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ARMORED MEDICAL RESEARCH LABORATORY
Fort Knox, Kentucky

Project No. 6-2, 6-4
413.74-1

28 December 1943

1. PROJECT: No. 6 - Vision in Tanks; Second Partial Report on Sub-Projects No. 6-2 - Study of Characteristics and Limitations of Present Visual Devices in Tanks; and 6-4 - Study of Means of Improving Sighting Telescopes. (Study of M-50, M-70, T-92 and T-93 and P&E pilot model).

a. Authority: Letter Commanding General, Headquarters Armored Force, Fort Knox, Kentucky, 400.112/6 GNOHD, dated September 24, 1942.

b. Purpose: To establish criteria for the selection of sight design and for the control of sight production.

2. DISCUSSION:

a. Proposals* were made in January of this year to -

(1) Improve the conventional telescopic sights which employ lenses for the erection of the image.

(2) Develop prism erecting sights, because of their inherently superior optical properties and their advantages in ballistic treatment.

b. The development of prism erecting sights has resulted in the M10 (or T8) dual periscopic sight and some progress has been made in the development of a lateral offset sight.

c. It is the purpose of this report to evaluate the progress in improvement of straight tube sights, in terms of criteria which refer particularly to the requirements of the using arm.

d. Tests were carried out upon -

(1) Two sights of M50 series (3 power, in small tube).

(2) Nineteen of the M70 series (3 power, in small tube).

(3) One Perkin and Elmer pilot model (2.77 power, in small tube).

(4) Two T93 series (3 power, in large tube).

(5) Two T92 series (5 power, in large tube).

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* Armored Medical Research Laboratory Partial Report on Visual Requirements Characteristics and Limitations of Present Visual Devices in Tanks and Means for Improving Sighting Telescopes and Periscopes, 23 January 1943.

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e. These tests included the determination of -

(1) Properties peculiar to a particular design or series.

Magnification
Apparent field
True field
Exit Pupil (on and off axis)

(2) Quality characteristics limited by design but also dependent upon manufacture.

Contrast and veiling haze
Axial resolving power
Field of good definition
Influence of size and centering of eye pupil

(3) Characteristics arising from manufacture.

Diopter setting of ocular (fixed focus)
Parallax
Eccentricity of optic axis.

f. An analysis of requirements is presented in Appendix I.

g. Results of tests are set forth in Appendix II.

h. Problems of manufacture are taken up in Appendix III.

3. CONCLUSIONS:

a. The M70 series design (3x, in small tube) is a substantial improvement over the M50 in quality of performance though not in apparent field or size of exit pupil.

b. The T93 series design (3x, in large tube) provides larger apparent field and exit pupil than the M70 but is deficient in quality of performance.

c. The T92 series design (5x, in large tube) also increases the apparent field and exit pupil but is even more inadequate in quality.

d. The Perkin and Elmer pilot (2.77x, in small tube) represents marked improvement over the M70 not only in quality but also in apparent field and exit pupil.

e. Redesigns of T92 and T93, though not available for laboratory test, have been inspected and appear to combine with larger field and exit pupil the essential improved quality.

f. Too little consideration has been given to the performance of sights in that portion of the field used for shooting at long ranges - both in selection of design and control of manufacture.

g. Ten of the nineteen M70 series sights tested should have been rejected, eight due to incorrect adjustment but only two due to imperfect optical parts. All were handicapped by incorrect adjustment.

4. RECOMMENDATIONS:

a. That the Perkin and Elmer sight replace the M70 series as far as manufacturing facilities permit but without obsolescence.

b. That the procedure in adjusting the M70 series sights during manufacture be modified to secure freedom from parallax and to insure use of positive eye accommodation (negative diopter setting) over the field occupied by reticle markings.

c. That new sight designs be chosen with respect to their performance at the longest range positions in the field.

d. That production tests be instituted to insure proper setting of lenses for adequate performance in the longest range positions in the field.

Submitted by:

Major F. S. Brackett, Sn C

APPROVED Willard Machle
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Commanding

4 Inclosures:

#1 - Appendix I
Analysis of Special Requirements of Sights
#2 - Appendix II
Results of Tests
#3 - Appendix III
Problems of Manufacture
#4 - Figures 1 to 7
Tables 1 to 4

APPENDIX I

ANALYSIS OF SPECIAL REQUIREMENTS OF SIGHTS

1. The almost universal practice of making elevation correction for range by displacing the target image within the sight field imposes severe demands upon optical properties:

a. The longest range position occurs the farthest from the center of the field, so this is the region of the field which should provide the best vision and the least parallax.

b. Optical construction is such as to yield the best definition in the center. The rapidity with which the definition degenerates as the point of attention moves out in the field depends upon the excellence of design and accuracy of manufacture.

c. Curvature of field generally present in optical systems and most marked in the lens erecting types (straight tube) introduces parallax which, if eliminated at the center, increases away from the center of the field.

d. Curvature of field also presents focal difficulties. Thus, if the eyepiece is set to give a zero diopter setting in the center (as for infinity) a positive diopter condition develops away from the center for which the normal eye cannot accommodate. This makes the image of distante objects appear blurred just where vision should be clearest.

2. This requirement that excellent vision and freedom from parallax be provided at the longest range position in the reticle has not been given sufficient recognition either in selection of design or in control of manufacture.

3. The excellence required of a sight depends upon the visual capacities of the gunners who must use it. Thus, the definition provided should be such that most of the gunners can exercise their utmost visual acuity in observing the detail of distant targets. It has been standard practice in optics to assume that most eyes will not do better in resolving power than 60 seconds. However, methods of determining resolving power are arbitrary and not readily translated into the usual designation by which vision is expressed. In order to establish a rational basis for resolving power requirements:

a. A resolution chart has been developed with a range from 2 to 90 seconds. It is of the reflection type with (nearly) parallel lines and equal 'black' and 'white' spaces. The 'white' is so illuminated as to yield 107 foot lamberts and the 'black' 7 foot lamberts.

