SAE Aerospace
An SAE International Group

AEROSPACE RECOMMENDED PRACTICE

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Reaffirmed 2012-06	
Superseding ARP798	

(R) Design Criteria for White Incandescent Lighted Aerospace Instruments

RATIONALE

ARP798A has been reaffirmed to comply with the SAE five-year review policy.

1. SCOPE

This SAE Aerospace Recommended Practice (ARP) covers the general requirements and test procedures recommended for use with white incandescent integrally lighted instruments. Its use should provide uniformity of illumination from instrument to instrument and legibility under daylight operation. An appendix is provided to familiarize the designer with some of the techniques used to obtain uniformity of color and illumination in various types of instruments.

1.1 Purpose

The purpose of this document is to recommend to the designer the various criteria and to familiarize him with techniques associated with white incandescent lighted aerospace instruments.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

AS25050 Color, Aeronautical, Lights and Lighting Equipment, General Specification for

2.1.2 U.S. Government Publications

Available from Document Automation and Production Service (DAPS), Building 4/D, 700 Robbins Avenue, Philadelphia, PA 19111-5094, Tel: 215-697-6257, http://assist.daps.dla.mil/quicksearch/

JAN-F-675 Coating of Glass Optical Elements (Anti-Reflection)

MS24367 Lamp, Incandescent, Miniature Integral Lighting

MS24515 Lamp, Incandescent, T-1, Sub-Midget Flanged

MIL-L-6363/8 Lamps, Incandescent, Aircraft Service, Single Contact Midget Flanged Base T-1-3/4 Bulbs

MS90451 Lamp, Incanescent, T-1 Bulb, Short, Integral Lighting

MIL-C-14806 Coating, Reflection Reduction, for Instrument Cover Glasses and Lighting Wedges

MIL-DTL-6363 Lamps, Incandescent, Aircraft Service, General Specification for

MIL-L-27160 Lighting, Instrument, Integral, White, General Specification for

FED-STD-595 Colors

2.1.3 Other Publications

ANSI C81.61 Electrical Lamp Bases

"Nomenclature & Standards" published by Illuminating Engineering Society

3. RECOMMENDATIONS

3.1 General

There are available to the designer many methods of integral lighting. A number of the more fundamental of these methods are discussed in Appendix A. There are several basic considerations and determining factors which must be taken in account when selecting a method of instrument illumination. They are:

a. The individual specifications of the instrument to be designed (military and/or commercial).

b. Environmental conditions (ambient illumination, high temperature, low temperature, etc.).

c. Power available (a-c, d-c, 5 V, 28 V, etc.).

d. The amount of space and weight allowed for the lighting device.

e. Cost.

3.2 Design and Construction

3.2.1 Materials

Materials used for the lighting system should be chosen to meet the high quality requirements of aerospace instruments. Special attention should be given to the functional and environmental conditions in which the instruments will be operated and tested. Lighting systems generally run considerably hotter than the environments in which they are operating. Materials should be selected with due consideration to their effects on the color of the illumination.

3.2.2 Lighting System

The lighting system should be so designed that the light sources are contained within the instrument enclosure. The lighting system should not interfere with the visibility of any portion of the instrument display. No marking should depend solely on one incandescent lamp for its illumination. The lighting system shall contain a minimum of two lamps and shall be designed so that no portion of the display depends on one lamp for more than 60% of its illumination. The lighting system should outlast the service life of the instrument and should in no way interfere with the correct operation of the instrument.

Appendix A describes some techniques which may be of value to the designer.

3.2.3 Cover Glass and Transparent Interfaces

The instrument cover glass and any other transparent element between the cover glass and the display, such as a lighting wedge, should be coated with reflection reducing films equal to or better than those specified in MIL-C-14806.

3.2.4 Lamps

The lamps shall conform to MIL-DTL-6363. Additional guidance on lamp selection can be found in SAE AS4156 and ANSI C81.61.

3.2.4.1 Characteristics

It will be noted that lamps such as MS24367, MS24515 and MS90451 allow considerable variation in the dimensions, power dissipation, candle power, life, and color temperature of the lamps. All these factors should be carefully considered when selecting the lamps to be used in a particular instrument. Should clear lamps fail to meet individual requirements for color or apparent color temperature of illumination, methods of coloring, as described below, may be used.

3.2.4.2 Colored Lamps

Any of the clear lamps referenced in 3.2.4 may be obtained coated, stained, or dyed to achieve a desired color or apparent color temperature. Such coatings should provide uniform coloration, and should have no perforations or openings through which uncolored light may escape. The coating should be such that light emitted by the lamp will meet specified requirements when the lamps are first turned on and after the lamps have warmed up to a stabilized operating condition. The lamp coatings should not crack, fade, peel, or discolor to any degre greater than the specified tolerance when subjected to and operated at the ambient temperatures encountered in the instrument for such period of time as indicated by the applicable specifications.

Should coated lamps fail to meet the specification requirements, colored glass lamps which do not deteriorate under ambient operating and test conditions may be used.

3.2.4.3 Filters

Filters may also be used with any of the lamps referenced in 3.2.4 to achieve desired color or apparent color temperature. Such filters should remain stable dimensionally, as well as in color and transmission, for such time and under such operating and test conditions as indicated by the applicable specifications.

