NATIONAL BUREAU OF STANDARDS REPORT

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The Effective Intensity of Flashing 399PAR Lamps

By
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U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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Foreword

Frequently the assumption is made that the intensity-time curve of an incandescent lamp which is flashed by switching power to the lamp is a square-wave. Effective intensities are then computed on this basis. Although this assumption is usually satisfactory for low-current (less than about 0.2 ampere) lamps, it is not satisfactory for the flashing lamps which are used in aviation ground-lighting service especially when these lamps are operated at voltages considerably below rated voltage. An example of this type service is the use of type 399PAR lamps (399-watt, 115-volt) for the "wave-off" and "cut" lights of optical landing systems.

The effective intensity of this lamp as a function of lamp voltage at a specified flash rate and duty cycle was needed for design purposes.

One approach to the problem is the computation of effective intensity as a function of voltage from instantaneous intensity-time curves obtained with the lamp operating at the specified flash rate and duty cycle. This method is relatively simple. However, if subsequently the effective intensity at a different flash rate and duty cycle is required, the entire photometric procedure would have to be repeated.

A second approach is the obtaining of instantaneous intensity-time curves for flashes which are so long that the lamp reaches its steady-state intensity during the flash. The effective intensity for any flash rate and duty cycle can be obtained from such curves by a suitable computational procedure.

The second approach was used in this study as it is probable that effective intensity data for this, or similar, lamps at other flash rates and duty cycles will be required in the future. Since the method may be useful in other applications, it is reported in detail in this report.

The Effective Intensity of Flashing 399PAR lamps

ABSTRACT

This report presents the results of a study of the intensity vs time, and of the effective intensity of flashing 399PAR lamps. These lamps are the type used as the wave-off lights in the optical landing system. The study includes the characteristics of the white light, as well as the beam transmitted through aviation-red and aviation-green filters, at the voltages applied to the datum lights on the seven steps of the optical landing system: 21, 27, 35, 44, 60, 80, and 115 volts.

1. MATERIAL TESTED

The lamp tested is a type 399PAR Airport-Approach lamp. It is a PAR-56, 399-watt, 115-volt lamp with a CC-13 filament, rated at an initial maximum intensity of approximately 30,000 candelas and a life of 100 hours.

Tests were made on one lamp only, since the relative intensities, not the intensity distributions, were under study.

2. TEST PROCEDURE

2.1 Measurements.

A circuit was assembled whereby the voltage applied to the lamp was adjustable by means of a variable autotransformer, and the duration of the "on" interval was continuously adjustable by means of a variable-speed motor driving a cam which applied the energizing voltage to the lamp through a snap-action switch. An oscilloscope provided a graphical presentation of the instantaneous intensity vs time curve.

Lamp voltages of 21, 27, 35, 44, 60, 80, and 115 volts (corresponding to the voltage steps of the shore-based optical landing system datum-light voltages) were applied for the white, red, and the green beams. In each of the 21 presentations, the "on" period was made long enough so that the peak instantaneous intensity of the flash became equal to the intensity of the steadily burning lamp at that applied voltage. The "on" period was further adjusted so that the known time-base scale of the flash could be later conveniently transferred to rectilinear-coordinate graph paper. The peak amplitude of the curve was then measured electronically. Photographic transparencies were recorded with an oscilloscope-record camera of the oscillograms of each of the 21 conditions.

2.2 Preparation of Graphs.

Each photographic transparency was mounted in a photographic enlarger, and the image was projected on a sheet of rectilinear-coordinate graph paper. The magnification was adjusted so that each integral second on the time-base scale of the image coincided with a major division on the time-base scale of the rectilinear graph paper. The images were then hand-traced on separate sheets of graph paper.

In order to show more clearly the relationship among the instantaneous intensity-time curves for each of the three colors at a given voltage, the curves on the rectilinear graphs were replotted on semi-log graph paper. The maximum of the white flash at 115 volts was taken as 100 on the relative intensity scale and was so plotted on the semi-log graph paper. All of the 21 curves were replotted on semi-log paper, and all of the curves are shown as relative to the white, 115-volt curve taken as 100.

3. COMPUTATION OF THE RELATIVE INTENSITIES

The procedure used for the computation of the effective intensity of flashing lights has been discussed in detail previously.[1]

Using the curves of instantaneous relative intensity vs time, shown in figures 1 to 7 of this report, the effective intensity of a flash of any duration for a 399PAR lamp may be computed using a slight modification of the method outlined in the paper referenced above.

A brief explanation of the method of computing the effective intensity at the selected flash rate (1/3 second on, 1/3 second off) follows. For clarity, the curve for a single flash of "clear" (white) light at 60 volts, figure 5, has been reproduced and shown in figure 8.

It is to be noted that on the first flash, the point "x" is not at the time t = 0, due to the thermal inertia of the filament. The intensity of the light increases from x to y, the steady state. The steady state exists from y to c (the distance between y and c can be extended indefinitely). At point c the energizing voltage is removed, and the intensity falls off linearly from c to z.

After several flashes, equilibrium is reached, and the intensity of each flash then is initiated at some point above x on the curve, since the filament no longer cools off to the ambient temperature (below z).

The intensity will rise during the time the lamp is on, in this example 1/3 second, to the point b. At this time the lamp is turned off and the intensity falls along the cooling curve for 1/3 second falling from the point b' to a'. The intensity-time curve is therefore the composite of a b and b'a', or a b a" as shown on the figure.

The problem is to find an intensity a such that the time to rise to a point b along the heating curve is equal to the ON time and the time to fall from b to a" along the cooling curve is equal to the OFF time. In this particular case both times are equal to 1/3 second.

This can be accomplished in the following manner.

1. Start at c and measure over 1/3 second to d.
2. Drop a vertical from d intersecting the curve at e.
3. Form triangle c'd'e' with d'c' equal to c d and d'e' equal to d e (shown in insert).
4. Slide this triangle along the rising part of the intensity-time curve, keeping d'e' vertical, until vertices c' and e' just touch the curve, at a and b.
5. The intensity a is the initial and terminal intensity and b, or b', is the maximum intensity of a repetitive flash with a duration of 2/3 second and a 50% duty cycle.

Note: This procedure is applicable only when the decay curve approximates a straight line. Only when the intensity scale is logarithmic, will the decay curve be a straight line.

There then remains the computation of the effective intensity of the flash a b a".

