NPIC INTERNAL USE ONLY

NPIC/TDS/D-935-67
13 July 1967

MEMORANDUM FOR: Chief, Exploitation Systems Branch, DS

ATTENTION : [redacted]

SUBJECT : Advanced Rear Projection Viewer [redacted] Project #02157)

REFERENCE : RADC Report of NOD-100 Viewer Test, dated 26 June 1967

1. Reference report was delivered to [redacted] who brought it to me for info. I have reviewed it and am generally impressed.

✓ 2. I suggest the report will be of considerable value to you for guiding monitors' attention in directing [redacted] pursuit of the viewer. I think it will also provide some help in refining our development objectives and evaluation procedures for this type of equipment. In that regard, I suggest you advise [redacted] of the availability and applicability of this report.

3. As a final wrap-up I'd appreciate your arranging for a feed-back comment to RADC in cooperation with [redacted] when you've had a chance to evaluate the report--say by the middle of August.

[redacted]

Deputy Chief, Development Staff, TDS

Attachment: (1)
Reference RADC report

Distribution:
Original - Addressee
1 - NPIC/TDS/EPS
2 - NPIC/TDS/DS (1 - Chief, SSB)

NPIC/TDS/D[redacted] (13 Jul 67)

NPIC INTERNAL USE ONLY

MEMO DATED 21 AUG.

ZOOM LENS
AT 20

[redacted]

MM RADIUS	MM THICKNESS	ND INDEX	$n_F - n_C$
94.75	2451.35	1.00000	.00000
12158.72	16.12	1.69100	.01261
206.70	35.43	1.64900	.01920
314.04	9.66	1.00000	.00000
551.36	16.12	1.69100	.01261
1324.37	22.57	1.00000	.00000
- 449.88	12.74	1.69100	.01261
948.31	7.62	1.00000	.00000
512.82	27.93	1.64900	.01920
- 283.36	12.74	1.69100	.01261
1194.42	274.00	1.00000	.00000
1263.30	11.38	1.72825	.02563
162.76	30.06	1.56873	.00902
- 362.66	12.44	1.00000	.00000
200.65	19.57	1.56873	.00902
- 946.49	53.81	1.00000	.00000
- 124.01	6.99	1.65160	.01113
173.23	12.89	1.00000	.00000
- 883.71	8.80	1.69895	.02325
- 82.95	7.57	1.00000	.00000
- 92.06	11.02	1.64250	.01108
510.03	114.80	1.00000	.00000
198.12	9.77	1.73520	.01768
135.51	13.72	1.60311	.00995
- 163.54	4.17	1.00000	.00000
589.36	9.83	1.52249	.00878
- 111.35	7.54	1.71736	.02431
- 456.83	36.55	1.00000	.00000
4711.25	7.24	1.69713	.01239
79.45	3.59	1.00000	.00000
86.32	8.85	1.72151	.02467
298.86	11.75	1.00000	.00000
- 127.80	12.72	1.69713	.01239
438.79	126.96	1.00000	.00000
1562.55	14.45	1.61272	.01045
- 209.33	.53	1.00000	.00000
387.16	30.90	1.61272	.01045
- 159.51	41.95	1.72151	.02467
- 1449.22	496.00	1.00000	.00000

FILM

This data [redacted] shall not be disclosed outside the Government or be duplicated, used or disclosed in whole or in part for any purpose other than to evaluate the proposal; provided, that if a contract is awarded to this offeror as a result of or in connection with the submission of such data, the Government shall have the right to duplicate, use, or disclose this data to the extent provided in the contract. This restriction does not limit the Government's right to use information contained in such data if it is obtained from another source.

12-19-67

ZOOM LENS (24X-70X RANGE) PRESCRIPTION AT 41X SETTING

ΔD = 96 mm

RADIUS MM	THICKNESS MM	n_d INDEX	$n_F - n_c$
96.00	2328.02	1.00000	.00000
6461.17	8.56	1.69100	.01261
109.84	18.83	1.64831	.01920
166.88	5.13	1.00000	.00000
292.99	8.56	1.69100	.01261
703.77	12.00	1.00000	.00000
-239.07	6.77	1.69100	.01261
503.94	4.05	1.00000	.00000
272.51	14.84	1.64831	.01920
- 150.58	6.77	1.69100	.01261
634.72	782.35	1.00000	.00000
- 1774.42	23.56	1.72151	.02467
268.50	44.95	1.61272	.01045
- 533.71	1.34	1.00000	.00000
281.63	26.09	1.61272	.01045
- 2388.30	13.75	1.00000	.00000
- 370.76	7.61	1.69680	.01239
272.41	6.79	1.00000	.00000
189.09	13.06	1.72151	.02467
- 4115.46	20.61	1.00000	.00000
- 372.56	7.61	1.69680	.01239
276.07	109.26	1.00000	.00000
- 5501.66	6.23	1.72151	.02467
438.85	14.60	1.57250	.00997
- 181.45	4.21	1.00000	.00000
206.68	14.60	1.57250	.00997
- 1168.67	17.53	1.72151	.02467
723.01	14.58	1.00000	.00000
- 324.21	6.70	1.69680	.01239
164.71	21.58	1.00000	.00000
176.64	11.47	1.72151	.02467
1998.00	7.94	1.69680	.01239
253.77	138.26	1.00000	.00000
908.59	16.62	1.61272	.01045
- 276.74	1.54	1.00000	.00000
174.27	31.32	1.61272	.01045
- 773.60	14.27	1.72151	.02467
174.10	36.44	1.00000	.00000
189.96	34.75	1.61272	.01045
3571.40	3.71	1.00000	.00000
332.58	24.81	1.61272	.01045
279.35	16.96	1.00000	.00000
- 239.72	14.66	1.72151	.02467
- 401.50	216.99	1.00000	.00000

117-10-04+02
12-14-67

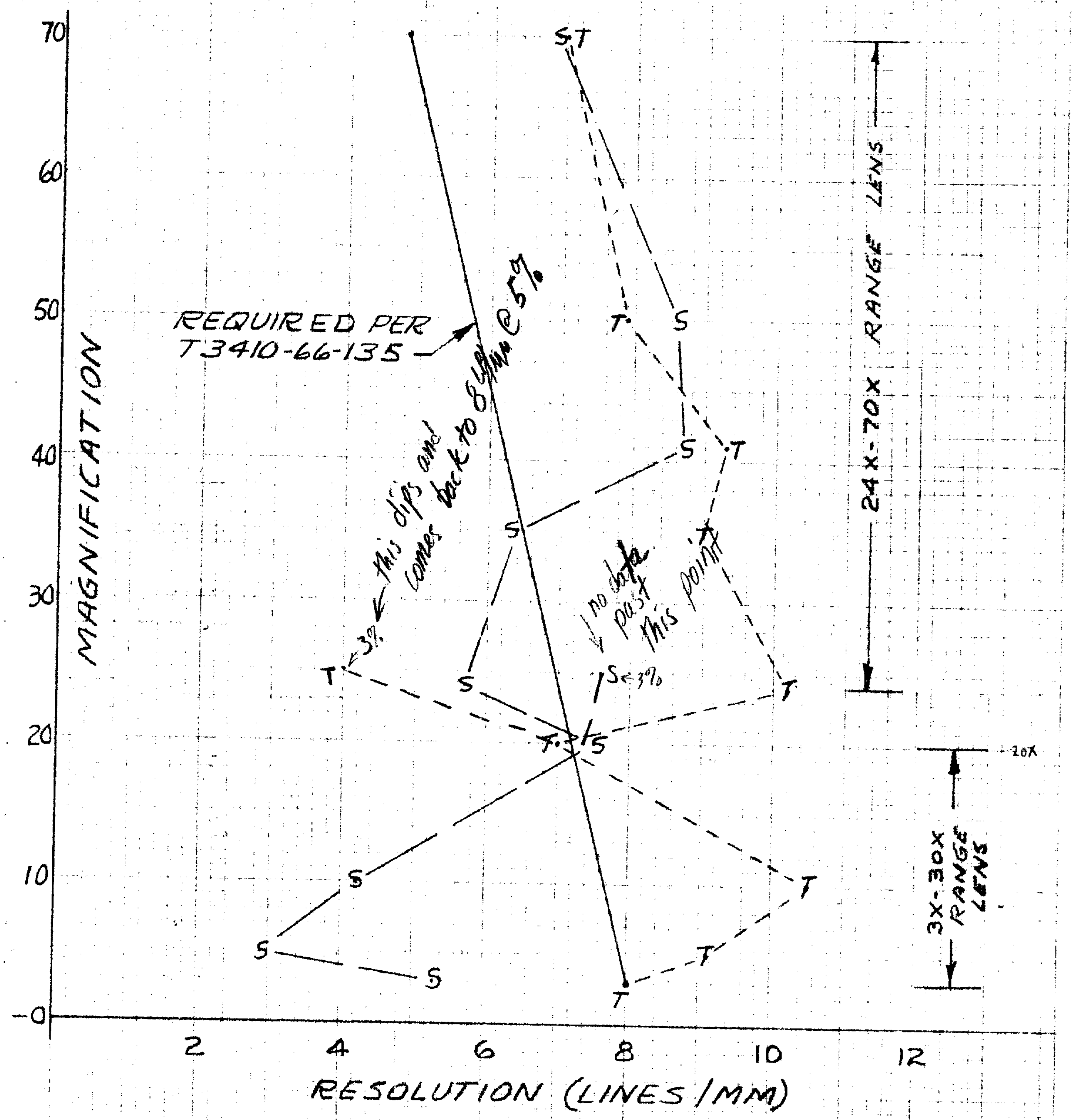
worse

Coma

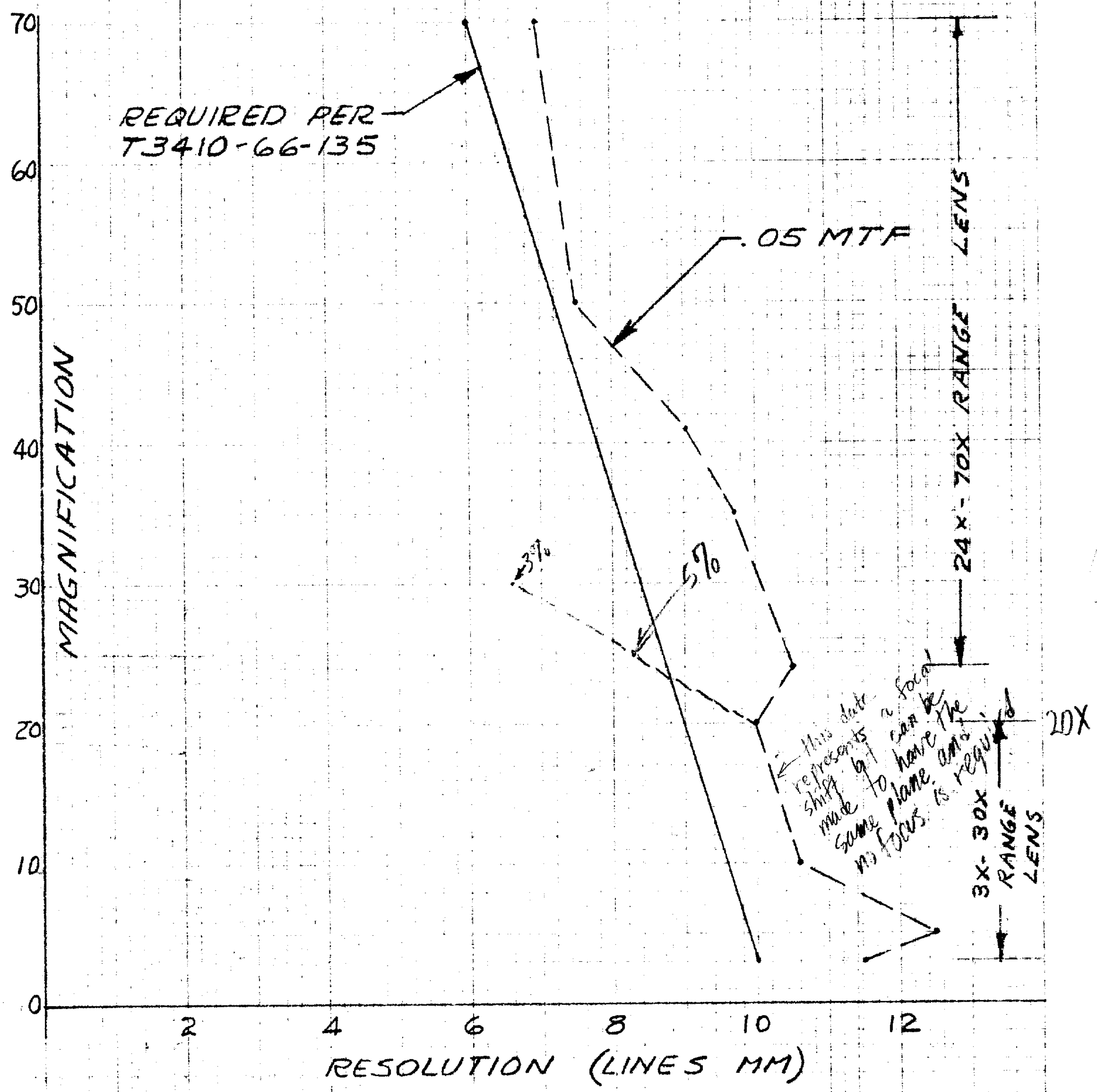
Spot Diagram

E F C will also be tried

GRAPH OF PREDICTED NOD 110/120 EDGE SCREEN RESOLUTION

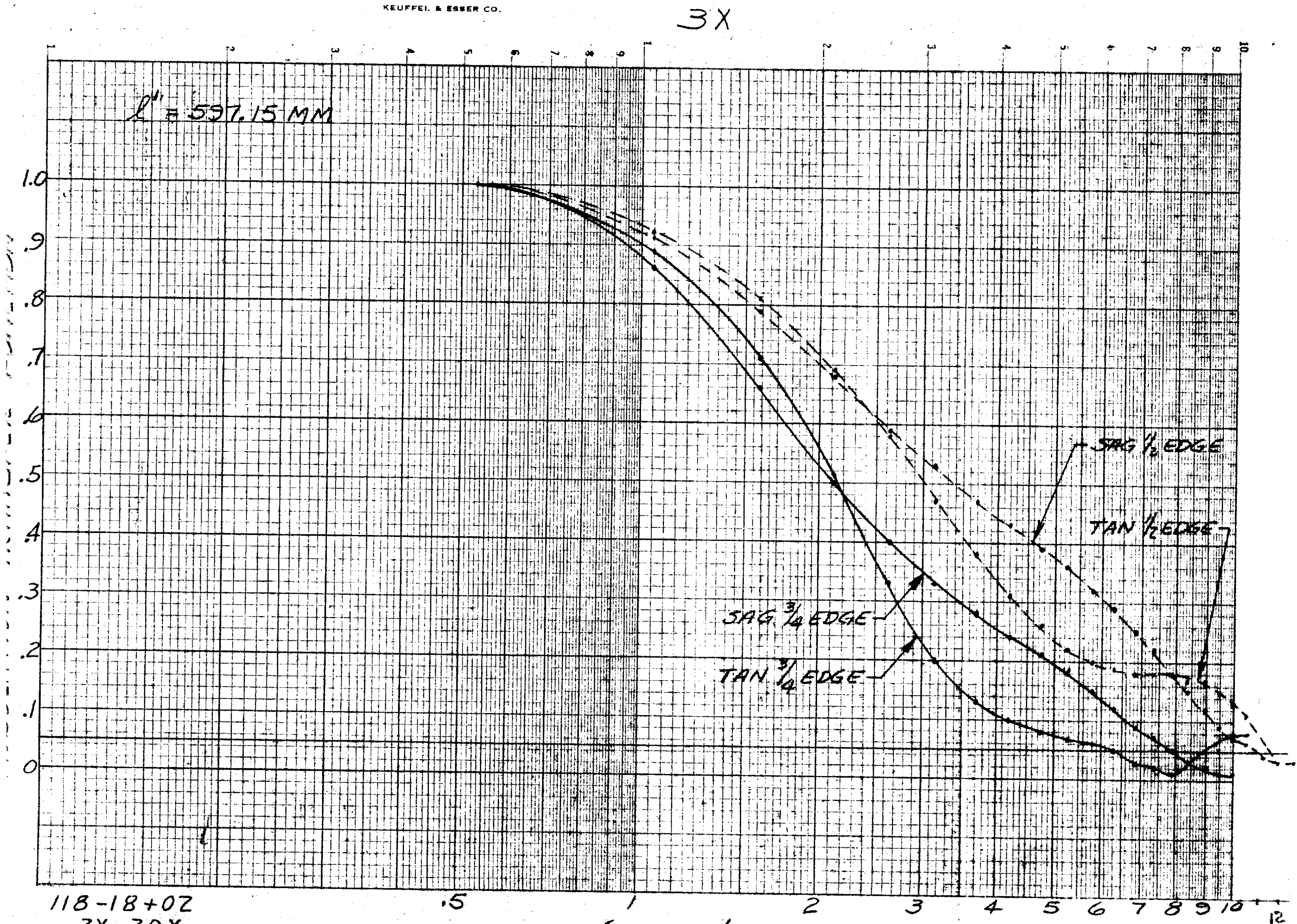


GRAPH OF PREDICTED NOD 110/120 AXIAL SCREEN RESOLUTION



This data represents a focal shift but can be made to have the same plane and no focus is required