3.2.5 Lamp Location

Lamps must be located within the confines of the outline drawing of the indicator. Typical lamp location for the various lighting systems may be found in Appendix A.

3.2.6 Lamp Circuits

The lamp circuit should preferably be designed to operate from a 5 V power system. All lamps should be connected in parallel. The lamp circuit should terminate in two electrically independent pins of the instrument connector. Resistors should not be used within the instrument to change the voltage applied to the lamps from that applied to the lighting terminals of the electrical connectors.

3.2.6.1 Dielectric Strength

The insulation should withstand without evidence of damage the application of a sinusoidal voltage at a commercial frequency between all electrical circuits connected together and the metal case for a period of 1 minute. The rms value of the sinusoidal voltage applied should be five times the maximum instrument lighting voltage 500 V, except for hermetically sealed helium filled instruments, where the test voltage should be 200 V rms.

3.2.6.2 Electrical Connector

Unless otherwise specified by the procuring activity, the electrical circuit for the lighting system should terminate in two electrically independent pins in the electrical connector used for other electrical terminals to the indicator. In the event the instrument does not require an electrical connector except for the lighting circuit, a connector having a minimum of two electrically independent pins should be provided. A suitable cap should be provided to protect the connector during shipment and storage. Unless otherwise specified by the procuring activity, the connector should be located on the back of the instrument case. A mating connector plug assembly with approximately 3 ft of wire attached to the lighting terminals should be furnished for Qualification or Preproduction test units.

3.2.7 Color

The color of the illuminated markings when 4.50 V ± 0.050 V applied shall be determined on which type of "white" is called out. There are three types of "white" color selections for instrument lighting: Aviation White, Instrument and Panel Lighting White, and Blue-Filtered White. The recommended "white" for new designs should be the Blue-Filter White or commonly known as "Air Force Blue-White". The rationale for this selection of "white" is that it can maintain a smaller color tolerance over the full brightness range. The selection of Air Force Blue-White will require filters over the lamps (in accordance to 3.2.4.3). The color coordinates for Air Force Blue-White is:

- "x" is not less than 0.420, or greater than 0.460 (using the CIE 1931 Chromaticity chart).
- "y" is not less than 0.385, or greater than 0.425 (using the CIE 1931 Chromaticity chart).

All other colors that are contained within the instrument (i.e., pointers, flags) shall adhere to color requirements of AS25050. For example, red flags should have the chromaticity coordinates of "Aviation Red".

3.2.8 Brightness

In the measurement of brightness, the lamps shall be operated at 5 V ± 0.050 or other specified rated voltage defined by the aircraft system. Unless otherwise specified the following values of brightness in foot lamberts are recommended:

White Areas: 1.00 fL ± 0.50 fL. The overall average of all white areas shall be contained with 1.00 fL ± 0.20 fL. This ensures a balanced cockpit between the other instruments.

Red Areas: 1.00 fL ± 0.50 fL.

Gray Areas: 0.60 fL ± 0.30 fL. The lower limit is due to the lower transmission levels of gray areas when compared to the white areas. This is due to the fact that one lamp may be illuminating both the white and gray areas.

Black Areas: 0.05 fL ± 0.03 fL when reflected light is used (i.e., wedge and ring lighting as shown in Figures 1 and 2) and 0.04 fL ± 0.02 fL for refracted light (i.e., back lighting as shown in Figures 4 and 5).

For all other colors, the brightness limits are governed by the approval of the procuring activity. However, the general guideline is to apply the brightness limits of 1.00 fL ± 0.50 fL.

For pointers, lubber lines, command bars, miniature airplane symbols and similar reference marks, a higher illumination level should be applied to have it stand out from the other light sources within the instrument. For such markings, 1.20 fL ± 0.50 fL shall be applied with the average brightness 0.10 to 0.50 fL higher than the average. This assist the operator in rading the key information components in a quick scan.

3.2.9 Stray Light

The lighting system shall be designed to prevent leakage of stray light and to shield all lamp filaments from direct view.

3.2.10 Dial Visibility

The lighting system should in no way restrict the visibility of any graduations, numerals, pointers, or other specific markings.

3.2.11 Knobs and Lettering

Unless otherwise specified in the applicable instrument specification, all indicia associated with instrument knob positions and all lettering on the instrument face shall be illuminated. The brightness range shall be as recommended in 3.2.8.

3.2.12 Indicia

The daylight presentation when unlighted shall conform to the specified document or may be any combination of colors best suited for the particular display. Black areas should conform to color No. 37038, white areas to color No. 37875, and grey areas to color No. 36373 of
FED-STD-595.

3.2.13 Flags

The presentation of warning flags shall be black markings on a red background. The black markings shall be color No. 37.38 and the red background shall be fluorescent color No. 38905 as specified in FED-STD-595. All other flag colors shall be governed by the approval of the procuring activity and use a color specified in FED-STD-595.

3.2.14 Contrast

Daylight contrast between the white and black portions of the indicator presentation should be 12 or greater. Contrast between the white and grey or the grey and black portions of the indicator display should be 5 or greater. Contrast "C" is defined as:

$$C = \frac{B_2 - B_1}{B_1} \quad \text{(Eq. 1)}$$

Where B_2 is the brightness of the grey or white and B_1 is the brightness of the black or grey portions of the instrument display.

