PAR 3

FINAL REPORT

Color Corrected 20X Lens
for the
10-20-40X Precision Enlarger

27 August 1964

Prepared by:

[redacted] STAT

Approved by:

STAT [redacted]

Declass Review by
NGA.

STAT [redacted]

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SUMMARY

The original lenses installed in the 10-20-40X Precision Enlarger have a narrow band color correction which prevents their use with color film, therefore a project was authorized to design a high performance lens for use with color films.

In Phase I of this project, a subcontract was let to [redacted] to design a special purpose high performance lens corrected for sequential narrow band exposures in three spectral regions suitable for color print making.

At a later date, Phase II was initiated as an amendment to the project to provide the 10-20-40X Precision Enlarger with the interim capability of producing color prints until a specially designed [redacted] lens should be available for use. In Phase II, a sample [redacted] 52mm document reproduction lens built by [redacted] was purchased for this purpose and installed and tested in the 10-20-40X Precision Enlarger.

Both phases of the project resulted in suitable designs. The 52mm [redacted] lens provided adequate performance for making maximum quality prints from existing production and experimental color materials. This lens was corrected for the full visible spectrum and, thus, was more convenient to use. For this reason, it is recommended in preference to the [redacted] lens design for 20X color enlargements. A secondary feature of the 52mm [redacted] lens is that it can be used to produce variable contrast black-and-white prints.

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SUBJECT: Color-Corrected 20X Lens for the 10-20-40X Precision Enlarger

TASK/PROBLEM

1. Provide a 20X lens design that is suitable for use on the 10-20-40X Precision Enlarger and also capable of producing enlargements from color film originals with minimum loss of information content.

INTRODUCTION

2. The original lenses installed in the 10-20-40X Precision Enlargers were corrected for a narrow spectral band to achieve maximum image quality in projection printing of black-and-white photographic materials. Because of this correction, their image quality over a wide spectral range (required in color print making) was relatively poor. The availability of high image quality in original aerial color photography, made possible by new film technology, created a need for new projection printing objective lens designs to produce color prints which preserve all the information present in the original photographs.

DISCUSSION

3. The problem of providing a suitable 20X color lens has been approached in two independent phases as follows:

STAT a. Phase I - [redacted] Lens Design

STAT b. Phase II - [redacted] Lens Sample

STAT 4. Phase I - [redacted] Lens Design:

STAT a. [redacted] Design Specification Number 103: Design Specification No. 103 for a high performance 20X lens corrected for sequential narrow band exposures in three spectral regions was prepared and a subcontract was placed with [redacted] STAT to design a lens that would be compatible with this specification. A copy of this specification appears as Appendix A of this report.

b. Phase I Plan:

(1) Using a 20X lens built to specification, a print was to be made by three separate exposures in a time sequence from a given color original onto a single sheet of color print stock. Each exposure was to be made with a different narrow pass band color filter (one, red; a second, green; and third, blue) to expose the three emulsions layers of the color print stock in time sequence. A high precision mechanical system was to be used to refocus the lens at its short conjugate between the various exposures to achieve optimum image quality for each color of light.

(2) Although the proposed sequential printing approach using the high performance 20X lens design increased the exposure time and the mechanical complexity of the enlarger, it was felt that such a combination also would increase the image quality over that which could be achieved by single exposure with a lens corrected for the full visible spectrum.

STAT c. [redacted] Lens Design:

STAT (1) The [redacted] lens design shown in Figure 1 (a copy of [redacted] STAT Drawing No. 5829) is a "Planar" type with the number of elements increased over the usual six-element form. The increase in elements will "divide the bending" and thus improve performance. A field flattening element is added to improve the off-axis quality.

(2) This lens system which has been corrected for an over-all object-image distance of 42.72 inches and a magnification of 19.7X has a focal length of 5.059 cm and operates at effective f/3.0. The lens exhibits no vignetting over the full format so the only loss in relative illumination will be due to the $\cos^4$ effect. The photo negative is registered against the plano surface of the field flattening elements so that any change in focus is accomplished by shifting the negative and field flattener element as a unit.