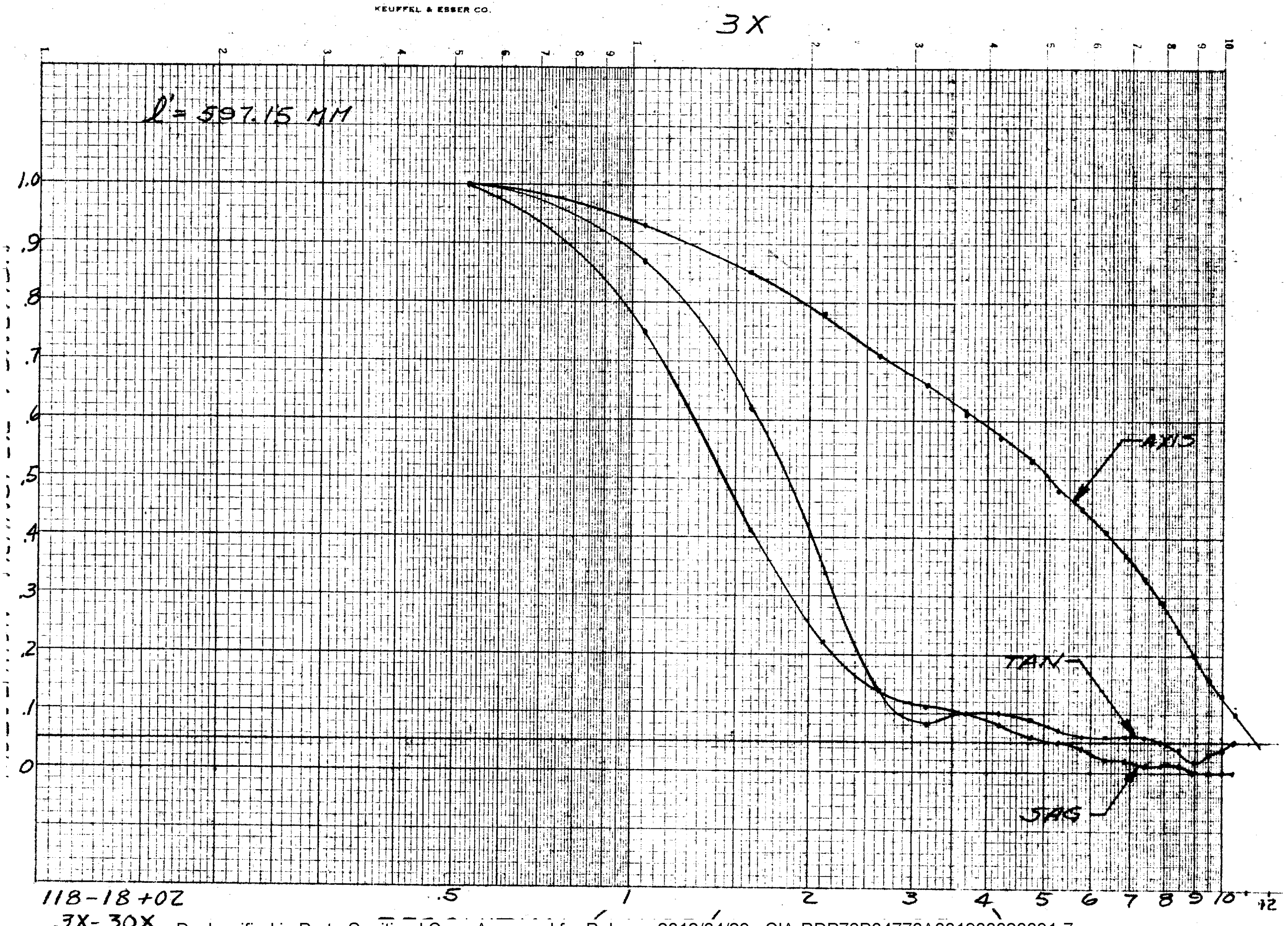
3X



118-18+0Z
3X-30

-18-67

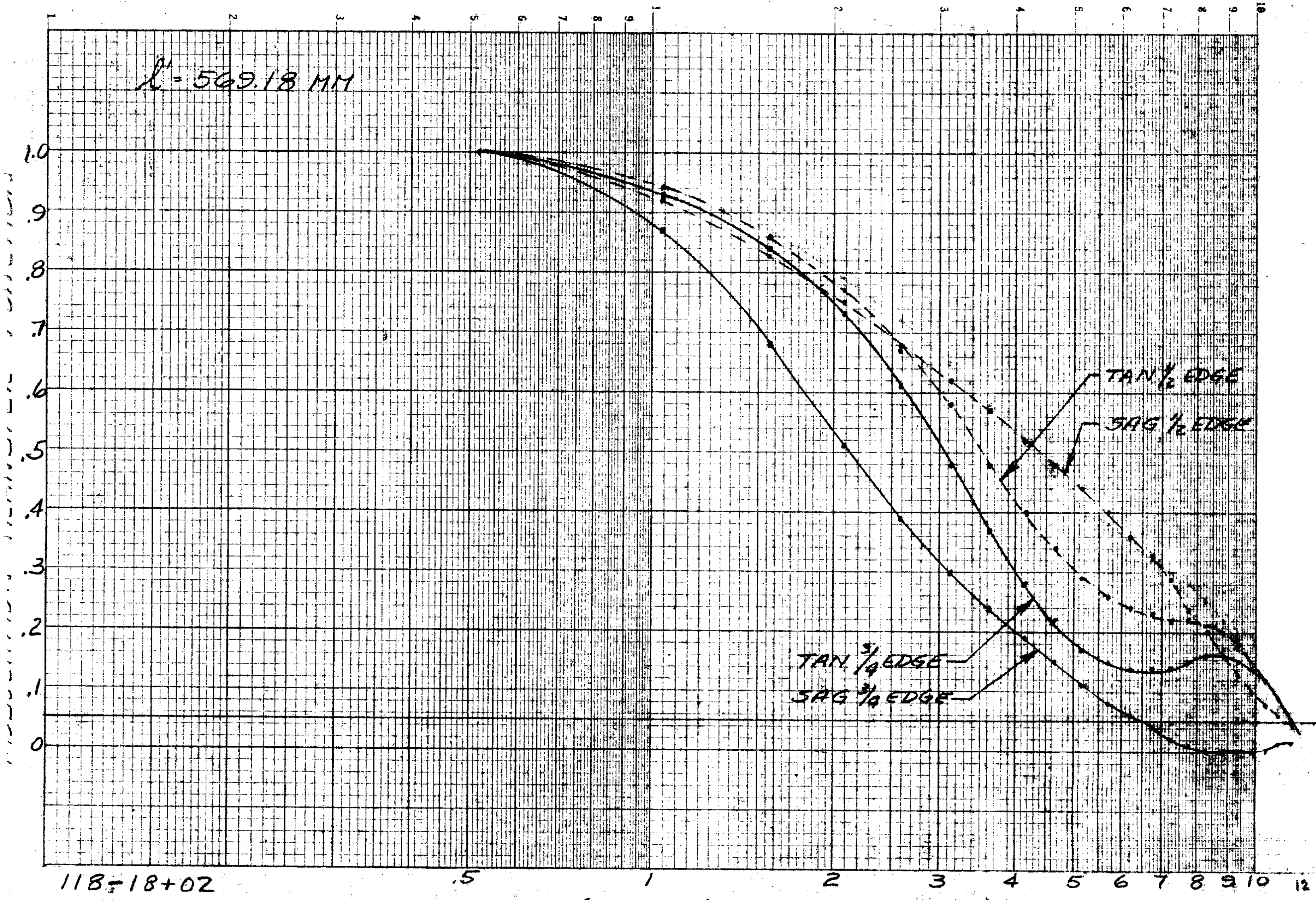
3X



118-18+0Z
3X-30X

12-18-67

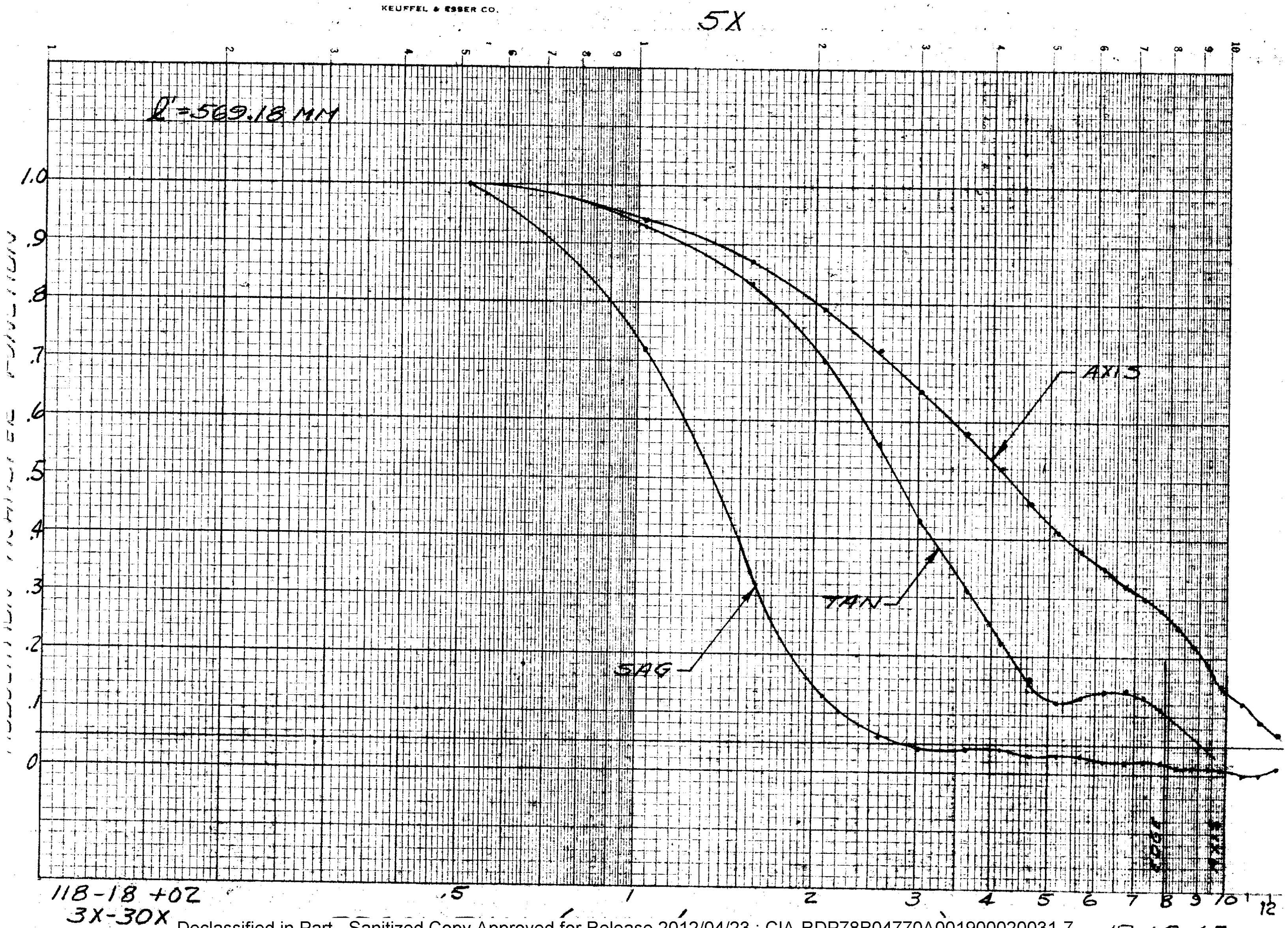
5X



118-18+02

3X-30

2-18-67

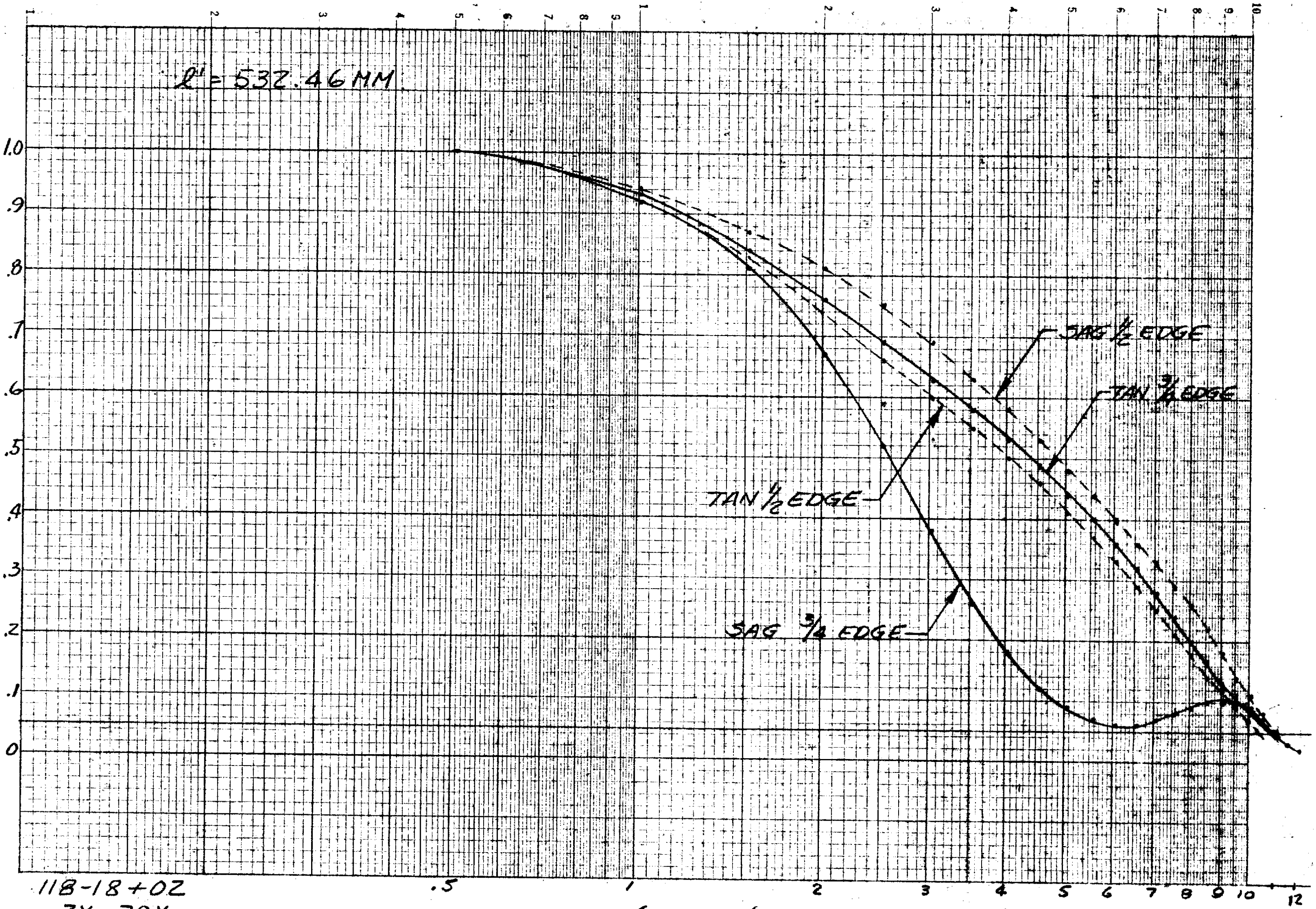


118-18 +02
3X-30X

12-18-67

2 CYCLES X 70 DIVISIONS MADE IN U.S.A.
KEUFFEL & ESSER CO.

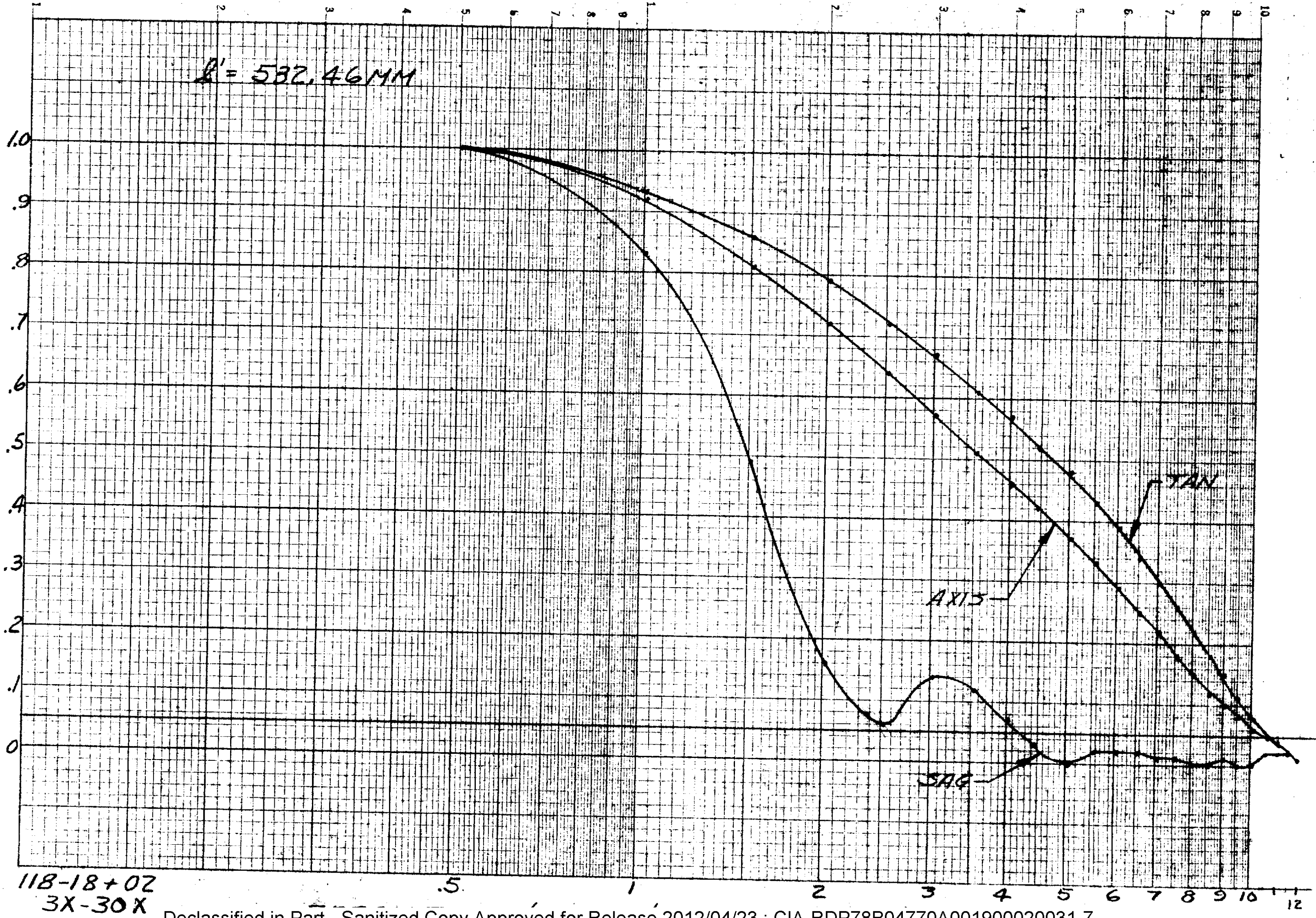
9.76X



118-18+0Z
3X-30

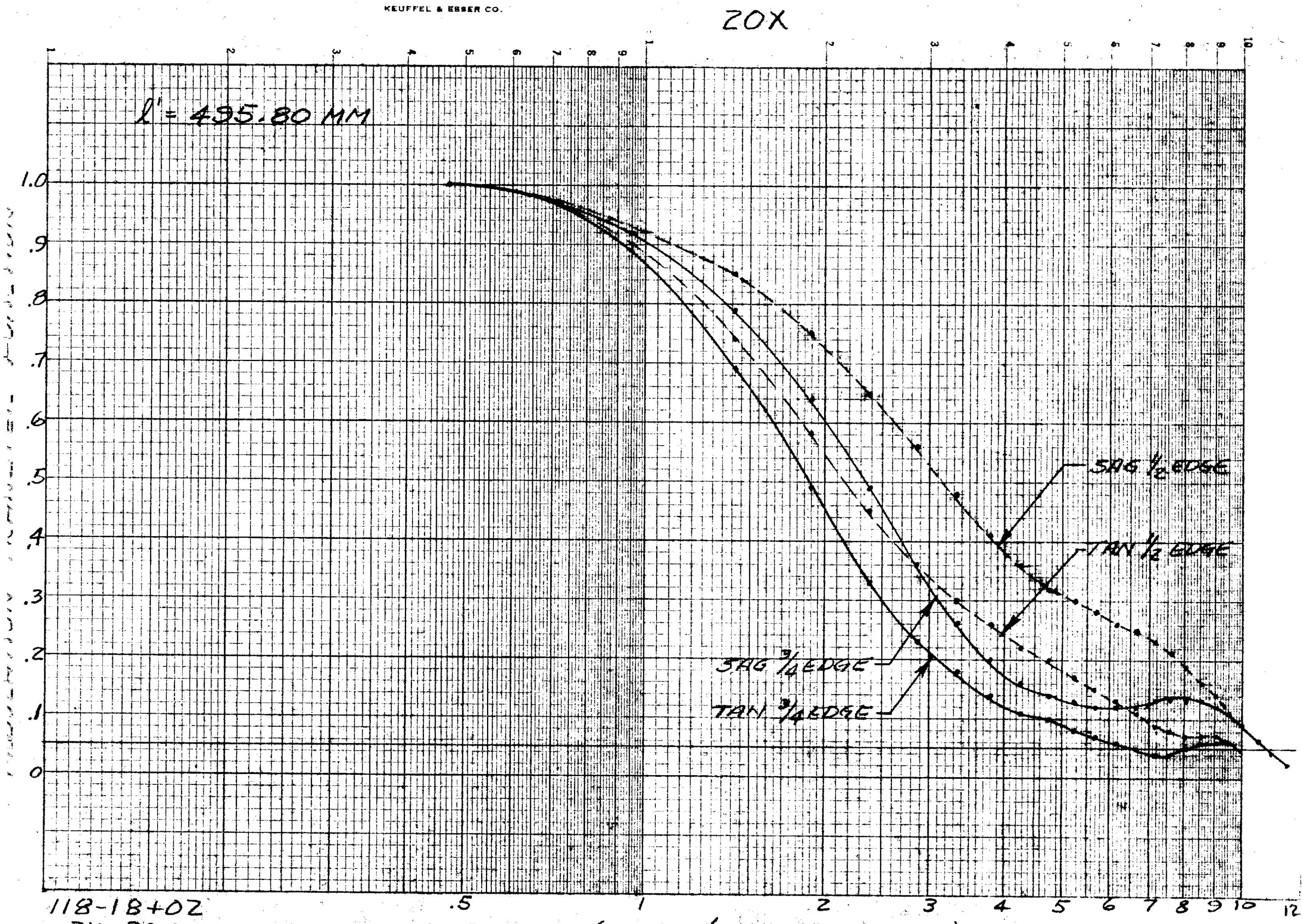
12-18-67

9.76 X



118-18+02
3X-30X

12-18-67



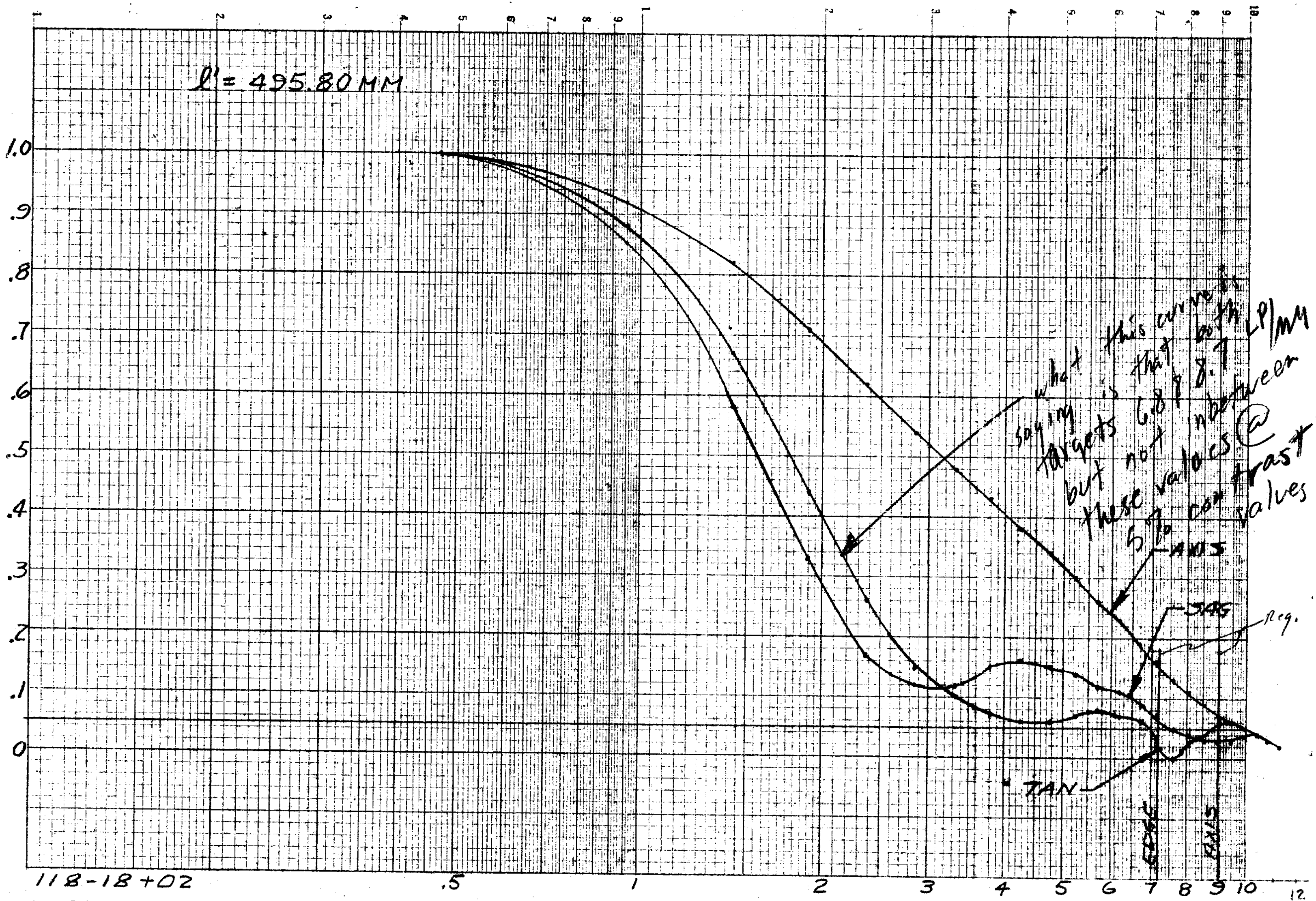
118-18+02

3X-30)

-18-67

20X

ℓ' = 495.80 MM



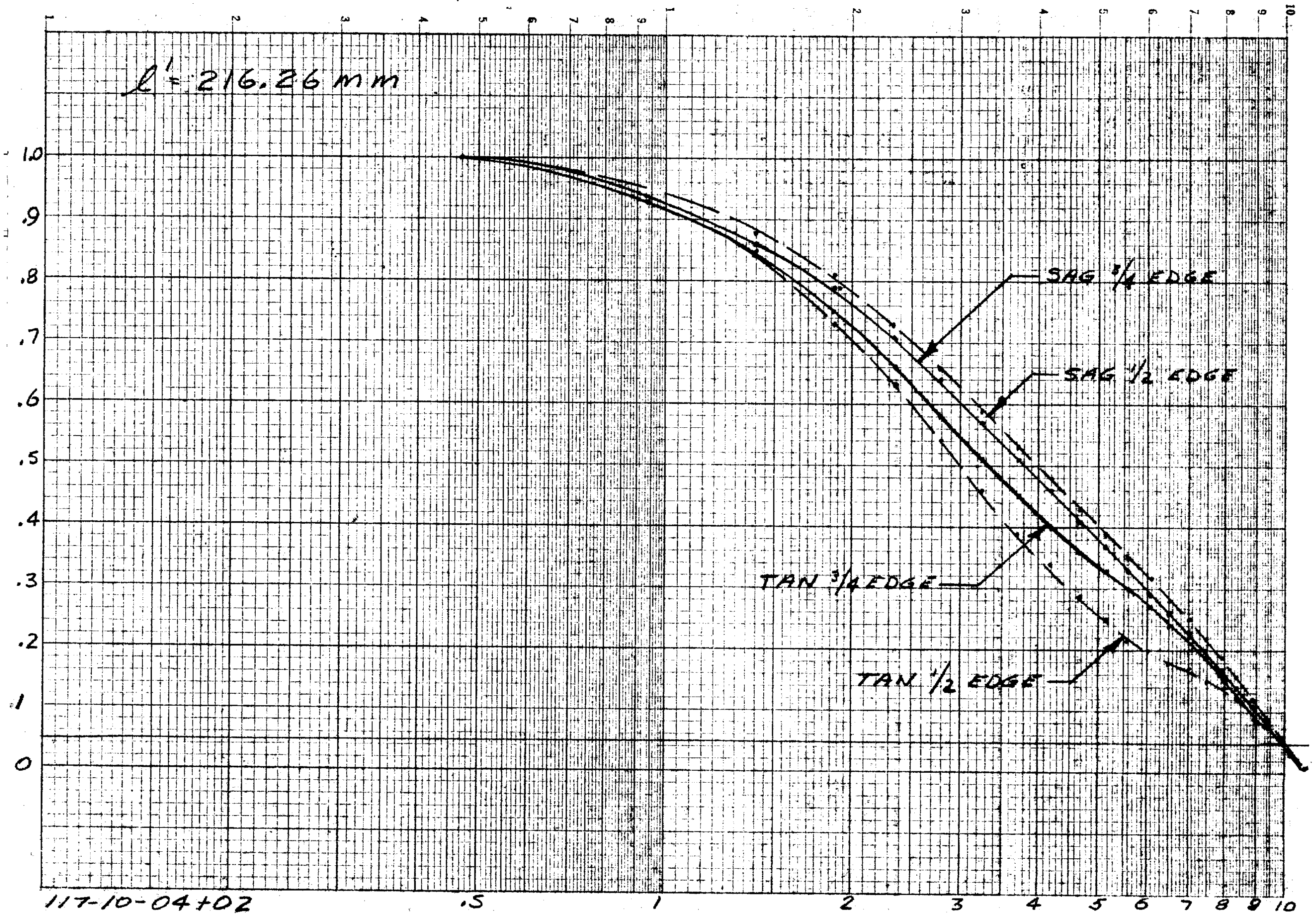
what this curve is saying is that both 6.8 & 8.7 LP/MM targets but not in between these values @ 5% contrast values

118-18+02

3X-30x

12-18-67

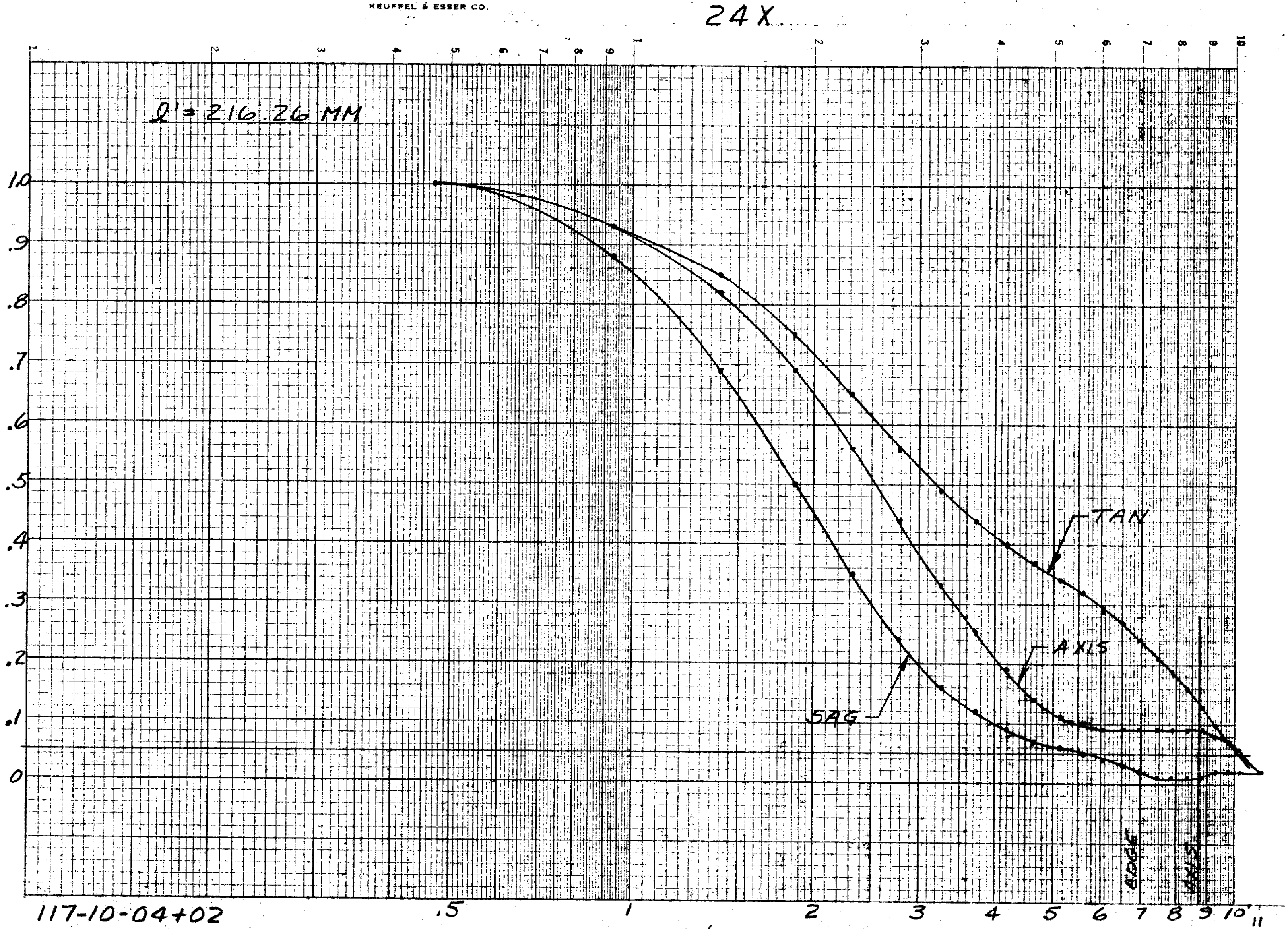
24X



117-10-04+02
24X-70

12-18-67

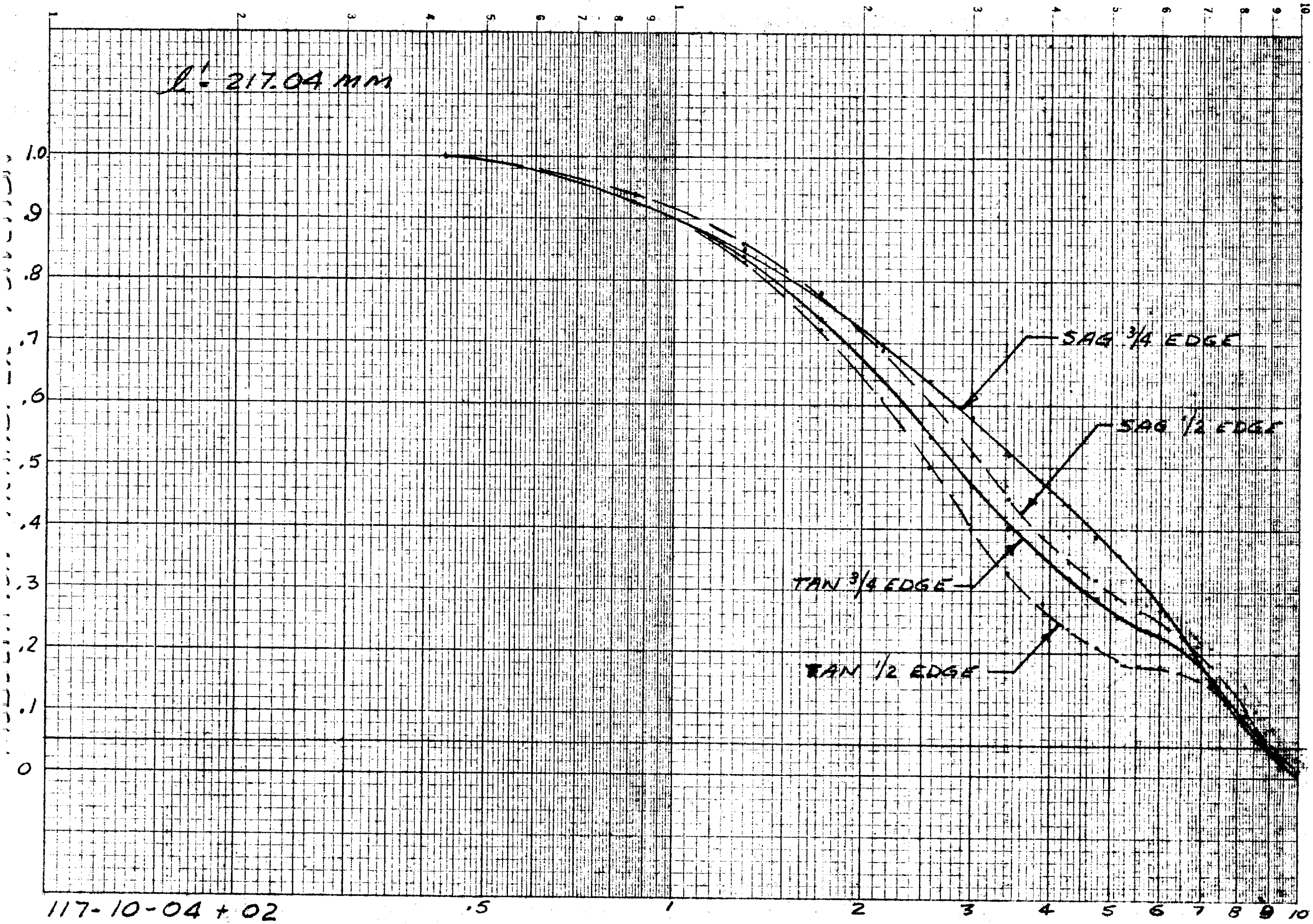
24X



117-10-04+02

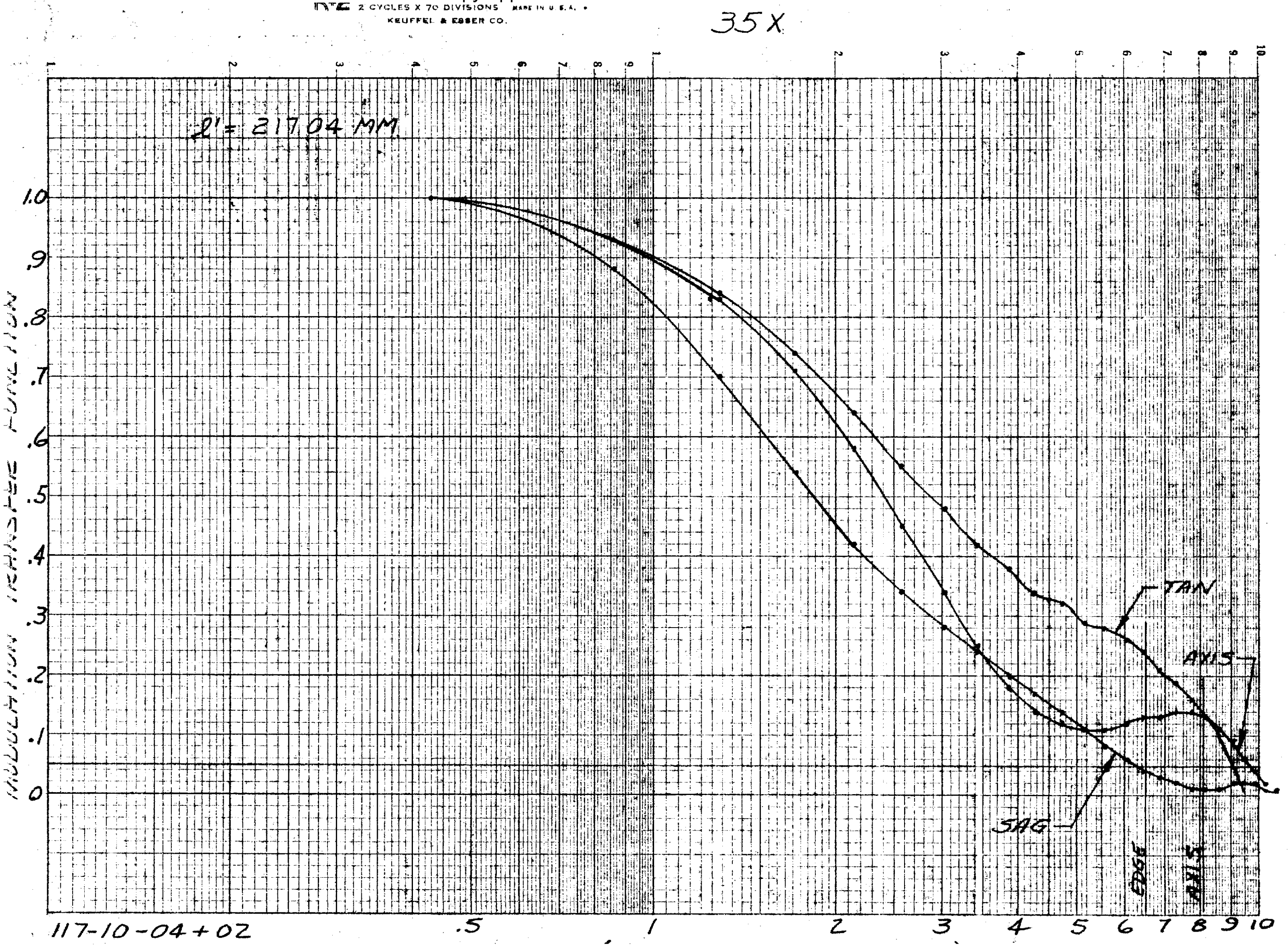
24X-7C

12-14-67



117-10-04 + 02
24X-7

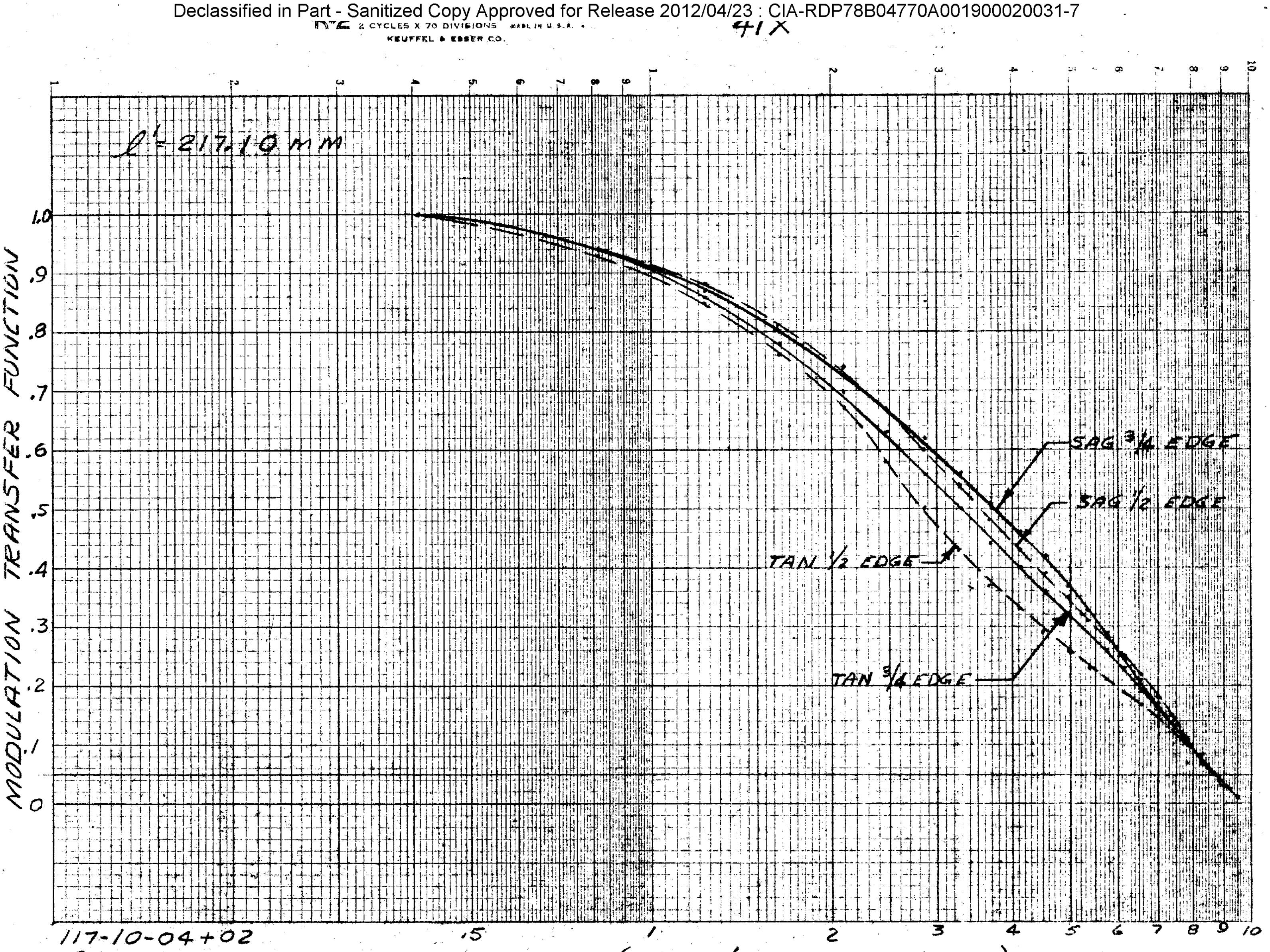
12-18-67



117-10-04+02

24X-7

41X

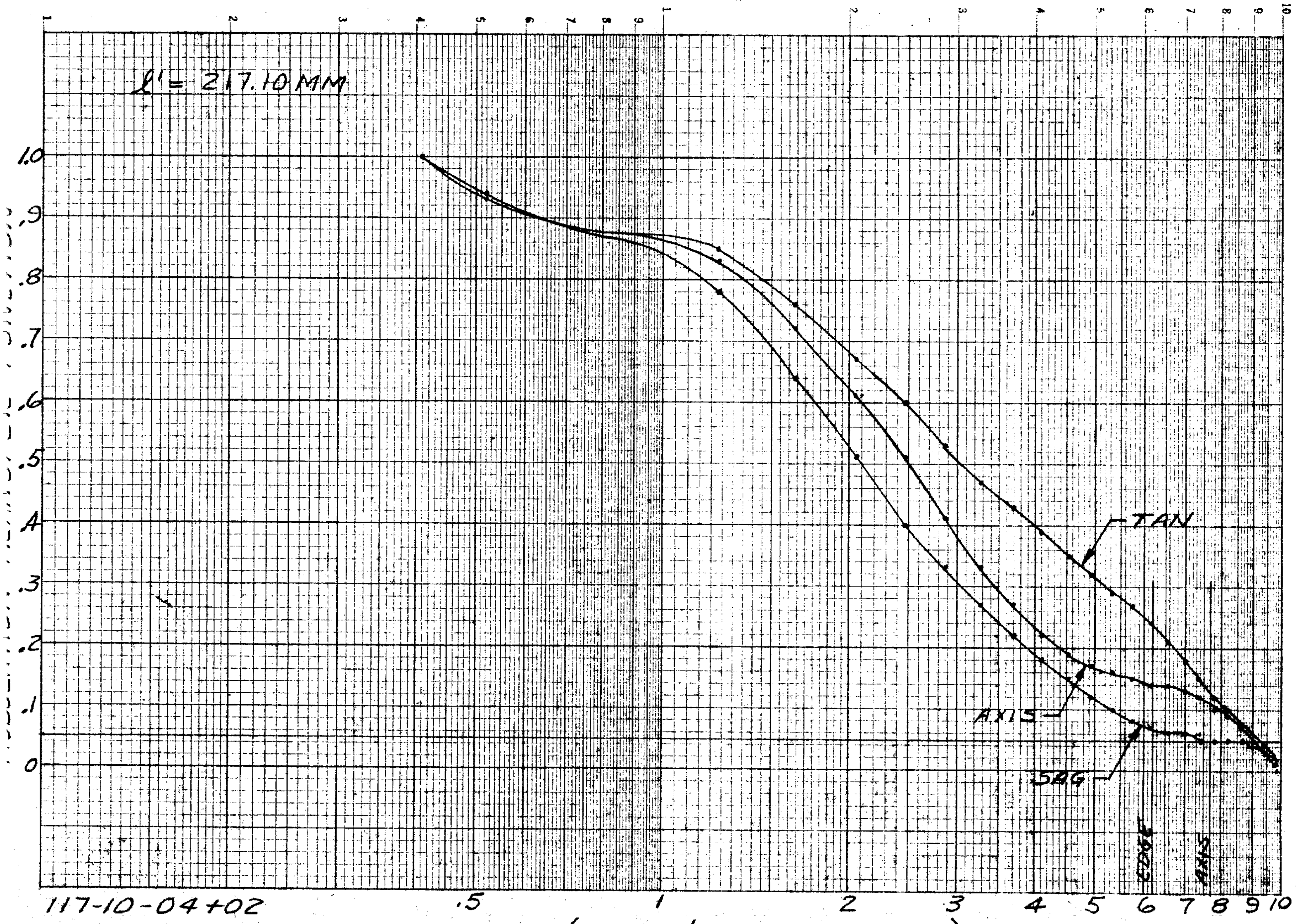


117-10-04+02
24X-T

12-18-67

KEUFFEL & ESSER CO.