The illumination for the contrast measurements should be furnished by uniform, diffused, artificial illumination. Contrast measurements should be taken with no coverglass or other transparent surface in front of the presentation. Several brightness measurements of the indicia and of the background should be taken with the axis of the brightness meter perpendicular t othe surface being measured. An average of the indicia and background readings should be used to determine conformance to the contrast valuees listed above.

4. GLOSSARY

Most of the definitions are from "Nomenclature & Standards" published by Illuminating Engineering Society.

PHOTOMETRIC QUANTITIES

Lumen - The lumen is the unit of luminous flux. It is equal to the flux through a unit solid angle from a uniform point source of one candle, or the flux on a unit surface all points of which are at unit surface from a uniform point source of one candle.

Candle - The candle is the unit of luminous intensity. It is defined as 1/60 of the intensity of one square centimeter of a black body radiator at the temperature of solidification of platinum (2,046 K).

Candlepower - Candlepower is luminous intensity expressed in candles.

Illumination - Illumination is the density of luminous flux on a surface; it is equal to the flux divided by the area when the latter is uniformly illuminated.

Footcandle - The footcandle is the unit of illumination, equal to the illumination on a surface one square foot in area on which there is a uniformly distributed flux of one lumen, or illumination on a usrface a distance of one foot from a uniform point source of one candle.

Quantity of Light - Quantity of light is the product of the luminous flux by the time it is maintained. The unit is the lumen-hour.

Brightness - Brightness is the luminous intensity of any surface in a given direction per unit of projected area of the surface as viewed from that direction.

Footlambert - The footlambert is a unit of brightness equal to the uniform brightness of a perfectly diffusing surface emitting or reflecting light at the rate of one lumen per square foot. The average brightness of any reflecting surface in footlamberts is the product of the illumination in footcandles by the reflection factor of the surface.

Apparent Candlepower - The apparent candlepower of an extended source of light measured at a specific distance is the candlepower of a point source of light which would produce the same illumination at that distance.

MATERIALS AND ACCESSORIES

Reflector - A reflector is a device, the chief use of which is to redirect the light of a lamp by reflection in a desired direction or directions.

Refractor - A refractor is a device, usually of prismatic glass which redirects the light of a lamp in desired directions principally by refraction.

Shade - A shade is a device, the chief use of which is to diminish or intercept the light from the lamp in certain directins where such light is not desirable. Frequently the functions of a shade and a reflector are combined in the same unit.

Globe - A globe is an enclosing device of clear or diffusing material to protect the lamp, to diffuse or redirect its light, or to modify its color.

Projector - A projector is a device which concentrates luminous flux within a small angle about a single axis.

Luminaire - A luminaire is a complete lighting unit consisting of a light source together with its direct appurtenances, such as the globe, reflector, housing, and such support as is integral with the housing.

Diffusing Surfaces and Media - Diffusing surfaces and media are those which break up the incident light and distribute it more or less in accordance with Lambert's cosine law of emission[1], as for example, rough plaster and white glass.

Diffuse-Specular - Diffuse specular surfaces are those which are essentially diffuse but contain an outer layer of glazed material which reflects specularity. Porcelain-enamel is a common example.

Perfect Diffusion - Perfect diffusion is that in which light is scattered uniformly in all directions by the diffusing medium.

Wide Angle Diffusion - Wide angle diffusion is that in whichlight is scattered over a wide angle.

Spread or Diffusing - Spread or diffusing surfaces (and media) are those which break up the incident light and distribute it as though the surface were incandescent, uniformly bright in all directions or approximately so. Examples are rough plaster, white glass, white plastic.

Narrow-Angle Diffusion - Narrow-angle diffusion is that in which light is scattered in all directions from the diffusing medium but in which the intensity is notably greater over a narrow angle in the general direction which the light would take by regular reflection or transmission.

Regular or Specular Reflection - Regular or specular reflection is that in which the angle of reflection is equal to the angle of incidence.

Diffuse Reflection - Diffuse reflection is that in which the light is reflected in all directions.

Regular Reflection Factor - The regular reflection factor is the ratio of the regularly reflected light to the incident light.

Diffuse Reflection Factor - The diffuse reflection factor is the ratio of the diffusely reflected light to the incident light.

Reflection Factor or Reflectance - The reflection factor or reflectance is the ratio of the light reflected to the incident light.

Diffuse Transmission - Diffuse transmission is that in which the transmitted light is emitted in all directions from the transmitting body.

Regular Transmission - Regular transmission is that in which the transmitted light is not diffused. In such transmission, the direction of the transmitted pencil of light has a definite geometrical relation to the corresponding incident pencil of light.

Regular Transmission Factor - The regular transmission factor is the ratio of regularly transmitted light to the incident light.

Diffuse Transmission Factor - The diffuse transmission factor is the ratio of the diffusely transmitted light to the diffuse incident light.

Transmission Factor - The transmission factor of a body is the ratio of the light transmitted to the incident light.

[1] Theoretically perfect diffusion follows Lambert's cosine law of emission: "The intensity of light (cp) in a certain direction radiated or reflected by a perfectly diffusing plane surface varies as the cosine of the angle between the emitted ray and a normal to the surface." The diffuse plane will be equally bright at all angles, since the projected area at any angle also varies with the cosine of the angle.