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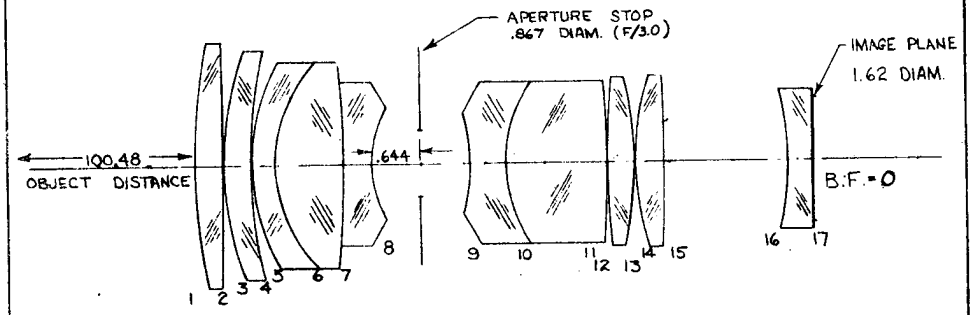

ALL DIMENSIONS IN CENTIMETERS

SURFACE	RADIUS	CLEAR APERTURE	THICKNESS OR SPACE	GLASS TYPE	N_e (5461 Å)	V NO.	DIAMETER
1	7.9624	3.033	.350	SCHOTT LAK-9	1.69400	54.80	3.23
2	-69.760	2.971	.010	—	1.0	—	—
3	4.2505	2.811	.350	LAK-9	1.69400	54.80	3.01
4	6.3554	2.650	.010	—	1.0	—	—
5	2.8040	2.515	.300	F-5	1.60718	38.02	2.72
6	1.9431	2.210	.891	SK-16	1.62287	60.29	2.72
7	-14.286	1.752	.380	F-5	1.60718	38.02	2.15
8	1.4853	1.262	1.288	—	1.0	—	—
9	-2.5433	1.119	.450	F-5	1.60718	38.02	2.11
10	1.8607	1.408	1.339	SK-16	1.62287	60.29	2.11
11	-14.991	1.912	.010	—	1.0	—	—
12	12.098	1.962	.350	LAK-9	1.69400	54.80	2.22
13	-4.9148	2.022	.010	—	1.0	—	—
14	3.7316	2.074	.370	LAK-9	1.69400	54.80	2.25
15	-24.246	2.050	1.635*	—	1.0	—	—
16	-3.9989	1.631	.322	BK-7	1.51871	64.20	1.83
17	∞	1.620					

E.F.L. (e LIGHT) = 5.059

MAGNIFICATION = 19.70 : 1

EFFECTIVE F/NO. = F/3.0

WAVELENGTH RANGE : 4358 Å — 6563 Å

*15 t — INCREASE BY .0048 FOR g + C FOCUS

[ ] 20X COLOR LENS FOR PRECISION ENLARGER

JUNE 27, 1963	J.K.S
SCALE - 2X	DWG 5829

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Figure 1. [ ] Lens Design for the 10-20-40X Precision Enlarger

(3) The residual distortion of this lens at the edge of the field (1.62 cm diameter at the short conjugate) is +0.016 percent. At the 2/3 field point (1.08 cm diameter), the value is +0.014 percent.

(4) The aberrational correction has been optimized for three spectral bands centered about 4358A (g-light), 5461A (e-light), and 6563A (c-light). Because of the large spectral range involved, a focal change of +0.048 mm is required for g and c wavelengths relative to the e wavelength. To maintain good correction over the full spectral range, it was necessary to use a triplet construction in the front-cemented lens group to better control the lower rim rays.

(5) The energy distribution on axis at the 2/3 field point and at the full field points for e, c, and g wavelengths is shown in Figures 2 through 4, and the corresponding spot diagrams are illustrated in Figure 5. The image at the e-wavelength band satisfied the design goal of 90 percent of the energy in a 3-micron diameter circle out to the edge of the field. The requirement of a 4-micron spot size for c-light is also met out to the edge of the field. In g-light, the 90 percent spot size is 3 microns at 2/3 field but increased to about 6 microns at the edge of the field.

(6) The magnification in the three spectral bands is such that 97 percent of the total energy at the 2/3 field falls within a single 5-micron diameter circle with a center at H' = 0.53953 cm and at the edge of the field 95 percent of the energy falls within a 5-micron circle centered at H = 0.80952.