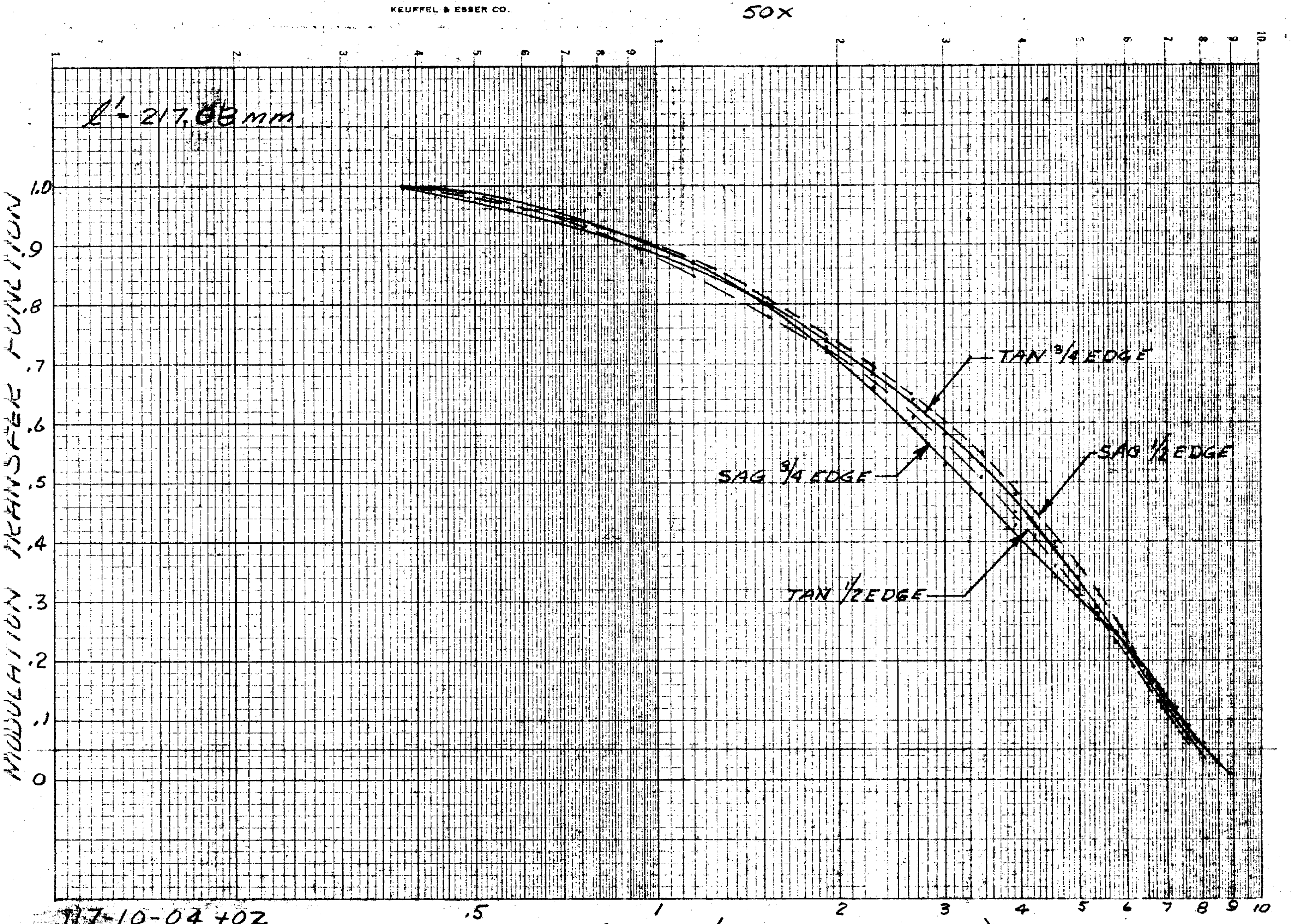
41X



117-10-04+02

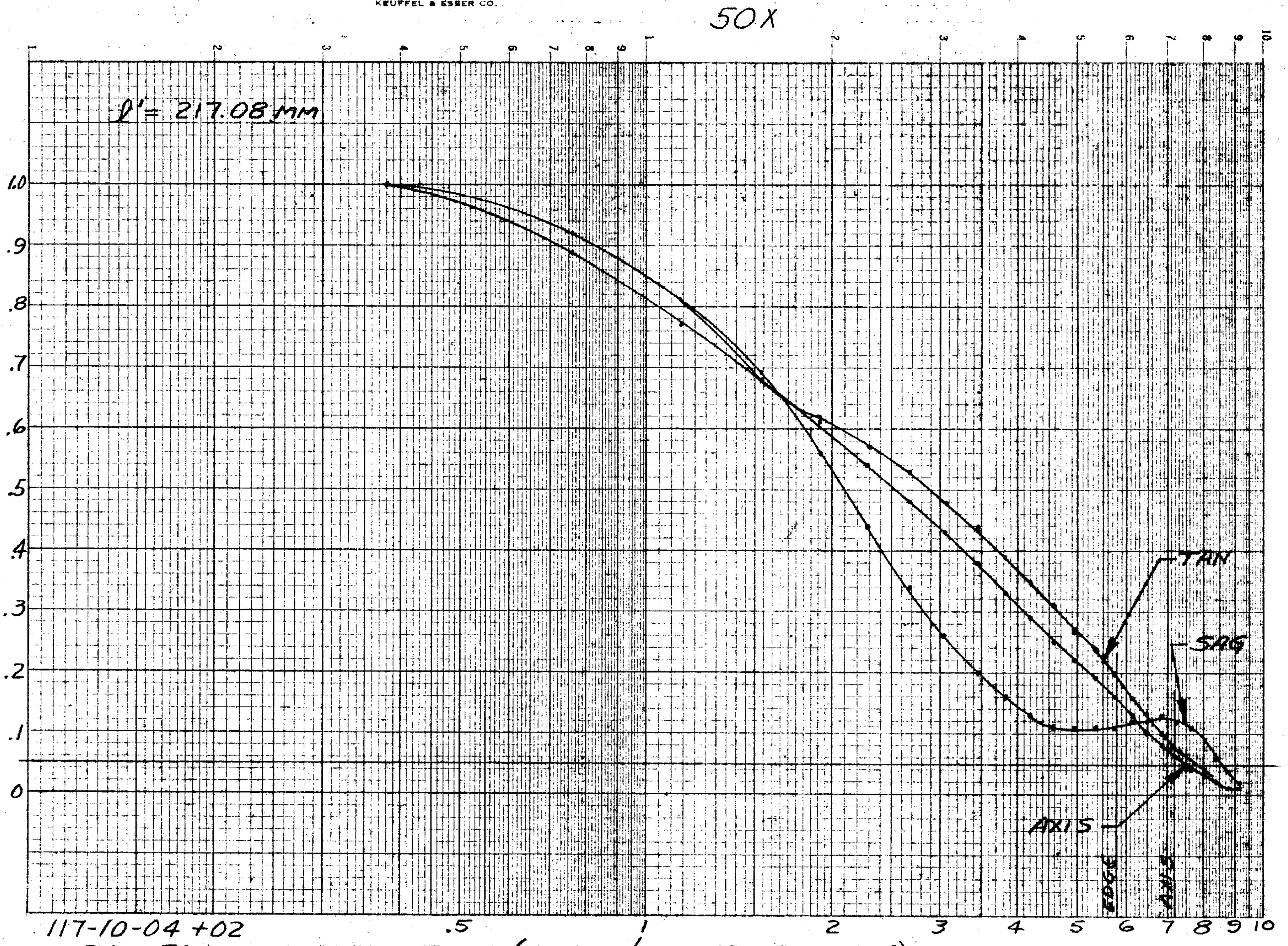
24X-T

12-14-67



117-10-04 +02
24X-7

12-18-67

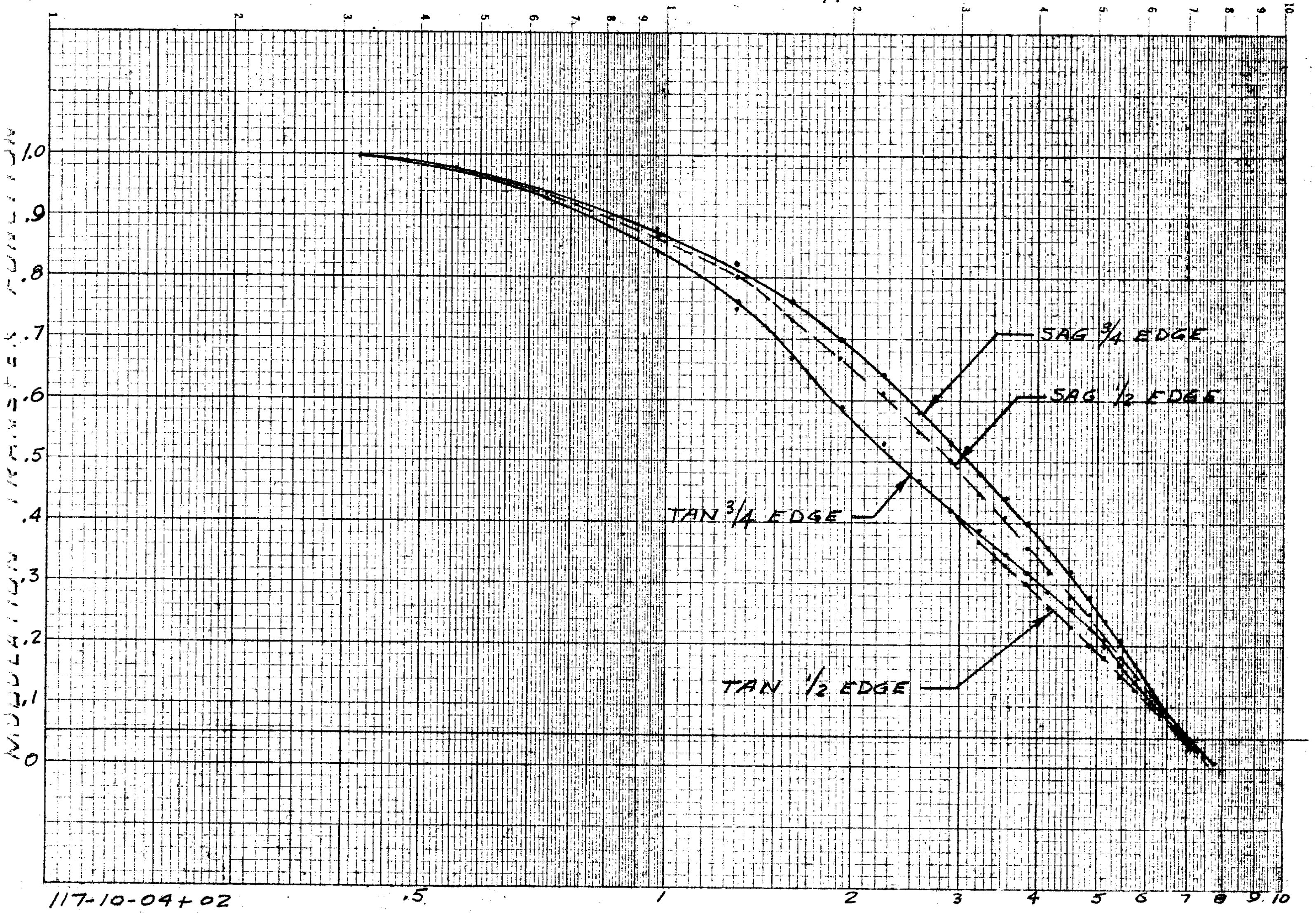


117-10-04 +02

24X-

12-13-67

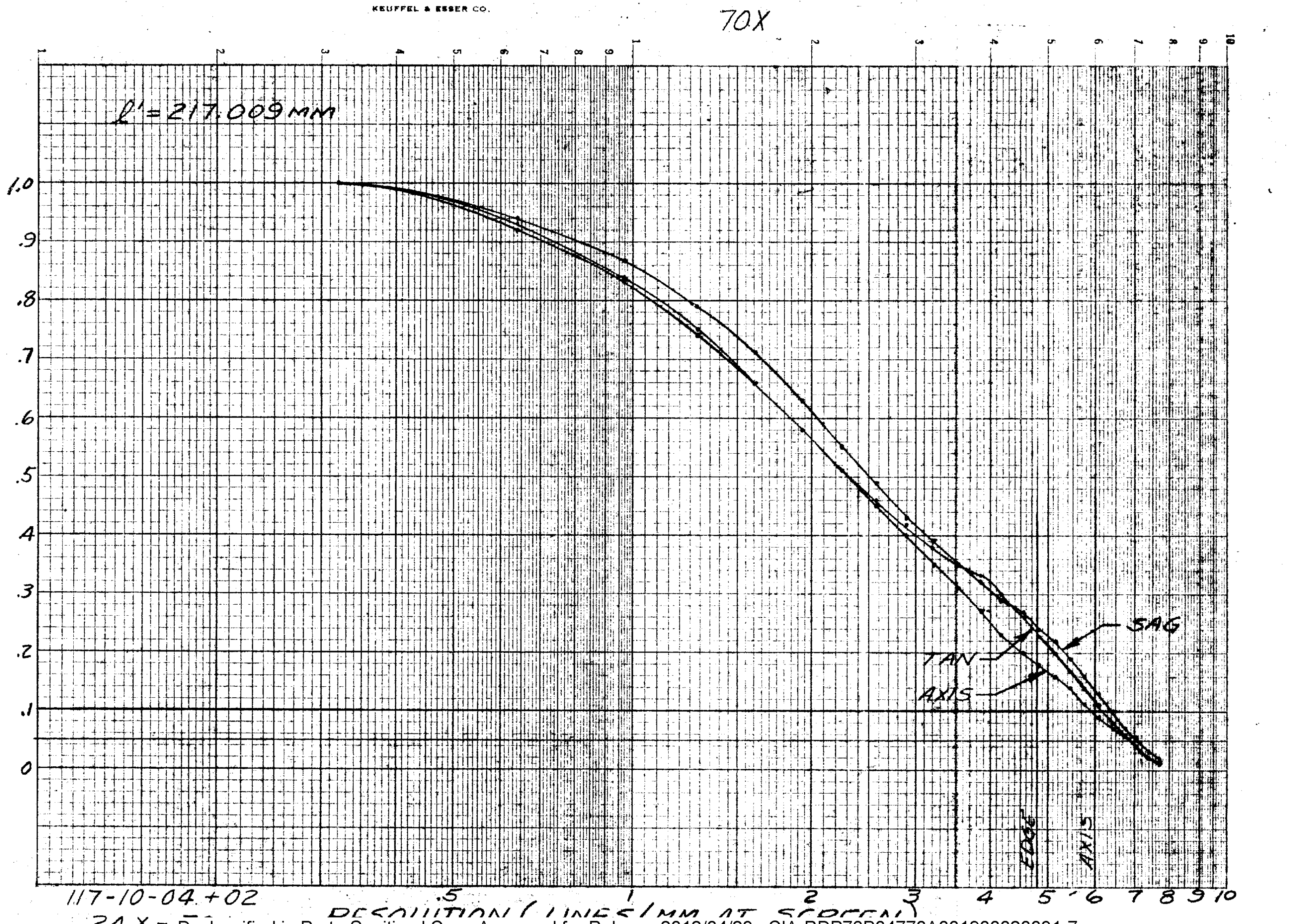
$\frac{1}{2}$ EDGE, $\frac{3}{4}$ EDGE



117-10-04+02

24 X - 7

12-19-67

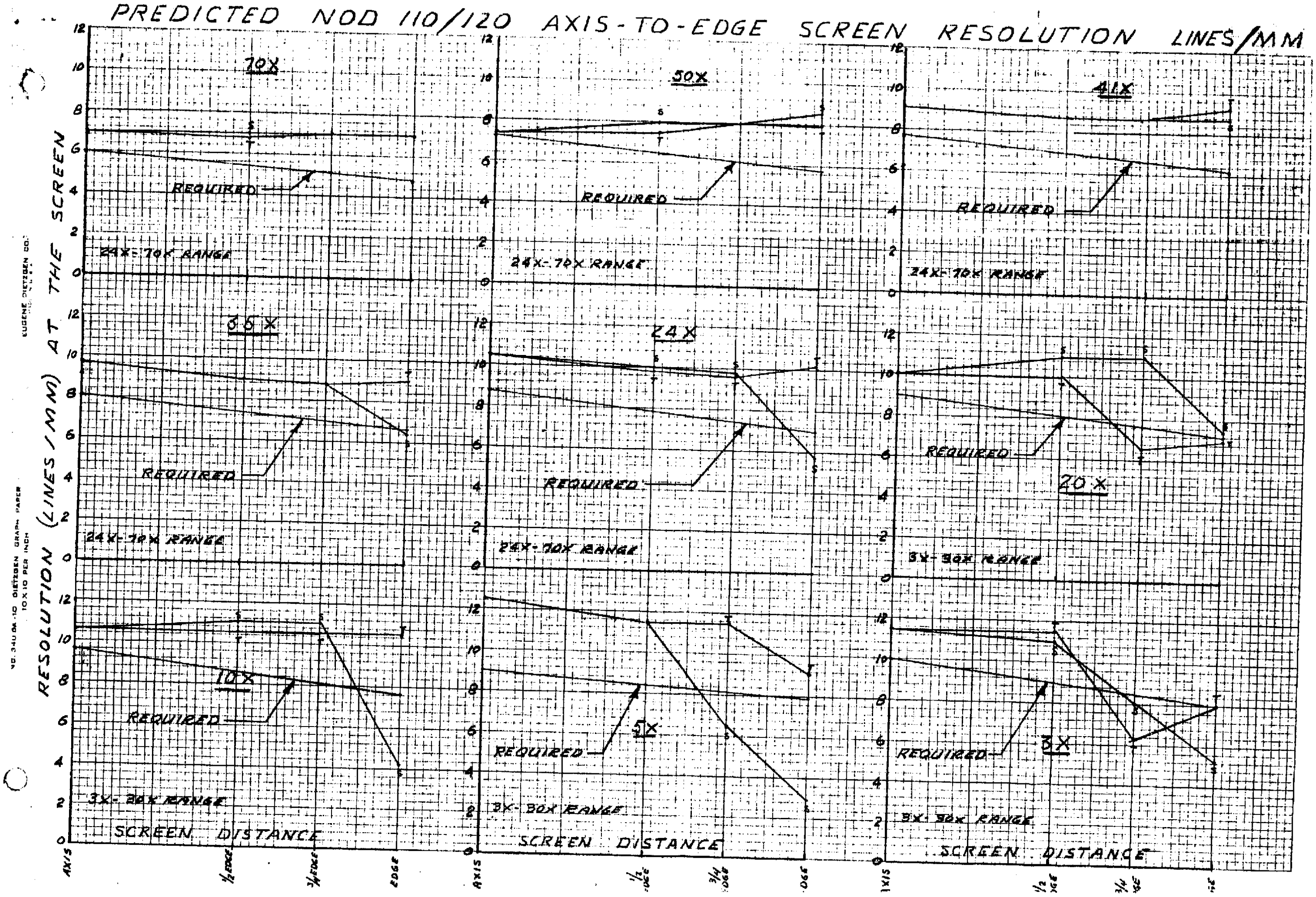


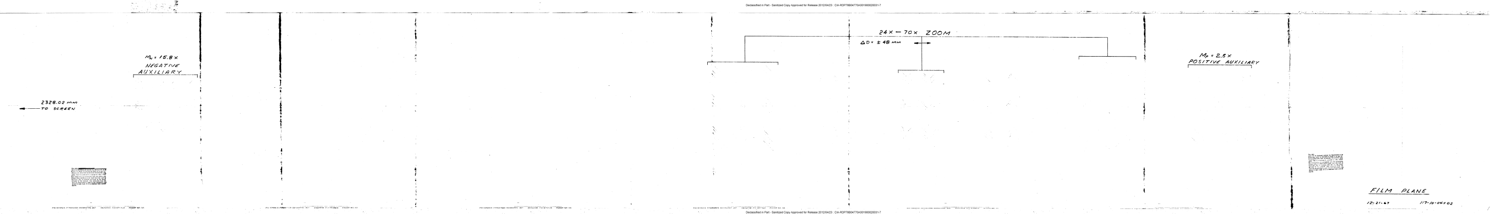
117-10-04+02

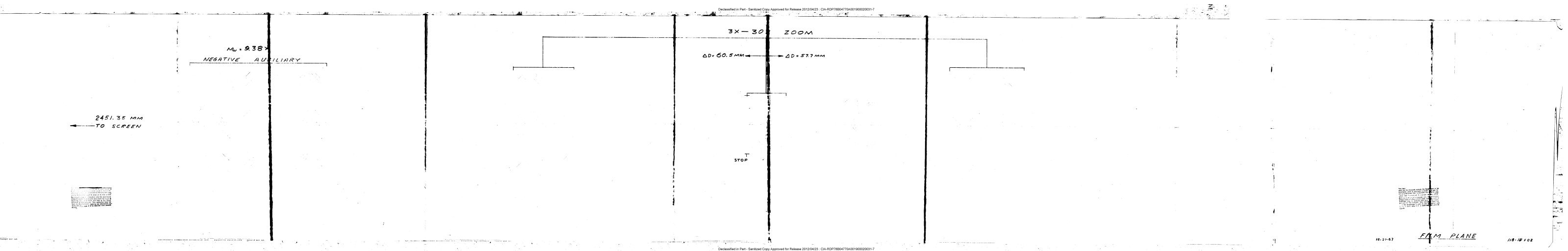
24X -

12-13-67

PREDICTED NOD 110/120 AXIS-TO-EDGE SCREEN RESOLUTION LINES/MM




$M_N = 15.8\times$
NEGATIVE AUXILIARY
2328.02 mm
TO SCREEN
24× — 70× ZOOM
$\Delta D = \pm 48$ mm
$M_P = 2.5\times$
POSITIVE AUXILIARY
FILM PLANE
12-21-67
117-10-04+02


2451.35 MM
TO SCREEN
M_N = 9.38X
NEGATIVE AUXILIARY
3X — 30
ZOOM
ΔD = 60.5 MM
ΔD = 57.7 MM
STOP
12-21-67
FILM PLANE
118-18 + 02

ZOOM LENS

LAYOUT

AND

ZOOM LENS PRESCRIPTION

at 20X

STAT

STAT

[redacted]

[redacted]

Ref: Y7040-67-762/EMC:ka

20 November 1967

Naval Reconnaissance & Technical Support Center
4301 Suitland Road
Suitland, Maryland 20390

STAT [redacted] Head - Target Division

Gentlemen:

Enclosed is a data sheet describing our Model 100 Rear Projection Viewer which you requested through the reader service of OPTICAL SPECTRA.

If you require any further information, please write or call me at

STAT [redacted]

Thank you for your interest in our equipment.

Yours very truly,

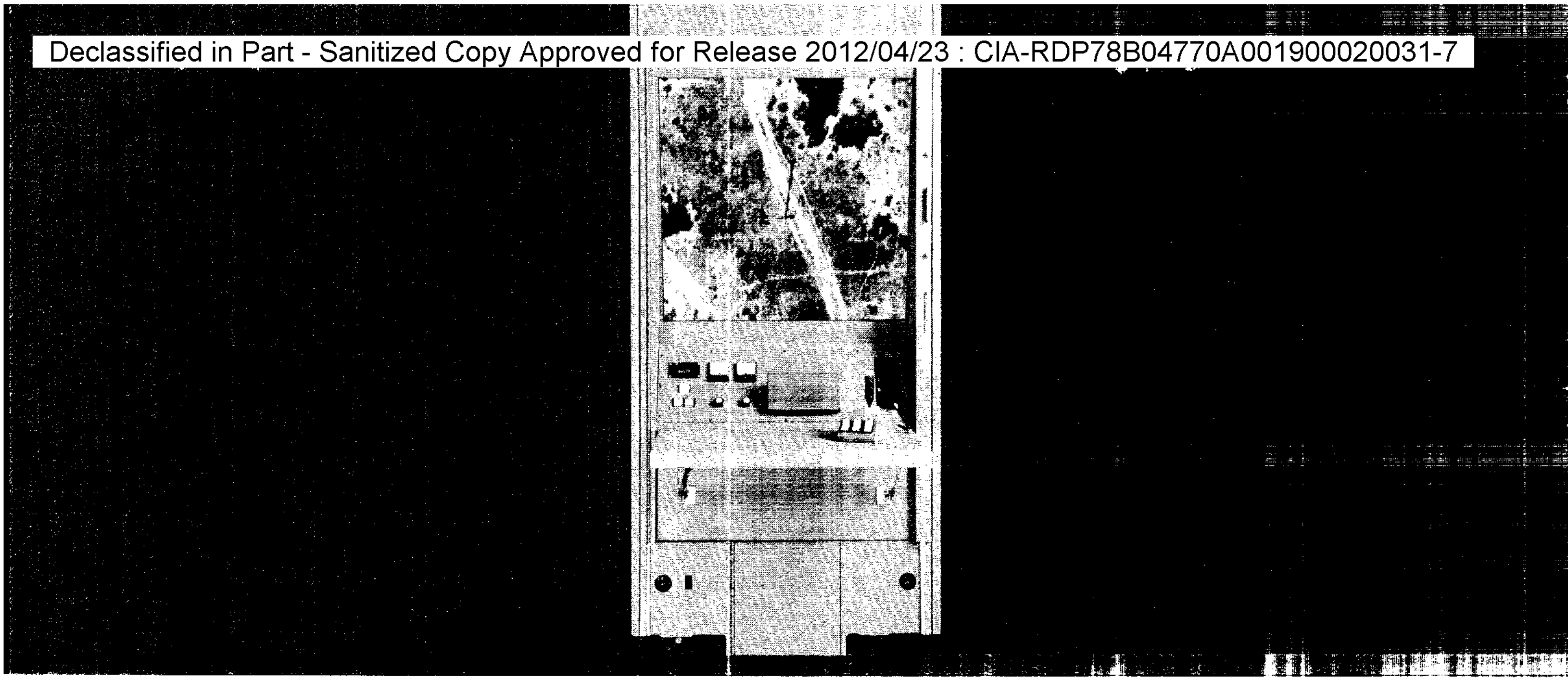
[redacted] STAT

Enclosure

STAT

[redacted]

ZOOM IN ON TARGET



In photo interpretation, the big picture can be deceiving. It's the details that allow decisions to be made quickly and confidently.

Magnification of images is an aid in evaluation, but the problem up to now has been a means to keep images in focus during enlargement, to keep them from blurring or losing detail because of step over-magnification.

STAT

Now, [redacted] offers its Model 100 rear projection screening viewer which allows operators to analyze any part of any frame up to 70 times its normal size — through continuously variable magnification. This allows the magnification to be stopped at any place within the 3 to 70 times range so that film images can be studied in precise focus.

Zoom in on a target with the Model 100 and you see the little picture — the whole picture — in detail unsurpassed for accuracy. Make your decisions in confidence, knowing you have viewed complex film footage in minute detail.

DESCRIPTION

The Model 100 is a complete viewing system, which includes many features that make it foremost for accurate and detailed imagery interpretation.

The rear projection viewer is controlled by an operator seated at a desk-type console to view film on a 30 x 30 inch screen. The non-reflective screen provides clear views of the projection from any angle, allowing several observers to witness the action.

The operator, using a control stick, can: (1) translate the image on the screen for both vertical and horizontal viewing; (2) control the speed of the film; (3) scan film frames across the width, as well as the length; (4) change the focus of the image; (5) select any magnification desired; and (6) rotate the image 360 degrees.

STAT

Included in the Model 100 is a [redacted] zoom lens, a completely optically compensated system with only one moving part. This eliminates the deterioration of parts due to wear — a drawback of conventional mechanically compensated zoom systems.

Images can be magnified from 3 to 70 times their normal size, and remain in focus throughout the zooming process. The Model 100 is all metal and has a light and dust free housing for the illumination and optical system.

The viewing screen and control panel swing out for easy access for film changing and maintenance.

A separate unit contains the air-cooling equipment. Interconnecting electrical cabling and flexible air ducts are provided between the unit and viewer.

STAT

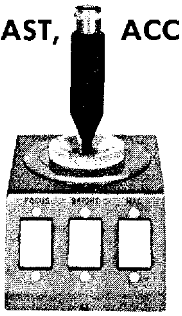
The [redacted] Model 100 is designed to operate in an office environment and will meet performance requirements in ambient temperatures ranging from 55 degrees to 90 degrees Fahrenheit.

UNSURPASSED FEATURES

- Film frames can be scanned in any desired direction
- Continuously variable magnification from 3 to 70X
- Accommodates film widths between 70 mm to 9.5 inches without spacers
- Front film loading at convenient height
- Film loading time measured in seconds
- Zoom system with only one moving part. No deterioration due to mechanical wear as common in other magnification systems
- Film gate opening variable from clamped to full open proportional to film speed

...AND DOZENS MORE

SURE, FAST, ACCURATE ...



• control stick movable for right/left handed operators • film footage counter • storage bin for reference material • adjustable focus • large, sturdy workshelf • 30 x 30 inch screen • viewing screen situated for optimum operator comfort • either reel can be supply or take-up • continuous variable illumination • zoom condenser provides even screen illumination • counterbalanced mirror swings up for cleaning and access to platens • most frequently used controls located in and around control stick.

EASE OF MAINTENANCE ...

• modularized circuitry to allow replacement by individual function • side panels quickly removed or replaced • rigid frame to maintain critical alignments • lamp adjustments while lamp is burning • platens removed easily for cleaning • interior light turns on when door is opened.

BUILT-IN SAFETY ...

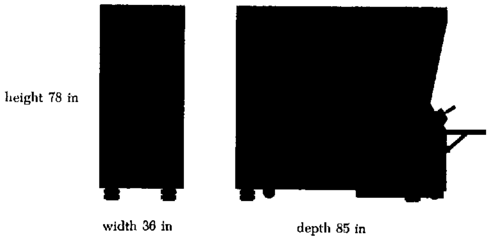
• efficient cooling system maintains film gate temperature below 100 degrees F. • fail safe transport prevents running of improperly loaded film • thermal protection in lamp housing • three-point mirror supports for strain-free mounting • circuit breaker on front panel to protect system • precision film tension control under both static and dynamic conditions • interlock and positive disconnect of lamp terminals when lamp compartment open.

FAST, SIMPLE FILM LOADING ...

• simple film path with no leader or threading devices • automatic film transport positioning for loading • automatic film rewind with stop before film leaves take-up spool • film drive motors reversible individually for emulsion in or out winding.

SPECIFICATIONS

FILM ACCOMMODATED	Roll film, all widths 70 mm to 9.5 inch thin and standard base; black and white or color transparencies; infrared or radar negatives
FILM CAPACITY	Maximum 1000-foot spools — AF Standard 51C17848
MAGNIFICATION	3x to 70x continuously variable
RESOLUTION	8 lines at 3x 6 lines at 70x — With high contrast resolution target
FOCUS	Automatic throughout magnification range. Manual override.
IMAGE ROTATION	±180 degrees continuous
SCREEN BRIGHTNESS	20 foot-lamberts at 70x with 1.5 ND film
ILLUMINATION UNIFORMITY	Less than 30 percent falloff, except at extreme corners at 3x to 3.7x
SCREEN SIZE	30 x 30 inches
IMAGE POSITIONING	Any point on 9.5-inch film can be brought to screen center at all powers
FILM SPEEDS (Forward or Reverse)	
HIGH RANGE (Slew)	5 to 50 in/sec parallel to film 0.01 to 3.3 in/sec transverse to film
LOW RANGE (Scan)	0.01 to 2.0 in/sec parallel or transverse
VIEWER DIMENSIONS	Height 78 in; depth 85 in; width 36 in
VIEWER WEIGHT	1500 pounds
COOLING MODULE	Height 18 in; depth 22 in; width 20 in
COOLING MODULE WEIGHT	60 pounds
POWER REQUIREMENTS	3.5 KVA, 115V, 60-cycle, single phase



STAT

[redacted] — where optical skills are combined with mechanical and electronic capabilities to solve the complex problems of photogrammetry. The Model 100 is an example of just one of [redacted] viewing systems. Let our long experience in this field go to work. Skilled engineers and technicians will find the solution — a reliable, accurate and economical system.

STAT

STAT

FOR INFORMATION REGARDING OPTICAL SYSTEMS CONTACT:

[redacted]

PUB. No. 117-2-67 PRINTED IN USA

STAT

STAT

[redacted]

[redacted]

April 20, 1967

STAT

[redacted]

Dear Jim:

George relayed your request for information on rear projection screen dynamic scanning. Unfortunately, we never did follow through on the very preliminary work I did.

The data I obtained was of a very high magnification and therefore not truly representative of normal screen viewing. The microscope through which the photo was taken is 38X. The image of the resolution chart is several hundred power. With above setup an orbital diameter of .040 inch and 40 cps worked very well. See attached figures 2 and 3.

Yours for more humanized factors,

Sincerely,

[redacted]

STAT

Enc.

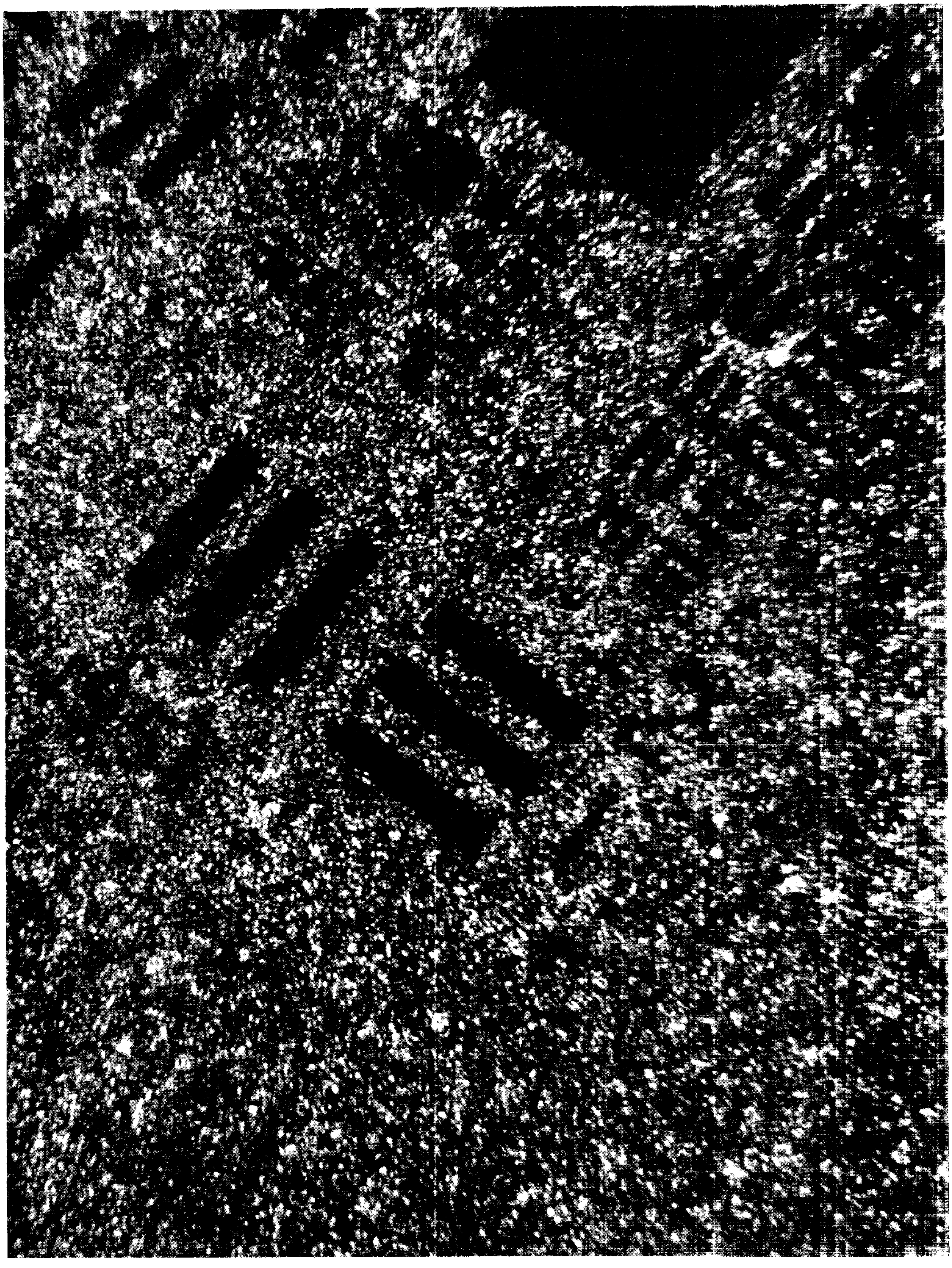


Figure 2. PROJECTED IMAGE ON STATIONARY REAR-PROJECTION SCREEN

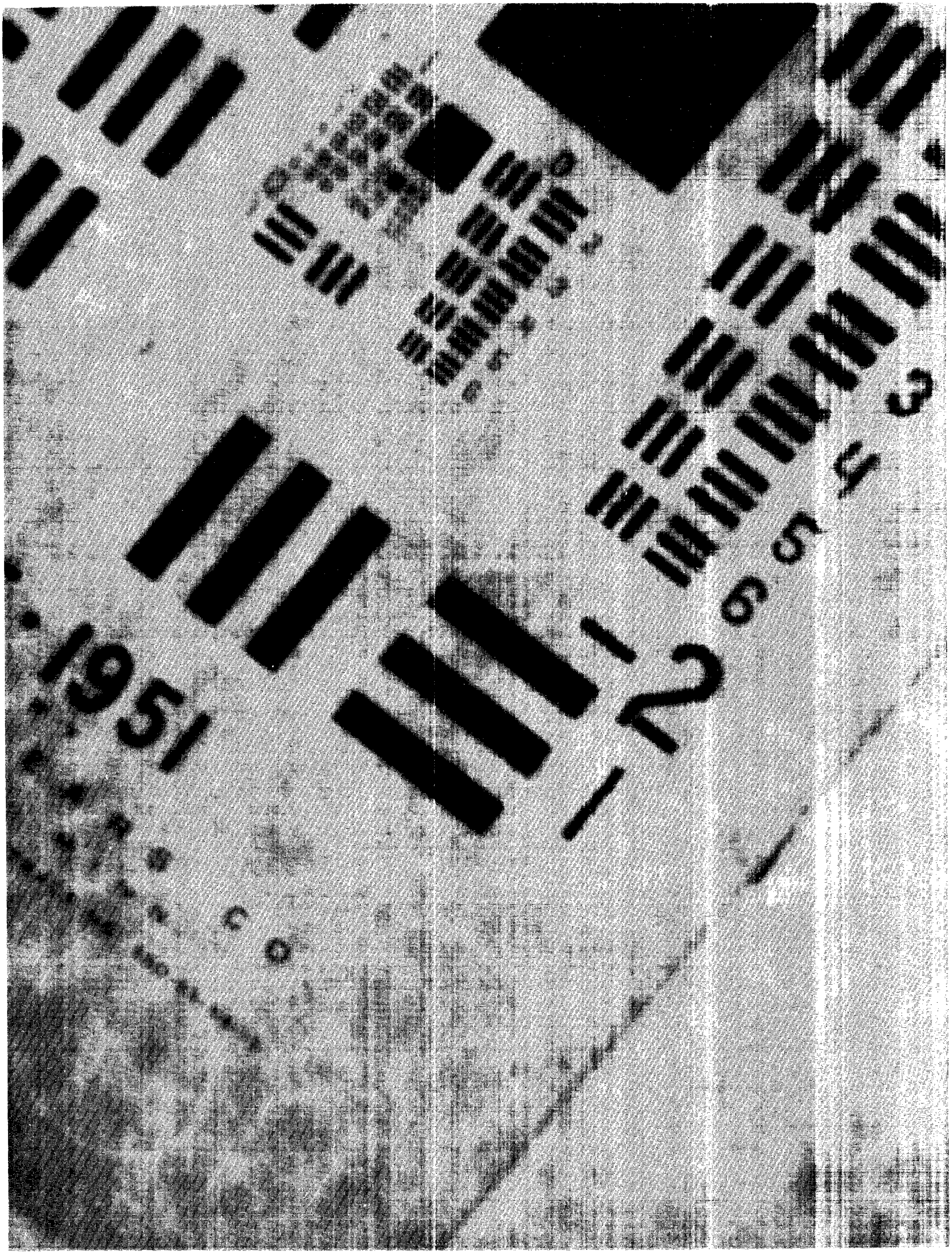


Figure 3. PROJECTED IMAGE ON DYNAMICALLY SCANNED REAR-PROJECTION SCREEN

704

BIBLIOGRAPHIC DATA SHEET

STAT

Author(s) [redacted]

Affiliation ARMY ELECTRONICS CMD FT MONMOUTH NJ

Title AN ANALYSIS OF DIRECTIONAL VIEWING SCREEN: A COMPARISON TO A MATTE-WHITE SURFACE

Periodical

No. Vol.