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b. The approximate equivalence to Snellen designation has been determined.

c. From acceptance tests on Armored Command personnel a statistical evaluation of gunner vision has been obtained.

4. The cumulative percentage of gunners of varying visual acuity is given in Figure 1 for a group of 1000 Armored Command gunners.

a. 2.4% had 20/10 vision (resolving 45 seconds) or better.

b. 31% had standard vision (resolving 60 seconds) or better.

c. 51% had 20/15 vision (resolving 67.5 seconds) or better.

d. 85% had 20/20 vision (resolving 90 seconds) or better.

5. In order not to limit the observer a three power sight must:

a. Resolve 15 seconds for the 2.4% of 20/10 vision or better.

b. Resolve 20 seconds for the 31% of standard vision or better.

c. Resolve 22.5 seconds for the 51% of 20/15 vision or better.

d. Resolve 30 seconds for the 85% of 20/20 vision or better.

6. The significance of these requirements may be seen from Figure 2.

a. Resolving power is plotted on the left (ordinates) against the angle from the center of the field (abscissae) in degrees. True field is indicated at the top, and apparent field at the bottom of the chart. Mils equivalent and range marks are also given at the bottom (Range for 75 mm gun APC-M61). On the right ordinates corresponding to designated visual acuity are given together with percentage of personnel having such vision.

b. One notes from the chart that a good M70 sight, for example resolves 7.5 seconds at the center while at 7.2 degrees apparent, or 43 mils from the center, it resolves only half as well or 15 seconds. This however, is still sufficient for all but the 2% gunners of best vision. At 9.3° apparent field or 55 mils from the center, 20 seconds resolving power, good enough for all but 31% of the gunners, is still maintained. This is near the 3800 yard range mark when the 800 mark is centered in the field.

7. The merits of different designs are compared as to resolving power over the essential field in Figure 2. Referring to the good examples of the type:

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a. T93 is inferior to all other three power types tested except near the center of the field.

b. M70 is superior to both T93 and M50 throughout.

c. The Perkin and Elmer is substantially better than the M70, increasing the range from 3300 yards to 4000 yards for best vision or from 3800 yards to 4300 for standard vision (30% gunners) i.e., from 55 mils to 72 mils from the axis. (A small correction for 2.77 power instead of 3 power has been introduced.)

8. It will be seen that a plus diopter setting of 0.23 seriously impairs value of the (M70) sight except on axis.

a. This will be seen from the following:

(1) Over 10% of gunners are limited in their vision even on axis (at 800 yards on reticle).

(2) 31% are limited beyond 2000 yards or 18 mils from the center.

(3) 51% are limited in visual detail beyond 2400 yards or about 25 mils from the center.

(4) 85% are limited beyond 2900 yards or 36 mils from center.

b. Six of the 19 M70 series sights tested were found to have improper focus of the order illustrated.

c. All suffered to some extent from this difficulty.

d. The M50 series was judged to be bad chiefly on this account. The degree of possible improvement in this sight by proper focus is indicated in the chart.

e. The M70 is little better than the M50 when badly focused.

9. Three times the resolving power of a good eye (10% gunners) has been plotted in Figure 2 by dotted lines. Two curves are shown, for the eye centered and also displaced 60 mils from the center. If the eye was always centered, both the T93 and the badly focused M70 (+0.23 diopters) would give fields with the appearance of being sharp. When, however, a gunner fixes his attention on the 4000 yard mark of the reticle (or about 60 mils from center) his visual requirement curve shifts over, as shown. Viewing from

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this position, a gunner of excellent vision (10%) using the M70 has the impression that the target and foreground are not quite sharp. To an average gunner the target will look sharp but the foreground will be somewhat blurred.

10. A tabular summary of the data on field of good vision for the various sights tested is given in Table I. Here the radius of true field in mils is given for different vision qualities together with the corresponding position on the reticle (75 mm gun APC-M61).

11. Inorder to compare the performance of T92 five power sight with T93 three power their resolving powers have been plotted in Figure 3 on the basis of apparent resolving power at the eye (right) against true field (bottom). The resolving power of a good eye (10%) is also plotted by dotted lines for a centered position. Here it will be seen that the T92 will not give a sharp image beyond 27 mils from axis even with the eye centered and that best vision (2.4%) is obtained only 7 mils from the axis against 14 mils for the T93.

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APPENDIX II

RESULTS OF TESTS

1. Observations and results of tests on good samples of the different designs are given in Tables II and III.

2. Table IV gives the results of tests on axis of nineteen M70 series sights:

a. Column 1 gives the diopter setting as found by use of an auxiliary telescope with an object at infinity. It will be noted that all these values lie within a range of 0.29 diopters, indicating fairly close control of setting. Unfortunately, however, the values which give good performance are negative settings of-0.5 diopter or greater, so these settings are uniformly bad. The inevitable conclusion is that the specified procedure for setting should be modified to secure values always more negative than-0.5 diopters.

b. Column 2 gives the diopter values for the reticle at the center. All these values are negative with respect to the image so that the difference given in the third column is always in the same direction and corresponds to a placement of the reticle always behind the image.

c. It is this difference (third column) that causes parallax and is sometimes referred to as the "parallax". In order to relate this difference in diopter value to the actual displacement of the image relative to the reticle when the eye is moved up and down (apparent parallax) the values estimated are given in the fourth column. The two values should be directly related but due to spherical aberration the effect is somewhat exaggerated. Thus, in Figure 4, the observed points are chiefly above the theoretical line relating mils displacement to diopter difference. From the standpoint of good gunnery, the mils displacement should never exceed 0.25 mils or 0.15 diopters difference. Furthermore the setting is in the wrong direction if one is to secure the least parallax for all parts of the reticle.

d. Axial resolving power is given in columns 5 and 6 (table IV), the first being for proper focus (obtained by the use of an auxiliary telescope) and the second as it appears in fixed focus (sixth column). The loss in resolving power due to the eye's inability to make negative accommodation to offset the improper setting runs as high as 12.5 seconds, even on axis.

e. By rotating the telescop its mount one can observe the circle through which the image moves. e radius of this circle (eccentricity) is given in the eighth column

f. The column headed 'haze' indicates the amount of veiling haze determined by the loss of resolving power when the sight is subjected to intense illumination just outside the central field. This is an arbitrary classification valid only in comparing sights of the same true field. A

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more widely applicable test is under development. Because of the crucial importance of good contrast this variation in freedom from haze should be studied exhaustively.

g. Under remarks are given the chief causes leading to our classification. Where there is loss of definition the information from star test is indicated.

h. In the last column is our classification of the 19 sights. Proper adjustment would have yielded eight excellent sights of which there are none as delivered. Only two would then remain to be rejected.