ILLUMINATING GLASSES

White Glass - White glass is highly diffusing glass having a nearly white, milky, or gray appearance. The diffusing properties are an inherent, internal characteristic of the glass.

Cased Glass - Cased glass is glass composed of two or more layers of different glasses, usually a clear, transparent layer to which is added a layer of white or colored glass. The glass is sometimes referred to as flashed, multi-layer, or polycased glass.

Homogeneous Glass - Homogeneous glass is glass of essentially uniform composition throughout its structure.

Enameled Glass - Enameled glass is glass which has had applied to its surface a coating of enamel. The enamel may be white or colored, and may have various degrees of diffusion.

Mat-Surface Glass - Mat-surface glass is glass whose surface has been altered by etching, sand- blasting, grinding, etc., to increase the diffusion. Either one or both surfaces may be so treated.

Prismatic Glass - Prismatic glass is clear glass into whose surface is fabricated a series of prisms, the function of which is to direct the incident light in diesired directions.

Transparent Glass - Transparent glass is glass having no apparent diffusing properties. Varieties of such glass are referred to as flint, crown, crystal, clear.

Polished Plate Glass - Polished plate glass is glass whose surface irregularities have been removed by grinding and polishing, so that the surfaces are approximately plane and parallel.

PHOTOMETRIC STANDARDS AND TESTS

Primary Luminous Standard - A primary luminous standard is one by which the unit of light is established and from which the values of other standards are derived. A satisfactory primary standard must be reproducible from specifications.

Secondary Standard - A secondary standard is one calibrated by comparison with a primary standard.

Working Standard - A working standard is any standardized luminous source for daily use in photometry.

Characteristic Curve - A characteristic curve is a curve expressing a relation between two variable properties of a luminous source, as candlepower and volts, candlepower and rate of fuel consumption, etc.

Curve of Light Distribution - A curve of light distribution is a curve showing the variation of luminous intensity of a lamp or luminaire with angle of emission.

ABBREVIATIONS

The following abbreviations have been adopted by the American Standards Association:

Candlepower - cp
Mean Horizontal Candlepower - mhcp
Mean Spherical Candlepower - mscp
Lumens per watt - lpw
Footcandle(s) - fc
Footlambert(s) - fL

Brightness Ratio - Brightness ratio is the ratio of the brightness of any two surfaces. When the two surfaces are adjacent, the brightness ratio is called the brightness contrast.

Color of Objects - The color of an object is the capacity of the object to modify the color of the light incident upon it.

Colorants - Substances which are used to produce the colors of objects are called colorants (dyes, pigments, inks, paints, and decorative coatings).

Dominant Wavelength - The wavelength of homogeneous light, which when combined with white light in suitable proportions, matches a color, is the dominant wavelength of the color.

Chromaticity - Chromaticity is the expression of color in terms of CIE codents.

ILLUMINANTS

Lamp - The term lamp is the generic term for an artificial source of light.

Incandescent Lamp - An incandescent lamp is a light source consisting of a glass bulb containing a filament electrically maintained at incandescence.

Efficiency of a Light Source - The efficiency of a light source is the ratio of the total luminous flux to the total power input. In an electrical lamp it is expressed in lumens per watt.

Color Temperature - The color temperature of a source of light is the temperature at which a black body must be operated to give a color matching that of the source in question.

Mean Horizontal Candlepower - The mean horizontal candlepower of a lamp is the average candlepower in the horizontal plane passing through the luminous center of the lamp. It is assumed that the lamp or other light source is mounted in the usual manner, as in the case of a filament lamp, with its axis of symmetry vertical.

Spherical Candlepower - The (mean) spherical candlepower of a lamp is the average candlepower of the lamp in all directions in space. It is equal to the total luminous flux of the lamp in lumens divided by 4 π.