Agency US ARMY

Publisher ARMY ELECTRONICS CMD FT MONMOUTH NJ

Place of Publication

Date of Publication 1964

Pages Classification UNCLASSIFIED

COMMENTS:

DDC# AD 609034 Ⓐ

SAIM Key

~~2.1.1b~~

~~1.2.1a~~

2.1.1b — 2.3.1c

2.3.2c

Status

[✓ a.] Ordered 7/29

b. In-house

c. Reviewed

Rapid Acquisition of Radar Targets from Moving and Static Displays

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Aerial-reconnaissance radar imagery can be presented to an observer for near-real time interpretation in two ways: as a continuously moving display or in discrete, static steps. Both were studied in a laboratory experiment designed to determine their effect on the probability and speed of target acquisition. The results indicated: (1) no significant differences in the number of real or false targets acquired, (2) significantly less time required to find a target on the moving display, and (3) the time difference increased as targets became more difficult to recognize and as the available observation time increased. The relevance of this study for equipment design considerations and the generality of the results to other near-real-time reconnaissance missions are discussed. It is concluded that even among a wide variety of conditions not included in this study, where targets are of simple, well-defined patterns capable of recognition with little study, the moving presentation mode—in balance—will result in better target acquisition performance.

INTRODUCTION AND SUMMARY

In recent years, there has been a growing emphasis on rapid target acquisition in military surveillance and reconnaissance systems. With the development of mobile, high-kill weapons, the importance of finding a target and destroying it within minutes has increased.

In airborne and spaceborne systems in which in-flight interpretation is required, pictorial sensor imagery is presented to the observer on a display. This imagery, collected at a rate proportional to vehicular velocity, can be presented to the observer in two ways:

1. it may be moved continuously across the display, or
2. it may be presented in a series of discrete, static steps.

The present study was designed to answer the question: When in-flight pictorial interpretation must be made in near-real time, how does the mode of presentation affect the speed and probability of target acquisition?

Twelve observers were selected from Hughes engineering personnel[2] on the basis of preliminary target acquisition tests and their performance during an extensive training period. These observers were asked to find military type targets in high-resolution, side-looking radar imagery representing terrain strips nine and eighteen miles wide. The same imagery was presented to the subject on a rear-projection viewer, being moved continuously across the display during one half of the study and being presented in a series of discrete, static steps during the other half. Different observers viewed the imagery on different size displays (i.e., 6-inch and 12-inch square) for different observation times (i.e., 10, 20 or 40 seconds). Analysis of the data indicated that:

1. Although more targets were found with the larger display, the smaller ground coverage, and the longer observation time, there were no significant differences in the number of real (or false) targets acquired from a moving or a static display.
2. The time required to find a target from the time it appeared on the display was significantly longer with the static display than with the moving display.
3. This difference in acquisition time favoring the moving display increased as the observation time increased or as the targets became more difficult to find because of varying display and image factors.

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now at Autonetics

[2] A number of experimental studies have failed to establish differences in the performance of experienced imagery interpreters and specially trained personnel when the task involves the recognition of well-defined targets (Rhodes, 1964; Nygaard, Slocum, Thomas, *et al.*, 1964).

4. The times required for an observer to find targets were significantly more variable with the static display than with the moving display.

It should be emphasized that the task was one of acquiring targets of simple, well-defined patterns which were generally recognizable with few fixations.

PREPARATION OF THE IMAGERY

Two film strips of side-looking, high resolution radar imagery were used in this study. Backgrounds for the strips were chosen from copies of available APS 73 side-looking, high resolution radar imagery. Preparation of these strips was accomplished in the manner described below.

Background. From imagery covering a ground path 18 miles wide, five frames, each 18 miles square, were selected. These frames were duplicated either three or four times to be arranged in a single strip of 18 background frames, representing a terrain path 18 miles wide and 324 miles long.

Target Embedding. Thirty targets were artificially embedded into the 18-frame background strip; no embedding cues were detectable. Each frame contained from zero to two targets of the eight basic patterns shown in Figure 1.

Frame Sequence. The individual background frames with targets were then assembled into an 18-frame strip. Backgrounds with the more-difficult-to-find-targets (established in a preliminary study) were located in the center of the strip with easier-to-find-combinations at either end. Frames having the same background were not placed adjacent to each other except in one instance in which the second frame was rotated 90°.

Preparation of the Second Strip. Preparation of the second strip was accomplished by taking one half of the original film and enlarging it to twice the size. Thus, while the 9-mile strip covered only half the ground area of the 18-mile strip, it was the same film width and twice as long. Some variation in the relative position of the frames in the magnified version was necessary in order to have all the targets appear in the half width used. Because four steps were required to prepare the final film positive from the original, there was some loss in resolution and a slight increase in contrast.

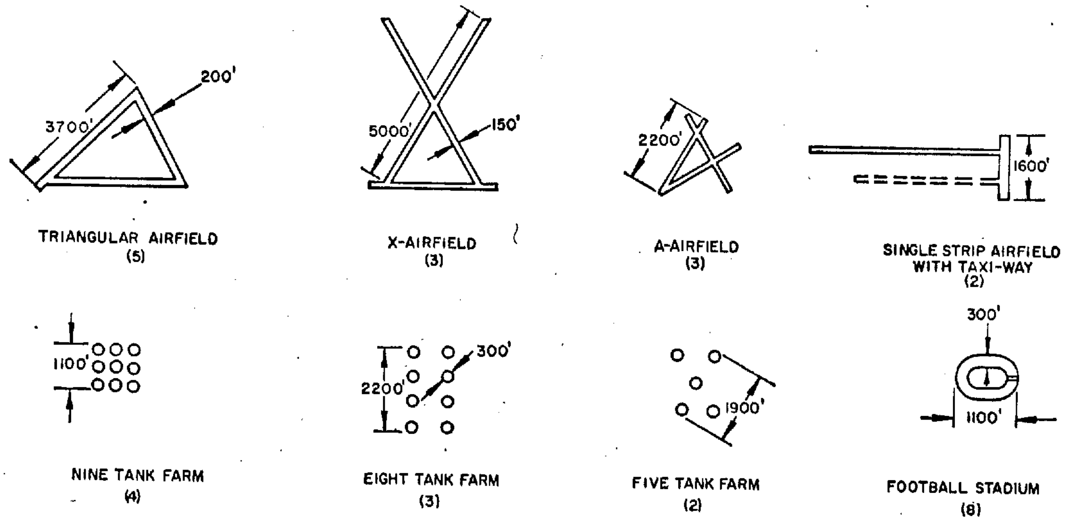

Fig. 1. Target patterns. Numbers in parentheses indicate the number of times out of 30 this identical target pattern occurred in the 324-mile film strip. Numbers in drawings indicate size of target dimensions in feet on the ground as measured from the original transparency.

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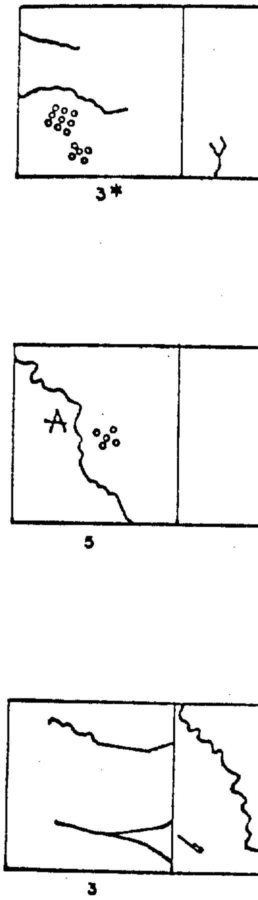

*NUMBERS IDENTIFY BACKGR

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Representative drawings of both film strips are shown in Figures 2 and 3. Artist's sketches rather than photographic reproductions are used for the illustrations in order that this report could be unclassified. The actual APS-73 radar imagery is Confidential.

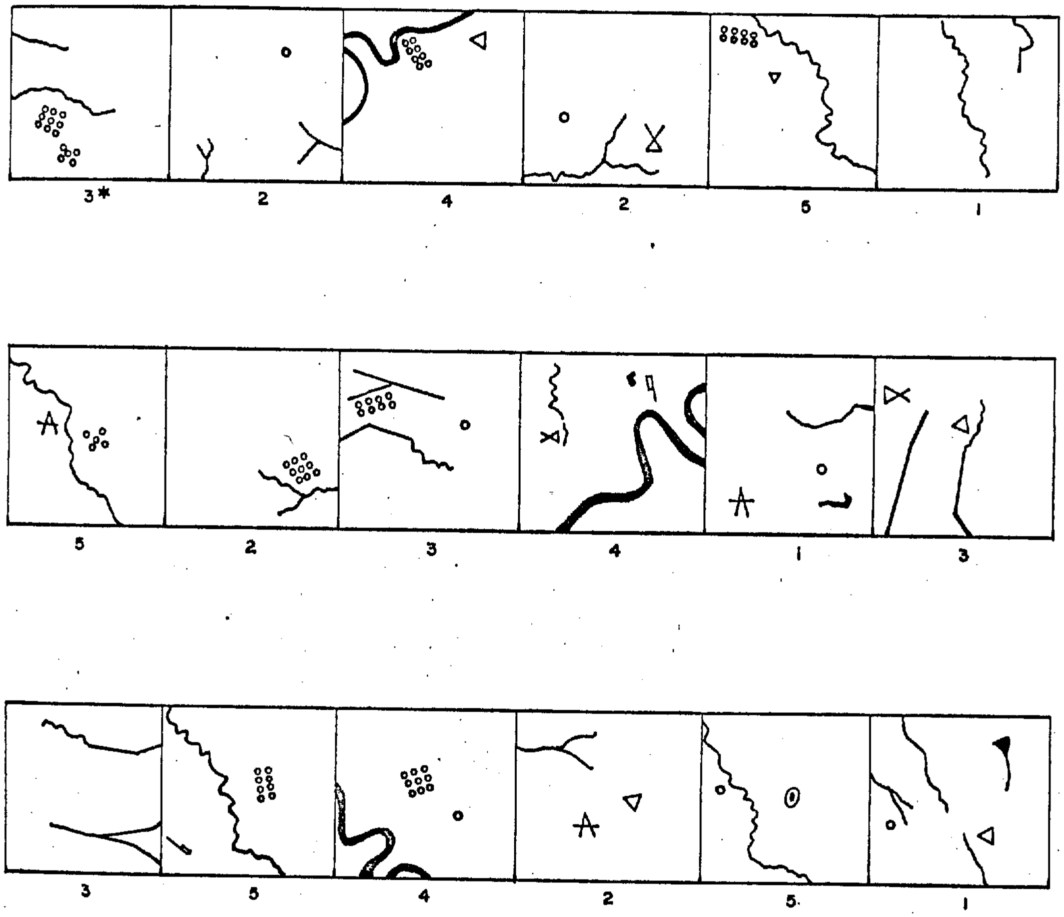
PARAMETER VARIATIONS

Five parameters were systematically varied in this experiment. These were:

1. Presentation mode: Moving or Static
2. Observation time: 10, 20 or 40 seconds
3. Display size: 6 x 6 or 12 x 12 inches
4. Ground coverage: 9 x 9 or 18 x 18 nautical miles
5. Target perceptual characteristics: Four groups

By using a Hughes Dynamic Imagery Viewer (1963) to present the imagery to the observers, presentation mode, observation time, and display size could be varied. Ground coverage was varied by using a different film strip, and the targets within the film strip provided the variations required for the different target characteristics groups.

Presentation Mode. The imagery could be presented either in a continuously moving mode or in a series of discrete, static steps.



*NUMBERS IDENTIFY BACKGROUNDS.

Fig. 2. Pictorial representation of 18-mile wide film strip.

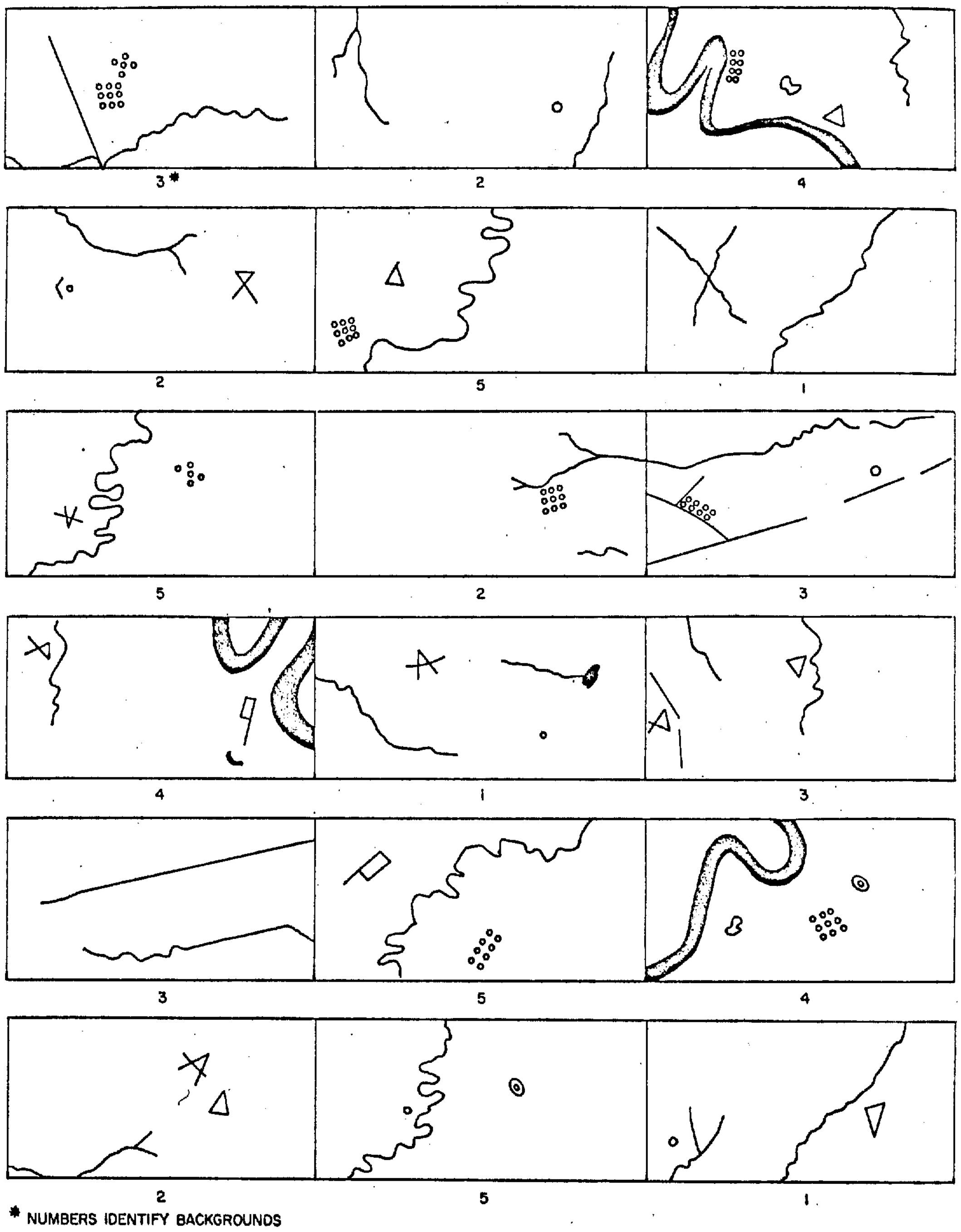
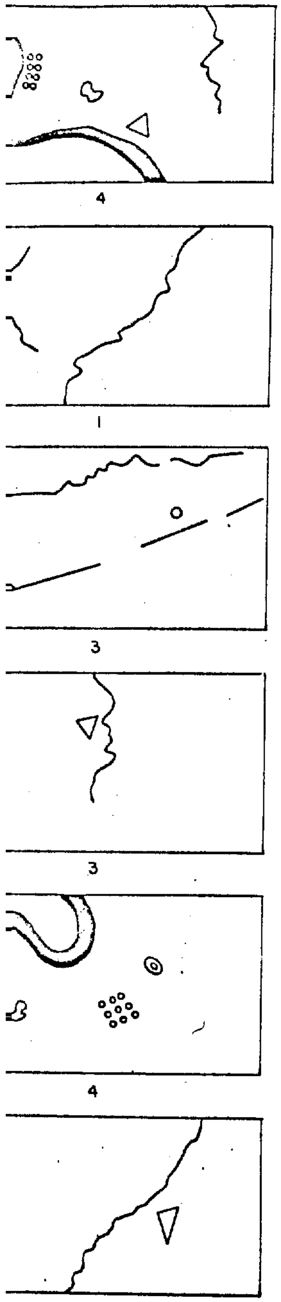


Fig. 3. Pictorial representation of 9-mile wide film strip.



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In the moving presentation mode, the imagery was moved steadily across the display in either direction. This mode simulates the near-real time situation in which a reconnaissance vehicle flies above the terrain at a designated rate while the sensor supplies a continuous radar map to the observer via the display.

In the static presentation mode, the same imagery was presented to the observer in successive static steps, one frame at a time. The image remained fixed on the screen for the amount of time required for the same area to move across the screen in the moving presentation mode. Between static presentations, while the imagery was changing to a new frame, a translucent screen moved between the projector and the screen to blur the image without reducing the screen brightness to zero. Blurring the image while changing frames prevented the observer from detecting targets during this interval and kept the total observation time equivalent in the two modes. The static mode simulated a near-real time situation in which the information from the sensor is stored until a complete frame has accumulated and is then presented statically to the observer while the next frame is being stored.

Display Size. Both a 6-inch and a 12-inch square display were used in the studies. The image was rear-projected onto a polacoat screen masked to one of the two display sizes. The screen was adjustable so that the entire image filled either display; thus, the scale factor on the 12-inch display was twice that for the same imagery on the 6-inch display while ground coverage remained constant. Average screen brightness was adjusted so that it remained constant for either display.

Observation Time. Observation time periods were limited to 10, 20, or 40 seconds. For the moving presentation mode, these were the times it took an object to appear on one edge of the display, move across to the other edge and disappear. For the static presentation mode, these were the periods of time during which a single frame was exposed.

Ground Coverage. The ground area covered by the radar imagery on the display was either 18 or 9 miles square. For a fixed display size, changing ground coverage from 18 to 9 miles square is equivalent to doubling the scale factor while holding display size constant.

Target Characteristics. The eight target types were divided into four groups with similar perceptual characteristics. This grouping served two purposes: (1) to combine enough data for meaningful analysis, and (2) to allow for broader generalizations than would be

TABLE 1
Perceptual characteristics of targets.

PERCEPTUAL CHARACTERISTICS		TARGET GROUPS			
		1	2	3	4
		Triangular Airfield	Other Airfields (Average)	Stadium	Tank Farms (Average)
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Size	Length of Longest Dimension*	3700 ft.	4320 ft.	1080 ft.	1380 ft.
	Width of Smallest Dimension*	180 ft.	130 ft.	300 ft.	300 ft.
Distinctiveness	Brightness Contrast	High	Low	High	Medium
	Target and Background Pattern Similarity	Low	High	High	Medium

*Dimensions expressed in feet on the ground.

8000 feet on the ground equal approximately one inch on a 12-inch square display for the 18-mile imagery.

At a viewing distance of 12 inches, an inch subtends approximately a 5-degree visual angle from the eye. At a viewing distance of 18 inches, the visual angle is approximately 3 degrees.

These relationships are double for the 9-mile imagery and halved for the 6-inch square display.

possible if results were expressed in terms of target class or the specific target patterns used in this study.

This classification of targets by perceptual characteristics is shown in Table 1.

Relationships Among Variables. Combinations of several variables in this experiment can be identified by other familiar classifications (Table 2). For example, combinations of observation time and ground coverage can be identified with *real world vehicular rates* over the terrain (Table 2A). Observation time can also be expressed in terms of *apparent movement rates,* that is, in terms of inches of movement per second when display size is taken into consideration (Table 2B), or in terms of degrees of movement per second when viewing distance is taken into consideration (Table 2D). Similarly, various combinations of display size and ground coverage result in different image *scale factor* values (Table 2C).

It should be noted that while the observation times expressed in Mach values appear high, when expressed in terms of degrees of movement per second they are considerably below the level at which a degradation in dynamic visual acuity has been observed (Miller and Ludwigh, 1960).

PROCEDURE

Observers practiced and were tested in a semi-darkened cubical room which served to attenuate external noise and visual distractions. No restrictions were placed upon their seating positions or viewing distance from the display. The practice periods and experimental sessions are described below.

Practice Period. The practice period served: (1) to select only observers proficient in recognizing radar targets, (2) to familiarize the observers with radar imagery and with the specific targets used in this study, and (3) to allow them to develop optimum search techniques for both the moving and static presentation modes.

A series of one-half to one-hour practice periods was given to each observer. An observer's total practice time was from two to four hours, depending upon his previous experience and ability to reach arbitrary performance criteria.

Those observers unfamiliar with radar were informed briefly how radar operates and how its pulses reflect from various ground objects to produce the light and dark returns on the display. All were given training in finding targets in radar imagery similar to that to be

TABLE 2
Some relationships among observation time, imagery ground coverage, and display size.

Observation Time, seconds	*(A) Real World Rates for Different Imagery Ground Coverages and Observation Times*		*(B) Movement on Screen for Different Display Sizes and Obervation Times*	
	Ground Coverage		*Display Size*	
	18 x 18 miles	*9 x 9 miles*	*6 x 6 inches*	*12 x 12 inches*
10	Mach 10.8	Mach 5.4	0.6 inch/sec	1.2 inch/sec
20	Mach 5.4	Mach 2.7	0.3 inch/sec	0.6 inch/sec
40	Mach 2.7	Mach 1.35	1.15 inch/sec	0.3 inch/sec

Display Size, inches	*(C) Image Scale Factors Resulting from Combinations of Display Size and Ground Coverage*		*(D) Apparent (Retinal) Movement with a 10-second Observation Time* for Different Display Sizes and at Different Viewing Distances*		
	Ground Coverage		*Distance from Display*		
	18 x 18 miles	*9 x 9 miles*	*6 inches*	*12 inches*	*18 inches*
6 x 6	1/216,000	1/108,000	5.3°/sec	2.8°/sec	1.9°/sec
12 x 12	1/108,000	1/54,000	9.0°/sec	5.3°/sec	3.7°/sec

*20 seconds (by ½);
40 seconds (by ¼)

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used in the experiment. Practice under both static and moving presentation modes was given; near the end of the practice period, the observation times were limited to those the observer would experience during the experiment.

Through these experiences, observers developed their own methods of search and established viewing distances most suitable for themselves.

Instructions. The following points were made during the initial instructions to the subjects and were re-emphasized throughout the experiment:

1. *Simulated Mission.* The following hypothetical situation was described to the observers:

An intelligence report has been received stating that enemy aircraft are about to take off from certain specified airfields to bomb friendly troops and installations. Also, missile launchers, hidden near certain specified fuel tank farms, are being prepared for immediate launch. An enemy headquarters coordinating these efforts is stationed in a football stadium.

It is vital that all these critical targets be found and destroyed as quickly as possible. Every second of delay could be critical, for our reconnaissance plane risks destruction if it is detected before it can detect and destroy the enemy. Furthermore, if the plane is detected, this would serve as a warning for enemy planes to take off and for missiles to be fired. Under these circumstances, it is better to bomb a nontarget than lose a real one.

2. *A Priori Information.* Observers were also shown small sections of radar imagery in which the targets to be recognized were embedded. These targets were the same size and shape as the ones to be recognized, but were not necessarily shown in the same orientation.

During a "hot" war, military-type targets would be less likely to be located in logical places and must be searched for everywhere. Thus, observers were told that targets would be located in practically any section of the display and would not appear in a systematic order or with a fixed frequency.

3. *Observer's Task.* The basic task before each observer was one of target recognition, that is, of finding targets on the display essentially identical to those shown during the briefing period. As soon as a target was recognized, the observer immediately pressed a button and put his finger on the target and named it. The observer was instructed to "get as many targets as quickly as possible, as soon as they appeared on the display."

Scoring. When the observer pressed his button, a mark was made on a graphic recorder on which a time base was provided. Locating and naming the target was done quickly and did not appear to disrupt the observer's continuing search. It did enable the experimenter to check the correctness of the response (both target and location) from a scoring chart that he held and marked. If the information was correct, the experimenter also pressed a button which put a verification mark on the graphic record.

In addition, a mark was automatically registered on the graphic record for each target after it appeared on the display. Time differences between the automatic target mark and the observer's mark indicated the time required to recognize that target once it appeared on the display. Time was determined to the nearest second. The presence of the observer's mark and the absence of the experimenter's mark enabled the number of false targets to be determined.

Experimental Sessions. Before each experimental session, observers were given short practice runs with the imagery, observation time, and display size similar to those used in the experiment.

EXPERIMENTAL DESIGN

The experimental design used in this experiment is shown in Table 3. Performance data was collected for all 24 combinations of presentation mode, ground coverage, observation time, and display size. Each observer was tested under the four combinations of mode and ground coverage. Different observers were tested under each of the different observation times and display sizes. Thus, six observers, each tested under four sets of condi-

TABLE 3
Experimental design

Observers	Observation Time (seconds)	Display Size (inches)	Presentation Mode			
			Moving		*Static*	
			Ground Coverage (miles)			
			9 x 9	*18 x 18*	*9 x 9*	*18 x 18*
			Trials			
1	10	6 x 6	3	2	4	1
7	10	6 x 6	1	4	2	3
2	10	12 x 12	3	2	4	1
8	10	12 x 12	1	4	2	3
3	20	6 x 6	4	1	3	2
9	20	6 x 6	2	3	1	4
4	20	12 x 12	4	1	3	2
10	20	12 x 12	2	3	1	4
5	40	6 x 6	4	1	3	2
11	40	6 x 6	2	3	1	4
6	40	12 x 12	3	2	4	1
12	40	12 x 12	1	4	2	3

tions, were required for a single replication. Two replications were run.

The order in which observers were tested on the four presentation mode and ground coverage combinations was partially counterbalanced. The order for observers tested under the same conditions of observation times and display size was reversed. Over the entire experiment, each of the four conditions run by all subjects appeared the same number of times during each of the four testing sessions.

Observers were tested morning and afternoon on two consecutive days. A different combination of mode and ground coverage was tested at each of the four sessions. A session consisted of two runs through the imagery—first forward and then backward, with a rest period in between. The actual

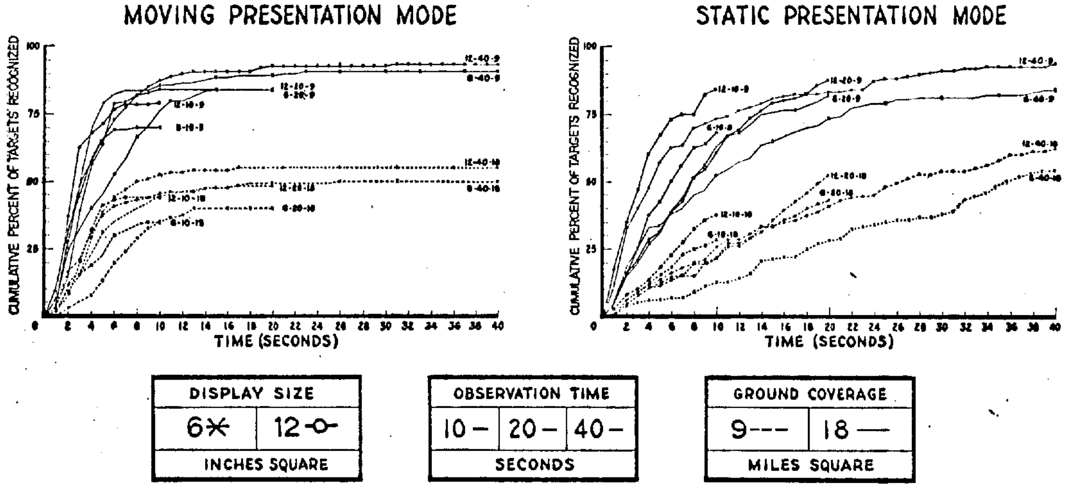

Fig. 4. Cumulative percent of radar targets recognized on moving and static display.

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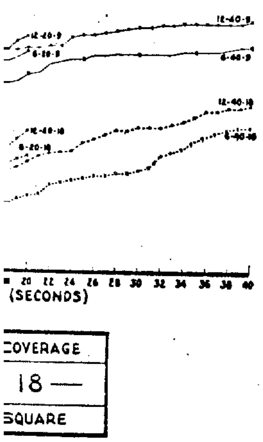

nd static display.

time required to run once through the 324-mile long imagery depended upon the particular combination of observation time and ground coverage being studied (Table 4).

RESULTS

Results of the experiment are graphically presented in Figure 4. The two plots show the

Table 4

Actual testing time for one run.

Ground Coverage (width)	Observation Time (seconds) 10	20	40
18 miles	3 minutes	6 minutes	12 minutes
9 miles	6 minutes	12 minutes	24 minutes

Table 5

Analysis of variance: percentage of targets recognized correctly.

Source of Variation	Degrees of Freedom	Mean Square	F[3]
TOTAL	191		
BETWEEN SUBJECTS	11	624.39	
Observation Time	2	2445.19	10.23[5]
Display Size	1	1725.97	7.22[5]
Time x Display Size	2	7.73	
Error uncorr.[2]	6	39.42	
WITHIN SUBJECTS	180		
Presentation Mode	1	3.70	
Ground Coverage	1	38844.50	49.78[5]
Target Characteristics	3	13137.88	31.35[6]
Mode x Ground Coverage	1	10.39	
Mode x Target	3	39.64	
Ground Coverage x Target	3	780.20	10.28[4]
Mode x Time	2	15.96	
Mode x Display Size	1	231.04	
Ground Coverage x Time	1	16.83	
Ground Coverage x Display Size	1	60.76	
Target x Time	6	238.66	
Target x Display Size	3	344.84	
Mode x Ground Coverage x Target	3	20.59	
Mode x Time x Display Size	2	32.58	
Ground Coverage x Time x Display Size	2	76.44	
Target x Time x Display Size	6	238.96	3.15[4]
Mode x Time x Target	6	43.73	
Mode x Ground Coverage x Display Size	1	101.13	
Ground Coverage x Target x Time	6	133.61	
Ground Coverage x Target x Display Size	3	78.72	
Mode x Ground Coverage x Time	2	148.89	
Mode x Target x Display Size	3	38.10	
Mode x Ground Coverage x Target x Time	6	44.27	
Mode x Ground Coverage x Display Size	3	141.84	
Mode x Ground Coverage x Time x Display Size	2	6.96	
Ground Coverage x Target x Time x Display Size	6	47.49	
Mode x Target x Time x Display Size	6	26.41	
Mode x Target x Time x Display Size x Ground Coverage	6	105.82	
Error corr.[2]	90	75.89	

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[1] This analysis was made on the arcsin transformation of the square root of the percentage data (G. W. Snedecor, Statistical Methods (4th Edition), 1946, Iowa State College Press, pp. 447-448).

[2] Two sources of variability attributable to chance can be calculated, i.e., that which is based on the uncorrelated data obtained from conditions on which different observers were tested and that which is based on the correlated data obtained from conditions on which the same observers were tested.

[3] Only F ratios significant at the 0.05 probability level or better are shown. Tests of significance were made by using the mean square of the appropriate error term[4] or by using the mean square[5] (or pooled mean square[6]) of the significant interactions containing the source of variation being tested.

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TABLE 6
Analysis of variance: median time to recognize targets.

Source of Variation	*Degrees of Freedom*	*Mean Square*	F[2]
TOTAL	*47*	18.43	
BETWEEN SUBJECTS	*11*		
Time	2	60.58	
Display Size	1	7.14	
Time x Display Size	2	4.22	
Error uncorr.[1]	6	3.73	
WITHIN SUBJECTS	*36*		
Mode	1	231.89	10.61[4]
Ground Coverage	1	125.14	
Mode x Ground Coverage	1	59.62	
Time x Ground Coverage	2	27.25	
Display Size x Ground Coverage	1	.41	
Mode x Time	2	43.28	
Mode x Display Size	1	.03	
Time x Display Size x Ground Coverage	2	3.86	
Mode x Time x Ground Coverage	2	27.26	12.17[3]
Time x Display Size x Mode	2	16.52	7.38[3]
Mode x Display Size x Ground Coverage	1	2.77	
Mode x Time x Display Size x Ground Coverage	2	2.44	
Error corr.[1]	18	2.24	

[1] Two sources of variability attributable to chance can be calculated, i.e. that which is based on the uncorrelated data obtained from conditions on which different observers were tested and that which is based on the correlated data obtained from conditions on which the same observers were tested.

[2] Only F ratios significant at the .05 probability level or better are shown. Tests of significance were made by using the mean square of the appropriate error term[3] or by using the mean square (or pooled mean square[4]) of the significant interactions containing the sources of variation being tested.

TABLE 7
Analysis of variance: range of times required by an observer to recognize 90 percent of recognizable targets.

Source of Variation	*Degrees of Freedom*	*Mean Square*	F[2]
TOTAL	*47*		
BETWEEN SUBJECTS	*11*		
Time	2	846.33	40.59[4]
Display Size	1	.34	
Time x Display Size	2	.58	
Error uncorr.[1]	6	11.58	
WITHIN SUBJECTS	*36*		
Mode	1	1365.34	65.49[4]
Ground Coverage	1	60.75	
Mode x Ground Coverage	1	33.33	
Time x Ground Coverage	2	16.75	
Display Size x Ground Coverage	1	3.00	
Mode x Time	2	286.33	
Mode x Display Size	1	10.07	
Time x Display Size x Ground Cover	2	3.25	
Mode x Time x Ground Coverage	2	20.85	4.62[3]
Time x Display Size x Mode	2	8.09	
Mode x Display Size x Ground Coverage	1	3.25	
Mode x Time x Display Size x Ground Coverage	2	2.24	
Error corr.[1]	18	4.51	

[1] Two sources of variability attributable to chance can be calculated, i.e., that which is based on the uncorrelated data obtained from conditions on which different observers were tested and that which is based on the correlated data obtained from conditions on which the same observers were tested.

[2] Only F ratios significant at the 0.05 probability level or better are shown. Tests of significance were made by using the mean square of the appropriate error term[3] or by using the mean square (or pooled mean square) of the significant interactions[4] containing the sources of variation being tested.

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probabilities of target recognition over time for each of the 12 combinations of observation time, display size, and ground coverage for the moving and static presentation modes.

The statistical treatment of the data is shown in Tables 5 through 9. Analyses of variances were calculated on the percentage of Targets Recognized Correctly (Table 5), Median Time for Recognizing Acquired Targets (Table 6), and the Time Ranges Required by an Observer to Recognize 90 Percent of the Targets Acquired (Table 7). Table 8 shows the Frequency of Recognizing False Targets, along with the results of tests of differences. Values for individual means of significant main effects and interactions in these analyses were plotted in the graphs of Figures 5 through 7.

The results of the analyses and data shown on the tables and figures are summarized in Table 9. The effect of each variable on each performance measure is given, and where the interactions among variables were found to be significant, the data has been summarized across variables.

In general, it would appear that within the range of conditions in this study, the same number of targets can be found with either the moving or static presentation mode, but that as observation times grow longer and target visibility becomes poorer it takes significantly longer and speed of performance is more variable with the static mode.

One result of interest is the comparative effects of the two combinations of display size

TABLE 8
False targets.

