NATIONAL BUREAU OF STANDARDS REPORT

6862

Development of Visual Landing Aids for Jet Aircraft

Final Report

By

Photometry and Colorimetry Section
Optics and Metrology Division

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

THE NATIONAL BUREAU OF STANDARDS

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Development of Visual Landing Aids for Jet Aircraft
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Photometry and Colorimetry Section
Optics and Metrology Division

Prepared for
Base Electrical Equipment Section
Wright Air Development Division
Wright-Patterson Air Force Base
Ohio

NBS

U. S. DEPARTMENT OF COMMERCE
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Development of Visual Landing Aids

Final Report

Abstract

This report is the final report of a series describing the development of visual landing aids for jet aircraft at the National Bureau of Standards for the Equipment Laboratory, Wright Air Development Center, under Delivery Orders 33(616)54-6 and 33(616)57-8.

1. OBJECTIVES

The original objective of the project as outlined in Exhibit WCLEE5-42, dated 4 June 1953, "Study to Determine the Optimum Runway Light Design for Jet Aircraft" was

1) " The study of the operational procedures of jet aircraft in landing and on the ground and the effects of these procedures upon the optical and mechanical design of the runway light;

2) " The development of a suitable compromise between the conflicting optical and mechanical requirements and the recommendations of a design based upon this analysis;

3) " Fabrication of sample lights conforming to this design. "

During the early phases of the project it became apparent that the operational and intensity-distribution requirements of runway lights could not be developed without considering the functions and intensity distributions of the other components of the visual landing aids system. Therefore, the scope of the project was expanded to include a study of the performance of these components with the development of the intensity-distribution requirements of all components of an integrated system of landing aids required to complement the runway lighting system. The intensity distribution requirements of these components were based on the following premises.

The runway lighting system and related systems should 1) furnish all the visual guidance required for circling approaches performed under visual flight rules (VFR) with no consideration given to the guidance supplied by the approach lights, if any, or from extraneous lighting, from the time the airfield is located until the aircraft has turned off the runway after completing the landing; 2) furnish the visual guidance required for straight-in approaches on runways where no approach lights are installed; and 3) provide the visual guidance required for the final stages of landings on runways with high-intensity approach lights.

Subsequently, with the initiation of Delivery Order 33(616)57-8, the scope of the project was expanded to include:

1. "The study of all visual landing aids required by aircraft during approach, landing, take-off, taxiing, and high speed ground maneuvering, from a distance of 100 miles from the airport until the aircraft has reached the parking area, the study to include interviews with pilots of many different aircraft and to be extensive enough to permit a complete statistical analysis of visual aid requirements; the establishment of firm technical requirements defining which visual aids must be visible during each portion of the landing operation, and the information which each aid should transmit.

2. "The development and testing of prototype samples of the specific new lights which the National Bureau of Standards has already recommended for use in runway lighting systems at USAF bases, such as circling lights, identification lights, and threshold lights.

3. "The development of prototype samples of any new lighting and marking aids revealed as necessary during the studies.

4. "The conducting of any laboratory, flight, and field tests considered necessary to verify preliminary recommendations and theoretical data."

2. SCOPE OF THE INVESTIGATION

The development program was conducted along the following courses.

1. Determination of the optical requirements of the components of a runway lighting system by means of a) pilot interviews to determine the operational requirements of the system, the deficiencies of the system in use, and the acceptability of proposed modifications; b) photometric testing of existing and prototype lights; and c) computation of the visual range and glare zones of these lights.

2. Determination of the mechanical requirements of the lights by interviewing maintenance personnel and inspecting facilities to determine deficiencies in the present units, by computing loads imposed upon landing gear by obstructions on the runway surface, by testing the mechanical strength of present and prototype lights, and by tests of the electrical characteristics of the lights.

3. Procurement and laboratory testing of prototype lights.

4. Preparation of specifications for lights proposed for service tests.

The four phases of the investigation were conducted concurrently. The results of the investigation have been reported in 51 detailed reports and memoranda (in addition to monthly reports) which were prepared and forwarded to Wright Air Development Center as individual tasks were completed. These reports are listed in Appendix A.

In June 1956 NBS Report 4741, Development of Optimum Runway Lights for Jet Aircraft (Interim Report No. 1) was issued. This report summarized the results of the investigation to that time. Material summarized in that report will not be repeated here except when required for clarity.

3. VISUAL GUIDANCE REQUIREMENTS OF A VISUAL LANDING-AIDS SYSTEM

A satisfactory visual landing aids system should supply the following visual guidance during a visual approach to an airfield and during a landing.

1. During the initial penetration :
   a. Location and identification of the airport,
   b. Location and identification of the runway.

2. During a circling approach:
   a. Distance from and direction of the runway, so that the downwind leg can be flown parallel to and at the desired distance from the runway,
   b. Location of and distance from the threshold and direction of the runway during the turn from the downwind leg to the base leg, on the base leg, and during the turn from the base leg to the final leg of the approach pattern.

3. On the final leg:
   a. Location of and distance from the threshold,
   b. Location of the horizontal plane through the threshold,
   c. Location and direction of the runway axis,
   d. Height above the runway or distance above or below a preferred glide path.

4. During flareout and touchdown:
   a. Height above the runway,
   b. Direction of the runway,
   c. "Horizon",
   d. Lateral boundaries of a safe landing area.

5. During rollout:
   a. Lateral boundaries of the runway surface,
   b. Direction of the runway axis,
   c. Location of turnoffs,
   d. Distance from and location of the upwind end of the runway.

During takeoff the visual guidance required of the runway light system is essentially the same as that required in the last phase of the approach and in the rollout. A system meeting the requirements for guidance during landing should also meet the requirements for guidance during takeoff.

4. LIGHTING FOR INITIAL PENETRATION

4.1 Location and Identification of the Airport

During a visual approach the location and identification of the airport are properly the function of the airport beacon and not of the runway lighting system. However, in the design of a runway lighting system, the visual guidance supplied by visual aids other than the runway lights must be considered. The pilots interviewed during 1954 - 56 were unanimous in their statement that the vertical coverage of the airport beacons then in use (Specification MIL-L-7158, using 1000-watt, C-13 filament lamps) was inadequate for the operation of jet aircraft. When the aircraft was above an altitude of 20,000 feet during VFR conditions, the airport was located not by means of the beacon, but by extraneous lighting on the field or in surrounding areas when the pilot was familiar with the location of these lights, or by radio aids. To be useful, the beacon should be visible and identifiable from a distance of 30 miles at altitudes of 20,000 to 30,000 feet when the visibility is "unrestricted," and from the range station from altitudes of 3000 to 5000 feet when the visibility is somewhat restricted. When the beacon could be seen, the coding was considered adequate.

Consideration of the intensity distribution of the beacon showed that the vertical beam spread was too narrow and that the elevation of the beam was too low. The desired regions of guidance were determined from statements obtained during pilot interviews (see figure 1). The effective intensities required for a light at the point 0 to be seen from selected positions on the boundaries of the regions of guidance were computed using selected transmissivities. From these computations recommended minimum effective intensities were developed. The regions of guidance covered by the proposed and the old beacons are also shown on figure 1. In order to obtain a beacon with an intensity distribution pattern which exceeded considerably the proposed minimum requirements, the National Bureau of Standards proposed the addition of a third drum to the beacon turntable, with the three drums oriented to provide two white flashes and one green flash spaced 120 degrees apart. A vertical spread lens was proposed for use in place of the present plain cover to provide the required vertical beam spread.

Conversion of the present beacons to the type recommended was considered not feasible. However, the Lighting Section of the Aeronautical Accessories Laboratory, WADC, developed an elegant, simple conversion for the present beacons, namely, the replacement of the 1000-watt, C-13 filament lamps with 1200-watt, CC-8 filament lamps

Regions of Guidance
Airfield Beacons

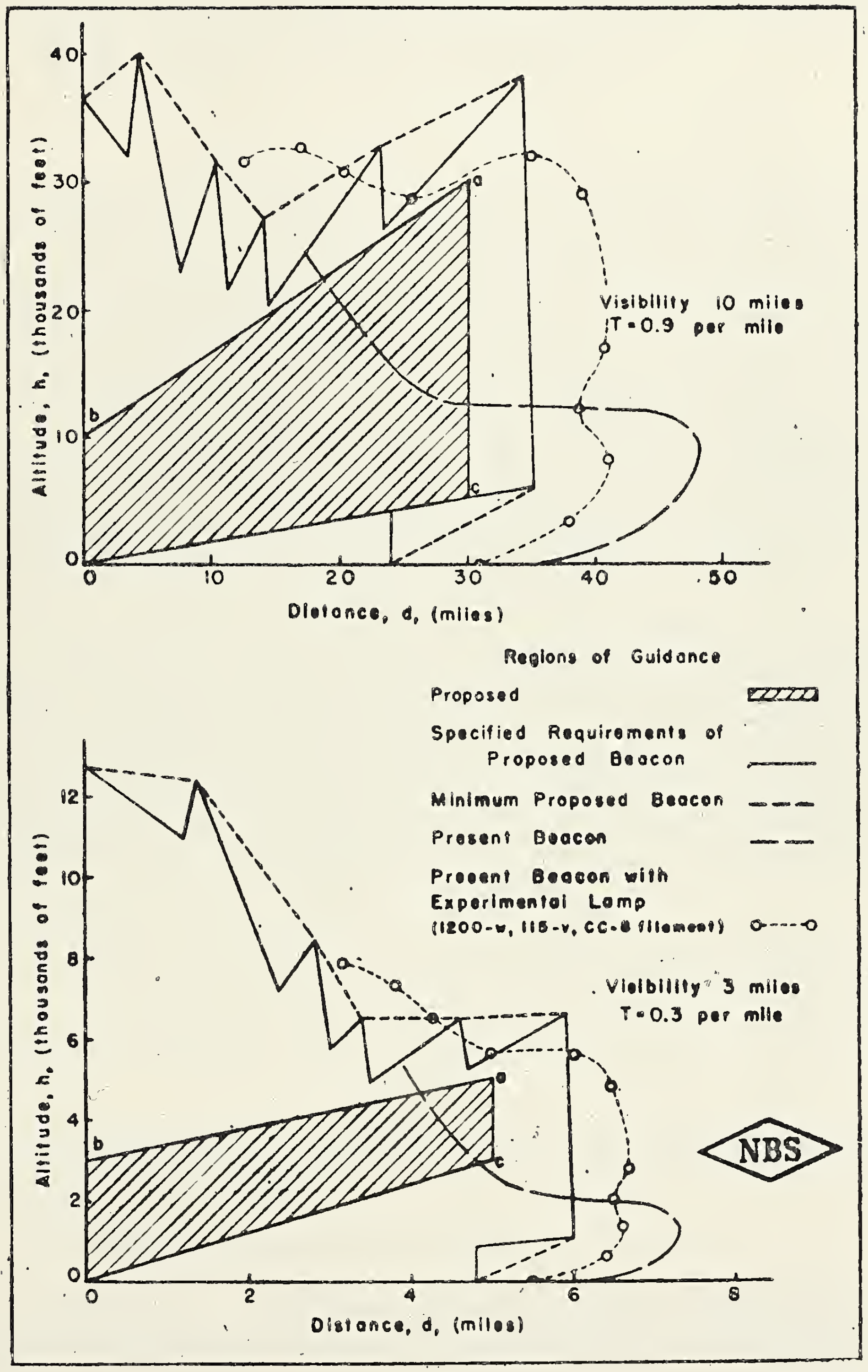


Figure 1

adjusted so the peak of the beam is at 5.5°. The effective intensity of the "white" beams of the modified beacon as a function of angle of elevation was computed using intensity distribution data obtained from the Lighting Section (WADC Photometric Data Curves 1290A - M). Visual range as a function of height was then computed. The results of these computations are also shown on figure 1.

4.2 Location and Identification of the Runway

4.2.1 General Requirements. One of the problems reported in the pilot interviews was that of locating and identifying the runway at night. The farther out the runway is located and identified, the more easily the pilot can plan the approach. The minimum acceptable visual range for VFR approaches is five miles, and the maximum visual range required was considered to be ten miles. The aircraft is generally less than 5000 feet above the ground during the period when the runway lights are used for guidance. The difficulties are twofold. Although the off-runway intensity of the present high-intensity runway lights is sufficient (about 1500 candles) to provide the desired visual range in clear weather when the light system is operated with an intensity step 5 corresponding to an intensity setting of 100%, the off-runway intensity is much too low to provide the desired visual range when the lights are operated on intensity steps 1 or 2.

The second difficulty is that of identifying the runway lights as runway lights once they are seen. When the lights are operated on intensity steps 4 or 5 (25% or 100% relative intensity) the intensity of the main beams of the runway light is so much greater than the intensity of the extraneous lights that the runway lights are conspicuous to aircraft near the extended centerline of the runway. When the system is operated on steps 1 or 2, this is not the case, and runway lights are often confused with street lights even when the aircraft is within the main beams of the lights.

The following solution to these difficulties was proposed:

a. Installation of lights at the ends of the rows of runway lights which, by means of their coding, will identify the runway lights.

b. Installation of lights that will have sufficient intensity in the off-runway directions when the runway light system is operated on intensity steps 1 and 2.

4.2.2 Runway Identification Lights.

4.2.2.1 Design. A study of various methods of identifying the runway, and of the pilot interviews indicated that runway identification lights should be flashing lights installed at the four corners of the

runway and should meet the following general requirements.

a. The lights shall be designed so that they will operate from a 6.6-ampere, or a 20-ampere series runway-light circuit.

b. The change in intensity shall be as small as feasible as the intensity setting of the runway lights is changed from step 1 to step 5.

c. The flash frequency shall be at least 40 flashes per minute and preferably higher.

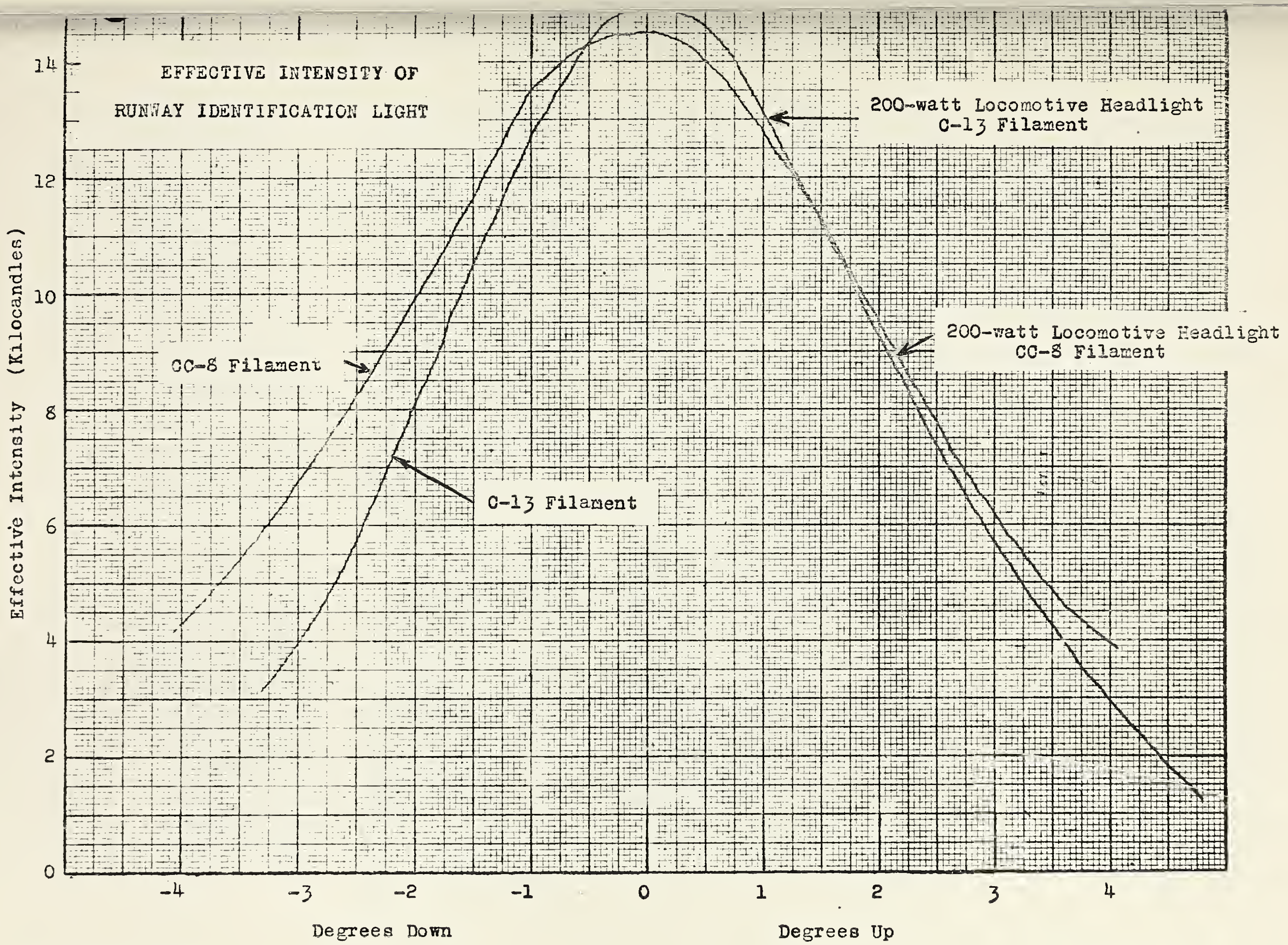
d. The effective intensity of the light should be at least 5000 candles for all angles of elevation between 2° and 10° for all azimuth angles greater than 10° outboard of the runway axis.

e. The effective intensity for all azimuth angles greater than 10° inboard of the runway axis shall not exceed 100 candles.

A specification based on these requirements was developed in cooperation with the Lighting Section, Equipment Laboratory, Wright Air Development Center, and issued as Exhibit WCLEE5-68A. In order to obtain runway identification lights for service testing, bids were requested twice for lights conforming to this exhibit, but no satisfactory bid was received. Therefore the National Bureau of Standards shops prepared preliminary design drawings.

The light was designed to be supplied with power through a 500-watt isolating transformer with a 20-ampere secondary, to mount on a 2-inch frangible coupling, and to be not more than 19 inches high. Two 200-watt, 30-volt, PAR-56 locomotive headlight lamps were rotated about a vertical axis at a speed of 40 revolutions per minute, thus producing a flash rate of 80 per minute. The vertical effective intensity distributions of a light of this type with a type C-13 filament and a similar lamp with a type CC-8 filament are shown in figure 2. The effective intensities shown are applicable to lamps operated at design voltage. When the light is operated from a series circuit, the lamp voltage will be below rated voltage by an amount determined by the type and capacity of the constant-current regulator. Generally the intensity under service conditions will be at least 75% of the intensity shown on figure 2.