As discussed in reference 1 the effective intensity is defined by the equation

$$I_e = \int_{t_1}^{t_2} \frac{I\,dt}{.2 + (t_2 - t_1)}$$

where I_e is the effective intensity, I is the instantaneous intensity and t_1 and t_2 are the limits of the integral where the limits t_1 and t_2 are chosen so that I_e is a maximum. It has been shown that I_e is a maximum when the limits t_1 and t_2 are the times when the instantaneous intensity, I, is equal to the effective intensity, I_e.

The computation of the effective intensity is then reduced to selecting a t_1 and t_2 so $I_e = I$ at t_1 and t_2. Since this curve is plotted on semi-log paper, the area under the curve cannot be integrated with a planimeter. Instead, I_e may be calculated from the expression

$$I_e = \frac{\Sigma I_{av} \cdot \Delta t}{.2 + (t_2 - t_1)}$$

where I_e is the effective intensity, and

I_{av} is the average instantaneous intensity during a small Δt, where Δt is small when compared with $(t_2 - t_1)$, the limits of the summation.

For simplicity, Δt in this case was taken as .05 sec or less, and I_{av} was taken as the I at the midpoint of the interval Δt.

This method is illustrated below, showing the computation of the effective intensity for the curve shown in figure 8.

It is convenient to separate the composite curve for the flash into two parts: the rising part, and the falling part. There will, therefore, be an initial t and a final t for each of the two parts. These will be called t_a and t_b, respectively, for the rising part, and t_c and t_d, respectively, for the falling part, with t_a corresponding to t_1 and t_d corresponding to t_2 of the integral.

Therefore $(t_2 - t_1) = (t_b - t_a) + (t_d - t_c)$.

An estimated I_e is chosen at 4.0. Then on the rising portion of the curve (with Δt taken as .05):

at 4.0, $t_a = .30$, $t_b = .45$, $(t_b - t_a) = .15$

at t =	.30		.35		.40		.45
I =	4.0		5.9		7.8		9.0
Iav =		4.95		6.75		8.4	

$I_{av}\Delta t = (4.95 + 6.75 + 8.4)(.05) = 1.005$

and on the falling portion of the curve (with Δt taken as $[t_d - t_c]$ since the curve is linear):

at 4.0, $t_c = .03$, $t_d = .11$, $(t_d - t_c) = .08$

at t =	.03		.11
I =	9.0		4.0
Iav =		6.5	

$I_{av}\Delta t = (6.5)(.08) = .520$

$$\Sigma\, I_{av}\Delta t = 1.005 + .520 = 1.525$$

$$(t_2 - t_1) = (t_b - t_a) + (t_d - t_c) = .15 + .08 = .23$$

$$I_e = \frac{\Sigma\, I_{av}\Delta t}{.2 + (t_2 - t_1)} = \frac{1.525}{.43} = 3.55$$

The computed I_e is lower than the estimated I_e, so the actual I_e lies somewhere between the two but nearer 3.55.

The next estimated I_e is chosen at 3.6.

Following the above procedure, the computed $I_e = 3.62$. This calculated I_e is close enough to the second estimated I_e to estimate that the actual effective intensity is 3.6.

Note: When the integration is made from a rectilinear plot with a planimeter, the usual procedure for the second step is to use the I_e obtained in step 1 as the estimated value of I_e for the computations of the second step. However, with the numerical summation used here, it is often more convenient to choose a round number near the I_e obtained in the first step. Since the value of I_e changes very slowly with estimated values of I_e near the "true" I_e, this procedure is satisfactory.

4. RESULTS

The instantaneous intensity-time characteristics for the seven voltages and three colors are shown in figures 1 to 7. Figure 8 shows the method of computing the effective intensity as described in paragraph 3 of this report. This curve is the same as the curve for white light on figure 5.

Figure 9 is a comparison of the relative intensity-voltage characteristics of a steady-burning 399PAR lamp (as reported in NBS Report 6190), the effective relative intensity-voltage characteristics of a flashing 399PAR lamp operating under the conditions shown, and the effective relative intensity-voltage characteristics of the flashing 399PAR lamp operating 12 volts above the datum-light voltage, as they are used as wave-off lights in the shore-based optical landing system. Note that this curve is plotted against the applied datum-light voltage.

Table I lists the effective intensities relative to the intensity of a steady-burning 399PAR lamp operating at 115 volts taken as 100. The effective intensities shown in this table are for a single, or the initial, flash and for the flash at equilibrium conditions for a flash rate of 90 flashes per minute with a 1/3 second "ON" period and a 1/3 second "OFF" period. This is the flash rate of the wave-off lights of the optical landing system which uses 399PAR lamps for this purpose.

TABLE I. EFFECTIVE INTENSITY OF FLASHING 399PAR LAMPS RELATIVE TO STEADY BURNING "WHITE" LAMPS AT 115 VOLTS TAKEN AS 100

Flash Rate: 90 Flashes per Minute
Cycle: 1/3 Sec. "ON", 1/3 Sec. "OFF"

Lamp Voltage	Color of Light	Relative Intensity: Nominal Steady Burning Condition	Single Flash	Flashing at Stable Condition
Volts		%	%	%
21	White	.10	-	.0080
	Red		-	.0039
	Green		-	.0030
27	White	.33	.0014	.042
	Red		-	.011
	Green		-	.0062
35	White	1.0	.025	.214
	Red		-	.084
	Green		-	.056
44	White	3.3	.19	.61
	Red		.051	.24
	Green		.025	.11
60	White	10	1.9	3.6
	Red		.53	.96
	Green		.40	.85
80	White	33	8.7	12.6
	Red		2.1	3.1
	Green		1.9	2.7
115	White	100	39	44.8
	Red		7.5	9.6
	Green		8.4	10.6

5. DISCUSSION

The method of computing the effective intensity of a flashing 399PAR lamp outlined in the preceding paragraph, paragraph 4, may be used for any flash rate for these lamps at any voltage for which the instantaneous intensity-time curve is known.

This method may, with sufficient accuracy for engineering estimates, be used for other lamps with approximately the same current rating.