5. NOTES

5.1 The change bar (l) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document.

PREPARED BY SAE COMMITTEE A-20, AIRCRAFT LIGHTING

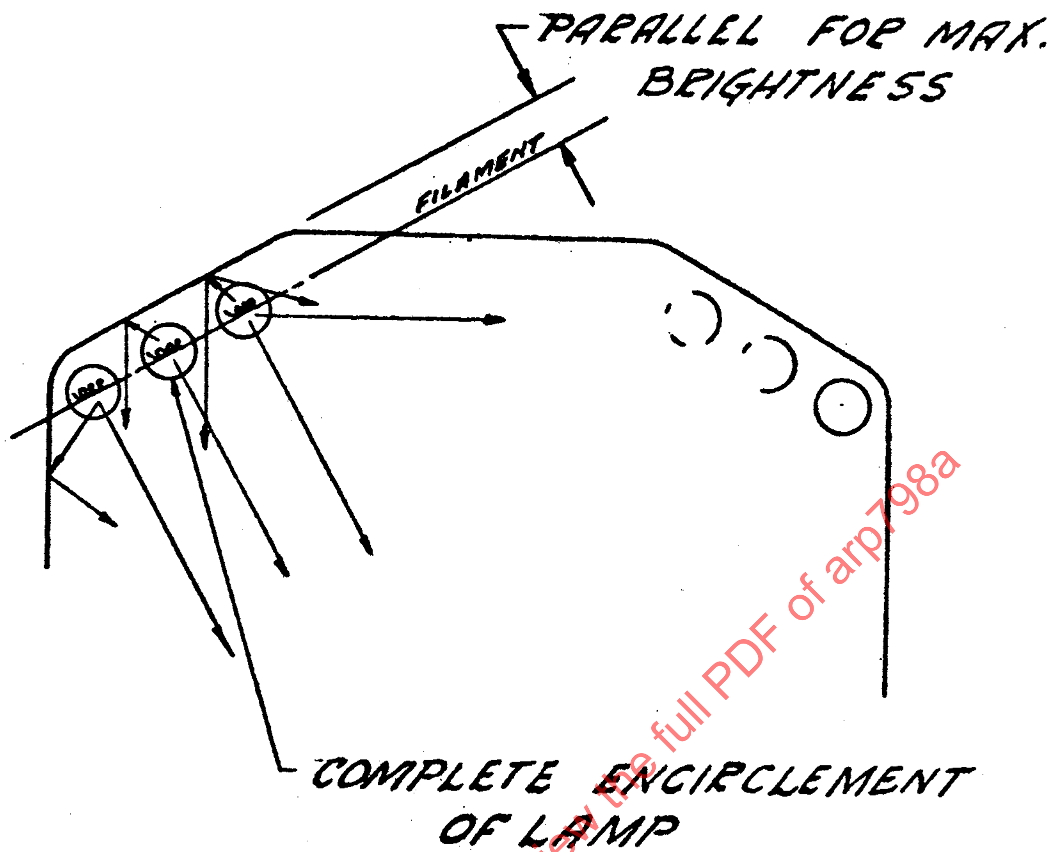