4.2.2.2 Drive Mechanism. Considerable effort was expended in obtaining a suitable motor drive for the light. The principal problem is obtaining a starting current sufficiently high to start an induction motor from a constant current circuit. Secondary problems are obtaining sufficient durability of the gears in a small gear reducer motor and the elimination of the voltage peaks developed across the motor by the effects of the saturated input transformer. The



EFFECTIVE INTENSITY OF
RUNWAY IDENTIFICATION LIGHT

Figure 2

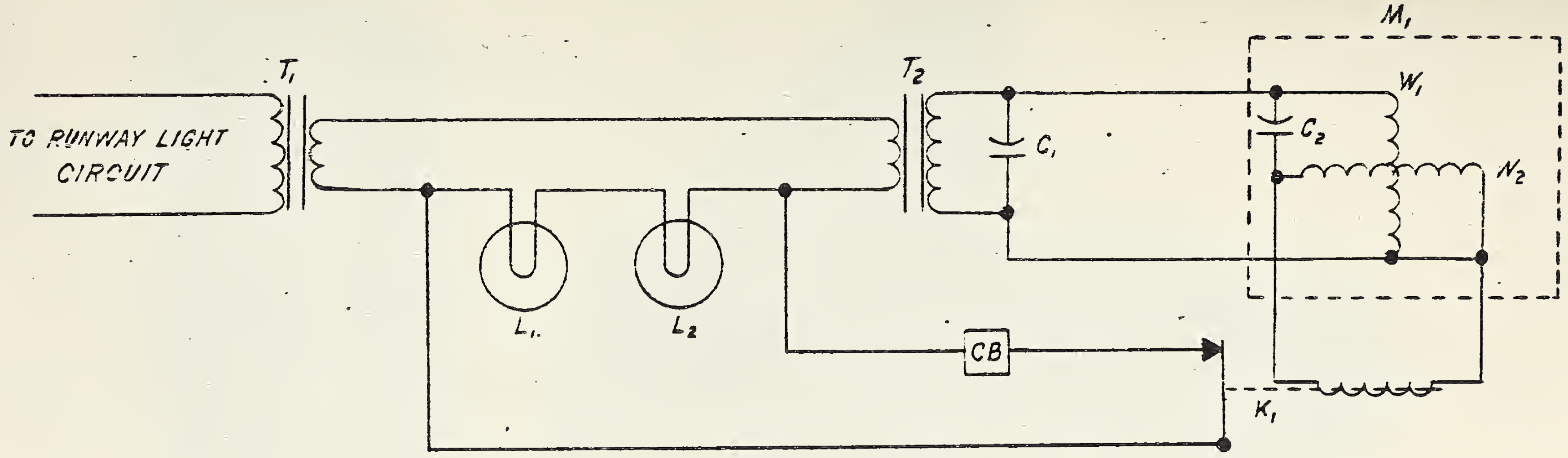
circuit developed to solve these problems is shown in figure 3. Capacitor C_1 is used to reduce the peaks of the voltage wave. Relay K_1 shorts the lamps when the relay is unenergized. Thus when power is first applied to the light, the lamps are shorted, and the current through the motor is high. However, the voltage drop across the motor starting-winding capacitor C_2 is so great that the voltage across the coil of relay K_1 is not sufficient to energize the relay. As the motor speed increases, the drop across capacitor C_2 decreases and hence the voltage across the coil of relay K_1 increases. The relay is energized thus removing the short across the lamps. Circuit breaker CB is installed to open the lamp shorting circuit and thus prevent "short-cycling" should one of the lamps burn out.

4.2.2.3 Field Tests. During the time the runway identification light was being designed, four type DCB-10 small airport beacons, modified to rotate the turntable at 40 rpm and to use two PAR-56 locomotive headlight lamps were obtained and sent to Wright Air Development Center for use in testing the principles of runway identification lighting. One of these lights and a lower intensity light were installed at two corners of runway 9-27 at Wright Field. The lights were to be tested only during approaches and not during landings, as the runway was closed to night landings. The lights were installed with the 180° shielding required to reduce the light toward the runway. However, no consideration was given to shielding in the directions in which lights could be glaring to aircraft on the ground taxying on to the runway. The lights were observed from the ground and reported to be glaring and, although pilot opinion was generally favorable, the test report recommended that the lights should not be adopted as an Air Force standard.

Four similar modified beacons were installed as a part of a high intensity sealane lighting system by the Norfolk Naval Air Station and have been in operational use for over a year. These lights were not shielded. Based upon the operational experience with these lights, the Bureau of Aeronautics recommended that these lights be installed at Navy land fields where the runway lighting was concealed by the lights surrounding it. Specification MIL-L-21703(Aer), Light, Runway Identification, was prepared under the auspices of the Bureau of Naval Weapons using the work described above as a base. Lights are now being procured for operational use. Figure 4 is a photograph of the preproduction light.

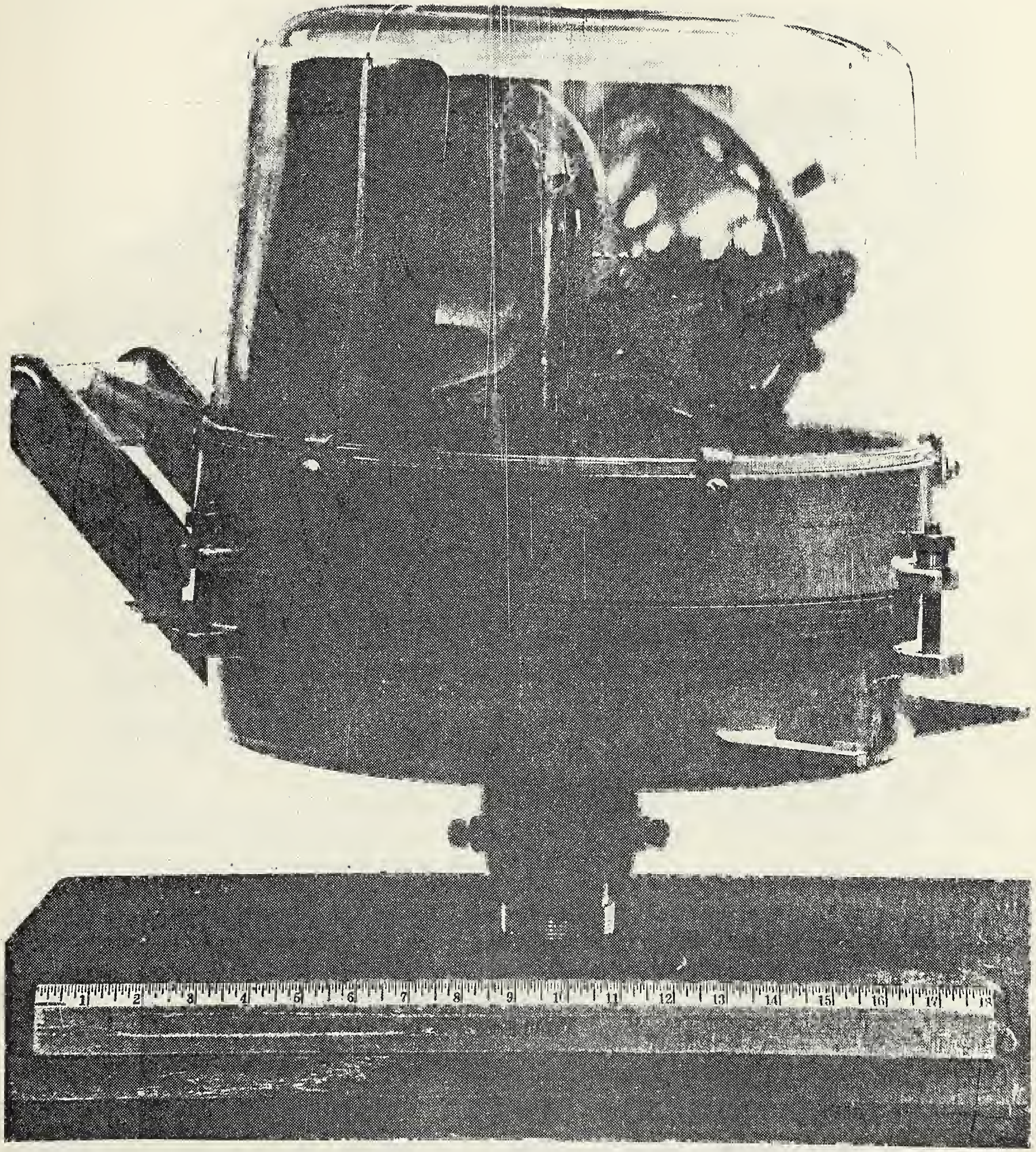
4.2.2.4 Comparison of Runway Identification Lights and Runway-End Identifiers. Concurrently with the development of the runway identification lights, civil organizations were studying the use of condenser discharge lights of the type used as sequenced flashing approach lights as "runway-end identifiers." Two of these lights are placed outboard of the threshold lights. Their primary purpose is to provide identification during straight-in approaches.

MODIFIED RUNWAY IDENTIFICATION LIGHT DRIVE



L_1, L_2	200-WATT, 30-VOLT LAMPS
T_1	6.6/20-AMPERE ISOLATING TRANSFORMER
T_2	8/117-VOLT TRANSFORMER
C_1	12 MFD, 440 VAC
C_2	3.75 MFD, 330 VAC (EXTERNALLY MOUNTED)
M_1	BODINE GEAR REDUCTION CAPACATOR MOTOR
W_1	RUNNING WINDING
W_2	STARTING WINDING
CB	THERMAL CIRCUIT BREAKER, 1.5 AMPERE
K_1	115-VOLT, N.C. RELAY

FIGURE 3



RUNWAY IDENTIFICATION LIGHT

Figure 4

A comparison of the characteristics of the two types of lights is given in table 1. All values given are typical.

Table 1. Characteristics of Runway Identification Lights and Runway-End Identifiers

	Runway Identification Light	Runway-End Identifier
Peak Effective Intensity	12,000 candles	15,000 candles
Horizontal Coverage	30° to 360° as required(2)	28° (1) (2) 48° (3)
Vertical Coverage	6° (1)	28° (1)
Can operate from series circuit	Yes	Yes
Flashes synchronized	No	Yes
Cost (not including installation) per light	$410	$780

(1) To 50% of peak intensity.

(2) For each unit.

(3) The total coverage of two lights, each toed out 10°.

The primary differences in the two types of lights are in their beam spreads. Operational experience and comparative testing are required to assess the effects of these differences.

4.2.3 Circling Guidance Lights. These lights serve to identify the runway as well as to provide guidance during circling approaches. They are discussed in the following section.

4.3 Lighting for Circling Approaches

4.3.1 Intensity Distribution Requirements. In addition to lights which identify the runway, lights are required which outline the runway in sufficient detail so that the pilot can plan and execute a circling approach pattern. The pilot interviews indicated, as was expected from an analysis of intensity distribution data, that the present runway

lights are not adequate for this purpose. The intensity distributions required to provide adequate guidance for fighter and bomber approach patterns were computed. Over much of the pattern the required intensities are of the same order as the intensity of the main beam and much greater than the off-axis intensities of the present runway lights. Since these intensities are required in relatively clear weather, it is obvious that a simple redesign of the present runway lights is not sufficient. Such a light would require about a tenfold increase in lamp wattage in order to provide the required intensity when the lights are operated on step 1 or step 2. Most of this power would be wasted during periods of low visibility when straight-in approaches are used and the lights are operated on step 4 or step 5.

Hence the use of lights designed especially to provide circling guidance was proposed. These lights would be spaced at 1000-foot intervals along each side of the runway. They would be operated either from a separate circuit or from the runway lighting circuit through a control unit which will maintain the intensity of the circling guidance lights at approximately full intensity when the runway lights are on steps 1, 2, and 3. The recommended minimum intensity of these lights as a function of angle is given in table 2.

Table 2. Recommended Minimum Intensity Distribution of Circling-Guidance Lights.

Elevation Angle (degrees)	Azimuth Angle (degrees)	Minimum Intensity (candles)
2 to 8	95 - 100 260 - 265	1,000
	100 - 120 240 - 260	5,000
	120 - 130 230 - 240	1,000
	130 - 150 210 - 230	800
	150 - 210	600
0 to 2, and 8 to 12	95 - 100 260 - 265	800
	100 - 120 240 - 260	1,000
	120 - 150 210 - 240	600
	150 - 210	400
12 to 20	95 - 265	200
20 to 60	95 - 265	100

The distribution was made symmetric about the 0° - 180° line although the intensities required in the direction of the base leg are higher than those required in the upwind direction. This decision was based upon the premises that circling guidance lights of only one type would be used on a runway and that both left-hand and right-hand patterns would be flown. The intensities recommended are a compromise between the essentially uniform horizontal intensity distribution required to locate the runway, the high intensities needed in the direction of the base leg during restricted visibility, and power consumption.

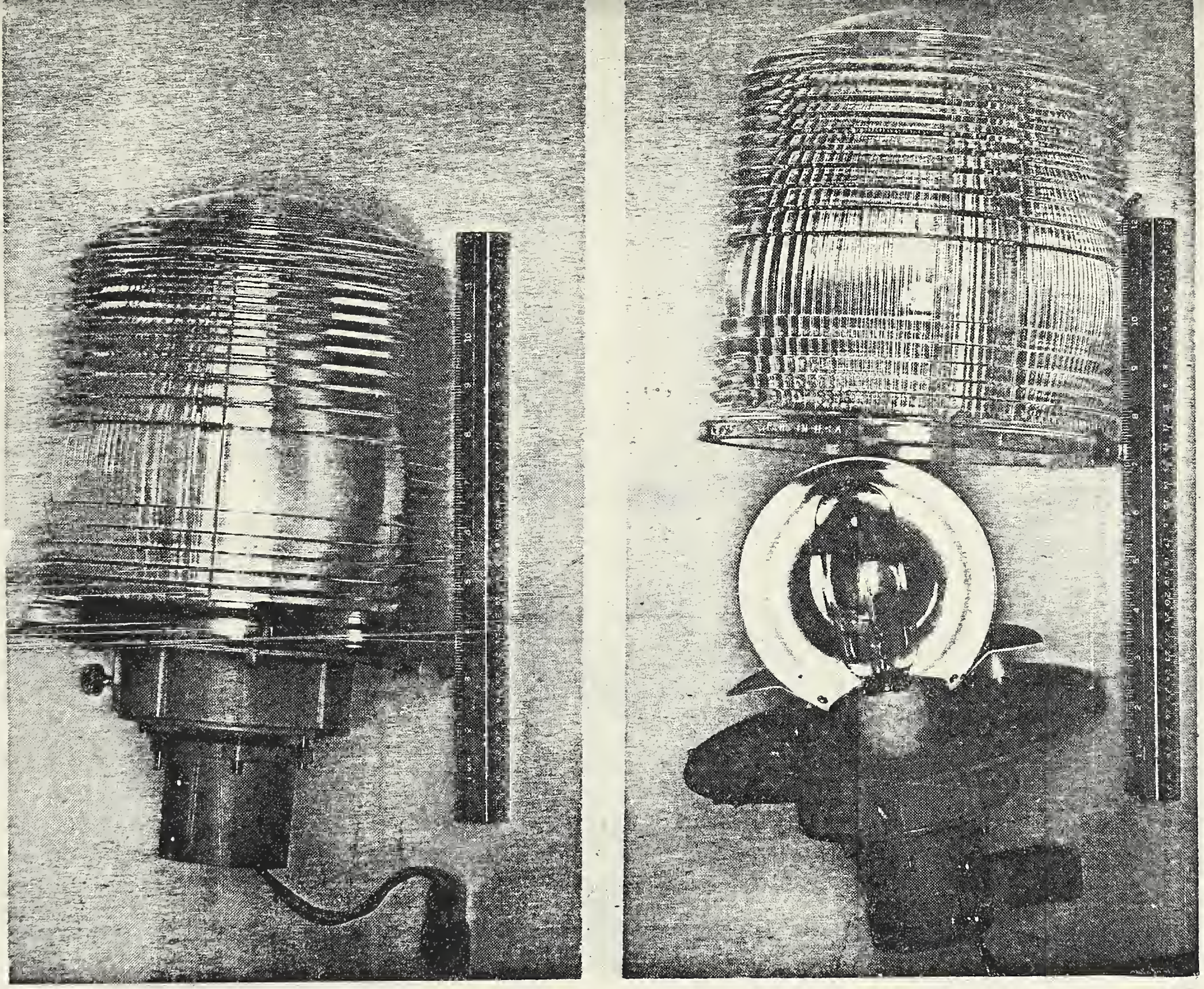
The recommended intensity distribution given in table 2 appears as a suggested practice in Section 21 of Attachment B of the Third Edition of Annex 14, Standards and Recommended Practices for Aerodromes, to the Convention on International Civil Aviation.

A service test quantity of circling guidance lights was procured from the A'G'A Division of Elastic Stop Nut Corporation. These lights are similar to the type C-2 and MB-1 overrun lights. The lens is similar in external appearance to the lenses of these units. A hemispherical metal shield is mounted between the lamp and the lens to shield the runway from direct illumination from the lamp filament. (See figure 5.)

When used with a 250-watt, 10-volt lamp, the light meets the intensity distribution requirements given above. When used with a 500-watt, 20-ampere lamp, the light exceeds these requirements considerably as shown on figures 6 and 7.

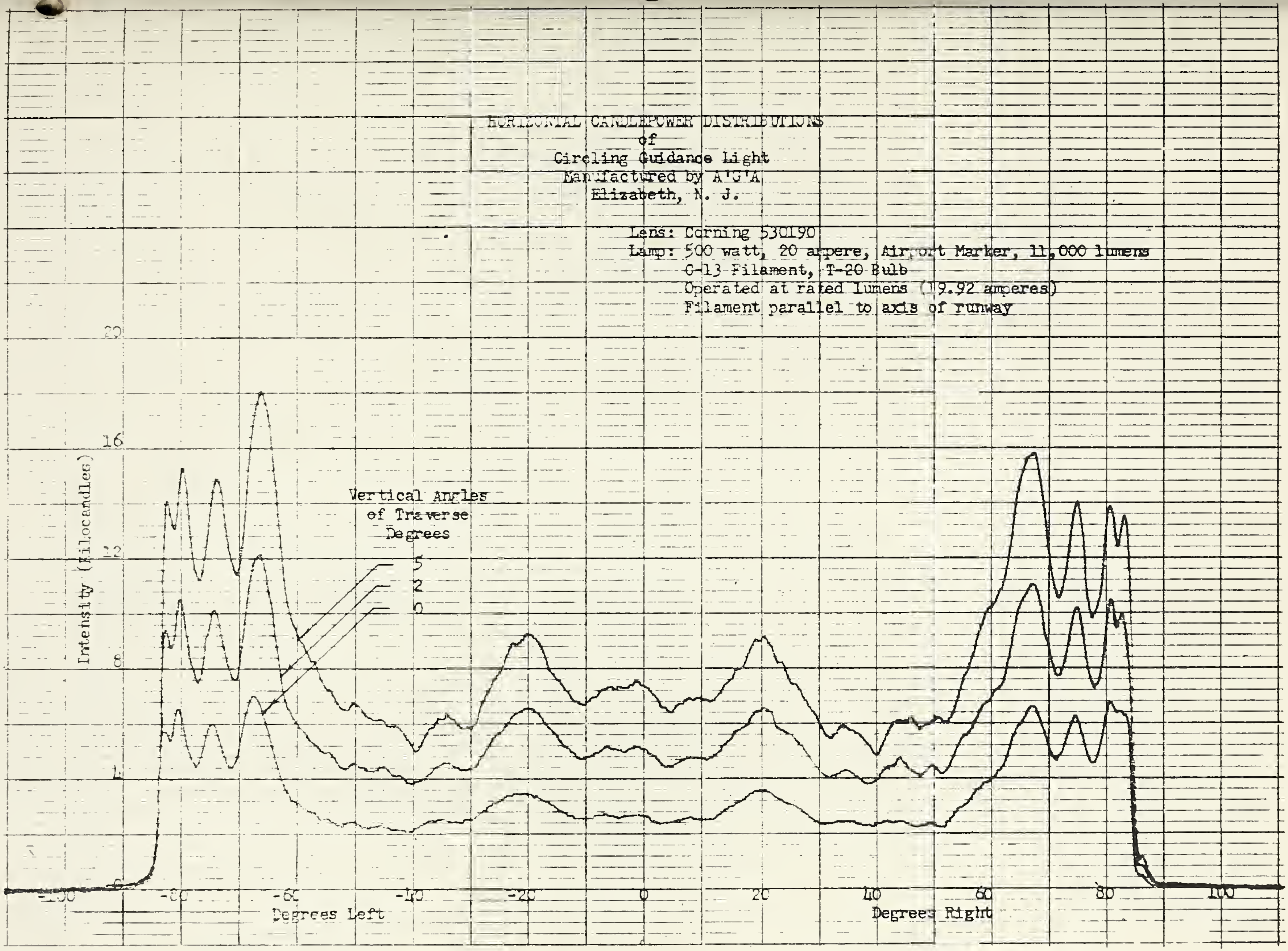
Specification MIL-L-22252(Aer), Light, Marker, Runway Circling, was prepared under the auspices of the Bureau of Naval Weapons and a quantity of circling guidance lights are being procured for operational use.