	As Assembled	If Properly Adjusted
E - Excellent	0	8
G - Good	5	5
F - Fair	4	4
R - Should be Rejected	10	2
	19	19

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APPENDIX III

PROBLEMS OF MANUFACTURE

1. The proper relation of object field, reticle and ocular is not achieved in any of the nineteen M70 sights tested.

2. The settings are so uniform as to suggest that the trouble lies in a fallacy of specified procedure rather than a failure on the part of the manufacturer to meet specifications.

a. All the diopter values found lie within a quarter diopter range, with one exception.

b. All the values of diopter difference between image and reticle are within a quarter diopter, with but one exception.

3. The correct arrangement is given in the upper part of Figure 5 - full lines.

a. Here it is shown that the object field curves slightly forward. Hence to secure minimum parallax for all parts of the reticle, the reticle plane should be slightly in front of the image plane at the center of the field. When this is done there is nowhere a difference of 0.1 diopter. From Figure 4 we have noted that 0.15 diopter difference causes less than 0.25 mils apparent parallax with this type of sight.

b. In order that there be nowhere over the field covered by reticle markings a positive diopter value, the ocular field must be pushed forward (the minimum displacement being -0.5 diopters with respect to the object field).

4. The resulting diopter values over the reticle field are given in Figure 6. Here it will be seen that the effective diopter values vary from -0.5 at the center to zero at the edge of the reticle markings (covering about 4° radius of true field).

5. For comparison, the average values of the present adjustment are given by dotted lines in Figure 6. Here it is seen that the present setting is such as to just place the reticle so that no appreciable loss of sharpness will be observed in the markings. Also the field is such that it will just be reasonably sharp at the center. Thus, if the inspection is made on axis these sights will just pass. If, however, they were tested 3° off axis in true field the loss of definition as well as the parallax would be excessive, as has been observed by our gunners.

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6. The loss of resolving power due to positive diopter setting, for which the eye cannot accommodate, is plotted in Figure 7. Most of the values on axis are in the range of relatively small loss but off axis the great losses arising from diopter values from plus 0.25 to 0.6 common as can be seen in Figure 6.

7. Contrast varies considerably from one M70 sight to another. Without disassembling the sights the cause cannot be definitely determined. It has been observed, however, that edges of the front windows often protrude and are not blackened. This is certainly a contributing cause. In general, contrast is lost in manufacture by -

a. Failing to blacken the edges of glass components.

b. Failure to blacken the inside metal surfaces.

c. Leaving out diaphragms called for.

d. Poor polish.

e. Failure to coat glass surfaces properly.

8. Loss of definition arises from:

a. Failure to so adjust the sight as to permit positive eye accommodation, already discussed at length. All nineteen sights suffered in varying degree from this.

b. Defects in optical parts or their mounting. Only two showed this type of difficulty to excess. Both of these showed split image in the star test. A common cause is the slipping of a lens during polishing, thus generating two surfaces. Axial astigmatism has been noted though not to excess. A common cause is grinding and polishing lenses in gangs so the outer lenses in the pattern receive a cylindrical distortion of the surface.

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TABLE I

FIELD OF GOOD VISION (TRUE)

Quality of Vision (Resolving power)	20/10 vision (45 sec.)		Standard (60 sec)		20/15 vision (67.5 sec)		20/20 vision (90 sec)	
Per cent of gunners with better vision	2.4%		31%		51%		85%	
Required resolving power of 3x sight	15 sec.		20 sec.		23 sec.		30 sec.	
	Range 100 yds	Mils Radius	Range 100 yds	Mils Radius	Range 100 yds	Mils Radius	Range 100 yds	Mils Radius
M50 - (poor focus)	*	*	8	0	16	11	23	23
M50 - Good	*	*	23	23	27	32	34	45
M70 - (poor focus)	*	*	20	18	24	26	29	36
M70 - (poor definition)	*	*	8	0	22	22	37	53
M70 - Good	33	43	38	55	39	59	43	70
P & E**	40	62	43	72	45	77	47	86
T93	18	14	22	21	23	25	27	32

* Required resolving power not achieved.

** Values for P & E corrected for 2.77 magnification instead of 3.

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TABLE II

GENERAL PROPERTIES OF THE SPECIFIC DESIGN

	P & E	M-70	M-50	T-93	T-92
Magnification	2.77x	3x	3x	3x	5x
Apparent Field	55°	37°	37°	68°	68°
True Field	20°	12.3°	12.3°	22.7°	13.6°
Exit pupil on axis	6.22	5.5	5.5	6.7	6.7
Exit pupil - off axis reduction	slight	severe	severe	moderate	moderate

TABLE III

QUALITY ATTAINED WITH GOOD MANUFACTURE

	P & E	M-70	M-50	T-93	T-92
Contrast (coated)	good	fair	fair	poor	poor
Field of good definition radius in mils	72	55	23	21	14
Definition with pupil enlarged or decentered	very good	good	poor	poor	poor
Transmission % (coated)	52	65	65	54	54