(7) From the nature of the spot diagrams shown in Figure 5, it is felt that the [redacted] lens design could produce an image in narrow-band green light comparable to that produced by the original 20X Precision Enlarger lens (M-171A) (see Figure 6c). Since the green-light (or magenta dye) image is the most important of the three images in a color photograph

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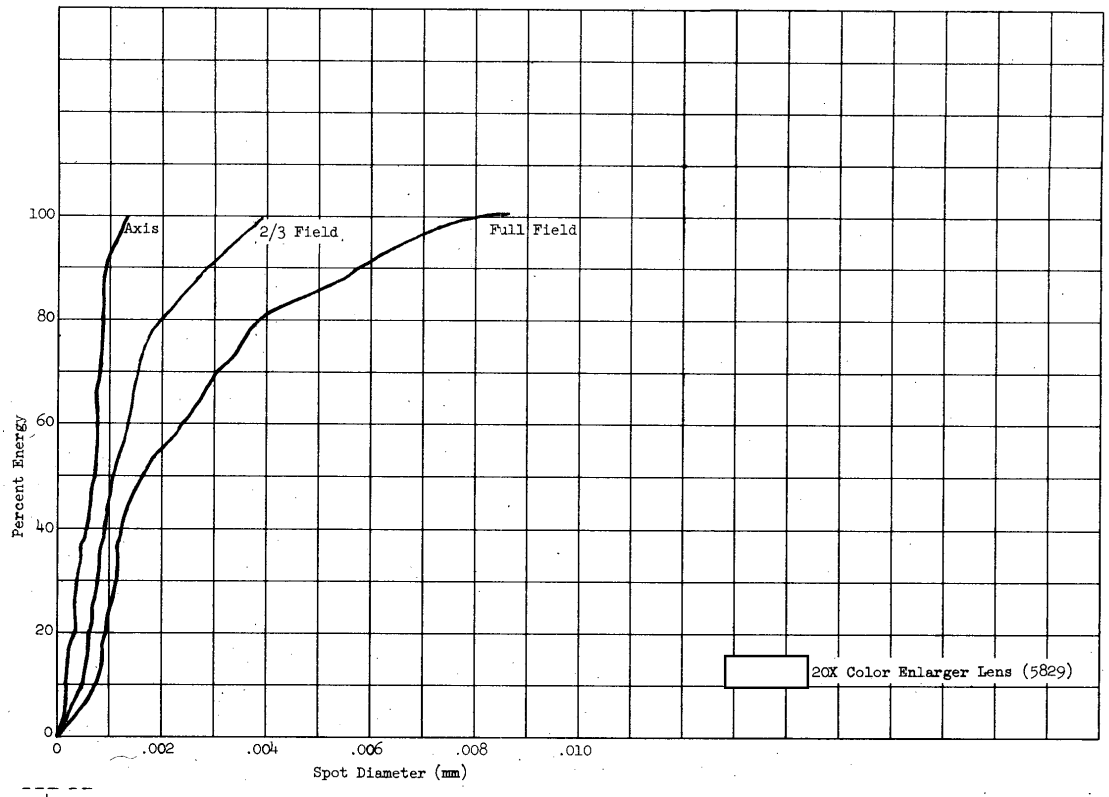

Figure 2. Energy Distribution for g Light (4358A), Focus Shift (+.048mm)