REFERENCES

1 Charles A. Douglas, Computation of the Effective Intensity of Flashing Lights, Ill. Eng. 52, 641, 1957.

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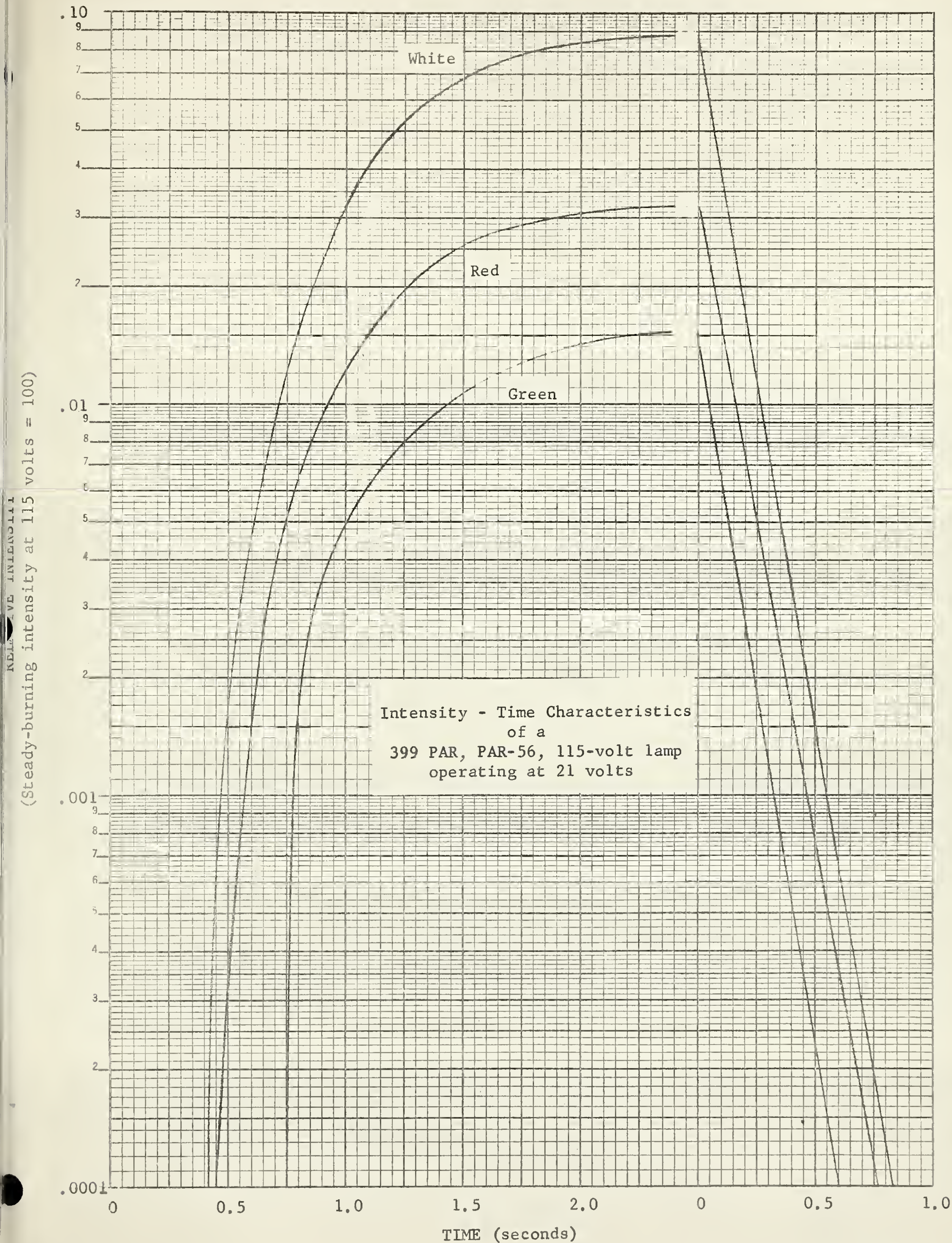


.10
.01
.001
.0001
White
Red
Green
Intensity - Time Characteristics
of a
399 PAR, PAR-56, 115-volt lamp
operating at 21 volts
(Steady-burning intensity at 115 volts = 100)
0
0.5
1.0
1.5
2.0
0
0.5
1.0
TIME (seconds)