4.3.2 Intensity Control of Circling Guidance Lights. If these circling guidance lights are to be operated from the series circuits supplying the runway lights, some method of reducing the change in intensity and power consumption as the current in the series circuit is varied is necessary. Otherwise, circling guidance lights which provide adequate intensity when the system is on step 1 would consume excessive power when the system is on steps 4 and 5. (The power consumption would increase about 10 times between steps 1 and 5.) In order to reduce the required regulator capacity, it is also highly desirable that the circling guidance lights be turned off when the system is on intensity setting 5 (100% intensity). This is permissible since circling guidance lights are of little, if any, value in weather conditions which require this intensity setting. If the circling guidance lights are turned off when the system is on step 5, then a regulator which is loaded to capacity by the runway lights when on step 5 will not be overloaded on step 4 by these runway lights plus a group of circling guidance lights which have a power consumption on step 4 equal to 30% of the capacity of the regulator.



CIRCLING GUIDANCE LIGHT

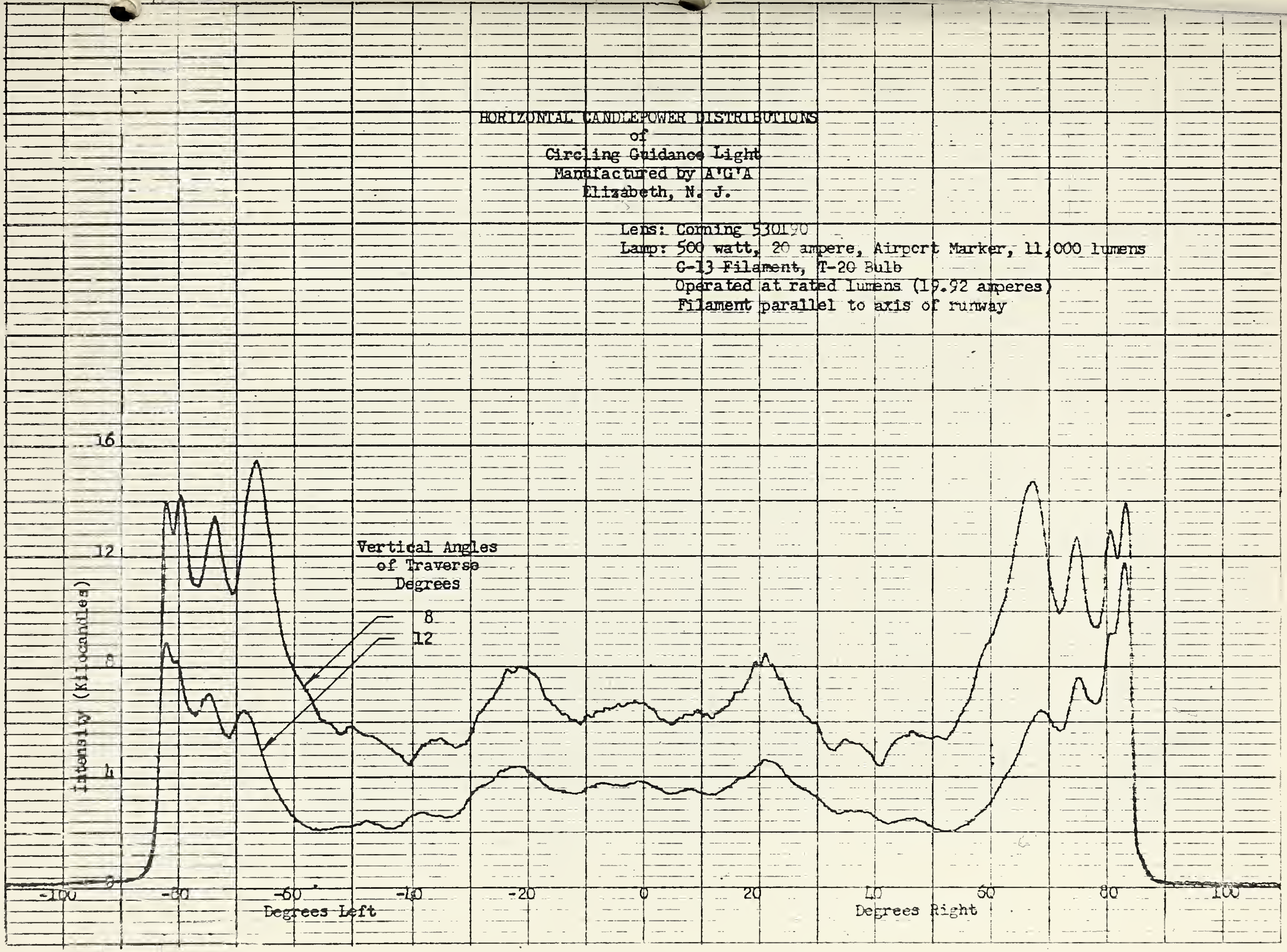
Figure 5



HORIZONTAL CANDLEPOWER DISTRIBUTIONS
of
Circling Guidance Light
Manufactured by A'G'A
Elizabeth, N. J.

Lens: Corning 530190
Lamp: 500 watt, 20 ampere, Airport Marker, 11,000 lumens
C-13 Filament, T-20 Bulb
Operated at rated lumens (19.92 amperes)
Filament parallel to axis of runway

Figure 6


HORIZONTAL CANDLEPOWER DISTRIBUTIONS
of
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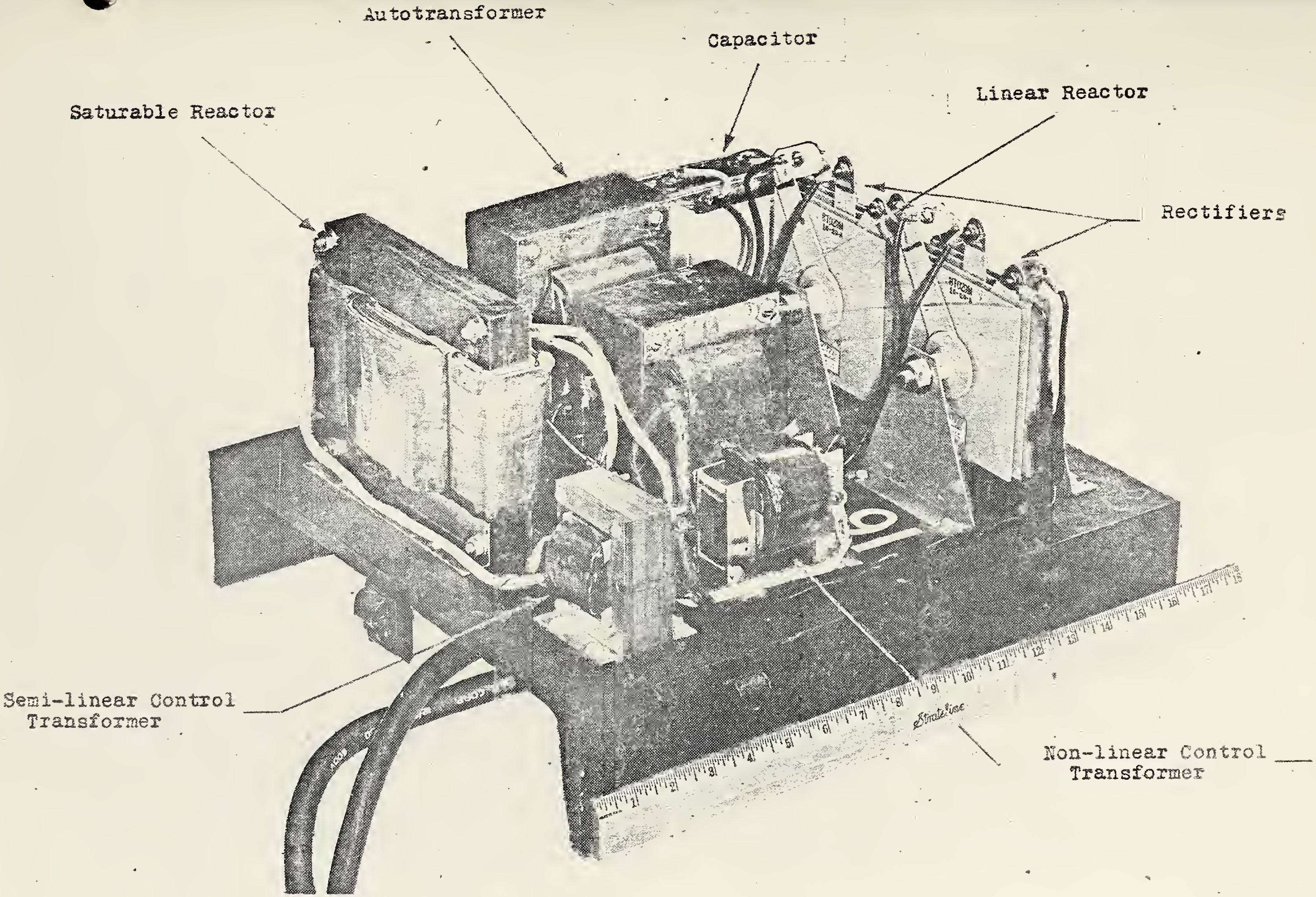
Elizabeth, N. J.

Lens: Corning 530190
Lamp: 500 watt, 20 ampere, Airport Marker, 11,000 lumens
G-13 Filament, T-20 Bulb
Operated at rated lumens (19.92 amperes)
Filament parallel to axis of runway

Figure 7

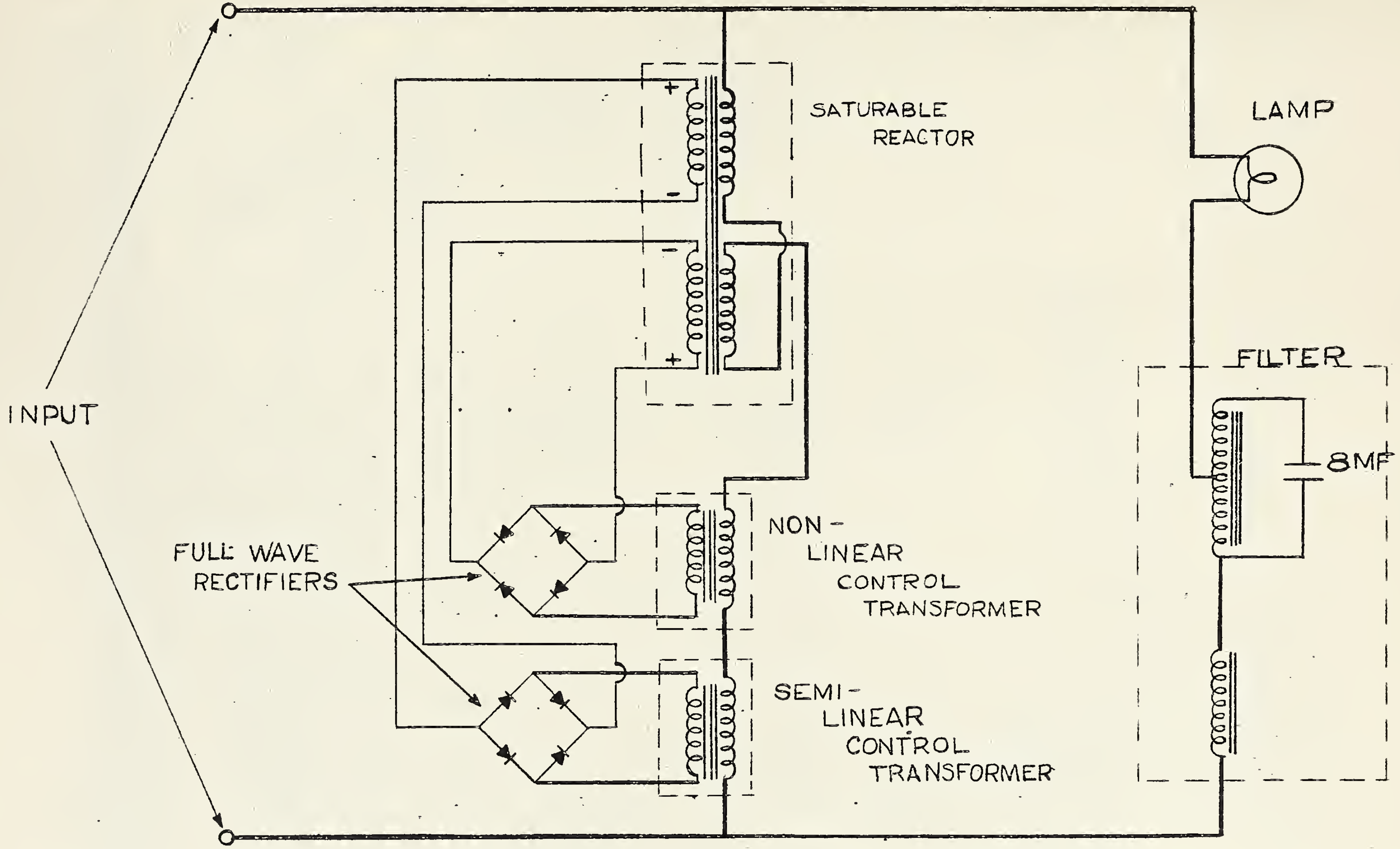
Following a suggestion made by the Lighting Section, Equipment Laboratory, Wright Air Development Center, that use of a saturable reactor connected in parallel with the lamp be considered as a means of controlling lamp current in place of a saturable isolating transformer, the principles of such a control were developed in cooperation with the Lighting Section. This control would utilize a direct-current winding to increase the saturation. The direct current would be obtained by using a rectifier connected into the circuit so that its output current is a function of the system current. With such a control it was hoped that it would be possible to obtain a relative intensity of at least 30% in the circling guidance lights when the relative intensity of the runway lights is 0.2% (step 1); to obtain a relative intensity in the circling guidance lights of approximately 100% when the relative intensity of the runway lights is varied from 1% to 25% (steps 2, 3, and 4); and to decrease the reactance of this shunt control when the relative intensity of the runway lights is 100%, so that the load imposed on the regulator by these lights would be significantly reduced when the system is on step 5.

An order with A'G'A for circling guidance lights included a requirement for intensity control units operating on the principles outlined above. The development of these units was considerably more difficult than had been anticipated. Two d-c control windings were required, one in which the current was proportional to the current through the lamp and the other, which produced an opposing field, in which the control current - lamp current relation was nonlinear. In addition, the harmonics produced by open-circuited isolating transformers in the lighting circuit disturbed the regulation of the control unit. The addition of filters was required to overcome the effects of these harmonics in both the linear and nonlinear control circuits. Consequently the unit was considerably larger, more complex, and more costly than had been anticipated. Figure 8, a photograph of the control unit showing the parts layout, and figure 9, the circuit diagram, illustrate the complexity of the unit. The relation between the current in the runway lighting system and the output current of the control unit is given in table 3. These data were taken with a 4-kilowatt, type C-1 regulator supplying the runway lighting load of about 4 kilowatts and with a 250-watt, 10-ampere lamp as the load on the intensity control unit. The input current to the regulator was supplied through a continuously variable autotransformer in order to obtain a continuously variable input current to the control unit. The current changes were made without interrupting the current. Hence the test conditions were somewhat more severe than service conditions.



INTENSITY CONTROL UNIT FOR CIRCLING GUIDANCE LIGHT (Cover Removed)

Figure 8



CIRCUIT DIAGRAM OF INTENSITY CONTROL UNIT FOR CIRCLING GUIDANCE LIGHT

Figure 9

Table 3. Performance of Intensity Control Unit for Circling Guidance Lights

Input Current to Control Unit (Amperes)	Output Current of Control Unit Load on Regulator 3.6 kw Resistive Plus Control Unit (Amperes)	Output Current of Control Unit Load on Regulator 2.8 kw Resistive Plus One 200-Watt Transformer Open-Circuited Plus Control Unit (Amperes)
Increasing Current		
2.8	8.1	8.3
3.4	8.9	9.0
4.2	9.3	9.3
5.2		9.6
5.4	9.4	7.2
5.5	9.3	
5.6	6.3	
6.6	6.7	8.6
Decreasing Current		
6.6	6.7	8.6
5.4	6.5*	7.3
5.2	9.5	7.2*
4.2	9.3	9.3
3.4	8.9	9.0
2.8	8.1	8.3

* Output current is 9.3 amperes after a momentary interruption of the primary current.

As shown by the table, the intensity control unit performs satisfactorily when the runway lighting system is on intensity step 1, 2, or 3. The performance with input currents corresponding to intensity steps 4 and 5 is marginal and is affected to some extent by the characteristics of the runway lighting circuit. In addition, some form of temperature compensation is required as the current at which the control unit "fires" is affected by the temperature of its components.

Despite these difficulties, further development of intensity control units is recommended for the cost of the control units will generally be less than the cost of adding a new circuit to an existing runway lighting system.

4.3.3 Required Spacing of Circling Guidance Lights. The pilots indicated during the pilot interviews that they desired, as would be expected, a circling guidance light at each runway light. This requires a spacing between lights of 200 feet. Such an installation, although desirable, would require more power than is available in most runway lighting systems. To determine the maximum useful spacing, simulated circling guidance lights were tested at the Technical Development Evaluation Center at Indianapolis. These tests indicated that a spacing of 1000 feet is optimum.

4.3.4 Threshold Lights. Threshold lights provide guidance during circling as well as straight-in approaches. An analysis was made of the required beam spread of threshold lights based on the premise that the aircraft should be within the main beam of these lights as the turn is made from the base leg to the final leg of the approach pattern. The following conclusions were drawn from this analysis.

1. The horizontal beam spread of the present threshold lights is not sufficient for the threshold lights to provide adequate guidance during the turn from the base leg to the final leg of the approach unless the distance of the base leg from the threshold is kept large and/or the angle of bank is large.