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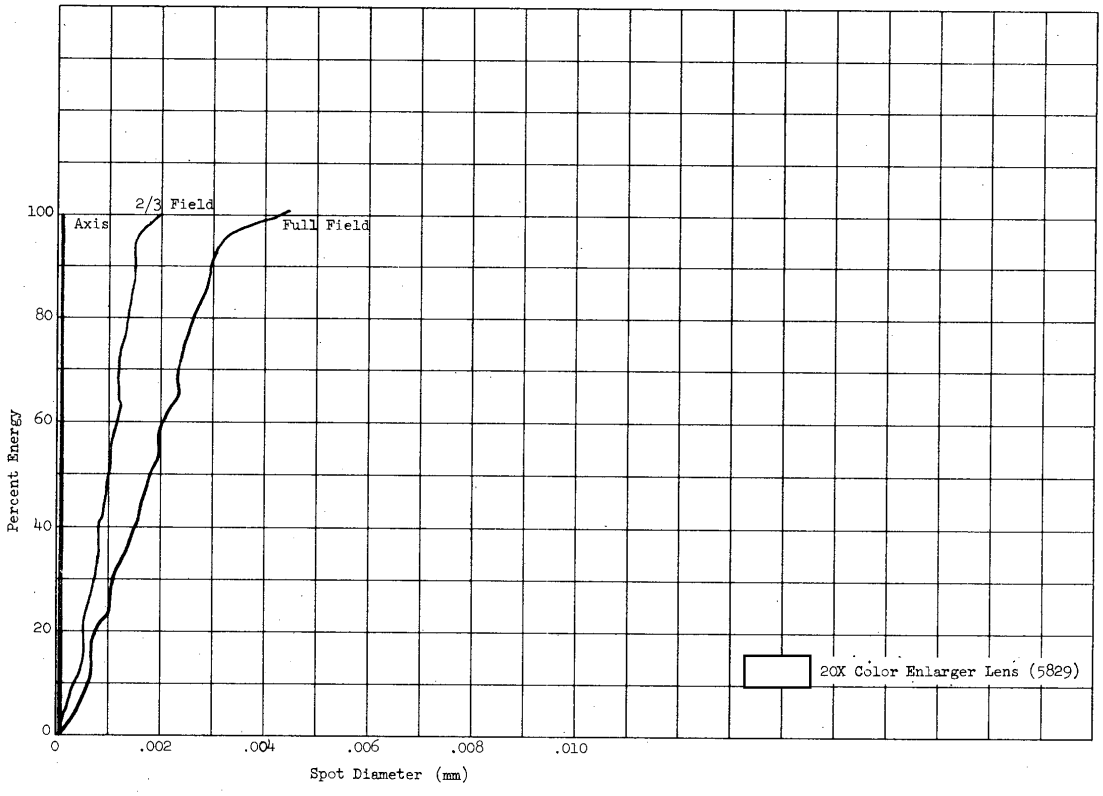

Figure 3. Energy Distribution for e Light (5461A)

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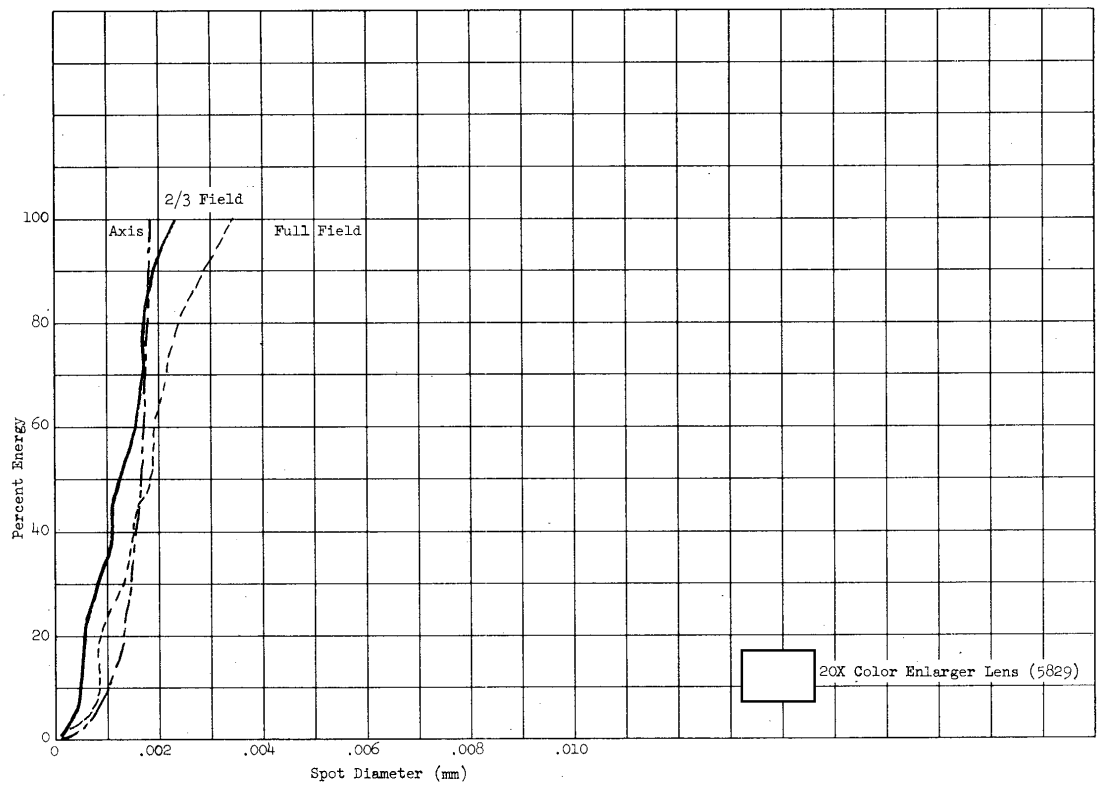