Figure 1

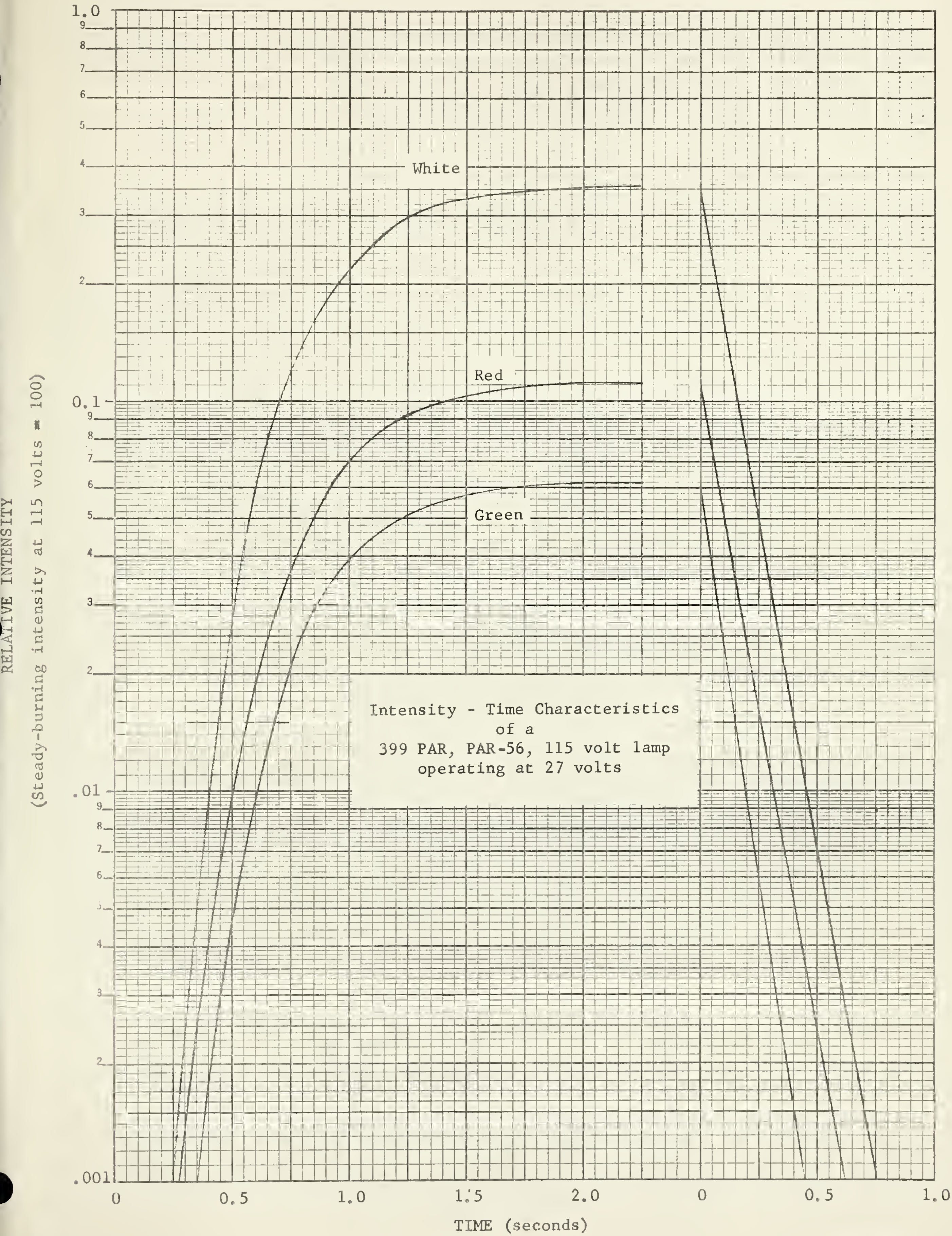

White
Red
Green
Intensity - Time Characteristics
of a
399 PAR, PAR-56, 115 volt lamp
operating at 27 volts
RELATIVE INTENSITY