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TABLE IV

RESULTS OF TESTS ON AXIS OF M70 SIGHTS

	Focal Setting Diopters			Parallax Apparent Mils	Resolution, seconds			Eccentricity Mils	Haze	Remarks	Grade
	Image	Reticle	Dif.		Focused*	Fixed†	Loss				
1	.00	-.03	.03	0	12.5	12.5	0	2	3		G
2	+.23	-.02	.25	.7	12.5	20.0	7.5	2	2	Parallax Focus & Split Image	R
3	+.16	-.07	.23	.5	7.5	12.5	5	2	0	Parallax	R
4	+.19	-.02	.21	.6	12.5	18.5	6	2	3	Flare parallax	R
5	+.03	-.16	.19	.4	10	11	1	3.5	4		G
6	-.05	-.21	.16	.3	20	20	0	3.5	10	Split image and haze	R
7	.00	-.03	.03	.0	8	8	0	2	5	Haze	F
8	+.17	.00	.17	.3	12.5	17.5	5	2	3		F
9	+.20	-.02	.22	.5	7.5	14	6.5	3.5	2	Parallax	R
10	+.22	.00	.22	.6	7.5	16	8.5	12	1	Parallax	R
11	+.22	.00	.22	.4	12.5	22.5	10	2	3	Focus and flare, parallax	R
12	+.23	.00	.23	.6	7.5	18	10.5	3.5	3	Parallax	R
13	-.06	-.21	.15	.3	17.5	17.5	0	3.5	7	Haze and Astig.	F
14	+.22	-.07	.29	.8	17.5	30	12.5	2	7	Haze-Parallax Focus & Split Image	R
15	+.09	-.09	.18	.3	12	16	4	1	4	Flare	F
16	+.10	-.08	.18	.3	9	12.5	3.5	1.5	3		G
17	+.07	-.09	.16	.3	21	23	2	1	4	Split Image	R
18	+.02	-.08	.10	.2	10	10.5	0.5	3.5	3		G
19	+.04	.00	.04	.1	10	12	2	1	3	Flare	G
Av	+.109	-.062	.171	.37	12	16.4	4.4	2.8			

G - Good
F - Fair
R - Should be rejected

* Resolution that would have been obtained if sight had been properly focused
† As received

Chart #4

FIG-1

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VISUAL ACUITY OF ARMORED COMMAND PERSONNEL

(1000 RANDOM EXAMINATIONS)