Figure 4. Energy Distribution for c Light (6563A), Focus Shift (+.048mm)

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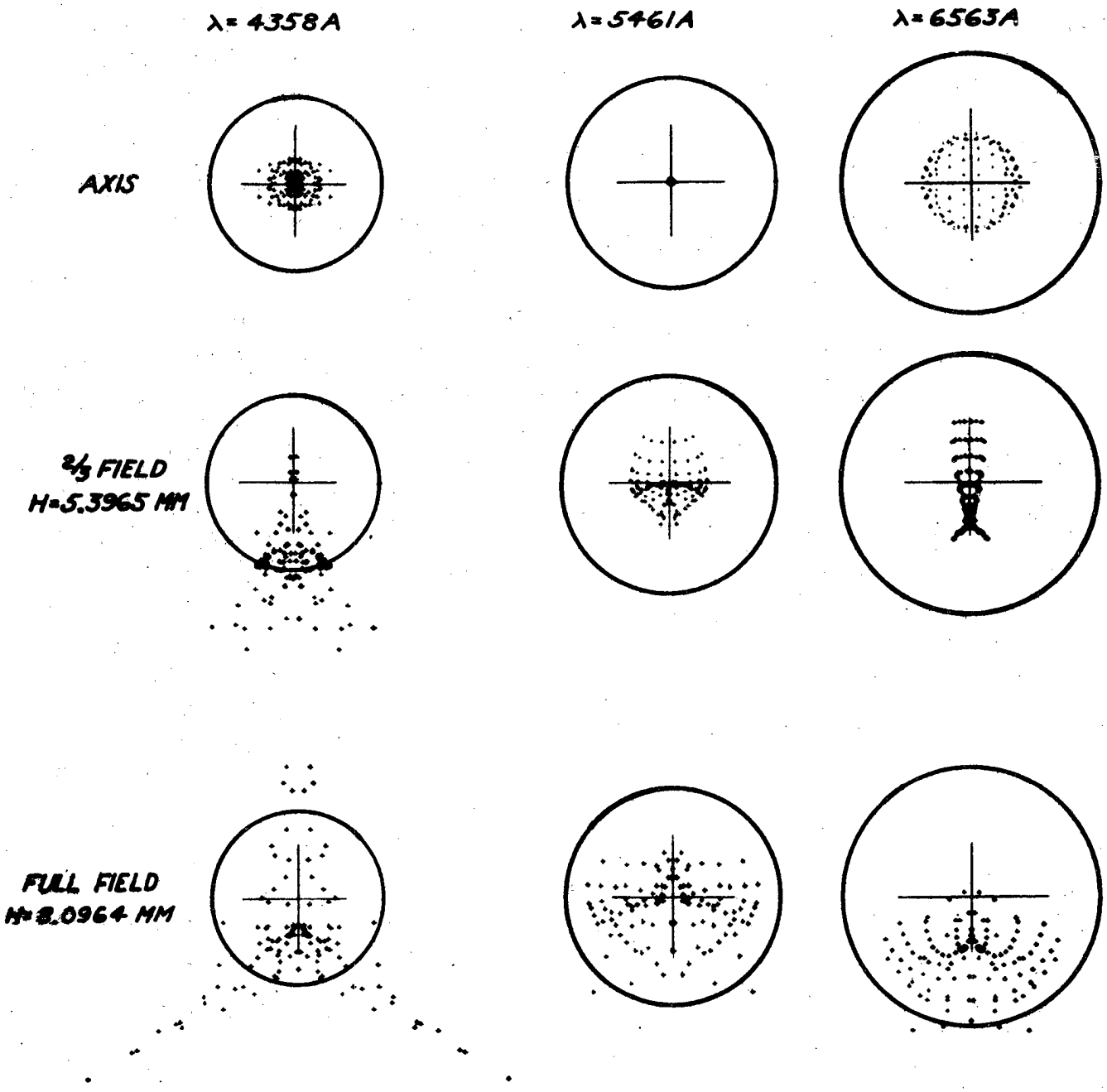