FREQUENCY OF ACQUIRING FALSE TARGETS FOR DIFFERENT TARGET-DISPLAY-SYSTEM CONDITIONS

TARGET		BACKGROUNDS				
GROUP	PATTERN	1	2	3	4	5
△	△	1	0	0	1	0
•	⋮⋮⋮	0	1	0	1	1
	⋮⋮	0	1	0	1	0
	⁙	0	0	0	0	6
◎	◎	6	5	6	5	4
✓	X	5	5	13	2	4
	A	3	5	3	5	0
	⊣	3	1	9	7	3

PRESENTATION MODE :			MOVING				STATIC			
DISPLAY SIZE :			6		12		6		12	
GROUND COVERAGE :			9	18	9	18	9	18	9	18
TARGET GROUP	TARGET PATTERN	OBSERVATION TIMES								
△	△	10						1		
		20							1	
		30								
•	⋮⋮⋮	10								
		20				1				
		30				1		1		
	⋮⋮	10								1
		20								
		30								1
	⁙	10								
		20						1		
		30	1	1			2	1		
◎	◎	10	1	1	3		1	1	3	
		20	1				1		2	
		30	3	2	1		6			
✓	X	10	1		3	3		1	2	
		20		1	1	2	1		1	1
		30	2	2			4		2	2
	A	10	1		2				1	1
		20	1		1				1	1
		30	2	1	1		1	1		1
	⊣	10			3		3		1	1
		20	1			1			1	
		30		2	2		5	3		

X^2 FOR FALSE TARGET FREQUENCIES

SOURCE	f	x^2	d.f.	SIGNIFICANCE $p \leq 0.05$
PRESENTATION MODE				
MOVING	49	0.75	1	NO
STATIC	58			
DISPLAY SIZE				
6 INCHES	58	0.75	1	NO
12 INCHES	49			
GROUND COVERAGE*				
9 MILES	70	0.23	1	NO
18 MILES	37			
OBSERVATION TIME				
10 SECONDS	35	12.6	2	YES
20 SECONDS	21			
40 SECONDS	51			

SOURCES	f	x^2	d.f	SIGNIFICANCE $p \leq 0.05$
TARGET GROUP*				
△	2	62.7	3	YES
•	11			
◎	26			
✓	68			
BACKGROUNDS*				
I	18	3.73	4	NO
II	18			
III	31			
IV	22			
V	18			

(*EXPECTED FREQUENCIES WEIGHTED FOR UNEQUAL n's)

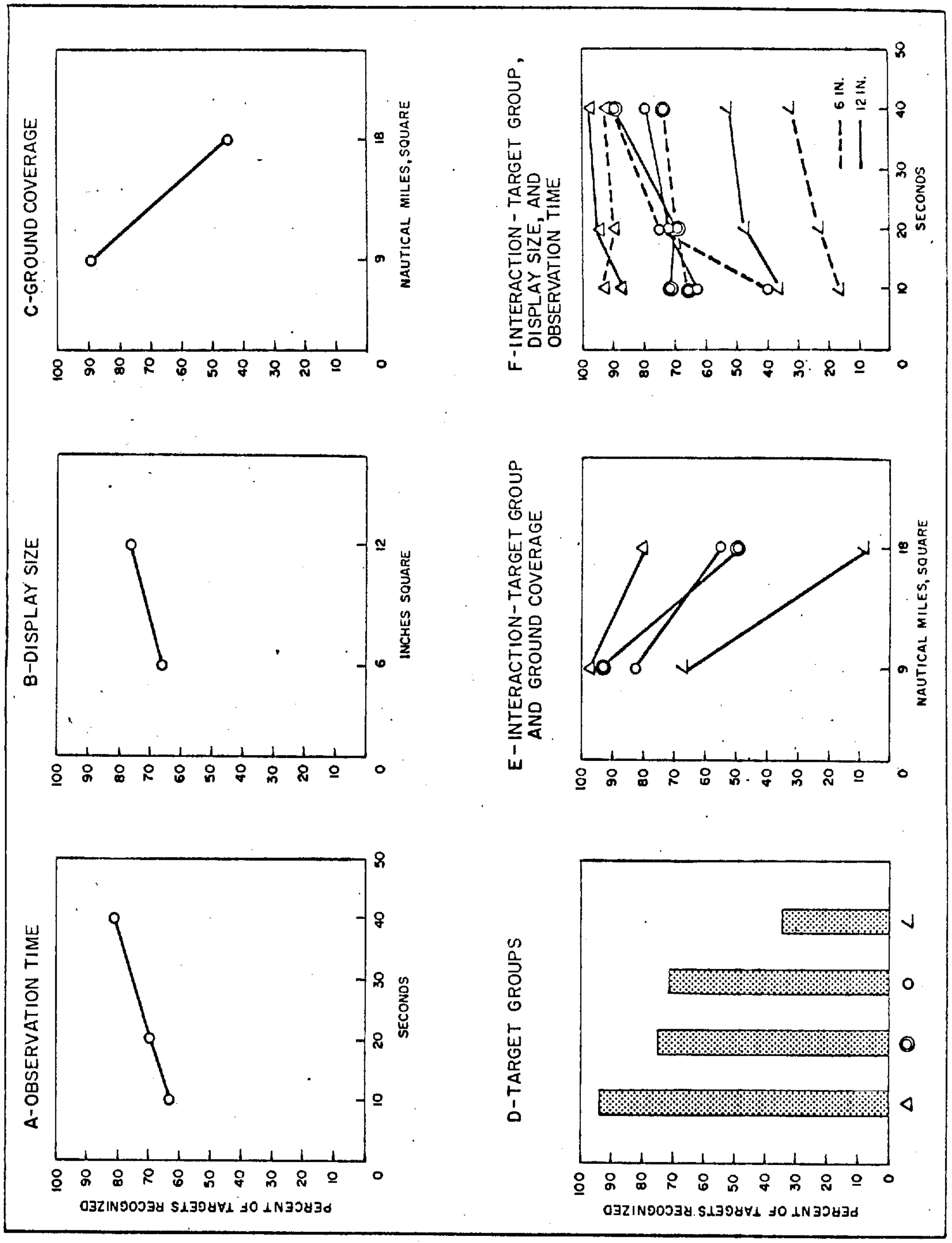
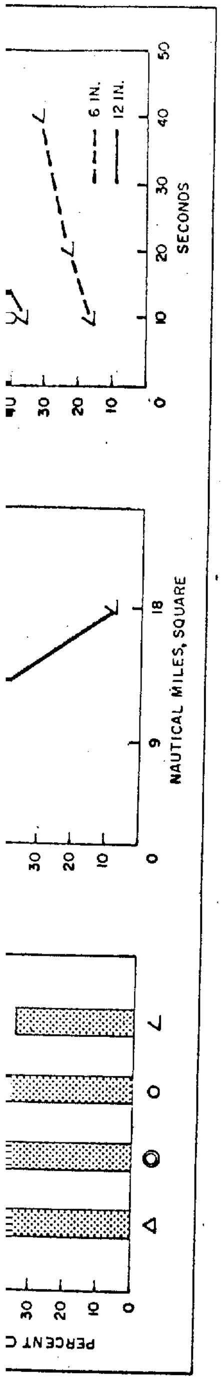


Fig. 5. Percent of targets recognized correctly (*transformed back from arcsin transformation used in analysis).*



ransformation used

TABLE 9
Summary of results showing effects of variables on performance.

	*VARIABLES**			
PERFORMANCE MEASURES	*STATIC VERSUS MOVING PRESENTATION MODES*	*OBSERVATION (10, 20, 40 SECONDS)*	*GROUND COVERAGE (9 x 9 OR 18 x 18 MILES AND DISPLAY SIZE (6" x 6" OR 12" x 12")*	*TARGET CHARACTERISTICS*
PERCENTAGE OF TARGETS CORRECTLY RECOGNIZED (TABLE 5)	No Effect (Table 5)	More targets recognized as time increased. (Figure 5A)	More targets recognized on larger display or with smaller ground area. (Figure 6B and C)	Larger and more distinctive targets were more often recognized (Figure 5D)
			Reducing ground coverage increased recognition of targets. Less distinctive targets showed greatest increase. (Figure 5E)	
		Targets with smallest widths were poorer with short observation times and small displays. Targets with longest dimensions improved with longer observation times and larger displays. (Figure 6F)		
MEDIUM TIME TO RECOGNIZE (TABLE 6)	Static took longer (Figure 6A)			(No Analysis)
	Recognition took longer with smaller displays and greater ground coverage. Differences were significant only when imagery was presented statically and for the longer observation times. (Figure 6 B and C)			
MEAN VARIABILITY IN OBSERVER'S RECOGNITION TIMES (TABLE 7)	Static more variable (Figure 7A)	Variability increased with longer observation (Figure 7BE)		(No Analysis)
	With a static presentation and with a longer observation time, variability was greatest when ground coverage was large. (Figure 7C) No effect due to display size. (Table 6)			
NUMBER OF FALSE TARGETS CALLED (TABLE 8)	No Effect (Table 8)	Significantly fewer false targets with 20-second observation time. (Table 8)	Twice as many false targets were called when film coverage was twice as much. (Table 8)	Seven times as many false targets were called when target patterns were judged more similar to background patterns. (Table 8)

* Where information extends across more than one variable, it refers to the interaction among the variables covered.

and ground coverage yielding the same scale factor. Both the 9-mile square ground coverage on the 6-inch display and the 18-mile square coverage on a 12-inch square display represented a scale factor of 1/108,000. On both displays, therefore, targets were of equal size. However, performance was *not* identical. The results in Table 10 illustrate the difference. Variations in ground coverage had a much greater effect on performance than variations in display size.

None of the previously mentioned analyses included an examination of changes in performance over the four experimental sessions. The number of targets recognized for each of the four sessions for all subjects under all conditions were:

I. 455 II. 453 III. 459 IV. 494

The average times to find and recognize targets for each of the four sessions were:

I. 6.2 secs. II. 6.6 secs. III. 5.9 secs. IV. 6.4 secs.

None of the values for either measure differs significantly from what could be expected by chance at the 0.05 probability level.

DISCUSSION

The present study clearly indicated that for the conditions under investigation, target acquisition performance was never better and often poorer when the imagery was presented in a series of static steps than when the imagery was presented in a continuous movement across the display. There was no difference between the two presentation modes in the probability of finding targets. However, under many conditions, those targets that were detected were found sooner on the moving

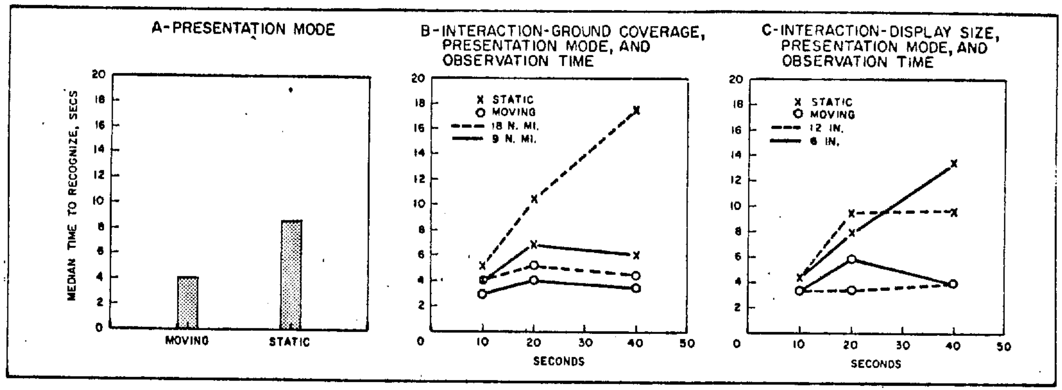


Fig. 6. Median time to recognize targets.

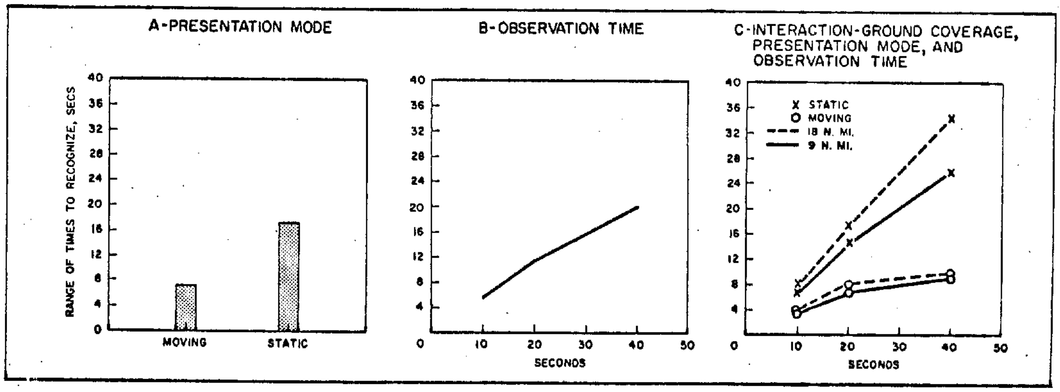


Fig. 7. Range of times to recognize targets.

6 secs. III. 5.9 secs.

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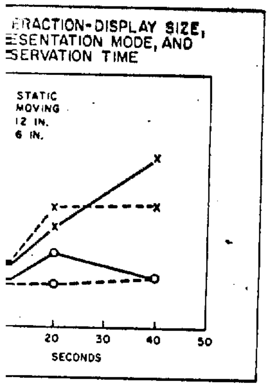

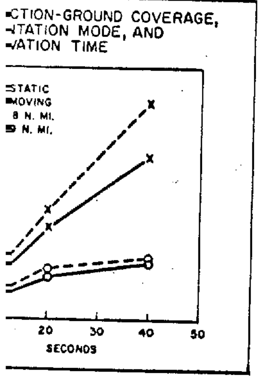

TABLE 10

Performance with combinations of ground coverage and display size yielding equal scale factors.

		Scale Factor 1/108,000	
Ground Coverage		*9 mi. sq.*	*18 mi. sq.*
Display Size		*6" sq.*	*12" sq.*
Percentage of Target Recognized (%)	Moving	89.8	52.2*
	Static	80.8	53.8*
	Av.	85.3	53.0*
Median Time to Recognize (secs)	Moving	22.0	23.0
	Static	37.5	66.0*
	Av.	29.8	44.5*
Range of Time to Recognize (secs)	Moving	7.3	6.8
	Static	15.2	19.8
	Av.	11.2	13.3
Number of False Targets Acquired**	Moving	7.0	8.0
	Static	12.0	9.0
	T	19.0	17.0

*Significant at .05 probability level.
**Corrected for twice as much 9-mile imagery.

display and with significantly less variability in performance.

Only one other published experiment, a study by Erickson (1964), was found that compared target acquisition with a moving (5, 7, and 10 degree/second) and with a static presentation mode. Although his method for measuring time with the static display differed from that of the present study and his imagery was not as representative of the real world, many of the relationships he discovered among the variables studied support those found in the present experiment. Erickson required 16 male observers to search for an incomplete ring (Landolt C) among a number of solid rings arranged systematically throughout a square field. Along with a number of other experimental conditions, he compared search performance in a moving and static field. Using percent of targets detected as the criterion, he found that performance deteriorated with a decrease in search time whether the image was moving or static. Erickson concluded that "target movement, per se, does not *necessarily* (sic) have a detrimental effect upon search performance within the 0 to 10 degree/second range" and his results suggest that, in fact, the percent of targets detected actually was greater with the moving imagery than with the static imagery when the observation time was shortest. The results comparing the two modes were shown in Figure 5 of his paper and can be summarized as shown in Table 11.

Although no statistics were applied, the extent of the difference between the percent acquired with a moving and static mode up to the 7° per second condition was almost negligible and possibly due to chance. At 10°/second, or the shortest observation time, the difference between the two modes had increased considerably, favoring the moving presentation mode.

In the experiments reported in this paper, the average visual angular rate was probably considerably less than 7° /second[3] and the lack of a significant difference in the percent of targets acquired agreed with the apparent results of Erickson's study. Erickson did not report any time-to-detection, so no comparison between the two tasks could be made on this

TABLE 11

Some results of Erickson's study.

Visual Angular Velocity in Moving Mode	*Available Search Time in Static Mode*	*Percent of Targets Detected*		*Percentage Difference*	*Ratio of Percentage Difference to Smallest Percentage*
		Moving	*Static*		
5°/second	2.9 second	77	81	4	.05
7°/second	2.0 second	61	64	3	.05
10°/second	1.4 second	50	40	10	.25

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[3] Since subjects were free to position their heads at any distance from the screen, the visual angular rate varied. This estimate of angular velocity was based on head positions measured in a subsequent, but similar study.

measurement. However, when the results of Erickson's study are combined with those of the present study an interesting relationship is suggested among relative performance effectiveness of the moving and static presentation modes, observation time, and the probability and speed of detection. The relationship suggested is as follows:

> At the slower speed there is little difference between the modes in terms of the number of targets acquired although those targets which are found are detected more quickly with the moving presentation mode; at faster speeds, there is little difference between the two modes in the time to acquire a target, but the probability of acquiring targets is higher with the moving presentation mode.

In both modes, performance deteriorates as observation times are shortened. In general, the moving presentation mode would seem to offer the greater advantage for target acquisition in near-real time. In the sections to follow, a rationale for the above statement will be developed and the implications for equipment design will be discussed.

An Explanation Of The Results Of The Present Experiment

The conditions under which the results of the present experiment were obtained should be carefully delineated. Although it is believed that these conditions are representative of those found in a great many actual reconnaissance missions, they are specified to avoid overgeneralizing to situations in which they do not exist. However, as it will be shown, the results obtained appear to have generality beyond the limits of the present study.

The conditions which existed in the present experiments were: (1) targets could essentially appear anywhere on the display; (2) the observation times were so short that a thorough search of the display was not possible, although at the slower observation times, several rough scans could be made; (3) some targets tended to be marginal in size, near the perceptual threshold; and (4) the observers were thoroughly briefed and made familiar with the targets' relatively well-defined patterns. These four conditions meant that a very fine, systematic scanning pattern was necessary to search the display and that the use of peripheral vision was limited. The observation time was spent primarily in searching for the target, which, when seen foveally, would generally be recognized immediately. Erickson, too, noted that with moving imagery, particularly at the faster rates, use of peripheral vision was limited.

In the present study, the observers were instructed to "find the targets as soon as possible after they appeared on the display." This meant that with the static presentation mode, a thorough and careful search in two dimensions over the entire display was required. With the moving presentation mode, however, the optimum strategy was to search the display in a single dimension along the edge at which the targets first appear while the imagery moves across the display. This searching procedure minimized the time to find the target and maximized the time available to study it before it disappeared (if further study were needed). The two search modes are illustrated in Figure 8.

Assuming no difference in scan rate or the effective cone of vision, the observer could scan the same area of the imagery in a specified period of time in both modes. This would suggest that the probability of finding a target would be the same with both presentation modes, and this theoretical equality was borne out by the empirical results. As observation times increased, a greater area could be scanned, and theoretically and empirically, more targets could be found.

The difference between modes in the time required to find a target after it appeared on the display is the result of the difference in the search techniques used. With the static presentation mode, the length of the search path between the initial fixation point and the target position was proportional to the time to find a target. Since these two end points could be located anywhere on the display, the time in which a target could be found could vary from almost instantaneously (if the two end

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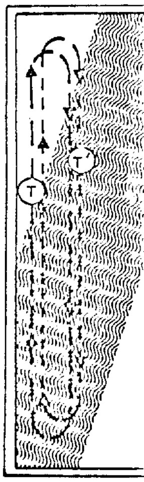

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points should coincide) to the length of the entire observation period (which was not sufficient in this study to allow a thorough search of the display). Therefore, the average time in which a target was found on the static display was approximately one-half of the observation period. As observation time increased, therefore, so did the average time to find a target, and the variability of the time to find a target.

These relationships do not hold for the moving presentation mode. If the observer searched optimally along the leading edge of the display, the maximum time to find a target was limited by the time the target stayed within the area covered by the effective visual cone along the leading edge. Average time to find was generally half of the width of this area which, being considerably less than the width of the entire display, would explain why time-to-find with the moving imagery was significantly shorter than with the static imagery. Furthermore, the width of the area subtended by the effective visual cone remained relatively constant even when display size or observation time was varied which tended to reduce the variability of the time-to-detect measurements. Casual observation suggests that variations in the effective visual cone came from a shift in the distance of the observer's head from the display and the distance the center of the scan pattern is from the edge of the display; these tended to be slight.

Supplemental Study. Although the empirical results supported these analytical conclusions, it was decided to check the possibility that they could be accounted for by the observers using a different scan rate for the two presentation modes. Perhaps, it was hypothesized, the results of the original experiment had been artifically produced by the *implied* instructions concerning search techniques with the static presentation mode. It may have been that allowing the observer to practice and become familiar with the length of the observation time available may have encouraged him to use all of that time to carefully scan the static display once. If he had instead made a rapid scan of the display first (or several rapid scans), he might have reduced his median time-to-find-targets by being able to pick up the more obvious targets quickly during the rapid scans.

To check this alternative, a supplemental study was carried out using two of the observers previously tested under the 40-second time limit. They were given two test sessions,

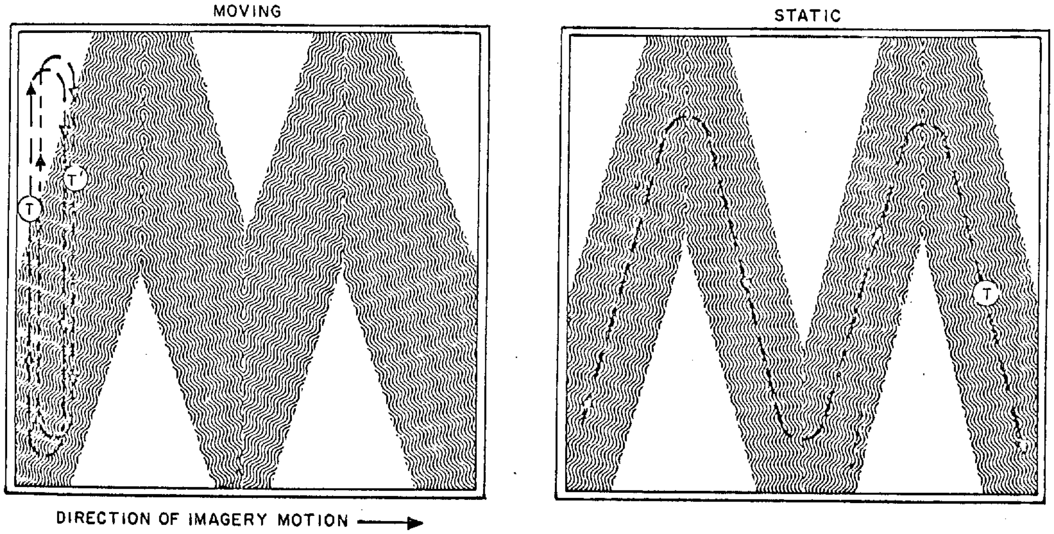

Fig. 8. Diagrams illustrating search paths and scannable areas with moving and static presentations for two rates. Broken lines represent path of eye movements. Shaded portion represents the area of imagery scanned within area of effective vision.

one for each of the two presentation modes. Only the 18-mile wide strip and the 12-inch square display were used with a 40-second observation time limit. The subjects were instructed—in fact, urged—to scan the display during the static presentations as rapidly and as often as they reasonably could. They were told to continue to scan the moving presentations in the same way they had done previously. The results are shown in Table 12.

Although performance in the static presentation mode tended to improve slightly over the original run, neither the overall results nor the conclusions drawn in the original study were changed by these results. This improvement may have been due to the increased scan rate used with the static presentation, or it could have resulted from the practice which the observers by this time had with the test imagery.

In either case, under the conditions examined here, the number of targets found with either mode of presentation did not differ more than could be expected by chance. The differences in the time required to find and recognize targets with the two presentation modes, however, remained relatively large.

Considerations for Equipment Design. Three other factors, in addition to those already described, favor the moving presentation over the static one. First, it has been found that it is difficult for an observer to make a precise and systematic search. Although he may conscientiously try to scan in a particular and regular manner and reports that he is doing so, eye movement records reveal this is not always the case (Townsend and Fry, 1960; White and Ford, 1960). In the static mode, this situation can lead to overlapping or unscanned areas, for the observer must search in two dimensions with no external restrictions applied to his search pattern. In the moving mode, however, using the leading edge of the display to guide his scan in one dimension while the imagery moves by in the second dimension reduces the inefficiency of search.

Second, even if it took the same time to find a target once it appeared on the display with either mode, the moving mode is still favored when time-to-find is critical. The reason for this preference is that a time delay is "built in" to the static mode. The delay is that required to allow the image to build up in the near-real-time mission. Thus, if a target lay just outside the section of the terrain being displayed during a single static presentation, it would have to wait a complete observation time period before it would appear on the next frame. On the other hand, with the continuously moving mode, the target would move onto the display within seconds after it was sensed by the radar.

Third, if the observer's task is to find a predefined target area rather than a target, the possible breaking up of the terrain context into two sequentially presented static frames could detrimentally affect the recognizability of the area pattern. Task effects will be analyzed later.

Scale Factor. In this study, the scale factor of the imagery could be enlarged in two ways: (1) by increasing the size of the display and filling it with an enlarged image, or (2) by decreasing the area of the terrain being displayed on a display of a given size. Both methods yielded results supporting the generally accepted contention that performance is improved with the larger scale factor. More targets were acquired and found in less time.

TABLE 12
Results of supplemental study of the effect of scanning instructions to two observers.

	Moving Presentation Mode		*Static Presentation Mode*	
	Number Recognized	*Median Time*	*Number Recognized*	*Median Time*
Original	33	3.5 seconds	37.5	14.8 seconds
Supplemental Test*	33.5	3.5 seconds	38.0	12.5 seconds

*18-mile wide imagery, 12-inch square display, 40-second observation time. Values are average of two observer's performance.

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However, the difference in results obtained by the two methods demonstrated that scale factor, *per se,* was not the critical factor to be considered when making optimum display design decisions. Although in both cases the target size was changed by the same amount, varying the amount of ground area displayed in the full frame affected performance more than varying the size of the display while holding ground area constant. This fact emphasizes the role that search and scanning techniques play in the recognition task. With the larger display, although the ground area presented was the same, the observer was required to search a static display area four times the previous size. With the moving display, the increase in search effort was only twice as great, since the observer searched only in one dimension along the leading edge. When ground coverage was reduced with display size held constant, not only was the target size increased, but the portion of the total image area occupied by the target was larger, a fact which was not so when the display size was also increased.

One other factor may have also reduced the effectiveness of increasing the display size. The apparent increase in target scale factor on the display when the larger display was used was partially offset by a shift in the observer's viewing distance to compensate for the change in display size. With the larger display, observers would tend to move back further, thus reducing the visual angle subtended by the target. Considerably less compensation was observed when the ground coverage was changed.

It should not be overlooked, however, that under some circumstances, reducing the area of ground covered within a fixed display size could be detrimental to reconnaissance performance. For one thing, to do so reduces the amount of contextual terrain information which in certain reconnaissance tasks can be critical in locating targets too small to be seen directly. Then, too, the reduction in ground coverage results in a corresponding decrease in the length of the observation time (for any fixed vehicle speed) and this may reach a limit beyond which the observer no longer has sufficient time to perceive the target.

Observation Time and Image Movement. In a near-real-time mission, the observer may have little control over the length of the observation time. Time, however, represents one of the most severely limiting factors in this form of reconnaissance and targets which might have eventually been discovered had the search time been longer, may not be detected.

When the imagery is moving, the shorter observation time creates an effect in addition to that of limiting the search period. In this case, observation time and movement combine to create an angular imagery rate which, if fast enough, results in a blurring and reduction of visual acuity (Miller and Ludwigh, 1960). It is this possibility that has made many design engineers skeptical of the use of moving imagery for reconnaissance tasks. In practice, however, this fear appears overemphasized for the following reasons.

First, most of the rates encountered in the airborne reconnaissance situation (as well as in the faster moving reconnaissance missions from space) are below the point at which blurring occurs. Second, and possibly even more important, current research results suggest that whatever the degradation in performance which results from a decrease in observation time with the moving imagery, a greater degradation will occur with the static imagery. As observation time decreases to a minimum, observers eventually reach a point where they stare at only one point on the display (Erickson, 1964). Under this condition, success in finding a target on the static display is reduced to being lucky enough to be staring at the correct spot at the right time—a highly unlikely occurrence. With the moving display, however, staring at one spot does permit the search of a greater area, namely, a line across the display as the imagery (however blurred it may be) moves by. For this reason, the probability of detection at the very fast speeds can be expected to be higher for the moving presentation mode, and this is exactly what Erickson (1964) found.

Both Erickson and the present experimenter noted that at excessively fast rates, observers have difficulty in searching only the lead edge.

Instead they begin to follow the rapidly moving image across the display. The absolute value where this occurs is not known, but it could be related to the velocity at which blur begins to have a noticeable effect and the observer attempts to track the image to compensate for the movement.

The blurring effect of movement could have an effect once the search phase of the task is over and the observer must study particular patterns in finer detail. This was not considered in the present studies. However, if this task were required, once the target had been found, the display could be turned off and the imagery studied statically if necessary.

But short observation times are not the only disturbing factor in this reconnaissance task. Longer observation times may also result in a performance decrement as an effect of the difficulty of maintaining a sustained vigilance. In this experiment, the longest observation period was 24 minutes. Although there were many more targets in this laboratory study than might be expected under field conditions. subjects reported feeling drowsy and of "blocking" while monitoring the continuously moving display over the longer time periods. With marginal targets, even at speeds in which there is sufficient time to study a display thoroughly, targets may be missed if the overall situation creates suboptimum levels of alertness in the observer.

Tasks. The task of the present study was one of target recognition. As stated earlier, the targets were clearly defined and readily recognizable once they were fixated foveally. Detailed examination was not required.

An exploratory investigation has been made comparing the moving and static presentation modes when the task was one of finding a *target area.* Tentative results suggest that the static, sequential frame mode may be preferred at the faster viewing rates. Aerial photographs covering nearly forty thousand square miles were used to simulate the view from an orbiting spacecraft through an optical telescope. For this situation, target area acquisiton relied primarily upon the recognition of gross terrain features and relatively few man-made objects. To accomplish this it was necessary that rivers and mountain patterns, for example, be examined over areas which could not be encompassed in one or a few visual fixations, and that numerous similar appearing features be studied and rejected before finding the correct ones. Observing these complex patterns appeared more easily accomplished when the image was static than by searching the lead edge of a moving display.[4] Furthermore, if clearly visible check-points of known space-time distances from the target area were found, the static, sequential frame presentation mode facilitated keeping track of the time interval more easily than did the continuously moving mode.

Although it is true that a continuously changing display does allow a continuity for following prebriefed terrain features into the target area while sequentially presented static frames conceivably could break up this continuity and the target area pattern, this disadvantage of the static mode seems outweighed by its advantages. Also, the continuity of the static presentation mode can be improved if there is not a one-hundred percent change in the image from frame to frame.

Partial Static Presentation Modes. Most of the disadvantages of the static presentation mode and the differences in performance between it and the moving presentation mode possibly may be removed if the frame-by-frame change is only a partial one each time. For example, if instead of each frame changing to a completely new image per frame the change would occur when only twenty-five percent of the image is new, several effects occur. First of all, the time available for each new portion is reduced proportionately from the total time that would be available if the entire frame had changed. Second, however, the observer would have a proportionately smaller area to study, and what is more important, he may now essentially duplicate the scan mode that proved optimal with the moving presentation mode, i.e., scan primarily along the lead edge. Furthermore, if the optimum percent of

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[4] Presumably a similar effect might be noted if targets were complex and ill-defined.

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partial frame change could be determined—relative to the width of the effective cone of vision—the sequential series of static changes may serve to better pace the observer and to delineate his scan without introducing the tendency for the eyes to follow the imagery as in the moving presentation mode. This might improve performance at the faster rates. Whether or not these speculations are true is an empirical question to be determined in a subsequent study.

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I AYVT II

Quantitative Measures

by H. R. Luxenberg and Q. L. Bonness

Editor's Note

This paper is one section of a report entitled "Display Techniques for Digital Weapons Control Systems" prepared by H. R. Luxenberg and Q. L. Bonness, of the Bunker-Ramo Corp., for the U.S. Naval Ordnance Test Station (NOTS), China Lake, Calif., under contract number N60530-10519. Another section of the same report appeared in the last issue of INFORMATION DISPLAY under the title "Photometric Units" by H. R. Luxenberg.

Introduction

Display device and system parameters are of two types:

(1) Those pertaining to system integration requirements with associated environmental and logistic considerations.

(2) Those pertaining to the interface with the observer.

The first category consists of such items as physical size, weight, power, signal levels, symbol encoding, interface requirements, temperature, humidity, shock, vibration, cost, reliability (MTBF), and maintainability (MTTR).

The second category includes such factors as brightness, contrast, color capability, resolution, viewing distance, and viewing angle.

All of these parameters are either available from the manufacturer (many must, of course, be properly discounted) or may be tested directly.

It is not the intent of this paper to duplicate detailed descriptive material which is already easily available and well presented in the current literature. For example, several good articles describe, in some detail, techniques for CRT character generation; others describe alphanumeric indicators, etc. Furthermore, it would be impractical to attempt to tabulate operating parameters for all currently available displays here. Several extremely good summaries are readily available, although even these suffer from some incompleteness. It is, however, the purpose of this paper to present a quantitative discussion of the physical units and psycho-physical significance of those parameters peculiar to display technology.

Since the function of a display unit is to transfer information to the operator by visual sensing, it is important to consider those parameters that determine the capability of the human eye to perceive information. Therefore, the following section discusses those factors that are important to the visual perception of information. A definition of each factor is given, and a discussion of the way in which it relates to the evaluation of display devices is included.

Brightness and Contrast

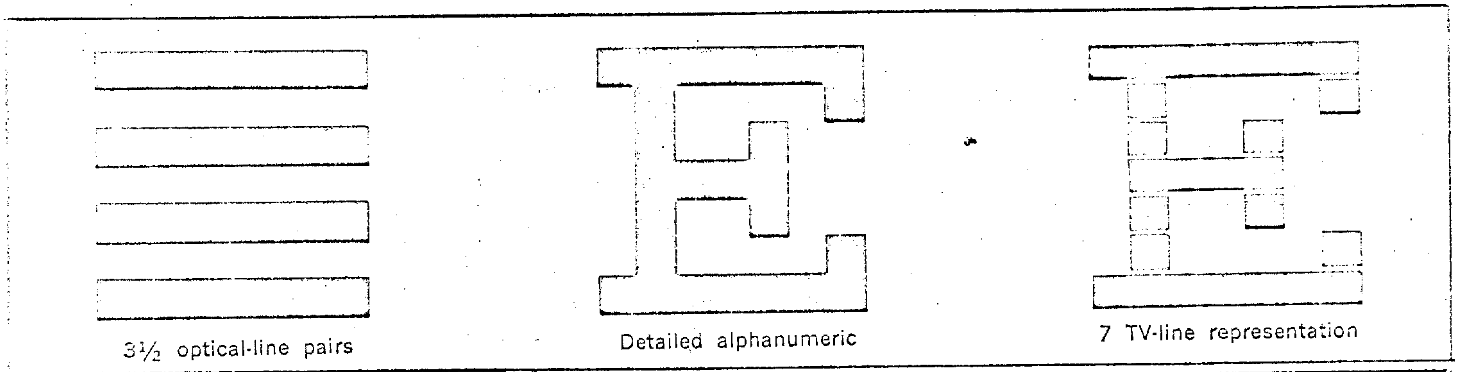
Contrast, not brightness, is the significant factor in display legibility. Brightness is generally specified because it is dependent only on the equipment, whereas contrast is generally a function of ambient lighting. Brightness is also specified because it would seem that the higher the brightness, the greater the visibility under higher ambient light. This is not necessarily true, since some displays of lower intrinsic brightness have better visibility than far brighter ones. (See Tables 1 and 2).