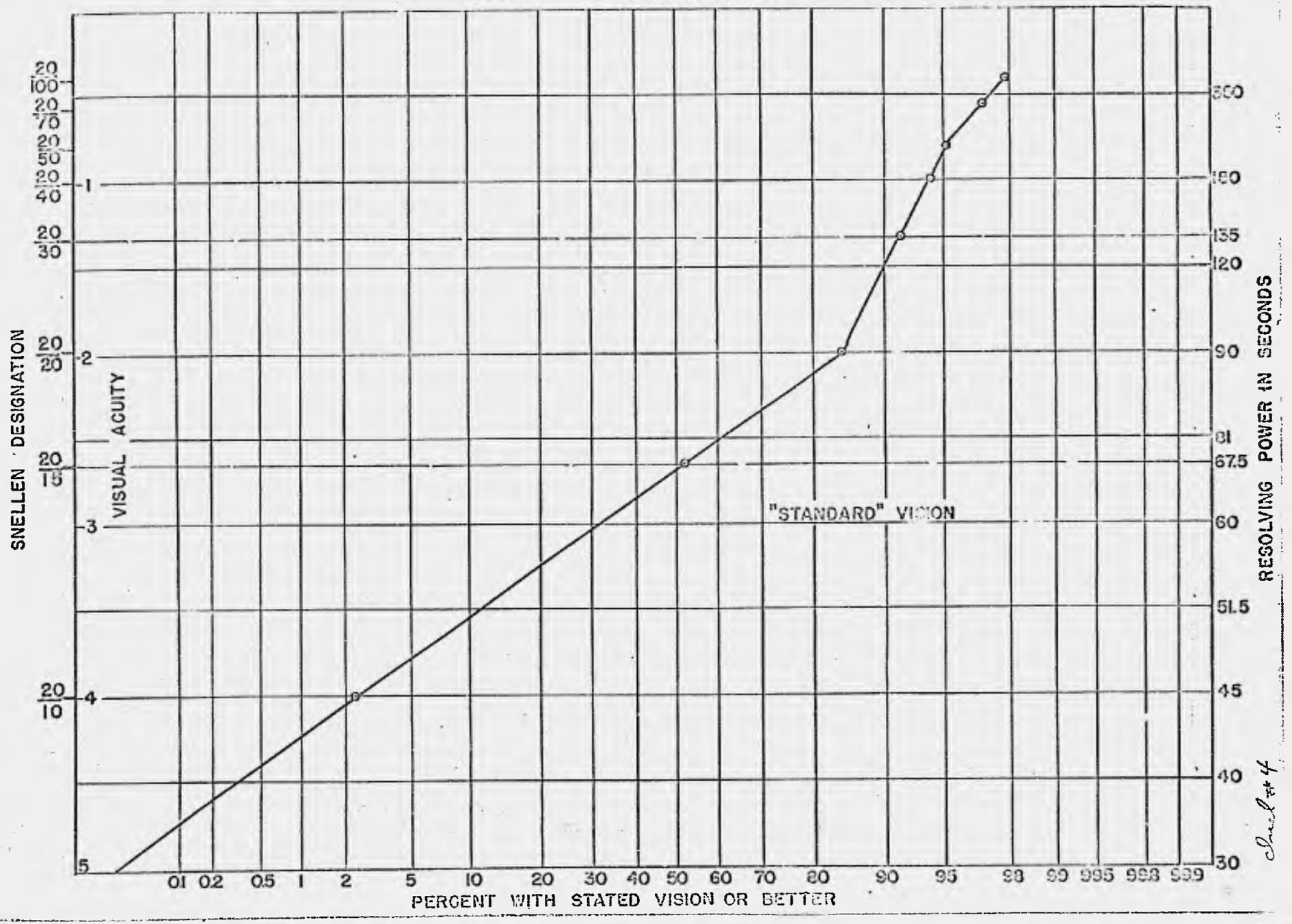

Chart #4

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