PARALLEL FOR MAX. BRIGHTNESS
FILAMENT
COMPLETE ENCIRCLEMENT OF LAMP

FIGURE 1

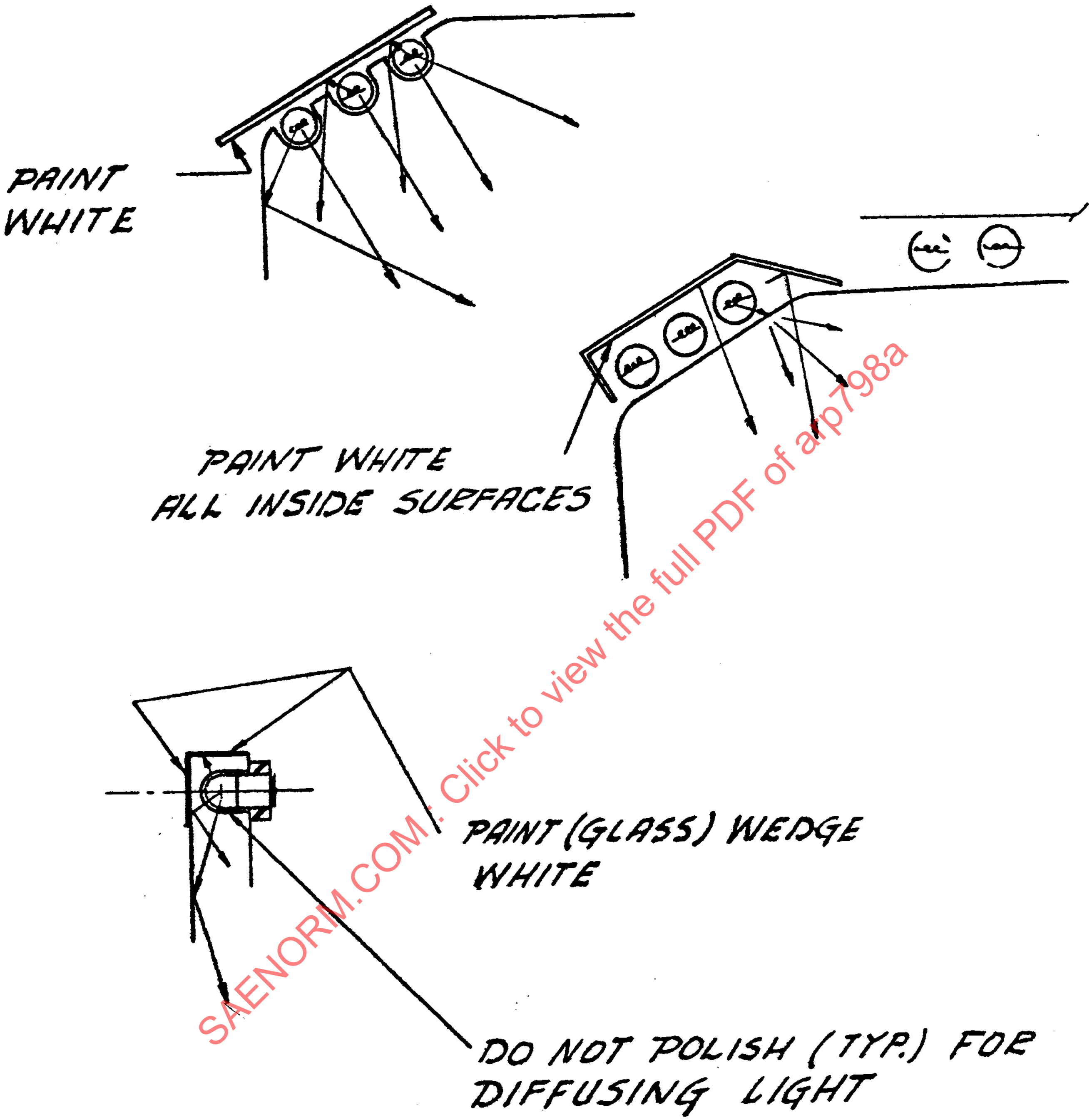
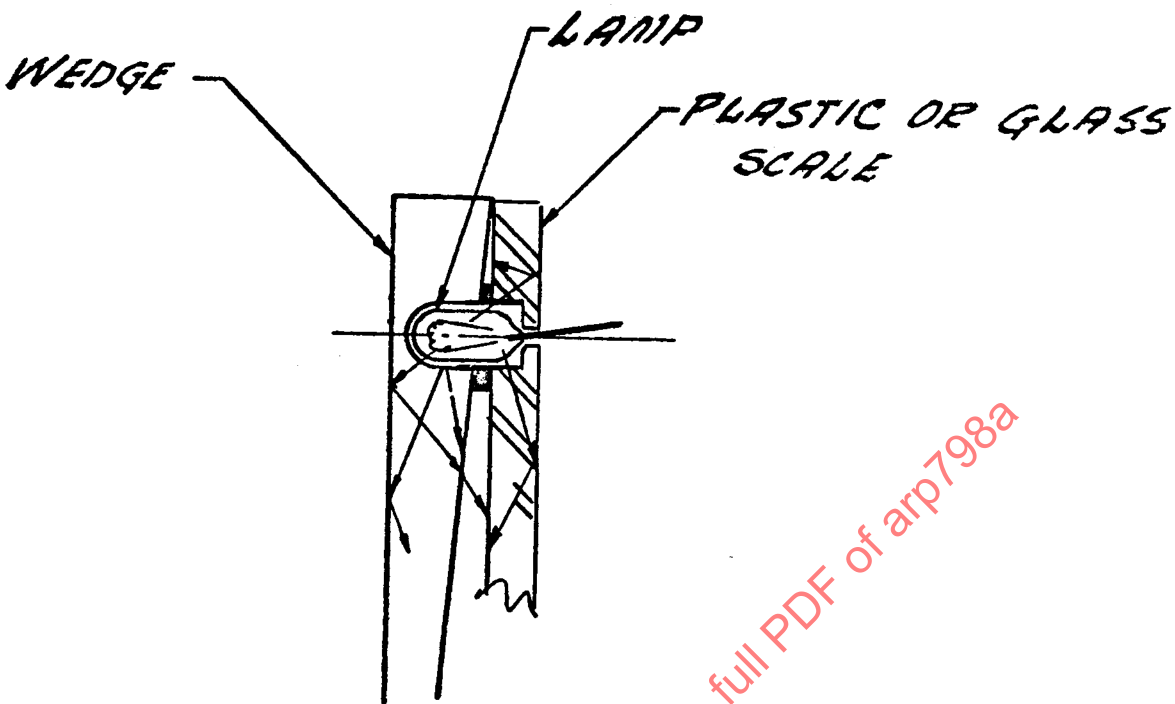