Furthermore, unnecessarily high brightness may be a luxury where ambient light is subject to control, since it has been determined experimentally that where observers have control over ambient lighting for reading they tend to choose lower values than are generally considered optimum. For example, under a controlled test[1], when the maximum available illuminations were 10, 30, and 45 foot-candles, the observers selected 5, 12, and 16 foot-candles as the optimum values.

The required brightness of a display should be obtained by the following procedure. First, select (preferably at the lowest acceptable level) the ambient light desired at the work station, and by means of a mockup measure the ambient light falling on the display surface. The source(s) of ambient illumination should be relocated, collimated or otherwise shielded to reduce this to a minimum. Acceptable contrast ratios are: for white symbols on a black background, 5 to 1; for line drawings or text on a white background, 25 to 1; for pictorial scenes, 100 to 1.

From a knowledge of the reflectivity of the display surface (unless it is glossy, unity is a conservative estimate), the brightness of the background is obtained, and multiplication by the desired contrast ratio will specify the brightness required of the symbols. For example, if the ambient illumination on an electroluminescent alphanumeric display whose luminance is 10 foot-lamberts can be held below two foot-candles, the resulting

Of Display Characteristics



3½ optical-line pairs

Detailed alphanumeric

7 TV-line representation

FIGURE 1: Character representation.

TABLE 1

Typical Brightness (foot-lamberts)*

Surface of the sun	4.8 × 10^8
Surface of a 60-watt frosted incandescent bulb ("hot spot")	36,000
Surface of a 60-watt "white" incandescent bulb	9,000
Surface of a 15-watt fluorescent tube	3,000
White paper in direct sunlight	9,000
Clear sky	2,000
Surface of moon, bright area	750
White paper on office desk	25
Pulsed electroluminescent mosaic panel	20
Television raster	20
Light valve, 10- by 10-foot diffusing screen, 2-kilowatt lamp	20
Theatre screen open gate	16

Note that pulsed electroluminescent mosaic panels have brightness comparable with television raster or opengate theatre screens.

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*Brightness values compiled from:

(1) D. G. Fink, TELEVISION ENGINEERING HANDBOOK, McGraw-Hill, 1959.
(2) IES LIGHTING HANDBOOK, THIRD EDITION, Illuminating Engineering Society, 1959.
(3) REFERENCE DATA FOR RADIO ENGINEERS, I. T. and T. Corp., 1949.
(4) Measurements and Calculations by the Authors.

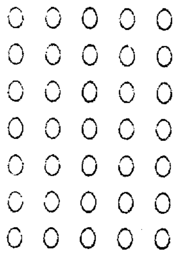


FIGURE 2: Full 5 x 7 dot mosaic (35 elements, full alphanumeric).

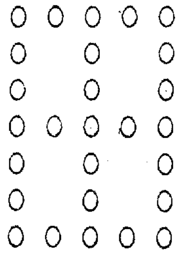


FIGURE 3: Reduced 5 x 7 dot mosaic (27 elements, numeric only).

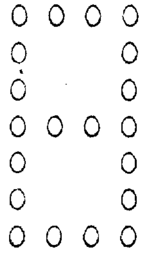


FIGURE 4: Reduced 4 x 7 dot mosaic (20 elements, numeric only).

contrast of 5 to 1 will be adequate for good legibility.

If, however, the observer is working at a desk where the illumination is 50 foot-candles, a sheet of white paper will have a luminance of 40 foot-lamberts and the 4-to-1 brightness difference between paper and display may prove annoying. Since the display brightness cannot be raised, the working lighting can be reduced. If the observer is given control over the ambient lighting, he will find an optimum (for him) working level.

Size-Resolution-Legibility

Resolution is generally described in terms of line pairs per millimeter (lines/millimeter). The average observer can resolve two lines that subtend an angle at the observer's eye of one minute. Since 1 minute of arc $\approx$ 0.0003 radian, the eye resolves at a viewing distance of 10 inches (250 millimeters) about 13 lines/millimeter.

TABLE 2
Contrast Levels

Textual copy (white on dark)	5-10 to 1*
Line drawings and black on white text	25 to 1
Photographs	100 to 1

*Legibility of fine detail degrades with increasing contrast if the eye is adapted to darker background level, because of dazzle effect.

There is some confusion in the literature between optical lines and television lines. Optical lines are synonomous with line pairs (i.e., an optical line consists of a black and white pair). To show one line pair on a television raster requires at least two television lines. Because the optical line pair may not coincide with the raster lines, more than two television lines are required. The correction factor of 1.4 is called the Kell factor[2]. Thus, one optical line pair requires 2.8 television lines, for full resolution.

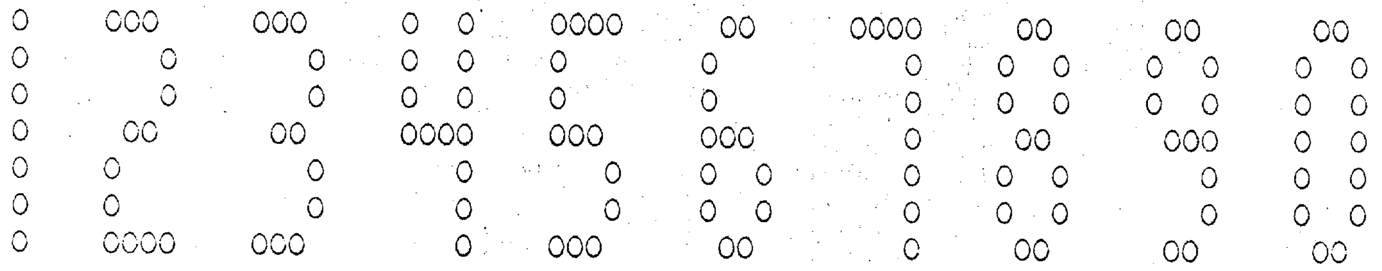
Resolution in terms of line pairs is significant for display purposes only when photographs are shown, where the observer is required to distinguish between two close objects. Actually, if the existence or nonexistence of a black line on a white background is to be determined, the line need subtend an angle of only 0.5 second at the eye.

If alphanumerics are to be legible, the vertical angle subtended at the eye should be at least 10 minutes of arc. Since 10 minutes of arc are approximately 1/360 radian, for each foot of viewing distance the character must be at least 1/30 inch in height. While the eye can resolve 10 optical line pairs in 10 minutes of arc, this does not mean that the detail present in an alphanumeric character requires 10 line pairs for legible presentation.

An examination of the "E" shown in Figure 1 reveals that no more than 3.5 optical line pairs are required. The seven-television-line representation of the "E" on the right side of the figure may appear somewhat crude when viewed close-up, but when viewed from a distance at which the lines are not resolved, it is quite legible.

Although the number of television lines used is just twice the number of optical line pairs for the illustration, near perfect registration of the raster scan to the figure being displayed was assumed. To take care of the misregistration problem, the Kell factor (2.8) is introduced. The product of 3.5 (the number of optical lines required) by 2.8 (the Kell factor) is very nearly 10, the number of television lines required to present a character of good legibility.

FIGURE 5: Numerics using reduced 4 x 7 dot mosaic.



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[1] A. C. Stocker, "Displays, Papers and Lighting," *Information Display*, Vol. 1, No. 1, pp 16-26, September/October 1964.

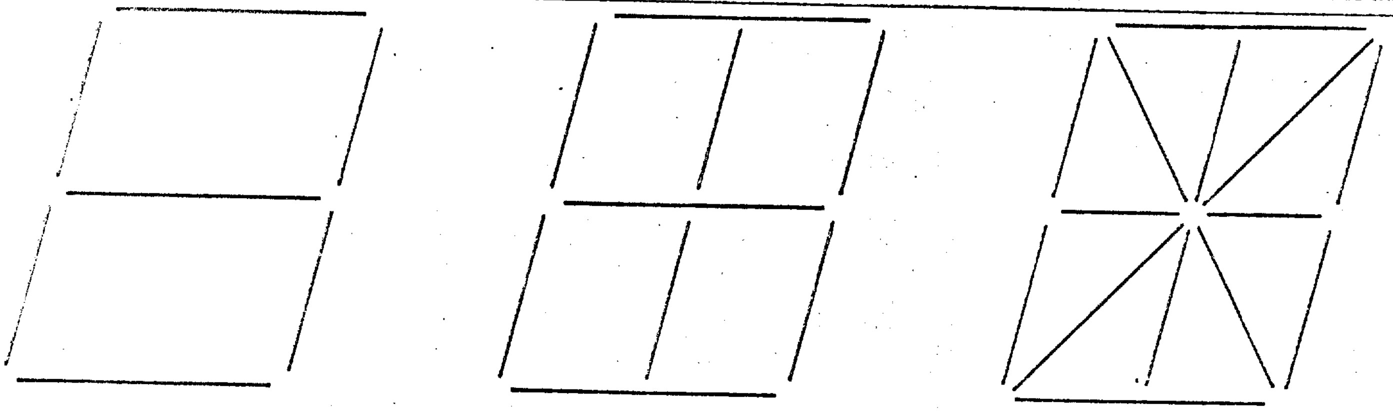
[2] D. G. Fink, *Television Engineering Handbook*, McGraw-Hill, 1959.

While the legibility of the characters depends on their structure, there is no universal agreement on the optimum character shape. Among the recommended shapes are the following:

(1) Modified gothic (sans serif) character of height/width ratio of 3 to 2 for most letters, with the exception of I, M, and W, and a stroke width of ⅙ of the character width.

(2) The same as above, but with a height/width ratio of 5 to 3 and a stroke width of 1/6 to 1/8 of the character height (MIL-SPEC-33558).

The authors prefer the 3 to 2 height/width ratio with a bolder stroke, say 1/6 of the character width. The character is then nine strokes tall by six strokes wide. A minimum of two stroke widths should be provided between adjacent symbols.



(a) The double-hung window (seven elements, numeric only).

(b) The double-hung window (nine elements).

(c) The starburst (14 elements, full alphanumerics; also available is a 16-element starburst with the upper and lower horizontal elements split).

NOTE: Segments may be electroluminescent, gas tube cathodes, electrofluors, or illuminated by incandescent or neon lamps.

FIGURE 6: Segmented character formats.

Special Character Shapes

While well shaped gothic characters are most attractive and are generally agreed upon as providing the ultimate in legibility, certain types of display implementation preclude their use. Instead, they present characters of a stylized shape made up of discrete elements. Once these are "learned" they become nearly as legible as the pure gothic to which they are an approximation. Devices in this class use either dot or stroke mosaics, as discussed below.

The primary reasons for the adoption of these types of characters are economy and simplicity of implementation, as is readily apparent from the following considerations. Alphanumeric data are stored and processed in data processors in data binary coded form, requiring a minimum of six bits per character, exclusive of parity and clock bits. These six bits permit display of a maximum of 63 characters (or 64 if the "blank" is counted). This number can include 26 alphas, 10 numerics, and up to 27 special symbols, including punctuation marks, etc.

While the 6-bit code can be decoded into 64 "lines," one per possible character, in many display applications it is found more desirable to reduce the number of decoded lines by assembling the characters from a smaller number of elementary elements, as, for example, by a dot or stroke mosaic.

Dot mosaics

The coarsest mosaic that is capable of providing easily legible alphanumeric symbols is a 5- by 7-dot mosaic, as shown in Figure 2. Here, only 35 decoded lines are required. If only numerics and a limited number of symbols are required (e.g., +, −, ., etc.), some of the elements are not required, and the number of lines may be reduced to 27, as shown in Figure 3.

For numerics only, the reduced 4- by 7-mosaic shown in Figure 4 is satisfactory. This mosaic requires only 20 lines. In general, dot mosaics present better appearing characters than stroke mosaics, but stroke matrices are more economical in the sense that fewer lines are required. However, stroke matrices with as many as 35 specially shaped elements have been devised; these give extremely good characters, far better appearing than the dot matrix, with no more operating complexity. The elements may also be arranged in a parallelogram rather than in a rectangle to provide sloped or "italic" characters.

Stroke mosaics

This type of character presentation is known variously as the bar matrix, the

depending on the manufacturer. The bars, strokes, or segments are arranged in a pattern similar to one of those shown in Figure 6.

The exact shape varies from one manufacturer to another, with some rounding of corners and minor variations in the way adjacent segments join.

The segments may be electroluminescent strips, electrochemical cells or cathodes in a glow discharge tube, or they may be trans-illuminated by neon or incandescent lamps. The power requirements, luminosity, and color differ in each method of implementation.

The characters are nearly as legible as those made from a 5- by 7-dot mosaic, but logic (switching) requirements are reduced from 35 inputs for the full 5-by-7 matrix to 16, 14, 9, or 7, depending on the type of bar matrix chosen. A decimal point or underline bar may be added in some instances. The same height/width/stroke ratios apply as for shaped characters.

Screen Characteristics

The length-lambert units of the previous section are defined by defining the luminance of a perfect diffuser, approximated by a fresh chalk surface, to be numerically equal to the incident illumination in length-candles (e.g., a perfect diffuser in bright sunlight is illuminated by 9000 foot-candles and has a luminance of 9000 foot-lamberts as seen from any direction).

For other-than-perfect diffusers, a reflectivity factor is used to obtain the luminance. Note that the reflectivity need not be less than unity and it may vary with direction.

For specular reflection the luminance of the reflected image is that of the source itself. If the perfect diffuser in the ror, the luminance of the mirror is .8 x 10^8 foot-lamberts (same as the solar surface) on the axis of the reflected rays and zero off-axis. Thus, the reflectivity or "gain" of the mirror in this case is a sharply peaked function with a maximum value of (4.8 x 10^8)/9000 or greater than 5 x 10^4.

Directional screen with flaked aluminum surfaces (to give high gains) are frequently used to obtain greater image brightness, but at the price of a restricted viewing angle. An increase of granularity in the aluminum paint provides a greater viewing angle; or the surface may be embossed with tiny convex mirrors, which will not be visible at normal viewing distances.

The mirrors spread the incident parallel rays into a cone generally of rectangular cross-section, to cover the audience space desired. The angles of the cone are simply related to the width or height and focal length of the tiny mirrors.

An analogous situation holds for rear-projection screens. The analog of a perfect mirror is a clear layer. Either more diffusion or a lenticular structure may be used to provide the desired spread of light. Except for very small screens (i.e., those subtending a small angle at both eye and source), gains greater than 2 to 3 produce visible and annoying "hot-spots."

Uniformity of Luminance

A projection screen (either front or rear) will not be uniformly luminous over its entire surface, although for all practical purposes it may appear so. In this section, the reasons for non-uniformity and practical limits are discussed.

The two major causes for screen fall-off are: (1) lack of uniformity in illumination, and (2) the variation of gain with the angle between line of sight and the reflected or transmitted projection ray. This angle is called bend-angle.

Illumination fall-off is primarily due to a $\cos^4 Ø$ factor which enters when a finite-area lamp source and conventional optics are used in the projector. The angle Ø is the half-angle subtended by the screen at the projector. With small sources and aspherical optics, the factor may be increased, perhaps to $\cos^3 Ø$ or better, but at a cost[3]. The easiest cure is to reduce Ø by increasing the projection distance. If space is limited, a folded optical path may be required.

Even with a uniformly illuminated screen, the illuminance will fall off with bend-angle, unless the screen is a perfect diffuser (constant gain). The angle at which the gain is one-half its peak value is called the half-power, or 50% bend-angle. Higher gains mean smaller half-power bend-angles, unless the gain is deliberately lowered by the addition of light absorbing material for contrast control (see below).

While the eye is extremely sensitive to luminance differences in adjacent areas, it is relatively insensitive to a gradual 2-to-1 variation over a large area. For this reason, a 2-to-1 variation in screen luminance is generally acceptable, and even a 3-to-1 variation will go unnoticed by the casual observer. Therefore, the restriction to a 30% fall-off (often seen in display specifications) is a luxury that the eye does not appreciate; a 50% fall-off is a much more reasonable specification value.

Contrast Control

From a knowledge of the incident illumination and the screen gain in the direction of view, the luminance is calculated by a simple multiplication. Unfortunately, ambient light is also reflected back to the observer, adding to both highlighting and shadow luminances, thus reducing their ratio (the "contrast").

With a front-projection screen the only effective means of control is to use a high-gain (directive) screen, placing the observer on the reflected projector ray and avoiding all ambient light sources in the neighborhood of the projector. Only scattered ambient light will then degrade the contrast. This directivity explains the effectiveness of the currently popular lenticular screen for home projection use. The lenticules direct the reflected light primarily into a sharply defined rectangular cone, with sharp fall-off outside, rather than into a broader region with gradual fall-off.

With rear-projection screen, more freedom is permitted in contrast control. A high-gain screen is inherently a poor reflector; hence, contrast is immediately enhanced, even with light sources on the line of sight. As the gain is reduced by increasing diffusion to provide the desired viewing angle, the front reflectivity is, unfortunately, increased.

The reflectivity may, in turn, be lowered by adding opaque material or a neutral density filter. This reduces the gain but does not change the bend-angle as in the case of increasing diffusion. The effect of the filter is discussed further under the section on projection systems which follows.

Projection System Parameters

In projection systems the amount of light reaching the projection screen is a function of a number of parameters, but for well designed optical systems certain rules of thumb are applicable. Several useful ones are:

(1) A light valve television system using a xenon arc lamp has an output of between 0.7 and 1.5 lumens/watt.

(2) A 35-mm slide projector using an incandescent lamp has an output of between 1 and 2 lumens/watt.

These are typical figures only, and the upper or lower limits may be exceeded by exceptionally well designed or by poorly adjusted equipments.

For a uniformly diffusing matte screen, the screen brightness in foot-lamberts is equal to the luminous output of the projector divided by the screen area in square feet. For example, the screen brightness produced by a 2000-watt xenon light valve operating at an output of one lumen/watt on a 10-foot square screen is 20 foot-lamberts.

Both front- and rear-projection screens may appear either brighter or dimmer than a uniform diffuser, depending on the nature of the screen and the line of view. The ratio of brightness to illuminance is a maximum when the line of view extends directly back to the projector for a rear-projection screen, or along the reflected ray from the projector for a front-projection screen.

This maximum value is referred to as the gain of the screen. Typical useful screen gains line in the range of 0.5 to 2.0, although higher-gain screens are used when the restricted viewing angles associated with them are not objectionable or are desirable.

The higher the screen gain the higher the contrast, in general, for both front- and rear-projection screens. This is true for rear-projection screens, since the reflection of ambient light from the front surface is low with high-gain screens. For front-projection screens, the directivity of higher-gain screens is such that off-axis ambient light is not directed into the viewing area.

An additional degree of contrast control is available with rear-projection screens, in that a neutral density faceplate may be incorporated. If the (one-way) transmission is x%, the two-way attenuation of reflected light is x^2%. A 50% neutral density faceplate thus attenuates the projected beam by a factor of two and the undesirable ambient reflection by a factor of four.

Because of all the variables introduced by the screen parameters and the ambient lighting conditions, it is not practicable to specify brightness and contrast values for a projection system without defining the viewing conditions. It is for this reason that projection systems are best defined in terms of lumens output.

Brightness in foot-lamberts for a unity-gain screen is obtained by dividing the lumen output by the screen area in square feet. Contrast is obtained by multiplying the ambient light in foot-candles by the screen reflectivity coefficient and computing the ratio of "light" to "dark"

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[3] Helmut Weiss, "Wide Screen Slide Projection," *Information Display*, Vol. 1, No. 1, pp 8-15, Sep-

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Author(s) Leifer, I., Spencer, C.J.D., Welford, W.T.

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[✓ b.] In-house 9-22-66
c. Reviewed

effective duration we mean the time during which the relative speed is less than the minimum for which the grainless effect occurs.

Figure 2 shows an attachment we have constructed for a microscope, using this principle; the front screen moves so that each point on it describes a circle of about 5-mm radius in a few seconds. The gap between the two screens is adjustable and we have found that a separation of up to a quarter of a millimeter has no discernible effect on the quality of the image. An alternative way of moving one screen is to vibrate it at ac-power-line frequency with an amplitude of about 0.5 mm; this is just as effective as the slowly moving rotating screen and perhaps slightly simpler and cheaper.

With this system we have found that an over-all magnification of 1000 permits the finest detail resolvable by means of an oil-immersion objective to be seen as clearly as by direct viewing and the screen luminance is increased to about 0.002 stilb. A further fourfold increase in luminance is obtained if the screens are etched to increase the forward transmission, as proposed by Dyson[5]; the etching produces a clearly visible structure on the screens which can be seen moving, but although this may be slightly distracting to the observer it does not impair the resolution of detail in the image. On account of the strongly peaked polar diagram of these screens it is desirable to use a field lens as indicated in Fig. 2 in order to obtain a uniformly illuminated field of view.

An alternative proposal for a grainless screen is to use a single rather rapidly moving screen[6]; we have tried this in the form of a disk-shaped screen revolving in its own plane and we have found that although an improvement in definition of the image was obtained it was not so marked as for the double screens. The steady movement of the screen through the field of view was always noticed and this was distracting, but worse still was the fact that large-scale variations in scattering over the screen showed up as a flicker with the period of rotation and this could only be eliminated by using a speed of rotation above about 30 rps, a rather high speed for a thin disk of glass. A single, rapidly oscillating screen was found to be quite useless.

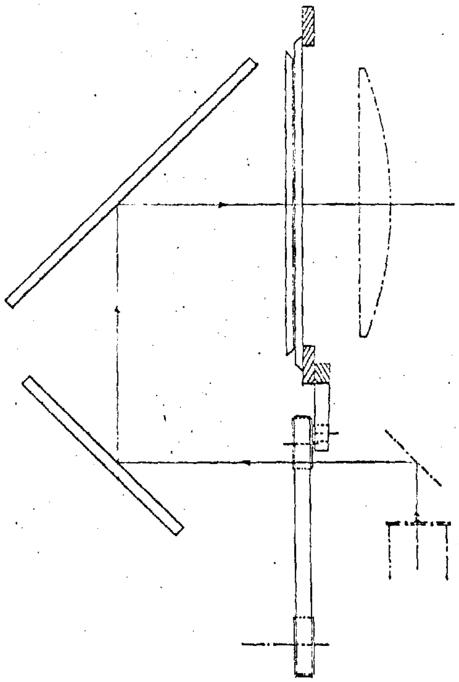

FIG. 2. Grainless screen. Light from the microscope eyepiece (lower right) after reflection from three mirrors forms the image on two ground glass screens (upper center) nearly in contact. The image may be viewed through a field lens (upper right) if the screens are etched for high forward transmittance. The ground-glass screen nearest the observer undergoes circular translation in its own plane at about 20 rpm from the motor drive (bottom center). In an alternative arrangement the moving screen is oscillated in its own plane at ac-power-line frequency.

To summarize, we have found the best results by using two screens separated by not more than 0.25 mm and with relative speed exceeding 1 mm/sec.

ACKNOWLEDGMENT

This work is supported financially by an extramural grant from the National Coal Board, but the opinions expressed are those of the authors and not necessarily those of the Board.

vibration concept

note: have seen ring of screen integration in which was quite effective; however was not able to compare with this double screen concept

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[5] J. Dyson, J. Opt. Soc. Am. 50, 519 (1960).

[6] N. H. Mason, British Patent 590,981 (1947). See also E. Lau and J. Reinitz: "Optik aller Wellenlängen" p. 229 (Berlin, 1959) and E. Lau and R. Schalge, Feingerätetechnik 7, 121 (1958).

Grainless Screens for Projection Microscopy

I. Leifer, C. J. D. Spencer, and W. T. Welford,
Technical Optics Section, Imperial College, London, S.W.7

and

C. N. Richmond
The Orangery, Kelvedon, Essex

(Received June 13, 1961)

Back-projection screens for projection microscopy with high luminance and no loss of definition are described; the screen grain is removed by the slow relative movement of two ground-glass screens placed face to face.

In routine sizing and counting of coal dust samples at National Coal Board Area Laboratories it is necessary to count particles as small as 0.5 μ. This is at present done with a projection microscope of conventional design with an opaque screen for front projection. In seeking ways to improve this technique we noticed that the picture had to be at least 50 cm from the eye because of physical obstruction of the view by the microscope, so that the magnification used was high, usually about 3000; the picture luminance was therefore very low, about 0.0002 stilb (candle/cm^2), with a 250-w high-pressure mercury lamp as light source.[1] At this low luminance the Fechner fraction is about twice its normal value[2] and the visual acuity is halved,[3] so that it is clearly desirable to increase the luminance considerably.

The obvious way to do this is to use a back-projection screen, so that the distance from the eye to the screen can be considerably reduced, the magnification reduced and the luminance correspondingly increased; but if this is done we find that the grain of the projection screen obscures the detail in the image. All projection screens have a more or less grainy, sparkling appearance, and the scale of the grainy appearance is considerably larger than that of the actual grain in the material. For example, Fig. 1 shows part of a microphotometer trace across a ground glass screen obtained by using a scanning spot 100 μ square and illuminating and collecting beams of N. A. 0.006; the standard deviation of the fluctuations in transmittance is ±23% and it can be seen that the scale of the irregularities is such that detail several hundred microns across would be obscured although the glass was "smoothed" (i.e., ground with the finest grade of emery as the last stage before polishing) and the grain size of the emery was only about 10 μ. The magnitude of the effect also depends on the numerical aperture of the illuminating and collecting beams, the values being chosen here to correspond approximately to conditions in projection microscopy.

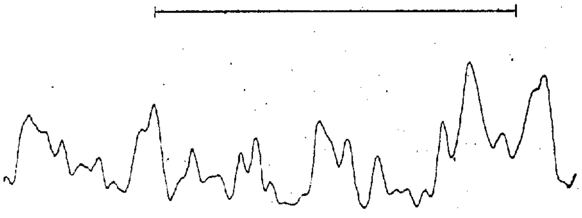

Fig. 1. Microphotometer trace across fine, ground-glass screen. Illuminating and collecting apertures both $f/80$, scanning spot 100μ square. The horizontal line at the top corresponds to 1 mm on the ground-glass screen.

This difficulty of graininess with small numerical aperture of the illuminating beam is found with all kinds of screens to a greater or less extent and it is probably unavoidable. A screen must have irregularities several microns in size if it is to scatter at all and these must be arranged in a random manner so that the screen does not become simply a two-dimensional diffraction grating; it is presumably the linear scale of the random variations in the screen structure which gives rise to the seen graininess, just as the graininess in a photographic emulsion corresponds not to individual grains of silver but to variations in grain density and clumping.

In order to circumvent this difficulty we have therefore applied an old idea[4] for a grainless screen to be used in engineering gauge projectors, etc. In this system two ground-glass screens are placed with their ground surfaces almost in contact and one is moved slowly in its own plane relative to the other; the sparkle and graininess are continually changing and are smoothed out by persistence of vision to give a perfectly grainless, smooth screen. The effect is quite startling for low-contrast objects of which the images are less than a millimeter in size on the screen, such objects are almost invisible when the screens are stationary but become brilliantly clear when the movement is started. The relative speed of the screens needs only to be quite slow, about 1 mm/sec, but the motion must be such that there are no stationary points or else if such a point does occur its effective duration must be less than, say, 1/25 sec; by

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[1] This source has a luminance of 20 000 stilbs and the theoretical screen luminance under the conditions of use described above is 0.006 stilb; the difference may reasonably be ascribed to reflection and absorption losses and to the difficulty of completely filling the condenser aperture with the image of the part of the source of maximum luminance.

[2] S. Hecht, J. gen. Physiol. 7, 235 (1924).

[3] S. Hecht, Arch. Opthalmol. 57, 564 (1928).

[4] F. A. MacAdam and Taylor, Taylor & Hobson Limited. British patent 592,815 (1947). See also K. J. Habell and A. Cox, *Engineering Optics* (Pitman Publishing Corporation, New York, 1948), p. 273.

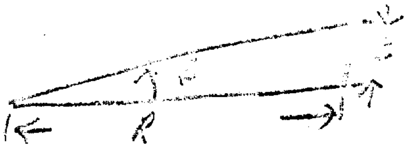
5-0773

The Determination of Display Screen Size And Resolution Based on Perceptual and Information Limitations

$= \frac{e}{R}$ (θ in radians)

e + R in same units

$= \frac{57.3e}{R}$ (θ in degrees)



by Glenn E. Whitham

Abstract

The material presented in this paper offers useful, handbook type information to enable the display system designer to determine rapidly the limiting values of basic display parameters so that he can devote his attention to those unique details inherent to the design of a specific system.

By considering displays in terms of their minimum resolvable elements, a series of design charts have been developed from which limiting design range values can be obtained for display element size, overall size, symbol size and maximum symbol quantity for ordered or random symbols. Within these limits more exact parametric values can be specified in terms of the effect on them of other system parameters. In this manner the feasibility of a display configuration can be verified in terms of fundamental limitations, and inconsistent requirements can be modified in the conceptual phase.

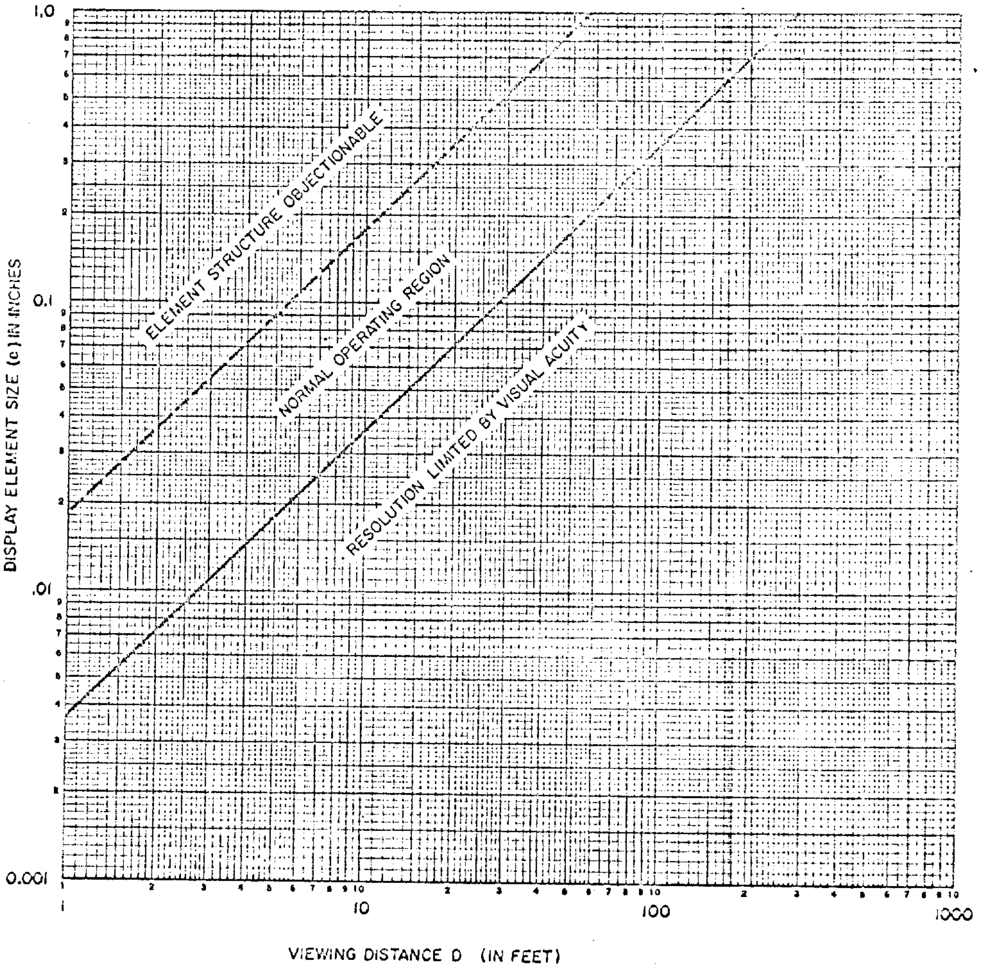


FIGURE 1: Relation of

Introduction

The designer of a display system has available many devices and techniques from which he can select the most suitable for his particular purpose. A primary factor that must be considered in making his selection is the determination of optimum values for such fundamental display parameters as size, resolution, and information content. The basic limitations to these parameters are visual perception, and format and amount of required information. Within these limitations an idealized first-order determination of display size and resolution has been obtained.

This paper contains a brief description of how these parameters are determined with resulting design values presented in chart form for use by the designer. Modification of these results can be made in accordance with unique conditions related to a specific system and with due regard to psyhcoperceptual limitations. The model considered is applicable to many systems with little or no modification.

Based on preliminary work of limited scope on random position data displays, it is evident that additional probability analysis of typical model situations would be useful in establishing further design limitations. However, considerable analysis time and computer programming time would be required to yield significant results.

This discussion is limited to two-dimensional displays with a highlight brightness range which permits employment of normal photopic vision. The discussion does not consider low contrast, gray scales, color, and viewing angles other than normal to the display surface.

Element Size

The determination of display element size or display resolution is predicated on a nominal visual acuity limit of one minute of arc for a subject having normal vision. To be sure, various factors such as element form affect this value somewhat, but for the first order solution they have been neglected. If each display element has a maximum dimension e, then the relation between e and the maximum viewing distance D at which two such adjacent elements can be discriminated is given by

$$e = 0.0003\ D \qquad (1)$$

This relation is shown as the solid line on Figure 1. From this chart the choice of element size can be made based on viewing distance.

Examples. A console display for a single operator is normally viewed at a distance of about 18 inches, at which distance the limiting resolvable element size would be 4 mils. Appreciably smaller elements cannot be resolved, but ele-

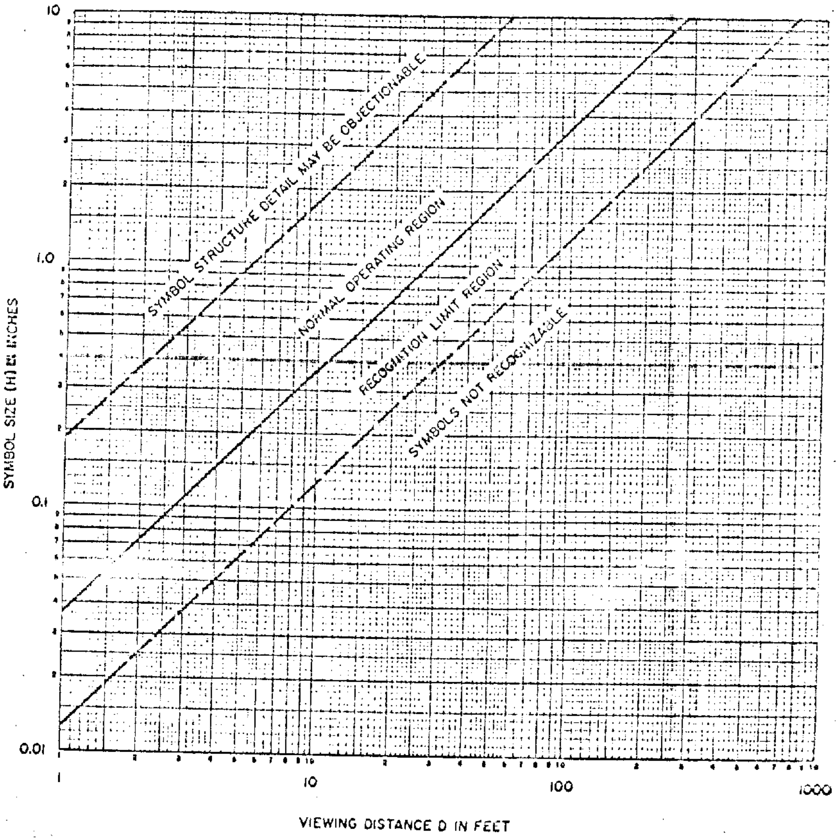
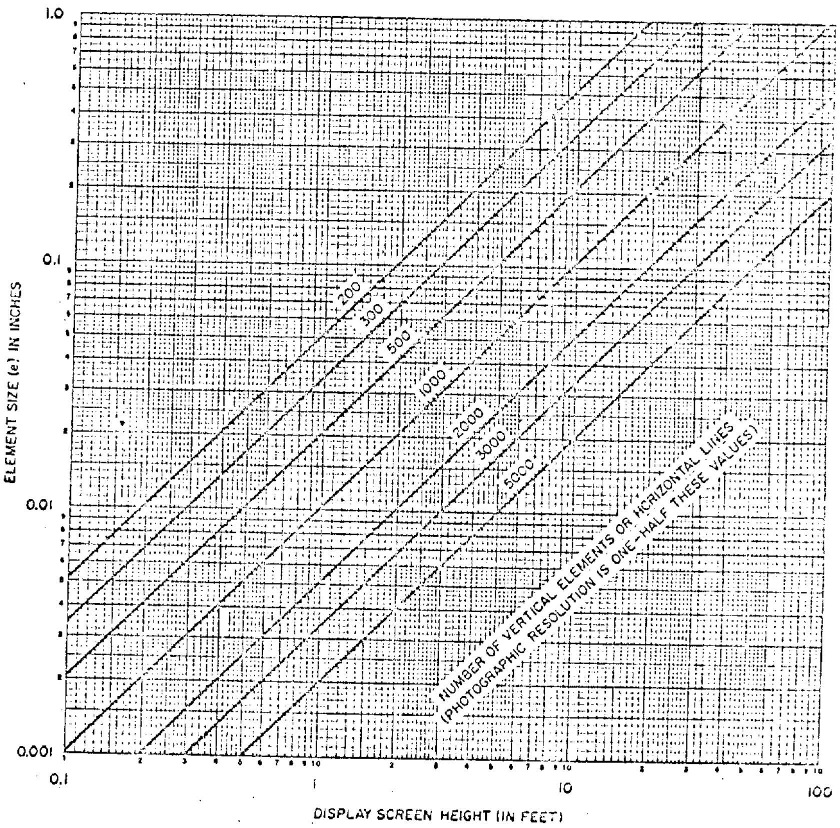


FIGURE 2: Relation of symbol resolution to viewing distance.