NOTE: THE CIRCLE ON EACH SPOT DIAGRAM REPRESENTS THE FIRST MINIMUM OF THE DIFFRACTION PATTERN FOR A POINT SOURCE IMAGE

Figure 5. Spot Diagrams - 20X Enlarger Lens,

[redacted] 5829

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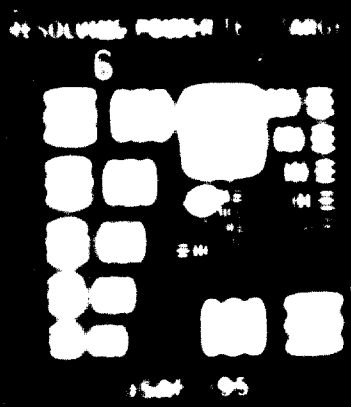
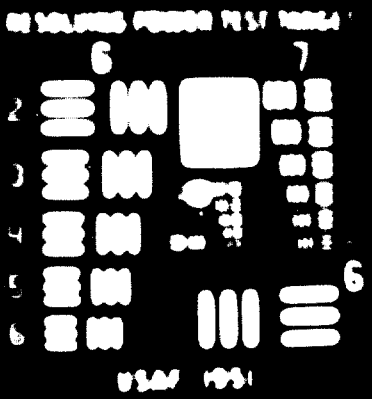
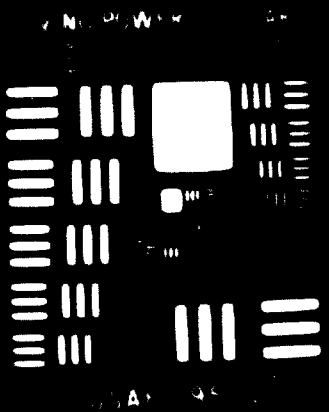


a) 52mm. [redacted] lens, full visible spectrum.



b) 52mm. [redacted] lens, green filter (W99).



c) 50mm. M171A lens, narrow band blue filter (Fabry-Perot, peak at 4050A).

Figure 6. Enlarged Prints (10X) of 20X Enlargements Made on Type 4404 Film with Lens and Lights Filtering as Noted

with respect to the appearance of sharpness, the [redacted] lens is apparently STAT
equivalent in image quality for color to the M-171A lens for black-and-white photographs. With a green filter and orthochromatic print stock, it might serve as a substitute for the M-171A lens in making black-and-white prints.

STAT 5. Phase II - The [redacted] Lens Sample: This phase of the project was initiated as a contract amendment to the original project authorization in an attempt to provide the 10-20-40X Enlarger with an interim capability of making 20X color prints and black-and-white prints on variable contrast paper (blue and green sensitive print stock) until a specially designed
STAT [redacted] lens should be available for use.

STAT STAT 6. [redacted] Lens Tests and Results:

a. A sample lens (a 52.7 mm [redacted] lens built by [redacted] STAT
STAT [redacted] had been tested as a document reproduction lens by another optical engineering group. This lens was procured and installed in a spare gate and focusing assembly and tested on the 10-20-40X Precision Enlarger Ser. No. 002 by making enlargements of reproduction target patterns. In this
STAT test, both [redacted] High Definition Aerial Film (Estar Thin Base), Type 4404,
STAT a panchromatic film, and [redacted] Special Ortho Aerial Duplicating Film, Type SO-242 were used with various types of color filters to learn lens performance in various spectral regions. The [redacted] lens performance was also STAT
compared to that of the original 20X Precision Enlarger lens (M-171A) with its narrow band interference filter. The details of this test and the resolution values are shown in Table 1.

b. Three 10X enlarged prints made from the 20X enlargements of high-quality 3-bar resolution target patterns (derived from USAF 1951) are shown in Figure 6. Print (a) was made with the [redacted] lens corrected for STAT
the full visible spectrum; the same lens corrected only for green light was used to make print (b); in making print (c), the 50-mm M-171A lens was used

TABLE 1

RESOLVING POWER TESTS OF 20X COLOR LENS FOR THE 10-20-40X PRECISION ENLARGER

Lens	Filter	Type 4404 Film (Panchromatic) Resolution*	Spectrum Band	Type SO-242 Film (Orthochromatic) Resolution	Spectrum Band	Type 8430 Film (Color Blind) Resolution	Spectrum Band
STAT	W2B (UV Blocking)	406/327	Full Visible	406/368	Blue & Green	----	----
	W99 (Green)	406/389	Green only	406/389	Green only	----	----
	Interference 4080A peak	645/351	Narrow Band Blue	----	----	645/534	Narrow Band Blue

* Resolving power values are expressed as lines/mm at the short conjugate of the lens. The number before the slash (/) is resolution on axis. The number following is the geometric mean of the average radial resolution and the average tangential resolution at the "corners" of the field (6 degrees off axis).