(Steady-burning intensity at 115 volts = 100)
TIME (seconds)
1.0
0.1
.01
.001
0
0.5
1.0
1.5
2.0
0
0.5
1.0

Figure 2

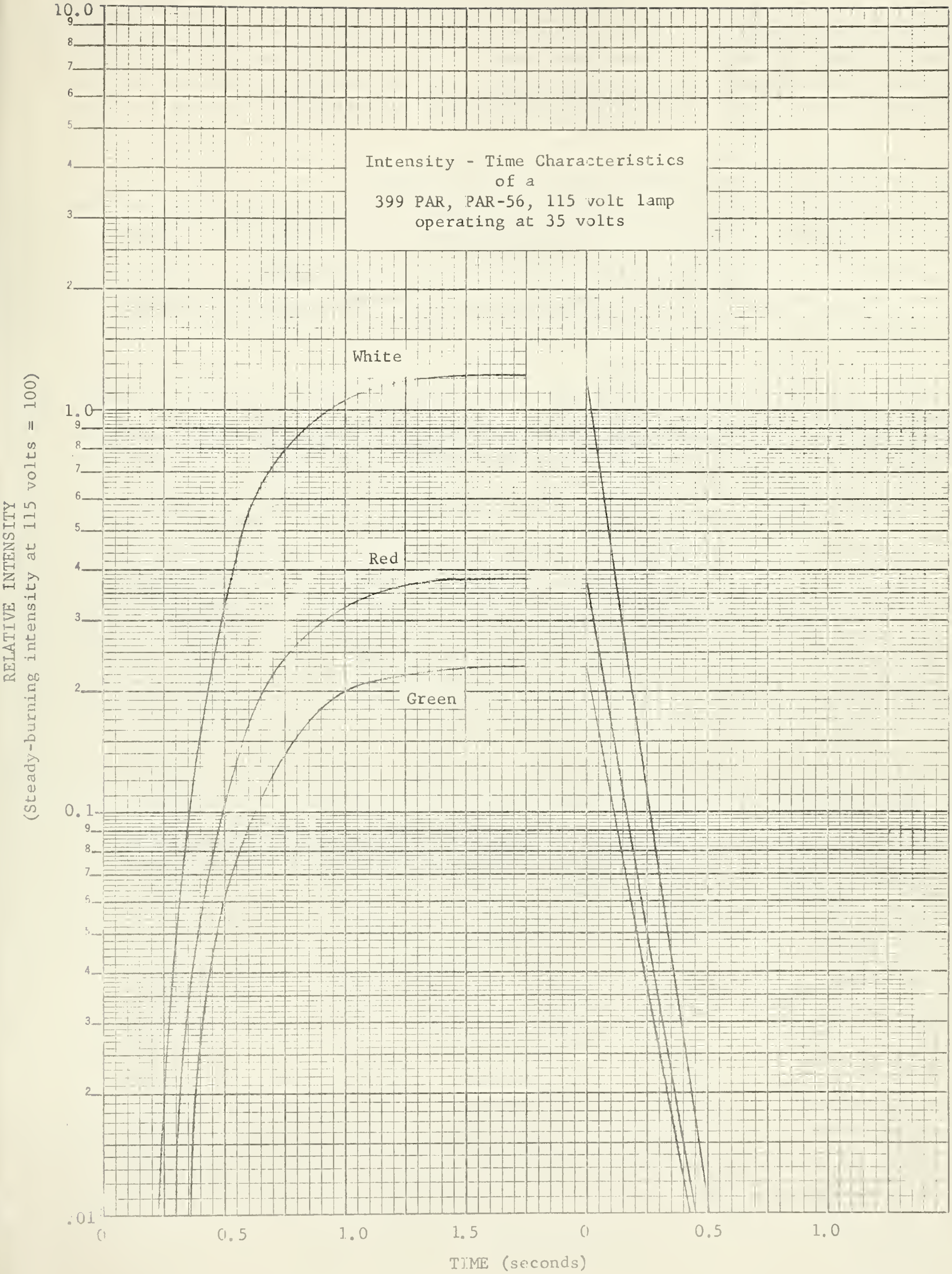
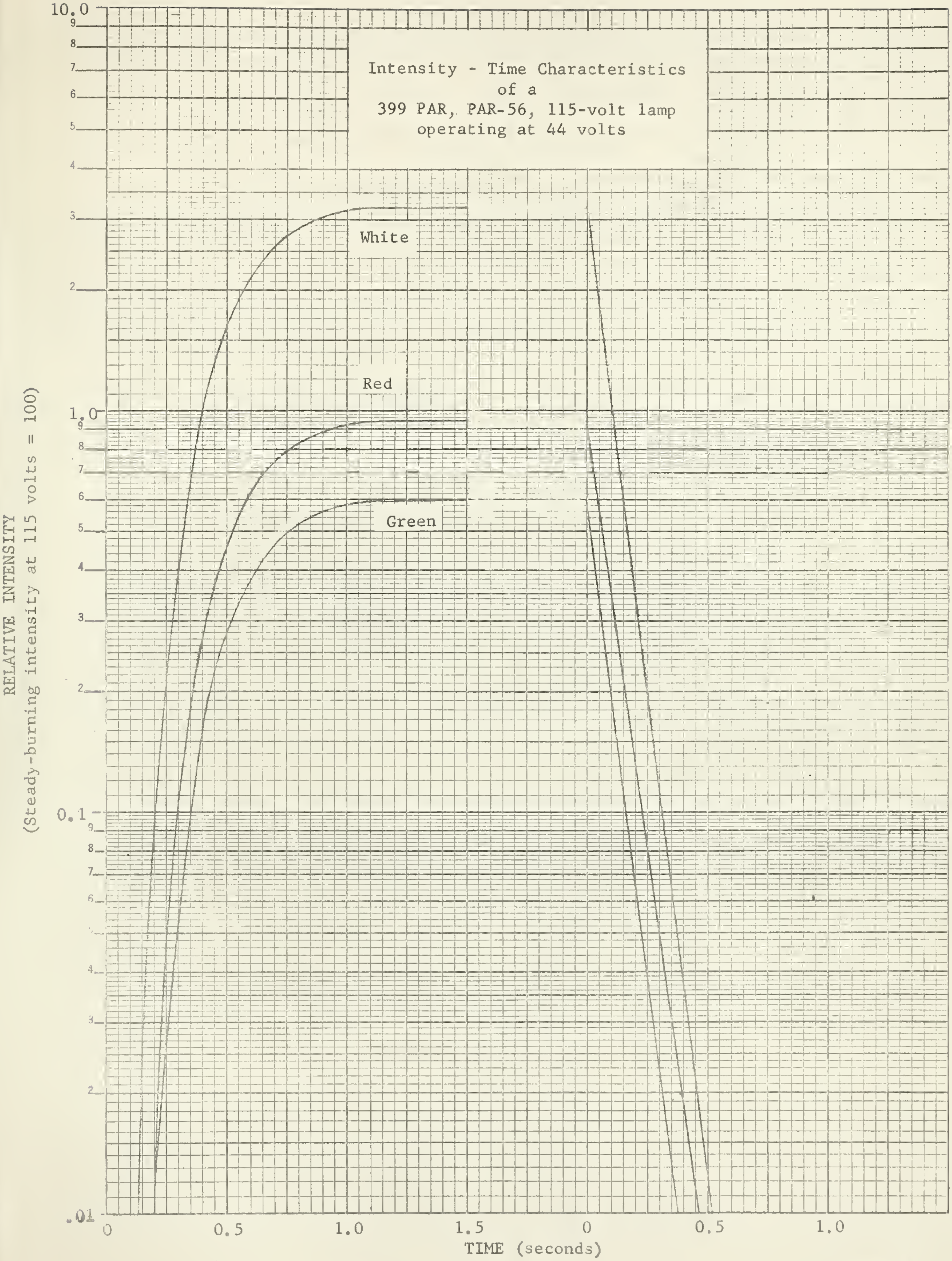