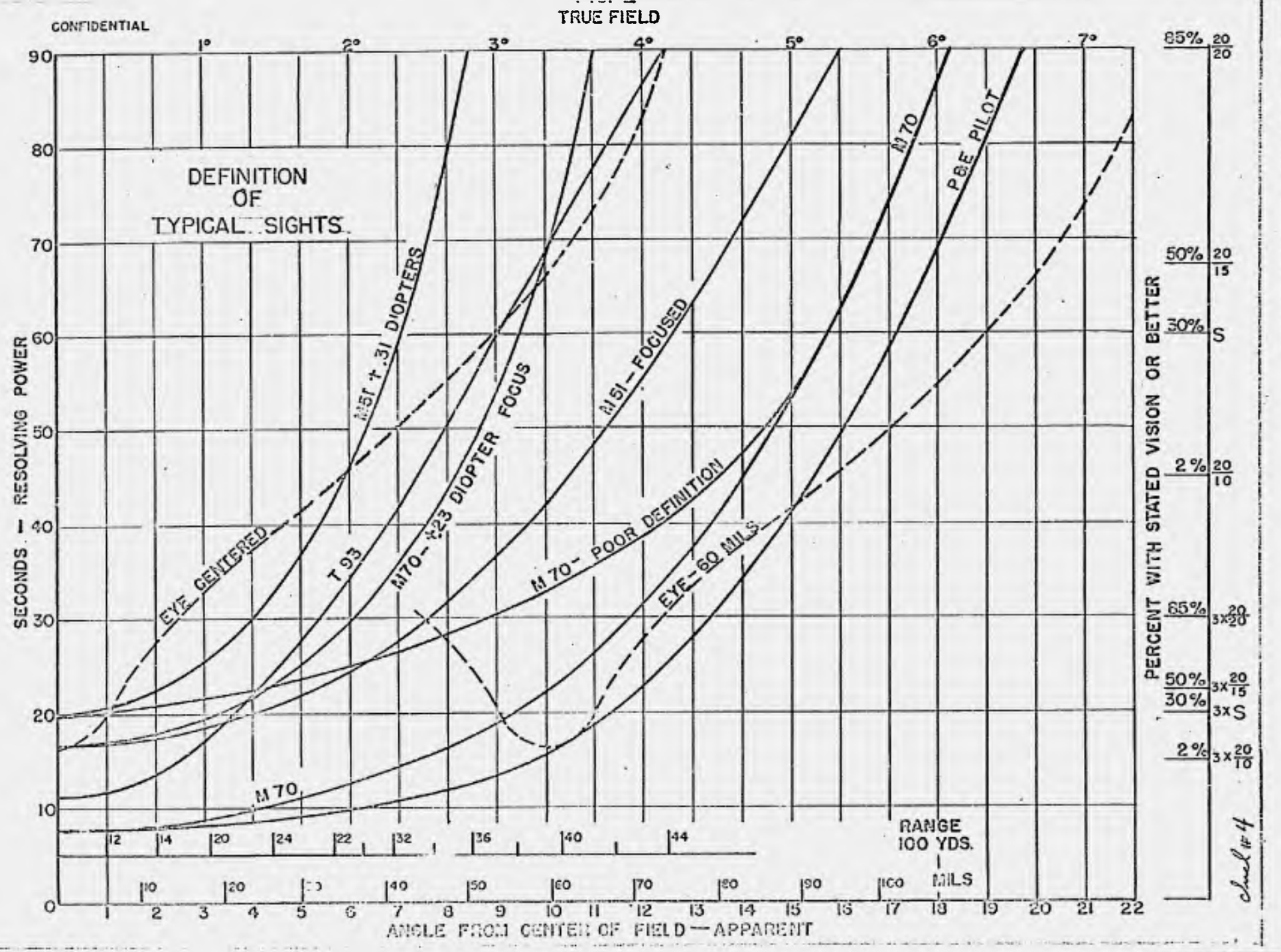

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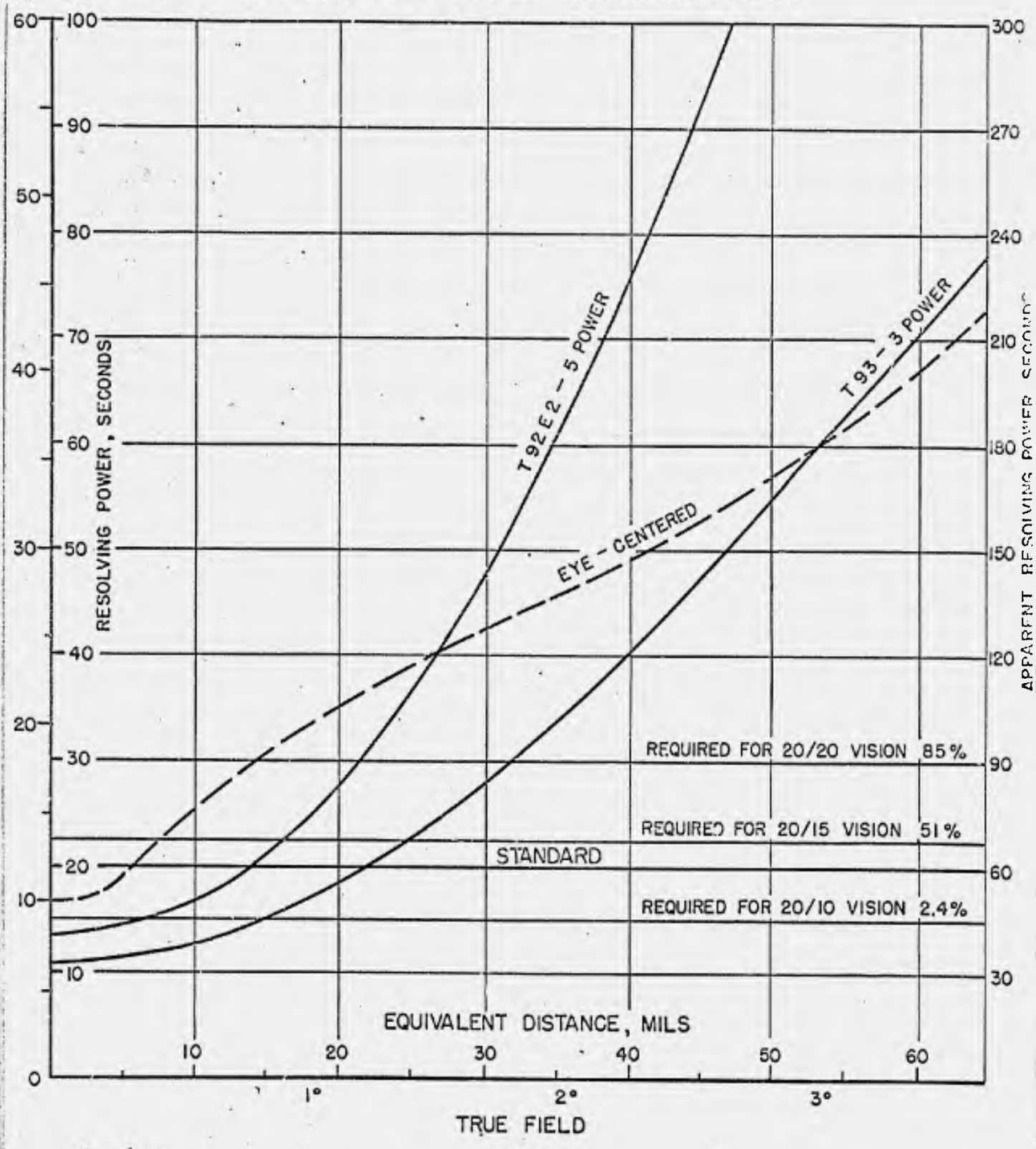
FIG. 3