** This f/2.0 lens which has a focal length of 52.7mm was used at f/4.0 in these tests.

*** This f/2.0 lens which has a focal length of 50mm was made especially for the 10-20-40X Enlarger by STAT In these tests it is used at f/2.8 with a narrow band Fabry-Perot filter with peak transmittance at 4050A.

with its narrow band second order Fabry-Perot interference filter. The 20X enlargement for the images shown was near the lens axis and was exposed on Type 4404 film (high-definition, extended panchromatic sensitizing) for all examples. The image sharpness of print (b) is considerably greater than that of print (a). Also, the image sharpness of print (c) produced by the M-171A lens with its narrow spectrum band is considerably greater than that produced with the lens corrected for a broad spectrum range.

c. A 20X color transparency which was made on the 10-20-40X Precision Enlarger with the 52mm [ ] lens is shown in Figure 7. STAT

d. The line spacing (lines/mm) of various test pattern targets for the 20X enlargements is shown in Table 2. The diameter of the Airy disc which in theory would just resolve the particular target is also given in this table. As a rough comparison, this diameter may be equated to the diameter of the circle which included 90 percent of the rays (see Figures 2, 3, and 4) to predict:

(1) The resolution capability of a lens design

(2) The energy distribution due to aberrations and diffraction of a lens being tested.

e. In the practical test of making 20X color enlargements from high-quality original aerial photographs with the [ ] lens, no image degradation is known to be caused by the lens. In addition, there is no observable color fringing, no apparent loss of detail in the corners of the print, or noticeable image distortion. Thus, the lens quality apparently exceeds requirements placed on it by production or experimental color materials now available. STAT

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Figure 7. Sample Color Transparency Made on the [redacted] Precision Enlarger Using a 52mm [redacted] Lens

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TABLE 2

RESOLUTION TARGETS USED TO TEST LENSES

(See Figure 6 and Table 1)

Target Group	Number Chart	Line Spacing	Airy Disc Dia. to Resolve the Target (Rayleigh Criterion)
6	1	64.0 lines/mm	.031mm
	2	71.8	.028
	3	80.6	.025
	4	90.5	.022
	5	101.6	.0197
	6	114.0	.0175
7	1	128.0	.0156
	2	144.0	.0139
	3	161.0	.0124
	4	181.0	.0110
	5	203.0	.0098
	6	228.0	.0088
8	1	256.0	.0078
	2	287.0	.0070
	3	323.0	.0062
	4	362.0	.0055
	5	406.0	.0049
	6	456.0	.0044
9	1	512.0	.0039
	2	575.0	.0035
	3	645.0	.0031

f. The test using orthochromatic film Type SO-242 was conducted to learn the performance of the lens for exposing variable contrast black-and-white print materials. In these materials, a change in the relative amount of green versus blue exposing light controls the print contrast. Therefore, a lens for printing on these materials must be corrected for blue and green light.

7. Comparison of Phase I and Phase II Lenses:

a. In making (a) 20X enlargements from present production and experimental color film and (b) 20X enlargements on variable contrast paper for briefing chart use, the 52mm [ ] lens is recommended over the [ ] lens design because:

(1) In the test conducted in Phase II of the project, the 52mm [ ] lens appeared to be adequate for 20X color prints and for 20X variable contrast black-and-white prints.

(2) The [ ] lens is not restricted to the time sequence of exposures proposed for the special lens designed by [ ] for the project and, thus, is more convenient to use.

(3) Being a commercial item, the [ ] lens is readily available at lower cost than the special design [ ] lens.