2. If the maximum desirable angle of bank is limited to 15° and the base leg is to be kept within 2 miles of the runway, a minimum beam spread of about 40° is required for approach speeds of 150 knots or less.

3. If the maximum desirable angle of bank is 30°, and the base leg is 2 miles from the runway, the minimum horizontal beam spread is about 20° for approach speeds of 150 knots or less and 40° for approach speeds of 250 knots or less.

The validity of these conclusions is demonstrated by the following extract from a report of a flight test conducted during this study.

"During this flight test, it was quite apparent that the narrow beam threshold light was not entirely satisfactory. It is of interest that in spite of the fact that the pilots were experienced test pilots and very familiar with the field, the approach --- was started using a radio compass heading. The plane was sufficiently off course at 3 miles out that the threshold and runway lights were not seen until the pilot, realizing from the position of the runway identification lights that he was off the extended centerline, maneuvered nearer the runway axis. Had these threshold lights been broad-beamed, they would have been picked up without this maneuver. - - - - When the aircraft had been lined up with the runway, the entire runway lighting pattern was easily visible. When the plane was close in, the threshold lights were too bright and caused glare."

Therefore, the use of type MB-2 lights in the wing bars of the threshold lighting system is recommended. These lights should be aligned so that the axis of their beams is 10° outboard of the extended runway axis.

The use of bidirectional threshold lights with a beam spread of 30° to 40° is considered unnecessary. On rollout or takeoff the aircraft is sufficiently close to the centerline of the runway that the beam spread of the present threshold lights is adequate for marking the upwind end of the runway. In addition, pilots report that on takeoff they make little use of the horizon guidance of the threshold light. Thus, long bars are not required on the upwind end of the runway. Therefore, a system using a combination of some unidirectional and some bidirectional lights appears desirable.

Flight tests were made using the facilities of the CAA Technical Development Evaluation Center, Indianapolis, using several spacings between the lights in threshold wing bars. There was no noticeable difference in the appearance of the bars when 2.5-foot and 5-foot spacings were used. (However, when the bars are viewed from distances of one mile or more, the effective intensity of a bar with a 2.5-foot spacing will be twice that of the bar with a 5-foot spacing.) A 10-foot spacing appeared slightly too great. From these observations it appears that a spacing of 5 to 8 feet will be satisfactory for the wing bars. It is believed that a somewhat greater spacing will be satisfactory for the threshold lights which extend across the end of the runway.

The choice of length for the threshold bars, or wings, is somewhat arbitrary since no data applicable to the problem were available. When some fighter-type aircraft are within a half mile of the threshold, only one bar or wing will be visible because of the obscuration produced by the aircraft structure as the aircraft approaches the flareout or nose-up attitude. In addition, during rain and snow, vision through the center panels of some canopies is poor. Therefore, the threshold bars should be long enough so that the desired horizon guidance will be obtained from one bar when the aircraft is within a half mile of the threshold.

If an angular length of 1° is taken as the minimum, then the bars should be at least 45 feet long. Flight observations at Indianapolis indicated that a length of 40 feet would be satisfactory. Current standards require 40-foot wing bars.

One of the principal difficulties in threshold lighting is the reduction in intensity resulting from the use of the green filters. Since the threshold lights are generally runway or approach lights to which filters have been added (or in which colored lenses have been substituted for clear lenses), the intensity of the threshold lights

is approximately 20% of the intensity of the runway or approach lights. They are, therefore, relatively inconspicuous. When the threshold lights are supplied by separate regulators, the reduction in intensity can be compensated for by operating these lights on an intensity setting one step higher than the intensity setting of the runway or approach lights. This procedure will, of course, produce no compensation when the intensity setting of the latter lights is step 5. When the threshold lights are supplied from the runway or approach light regulators, the use of saturated isolating transformers or special controls, for example monocyclic squares operated in the reverse direction, would produce a similar effect but these methods do not appear feasible at present. Use of higher wattage lamps in the threshold lights will produce limited compensation. The addition of some lights of narrower beam spread to the threshold lighting system would add conspicuity to the system when the aircraft is aligned with the runway. For example, the 200-watt, 30-volt, PAR-56 locomotive headlight lamp when used with a green filter has a peak intensity of about 40,000 candles and a beam spread comparable to the beam spread of type C-1 runway lights. Testing of the feasibility of lights of this type as part of the threshold system is recommended.

5. LIGHTING AND MARKING FOR THE FINAL APPROACH AND LANDING

Studies of the configurations of approach and runway lighting systems were considered as outside the scope of this project. Consideration was given to the fundamental principles involved in the design and operation of the lights of these systems.

5.1 Problems in the Control of Glare in Approach and Runway Light Systems

Present practice is to control the glare from approach and runway light systems by choosing a beam pattern for the lights so that the pilot is outside the main beam of a light when the distance to the light is short, and by changing the current through all lamps in the system thereby reducing the intensity of the system when the visibility is good. Since restricting the beam of the lights reduces the region in which the lights provide guidance and since reducing the intensity of the lights reduces their visual range, some compromise is necessary in the design of the system.

The present trend to lights on the centerline of the approach zone and runway and to narrow gauge lighting has accentuated these problems.

The increase in the angles at which the pilot views a light as the distance to the light decreases will also be smaller, becoming nearly zero for centerline lights in the touchdown zone. Thus the possibilities

of the control of glare of these lights by means of beam pattern are limited. The minimum distances between the pilot and the lights will be smaller, thus requiring lower intensity settings for a given visibility condition.

The maximum useful intensity of a signal light may be computed as a function of the atmospheric transmittance and the distance between the pilot and the light. The results of such a computation are shown in figure 10. The minimum useful illumination is about one one-thousandth of the intensities shown and the optimum illumination is about one one-fortieth of the intensities shown. Note that when the viewing distance is small, the maximum useful intensity is low both in fog and in good visibility and that as the viewing distance increases, the maximum useful illumination in fog increases rapidly. The maximum, and also the optimum and the minimum, useful intensity can be obtained from these curves if the minimum distance between the light and the intersection of its main beam and the path of the airplane is known. In the inner approach zone this minimum distance is of the order of 400 to 600 feet. On the other hand, the minimum distance at which the pilot is within the main beam of the lights in the outer approach zone is of the order of 1200 feet. Hence the lights of the inner approach zone will become glaring even in dense fog if they are operated at intensities higher than 5% of full intensity. On the other hand, if the intensity of the lights in the outer approach zone is reduced from full intensity to 5% intensity when the visibility is 1000 feet, the pilot will not see the outer 1000 feet of the approach light system. Thus, operating the present approach light systems at reduced intensity in order to reduce glare in the inner approach zone can seriously reduce the effectiveness of the outer part of the approach light system. Modification of the system so that the lights in the outer zone have somewhat higher intensity than those in the inner zone appears desirable.

Improvement should be made in the means of obtaining the proper intensity setting. Several methods of obtaining improved intensity control are feasible. Among these are,

1. A completely automatic system which will compensate for changes in both background brightness and atmospheric transmittance,

2. A meter in the transmissometer indicator circuit which indicates directly the proper intensity setting,

3. The simple expedient of using a single brightness selector switch and marking the positions of this switch with the visibilities corresponding to the positions instead of with an arbitrary number.

Maximum Useful Intensity of Signal Lights
As a Function of Viewing Distance

(Nighttime Conditions)

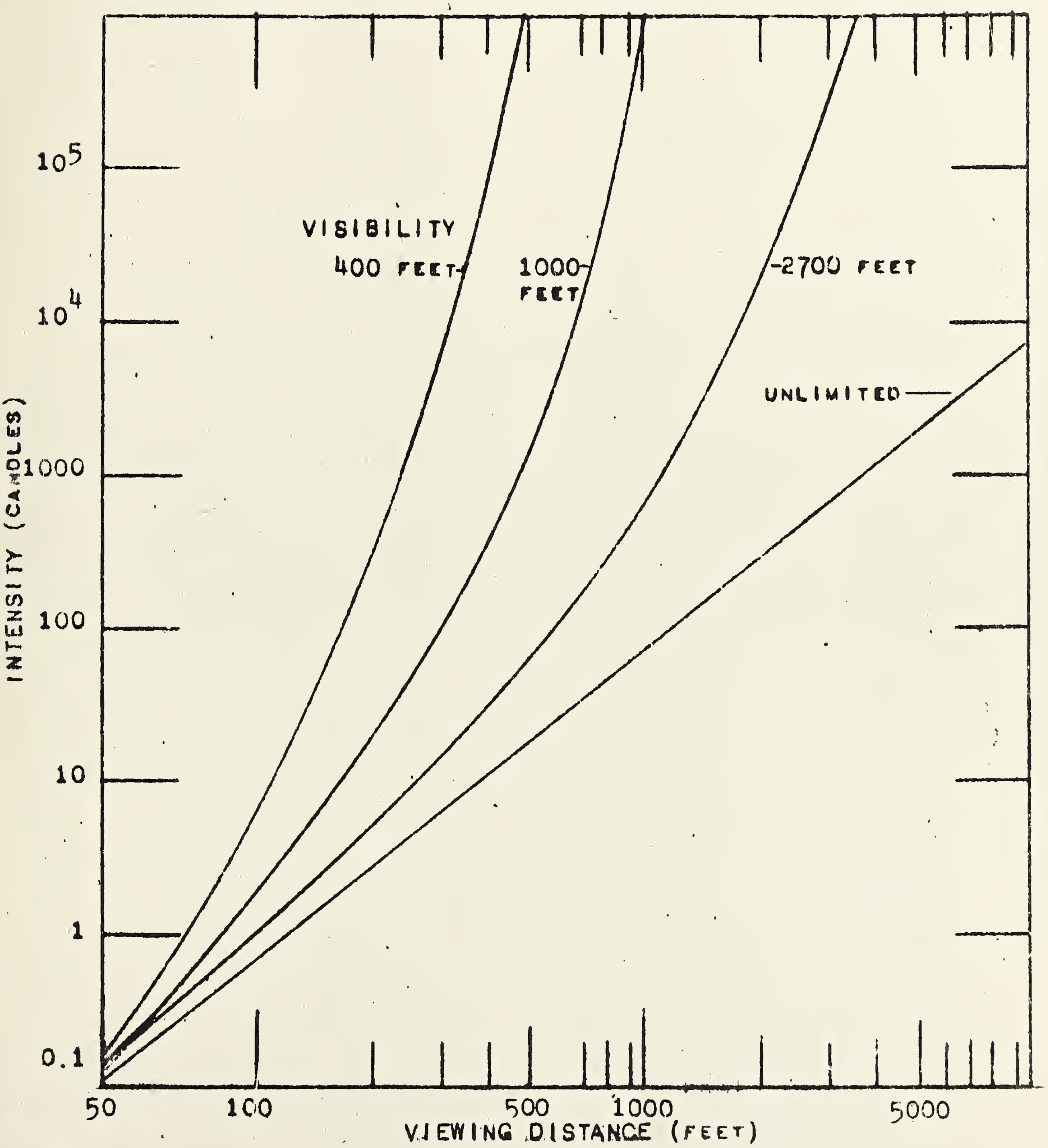
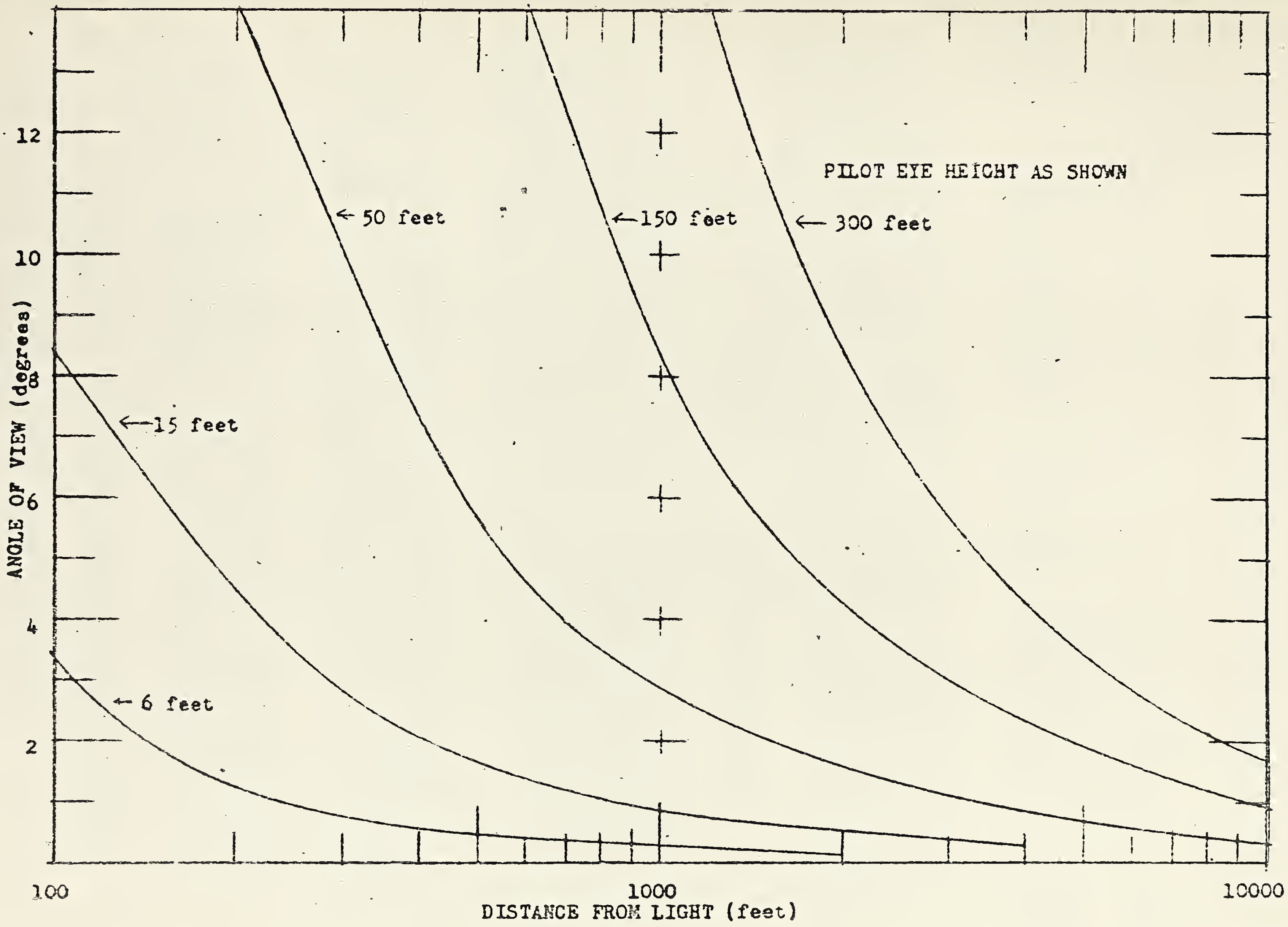


Figure 10



RELATION BETWEEN ANGLE OF VIEW AND PILOT EYE HEIGHT

Figure 11

Table 4. Minimum Length of 5000-Candle Flush Lights (Top of Luminous Area 0.5 Inch Below Runway Surfact)

Distance From Light	Required Light Length (feet)											
Pilot Eye Height (ft)⟶	6			15			50			150		
	L	L'	L+L'	L	L'	L+L'	L	L'	L+L'	L	L'	L+L'
500	1.3	3.5	4.8	.51	1.4	1.9	.15	.42	.57	.05	.14	.19
1000	2.6	6.9	9.5	1.0	2.8	3.8	.31	.83	1.1	.10	.28	.38
2000	5.1	13.9	19.0	2.0	5.6	7.6	.62	1.6	2.2	.20	.56	.76
5000	12.8	34.8	47.6	5.1	13.9	19.0	1.5	4.2	5.7	.51	1.4	1.9

It can be seen that a completely flush light must be several feet long in order to direct an intensity of 5000 candles toward a point 6 to 15 feet above the runway surface and 1000 feet from the light. On the other hand, a semiflush light with a projected luminous area 6 inches wide and only 0.2 inch high will produce this intensity. Thus it is evident that in so far as operational conditions permit, the aperture of the lights should be brought above the runway surface.

5.3 Photometric Considerations in the Design of Approach and Runway Lights

5.3.1 Intensity Distribution Pattern. As part of the project, consideration was given to the choice of intensity for approach and runway lights. The choice is a compromise between the requirements for high intensity and the requirement for a large angular coverage. Hence, there is no one "optimum" intensity distribution pattern since each pattern is a function of the operational conditions on which it is based. However, the following requirements are applicable to all designs of intensity distribution patterns.

Lights must be designed and adjusted to have visual ranges in excess of the minimum forward distance required for the pilot's guidance. This must hold over the entire region of guidance for all weather conditions in which the system is to be used. The performance of a lighting system is generally very poor under visibility conditions much lower than those for which it is adjusted.

On the other hand, the performance of the system may be unsatisfactory in less stringent visibility conditions if the path of flight does not lie within the main beam of the lights from a point several miles out to a point within a few hundred yards of the light. To avoid this difficulty, it is necessary that the beam patterns of the light meet the following conditions.

1. The elevation of the lower edge of the beams of approach lights be no greater than the angle of the glide path.

2. The lower edge of the beams of both edge and inset runway lights and centerline lights be approximately horizontal.

3. The outboard edge of the beams of runway edge and narrow gauge lights be parallel to or outboard of the line of lights.

The location of the other edges of the beams are determined by the region of guidance which is to be covered and the minimum visual range at which the lights provide suffiecent guidance to meet the operational requirements.

The minimum intensity required to produce this visual range is determined by the minimum transmittance (or meteorological visibility) in which the required visual range is to be produced and by whether the lights are intended for night use only or for day as well as night use. Note that, as shown in the preceding section, the minimum intensity for one section of a system may exceed the maximum useful intensity for another part of the system.

If the required intensity can not be obtained with the beam spread required, it is essential that the configuration be redesigned or that the minimum weather conditions be raised to the point at which the required visual range is obtained. Reducing the beam spread of the lights to obtain the required intensity, as has often been done in the past, will produce an unsatisfactory system.

5.3.2 Beam Spread of Approach Lights. If the approach lights are to cover a region bounded by a rectangular portal at the outer end of the approach light system and a smaller rectangular portal at the threshold, then relatively narrow beam spreads would be satisfactory. This is the assumption used in computing the beam patterns shown in section 18 of Attachment B to Annex 14*and in the design of most approach lights. However, experience at the Landing Aids Experiment Station showed that a horizontal beam spread of 30 degrees was desirable. Hence, all sealed-reflector approach light lamps used in this country have been designed with this beam spread. Recently Calvert has made a theoretical study of the required horizontal beam spread based upon the departures from the ideal flight path expected when various types of couplings are used between the precision electronic approach aid and the aircraft controls and upon the magnitude of the corrections that a pilot is willing (or able) to make. He also concluded that a 30 degree horizontal spread is desirable. It is possible that this beam spread can be decreased somewhat as use of automatic couplers and "zero-readers" becomes general if the visibility minimums are not reduced appreciably below the minimum visibility for which the lighting systems are now designed.