Intensity - Time Characteristics
of a
399 PAR, PAR-56, 115 volt lamp
operating at 35 volts
White
Red
Green
RELATIVE INTENSITY
(Steady-burning intensity at 115 volts = 100)
10.0
1.0
0.1
.01
0
0.5
1.0
1.5
0
0.5
1.0
TIME (seconds)

Figure 3



Intensity - Time Characteristics
of a
399 PAR, PAR-56, 115-volt lamp
operating at 44 volts
White
Red
Green
RELATIVE INTENSITY
(Steady-burning intensity at 115 volts = 100)
TIME (seconds)
10.0
1.0
0.1
.01
0
0.5
1.0
1.5
0
0.5
1.0

Figure 4

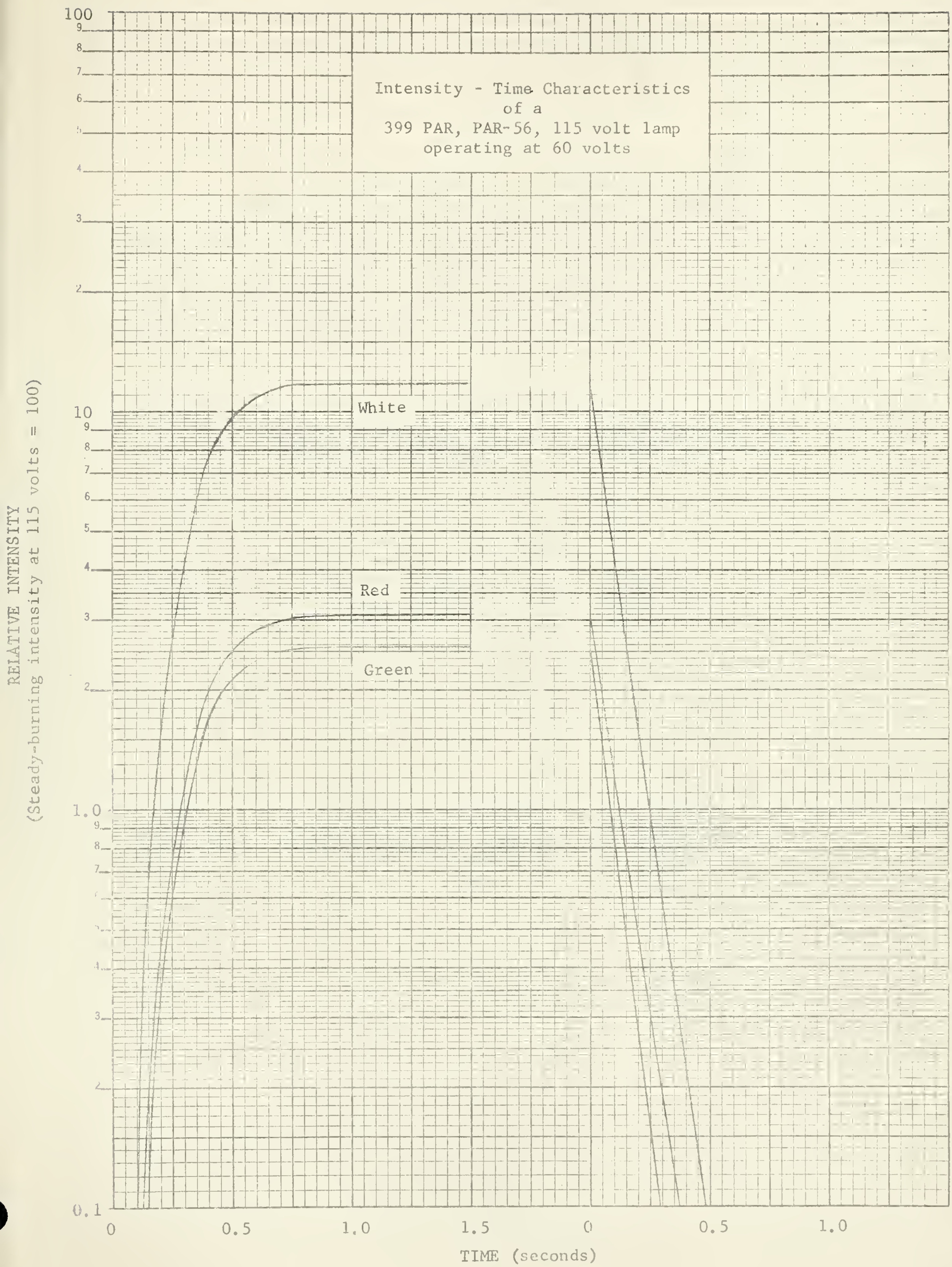

Intensity - Time Characteristics
of a
399 PAR, PAR-56, 115 volt lamp
operating at 60 volts
White
Red
Green
RELATIVE INTENSITY
(Steady-burning intensity at 115 volts = 100)
100
10
1.0
0.1
0
0.5
1.0
1.5
0
0.5
1.0
TIME (seconds)