PAINT
WHITE
PAINT WHITE
ALL INSIDE SURFACES
PAINT (GLASS) WEDGE
WHITE
DO NOT POLISH (TYP.) FOR
DIFFUSING LIGHT

FIGURE 2



COMBINATION OF WEDGE & BACK LIGHTING USING SAME LAMP

FIGURE 3

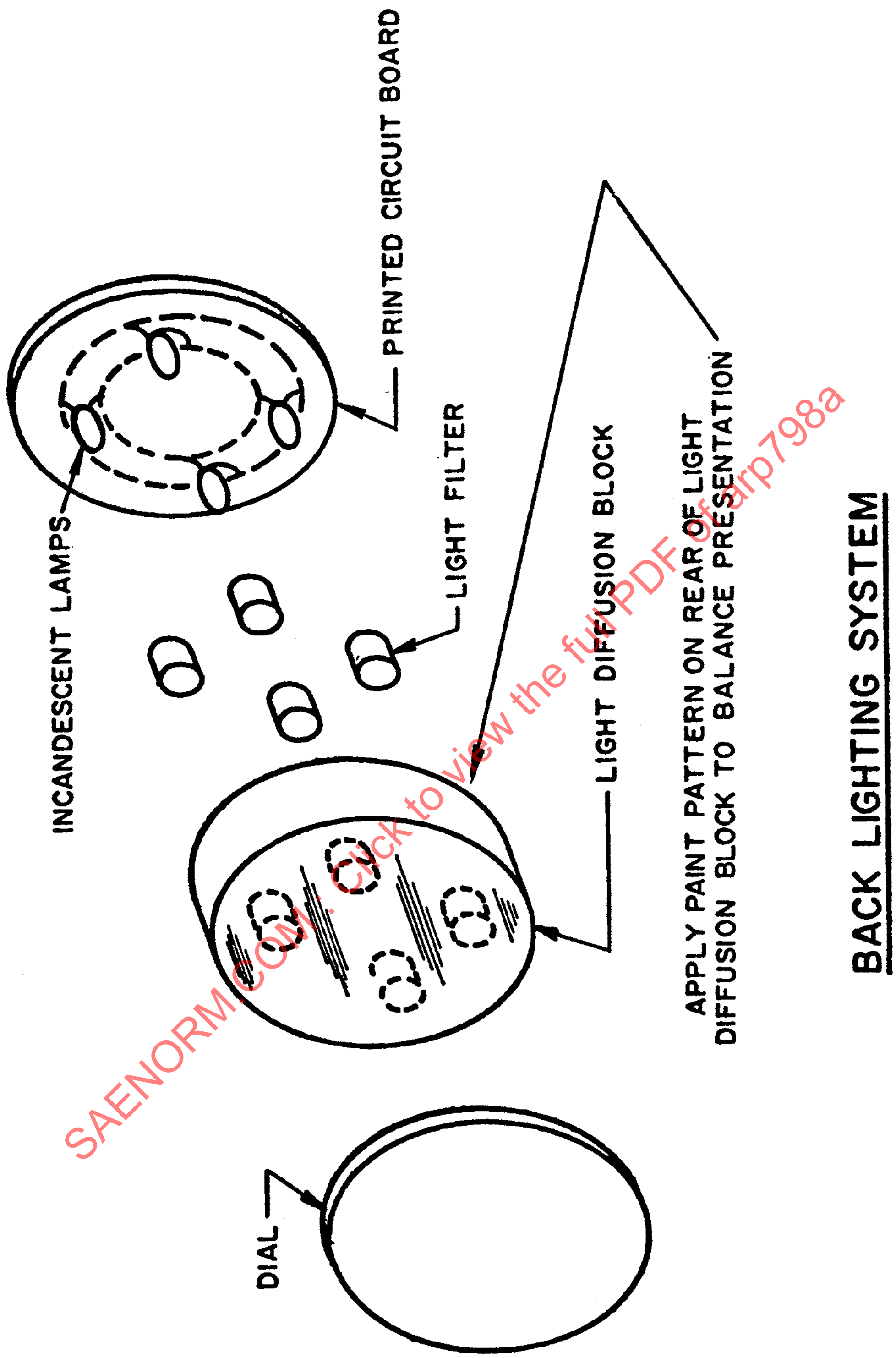

PRINTED CIRCUIT BOARD
INCANDESCENT LAMPS
LIGHT FILTER
LIGHT DIFFUSION BLOCK
APPLY PAINT PATTERN ON REAR OF LIGHT
DIFFUSION BLOCK TO BALANCE PRESENTATION
BACK LIGHTING SYSTEM
DIAL