The vertical beam spread of an approach light designed on the premises given in section 18 of Attachment B to Annex 14*is rather small. Even if the airplane is on the glide path, it will be below the beam of the lights in the outer part of the approach light system when the

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* Third Edition of Annex 14, Standards and Recommended Practices for Aerodromes, to the Convention on International Civil Aviation.

distance to these lights is much greater than the minimum visual range for which the lights were intended to be used. This was the situation with the type 250PAR lamps which were formerly used at civil fields. For this reason, the type 350PAR and succeeding lamps have had vertical beam spreads sufficiently great that the elevation of the lower edge of the beam need not be greater than the angle of the glide path, even though the lights are elevated to provide satisfactory coverage when the visual range of the lights is as low as 1200 feet. This required a vertical beam spread of about 12 degrees.

At present only the United States is using lights with wide horizontal and vertical beam spreads extensively. The British are changing to approach lights with a similar beam pattern. A French prototype with a similar pattern is being developed.

The beam spread requirements for lights in the inner approach zone are less severe, the minimum horizontal beam spread being about 10 degrees and the minimum vertical beam spread being about 6 degrees.

Note: In computing these beam spreads it is assumed that the lights are adjusted so that the top edge of the beam is 50 feet above the glide path at a distance of 1200 feet from the light, the elevation of the glide path is 3° and the glide path intersects the runway 1000 feet from the threshold.

5.3.3 Beam Spreads of Threshold and Runway Lights. The intensity distribution pattern of threshold and runway lights was computed in a similar manner, assuming a minimum visual range of 1200 feet. The characteristics of these lights are given in table 5. Approximate beam spreads applicable to other minimum visual ranges may be obtained from the values given by multiplying them by the ratio of 1200 to the new visual range (assuming no other changes in the design parameters).

Table 5. Intensity Distribution Pattern of Runway and Threshold Lights

Type of Light	Vertical Beam Spread	Elevation of Beam Axis	Horizontal Beam Spread	Toe-in of Beam Axis
Threshold	6°	6°	10° (1) (4)	5° (1) (4)
Runway Edge	5°	3°	10° (1) (4)	5° (1) (4)
Runway Centerline	3°	1.5°	10° (5)	0°
Narrow Gauge	5°	4.5° (2) 3° (3)	10° (5) 3° (6)	0° 1.5 (6)

Notes:
1. Applicable only to straight-in approaches.
2. Threshold end.
3. Upwind end.
4. For 200-foot wide runway.
5. Assuming coverage 50 feet on either side of line of lights.
6. To cover narrow gauge lane only.

5.4 Field Evaluation of Runway Marking Materials

Preliminary flight tests of the runway floodlighting system installed in the touchdown area of Runway 36 at Washington National Airport indicated that the surface of the asphalt runway lacked sufficient "texture" and that a marking pattern more elaborate than the standard runway marking pattern was desirable. The installation of such a pattern provided an opportunity to compare the relative performance of various types of materials for use as runway markings in the touchdown area. Therefore, a test pattern using eight types of marking materials was designed and installed. Measurements were made of the relative brightnesses of the various marking materials under a) daylight illumination, b) floodlight illumination, and c) illumination from simulated aircraft landing lights.

To simulate landing lights a generator truck which was available at this Bureau was equipped with a boom extending horizontally 36 feet from either side at the level of the truck roof about 11 feet from ground level, and an observation platform was constructed on the roof of the truck body. Two pairs of 600-watt aircraft landing lights were attached to the booms at points giving horizontal separations of 72 feet between the outboard pair and 36 feet between the inboard pair. An observer on the observation platform with his eye about 16 feet above ground level would be in the same position with respect to the landing lights and the runway as a pilot would be in the cockpit of an average transport aircraft with the main landing gear of the aircraft touching the runway. By setting instruments at this eye height and using the outboard landing lights with the truck on the runway, measurements could be made of the runway markings under the same general conditions present when a pilot is viewing the markings with the aircraft in contact with the runway. By using the inboard landing lights, measurements could be made at one-half the divergence angle of the outboard lights. The angles of divergence for the inboard and outboard lights are approximately 5° and 10° respectively.

Subsequent to the originally planned measurements using the inboard and outboard landing lights, a set of measurements was made using centrally located lights (1/2° angle of divergence) to see if the results could be extended to include those stages of the approach in which the angle of divergence was small.

The data presented in the task report were of necessity very limited and were based only upon the performance of materials placed within the touchdown area of a very heavily used asphalt runway with a "rough" finish to its surface. It was therefore recommended that comparative service tests be made using those materials considered suitable for additional tests. Runways in different climatic areas

and having different degrees of usage should be marked, using on each of these runways all the materials to be tested, in a statistically planned distribution in the standard runway marking pattern. The performance of these materials should be evaluated primarily from motion pictures taken from an airplane under day and night, up-sun and down-sun, wet, and dry conditions. Brightness and reflectance measurements could be used to supplement the photographs if necessary. An evaluation based upon personal opinion, pilot or ground personnel, should be avoided.

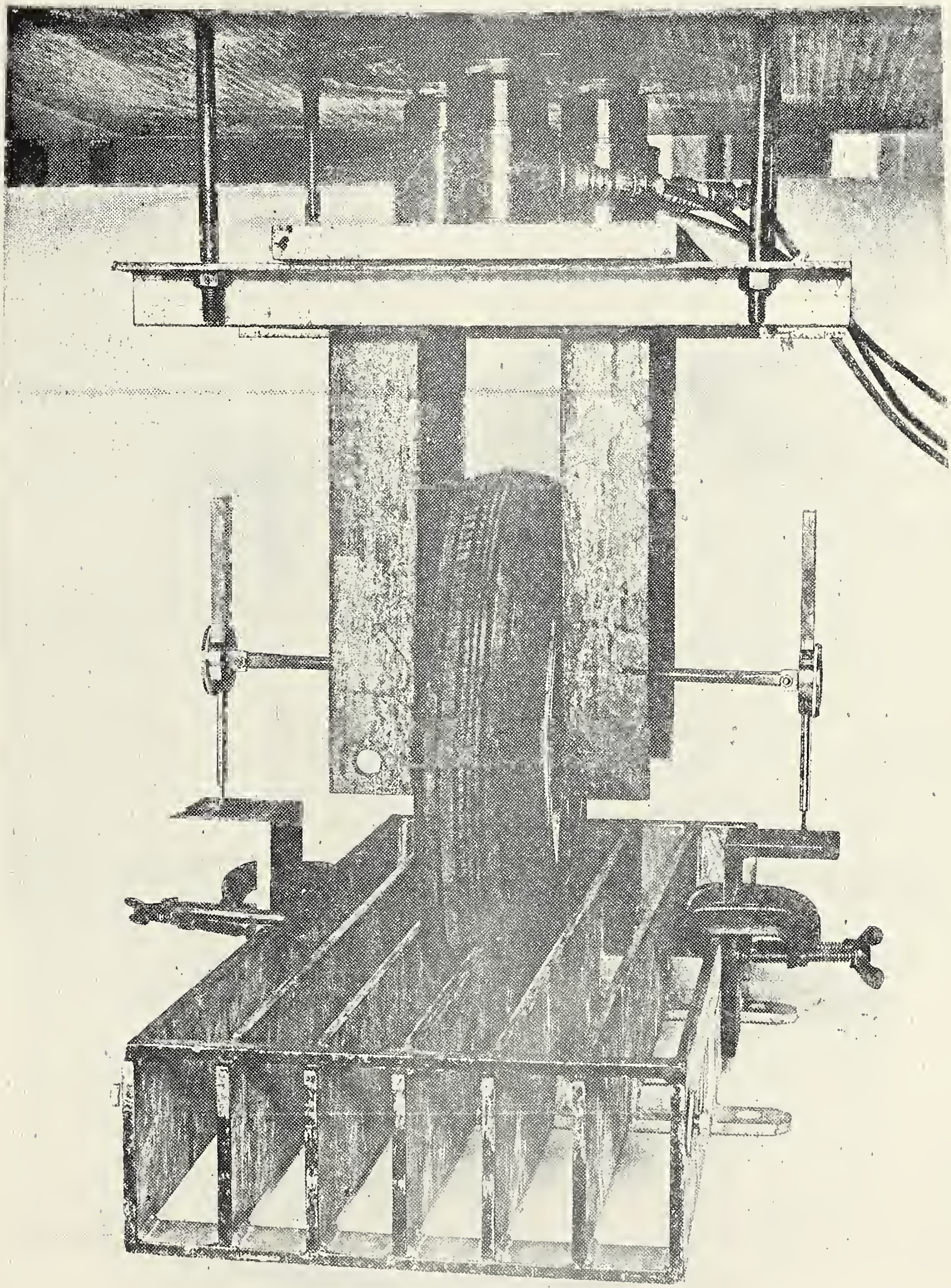
5.5 Summary of Studies of the Effects on Aircraft of Lights Projecting Above the Runway Surface

Static load deflection tests were made of aircraft wheels on flush lights of the several types used or considered for use in the surface of the runway. Observations during these tests indicated that the smaller wheels would have difficulty in traversing open grid lights in which the tire is supported by only one grid, in that the tire would be required to climb out of a hole. See figure 12. Later model open grid lights showed considerable improvement in this respect. Figure 13 shows load-deflection curves for one of the later open grid lights. Note that the wheel climbs approximately 0.3 inch during its traverse of the last 8 inches of the grid, of which a rise of approximately 0.2 inch takes place during the last 3 inches. The distance the larger wheels climb is somewhat less than that for the small wheel. Figure 14 shows the static loading of an early model of a flush type light by aircraft tires.

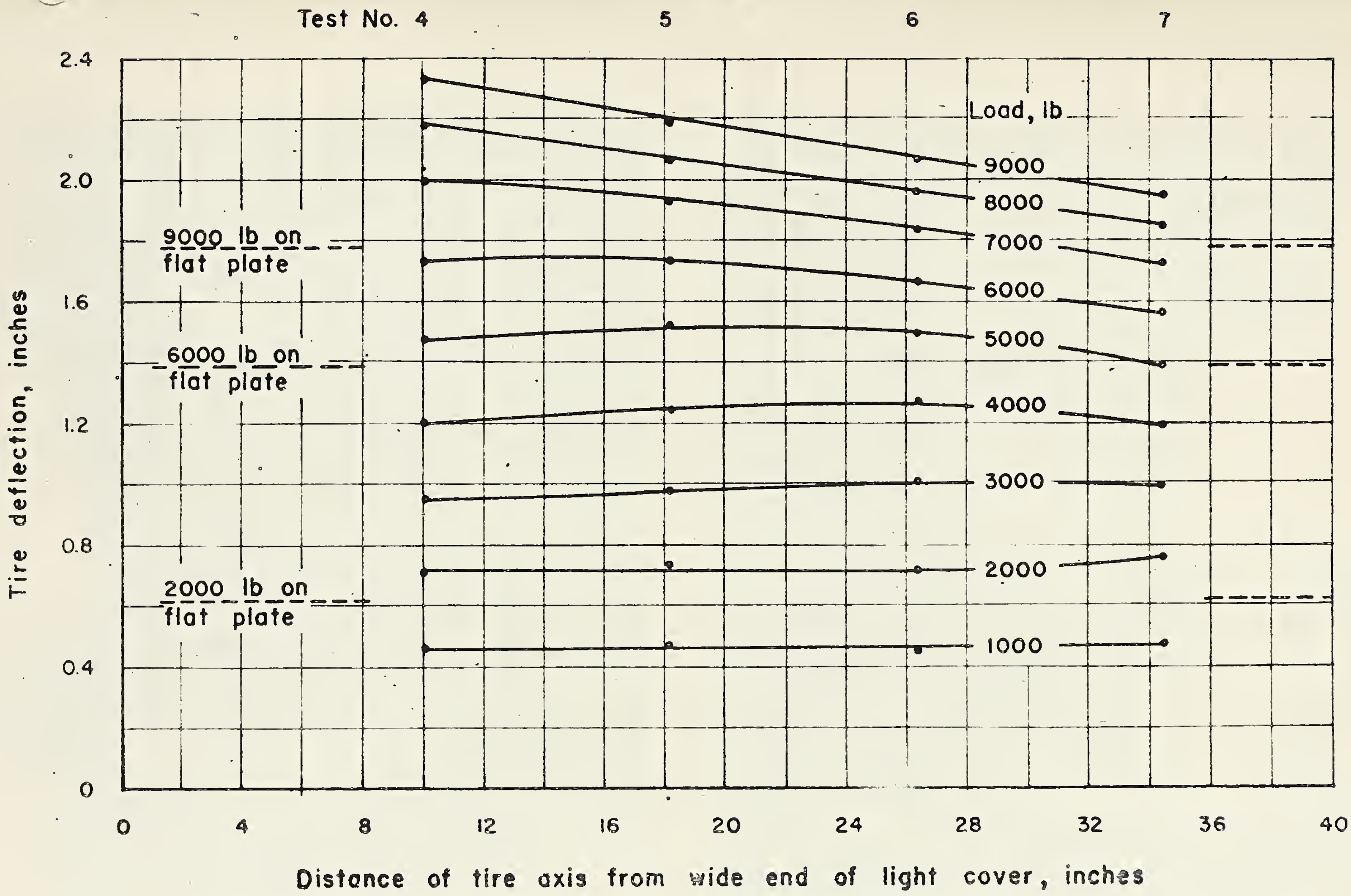
Analytical studies of the loads due to taxying an airplane at different speeds over runway lights of various heights and lengths showed that an important factor was the projected height above the runway. For an F-86H nose wheel, the tire deflection was approximately equal to the light height. For most of the range of taxying speeds there is a definite relationship (not necessarily a straight line) between the tire deflections and the resultant forces applied to the airplane.

Comments and opinions on protruding lights in runways were requested from the airframe manufacturers in September 1956 and June 1957. Eleven divisions and/or companies participated. They presented a divergence of opinions with supporting data and discussion. The protrusions under consideration were button type lights 1-1/4 inches or 1-3/4 inches high and the elongated grid lights 1/2 inch high. A partial summary by light height follows:

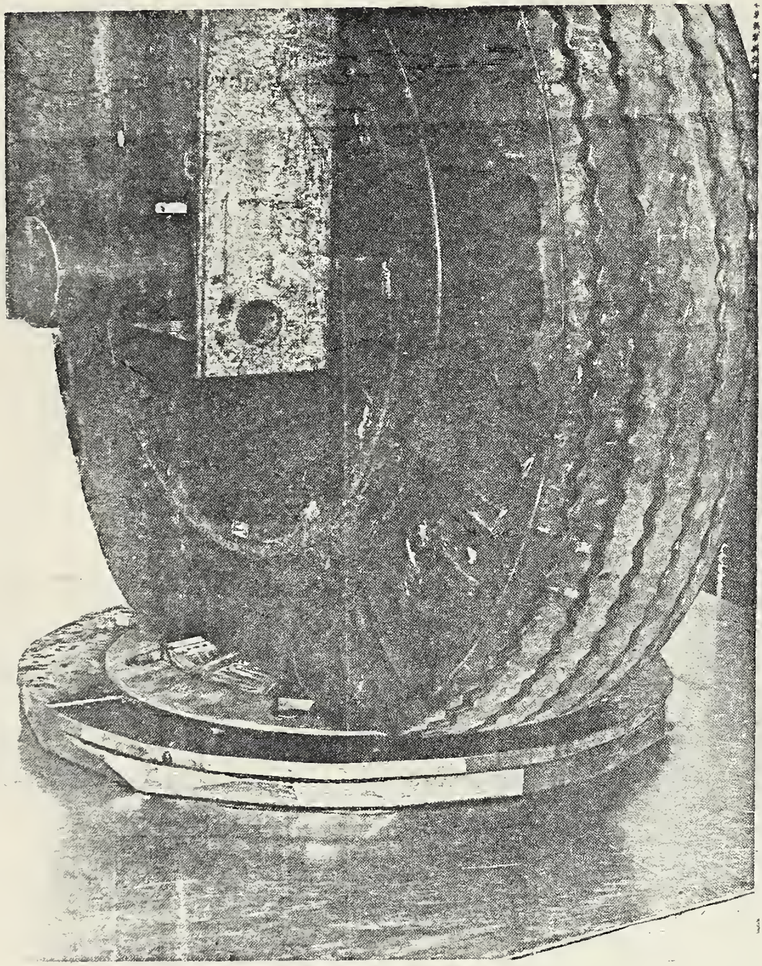
Grid light, 1/2 inch high. Most manufacturers indicated that traversing this protrusion (assumed to act as a continuous surface)



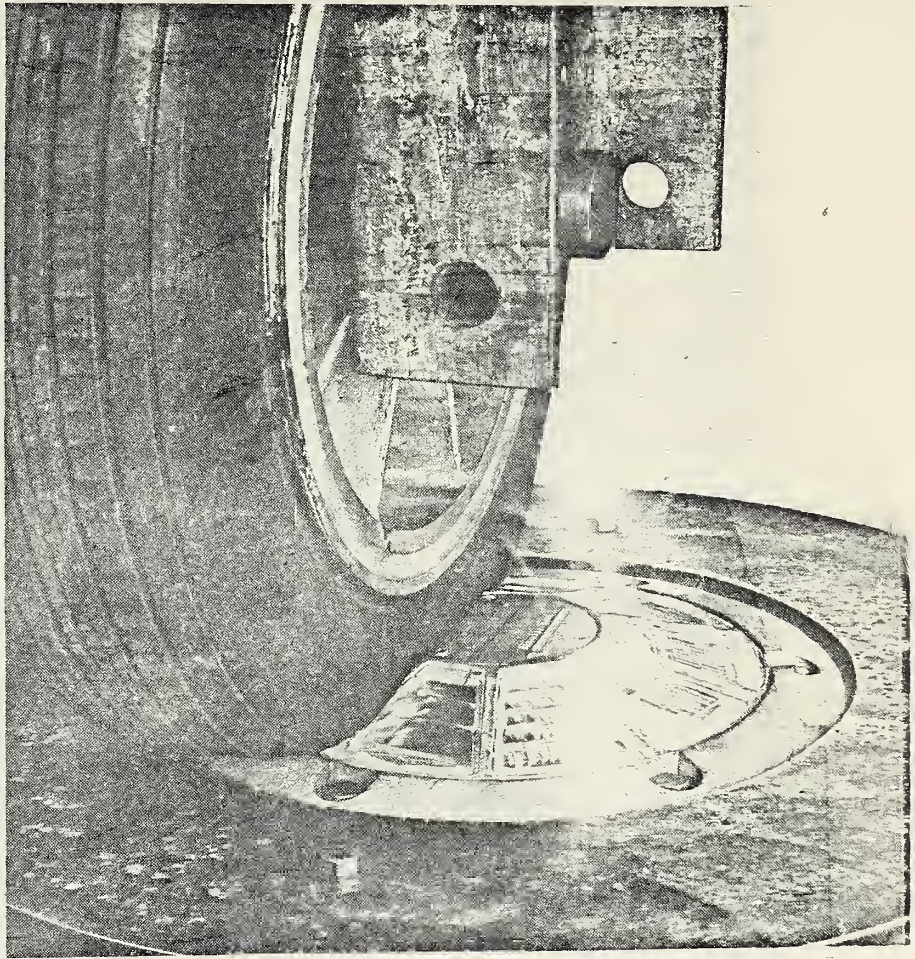
A load of 5,600 lb applied through a 20x4.4 tire.



DEFLECTION vs. POSITION of a 20x4.4 TIRE on an OPEN GRID LIGHT COVER WITH VARIOUS LOADS



A load of 20,000 lb applied through a 26x6.6 tire.