Figure 5

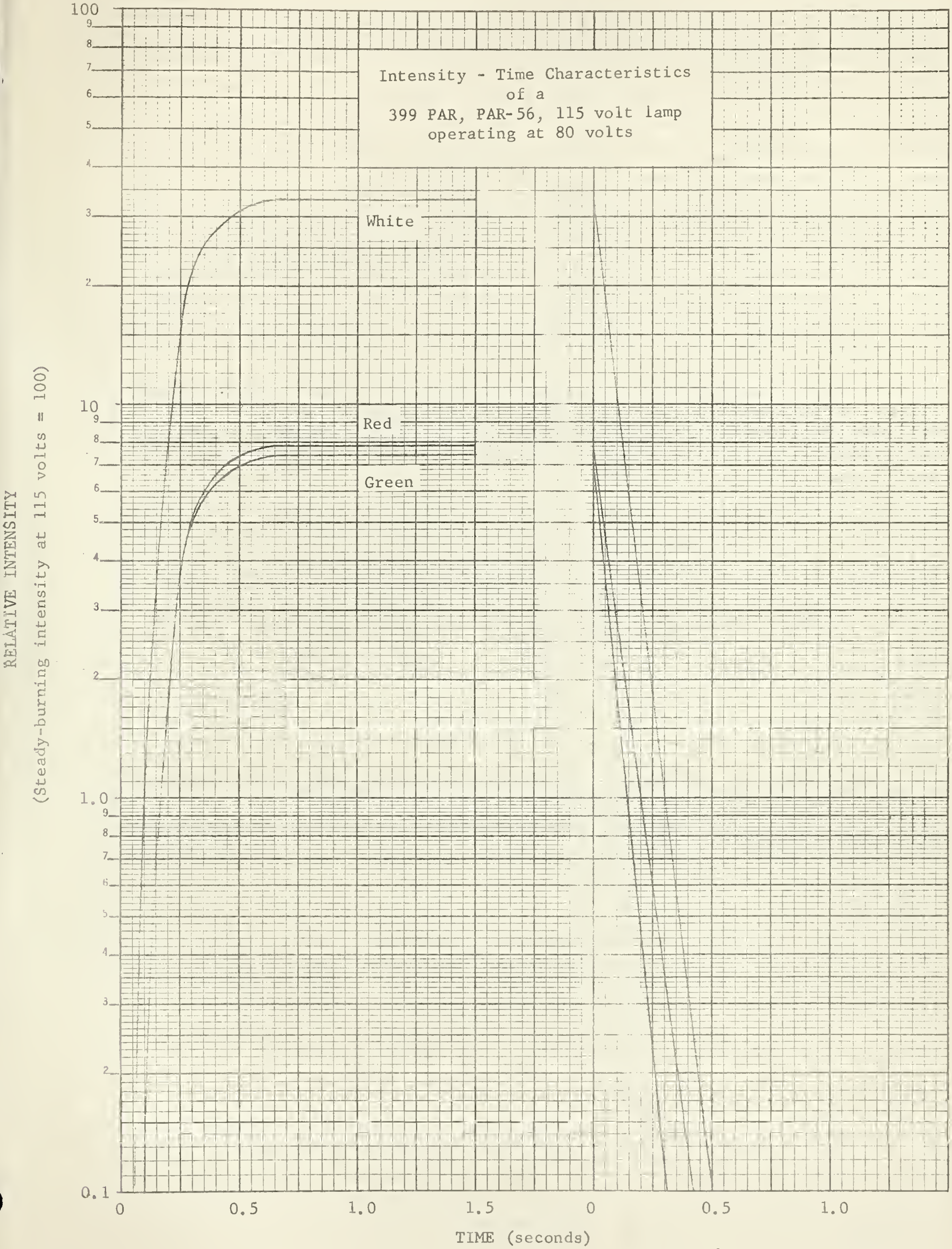
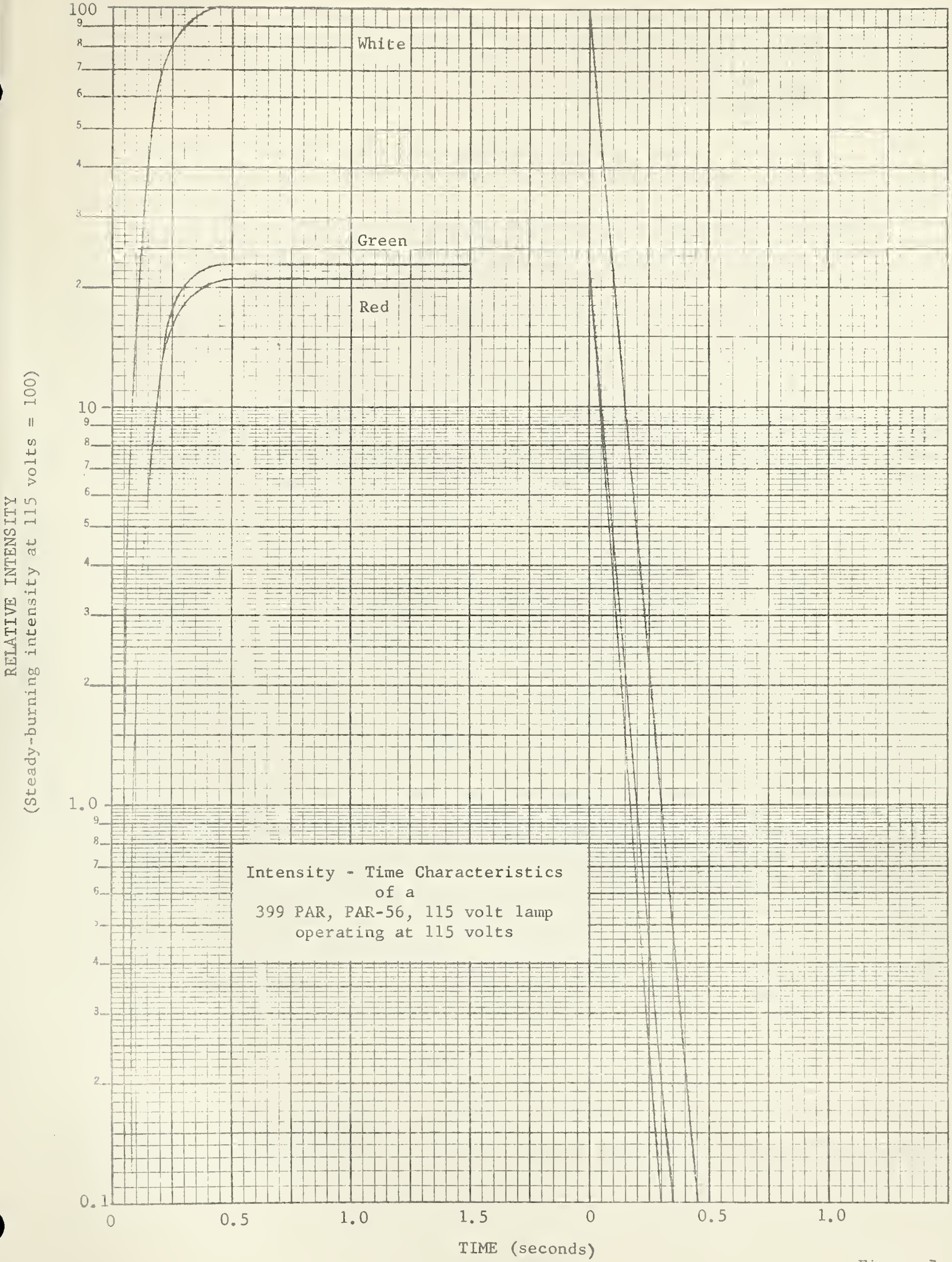
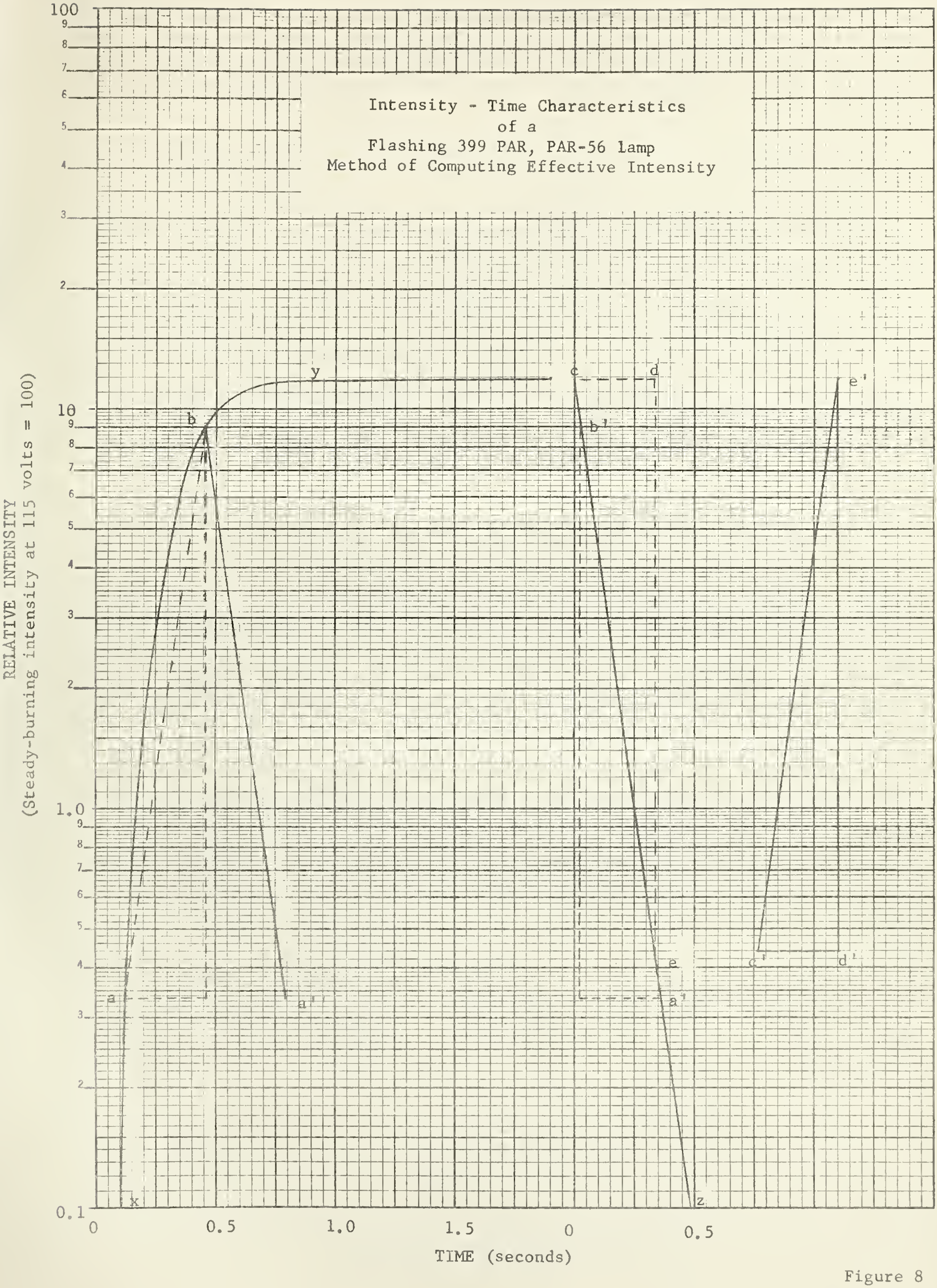