FIGURE 4

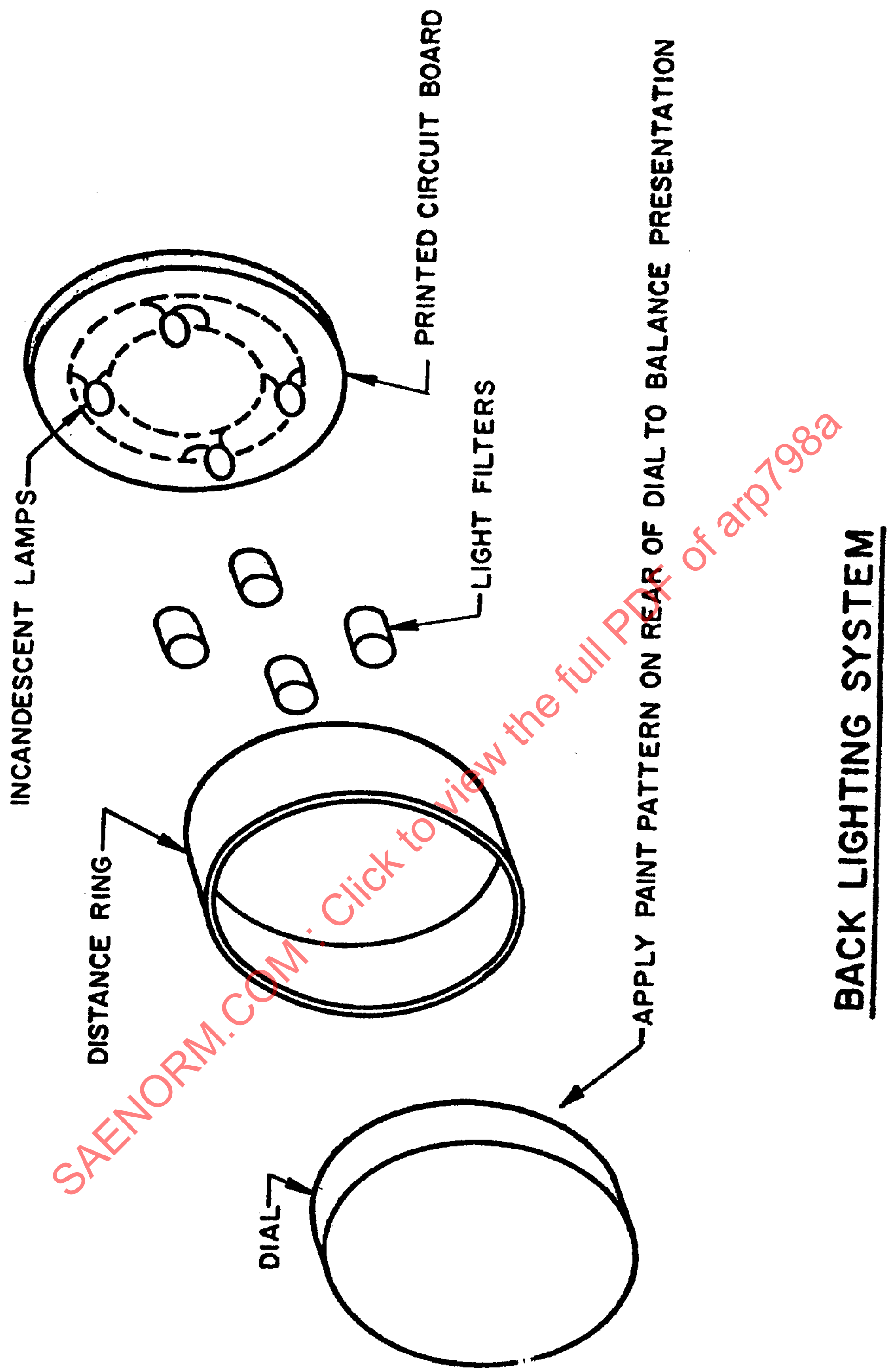

PRINTED CIRCUIT BOARD
INCANDESCENT LAMPS
LIGHT FILTERS
APPLY PAINT PATTERN ON REAR OF DIAL TO BALANCE PRESENTATION
DISTANCE RING
DIAL
BACK LIGHTING SYSTEM

FIGURE 5

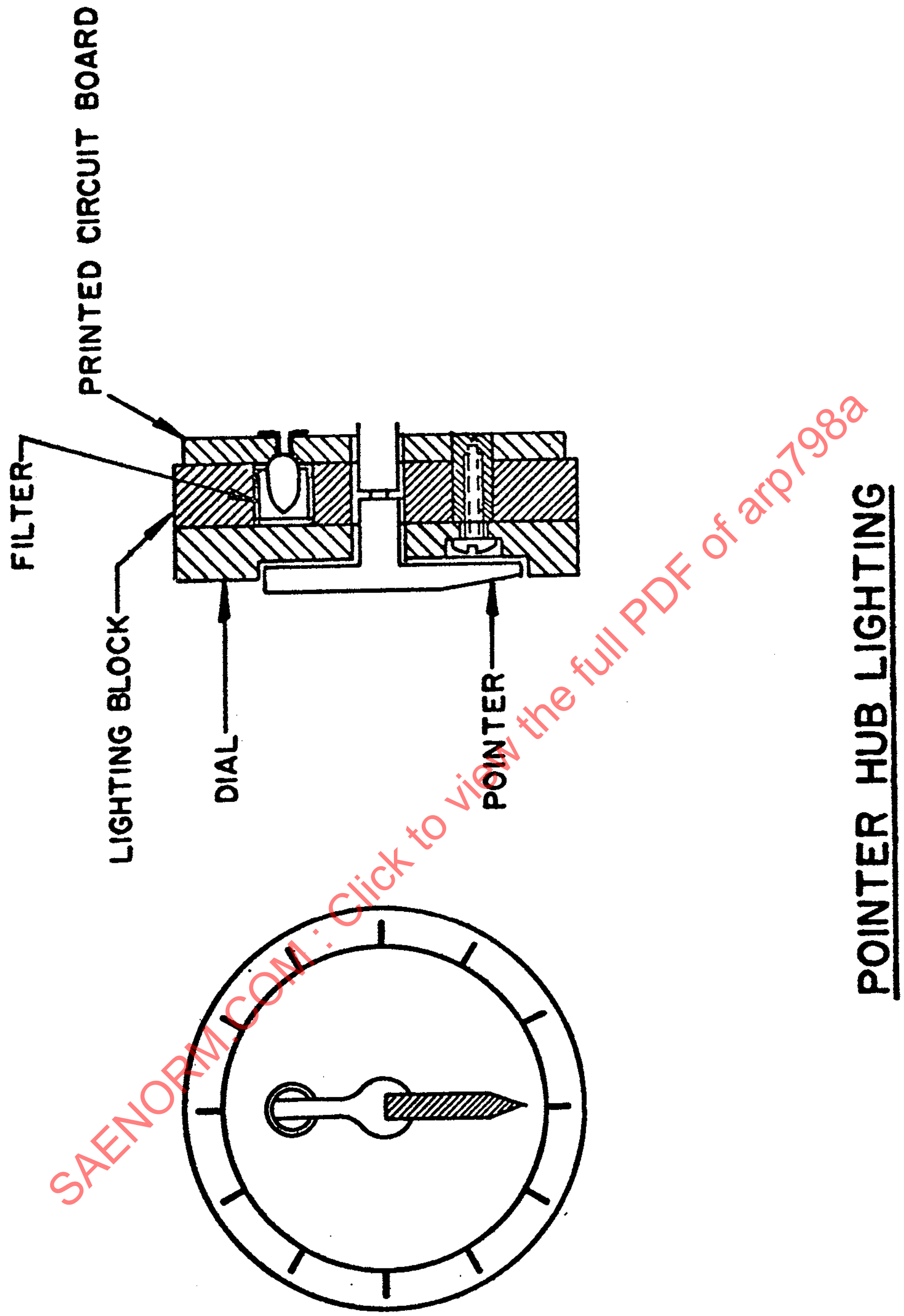

PRINTED CIRCUIT BOARD
FILTER
LIGHTING BLOCK
DIAL
POINTER
POINTER HUB LIGHTING

FIGURE 6