A load of 8,00 lb applied through a 20x 4.4 tire.

Figure 14

would not cause direct structural failure. There were questions about the coefficient of friction for rubber on steel with the accompanying effect on braking and steering characteristics.

Button type, 1-1/4 inches high. Manufacturers were about evenly divided as to whether this height would cause damage or not. The most critical comments concerned effects on land based fighters and those bombers and transports with relatively flexible wing and fuselage structures. The manufacturers of carrier-based aircraft indicated that the aircraft they manufactured could traverse lights of this height without difficulty.

Button type, 1-3/4 inches high. Only makers of carrier-based planes and transports for rough field operations indicated that lights of this height would not cause difficulties.

Button type, 1/2 inch high. Only two manufacturers of large, relatively flexible-wing aircraft were completely opposed to the use of these lights.

There was concern about the accumulative effects (fatigue) due to striking obstructions.

A limited experimental investigation was conducted by NACA to supplement the work of the National Bureau of Standards. A F-94C nose gear and a B-57 main gear were tested on their landing-load track with various lights. The grid light and a 7/8-inch-high button light were roughly equivalent when compared on the basis of increased loads measured for the F-94C (20 x 4.4 wheel) nose gear and there was a significant increase in load due to raising the button type to 1-1/2 inches. When the nose gear traversed the grid light at an angle to the bars, yawing of the wheel was observed. The maximum loads measured for the nose gear were caused by colliding with the C-1 light on a frangible coupling. The increases in loads due to the B-57 main gear taxying over various lights were much smaller, proportionally, than for the F-94C nose gear.

A study was made also of the characteristics of frangible couplings. The impacts required to break 90% of the couplings submitted were within the range 10 ± 4 foot-pounds. Consideration was given to methods of test suitable for use in routine testing for conformance to procurement specifications. Since for a given manufacturing process, material and geometry of frangible adapter, there is a relationship between the static breaking moment and the impact breaking strength, the use of the static breaking moment only should be considered for procurement specifications. However, when the manufacturing process, material or geometry of the adapter is changed, both the static and impact strengths should be determined.

6. MISCELLANEOUS TASKS

6.1 Evaluation of Flashing Lights

In order to design lighting systems using flashing lights and to determine the effectiveness of these lights, a means of evaluating lights emitting flashes of different durations and of comparing these lights with steady burning lights was developed.

It is convenient to evaluate flashing lights in terms of effective intensity, I_e, that is, the intensity of a fixed light which will appear equally bright. Blondel and Rey found that for an abrupt flash at threshold illuminance

$$I_e = \frac{It}{a + t}, \qquad (1)$$

where _I_ is the instantaneous intensity, _t_ is the duration of the flash, and _a_ is a constant. They found that _a_ was equal to 0.21 when _t_ is in seconds.

The flash from most lights used in aviation service is not abrupt and in many instances equation (1) is not applicable to the computation of the effective intensity. Therefore it was suggested that the effective intensity be computed by means of equation (2).

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

An equation of this form was originally suggested by Blondel and Rey, but had rarely been used. The principal problem in the use of this equation is the proper choice of the limits t_1 and t_2. It was proposed that these times be so chosen to make the value of I_e a maximum.

It was shown that I_e is a maximum when the limits t_1 and t_2 are the times when the instantaneous intensity is equal to I_e. The

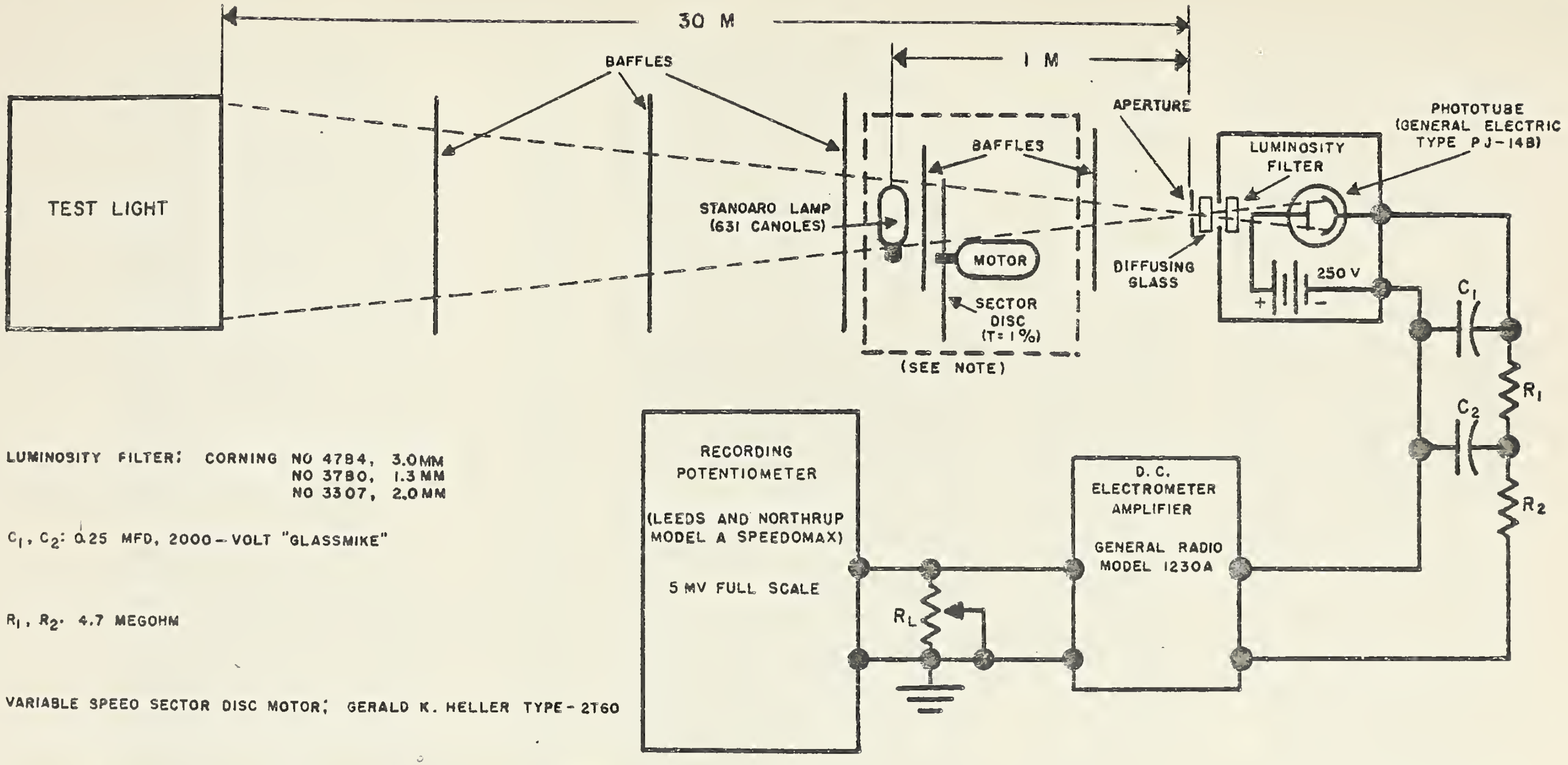
maximum value of I_e may be readily obtained in a very few steps by using as the limits of each step the times corresponding to the computed value of I_e obtained in the preceding step.

Concern has frequently been expressed about the choice of the limits for the integral of the Blondel-Rey relation for computing the visual range of a flashing light. It seems illogical to extend the limits of the integral beyond the times when the instantaneous intensity is below the threshold intensity for steady burning lights so that intensities which are below threshold, even for a steady burning light, are included, or to exclude intensities which are above threshold for steady burning lights. Using this reasoning, Blondel and Rey suggested that the limits of the integral of equation (2) be the times when the instantaneous intensity is equal to the threshold intensity. These are also the limits which make the effective intensity and hence the computed visual range of the light a maximum. Therefore, the use of these limits in evaluating the performance of a lighting unit appears to be a logical choice.

6.2 Photometer for Measurement of the Effective Intensity of Condenser Discharge Lights

In the past, measurements of the effective intensity of condenser discharge lights have generally been made by two methods: (1) coupling the output of a phototube to a cathode-ray oscilloscope, photographing the trace of the instantaneous intensity against time, integrating the area under the curve and computing the effective intensity; and (2) charging a capacitor by the photoelectric current generated by one or more flashes and measuring the voltage developed with a vacuum-tube voltmeter. Both of these methods are time consuming when an intensity distribution curve of a projector using a condenser discharge lamp is desired. In addition, there is often uncertainty about the accuracy of the correction of the spectral response of the photometric system to the CIE standard observer luminosity function; the sensitivity may be so low that short photometric distances are required; and the phototube may be saturated during part of the flash destroying the linearity of the system. A method which will allow measurements of the effective intensity distribution of condenser discharge units to be made and recorded automatically, and at the same time overcome these difficulties, was developed.

The effective intensity photometric system is shown in figure 15. Light from either the test unit or the standard lamp falls on a diffusing glass so that the distribution of illumination on the photosensitive surface of the phototube is independent of the distance of the light source. A small aperture in front of this glass is used to control the illumination on the phototube. The light then passes through the luminosity filter to the phototube. This filter is so designed that the spectral response of the phototube-filter-diffusing glass combination is essentially that of the luminosity function of



LUMINOSITY FILTER: CORNING NO 4784, 3.0MM
NO 3780, 1.3 MM
NO 3307, 2.0 MM

C_1, C_2: 0.25 MFD, 2000-VOLT "GLASSMIKE"

R_1, R_2: 4.7 MEGOHM

VARIABLE SPEED SECTOR DISC MOTOR; GERALD K. HELLER TYPE-2T60

COMPONENTS WITHIN THE DOTTED LINES ARE IN PLACE ONLY DURING CALIBRATION

R_L, CALIBRATION ADJUSTING RESISTOR; DECADE BOX 9 x (10+1+0.1+0.01)

EFFECTIVE-INTENSITY PHOTOMETRIC SYSTEM

NBS

FIGURE-15

the CIE standard observer. The correction of the spectral sensitivity of the phototube is sufficiently accurate for the photometry of any "white" light. The output current of the phototube is smoothed by the resistance-capacitance network so that the d-c electrometer-amplifier will not be overloaded during the flashes and so that output current will be sufficiently stable to produce a smooth curve on the recording potentiometer. The output of the system is, of course, proportional to the average photoelectric current and hence to the average illumination at the phototube.

Because of the time constant of the input circuit, the recorder responds to the average current of the phototube. During a flash the photoelectric current charges capacitor C_1 and the voltage across the phototube is not decreased appreciably. Hence the phototube does not saturate and the photoelectric current is at all times proportional to the illumination on the phototube.

The photometer system described here is, of course, not limited to the photometry of condenser discharge lights only, but is applicable to any light having a flash duration of less than about one millisecond (between the times when the intensity is about 5% of peak intensity). The effective intensity distributions of lights with flash durations somewhat longer than one millisecond (about 0.01 second) can often be recorded automatically with this system if a suitable correction factor is included in the calibration. However, experience has shown that the correction factor to be applied to flashes generated by rotating lights (such as beacons) is not constant but varies with the angle of view. Hence the effective intensity of lights of this type should be computed by the method described in section 6.1.

The instruments required for a photometer for flashing lights were supplied to the Lighting Section, Wright Air Development Center.

6.3 Photoelectric Tristimulus Colorimeter

6.3.1 Theory of Operation. A photoelectric tristimulus colorimeter is being developed for use in determining the chromaticity of colored signal lights. The colorimeter consists of a precision tristimulus photoelectric photometer and a d-c electronic amplifier. The radiant energy receptor is a vacuum phototube. Light from the source passes through one optical system and illuminates one phototube. Tristimulus filters are inserted into the light path one at a time and the output of the phototube is read for each filter. If the filters are suitably designed, these readings are directly proportional to the tristimulus values X, Y, and Z. The chromaticity coordinates

are determined from the equations

$$X = i_x/(i_x + i_y + i_z)$$

$$Y = i_y/(i_x + i_y + i_z)$$

$$Z = i_z/(i_x + i_y + i_z)$$

where i_x, i_y, and i_z are the output readings using tristimulus filters X, Y, and Z, respectively. Operation and readout of the instrument are manual. A photometric system similar to that described in section 6.2 is used. Therefore, the instrument is suitable for use with flashing lights. Two basic design problems are involved in the construction of the colorimeter: (a) Design of accurate tristimulus filters, and (b) Design of an instrument which will measure the output currents of the phototube with sufficient accuracy. The solution of problem (b) is discussed in section 6.4. The problems involved in the design of the filters are discussed below.

6.3.2 Design of Tristimulus Filters. Three filters, the spectral transmittance of which will provide phototube-filter combinations with spectral responses proportional to the spectral distributions of the CIE tristimulus functions $\overline{x}$, $\overline{y}$, and $\overline{z}$ are required. To obtain filters with stable transmittance values, the filters are made of glass. To obtain the desired spectral responses each filter must consist of several components. To obtain maximum sensitivity and latitude for adjustment, an additive filter system is used; that is, instead of passing through all components sequentially, the light is divided into several portions and each portion is passed through one component of the filter. The fractions transmitted are then combined and transmitted to the phototube.

6.3.3 Status of Development. Computations of the filters have now been completed and the glasses are now being ground to the required thickness. Construction of the remainder of the photometer has been carried as far as is possible pending completion of the filters. The instrumentation required for measuring the phototube output has been completed and delivered. (See section 6.4)

6.4 Potentiometer for the Measurement of Small Currents

In order to obtain sufficient accuracy in the chromaticity determinations made with a photoelectric tristimulus colorimeter described in the preceding paragraph, relative measurements must be made of very small photoelectric currents (of the order of 10^{-10} to 10^{-11} ampere) with three-place accuracy. The then commercially available

micro-microammeters had more than sufficient sensitivity for the purpose, but the uncertainties in relative measurements made with these instruments were about ten times the acceptable uncertainties.

Measurements of the voltage drop which is developed across a high resistance load by the photoelectric current can be made with a potentiometer with sufficient accuracy when the potentiometer is used with a sensitive low current galvanometer as a null detector. For convenience of operation an "electronic galvanometer" should be used. as the null detector.

A study of the circuitry of the General Radio Model 1230A Electrometer-Amplifier indicated that this instrument could be modified so that it could not only function as the "electronic galvanometer" with the sensitivity controlled by the VOLTS switch of the instrument, but that the input resistors and the input-resistance switch could be used as the load resistors for the phototube and current range selecting switch respectively. Figure 16 is an elementary schematic diagram of the modified electrometer-amplifier with a circuit diagram of the potentiometer.

The instrument can measure small photoelectric currents with an accuracy of 0.1%.

A potentiometer unit was furnished the Lighting Section, WADC, for use with the Electrometer-Amplifier which was supplied as a component of the photometer for flashing lights described in section 6.2.

6.5 Current-Intensity, Voltage-Intensity, and Current-Voltage Characteristics of Airfield Lighting Lamps

Intensity control is now used on nearly all runway and approach light systems and on some taxiway light systems. The increasing complexity of the problems of intensity control has increased the need for information on the relative intensity characteristics of lamps used in approach, runway, and taxiway lighting as a function of the applied current or voltage. (Relative intensity is defined as the ratio, in percent, of the intensity of a lighting unit or lamp operated at a given current or voltage to the intensity of the same lighting unit or lamp operated at rated current or voltage.) In addition, information on the effect of color filters upon the relative intensity is needed. NBS Report 6190 was prepared to meet this need. It is believed that the data are now sufficiently complete that the characteristics of new lamps can be determined by comparison with data given in the report for similar lamps with an accuracy sufficient for most engineering purposes.

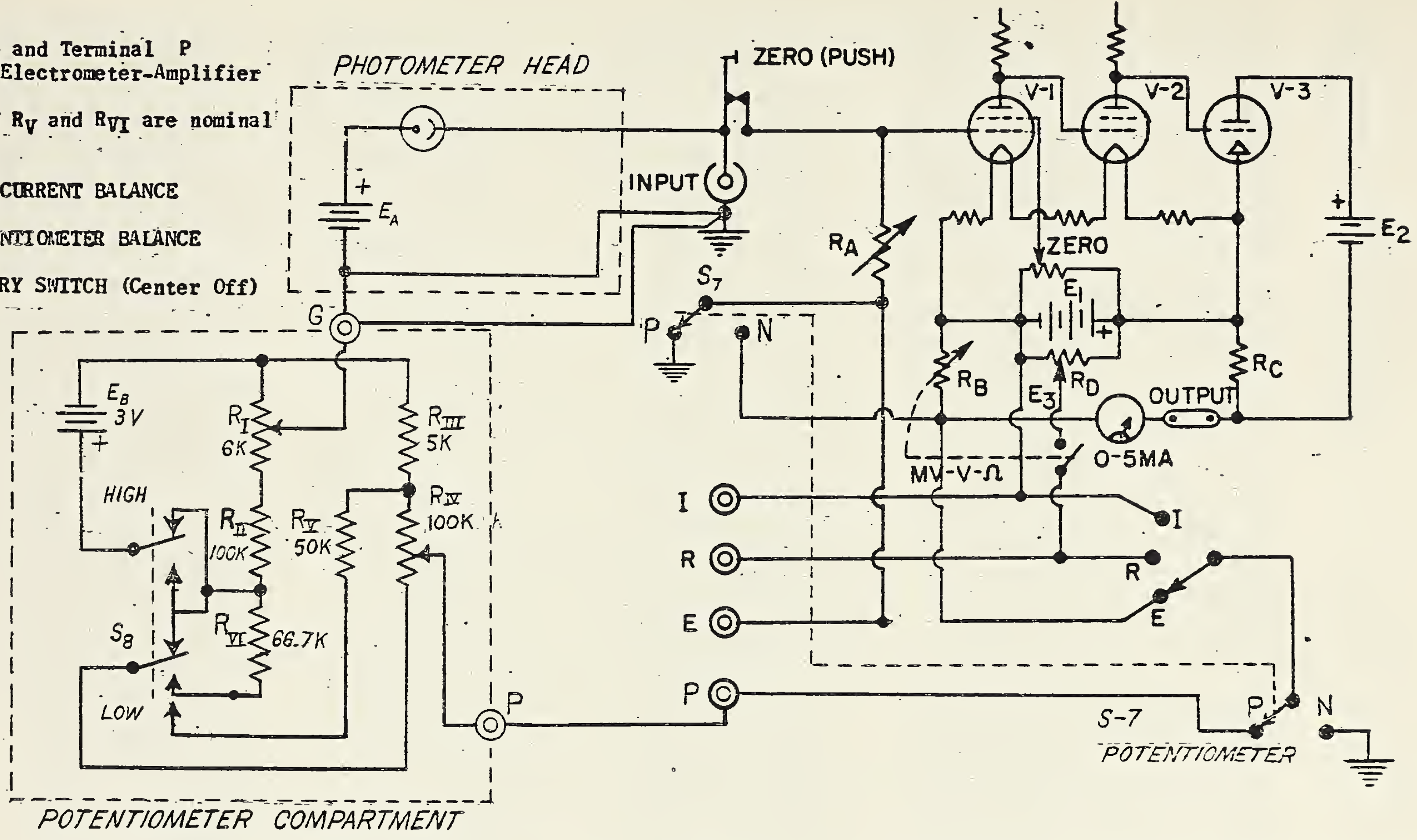
Switch S_7 and Terminal P added to Electrometer-Amplifier

Values of R_V and R_{VI} are nominal values.