COMPARISON OF T92 AND T93
IN TERMS OF APPARENT RESOLVING POWER



Incl #4

FIG. 3

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RELATION BETWEEN APPARENT PARALLAX
AND
DIOPTER DIFFERENCE IN FOCAL SETTING OF IMAGE AND RETICLE
(OBSERVED & THEORETICAL)

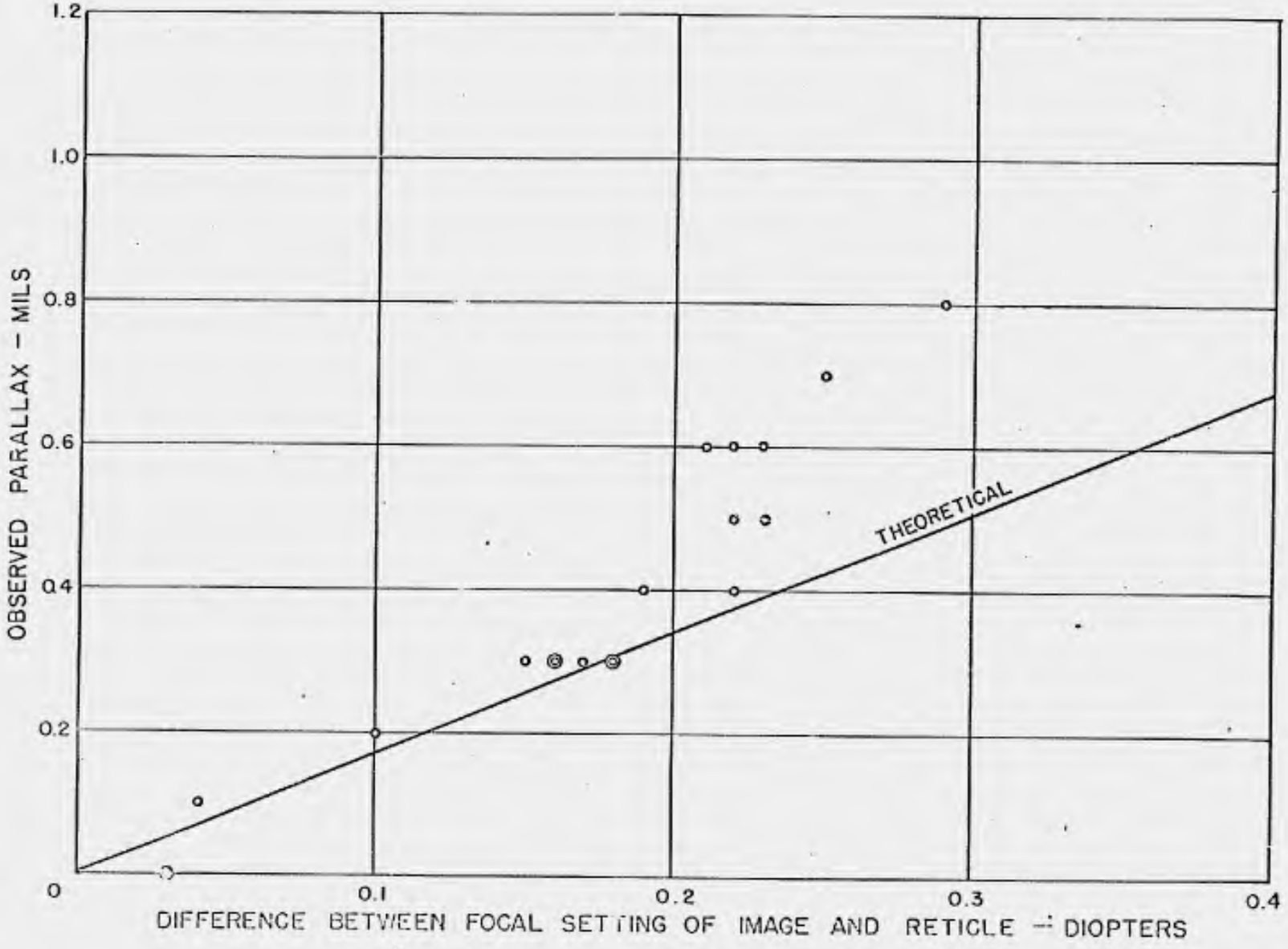

FIG. 4

FIG. 4

Sheet #4

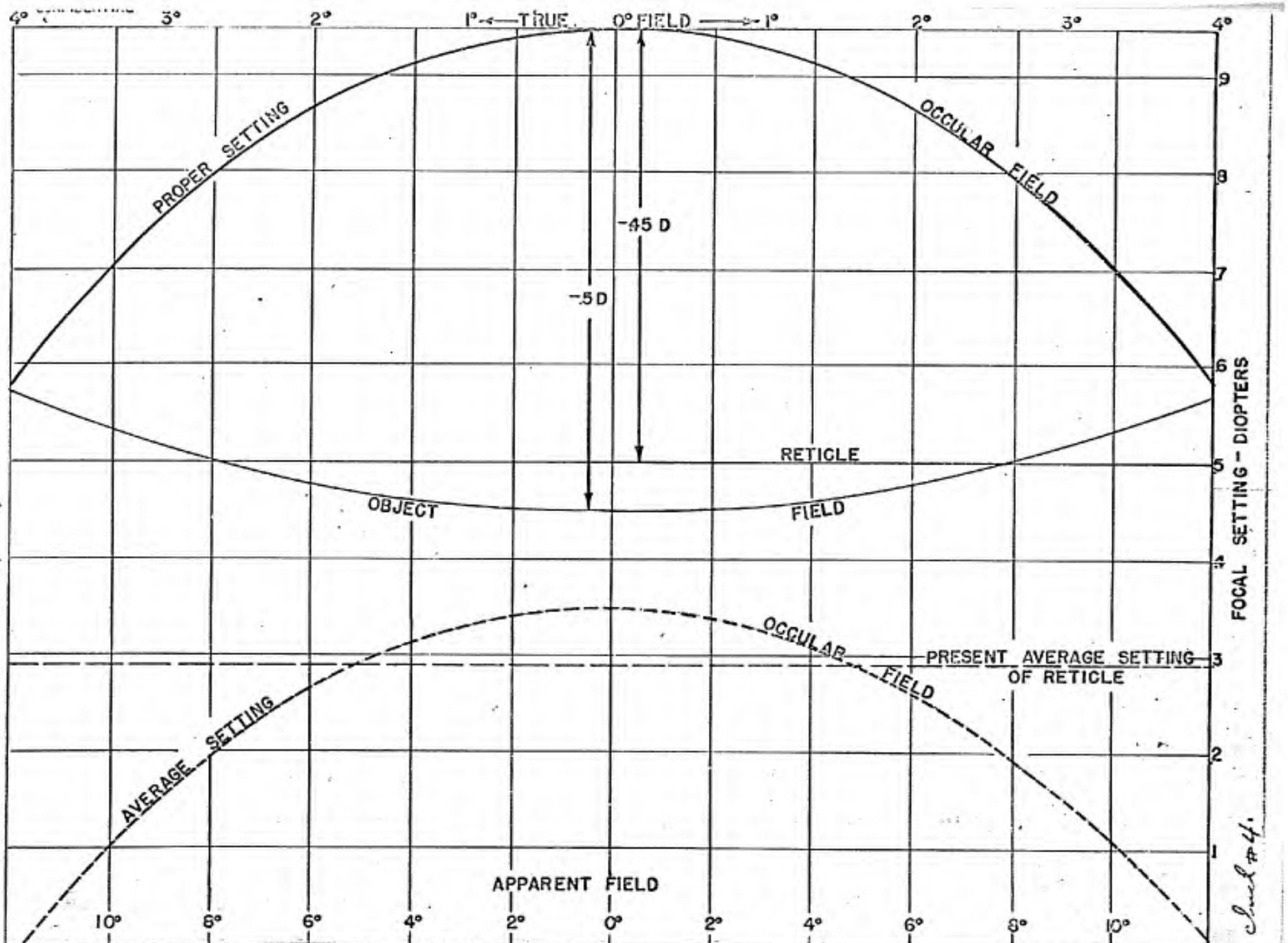

FIG. 5 FOCAL RELATIONSHIP

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FOCAL SETTING OF OCCULAR AND RETICLE IN RELATION TO EYE ACCOMODATION PRESENT AND RECOMMENDED SETTING