The recommendation of the [ ] lens over the more sophisticated lens for making 20X color enlargements is upon the basis that no appreciable improvement in print quality would be obtained from the present original color photographs.

b. For 10X and lower magnification, it is recommended that the two lens designs be compared again because it cannot be assumed that the same conclusions will hold for the necessary longer focal length versions of the two lenses. In increasing the focal length of a lens, the geometric aberrations are increased in proportion to the focal length increase. At the 50mm focal length of the samplesin this test, the geometric aberrations in the

STAT [ ] lens are sufficiently small to be unobjectionable relative to the quality of available original color material. This may not be true, however, at twice the focal length.

CONCLUSIONS

8. The predicted performance of a lens made to the [ ] design is STAT
STAT better than [ ] specification and should provide excellent 20X color enlargements.

STAT 9. The [ ] lens quality apparently exceeds the requirements placed on it by production or by experimental color materials now available. Furthermore, this lens is judged adequate for 20X enlargements upon variable contrast black-and-white paper for briefing chart use.

RECOMMENDATIONS

STAT 10. The [ ] lens is recommended over the [ ] lens. (See paragraph STAT 7a and b).

11. For 10X and lower magnifications, the two lenses should be compared again since it cannot be assumed the same conclusions will bear up at the longer focal-length version of the two.

APPENDIX A

DESIGN SPECIFICATION

FOR

20X COLOR LENS FOR 10-20-40X PRECISION ENLARGER

Focal Length:	Approximately 2.0 inches. (Overall conjugate distance 42.80 inches)
Aperture:	f/2.0 to f/4.0 - may be selected from this range for optimum image quality.
Magnification:	20:1
Short Conjugate Field Diagonal:	0.368 inches
Long Conjugate Field Diagonal:	12.75 inches
Angular Field:	Approximately 9 degrees
Wavelength Range:	Three narrow spectrum bands (70 to 100 Angstroms half pass band width) centered about 4358A, 5461A, and 6563A, respectively.
Corner Illumination:	Should follow $\cos^4$ law if this does not reduce image quality. No vignetting is a desirable condition.
Distortion:	Less than 0.05 percent
Performance:	In the short conjugate, the design goals are: (a) In the band centered about 5461A, 90 percent of the rays should fall within a 3-micron circle over at least 6 degrees of the field.

(b) In the bands centered about 4358A and 6563A, 90 percent of the rays should fall within a 4-micron circle over at least 6 degrees of the field.

(c) Magnification in the three spectrum bands shall be such that 90 percent of the rays from the three bands fall within a single 5-micron circle over at least 6 degrees of the field.

Special Conditions:

(a) The negative will be registered against the plano surface of a glass element between the film and the main lens assembly. This element may be a .125-inch thick plate (C-1 glass) or it may be a "field flattener" with one plano surface at the focal plane.

(b) If the lens performance is improved by doing so, the short conjugate distance in the system can be adjusted by moving the negative gate between sequential exposures in the three spectrum bands.

REFERENCES

1. Project Authorization Request, Color Corrected Lens for the 10-20-40X Precision Enlarger, PAR 3 — 25 April 63

2. Quarterly Reports, PAR 3, Contract EB-1492 — 1 July 63; 1 October 63; 17 January 64; 31 March 64; 28 June 64

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STAT

MEMORANDUM FOR: [redacted]

Here is PSD's requirement - Our job is to coordinate the joint procurement with DIA, AMS and any others we can locate

Bill M.

(DATE)

FORM NO. 101 REPLACES FORM 10-101
1 AUG 54 WHICH MAY BE USED. (47)

STAT

MEMORANDUM FOR: [redacted]

Here is the approval for NPIC requirements. [redacted] is best to [redacted] would like #1 + #2 for NPIC and wants earliest possible delivery.

28 Sep

(DATE)

STAT

FORM NO. 101 REPLACES FORM 10-101
1 AUG 54 WHICH MAY BE USED. (47)

Memo George Coordinate 3 Sept 64

TAT To: [redacted]

Subj: 10-20-40 Enlarger Joint Purchase

1. By JWC instruction I contacted [redacted] TAT DIA-AP to determine the status of their procurement of subject enlargers.

2. We reported that they are in process of setting up purchase of two Durst DIASA, Mo. [redacted] STAT cognizant individual.

3. JWC would like for their purchase to be coordinated with ours if this can be arranged. We are also in the process of setting up a purchase for two.

4. AMS is also in process of [redacted] STAT getting one