Intensity - Time Characteristics
of a
399 PAR, PAR-56, 115 volt lamp
operating at 80 volts
White
Red
Green
RELATIVE INTENSITY
(Steady-burning intensity at 115 volts = 100)
100
10
1.0
0.1
0
0.5
1.0
1.5
0
0.5
1.0
TIME (seconds)

Figure 6



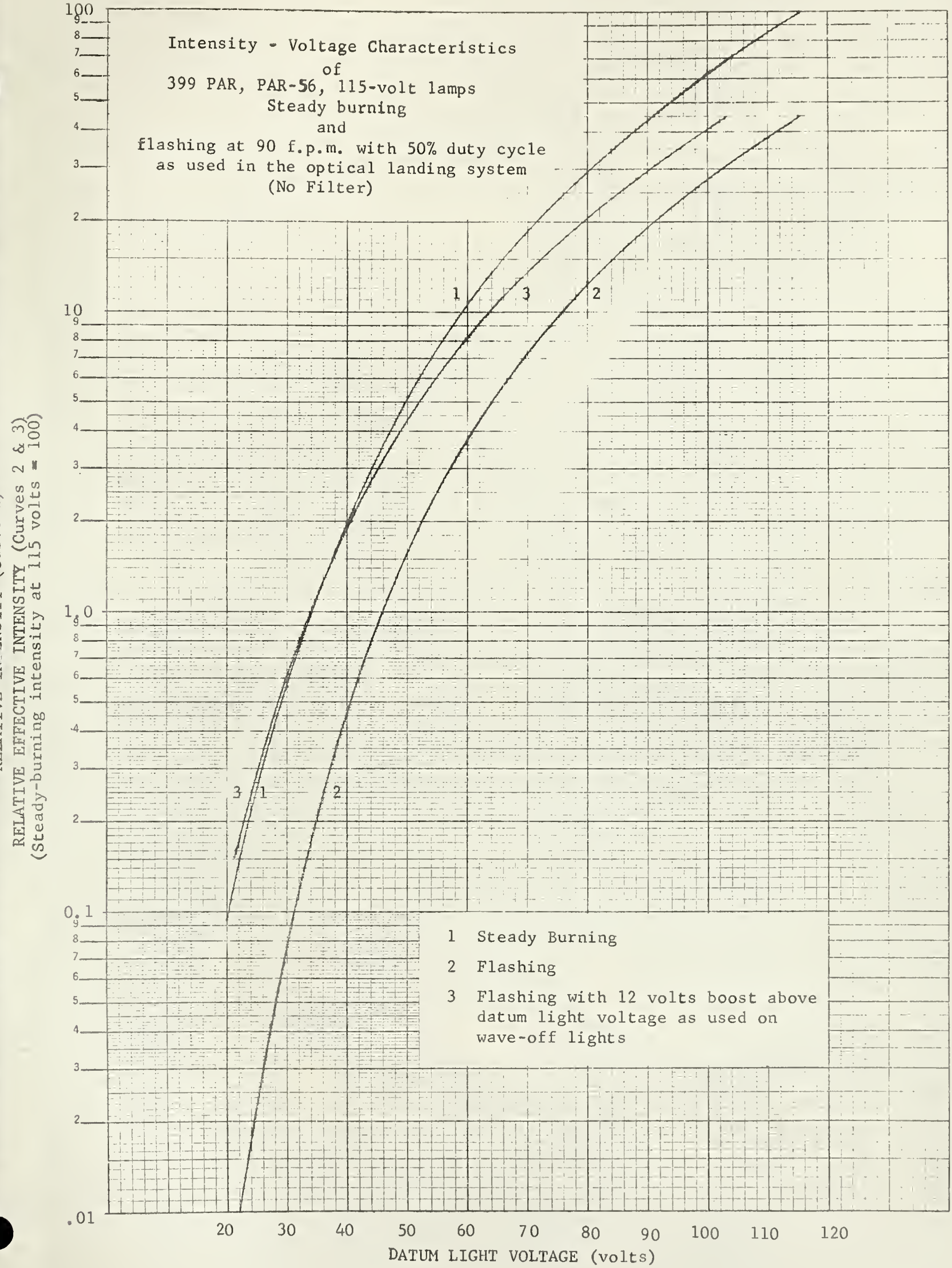
RELATIVE INTENSITY
(Steady-burning intensity at 115 volts = 100)
White
Green
Red
Intensity - Time Characteristics
of a
399 PAR, PAR-56, 115 volt lamp
operating at 115 volts
100
10
1.0
0.1
0
0.5
1.0
1.5
0
0.5
1.0
TIME (seconds)

Figure 7



Intensity - Time Characteristics
of a
Flashing 399 PAR, PAR-56 lamp
Method of Computing Effective Intensity
RELATIVE INTENSITY
(Steady-burning intensity at 115 volts = 100)
TIME (seconds)
100
10
1.0
0.1
0
0.5
1.0
1.5
0
0.5
a
b
y
c
d
e'
b'
a'
e
c'
d'
x
z

Figure 8



Intensity - Voltage Characteristics
of
399 PAR, PAR-56, 115-volt lamps
Steady burning
and
flashing at 90 f.p.m. with 50% duty cycle
as used in the optical landing system
(No Filter)
RELATIVE INTENSITY (Curve 1)
RELATIVE EFFECTIVE INTENSITY (Curves 2 & 3)
(Steady-burning intensity at 115 volts = 100)
DATUM LIGHT VOLTAGE (volts)
100
10
1.0
0.1
.01
20
30
40
50
60
70
80
90
100
110
120
1
2
3
1 Steady Burning
2 Flashing
3 Flashing with 12 volts boost above datum light voltage as used on wave-off lights

Figure 9