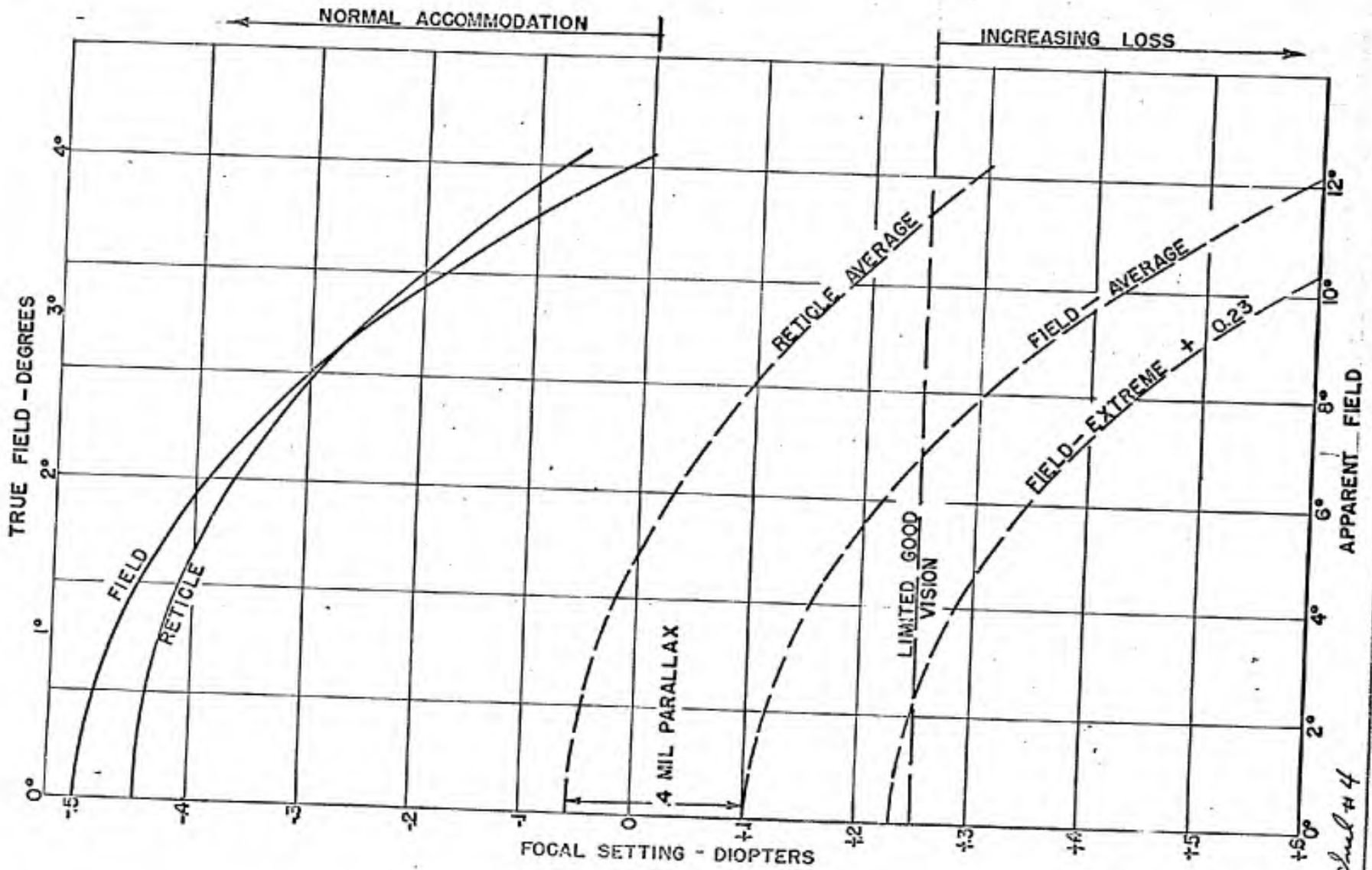

FIG. 6

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FIG. 7

LOSS IN RESOLVING POWER FROM IMPROPER FOCUS

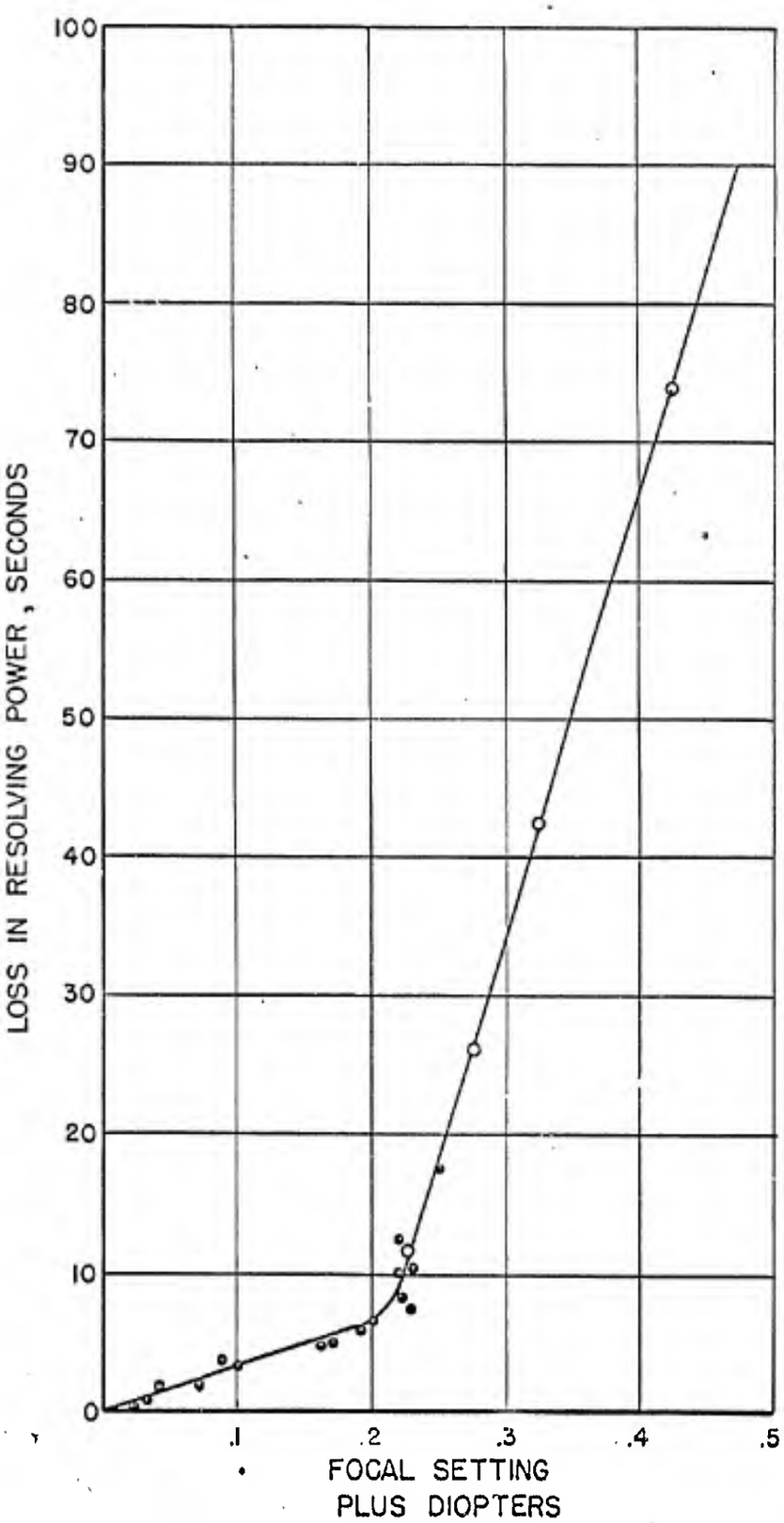

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FIG. 7