R_I, DARK CURRENT BALANCE

R_{IV}, POTENTIOMETER BALANCE

S_8, BATTERY SWITCH (Center Off)



POTENTIOMETER AND ELEMENTARY SCHEMATIC DIAGRAM OF MODIFIED GENERAL RADIO TYPE 1230-A D-C AMPLIFIER AND ELECTROMETER

NBS REPORT 6862

FIGURE 16

Relative intensity-current curves for several 6.6-ampere and 20-ampere series lamps used in airfield light service are shown in figures 17 and 18, respectively.

Because the transmittance of color filters is a function of the color temperature of the source, the relative intensity characteristics of colored lights will differ from those of similar lights which are "white." The determination and presentation of the relative intensity characteristics of each type of lamp for each aviation color would be unduly expensive. Therefore a study was made to determine representative correction curves. Relative intensity characteristics were determined for several of the types of lamps commonly used in combination with filters representative of the limits of the aviation colors. It was found that the data were adequately represented by the lines plotted on figure 19. These lines show the relative intensity of lights meeting the specification requirements for aviation colors as a function of the relative intensity of the same light used without a filter.

6.6 Synchronizing Flasher

The synchronized flashing of obstruction and identification lights without the use of a common power supply or auxiliary control cables is very desirable. A method of accomplishing this is the use at each lamp of a small synchronous motor switch which will return to a zero position whenever power is cut off. A switch of this type was constructed and tested. The unit functioned satisfactorily but at the present stage of development the operating life is too short.

6.7 Cooperation with Other Organizations

Throughout the course of this project personnel assigned to it participated in the activities of and furnished technical assistance to government organizations and other technical groups in order that personnel of these groups be kept informed of the results of this project and that project personnel be kept informed of the results of the work of these groups. Examples of these activities are given below.

6.7.1 Runway Lighting Patent Suit. A search was made of the technical literature and the National Bureau of Standards files for references pertinent to the patent infringement suit of the Welsbach Corporation. A memorandum listing these references and discussing their pertinency was prepared and forwarded, with copies of most of the documents referenced, to the Department of Justice. Recently a letter was received from the Department of Justice stating that the patent infringement suit of the Welsbach Corporation has been settled and thanking the Bureau for the assistance given in marshalling material and making studies pertinent to the suit.

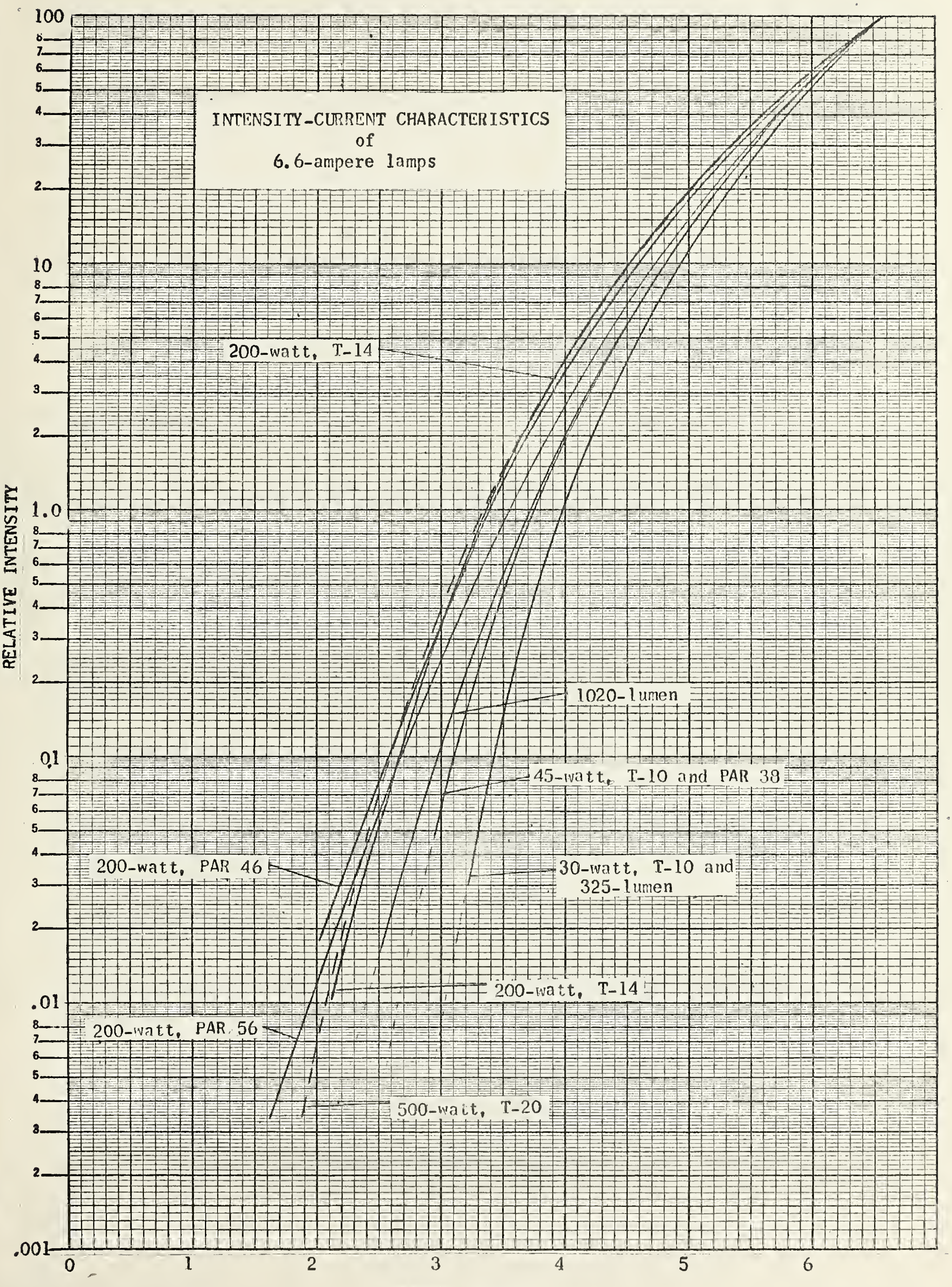
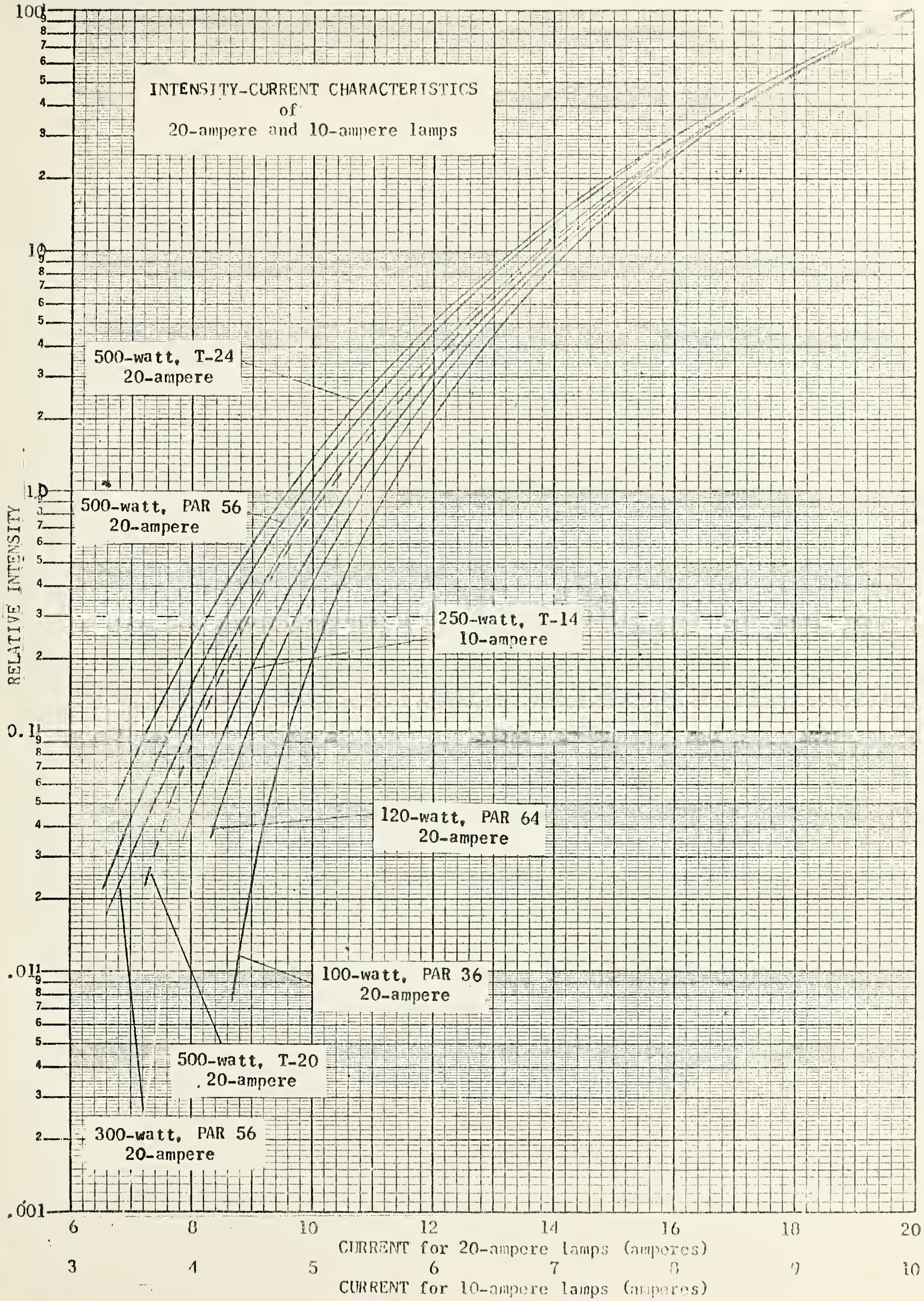

INTENSITY-CURRENT CHARACTERISTICS
of
6.6-ampere lamps
100
10
1.0
0.1
.01
.001
RELATIVE INTENSITY
0
1
2
3
4
5
6
CURRENT (amperes)
200-watt, T-14
1020-lumen
45-watt, T-10 and PAR 38
200-watt, PAR 46
30-watt, T-10 and 325-lumen
200-watt, T-14
200-watt, PAR 56
500-watt, T-20

Figure 17



NBS Report 6862

Figure 18

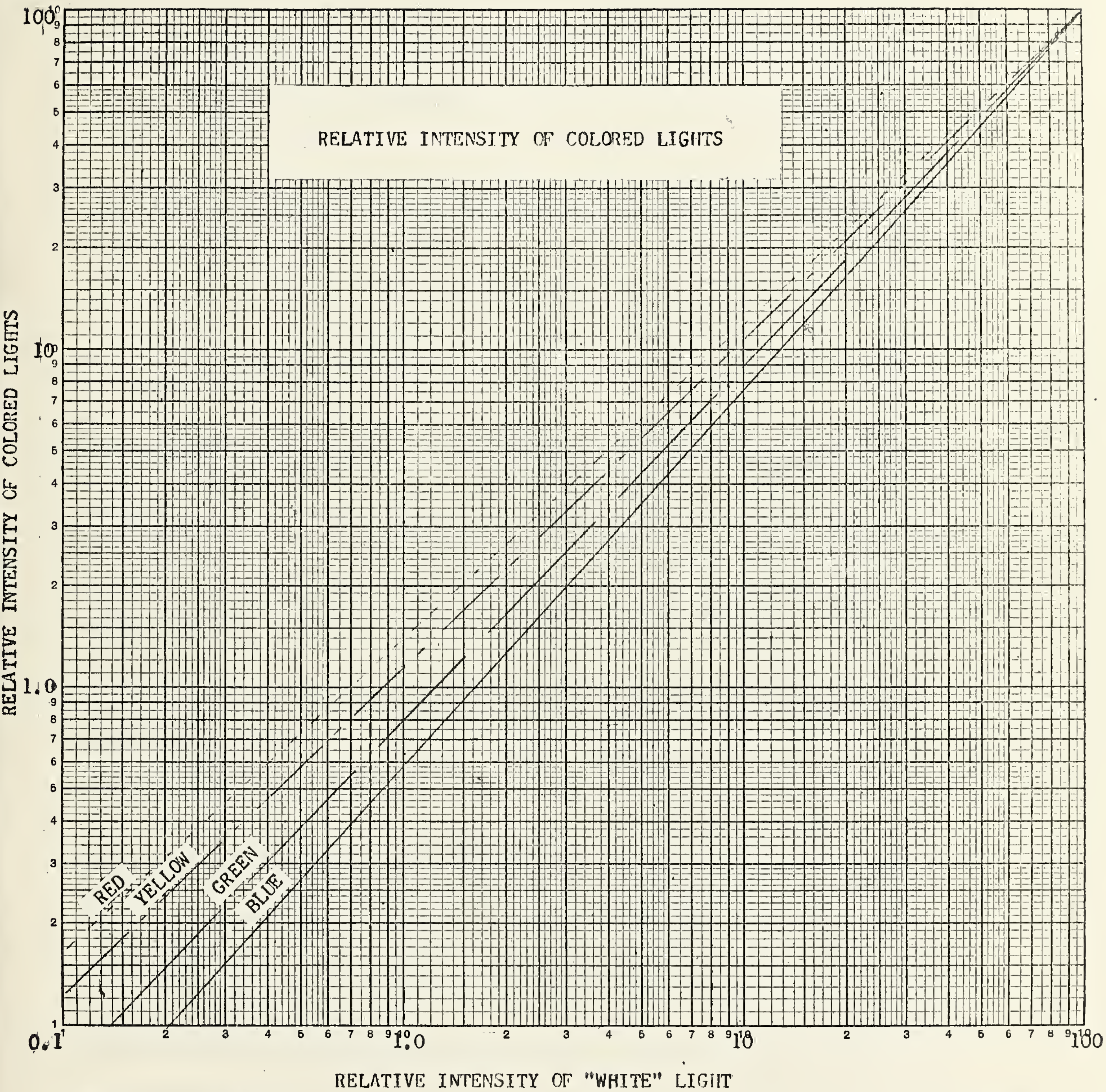

RELATIVE INTENSITY OF COLORED LIGHTS
RELATIVE INTENSITY OF COLORED LIGHTS
RELATIVE INTENSITY OF "WHITE" LIGHT
RED
YELLOW
GREEN
BLUE
0.1
1.0
10
100
0.1
1.0
10
100

Figure 19

6.7.2 Meeting of Visual Landing Aids Panel. Mr. Douglas attended the meetings of the ICAO Visual Landing Aids Panel held in London from January 5 to 20, 1957 as technical advisor to the U. S. Delegate. The emphasis at these meetings was primarily on visual aids for use in good and in moderately restricted visibility. None of the findings or recommendations of the Panel were in conflict with those developed during the course of this project and reported in the Interim Report (NBS Report 4741). The U. S. Delegation was able to execute and defend the U. S. position in every respect.

6.7.3 CIE Meeting. Mr. Douglas attented the meetings of the CIE Working Party on Aviation Ground Lighting which were held in London on September 30 and October 1, 1958. The meetings were devoted primarily to an exchange of technical information and views of factors related to these items. One purpose of this exchange was to provide guidance for some of the countries which are now becoming active in the field of aviation ground lighting. The group also inspected the lighting installations at Gatwick Airport from the ground and from the air.

The problem of a suitable intensity distribution for approach lights had been referred to the group by the International Civil Aviation Organization. The group decided after thorough discussion to recommend the distribution now used by the U. S. and described in the report of the Sixth Session of the Aviation Ground Aids Division of ICAO. The group also recommended to ICAO that beam spreads of lights be given as the spread at 50% of peak intensity and that omnidirectional lights be defined as lights having a maximum change in intensity with azimuth of less than 4 to 1 at each angle of elevation.

6.7.4 IES Aviation Lighting Committee. Papers were presented at several of the Technical Sessions of the Aviation Lighting Committee (see Appendix B) so that the personnel in government and industry concerned with aviation ground lighting were informed of the results of this project.

6.7.5 Aviation Ground Aids Section, Air Coordinating Committee. Technical assistance was given Aviation Ground Aids Section and special working groups set up by this section on several occasions. In this connection an extensive study was made of the visual range of tall towers. It was concluded from this study that the visual range of these towers was insufficient during daylight. A system of high intensity lights was suggested for use on the towers during daylight hours. Specifications for these lights and for improved lights for night use were drafted.

6.7.6 CAA Ad Hoc Runway Lighting Task Group. Assistance was given the Task Group on Runway Lighting Fixtures set up to advise the Administrator, Civil Aeronautics Administration, in collecting and analyzing photometric data and in preparing the report of the Task Group.

7. PROBLEMS IN AVIATION GROUND LIGHTING

In NBS Report 5753, Some Problems in Approach Lighting, some of the primary problems in approach lighting were reviewed. A paper based on this report was presented at the meeting of the Aviation Lighting Committee held at Wright Field in October 1957. Since this discussion is applicable not only to approach lighting but to ground lighting in general, it is summarized here.

With the development of improved electronic approach aids and couplers, and of improved visual landing aids, we are approaching the goal of "all-weather" take-offs and landings. We can expect some of the perennial problems in lighting to reappear, possibly in new form. Among these problems are:

1. Standardization
2. Field Testing
3. Elevation Guidance
4. Control of Glare (Discussed in section 5.1)

7.1 Problems in Standardization

Standardization in all phases of aviation lighting and marking is highly desirable both on a national and an international scale.

Progress in obtaining standardization in approach light configurations has been very slow during the past decade even though many pilots have stated that they considered standardization so important that they would willingly accept a system which they considered less than optimum in order to expedite the installation of approach lights.

These problems should have been expected. There are different views as to the relative importance of the different types of guidance to be supplied by the approach light configuration; there are differences in the accuracy of the coupling to the instrument landing system; there are differences in the capabilities of pilots and in the characteristics of aircraft; there are sometimes restrictions placed on the length of the system and on the permissible location of lights which are based on requirements other than lighting; and last, but by no means least, there are the differences in opinions as to the value of the various components which might be used to build a system. There are differences of opinion not only between the pilot and the engineer, but also between engineer and engineer and pilot and pilot. With all these factors to consider, the wonder is not that standardization has been so slow, but that standardization can be obtained at all.

Perhaps we have been too much concerned with obtaining complete standardization of configuration when we should have first worked

for configurations which were compatible. Two configurations are compatible if a pilot who is experienced with one configuration will not be misled if he takes a reflexive action when flying the other system.

There has been no significant change during the last few years in the relative merits of the British and the U. S. approach light systems. It appears that world-wide standardization can be obtained only by a system with both the British cross bars and the U. S. barettes. This could be called either an ALPERT or a CALPA system in order to maintain the identity of the originators of the two original systems.