FIGURE 3: Relation of screen height to element size and number of vertical elements or horizontal lines.



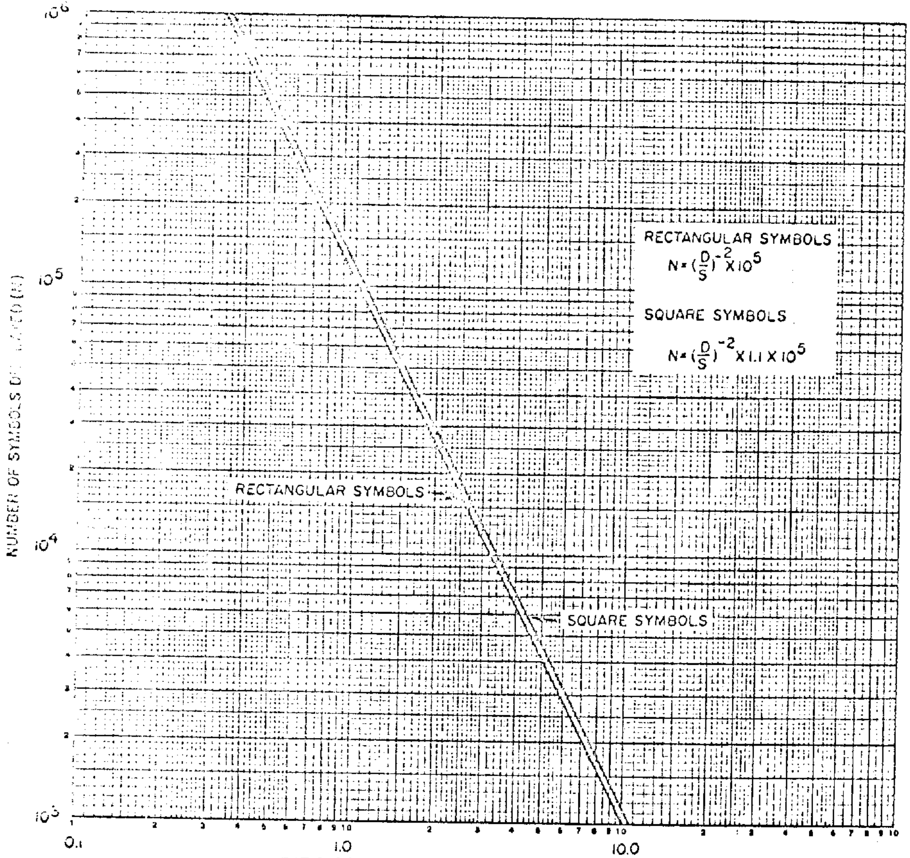
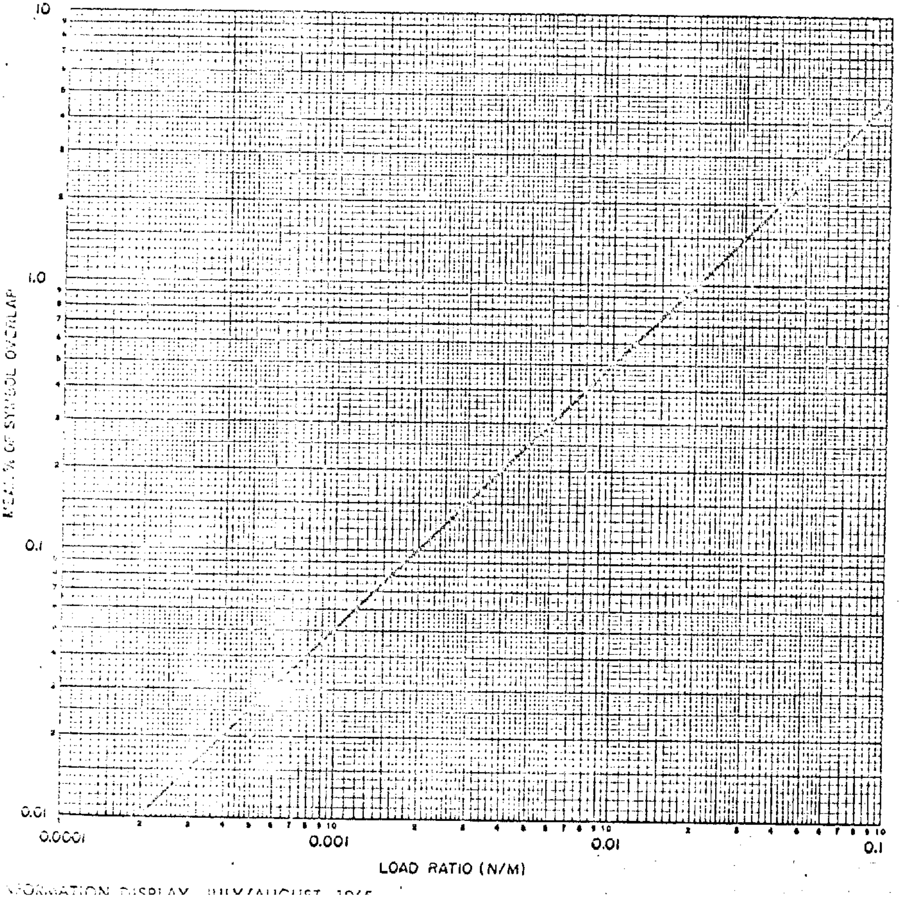


FIGURE 4: Maximum number of symbols of limiting resolution that can be displayed on a square screen having side dimension "S".

FIGURE 5: Mean percentage overlap of random symbols as a function of display load.



ments of two or three times the limiting value will result in acceptable displays, and greater than about five times will produce an objectionably "grainy" display. Thus it can be seen that for CRT displays the usual spot size range of 5 to 20 mils is quite compatible with the visual perception requirements of a console display.

The same procedure can be used to determine element size for group displays. Figure 1 shows that a typical acceptable element size range is 0.1 to 0.5 inch for a viewing distance of 30 feet.

Symbol Size

For the special, but rather important case where the display format is comprised largely of symbology, a determination can be made of the required symbol size for a given viewing distance. Assuming that the desired symbols can be formed from a matrix having no more than 10 x 10 elements, a symbol will visually subtend 10 minutes of arc in the limiting resolution case. Actually, while recognition of symbol form can often be made below this limit, smaller symbols would not normally be used. Symbols of three to five times the minimum size are usually acceptable, but will degrade the maximum display data capability.

The relationship of symbol size to viewing distance is indicated in Figure 2. For console displays, a symbol size range of 0.05 to 0.25 inch is appropriate, while for a group display viewed at 30 feet, the range is 1.0 to 5.0 inches.

Line Resolution

It is sometimes convenient to specify display resolution in terms of lines: the number of horizontal lines in a TV raster, or the number of resolvable line pairs in a specified distance, as used for measuring photographic resolution. Figure 3 shows the relationship of the total number of vertical elements or horizontal raster lines in a display to the display height and element size. The equivalent number of line pairs is, of course, one-half the number of elements or raster lines.

Determination is made of the number of vertical elements or raster lines in conformance with the positional accuracy or resolution requirements of the displayed data. Having determined this, the maximum element size can be found for any specific screen height.

Examples: For a typical 500-line TV screen with a height of 15 inches, the maximum element size is 25 mils (see Figure 3) which is consistent with the spot size of normal TV CRT's. Situation type data displays usually require a resolution and differential position discriminability. However, equipment limitations have often resulted in the use of fewer than the optimum number of lines.

Load

The amount of information which can be displayed by a symbology format is proportional to the total number of discrete symbols which can be simultaneously presented. To determine this number, an analysis is first made based on an ordered array of adjacently placed, non-overlapping symbols occupying the entire area of a square display surface. Following this, an approach to the problem of randomly distributed symbols is investigated based on acceptable levels of data loss by symbol overlap for various display load factors.

Ordered Symbol Arrays

For an ordered array we will consider two cases: an array of rectangular symbols spaced vertically and horizontally, as typified by an alphanumeric message format; and an array of adjacent square symbols, representing the maximum number of non-overlapping symbols possible for a situation display.

Rectangular Symbols

For this case, rectangular symbols with a height H and width of 0.65H are used, and are spaced vertically by 0.5H and horizontally by 0.1H.

Thus, each symbol occupies an area of 0.75H by 1.5H. If the symbol height visually subtends 10 minutes of arc for limiting conditions, then the total symbol area will subtend 7.5 by 15 minutes of arc. For a square screen having a side dimension S, it can be shown [1,2] that the number N of symbols of limiting resolution which can be accommodated is given by the relation

$$N = \left(\frac{D}{S}\right)^{-2} \times 10^5 \qquad (2)$$

where D/S is the ratio of viewing distance to screen size.

Square Symbols

If square adjacent symbols, which visually subtend 10 minutes of arc for each side are used, the maximum number is given by [1]

$$N = \left(\frac{D}{S}\right)^{-2} \times 1.1 \times 10^5 \qquad (3)$$

Practical limits for the value of D/S normally lie in the range between 1 and 5. Plots of equations (2) and (3), given in Figure 4, demonstrate that maximum symbol populations are between 4×10^3 and 10^5 for normal values of D/S. While these values are attainable for ordered formats, a more complex problem is posed where symbols are randomly positioned, as in a typical situation display.

Random Symbol Arrays

An approach to this problem was made by considering a square matrix of M total symbol positions and having N symbols of square shape randomly placed

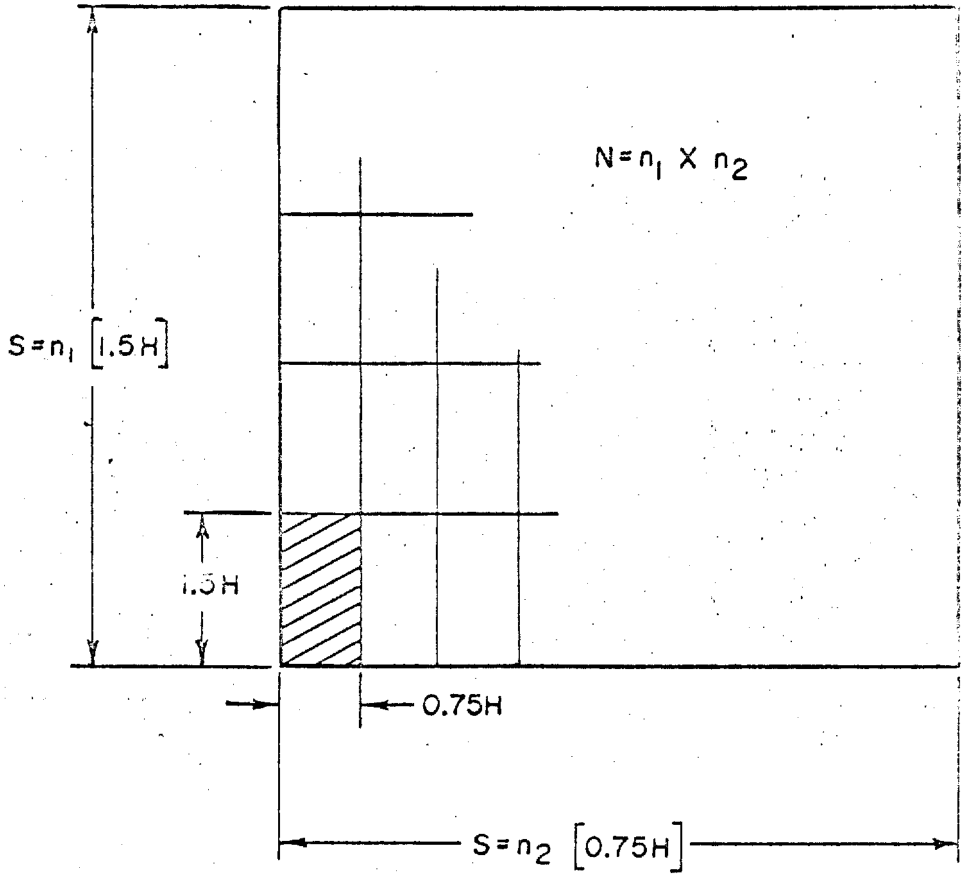


FIGURE A-1

expression was derived[3] for the mean value of the probability that two or more symbols would occupy the same position as a function of the display load ratio N/M. In Figure 5 the mean value of the percentage of overlapping symbols is plotted as a function of the load ratio. The series expression for the distribution of this probability function is not easily evaluated, but is expected to be rather broad. Inspection of Figure 5 indicates that for these conditions, the mean overlap percentage is equal to half the load percentage. Extrapolation of this data is difficult, since neither the overlap distribution function nor the analysis of partial overlap situations is readily subject to analytical expression. However, it might reasonably be postulated that load values of one to five percent would result in acceptably small overlap percentages for typical applications.

For a specific set of conditions, a more exact analysis can be effected by use of Monte Carlo techniques in conjunction with suitable computer programs which take into consideration various data formats, format distributions, and the degree to which data is not randomly positioned. Having this type of data, realistic maximum display load values can be specified for various degrees of data degradation caused by symbol overlaps.

Conclusion

It should be realized that while the

mate determination of values for such major display parameters as overall size, resolution, symbol size and maximum information content, there always remains the necessity to consider system information requirements at the man-display interface, and other psycho-physical limitations of perception which may preclude use of the maximum physical capabilities of the display system.

Appendix A: Determination of Maximum number of Symbols of Limiting Resolution that can Occupy a Square Screen

Equation 1 of the text showed that the relation between minimum resolvable element size and viewing distance D is

$$e = 0.0003\ D \qquad (1)$$

For a symbol of height H which is 10 times e, the relation between symbol size H and viewing distance D is therefore

$$e = 0.003\ D \qquad (A1)$$

It is this relation which is plotted in Figure 2.

Assuming a rectangular symbol having a height H and a width of 0.65H, which is a typical proportion for alphanumeric characters, we can establish nominal horizontal and vertical separations of 0.1H and 0.5H, respectively. Thus, each sym-

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[1] See Appendix A.

[2] These relations strictly hold only for viewing the screen at a normal angle.

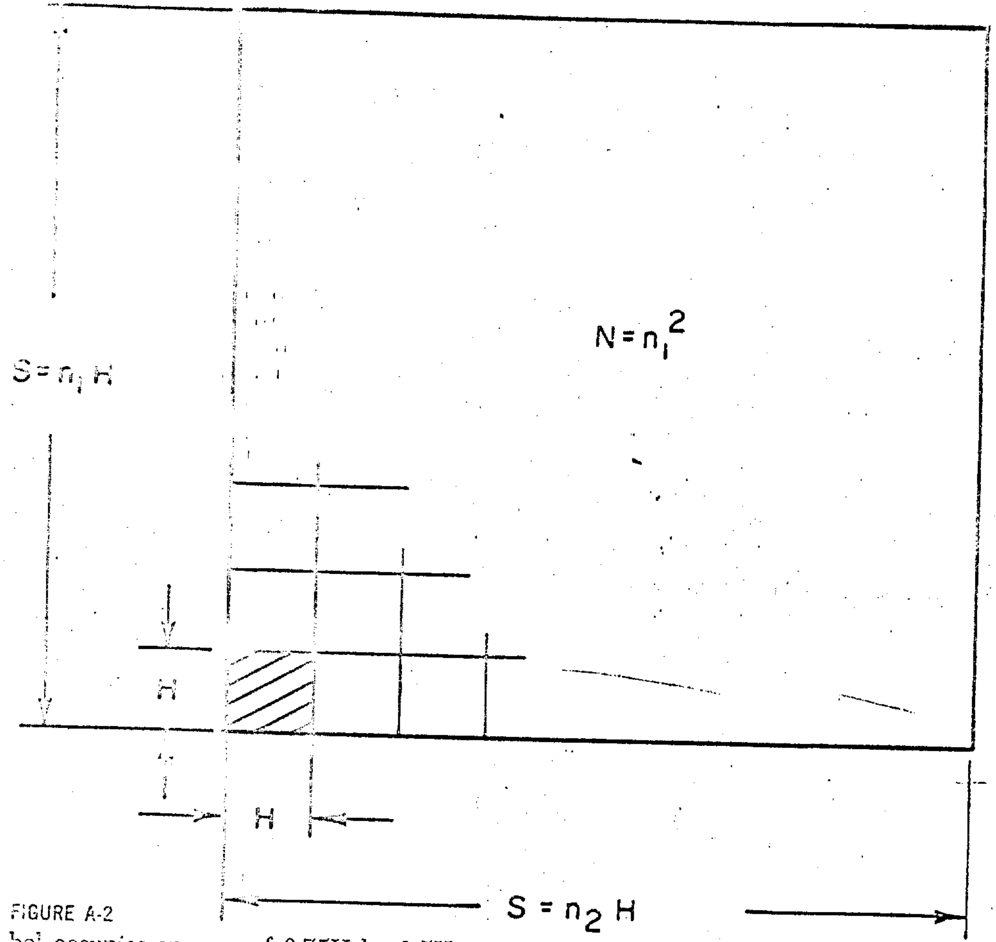


FIGURE A-2

bol occupies an area of 0.75H by 1.5H. these symbols comprise the total area of a square screen having a side dimension S, as in Figure A-1, the total number of symbols will be the product of the numbers along the vertical and horizontal sides, n_1 and n_2. However, n_1 and n_2 are related by the proportion of the symbol area so that

$$n_2 = n_1 \frac{1.5}{0.75} = 2n_1 \tag{A2}$$

Thus,

$$N = n_1 \times n_2 = 2n_1^2. \tag{A3}$$

But,

$$n_1 = \frac{S}{1.5H} \tag{A4}$$

so that (A3) becomes

$$N = 2 \left[\frac{S}{1.5H}\right]^2 = 0.89 \left[\frac{S}{H}\right]^2 \tag{A5}$$

Substituting (A1) for H gives

$$N = 0.89 \left[\frac{S}{3 \times 10^{-3} D}\right]^2$$

$$0.89 \times 10^5 \left(\frac{S}{D}\right)^2 \approx \left(\frac{D}{S}\right)^{-2} \times 10^5 \tag{A6}$$

which relates the maximum number of normally discriminable symbols to the ratio of viewing distance to screen size.

For the case of square symbols of height H adjacently located on a square screen having a side dimension S, as in Figure A-2, the total number of discriminable symbols is

$$N = n_1 \times n_2 = n_1^2 = \left[\frac{S}{H}\right]^2$$

$$= \left[\frac{S}{3 \times 10^{-3} D}\right]^2$$

$$= \left(\frac{D}{S}\right)^{-2} \times 1.1 \times 10^5 \tag{A7}$$

It should be emphasized that these represent maximum limit values which appreciably exceed those which normally would be used when other factors such as the effects of symbol size and quantities on human information assimilation rates are considered.

Appendix B: Determination of Overlap Probability of Randomly Placed Symbols

A partial analytic solution to the problem of randomly placed symbols can be obtained by considering a matrix having M total symbol locations and which contains N symbols located at random. The mean value of the number of symbols which overlap, i.e., are not uniquely located, enables determination of the mean overlap percentage. Evaluation of the distribution of this function is also required for a complete solution to the problem

To find the mean value of the number of overlaps, let D be the total number of occupied matrix locations. The mean number of overlaps P is then

$$\overline{P} = N - \overline{D} \tag{B1}$$

The probability that a given location will not be chosen is

$$\left(\frac{M-1}{M}\right)^N$$

and the probability that it will be chosen once or more is

$$1 - \left(\frac{M-1}{M}\right)^N$$

Therefore, the mean value of D, which is the mean value of unique locations chosen is

$$\overline{D} = M \left[1 - \left(\frac{M-1}{M}\right) N\right] \tag{B2}$$

From (B^1) and (B^2) it follows that the mean number of overlaps is

$$\overline{P} = N - M \left[1 - \left(\frac{M-1}{M}\right) N\right] \tag{B3}$$

Numerical evaluation of (B^3) directly using realistic values is difficult. However, the fact that

$$\left(1 - \frac{x}{y}\right)^y \cong e^{-x} \tag{B4}$$

if $y >> x$ permits use of tables of natural logarithms or Poisson distributions for evaluation if (B^3) is put in the form

$$\overline{P} = N - M \left[1 - \left(1 - \frac{1}{M}\right) N\right]$$

$$= N - M \left[1 - \left(1 - \frac{N/M}{N}\right) N\right]$$

$$\cong N - M \left[1 - e^{-N/M}\right] \tag{B5}$$

The mean percentage of symbol overlap $\overline{\sigma}$ is thus

$$\overline{\sigma} \cong 100 \left[\frac{N - M\left[1 - e^{-N/M}\right]}{N}\right]$$

$$\cong 100 \left[1 - \frac{M}{N}\left(1 - e^{-N/M}\right)\right] \tag{B6}$$

which has been evaluated and plotted in Figure 5 of the text.

Evaluation of the overlap distribution function leads to iterative expressions which are impractical to evaluate except by use of a computer. While this was beyond the scope of the present investigation, it is evident that further effort in this area would yield useful data.

The author would like to acknowledge the assistance of Mr. David M. Jones

Examples: Electroluminescent panel, panel of light vanes, light amplifier panel.

4. *True 3-D* — "Crystal Ball" display.
   a. Rotating panel
   b. Oscillating plan
   c. Illuminated interstices
   d. Projecting rods

Physical Characteristics
(Performance parameters)

1. *Size Limitations* — Size of CRT or projection screen, etc.
2. *Brightness* — (More properly known as luminance)
3. *Ambient Limitations* — Darkened room, polarized lighting, broad band blue, etc.
4. *Response Time* — This could mean writing speed, frame time, target updating time.
5. *Resolution* — Ability to distinguish two separate targets is measured in many ways.
6. *Updating Capability*
7. *Hard Copy Capability*
8. *Symbol Limitations*
9. *Color and Halftone Capability*
10. *Storage*

Conclusions

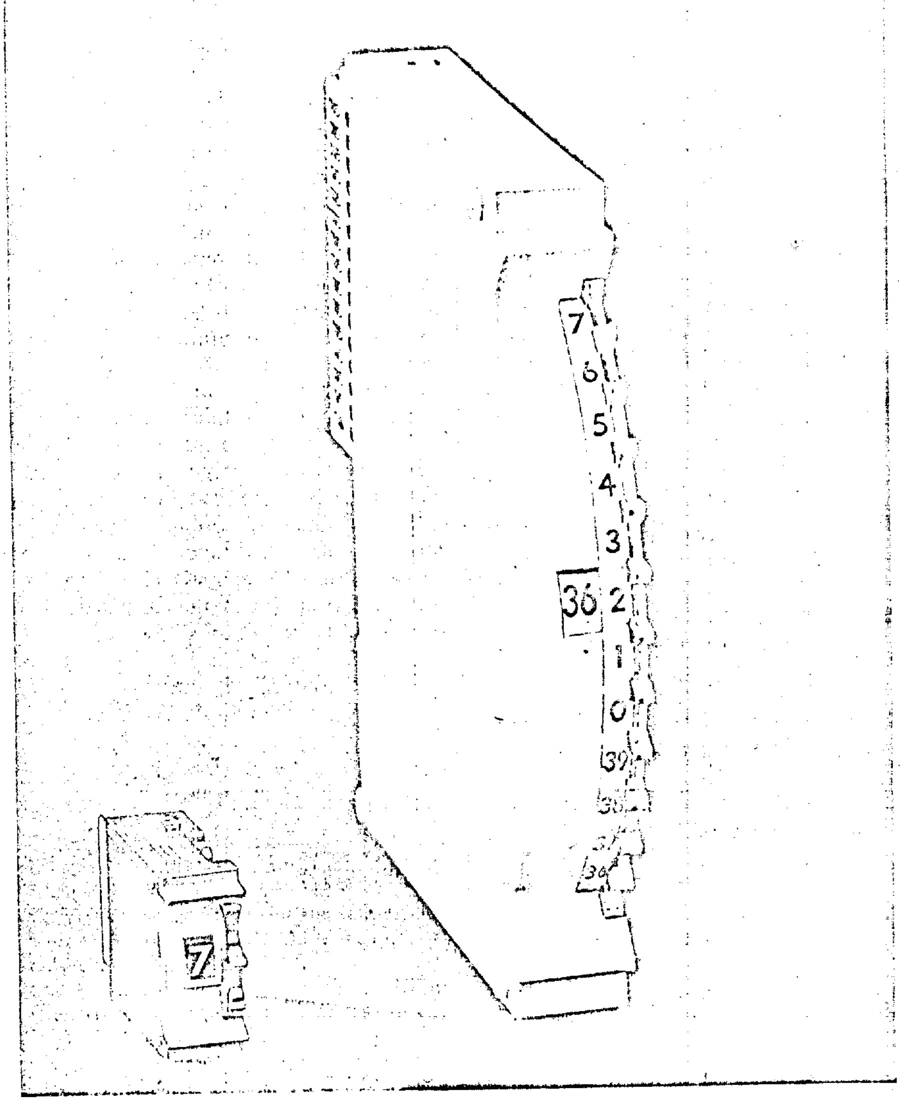
While the foregoing attempt at display categorization and classification is admittedly incomplete, it does serve to shift emphasis from the usual designer's viewpoint to one which regards a display as a black box performing certain functions. Once the desired functions have been determined and performance parameters specified, then one can begin to select suitable hardware. Please note that this material represents the views of the author only, and in releasing it for publication the U.S. Naval Research Laboratory does not necessarily endorse the contents.

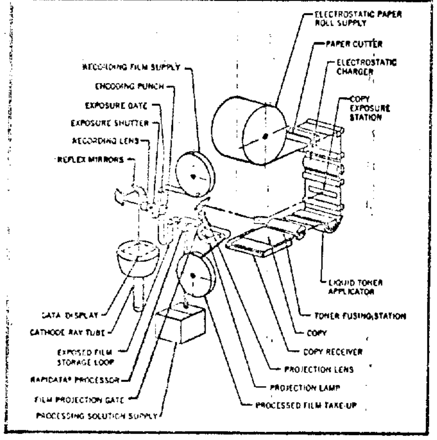
H. G. TALMADGE, *Head*
Display Techniques Section
U.S. Naval Research Lab.
Washington, D.C.

Whitham statement challenged

In reading the article *The Determination of Display Screen Size and Resolution Perceptual Limitations* by Mr. (Glenn E.) Whitham, (*ID, Vol. 2. No. 4, July/Aug.* '65) he makes the statement, "The equivalent number of line pairs is, of course, one-half the number of elements or raster lines." This statement holds true for a chart or device which actually has line pairs spaced exactly upon the raster. However, if other information than this rather limited item is displayed, resolution is somewhat less than what you might expect. A figure often used is 1.4. I trust that author Whitham will be a little more specific as to his intentions in the future.

JOHN SHAVER, P.E.
The Bunker-Ramo Corp.
Sierra Vista, Ariz.





Mr. Whitham submitted the following reply, in response to ID's request for his answer to Mr. Shaver's letter.—Ed.

Mr. Shaver is indeed correct in pointing out that the resolution of a line raster along the axis normal to the lines is degraded for arbitrary display subject material to a value less than indicated by consideration only of the line structure. This resolution loss factor has been found by various experimental[1, 2, 4] and theoretical[3] studies to lie in the range of 0.53 to 0.85, with 0.7 a good nominal figure. For obtaining a given value of display resolution the number of lines required is 1/0.7 or 1.4 times the number of desired resolution elements along the axis normal to the lines. This correction factor is commonly known as the Kell factor. Further discussion of this subject was included on page 10 of the paper by Dr. Luxenberg, *Quantitative Measures of Display Characteristics* which just preceeded my paper in the July/August 1965 issue of *Information Display.*

Glenn E. Whitham
Staff Engineer
Raytheon Company
Wayland, Mass.

1. R. D. Kell, A. V. Bedford, and M. A. Trainer, "An experimental television system-the transmitter", Proc. I. R. E., Vol. 22, pp 1246-1265; November 1937.
2. A. V. Bedford, "Figure of merit for television performance", R. M. A. Eng., Vol. 2, pp. 5-7; November 1937.
3. H. A. Wheeler, A. V. Loughren, "The fine structure of television images", Proc. I. R. E., Vol. 26, pp. 540-575; May 1938.
4. Baldwin, "'Subjective Sharpness of television images", Proc. I. R. E., Vol. 38, pp. 458-468, 1940.

P.S. The second sentence of the last paragraph on page 17 of my paper should read, "Situation type data displays usually require a resolution of about 1000 to 2000 elements for adequate symbol resolution and differential position discriminability."

Information requested

We have been doing a considerable amount of work in the field of electroluminescent displays, and in the course of this work several product ideas have evolved in the area of moving pointer and moving scale panel indicators.

In order to determine the direction our product development work should take we are trying to collect as much information as possible on desirable characteristics of panel indicators, user preferences and requirements and the potential value of electroluminescent displays in providing a useful product improvement.

Any information that you could supply which would be helpful in this investigation would be greatly appreciated, including suggestions of other possible sources of information.

C. H. Warshaw
Industrial Products Manager
Huyck Systems Co.
Huntington Station
Long Island, N.Y.

We are presently engaged in a study of the graphic recording field for process control and laboratory usage, and are interested in future trends in this area. Therefore, I would appreciate information that you feel may be helpful to us.

L. P. Lane
Arthur D. Little, Inc.
Cambridge, Mass.

I am very interested in an area of the field in which I find no reference contained in recent issues of your magazine. This is in the requirements, theory and/or construction of display and status boards posted manually from the rear. I have seen several in operation in military installations but have never had the forethought to look into the manufacturing stage.

Could I impose upon your good offices to look among your advertisers and contributors and to furnish me some contacts with technical competence in this particular area. I will be very appreciative of any assistance you can render in this search.

Henry D. Batey
Chief, Graphics
United Aircraft Corp. Systems Center
Farmington, Conn.

ID readers who can contribute desired information are urged to communicate directly with the above correspondants — Ed.

SID and Journal helpful

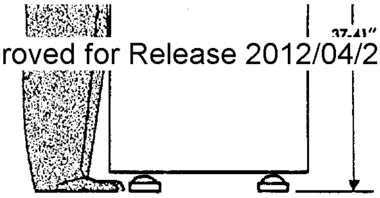
Both the activities of the *Society for Information Display* and the articles in *Information Display* are of great interest to me. Material presented in the Journal has contributed significantly to my knowledge and understanding of data display technology.

It is my responsibility to design and implement the "Total Information System", culminating in display design in the following categories:

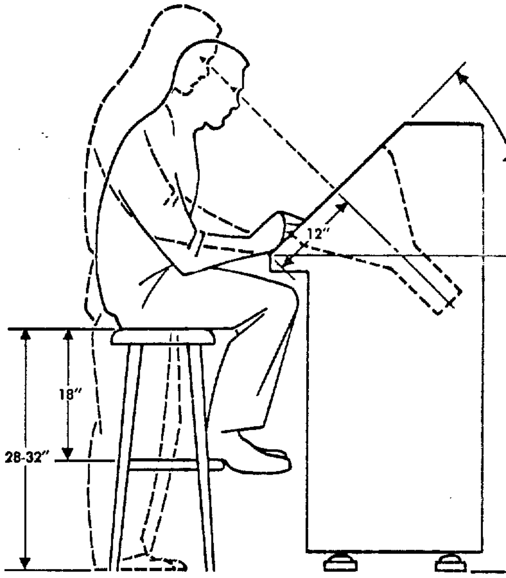
1. Large Area Display
2. Small Area Display
3. Desk Top Display

The project in which I am engaged is designed to provide the company with a system in the 1970's that will be suitable to the environment at that time.

John P. Thompson
Director of Data Processing
Hoffmann-La Roche, Inc.
Nutley, N.J.

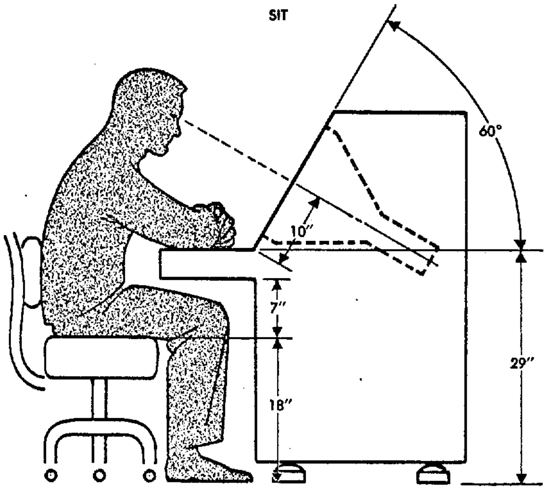


STAND



SIT-STAND

SIT



The illustrations show recommendations for angular mounting of visual displays such as PPI-type CRT's. These dimensions are only approximate. They do, however, represent usable standards for about 90 per cent of the male population.

From Human Engineering Guide
for Equipment Designers"
by Wesley Woodson & Donald Conover
1964 University of California Press

DISPLAYS, PAP

The Visual System in

In command centers we find for the first time the need to read cathode-ray displays, projection displays, and hard copy under the same level of illumination. Neither the illumination of theatres nor that of offices is suitable, the one being too low for reading papers and the other too high for reading displays.

This paper shows a method for computing the illumination at which both displays and hard copy can be read with equal ease, or conversely for showing the advantage given one data source over the other by the use of a different level of illumination. Properties of displays and hard copy needed in the computation are given, and a sample computation is presented. It is shown that the computed value of illumination is both satisfactory and compatible with the recommendations of the Illuminating Engineering Society. Means for avoiding eye strain and fatigue (applicable to any level of illumination) are restated.

If a command or management center is to be successful, the human decision maker must receive all the assistance from his data sources that the state of the art permits. To this end the display equipment, the hard copy, and the illumination must all be matched to the needs of the user. There is much information on the size, shape, etc. of the symbols that should be presented, a great deal of information on the techniques for producing and presenting the symbols, but very little on the environment in which the displays should operate. This paper is an attempt to fill a major part of this gap—the illumination of the operating area.

One may ask why this should be a serious question, since the subject of illumination has received so much attention in the last fifty years. The reason is that in command centers one finds for the first time that self luminous displays—cathode ray tubes, electroluminescent panels, projection screens, etc.—are combined with reflective displays—messages, maps, operating plans, budgets, schedules, etc.—with the requirement that they be used in close sequence. It follows that the illumination must be at one time suitable for the electronic displays and for the hard copy.

