accuracy required. Equipment is in design for this purpose, but engineering, optical, and electronic problems are large, and lead-times for such development are quite long. However, stereo-measurements are expected to increase as equipment becomes available.

Surveillance Photography

This category of coverage is described as that which provides subsequent and repeated looks at known target areas to determine changes in configuration and activity and to permit determination of rates of change.

The emphasis of such photography is again directed toward area coverage but coupled with a capability to detect the small features necessary to identify subtle changes. The C/M system meets these requirements reasonably well.

Surveillance requirements are presently beginning to over-ride those of search as total coverage increases. As this occurs the requirement for large area coverage begins to diminish and increased importance is associated with the ability to detect and measure smaller images.

This connotes increasing emphasis in the use of stereoscopic coverage for these purposes, again particularly in the indexing and detailed reporting phases. Time constraints in immediate reporting-out on surveillance coverage preclude stereo examination except in specific instances of inconclusive interpretations from monoscopic viewing.

About the same percentage of stereoscopic examination of surveillance coverage applies as with search coverage. The trend toward more use of stereo will follow the increased use of C/M material for surveillance purposes. The same equipment limitations apply, and as additional stereo equipment becomes available, the stereoscopic photography will be used proportionately more.

Technical Intelligence Photography

The C/M system does not qualify in any regard as a technical intelligence collection system. [redacted]

Considerations for the case of stereoscopic photography for the C/M system [redacted]

C/M is "film capacity limited", [redacted]. [redacted]

Conclusions

The question seems to have narrowed down to considering the use of C/M to provide some non-stereo coverage over areas of lesser interest in order to increase total coverage per mission. It has been noted that C/M is being used increasingly for surveillance vice search coverage. This indicates that the use of stereo will increase accordingly as the transition from search to surveillance use becomes more complete. It follows that the C/M system will be used less over areas of smaller interest and the coverage concentrated over areas of high enough interest to warrant continued surveillance. This places limitations upon the occasions when non-stereo would be taken, based upon the original premise that it would be used for searching areas of only marginal interest.