7.2 Problems in Testing

Obtaining conclusive results in the comparative evaluation of approach light configurations is a very difficult, if not impossible, task. This is clearly demonstrated by the general reluctance to accept test results of organizations other than one's own, and the fact that formal flight tests have rarely, if ever, resolved major differences of opinion regarding the relative value of different types of approach and runway lighting systems. The moment-to-moment and place-to-place variations in fog density are generally so great that no two approaches are made in the same visibility condition. The number of approaches that can be made in low visibility conditions during the period allowed for testing is seriously limited. Hence it is very difficult to develop an experimental design which will satisfactorily randomize the tests and which will provide sufficient controls so that a quantitative measure of the difference can be obtained of the guidance furnished by the systems under test.

Thus, in the past, evaluations have generally been based upon either pilot opinion or the application of arbitrary criteria as a measure of performance. Neither of these alternatives is entirely satisfactory. The results obtained with either are very dependent upon the personal bias. It is very difficult for one to be objective about his own creations and other matters in which he has a strong personal interest. Yet nearly all tests of lighting configurations are under the direction of people with a strong personal interest in one of the configurations being tested. Frequently the opinions of these persons influence not only their own conclusions, but also the conclusions of others participating in the tests. Knowing the background of those conducting the tests, it is often possible to predict the test conclusions in advance of the tests.

Because of this difficulty in obtaining conclusive results from formal flight test programs, a much more extensive use of service tests is needed. Thus, where major differences of opinion can not be resolved by a series of flight tests, one or more installations of

each of the systems under consideration should be made in order to obtain service experience. This will produce some departures from standardization. However, this is considered more advantageous than delaying installations while additional, and often futile, efforts are made to resolve the differences by further flight testing.

Other factors which tend to invalidate or give misleading results in the testing are:

1. Failure to separate the variables.

2. Application of results obtained with special test crews or in special test flights to service conditions in general.

3. Lack of suitable controls in the design of the experiment.

4. Extrapolation of results to visibility conditions considerably different from those in which the tests were made.

5. Deficiencies in reporting such weather data as visibility and ceiling.

7.3 Problems in Elevation Guidance

The mirror landing system and other optical glide path systems supply elevation guidance by defining the glide path and indicating to the pilot his angular deviation from this path. These systems provide not only a sensitive indication of the departure from the indicated glide path, but also a good indication of the rate at which the airplane is changing the departure from this path. However, these devices must be located on the line of intersection of the plane of the glide path and the ground. Hence they are not visible until very late in the approach if the visibility is much less than one-half mile. The slopeline and the Navy composite approach light systems indicated the direction of displacement from a preferred glide path when three or more lights on each side of the system could be seen. However, a considerable amount of experience was required to obtain a quantitative measure of the displacement from the preferred path and the rate of change of displacement especially when the airplane was displaced from the centerline of the approach zone.

In the other approach light systems the pilot receives visual information indicating his height above the runway and his rate of descent from the changes in the appearance of the pattern of approach lights and from the appearance of the lighting units themselves. Use of this type of information to determine visually if the path of the aircraft will cross the threshold at a satisfactory height presupposes a knowledge of the distance of the aircraft from the threshold. When the

visual range is one-half mile or more, this presents no problem. However, in very restricted visibility conditions the present U. S National Standard approach light system (configuration A) does not present adequate distance-from-threshold information.

That height judgment during the landing is difficult in good weather as well as bad and requires considerable pilot training is evident from the frequency of undershoots in good weather. Thus a visual glide path system would be useful most of the time even though it is located near the touchdown point. Therefore, the principles of operation of the different visual glide path systems were reviewed.

Visual glide path systems fall into two general catagories: 1) systems which define the glide plane by two or more lights (or marks) or bars of lights (or marks) located in the glide plane, and 2) those which define low, on-glide path, and high sectors by coded signals.

Examples of systems of the first type are the Cumming-Lane Double Bar, the Air Force "Meat Ball", and the Navy POMOLA. The "Mirror" and the Navy "Lens" optical landing systems are special cases of systems of this type in which the rear (lower) set of lights is replaced by a virtual source which is below the level of the landing surface, thus decreasing the height required for the forward lights of the system. Each of these systems provides information concerning the magnitude of the displacement from and the rate at which the aircraft is approaching the glide path. However, systems of this type become insensitive at distances greater than about 50 times the separation between the forward and rear elements of the system.

Examples of systems of the second type are the Tricolor system and, at large viewing distances, the Navy High-Low Addition to the Mirror or Lens Optical Landing Systems. Systems of this type provide an insensitive measure of the displacement from the glide path and very little "rate" information. In addition, as the distance from the indicator becomes small, the on-glide path sector becomes so narrow that it is difficult for the pilot to stay within this sector. Efforts have been made to improve the performance of three-color systems by using two indicators set side by side at slightly different elevations, thus providing a six-color system, without marked success.

Recently the Royal Aircraft Establishment developed a system utilizing two sets of two-color (red-white) indicators set not side by side but set 500 to 1000 feet apart along the edge of the runway, thereby providing an on-glide path sector of relatively constant width.* The transition between the colors was not sharp but required about one-half

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* Described on page 89 of Third Edition of Annex 14, Standards and Recommended Practices for Aerodromes, to the Convention on International Civil Aviation.

degree. Thus the pilot received a more sensitive displacement indication and some rate information as the lights of a set changed from red through pink to white, or conversely. Sensitivity to the color chage is increased by the contrast with the lights of the other set which are either red or white.

Two feasibility models of RAE glide path indicators were prepared for the use of Wright Air Development Center in their tests of glide angle indicators. These indicators were intended for the testing of principles only, not as service test models. Five readily available lamps and elliptical reflectors were used in each unit. The peak intensity of each lamp-reflector combination was about 5000 candles in the white sector. Thus the total intensity of the unit was about 25,000 candles when the viewing distance was large (compared with 60,000 candles for an RAE unit). However, during the tests at WADC the units were operated much below full voltage although the intensity was considered inadequate. Only one unit was used at each location compared with the six (three on each side of the runway) now used by the RAE at each location. Thus, although the system has many desirable characteristics, the conclusions reached at WADC were generally negative.

8. CONCLUSIONS

(Note: The data supporting some of these conclusions has not been discussed in this summary report, but is contained in NBS Report 4741 and other documents listed in Appendix A.)

1. The coverage of the airfield beacon as now modified for use on military airfields is adequate for jet aircraft operation.

2. For jet aircraft operation it is essential that the runway be located and identified from as great a distance as practicable. The off-axis guidance of the present runway lights is inadequate when the lighting system is operated on the brightness settings used for clear weather. Hence, auxiliary lights are required for this purpose. Runway identification lights were developed for this purpose.

3. It is not practicable to obtain sufficient off-axis guidance from the lights of a high intensity runway lighting system which supply the axial guidance. Auxiliary lights are required. Circling guidance lights were developed for this purpose.

4. The downwind corner of the runway should be well marked and visible from the downwind leg. No runway light has a satisfactory intensity distribution for this function with the landing pattern used by the large jet bombers. Runway-end identifiers and runway identification lights fill this requirement.

5. The beam spread of a threshold lighting system comprised of runway lights is not sufficient to provide satisfactory guidance during the turn from the base leg to the final leg of the approach for aircraft with high approach speeds. The addition of wide-beam approach lights to the threshold lighting system provides the required coverage.

6. The intensity distribution of the present high intensity elevated approach lights is satisfactory.

7. For runway visual ranges of 400 yards or more, the intensity distribution of the present high intensity runway lights is satisfactory for straight-in approaches when the distance between the rows of lights is 200 feet or less and is marginal when the distance between rows is 300 feet. The horizontal beam spread of the type MB-1 light is sufficient for use in 300-foot-wide runways. These lights appear to be satisfactory mechanically.

8. Gaps in the runway lighting system are not considered serious except in the touchdown area and where the gaps are very long. These gaps may be filled with lights of the types now in use in narrow gauge systems.

9. In low visibility approaches the pilots are more concerned with finding and seeing the runway lights than they are with the adverse effects of glare.

10. A greater use of the principle of compatibility should provide sufficient flexibility in the design of configurations so that differences in operational requirements, differences in thinking, and limitations because of terrain can be met and should reduce the effort spent in trying to attain a complete and rigid standardization. (Complete standardization may not even be a desirable goal.)

11. The need for elevation guidance is expected to become more critical as minimums are lowered. Development of new methods of elevation guidance may be required.

12. The present marking of turnoffs is inadequate.

9. RECOMMENDATIONS

1. That efforts be made to have the beacons at civil airports and on the airways modified to provide the wide vertical beam spread of the beacons now being used at military airports.

2. That comparative tests be made, under controlled test conditions, of runway identification lights and runway-end identifiers in order to assess the advantages of the two types of beam spreads.

3. That circling guidance lights be procured and installed on runways with high intensity lighting at two or more airfields for tests of operational suitability and pilot acceptance.

4. That tests of operational suitability be made of approach light systems in which the outer portion is operated at a higher intensity setting than the inner section under night conditions.

5. That a study be made of the feasibility of adding the bars of the Calvert approach light system to the U. S. standard approach light system. This will require a study of methods of preserving the identity of the 1000-foot bar.

6. That service tests be made of threshold lighting systems modified by the addition to the outboard ends of the threshold lighting system of unidirectional lights having a horizontal beam spread of approximately 30° and of narrow beam high intensity unidirectional lights.

7. Use of type MB-1 lights, modified to have a lower elevation of the beams, on all runways over 200 feet wide.

8. Development of a light with an intensity distribution suitable for use on runways which are not served by precision instrument approach aids.

9. Development of a flush light of the class B type (Specification MIL-L-26202) or equivalent, with greater vertical beam spread than the present lights of this type.

10. Use of centerline lights and greater use of paint in marking runway turnoffs and taxiway intersections.

11. Use of a system of runway markings in which in the touchdown area the centerline markings are replaced, or supplemented with markings outside the high wear area.

12. Continued development and operational testing of angle-of-approach indicators and other systems of elevation guidance. The following factors should be considered in these studies.

a. Knowledge of the rate of change of displacement from the glide path or height above the runway is perhaps as important as knowledge of the displacement or height.

b. An indication to the pilot that his present course will lead to a safe touchdown, an undershoot, or an overshoot seems preferable to an indication that he is on, below, or above the glide path.

US NBS COMM DC

APPENDIX A

REPORTS AND MEMORANDA FORWARDED TO WRIGHT AIR DEVELOPMENT CENTER AS PART OF DELIVERY ORDERS 33(616)54-6 and 33(616)57-8

1.	NBS Report 4086	Results of Static Loading Tests of Elfaka Gratings by Aircraft Tires
2.	NBS Report 4358	Static Loading Tests of Flush-Type Runway-Light Heads
3.	NBS Report 4449	Analysis of Mercury Lamps and Filter Combinations for Use as Aviation-Green Lights
4.	NBS Report 4554	Computation of the Effective Intensity of Flashing Lights
5.	NBS Report 4565	Static Loading Tests of A.G.A. Expendable Top Runway-Light Head Assemblies with Glass Covers
6.	NBS Report 4574	Landing Gear Loads Resulting from Taxying Airplane Over a Projecting Runway Light. Progress Report No. 1
7.	NBS Report 4741	Development of Optimum Runway Lights for Jet Aircraft, Interim Report No. 1
8.	NBS Report 4783	Static Loading Tests of an A.G.A. Expendable Top Runway Light Head Assembly with a Glass Cover
9.	NBS Report 5239	Breaking Strength of Frangible Tube Base Adapters
10.	NBS Report 5294	Photometer for the Measurement of the Effective Intensity of Condenser-Discharge Lights
11.	NBS Report 5403	Static Load-Deflection Relations for 20 x 4.4 and 32 x 8.8 Aircraft Tires on an Elfaka Model C Runway Light Cover
12.	NBS Report 5641	Landing Gear Loads Resulting from Taxying an Airplane Over a Projecting Runway Light
13.	NBS Report 5676	Results of Questionnaire on Forces on Landing Gears Due to Guidance Lights on Runways
14.	NBS Report 5747	Problems in the Control of Glare in Approach- and Runway-Light Systems
15.	NBS Report 5753	Some Problems in Approach Lighting
16.	NBS Report 6190	Current-Intensity, Voltage-Intensity, and Current-Voltage of Airfield Lighting Lamps
17.	NBS Report 6422	Potentiometer for Measurement of Small Photoelectric Currents
18.	NBS Report 6549	A Field Evaluation of the Relative Brightnesses of Eight Types of Runway Marking Materials
19.	21P-11/56	Photometric Tests of an Elfaka Flush Light (USA Model C)

20.	21P-8/58	Photometric Tests of a Feasibility Model of a Flush Light
21.	21P-14/58	Photometric Tests of Three 35-Watt and Three 100-Watt Reflector Marker-Light Lamps
22.	21P-17/58	Photometric Tests of an Elfaka Flush Light (USA Model C)
23.	21P-22/58	Photometric Tests of a Circling-Guidance Light
24.	21P-22/58 (Supplemetary)	Photometric Tests of a Circling-Guidance Light
25.	21P-34/58	Comparative Intensity Distributions of Seven Type C-1 Elevated Runway Marker Lights
26.	Memorandum	Feasibility of Using Completely Flush Lights
27.	Memorandum	Runway Locator Lights
28.	Memorandum	Computation of the Loads Developed in the Landing Gear When an Airplane Taxies Over a Runway Light
29.	Memorandum	Analysis of the Operational Requirements of Threshold Lights
30.	Memorandum	Recommendations for Intensity Distributions of Airport Beacons
31.	Letter Rep.	Effective Intensity of Flashing Lights
32.	Letter Rep.	Intensity Requirements for Circling-Guidance Lights of Runway Lighting Systems
33.		Overlays of Runway Patterns of Selected Airfields
34.	Memorandum	Guidance for Circling Approaches
35.	Memorandum	Required Length of Flush-Type Lights
36.	Tentative Draft	Specification for a Fixed Circling-Guidance Light
37.	Tentative Draft	Specification for Flashing Runway Identification Light
38.	Travel Rep.	Memo of Visit to CAA Technical Development and Evaluation Center, Indianapolis, Indiana, February 16-18, 1955
39.	Travel Rep.	Summary of Flight Tests of Downwind and Threshold Lights at Indianapolis, Indiana, April 13 & 14, 1955
40.		12 Reports of Interviews at Air Force Bases
41.	Memorandum	Estimate of Heating Requirements for Elfaka Flush Light Model C
42.		Drawing of Runway Identification Light
43.	Memorandum	Memorandum Report of Runway Lighting Conference 8-15-57
44.	Memorandum	Memorandum Report of Meeting of Task Group on Flush Runway Lights 8-29-57
45.	Travel Rep.	Report of Visit to NACA, Langley Field, Va. 9-5-57
46.	Memorandum	Some Considerations in the Design of a Photoelectric Tristimulus Colorimeter
47& 48.	Memoranda (2)	Test Installation of Runway Markings at Washington National Airport
49.	Memorandum	An Air Strip Lighting Synchronizer
50.	Memorandum	A Discussion of References Pertinent to Bartow Beacons Inc. and the Welsbach Corporation vs. the United States
51.	Lab. Rep. 6.4/295-6	Static Load Tests of a Dobson Corporation Landing Light

APPENDIX B

Papers Presented

Lighting and Marking of Tall Towers, C. A. Douglas, I.E.S. Aviation Lighting Committee Meeting, November 1954

Development of Runway Lights for Jet Aircraft, C. A. Douglas, I.E.S. Aviation Lighting Committee Meeting, October 1956

Photometric Concepts of the Andrews Field Tests, C. A. Douglas, I.E.S. Aviation Lighting Committee Meeting, May 1957

Computation of the Effective Intensity of Flashing Lights, C. A. Douglas, I. E. S. National Technical Conference, September 1957

Problems in Approach Lighting, C. A. Douglas, I.E.S. Aviation Lighting Committee Meeting, October 1957

Forces Between Runway Lights and Landing Gear, L. K. Irwin, I. E. S. Aviation Lighting Committee Meeting, June 1956

APPENDIX C

Papers Published

Charles A. Douglas, Computation of the Effective Intensity of Flashing Lights, Illuminating Engineering, Vol. 52, p. 641 (1957)

Charles A. Douglas, Photometer for Measurement of Effective Intensity of Condenser-Discharge Lights, Illuminating Engineering, Vol. 53, p. 205 (1958)

U.S. DEPARTMENT OF COMMERCE
Frederick H. Mueller, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards at its major laboratories in Washington, D.C., and Boulder, Colorado, is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section carries out specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant publications, appears on the inside of the front cover.

Washington, D.C.

Electricity. Resistance and Reactance. Electrochemistry. Electrical Instruments. Magnetic Measuments. Dielectrics.

Metrology. Photometry and Colorimetry. Refractometry. Photographic Research. Length. Engineering Metrology. Mass and Scale. Volumetry and Densimetry.

Heat. Temperature Physics. Heat Measurement. Cryogenic Physics. Rheology. Molecular Kinetics. Free Radicals Research. Equation of State. Statistical Physics. Molecular Spectrocopy.

Radiation Physics. X-ray. Radioactivity. High Energy Radiation. Radiological Equipment. Nucleonic Instrumentation. Neutron Physics. Radiation Theory.

Chemistry. Surface Chemistry. Organic Chemistry. Analytical Chemistry. Inorganic Chemistry. Electrodeposition. Molecular Structure and Properties of Gases. Physical Chemistry. Thermochemistry. Spectrochemistry. Pure Substances.

Mechanics. Sound. Pressure and Vacuum. Fluid Mechanics. Engineering Mechanics. Combustion Controls.

Organic and Fibrous Materials. Rubber. Textiles. Paper. Leather. Testing and Specifications. Polymer Structure. Plastics. Dental Research.

Metallurgy. Thermal Metallurgy. Chemical Metallurgy. Mechanical Metallurgy. Corrosion. Metal Physics.

Mineral Products. Engineering Ceramics. Glass. Refractories. Enameled Metals. Constitution and Microstructure.

Building Technology. Structural Engineering. Fire Protection. Air Conditioning, Heating, and Refrigeration. Floor, Roof, and Wall Coverings. Codes and Safety Standards. Heat Transfer. Concreting Materials.

Applied Mathematics. Numerical Analysis Computation. Statistical Engineering. Mathematical Physics.

Data Processing Systems. SEAC Engineering Group. Components and Techniques. Digital Circuitry. Digital Systems. Analog Systems. Applications Engineering.

Atomic Physics. Spectroscopy. Radiometry. Mass Spectrometry. Solid State Physics. Electron Physics. Atomic Physics.

Instrumentation. Engineering Electronics. Electron Devices. Electronic Instrumentation. Mechanical Instruments. Basic Instrumentation.

- Office of Weights and Measures.

Boulder, Colorado

Cryogenic Engineering. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Gas Liquefaction.

Radio Propagation Physics. Upper Atmosphere Research. Ionosphere Research. Regular Prediction Services. Sun-Earth Relationships. VHF Research. Radio Warning Services. Airglow and Aurora. Radio Astronomy and Arctic Propagation.

Radio Propagation Engineering. Data Reduction Instrumentation. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Propagation-Terrain Effects. Radio-Meteorology. Lower Atmospheric Physics.

Radio Standards. High-Frequency Electrical Standards. Radio Broadcast Service. Radio and Microwave Materials. Electronic Calibration Center. Microwave Circuit Standards.

Radio Communication and Systems. Low Frequency and Very Low Frequency Research. High Frequency and Very High Frequency Research. Modulation Systems. Antenna Research. Navigation Systems. Systems Analysis. Field Operations.

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