There is an extensive literature on the illumination of rooms for self-luminous displays, beginning with the data gathered by the then Society of Motion Picture Engineers on the lighting of movie theaters. This art was adapted during the war for radar display rooms and other weapons control centers, and extended by use of narrow-band light to take advantage of a color difference. The philosophy of minimum illumination is still seen in rooms where edge-lit, grease-pencil plots are kept. With the advent of brighter displays there came a demand that we "come up out of the caves" into an office atmosphere.

IES Recommendations

The recommendations of the IES (Illuminating Engineering Society) "reflect a consideration of many variables such as visual data, . . . economic factors, convenience, and availability." On examination it is found that their visual data are based on reflective materials—the reading of papers, the performance of shop tasks, etc. It has long been known that when such tasks are difficult because of poor form, extra fine lines, low contrast, etc. a higher level of illumination is helpful. It has been a long time since electric illumination has been expensive, and it is certainly convenient and available. One must conclude that there is no factor in the IES's considerations which exerts a strong influence toward lower illumination, and since they have no control over the quality of material in view, it is quite proper that their recommendations be generous.

Obviously, in a command center a compromise between these extremes is required, and the compromise must be pleasing to persons of high rank. With due attention to the opposite effect of illumination on reflective and self luminous displays, a best illumination can be achieved, and at the present state of the art it will be a very satisfactory illumination if the conditions are met with reasonable care.

The Data

It has long been known that the ease of seeing is related to the illumination, the size of the detail that must be seen, and to the contrast of that detail to the background; and various pairs of these variables have been studied parametrically until the relations are well known. During an eight year research (as of 1959) Dr. H. Richard Blackwell has related these four variables using the same group of observers.

In these experiments the subjects faced a hollow box which covered a wide field of view and which was illuminated evenly with white light. Near a reference mark on the back wall there was a translucent spot of white plastic which appeared the same brightness as the rest of the wall under the front illumination, but which could be back illuminated to a higher level, and the equipment was so built that both brightnesses, the size of the spot, and the duration of its back illumination could be varied over wide ranges.

The observers were thoroughly trained in practice runs not included in the data, to eliminate variation ascribable to learning. They sat before the box for a sufficient time for their eyes to become adapted to the light level to be used; they were then told the limits of a time interval in which the spot might, or might not, have been back illuminated, and were asked to decide whether or not they had seen it.

Since the same color light was used for the background and the spot, the contrast could be computed using the simple relation:

$$C = \frac{B_H - B_L}{B_L} \qquad (1)$$

where C is the contrast
B_H is the higher of the two brightnesses
and B_L is the lower of the two brightnesses

This expression for contrast has a value which varies from zero to infinity, and (unlike some) it has the advantage that the zero value conforms to the condition which has no visible contrast.

Over 80,000 observations were made. For each set of conditions the data were

S, and LIGHTING

Command Centers

by A. C. STOCKER

first corrected for the known percentage of lucky guesses, then were fit to the normal ogive so that the 50% point (the point of maximum slope) could be determined with accuracy. The curves were then smoothed by the use of the known parametric relations between pairs of variables. At [illegible] of this process it was found that an introduced variation as small as 2% would require an obvious violation of one of the parametric relations.

This work has been reported in various stages of progress, references 1, 2, and 3 being the more important and carrying references to the others. The complete data, without some of the details of how they were gotten, are given in reference 3. Because all the data came from the same basic source, because all four variables are covered, and because of the care used in smoothing, it is felt that the results constitute an unusually useful statement of fact.

To extend these data to the conditions and requirements of practical seeing, Dr. Blackwell uses the concept of field factors by which to multiply the required contrast. A factor to compensate for the difference between skilled observers using forced choice and the ordinary reader facing a new problem was determined experimentally. Factors for off-axis viewing, for the lack of warning, and for the frequency of presentation were determined experimentally. The latter three were checked with reasonable accuracy by use of a task evaluator, an instrument whereby a task and a test spot could both be viewed under conditions of controlled contrast and that contrast reduced to minimum visibility.

The development of the field factor concept is described in reference 3. The overall factor, as determined by the process described above, is in the range from 30 to 37.

While the basic data are felt to be valid beyond doubt, the value of the field factors has been questioned, some workers feeling that the proposed values lead to too low a level of illumination. The author has arbitrarily used an overall value of 40 in making up his human performance curves; however, it will be shown later that the value of the field factor has no bearing on the selected illumination so long as the same value is used in the computations for both hard copy and self-luminous displays.

The author has applied a field factor (40) to the data of reference 3 for detail subtending angles of 1, 2, and 4 minutes of arc, and for illuminations between 0.1 and 100 footcandles and has interpolated for easier use. The resulting curves are given as Figures 1, 2, and 3.

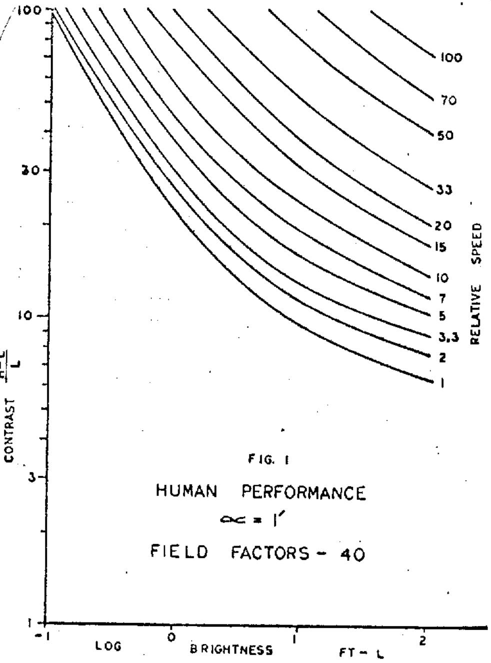


Fig. 1 Human performance when reading symbols with a stroke width (alpha) of one minute of arc.

It must be stressed that the speeds shown in Figures 1, 2, and 3 are not reading speeds, but are the inverse of the times when the spot was back illuminated in the tests. The term "reading ease" was considered for a while, but it is hard to conceive of an ease of 100, so the term "relative perception speed" was finally chosen.

The Selection of an Illumination Level

It is obvious that both the self-luminous and the reflective displays must be readable; lacking other indication it will here be assumed that they should be equally readable. The optimum illumination level is, then, that which gives each the same relative perception speed. This may easily be found once the data are put in the proper form.

The preparation of data for reflective displays (hard copy) is simple.
The steps are these:

a) Determine the minimum size of detail that must be easily readable, compute the angle this will subtend at the observer's eyes, and select the curve with this value of alpha.
b) Determine the contrast of the material, and lay a straightedge across the curve at this value.
c) Multiply selected values of illumination by the reflectivity of the paper to establish the background brightness.
d) For each value of brightness, read the relative perception speed.

The preparation of data for the self-luminous type of display is a little more complex. The steps are these:

a) Determine the minimum size of detail that must be easily readable, compute the angle this will subtend at the observer's eyes, and select the curve for this value of alpha.
b) Determine the excitation brightness available at the screen (that supplied by either the electron beam or the projector) and apply factors for the gain and loss of the screen to achieve the visible brightness of the symbols.
c) Apply factors for the reflectivity of the screen, attenuation of its support, the effectiveness of hoods, etc., to selected values of ambient illumination to determine the background brightness.
d) Compute the contrast from item b) and c) above. (These computations are discussed at greater length under Properties of Displays and Hard Copy.)
e) For each value of illumination, lay

a straightedge across the curve at the resultant contrast, and at the corresponding value of background brightness, read the relative perception speed.

To determine the optimum value of illumination, plot relative perception speed vs. illumination for both types of displays. It is obvious that one will have a positive slope and one a negative; the point where they cross is, then, the illumination at which the two types can be read with equal ease.

Properties of Displays and Hard Copy

Before the design of a command center can be started, it is necessary to have at least an idea of the properties of the display materials that will be used therein. This section will discuss the properties of a representative sample of materials, and will discuss some of the steps that may be taken to assure good legibility.

Hard Copy—Hard Copy will long continue to carry a large and important portion of the information needed in a command center. Yet the information that is available on the properties of hard copy is very limited. The size of type, for instance, is the size of the block on which the face is cut, not the size of the face itself, and there are only very general statements on the reflectivity of papers and inks. For that reason a series of measurements was made.

In these measurements the symbol height was taken as the prependerant height—if the word was in lower case, then the height of a lower case a, e, o, n or similar letter was measured. Some letters have a variable stroke width. However, experience has shown that the intelligence is carried in the heavier portions of the symbol; it is in fact possible to read material in which a faulty reproduction process has eliminated the thin strokes completely. So when a variable stroke width was encountered, the heavier portion of the stroke was measured. These data were taken with a measuring microscope.

The determination of reflectivity presented a problem because of the small area available in the symbol and the known tendency of the human eye to be influenced by the surroundings. A series of paper chips varying from white to black were gotten by selecting from paper stocks where that was possible, and by dyeing to fill the gaps. These chips were placed in a diffuse white illumination measured with a Weston Illuminometer, their brightness was measured with a Spectra Spot Brightness Meter, and their reflectivity was computed. These chips could then be compared directly to the paper of a display. The reflectivity of symbols was determined by placing a chip partially across

TABLE 1
PROPERTIES OF HARD COPY

MATERIAL	HEIGHT	STROKE				
	Mils	Mils	Angle @ 14" Mins	Color	Reflect.	Contrast
Maps						
Army Map Service, NK 18-11						
Paper				white	.65	
Names—large	160	24	5.5	black	.07	8.3
small	40	9	5.2			
Highways		38	9.5	rd & blk		high
Railroads		7	1.7	black		
Creeks		5	1.2	blue	.1	5.5
Contours		5	1.2	tan		fair
Elevations	52	7	1.7			
Sectional Air Chart, Winston Salem						
Paper				Color wash to indicate ground altitude, Est. Avg.	50	
Names—large	110	20	5	black	.1	4
small	44	7	1.7			
Smallest print	40	8	2			
Highways		25	5.5	gray	.3 Est.	.6
Scale tics		8	2			
Contours		9	2	tan		fair
Nautical Chart, H.O. 1290						
Paper				white	.65	
Names—large	144	14	3.5	black	.09	6.2
small	40	10	2.5			
Smallest print	24	5	1.2			
Depth contours		5	1.2			
Soundings	60	9	1.2			
Geological Survey, Redmond, Washington						
Paper				white	.7	
				Green overprint for wooded areas		
Names—large	120	15	3.7	black	.1	6
small	60	10	2.5			
Smallest print	45	7	1.7			
Highways		25	5.5	red & blk		high
Roads	dual	6	1.5			
Creeks		8	2	blue		good
Contours		5	1.2	tan		fair
Office Material						
Good pulp paper					.7	
Average pulp paper					.65	
Yellow copy paper					.5	
Typewriter samples						
Paper					.7	
Make A Electric	110	15	3.7	black	.1	6
Make B Elite	110	10	2.5	black	.12	4.8
Make B Pica	114	10	2.5	black	.1	6
Make B Pica—old ribbon	114	7	1.7	gray	.15	3.7
Teletype printer						
Paper				gray	.6	
With new ribbon	105	20	5	black	.1	5
With old ribbon, top		12	2.7	black	.12	4
With old ribbon, bottom		Indef.			.2	2
Computer Printer output						
Make C	95	9	2.2	black	.08	7.9
Make D	100	10	2.5	black	.1	6
Make E	100	17	4.2	black	.08	7.1
As a basis for comparison—						
New York Times						
Paper					.46	
Text	55	10	2.5	black	.1	3.6
Office Copiers						
Make F (translucent material)						
Paper—on dark desk					.45	
Print					.12	2.8
Paper—on white paper					.65	
Print					.12	4.4
Make G (opaque material)						
Paper					.65	
Print					.10	5.5
Pencil						
Pulp paper					.65	
Mechanical pencil, .032" lead, HB		20	5	black	.2	3.3
2H newly sharpened		10	2.5	black	.25	2.3
2H fairly dull		15	3.7			
B newly sharpened		12	2.7	black	.12	4.5
B dull		40	10			

of type and examining the type the edge of the chip through a low power microscope, the microscope magnifying the type to the point where a good comparison could be made. Some materials, pencil as an example, had to be measured under diffuse light to prevent specular reflection.

The data gathered in these tests are given in Table 1. Special attention is invited to the data on office copying machines, pencil copy, and typewriter and teletype output. It will be noted that the contrast can be raised materially, and in some cases the width of the stroke increased by a significant factor, by the proper selection of equipment and materials and the use of fresh ribbons. One must conclude that the legibility of the hard copy is to that extent a function of the interest shown by the members of the staff.

Self-Luminous Displays—Self-luminous displays—cathode ray tubes and projection screens—must combat the ambient illumination, so much of this section will have to do with means for maintaining good contrast. The light in the symbol, the light that carries the useful information, comes from either an electron beam or a projector; we will consider cathode ray tubes first.

Rather than get into a discussion of products, the author will here assume that the tube has a brightness of 50 foot-lamberts available at the phosphor, and offers assurance that this level is within the state of the art using crystalline phosphors. The reflectivity of the phosphor is assumed to be 85%, highly diffusive. The problem, then, is to achieve as good contrast as is possible with this device.

The first step to consider is the use of a gray glass for the face plate of the tube. It is true that such glass reduces the brightness of the symbols by the transmission (filter factor) of the glass. But the ambient illumination must pass through the glass twice, so the contrast is increased by the inverse of the filter factor. This can be a significant amount; RCA lists face plates with filter factors in two groups, one near 0.75 and one near 0.4.

The next step is the use of a cap-bill hood to keep as much as possible of the ambient illumination from falling on the screen. Properly designed, such a hood can easily have a factor of 0.5 without restricting the viewing angle.

The effectiveness of a hood may be increased by limiting the angles at which the light approaches the equipment, as can be done by hanging properly designed honeycomb gratings below the light sources. The light can still come from the major portion of the ceiling, so it is fully diffuse (or indirect); it is merely limited to those angles which will not get under the hood. It is believed that the hood factor can be changed from 0.5 to 0.25 by this means.

After these steps, the direct ambient light will be reduced to the point where the light reflected from the equipment, from white shirts, etc., becomes important. Such secondary sources can be objectionable when they are specularly reflected from the tube face and appear as unwanted images superposed on the data. Glossy finishes should not be used on equipment, furniture, etc.; a medium gray mat surface is much less objectionable. Such light as remains can be rendered innocuous by etching the tube face to a fine mat surface. This is not truly a non-reflecting coating—it merely spreads the reflection over such a large area that the brightness is reduced and the shape of the source obscured. It is, however, a very effective step.

Circular polarizer use

A circular polarizer can be used for the functions of the filter glass and the mat first surface, either for better performance or when the desired properties cannot be had in the available tube. It is not a complete cure, for it itself has bright specular reflection from its front surface. However, it may be used as a plane surface, and the range of incident angles that gives objectionable reflections from a plane surface is much less than the range that gives reflections from a spherical surface.

Projection displays can also take advantage of absorption in the screen support, of a hood, of directive room light, and (in some types) of a mat front surface on the screen. In addition, they can take advantage of directivity.

Directive screens reflect (or transmit) more light in a preferred direction than in other directions. They therefore are said to have "gain", this being the ratio of the brightness in the preferred direction to the brightness of a highly diffusive screen subject to the same illumination. Values between 2 and 10 are common. If the viewers can be located along the preferred axis, the brightness of the data symbols will be increased while that from light sources not near the projector will be decreased, and an increase in contrast will result. This effect reaches its peak in rear projection screens, where the steps which decrease the diffusion of the projected light also decrease the reflectivity to ambient light, and where it is possible to take advantage of a filtering support material.

However, a fundamental characteristic of gain is its sensitivity to changes in angle. Assuming the plane of the screen is correct for the location of the projector and the center of the audience, there will still be a change in brightness due to looking at different portions of the screen or to the viewer's moving about the room. If this change is to be held within acceptable bounds, then directivity must be used with care.

The quantitative relations follow, all based on the fundamental relations that:

$$C = \frac{B_H - B_L}{B_L} \qquad (1)$$

$$B = I \; R \qquad (2)$$

$$I_p = \frac{L_p}{A} \qquad (3)$$

For hard copy:

$$B_H = I_A R_p$$

$$B_L = I_A R_I$$

substituting in (1)

$$C = \frac{R_p - R_I}{R_I} \qquad (4)$$

For both cathode-ray tubes and projection screens the brightness of the symbol is the sum of that produced by the intended excitation and that of the background as produced by stray electrons or the transmission of "opaque" parts of the film.

For cathode-ray tubes:

$$B_H = B_{ph} T + B_L$$

$$B_L = I_a R_{ph} T^2 + B_x T$$

substituting in (1)

$$C = \frac{B_{ph}}{I_a R_{ph} T + B_x}$$

For front projection:

$$B_H = \frac{L_p}{A} G + B_L$$

$$B_L = B_a + B_x G$$

Here B_a is the sum of the brightnesses due to the individual room illuminants, each with the value of gain required by its angles. This is so complex that the value is usually determined by measurements on a mockup or on the final assembly.

substituting in (1)

$$C = \frac{L_p G}{A\,(B_a + B_x G)}$$

For rear projection, with the diffusing layer on the projector side of the screen:

$$B_H = \frac{L_p}{A} GT + B_L$$

$$B_L = B_a + B_x GT$$

$$B_a = I_a R_s T^2$$

A single expression for B_a is made possible here by the small difference in reflectivity for the angles of the different room illuminants.

substituting in (1)

$$C = \frac{L_p G}{A(I_a R_s T + B_x G)}$$

In the above:

A = Area of the projection screen, in square feet.

B = Brightness, in foot-lamberts.

B_a = Brightness due to the ambient illumination.

B_H = The higher of two brightnesses.

B_L = The lower of two brightnesses.

B_{ph} = Brightness of a phosphor due

to electron impact or other excitation.

[illegible] = Brightness due to unintentional excitation, as by stray electrons or transmission through the "opaque" areas of the film.

C = Contrast

G = The gain of a projection screen for the incident and reflected angles involved. Note – commercial values for G usually include the reflectivity, so it is not stated separately.

I = An illumination, in footcandles.

I_a = The ambient illumination.

I_p = The projected illumination.

L_p = The light flux delivered to the screen by the projector, in Lumens.

R = The reflectivity.

R_p = The reflectivity of the paper.

R_I = The reflectivity of the ink.

R_{ph} = The reflectivity of the phosphor.

R_s = The reflectivity of the projection screen.

T = The transmission (filter factor) of the screen support where the support is between the screen and the observer.

Sample Computation

In order to demonstrate the process and to get a feeling for the level of illumination the process will indicate, a sample calculation was carried through using the nearest value of alpha for which there was a curve available (Figures 1, 2, and 3.)

For hard copy, an Army Map Service map, two typewriters with different weight of type face, a teletype machine, and a mechanical pencil were taken as representative of the materials that might be found in a military command center.

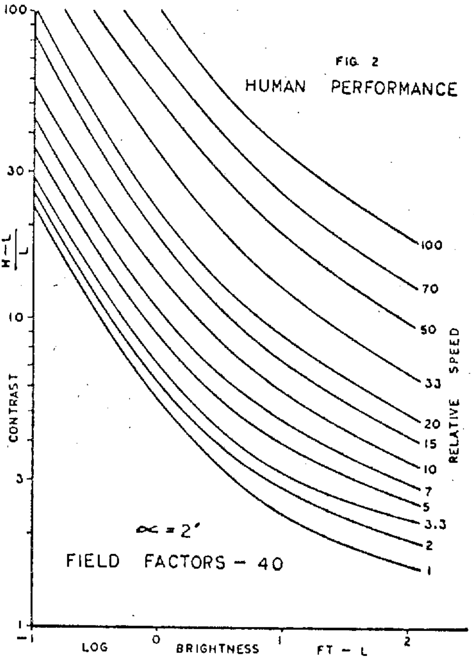


Fig. 2 Human performance when reading symbols with a stroke width (alpha) of two minutes of arc.

The results of the computation are given in Table 2 and plotted in Figure 4.

For the display, a cathode ray tube was chosen and assumed to have a phosphor with a brightness of 50 foot-lamberts and a reflectivity of 0.85. Filter factors of 0.4 or 0.75 were used, alpha was taken as 2′ or 4′, and the hood factor was taken as 0.5 or 0.25. These conditions can also be met in a projection display if the screen size is properly balanced to the available projected light. The results of the calculation are given

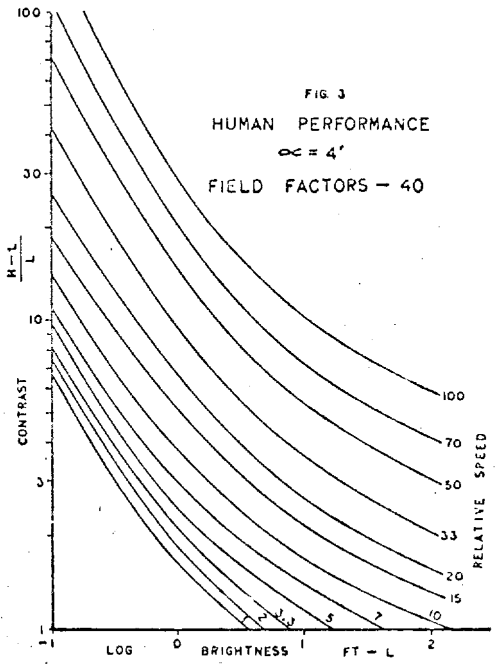


Fig. 3 Human performance when reading symbols with a stroke width (alpha) of four minutes of arc.

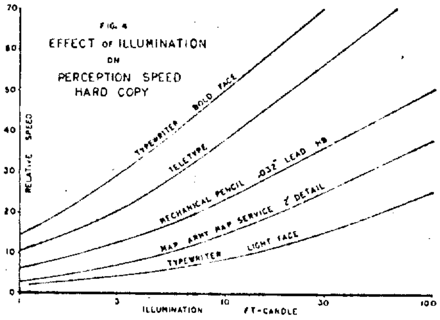


Fig. 4 The effect of illumination on human perception speed when reading hard copy.

These speed va [illegible]

may

TABLE 2

READABILITY OF HARD COPY

Item	AMS Map		Typewriter Make A		Typewriter Make B		Teletype		Pencil HB .032″ lead	
Paper Refl.	.65		.7		.7		.6		.7	
Contrast	8.3		6		6		5		3.3	
Min. Alpha Mins.	2		4		2		4		4	
Illumination ft-candle	B	Speed*	B	Speed*	B	Speed*	B	Speed*	B	Speed*
1	.65	2.7	.7	14.5	.7		.6	10.5	.7	6.2
2	1.3	5.8	1.4	22	1.4	3.2	1.2	16	1.4	10
4	2.6	8.3	2.8	35	2.8	5.5	2.4	25	2.8	14.8
8	5.2	13	5.6	45	5.6	7.7	4.8	35	5.6	21
12	7.8	16.5	8.4	55	8.4	9.7	7.2	42	8.4	26
20	13	21	14	63	14	13	12	48	14	33.3
40	26	28	28	75	28	17	24	62	28	40
80	52	35	56	90	56	23	48	73	56	47
100	65	38	70	96	70	25	60	80	70	50

*See text for meaning.

er, this implies a larger symbol reduction in the number of sym- that can be presented on a given e screen. The specification writer is ced with a compromise, which he must ke with the knowledge that the selection of a too-small symbol will impose a penalty in legibility, and that this penalty will have to be paid day after day by the commander and his staff.

The display plotted in curve "B" of Figure 5 and the Army map were then selected as representing the displays that might be considered the critical pair in some fictitious command center, and their curves were replotted in Figure 6. It is obvious that their crossing point specifies the illumination at which the critical hard copy and the critical display can read with equal ease.

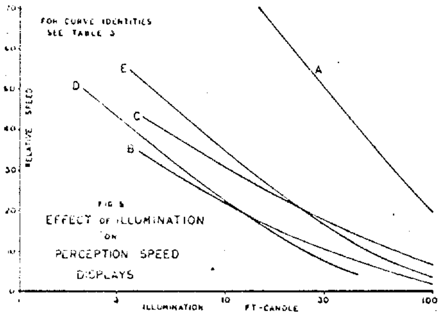


Fig. 5 The effect of illumination on human perception speed when reading self-luminous displays.

It should be stated again that the speed scale is not the reading speed, but merely a way of achieving comparison.

Several things can be learned from Figure 6. For one, it is possible that either class of display can be improved. The brightness of the cathode ray tube may be increased or the suppression of the ambient illumination improved; the map may be printed on better paper, or its contrast may be increased by a change of ink. The interesting point is that any improvement will raise the curve for that display, and if the value of illumination is adjusted to suit, the ease of reading of *both* displays will be improved.

Second, it must be recognized that it will sometimes not be possible, or perhaps desirable, to use the value of illumination that the computation calls for. On such an occasion the plot offers numerical indication of the advantage given one type of display and the penalty imposed on the other by the required level of illumination.

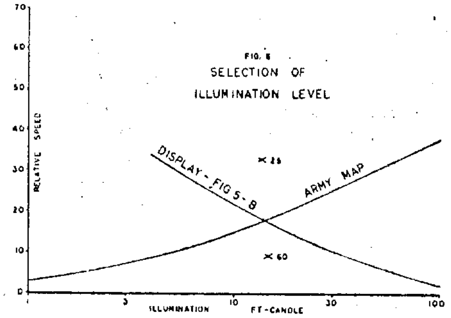


Fig. 6 The selection of an optimum illumination for reading both hard copy and self-luminous displays is accomplished when the relative perception speeds are equal.

And third, the small crosses marked 25 and 60 represent the crossing points of two other sets of curves for the same displays but based on human performance curves in which the field factors were taken as 25 and 60. The three crossings indicate the same value of illumination to within the accuracy with which the performance curves can be read and their plot smoothed; it must be concluded that the value of the field factor has no bearing on the computed value of illumination so long as the same factor is used in the computations for both self-luminous displays and hard copy.

Suitability of the Computed Illumination

Since the computed level of illumination is markedly lower than the general recommendations of the Illuminating Engineering Society for offices, it is proper to question whether or not it is suitable. This must be asked in two parts—is it sufficient? and is it pleasing?

Many years ago a number of observers were given control of the illumination and were asked to find the value that was best for reading the *Saturday Evening Post.* The reported values follow:[6]

Available value of illumination, foot candles	10	30	45
Chosen value	5	12	16

The very human tendency to choose a middle value is apparent, and it must be remembered that the observers were accustomed to a lower level of illumina-

Based on hi contrast should be much brighter for photos

TABLE 3

READABILITY OF DISPLAYS

Phosphor — Brightness, 50 ft-L; Reflectivity, 85 %

Filter Factor	0.4			0.4			0.4			0.75			0.75		
Symbol B ft-L	20			20			20			37.5			37.5		
Alpha Minutes	4			2			2			2			2		
Hood Factor	.5			.5			.25			.5			.25		
Illumination ft-candle	Backgd. B ft-L	C	Speed*	Backgd. B ft-L	C	Speed*	Backgd. B ft-L	C	Speed*	Backgd. B ft-L	C	Speed*	Backgd. B ft-L	C	Speed*
1	.068	294		.068	294		.034			0.239	156		0.119	315	
2	0.136	147		0.136	147		.068	294		0.478	78.5	51	0.239	156	
4	0.272	73.6	101	0.272	73.6	33	0.136	147		0.956	39.2	36	0.478	78.5	51
8	0.544	36.8	87	0.544	36.8	25	0.272	73.6	33	1.91	19.6	27	0.956	39.2	36
12	0.816	24.5	76	0.816	24.5	19.5	0.408	49	28	2.87	13	19	1.44	26	31
20	1.36	14.7	60	1.36	14.7	13.5	0.68	29.4	23	4.78	7.85	12	2.39	15.7	23
40	2.72	7.36	42	2.72	7.36	7.9	1.36	14.7	13.5	9.56	3.92	4.8	4.78	7.85	12
80	5.44	3.68	25	5.44	3.68	3.1	2.72	7.36	7.9	19.1	1.96		9.56	3.92	4.8
100	6.8	2.94	19.5	6.8	2.94	1.6	3.4	5.89	6.2	23.9	1.57		11.9	3.15	3.3
Curve in Figure 5		A			B			C			D			E	

*See text for meaning.

a than are we today. However, it is also apparent that there is no pressing human need for high levels when the contrast is good.

And in their work on the utility of colored illuminants, Feree and Rand[7] tested the eyes of their observers both before and after reading for three hours in Table 3 and plotted in Figure 5.

The difference between curve "A" (four minutes of arc) and the other curves (two minutes) is notable. One is tempted to say that a stroke width of four minutes should always be used. with a colored illumination of only 0.3 ft-candle. There was a measurable loss, but the significant fact is that it was possible to read for that time with an undesirable light and at such a low level.

One must conclude, then, that the computed level of illumination is above the minimum by a factor of at least forty, and that it is in a range that has been selected as optimum in tests where the observer could control the level of illumination.

It is clear from the above data that the computed level of illumination is sufficient, but that does not assure that it will be pleasing. The reason why it may be one and not the other is that the eye does not see illumination—it sees the brightness of the work and its surroundings that result from that illumination.

The sources of illumination should be distributed, but not evenly distributed. Completely diffuse illumination creates a somnolent atmosphere, while the inclusion of some concentration points helps seeing through the formation of the shadows by which form is perceived. And of course no light source whose brightness is materially higher than that of the walls should be within the field of views of the operating people.

The ratio of brightnesses within the field of view should be low. This effect is most easily achieved by using the same finish for similar objects and keeping the illumination reasonably even. Such variation in brightness as exists should follow as closely as possible the rule that the ceiling be brightest, the walls next bright, the furniture and equipment next, and the floors least bright, but not dark. The IES recommends that the reflectivities be walls, 0.5; furniture and equipment, 0.35, and floors, 0.3. It should be noted that hard copy, with a paper reflectivity near 0.7 and ink reflectivity near 0.1, will have good contrast within itself without either the paper or the ink being markedly different from its surroundings.

Wall projection screens present a problem because the symbol brightness is limited and it is necessary to achieve the required contrast by keeping the background dark. Hence, the screen must be carefully screened from all room lights. However, the area immediately around the screen must be as bright as the rest of the wall. This surrounding area can be illuminated by highly directive lights, it can be back lighted, it can be set back of the screen and illuminated by lights behind the screen, it can be made fluorescent and excited by ultraviolet light, etc. When done properly the symbols will be brighter than the walls and the background darker; the presence of the walls will make the screen appear to have a greater contrast than it actually has, and at the same time will maintain the balance of brightness with the rest of the room.

A clear and public example of the effectiveness of balanced brightness is available in the two reading rooms of the Congressional Library in Washington. The old reading room in the main building is equipped with dark furniture. At night the walls are relatively dark, and the darkness of the ceiling is relieved only by an illuminated painting. Lights over the desks illuminate only the writing surface. In the day the walls are much brighter, but the windows to the south and the spots of sunlight to the north make severe glare spots. Study in this room is very tiring, eye strain setting in after an hour or two. The reading room in the Annex is illuminated with artificial sources only, using desk lights similar to those in the old room plus indirect illumination. The ceiling is the brightest part of the room, the walls are next bright, and the furniture is relatively light. There are no glare spots. One can study for hours in this room without fatigue. The comparison is striking proof of the desirability of a low ratio of brightnesses: it is even more striking when one realizes that the illumination on the writing surfaces in the two rooms is the same.

It is clear, then, that the process outlined in this paper provides equal ease of reading for both hard copy and displays, that the resultant illumination is entirely adequate, and that it can be made pleasing. There remains only the problem of those officers who normally work in brightly lit offices and who must move to the command center on the occasion of an alert. Luckily the computed illumination for the command center is less than that to be expected in offices by a factor of only three to six. It is felt that a smooth transition can be made possible by setting the illumination of the intervening halls and anteroom at a value intermediate between those of the offices and the command center.

As in most system studies, this work shows that much can be done by a number of small steps taken together. It must be noted that one of these steps, that of providing a limited range of brightnesses, has long been known but has frequently been overlooked.

There is no easy way to compute the effectiveness of hoods, means for directing the illumination, etc. One solution is to make the display contractor responsible for the entire installation and to provide time and funds for either a mockup or extensive tests in location. An approach that would save the cost of repeated mockups is for the Government to make the tests, to provide a suitable room, to specify the design of the hoods, and to relieve the contractor from responsibility for the contrast.

Conclusions

a) The described process readily gives the illumination level at which hard copy and self-luminous displays are equally readable, or gives a quantitative statement of the advantage given one data source over the other when a different illumination level is used.

b) The current art for cathode-ray displays permits an adequate level of illumination if known techniques for maintaining contrast are used. The same is true for projection displays if the screen area is reasonable.

c) This level of illumination will be pleasing if the color of the ceiling, walls, furniture, equipment, and floors, and the distribution of illumination gives a small range of brightness with a proper distribution of brightness.

d) The values for the contrast of hard copy given herein should be re-examined. If the listed values are low, then correct values will permit a new selection of illumination with which both the hard copy and the displays can be read more easily. If the listed values are correct, then similar values can be used in future display specifications with a financial saving for the customer. ⊙

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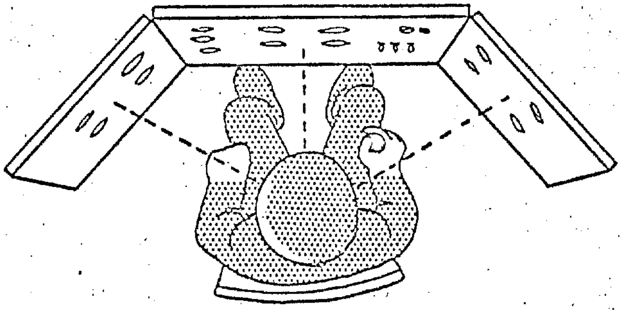
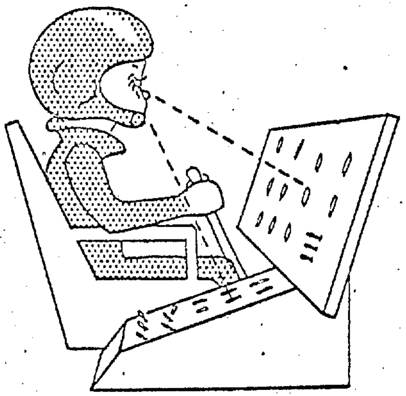
INSTRUMENT PRIORITY, POSITION, VIEWING ANGLE, AND DISTANCE

Optimum Position: In general, the optimum location for instruments is directly before the operator from eye level to about 30° below eye level. For pilots or other vehicle operators, the optimum location is just below the windshield. The most important and frequently used instruments should be placed in this most favorable area. Instruments used for controlling direction (such as aircraft heading indicators) are preferably located directly ahead of the operator. If there are two or more such direction instruments they are preferably arranged along a vertical line.

Viewing Angle: The most favorable angle for viewing instruments is perpendicular to the dial faces. Extremely oblique viewing angles should be avoided by angling the ends, bottom or top of large panels. Viewing angles up to 45° are considered satisfactory, provided needed information on the dial is not obscured by the bezel, lighting shield, or other obstruction, and if some loss of reading precision due to parallax can be tolerated.





Viewing Distance: Viewing distance for instrument panels need be limited only if the operator is required to manipulate knobs or switches on the panel from his normal seated position. This distance is normally fixed at 28 inches from the eyes for vertical panels. The instrument size must be increased proportionally for longer viewing distances.

Horizontal and Vertical Separation: The difficulty of shifting between instruments increases with separation distance. Vertical eye movements are more difficult than horizontal shifts in fixation. Distance between instruments should be minimized. Horizontal separations are preferred to vertical separations. (Fitts and Simon, 1952.)

from ~~th~~ "Visual Presentation of Information" Baker, CA & Grether, W.